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U.S. NAVY SALVAGE MANUAL VOLUME 1 STRANDINGS AND HARBOR CLEARANCE

SUPERSEDES: NAVSEA S0300-A6-MAN-010 - 4 JULY 1989
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PUBLISHED BY DIRECTION OF COMMANDER, NAVAL SEA SYSTEMS COMMAND

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FOREWORD

This volume is the first in a series of five related publications that comprise the *U.S. Navy Salvage Manual.* Each volume in the family addresses a particular aspect of salvage with the primary purpose to provide practical information of immediate use to Navy salvors in the field. The secondary purpose is to provide an educational vehicle for learning the technical and practical aspects of our business before applying them to the difficult venue of salvage. These are not cookbooks; they are guidance. Salvors must use imagination, intellect, and experience to expand the basic information and apply it to a particular situation.

Volume 1 provides the basic foundation of naval architecture and its application to marine salvage. The salvor must have a firm grasp of the principles of naval architecture to understand how ships will react as they grapple with various salvage problems and to safeguard personnel and equipment. The discussion then expands to salvage of sunken ships, object and/or wreck removal, and port opening/harbor clearance. The manual presents practical information and specific techniques previously employed to solve real problems associated with actual salvage operations.

Frequently, the demands of the job will call for salvage to be performed in remote locations using old ships and limited equipment – situations for which there is no substitute for experience and the good judgment that results from a thorough understanding and mastery of the basic concepts and principles. Marine salvage and associated diving operations are inherently hazardous; well thought out plans and procedures are essential for success. Prudent salvors will study the material in this manual and will take every opportunity to learn all they can about salvage before they are called upon to practice it.

Salvage is a profession that encompasses multiple fields, is interdisciplinary, and by its very nature requires healthy doses of technical innovation and improvisation. Keep this manual close to your waterfront, and consult it frequently.

J. R. WILKINS III
Supervisor of Salvage and Diving
Director of Ocean Engineering

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STANDARD NAVY SYNTAX SUMMARY

Since this manual will form the technical basis of many subsequent instructions or directives, it utilizes the standard Navy syntax as pertains to permissive, advisory, and mandatory language. This is done to facilitate the use of the information provided herein as a reference for issuing Fleet Directives. The concept of word usage and intended meaning which has been adhered to in preparing this manual is as follows:

"Shall" has been used only when application of a procedure is mandatory.

"Should" has been used only when application of a procedure is recommended.

"May" and "need not" have been used only when application of a procedure is discretionary.

"Will" has been used only to indicate futurity; never to indicate any degree of requirement for application of a procedure.

The usage of other words has been checked against other standard nautical and naval terminology references.

CHAPTER 1
INTRODUCTION

1-1 INTRODUCTION.

Salvors of damaged, stranded, or sunken ships need a basic understanding of the geometry, stability, and strength of intact ships. Armed with such an understanding, salvors can appreciate how those properties vary in a ship to be salvaged.

Ship calculations made in the field on salvage jobs are not the same precise calculations made in a design office. Approximations and assumptions based on information obtainable at the scene must be made.

This volume of the *U.S. Navy Salvage Manual* provides an overview of basic salvage, naval architecture, and engineering principles, and serves as a guide and basic reference for U.S. Navy salvors engaged in strandings, port opening/harbor clearance, harbor salvage, wreck removal, and ship salvage operations in both wartime and peacetime. These engineering principles serve as a basis for the technical procedures and calculations used when raising, clearing, burying, or flattening sunken or partially sunken ships.

Salvors should consider the material in this volume as a starting point and, whether faced with a single sunken ship or a harbor with multiple wrecks, give free range to their imagination, creativity, and ability to innovate. They must have full confidence in their skill and experience.

1-2 MANUAL ORGANIZATION.

This manual has two distinct themes that are interrelated – strandings and harbor clearance. Each theme is supported by the earlier chapters that provide an overview of engineering principles and basic salvage techniques.

Chapter 2 provides planning and survey guidance that precedes any salvage operation. Chapter 3 addresses the geometry of ships and how the properties of ships are determined or calculated. Chapters 4 and 5 present ship stability, the effects of weight, and basic ship strength. Subsequent chapters of this volume and other volumes of the *U.S. Navy Salvage Manual* address conditions found on certain kinds of casualties. Chapters 2 through 5 are background for them all and should be used with later chapters in this volume and those in other volumes. In many situations, the complexity of required salvage calculations exceeds the scope of this *U. S. Navy Salvage Manual* series. In those instances, the services of a salvage engineer or naval architect should be obtained.

This volume is derived from *U.S. Navy Ship Salvage Manual, Volume 1 (Strandings)* (1989) and *Volume 2 (Harbor Clearance)* (1990). While the combining of these two volumes reduced duplicity, several factors influenced this revision – including revised salvage techniques, technological advances, recent non-traditional threats, and innovative ship designs and revised missions developed over the last decade to address these new threats.

CHAPTER 2
SURVEYS AND PLANNING

2-1 INTRODUCTION.

Having a well thought-out and organized salvage plan is vital to the success of any salvage operation. A detailed survey of the casualty and salvage site provides the salvor with the necessary background information from which to form a comprehensive plan. To develop a workable salvage plan, salvors must evaluate the position and condition of the ship, understand the complexities of the given situation and conceptualize the work and methods necessary to accomplish the aims of the operation. Planning must proceed from broadly based tactics covering entire operations to detailed plans for specific ships or other portions of an operation. In all cases, the plan must serve the *purpose* of the operation; then balance the *work* to be done with the *resources* available and the *schedule* required.

Operational conditions are dynamic and may change several times throughout the course of the salvage operation. The development of the salvage plan begins when the initial information about the casualty is received. The plan is a living document and continues to evolve throughout the operations.

In extensive operations, the salvage plan includes both the harbor clearance plan that is administered by the senior salvage officer and staff, and the individual ship salvage plans. This chapter addresses planning for single ship salvage as well as multi-vessel salvage operations.

2-2 SALVAGE OPERATIONS.

No classification system can adequately describe all aspects of marine salvage. A brief examination of the various types of salvage *can,* however, illustrate how varying conditions play a major role in the level of effort required in the salvage operations.

2-2.1 Offshore Salvage. The refloating of ships stranded or sunk in exposed coastal waters is called offshore or coastwise salvage. The casualties exposed to swell, currents and weather are the most vulnerable and difficult on which to work. They tend to deteriorate more rapidly than the casualties in protected harbors. Windows of opportunity, for the salvor, created by abnormally high tides or fair weather may be short lived and not reopen for weeks or months, during which time the casualty continues to deteriorate. Salvage assistance must be rapid and effective in order to preserve the value of the ship and cargo. Offshore salvage is conducted from pre-outfitted salvage vessels and tugs. Portable fly-away dive and chamber systems may be transported by helicopter or small boat to a platform of opportunity. Unprotected waters are much less hospitable for the employment of floating cranes, construction tenders, dredges, and accommodation barges. This equipment is designed more for operations in sheltered waters. It takes time and money to locate salvage ships and marry portable equipment to platforms of opportunity. In addition, this salvage equipment may not be readily available due to prior commitments or long transit time from the nearest port. Prior to mobilizing the salvage forces to an offshore area, the salvor should have performed both an accurate and thorough survey. The survey will assist in ascertaining the casualty's condition and provide the proper input to determine the number and type of assets to employ. This is especially difficult in an exposed area.

2-2.2 Harbor Salvage. The term harbor salvage is used for the salvage of ships stranded or sunk in sheltered waters. Casualties in harbors or other sheltered waters are not normally subjected to the same deterioration caused by sea and marine weather conditions as offshore salvage casualties. The survey and planning stages are not as time-dependent unless the casualty is an obstruction to a navigation channel or commercial facility. Access to carpenters, stevedores, and general labor can be hired from local labor pools. Equipment such as floating cranes and barges are typically more readily available.

2-2.3 Cargo and Equipment Salvage. In certain cases, saving the cargo and equipment aboard a casualty may have a higher priority than saving the casualty itself. The cargo may pose an environmental hazard or may include critical war materials, sensitive military items, machinery, or weapons mounts that may need to be removed in a timely fashion. This was the case on the battleships ARIZONA and UTAH at Pearl Harbor during WWII.

2-2.4 Wreck Removal. Removal of hazardous or unsightly wrecks that have little or no salvage value provides salvors with many options. Wrecks are refloated or removed by the most feasible method available, without regard for the salvage value of the wreck. In many of these cases, removal of hazardous materials aboard the wreck must take place prior to dealing with the wreck. Salvors may cut the wreck into easily handled sections or refloat and remove the casualty in one piece, based on their initial evaluation of which technique would be more appropriate.

2-2.5 Afloat Salvage. The salvage of a vessel that is damaged but still afloat is called afloat salvage. This type of salvage requires unique services. Assisting in the damage control efforts aboard the ship is the first and most useful service that can be rendered by the salvor. In this situation, the primary goal of the ship's Captain is to stabilize the vessel first, before the salvage plan and engineering plan are implemented.

2-2.6 Clearance. The term "clearance" refers to the coordinated removal or salvage of numerous casualties in a harbor or waterway. Harbor clearance typically follows a catastrophic event such as sabotage or an intentional bombing within a port or a severe natural event such as a tsunami or hurricane. There may be multiple-obstructions with varying degrees of damage due to collision, fire or explosions. In a CONUS clearance situation affecting navigation channels, the Captain of the Port plays a major role in determining salvage prioritization.

Harbor salvage jobs may carry with them a sense of urgency equal to that of stranding salvage. When the ship is to be returned to service, its military or commercial value and integrity must be retained, and the salvage operation must proceed quickly so that the ship can be repaired and returned to service as soon as possible. Clearance of berths and channels carry a similar urgency, but with an important difference—clearance of the berth or channel may be more important than the salvage of the ship. Often in such situations, the ships are simply refloated and either taken to deep water and sunk, or removed to some place where the hulk will not be a problem. In these cases, there is little point in attempting to preserve the value of the ship or to avoid further damage. The sole purpose of the operation is to dispose of the wreck as quickly as possible by whatever means and equipment available. In numerous other cases, the urgency is not so great and the complexity of the job is such that detailed planning and assembly of resources for the most cost-effective solution is possible.

In a major harbor clearance with numerous wrecks, priorities are set for the work. Wrecks whose removal will yield the greatest results are attacked first.

Setting priorities for the work and determining the ultimate disposition of the wreck is one of the first and most important steps in the salvage of sunken ships. Tactical, political, and economic considerations, as well as technical factors all influence how and in what order work will be performed.

2-3 PLANNING HARBOR CLEARANCES.

A major difference exists between harbor clearance operations resulting from combat casualties or natural disasters, and the clearance of a deliberately blocked port in wartime. In the former case, there will be no information available upon which clearance plans can be based before the casualties occur. Satellite, aerial photography, and other types of reconnaissance can provide information on blocked ports and give an advance indication of the effort that will be required for the clearance.

2-3.1 The Harbor Clearance Plan. The harbor clearance plan provides the overall plan for the clearance operation. It is administered and maintained by the senior salvage officer. It provides:

- A statement of the objective of the operation and chain of command
- An organizational diagram with names of key personnel
- The order in which each vessel is to be cleared
- The techniques to be employed on each vessel
- The disposition of each vessel
- Special materials/equipment needed
- Engineering support required
- Contractor support needed
- The employment, coordination, and scheduling of personnel and equipment
- Logistical requirements and schedules for personnel and equipment
- Communications, record, and report information
- Pollution and hazardous material control measures
- Overall safety requirements
- Liaison with interested organizations, particularly the controlling activity
- Consideration for International Safety Management (ISM) Code Procedures
- Consideration for Vessel Response Plan (VRP) Expansion
- Funding.

2-3.2 Deliberately Blocked Ports. The military purposes of capturing ports are to deny their use by the enemy, for their logistics, while at the same time, using the port facilities to move material and supplies required by advancing forces. Retreating enemy forces can be expected to use their resources to block the waterways, berths, and facilities of the ports that would require clearance before use. When blocking a harbor, it is the enemy's purpose to make its clearance as difficult, dangerous, and time-consuming as possible. In a skillfully blocked harbor, wrecks will be stacked one above the other, mined, booby-trapped, and damaged in ways that make their removal difficult. Despite optimum use of reconnaissance and careful evaluation of collected intelligence, the information used for planning will be incomplete. Harbor clearance plans must be flexible to allow changes as additional information becomes available.

Harbor clearance planning is an integral part of the logistical planning for ports that are to be cleared as part of a military campaign. As such, harbor clearance planning must begin early in the campaign planning and must include all organizations involved.

As early as is feasible, a series of conferences should be held to initiate planning. These conferences should include at least the naval organization responsible for harbor clearance work, the logistics commander within Military Sealift Command, the Military Traffic Management Command (under the U.S. Army Transportation Corps), the Army Corps of Engineers, and the U.S. Coast Guard (CONUS). As the ultimate user of the facilities, the U.S. Army Transportation Corps, calls upon other organizations for services and should chair the conferences.

The specific purposes of these conferences are to:

- Identify for all participants the facilities in the port that will be required.
- Establish joint priorities for bringing facilities back into service.
- Identify the harbor clearance resources that will be required.
- Establish procedures for the dissemination of intelligence information that will affect the harbor clearance.
- Establish working relationships among the diverse elements that will be working together toward a common goal.

Planning should proceed based on the best information available, tempered with experience. When planning the resources to be employed, decisions should be made that favor additional resources to cover contingencies. It is far better to have an excess of people and equipment on hand than to delay work while additional resources are brought in. Experience has shown that the same techniques and equipment are not universally applicable in every harbor clearance operation. Specialized personnel and equipment should be identified and located in the event they are needed.

Harbor clearance survey teams, with express sites or facilities to survey, should enter the port shortly after the assault troops. The survey teams should have the following specific duties:

- Collecting plans and information on cargoes of sunken ships from the inhabitants of the port, shipping offices, and the ships themselves
- Developing information as to how the ships were sunk—particularly, whether they were sunk by combat action or deliberately sunk by the retreating enemy
- Taking soundings throughout the harbor and marking charts appropriately
- Marking on large-scale charts the locations of all wrecks and indications of sunken ships, such as air bubbles and oil slicks
- Marking wrecks with signs to prevent other organizations from boarding and removing material of use in the harbor clearance operation. Signs indicating the presence of poison gas have proven most effective, especially where organic matter is de-composing, or an unpleasant odor can be emitted by chemicals or stink bombs.
- Locating and laying claim to suitable staging and billeting areas on the waterfront.

The results of the initial surveys will be sent immediately to the harbor clearance headquarters where they will be used to update information gathered before the assault. Significant discrepancies between the pre-assault information and that gathered by on-site surveys could be expected. Plans are modified based on the best information available. It may be necessary to rearrange the priority list and commence work on facilities where the maximum benefit may be gained rapidly. Facilities that require a great deal of work, commitment of resources, and time to clear but are not as high a priority can be salvaged at a later time.

The harbor clearance plan for deliberately blocked harbors will be based on the intelligence estimates, modified by the initial survey and the further development of information as work progresses. Clearance of deliberately blocked harbors must be coordinated with the other organizations working in the area. Because of differing and usually rapidly changing military requirements, the harbor clearance plan must be constantly revised. Daily conferences should be held among the harbor clearance organization, Army Transportation Corps, and the Corps of Engineers. In these conferences, the joint priority list prepared before the port was taken can be updated to meet the Transportation Corps' needs. The conference will allow the Corps of Engineers and harbor clearance organizations to effectively meet the Transportation Corps' needs and stay clear of lines of supply and port rehabilitation work where they would interfere with the primary work in the port.

2-3.3 Combat Casualties and Natural Disasters. When port facilities are blocked by combat casualties or natural disasters, there is no advance warning of the number, type, or condition of the casualties. All information must be gathered on-site following the incident, often in an atmosphere of great confusion and competing priorities. When such a situation occurs:

- Local people should begin to assess the situation and act to refloat and secure ships and craft needing immediate assistance.
- An experienced salvage officer, the force salvage engineer and a small team, should be flown to the scene as soon as possible to assess the overall condition and make an initial determination of the resources required.
- There should be daily meetings between the salvage officers, port authority and the Coast Guard (CONUS). This is to ensure that requirements are being met and harbor clearance operations are not interfering with other port operations.
- Mobilization of salvage resources should commence immediately. Mobilization plans can be modified as additional information becomes available.
- As the ships that have become casualties are identified, plans and information on the ships should be requested from appropriate authorities and sent to the scene.

Priorities for work are established in a process similar to medical triage. The first efforts are put into those cases where the return is likely to be greatest. These include vessels and craft that:

- Can be used in the harbor clearance work
- Have high operational priorities
- Are in precarious situations that are likely to deteriorate if not tended to quickly
- Present serious pollution hazards
- Are relatively simple salvage jobs that can be completed quickly with minimum resources.

Generally, in harbor clearances resulting from combat casualties or natural disasters, it is possible to follow a well-prepared plan closely. Liaison with the organization responsible for the port is of utmost importance. There should be daily meetings between the senior salvage officer and the port authority to ensure that the latter's requirements are being met and that the harbor clearance operation is not interfering with other operations in the port.

2-3.4 Individual Casualties. Major harbor clearance operations are a combination of harbor salvage and wreck removal operations on individual ships. Each ship is treated as its circumstance dictates. When the entire operation consists of the salvage or removal of a single ship, planning may ignore the operational and logistical aspects of dealing with numerous wrecks and concentrate on the individual casualty. The removal of an individual casualty may be extremely time-sensitive because the sunken vessel blocks a waterway or berth. As with a major harbor clearance, a salvage officer, the force salvage engineer and a small team should be sent to the site immediately to evaluate the casualty and commence planning.

Individual salvage plans are developed for each ship to be cleared. These plans have two parts: the main body and the supporting annexes. The main body contains:

- Basic information identifying the ship and the condition as it lies
- A general statement of the techniques to be used, with a summary rationale for the selection (in most situations this is driven by costs)
- An engineering estimate that includes all pertinent calculations for the planned refloating or removal
- An overall schedule
- Pollution control measures
- The results of the safety survey and the safety officer's recommendations with specific hazards, precautions, briefings, and safety training listed.

The supporting annexes are detailed plans for each phase of the operation and each technique employed. Annexes may be subdivided if the scope of the work warrants. Each annex contains:

- A list of all tasks
- The order in which they will be accomplished
- Task schedules
- Personnel and equipment required
- Responsibilities by name or job title
- Definition of interfaces with other tasks
- Coordination requirements.

2-4 SALVAGE SURVEYS.

The purpose of the salvage surveys is to gather information about the casualties by inspecting the ships and the conditions surrounding them. The primary purpose of a survey is to gather and organize information to be used in developing the salvage plan or plans. The survey is a dynamic process that is never truly complete. It begins as soon as the first salvor arrives at the salvage site and continues throughout the operation. The keys to a good survey are verification of observations and the organization and presentation of the information collected. A salvage survey form is used as a memory aid and assists in organizing the information. There is no perfect survey form; the surveys presented in Appendices K and L, Salvage Survey Forms, have been formulated as a result of many years' experience and are very comprehensive. The forms may be modified to include information applicable to the particular casualty, to exclude information that does not apply, and in any other way that makes it more useful to the situation at hand.

A survey will report only observations. It is the salvors' task to interpret the conditions observed and determine what they mean about the condition of the ship. Like the survey, the interpretation of the results must be an ongoing process that continues throughout the operation and is constantly revised, as the survey is refined.

2-4.1 Initial Overall Surveys. Initial overall harbor clearance surveys should:

- Inventory the ships to be salvaged or cleared
- Categorize them by condition
- Establish priority for their clearance
- Determine the general technique and type of equipment to be employed.

2-4.2 Survey Breakdown. For each individual ship a salvage survey must be conducted. The salvage survey can be broken into several interdependent surveys. These include the following surveys:

- Preliminary
- Detailed Surveys
  (1) Topside
  (2) Interior hull (including machinery)
  (3) Diving and exterior hull
  (4) Hydrographic
  (5) Site safety
  (6) Cargo
  (7) Pollution potential.

This survey must be conducted personally by the senior salvage officer. Figure 2-1 is a sample form for summarizing the results of overall harbor clearance surveys.

While the senior salvage officer and immediate staff are conducting the overall survey and preparing the harbor clearance plan, survey teams commence surveys of the individual vessels.

HARBOR CLEARANCE SUMMARY SHEET DATE: 8/3 AT: BLOCKED HARBOR

WRECK NUMBER	1	2	3	4	5	6
TYPE	MINE CLEARANCE	ORDNANCE CLEARANCE	TANKER	CARGO	BARGE	DUMPED VEHICLES
SIZE	SECTOR I	SECTOR I	100,000 TONS	300’	100’ X 40’	RAIL CARS MOBIL CRANE
CONDITION	MOORED LINES	DUMPED ORDNANCE	SUNK, MAIN DECK 4’ UNDER WATER	SUNK AT PIER 7 SECTOR II	SUNK IN MAIN CHANNEL	OBSTRUCT PIER 5/6
CLEARANCE TECHNIQUE	SWEEP	REMOVE	BLOW WITH COMPRESSED AIR	PATCH & PUMP	WRECK IN PLACE	LIFT AND REMOVE SAVE CRANE
EQUIPMENT	MSB’S		8 COMPRESSORS	4-6" PUMPS	U/W TORCHES 60-TON CRANE	U/W TORCH 100-TON CRANE (ARMY)
TEAM	MSB 102, 127	EOD MU 11	1	3	1	2
PRIORITY	1	1	2	4	3	1
COMMENT	COMPLETE	IN PROGRESS	COMPLETE	START 8/7	IN PROGRESS	IN PROGRESS

Figure 2-1. Harbor Clearance Sample Summary Sheet.

2-4.2.1 **Preliminary Survey.** The preliminary survey, or "desktop survey" verifies information received from the casualty, ship's company, owners or other observers. All reports should be checked because preliminary observations may no longer pertain or information important to salvors may have been overlooked. This survey should be conducted to assemble as much documented information as possible about the vessel, its contents, and the salvage site. The documented information aids in initial evaluation of the situation and provides starting points for detailed surveys.

The preliminary survey should begin before salvage resources arrive. Intact ship information for naval ships may be obtained from squadron maintenance officers, ships of the same class, or the Naval Sea Systems Command. Merchant ship engineering information can be obtained from the ship owners or their agents. Information on many merchant vessels is also available through the U.S. Coast Guard Headquarters or the National Cargo Bureau and the classification society registers. Aerial or satellite reconnaissance of the stranding site can also provide basic information about the casualty. Early information forms a basis for preliminary planning and initial estimates of the effort, time, and assets required for the salvage. The salvage assets dispatched to the scene are determined by the information available at mobilization. The ability of the salvage forces to stabilize the casualty immediately will ultimately play a major role in the success or failure of the salvage operation. The inability to mobilize forces quickly may cause the loss of a fair weather window or play a significant role in the deterioration of the casualty pushing it beyond the point of salvage.

The preliminary survey paints a general picture of the location and disposition of the casualty, pre and post-stranding drafts (if floating).

The specific information gathered in the preliminary survey will vary depending on if the casualty is a stranding, capsized ship or a sinking, but will cover the following areas:

- Date, time, name and type of casualty
- Location (lat/lon and positioning source of information, chart)
- Builder, owner and age of casualty
- Nearest port and nearest U.S. or support Allied Naval facility
- Extent and type of damage to the ship forward, amidships and aft drafts and tide state at time of observation
- Crew status
- Point of contact
- Solid cargo (type, cargo list or manifest, location and amount)
- Hazardous materials (spill likely?) or ammunition onboard
- Status of liquid loading (fuel, fresh water, ballast, other)
- Displacement, tonnage
- Status of ships machinery
- Weather conditions, current and forecast: wind (direction and speed), precipitation, temperature
- Oceanographic conditions, current and at time of stranding: tides (range, reference station and predictions, access to real-time tides), direction and height of seas and swells, currents
- Type of seafloor at site, soundings along the entire length of ship
- Assistance available on scene.

2-4.2.2 **Detailed Survey.** The detailed survey refines the preliminary survey and collects the specific information in the Detailed Survey Form. This includes information on the following areas:

- Topside
- Interior hull (including machinery)
- Diving and exterior hull
- Hydrographic
- Safety.

2-4.2.2.1 **Topside Survey.** The topside survey gathers information about the exterior of the ship above the weather decks. Particular items of concern are:

- The type, location, safe working load, and operating condition of all deck machinery
- The location and estimated safe working load of tug and beach gear attachment points including working space for pulling devices
- The location and estimated weight of top hamper and superstructure if it appears that topside weight must be removed
- The operating condition of the ship's boats.

2-4.2.2.2 **Interior Hull Survey.** The interior hull survey includes the machinery status and condition, which are of great interest to the salvor. The availability of electrical power, compressed air, deck machinery, pumps and other equipment can greatly simplify the salvor's job. Operational propulsion machinery can assist the refloat effort and control the casualty once it is free from the beach.

The total value of the casualty may be significantly affected by the condition of the machinery plant. For example, refrigerated goods may require certain equipment to prevent degradation or hazard formation. The operating condition of the ventilation systems can effect the accumulation of dangerous gasses. These gasses need to be identified and taken into consideration during the salvage operations.

CAUTION

Interior spaces, holds, tanks, or voids should never be entered until it has been determined positively that they contain safe breathable atmosphere, or until all hands are equipped with and are using protective equipment and comply with Chapter 6 of the *U.S. Navy Salvage Safety Manual* (S0400-AA-SAF-010).

CAUTION

Flooding can severely damage machinery if the water level rises and falls, exposing saltwater-drenched machinery to the air.

Casualty machinery should not be operated without the concurrence of the ships officers. Machinery to be operated should be inspected for proper alignment to ensure cooling water, fuel, and lubrication systems are operational. Hull damage can disrupt machinery alignment. Undamaged machinery in dry spaces can be rendered inoperative if sea chests are blocked or later silted up. Machinery can be severely damaged if operated without cooling water (It is often possible to use portable salvage pumps to supply cooling water through direct connections or deck fittings). Boiler, gas turbine, and diesel engine fuel supplies may be lost or contaminated on stranding. Improvised fuel systems may be required to restore operations.

The interior hull survey gathers information about the interior of the ship and its contents. The interior survey includes:

- Examining in detail the condition and contents of every space below the main deck
- Soundings of all spaces containing liquids
- Determining the condition of the main drain system and its equipment
- Determining the location and operating condition of all cargo and ballast pumps and the arrangement of associated piping and manifolds
- Determining the location and condition of all cargo and stores and obvious hazards such as flammables and chemicals
- Determining the location, weight, cube, and class of all ammunition magazines and the operating status of the magazine sprinkler systems and location of their controls
- Determining the location of all structural damage: holes, tears, cracks, weeping seams, panting bulkheads, etc.
- Determining the location, type, and estimated weight of loose or displaced cargo or equipment
- Investigating items of special interest, such as interior areas to rig beach gear or places to cut holes for connecting points
- Determining the availability and location of material that may be useful in salvage.
- Determining the location and size of any cross-connections for liquid tanks that could be closed or left open.

2-4.2.2.3 Diving and Exterior Hull Survey. The diving survey includes the underwater portions of the ship's hull and the exterior portion of the hull below the main deck. The latter is not normally underwater but is included in the same survey for continuity and convenience. In some cases, sea conditions may be such that diving operations are either impossible or severely limited. In such cases, the interior survey must be especially comprehensive, and conclusions about the bottom may have to be drawn from topside observations alone. The diving survey includes:

- The amount of the hull in contact with the seafloor and a description of the points of contact
- The existence and location of pinnacles
- The existence and location of impalement
- The location and size of all cracks, tears, and holes in the underwater portion of the hull and in the portion between the waterline and the weather deck
- The condition of all sea suctions, valves, and fittings and whether or not they are clear
- The condition and operability of all underwater appendages, including bilge keels, sonar domes, sensors, stabilizers, rudders, shafting and bearings, and propellers
- Signs of leaks or escaping fuels, pollutants, or liquids
- The type of seafloor soil and the presence, location, and extent of scouring or buildup.

2-4.2.2.4 Hydrographic Survey. The hydrographic survey documents the condition of the sea and seafloor in the area where operations will be taking place. Included in the hydrographic survey are:

- Comparison of the observed tides with the predicted tidal information
- Determining the strength, period, and times of local currents, and the durations of high and low water slack and their relationship to the times of high and low tide
- Periodic observations of the sea and swell height period and direction of seas, and their impact on the salvage operation
- Soundings all around the stranded ship in the area where beach gear will be laid, and in the area in which salvage or other ships will operate
- A seafloor profile chart of the beach gear area to assist in design of the beach gear legs
- When possible, a multi-beam sonar survey of the submerged wreck and surrounding area.

2-4.2.2.5 Safety Survey. A site survey, including a thorough risk assessment, is made by the first team to arrive at the salvage site. The safety officer shall utilize the Navy's Operational Risk Management (ORM) Policy as defined in OPNAV 3500.39 to determine applicable safety requirements and ensure all identified hazards/risks, assessments and controls are provide to the salvage officer for incorporation into briefs, notices and written plans and the salvage plan.

2-4.3 Survey Forms. Collected information will be somewhat different for sunken ships than for stranded ships. Appendices K and L contain comprehensive salvage survey forms for sinking or stranded ships. As with the form for stranded ships, this form may be modified to fit the circumstances. In surveying sunken ships, survey teams probably will be prohibited from making an orientation walk-through of the ship and usually will not have access to the ship’s officers. Survey teams must be led by experienced salvors knowledgeable in ship construction who can develop a picture of the condition of the ship based on the information that the survey team obtains.

2-4.4 Survey Teams. Rapid, accurate gathering of information requires well-organized and highly trained survey teams. Information is prioritized so that the most important information is obtained first. Personnel making salvage surveys are organized into teams qualified to look at the portion of the ship that they will be surveying.

A pre-survey orientation walk-through of a stranded ship with its crew, if available, is essential on large ships and valuable on all ships. The salvage officer must personally make a complete walk-through of the stranded ship, preferably in company with his most experienced people and the stranded ship's officers. First-hand knowledge is necessary to fitting survey reports together.

Personnel who know hull and machinery systems should make the interior survey. Personnel with experience maintaining and operating deck machinery and rigging systems are the best members for the topside survey team.

The diving team makes the underwater portion of the survey and surveys the exterior portion of the hull between the waterline and the main deck. Because of the difficulty of obtaining accurate information underwater, the diving team should be led by an especially experienced salvor.

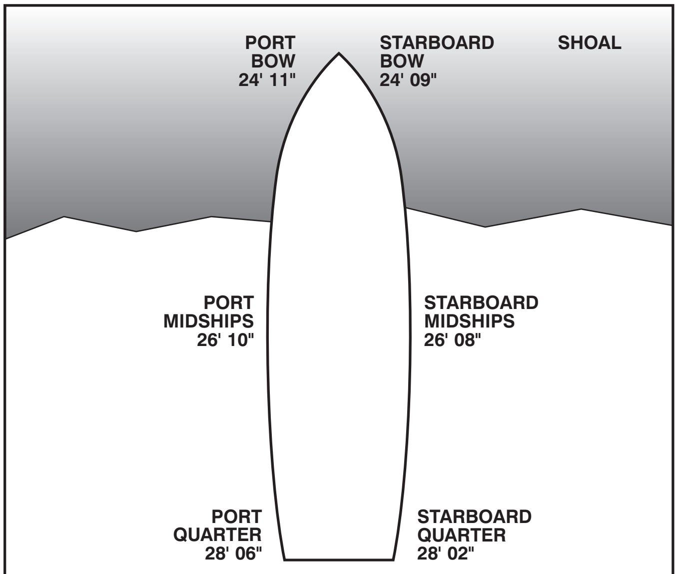

Figure 2-2. Drafts of Ship for Example 2-1.

2-4.5 Survey Techniques. This chapter serves as a reference guide for salvage surveys, however, survey technique vary from salvor to salvor and depend upon the casualty itself. There are ideas and techniques for making surveys that have proven useful through the years. Some of these are described in this section; the list is not all-inclusive. Salvors should consider the following bullets as a starting point from which to develop their own methods as their experience grows:

- **Obtain Accurate Casualty Drafts.** Obtaining accurate stranded drafts is difficult, but they form the basis for many salvage calculations. For instance, the ground reaction calculation is dependent on drafts; ground reaction shapes much of the operation. Effort expended to obtain accurate grounded drafts is well spent.

  (1) The Mean-of-Quarter-Means Method is the most accurate method of determining a casualty's draft. In this method:

  (a) A series of readings are taken at stations on each bow, each quarter, and each side amidships as shown in Figure 2-2. Ten readings are taken at the top of the swell and ten readings are taken in the trough. The readings at each station are averaged to determine the draft at that station.

  (b) The averages on the port and starboard bows are then averaged to determine the draft forward; similarly, the port and starboard drafts aft are averaged to determine the draft aft.

  (c) The forward and after drafts are averaged.

  (d) The observed drafts on the port and starboard sides amidships are averaged.

  (e) The results obtained in steps c and d are averaged.

  (f) The average of the results obtained in steps d and e are averaged to obtain the draft used for salvage calculations.

  (2) In swells, draft readings taken from a boat are the most accurate.

  (3) Whenever drafts are taken, the time, date, and state of the tide are recorded and drafts are reduced to the tide datum; normally that datum is the same as that of charts of the local area. Reduction to the tide datum is required because the draft readings of a stranded ship vary with the tide. When ground reaction at datum is known, the effect of tide on ground reaction can be determined.

EXAMPLE 2-1
CALCULATION OF MEAN DRAFT – MEAN-OF-QUARTER METHOD

A ship is grounded as shown in Figure 2-2. The average of ten draft readings, taken at the top and bottom of the swell, gives the following results:

Starboard bow	24’09"
Port bow	24’11"
Starboard Midships	26’08"
Port Midships	26’10"
Starboard quarter	28’02"
Port quarter	28’06"

Determine the mean draft for salvage calculations by the mean-of-quarter-means method.

a. Step a, averaging of readings taken on the top and bottom of the swell has been performed in the data given.

b. Average the drafts on the port and starboard bow and the drafts on the port and starboard quarters to determine the drafts forward and aft:

Starboard bow	24’09"	Starboard quarter	28’02"
Port bow	24’11"	Port quarter	28’06"
Draft forward	24’10"	Draft aft	28’04"

c. Average the forward and after drafts:

Draft forward	24’10"
Draft aft	28’04"
Average	26’07"

CONTINUED ON NEXT PAGE

EXAMPLE 2-1 (CONTINUED)
CALCULATION OF MEAN DRAFT – MEAN-OF-QUARTER METHOD

d. Average the observed drafts amidships:

Starboard amidships	26'08"
Port amidships	26'10"
Average	26'09"

e. Average the results of steps c and d:

Result of step c	26'07"
Result of step d	26'09"
Average	26'08"

f. Average the results of steps d and e:

Result of step d	26'09"
Result of step e	26'08"
Mean draft	26'08.5"

NOTE

The amidships draft, determined by averaging draft readings amidships, may not be the same as the mean draft determined by taking the mean-of-the-forward and -after draft. The difference may be accounted for by hog or sag of the ship's hull. The salvage officer should look for conditions of loading or of the grounding that explain the hog or sag.

- **Determine Ship Movement.** Early in the salvage operation, it should be determined if the ship is moving. The fastest way to get an indication of movement is to select ranges from natural landmarks, or, if the depth of water permits, establish reference pole ranges and observe if the ship falls off the ranges. One range should parallel the ship's centerline and another should be on the beam. Alternatively, the heading and bearings of fixed, easily identifiable objects should be recorded at regular short intervals. When no movement is observed for some time, the interval between readings may be increased.

- **Determine Hogging and Sagging.** If the hull is lifting to the rising tide or swells, the hull should be checked for hogging or sagging. Dial indicators installed between frames measure deflection of the hull. Increases in hull deflection indicate an increase in hull stresses. Sudden increases may indicate that the stresses are increasing sharply, that hull failure is possible, and that changes in loading must be made quickly to reduce stresses.

- **Note Hull Stress or Distortion.** Reports of damage prepared by the ship can assist in prioritizing areas to be surveyed. Particular attention should be paid to secondary damage such as abnormal bulkhead flexing, cracked seams, hatches and doors that no longer close, cracking or flaking paint, or other signs of stress or hull distortion. As these items may indicate more serious damage, their cause should be determined. The diving team should be briefed on the location and type of all damage found inside the hull so that they may check for underwater damage in the same areas. Frame numbers, spray-painted on the hull, help diving boat crews to orient themselves along the length of the ship.

- **Compare Compartment Names Against Ships General Arrangement Plans.** During the internal survey, all compartment names and numbers should be verified against the ship's general arrangement plans. An adhesive sticker or spray of paint next to the label plate will indicate the space has been examined. Ship's plans should be marked with the locations of all sounding tubes, access hatches, watertight fittings, fire stations, electrical control boxes, deck drains, and other items of interest. Damage control compartment check-off sheets in naval ships are excellent sources of information on these items. The compartment check-off list must be verified against the actual locations.

- **Sound Tanks.** All tanks should be sounded frequently and the soundings compared to those taken before and since the stranding. In fuel and other oil tanks, the presence of water should be checked with indicator paste, thief samples, or by opening the tanks.

- **Take Underwater Video.** Whenever possible, video should be used for underwater surveys. Video — particularly low-light-level video — has greater sensitivity and can record more detail than the diver's eye. Videotapes can be reviewed repeatedly at the convenience of the viewers. Technical personnel who are not divers may get a direct visual impression of the condition of the underwater hull. Videotapes of areas of the hull in contact with the seafloor, of underwater damage, and of hull appendages and openings are particularly valuable.

- **Install Tide Gage.** Tides may vary, both in height and time, from those predicted in the tide tables. A tide gage, like the one described in Chapter 5, should be set up, and regular readings taken and compared to predicted tides. Local mariners can often provide the best information about tides and currents at the stranding site.

- **Take Soundings or Perform Hydrographic Survey.** A small boat equipped with a portable depth finder calibrated to the sea surface speeds up the hydrographic survey. The depth finder's accuracy should be confirmed periodically with a sounding lead. Soundings are reduced to the chart datum and plotted on a large-scale chart or plotting sheet. All pinnacles, coral heads, reef edges, shoals, and other underwater hazards are marked with a buoy or highly visible pole. If barges or other ships must be brought alongside the stranded ship to ensure there is sufficient water to approach, lie alongside without bottoming, and retract after loading, salvors should make a particularly thorough depth survey of the area to be used is made.

- **Recheck.** Checks and rechecks on the initial survey will result in several visits to the same areas. Uniform observations will result if the same team repeats the surveys and each member is responsible for specific items.

2-4.6 Correlation of Survey Information. The survey will produce a great deal of information that must be assembled, analyzed, and presented in a way that will be useful during the development of the salvage plan and can be easily revised and available during the operation. Graphic methods are particularly appropriate for assembling and presenting survey information. Some methods that have proven successful include:

- A master status board displaying the most significant information. (The status board should include information in which changes may impact the operation. Such information may include tank soundings, deck machinery status, ballast condition, cargo offload, etc. Major tasks and the target dates for their completion and a daily schedule of activities should be included. The status board should be displayed where all salvage personnel can see it.)
- Marked-up profile and plan views of the ship showing damage, flooded spaces, patches, repairs, work-arounds, etc. (These should be kept up to date as the operation progresses. Damage control plates on Naval ships give three-dimensional views and are well suited to this use.)
- Computer programs for salvage operations currently exist and are effective. These programs are excellent ways to store, retrieve, and manipulate data from the surveys and to convert them into a useful format.

2-4.7 Retention of Information. An accurate historical file must be maintained of all surveys, salvage plans, actions taken, and equipment and material used during the operation.

Photographs and video tapes are to be included in the file. This information will be used in preparing the final salvage report and as support documentation when requesting reimbursement.

2-5 THE SALVAGE PLAN.

The salvage plan enumerates the work to be done, matches it with the resources available, schedules it, sets forth the responsibilities of individuals and organizations, and provides a vehicle for coordination of all salvage efforts to meet target dates and times. The development of the salvage plan begins when the initial information about the casualty is received and continues throughout the operation. A good salvage plan:

- Takes personnel safety into consideration
- Coordinates harbor clearance work with operational requirements of port users and other work in progress in the port
- Includes work schedules
- Includes cost estimates
- Identifies, assigns, and schedules resources
- Is dynamic and subject to constant revision
- Identifies areas of weakness
- Is the responsibility of, and is approved by, the senior salvage officer.

2-5.1 The Planning Process. The steps in the planning process are:

a. Selecting the techniques that will be employed.

b. Dividing the techniques into logical steps or tasks.

c. Correlating the information gathered in the surveys with each task.

d. Estimating the time to complete each task.

e. Organizing the tasks into a schedule (First, tasks that must be completed in sequence are scheduled in order. Next, tasks that can start or finish independently or in parallel with other tasks are scheduled).

f. Matching equipment and personnel with tasks to obtain the most efficient combination (Rearrangement of the schedule may be required to balance the tasks with resources).

g. Selecting a target refloating date that balances preparations with the maximum expected tides (Factors such as having a dry-dock available, weather, or permission to enter a safe haven may influence the target date).

h. Improving the completion date by reevaluating the plan to revise the organization of tasks and the allocation of resources.

2-5.2 Salvage Plan Development. Development of the salvage plan parallels the salvage operation. A preliminary salvage plan develops during the early portion of the stabilization phase and evolves into a detailed plan for refloating.

The preliminary plan develops as information is received from the stranded ship and is confirmed in the surveys. This plan forms the foundation of the refloating plan.

The refloating plan divides the refloating effort into logical tasks and schedules them in the order in which they are to be completed.

Choices must be made during the salvage plan development whether tasks are to be performed in parallel or sequentially. The choice is influenced by the experience and composition of the salvage crew. To expedite the operation, many tasks should be performed in parallel with adequate supervision and without mutual interference and a decline in safety. Many salvage operations have been delayed because of attempts to undertake more tasks simultaneously than could be coordinated. During critical portions of the operation, the number of tasks undertaken in parallel should be minimized.

2-5.3 Salvage Plan Organization. The salvage plan has two major parts: the main body of the plan and the supporting annexes. The main body contains the following:

- Basic information to identify the ship and the condition of the stranding, such as the ship's name, dimensions, hydrostatic data, location of stranding, etc.
- An engineering estimate prepared by the salvage engineer or the senior salvage officer, that specifically includes calculations for:
  (1) The ground reaction
  (2) The freeing force
  (3) Location of the neutral loading point, if applicable
  (4) Stability — both aground and afloat
  (5) Strength of the hull girder, damaged areas, attachment points, and rigging
  (6) A summary of the rationale for selection of specific retraction and refloating techniques based on sound engineering practices

(7) Hydrographic information, including data gathered during the detailed hydrographic survey, displayed in appropriate charts and tables. Dangerous waters, danger bearings, danger sectors and other navigation information should be provided for use by ships and boats engaged in the salvage operation. Action taken to mark isolated dangers, establish tide gages, navigational ranges, etc., is included.

- Potential pollution and specific pollution control techniques and response resources, and pollution control's impact on the salvage operation.
- The results of the safety survey and the safety officer's recommendations should be detailed with specific hazards identified and precautions listed. Action necessary to comply with the recommendations, including safety briefings and training, is listed.

The supporting annexes are detailed plans for each refloating technique used. Some of these annexes may be subdivided into appendices or additional annexes if the scope of the task warrants. The more complex the operation, the greater the number of supporting annexes. The annexes should contain a list of all tasks, the order in which they will be accomplished, the resources assigned to each task, a schedule, and assignment of responsibilities by name or job title. Integration with and interfaces between techniques described by other annexes should be identified.

When the size and complexity of the operation requires an intense management effort, a separate coordination annex is prepared. A task list showing start times, duration and completion times, and a supporting resource list showing equipment and personnel assigned to each task, is included, along with the task sequence and a task-versus-time chart.

As the salvage plan and its supporting annexes are being developed, the salvage teams commence work. Often, the work will begin before the annex is complete. Close supervision of work started before the completion of planning is necessary to ensure the work remains in conformance with the plan and its intent so that effort is not wasted.

2-5.4 Summary. Ship salvage is difficult and complex work that requires careful planning. Although a good salvage plan will not ensure success, an operation that is not well planned and thought-out has little chance of success. The survey and the planning processes are dynamic. Several surveys will be taken in the course of the salvage operation and the original salvage plan may be modified as circumstances dictate.

2-6 SALVAGE REPORTS.

Following the operation, reports are prepared in compliance with Commander, Naval Sea Systems Command Instruction 4740.8 (series) and other current directives. The reports are used as:

- Historical records of operations
- Training documents
- A basis for reimbursement of participating units for equipment losses and out-of-pocket expenses
- A basis for claiming reimbursement to the Navy for operations undertaken for other Government agencies, foreign governments, or commercial interests.

A sound salvage plan, a well-executed operation, and a correctly prepared report are hallmarks of professionalism.

2-6.1 The Post Salvage Operations Report. The Post Salvage Operations Report is a letter report submitted to Commander, Naval Sea Systems Command following each salvage operation. The report may be used outside the Navy and should be complete, accurate, and explicit in detail. The purposes of this report are to:

- Provide a basis for reimbursement to the Navy for salvage costs or for a salvage claim by the Navy against the owner when vessels other than Navy ships are salvaged
- Provide a basis for reimbursement of participating units for equipment losses and out-of-pocket expenses
- Document salvage efforts that may be used in litigation
- Document the operation and its costs for fiscal support
- Document the operation for historical and training purposes.

Section 4 of Commander, Naval Sea Systems Command Instruction 4740.8 (series) provides detailed preparation and submission procedures for the Post Salvage Operation Report.

2-6.2 The Salvage Technical Report. The Salvage Technical Report is an optional letter report submitted to Commander, Naval Sea Systems Command following each salvage operation or at any other time. This report is intended for the internal use of naval activities. The purposes of this report are to:

- Provide information on the performance of salvage equipment to the Supervisor of Salvage
- Provide information on both effective and ineffective salvage techniques and procedures
- Provide information on safety problems and solutions
- Provide recommendations based on field experience, which will improve the effectiveness of salvage equipment and procedures.

Section 5 of Commander, Naval Sea Systems Command Instruction 4740.8 (series) provides detailed preparation and submission procedures for the Salvage Technical Report.

Salvage reports are important documents and deserve careful preparation and close attention to detail and accuracy. Good salvage reports are as much the mark of a professional salvor as a well-executed salvage operation.

Examples of Salvage Reports and Salvage Technical Reports are included in Volume 1 of the *U.S. Navy Salvage Manual* series. Supervisor of Salvage office is the contact point for all salvage reports and technical reports. TWA Flight 800 Salvage Report, can be accessed online under the Supervisor of Salvage URL www.supsalv.org/.

CHAPTER 3
BASIC SALVAGE NAVAL ARCHITECTURE

3-1 INTRODUCTION.

This chapter addresses the geometry of ships and how the properties of ships are determined or calculated. Chapters 2 through 4 present ship stability, the effects of weight, and basic ship strength. Subsequent chapters of this volume and other volumes of the *U.S. Navy Salvage Manual* address conditions found on certain kinds of casualties. These first four chapters are background for them all and should be used with later chapters in this volume and those in other volumes. In many situations, the complexity of required salvage calculations exceeds the scope of this *U.S. Navy Salvage Manual* series. In those instances, the services of a salvage engineer or naval architect should be obtained.

Salvors of damaged, stranded, or sunken ships need a basic understanding of the geometry, stability, and strength of intact ships. Armed with such an understanding, salvors can appreciate how those properties vary in a ship to be salvaged. Understanding the properties of intact ships allows salvors to:

- Make soundly based approximations and assumptions which ensure that calculations are on the "safe side"
- Understand the behavior of the damaged ship
- Have greater skill as salvors.

Ship calculations made in the field on salvage jobs are not the same precise calculations made in a design office. Approximations and assumptions based on information obtainable at the scene must be made.

3-2 THE GEOMETRY OF SHIPS.

For any ship, the hull form chosen by the designer determines the stability and strength characteristics. To work effectively with these characteristics, the form of the ship must be described in a standard way. A ship is a complex shape that can be accurately defined by comparing it with two- and three-dimensional figures. Knowledge of the geometry of ships is necessary to the understanding of ship stability and strength.

3-2.1 Location of Points Within a Ship. Because a ship is a three-dimensional object, references must be established for locating points in, on, and about the ship. The position of any point in the ship can be described by measuring its position from reference lines and planes.

3-2.1.1 Reference Lines and Planes. The reference lines and planes used to locate points on ships are:

- The Forward Perpendicular (FP): A vertical line through the forward extremity of the design waterline — the waterline at which the ship is designed to float.
- The After Perpendicular (AP): A vertical line at or near the stern of the ship. In naval practice, the after perpendicular is through the after extremity of the design waterline, while in merchant practice the after perpendicular usually passes through the rudder post.
- The Midships Section (MS): A plane passed athwartships halfway between the forward and after perpendiculars.
- The Centerline (CL): A vertical plane passing fore and aft down the center of a ship.
- The Baseline (BL): A fore-and-aft line passing through the lowest point of the hull.

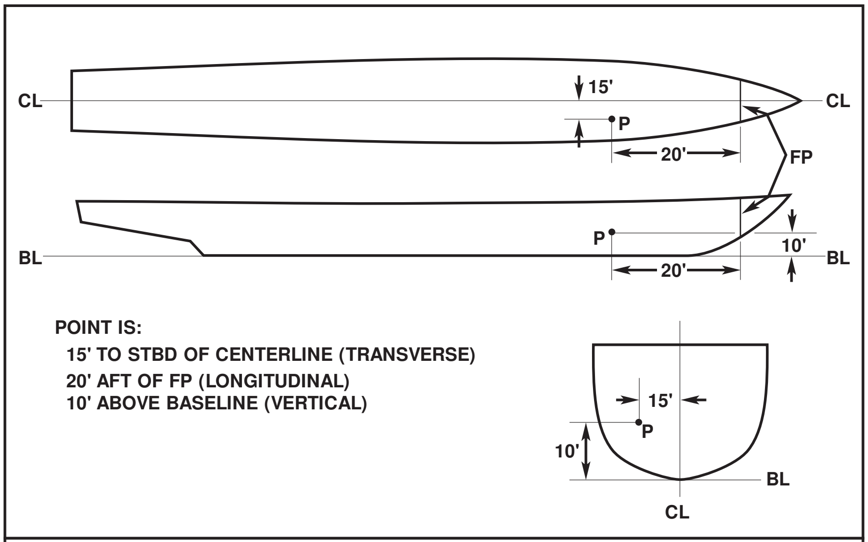

Figure 3-1. Locating a Point In or About a Ship.

3-2.1.2 Location of Points. The position of any point in the ship can be described by measuring its:

- Height above the baseline or keel
- Position to either side of the centerline
- Position fore and aft from the midships section or from one of the perpendiculars.

For instance, a point may be 10 feet above the baseline, 15 feet to starboard, and 20 feet abaft the forward perpendicular. Figure 3-1 shows where this point lies and how the three coordinates describe its exact position.

3-2.2 Measurement of Ships. In describing a ship, some special terms and relationships are used that have precise meanings. The salvor must be familiar with these terms to understand the principles that are being discussed. This paragraph defines some of the terms used in describing the geometry of ships.

3-2.2.1 Principal Dimensions. The principal dimensions of a ship are length between perpendiculars, beam, draft, and depth. These quantities are defined as:

- Length Between Perpendiculars (LBP or L): The horizontal distance between the forward and after perpendiculars is the length between perpendiculars. Length between perpendiculars is measured in feet.

- Beam (B): The breadth of the ship at the broadest point is the beam. Beam is measured in feet.

- Draft (T): The vertical distance between the waterline and the deepest part of the ship at any point along the length is the draft. Draft is measured in feet. Drafts are usually measured at the forward (draft forward, T_f) and the after perpendiculars (draft aft, T_a). The mean draft (T_m), frequently used in salvage calculations, is the average of the forward and after drafts. The draft is assumed to be the mean draft if the point at which the draft is taken is not specified. The navigational draft of a ship accounts for sonar domes, pit swords, and other underwater appendages. The navigational draft is never used for salvage calculations.

- Depth (D): The distance between the baseline and the uppermost watertight deck is the depth. Depth is measured in feet.

3-2.2.2 Other Measurements. Some other measurements, in addition to the principal dimensions, used in describing ships include:

- Length Overall (LOA): The extreme length of the ship along the centerline is the length overall. Length overall is measured in feet.

- Length on Design Load Waterline (LWL): The length along the centerline at the waterline in the ship's design loaded condition is the length on design load waterline. Length on design load waterline is measured in feet.

- Freeboard (F): The distance between the waterline and the uppermost watertight deck at any location along the ship is freeboard. Freeboard is measured in feet.

- Displacement Volume (V): The displacement volume is the total volume of the underwater hull. Displacement volume is measured in cubic feet.

- Displacement (W): The displacement is the weight of the ship and all cargo on board and is measured in weight units, usually in long tons of 2,240 pounds. Displacement is directly related to displacement volume and is normally obtained by dividing the displacement volume by 35, the number of cubic feet of saltwater in a long ton. When the ship is in fresh water, displacement is obtained by dividing by 35.9 (commonly rounded to 36).

- Buoyancy: Any ship partially or wholly immersed in water will experience an upward push called buoyancy. The force of buoyancy is equal to the weight of the volume of water the ship displaces.

- Reserve Buoyancy: The watertight volume between the waterline and the uppermost continuous watertight deck is the reserve buoyancy of the ship. It is available to enable the ship to take on additional weight.

- Moment of Inertia (I): The moment of inertia is a measurement of a plane surface's resistance to rotation about an axis in the same plane. The magnitude of moment of inertia depends upon the shape of the surface and varies with the axis used for rotation. The moment of inertia is measured in the fourth power of a linear unit such as $feet^4$ or $inches^4$ or a combination of both.

- Tonnage: Tonnage is a description of the cargo capacity of a merchant ship. Tonnage is a volume measurement and does not indicate displacement.

- Trim: Trim is fore-and-aft inclination. Trim is measured as the difference between the drafts at the forward and after perpendiculars. Ships designed to have drag (a deeper draft aft than forward) have zero trim when floating at or parallel to the design drafts. Excessive trim, usually considered to be more than one percent of the length of the ship, can be dangerous because it increases the danger of plunging (sinking by the bow or stern).

Calculated values can be no more accurate than the measurements upon which they are based. Final values should be rounded to the precision of the least accurate measurement. If, for example, the long side of a rectangle is measured to within the nearest half foot, and the short side to within the nearest inch, the calculated area should be rounded to the nearest half square foot.

The effects of accuracy should be taken into account when making measurements and calculations. Longitudinal ship dimensions and stability parameters are usually much larger than their transverse and vertical counterparts. A 5-foot variance in the measurement of the length of a 400-foot ship gives an error of only 1.25 percent, while a 5-foot variance in the measurement of the same ship's 50-foot beam represents a 10 percent error. In general, longitudinal measurements and calculations can be taken to the nearest foot. Transverse and vertical measurements should be accurate to the nearest inch to support calculated values to the nearest inch or tenth of foot.

When measurements and calculated values are converted to different units, the answer should be carried to the number of decimal places that will maintain the same precision. For example, an inch is one-twelfth, or approximately one-tenth of a foot. A measurement taken to the nearest inch should be rounded to the nearest tenth when converted to feet. In the same manner, measurements made to the nearest eighth-inch should be rounded to the nearest hundredth-foot, while measurements to the nearest sixteenth-inch should be rounded to the nearest five-thousandths (0.005) of a foot. This is particularly important when very precise plating thickness, normally measured in inches, is converted to feet.

3-2.3 Coefficients of Form. Coefficients of form are dimensionless numbers. When multiplied by the appropriate principal dimensions, they yield the areas and volumes of the hull. Coefficients of form are developed from the line plans by calculating an area or volume for the actual hull form and then dividing it by the area or volume of a geometric body formed by the principal dimensions. The following paragraphs describe the coefficients commonly used in salvage. Table 3-1 gives sample coefficients for different types of ships.

Table 3-1. Sample Coefficients of Form.

Type Ship	Block Coefficient C_B	Midships Coefficient C_M	Waterplane Coefficient C_{WP}
Cruise Ship	0.597	0.956	0.725
Ocean Cargo	0.775	0.992	0.848
Tanker	0.757	0.978	0.845
Replenishment Ship (AOR-1 Class)	0.646	0.980	0.981
Great Lakes Freighter	0.874	0.990	0.918
Aircraft Carrier (CV-59 Class)	0.578	0.984	0.729
Battleship (BB-61 Class)	0.594	1.000	0.694
Cruiser (CGN-38 Class)	0.510	0.810	0.780
Destroyer (DD-963 Class)	0.510	0.850	0.760
Frigate (FFG-7 Class)	0.470	0.770	0.750
Harbor Tug	0.585	0.892	0.800

Coefficients of form for all U.S. Navy ships can be obtained from Naval Sea Systems Command, Code 55W. Coefficients of form for merchant vessels are available from the National Cargo Bureau, telephone (212) 785-8300. The name and type of vessel must be provided to access the data files.

3-2.3.1 Block Coefficient (C_B). The block coefficient is the ratio of the volume of a ship at a particular draft to a rectangular block of the same length, breadth, and draft as the ship. Block coefficient varies from about 0.5 for a fine-lined ship to 1.0 for a rectangular barge. The block coefficient allows displacement to be determined directly from the principal dimensions. The block coefficient is equal to:

$$C_B = \frac{V}{L \times B \times T}$$

To determine displacement:

$$V = C_B \times L \times B \times T$$

$$W = \frac{C_B \times L \times B \times T}{35} \text{ (saltwater)}$$

$$W = \frac{C_B \times L \times B \times T}{36} \text{ (fresh water)}$$

Figure 3-2 shows the block coefficient relationship.

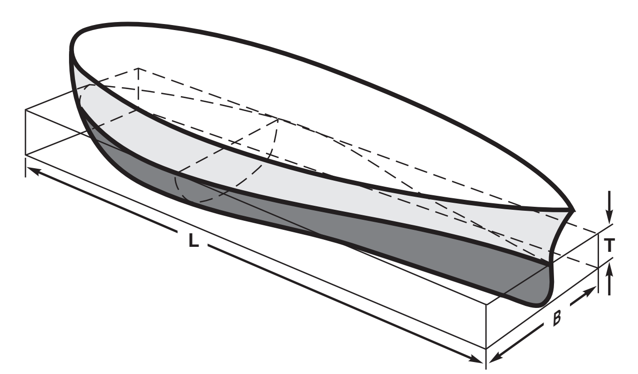

Figure 3-2. Block Coefficient Relationship.

NOTE

A ship passing from saltwater into fresh water will not change displacement but will change displacement volume. The draft will increase in the ratio 36/35. When the ship passes from fresh water to saltwater, the ratio is reversed to 35/36 to determine the decrease in draft.

NOTE

Throughout these first four chapters, a single method of making calculations is presented. Other methods exist and may be useful under certain circumstances. A summary of other relationships is given in Appendix C without detailed explanations.

EXAMPLE 3-1
CALCULATION OF DISPLACEMENT VOLUME AND DISPLACEMENT

A ship is 500 feet long with a beam of 52 feet and a draft of 22 feet; the block coefficient is 0.75. What is the:

a. Displacement volume?

b. Displacement in saltwater?

c. Displacement in fresh water?

(1) Displacement Volume

$$V = C_B \times L \times B \times T$$

where:
C_B = Block Coefficient - 0.75
L = Length - 500 feet
B = Beam – 52 feet
T = Draft - 22 feet

V = 0.75 x 500 x 52 x 22
V = 429,000 cubic feet

(2) Displacement in Saltwater

$$W = \frac{V}{35} \text{ saltwater}$$

$$W = 12{,}257 \text{ tons}$$

(3) Displacement in Fresh Water

$$Wf = \frac{V}{36} \text{ fresh water}$$

$$Wf = 11{,}917 \text{ tons}$$

3-2.3.2 Midships Section Coefficient (C_M). The midships section coefficient is the ratio of the area of the midships section (A_M) at a particular draft, to a rectangle of the same draft and breadth of the ship. The midships section coefficient varies from about 0.8 for fine-lined ships to 1.0 for a rectangular barge. C_M is equal to:

$$C_M = \frac{A_M}{B \times T}$$

Figure 3-3 shows the midships coefficient relationship.

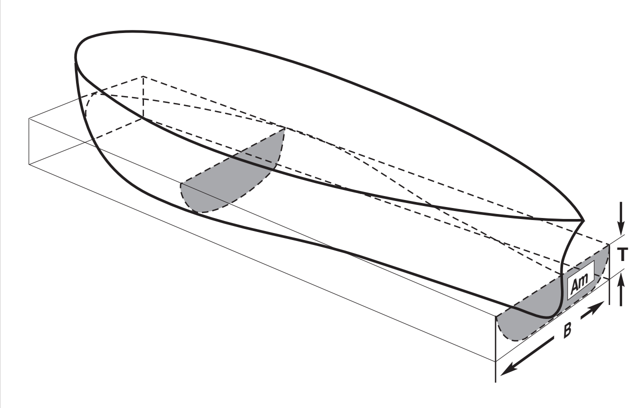

Figure 3-3. Midships Coefficient Relationship.

3-2.3.3 Waterplane Coefficient (C_{WP}). The waterplane coefficient is the ratio of the area of the waterplane, (A_{WP}), to a rectangle of the same length and breadth of the ship. The waterplane coefficient varies from about 0.7 for a fine-lined ship to 1.0 for a rectangular barge. C_{WP} is equal to:

$$C_{WP} = \frac{A_{WP}}{L \times B}$$

Figure 3-4 shows the waterplane coefficient relationship.

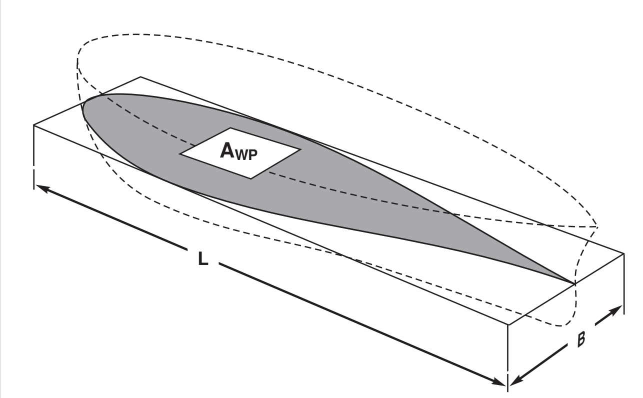

Figure 3-4. Waterplane Coefficient Relationship.

3-2.3.4 Tons Per Inch Immersion (TPI). One of the most useful characteristics of a ship is tons per inch immersion, or the amount of weight that when added or removed from the ship will change its draft by one inch. Tons per inch immersion is measured in long tons. To understand the principle of tons per inch immersion, consider a barge with straight sides and ends:

The fresh water displacement of this barge is:

$$W = \frac{C_B \times L \times B \times T}{35}$$

Since C_B = 1.00 for the barge described, the displacement is equal to:

$$W = \frac{L \times B \times T}{35}$$

Then for any one-foot slice of the barge, T = 1 and the displacement of that slice becomes:

$$W = \frac{L \times B}{35}$$

Carrying the logic one step further so that the slice is now one inch thick, and recognizing that for the barge L x B = A_{WP}, or the area of the waterplane, the displacement of the slice becomes:

$$W = \frac{A_{WP}}{35 \times 12}$$

The displacement of the one-inch slice is the amount of weight that must be added or removed from the ship in order to change the draft one inch. This is the tons per inch immersion. For a ship shape, it is expressed as:

$$TPI = \frac{A_{WP}}{35 \times 12} \quad or \quad TPI = \frac{C_{WP} \times L \times B}{35 \times 12} \quad and \quad TPI = \frac{A_{WP}}{420}$$

EXAMPLE 3-2
CALCULATION OF TONS PER INCH IMMERSION

A ship is 350 feet long with a beam of 42 feet. The waterplane coefficient is 0.75. What is the tons per inch immersion?

$$TPI = \frac{CWP \times L \times B}{420}$$

$$TPI = \frac{0.75 \times 350 \times 42}{420}$$

$$TPI = 26.25$$

3-3 SOURCES OF INFORMATION.

One of the best places for salvors to find information about the structure of a ship is onboard the ship itself. Information such as curves of form, total displacement, and height of the center of buoyancy above the keel are generally found in the Chief Mate's office or Ships Office. Ships Plans, along with the Trim and Stability booklet, contain the key information needed in the event of a casualty or for planning a salvage operation. Tankers typically have loading instruments indicating which tanks are full and which are empty. This information is vital in determining hull stress. Computer programs such as Cargo Max are used for loading and unloading vessels and utilized in salvage and damage control scenarios. If the ship's plans and other information have been damaged during a catastrophic event, the designated flag state or organization that approved the trim and stability of the ship would be an off-site source of information. For U.S. flagged ships, the U.S. Coast Guard Maritime Safety Center would hold the information. Organizations such as American Bureau of Shipping or Lloyds Register of Shipping may also be excellent sources of ships plans and information for specific ships. Some of the key pieces of information are listed in the following paragraphs.

3-3.1 Curves of Form. The Curves of Form, also called Displacement and Other Curves or Hydrostatic Curves, are graphic representations of the properties of a ship that depend upon the underwater form or shape of the ship. These curves show the variation of the properties of a ship with changes in draft. They are among salvors' most valuable tools because they give exact values of the ship's properties and eliminate the necessity to estimate these properties when making salvage calculations. The vertical scale is feet of mean draft, while the bottom horizontal scale is tons of displacement. When displacement tons are not appropriate units, other scales or scale factors are provided to convert the readings into the proper units. Figure FO-1 is a complete set of Curves of Form for an FFG-7 Class guided missile frigate. In this figure, the curves are labeled by name. A brief explanation of the use of each curve is presented in the following paragraphs.

3-3.1.1 Total Displacement. The displacement curve gives the total displacement of the ship in saltwater. To determine displacement, enter with mean draft and read horizontally across to the curve, then read down to the corresponding displacement. To determine the displacement in fresh water, multiply the displacement in saltwater by 35/36.

3-3.1.2 Height of the Center of Buoyancy above the Keel (VCB). The height of the center of buoyancy is determined by entering with mean draft, reading horizontally to the curve labeled VCB, then reading down to the scale.

3-3.1.3 Longitudinal Position of the Center of Buoyancy (LCB). The longitudinal position of the center of buoyancy is given as a distance abaft the midships section. LCB is determined by entering with mean draft, reading horizontally to the curve, then reading up to the scale.

3-3.1.4 Longitudinal Center of Flotation (LCF). Like the curve for the longitudinal center of buoyancy, the curve for the longitudinal center of flotation provides a position relative to the midships section. The distance is determined the same way as the longitudinal center of buoyancy.

3-3.1.5 Tons Per Inch Immersion (TPI). This curve provides an alternative to the calculation of TPI given in Paragraph 3-2.3.4. To determine TPI, enter with the mean draft, read horizontally to the TPI curve, then read down to the scale. The values given are for saltwater only. Tons per inch immersion in fresh water may be obtained by multiplying the value from the curve by 35/36.

3-3.1.6 Height of the Transverse Metacenter (KM_T). This curve gives the height of the transverse metacenter above the keel. To find the value of KM_T, enter with mean draft, read horizontally to the KM_T curve, then read down to the scale.

3-3.1.7 Moment to Change Trim One Inch (MTI). The approximate moment to change trim one inch is determined by entering with mean draft, reading horizontally to the MTI curve, and reading up to the MTI scale. This value is used in salvage operations to determine the effects on trim of weight removals, additions, or redistribution.

NOTE

Additional information may be found in the Curves of Form of other classes of ships.

3-3.1.8 Displacement Correction for Trim. A correction to displacement for trim is required to obtain total displacement if the longitudinal center of flotation (the point about which the ship trims) is not at the midships section.

Because a ship trims about the center of flotation,

- When the LCF is aft of amidships:
  - (1) Trim by the stern decreases midships draft
  - (2) Trim by the bow increases midships draft
- When the LCF is forward of amidships:
  - (1) Trim by the stern increases midships draft
  - (2) Trim by the bow decreases midships draft.

Displacement increases or decreases in the same way as midships draft.

A correction can be applied to the midships draft to determine an equivalent mean draft that will give an accurate displacement from the displacement curve (defined in Paragraph 3-3.1.1).

The correction is determined by:

$$TC = \frac{dxt}{L}$$

where:

TC	=	Correction to mean draft for trim in inches
d	=	Distance from the midship
t	=	Trim in inches
L	=	Length between perpendiculars in feet

The trim correction is applied to the mean draft to obtain an equivalent mean draft (T_{EQ}) as follows:

$T_{EQ} = T_M + TC$	LCF aft of midships with trim by the stern, or LCF forward of midships with trim by the bow
$T_{EQ} = T_M - TC$	LCF forward of midships with trim by the stern, or LCF aft of midships with trim by the bow

Entering the displacement curve (Paragraph 3-3.1.1) with the equivalent mean draft will give an accurate displacement.

Alternatively, the change in displacement can be calculated by multiplying the trim correction (TC) by the tons per inch immersion (TPI) (defined in Paragraph 3-2.3.4) and adding or subtracting, as appropriate, the product from the original displacement obtained from the curve.

NOTE

This method of calculating the change of displacement with trim is valid only when trim is less than one percent of the ship's length. When trim is greater than one percent of ship's length, an accurate displacement can be obtained only by calculating the displacement directly from the ship's characteristics.

3-3.2 Inclining Experiment. An inclining experiment is a test conducted during construction of a ship, or after major modifications, to determine the stability of the ship. The most important piece of information generated by an inclining experiment is the location of the center of gravity for a given condition of loading. This information is provided in the *Booklet of Inclining Experiment Data* or *Report of Inclining Experiment*, along with other information such as:

- Complete stability information for certain conditions of loading, including maximum and minimum operating conditions
- A detailed statement indicating weight and location of boats, aircraft, ordnance equipment, and permanent ballast
- A summary of the consumable loads such as fuel, water, ammunition, and stores in each condition, including displacement, height of the center of gravity (KG), metacentric height (GM), and drafts for each load condition
- A table of approximate changes in metacentric height due to added weights
- Displacement and other curves
- Curves of statical stability for specified operating conditions
- ASTM Standard F1321-92 for inclining.

It is customary to perform an inclining experiment on only one or two ships of any class, applying the information obtained to all ships of the class. When inclining experiment data is used, any changes made since the experiment must be accounted for.

3-3.3 Stability and Loading Data Booklet. Information on limiting drafts, table of tank capacities, and cross curves of stability, formerly included in the *Inclining Experiment Booklet*, is provided to Navy ships in the *Stability and Loading Data Booklet*.

3-3.4 Damage Control Book. Damage control books issued to Navy ships contain text, tables, and diagrams provide information concerning the ship's damage control characteristics and systems. These books normally include the information described in Paragraphs 3-3.4.1 through 3-3.4.5 and may reproduce information from tank sounding tables, the *Stability and Loading Data Booklet*, cross curves of stability, and other sources. Copies of the damage control book are maintained in damage control central, each repair locker, and on the bridge.

3-3.4.1 Liquid-Loading Diagram. The liquid-loading diagram is a series of plan views of the ship showing all tanks and voids fitted for carrying liquids. Figure 3-5 shows the format in which the following information is presented for each tank:

- Tank location and boundaries
- Compartment number (center)
- Long tons of seawater to completely flood the compartment, allowing for permeability (upper left hand corner)
- List in degrees caused by completely flooding the compartment (upper right hand corner)
- Changes in draft forward and aft, in inches, caused by completely flooding the compartment (lower corners).

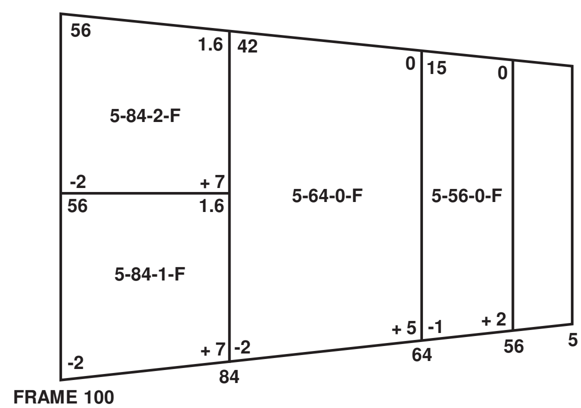

Figure 3-5. Sample Liquid-Loading Diagram Format.

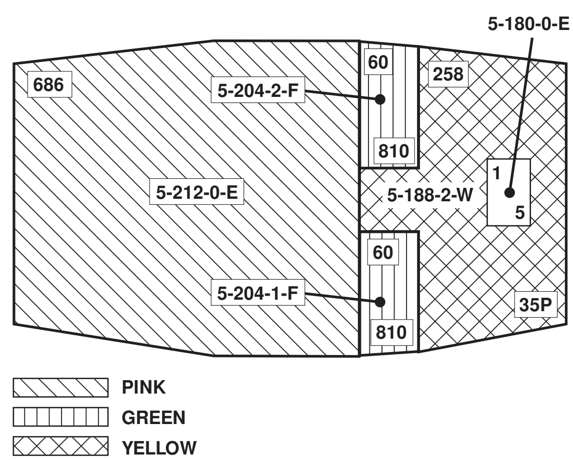

Figure 3-6. Sample Flooding-Effect Diagram Format.

Each tank is colored to indicate its use in accordance with the color code given on the actual diagram. The data given for list and trim are based on a specified condition of loading and may not be applicable when the ship is unusually loaded or severely damaged.

3-3.4.2 Flooding-Effect Diagram. The flooding-effect diagram is a series of plan views showing all watertight, oiltight, airtight, fumetight, and fire-retarding subdivisions. Figure 3-6 is the format of the diagram giving the following information:

- Compartment number (center)
- Long tons of saltwater to flood the compartment (upper left-hand corner)
- Transverse moment in foot-tons for all asymmetrical and off-center compartments (lower right-hand corner)
- Relative effect on stability, indicated by the following color code:

(1) Pink: Flooding impairs stability due to added high weight, free surface effect, or both.

(2) Green: Flooding improves stability even if free surface exists.

(3) Yellow: Solid flooding improves stability, but flooding with free surface impairs stability.

(4) No color: Flooding has no appreciable effect on stability.

Flooding-effect diagrams provide a ready reference for the location of watertight boundaries in the intact ship. These diagrams also provide information on transverse moments due to flooding (assuming that the boundaries remain intact).

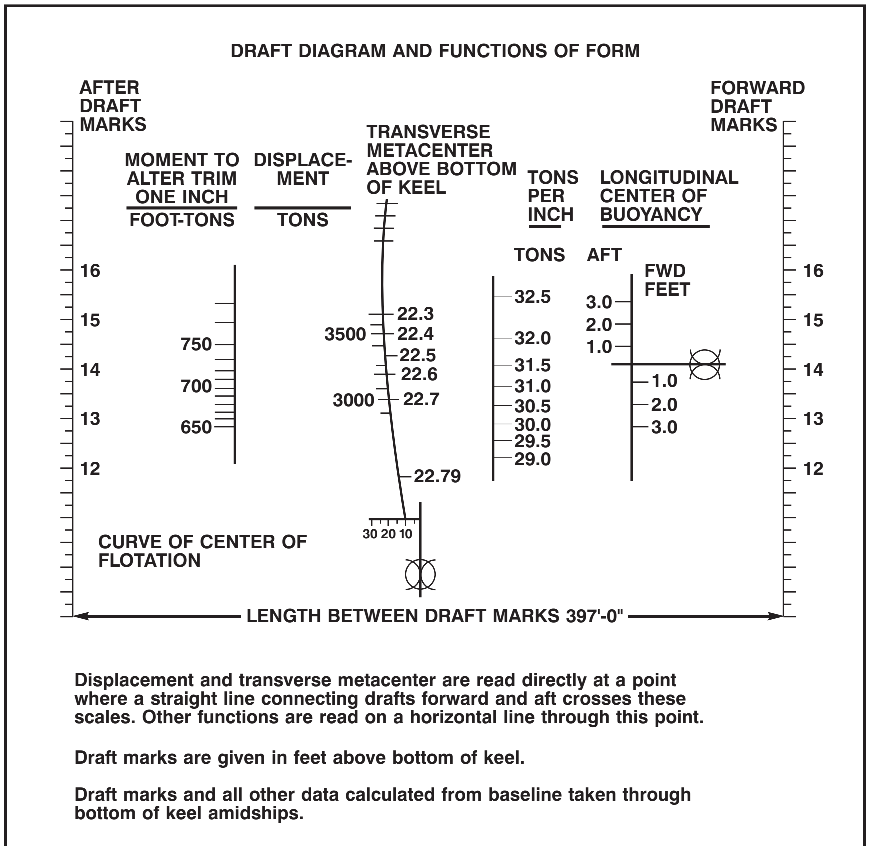

Figure 3-7. Draft Diagram and Functions of Form for the FFG-7 Class Frigate.

3-3.4.3 Draft Diagram. The draft diagram in the damage control book is a nomogram for determining the displacement from observed drafts. These nomograms are generally less accurate than the displacement curve, are developed for saltwater drafts only, and are not valid when the ship is excessively trimmed. Other functions of form may be included on the draft diagram. Figure 3-7 is a draft diagram for the FFG-7 Class frigate.

3-3.4.4 Damage Control Plates. Damage control plates, provided with the damage control book, consist of a series of plan and profile drawings of the ship and show:

Watertight, oiltight, fumetight, and airtight subdivision of the ship and all fire zones

- Routing of fire main and drainage piping systems
- Location of all watertight and fumetight doors, hatches, and scuttles
- Routing of ventilation systems.

The flooding-effect and liquid-loading diagrams are included in the damage control plates. The liquid-loading diagram is Plate No. 1. Measurements should not be scaled from any of the damage control plates, as they are not drawn to scale and views are often distorted.

3-3.4.5 Tables and Drawings. The damage control book includes numerous tables and drawings showing the locations of:

- Watertight and fumetight doors, hatches, and scuttles
- Ventilation fittings, fans, and controllers
- Fire main piping valves and stations
- Drainage system piping and valves
- Sound-powered phone circuits and jacks.

3-3.5 Tank Sounding Tables/Curves. These curves or tables correlate tank soundings (levels) to volume in gallons. Some curves give the center of gravity of the liquid for any sounding. Some give moment of inertia of the free surface in the tank.

3-3.6 Compartment Areas and Volumes. Tables showing the plan area and volumes of watertight compartments are prepared for Navy ships as part of their drawing set. These tables may be included in the damage control book or maintained separately.

3-3.7 Booklet of General Plans. The Booklet of General Plans prepared for Navy ships is a complete set of arrangement plans for the ship. Plan views of each deck, profiles, and a number of transverse sections are usually included. Tables of principal dimensions and heights of various decks and objects are often included. Limited scantlings are sometimes available. Dimensions may be derived from these plans.

3-3.8 Deadweight Scale. Merchant ships carry a deadweight scale showing deadweight capacities, moment to trim one inch, and tons per inch immersion corresponding to various drafts from below lightweight to displacement fully loaded. Figure 3-8 is a typical merchant ship deadweight scale.

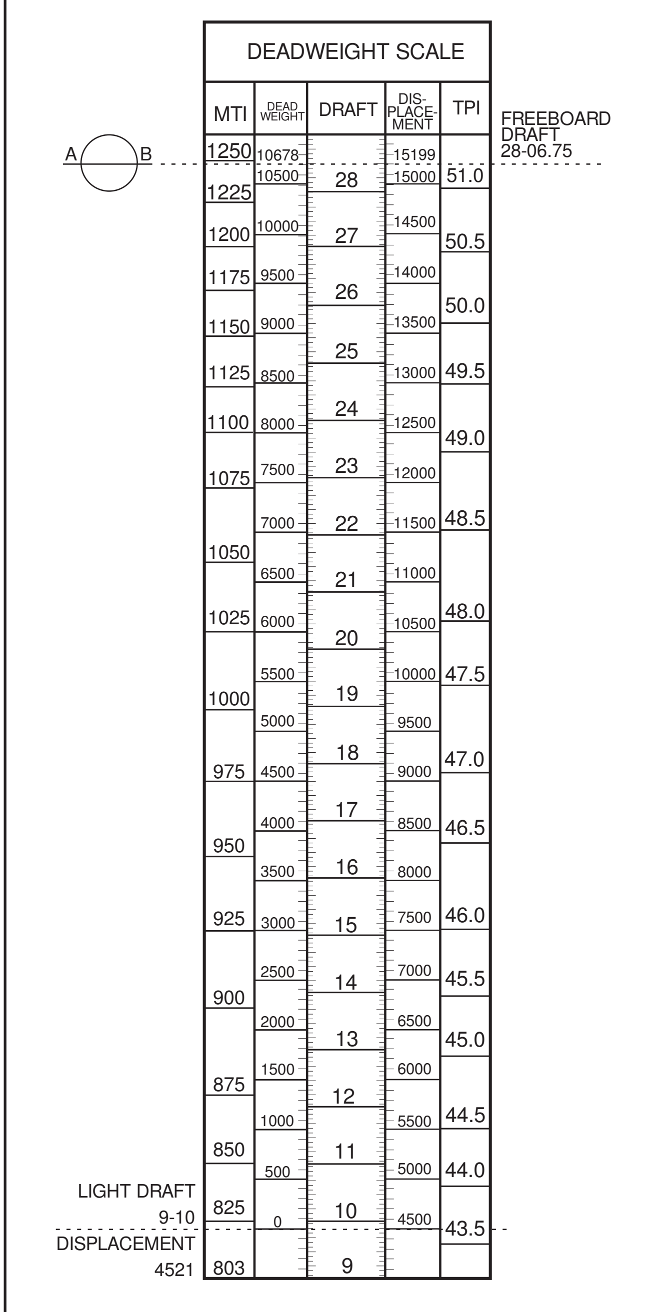

Figure 3-8. Typical Deadweight Scale Used on Merchant Ships.

3-3.9 Capacity Plan. A merchant ship's capacity plan will show the cubic capacities of tanks and cargo-carrying spaces such as holds, 'tween decks, and shelter decks. Tank capacity in tons of fuel, saltwater, or other liquids may be included.

3-3.10 Trim and Stability Booklet. Merchant ships usually have a trim and stability booklet containing stability and trim characteristics for various conditions of loading, either as curves of form or tabulated.

3-3.11 Structural Plans. Structural plans show arrangements and dimensions of the ship's structure. The midships section, shell expansion, and deck plans are the most useful in salvage.

3-3.12 The Lines. The shape of a ship is developed to meet specific requirements of speed, seakeeping ability, stability, and capacity. The lines, or the lines plan, precisely define the shape of a ship. To form the lines, three sets of mutually perpendicular planes are passed through the hull. The intersections of these planes with the hull form the lines of the ship. Like other engineering drawings, the lines plan is composed of views from ahead (and astern), from above, and from the starboard side. Figure 3-9 shows the development of the body plan, the half-breadth plan, and the sheer plan from a three-dimensional hull form. Figure FO-2 is an abbreviated lines plan drawing for the FFG-7 Class guided missile frigate.

3-3.13 Offsets. Offsets are measurements made from the centerline to the side of every station at each waterline. They are usually presented in a table in the form feet-inches-eighths. A typical offset for station four at the 16-foot waterline might be read as 37-2-3, indicating 37 feet 2 and three-eighths inches. This offset locates the precise point on the skin of the ship at station four, sixteen feet above the baseline and 37 feet 2⅜ inches from the centerline. The complete lines drawing can be constructed from the offsets.

3-3.13.1 The Body Plan. The body plan is the view from the ends of the ship. It is the most commonly seen and most important of the three views. The body plan often stands alone and the other views are derived from it. The body plan is formed by passing vertical planes across the ship like slices in a loaf of bread. The planes are at equally spaced intervals called stations along the length of the ship. More closely spaced stations, generally at half the usual interval, are used when the shape of the hull form changes rapidly, such as near the bow and stern. The intersection of the planes with the sides of the ship defines the shape of the sections. The body plan shows the sections on a single drawing. Because ships are symmetrical about the longitudinal centerline, a half-view of the stations from the bow to the midships station is drawn on the right side of the body plan, and a similar view of stations from the midships station to the after station is drawn on the left.

3-3.13.2 The Half-Breadth Plan. The half-breadth plan, or waterlines plan, views the ship from above. It defines the shape of the ship on horizontal planes passed fore and aft through the ship's hull parallel to the designer's waterline. The intersections of the planes with the hull show the shape of the waterline at the height of the plane. Because the ship is symmetrical about the centerline, only the waterlines for one side are drawn on a half-breadth plan.

3-3.13.3 The Sheer Plan. The sheer plan is a view of the ship from the starboard side. Vertical planes are passed fore and aft through the ship parallel to the longitudinal vertical centerline. Planes are spaced close enough between the centerline and the extreme beam to accurately define the shape of the ship. The lines formed by the intersection of the planes with the hull are called buttocks.

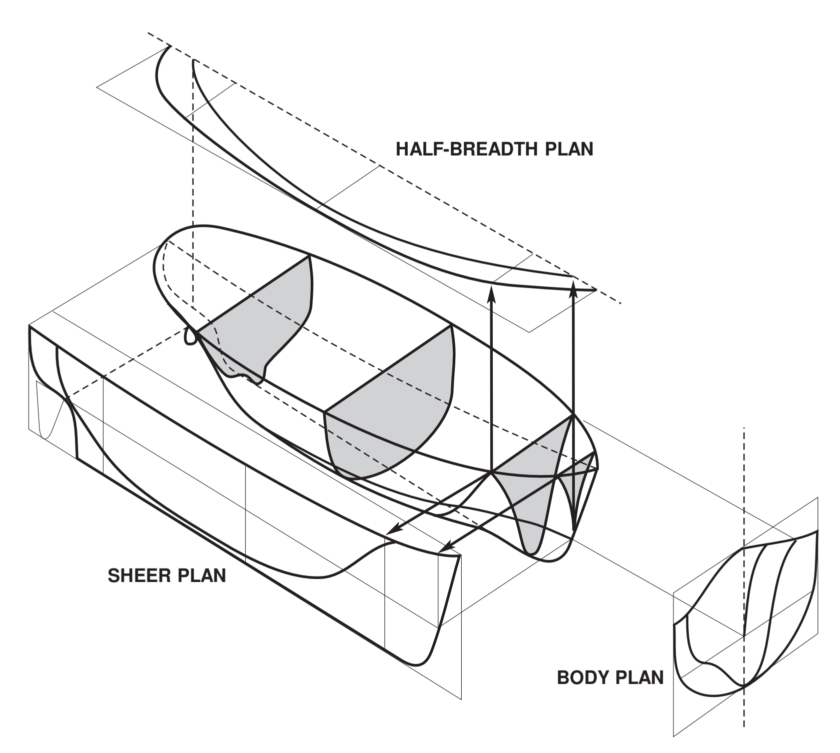

Figure 3-9. Development of Lines Plans.

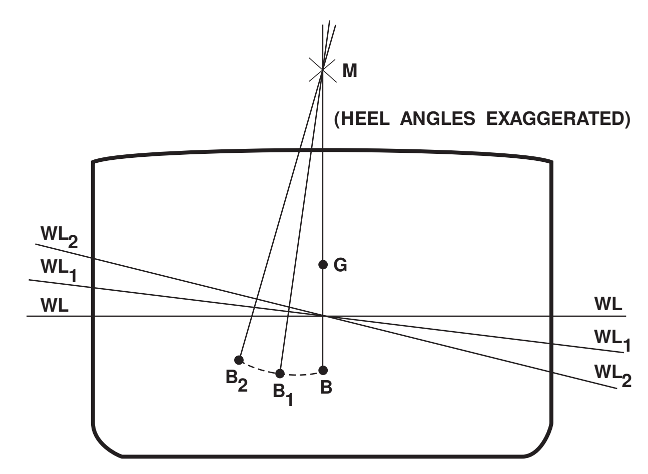

Figure 3-10. Relationship of Centers During Inclination.

3-3.13.4 Bonjean Curves. Bonjean curves are developed from the lines plans. The curves show the submerged area of each station as a function of draft. The areas can be used to calculate the displacement volume of the ship regardless of the ship's trim. Figure FO-3 shows the Bonjean curves of the FFG-7 Class ship.

3-4 CENTERS.

Certain points in the ship are described as centers for the forces that affect the ship or the behavior of the ship. The most important of these to the salvor are discussed in the following paragraphs.

3-4.1 Center of Gravity (G). Though the weight of the ship is distributed throughout the ship, it can be considered to act through a single point called the center of gravity. If the ship were to be suspended from a single thread, that thread would be connected at the center of gravity for the ship to remain upright and on an even keel. The weight always acts vertically downward through the center of gravity. The location of the center of gravity of a ship is solely a function of weight distribution within the ship. The center of gravity is in a fixed position for each condition of loading of the ship, but moves whenever there is a weight addition, removal, or movement within the ship.

3-4.2 Center of Buoyancy (B). The center of buoyancy is the geometric center of the submerged hull. The force of buoyancy acts vertically upward through the center of buoyancy. When the ship is at rest, with or without a list, the center of buoyancy is usually directly below the center of gravity. As the ship is disturbed, the center of buoyancy moves to the new center of the submerged hull. The force of buoyancy then acts vertically upward through the new center of buoyancy. When the centers of gravity and buoyancy are not aligned vertically, the forces of gravity and buoyancy acting through their respective centers tend to rotate the ship.

3-4.3 Metacenter (M). The metacenter is an imaginary point that is of prime importance in stability. When the ship is inclined to small angles, the intersection of the line or action of the buoyant force acting vertically through the new center of buoyancy and the now inclined centerline of the ship is the metacenter. In a stable ship, the metacenter lies above the center of gravity. Figure 3-10 shows the relationship between the metacenter, the center of buoyancy, and the center of gravity as the ship inclines. For purposes of illustration, the angles of inclination are exaggerated.

3-4.4 Center of Flotation (CF). The center of flotation is the geometric center of the waterline plane. The center of flotation is important in longitudinal stability because it is the point about which the ship inclines or trims in the fore-and-aft direction.

3-5 FORCES AND MOMENTS.

Forces and moments are physical quantities that cause ships to act as they do. The basic definitions of interest to salvors are given in the following paragraphs.

3-5.1 Forces. A force is a push or pull applied in a particular direction at a specific location that tends to cause movement. A force must have three things:

- Magnitude
- Direction
- Location.

Forces are measured in units of weight such as pounds or tons.

3-5.1.1 Internal Forces. Internal forces are forces characteristic of the floating ship and exist at all times. The internal forces affecting ships are gravity acting vertically downward and buoyancy acting vertically upward.

3-5.1.2 External Forces. External forces are forces that are applied from outside the ship and disturb the ship. Examples of such forces are:

- The sea
- Wind
- Collision
- Grounding
- Shifting of weight on board
- Addition or removal of weight.

3-5.2 Moments. A force applied to an object can cause it to move in a straight line or to rotate about an axis. The effect of a force that causes rotation is the moment of the force. To create a moment, a force must be applied at a distance from the axis about which rotation occurs. The moment is equal to the force multiplied by the perpendicular distance from the axis. The distance of the force from the axis is called the moment arm or lever arm. Because force is measured in units of weight and the lever arm is measured in units of length, the value of a moment is measured in units that are the product of length times force; i.e., foot-tons, foot-pounds, or inch-pounds.

3-5.2.1 Couples. When two forces act in opposite directions along parallel lines, they set up a special case of the moment called a couple. The magnitude of the couple is equal to the product of the average of the forces and the distance between their line of action. Couples are measured in the same units as moments.

3-5.2.2 Moment of Inertia. Moment of inertia is a measure of a plane surface's resistance to rotation about an axis in the same plane. The magnitude of moment of inertia depends upon the shape of the surface and varies with the axis used for rotation. The moment of inertia is measured in the fourth power of a linear unit, such as feet^4 or inches^4, or a combination of both. Moment of inertia of waterplane is an important parameter in stability and strength calculations. Moment of inertia of a rectangle about an axis through its center is given by:

$$I = \frac{l \times b^3}{12} = \frac{(l \times b) \times b^2}{12} = \frac{a \times b^2}{12}$$

where:

I = Moment of inertia, feet^4 or inches^4
l = Length of the rectangle, feet or inches
b = Width of the rectangle, feet or inches
a = Area of the rectangle, feet^2 or inches^2

Relationships for moments of inertia of other shapes are given in Appendix C.

3-6 COMPUTER PROGRAMS THAT AID IN SALVAGE CALCULATIONS.

U.S. Navy salvage engineers from the Supervisor of Salvage (SUPSALV) office provide operational and technical assistance to the fleet as well as other federal agencies. The Army Corps of Engineers, the U.S. Coast Guard and the Department of State have sought the expertise of SUPSALV salvage engineers in multiple operational areas, including:

- Naval architecture
- Salvage equipment
- Salvage operations and procedures
- Diving
- Towing
- Pollution abatement.

The U.S. Navy Salvage engineers use a variety of computer programs to support key operational decisions in salvage scenarios. Changes and improvement in these programs occur annually. The computer programs used by SUPSALV salvage engineers during the planning and operational phases of salvage jobs include:

- U.S. Navy Program of Ships Salvage Engineering (POSSE)
- Salvage Calculation Program (SCP)
- CARGOMAX.

Following is a brief description of these programs as well as a description of POSSE Technotes.

3-6.1 U.S. Navy Program of Ships Salvage Engineering (POSSE). POSSE is a powerful salvage response software. It can perform multiple salvage engineering analyses such as real-time engineering analysis of complex ship salvage situations including the assessment of:

- Ships stability
- Drafts and trim
- Intact or damaged structural strength
- Ground reaction and freeing force
- Oil outflow and flooding
- Lightering (weight removal plan)
- Tidal effects.

The development of POSSE began in 1989 through a cost-sharing agreement between Herbert Engineering Corporation and SUPSALV. The original program has been in a constant stage of revision and improvement due to a large part to the advancement of computer technologies. One of the benefits of the cost-sharing agreement is that POSSE is fully compatible with commercial salvage response software HECSALV and shipboard loading program CARGOMAX. It can also read data files of other commercial salvage response programs, including General Hydrostatics (GHS), a PC-based simulator of vessels in fluids and fluids in vessels.

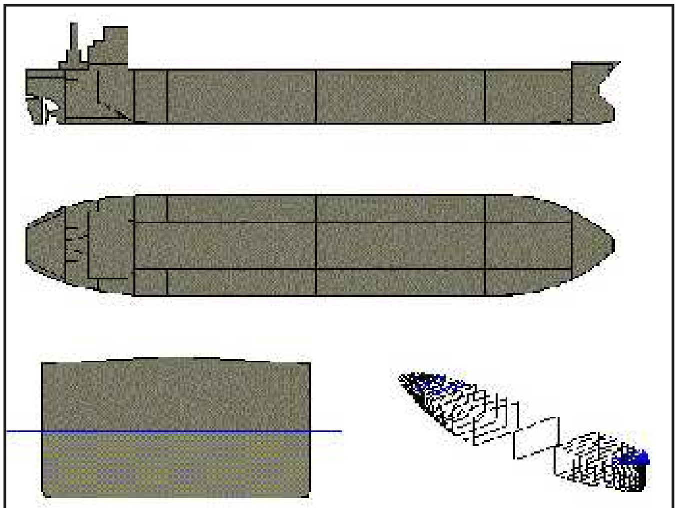

Figure 3-11. Ship's Hull and Compartment Configuration.

POSSE has the capability to perform rigorous numerical integration of hull and compartment offsets to calculate volumes. Forces (weight, buoyancy, reaction) are iterated to obtain equilibrium (afloat and aground). Effects of hull deflection can be included in the output. Hull girder deflections can also be calculated based on hull girder inertias. Figure 3-11 shows an example of the ship's hull and compartment configuration from the program. This illustration can help the salvor visualize, from all aspects, the specific ship salvage issues.

3-6.1.1 POSSE Features. POSSE features include but are not limited to:

- Non-rigid ground definition, including Multiple Point Grounding (MPG) analysis (Figure 3-12): Allows the salvage engineer to evaluate the effects of multiple contact points (up to and including complex drydock blocking analyses), a simple shelf, or a penetrable shelf.
- Tide/Lightering Sequence (TLS): Allows the salvage engineer to calculate and display time-phased calculations of tide height, ballasting/deballasting/transfer of liquids from intact tanks, transfer of liquids and oil/water outflow / flooding from damaged tanks, ground reaction, bending moments, shear forces, hull girder stresses, etc. A lightering plan, including transfer rates, start and stop times, and discharge amounts can be developed and printed for distribution to the salvage team.
- Hull axis rotation: Allows the salvage engineer to model capsized vessels and conduct detailed analyses for parbuckling/righting.

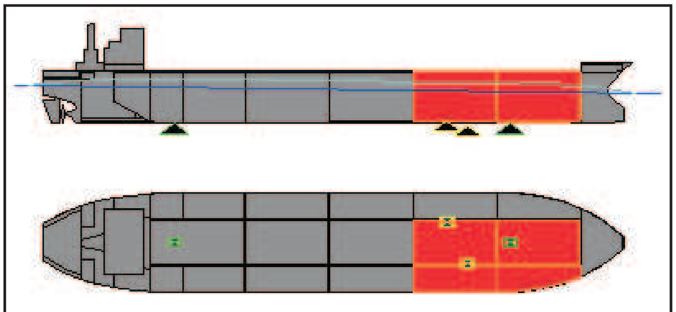

Figure 3-12. Multiple Grounding Point Analysis.

- Interfaces with the U.S. Navy's Ship Motion Program (SMP) and Ultimate Strength Program (ULSTR): Allows the salvage engineer to provide improved evaluations of dynamic wave bending moments and ultimate/residual strength characteristics of intact and damaged hull structure. SMP's results can also be used to provide detailed ship motions information (wave slap, accelerations, etc.).

3-6.2 POSSE Technotes. Salvage engineers have shared their experiences and lessons learned with each application of POSSE to salvage calculations, damage assessment, modeling and simulation and drydocking evaluation. The informal network of shared information was powerful and underscored the broad application and merit of POSSE. It also provided computer programmers the necessary information to make improvements to the original program. The Navy saw the value in sharing the information and decided to document this information for broader distribution. In 1997, SUPSALV produced the first edition of POSSE Technotes to provide basic overview and lessons learned of POSSE applications for real-life salvage situations.

POSSE Technotes has developed into a formatted newsletter published periodically. It is distributed to Engineering Duty Diving and Salvage Officers as well as other users. POSSE Technotes can also be accessed through the SUPSALV website, www.supsalv.org. POSSE Technotes provides overviews of accidents or incidents that resulted in salvage operations and utilization U.S. Navy Program of Ships Salvage Engineering. A detailed description of the various applications of POSSE include but is not limited to: the evaluation of the effects of multiple grounding points, time-phased tidal variations, ships stability, buoyancy, strength applications including drydocking and shipboard liquid transfers.

Contributing authors to the articles for POSSE Technotes include USN salvage engineers and other POSSE users. Some of the articles include comparisons between POSSE re-floating draft predictions and actual draft values. POSSE generated values are also used as input to detailed modeling and simulation. This application is described in the newsletter. A "special considerations" or "lessons learned" section provides the readers invaluable information about the timeliness and relevance of POSSE to the unique salvage or drydock situation.

3-6.3 Salvage Calculation Program. In 1998, the Submarine and Integrated Undersea Surveillance System (IUSS) Training Requirements Review (SITRR) for Navy diving and salvage training and Chief of Naval Operations Salvage Executive Steering Committee recognizing the value of POSSE for generating the necessary calculations and data to support large salvage jobs. They requested that NAVSEA 00C develop a computer based salvage calculations program for smaller salvage jobs. The purpose of the computer tool was to supplement the instruction of the "hand calculations" taught in the Salvage Officer course at Naval Diving and Salvage Training Center. This tool was intended to be a "mini-POSSE" program and used in simple salvage operations if more complex salvage engineering analysis were not required. Responding to the request, NAVSEA developed the "Salvage Calculation Program" (SCP).

SCP is a menu-driven Windows-program with full Windows functionality. The program provides the same logic flow and calculations that are taught in the Navy Salvage Officer course focusing on calculations for:

- Conduct of stranding
- Afloat stability
- Trim (intact or damaged).

Data input to the program requires prior knowledge or documentation of the vessel's hydrostatic properties and weight. There are no internal parametric approximations in SCP program. The results from the program are only as good as the accuracy of the input data. The SCP menu includes "File", "Edit", "Base", "Weight", "Flood", "Strand", "Results", "Tools", "Window", and "Help". With this basic program, a baseline condition of the vessel is established under the "base" menu. This data entry includes hydrostatic properties such as curves of form, vessel weights, centers of gravity, righting arm data, strength information (section moduli and sheer areas defined) and plan/profile/section offsets. Any vessel weights that vary from the baseline condition are added or removed in the "weight" menu.

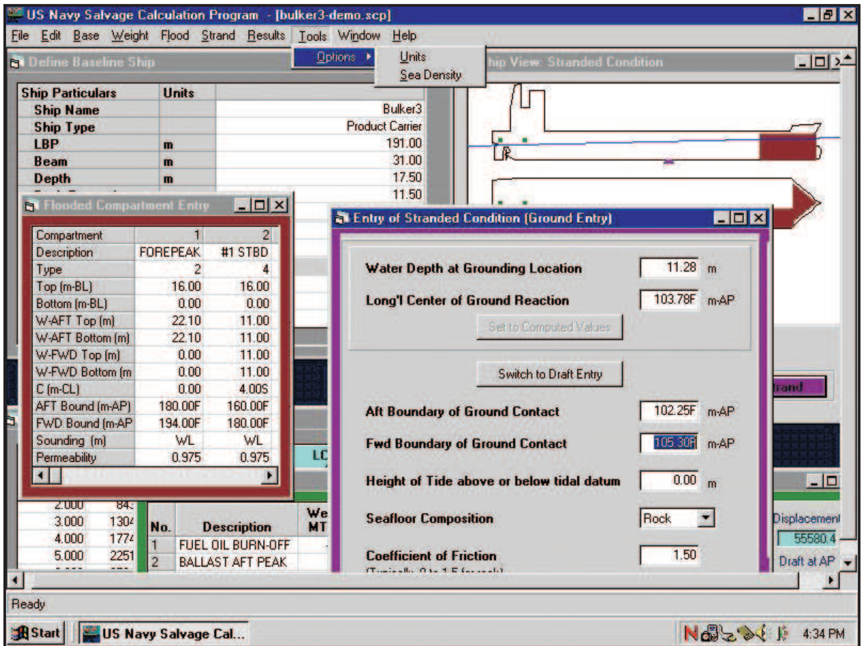

Figure 3-13. U.S. Navy Salvage Calculation Program.

Figure 3-13 shows a SCP screen including the entries for the flooded compartment in the forepeak and #1 starboard compartments. It also shows entries for the stranded condition including the water depth at the grounding location, longitudinal center of ground reaction, the aft boundary of ground contact, the forward boundary of ground contact, the height of tide above or below tidal datum, the seafloor composition and the coefficient of friction.

Under the "flood" menu, damaged compartments of simple shape can be modeled. Effects of free surface and varying ship waterlines are included in the calculations. The "strand" menu allows for entry of stranded drafts and location, taking into consideration the effects of tidal changes on stranding calculations. The stranding results are graphical and tabular in format and provide the user a view of individual casualty conditions such as free floating flooded condition, stranded condition, and stranded condition with tidal change. The "tools" menu allows the user to select units in English or metric, display precision, reference frames and water density. A Microsoft Word version of the Help document is available through the "help" menu.

NOTE

SCP may have significant limitations when dealing with complex salvage situations. SCP is much less capable than the Program of Ship Salvage Engineering (POSSE), which is a detailed naval architecture and salvage engineering program. For more complex salvage situations, utilization of POSSE by an experienced salvage engineer is highly recommended, vice relying solely on SCP.

3-6.4 CargoMax. CargoMax™ is a shipboard loading calculation program that was developed by Herbert Engineering Corporation and designed as a field tool to aid in the calculation of survey and trimming data accurately and quickly. It precisely calculates ship stability and stress characteristics based on any loading condition specified by the user. CargoMax™ can also apply when transporting multiple grades of cargo with varying loading patterns. It has proven itself to be a valuable tool to maximize vessel utilization, increase cargo loading efficiency, increase crew productivity, and monitor margins of safety during loading and discharge. It has contributed to the safety of the vessel by reducing human error in cargo loading. Numerous options are available to provide even greater utility for specific crew operations.

CargoMax™ has been installed on over 500 vessels including tankers, containerships, bulk carriers, RO-ROs and tank barges. It has been approved by all major Classification Societies and comes with a lifetime guarantee.

Features of the **CargoMax™** Windows interface include:

- Standard Windows user interface with full mouse and keyboard control of all functions
- Fully integrated context sensitive help
- Quickstart Screen at startup (how to get around)
- Context menus which allow quick access to all applicable program options
- Standard user's manual fully included in the on-line help
- Continuously updated results bar showing drafts, trim, list, GM, and longitudinal strength
- Continuously updated strength plots and hold plans
- One primary entry window with all weight groups accessible with simple [tabs]
- Simple and direct access to all key data and results.

Standard calculations and options include:

- Loading condition entry with no limit to the number of stored load cases
- Trim and draft calculations at the perpendiculars and marks
- Stability calculation (GMt, righting arm to IMO requirements)
- Bending moment, shearing force, and torsional moment compared to "At Sea" and "In Harbor" allowables
- Grade entry library for oil and cargo tanks automatically maintained.
- "API" density and VCF calculations
- Tool for observed draft entry
- HECSALV salvage response software compatibility
- Class approved.

Special function and calculation options include:

- Ullage/Sounding Entry w/trim, heel and wedge corrections
- Interface to Tank Gauging System
- Cargo Oil Rate Screen and Loading History Log
- Marpol/IBC direct damage required GMt calculation
- Liquefied Gas Calculations (LNG/LPG)
- IMO 13G calculations for Hydrostatic Balanced Loading (HBL)
- Special ROB/OBQ reports
- Damage Stability Option
- Automatic Distribution of cargo Oil and Ballast
- Grain Stability Option
- Cargo Loading Restriction Checking
- Local Hull Girder Shear Force Adjustments per Class Rules
- Hull deflections
- Detailed Container Entry with Lashing Calculations
- Bulk Cargo Pile Geometry Calculations
- Detailed Bulk Cargo Buildup.

3-6.5 HECSALV. HECSALV is a salvage response program that provides naval architects or salvage engineers the ability to quickly evaluate the damaged conditions of a ship. In particular, this program has the ability to assist the user in analyzing the intact condition, free-floating damage cases and various types of groundings. Salvage features include:

- Single and double pinnacle and shelf grounding analysis
- Strength and deflection analysis for flooding or grounded cases
- Damaged or corroded strength analysis based on actual section properties
- Evaluation of lightering plans
- Tidal variation analysis for grounded cases
- Actual oil outflow based on vertical extent of damage
- Specification of partially flooded tanks in the damaged condition
- Specification of internal pressurization for damaged compartments.

CargoMax™ load cases can be read by HECSALV for setting up the salvage response evaluation. CargoMax™ and HECSALV also share the same basic data files so that data created for CargoMax™ can be used for the HECSALV data model.

CHAPTER 4
STABILITY AND WEIGHT

4-1 INTRODUCTION TO STABILITY.

This chapter discusses the stability of intact ships and how basic stability calculations are made. Definitions of the state of equilibrium and the quality of stability as they apply to ships are given in the following paragraphs.

4-1.1 Equilibrium. A ship floating at rest, with or without list and trim, is in static equilibrium; that is, the forces of gravity and buoyancy are balanced. They are equal and acting in opposite directions and are in a vertical line with each other.

4-1.2 Stability. Stability is the measure of a ship's ability to return to its original position when it is disturbed by a force and the force is removed. A ship may have any one of three different kinds of stability, but only one at a time. Stability of an intact vessel is generally described as its reaction to being inclined to a small angle of heel. At small angles of heel, the metacenter is fixed. The metacenter starts to move after the ship is inclined past 7 to 10 degrees.

4-1.2.1 Positive Stability. If the ship tends to return to its original position after being disturbed by an external force, it is stable, or has positive stability. In the case of positive stability, the metacenter is located above the ship's center of gravity. As the ship is inclined, righting arms are created which tend to return the ship to its original, vertical position.

4-1.2.2 Negative Stability. If the ship tends to continue in the direction of the disturbing force after the force is removed, it is unstable, or has negative stability. In this case, the ship's center of gravity is located above the metacenter. As the ship is inclined, negative righting arms (otherwise called upsetting arms) are created which tend to capsize the ship.

4-1.2.3 Neutral Stability. A third state, neutral stability, exists when a ship settles in the orientation it is placed in by the disturbing force. Neutral stability seldom occurs to floating ships, but is of concern in raising sunken ships because a ship rising through the surface passes through a neutral condition. While the ship is neutrally stable, even a very small disturbing force may cause it to capsize. When a ship is neutrally stable, the metacenter and the ship's center of gravity are in the same location. As the ship is inclined, no righting arms are created.

4-2 TRANSVERSE STABILITY.

Transverse stability is the measure of a ship's ability to return to an upright position after being disturbed by a force that rotates it around a longitudinal axis. The following paragraphs define the elements of transverse stability and provide a method to calculate the transverse stability characteristics of a vessel.

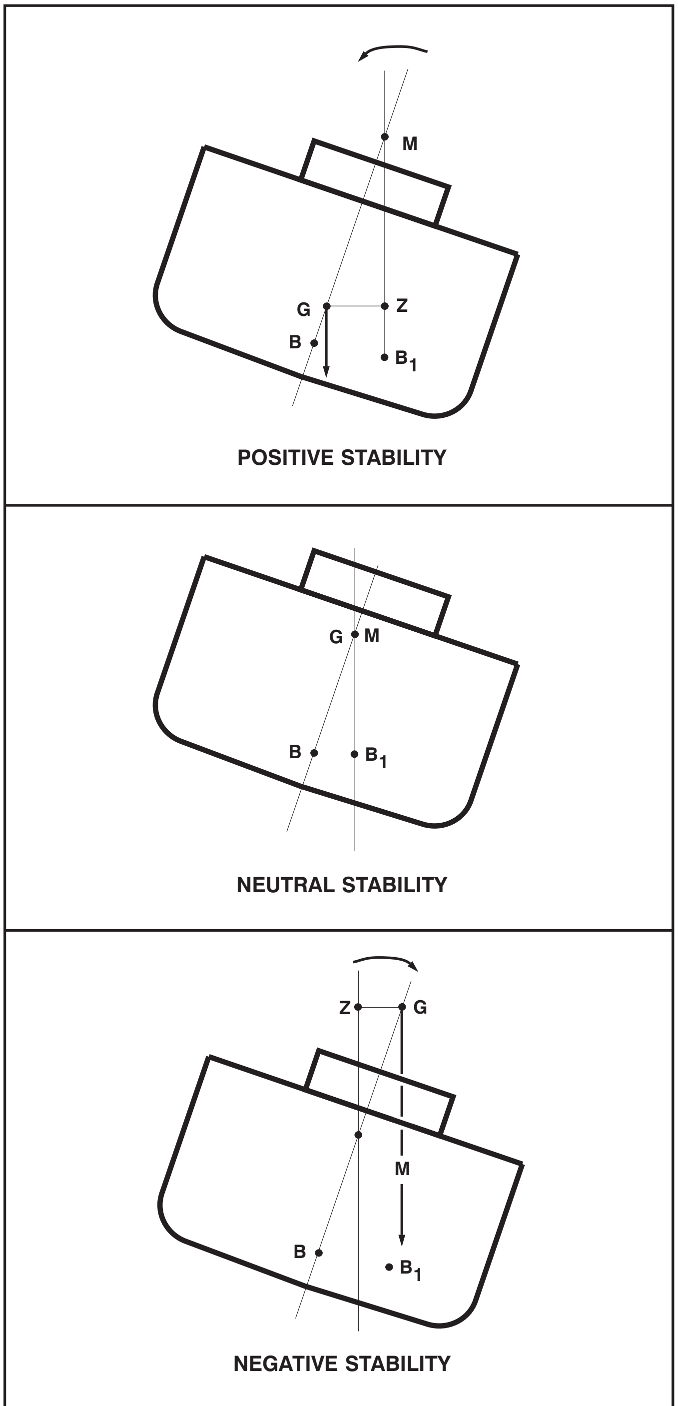

Figure 4-1. Positive, Neutral and Negative Stability.

4-2.1 Height of the Center of Gravity (KG). One of the primary concerns in transverse stability is the height of the center of gravity above the keel. This distance is measured in feet. In most ships, the center of gravity lies between a point six-tenths of the distance between the keel and the main deck. The position of the center of gravity depends upon the position of weights in the ship and changes whenever weight is added, removed, or shifted. To calculate the height of the center of gravity, the following steps are necessary:

a. Classify all the weights in the ship.

b. Determine the height of each weight above the keel.

c. Multiply each weight by the height above the keel to determine the moment of the weight.

d. Total the weights and the moments of weight.

e. Divide the total of the moments of weight by the total weight to determine the height of the center of gravity.

EXAMPLE 4-1
CALCULATION OF THE HEIGHT OF THE CENTER OF GRAVITY (KG)

A ship has the following weights on board:

Material	Weight W (LT)	Height above the keel KG (ft)
Ship's structure	2,000	15
Machinery	500	10
Stores	400	20
Fuel	250	5
Cargo	800	14

What is the height of the center of gravity?

A tabular format is convenient for this type of calculation.

	Weight W	Height above keel KG	Moment of Weight W x KG
	2,000	15	30,000
	500	10	5,000
	400	20	8,000
	250	5	1,250
	800	14	11,200
Sums	3,950		55,450

Height of the center of gravity:

$$KG = \frac{\text{sum of the moments of weight}}{\text{total weight}}$$

$$KG = \frac{55{,}450}{3{,}950}$$

$$KG = 14.04 \text{ feet}$$

Weight additions and removals will either raise or lower the center of gravity. The movement of the center of gravity will cause the metacentric height to increase or decrease. There are four possible effects:

- Weight additions above the center of gravity will cause the center of gravity to move upward, toward the metacenter, decreasing metacentric height.
- Weight additions below the center of gravity will cause the center of gravity to move downward, away from the metacenter, increasing metacentric height.
- Weight removals above the center of gravity will cause the center of gravity to move downward, away from the metacenter, increasing metacentric height.
- Weight removals below the center of gravity will cause the center of gravity to move upward, toward the metacenter, decreasing metacentric height.

The new height of the center of gravity is calculated using the same principle used to calculate the original height of the center of gravity; that is,

$$KG = \frac{\text{sum of the moments of weight}}{\text{total weight}}$$

for a weight addition:

$$KG_1 = \frac{(KG \times W) + (kg \times w)}{(W + w)}$$

where:
KG_1 = The new position of the center of gravity
KG = The old position of the center of gravity
W = The ship weight (displacement) before the weight addition
w = The weight added
kg = The height of the added weight above the keel

Often it is adequate to know the change of the height of the center of gravity. The change can be applied to GM to assess the change of stability. The magnitude of the change is:

$$GG_1 = \frac{Gg \times w}{W \pm w}$$

where:
GG_1 = The distance between the old and new centers of gravity
Gg = The distance between the center of gravity and the weight being added or removed

EXAMPLE 4-2
CALCULATION OF THE CENTER OF GRAVITY MOVEMENT WITH WEIGHT CHANGES

a. The center of gravity of a ship with a displacement of 3,625 tons is 21 feet above the keel. A weight of 150 tons is added 30 feet above the keel. What is the height of the new center of gravity?

$$KG_1 = \frac{(KG \times W) + (kg \times w)}{(W + w)}$$

$$KG_1 = \frac{(21 \times 3{,}625) + (30 \times 150)}{(3{,}625 + 150)}$$

$$KG_1 = \frac{(76{,}125) + (4{,}500)}{3{,}775}$$

$$KG_1 = \frac{80{,}625}{3{,}775}$$

$$KG_1 = 21.36 \text{ feet}$$

b. In the same ship, instead of being added 30 feet above the keel, the same weight is added 5 feet above the keel. What is the new height of center of gravity?

$$KG_1 = \frac{(21 \times 3{,}625) + (5 \times 150)}{(3{,}625 + 150)}$$

$$KG_1 = \frac{(76{,}125) + (750)}{3{,}775}$$

$$KG_1 = \frac{76{,}875}{3{,}775}$$

$$KG_1 = 20.36 \text{ feet}$$

If weight is removed, the same principle applies, but the signs are changed:

$$KG_1 = \frac{(KG \times W) + (kg \times w)}{(W + w)}$$

c. If the weight in step a. of this example is removed rather than added, what is the new height of the center of gravity?

$$KG_1 = \frac{(KG \times W) - (kg \times w)}{(W - w)}$$

$$KG_1 = \frac{(21 \times 3{,}625) - (30 \times 150)}{(3{,}625 - 150)}$$

$$KG_1 = \frac{71{,}625}{3{,}475}$$

$$KG_1 = 20.61 \text{ feet}$$

EXAMPLE 4-2 (CONTINUED)
CALCULATION OF THE CENTER OF GRAVITY MOVEMENT WITH WEIGHT CHANGES

d. If the weight in step b. of this example is removed rather than added, what is the new height of the center of gravity?

$$KG_1 = \frac{(KG \times W) - (kg \times w)}{(W - w)}$$

$$KG_1 = \frac{(21 \times 3{,}625) - (5 \times 150)}{(3{,}625 - 150)}$$

$$KG_1 = \frac{75{,}375}{3{,}475}$$

$$KG_1 = 21.69 \text{ feet}$$

e. If a weight of 150 tons is added 16 feet above the center of gravity, what is the change in the height of the center of gravity?

$$GG_1 = \frac{Gg \times w}{W \pm w}$$

$$GG_1 = \frac{(16 \times 150)}{(3{,}625 + 150)}$$

$$GG_1 = \frac{2{,}400}{3{,}775}$$

$$GG_1 = 0.64 \quad \text{feet upward, reducing initial stability}$$

f. If in the same ship 200 tons is removed 10 feet below the center of gravity, what is the change in the height of the center of gravity?

$$GG_1 = \frac{Gg \times w}{W - w}$$

$$GG_1 = \frac{(10 \times 200)}{(3{,}625 - 200)}$$

$$GG_1 = \frac{2{,}000}{3{,}425}$$

$$GG_1 = 0.58 \quad \text{feet upward, reducing initial stability}$$

4-2.2 <u>Height of the Center of Buoyancy (KB)</u>. The height of the center of buoyancy above the keel or baseline is another important distance in stability. This distance is measured in feet. Because the center of buoyancy is the geometric center of the underwater body of the ship, the height of the center of buoyancy depends upon the shape of the ship. In flat-bottomed full ships, such as carriers and tankers, the center of buoyancy is lower than in finer lined ships, such as destroyers or frigates. Calculation of the location of the center of buoyancy for ship shapes is a lengthy and tedious process. The height of the center of buoyancy is contained in the curves of form.

When curves of form are not available, estimates sufficient for salvage work may be made as follows. The height of the center of buoyancy is half the draft for a rectangular barge. In a ship's form, the center of buoyancy lies between 0.53 and 0.58 of the draft. A reasonable first approximation of the height of the center of buoyancy that is sufficiently accurate for salvage work is 0.55 times the mean draft.

4-2.3 <u>Transverse Metacentric Radius (BM)</u>. The transverse metacentric radius is the distance between the center of buoyancy and the metacenter. Transverse metacentric radius is measured in feet. It is defined as the moment of inertia around the longitudinal axis of the waterplane at which the ship is floating divided by the displacement volume.

$$BM = \frac{I}{V}$$

If the shape of the waterplane is known, the moment of inertia of the waterplane can be defined exactly. For salvage work, a reasonably accurate approximation may be made by:

$$I = C_{IT} \times L \times B^3$$

where:

C_{IT} = The transverse inertia coefficient and is equal to $C_{WP}^2/11.7$
L = Length between perpendiculars
B = Beam

EXAMPLE 4-3
CALCULATION OF THE TRANSVERSE METACENTRIC RADIUS

An FFG-7 Class ship is 408 feet long with a beam of 44 feet and draws 14.5 feet. Her block coefficient is 0.487 and her waterplane coefficient is 0.754. What is her transverse metacentric radius (BM)?

a. Determine the transverse inertia coefficient.

$$C_{IT} = \frac{C_{WP}^2}{11.7}$$
$$C_{IT} = \frac{0.754^2}{11.7}$$
$$C_{IT} = 0.0486$$

b. Calculate the moment of inertia of the waterplane.

$$I = C_{IT} \times L \times B^3$$
$$I = 0.0486 \times 408 \times (44)^3$$
$$I = 1{,}689{,}096 \text{ feet}$$

c. Calculate the displacement volume.

$$V = C_B \times L \times B \times T$$
$$V = 0.487 \times 408 \times 44 \times 14.5$$
$$V = 126{,}768 \text{ feet}^3$$

d. Divide the moment of inertia by displacement volume to determine the transverse metacentric radius.

$$BM = \frac{I}{V}$$
$$BM = \frac{1{,}689{,}096}{126{,}768}$$
$$BM = 13.32 \text{ feet}$$

The value of the metacentric radius derived from the curves of form is 13.4 feet. The calculated value is sufficiently accurate for salvage work.

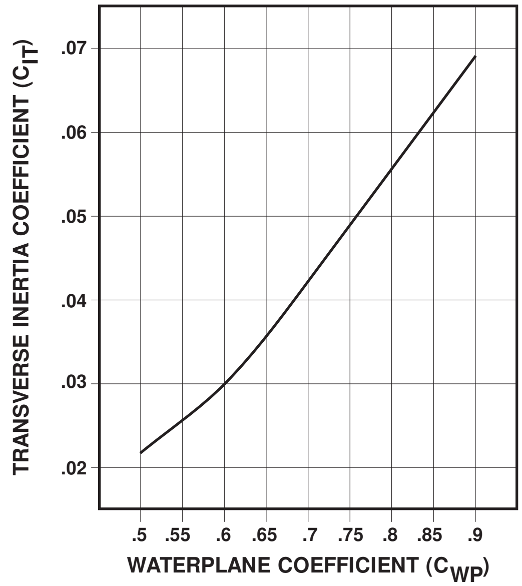

Figure 4-2. Transverse Inertia Coefficient.

The transverse inertia coefficient may also be obtained from Figure 4-2 by entering along the horizontal scale with the waterplane coefficient, reading up to the curve, then across to the vertical scale.

NOTE

The expression for transverse inertia coefficient is derived from the analysis of numerous ships and is a reasonable approximation for use in salvage. For a vessel or a barge with a rectangular waterplane (C_{WP} = 1.0), an exact calculation is:

$$I = \frac{(L \times B^3)}{12}$$

4-2.4 Height of the Metacenter (KM). The height of the metacenter is the distance between the keel and the metacenter. The height of the metacenter is measured in feet. It is the sum of the height of the center of buoyancy and the metacentric radius, that is:

$$KM = KB + BM$$

For an upright ship, the metacenter lies on the same vertical line as the center of buoyancy and the center of gravity. If the curves of form are available, KM can be determined directly from them.

4-2.5 Metacentric Height (GM). The metacentric height, measured in feet, is the distance between the center of gravity and the metacenter and is the principal indicator of initial stability. A ship whose metacenter lies above the center of gravity has a positive metacentric height and is stable; conversely, a ship with the metacenter below the center of gravity has negative metacentric height and is unstable. With the distances KB, BM, and KG known, GM can be calculated:

$$GM = KB + BM - KG$$

and

$$GM = KM - KG$$

4-2.6 Righting Arm (GZ). In an upright ship in equilibrium, the forces of gravity and buoyancy act equally in opposite directions along the vertical centerline. As the center of buoyancy shifts when the ship heels, these two opposing forces act along parallel lines. The forces and the distance between them establish the couple which tends to return a stable ship to the upright position. The righting arm is the distance between the lines of action of the weight acting through the center of gravity and the force of buoyancy acting through the center of buoyancy at any angle of inclination. Righting arms are measured in feet. Figure 4-3 shows the righting arm for an inclined stable ship.

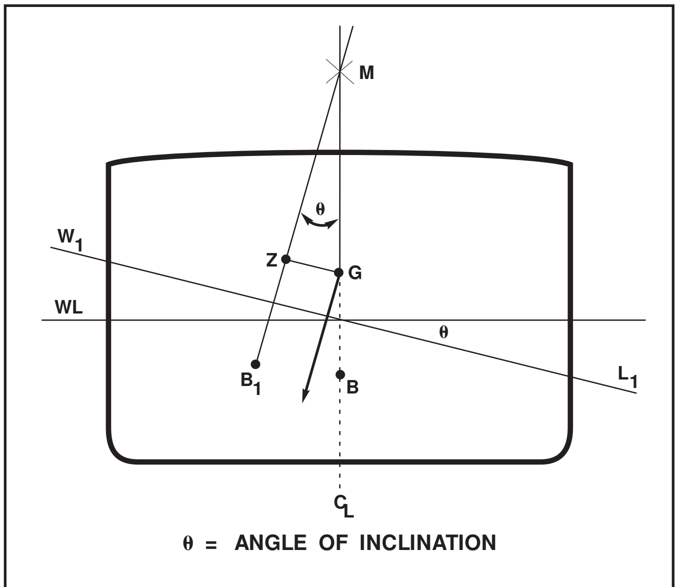

Figure 4-3. Righting Arm.

The length of the righting arm varies with the angle of inclination. The ratio of the righting arm to the metacentric height, GZ/GM, is equal to the sine of the angle for any small angle. If the sine of the angle is represented by Sin θ, the equation can be written as:

$$\text{Sin}\,\theta = \frac{GZ}{GM}$$

or

$$GZ = GM \times \text{Sin}\,\theta$$

This equation provides a convenient means of calculating righting arm for small angles of inclination. At angles of heel greater than about ten to fifteen degrees, the metacenter moves away from the centerline, and the relationship between the metacentric height and righting arm is no longer exact. The righting arm at large angles of heel can be determined from the statical stability curve described in Paragraph 4-2.9.

4-2.7 Righting Moment (RM). The righting moment is the couple of the weight and buoyancy of an inclined ship. This moment acts to return the ship to an upright position. Righting moment is measured in foot-tons. Because forces creating the couple (the weight and buoyancy of the ship) are equal, opposite, and equal to the displacement, the righting moment is the product of the displacement of the ship and the righting arm, or:

$$RM = W \times GZ$$

The size of the righting moment at any displacement and angle of inclination is a measure of the ship's ability to return to an upright position. As the righting moment at any displacement is directly proportional to the righting arm, the righting arm may be used as an indicator of stability.

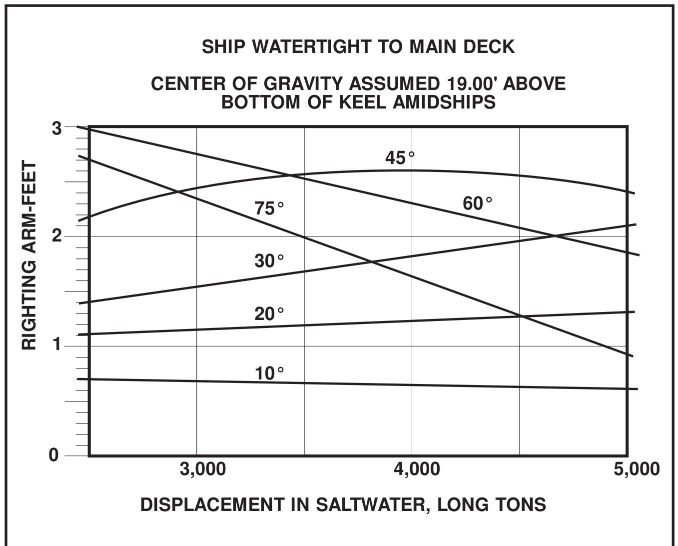

Figure 4-4. Cross Curves of Stability.

4-2.8 Cross Curves of Stability. The cross curves of stability are a set of curves, each for a different angle of inclination, that show righting arm changes with displacement. A set of cross curves of stability for the FFG-7 Class ship are shown in Figure 4-4. Note that a particular height of the center of gravity has been assumed in computing the curves. The importance of this assumption is explained in Paragraph 4-2.9. To use the cross curves, enter on the horizontal scale with the displacement of the ship, read up to the curve representing the angle of interest, and read across to the vertical scale to determine the value of the righting arm.

For example, to obtain the righting arm at 3,200 tons displacement at an angle of 30 degrees, enter the curves of Figure 4-4 along the horizontal scale with 3,200 tons, then:

a. Read up to the intersection with the 30-degree curve.

b. Read across to the vertical scale where it can be seen that the righting arm (GZ) is 1.67 feet.

The principal use of the cross curves of stability is in constructing the curve of statical stability.

4-2.9 The Curve of Statical Stability. The curve of statical stability (or simply the stability curve) shows righting arm changes as the ship inclines at a particular displacement. Righting arm, in feet, is plotted on the vertical scale while the angle of inclination, in degrees, is plotted on the horizontal scale.

The curve of statical stability, when plotted and corrected as described below, will provide the following information:

- Range of inclination through which the ship is stable (Range of Stability)
- Righting arm at any inclination
- Righting moment at any inclination
- Angle at which maximum righting arm and maximum righting moment occur
- Metacentric height.

4-2.9.1 Plotting the Curve of Statical Stability. Figure 4-5 is the curve of statical stability taken from the cross curves shown in Figure 4-4 for a displacement of 3,200 tons. The curve was constructed by:

a. Entering the cross curves along the 3,200-ton displacement line.

b. Reading up to the angle of inclination and across to determine the righting arm for that angle of inclination and displacement.

c. Repeating the last step for each angle plotted in the cross curves.

d. Plotting the values obtained and drawing the curve.

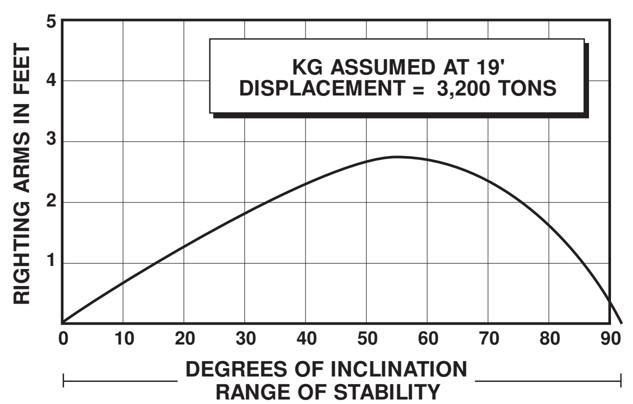

Figure 4-5. Statical Stability Curve.

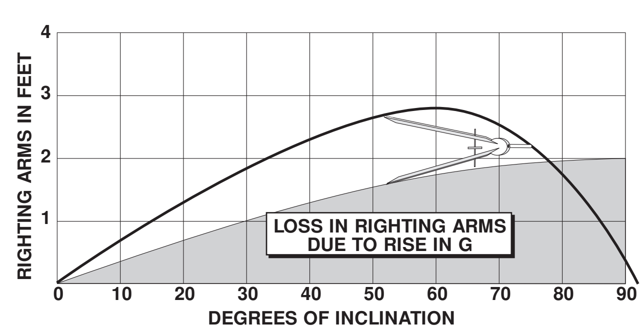

Figure 4-6. Correction to Statical Stability Curve, CG is 2 Feet Above Assumed Point.

4-2.9.2 Height of Center of Gravity Correction. The cross curves of stability are calculated for a particular height of the center of gravity. When the center of gravity has a different height, the metacentric height and the stability curve change. If the actual center of gravity lies above the assumed center of gravity, the metacentric height is decreased and the ship is less stable; conversely, if the actual center of gravity is below the assumed center of gravity, the metacentric height is increased and the ship is more stable. The correction at any angle of inclination is the product of the difference between the actual and assumed heights of the center of gravity and the sine of the angle of inclination, or:

$$\text{correction} = GG_1 \times \sin\theta$$

where:

GG_1 is the difference between the actual and assumed heights of the center of gravity. Thus, if the center of gravity is two feet above the assumed center of gravity, the correction can be calculated as

Angle θ	Sine of the angle $\sin\theta$	Height difference GG_1	Correction $GG_1 \sin\theta$
0	0	2	0
10	0.174	2	0.35
20	0.342	2	0.68
30	0.500	2	1.00
45	0.707	2	1.41
60	0.866	2	1.73
75	0.965	2	1.93
90	1.000	2	2.00

The corrections are plotted to the same scale as the curve of statical stability as shown in Figure 4-6. The corrected curve of statical stability is drawn by plotting the difference between the two curves as shown in Figure 4-7. If the actual height of the center of gravity is less than the assumed height, the calculation is done in the same manner, however, the correction curve is plotted below the horizontal axis as shown in Figure 4-8. The new statical stability curve is again the difference between the two curves as shown in Figure 4-9.

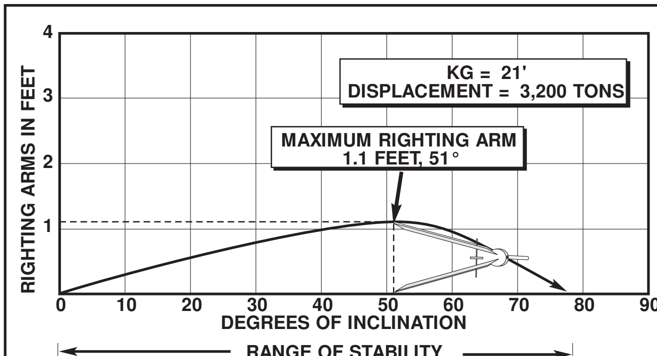

Figure 4-7. Corrected Statical Stability Curve.

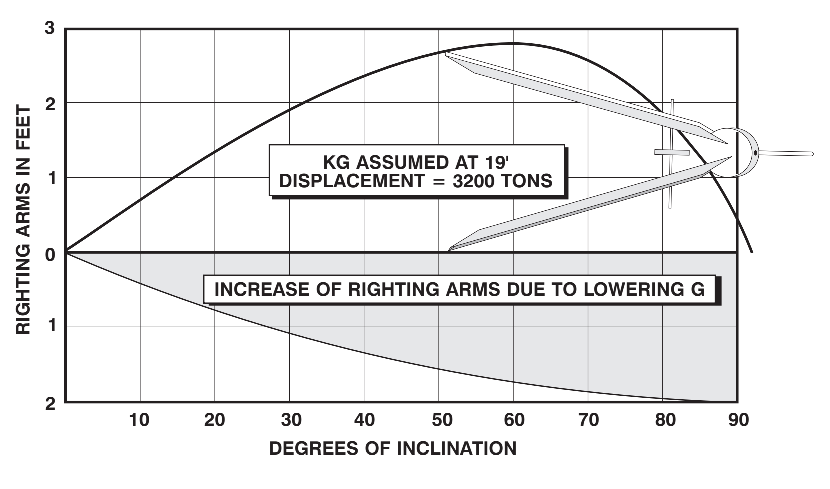

Figure 4-8. Correction to Statical Stability Curve, G 2 Feet Below (KG = 17') Assumed Point.

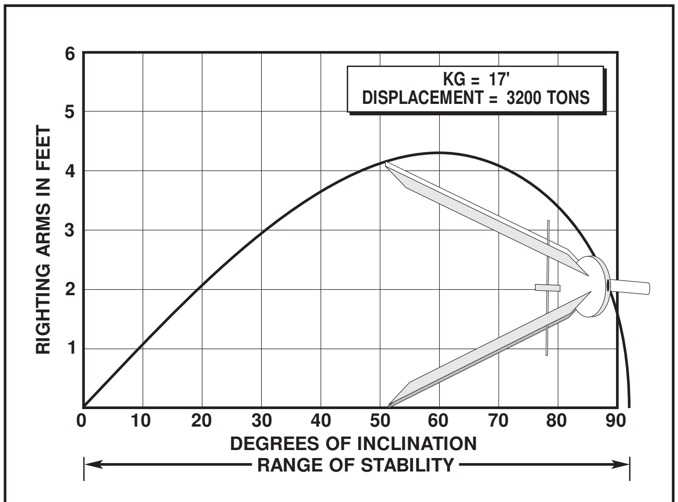

Figure 4-9. Corrected Statical Stability Curve.

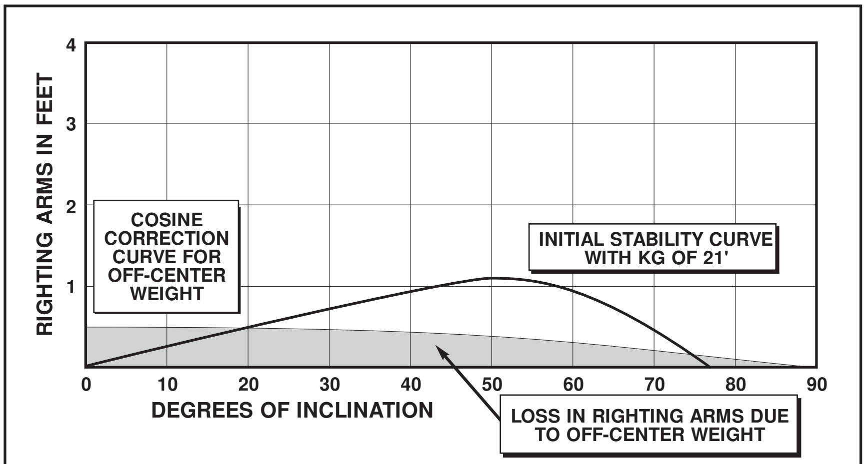

Figure 4-10. Correction to Statical Stability Curve for Transverse Shift of G.

4-2.9.3 Off-Center Weight Correction. When there is off-center weight and the center of gravity is no longer on the centerline, a list results and there is deterioration in the stability characteristics, including a reduction in righting arm toward the side to which the ship is listing. The reduction in righting arm is equal to the product of the distance between the new center of gravity and the centerline times the cosine of the angle of inclination, or:

$$\text{correction} = GG_1 \times \cos \theta$$

where:
GG_1 is the distance between the centerline and the new position of the center of gravity. Thus, if the center of gravity is 0.5 feet from the centerline, the correction can be calculated as:

Angle θ	Cosine of the angle $\cos \theta$	Horizontal distance GG_1	Correction $GG_1 \times \cos \theta$
0	1.000	0.5	0.50
10	0.985	0.5	0.49
20	0.940	0.5	0.47
30	0.866	0.5	0.43
45	0.707	0.5	0.35
60	0.500	0.5	0.25
75	0.259	0.5	0.13
90	0	0.5	0

As is done with the height corrections, the off-center eight corrections are plotted to the same scale as the curve of statical stability. The corrected curve of statical stability is drawn by plotting the difference between the two curves as shown in Figures 4-10 and 4-11.

The angle at which the corrected curve of statical stability crosses the horizontal axis is the angle of list caused by the off-center weight.

4-2.9.4 Range of Stability. The range of stability is the number of degrees through which the ship is stable or the number of degrees through which the ship can heel without capsizing. The range of stability may be measured directly from the statical stability curve and its limit is the intersection of the curve and the horizontal axis. For instance:

- In Figure 4-5, the uncorrected stability curve, the range of stability is from 0 degrees to more than 90 degrees.
- In Figure 4-7, the stability curve corrected for height of the center of gravity, the range of stability is from 0 degrees to 77 degrees.
- In Figure 4-11, the stability curve corrected for off-center weight, the range of stability is 20 degrees to 75 degrees.

4-2.9.5 Righting Arm and Righting Moment. The righting arm at any inclination may be read directly from the curve. Because each stability curve applies only to a specific displacement, the righting moment can be obtained directly for any angle by multiplying the righting arm by the displacement. In Figure 4-7, the maximum righting arm is 1.1 feet, the maximum righting moment is 3,520 foot-tons, and the angle where the maximums occur is 51 degrees. Similarly, in Figure 4-11 the maximum righting arm is 0.83 feet, the maximum righting moment is 2,656 foot-tons, and the angle where the maximums occur is 49 degrees.

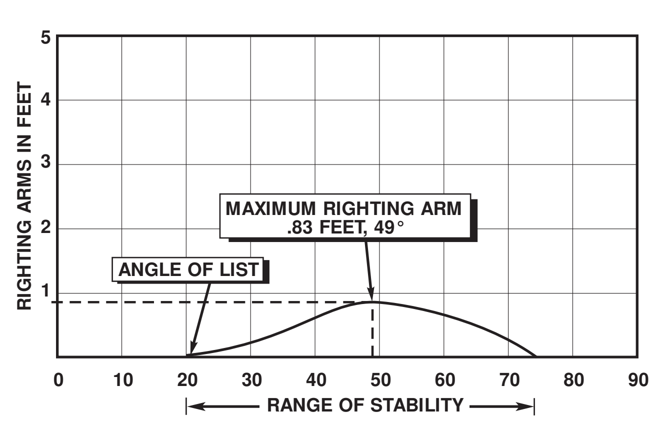

Figure 4-11. Corrected Statical Stability Curve for Transverse Shift in G.

4-2.9.6 Metacentric Height. The metacentric height may be obtained directly from the curve of statical stability by:

a. Erecting a perpendicular to the horizontal axis at 57.3 degrees (one radian).

b. Drawing the tangent to the statical stability curve at the origin.

The intersection of the two lines indicates the metacentric height. In Figure 4-12, the metacentric height of the ship with stability curve 1 is 3.47 feet, and that of the ship with stability curve 2 is 1.47 feet.

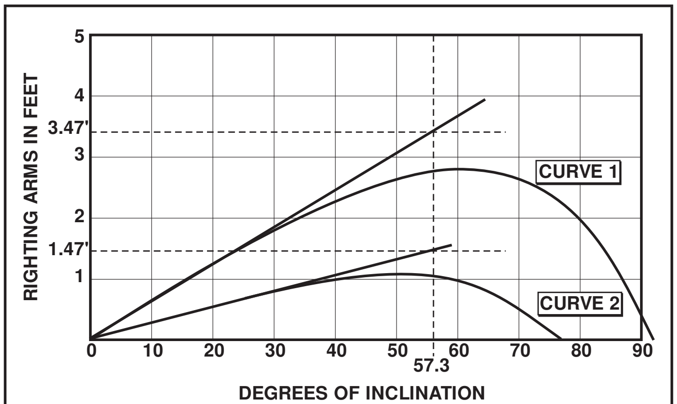

Figure 4-12. Metacentric Height from Statical Stability Curves.

4-3 STABILITY OF SUNKEN SHIPS.

The initial stability of a ship, sunken and resting upright on the seafloor, depends primarily upon whether the main deck is above water, partially submerged, or completely submerged.

EXAMPLE 4-4
SUNKEN SHIP STABILITY MAIN DECK ABOVE WATER

An FFG-7 Class ship with the characteristics given on the curves of form in Figure FO-1 is flooded throughout and sunk on an even keel with a draft of 28 feet. The hull depth is 30 feet. The center of gravity *(G)* is 21 feet above the keel. Determine the following:

- The metacentric height of the ship as she lies
- The metacentric height of the ship when she is floating at a draft of 25 feet
- The ship is divided into seven compartments with the lengths and effective breadths listed below. If all compartments have free surface, is the ship stable when floating at a draft of 25 feet?

Compartment	*l*	*b*
(1)	35	20
(2)	55	30
(3)	85	40
(4)	95	45
(5)	85	40
(6)	55	35
(7)	35	30

- If all matters are equal, which compartments should be dried out to eliminate free surface and make the ship stable?

a. Metacentric height as she lies:

Figure FO-1 provides a curve of the height of the metacenter above the keel (KM_T) for drafts up to 28 feet. From this curve:

KM_T	=	24.6 feet
KG	=	21.0 feet
GM	=	3.6 feet

b. Metacentric height floating at a draft of 25 feet:

KM_T may be obtained from Figure FO-1

KM_T	=	23.6 feet
KG	=	21.0 feet
GM	=	2.6 feet

c. Free surface effect, free surface in all compartments:

The total volume of the ship is obtained by multiplying the displacement of the ship obtained from Figure FO-1 (7,900 tons) by 35.

$$fs = GG_1 = \frac{i}{v}$$

$$i = \frac{lb^3}{12}$$

$$v = w \times 35$$

$$fs = \frac{lb^3}{12 \times w \times 35}$$

For a typical compartment:

$$fs = \frac{(85)(40)^3}{12 \times 7{,}900 \times 35}$$

$$fs = 1.64 \text{ feet}$$

Compartment	*l*	*b*		Free Surface Effect
(1)	35	20		0.08 feet
(2)	55	30		0.45 feet
(3)	85	40		1.64 feet
(4)	95	45		2.61 feet
(5)	85	40		1.64 feet
(6)	55	35		0.71 feet
(7)	35	30		0.28 feet
			Total	7.41 feet

CONTINUED ON NEXT PAGE

EXAMPLE 4-4 (CONTINUED)
SUNKEN SHIP STABILITY MAIN DECK ABOVE WATER

The effect of free surface in all compartments is a virtual rise in gravity of 7.41 feet.

KM_T = 23.60 feet
KG_1 = 21 + 7.41 = 28.41
GM = -4.81 feet

The ship is unstable.

d. Compartments to be dried out:

Any combination of compartments can be dried out that will reduce the free surface effect by more than 4.82 feet. Some possible combinations are:

Compartment	FS Effect	Compartment	FS Effect
(3)	1.64	(4)	2.61
(4)	2.61	(3) or (5)	1.64
(5)	1.64	(6)	0.71
Total	5.89	Total	4.96

Any other combination would require drying out at least four compartments. The best solution is to dry out compartments (3), (4), and (5), as drying these three compartments gives the largest and safest margin. The practical salvor will select those compartments that are the easiest to dewater. In some instances, it may be preferred to press up the flooded compartment.

EXAMPLE 4-5
SUNKEN SHIP STABILITY MAIN DECK PARTIALLY ABOVE WATER

An FFG-7 Class ship with the characteristics given in the Curves of Form in Figure FO-1 is flooded throughout and sunk so that she lies with the main deck partially above the water, similar to the ship in Figure 4-14. The dimensions are l=250 and b=32. The waterplane coefficient for the portion above water may be taken as 0.72. The center of gravity is 22 feet above the keel. In this condition, the ship displaces 9,350 tons.

- What is the metacentric radius?
- What is the metacentric height? Is the ship stable?

a. Metacentric radius:

Metacentric radius is a function of the geometry of the waterplane and the volume of the underwater body of the ship.

$$BM = \frac{I}{V}$$

In this case, the waterplane has a length of 250 feet, a breadth of 32 feet and an estimated waterplane coefficient of 0.72. The moment of inertia of the waterplane can be determined by:

$$I = \frac{(C_{WP})^2}{11.7} \times L \times B^3$$

as described in Paragraph 3-2.2.2, of this Manual.

$$I = \frac{(0.72)^2}{11.7} \times 250 \times (32)^3$$

$$I = 362,969 \quad \text{feet}^4$$

$$V = 9,350 \times 35$$

$$V = 327,250 \quad \text{feet}^3$$

$$BM = \frac{362,969}{327,250}$$

$$BM = 1.11 \quad \text{feet}$$

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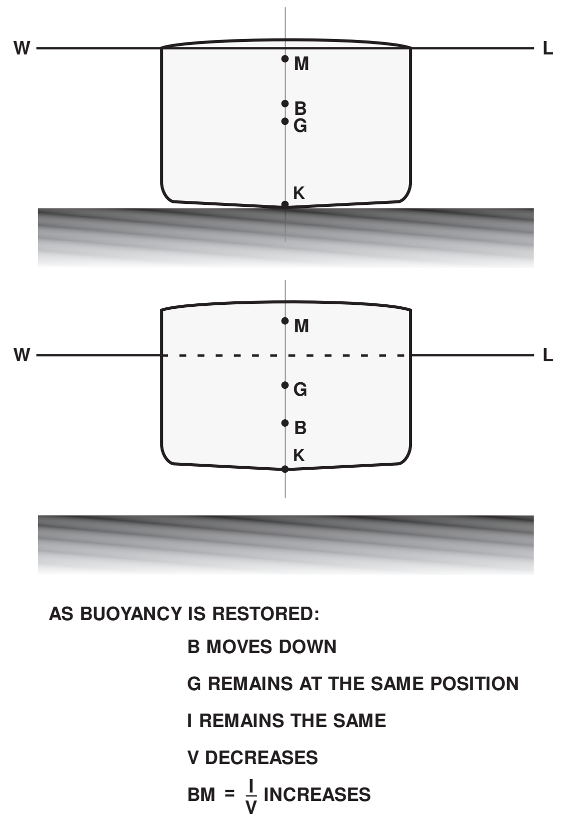

Figure 4-13. Sunken Ship Stability, Main Deck Above Water.

EXAMPLE 4-5 (CONTINUED)
SUNKEN SHIP STABILITY MAIN DECK PARTIALLY ABOVE WATER

The metacentric radius is small because waterplane is small and the volume of the underwater body is extremely large—much larger than it would be for the ship completely afloat.

b. Metacentric height:

From the curve of KB in Figure FO-1, it is reasonable to assume a KB of about 17 feet for the ship as she lies.

KB = 17.00
BM = +1.11
KM = 18.11 feet
KG = -22.00
GM = -3.89 feet

The ship is unstable.

4-3.1 Main Deck Above the Surface. If the ship is sunk with the main deck above the surface of the water, there is a waterplane and the metacentric radius (BM) and metacentric height *(GM)* can be calculated or estimated. In such cases, the center of buoyancy *(B)* may lie above the center of gravity *(G)*. As can be seen from Figure 4-13, the hull will be stable in this condition. When buoyancy is restored, the center of buoyancy moves down in the hull, crossing the position of the center of gravity, eventually lying below it. As this happens, the metacentric radius increases because the moment of inertia of the waterplane *(IT)* remains the same and the displacement volume *(V)* decreases. Ideally, the ship will remain positively stable throughout the process. If, however, the ship was unstable in her afloat condition, she will be unstable as that condition is restored. The addition of high weight or the removal of low weight during the salvage operation can cause an unstable afloat condition. Far more common is a loss of positive stability caused by free surface in an otherwise stable ship being refloated. It is possible that the free surface effect will be so great that the ship cannot be made positively stable under some conditions. When this occurs, precautions must be taken to prevent capsizing. Methods to prevent capsizing of sunken ships during refloating are discussed in Paragraph 4-3.4.8..

4-3.2 Main Deck Partially Above the Surface. If the ship is sunk so that the main deck is partially above the surface, the metacentric radius may be calculated based on the moment of inertia of the existing partial waterplane. Because of the relatively small value of the moment of inertia of the waterplane and the large underwater volume, the metacentric radius may be quite small. Depending on the location of the center of gravity, the metacentric height may be positive, negative, or in rare cases, zero. As buoyancy is restored, the length of the waterplane increases causing the moment of inertia of the waterplane to increase and the underwater volume to simultaneously decrease. The overall result is that the metacentric radius increases and the ship becomes potentially more stable. As when the main deck is completely above water, the overall stability of the ship depends upon the position of the center of gravity and the free surface in partially flooded spaces. Figure 4-14 and Example 4-5 illustrate the stability situation in a ship being raised in which the main deck was initially partially above water.

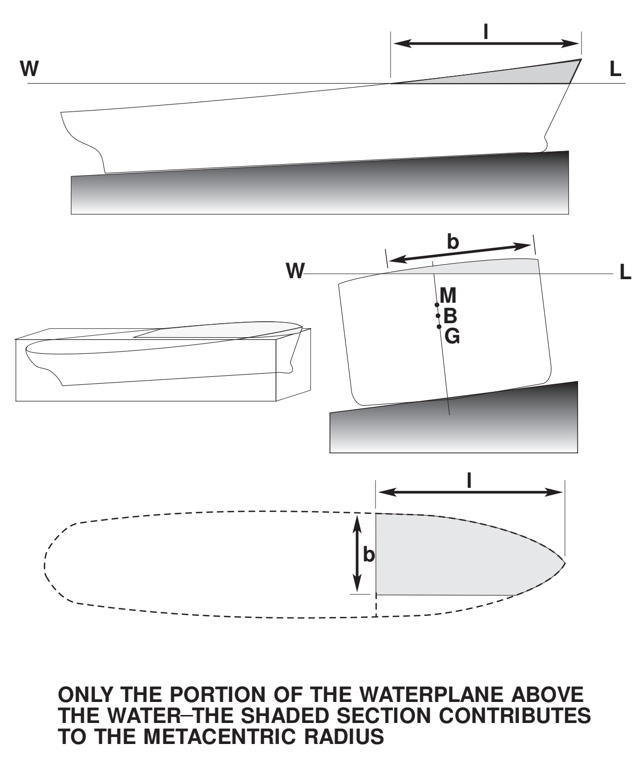

Figure 4-14. Sunken Ship Stability, Main Deck Partially Above Water.

4-3.3 Main Deck Submerged. By far, the most complex and difficult stability situation occurs when a ship is to be raised from a position where the main deck is completely submerged. In this condition, there is no metacentric radius because there is no waterplane. The positions of the metacenter and the center of buoyancy are coincident, and the distance between the centers of gravity and buoyancy *(BG)* becomes the measure of stability. It should be emphasized that *B* and *G* must be in line vertically, both transversely and longitudinally, at equilibrium. If *B* is above *G*, as

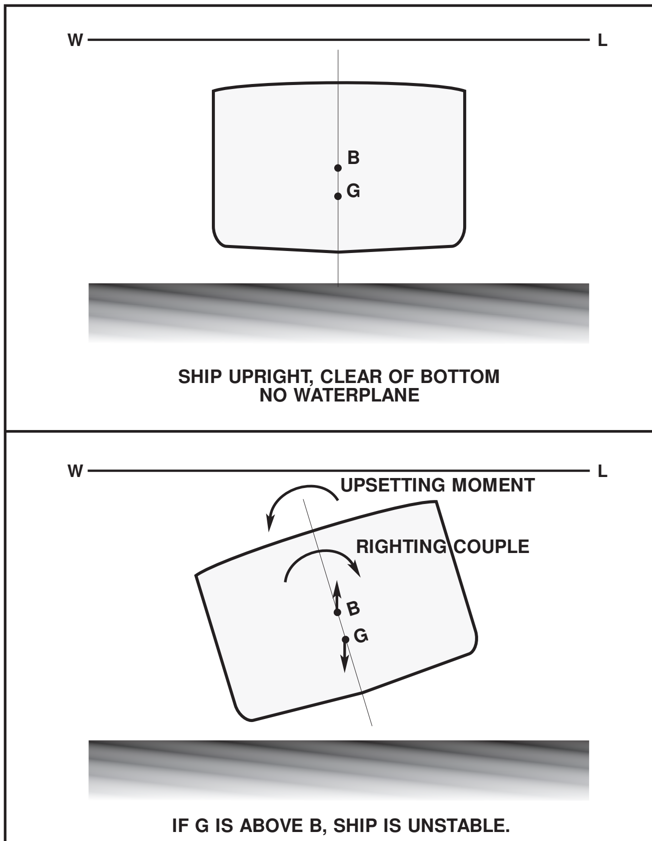

Figure 4-15. Sunken Ship Stability, Completely Sunken Ship.

shown in Figure 4-15, the ship is stable. If *B* and *G* are co-located, stability is neutral. If *B* is below *G*, the ship is unstable. When a stable ship is displaced from an upright position, a righting couple will be formed by the weight and buoyancy. In an unstable ship, the couple formed by weight and buoyancy acts to upset the ship. Stability of a completely submerged ship is generally not a concern if the ship is resting and restrained from capsizing by the seafloor; however, it will be of concern if the ship has floated free, but is still completely submerged.

As the ship begins to surface and develop a waterplane, a metacentric radius is formed and normal stability considerations apply. The metacentric radius is quite small at first; the metacentric height probably will be negative and the ship unstable, especially when there is appreciable free surface. As additional waterplane is gained and the underwater volume decreased, the ship becomes more stable. The period between the time the ship being raised begins to develop a waterplane and when it becomes positively stable is critical. During this period, the ship must be stabilized to prevent capsizing. Figure 4-16 illustrates the stability of a ship being raised from a completely submerged condition.

4-3.4 Longitudinal Stability. Longitudinal stability is the measure of a ship's ability to return to its original position after being disturbed by a force that rotates it around a transverse axis. Longitudinal stability is important to refloating operations because changes in the longitudinal stability of a stranded or sunken ship will not be apparent since the ship does not respond in the same manner as a ship afloat. The changes must be calculated to ensure salvors have an accurate assessment of the actual longitudinal stability situation.

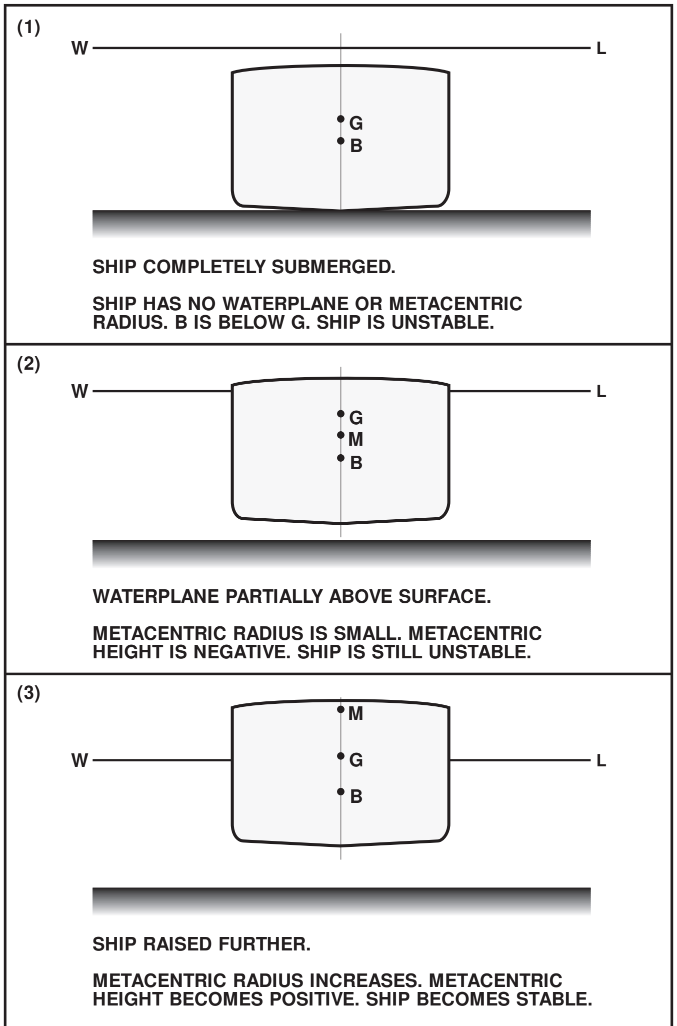

Figure 4-16. Development of Stability in Raising a Completely Sunken Ship.

Because of the contribution of length to the longitudinal moment of inertia of the waterplane, ships with any significant length of waterplane are inherently longitudinally stable. In ships with little or no internal transverse subdivision, free surface may present a major problem while the ship is being raised. The greatest danger to longitudinal stability from free surface lies not in the reduction of longitudinal metacentric height but in the trimming moment caused by the mass of water rushing to the low end of compartments as the ship trims from redistribution of weight. If transverse subdivision is non-existent or inadequate, the trimming moment may cause the ship to trim sufficiently to allow downflooding with subsequent loss of buoyancy and plunging. In a submerged hull, trim is effected by the longitudinal separation of *B* and *G*. Longitudinal and transverse stability are essentially the same, in this situation, because there is no waterplane.

A ship with no waterplane and no longitudinal metacentric radius has only the longitudinal righting moment provided by the relative positions of the centers of gravity and buoyancy. Care must be taken to raise the ship so that trim does not develop, or to keep it in contact with the bottom.

EXAMPLE 4-6
CALCULATION OF THE LONGITUDINAL CENTER OF GRAVITY

Material	**Weight (w)** (Long Tons)	**Distance from the FP (lcg)** (Feet)
Ship's structure	2,000	225
Machinery	500	210
Stores	400	201
Fuel	250	180
Cargo	800	220

What is the longitudinal position of the center of gravity?

A tabular form is convenient for this type of calculation.

	Weight (w) (Long Tons)	**Distance from FP (lcg)** (Feet)	**Moment of Weight (w x lcg)** (Foot Tons)
	2,000	225	450,000
	500	210	105,000
	400	201	80,400
	250	180	45,000
	800	220	176,000
Sums	3,950		856,400

$$\text{Distance of LCG from FP} = \frac{\text{sum of the moments of weight}}{\text{total weight}}$$

$$LCG = \frac{856{,}400}{3{,}950}$$

$$LCG = 216.8 \text{ feet (or 217 feet) abaft the FP}$$

4-3.4.1 <u>Longitudinal Position of Center of Gravity (LCG)</u>. The longitudinal position of the center of gravity is as important to longitudinal stability as the height of the center of gravity is to transverse stability. Its position is determined solely by the distribution of weight along the length of the ship. The longitudinal position of the center of gravity is measured in feet from the midships section or the forward perpendicular. It is determined in a manner similar to determining the height of the center of gravity above the keel in that the sum of the moments of the weights about either the forward perpendicular or the midships section is divided by the total weight to obtain the desired position. The following steps are necessary:

a. Classify all the weights in the ship.

b. Determine the longitudinal distance of each weight from the reference.

c. Multiply each weight by the longitudinal distance from the reference to determine the moment of the weight.

d. Total the weights and the moments of weight.

e. Divide the total of the moments of weight by the total weight to determine how far the longitudinal position of the center of gravity lies from the reference.

4-3.4.2 Longitudinal Position of the Center of Buoyancy (LCB). The longitudinal position of the center of buoyancy is measured in feet from either the forward perpendicular or the midships section. For a ship in equilibrium, the longitudinal position of the center of buoyancy is in the same vertical line as the longitudinal position of the center of gravity. At any given time, there is only one point that is the center of buoyancy; the height and longitudinal position are two coordinates of that single point. Determination of the longitudinal position of the center of buoyancy is lengthy and tedious, requiring calculation of the underwater volume of the ship and its distribution. The longitudinal position of the center of buoyancy may be obtained from the curves of form. In salvage, the longitudinal position of the center of buoyancy is important primarily in making strength calculations when buoyancy must be distributed to place the longitudinal positions of the centers of gravity and buoyancy in the same vertical line.

4-3.4.3 Longitudinal Center of Flotation (LCF). The longitudinal center of flotation is the point about which the ship trims. It is the geometric center of the waterline plane. The longitudinal position of the center of flotation is measured in feet from either the midships section or the forward perpendicular. In ships of normal form, it may lie either forward or aft of the midships section. In fine-lined ships, the longitudinal center of flotation is usually slightly abaft the midships section. The longitudinal position of the center of flotation is required to calculate final drafts when trim changes. It can be calculated if the exact shape of the waterplane is known, or it may be obtained from the curves of form. If the position cannot be obtained, it can be assumed to be amidships.

4-3.4.4 Longitudinal Metacenter (M_L). The longitudinal metacenter is an imaginary point of importance in longitudinal stability. Like the transverse metacenter, it is located where the force of buoyancy's lines of action running through the longitudinal center of buoyancy intersects the vertical line through the center of buoyancy of the untrimmed ship. While the center of gravity and the center of buoyancy are points whose heights above the keel and longitudinal position are two coordinates of the same point, the transverse metacenter and the longitudinal metacenter are separate points, each with its own set of coordinates.

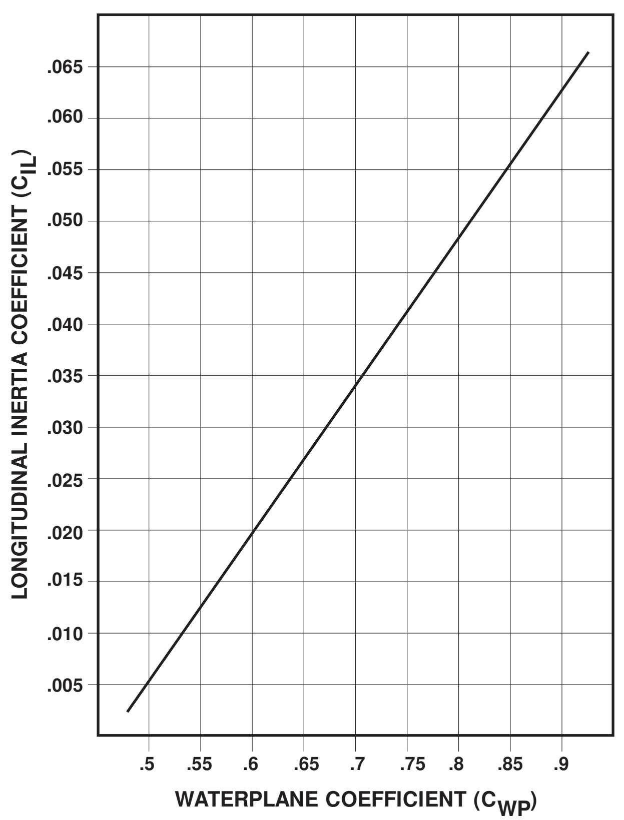

Figure 4-17. Longitudinal Inertia Coefficient.

4-3.4.5 Longitudinal Metacentric Radius (BM_L). The longitudinal metacentric radius is the distance between the center of buoyancy and the longitudinal metacenter. The longitudinal metacentric radius is measured in feet. It is defined as the moment of inertia of the waterline waterplane about a transverse axis divided by the volume of displacement.

$$BM_L = \frac{I_L}{V}$$

If the shape of the waterplane is known, the moment of inertia of the waterplane can be defined exactly. For salvage work, a reasonably accurate approximation may be made by:

$$I_L = C_{IL} \times B \times L^3$$

where:

C_{IL}	=	The longitudinal inertia coefficient and is equal to $(0.143 \times C_{WP} - 0.0659)$
B	=	Beam
L	=	Length between perpendiculars

NOTE

The longitudinal inertia coefficient may be obtained directly from Figure 4-17 by entering along the horizontal scale with the waterplane coefficient, reading up to the curve, and then reading across to the vertical scale.

4-3.4.6 Height of the Longitudinal Metacenter (KM_L). The height of the longitudinal metacenter is the distance between the metacenter and the keel, and is measured in feet. The height of the longitudinal metacenter is the sum of the height of the center of buoyancy and the longitudinal metacentric radius, or:

$$KM_L = KB + BM_L$$

where:

KM_L	=	The longitudinal height of the metacenter
KB	=	The height of the center of buoyancy
BM_L	=	Longitudinal metacentric radius

4-3.4.7 Longitudinal Metacentric Height (GM_L). The longitudinal metacentric height is the distance between the height of the center of gravity and the longitudinal metacenter measured in feet. The longitudinal metacentric height is the difference between the longitudinal height of metacenter and the height of the center of gravity, or:

$$GM_L = KM_L - KG$$

where:

GM_L	=	Longitudinal metacentric height
KM_L	=	Height of the longitudinal metacenter
KG	=	Height of the center of gravity

EXAMPLE 4-7
CALCULATION OF THE LONGITUDINAL METACENTRIC RADIUS

An FFG-7 Class ship is 408 feet long with a beam of 44 feet and draws 14.5 feet. Her block coefficient is 0.467 and her waterplane coefficient is 0.754. What is her longitudinal metacentric radius (BM_L)?

a. Determine the longitudinal inertia coefficient:

$$C_{IL} = (0.143 \times C_{WP} - 0.0659)$$

$$C_{IL} = (0.143 \times 0.754 - 0.0659)$$

$$C_{IL} = 0.0419$$

b. Calculate the moment of inertia of the waterplane:

$$I_L = C_{IL} \times B \times L^3$$

$$I_L = 0.0419 \times 44 \times (408)^3$$

$$I_L = 125{,}212{,}356 \text{ feet}^4$$

c. Calculate the displacement volume:

$$V = C_B \times L \times B \times T$$

$$V = 0.487 \times 408 \times 44 \times 14.5$$

$$V = 126{,}768 \text{ feet}^3$$

d. Divide moment of inertia by displacement volume to get longitudinal metacentric radius:

$$BM_L = \frac{I_L}{V}$$

$$BM_L = \frac{125{,}212{,}356}{126{,}768}$$

$$BM_L = 987.73 \text{ feet (or 988 feet)}$$

4-3.4.8 Keeping the Ship Upright. As the ship is raised, various methods are used to prevent it from capsizing while it passes through ranges where it is inherently unstable or develops instability from free surface. The most common method is to refloat one end of the vessel while keeping the other end firmly in contact with the bottom. The contact with the ground prevents the ship from taking on a dangerous list or capsizing. In deep water, keeping one end of the ship in contact with the ground and limiting the rise of the other end prevents extreme trim.

Before the grounded end is raised, free surface in the floating end is reduced by dewatering. Spaces low in the ship, such as double-bottom tanks, may be flooded and pressed up to both eliminate free surface and to lower the center of gravity and increase the metacentric height.

At the same time, topside weights are removed and other portable weights moved as low in the ship as possible to lower the center of gravity. With free surface minimized from the floating part of the ship and the center of gravity as low as practicable, the grounded end may be raised. These methods are not always adequate; careful stability calculations with detailed consideration of free surface should be made before attempting to raise the grounded end.

Large free surfaces can be broken up by repairing damaged bulkheads and by building temporary bulkheads within flooded spaces. The work of building temporary bulkheads is considerably reduced if the bulkhead is built with high-pressure concrete pumped into simple forms. Both bulkhead reinforcements and temporary bulkheads should be built wider at the base than at the top to assist in lowering the center of gravity.

A force may be applied to the ship being raised to produce a moment that counters an upsetting moment. This is done by attaching cranes or tackles rigged to apply a vertical force near the side of the ship. When the ship begins to list, a force is applied to counter the list and bring the ship back to the upright position. Figure 4-18 shows methods of accomplishing this technique.

As illustrated in Figure 4-19, pontoons, barges, or lift craft may be rigged to provide a force that counters a heeling moment and keeps the ship upright. The pontoons must be rigged tightly to the ship so that when the ship begins to heel, she will also attempt to submerge the pontoon on the low side. The additional buoyancy of the submerging pontoon, coupled with the loss of buoyancy from the pontoon on the high side, creates a moment that rotates the ship back to an upright position. Tightly rigged pontoons and lift craft not only provide an uprighting force from their buoyancy but act as an increased waterplane of a system composed of the ship and pontoons. The waterplane of the pontoons increases the metacentric height and overall stability of the ship-pontoon system. This advantage is gained only when the ship and pontoons are so tightly rigged that they function as a unit. If the ship is free to render in a cradle formed by the rigging, the pontoons provide only buoyancy.

Ships sunk in harbors have been kept upright by rigging purchases from their mastheads to anchoring points ashore. If this method is attempted, the ship should be held securely by mooring lines, as there will be a tendency for the ship to kick out from under the strain of the purchases on the masts. Figure 4-20 illustrates this technique.

One of the most secure methods of controlling the ship is to rig beach gear and haul the ship into shallower water as it is lightened or lifted. The beach gear is kept under constant heavy tension so that the ship moves into shallower water in constant contact with the bottom until it has reached a location where it may safely be dried out and refloated. Beach gear rigged ashore may be hauled with winches, linear pullers, or heavy vehicles. Tugs may be used to help move and direct the ship. Ashore, heavy tracked vehicles may also be used to haul lines for positioning the ship.

Keeping a ship in contact with the bottom, either at one end or all along her length, also assists in controlling trim and preventing the loss of longitudinal stability caused by water rushing to the low end.

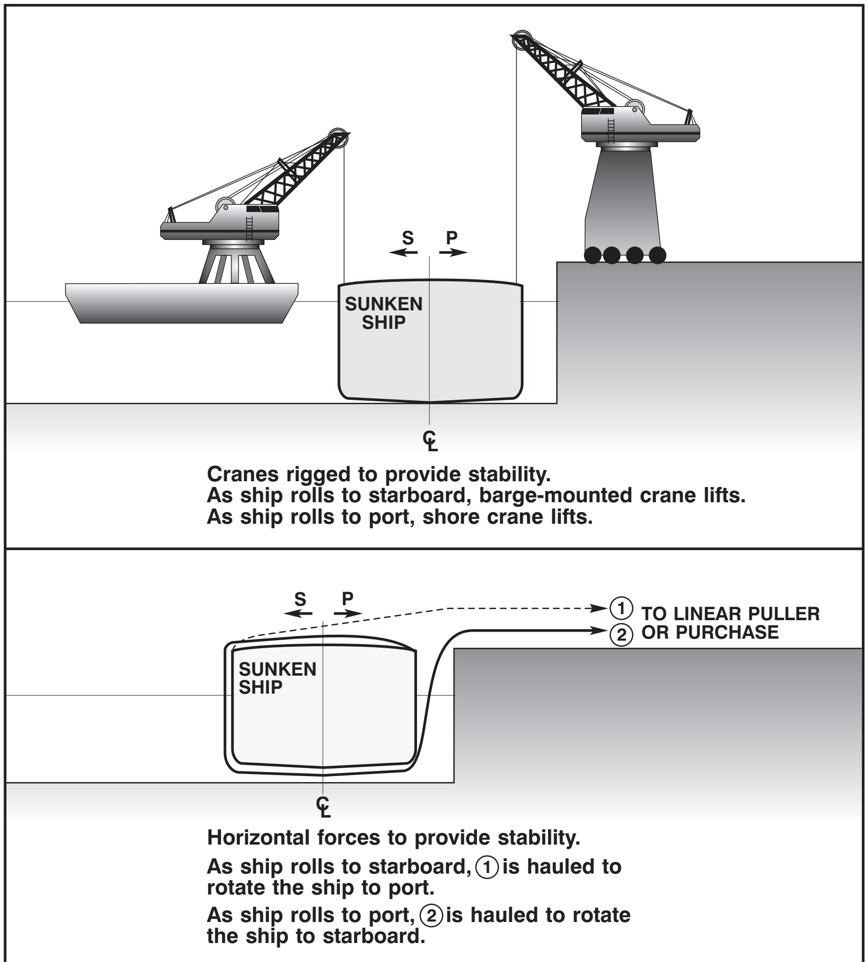

Figure 4-18. Stabilizing Sunken Ships with Cranes or Tackles.

4-4 INTRODUCTION TO WEIGHT AND IMPAIRED STABILITY.

Weight aboard ships affects many things, including hull characteristics, stability and strength. As a result, salvors must understand the relationship between weight and ships. This chapter explains that relationship and demonstrates how the effects are calculated.

With an understanding of the geometry of ships and basic stability and weight in an intact ship, salvors may begin to consider the changes that occur when ships are damaged. The second portion of this chapter addresses impaired stability, or the stability of a damaged ship, and presents methods for calculating its effects.

Weight additions and removals result from loading and offloading cargo, stores, and equipment; fueling; using potable water, fuel, and other consumables; ballasting; and numerous other evolutions. When a weight is added or removed three things happen:

- The displacement changes
- The center of gravity moves
- Moments that trim or incline the ship are produced.

Displacement changes carry with them draft changes and attendant changes in the hydrostatic properties. The change in the transverse metacentric height (GM) is particularly important because of its effect on stability. Both weight additions and removals may change the moment of inertia of the waterplane. Weight additions will increase and weight removals will decrease displacement volume.

Movement of the center of gravity causes any of several effects, depending on where the weight is added or removed:

- Weight added below the center of gravity causes the center of gravity to move downward. The metacentric height will thus be increased. Weight removed below the center of gravity has the opposite effect on the center of gravity and the metacentric height.

- Weight added above the center of gravity causes the center of gravity to move upward. The metacentric height will thus be decreased. Weight removed above the center of gravity has the opposite effect on the center of gravity and the metacentric height.

- Weight added or removed forward or aft of the center of gravity causes the center of gravity to move. If a weight is added forward or aft of the center of gravity, the ship will trim.

- Weight added or removed to port or starboard of the center of gravity causes the center of gravity to shift transversely and the ship to list.

- Weight added or removed at the center of gravity has no effect on the position of the center of gravity. The only effect on metacentric height is that caused by the change in metacentric radius (BM), which results in the change in displacement volume and a less significant change in waterplane area and shape.

Calculations of the effect of weight addition or removal are done in two parts:

a. The weight is treated as if it had been added at the center of gravity, and its effect on displacement is calculated.

b. The weight is moved to its actual location and its effect on metacentric height, trim, and list are calculated.

4-4.1 Weight Additions and Removals at the Center of Gravity. The principal effect of weight addition or removal at the center of gravity is to change displacement by the amount of weight that is added or removed. When weight is added, the increase in displacement requires that the ship sink to a new draft. The new waterline is parallel to the waterline at which the ship floated prior to the weight being added; accordingly, the change in draft is known as parallel sinkage. When weight is removed, there is a decrease in displacement with a corresponding rise to the new drafts. The distance that the ship sinks or rises, in inches or centimeters, is equal to the weight added or removed divided by the tons per inch or centimeter immersion:

$$\text{Parallel sinkage (or rise)} = \frac{w}{TPI}$$

where:
w = The weight added (or removed)
TPI = Tons per inch immersion

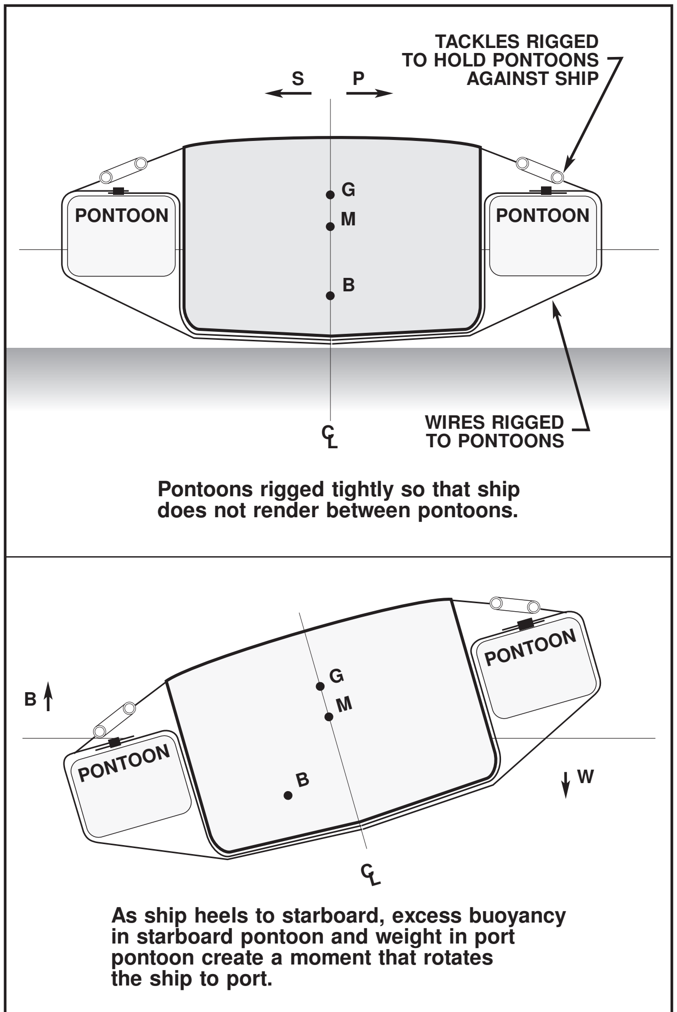

Figure 4-19. Pontoons Rigged to Stabilize Sunken Ship During Refloating.

4-4.2 Other Effects of Weight Additions and Removals. Weight that is not added exactly at the center of gravity affects the stability, trim, and list of the ship in addition to displacement. Each effect can be determined separately (see Example 4-15).

4-4.2.1 Longitudinal Effects of Weight Additions and Removals. The addition or removal of weight causes changes in the longitudinal position of the center of gravity and in trim. These changes are explained in the following:

a. Movement of the Center of Gravity. When weights are added or removed at a distance from the longitudinal position of the center of gravity, the center of gravity moves toward the weight to a new position determined by the size and position of the weight. The new position of the center of gravity can be calculated by the same principles as new heights of the center of gravity:

b. Trimming Moment. The trimming moment created by a weight addition or removal is usually more important than the movement of the center of gravity. The trimming moment created by weight addition or removal is the product of the weight and its longitudinal distance from the center of flotation.

$$MT = w \times d$$

where:
MT = Trimming moment
w = Weight causing the moment
d = Distance from the center of flotation.

EXAMPLE 4-8
CALCULATION OF DRAFT CHANGE WITH WEIGHT ADDITION

A weight of 75 tons is added at the center of gravity of an FFG-7 Class ship drawing 14.5 feet forward and aft. How much does her draft increase?

The draft increase, or parallel sinkage, equals the weight added divided by the tons per inch immersion.

$$\text{Parallel sinkage (or rise)} = \frac{w}{TPI}$$

a. Determine the tons per inch immersion from the Curves of Form.

b. Determine the parallel sinkage by dividing the weight by the tons per inch immersion:

$$\text{Parallel sinkage (or rise)} = \frac{w}{TPI}$$

$$\text{Parallel sinkage (or rise)} = \frac{75}{32.0}$$

$$\text{Parallel sinkage (or rise)} = 2.34 \text{ inches}$$

If the weight had been removed instead of added, parallel rise would be 2.34 inches.

EXAMPLE 4-9
CALCULATION OF LONGITUDINAL MOVEMENT OF THE CENTER OF GRAVITY WITH WEIGHT CHANGES

a. In a ship displacing 3,475 tons, the longitudinal position of the center of gravity (LCG) is 210 feet from the forward perpendicular. A weight of 50 tons is added 100 feet aft of the forward perpendicular. What is the new longitudinal position of the center of gravity?

Applying the principle that the location of the center of gravity can be found by dividing the sum of the moments of weight by the total weight, then:

$$LCG_1 = \frac{(LCG \times W) + (lcg \times w)}{(W + w)}$$

where:
LCG_1 = The new longitudinal position of the center of gravity
LCG = The original longitudinal position of the center of gravity
W = The original weight (displacement)
lcg = The location of the added weight
w = The added weight

$$LCG_1 = \frac{(210 \times 3{,}475) + (100 \times 50)}{(3{,}475 + 50)}$$

$$LCG_1 = \frac{734{,}750}{3{,}525}$$

$$LCG_1 = 208.4 \text{ feet from the forward perpendicular}$$

CONTINUED ON NEXT PAGE

Weight additions and removals create one of four kinds of trimming moments:

- A weight addition forward of the center of flotation creates a moment that causes the ship to trim down by the bow.
- A weight addition abaft the center of flotation creates a moment that causes the ship to trim down by the stern.
- A weight removal forward of the center of flotation creates a moment that causes the ship to trim down by the stern.
- A weight removal abaft the center of flotation creates a moment that causes the ship to trim down by the bow.

EXAMPLE 4-9 (CONTINUED)
CALCULATION OF LONGITUDINAL MOVEMENT OF THE CENTER OF GRAVITY WITH WEIGHT CHANGES

b. In the same ship, a weight of 50 tons is added 100 feet abaft the center of gravity. How far does the longitudinal position of the center of gravity move?

$$GG_1 = \frac{Gg \times w}{W + w}$$

$$GG_1 = \frac{(100 \times 50)}{(3,475 + 50)}$$

$$GG_1 = \frac{5,000}{3,525}$$

$$GG_1 = 1.42 \text{ feet aft}$$

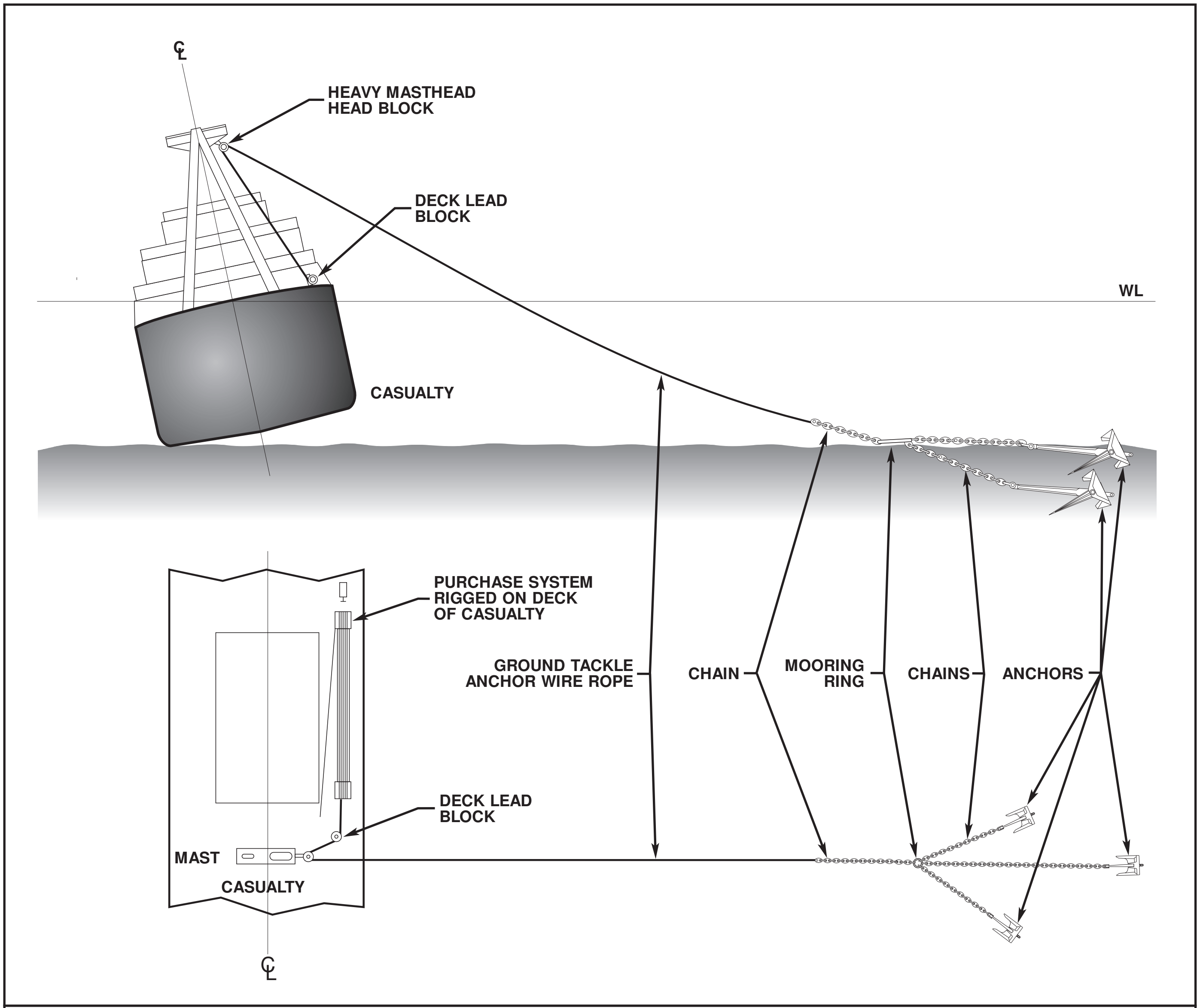

Figure 4-20. Restraining a Casualty with Masthead Tackle.

4-4.2.2 Trim. The quantities necessary for determining trim and how they are used are explained in the following paragraphs.

4-4.2.2.1 Trimming Moment. A trimming moment is a moment exerted by a weight anywhere in the ship acting about the center of flotation. A trimming moment causes the ship to trim, or tip, around the center of flotation. There is no special symbol for trimming moment, though M is convenient to use. Trimming moment is measured in foot-tons. For instance, a weight of 25 tons placed 100 feet forward of the center of flotation would have a trimming moment of 2,500 foot-tons by the bow. Paragraph 4-4.2.1 provides an example for longitudinal effects of weight additions and removals.

EXAMPLE 4-10
CALCULATION OF MOMENT TO TRIM ONE INCH

What is the approximate moment to change trim one inch for the FFG-7 Class ship described in Example 4-7.

To calculate the approximate moment to trim one inch:

$$MT1 = \frac{(BM_L \times W)}{(12 \times L)}$$

From the calculation in Example 2-4:

$$BM_L = 988 \text{ feet}$$
$$L = 408 \text{ feet}$$
$$V = 126{,}768 \text{ cubic feet}$$

Displacement can be calculated from displacement volume:

$$W = \frac{126{,}768}{35}$$
$$W = 3{,}622 \text{ tons}$$

then:

$$MT1 = \frac{(988 \times 3{,}622)}{(12 \times 408)}$$
$$MT1 = 730.9 \text{ foot-tons}$$

MT1 from the curves of form is 745 foot-tons. The value based on calculation is within 10 percent of the actual MT1 and is a reasonable approximation for salvage work.

4-4.2.2.2 Moment to Change Trim One Inch (MT1). The trimming moment required to cause a change in trim of one inch (1") is known as the Moment to Change Trim One Inch. The MT1 for any ship depends upon the hull form and may be either obtained from the curves of form or calculated by:

$$MT1 = \frac{(GM_L \times W)}{(12 \times L)}$$

where:

GM_L	=	Longitudinal metacentric height
W	=	Displacement
L	=	Length between perpendiculars

As the longitudinal metacentric radius, BM_L, is easily obtained and is not very different from the longitudinal metacentric height, GM_L, it is often used to determine an approximate MT1 by:

$$MT1 = \frac{(BM_L \times W)}{(12 \times L)}$$

Additional methods of calculating the approximate moment to change trim one inch can be found in Appendix C.

NOTE

The Greek letter delta (δ) is used in conjunction with symbols to mean "the change in" the quantity that the symbol represents.

4-4.2.2.3 Trim Calculations. In salvage, trim calculations are usually made to determine the changes in draft fore and aft resulting from a change in trimming moment. The calculation has three parts:

a. Determination of the trimming moment

b. Determination of the total change of trim by dividing the trimming moment by the moment to change trim one inch, or:

$$\delta\text{trim} = \frac{\text{trimming moment}}{MT1}$$

c. Determination of the new drafts. When a ship trims, one end gains draft while the other end loses draft. For instance, a ship that trims by the bow gains draft at the bow and loses draft at the stern. The total trim is the sum of the amount gained at one end and lost at the other. As a ship trims about the center of flotation, the amount of change at the bow is proportional to the ratio of the product of the change of trim multiplied by the distance between the forward perpendicular and the center of flotation — and the length of the ship, or:

$$\delta T_f = \frac{\delta\text{trim} \times (FP \text{ to } LCF)}{L}$$

The new draft forward will be the old draft forward with the change added or subtracted as appropriate:

$$\text{New } T_f = \text{Original } T_f \pm \delta T_f$$

Likewise, the change in trim aft is equal to the ratio of the product of the change of trim multiplied by the distance between the after perpendicular and the center of flotation — and the length of the ship, or:

$$\delta T_a = \frac{\delta\text{trim} \times (AP \text{ to } LCF)}{L}$$

The new draft aft will be the old draft aft with the change added or subtracted as appropriate:

$$\text{New } T_a = \text{Original } T_a \pm \delta T_a$$

EXAMPLE 4-11
CALCULATION OF TRIM

The FFG-7 Class ship described in Example 4-10 is floating at a draft both forward and aft of 14.5 feet. The center of flotation is twenty-five feet abaft the midship section. A trimming moment of 25,000 foot-tons by the bow is introduced. What are the new drafts?

The first step, the determination of trimming moments, is not necessary because that information is already available; i.e., M = 25,000 foot-tons.

To obtain the total change in trim, divide the trimming moment by the moment to change trim one inch:

$$\delta \text{trim} = \frac{M}{MT1}$$

Moment to trim one inch is 745 foot-tons from the curves of form; therefore

$$\delta \text{trim} = \frac{25,000}{745}$$

$$\delta \text{trim} = 33.6$$

To obtain the new draft forward, determine the distance from the FP to the LCF:

$$FP \text{ to } LCF = \frac{L}{2} + 25$$

$$FP \text{ to } LCF = \frac{408}{2} + 25$$

$$FP \text{ to } LCF = 229$$

then:

$$\delta T_f = \frac{\delta\text{trim} \times (FP \text{ to } LCF)}{L}$$

$$\delta T_f = \frac{33.6 \times 229}{408}$$

$$\delta T_f = 18.9'' \text{ or } 1'\ 7''$$

$$\text{New } T_f = \text{Old } T_f + \delta T_f$$

$$\text{New } T_f = 14'6'' + 1'7''$$

$$\text{New } T_f = 16'1''$$

CONTINUED

EXAMPLE 4-11 (CONTINUED)
CALCULATION OF TRIM

To obtain the new draft aft, determine the distance from the AP to the LCF:

$$AP \text{ to } LCF = \frac{L}{2} - 25$$

$$AP \text{ to } LCF = \frac{408}{2} - 25$$

$$AP \text{ to } LCF = 179$$

then:

$$\delta T_a = \frac{\delta\text{trim} \times (AP \text{ to } LCF)}{L}$$

$$\delta T_a = \frac{33.6 \times 179}{408}$$

$$\delta T_a = 14.7'' \text{ or } 1'\ 2.7''$$

$$\text{New } T_a = \text{Old } T_a - \delta T_a$$

$$\text{New } T_a = 14'\ 6'' - 1'\ 2.7''$$

$$\text{New } T_a = 13'\ 3.3''$$

A method to check the accuracy of the draft calculations is to add the change in draft forward and the change in draft aft, and compare the result with the total change in trim. These quantities should be equal. In the previous example the total change in trim was 32.9 inches.

δT_f	=	18.9"
δT_a	=	14.7"
		33.6"

Since the sum of the draft changes is equal to the total change in trim, the calculation was performed correctly.

EXAMPLE 4-12
CALCULATION OF TRIMMING MOMENT

a. A weight of 50 tons is added 100 feet forward of the center of flotation. What is the trimming moment? In which direction does the ship trim?

$$M = w \times d$$
$$M = 50 \times 100$$
$$M = 5{,}000 \text{ foot–tons}$$

Because the weight is added forward of the center of flotation, the ship trims down by the bow.

b. A weight of 50 tons is removed 100 feet abaft the center of flotation. What is the trimming moment? In which direction does the ship trim?

$$M = w \times d$$
$$M = 50 \times 100$$
$$M = 5{,}000 \text{ foot–tons}$$

Because weight is removed abaft the center of flotation the ship trims down by the bow.

4-4.2.3 <u>Effects of Off-Center Weight Additions and Removals</u>. The addition or removal of off-center weight causes changes both in the transverse position of the center of gravity and in inclination.

a. Movement of the Center of Gravity. The addition or removal of an off-center weight moves the center of gravity off the centerline. Applying the same principles used when dealing with the height and longitudinal position of the center of gravity, the distance an off-center weight addition or removal moves the center of gravity can be determined.

$$GG_1 = \frac{Gg \times w}{W \pm w}$$

EXAMPLE 4-13
CALCULATION OF THE TRANSVERSE MOVEMENT OF THE CENTER OF GRAVITY

In a ship displacing 3,475 tons, 150 tons are added 20 feet to starboard of the centerline. How far does the center of gravity move transversely?

$$GG_1 = \frac{20 \times 150}{3,475 + 150}$$

$$GG_1 = 0.83 \quad \text{feet to starboard}$$

b. Inclining Moment. When an off-center weight is added or removed, weight acting through the new center of gravity and buoyancy acting through the old center of buoyancy form a couple known as the inclining moment. The effect of the inclining moment is to cause the ship to incline toward the side with the greatest weight until the centers of gravity and buoyancy are again in a vertical line. The magnitude of the inclining moment is:

$$M_I = W \times GG_1$$

where:

M_I = The inclining moment, and the other symbols are as previously defined.

W = Total weight (displacement), with weight change included

The inclining moment will produce a list that is equal to:

$$\theta = \tan^{-1} \frac{w \times Gg}{W \times GM} = \tan^{-1} \frac{GG_1}{GM}$$

where:

θ = The angle of inclination

$\tan^{-1}$ = A symbol meaning "the angle whose tangent is ...."

4-4.3 Combined Effects. A single weight addition or removal can have all of the effects described above. Each effect can be assumed to occur independently. Accordingly, each can be calculated separately as if the effects were occurring one after the other.

4-4.4 Weight Shifts. Weight shifts — moving weight from one location to another in a ship — have the same effect as removing the weight from its original location and adding it at its new location. Because the same weight is removed and then added, there is no effect on displacement and no parallel sinkage or rise. Depending on the nature of the shift, there may be an effect on the height, longitudinal position, and transverse position of the center of gravity. For example, if a weight low on the port side aft is shifted to a position high on the starboard side forward, the following things will happen:

EXAMPLE 4-14
CALCULATION OF THE INCLINING MOMENT AND ANGLE OF INCLINATION

What is the inclining moment created in Example 4-13 when the displacement is 3,625 tons and the new center of gravity is 0.83 feet to starboard of the centerline?

$$M_I = W \times GG_1$$

$$M_I = 3,625 \times 0.83$$

$$M_I = 3,008.75 \quad \text{foot-tons}$$

If the ship has a metacentric height of 3 feet, what is the angle of inclination after the addition of the weight?

$$\theta = \tan^{-1} \frac{w \times Gg}{W \times GM}$$

$$\theta = \tan^{-1} \frac{150 \times 20}{3,625 \times 3}$$

$$\theta = \tan^{-1} \frac{3,000}{10,875}$$

$$\theta = \tan^{-1} 0.2759$$

$$\theta = 15.4 \text{ to starboard}$$

- The center of gravity will shift upward.
- There will be a decrease in metacentric height.
- The center of gravity will shift forward.
- A trimming moment will be created that will trim the ship down by the bow.
- The center of gravity will shift to starboard.
- An inclining moment will be created that will list the ship to starboard.

Each effect can be calculated independently. Often it is adequate to know the change of the height of the center of gravity. The change can be applied to GM to assess the change of stability. The magnitude of the change for a weight shift is:

$$GG_1 = \frac{Gg \times w}{W \pm w}$$

where:

GG_1 = The distance between the old and new centers of gravity.

Gg = The distance the weight was shifted.

W = Displacements

w = Weight moved

EXAMPLE 4-15
CALCULATION OF COMBINED EFFECTS OF WEIGHT ADDITION

A weight of 100 tons is added to the FFG7 whose characteristics are described below and in FO-1. The weight is added 30 feet above the keel, 150 feet abaft the midships section, and 10 feet to port of the centerline.

Determine:

The ship's new forward, after, and mean drafts

The new metacentric height

The list

Ship's Characteristics:

L	=	408 feet	B	=	44 feet
T_M	=	14.5 feet	C_B	=	0.487
C_{WP}	=	0.754	KG	=	21 feet
LCF	=	23 feet abaft midships	TPI	=	32 tons
LCG	=	2 feet abaft midships	W	=	3,475 tons
MT1	=	745 foot-tons			

a. The new drafts:

Add the weight at the center of gravity and determine the new displacement, the new draft caused by parallel sinkage, and the new height of the metacenter.

Determine new weight (displacement):

$$W_1 = W + w$$

$$W_1 = 3,475 + 100$$

$$W_1 = 3,575 \quad \text{tons}$$

Determine new draft at LCF:

$$\text{New} \quad T = \text{Old} \quad T + \frac{w}{TPI}$$

$$\text{New} \quad T = 14.5 + \frac{100}{32}$$

$$\text{New} \quad T = 14' \quad 6" + 3.1"$$

$$\text{New} \quad T = 14' \quad 9.1" \quad \text{or} \quad 14.76'$$

Determine the new trim.

Determine the trimming moment:

$$M_T = w \times d$$

$$M_T = 100 \times (150 - 23)$$

$$M_T = 12,700 \quad \text{foot-tons}$$

Determine the change in trim:

$$\delta\text{Trim} = \frac{M_T}{MT1}$$

$$\delta\text{Trim} = \frac{12,700}{745}$$

$$\delta\text{Trim} = 17.0"$$

CONTINUED

EXAMPLE 4-15 (CONTINUED)
CALCULATION OF COMBINED EFFECTS OF WEIGHT ADDITION

Determine the new forward and after drafts.

$$\delta T_f = \delta \quad \text{trim} \times \frac{\text{(Distance from FP to LCF)}}{\text{LBP}}$$

$$\delta T_f = 17.0 \times \frac{227}{408}$$

$$\delta T_f = 9.5"$$

$$\text{The new } T_f = \text{Old} \quad T_f - \delta \quad T_f$$

$$\text{The new } T_f = 14' \quad 9.1" - 9.5"$$

$$\text{The new } T_f = 13' \quad 11.6"$$

$$\delta T_a = \delta \quad \text{trim} \times \frac{\text{(Distance from AP to LCF)}}{\text{LBP}}$$

$$\delta T_a = 17.0 \times \frac{181}{408}$$

$$\delta T_a = 7.5"$$

$$\text{The new } T_a = \text{Old} \quad T_a - \delta \quad T_a$$

$$\text{The new } T_a = 14' \quad 9.1" + 7.5"$$

$$\text{The new } T_a = 15' \quad 4.6"$$

$$\text{Tm} = \frac{T_a + T_f}{2}$$

b. The new metacentric height:

Height of the metacenter is determined from the hydrostatic tables to be 22.4 feet at the new mean draft of 14 feet 8 inches.

$$KM = 22.4'$$

Move the weight vertically to determine the new KG and GM. The weight was placed 9 feet above the center of gravity of the ship.

$$GG_1 = \frac{w \times Gg}{W}$$

$$GG_1 = \frac{(100 \times 9)}{3,575}$$

$$GG_1 = 0.25'$$

GG_1 must be added to KG to find KG_1.

$$KG_1 = KG + GG_1$$

$$KG_1 = 21' + 0.25'$$

$$KG_1 =_1 21.25'$$

Determine GM:

$$GM = KM - KG$$

$$GM = 22.4 - 21.25$$

$$GM = 1.15'$$

CONTINUED ON NEXT PAGE

EXAMPLE 4-15 (CONTINUED)
CALCULATION OF COMBINED EFFECTS OF WEIGHT ADDITION

c. The list:

Determine the transverse shift of the center of gravity:

$$GG_1 = \frac{w \times Gg}{W}$$

$$GG_1 = \frac{(100 \times 10)}{3{,}575}$$

$$GG_1 = 0.28' \text{ to port}$$

Determine the list:

$$\theta = \tan^{-1} \frac{w \times Gg}{W \times GM}$$

$$\theta = \tan^{-1} \frac{100 \times 10}{3{,}575 \times 1.15}$$

$$\theta = \tan^{-1} \frac{1{,}000}{4{,}111}$$

$$\theta = \tan^{-1} 0.243$$

$$\theta = 13.7 \text{ to port}$$

EXAMPLE 4-16
CALCULATION OF COMBINED EFFECTS OF WEIGHT SHIFTS

A weight of 100 tons is shifted on a ship whose characteristics are given below.

LCF	=	23 feet abaft midships	KM	=	22.4 feet
T_f	=	14 feet 6 inches	LBP	=	408 feet
LCG	=	2 feet abaft midships	KG	=	19 feet
MT1	=	745 foot-tons	W	=	3,475 tons
T_a	=	14 feet 6 inches			

The original position of the weight was 150 feet abaft midships, 10 feet to port of the centerline, and 5 feet above the keel. The weight is shifted to a new position 100 feet forward of midships, 20 feet to starboard of the centerline, and 30 feet above the keel.

Determine:

The new drafts

The new metacentric height

The list

a. The new drafts:

As there is no change in displacement, there is no parallel sinkage or rise. There is trim.

To determine the trimming moment, calculate the trimming moment caused by removing the weight.

$$M_{TR} = w \times (\text{distance from } LCF)_R$$

Calculate the trimming moment caused by adding the weight:

$$M_{TA} = w \times (\text{distance from } LCF)_A$$

CONTINUED

EXAMPLE 4-16 (CONTINUED)
CALCULATION OF COMBINED EFFECTS OF WEIGHT SHIFTS

Add the two:

$$M_T = w \times (\text{distance from } LCF)_R + w \times (\text{distance from } LCF)_A$$

$$M_T = w \times \left[(\text{distance from } LCF)_R + (\text{distance from } LCF)_A\right]$$

Since the weight was removed abaft LCF and added forward of LCF,

then:

$$(\text{distance from } LCF)_R + (\text{distance from } LCF)_A = \text{total distance}$$

$$M_T = 100 \times (127 + 123) = 100 \times (150 + 100)$$

$$M_T = 25{,}000 \text{ foot-tons}$$

$$\delta \text{ Trim} = \frac{M_T}{MT1}$$

$$\delta \text{ Trim} = \frac{25{,}000}{745}$$

$$\delta \text{ Trim} = 33.56''$$

The ship will trim down by the bow.

The new draft forward:

$$T_f = \delta\text{Trim} \times \frac{\frac{L}{2} + 23}{L} + \text{Original } T_f$$

$$T_f = 33.56 \times \frac{\frac{408}{2} + 23}{408} + 14.5$$

$$T_f = 18.67 + 14' \; 6''$$

$$T_f = 1' \; 6.67'' + 14' \; 6''$$

$$T_f = 16' \; 0.67''$$

The new draft aft:

$$T_a = \text{Original } T_a - (\delta \text{ Trim-} T_f)$$

$$T_a = 14' \; 6'' - (33.56'' - 18.67'')$$

$$T_a = 14' \; 6'' - 14.89''$$

$$T_a = 14' \; 6'' - 1' \; 2.89''$$

$$T_a = 13' \; 3.11''$$

To check the accuracy of the draft calculation:

$$\delta T_f = 18.67''$$

$$+ \; \delta T_a = \underline{14.89}$$

$$\delta \text{Trim} = 33.56''$$

b. The new metacentric height:

$$GG_1 = \frac{w \times Gg}{W}$$

$$GG_1 = \frac{(100 \times 25)}{3{,}475}$$

$$GG_1 = 0.72'$$

CONTINUED ON NEXT PAGE

EXAMPLE 4-16 (CONTINUED)
CALCULATION OF COMBINED EFFECTS OF WEIGHT SHIFTS

The new KG is then:

$$KG_1 = KG + GG_1$$
$$KG_1 = 19 + 0.72$$
$$KG_1 =_1 19.72'$$

then:

$$GM = KM - KG$$
$$GM = 22.4 - 19.72$$
$$GM = 2.68'$$

c. The list:

$$GG_1 = \frac{w \times Gg}{W}$$
$$GG_1 = \frac{100 \times (10 + 20)}{3,475}$$
$$GG_1 = 0.863'$$
$$\theta = \tan^{-1} \frac{GG_1}{GM}$$
$$\theta = \tan^{-1} \frac{0.863}{2.68}$$
$$\theta = 17.8 \text{ to starboard}$$

4-5 IMPAIRED STABILITY.

A ship's stability can be impaired by a number of causes:

- Injudicious addition, removal, or shifting of weight
- Flooding
- Free-surface effect from loose water (see Paragraph 3-3.3)
- Free communication with the sea (see Paragraph 3-3.4)
- Any combination of the above.

The first three conditions can occur in intact ships. Only free communication with the sea requires damage to the hull. The following paragraphs discuss the effects of these conditions on stability.

4-5.1 Weight Control. The distribution of weight in a ship controls the location of the center of gravity, and the location of the center of gravity directly affects both longitudinal and transverse stability. Weight additions, removals, and shifts must be strictly controlled at all times to control the position of the center of gravity. Weight changes must be planned before the evolution, because a poorly thought-out weight change may place the ship in danger. In normal ship operations, the following should be avoided:

- Addition of weight that causes the ship to sink beyond her established limiting draft or to have insufficient reserve buoyancy for safe operation.
- Additions of weight high in the ship, removals of weight low in the ship, and weight shifts from low to high that cause a rise in the position of the center of gravity and a loss of transverse stability.
- Weight additions, removals, or shifts that result in trims of more than one percent of the ship's length.
- Weight additions, removals, or shifts that result in off-center weight and a list.

Control of weight is crucial to normal ship operations and is even more important during when a ship is damaged or during salvage operations. When normal conditions do not exist on board, special care must be taken to control weight changes so the ship is not endangered. Weight removals from the ship must be controlled; the effect of each on the displacement, transverse stability and trim must be known before the weight is removed. Removal of weight in the wrong place or removal of too much weight can place the ship in a hazardous condition or cause it to be unstable when refloated. During salvage operations, large quantities of heavy equipment often are brought on board the ship being salvaged. The location of this equipment and material must be planned beforehand so that excessive weight is not added high in the ship.

4-5.2 Flooding. Flooding is one of the greatest hazards to a ship because it can lead to loss of the ship through:

- Loss of reserve buoyancy that, if extensive enough, can cause the ship to sink, or
- Loss of stability that may lead to capsizing.

Flooding can be caused by firefighting water, liquid storage or transfer system damage, hull breaches from collision, grounding, explosion, or any other casualty that lets liquid into the watertight envelope of the ship. In addition to the problem of increased weight presented by the flood water, loose water (water free to move from side to side as the ship rolls) causes other serious consequences that are discussed in Paragraph 4-5.3.

Compartments in ships other than tanks or void spaces are usually partially filled with equipment, machinery, stores, cargo, or other materials. Because this material takes up a portion of the space in the compartment, the amount of water the compartment will hold is reduced. The volume of a compartment that can be flooded divided by its total volume is the permeability of the compartment. For instance, if a compartment has a volume of 4,000 cubic feet and contains 2,000 cubic feet of equipment, only 2,000 cubic feet can be filled with water, and the compartment has a permeability of 2,000/4,000 or 0.5. In calculating the effects of flooding, permeability should be taken into account to make the most accurate determination of the amount of water in the ship.

Flood water can be treated like added weight; its effect on displacement, the center of gravity, trim, and list can be calculated in the same way as solid weight would be if added in the same location.

When a ship has flooding caused by damage, every effort must be undertaken to contain the flooding and to make sure it is not spreading progressively throughout the ship. Flooding can be expected to spread through every possible means including piping, cableways, and drain systems. Damaged piping systems or unused piping systems in older ships are particularly dangerous. The initial damage survey should be followed by frequent rechecks of compartments and tanks to ensure flooding is not spreading. Flooding from firefighting water can be particularly dangerous because:

- It may be high in the ship
- It may drain down, affecting several compartments and creating a free surface in each.

Whenever a fire is fought with water or other liquids, attention must be paid to where those liquids go, both during and after the fire.

4-5.3 Free Surface. If a compartment is partially filled with liquid, the liquid moves from side to side as the ship rolls, and the free surface attempts to remain level. The effect of this free surface is to cause the liquid to flow to the low side when the ship heels. Stability is affected the same way as it would be by a rise in the center of gravity; that is, the metacentric height is reduced and the ship becomes less stable. The effective or virtual rise in the center of gravity is:

$$GG_1 = \frac{i}{V}$$

where:

- GG_1 = The virtual rise in the center of gravity
- i = The moment of inertia of the tank or compartment with the free surface; for a rectangular compartment with b (width) and l (length)*:

$$i = \frac{b^3 \times l}{12}$$

- V = The displacement volume of the ship, NOT the volume of the tank with the free surface.

*Appendix C addresses irregular surfaces.

EXAMPLE 4-17
CALCULATION OF THE VIRTUAL RISE IN THE CENTER OF GRAVITY FROM FREE SURFACE

A ship with a displacement volume of 429,000 cubic feet has partial flooding in a compartment 50 feet wide and 30 feet long. What is the virtual rise in the center of gravity caused by the free surface in the tank?

$$GG_1 = \frac{i}{V}$$

$$i = \frac{b^3 \times l}{12} = \frac{50^3 \times 30}{12} = 312{,}500 \text{ ft}^4$$

$$GG_1 = \frac{312{,}500}{429{,}000}$$

$$GG_1 = 0.728 \text{ feet (or } 0.73 \text{ feet)}$$

The effect of the free surface is equivalent to raising the center of gravity 0.728 feet and decreasing the metacentric height by the same amount.

If free surface exists in several tanks or compartments, the effect of each free surface must be calculated separately and the sum applied to the center of gravity to determine the total virtual rise in the center of gravity. Free surface should be eliminated wherever possible by either pressing tanks up until they are full or emptying them completely.

For a more complete description of the free surface effect refer to the *U.S. Navy Salvage Engineer's Handbook, Volume 1*, Section 1-9.2.1. This section describes and illustrates the free surface effect, pocketing and the pocketing angle.

4-5.3.1 Surface Permeability. If a compartment contains equipment, cargo, or stores that pierce the surface of the flood water, the free surface is reduced. Surface permeability is defined as the moment of inertia of the actual free surface divided by the moment of inertia of the same surface with no objects projecting through. Surface permeability usually varies at different levels in the compartment. Naval architects may consider surface permeability when developing tables or curves of free surface area or effect for tanks, but prudent operators will ignore surface permeability in calculating free surface for two reasons:

- Surface permeability is very difficult to estimate. An error in estimating it can lead one to believe the ship is more stable than it actually is.
- If surface permeability is neglected, the calculations will indicate less stability than the ship actually possesses. The error is on the "safe side" for salvors.

4-5.3.2 Pocketing. When the ship rolls and the liquid moves to expose the deck or to cover the overhead of a flooded compartment, pocketing occurs. Because the free surface is reduced, the virtual rise of the center of gravity is reduced. Naval architects normally account for pocketing when developing tables or curves of free surface effect for tanks. When free surface is calculated manually, and it is certain that pocketing is occurring, the estimate for free surface effect be reduce by 25%. If there is any doubt, no correction should be made.

4-5.4 Free Communication. When a ship is damaged so that the sea flows freely in and out of the ship, free communication with the sea exists. There are three effects from this kind of flooding:

- Added weight from the water taken on board. This weight is usually low in the ship and may lower the center of gravity.
- The free-surface effect from the loose water. This effect causes a virtual rise in the center of gravity and decreases metacentric height.
- When the flooded compartment is off-center, there is an additional virtual rise in the center of gravity from the free-communication effect.

When an off-center compartment is flooded, the ship takes on a list. As the list increases, additional water enters the ship and levels off at the external waterline. The additional water causes the ship to list further and additional water enters the ship. The process continues in decreasing increments until equilibrium is reached. The additional water flowing into an off-center compartment is the free-communication effect. Free-communication effect always causes a loss of stability. There is no free-communication effect in a flooded centerline compartment because the high side of the compartment loses a quantity of water roughly equal to that gained on the low side. The virtual rise of the center of gravity due to free communication can be calculated by:

$$GG_1 = \frac{(a \times y^2)}{V}$$

where:

- GG_1 = The virtual rise of the center of gravity due to free communication with the sea
- a = The surface area of the flooded compartment
- y = The distance from the centerline of the ship to the center of gravity of the flooded compartment

The free communication and its effect can be eliminated by patching the hole so water cannot flow freely through it.

EXAMPLE 4-18
CALCULATION OF THE VIRTUAL RISE OF THE CENTER OF GRAVITY FROM FREE COMMUNICATION

In a ship whose displacement volume is 429,000 cubic feet, a compartment whose surface dimensions are 20 by 30 feet, and whose center of gravity is 25 feet off the centerline, is in free communication with the sea. What is the virtual rise in the center of gravity due to the free-communication effect?

$$GG_1 = \frac{(a \times y^2)}{V}$$

$$a = (20 \times 30) = 600$$

$$GG_1 = \frac{(600 \times 25^2)}{429{,}000}$$

$$GG_1 = \frac{375{,}000}{429{,}000}$$

$$GG_1 = 0.874 \text{ feet (or } 0.87 \text{ feet)}$$

The virtual rise in the center of gravity from free communication with the sea is 0.874 feet; the metacentric height is decreased by the same amount.

EXAMPLE 4-19
CALCULATION OF THE COMBINED EFFECTS OF FREE SURFACE, FREE COMMUNICATION AND OFF-CENTER WEIGHT

A ship whose cross section is shown in Figure 4-21 is involved in a collision that ruptures the hull into an off-center compartment amidships. The compartment is 14 feet wide, 20 feet long, and 8 feet high. The longitudinal axis of the compartment is 18 feet to port of the ship's centerline. Before the hatches to the damaged compartment can be closed, 2 feet of seawater enter an adjacent compartment 20 feet long, 11 feet wide, and 8 feet high. The adjacent compartment is immediately inboard of the damaged compartment. The kg of each compartment is 12 feet. The characteristics of the ship are:

LBP	=	400 feet	B	=	50 feet
T	=	20 feet	W	=	6,250 tons
C_B	=	0.56	C_{WP}	=	0.70
LCF	=	Midships	TPI	=	33.33 tons
KG	=	14 feet	KM		20.58 feet

Determine the combined effect of free surface and free communication on GM and the induced list.

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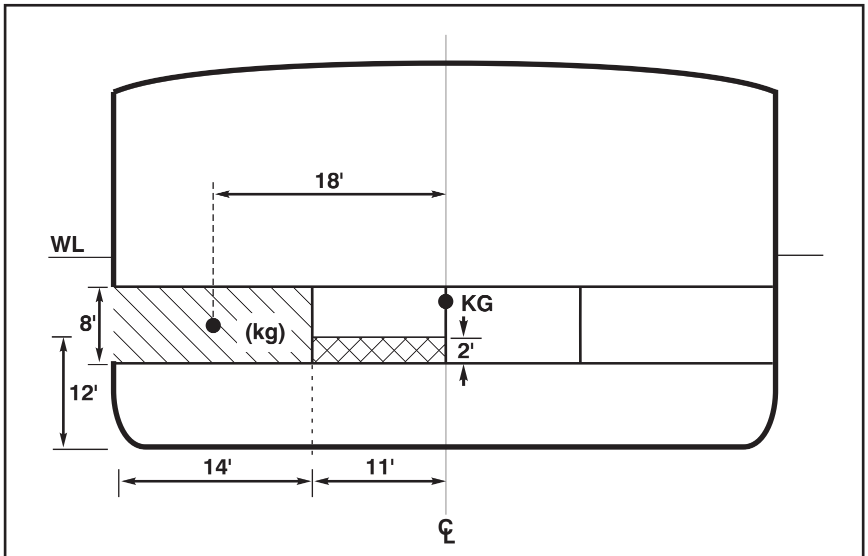


Figure 4-21. Vessel Cross Section for Example 4-19.

Movement of the center of gravity may either increase or decrease stability, depending upon where the weight is added. Free-surface and free-communication effects ALWAYS decrease stability. Each effect occurs independently of the others and can be calculated separately.

NOTE

The actual condition of the outboard compartment will be in a constant state of change as the ship rolls. At times, the space will be completely flooded with no free-surface effect, and at other times it will only be partially filled, reducing the weight of the flood water but allowing free surface. Using the weight of the totally flooded compartment and allowing for free surface in the calculations give the safest result.

4-5.5 Combined Effects of Flooding. The combined effects of flooding are:

- Increase in displacement
- Movement of the center of gravity
- Free-surface effect
- Free-communication effect.

4-5.6 List. A list is an inclination of a ship while the ship is in equilibrium. Listing is a symptom rather than a cause of impaired stability, but is common enough and potentially serious enough to warrant discussion here. A list has three possible causes:

- Off-center weight
- Negative metacentric height (GM)
- A combination of off-center weight and negative metacentric height.

EXAMPLE 4-19 (CONTINUED)
CALCULATION OF THE COMBINED EFFECTS OF FREE SURFACE, FREE COMMUNICATION AND OFF-CENTER WEIGHT

a. Determine the draft and displacement after damage:

(1) Determine the weight of the flood water:

$$w = \frac{l \times b \times d}{35}$$

where:

w = Weight of the loose water
l = Length of the free surface
b = Breadth of the free surface
d = Depth of the loose water

$$\text{Outboard compartment}, w_1 = \frac{20 \times 14 \times 8}{35} = 64 \text{ tons}$$

$$\text{Inboard compartment}, w_2 = \frac{20 \times 11 \times 2}{35} = 13 \text{ tons}$$

The new displacement is:

$$W_1 = W + w_1 + w_2 = 6,250 + 64 + 13 = 6,327 \text{ tons}$$

(2) Determine the new mean draft:

$$\delta T = \frac{w_1 + w_2}{TPI} = \frac{64+13}{33.33} = 2.3"$$

$$\text{New } Tm = \text{Old } T_M + \delta T = 20' + 2.3" = 20' \ 2.3" \text{ or } 20.19'$$

b. Determine the new KG with the added weight of the flood water:

Weight (w)	Height above keel (kg)	Moment of Weight (w x kg)
6,250	14	87,500.00
64	12	768.00
13	9	117
6,327		88,385

$$KG_1 = \frac{\text{sum of the moments of weight}}{\text{total weight}} = \frac{88,385}{6,327} = 13.97'$$

c. Determine the new KM due to the change in draft and displacement:

$$KM_1 = KB_1 + BM_1$$

$$KM_1 = (0.55 \times T) + \frac{(L \times B^3 \times C_{IT})}{V}$$

$$C_{IT} = \frac{(C_{WP})^2}{11.7} = \frac{.70^2}{11.7} = 0.0419$$

$$KM_1 = (0.55 \times 20.19) + \frac{(400 \times 50^3 \times 0.0419)}{6,327 \times 35}$$

$$KM_1 = 20.57'$$

d. Determine the new GM:

$$G_1M_1 = KM_1 - KG_1 = 20.57 - 13.97 = 6.6'$$

CONTINUED

EXAMPLE 4-19 (CONTINUED)
CALCULATION OF THE COMBINED EFFECTS OF FREE SURFACE, FREE COMMUNICATION AND OFF-CENTER WEIGHT

e. Determine the virtual rise of G due to free surface in both compartments and free communication in the outboard compartment.

(1) Free surface (outboard compartment):

$$GG_1 = \frac{i}{V} = \frac{\frac{b^3 \times l}{12}}{V} = \frac{\frac{14^3 \times 20}{12}}{6,327 \times 35} = \frac{4,573}{221,445} = 0.02'$$

(2) Free surface (inboard compartment):

$$GG_2 = \frac{i}{V} = \frac{\frac{b^3 \times l}{12}}{V} = \frac{\frac{11^3 \times 20}{12}}{6,327 \times 35} = \frac{2,218}{221,445} = 0.01'$$

(3) Free communication (outboard compartment only):

$$GG_3 = \frac{(a \times y^2)}{V} = \frac{(l \times b) \times y^2}{V} = \frac{(20 \times 14) \times 18^2}{6,327 \times 35} = \frac{90,720}{221,445} = 0.41'$$

f. The combined effects of free surface and free communication on GM can be summarized:

$$GM = G_1M_1 - GG_1 - GG_2 - GG_3$$
$$GM = 6.6 - 0.02 - 0.01 - 0.41$$
$$GM = 6.16'$$

g. Determine the list:

The centers of gravity of the outboard and inboard compartments are 18 feet and 5.5 feet respectively off the centerline to port:

$$GG_T = \frac{(w_1 \times Gg_1) + (w_2 \times Gg_2)}{W + W_1 + W_2}$$

where:

GG_T = The transverse distance the center of gravity moved
w_1 = Weight of the water in the outboard compartment
w_2 = Weight of the water in the inboard compartment
d_1 = Distance from the center of gravity of the water in the outboard compartment to the center of gravity of the ship
d_2 = Distance from the center of gravity of the water in the inboard compartment to the center of gravity of the ship
W_1 = The displacement of the ship including the flood water ($W_1 = W + w_1 + w_2$)

$$GG_T = \frac{(64 \times 18) + (13 \times 5.5)}{6,327} = \frac{1,224}{6,327} = 0.19' \text{ to port}$$

h. Determine the list:

$$\theta = \text{Tan}^{-1} \frac{GG_T}{GM}$$
$$\theta = \text{Tan}^{-1} \frac{0.19}{6.16}$$
$$\theta = \text{Tan}^{-1} \ 0.0308$$
$$\theta = 1.76 \text{ degrees to port}$$

Whenever there is a list, it is very important to determine the cause of the list before attempting to correct it. The wrong "corrective" measure may make the situation worse. When disturbed, ships with off-center weight behave differently from ships with negative metacentric height.

- A ship with off-center weight will return to the same listed position when it is disturbed.
- A ship with negative metacentric height may roll sluggishly or loll and settle with equal facility at the same angle on either side. The angle of loll is the heel angle where the combined effects of the outboard shift of center of buoyancy and change in waterplane shape raise the metacenter to a point above the center of gravity. The angle of loll may be estimated by:

$$\theta = \tan^{-1} \frac{2 \times GM}{BM^{1/2}}$$

- A ship with both off-center weight and negative metacentric height will loll, but will settle with a greater list toward the side with the off-center weight.

A ship with negative metacentric height is in a very dangerous condition. A positive metacentric height should be restored immediately. In general, negative metacentric height is dealt with by redistributing weight in the ship, removing high weight or adding low weight to move the center of gravity downward, or recovering lost waterplane to increase the transverse metacentric radius. If attempts are made to correct list caused by negative metacentric height by shifting weight to the high side, the ship may suddenly reverse her direction of loll, assuming an even greater angle of heel to the opposite side, or even capsize.

A list caused by off-center weight is dealt with by shifting or removing the off-center weight. Care must be taken not to overcompensate by removing more weight than is necessary or by removing weight that will decrease metacentric height.

4-7 STRENGTH OF SUNKEN SHPS.

The local, longitudinal bending and shear strength of sunken ships is often impaired by the damage that led to their sinking. The strength of the sunken ship can have a major effect on the methods used to salvage it.

Weakened local areas can usually be reinforced adequately by simple double patches, or may sometimes be ignored where patches are placed to restore the watertight envelope. The decision whether or not to repair locally weak areas depends upon the loads that will be placed in those area during the salvage operation, the nature of the potential failure, and the consequences of a failure

CAUTION

Cracks that are simply plugged and welded are not secured against growth under load. This type of repair should be accepted only in those cases where loads are low and growth in the crack can be tolerated. The proper complete repair for cracks is doubling. Doubling is discussed below and in greater detail in Chapter 10, Dewatering.

Local cracks can be dangerous, particularly if they are in high-stress areas. These cracks may grow as the operation proceeds and may eventually lead to serious failure. Cracks may be plugged with convenient patching material or doubled to prevent leakage through them. To prevent the cracks from growing, crack ends should be drilled and plugged. Doublers should not be placed over cracks without drilling the ends, as the crack will simply grow past the doubler. Cracks in areas that will not be highly stressed at any time during the operation are not as dangerous as those in high-stress areas. Such cracks may be repaired or left alone depending upon their size, location, orientation, and the stress levels they are likely to see. Each should be individually evaluated and monitored for growth during the operation.

Longitudinal and shear strength in sunken ships are evaluated in the same way they are for intact ships. Methods for determining longitudinal and shear strength are described in Chapter 5, Strength of Ship. If an evaluation of the longitudinal and shear strength reveals adequate strength, salvage may proceed. There must be an adequate margin of strength at each stage of salvage to preclude failure and to allow for unknown conditions.

If the survey or initial strength evaluation shows that the hull girder has failed, or that failure is probable during salvage, the hull must be reinforced or extraordinary measures adopted to prevent catastrophic failure and to allow completion of the operation. Even in ships to be disposed of, structural failure must be prevented, as it may occur at the worst possible time and result in a situation worse than the initial sinking.

When there is no failure of the hull girder, but failure can be expected during salvage, the hull may be reinforced by providing additional material in way of incipient failure to restore the section modulus or increase the shear area. Such reinforcement should be designed by salvage engineers and installed strictly in accordance with their specifications. Failure to follow the specifications exactly may result in inadvertently setting up shear or bending stress concentrations or other dangerous conditions.

The most common type of hull failure is compressive failure of the deck or bottom structure. Compressive failure can be recognized by athwartships buckling—up-and-down wrinkles in the plate—in way of the failed section. Buckled structure has essentially no ability to carry compressive load but may carry almost its entire design tensile load. Ships that have failed in compression may be raised by distributing weight and buoyancy in the ship so that the failed plating is in tension throughout the salvage operation.

CAUTION

The method described below of using chain and wire rope in tension to bridge broken structure seems attractive and has worked. However, it is extremely difficult to execute properly and safely. Bridging broken ships with tension members is a desperation technique.

Ships may fail in tension by breaking athwartships at the section of highest bending stresses. A broken structure is incapable of carrying either tensile or compressive load. Tensile failures may be bridged by rigid members—such as stiffened plate—capable of carrying tensile and compressive loads. They may also be bridged, and the two sections held together by flexible members, such as chain or wire rope that can carry only tensile loads. Throughout the operation, bridges of flexible material must be exposed only to tensile loads in the range that the bridge is designed to carry. The type and size of the load can be controlled by controlling the weight and buoyancy distribution in the ship.

Shear failure may be dealt with most simply by adjusting weight and buoyancy to keep shear stresses in the failed area to a maximum of 25 percent of design shear stress. Attempts to double plate in the affected areas generally are unsuccessful because the deformation of the plating and internals usually prevents making the structure sufficiently straight and continuous for proper load carrying.

Massive hull damage that leaves the ship in one piece but with a hinge likely or already developed requires a decision about the basic techniques to be used. The ship may be:

- Cut into pieces with each piece refloated separately
- Refloated by zero-stress/zero-shear techniques
- Wrecked in place.

When portions of the hull can be made watertight and stable, the wreck may be cut into sections and each section refloated individually. Each section may be handled by methods that are most appropriate for it. For instance, one may be refloated while another is wrecked in place. However, cutting the wreck into sections may be time-consuming and expensive. The salvor must now deal with partial ships, none of normal form, each of whose stability and other characteristics must be established by on-site engineering analysis.

Often the most efficient and sophisticated means of floating a badly damaged sunken ship is by using zero-shear/zero-stress methods. With these methods, the ship is loaded so that throughout the operation, shear force and bending moment are zero at the hinge or section where a hinge is likely to develop. Zero-stress/zero-shear techniques require detailed engineering analysis and planning, as well as careful attention to the hull loading throughout the operation.

Wrecking in place is always an option but is dependent upon the availability of equipment to cut the wreck effectively and to lift and handle the pieces. Wrecking in place may be the most labor-intensive, time-consuming, and expensive option; on the other hand, it is usually a zero-risk-of-failure option.

4-8 CONTENTS OF THE SHIP.

The contents of sunken and capsized ships are of interest to salvors for several reasons. The contents, including installed equipment, military payload, and cargo, may:

- Have military or commercial value that gives priority to its recovery
- Require removal to bring the weight to be raised within the limits of the equipment to be used
- Require removal to give access for patching or shoring
- Present a hazard because of the nature of the material
- Present a hazard because of the action of the material underwater.

Where material or equipment is to be removed for preservation and further use, removal techniques must be tailored to the individual material and equipment. The techniques used will normally include methods to prevent further deterioration. Depending on the circumstances, preservation and storage of equipment may be the responsibility of either the salvor or a special team established for that purpose.

Removal of equipment or material to reduce weight or provide access will usually require normal rigging and stevedoring methods. When the material is submerged, great amounts of diver time may be required to rig and remove it. Whenever practical, methods designed to reduce the work of the divers should be employed because diving is a slow, labor-intensive, expensive, dangerous, and inefficient way to accomplish work. Arrangements must be made before beginning removals to take the materials away from the work site and preserve or dispose of it. The nature of the arrangements will depend upon the nature of the materials, the tactical situation, and the requirements of local authorities.

The nature and hazard presented by the contents of the ship vary with the materials carried and the length of submersion. Of immediate concern at a sinking is the pollution caused by fuel oil, cargo oil, or other pollutants leaking from the ship. Removal of fuel oil and cargo oil is discussed in detail in *U.S. Navy Salvage Manual, Volume 5* (S0300-A6-MAN-050). Handling of other polluting cargoes must be addressed in an ad hoc manner and requires expertise in the particular material. The *U.S. Navy Salvage Safety Manual* (S0400-AA-SAF-010) should be consulted and advice sought from the emergency response systems listed therein.

The U.S. Coast Guard has specific statutory responsibilities for providing on-scene coordination at hazardous material spills in navigable waters in the U.S. including the coastline, selected rivers and the Great Lakes. The Coast Guard's responsibilities and expertise must be recognized, and they must be involved from the outset in any sinking with hazardous materials.

The U.S. Army Corps of Engineers Military Programs Environmental Division also has statutory responsibilities for providing management, design and execution of a full range of cleanup and protection activities including:

- Cleaning up military sites contaminated with hazardous waste, radioactive waste or ordnance
- Complying with federal, state and local environmental laws and regulations
- Minimizing use of hazardous materials
- Conservation of natural and cultural resources

Sunken warships can be expected to contain ordnance of various types. Expertise in the particular ordnance and its characteristics should be obtained before attempting to move or work near it. Ships deliberately sunk to block waterways as part of hostile action may contain booby traps designed to deter their removal. It may be necessary to call in Explosive Ordnance Disposal teams to handle ordnance and remove booby traps.

Exposure to either fresh water or saltwater, or removal of some substances to the air after submersion, may initiate chemical reactions that create a hazardous condition or cause normally benign materials to become dangerous. For instance, organic material decaying in a closed, flooded compartment may generate hydrogen sulfide that will dissolve in the flood water, forming sulfuric acid; propellants and warheads used in ordnance may become unstable or degenerate from exposure to water; or, pressure vessels and piping may corrode and release their contents. Extreme care must be taken to ensure that hazards in a sunken ship are identified and the dangers to both personnel and the environment are reduced to an acceptable level.

Of particular concern is the generation of explosive, oxygen-displacing, or toxic gases by decomposition of organic matter within the ship or by decomposition of organic contents of the water in which the ship lies. If the gases are not soluble in water, they will collect in pockets under horizontal surfaces or may find their way into compartments under atmospheric pressure. Explosive gases present a potential danger whenever spark-producing equipment is being operated, while oxygen-displacing and toxic gases present a direct hazard to personnel. Whenever there may be gases present, the requirements of the *U.S. Navy Salvage Safety Manual* should be followed precisely.

Whenever a problem with hazardous or deteriorating materials is known or suspected, a marine chemist is an invaluable addition to a salvage team. The services of a marine chemist may be arranged through the Supervisor of Salvage.

CHAPTER 5
STRENGTH OF SHIPS

5-1 INTRODUCTION.

The longitudinal strength of a ship is its ability to carry the stresses imposed by its loading. Longitudinal strength is determined by a ship's design and construction. Regulatory bodies establish standards for strength based on the intended use of the ship. In the United States, the Naval Sea Systems Command (NAVSEA) sets standards for naval ships, and the American Bureau of Shipping (ABS) and Maritime Administration (MARAD), for merchant ships. Warships are built with a greater reserve of strength than merchant vessels because much of their effectiveness lies in their ability to survive battle damage. Salvors must be able to analyze the strength of the ship to determine acceptable loading, assess the potential for salvage, and plan necessary repairs. Strength analysis is a sequential process in which three things are determined:

- The effect of forces acting on the ship
- Resulting stresses
- The ability of the ship's structure to carry these stresses.

A ship's hull is like a hollow girder or beam and is often referred to as the hull girder. The behavior of a ship's hull girder is described in the following paragraphs. Longitudinal strength analysis and its importance in salvage operations are also described.

Precise hull strength calculations are very complex and are the domain of the salvage engineer, but it is imperative that all salvors understand the basic principles involved. Experienced salvors should be able to make reasonable estimates of a casualty's hull strength in the absence of a salvage engineer.

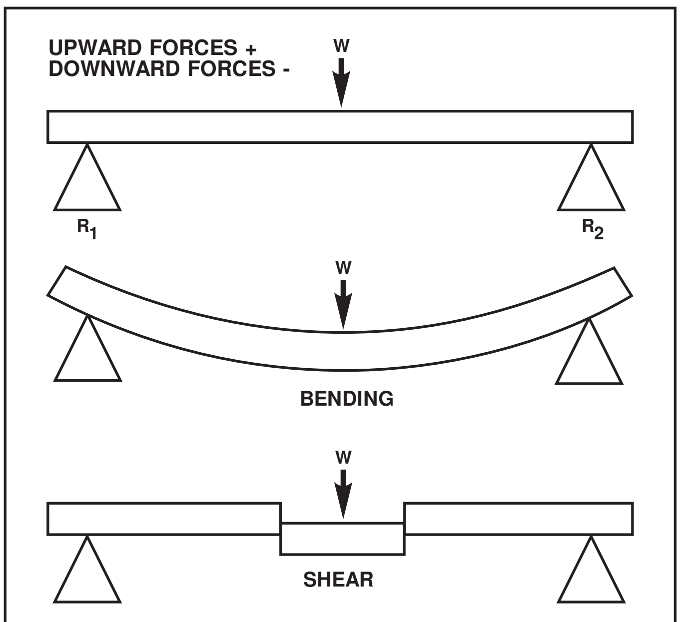


Figure 5-1. Simple Beam with Concentrated Load.

5-2 BEAM THEORY.

A simple beam is one that lies on its supports and is subject only to vertical forces. A downward vertical force causes a reaction acting upward at the supports. For equilibrium, the downward force (W) must equal the sum of the reactions at the support (R_1 and R_2).

$$W = R_1 + R_2$$

where:
W = Downward force
R = Reaction at the support

If the downward force is at the center of the beam, each reaction will support half the weight.

$$R_1 = R_2 = \frac{W}{2} \text{ (for a weightless beam)}$$

Load is a general term for the forces on a beam. By convention, loads acting upward are positive (+); downward-acting loads are negative (-). The load acts to bend the beam. The downward forces and the upward reactions at the supports also try to shear or slide two adjacent sections of the beam relative to each other as shown in Figure 5-1.

5-2.1 Shear. The shear, or shear force, at a section is the sum of the forces acting to one side of the section. A girder is rigid and resists bending. Girders can shear, if the forces are great enough. The forces tending to shear are the same forces that tend to bend the girder; the two effects are related. There is only one value for the shear at any section. The sum of the forces to one side of any section will be numerically equal to the sum of the forces on the opposite side.

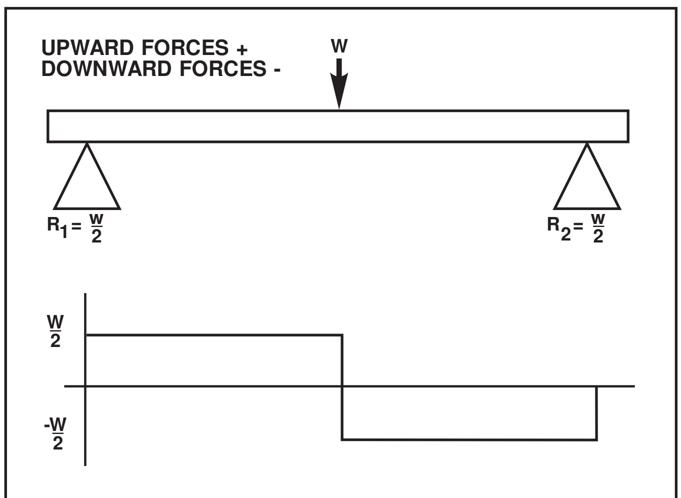


Figure 5-2. Shear Curve for a Beam with Concentrated Load.

In the beam in Figure 5-2, the only force to the left of any point between R_1 and W is the upward force (equal to +W/2) at the support; shear force at this point is therefore +W/2. The shear force can be calculated at several points along the length of the beam and plotted on a graph as a shear curve. Shear is determined for points immediately to the right and left of concentrated loads and assumed to change abruptly at the point of loading.

In plotting shear curves, shear is taken as the sum of forces to the left of any point along the beam. Shear is determined by working from left to right along the beam. The shear at any point is the sum of those forces from the left end of the beam up to that point, or the sum of the forces "left behind." The graph in Figure 5-2 is the shear curve for a girder under a concentrated load. Following the curve from left to right, shear is zero at the left end of the beam, but increases abruptly to +W/2 at the support. Shear remains constant at this value until reaching the force at the center. There it changes by -W to -W/2. Shear remains constant at -W/2 until the value decreases to zero at the right support.

EXAMPLE 5-1
CALCULATION OF SHEAR IN A BEAM WITH A CONCENTRATED LOAD

A 12-foot weightless girder is loaded with a 10-ton weight at the center as shown in Figure 5-3. Develop the shear curve.

The reactions at the support each equal half the weight, or +5 tons. As shear is the sum of forces or loads to the left of a point, shear changes only at the points where loads are applied. The shear curve is developed by finding shear at the ends and immediately to the right and left of center, and then connecting these points with straight lines as shown in Figure 5-3:

Location	Shear
Left Support	0
Immediately right of left support	+5 tons
Immediately left of center	+5 tons
immediately right of center	5 - 10 = -5 tons
immediately left of right support	-5 tons
Right support	-5 + 5 tons = 0

5-2.2 <u>Bending Moment</u>. The bending effect at any point on the beam depends on the moments created by loads acting at distances from that point. The bending moment at any point is the sum of the moments of the forces to one side of that point. Maximum bending moment occurs under the concentrated load at midspan, and is given by:

$$M = \frac{W}{2} \times \frac{L}{2} = \frac{W \times L}{4}$$

where:
L = Length of beam

The bending moment on the girder is plotted in Figure 5-4. Bending moment is zero at the supports because, being simply supported, there is no force acting on the lever arm on the outboard side, so there can be no moment. There is initially only one force to the right end of the girder to create a moment — the reaction at the support. As the moment arm is gradually increased by moving to the left, moment increases in direct proportion. To the left of center, the moment of the weight at the center is added to the moment of the reaction. Because the two moments are opposite in sign, they tend to cancel each other. Because the weight is twice as large as the reaction, its moment increases at twice the rate of the reaction's moment and causes the bending moment to gradually decrease to zero at the left support.

EXAMPLE 5-2
CALCULATION OF BENDING MOMENT IN A BEAM WITH A CONCENTRATED LOAD

Develop the bending moment curve for the 12-foot weightless girder supported at both ends with a weight of 10 tons loaded at the center.

The bending moment curve will follow the same form as the curve in Figure 5-4; that is, straight lines from 0 at the ends to a maximum at the center. Calculate the bending moments at the center:

$$M_{MAX} = \frac{W \times L}{4}$$
$$M_{MAX} = \frac{-10 \times 12}{4} =$$
$$M_{MAX} = \frac{-120}{4}$$
$$M_{MAX} = -30 \text{ foot–tons}$$

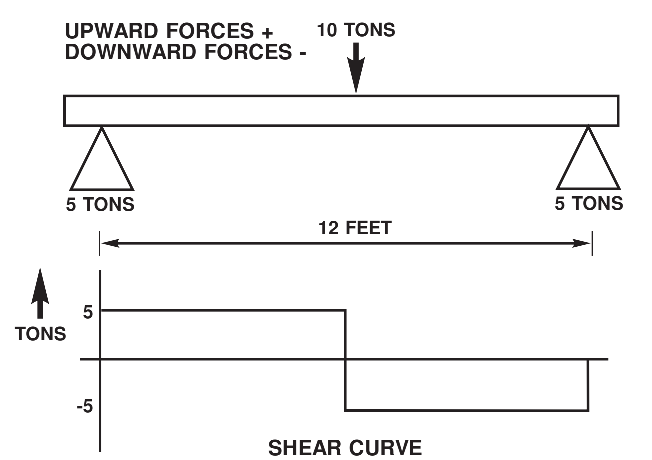


Figure 5-3. Shear Curve for a Beam with 10-Ton Load at Center.

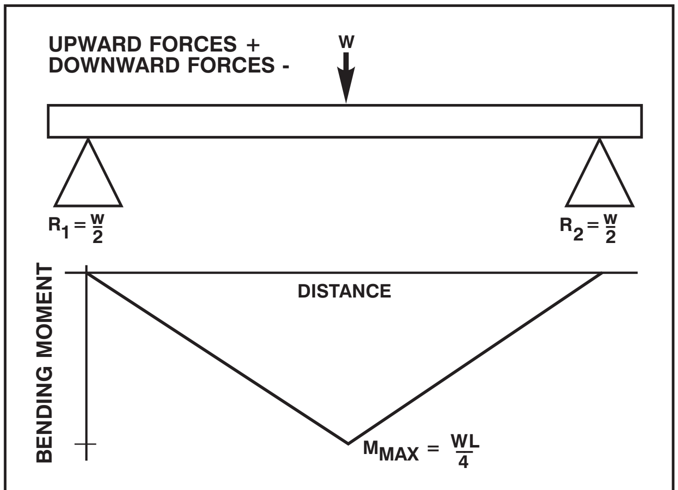


Figure 5-4. Bending Moment Curve for a Beam with Concentrated Load.

5-2.3 Distributed Load. Figure 5-5 shows the shear and bending moment curves for a simply supported beam loaded with an evenly distributed weight.

If w is the weight-per-unit length, then:

$$W = w \times L$$

where:
- W = Total weight
- w = Weight-per-unit length
- L = Length of the beam between supports

Because the weight is evenly distributed, each support will bear half the weight with a reaction of W/2. Examining the shear force to the left of a point:

$$S = \frac{w \times L}{2} - (w \times L)$$

then:

$$S = w \times \left(\frac{L}{2} - d\right)$$

where:
- S = Shear
- w = Weight-per-unit length
- L = Length of the beam between supports
- d = Distance from the left support

Shear force along the length of the beam increases from zero at the left support to a value equal to the reaction, (w × L)/2. Shear then decreases linearly to zero at the center of the girder. Shear continues to decrease to a maximum value of -(w × L)/2 at the right support where it drops to zero.

Bending moment will reach its maximum value at the center of the beam. At this point, the difference between the moments due to weight and reaction is greatest. Maximum bending moment value is:

$$M = \frac{w \times L^2}{8}$$

The shear and bending moment curves for a beam with a distributed load are illustrated in Figure 5-5.

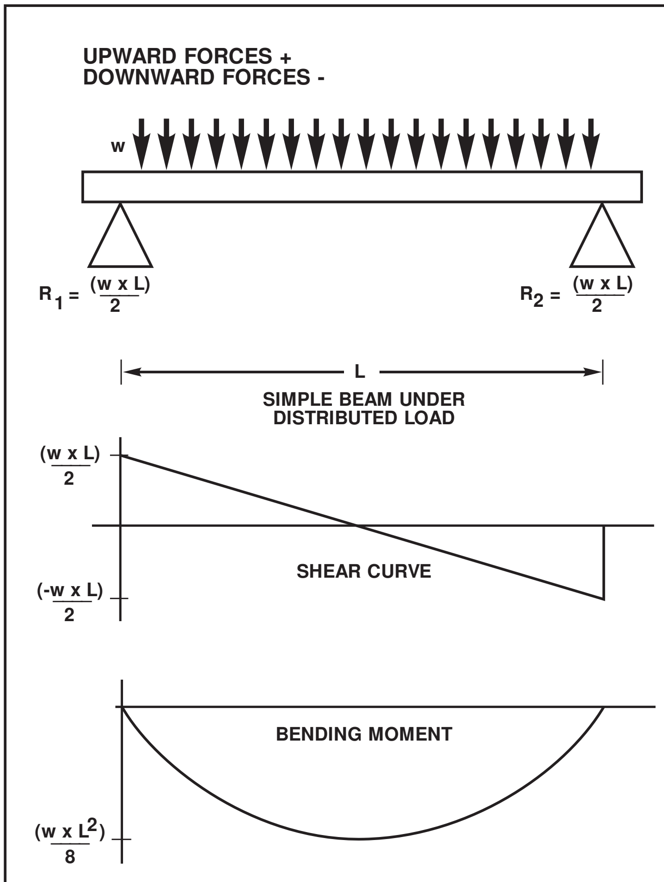


Figure 5-5. Shear and Bending Curves for a Beam with Evenly Distributed Load.

If the weight is evenly distributed along the length of the beam, the shear curve will pass through zero at the center of the beam and the bending moment curve will be a parabola with its maximum at center of the beam.

One distributed weight on an actual beam is the weight of the beam. In the case of a ship, this weight must be considered along with other distributed or concentrated loads. Example 5-3 demonstrates the method for determining the shear and bending moment curves for a beam with an evenly distributed load.

EXAMPLE 5-3
CALCULATION OF SHEAR AND BENDING MOMENT IN A BEAM WITH A DISTRIBUTED LOAD

A 40-foot beam weighing 10 tons is supported at both ends. The beam is uniform in shape and weight evenly distributed along the entire length. Develop the shear curve and the maximum bending moment.

a. Shear curve:

Start at the left end of the beam:

$$w = \frac{10}{40} = .25 tons/ft.$$

$$S = w \times \left[\left(\frac{L}{2}\right) - d\right]$$

$$S_{40} = .25 \times \left[\left(\frac{40}{2}\right) - 0\right]$$

$$S_{40} = +5 \text{ tons}$$

$$S_{30} = 0.25 \times \left[\left(\frac{40}{2}\right) - 10\right]$$

$$S_{30} = +2.5 \text{ tons}$$

$$S_{20} = 0.25 \times \left[\left(\frac{40}{2}\right) - 20\right]$$

$$S_{20} = 0 \text{ tons}$$

$$S_{10} = 0.25 \times \left[\left(\frac{40}{2}\right) - 30\right]$$

$$S_{10} = -2.5 \text{ tons}$$

$$S_{0} = 0.25 \times \left[\left(\frac{40}{2}\right) - 40\right]$$

$$S_{0} = -5 \text{ tons}$$

Summary

D	S
0	-5.0
10	-2.5
20	0
30	+2.5
40	+5.0

These points are then plotted in Figure 5-6 to obtain the shear curve.

CONTINUED

EXAMPLE 5-3 (CONTINUED)
CALCULATION OF SHEAR AND BENDING MOMENT IN A BEAM WITH A DISTRIBUTED LOAD

b. Bending moment curve:

NOTE

Since weight acts in a downward direction, w is always expressed as a negative value when developing the bending moment curve. This convention ensures that the curve developed shows the direction of the forces acting on the beam.

$$M_{MAX} = \frac{\left(-w \times L^2\right)}{8}$$

$$M_{MAX} = \frac{\left(-.25 \times 40^2\right)}{8}$$

$$M_{MAX} = -50 \text{ foot–tons}$$

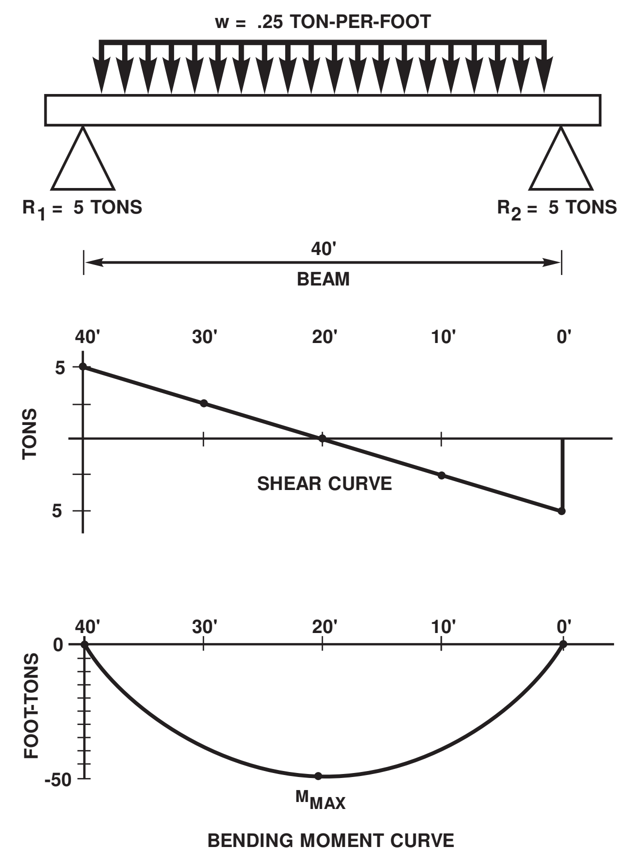


Figure 5-6. Bending Moment and Shear Curves for Example 5-3.

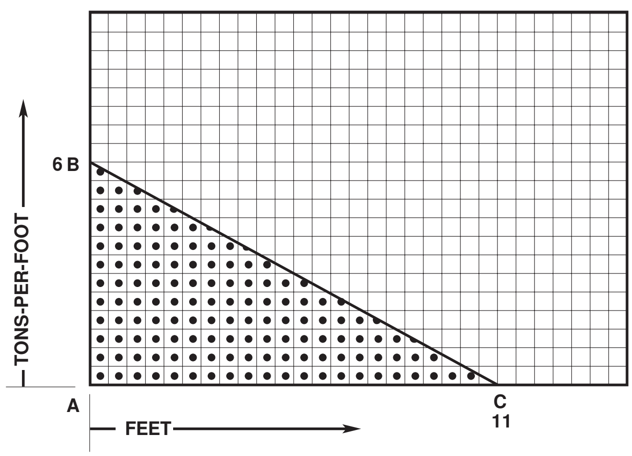
5-2.4 Relationship Between Curves. A load curve — the difference between the reaction and weight curves — can be drawn for beams with distributed weight and support. Relationships that exist between the load, shear, and bending moment curves can be used to determine shear and bending moment in ships' beams.

- Shear at any point is equal to the area under the load curve from the end of the beam to that point.
- Bending moment at any point is equal to the area under the shear curve from the end of the beam to that point.

Because of these relationships, shear and bending moment can be found for any point in a beam whenever a load curve can be drawn and points of zero shear and bending moment can be identified.

The area under a curve is the area between the curve and the horizontal axis and can be found by:

- Simple geometry if the curves are relatively straight lines
- Drawing the curves on graph paper and counting the squares under the curve. This method is simple and will provide reasonably accurate results. Figure 5-7 contains an example of estimating the area under a curve using graph paper.



AREA OF TRIANGLE ABC = 1/2x(11 FEET)x(6 TONS/FOOT) = 33 TONS.
AREA BY COUNTING SQUARES:
EACH SQUARE MEASURES 1/2 FOOT BY 1/2 TON/FOOT = 1/4-TON. 120 WHOLE SQUARES UNDER THE CURVE, 26 PARTIAL SQUARES EQUIVALENT TO 13 FULL SQUARES FOR A TOTAL OF 133 SQUARES. 133 X 1/4-TON = 33-1/4 TONS.

Figure 5-7. Finding Area Under a Curve.

5-3 LOAD, SHEAR, AND BENDING MOMENT IN SHIP GIRDERS.

Determining shear and bending moments in hull girders is more complicated than in simple beams, because:

- The weight of the hull girder is neither negligible nor evenly distributed.
- Weights placed on a ship may be either concentrated, unevenly distributed, or evenly distributed.
- The reaction, buoyancy, is unevenly distributed over the length of a floating ship. The distribution of buoyancy depends on the distribution of the underwater volume of the hull, which changes with shifts in draft, trim, or passage of waves.

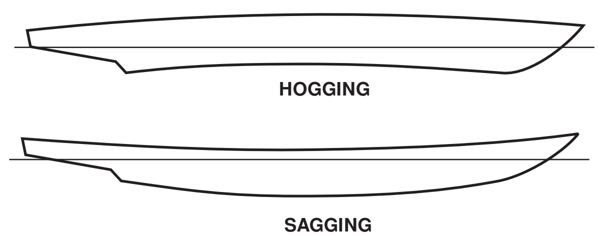


Figure 5-8. Hogging and Sagging.

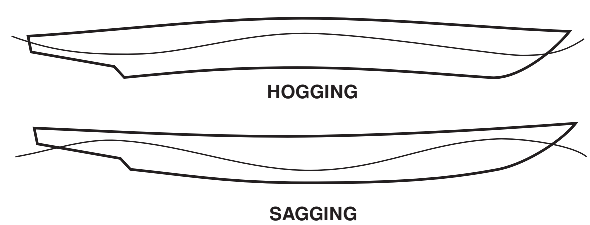


Figure 5-9. Hogging and Sagging Increasd by Wave.

Hogging and sagging are two conditions that reflect weight and buoyancy distribution. When a ship is hogging, buoyancy exceeds weight in the midships region and weight exceeds buoyancy near the ends. The distribution of forces tends to bend the ends of the ship downward. The opposite condition is called sagging. These conditions are shown in Figure 5-8.

Depending on the distribution of weight within the ship, either of these conditions can occur in still water. Some ships can literally "break their backs" if improperly loaded. Figure 5-9 shows how hogging and sagging can be increased by wave action. When a ship passes through seas, the ship may alternately hog and sag as the waves pass.

5-3.1 Weight, Buoyancy, and Load Curves. In order to obtain a load curve, two curves must be developed:

- A weight curve showing the weight distribution
- A buoyancy curve showing the buoyancy distribution.

The load curve is the difference between the buoyancy and weight curves.

5-3.1.1 The Weight Curve. Weights in a ship can be divided into two categories:

- Fixed weights that are a permanent part of the ship
- Variable weights that change with loading

a. Fixed weights include:

(1) The hull structure
(2) Superstructures and deck houses
(3) Machinery
(4) Weapons launchers
(5) Masts, kingposts, cranes, etc.

b. Variable weights include:

(1) Fuel
(2) Missiles and ammunition
(3) Boats and aircraft
(4) Cargo
(5) Stores
(6) Crew and effects
(7) Miscellaneous weights.

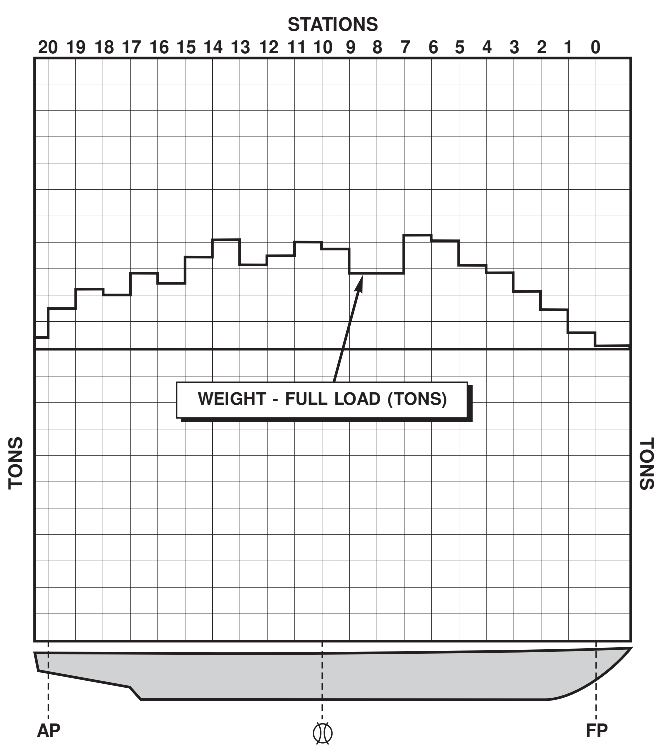
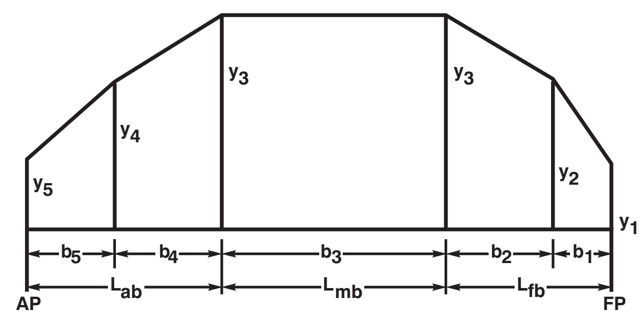


Figure 5-10. Weight Curve and Profile.

The positions of variable weights may be determined from arrangement and loading plans. Weights are placed in the proper position along the length of the hull. After all variable weights have been accounted for and subtracted from the displacement, the remaining weight is the lightship weight. The weights of major components, like superstructures and machinery, can be estimated and placed in position by simply looking at the ship and locating them accordingly. The remaining weight may be distributed in the same form as the still water buoyancy curve. Alternatively, the fixed weight may be distributed by assuming two-thirds of the total follows the still water buoyancy curve, and the remaining one-third is in a trapezoid whose center of gravity corresponds to the longitudinal position of the center of gravity of the ship. Figure 5-10 shows a weight curve for a ship along with its profile.



$L_{mb} = (1.74C_B - 1.002)L$ $\quad b_1 = (0.61 - 0.615\ C_B)L$ $\quad y_1 = 0.04y_3$

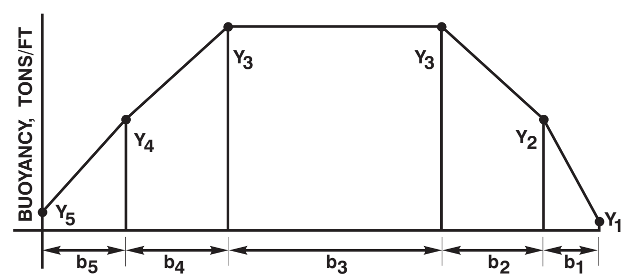
$L_{fb} = (1.186 - 1.17C_B)L$ $\quad b_2 = L_{fb} - b_1$ $\quad y_2 = C_B\ y_3$

$L_{ab} = L - L_{mb} - L_{fb}$ $\quad b_3 = L_{mb}$ $\quad y_3 = B_{mb}/L_{mb}$

$B_{mb} = \dfrac{L_{mb}\ B\ T_m\ C_m}{35}$ $\quad b_4 = L_{ab} - b_5$ $\quad y_4 = C_B\ y_3$

$b_5 = 0.2L$ $\quad y_5 = 0.08y_3$

Figure 5-11. Approximate Buoyancy Curve for Full-Bodied Ship.



LENGTH, FT	BUOYANCY, TONS/FT
b_1 = 76.7	y_1 = 1.01
b_2 = 79.3	y_2 = 17.10
b_3 = 72.5	y_3 = 25.14
b_4 = 91.5	y_4 = 17.10
b_5 = 80.0	y_5 = 2.01

Figure 5-12. Approximate Buoyancy Curve for Example 5-4.

5-3.1.2 The Buoyancy Curve. The underwater volume of the ship's hull determines the buoyancy distribution. The buoyancy-per-foot at any point is the buoyancy of a one-foot- thick slice of the submerged hull at that point, or the area of the section times one foot divided by 35 cubic feet per ton of seawater. Areas of sections can be obtained from curves of sectional areas (Bonjean curves). Sectional areas can also be developed from general plans, body plans, offsets, or direct measurement. Such complex calculations are normally left to the salvage engineer.

For full-bodied ships with a block coefficient significantly greater than 0.6, the buoyancy curve can be approximated by a rectangle and four trapezoids. For this approximation, the ship's length is divided into three sections, the forebody, the midbody, and the afterbody; the forebody and afterbody are again divided into two sections each, and the heights of the rectangle or trapezoids are calculated to give a curve like the one shown in Figure 5-11.

The steps in the calculation are:

a. Calculate the length of the midbody:

$$L_{mb} = [(1.74 \times C_B) - 1.002] \times L$$

where:
L_{mb} = Length of the midbody
C_B = Block coefficient
L = Length between perpendiculars

b. Calculate the lengths of the forebody and afterbody:

$$L_{fb} = [1.186 - (1.17 \times C_B)] \times L$$

$$L_{ab} = L - L_{mb} - L_{fb}$$

where:
L_{fb} = Length of the forebody
L_{ab} = Length of the afterbody

c. Calculate the buoyancy of the midbody:

$$B_{mb} = \frac{(L_{mb} \times B \times T_m \times C_M)}{35}$$

where:
B_{mb} = Buoyancy of the midbody
B = Beam
T_m = Mean draft
C_M = Midships coefficient

d. Calculate the bases and ordinates for the curve:

$$b_1 = [0.61 - (0.615 \times C_B)] \times L \qquad y_1 = 0.04 \times y_3$$
$$b_4 = L_{ab} - b_5 \qquad y_2 = C_B \times y_3$$
$$b_2 = L_{fb} - b_1 \qquad y_3 = \frac{B_{mb}}{L_{mb}}$$
$$b_3 = L_{mb} \qquad y_4 = C_B \times y_3$$
$$b_4 = L_{ab} - b_5 \qquad y_5 = 0.08 \times y_3$$
$$b_5 = 0.2L$$

EXAMPLE 5-4
CALCULATION OF THE APPROXIMATE BUOYANCY CURVE

An auxiliary ship is 400 feet long with a beam of 50 feet and a draft of 20 feet. The block coefficient is 0.68; the midships coefficient is 0.88. Determine the approximate buoyancy distribution.

a. Calculate the length of the midbody:

$$L_{mb} = [(1.74 \times C_B) - 1.002] \times L$$

$$L_{mb} = [(1.74 \times 0.68) - 1.002] \times 400$$

$$L_{mb} = 0.181 \times 400$$

$$L_{mb} = 72.5 \text{ feet}$$

CONTINUED

EXAMPLE 5-4 (CONTINUED)
CALCULATION OF THE APPROXIMATE BUOYANCY CURVE

b. Calculate the length of the forebody and afterbody:

Forebody:

$$L_{fb} = [1.186 - (1.17 \times C_B)] \times L$$
$$L_{fb} = [1.186 - (1.17 \times 0.68)] \times 400$$
$$L_{fb} = 0.39 \times 400$$
$$L_{fb} = 156 \text{ feet}$$

Afterbody:

$$L_{ab} = L - L_{mb} - L_{fb}$$
$$L_{ab} = 400 - 72.5 - 156$$
$$L_{ab} = 171.5 \text{ feet}$$

c. Calculate the buoyancy of the midbody:

$$B_{mb} = \frac{(L_{mb} \times B \times T_m \times C_M)}{35}$$
$$B_{mb} = \frac{(72.50 \times 50 \times 20 \times 0.88)}{35}$$
$$B_{mb} = 1{,}823 \text{ tons}$$

d. Calculate the bases and ordinates:

$$b_1 = [0.61 - (0.615 \times C_B)] \times L \qquad y_3 = \frac{B_{mb}}{L_{mb}}$$
$$b_1 = [0.61 - (0.615 \times 0.68)] \times 400 \qquad y_3 = \frac{1{,}823}{72.5}$$
$$b_1 = 76.7 \text{ feet} \qquad y_3 = 25.14$$

$$b_2 = L_{fb} - b_1 \qquad y_1 = 0.04 \times y_3$$
$$b_2 = 156 - 76.7 \qquad y_1 = 0.04 \times 25.14$$
$$b_2 = 79.3 \text{ feet} \qquad y_1 = 1.01$$

$$b_3 = L_{mb} \qquad y_2 = y_4 = C_B \times y_3$$
$$b_3 = 72.50 \text{ feet} \qquad y_2 = y_4 = 0.68 \times 25.14$$
$$y_2 = y_4 = 17.10$$

$$b_5 = 0.20 \times L$$
$$b_5 = 80 \text{ feet}$$

$$b_4 = L_{ab} - b_5 \qquad y_5 = 0.08 \times y_3$$
$$b_4 = 171.5 - 80 \qquad y_5 = 0.08 \times 25.14$$
$$b_4 = 91.5 \qquad y_5 = 2.01$$

Summary

b_1 = 76.7 feet	y_1 = 1.01
b_2 = 79.3 feet	$y_2 = y_4 = 17.10$
b_3 = 72.5 feet	y_3 = 25.14
b_4 = 91.5 feet	y_5 = 2.01
b_5 = 80.0 feet	
L = 400.0 feet	

Figure 5-12 shows the approximate buoyancy curve for the ship in this example.

For a floating ship:

- The area under the weight curve and the buoyancy curve must be equal.
- The geometric centers of the two areas — the centers of buoyancy and gravity — must be on the same vertical line.

Because the curves are approximations, if these conditions are not met, the curves can be adjusted by trial and error until they are.

5-3.1.3 Load Curve. The load curve is the vertical distance between weight curve and buoyancy curve at any point along the ship's length. The load curve is constructed by plotting these differences. Typical weight load and buoyancy curves are shown in Figure 5-13. For a floating ship, the areas under the curve above and below the axis are equal. The faired buoyancy curve is usually stepped, as described in Paragraph 5-3.2.4 to facilitate calculations using the mean load value of each station.

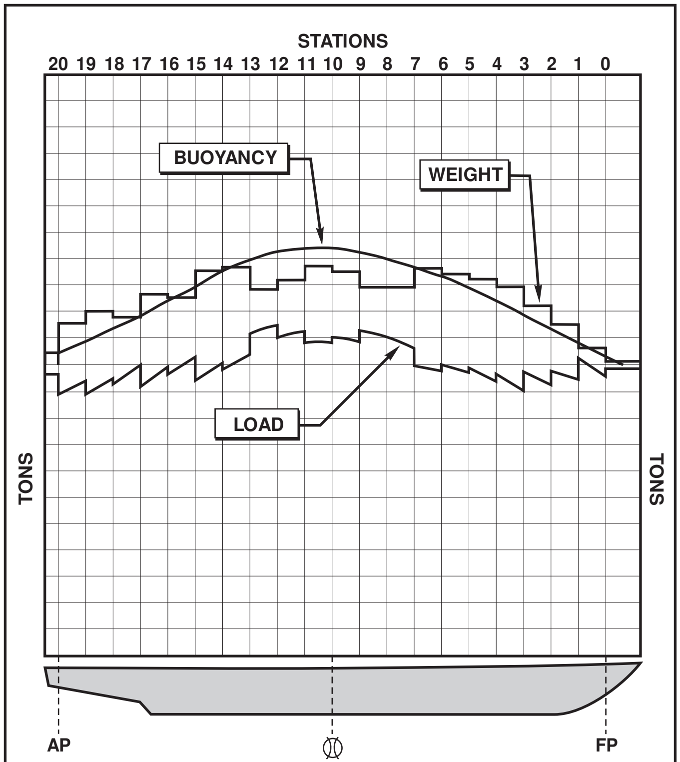


Figure 5-13. Weight, Buoyancy, and Load Curves.

5-3.2 Shear and Bending Moment. Both the shear force and bending moment on the ends of a ship are zero. Shear and bending moment curves can be developed by working from one end of the ship to the other.

5-3.2.1 Shear Curve. The shear curve is developed by summing the areas under the load curve from left to right along the length of the ship. On reaching the end, the value of shear should be zero. In practice, small errors in plotting the weight and buoyancy curve will usually result in some value of shear being obtained at the end of the ship. In salvage work, a small value of shear at the end of the ship will not cause significant errors in the bending moment and stress calculations. If the value is large, the weight, buoyancy, load, and shear curves should be checked and adjusted as necessary.

5-3.2.2 Bending Moment Curve. The bending moment curve is developed by summing the areas under the shear curve from right to left along the length of the ship. The value at both ends should be zero. If a large value is obtained, the source of the error must be determined and corrected.

5-3.2.3 Relationships Between Curves. The relationship between curves has several features that can serve as checks:

- When the load is zero, shear is maximum or minimum, and there is a change in curvature in the bending moment curve.
- When the load is maximum, a change in curvature occurs in the shear curve.
- When shear is zero, the bending moment is maximum or minimum.

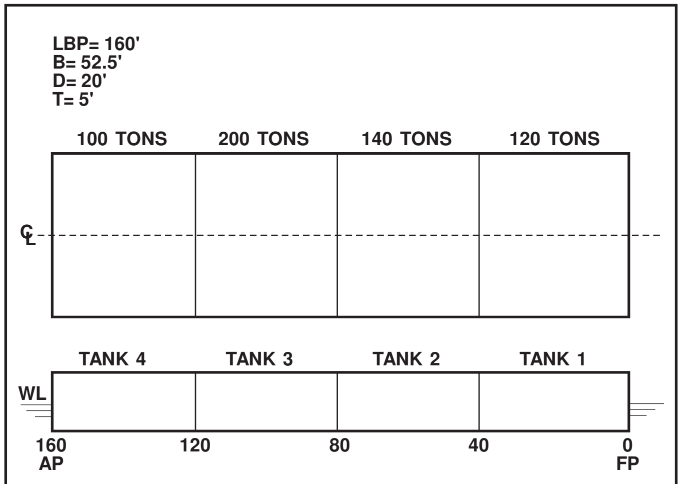


Figure 5-14. Rectangular Barge.

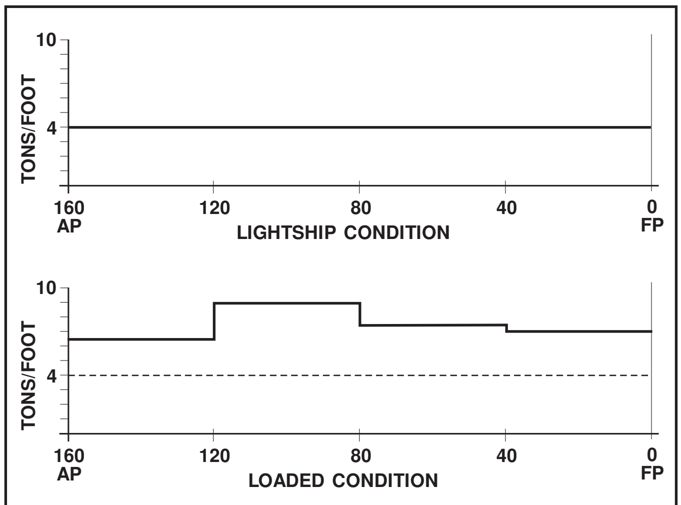


Figure 5-15. Weight Curves.

The following example develops the weight, buoyancy, load, shear, and bending moment curves for a rectangular barge.

EXAMPLE 5-5
CALCULATION OF WEIGHT, BUOYANCY, LOAD, SHEAR, AND BENDING MOMENT CURVES FOR A RECTANGULAR BARGE

The rectangular barge in Figure 5-14 is 160 feet long, 52.5 feet wide, and floats at a draft of 5 feet in salt water. The barge is divided into 4 equal tanks containing liquid cargo:

No 1 tank		120 tons
No 2 tank		140 tons
No 3 tank		200 tons
No 4 tank		100 tons
	Total:	560 tons

Develop the weight, buoyancy, load, shear, and bending moment curves for the barge.

a. Weight curve:

$$\text{Total Weight} = \frac{(160 \times 52.5 \times 5)}{35} = 1,200 \text{ tons}$$
$$\text{Cargo Weight} = 560 \text{ tons}$$
$$\text{Lightship Weight} = 1,200 - 560 = 640 \text{ tons}$$

The weight is evenly distributed over the length of the rectangular barge. The weight-per-foot length of the barge is therefore:

$$w = \frac{640 \text{ tons}}{160 \text{ feet}}$$
$$w = 4 \text{ tons/foot}$$

The lightship weight curve is as shown in Figure 5-15.

The liquid cargo weights are evenly distributed in each 40-foot tank; their weight-per-foot lengths are:

$$w_1 = \frac{120}{40} = 3 \text{ tons/foot}$$
$$w_2 = \frac{140}{40} = 3.5 \text{ tons/foot}$$
$$w_3 = \frac{200}{40} = 5 \text{ tons/foot}$$
$$w_4 = \frac{100}{40} = 2.5 \text{ tons/foot}$$

These weights are then added to the lightship weight curve to give the total weight curve shown in Figure 5-15.

b. Buoyancy curve:

The buoyancy equals the total weight of the barge and cargo or:

$$B = 1,200 \text{ tons}$$

The barge has zero trim and is uniform in cross section throughout its length. Buoyancy is evenly distributed. Buoyancy-per-foot is:

$$b = \frac{1,200 \text{ tons}}{160 \text{ feet}}$$
$$b = 7.5 \text{ tons/foot}$$

The buoyancy curve is plotted along with the weight curve. The difference between these two curves is the load curve. Forces acting downward are negative and forces acting upward are positive. Since weight acts downward and buoyancy acts upward, their values are negative and positive, respectively. Figure 5-16 shows the load curve for the barge. There is more buoyancy than weight at the ends of the barge; the barge is sagging.

CONTINUED

EXAMPLE 5-5 (CONTINUED)
CALCULATION OF WEIGHT, BUOYANCY, LOAD, SHEAR, AND BENDING MOMENT CURVES FOR A RECTANGULAR BARGE

c. Shear curve:

Shear will be zero at the ends of the barge. Shear at any point along the barge is equal to the area under the load curve from the end of the barge up to that point. Shear should be calculated at any point along the barge that the value of the load curve changes. The shear curve in Figure 5-17 was constructed by determining shear in this manner.

Starting from the left end or stern:

$$S_a = \text{Sum of areas under load curve from AP to point } a$$

where:

S_a	=	Shear in tons at point a
w	=	Weight-per-unit length of the section in tons
d	=	Distance in feet to the right of the point

then:

$$S_{160} = 0 \text{ tons (by convention)}$$

$$S_{120} = 1 \times 40 \text{ tons (by convention)}$$
$$S_{120} = 1 \text{ ton/foot (distance from AP to 120-foot section)}$$
$$S_{120} = 1 \text{ ton/foot} \times 40 \text{ feet}$$
$$S_{120} = 40 \text{ tons}$$

$$S_{80} = (1 \times 40) + (-1.5 \times \text{distance from 120-foot section to 80-foot section})$$
$$S_{80} = (1 \times 40') + (-1.5 \times 40')$$
$$S_{80} = (40) + (-60)$$
$$S_{80} = -20 \text{ tons}$$

$$S_{40} = 40 + (-60) + (0 \times \text{distance from 80-foot section to 40-foot section})$$
$$S_{40} = -20 + (0 \times 40')$$
$$S_{40} = -20 \text{ tons}$$

$$S_0 = 40 + (-60) + 0 + (0.5 \times \text{distance from 40-foot section to FP})$$
$$S_0 = -20 + (0.5 \times 40')$$
$$S_0 = 0 \text{ tons}$$

Summary

D	S
0	0
40	-20
80	-20
120	40
160	0

d. Bending moment curve:

The bending moment curve is developed from the shear curve. The bending moment is equal to the sum of the area under the shear curve to the right of the point for which it is being calculated. Bending moment should be calculated for at least the following points:

- Wherever the shear curve crosses the axis — this is a point of maximum bending moment
- Whenever the shear curve changes direction.

For the barge, starting at the right end, or bow, calculate the bending moment:

$$M = \text{Sum of the areas under the shear curve}$$

CONTINUED ON NEXT PAGE

EXAMPLE 5-5 (CONTINUED)
CALCULATION OF WEIGHT, BUOYANCY, LOAD, SHEAR, AND BENDING MOMENT CURVES FOR A RECTANGULAR BARGE

$$M_0 = 0\times\ (0 \text{ tons} \times 1/2)$$
$$M_0 = 0 \text{ foot-tons}$$

$$M_{40} = (M_0) + (40' \times \text{-}20 \text{ tons} \times 1/2)$$
$$M_{40} = 0 + (\text{-}400)$$
$$M_{40} = -400 \text{ foot-tons}$$

$$M_{80} = (M_{40}) + (40' \times \text{-}20 \text{ tons})$$
$$M_{80} = (-400) + (-800)$$
$$M_{80} = -1,200 \text{ foot-tons}$$

$$M_{93.3} = (M_{80}) + (13.33' \times -20 \text{ tons} \times 1/2)$$
$$M_{93.3} = (-1,200) + (-133)$$
$$M_{93.3} = -1,333 \text{ foot-tons}$$

$$M_{120} = (M_{93.3}) + (26.67' \times 40 \text{ tons} \times 1/2)$$
$$M_{120} = (-1,333) + (533)$$
$$M_{120} = -800 \text{ foot-tons}$$

$$M_{160} = (M_{120}) + (40' \times 40 \text{ tons} \times 1/2)$$
$$M_{160} = (-800) + (800)$$
$$M_{160} = 0 \text{ foot-tons}$$

Summary

D	M	
0	0	
40	-400	
80	-1,200	
93.3	-1,333	(Maximum)
120	-800	
160	0	

CONTINUED

EXAMPLE 5-5 (CONTINUED)
CALCULATION OF WEIGHT, BUOYANCY, LOAD, SHEAR, AND BENDING MOMENT CURVES FOR A RECTANGULAR BARGE

Bending moment at 93.3 feet was calculated because the shear curve crossed the axis at this point.

Figure 5-17 also shows the bending moment curve. Note that the maximum bending moment is aft of amidships.

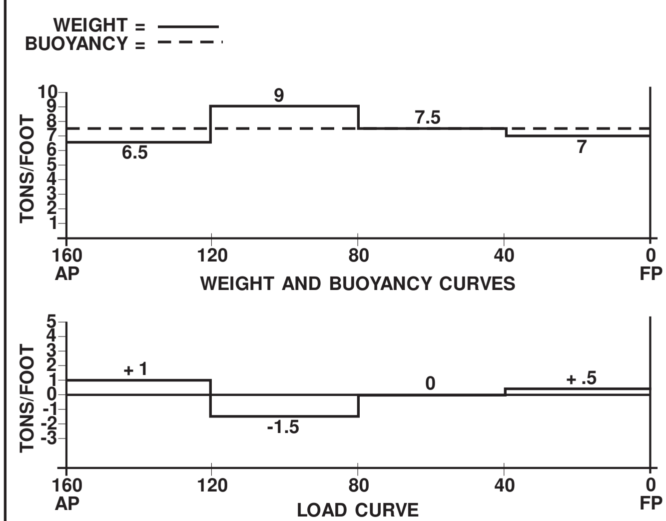


Figure 5-16. Development of Load Curve for Barge.

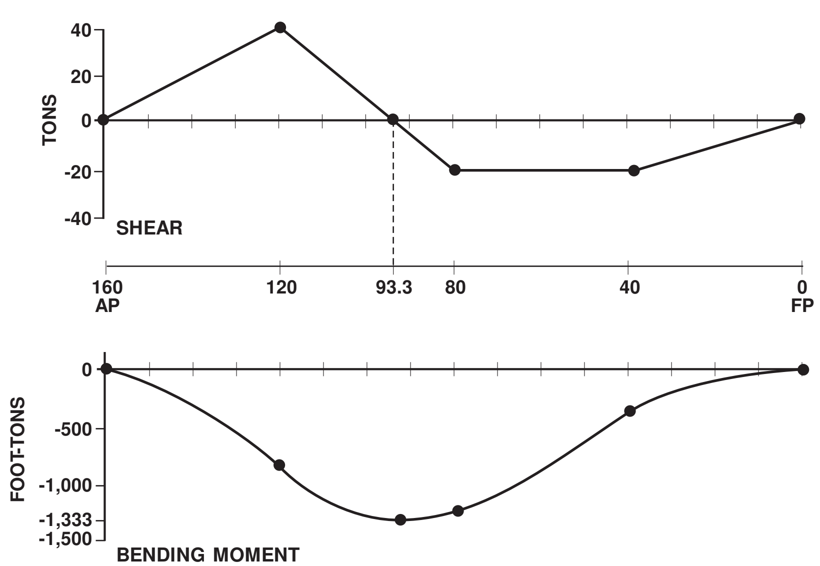


Figure 5-17. Shear and Bending Moment Curves for Barge in Example 5-5.

5-3.2.4 Conventions. The convention that downward forces are negative results in:

- For sagging hulls:
  (1) Positive shear on the left side of the plot
  (2) Negative shear on the right side
  (3) Negative bending moment.

- For hogging hulls:
  (1) Negative shear on the left side of the plot
  (2) Positive shear on the right side
  (3) Positive bending moment.

If weight and buoyancy information is available for stations, as in Figure 5-13, the calculation for more complex hull forms are lengthier but no more difficult than the examples presented. Salvors should develop and use the shear and bending moment curves as tools in planning weight changes if significant stress levels are anticipated due to high loads and/or damage to the hull girder.

Developing the load curve can be simplified if weight and buoyancy curves are both stepped curves. Weight curves are normally developed and provided as stepped curves. A stepped buoyancy curve can be developed from a faired curve as shown in Figure 5-18.

Horizontal segments between stations connected by vertical lines at the stations approximate the faired buoyancy curve. The height of each horizontal segment is found by taking the average of the buoyancy-per-foot values at the stations at either end. For example, the values at stations 4 and 5 in Figure 5-18 are 12 and 14 tons-per-foot, respectively, giving an average of 13 tons-per-foot, as plotted on the stepped curve.

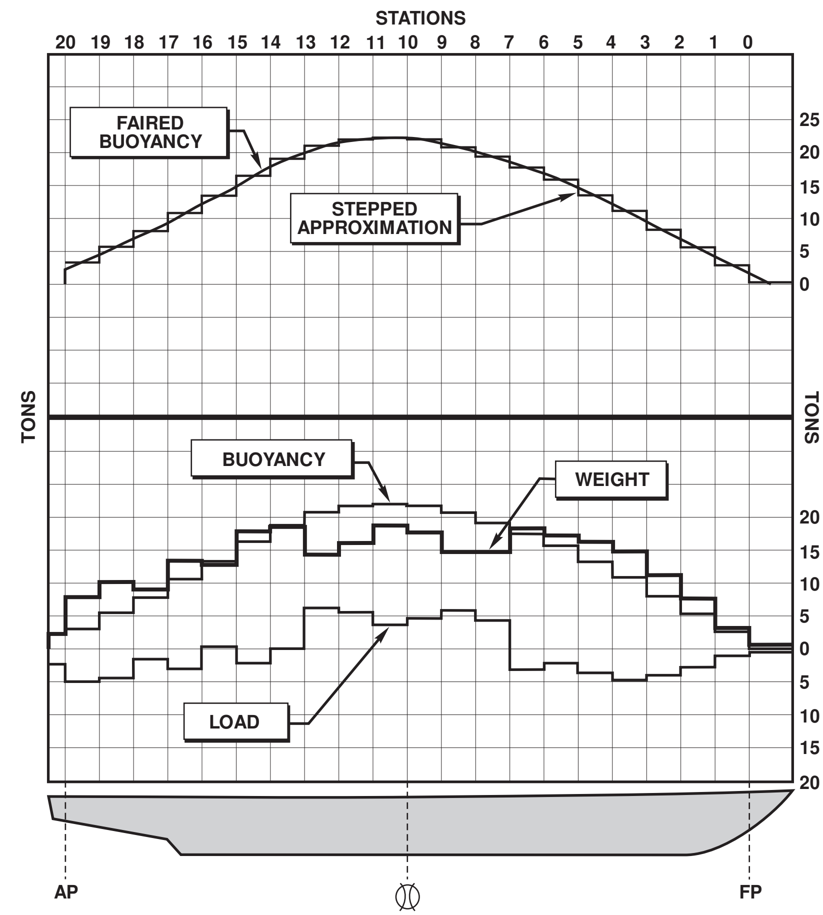


Figure 5-18. Development of Load Curve for Ship Hull.

5-4 STRESS.

Stress is the force-per-unit area that acts on the ship's structure. Stress causes the material to elongate or deform. The amount of elongation or deformation of the material is strain. In ship structures, stress and strain are directly proportional. Figure 5-19 shows three types of stress discussed below.

5-4.1 Axial Stress. Axial stresses result from two forces acting in opposite directions on the same line. Tension, or tensile stress, results from forces pulling against one another. Compression or compressive stress results from forces pushing against each other. The average stress in a member under pure tension or compression is given by:

$$\sigma = \frac{F}{A}$$

where:

σ (sigma) = Axial stress
F = Applied force
A = Cross sectional area affected

Stress is measured in units of force and area, such as pounds per square inch (psi).

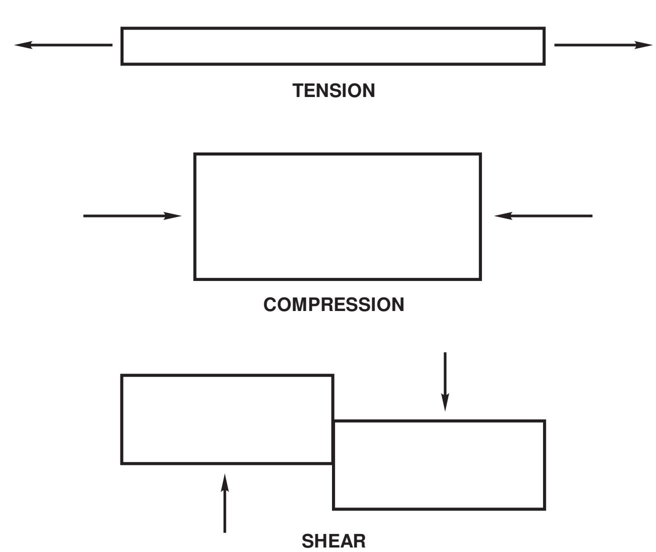


Figure 5-19. Types of Stress.

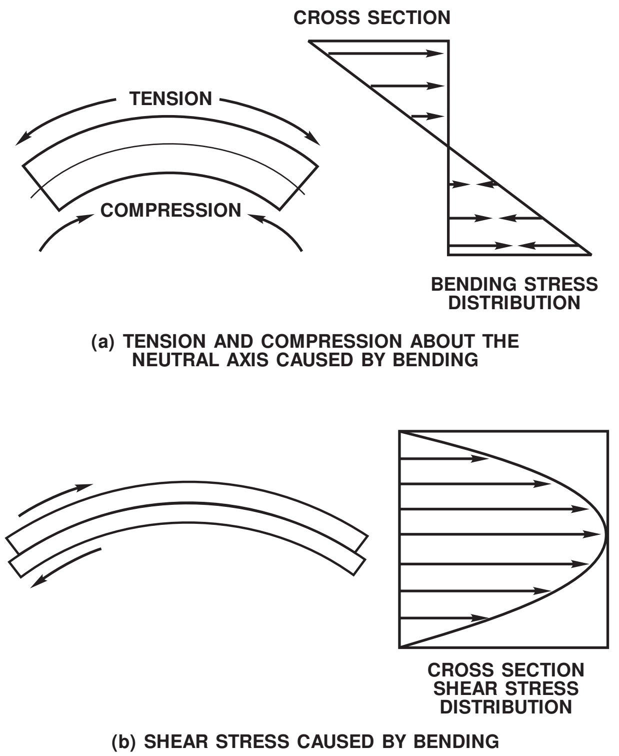


Figure 5-20. Stresses Due to Bending.

5-4.2 Bending Stresses. The beam in Figure 5-20 is loaded so the ends bend downwards. The upper side fibers are in tension and are stretched. The lower side fibers are in compression and are shortened. The outer fibers on the convex side of the beam must stretch farther than the inner fibers. On the concave side, the outer fibers are shortened more than those nearer the center. The change in length through the beam is the strain. Strain can be measured and indicates the stress at any point.

5-4.3 The Neutral Axis. Tensile and compressive stresses on opposite sides of a bending beam steadily decrease toward the center of the beam. They reach zero at a transitional plane known as the neutral axis. Figure 5-20(a) also shows this relationship. The location of the neutral axis depends on the arrangement of the components that make up the beam.

5-4.4 Shear Stress. Shear stress is the result of two forces acting in opposite directions along parallel lines. Shear tries to tear the material between the two forces. The average value of shear stress is given by:

$$\tau = \frac{F}{A}$$

where:

F = Applied force
τ (tau) = Shear stress
A = The area being sheared

Bending also induces shear stress. As the beam is bent, the fibers attempt to slide across each other as shown in Figure 5-20(b). The layers of material in a solid beam are restrained from sliding across each other, causing shear stresses in the layers. The shear stress increases from a minimum at the outer layers to a maximum at the neutral axis.

5-5 STRESSES IN THE HULL GIRDER.

The distribution of stress through any section of the hull girder depends on:

- The area and arrangement of material in that section
- The magnitude of the shear force or bending moment at that section.

5-5.1 Bending Stress. The distribution of bending stress through a section of a girder depends on the moment of inertia of the section about the neutral axis:

$$\sigma = \frac{M \times y}{I}$$

where:

σ = Fiber stress
M = Bending moment
y = Distance from neutral axis in feet
I = Moment of inertia about the neutral axis

The maximum bending stresses occur where y is maximum.

$$\sigma_{max} = \frac{M \times y_{max}}{I}$$

where:

σmax = Maximum stress
ymax = Maximum distance from the neutral axis in feet

5-5.2 Section Modulus. The quantity I/ymax is known as the section modulus (Z). The section modulus is the primary indicator of a ship's ability to resist shear force and bending moment. The maximum bending stress is given by:

$$\sigma_{max} = \frac{M}{Z}$$

Structural elements that are not continuous for a significant portion of the ship's length do not contribute to the structure's ability to carry longitudinal bending loads. Generally, only elements continuous for at least half the length of the ship should be included in the section modulus calculation. The neutral axis passes through the center of area of the cross section. The distance from the neutral axis to any axis is found by dividing the sum of the moments of areas about that axis by the sum of the areas. The girder cross section is broken up into sections whose areas and centers can be found easily. A baseline is established at the bottom of the girder, and the height of the neutral axis is calculated using a tabular format similar to the one below:

Section	a in^2	y in	ay in^3
part 1			
part 2			
Totals	A		AY

$$\text{Height of Neutral Axis} = \frac{AY}{A}$$

where:

a = Area of individual section
y = Height of center of area of individual section above baseline
A = Sum of individual areas
AY = Sum of moments of individual areas

The moment of inertia, I, of the beam about any axis is the sum of the moments of inertia, i, of the individual segments about that axis. If the moment of inertia of a section about an axis through its center of area is known, its moment of inertia about a parallel axis can be found by:

$$I = I_C + \left(A \times d^2\right)$$

where:
- I = Moment of inertia about any axis
- I_c = Moment of inertia about an axis through the center of area= I_{NA}
- A = Area of the section
- d = Distance between axes

When the neutral axis is not equidistant from the upper and lower edges of the girder, an upper and lower section modulus must be determined by:

$$Z_t = \frac{I_{NA}}{y_t}$$

$$Z_b = \frac{I_{NA}}{y_b}$$

where:
- Z_t = Section modulus for top of beam
- Z_b = Section modulus for bottom of beam
- y_t = Distance from the neutral axis to top of beam
- y_b = Distance from the neutral axis to bottom of beam

For more complex girders, such as ship hull girders, it is more convenient to first find the moment of inertia about the keel (I_K). This procedure allows simultaneous summing of the areas and moments needed to find the neutral axis and moment of inertia.

Section	a in^2	y in	ay in^3	ay^2 in^4	i in^4
part 1					
part 2					
Totals	A		AY	AY^2	I

$$\text{Height of Neutral Axis} = d = \frac{AY}{A}$$

$$I_K = AY^2 + I$$

$$I_{NA} = I_K - \left(A \times d^2\right)$$

$$Z_t = \frac{I_{NA}}{y_t}$$

$$Z_b = \frac{I_{NA}}{y_b}$$

Individual moments of inertia (i) are calculated only for components with significant vertical dimensions although their ay^2 term is included. The moments of inertia of components with small vertical dimensions, (usually less than 10% of the depth of the hull), are so small that their effect on the overall calculation is negligible. The value of i for rectangular sections is calculated by the relation $i = ah^2/12$ (which is equivalent to $lb^3/12$). Relationships for i of other cross-sectional shapes are given in Appendix C.

EXAMPLE 5-6
SECTION MODULUS CALCULATION FOR A BEAM

Calculate the section modulus of the beam shown in Figure 5-21.

Section	Dimen-sions (in)	a (in^2)	y (in)	ay (in^3)	ay^2 (in^4)	h (in)	i (in^4)
Top flange	12x1	12.0	10.5	126.0	*1,323.0	1.0	*1.00
Vertical web	10x1	10.0	5.0	50.0	250.0	10.0	83.33
Totals		22.0		176.0	1,573.0		84.33

d = AY/A	=	176/22	=	8.00 inches
I_K = AY^2 + I	=	1,573.00 + 84.33	=	1,657.33 $inches^4$
I_{NA} = $I_K - Ad^2$	=	1,657.33 - (22 x 8^2)	=	249.33 $inches^3$
y_t = Depth - d	=	11-8	=	3.00 inches
Z_t = I_{NA}/y_t	=	249.33/3	=	83.11 $inches^3$
y_b = d			=	8.00 inches
Z_b = I_{NA}/y_b	=	249.33/8	=	31.17 $inches^3$

*Note that the contribution of individual (i) of flange to total I_K is 1/1,657.33 = .0006 and could have been left out of the calculation.

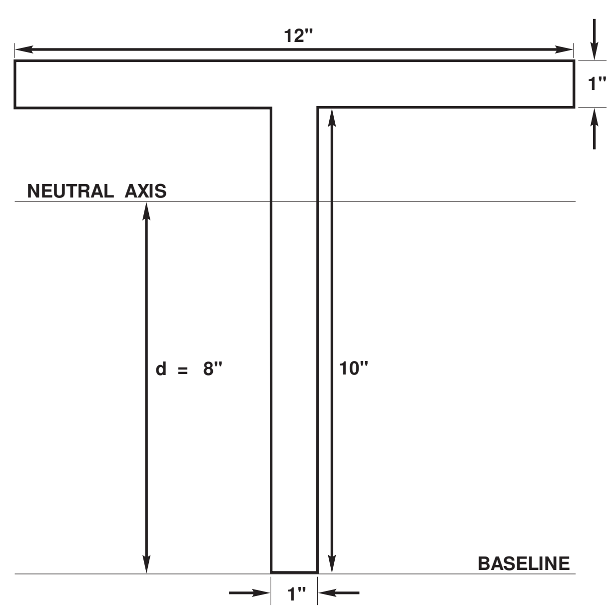


Figure 5-21. "T" Beam.

EXAMPLE 5-7
SECTION MODULUS CALCULATION FOR A RECTANGULAR BARGE

Calculate the section modulus of the barge in Figure 5-22, whose cross section and dimensions are given below.

Section	b (in)	h (in)	a (in^2)	y (in)	ay (in^2 ft)	ay^2 (in^2 ft^2)	h (ft)	i (in^2 ft^2)
Deck Girder (V)	0.625	12	7.5	19.5	156	3044	1.0	0.67
Deck Girder (H)	5.375	0.625	3.36	19.0	57	1209	0.007	0.0025
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Plating	630	0.625	394	20.0	7865	157090	0.1	0
Port Side Members								
Side Plating	0.375	240	90	10.0	900	9000	20.0	3000
Sheer Strake	0.625	30	19	18.8	352	6592	2.5	10
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Side Stringer (H)	6	0.5	3	6.7	20	133	0.0	0
Side Stringer (V)	0.5	2.5	1	6.6	8	54	0.2	0
Side Stringer (H)	6	0.5	3	13.3	40	533	0.0	0
Side Stringer (V)	0.5	2.5	1	13.2	17	219	0.2	0
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Stbd Side Members								
Side Plating	0.375	240	90	10.0	900	9000	20.0	3000
Sheer Strake	0.625	30	19	18.8	352	6592	2.5	10
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Side Stringer (H)	6	0.5	3	6.7	20	133	0.0	0
Side Stringer (V)	0.5	2.5	1	6.6	8	54	0.2	0
Side Stringer (H)	6	0.5	3	13.3	40	533	0.0	0
Side Stringer (V)	0.5	2.5	1	13.2	17	219	0.2	0
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Keel Strake	24	2	48	0.1	4	0	0.2	0
Vertical Keel	2	24	48	1.0	56	65	2.0	16
Keel Top Rider	18	1	18	2.0	40	88	0.1	0
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.46	5	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Bottom Plating	630	0.75	473	0.0	15	0	0.1	0
Totals			1,447.		12,781	229,794		6,062

$d = AY/A = 12{,}781/1{,}447 = 8.83$ ft

$I_K = AY + I = 229{,}794 + 6{,}062 = 235{,}856\ in^2\ ft^2$

$I_{NA} = I_K - Ad^2 = 235{,}856 - (1{,}447 \times 8.83^2) = 123{,}036\ in^2\ ft^2$

$y_t = \text{Depth} - d = 20 - 8.83 = 11.17$ ft

$Z_t = I_{NA}/y_t = 123{,}036/11.17 = 11{,}015\ in^2$ ft

$y_b = d = 8.83$ ft

$Z_b = I_{NA}/y_b = 123{,}036/8.83 = 13{,}934\ in^2$ ft

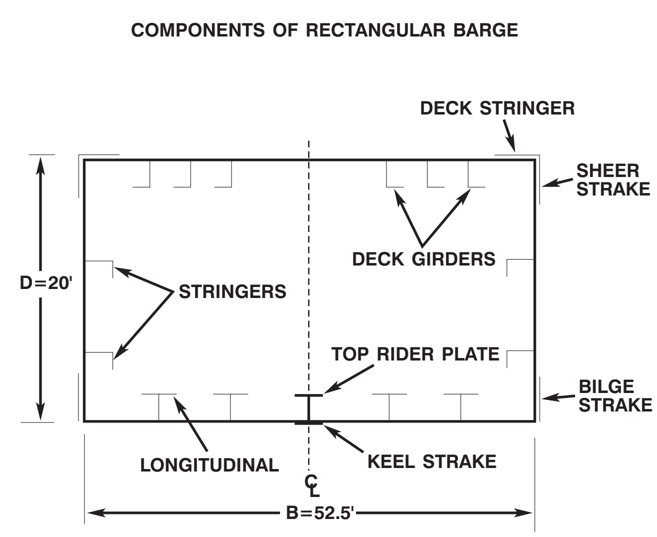


Figure 5-22. Cross Section of a Barge for Example 5-7.

When the bending moment and section modulus have been calculated, the bending stress can be calculated using the method given in Paragraph 5-5.1.

Because intact ships are usually symmetrical about the centerline, normally only the areas and moments of inertia of the components on one side of the ship's centerline are calculated. The results are then multiplied by two to determine the section modulus for the whole section.

EXAMPLE 5-8
CALCULATION OF BENDING STRESS IN A BARGE

Using the section modulus from the previous example, calculate the maximum bending stresses if the hogging bending moment is 100,000 foot-tons.

$\sigma = M/Z$

For the top of the barge:

$\sigma = M/Z_t$

$\sigma = 100{,}000/11{,}015$

$\sigma = 9.08$ tons per square inch (tsi) in tension

$\sigma = 9.08 \times 2{,}240 = 20{,}339$ psi

For the bottom of the barge:

$\sigma = M/Z_b$

$\sigma = 100{,}000/13{,}934$

$\sigma = 7.18$ tsi in compression

$\sigma = 7.18 \times 2{,}240 = 16{,}083$ psi

EXAMPLE 5-9
CALCULATION OF SHEAR STRESS IN A BARGE

Determine the shear stress in the barge whose section modulus was calculated in Example 5-7. The barge has a shear of 1,500 tons at the quarter length point for a specific condition of loading. Since the barge is of uniform construction throughout its length, the areas of the individual components used for the midship section modulus calculation can be used. In a vessel of other-than-uniform construction, the sectional areas of the components at that section would have to be determined to complete the following calculation.

Section	b (in)	h (in)	a (in^2)	y (ft)	y (NA) (ft)	AY (in^2 ft)
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Girder (V)	0.625	12	8	19.5	10.7	86
Deck Girder (H)	5.375	0.625	3	19.0	10.2	31
Deck Plating	630	0.625	394	20.0	11.2	4413
Port Side						
Side Plating	0.375	134	50	14.4	5.6	280
Sheer Strake	0.625	30	19	18.8	10.0	190
Deck Stringer	30	0.625	19	20.0	11.2	213
Side Stringer (H)	6	0.5		6.7	-2.1	
Side Stringer (V)	0.5	2.5		6.6	-2.2	
Side Stringer (H)	6	0.5	3	13.3	4.5	14
Side Stringer (V)	0.5	2.5	1	13.2	4.4	4
Bilge Strake	0.625	30		1.3	-7.5	
Stbd Side						
Side Plating	0.375	134	50	14.4	5.6	280
Sheer Strake	0.625	30	19	18.8	10.0	190
Deck Stringer	30	0.625	19	20.0	11.2	213
Side Stringer (H)	6	0.5		6.7	-2.1	
Side Stringer (V)	0.5	2.5		6.6	-2.2	
Side Stringer (H)	6	0.5	3	13.3	4.5	14
Side Stringer (V)	0.5	2.5	1	13.2	4.4	4
Bilge Strake	0.625	30		1.3	-7.5	
Keel Strake	24	2		0.1	-8.7	
Vertical Keel	2	24		1.2	-7.6	
Keel Top Rider	18	1		2.2	-6.6	
Longitudinal (H)	12	1		1.0	-7.8	
Longitudinal (V)	1	11		0.5	-8.3	
Longitudinal (H)	12	1		1.0	-7.8	
Longitudinal (V)	1	11		0.5	-8.3	
Longitudinal (H)	12	1		1.0	-7.8	
Longitudinal (V)	1	11		0.5	-8.3	
Longitudinal (H)	12	1		1.0	-7.8	
Longitudinal (V)	1	11		0.5	-8.3	
Bottom Plating	630	0.75		0.0	-8.8	
Totals			643			6,517

$$d = 8.83$$

$$I_{NA} = 123{,}036 \ \text{in}^2\text{ft}^2$$

$$\text{Shear} = 1{,}500.00 \ \text{tons}$$

$$\text{b=0.0625 ft}$$

$$\text{Shear stress} = \frac{S \times AY}{144 \times I \times b}$$

$$\text{Shear stress} = \frac{1{,}500 \times 6{,}517}{144 \times 123{,}036 \times 0.06} = 9.2 \ \text{tsi}$$

$$\text{Shear stress} = 9.2 \times 2{,}240 = 20{,}608 \ \text{psi}$$

Note: The constant 144 $\text{inches}^2/\text{feet}^2$ is used to give an answer in tsi when shear is in long tons, AY is in inches^2 feet, I_{NA} is in inches^2 feet^2 and b is in feet.

5-5.3 Shear Stress in the Ship's Girder. The shear forces along the ship's length tend to move one section of the ship relative to the adjacent section. Shear stress at the neutral axis is given by:

$$\tau = \frac{S \times (AY)}{I \times b}$$

where:

- τ = Shear stress at the neutral axis
- S = Shear force at the section
- AY = Moment about the neutral axis of the part of the section above the neutral axis
- I = Moment of inertia of the section about the neutral axis
- b = Total width of material at the neutral axis

Moment of inertia is obtained as part of the section modulus calculation described in Paragraph 5-5.2. The quantity AY is determined by finding the area of each element of the cross section, multiplying that area by the distance from its center to the neutral axis, and summing the products in the same manner that AY about the keel was determined in the initial section modulus calculation.

Shear stress is maximum at the neutral axis because the moment of area about the neutral axis involves the maximum amount of material.

5-5.4 Pulling Loads. When a ship is pulled, the pull is distributed into the ship's structure relatively evenly as pure tensile loading. Pulling load adds to the stress in those members under tension and decreases the stress in members under compression. In comparison with bending loads, pulling loads are usually quite small, but should be included in salvage strength analysis. Pulling loads are calculated by dividing the total amount of pull being applied by the total area of the material in the midships or other section.

EXAMPLE 5-10
CALCULATION OF PULLING STRESS

The barge described in the preceding example has a total area of structure amidships of 1,447 square inches, tensile bending stress in the deck of 20,339 psi and compressive bending stress in the bottom of 16,083 psi. If a pull of 250 short tons is applied to the grounded barge, what is the resulting stress?

Pulling stress:

Stress = Pull/Area

Stress = (250 x 2,000)/1,447

Stress = 346 psi

Deck stress:

Deck stress = bending stress (tension) + pulling stress

Deck stress = 20,339 + 346

Deck stress = 20,685 psi (tension)

Bottom stress:

Bottom stress = bending stress (compression) - pulling stress

Bottom stress = 16,083 - 346

Bottom stress = 15,737 psi (compression)

Table 5-1 Material Strengths.

MATERIALS	YIELD STRESS, PSI σY	ULTIMATE STRESS, PSI σU	YIELD STRESS, PSI τY	ULTIMATE STRESS, PSI τU
METALS				
STEELS				
Mild Steel	28,000 - 43,000	53,000 - 64,000	15,000 - 23,000	29,000 - 35,000
Shipbuilding Steel (ASTM 131)	32,000	58,000 - 71,000	17,000	32,000 - 39,000
Wrought Iron	26,000	47,000	14,000	26,000
HY 80	80,000	130,000	44,000	71,000
HY 100	100,000	not specified	55,000	not specified
High-Strength, Low-Alloy (HSLA)				
ASTM A242	50,000	70,000	27,000	36,000
ASTM A440	46,000	67,000	25,000	37,000
ALUMINUM ALLOYS				
Non-Heat-Treated (6061)	8,000	18,000	4,400	10,000
Heat-Treated (5056)	22,000	42,000	12,000	23,000

NON-METALS	TENSILE[1]	COMPRESSIVE[1]	SHEAR[2]
WOODS			
Douglas Firs	12,400	7,400	1,160
Oak	15,000	7,000	2,000
White Pine	9,000	5,000	1,000
Spruce	10,000	5,500	1,100

Notes:
1. Load applied parallel to grain
2. Load applied across grain

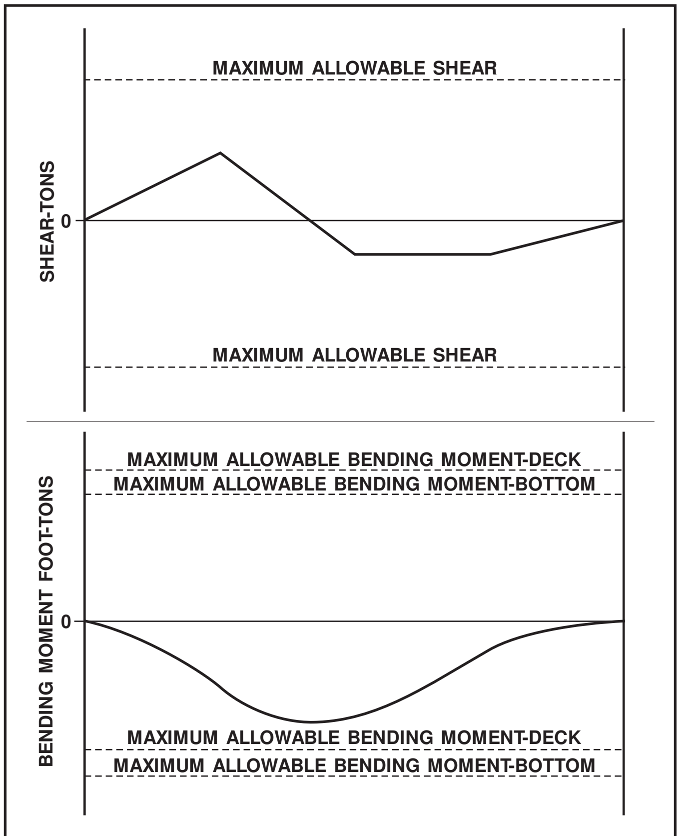


Figure 5-23. Maximum Allowable Shear and Bending Moment.

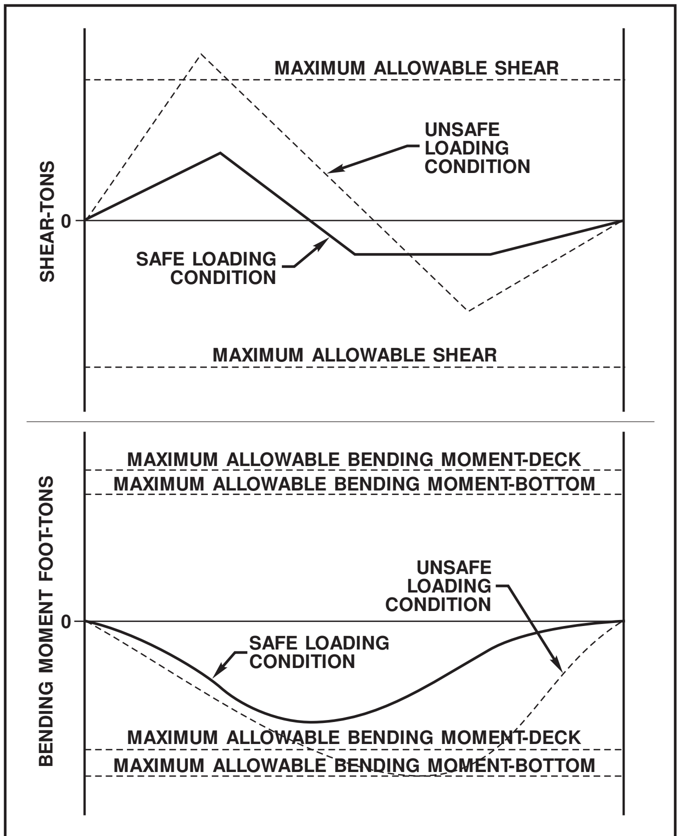


Figure 5-24. Determining Safe Loading Conditions Using Curves.

5-6 STRENGTH OF MATERIALS.

The measure of a material's strength is the maximum stress it can carry. Shipbuilding materials reach a tensile stress level called the yield point after which any change in shape is permanent. Stress levels exceeding the yield point are required to actually break the material (the ultimate stress level), however, the material has already failed. In tension, ultimate failure will be an actual fracture; in compression, a buckle may occur that may or may not tear the material. Yield stress is the maximum acceptable stress. Many materials show different strength characteristics under different types of stress (tensile, compression, or shear). Table 5-1 gives the properties of common shipbuilding materials.

For ductile materials (i.e., most metals), shear strength is approximately 55 to 60 percent of the tensile strength:

$$\tau_y \approx .55 \times \sigma y$$

$$\tau_u \approx .55 \times \sigma u$$

The relationship is not valid for non-ductile materials, such as wood, concrete, plastics, fiberglass, etc.

5-6.1 Failure. Failure of the hull girder is often subtle. Slender structural members, such as plating and longitudinals, fail in compression by buckling or bending. Buckled plating or structural members have failed and must be replaced or reinforced, not straightened. Structural members can fail under shear stress as well as bending stress. Shear failure is characterized by wrinkles or cracks in side plating at a 45-degree angle to the line of stress. Shear failure is generally less serious than bending failure, except in very large ships.

5-6.2 Safety Factors. The safety factor is the ratio between the design or safe working stress of a structure and the stress at failure. An appropriate safety factor keeps stresses well below the failure point and allows for manufacturing defects and inconsistencies in loading. Safety factors are specified by regulatory agencies, depending on intended use of systems and components. In salvage, it is not always possible to use a standard safety factor, and a reduced safety factor must often be accepted. Salvors cannot disregard safety factors, however. Each situation must be examined to determine acceptable stresses and loads. A reduced safety factor represents an increased chance of failure. When accepting a risk of failure, its consequences must be evaluated in terms of the effect on the overall job.

5-7 STRENGTH IN SALVAGE OPERATIONS.

A ship is designed and constructed to withstand expected shear forces and bending moments. In an intact floating ship, maximum bending moment occurs near the midships region and maximum shear near the quarter length points. These sections are designed to ensure that stresses remain within acceptable limits. Two conditions common to salvage operations may require that the stress levels be examined at other points:

- The ship may be loaded in ways not foreseen by the designer. Because of flooding, grounding, or other unusual conditions of loading, maximum bending moment can occur at some section other than midships. Similarly, maximum shear may be at some point other than the quarters.
- Damage can alter the stress distribution at a section so that maximum stress can occur in some section other than where maximum bending moment or shear occurs. Damage, even over a short distance, disrupts the continuity of longitudinal members and reduces the section modulus for some distance on either side of the damaged section.

The load, shear, and bending moment curves of a casualty must be examined carefully. The following items should receive attention:

- Stress levels should be determined wherever shear or bending moment are maximum or the section modulus is reduced.
- The effects of salvage actions on load, shear, and bending moment should be examined before taking the actions.
- Accesses should not be cut in locations that will reduce the section modulus or strength member continuity.

The components of the hull girder are arranged to give enough section modulus to carry anticipated loads. The sheer strake, strength deck, keel, and bottom longitudinals and plating are subjected to the highest loading stress levels. These components are critical to the strength of the hull girder. In salvage operations, strength members should be inspected carefully for damage, and care should taken to avoid unnecessary damage to members subject to high stress levels. Damage to members close to the neutral axis, such as a hole near the waterline, caused by collision or contact weapons, generally has less impact on longitudinal strength than damage to the keel or a strength deck located at a greater distance from the neutral axis. Some damage, such as holes, wrinkles, cracks, and torn plating, is obvious. Other damage may be less obvious or may be inaccessible for inspection. Salvors should inspect the ship's structure frequently for signs of damage. Some of the signs of damage are:

- Rust and scale newly flaked from structural members or cracked or flaking paint on structural members
- Double-bottom plating setup or with the lines of internal structure very obvious
- Changes in the alignment of masts and other fixed topside installations
- Long shallow indentations of plating that can best be seen by placing the eye close to the structure and looking along it or by shining a light parallel to the plating for better viewing.
- Cracked welds
- Cracked deck coating
- Misalignments
- Changes in any of the above.

There are three primary uses for strength calculations in salvage:

- To analyze the stress in the hull in the condition in which salvors find the ship
- To determine the effect on ship's strength of planned salvage actions
- To determine the ability of a damaged hull to carry loads.

5-7.1 Initial Analysis. The initial analysis of a casualty's strength includes development of the bending moment curve and determination of the section modulus and bending stress to establish a baseline for other calculations. The maximum allowable bending moment can be found by multiplying the yield stress of the material by the section modulus. A calculation of the maximum allowable shear may be made by substituting the maximum allowable shear stress and solving for the shear required to produce this stress.

When the structure is damaged, wasted, or its condition unknown, a safety factor may be added to keep the applied stress below the maximum allowable. Maximum allowable bending moment shear should be plotted on the bending moment and shear force curves as shown in Figure 5-23.

5-7.2 Analysis of Planned Actions. When a salvage action is planned that will affect the load, and thus the shear and bending moment, the effect of the action should be analyzed by developing and plotting new shear and bending moment curves. If the values of the maximum bending moment and shear are below the allowable maximums, the new load is safe. If they exceed the maximum, the action should not be taken. Figure 5-24 shows this principle.

5-7.3 Damaged Strength. When a ship's structure has suffered damage, the ability of the ship to carry the design loads is reduced. If the strength is reduced enough, the hull may fail catastrophically under conditions that it could normally withstand. The most serious problem is usually bending of the hull. The ability of a damaged ship to carry bending loads can be estimated by considering all missing or damaged plating as simply not present when calculating the section modulus.

EXAMPLE 5-11
SECTION MODULUS, SHEAR, AND BENDING STRESS IN A BARGE DAMAGED BY GROUNDING

The barge whose section modulus was calculated in example in 5-7 has grounded on a hard bottom and taken the following damage on the port side as shown in Figure 5-25:

Bottom plating and internals are missing from the bilge strake to a point 15 feet inboard of the bilge strake. Bilge strake and side plating are heavily indented and wrinkled between the bottom and the first side stringer.

What is the effect on section modulus, bending stress, and shear stress if the bending moment is 100,000 foot-tons, hogging?

a. Section modulus of damaged barge:

Consider all plating and longitudinals that are damaged to be non-existent.

Section	b (in)	h (in)	a (in^2)	y (ft)	ay (in^2 ft)	ay^2 (in^2 ft^2)	h (ft)	i (in^2 ft^2)
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Plating	630	0.625	394	20.0	7865	157090	0.1	0
Port Side								
Side Plating	0.375	**160**	60	13.3	800	10667	13.3	889
Sheer Strake	0.625	30	19	18.8	352	6592	2.5	10
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Side Stringer (H)	6	0.5	3	6.7	20	133	0.0	0
Side Stringer (V)	0.5	2.5	1	6.6	8	54	0.2	0
Side Stringer (H)	6	0.5	3	13.3	40	533	0.0	0
Side Stringer (V)	0.5	2.5	1	13.2	17	219	0.2	0
~~Bilge Strake~~	~~0.625~~	~~30~~	~~19~~	~~1.3~~	~~23~~	~~29~~	~~2.5~~	~~10~~
Stbd Side								
Side Plating	0.375	240	90	10.0	900	9000	20.0	3000
Sheer Strake	0.625	30	19	18.8	352	6592	2.5	10
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Side Stringer (H)	6	0.5	3	6.7	20	133	0.0	0
Side Stringer (V)	0.5	2.5	1	6.6	8	54	0.2	0
Side Stringer (H)	6	0.5	3	13.3	40	533	0.0	0
Side Stringer (V)	0.5	2.5	1	13.2	17	219	0.2	0
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Keel Strake	24	2	48	0.1	4	0	0.2	0
Vertical Keel	2	24	48	1.2	56	65	2.0	16
Keel Top Rider	18	1	18	2.2	40	88	0.1	0
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
~~Longitudinal (H)~~	~~12~~	~~1~~	~~12~~	~~1.0~~	~~12~~	~~13~~	~~0.1~~	~~0~~
~~Longitudinal (V)~~	~~1~~	~~11~~	~~11~~	~~0.5~~	~~6~~	~~3~~	~~0.9~~	~~1~~
Bottom Plating	**450**	0.75	338	0.0	11	0	0.1	0
Totals			1,240		12,635	231,416		3,941

$d = AY/A = 12{,}635/1{,}240 = 10.19 \text{ ft}$

$I_K = AY^2 + I = 231{,}416 + 3{,}941 = 235{,}357 \text{ in}^2 \text{ ft}^2$

$I_{NA} = I_K - Ad^2 = 235{,}357 - (1{,}240 \times 10.19^2) = 106{,}600 \text{ in}^2 \text{ ft}^2$

$y_t = \text{Depth} - d = 20 - 10.19 = 9.81 \text{ ft}$

$Z_t = I_{NA}/y_t = 106{,}600/8.87 = 10{,}866 \text{ in}^2 \text{ ft}$

$y_b = d = 10.19 \text{ ft}$

$Z_b = I_{NA}/y_b = 106{,}600/10.19 = 10{,}461 \text{ in}^2 \text{ ft}$

CONTINUED ON NEXT PAGE

EXAMPLE 5-11 (CONTINUED)
SECTION MODULUS, SHEAR, AND BENDING STRESS IN A BARGE DAMAGED BY GROUNDING

b. Section modulus by alternate method:

If the section modulus for the intact section has already been calculated or is available from the ship's drawings, section modulus for the damaged section can be calculated by deducting the contribution of the damaged or missing members.

First, sum areas and moments for all damaged plating and longitudinals:

Section	b (in)	h (in)	a (in^2)	y (ft)	ay (in^2 ft)	ay^2 (in^2 ft^2)	h (ft)	i (in^2 ft^2)
Side Plating	0.375	240	90	10.0	900	9000	20.0	3000
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Bottom Plating	630	0.75	473	0.0	15	0	0.1	0
			605		956	9045		3011

Deduct these sums from the totals for the intact section:

	a	ay	ay^2	i
Intact Section	1,447	12,781	229,794	6,062
- Damaged Member Totals	604	956	9,045	3,011
Sub-totals	843	11,825	220,749	3,051

Sum areas and moments for residual portions of members that have been deducted, (upper part of the side plating and starboard part of the bottom plating):

Section	b (in)	h (in)	a (in^2)	y (ft)	ay (in^2 ft)	ay^2 (in^2 ft^2)	h (ft)	i (in^2 ft^2)
Side Plating	0.375	**160**	60	13.3	800	10667	13.3	889
Bottom Plating	**450**	0.75	338	0.0	11	0	0.1	0
Totals			398		811	10,667		889

Add these sums to the sub-totals calculated above:

	a	ay	ay^2	i
Sub-totals	843	11,824	220,749	3,052
+ Residual Portion Totals	398	811	10,667	889
Damaged Section Totals	1,241	12,635	231,416	3,941

The area and moment totals are similar to those calculated in part a. of this example and could be used to calculate d, I_K, and I_{NA} as in part a, with similar results. Slight round-off errors are not significant.

Note that for partially damaged members, areas and moments for the entire member must be deducted from the intact section totals. Areas and moments for remaining sound portions of the members are then added. Simply deducting areas and moments of the damaged portion of the member will introduce errors in the ay, ay^2, and i terms.

c. Bending stress calculation:

$$\text{Deck stress} = \frac{100{,}000}{10{,}866}$$

$$\text{Deck stress} = 9.20 \text{ tons per square inch in tension}$$

$$\text{Deck stress} = 9.20 \times 2{,}240 = 20{,}608 \text{ psi}$$

$$\text{Bottom stress} = \frac{100{,}000}{10{,}461}$$

$$\text{Bottom stress} = 9.56 \text{ tons per square inch in compression}$$

$$\text{Bottom stress} = 9.56 \times 2{,}240 = 21{,}414 \text{ psi}$$

CONTINUED

EXAMPLE 5-11 (CONTINUED)
SECTION MODULUS, SHEAR, AND BENDING STRESS IN A BARGE DAMAGED BY GROUNDING

d. Shear stress at neutral axis for damaged barge:

$$d = 10.19 \text{ ft}$$
$$I_{NA} = 107{,}600.00 \text{ in}^2 \text{ ft}^2$$
$$\text{Shear} = 1{,}500.00 \text{ tons}^2$$
$$b = 0.0625 \text{ ft}$$

Section	b (in)	h (in)	a (in^2)	y(BL) (ft)	y(NA)	ay(NA) (in^2 ft)
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Girder (V)	0.625	12	8	19.5	9.3	74.4
Deck Girder (H)	5.375	0.625	3	19.0	8.8	26.4
Deck Plating	630	0.625	394	20.0	9.8	3861
Port Side						
Side Plating	0.375	118	44	15.1	4.9	216
Sheer Strake	0.625	30	19	18.8	8.6	163
Deck Stringer	30	0.625	19	20.0	9.8	186
Side Stringer (H)	6	0.5		6.7	-3.5	0
Side Stringer (V)	0.5	2.5		6.6	-3.6	0
Side Stringer (H)	6	0.5	3	13.3	3.1	9
Side Stringer (V)	0.5	2.5	1	13.2	3.0	3
Stbd Side						
Side Plating	0.375	118	44	15.1	4.9	217
Sheer Strake	0.625	30	19	18.8	8.6	161
Deck Stringer	30	0.625	19	20.0	9.8	184
Side Stringer (H)	6	0.5		6.7	-3.5	0
Side Stringer (V)	0.5	2.5		6.6	-3.6	0
Side Stringer (H)	6	0.5	3	13.3	3.1	9
Side Stringer (V)	0.5	2.5	1	13.2	3.0	4
Bilge Strake	0.625	30		1.3	-8.9	0
Keel Strake	24	2		0.1	-10.1	0
Vertical Keel	2	24		1.2	-9.0	0
Keel Top Rider	18	1		2.2	-8.0	0
Longitudinal (H)	12	1		1.0	-9.2	0
Longitudinal (V)	1	11		0.5	-9.7	0
Longitudinal (H)	12	1		1.0	-9.2	0
Longitudinal (V)	1	11		0.5	-9.7	0
Longitudinal (H)	12	1		1.0	-9.2	0
Longitudinal (V)	1	11		0.5	-9.7	0
Bottom Plating	450	0.75		0.0	-10.2	0
Totals			637			5,609

$$\text{Shear stress} = \frac{S \times AY}{144 \times I \times b}$$

$$\text{Shear stress} = \frac{1{,}500 \times 5{,}603}{144 \times 106{,}600 \times 0.0625} = 8.76$$

$$\text{Shear stress} = 8.76 \times 2{,}240 = 19{,}622 \text{ psi}$$

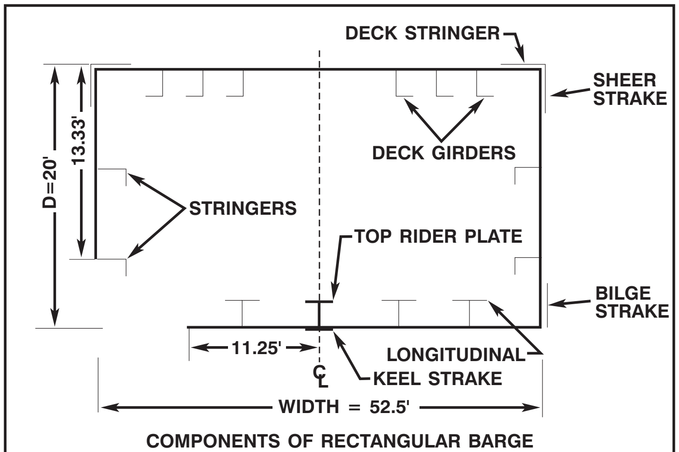


Figure 5-25. Barge Damaged by Grounding for Example 5-11.

EXAMPLE 5-12
SECTION MODULUS, SHEAR, AND BENDING STRESS IN A BAGE DAMAGED BY COLLISION

The barge in Example 5-11 has been refloated and repaired. While it is being towed out of the ship yard, it is in collision with a clipper bowed yacht that holes the port side amidships from two feet above the bilge strake to two feet below the stringer plate. Figure 5-26 shows the damage sustained in the collision. The barge is loaded with cumshaw from the shipyard and sleeping shipyard workers, so the bending moment is the same as in the preceding example. What is the effect of the damage on section modulus and bending stress?

a. Section modulus of damaged barge:

Consider all plating and longitudinals that are damaged to be non-existent.

Section	Dimensions (in)	h (in)	a (in^2)	y (ft)	ay (in^2 ft^2)	ay^2 (in^2 f^{t2})	h (ft)	i (in^2ft^2)
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Girder (V)	0.625	12	8	19.5	146	2852	1.0	1
Deck Girder (H)	5.375	0.625	3	19.0	64	1209	0.1	0
Deck Plating	630	0.625	394	20.0	7865	157090	0.1	0
Port Side								
Side Plating	0.375	24	9	19.0	171	3249	2.0	3
Side Plating	0.375	66	25	2.8	68	187	5.5	62
Sheer Strake	0.625	24	15	19.0	285	5415	2.0	5
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Stbd Side								
Side Plating	0.375	240	90	10.0	900	9000	20.0	3000
Sheer Strake	0.625	30	19	18.8	352	6592	2.5	10
Deck Stringer	30	0.625	19	20.0	375	7500	0.1	0
Side Stringer (H)	6	0.5	3	6.7	20	133	0.0	0
Side Stringer (V)	0.5	2.5	1	6.6	8	54	0.2	0
Side Stringer (H)	6	0.5	3	13.3	40	533	0.0	0
Side Stringer (V)	0.5	2.5	1	13.2	17	219	0.2	0
Bilge Strake	0.625	30	19	1.3	23	29	2.5	10
Keel Strake	24	2	48	0.1	4	0	0.2	0
Vertical Keel	2	24	48	1.2	56	65	2.0	16
Keel Top Rider	18	1	18	2.2	40	88	0.1	0
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Longitudinal (H)	12	1	12	1.0	12	13	0.1	0
Longitudinal (V)	1	11	11	0.5	6	3	0.9	1
Bottom Plating	630	0.75	473	0.0	15	0	0.1	0
Totals			1,381		11,969	222,112		3,126

d	=	AY/A	=	11,969/1,381	=	8.67 ft
I_K	=	$AY^2 + I$	=	222,112 + 3,126	=	225,238 in^2 ft^2
I_{NA}	=	$I_K - Ad^2$	=	225,238 - (1,381 x 8.67^2)	=	121,430 in^2 ft^2
y_t	=	Depth - d	=	20 - 8.67	=	11.33 ft
Z_t	=	I_{NA}/y_t	=	121,430/11.33	=	10,718 in^2 ft
y_b	=	d			=	8.67 ft
Z_b	=	I_{NA}/y_b	=	121,430/8.67	=	14,006 in^2 ft

b. Bending stress:

$$\text{Deck stress} = \frac{100,000}{10,718}$$

$$\text{Deck stress} = 9.33 \text{ tsi in tension}$$

$$\text{Deck stress} = 9.33 \times 2,240 = 20,899 \text{ psi}$$

$$\text{Bottom stress} = \frac{100,000}{14,006}$$

$$\text{Bottom stress} = 7.14 \text{ tsi in compression}$$

$$\text{Bottom stress} = 7.14 \times 2,240 = 15,994 \text{ psi}$$

CONTINUED ON NEXT PAGE

EXAMPLE 5-12 (CONTINUED)
SECTION MODULUS, SHEAR, AND BENDING STRESS IN A BARGE DAMAGED BY COLLISION

c. Shear stress calculation for damaged barge:

$$d = 8.67 \text{ ft}$$
$$I_{NA} = 121{,}430 \text{ in}^2 \text{ ft}^2$$
$$\text{Shear} = 1{,}500 \text{ tons}^2$$
$$b = 0.0313 \text{ ft}$$

Section	b (in)	h (in)	a (in^2)	y (BL) (ft)	y (NA) (in^2 ft)	ay (NA) (in^2 ft)
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Girder (V)	0.625	12	8	19.5	10.8	86
Deck Girder (H)	5.375	0.625	3	19.0	10.3	31
Deck Plating	630	0.625	394	20.0	11.3	4452
Port Side Members						
Side Plating	0.375	24	9	19.0	10.3	93
Side Plating	0.375	66		2.8	-5.9	0
Sheer Strake	0.625	24	15	19.0	10.3	155
Deck Stringer	30	0.625	19	20.0	11.3	215
Bilge Strake	0.625	30		1.3	-7.4	0
Stbd Side Members						
Side Plating	0.375	136	50	19.3	5.6	280
Sheer Strake	0.625	30	19	18.8	10.1	192
Deck Stringer	30	0.625	19	20.0	11.3	215
Side Stringer (H)	6	0.5		6.7	-2.0	0
Side Stringer (V)	0.5	2.5		6.6	-2.1	0
Side Stringer (H)	6	0.5	3	13.3	4.6	14
Side Stringer (V)	0.5	2.5	1	13.2	4.5	5
Bilge Strake	0.625	30		1.3	-7.4	0
Keel Strake	24	2		0.1	-8.6	0
Vertical Keel	2	24		1.2	-7.5	0
Keel Top Rider	18	1		2.2	-6.5	0
Longitudinal (H)	12	1		1.0	-7.7	0
Longitudinal (V)	1	11		0.5	-8.2	0
Longitudinal (H)	12	1		1.0	-7.7	0
Longitudinal (V)	1	11		0.5	-8.2	0
Longitudinal (H)	12	1		1.0	-7.7	0
Longitudinal (V)	1	11		0.5	-8.2	0
Longitudinal (H)	12	1		1.0	-7.7	0
Longitudinal (V)	1	11		0.5	-8.2	0
Bottom Plating	630	0.75		0.0	-8.7	0
Totals			595			6323

$$\text{Shear stress} = \frac{S \times AY}{144 \times I \times b}$$

$$\text{Shear stress} = \frac{1{,}500 \times 6{,}323}{144 \times 121{,}430 \times 0.0313} = 17.33 \text{ tsi}$$

$$\text{Shear stress} = 17.33 \times 2{,}240 = 38{,}819 \text{ psi}$$

Note: This stress is greater than the yield stress in shear of 17,600 psi for common shipbuilding steel. The barge has not necessarily broken in two, but since the residual strength of the steel cannot be determined by the methods presented in this manual, the section is considered to have failed. Immediate corrective actions are:

- Change the loading of the barge to reduce shear force at the failed section
- Reinforce the failed section by shoring
- A combination of both actions.

In fact, plating and longitudinals that are damaged have residual strength that can contribute to the section modulus. The estimates of residual strength are beyond the scope of this manual and should be made by a salvage engineer or naval architect.

Some types of damage are particularly dangerous. Every salvor should be able to recognize them and know that the problem they represent is serious. Dangerous types of damage include, but are not limited to:

- Buckling of plate and stiffeners, or failure in compression, is characterized by in-and-out displacement of the plating or stiffener in a plane perpendicular to the primary load. Structure that has buckled has essentially lost all of its ability to carry compressive loads, but has a large portion of its ability to carry tensile loads remaining.
- Heavily indented or dished plate in large areas cannot carry compressive loads as great as plating that is straight. The tensile strength remains about the same.
- Cracking may occur around the edges of other damage or by itself. The greatest danger of cracks is that they will grow under tensile load. Vertical cracks in the sides or athwartship cracks across the decks or bottoms are more dangerous than fore-and-aft cracks. Diagonal cracks are also dangerous because they have a component in the vertical or athwartships direction and can grow under load.
- Fire-damaged plate has suffered a loss of strength from wastage and changes in characteristics and may have essentially no residual strength in either tension or compression.

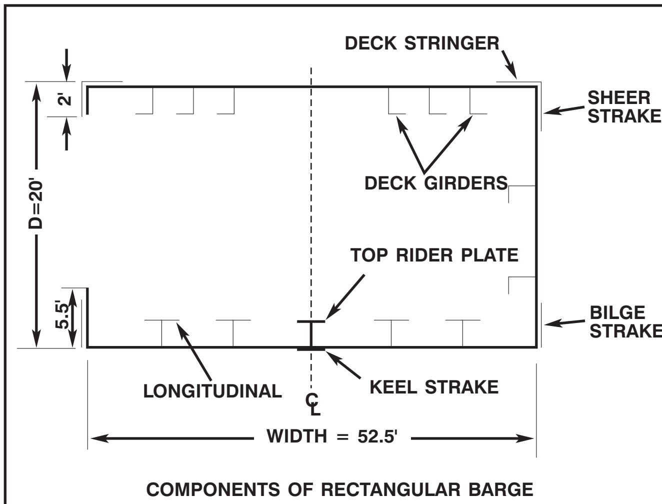


Figure 5-26. Barge Damaged by Collision for Example 5-12.

Temporary repairs to restore the strength of ship's structure must be made properly so that they do not introduce new problems that are more severe than the ones they solve. In 2000, the USS COLE, was severely damaged at the waterline due to a catastrophic explosion she sustained while refueling in Yemen. Temporary repairs were made to the hull of the ship that provided the necessary hull integrity needed to transfer the ship to a drydock vessel. The ship was subsequently transferred back to the United States for full repairs. The initial temporary repairs focused on two key aspects. The first aspect was the stability of the ship, and closing the hole in the hull in such a way as to prevent further negative impact on ship stability. A principle consideration was free surface effect of water flowing in and out of the hole. The second critical aspect was assuring the repair structure and welds were performed in such a manner as to regain the structural integrity of the ship prior to transport or drydocking.

An initial survey of the remaining structure was important for determining how a temporary repair would be conducted. The stresses to the hull while the USS COLE was transferred from a floating condition to a drydocked condition aboard the docking ship were significant. Structural Engineers developed a repair patch utilizing steel beams and plating that effectively closed the hole and attached to the remaining hull structure.

Improperly designed temporary repairs have led to ship losses. Design of such repairs is beyond the scope of this manual. All such designs should be made by a salvage engineer or naval architect. The best option for salvors is to redistribute the load to reduce shear and bending moment forces at the damaged section until a salvage engineer or naval architect can assess the situation.

CHAPTER 6
THE STRANDED OR SUNKEN SHIP

6-1 INTRODUCTION.

A ship that is grounded intentionally is beached; one that is grounded unintentionally is stranded. A stranded ship is in a position her designers, builders, and operators never intended. Whether warship, cargo carrier, or service or industrial vessel, she is immobile and subject to very different forces and conditions than when in normal service. The ability to evaluate the position and condition of the ship, to understand the difficulties she is in, and to develop a plan to see the ship safely afloat sets salvors apart from other seamen.

A stranded ship is no longer mobile and floating freely on the surface of the sea supported by buoyancy. A portion of her weight rests upon the ground. The distribution of the forces supporting the ship is altered. This redistribution of support has several effects:

- The weight on the ground acts like the removal of the same weight at the keel and changes the ship's stability characteristics.
- The ground, particularly rocky seafloors, can cause extremely high local loading and damage or penetrate the hull.
- The change in support alters the load in the ship causing, in turn, changes in shear force and bending moment.

The stranded ship will not respond to the hull loading in the same way as when she is afloat due to the new disturbing forces. In this new environment, ship stability changes as do the distribution of forces, making the ship more vulnerable to further damage.

The seafloor may not be a solid support. It may behave as a very dense fluid, moving in response to the forces the ship and the environment apply. Changes in the seafloor and in the way it supports the ship can cause the stranded ship's position to change.

The conditions of a stranding are seldom fully defined in the beginning and often are not completely defined during the salvage operation. Salvage of a stranded ship is time-critical because weather and sea conditions always worsen the situation. There is no time to wait until conditions are optimum or until all information is known. Salvors must obtain the best information possible, estimate unobtainable information, develop the salvage plan, and refloat the ship without delay. There are many methods for refloating stranded ships; none is correct in every circumstance. There is no simple formula. Salvors are limited only by their knowledge and imagination. This chapter addresses conditions that affect stranded ships and what their effects are. It is representative rather than all inclusive and should serve as a guide and starting point, not a rule book, for evaluation of a stranding salvage.

In cases other than military emergencies, salvors' first attention must be given to the prevention and control of pollution. Due regard must be given to the responsibilities of government agencies for pollution control and their requirements. Pollution control and abatement efforts may delay the commencement of salvage work or limit the methods of salvage available, but are of paramount importance. To this end, a Federal On-Scene Coordinator (FOSC) may be assigned by the Coast Guard as well as personnel from other Federal and local agencies, in addition to a pre-designated Navy On-Scene Coordinator (NOSC), to help provide the expertise and guidance to protect the environment. This chapter does not address in detail pollution control during salvage but notes how pollution control may affect stranding salvage operations. *U.S. Navy Salvage Manual Volume 5, POL Offloading* (S0300-A6-MAN-050) and *Volume 6, POL Spill Response* (S0300-A6-MAN-060) provide specific guidance for pollution control during salvage operations.

Most harbor clearance work deals with sunken and capsized ships. These ships are nearly always damaged. Ships sink or capsize because they lose their buoyancy or stability through battle damage, collision, weather damage, intentional flooding, or other means. Damage makes salvage more difficult than it would be for an intact ship in the same place. Beyond this, and the fact that the ships are largely or totally supported by the ground, the common circumstances of stranded ships do not apply to sunken ships. Ships may sink completely beneath the surface, sink only partially, so they lie on the seafloor partially above the surface, or they may be partially supported by their buoyancy. In any of these conditions, they may be upright or capsized.

There are a limited number of methods of salvaging sunken ships, though the variations of the basic means are almost infinite. Sunken ships may be removed by:

- Restoring buoyancy
- Physical lifting with external forces
- Wrecking in place.

Capsized ships may be removed by:

- Rolling upright and refloating
- Refloating on their side or upside down
- Wrecking in place.

All salvage work is a combination of seamanship and engineering. In stranding salvage, seamanship dominates; salvage or clearance of sunken ships requires a greater proportion of engineering. This chapter discusses the influences salvors must consider in raising or removing sunken ships, and introduces some of the calculations used in harbor clearance. Because of the importance of ship engineering in the salvage of sunken ships, a thorough grasp of the first five chapters of this manual is a prerequisite to understanding this chapter.

Most sunken ships being salvaged will come afloat before all the buoyancy lost in the sinking has been recovered. Water remaining on board can cause dangerous free surface and problems with stability, list, and local and overall hull strength. Salvage of sunken ships requires not only the recovery of sufficient buoyancy to bring the ship afloat, but also the distribution of that buoyancy to obtain satisfactory conditions of stability, trim, and strength.

6-2 INFLUENCES ON STRANDED, CAPSIZED, OR SUNKEN SHIPS.

Influences on strandings or sinkings can be categorized as the:

- Ship
- Seafloor
- Sea
- Stranding conditions/sinking conditions
- Location
- Weather
- Salvors.

All influences are not equally important; all are not applicable in every case; their relative importance varies. Salvors must understand the important influences in each case and how they affect salvage planning and salvage operations. All of the influences must be evaluated to determine their relative value and priority in a particular stranding or sinking.

6-2.1 The Ship. Ship-related influences on salvage operations are:

- Condition, character, and type of ship
- Draft before and after the stranding
- Stability characteristics, both afloat and as she lies
- Intact structural strength
- Damage suffered in the stranding or sinking
- Probable damage during the salvage
- Type and location of movable weight on board
- Weight handling and pulling equipment on board
- Type, quantity, and containment of pollutants and hazardous materials on board
- Value of the ship and/or her cargo, cost of salvage, cost of repair
- Composition, competence, and attitude of the ship's crew.
- Remaining military or commercial value.

6-2.2 The Seafloor. Seafloor-related influences on salvage operations are:

- Composition and consistency of the seafloor under the ship
- Slope of the seafloor under the ship
- Composition and slope of the seafloor where ground tackle will be laid
- Movement of the seafloor in the vicinity of the ship.

6-2.3 The Sea. Sea-related influences on salvage operations are:

- Depth of water under and around the ship
- Depth of water between the ship and deep water
- Tide
- Swell
- Surf
- Prevailing seas
- Current
- Diving conditions.

6-2.4 The Stranded, Capsized, or Sinking Condition. Stranding condition-related influences on salvage operations are:

- The attitude of the ship relative to the ground and the shore
- The area of the ship in contact with the seafloor
- Changes in list and trim caused by the stranding
- Pollution (actual or potential)
- Work and time required for the salvage
- Time available
- Whether or not the ship is capsized
- Whether or not the main deck is submerged.

6-2.5 The Location. Location-related influences on salvage operations are:

- Crucial need of the berth the ship occupies or the waterway she blocks
- Local industrial and transportation facilities
- Location of salvage forces and the time for them to arrive
- Distance from drydocking facilities
- Environmental sensitivity
- Government regulation
- Political circumstances
- Tactical situation.

6-2.6 The Weather. Weather-related influences on salvage operations are:

- Prevailing weather
- Seasonal weather
- Local weather effects
- Available forecasts.

6-2.7 The Salvors. Salvor-related influences on salvage operations are:

- Access to ships' plans
- Availability and competence of salvors and salvage engineers
- Type and availability of salvage equipment and ships
- Availability of pollution control personnel and equipment
- Availability of time to do work required to refloat the casualty.

6-3 GROUND REACTION.

When a ship strands under her own power or is driven ashore by the sea, her momentum carries her up the beach or reef. The ship is no longer supported entirely by buoyancy; she is supported by a combination of buoyancy and the ground. In stranding, the ship loses an amount of buoyancy that is exactly equal to the amount of weight supported by the ground; this quantity is the ground reaction. Ground reaction is represented by the symbol R and is measured in long tons. Ground reaction is often referred to as "tons aground."

The amount of the ground reaction must be determined because it is of vital importance throughout the salvage operation. The ground reaction is not a set figure but varies. Anything that changes either the buoyancy or weight of the ship changes the ground reaction.

One of the principal causes of variation is the tide. When the tide rises and the ship is unable to rise with the tide, the ship gains buoyancy; a larger portion of her weight is supported by the sea, and the ground reaction is reduced. When the tide drops, so does the buoyancy, and the ground reaction increases. Weight changes aboard the ship also change the ground reaction. During the course of the salvage operation, salvors must reduce the ground reaction enough to free the ship. They may also elect to increase the ground reaction temporarily to prevent the ship from being driven farther ashore by the sea.

6-3.1 The Distribution and Center of Pressure of the Ground Reaction. The ground reaction is distributed along the grounded length. Except in cases where the ship is aground on a pinnacle, or so that a very short portion of its length is in contact with the seafloor, the distribution of the ground reaction cannot be accurately determined.

CAUTION

The method described on the following page for determining a distribution of ground reaction and its center of pressure is approximate. Salvors should be alert to responses by the ship that do not match exactly the expected response. They should attempt to analyze these responses to obtain a better approximation of ground reaction distribution and the location of the center of pressure.

A reasonable assumption is that ground reaction is evenly distributed along the grounded length of the ship. This distribution of ground reaction is shown in Figure 6-1. The area under the ground reaction distribution curve is the ground reaction. The estimated ground reaction distribution in tons per foot can be calculated. The reaction will be:

$$r = \frac{R}{l}$$

where:

r = Ground reaction in tons per foot
R = Total ground reaction in long tons
l = Grounded length in feet

The center of pressure of the ground reaction is the point at which the ground reaction would act if concentrated. The location of this point is needed to determine the effect of weight changes on the ground reaction. Also, it is the point about which the ship will pivot. The center of pressure lies one-half of the grounded length from either end.

6-3.2 Determination of Ground Reaction. The first salvage calculation determines the ground reaction. Several methods are available for making the calculation. The methods are not equally applicable to all strandings. The method most suitable for the particular stranding must be chosen. The ground reaction acts much like a weight removal at the keel, causing the ship to both rise bodily in the water and to trim. The amount of trim and bodily rise vary with the conditions of stranding and are not predictable. Two methods of calculation, the change of displacement method and the change of draft forward method take both bodily rise and trim into consideration. Their use is appropriate in all strandings, however, the change in draft forward method may not give accurate results if the center of pressure of the ground reaction cannot be accurately estimated. The tons per inch immersion method considers only bodily rise, the change in trim method only trim. Their use is appropriate when bodily rise or trim is the dominant effect.

Most of the methods of calculating ground reaction require knowledge of the ship's afloat drafts before stranding. This information is often not available directly. Drafts at the time of departure from the last port will be found in the ship's log. From these drafts and known weight changes between the time of sailing and the time of stranding, drafts immediately before stranding can be estimated.

EXAMPLE 6-1
CALCULATION OF GROUND REACTION DISTRIBUTION

A ship is aground for the first hundred feet of her length. The total ground reaction is 1,000 tons. What is the ground reaction along the grounded length?

$$r = \frac{R}{l} = \frac{1{,}000}{100}$$

$$r = 10 \text{ tons per foot}$$

The ground reaction is the same all along the grounded length.

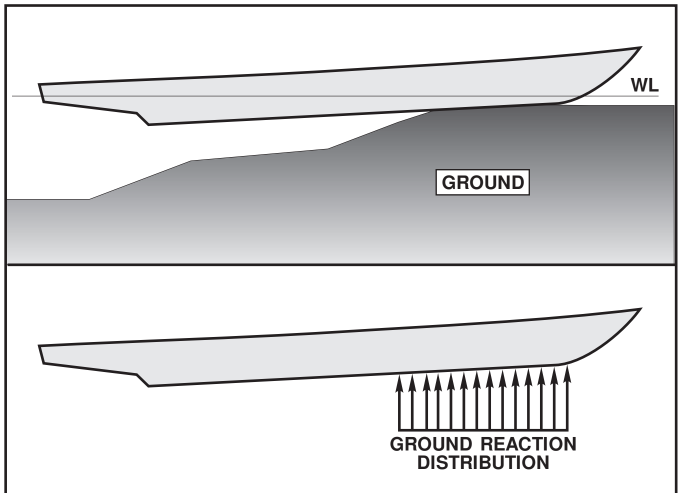


Figure 6-1. Distribution of Ground Reaction.

EXAMPLE 6-2
CALCULATION OF THE LOCATION OF THE CENTER OF PRESSURE

A ship grounded by the bow lies aground from a point 20 feet from the forward perpendicular to a point 200 feet from the forward perpendicular. Where is the center of pressure of the ground reaction?

The grounded length is:

$$200 - 20 = 180 \text{ feet}$$

The center of pressure lies at one-half of this length. In this case 180/2 or 90 feet from the forward end of the grounded length.

Since the grounded length begins 20 feet from the forward perpendicular the center of pressure of the ground reaction lies 90 + 20 or 110 feet from the forward perpendicular.

NOTE

Salvors should calculate ground reaction by the method that they feel best suits the stranding conditions. They should also calculate by other methods to verify the assumptions made in the initial estimate of ground reaction.

CAUTION

In determining the ground reaction, care must be taken to ensure that the most accurate possible drafts are taken. Chapter 9 describes the methods for making salvage surveys (See Paragraph 9-2.2.2) for determining drafts. In the case of ships that have stranded just before entering or just after leaving port, care must be taken that all drafts are on the same basis, that is, saltwater or fresh water (the type of water in which the ship is stranded should be used).

6-3.2.1 Change of Displacement Method. The determination of ground reaction may be made by entering the Functions of Form Diagram or Curves of Form with drafts before and after stranding and reading the displacements for the two conditions. The difference in the displacements is the ground reaction. If the ship is trimmed when aground, a trim correction to displacement should be calculated and applied to the stranded displacement. The stranded displacement should be referenced to low water.

$$R = W_b - W_g$$

where:

R	=	Ground reaction
W_b	=	Displacement immediately before stranding
W_g	=	Displacement after stranding

When the stranded ship is trimmed, a correction to displacement for trim should be made by the method described in Paragraph 3-3.1.8.

6-3.2.2 Change of Draft Forward Method. The change of draft forward method may be used for all strandings to estimate ground reaction when the center of pressure of the ground reaction is known or can be estimated with reasonable accuracy. The change in draft forward method considers the ground reaction to be a weight removal at the keel that causes the ship to rise bodily and to trim. The total change in draft forward is the sum of the changes caused by bodily rise and trim, or:

Change in draft forward = bodily rise + trim forward.

$$T_{fa} - T_f s = \frac{R}{TPI} + \left(\frac{R \times d_r}{MT1}\right) \times \left(\frac{d_f}{L}\right)$$

where:

T_{fa}	=	Draft forward before stranding
T_{fs}	=	Draft forward after stranding
d_f	=	Distance from the center of flotation to the forward perpendicular
d_r	=	Distance from the center of flotation to the center of ground reaction

Solving the equation for R and simplifying it algebraically:

$$R = \frac{(TPI) \times (MT1) \times (L) \times (T_{fa} - T_{fs})}{(MT1 \times L) + (d_r \times d_f \times TPI)}$$

6-3.2.3 Tons per Inch Immersion Method. The tons per inch immersion method multiplies the change in mean draft by the tons per inch immersion to estimate the ground reaction. This method considers only the bodily rise of the ship and is suitable for a first estimate of ground reaction, and use when the trim of the ship has not been changed greatly by the stranding. When there is trim, the accuracy of the method can be improved by correcting the mean draft for trim by the method described in Paragraph 3-3.1.8.

$$R = (T_{mbs} - T_{mas}) \times TPI = \delta T_M \times TPI$$

where:

T_{mbs}	=	Mean draft before stranding
T_{mas}	=	Mean draft after stranding

6-3.2.4 Change of Trim Method. The change of trim method is most useful when the total trim exceeds one percent of the ship's length and the center of pressure of the ground reaction is known or can be estimated with reasonable accuracy. Ground reaction is estimated by considering a force that causes the trim to change. This method does not consider bodily rise and is most useful where change in trim is the dominant effect of the grounding.

$$R = \frac{MT1 \times t}{d_r}$$

where:

t = total change in trim in inches

EXAMPLE 6-3
CALCULATION OF GROUND REACTION

This example calculates ground reaction for two ships with approximately the same ground reaction, grounded under different conditions, and compares the results obtained with different methods. The first ship has little trim; the second, trim in excess of one percent of length.

a. An FFG-7 Class ship whose Curves of Form are given in Figure FO-1 strands. Immediately before stranding, the drafts are 14 feet 6 inches forward and aft. The ship has stranded on a gently sloping beach for much of its length.

The drafts after stranding are 13 feet 10 inches forward and 14 feet 0 inches aft.

The following quantities are known or have been calculated:

TPI = 32.5

MT1 = 750

Center of flotation = 23.4 feet abaft

Center of pressure of ground reaction = 50 feet forward of amidships

Displacement before stranding = 3,475 tons

Displacement after stranding = 3,250 tons

Calculate the ground reaction:

(1) Change in displacement method.

$$W_b = 3{,}475$$
$$W_s = 3{,}250$$
$$R = W_b - W_s$$
$$R = 3{,}475 - 3{,}250$$
$$R = 225 \text{ tons}$$

(2) Change in draft forward method.

$$R = \frac{(TPI) \times (MT1) \times (L) \times (T_{fa} - T_{fs})}{(MT1 \times L) + (d_r \times d_f \times TPI)}$$

$$R = \frac{(32.5) \times (750) \times (408) \times (8)}{(750 \times 408) + (73.4 \times 227.4 \times 32.5)}$$

$$R = 93.8 \text{ tons}$$

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EXAMPLE 6-3 (CONTINUED)
CALCULATION OF GROUND REACTION

(3) Tons per inch immersion method.

$$\delta T_{mbs} = 14' \ 6"$$
$$T_{fas} = 13' \ 10"$$
$$T_{aas} = 14' \ 0"$$
$$T_{mas} = 13' \ 11"$$
$$\delta TM = 14' \ 6" - 13' \ 11" = 7"$$
$$R = TPI \times TM$$
$$R = 32.5 \times 7$$
$$R = 227.5 \text{ tons}$$

(4) Change of trim method.

$$t = 2"$$
$$R = \frac{MT1 \times t}{d_r}$$
$$R = \frac{750 \times 2}{73.4}$$
$$R = 20.4 \text{ tons}$$

The results obtained by the change of displacement method and the tons per inch immersion method are very close to one another. Those obtained by the change in draft forward method and the change of trim method are very low and obviously inaccurate. They are inaccurate because the center of pressure is not clearly defined and small errors in estimating its position make large differences in the result. The change of trim method is doubly inappropriate; first, because the center of pressure of the ground reaction is poorly defined, and second, because bodily rise, rather than trim, is the dominant effect of the stranding.

b. An FFG-7 Class ship whose Curves of Form are given in Figure FO-1 strands. Immediately before stranding, the drafts are 14 feet 6 inches forward and aft. The ship has stranded on a pinnacle.

The drafts after stranding are 11 feet 6 inches forward and 15 feet 10 inches aft.

The following quantities are known or have been calculated:

TPI = 32.5

MT1 = 750

Center of flotation = 23.4 feet abaft of midships

Center of pressure of ground reaction = 50 feet Abaft the forward perpendicular

$$dr = \frac{408'}{2} - 50' + 23.4'$$
$$dr = 177.4'$$

Displacement before stranding = 3,475 tons

CONTINUED

EXAMPLE 6-3 (CONTINUED)
CALCULATION OF GROUND REACTION

Calculate the ground reaction:

(1) Change in displacement method.

$$T_{fas} = 11' \ 6"$$
$$T_{aas} = 15'10"$$
$$T_{mas} = 13' \ 8"$$
$$TC = \frac{d \times t}{L}$$
$$t = 15'10" - 11' \ 6" = 52"$$
$$TC = \frac{23.4 \times 52}{408}$$
$$TC = 3.0$$
$$T_m = T_{mas} + TC$$
$$T_m = 13'11"$$

From the Curves of Form, displacement for T_m = 13' 11" = 3,250 LT

$$R = W_b - W_g$$
$$R = 3{,}475 - 3{,}250$$
$$R = 225 \text{ tons}$$

(2) Change in draft forward method.

$$R = \frac{(TPI) \times (MT1) \times (L) \times (T_{fa} - T_{fs})}{(MT1 \times L) + (d_r \times d_f \times TPI)}$$
$$R = \frac{(32.5) \times (750) \times (408) \times (36)}{(750 \times 408) + (177.4 \times 227.4 \times 32.5)}$$
$$R = 221.4 \text{ tons}$$

(3) Change of trim method.

$$t = 52"$$
$$R = \frac{MT1 \times t}{d_r}$$
$$R = \frac{750 \times 52}{177.4}$$
$$R = 219.8 \text{tons}$$

(4) Tons per inch immersion method.

$$T_{mbs} = 14' \ 6"$$
$$T_{fas} = 11'6"$$
$$T_{aas} = 15' \ 10"$$
$$T_{mas} = 13' \ 8"$$
$$\delta TM = 14' \ 6" - 13' \ 8" = 10"$$
$$R = TPI \times \delta TM$$
$$R = 32.5 \times 10"$$
$$R = 325 \text{ tons}$$

Because the extreme trim of the ship changes the hydrostatic characteristics somewhat, the results obtained by the four methods vary considerably. The tons per inch immersion method especially gives results whose accuracy can be questioned. The wide range of results obtained in this example emphasizes three things about ground reaction calculations:

- All ground reaction calculations are approximations and are subject to error.
- All calculations should be checked by estimating ground reaction by another method.
- Salvors must evaluate the casualty and the conditions of the stranding when deciding what method of calculating ground reaction to rely upon.

6-3.2.5 <u>Summary</u>. In calculating ground reaction, the following things should be kept in mind:

- All methods give results that are approximate.
- The Curves of Form are the preferred source of hydrostatic data.
- In actual strandings, the accuracy of draft readings may be only + six inches and the center of pressure of the ground reaction may be estimated only roughly. The results will be no more accurate than the basic data.

- Ground reaction should always be calculated by two methods and the results compared. The results may not be the same, but should be reasonably close.
- The change in displacement method and the change in draft forward method may be used in all strandings.
- A trim correction to displacement should be used with the change in displacement method if the ship is trimmed after stranding.
- The change of draft forward and change of trim methods require that the center of pressure of the ground reaction be known or estimated with some accuracy.
- The tons per inch immersion method requires a minimum of data and may be used for a rough first estimate. A correction for trim improves accuracy when there is significant trim. The most accurate results should be expected only when there is little trim.
- The most accurate results should be expected from the change in trim method when trim is greater than one percent of the ship's length.

6-3.3 Effect of Weight Changes on Ground Reaction. Floating ships are supported by buoyancy that exactly equals the weight. Stranded ships are supported by a combination of buoyancy and ground reaction. The sum of the buoyancy and ground reaction exactly equals the weight. That is:

$$W = B + R$$

Any change in weight must be matched by a change of the same amount in the sum of the ground reaction and in the buoyancy supporting the ship. If the ship is restrained so that she cannot change her position to change buoyancy, all the change must be in the ground reaction. If, however, the ship can trim so that buoyancy can change, ground reaction may increase, decrease, or remain the same, depending upon where the weight change occurs and the way the bottom supports the ship.

In the first case shown in Figure 6-2, the ship is supported along its entire length. The ship is completely restrained from gaining buoyancy by either sinking lower in the water or trimming. The change in ground reaction must be the same as any change in weight because the total of ground reaction and buoyancy must equal the weight, and the buoyancy cannot change.

In the second case shown in Figure 6-2, the ship is supported at a single point, or is aground on a pinnacle. The ship is restrained at the point P. It cannot sink deeper. It cannot rise until the draft at the point is reduced so it no longer is supported. It can rotate about P and will do so in response to weight changes. When the ship rotates about P the buoyancy will change and there will be a corresponding change in the ground reaction. Weight added or removed at the point of support causes no rotation thus no change in buoyancy. In this case the change in ground reaction will equal the weight change.

Stranded ships are usually supported by the bottom along some portion of their length, as shown in the third case in Figure 6-2. In this case, the point P about which the ship can rotate shifts to the end of the area supported by the ground. The ship is restrained so that it cannot increase draft by the bow, only by the stern. If the ship does not rotate, the change in ground reaction will be the same as the weight change. If the ship rotates, it will gain buoyancy. The sum of buoyancy and ground reaction will continue to equal the total weight of the ship.

In actual strandings the support is seldom as clearly defined as shown in Case 3. The point at which support ends may not be readily identified. The point about which the ship rotates will very likely lie somewhere between the center of pressure of the ground reaction and the end of support, depending on the type of soil and the grounding conditions. The point about which the ship rotates may change as the operation progresses and as the tidal and sea conditions change.

NOTE

The determination of the neutral loading point described below is approximate. Generally, ships are in contact with the ground over a substantial length of their hull. They do not act as simple levers supported at a single point. The center of pressure of ground reaction is not accurately defined and the center of flotation may be moved well aft by the dislocation of the waterline from its normal position. Calculations of the neutral loading point and the effect of weight changes on ground reaction should be treated as approximations with a large margin of error.

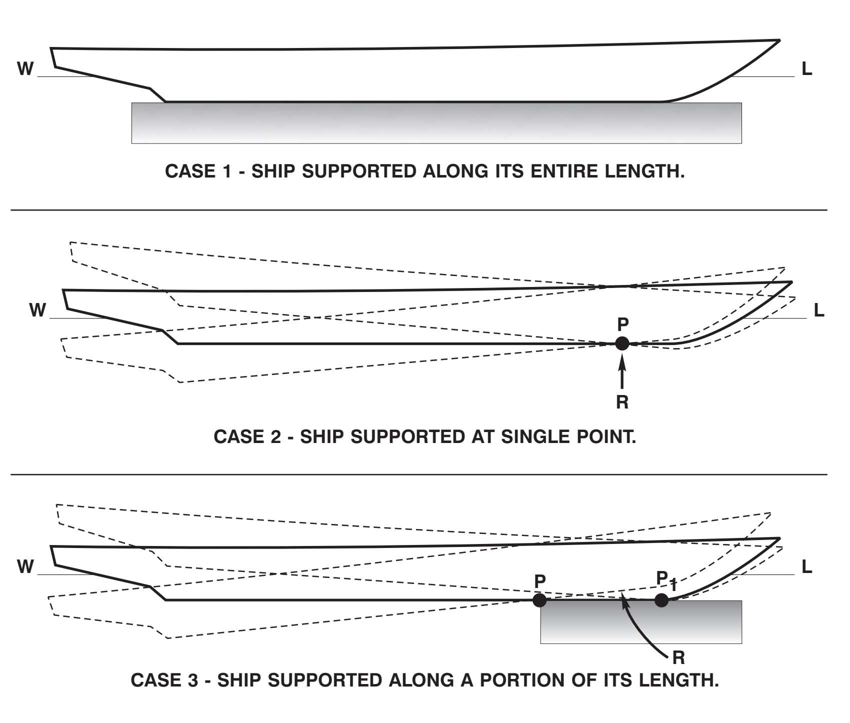


Figure 6-2. Ground Restraints on a Stranded Ship.

6-3.3.1 The Neutral Loading Point. A grounded ship often has a point where weight can be added or removed without changing the ground reaction; this point is the neutral loading point. The neutral loading point is the point at which weight addition causes parallel sinkage at the effective point of grounding that is exactly balanced by the change of trim, or:

Parallel sinkage - Change of trim = 0

Figure 6-3 shows the location of the points that are important in determining the location of the neutral loading point. The neutral loading point (NP) is located at:

$$d_n = \frac{(MT1 \times L)}{TPI \times d_r}$$

where:

d_n	=	Distance from the LCF to the NP
MT1	=	Moment to change trim one inch
L	=	Length between perpendiculars
TPI	=	Tons per inch immersion
d_r	=	Distance from the center of pressure of the ground reaction to the LCF

The neutral loading point concept applies exactly to a ship grounded on a pinnacle. It is less accurate in other grounding situations. In general, if the center of pressure of the ground reaction is less than L/8 from the center of flotation, the NP will be off the ship and the ship may be considered to be stranded along its entire length.

Weight additions or removals at the neutral loading point do not change the ground reaction.

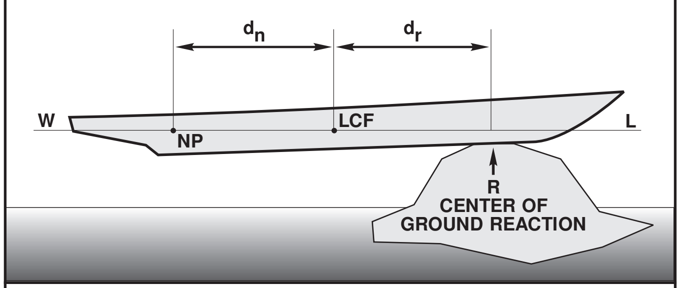


Figure 6-3. Distances Needed to Locate the Neutral Loading Point.

EXAMPLE 6-4
CALCULATION OF THE LOCATION OF THE NEUTRAL LOADING POINT

An FFG-7 Class ship 408 feet long is grounded on a pinnacle 50 feet from the forward perpendicular. The following information about the ship is known:

$$MT1 = 783 \qquad TPI = 32.5$$

LCF is 23 feet abaft midships or 227 feet abaft the forward perpendicular.

What is the location of the neutral loading point?

$$d_n = \frac{(MT1 \times L)}{(TPI \times d_r)}$$

a. Distance between the center of pressure and the center of flotation:

$$d_r = 227 - 50$$
$$d_r = 177 \text{ feet}$$

b. Location of the neutral loading point:

$$d_n = \frac{(MT1 \times L)}{(TPI \times d_r)}$$

$$d_n = \frac{(783 \times 408)}{(32.5 \times 177)}$$

$$d_n = \frac{319{,}464}{5{,}752.5}$$

$$d_n = 55.5 \text{ feet abaft the center of flotation}$$

6-3.3.2 **Estimates of Changes in Ground Reaction Caused by Weight Changes.** As discussed in Paragraph 6-3.3, any change in weight must be reflected by an equal change in the sum of buoyancy and ground reaction. If a stranded ship does not trim in response to a weight change, the immersed volume of the hull, and hence the force of buoyancy, are unchanged. The entire weight change (addition or removal) is therefore taken up by a change in ground reaction ($\Delta R = +w$). If the ship trims about any point other than the center of flotation, as it must when aground, buoyancy will change. Part of the weight change is reflected in the change in buoyancy and the remainder in a change of ground reaction. Because the pivot is often difficult to define and can change, determinations of the change in ground reaction that would result from weight changes in actual strandings are based on complex and inexact calculations. These calculations are usually performed by a naval architect or salvage engineer. Approximate predictions of change in ground reaction caused by weight change can be made if it is assumed that the ship pivots about the center of ground reaction. The following relationships can then be established:

- Weights added or removed at the pivot point (center of ground reaction) cause a change in ground reaction equal to the weight change, with no change in buoyancy (or trim).
- Weights added or removed at the neutral loading point (described in Paragraph 6-3.3.1) cause a change in buoyancy equal to the weight change, with no change in ground reaction.
- The proportion of the weight change taken up by change in ground reaction can be assumed to vary in a linear manner from 0 at the neutral loading point to 100 percent at the center of ground reaction, as shown in Figure 6-4.

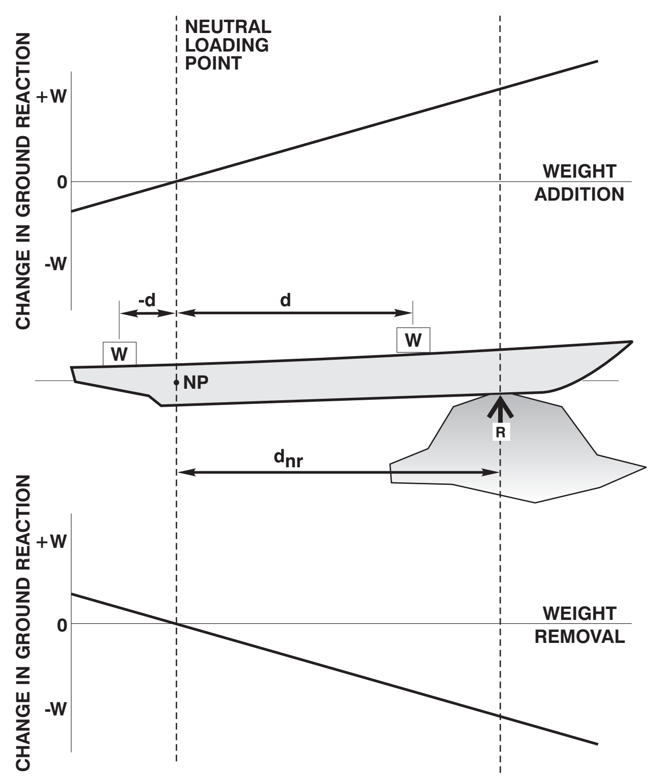


Figure 6-4. Effects of Weight Changes on Ground Reaction.

The change in ground reaction (δR) resulting from a weight change at any point along the length of the ship can thus be predicted by the following relationship:

$$\delta R = w \times \frac{d}{d_{nr}}$$

where:

w = Weight added or removed

d = Distance from the added or removed weight to the neutral loading point

d_{nr} = Distance from the neutral loading point to the center of ground reaction

d_{nr} = $d_n + d_r$

Ground reaction will increase when weight is added forward of the neutral loading point or removed aft of the neutral loading point. Ground reaction will decrease when weight is removed forward of the neutral loading point or added aft of the neutral loading point.

Although this relationship and the plot in Figure 6-4 imply that removing weights forward of the center of ground reaction will reduce ground reaction by an amount greater than the weight removed, this is true only for a ship grounded on a pinnacle with a significant portion of the ship forward of the pinnacle. Even in this case, the relation between weight removed forward of the center of ground reaction and the change in ground reaction is not linear. For conservative estimates, it should be assumed that weight changes forward of the center of pressure change ground reaction by an amount equal to the weight change. For points aft of the center of ground reaction, the linear relationship will give reasonable estimates of change in ground reaction if the ship is able to trim.

The change in forward and after drafts can be predicted by relating the change in buoyancy to a corresponding change in mean draft:

$$\delta T_m = \frac{\delta B}{TPI}$$

$$\delta T_a = \delta T_m \times \frac{d_a + d_r}{d_r}$$

$$\delta T_f = \delta T_m \times \frac{-d_f}{d_r}$$

where:

δB = Change in buoyancy = w - δR

δT_m = Change in mean draft

δT_a = Change in draft aft

δT_f = Change in draft forward

d_a = Distance from LCF to after perpendicular

d_r = Distance from LCF to pivot point (center of ground reaction)

d_f = Distance from center of ground reaction to forward perpendicular

In the normal stranding case, where the pivot point is forward of the LCF and aft of the forward perpendicular, δT_f will be opposite δT_m and δT_a. That is, for an increase in T_m, T_a will also increase but T_f will decrease; for a decrease in T_m, T_a will decrease and T_f will increase.

When the center of ground reaction is well forward, T_a is very nearly twice δT_m, and δT_f is negligible.

Changes in forward and after drafts should be checked after weight changes and while major weight changes are in progress. If, after accounting for differences due to rise or fall of tide, draft changes are not as predicted, the ship is not pivoting about the center of ground reaction and actual change in ground reaction is different from what was predicted. Specifically, for a ship grounded forward:

- Change in draft aft less than predicted indicates a greater change in ground reaction than predicted.
- Change in draft aft greater than predicted indicates that change in ground reaction is less than predicted.
- No change in forward and after drafts indicates that the entire weight change was taken up by change in ground reaction; the ship is unable to trim, or the trimming moment induced by the weight change was not great enough to actually trim the ship.

Example 6-5 illustrated the relative merits of removing weight forward and adding weight aft to reduce ground reaction. Note that weight removal forward caused a greater reduction in ground reaction even though a smaller weight change was involved. Weight addition aft would cause an extreme floating trim, a condition that should be corrected prior to towing as the ship would have marginal reserve buoyancy in this condition (the limiting draft aft for this class ship is 16 feet 8 inches). On the other hand, removal of low weight forward caused a rise in G, while weight addition aft actually lowered G.

Weight addition to reduce ground reaction is a seldom-used technique and is of use only in casualties where there is little removable weight, or the available weight is so located that its removal will adversely affect stability. It is emphasized that this method should be used only when the location of the center of ground reaction is well forward (or aft), known or estimated with a high degree of confidence, and salvors are equally certain that the ship is free to trim. If, in Example 6-5, the ship had been grounded so that the center of ground reaction was 23 feet forward of midships, the neutral loading point would have been abaft the fantail and weight addition anywhere would have increased ground reaction. For this example, weight additions aft will not cause a significant reduction in ground reaction (greater than 30 percent of the weight added) unless the center of ground reaction is at least 72 feet forward of midships. The center of ground reaction could be sited 72 feet forward of midships (132 feet aft of the forward perpendicular) if the ship were aground over 264 feet of her length, or if she were aground across a bar or reef. Even when a ship is aground over a shorter length, 25 to 30 percent of her length, for example, and a "neutral loading point" can be defined, the ship may not be truly free to trim. Weight additions aft may well increase rather than reduce ground reaction.

Weight removal is the preferred method of reducing ground reaction in almost all cases. In certain conditions of stranding, however, weight addition aft can provide an effective means to reduce ground reaction in warships, oceanographic vessels and other ship classes with little readily removable weight.

EXAMPLE 6-5
PREDICTED CHANGE IN GROUND REACTION AFTER A WEIGHT CHANGE

a. An FFG-7 Class ship whose Curves of Form are given in Figure FO-1 strands on a pinnacle. Immediately before stranding, the drafts are 14 feet 6 inches forward and aft. The drafts after stranding are 11 feet 5 inches forward and 16 feet 2 inches aft.

The following quantities are known or have been calculated:

TPI = 32.5

MT1 = 750

KG = 18 feet

Center of flotation = 23 feet abaft midships

Center of pressure of ground reaction = 50 feet abaft the forward perpendicular = 154 feet forward of midships

dr = 177 feet

Neutral loading point = 53 feet abaft the Center of Flotation = 76 feet abaft midships

Displacement before stranding = 3,475 tons

R is estimated at 230 tons (228 by change in draft forward, 242 by change in trim method)

CONTINUED ON NEXT PAGE

EXAMPLE 6-5 (CONTINUED)
PREDICTED CHANGE IN GROUND REACTION AFTER A WEIGHT CHANGE

Salvors contemplate flooding a compartment aft or removing diesel fuel from tanks forward of midships to reduce ground reaction.

Calculate the change in ground reaction, change of KG, change in drafts aground, and new drafts aground for each action.

(1) Flooding aft:

Compartment to be flooded: 5-368-01-E

Capacity, seawater = 200 tons (from the FFG-7 Class flooding effect diagram)

lcg = 180 feet aft of midships (estimated from arrangement plans)

kg = 15 feet (estimated from the profile plan)

Change in ground reaction:

$$\delta R = w \times \frac{d}{d_{nr}}$$

$$\delta R = 200 \times \frac{-180+76}{177+53}$$

$\delta R = -90$ tons (decrease for weight added aft of neutral point)

$$R_{new} = R_{old} + \delta R$$
$$R_{new} = 230 - 90$$
$$R_{new} = 140 \text{ tons}$$

Change of KG:

$$GG_1 = \frac{Gg \times w}{W + w}$$

$$GG_1 = \frac{(15-18)\times 200}{3{,}475+200}$$

$$GG_1 = -0.16 \text{ feet}$$

Change in drafts aground:

$$\delta T_m = \frac{\delta B}{TPI} = \frac{200+90}{32.5}$$

$\delta T_m = 8.9$ inches (increase with added weight)

$$\delta T_a = \delta T_m \times \frac{d_a + d_r}{d_r}$$

$$d_a = 204 - 23 = 181 \text{ feet}$$
$$d_r = 154 + 23 = 177 \text{ feet}$$

$\delta T_a = 8.9 \times \frac{181+177}{177} =$ 18 inches (increase)

$$\delta T_f = \delta T_m \times \frac{-d_f}{d_r}$$

$$d_f = 50$$

$\delta T_f = 8.9 \times \frac{-50}{177} =$ 3 inches (decrease)

(Because center of ground reaction is well forward, $\delta T_a \approx 2 \times \delta T_m$, and δT_f is negligible.)

New drafts aground:

$T_a = 16'\ 2'' + 1'\ 6'' = 17'\ 8''$

$T_f = 11'\ 5'' - 3'' = 11'\ 2''$

(not accounting for rise or fall of tide)

EXAMPLE 6-5 (CONTINUED)
PREDICTED CHANGE IN GROUND REACTION AFTER A WEIGHT CHANGE

(2) Removing fuel forward:

Tanks to be emptied: 6-116-1-F, 5-116-2-F, 5-140-1-F, 5-140-2-F

Combined Capacity = 188 tons

lcg = 68 feet forward of midships

kg = 7.4 feet

(Combined capacity and center of gravity calculated from data from the FFG-7 Damage Control Book)

Change in ground reaction:

$$\delta R = w \times \frac{d}{d_{nr}}$$

$$\delta R = -188 \times \frac{(68+76)}{177+53}$$

$$\delta R = -118 \text{ tons}$$
$$R_{new} = R_{old} + \delta R$$
$$R_{new} = 230 - 118$$
$$R_{new} = 112 \text{ tons}$$

Change of KG:

$$GG_1 = \frac{Gg \times w}{W + w}$$

$$GG_1 = \frac{(7.4-18)\times(-188)}{3{,}475+(-188)}$$

$$GG_1 = +0.61 \text{ feet}$$

Change in drafts aground:

$$\delta T_m = \frac{\delta B}{TPI} = \frac{-188+118}{32.5}$$

$\delta T_m = -2.2$ inches (decrease with weight removal)

$$\delta T_a = \delta T_m \times \frac{d_a + d_r}{d_r}$$

$\delta T_a = -2.2 \times \frac{181+177}{177} = -4.4$ (or 4) inches (decrease)

$$\delta T_f = \delta T_m \times \frac{-d_f}{d_r}$$

$\delta T_f = -2.2 \times \frac{-50}{177} = 0.6$ inch (increase)

(Again, $\delta T_a = 2 \times \delta T_m$, and δT_f is negligible because center of ground reaction is well forward.)

New grounded drafts:

$T_a = 16'\ 2'' - 4'' = 15'10''$

$T_f = 11'\ 5'' + .6'' = 11'\ 5.6''$ (probably not observable)

(not accounting for rise or fall of tide)

6-4 THE EFFECTS OF THE SEAFLOOR.

Ships strand on rock, coral, hardpan, sand, mud, and various combinations of the above. Beaches may be smooth with long gentle slopes or rough with abrupt and rugged contours. The type and nature of the seafloor affect the stranding and the work required to refloat the ship. Effects of the seafloor on salvage operations include:

- Friction
- Suction
- Damage and impalement
- Seafloor movement
- Sinking into the seafloor
- Silting
- Seafloor slope

6-4.1 Friction. One of the most important characteristics of the seafloor is the friction that develops between it and the stranded ship's hull. The amount of friction depends upon a number of factors including:

- The ground reaction
- Seafloor composition
- Seafloor slope and uniformity
- Shape of the ship's underwater body
- Dynamic effects.

CAUTION

The many variables affecting the development of friction can cause results that are as much as 20 percent in error. Prudent salvors will not expect an exact solution and will choose the value that gives the most conservative result.

The amount of pulling force required to free a ship can be estimated by multiplying the ground reaction by a coefficient of friction. Exact figures for coefficients of friction for seafloor and shore soils are not available. Approximate values have been developed by salvors from experience; they are:

Type of Seafloor	Coefficient of Friction
Silty soil or mud	0.2 to 0.3
Sand	0.3 to 0.4
Coral	0.5 to 0.8
Rock	0.8 to 1.5

These factors are applied in the following manner:

CAUTION

While ground reaction is measured in long tons of 2,240 pounds, freeing force — like lifting forces — is measured in short tons of 2,000 pounds. Ground reaction must be multiplied by 1.12 to obtain short tons or by 2,240 to obtain pounds.

$$F = 1.12 \times \mu \times R$$

where:
F = Pulling force required to free the stranded ship in short tons
μ = Coefficient of static friction
R = Ground reaction in long tons

The coefficients of friction given above are static coefficients. When the ship begins to move, a dynamic coefficient of friction applies. The dynamic coefficient of friction is much smaller than the static coefficient. Once a ship has begun to move, it should be kept moving; if it stops, the coefficient of friction returns to the higher value of the static coefficient of friction.

EXAMPLE 6-6
CALCULATION OF FREEING FORCE REQUIRED

A ship is 1,000 tons aground on a coral seafloor. What freeing force is required?

$$F = 1.12 \times \mu \times R$$

The coefficient of friction, (μ), for coral varies between 0.5 and 0.8. To be conservative, the value that will give the greatest freeing force, in this case 0.8, is chosen.

$$F = 1.12 \times 0.8 \times 1{,}000$$
$$F = 896 \text{ short tons}$$
$$F = 896 \times 2{,}000 = 1{,}792{,}000 \text{ pounds}$$

For rigid bodies, friction is independent of the areas in contact. This is not true for ships and soils because soil can behave more like a very dense fluid than a rigid body. Experience indicates that the coefficient of friction may decrease when the pressure on the seafloor is very high. Ships with fine lines forward, stranded on sand or gravel seafloors, may be trimmed hard down by the bow to increase the pressure on the ground. The decrease in coefficient of friction offsets the increase in ground reaction, and the ship may refloat with less effort than expected.

If dynamic conditions can be introduced under the ship, the force to refloat will be reduced. Methods of doing this include:

- Operating the ship's machinery to set up vibrations in the ship's structure (caution must be taken as there may be possible hazards in operating the stranded ship’s machinery while aground. Clogged sea suctions due to seafloor material could impair the safety and operation of ship’s machinery)
- Moving large weights on the stranded ship
- Setting off underwater explosions nearby to induce seafloor movement
- Making retraction attempts when there is a swell running
- Setting up an artificial swell by having high speed ships pass perpendicular to the stranded ship
- Wrenching with tugs or ground tackle.

6-4.2 Suction. Cohesive soils creating a suction will increase the force required to lift the vessel. The amounts of suction and breakout force required vary with the seafloor soil and the amount of time the object has rested on the bottom. The total uplift force always includes the underwater weight of the object plus the weight of any seafloor material being lifted. Time and force are factors to be considered in breaking an object out of the seafloor. An object may be broken free by either a small force applied over a long period of time or a large force applied over a short period.

In either case, the theoretical and empirical breakout forces are difficult to calculate accurately due to the large number of variables and unknowns, and in most calculations are overestimated. The salvor's primary interest in the field lies in taking steps that will reduce the breakout forces. If sufficient upward force is applied to both lift the ship and break the suction quickly, there will be an excess of upward force when the suction breaks, and the ship may rise suddenly and out of control. Steady application of a force slightly greater than that calculated to lift the ship over a period of time usually will overcome the suction forces of cohesive soils and allow the ship to rise under control. Inducing dynamic effects is often referred to as *breaking suction.*

Breaking suction is correct in a stranding only if the ship is stranded on mud or silt; a situation found in harbors and estuaries, but seldom offshore. Mud is a mixture of water and clay; when it is subject to pressure, it breaks down, usually unevenly, along the bottom of the stranded ship. The clay forms layers that restrict the movement of water and prevent the hydrostatic pressure under the ship from changing, in effect, holding the ship to the seafloor. To overcome this suction effect, a hogging line may be dragged under the ship, or a fire hose and nozzle may be used to break up the clay layers, or air may be blown under the ship. Other methods of breaking suction involve different ways of applying the lifting force. They include applying the lifting force to one end of the ship at a time, alternately applying and releasing the lift force and applying a lateral force that acts to rock the ship in place. Suction is more commonly a problem when raising sunken ships and objects and the freeing force is acting vertically.

6-4.3 Damage and Impalement. If the stranded ship's bottom is damaged and offers sharp points or surfaces that reduce smooth sliding, it will greatly increase the effective coefficient of friction. To account for the increase in friction, either 0.5 or half the value of the coefficient of friction, **whichever is larger**, should be added to the tabulated values.

If the ship is impaled on rock or coral heads, or the plating is so badly damaged that it acts as an anchor, the damaged plating must be removed, the ship's structure trimmed so she will pull clear, or the rock or coral head removed. If this is not done, it is usually impossible to generate enough force to free the ship.

6-4.4 Seafloor Movement. Some seafloors — particularly sand — move in response to weather and may build up and recede from the ship. In one common pattern, seafloor material will move into the beach and build up in good weather and move away from the beach in heavy weather. In another independent pattern, sand waves with significant crests and hollows may move up and down the beach and cause buildups and recessions around the ship.

Movement of material into and away from the beach may be detected and gaged by stakes with the heights marked. The height of the sand and the prevailing weather, including the state of the tide, should be observed at the same time every day.

The movement of sand in waves along the beach can be determined by placing stakes at successive crests, marking the height of the crests, and observing the heights and position of the crests relative to the initial position.

If distinct patterns of seafloor movement are noted, they must be taken into account in salvage decisions.

6-4.5 Sinkage into the Seafloor. The weight of the ship resting on the seafloor may exceed the bearing strength of the soil. In these cases, the ship settles into the seafloor until she rests on firmer soil or until the soil compacts and becomes able to support the weight. Sinkage into the seafloor may not be immediate but will continue at a declining rate from the time the ship first comes to rest until equilibrium is reached. When sinkage into the seafloor occurs, the ship will effectively rest in a hole. In cohesive soils, suction will hold the ship in the hole and increase the lift forces required.

Ships sunk with their main deck above water may submerge their main deck as they settle into the seafloor. Salvors should be aware of this possibility, and should determine if sinkage is occurring, and at what rate, by making regular measurements of the freeboard at the same tidal height. To predict the depth of sinkage, core samples of the seafloor should be taken and analyzed by a laboratory with expertise in soil mechanics. Analysis through the Navy Civil Engineering Laboratory or other qualified institution can be arranged if necessary. If it is possible that sinkage will immerse the main deck of the ship, cofferdams may be built to preclude the problems associated with an immersed main deck.

If the ship is to be moved in contact with the seafloor, the ship must first be lifted clear of the hole in which she lies. In cases of critical stability, attempting to lift her clear may result in the ship's being clear of the seafloor and unstable with a high probability of capsizing. If a tidal lift (Chapter 5) is being made, the vertical distance the ship can be raised by tidal lift must be sufficient to raise it out of the hole or the lift must be augmented.

6-4.6 Silting. Silt and mud enter sunken hulls through every possible opening. Silt or mud in the ship is weight that must be either removed or overcome during the refloating. The weight of mud varies with the type of soil, but 100 pounds per cubic foot in water suffices for salvage calculations until a more accurate figure can be obtained by weighing samples of mud from the ship. Whenever there is a possibility that mud has entered the hull, the worst possible assumptions of the quantity and its location should be made.

Often it is necessary to remove silt and mud to lighten the ship and to make her behavior more predictable. Major sources of silt flowing into the ship should be blocked before removal is started. If the inflow is not stopped or greatly reduced, silt may enter the ship faster than it can be removed, and the removal work will be unprofitable. Air lifts are generally the fastest and most practical way of removing silt. Silt may also be removed with water jets, jet pumps, and by lifting it out with clamshell buckets.

6-4.7 Seafloor Slope. Often, sunken ships are not refloated in a single step, but are made lighter and moved into shallower water in several steps. The ship may be intentionally kept in contact with the seafloor while it is moved to minimize the possibility of its capsizing. The slope of the seafloor under the ship between planned successive positions of relocation is very important if this method is to be used, as it determines the distance a ship may be moved with a specific amount of lift. A thorough hydrographic survey of the route to shallow water must be made to ensure the ship can be moved along the planned route and that there are no underwater obstructions that may either impede progress or further damage the ship. As a minimum, the hydrographic survey should consist of fine-grained fathometer readings supplemented by a side-scan sonar survey or wire drag along the planned route. Particular attention should be paid to areas in which the ship will be set down to prepare her for subsequent moves. If the ship must be raised clear of a hole or lifted over an obstruction, it may not be feasible to move her while maintaining contact with the seafloor.

6-5 THE EFFECTS OF THE SEA.

There are five effects of the sea that are quite important in strandings: the tide, tidal currents, swells, the scour of the surf and hydrostatic pressure. Their effects are quite different and generally independent of one another.

6-5.1 Tides. Tides are important in harbor clearance for two reasons:

- They increase the depth of water possibly covering the deck and causing downflooding through hatches, doors and other openings, and increase the hydrostatic pressure on the ship.
- They increase the buoyancy in the ship and availability to tidal lifting devices. When making tidal lifts with pontoons or lift craft, the height of the available lift is directly related to the height of the tide.

Tides should be observed and a tide gage and records maintained. Salvors should be particularly aware of how tides at the salvage site vary from predicted values. Patches, cofferdams, and other items affected by either hydrostatic pressure or water depth should be designed for the highest tide likely during the salvage operation. A generous margin should be allowed.

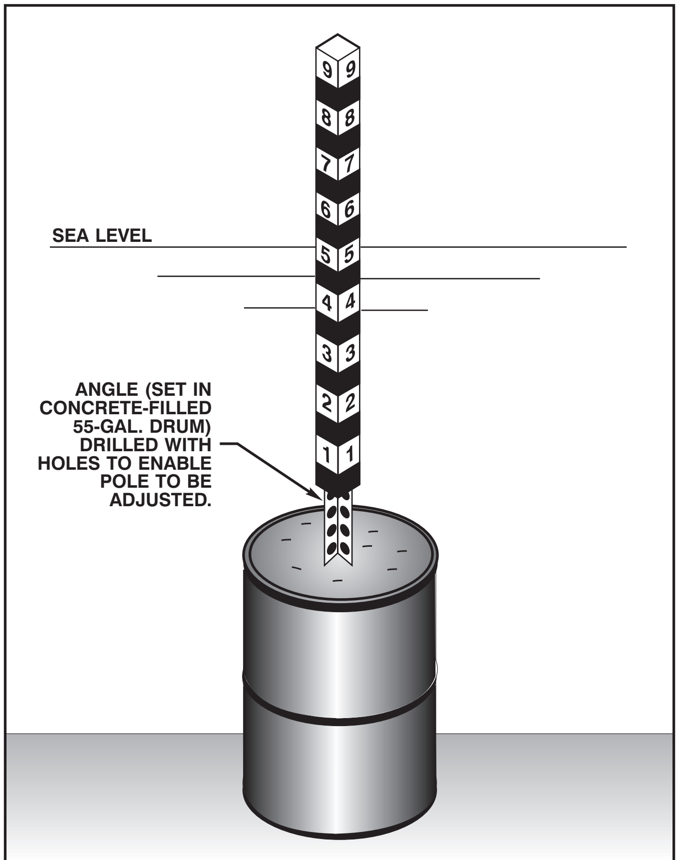


Figure 6-5. Typical Salvors' Tide Gage.

The range of the tide varies considerably throughout the world from more than 40 feet in some places to only a few inches in others. Some places may have two tides a day; some only one. Where there are two tides, one is usually much higher than the other. The tide may stand at high water for two hours or for no more than twenty minutes. All these things must be considered in strandings. By understanding the local behavior of the tide, and how it influences a stranding, salvors can take action to reduce the unfavorable effects and to use the tide as a tool.

6-5.1.1 <u>Effect of the Tide on Ground Reaction</u>. The waterline of a stranded ship rises and falls with the tide. When the tide is highest, the buoyancy of the ship is greatest, and the ground reaction is decreased by the amount of buoyancy gained. Conversely, when the tide falls, buoyancy decreases and the ground reaction increases.

If the tide range is great, and if the ship stranded at or near low water, she may refloat on the rising tide, or she may become so light upon the ground that she is no longer secure against being driven farther ashore or broached. The buoyancy gained from the tide may greatly reduce the force required to refloat the ship. If the ship stranded at or near high water where the tide range is great, the loss of buoyancy at low water may cause the ship to become unstable or sit hard enough that the bottom of the ship is crushed or penetrated by rocks.

When the ship is supported along most of its length so that it cannot trim, the change in ground reaction caused by the tide may be calculated by multiplying the change in height of the tide by the tons per inch immersion. When the ship can trim with the tide, the change in ground reaction may be calculated by:

$$\delta R = \frac{-t \times TPI \times MT1 \times L}{\left(TPI \times d^2\right) + \left(MT1 \times L\right)}$$

where:

δR = Ground reaction changes because of tide change
t = Tide change in inches
d = Distance between the center of pressure of the ground reaction and the center of flotation

Where the tide range is moderate, the effects will not be as great. Tidal effects must always be considered so that the ship is properly secured and advantage is taken of the tide during refloating operations.

In an area with a very small tide range, it may be difficult to remove enough weight from the ship to reduce the ground reaction sufficiently for refloating. In these cases portions of the ship's structure may have to be removed, or the ground removed from under the ship by scouring or dredging.

EXAMPLE 6-7
CALCULATION OF GROUND REACTION CHANGE WITH TIDE

An FFG-7 Class ship stranded at one foot below high water with the center of pressure of the ground reaction 75 feet from the forward perpendicular. The ground reaction at grounding is 500 tons; the tide range is four feet. The ship's TPI is 32.5 tons; her MT1 is 783 foot-tons. What is the ground reaction at high tide? At low tide?

$$\delta R = \frac{-t \times TPI \times MT1 \times L}{\left(TPI \times d^2\right) + \left(MT1 \times L\right)}$$

High Tide. At high tide, the ground reaction will be less than when the ship strands. As the tide will rise one foot:

$$t = 12$$

Assuming the center of flotation is 23 feet abaft midships or 227 feet abaft the forward perpendicular:

$$d = 227 - 75 = 152 \text{ feet}$$

and

$$\delta R = \frac{-t \times TPI \times MT1 \times L}{\left(TPI \times d^2\right) + \left(MT1 \times L\right)} = \frac{-(12 \times 32.5 \times 783 \times 408)}{\left(32.5 \times 152^2\right) + (783 \times 408)}$$

$$\delta R = \frac{-124{,}590{,}960}{1{,}070{,}344} = -116.4 \text{ (or 116) tons}$$

$$R_{ht} = 500 - 116 = 384 \text{ tons}$$

Low Tide. At low tide, the ground reaction will be greater than when the ship stranded. As the tide will fall three feet:

$$t = 36$$

$$\delta R = \frac{t \times TPI \times MT1 \times L}{\left(TPI \times d^2\right) + \left(MT1 \times L\right)} = \frac{(36 \times 32.5 \times 783 \times 408)}{\left(32.5 \times 152^2\right) + (783 \times 408)}$$

$$\delta R = 349.2 \text{ (or 349) tons}$$

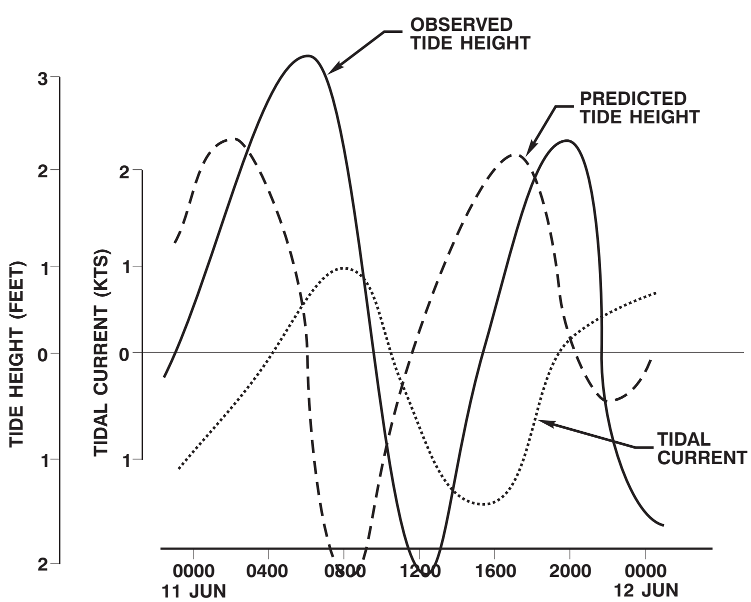
$$R_{ht} = 500 + 349 = 849 \text{ tons}$$

6-5.1.2 <u>Determination of Tides</u>. Because of their typically dominant effects on the stranding, local tidal conditions must always be determined. Information in tide tables are predictions and may not be precisely accurate at a stranding site where local conditions affect the tide. In addition, tide tables are based on data for primary and secondary stations that are often remote from the stranding site. To ensure the best possible information, salvors should determine the tidal conditions that actually occur at the stranding site by setting up a tide gage.

Figure 6-5 shows a satisfactory tide gage for salvage work. It is simply a piece of lumber, 2×6 inches or larger, longer than the estimated tide range, painted in bands of very visible and strongly contrasting colors, and bolted to a piece of angle. The angle in turn is set in a concrete-filled 55-gallon drum. The required length of the tide gage can be estimated from tide range predictions in the tide tables, observation of the high and low water marks on the shore, and local information. In setting up a tide gage, three things are important:

- The gage must be firmly planted and braced so that it remains upright and in place in the surf, tidal surge, and disturbances of the salvage operations.
- The gage must be located in a position where it will not be in the way of the salvage operations, including maneuvering ships, small boat operations, and ground tackle.
- The gage must be readable by both day and night from the bridge of the stranded ship.

With the tide gage in place, observations should be made and compared with other tidal information, such as tide table predictions, by keeping a comparative plot of observations and predictions as shown in Figure 6-6.



TIME	HEIGHT (FT)		CURRENT (KTS)
	OBS	PRED	
0000	0	1.2	-1.1
0400	2.6	2.0	0
0800	1.9	-2.1	+0.9
1200	-2.1	.2	-.06
1600	0.4	1.8	-1.4
2000	2.2	.2	+0.2
0000	-1.8	0	+.06

Figure 6-6. Typical Tide Plot.

6-5.1.3 The Effect of Weather on Tides. Weather disturbances cause changes in normal tidal patterns. Sustained winds can cause tides to be higher or lower than normal depending upon the relative direction of the wind and tide. Onshore winds cause higher tides; offshore winds cause lower tides. In areas with relatively small tidal ranges, the marine weather conditions may cause a more significant rise in water level than the astronomical tides. This is also the case in navigable rivers, where runoff from spring melt or heavy rains will increase the water level in the river more rapidly and more significantly than the tides. Low pressure areas associated with storms cause a rise in the sea level known as a storm surge. A storm surge combined with the tidal rise may produce a large rise. If the ship is protected from the direct force of heavy seas, a storm surge may assist in refloating a heavily stranded ship by providing additional buoyancy.

6-5.2 Tidal Currents. The ebb and flow of the tide can produce currents that may change the stranded ship's head, drive it ashore, limit diving operations, complicate ship and boat operations close to the stranded ship, and delay or otherwise disrupt salvage operations.

The relation of tidal current to tide rise varies from place to place. The time of slack water generally does not coincide with the time of maximum or minimum tide, and the time of maximum current does not correspond with the most rapid change in the height of the tide.

Tidal currents often vary from predicted values at or near tide stations and are frequently quite different at more distant locations. When tidal currents are important to operations, salvors should determine the local tidal current conditions along with the height of the tide. In the absence of other methods, measurements may be made by timing the passage of a chip along a known distance. Tidal current velocities should be plotted and compared with tide heights to determine the relationship between tidal current and height.

Once the local tidal current conditions have been established, operations that are restricted by strong currents can be planned for periods of slack water or weaker currents. In extreme conditions, it may be necessary to build tidal current deflectors.

6-5.3 Swells. Swell has three principal effects on the salvage of sunken ships. The first effect is to increase depth and hydrostatic pressure during the passage of the swell. Concurrently, buoyancy increases. If the ship is somewhat buoyant, she may walk with the swell and move farther inshore. Patches, cofferdams, and other items affected by either hydrostatic pressure or water depth should be designed for the highest swell likely during the salvage operation. A generous margin should be allowed, especially if the area is exposed to storm-generated swells. If the ship is resting lightly on the bottom and subject to being forced farther ashore by the swell, she should be weighted down and secured until preparations for raising are complete. Seafloor suction probably will not develop in a ship buoyant enough to be moved by swell. Weighting the ship down to stabilize its position may result in the development of suction and an increase in the force and time required to break the ship out of the seafloor.

The second major effect of swell on sunken ships is to cause flexure or panting of the shell, when the interior of the ship is not flooded or the liquid in the ship is still and the pressure on the outside constantly varies with the passing swell. Repeated flexure can cause low-cycle fatigue cracking in the plating with eventual total failure. If panting is severe, failure is likely. If the interior of the structure is accessible, temporary stiffeners can often be installed between permanent structural members to reduce panting.

The third major effect of swell is to impart motion to ships and craft working alongside the sunken ship. The motions create a safety problem for personnel and make materials handling both difficult and dangerous. When floating cranes are used to lift the wreck, the swell may cause dynamic loading that exceeds the capacity of the cranes. The sea motions caused by swell and the accompanying surge can limit the ability of divers to work around the sunken ship.

Storm-generated ocean waves become swells as they approach the coastline. When the water deepens quickly, as it does in much of the Pacific and many other places, the swells become very large. As the swell passes the stranded ship, there is a horizontal impact, and, in the region of the crest, buoyancy is temporarily increased and ground reaction reduced. This results in a change in the distribution of the ground reaction, and in the location of the center of pressure that serves to break up the static condition under the ship and makes it easier to move. This breakup of static conditions is useful when the ship is being refloated, but it is dangerous at other times as it may allow the ship to be driven farther ashore or broached.

If the swells are frequent and large, the combination of impact and increased buoyancy act to move the ship farther ashore and cause a moment that rotates the ship until it is broached or lies broadside to the beach. There may also be structural damage to the ship from the swells breaking against it. Swells can break up a grounded ship in days or, in extreme conditions, in hours.

Broaching creates a serious situation on any type of seafloor. On rock, a broached ship will bear hardest on the rock under its inshore bilge. The swell impacting against the offshore bilge pushes the ship farther onto the rock and causes it to roll and grind heavily on the rock. On sand or gravel, scouring occurs. Scouring is discussed in Paragraph 6-5.4. A ship that is stranded at one end, with the other end floating, may pound heavily on the seafloor in the swell. Severe bottom damage, including impalement on rocks, is possible.

CAUTION

When taking on ballast or flooding the hull, care must be taken to prevent spilling polluting materials and to avoid setting up a situation that could result in pollution when the flood water is removed.

If a stranded ship is lively in the swell, it is in a very dangerous condition that will deteriorate unless immediate action is taken. When the ship is lightly aground and resources are at hand, an attempt should be made to refloat the ship. If ground reaction calculations show that immediate refloating is impossible, action must be taken to keep the ship from moving inshore and rotating. Appropriate action consists of holding the ship with tugs or ground tackle, weighing the ship down by taking on ballast, or by deliberately flooding spaces that will increase the ground reaction by any means that are available, including opening the hull or bottom.

6-5.4 **Scouring.** If the seafloor is subject to scouring and a large tidal or normal current is present, the disruption of normal current patterns will result in scouring of the seafloor under the ship. As scouring continues, there are two possible adverse effects:

- The ship may gradually sink deeper into the seafloor. If she sinks far enough, the main deck may be submerged and the salvage operation complicated.

- Portions of the ship may no longer be supported by the seafloor; stress can develop that can break the ship. When the ship breaks, new scour patterns will be established that may cause parts of the ship to sink deeper or, in extreme cases, to break again.

With the exception of the time-consuming and costly task of building barriers to deflect current, there is little salvors can do to prevent scouring. They should be aware of the possibility and alert to its occurrence. In conditions where scouring is likely and diving is possible, regular underwater inspections should be made of the seafloor and the way the ship is supported. Video is useful for these inspections because videotapes from sequential inspections can be compared to establish the rate of scour.

When diving is not possible, salvors should be alert to signs of scouring, such as decreases in freeboard or changes in attitude at the same tide conditions. Increased deflection of the hull indicates increased stresses that precede breaking. Deflection can be measured by establishing a leveled line on as long a base length as possible and measuring the distance from the line to the deck, or by measuring the amount the line varies from the level on successive readings. The noises a ship makes as it works is a rough indicator of changes in stress level. An increase in the magnitude and frequency of the creaks and groans from a ship's structure is an indication of increased stresses and can roughly indicate the rate at which stresses are growing.

Scouring occurs when the sand and gravel under the hull are washed away by the action of the surf. The situation is particularly dangerous when a stranded ship broaches. Currents produced by swells breaking against the ship sweep around the ends with great velocity. These currents carry seafloor materials away from under the ends of the ship and build them up in a sand spit amidships on the inboard side. As the material is cut away from under the ends of the ship, an extreme hogging condition results that will eventually cause failure of the hull. Figures 6-7A and 6-7B show how scour and eventual breakup happens when a ship is broached on sand or gravel. Every effort should be made to swing a broached ship around so that it lies at right angles to the beach.

Even ships perpendicular to the beach are not secure from scouring. If there are currents parallel to the beach, material may be swept out from under the end of the ship until stresses become high enough that, in extreme cases, the hull breaks. The danger is greater when there is a large tide range. To a ship lying at right angles to the beach, swells trying to drive it farther ashore or broach it generally present a much greater danger than scouring.

6-5.5 **Hydrostatic Pressure.** A sunken ship is acted upon by hydrostatic pressure above atmospheric pressure that increases with depth. Pressure complicates the salvage of sunken ships and is one of the reasons why deeply sunken ships are seldom salvaged. Pressure varies with depth along the hull. The pressure at the top of the hull will be less than the pressure at the bottom. The pressure above atmospheric at any depth can be calculated by multiplying the sea water depth by 0.445:

$$p_h = 0.445 \times d$$

where:

p_h = hydrostatic pressure in pounds per square inch (psi)
d = water depth in feet.

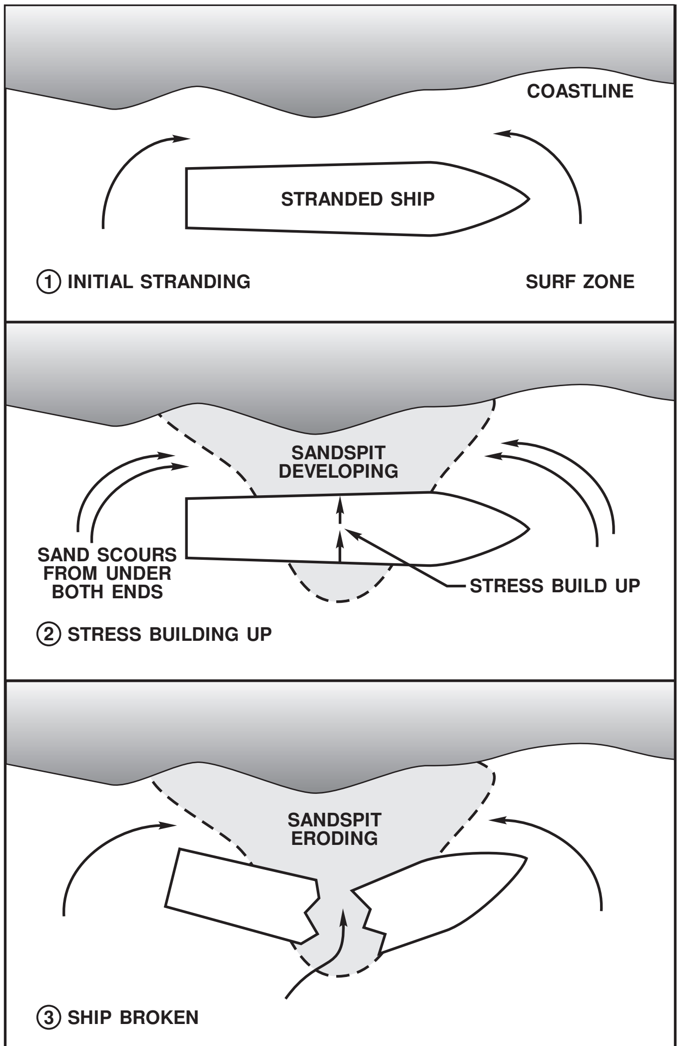


Figure 6-7A. Effects of Broaching. (Typical Scouring-Situation Casualty)

EXAMPLE 6-8
CALCULATION OF HYDROSTATIC PRESSURE

What is the hydrostatic pressure at a depth of 10 feet? At a depth of 25 feet?

$$p_h = 0.445 \times d$$

At 10 feet:

$$p_h = 0.445 \times 10$$
$$p_h = 4.45 \text{ psi}$$

At 25 feet:

$$p_h = 0.445 \times 25$$
$$p_h = 11.13 \text{ psi}$$

One of the principal characteristics of hydrostatic pressure is its effect on the flow of water through an opening. The quantity of water that flows through an opening in the side of a ship or a bulkhead is proportional to the size of the opening and the depth below the waterline.

Figure 6-7B. Ex-USS TORTUGA Stranded on San Miguel Island.

EXAMPLE 6-9
FLOW THROUGH A HOLE

A ship has an opening approximately 2 feet square in the hull 15 feet below the waterline. How many gallons of water will enter the ship per minute?

a. Estimate the depth of the geometric center of the opening below the surface.

$$H = 15 \text{ feet}$$

b. Estimate the area of the hole.

$$A = 2 \times 2$$
$$A = 4 \text{ square feet}$$

c. Determine the flow through a one-square-foot hole.

From Figure 6-8, Q = 14,000 gallons per minute

d. Flow through a four-square-foot hole is:

$$Q = 4 \times 14{,}000$$
$$Q = 56{,}000 \text{ gallons per minute.}$$

e. Using the flow calculation:

$$Q = A \times (2 \times g \times H)^{1/2}$$
$$Q = 4 \times (2 \times 32.2 \times 15)^{1/2}$$
$$Q = 124.3 \text{ cubic feet per second}$$
$$Q = 124.3 \times 60 \text{ seconds per minute} \times 7.48 \text{ gallons/cubic foot}$$
$$Q = 55{,}786 \text{ gallons per minute}$$

Flow may be calculated by:

$$Q = A \times (2 \times g \times H)^{1/2}$$

where:

Q = flow in cubic feet per second
A = area of the hole in square feet
H = depth of the center of the hole below the surface in feet
g = gravity which equals 32.2 feet/second^2

Figure 6-8 gives the flow through a one-square-foot opening at depths to one hundred feet in cubic feet per second, gallons per minute, and tons per hour.

To calculate the flow through any size hole:

a. Estimate the depth of the geometric center of the opening below the surface.

b. Estimate the area of the opening.

c. Enter Figure 6-8 with the depth of the opening below the surface, read across to the curve and down to the appropriate scale to obtain the flow in desired units through a one-square-foot opening.

d. Multiply the value obtained from the curve by the area of the hole to find the total flow.

Alternatively, the equation may be used to calculate the flow directly.

The hydrostatic pressure exerted on a sunken ship must be taken into account throughout the salvage operation. Because a sunken ship is generally filled with water, the pressure acts equally on all surfaces. The pressure on the top of a deck, for instance, is approximately the same as the pressure on the bottom, and there is no load caused by the pressure on the deck. The difficulty occurs when there is a large difference in pressure—or pressure differential—across a bulkhead or deck.

EXAMPLE 6-10
PRESSURE DIFFERENTIAL ON A PATCH

A ship is sunk so that an opening to be patched lies a maximum of 36 feet below the surface; when the ship is afloat, the opening will lie 15 feet below the surface.

- What will the hydrostatic pressure differential across the patch be when the compartment is pumped dry and open to the atmosphere when the ship is on the bottom?
- When the ship is afloat?
- What pressure must the patch be designed to withstand?

a. Hydrostatic pressure with the ship on the bottom:

$$ph = 36 \times 0.445$$
$$ph = 16.02 \text{ psi}$$

b. Hydrostatic pressure, ship afloat:

$$ph = 15 \times 0.445$$
$$ph = 6.675 \text{ psi}$$

c. Design pressure:

Design pressure must be 16.02 psi, the higher of the two values.

There are three common situations in the salvage of sunken ships where large pressure differentials must be taken into account. The first involves patches placed on compartments to be dried out while the ship is on the bottom. Such patches must be designed to withstand the full hydrostatic pressure differential that is applied, not merely the differential acting on the patch when the ship is afloat.

The second common situation occurs when one compartment is pumped dry and the adjacent compartment is flooded. In this case, there is atmospheric pressure in the dry compartment and a pressure differential of 0.445 times the total depth of water in the adjacent compartment. Bulkheads are designed for a pressure differential equivalent to a head of only four to six feet of water greater than the depth of the bulkhead. If the ship is old, has been sunk for a long time, is damaged, or the bulkhead is otherwise in poor condition, it may not be able to carry this load. If the pressure differential is great or the strength of the bulkhead is questionable, the bulkhead can be reinforced by shoring or by building a wooden false bulkhead adjacent to it and placing concrete between the real and false bulkheads.

The third common situation occurs where ships are pumped out while their decks are submerged. In these cases, the top of the deck is exposed to the hydrostatic pressure at the water depth above the deck while there is only atmospheric pressure underneath. The resulting hydrostatic pressure may cause the deck to collapse. Normally, if the main deck is submerged more than six feet, the deck will have to be shored to prevent collapse. Shoring of submerged decks by divers is time-consuming and expensive. If the deck is submerged more than sixteen feet, the amount of shoring and the effort required to place it is generally not justified. It is preferable to raise the ship by a method that does not expose the deck to a hydrostatic pressure differential, or to introduce compressed air to partially compensate for the hydrostatic pressure.

6-6 STABILITY OF STRANDED SHIPS.

The stability of a stranded ship is influenced strongly by how the ship rests on the ground. If a ship is stranded on a fairly flat seafloor, there is little danger of capsizing. On the other hand, a ship stranded on a pinnacle and able to incline freely in one or both directions may be in a dangerous situation. A great tide range with the accompanying large changes in ground reaction will complicate the stability problem. Salvors must be aware of the effects of stranding on stability in order to evaluate each situation individually.

6-6.1 Effect of Ground Reaction. Ground reaction has all the same effects on stability as does the removal of the same number of tons of weight at the keel. There are two effects that may be determined:

- The effective or virtual rise in the height of the center of gravity (G)
- The change in the metacentric height (GM) after grounding.

6-6.1.1 Rise in the Center of Gravity. When a ship is aground, the effective position of the center of gravity may be determined by:

$$KG_1 = \frac{(KG \times W)}{(W - R)}$$

where:

- KG_1 = Effective height of the center of gravity above the keel when the ship is aground
- KG = The original height of the center of gravity above the keel
- W = Weight of the ship
- R = Ground reaction

EXAMPLE 6-11
CALCULATION OF THE EFFECTIVE HEIGHT OF THE CENTER OF GRAVITY AFTER GROUNDING

A ship of 3,510 tons is 500 tons aground. The height of the center of gravity before grounding was 18.9 feet. What is the effective height of the center of gravity after grounding?

$$KG_1 = \frac{(KG \times W)}{(W - R)}$$

$$KG_1 = \frac{(18.9 \times 3{,}510)}{(3{,}510 - 500)}$$

$$KG_1 = 22.04 \text{ feet}$$

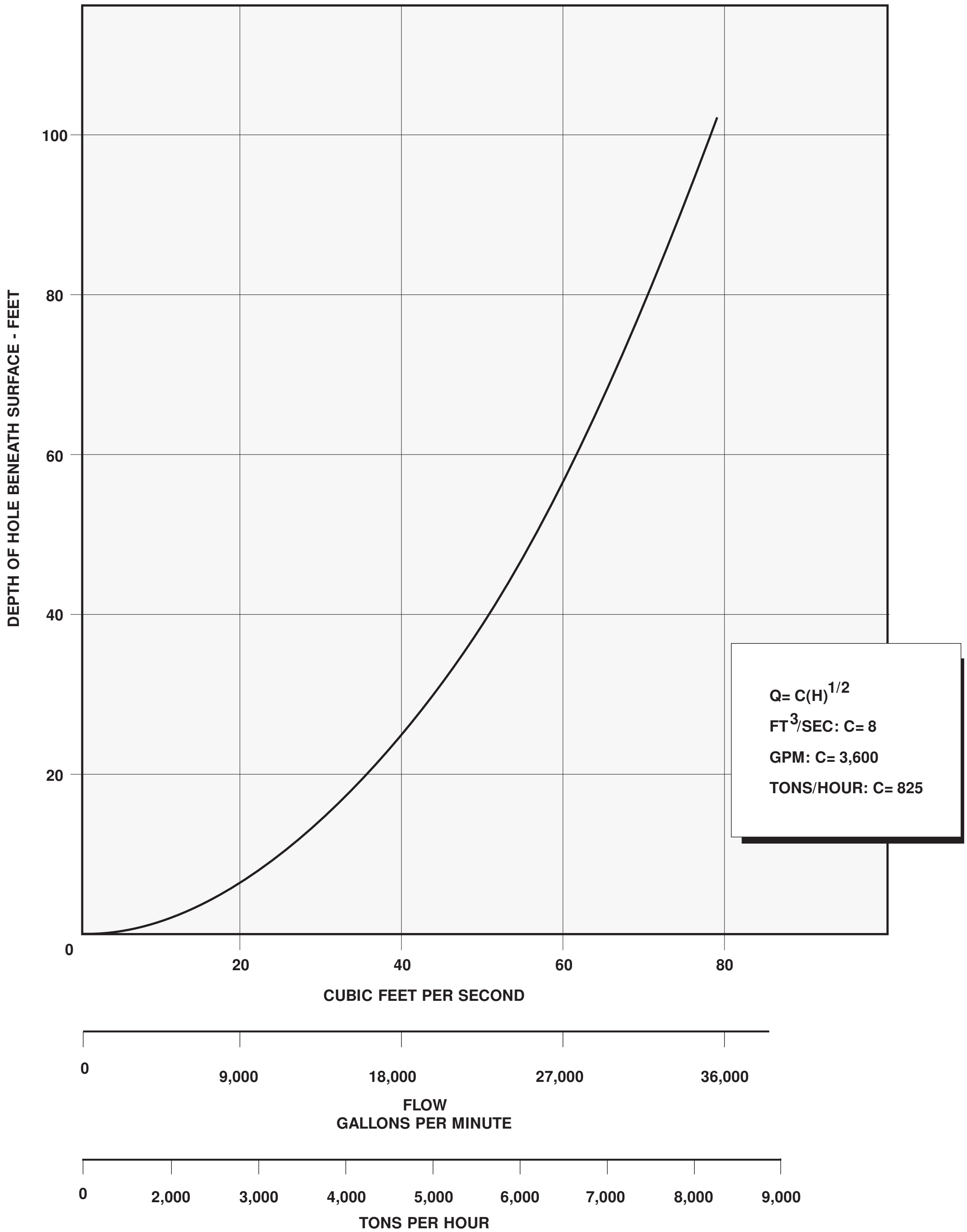


Figure 6-8. Flow Through a One-Square-Foot Hole.

The amount of rise may also be calculated:

$$GG_1 = \frac{(KG \times R)}{(W - R)}$$

where:

GG_1 = The rise in the height of the center of gravity and other symbols are as previously defined

EXAMPLE 6-12
CALCULATION OF METACENTRIC HEIGHT AFTER GROUNDING

In the previous problem, what is the rise of the center of gravity?

$$GG_1 = \frac{(KG \times R)}{(W - R)} = \frac{(18.9 \times 500)}{(3{,}510 - 500)} = \frac{9450}{3010} = 3.14 \text{ feet}$$

To check:

$$KG_1 = KG + GG_1 = 18.9 + 3.14 = 22.04 \text{ as in Example 6-11}$$

The change in position of the center of gravity is a virtual change. The center of gravity does not actually move because weight distribution remains the same. However, the ship behaves as if the center of gravity were at the new location.

6-6.1.2 Change in Metacentric Height. After grounding, the ship's waterline is different than when she is floating free. Because she has a new waterline with a new shape and a new moment of inertia and because the underwater hull volume has changed, there is a new position for the metacenter. The new height of the metacenter above the keel (KM) may be determined from the Curves of Form by entering with the mean draft while aground. The change in the position of the metacenter is the difference between the old and new positions.

EXAMPLE 6-13
CALCULATION OF METACENTRIC HEIGHT AFTER GROUNDING

Following the grounding described in the previous two examples the metacenter is 21.38 feet above the keel (KM = 21.38). What is the new metacentric height?

$$GM = KM - KG$$
$$GM = 21.38 - 22.04$$
$$GM = -0.66 \text{ feet}$$

The metacentric height aground, like the metacentric height afloat, is equal to:

$$GM = KM - KG$$

A stranded ship with a negative metacentric height will often take on a list. The angle of the list will be limited by the restraint of the seafloor, or the ship reaching an angle where it is again stable. If the negative metacentric height is large and the ship is stranded on a pinnacle and free to incline, or if it has fine lines and is aground only at the bow, there is a danger of capsizing.

In cases where there is a large range of tide and the low water waterline is much lower than the high water waterline, the movement of the metacenter will be very significant and large negative metacentric heights will develop.

If a large portion of the ship's bottom is supported by the ground, there is no danger of capsizing. If, however, the ship is on a pinnacle, the danger is much greater and care should be taken in handling weights on board to keep weight and the center of gravity as low in the ship as possible. Additionally, care should be taken to eliminate or not to develop free surface and free communication.

6-6.1.3 Off-Center Grounding. If the ship is grounded along one side or on an off-center pinnacle or ledge, the off-center ground reaction will create an upsetting moment that will cause the ship to list. The ground reaction can be considered an off-center weight removal at point of grounding, and the upsetting moment and list calculated by the means discussed in Chapter 4 for other weight removals and off-center weights.

6-6.2 Effect of the Seafloor. If the seafloor material is somewhat soft, it will assume the shape of the bottom of the ship and assist in preventing capsizing. Harder seafloors will also restrain the ship, though they may not assume the shape of the ship.

6-6.3 Summary of Stranded Stability. It is unlikely a stranded ship will capsize unless the range of stability is severely reduced and there is a large upsetting moment. As the ship inclines, she will reach an angle at which she will overcome friction and slide easily along the seafloor. This angle is generally much less than the range of stability. As a ship approaches the angle at which she will slide, the amount of pull needed to free her becomes quite small. If a pull is made with the ship heeled, the attachment to the hull must be below the center of gravity to prevent creating an upsetting moment that could capsize the ship. Allowing a ship to heel and pulling while it is in this condition are not good salvage practices because of the narrow margin for error during the refloating and the likelihood of an unstable condition on refloating. Salvors should pay particular attention to the state of the tide and tide-caused changes in ground reaction and stability.

6-6.4 Stability During and After Refloating. During refloating, the ground reaction reduces to zero and the stability, draft, and trim return to the afloat condition for the "as refloated" conditions of displacement and weight distribution. If the ship is stable before refloating, it will become more stable during the refloating process and will be stable when afloat. If, however, the ship has a negative metacentric height while aground, she may either:

- Become more stable as the ground reaction is reduced and refloat in a stable condition
- Refloat in an unstable condition.

In the first condition, the ship must be refloated quickly in one pull in order to pass from the unstable to the stable condition as rapidly as possible. Every effort should be made before refloating to eliminate destabilizing conditions, such as free surface and unnecessary high weight in the ship. Ships should not be refloated when they are unstable except in cases of extreme emergency, because there is a high risk of losing the ship or creating a much more difficult salvage situation.

During the salvage operation weight must be controlled in the stranded ship to prevent weight from migrating upward where it reduces stability, or moving to one end of the ship where it creates excessive trim in the refloated ship. Weight control in stranded ships is discussed in Paragraph 6-8. Before refloating, free surface should be minimized and free communication eliminated.

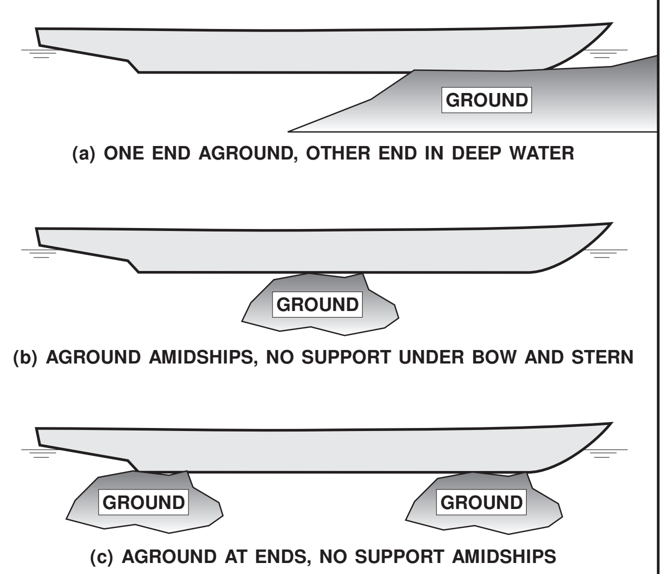


Figure 6-9. Potentially High-Bending-Moment Strandings.

6-7 STRENGTH OF STRANDED SHIPS.

A stranded ship is not supported by buoyancy alone, but by a combination of buoyancy and ground reaction or, in extreme cases, totally by ground reaction. In all cases, the sum of the ground reaction and the buoyancy is exactly equal to the weight of the ship. The load curve is changed because the support is not distributed in the same way as the buoyancy of the ship afloat.

When the load distribution is changed, the shear force and bending moments are changed and may rise to dangerous levels. In an afloat ship, the longitudinal position of the center of gravity and the center of buoyancy is the same. When the ship is aground, the longitudinal position of the center of buoyancy will be changed, and the center of pressure of the ground reaction becomes a factor. If the three centers are not in the same vertical line, the shear force and bending moment curves will become unbalanced and require correction. The calculation of the shear force and bending moment curves for stranded ships is extremely complex and should normally be done by a salvage engineer.

While calculation of the bending moment in stranded ships is left to the salvage engineer, all salvors should be able to recognize situations in which high bending moments may occur. The bending moment of a stranded ship depends very much on the arrangement and weight distribution of the floating ship. A ship with loading that produces high bending moments afloat is likely to develop a dangerously high bending moment when stranded. The following situations are typical of those in which a high bending moment is likely to occur:

A ship grounded with one end on a shelf or beach and the other in deep water (Figure 6-9(a)).

A ship supported by the ground amidships with no support from the ground at the ends (Figure 6-9(b)).

A ship supported by the ground at both ends with no support from the ground amidships (Figure 6-9(c)).

Large amounts of hog and sag are indicators of high bending moments. Hog and sag may be determined by establishing a level line with a transit or simply a leveled length of small stuff and measuring the distance between the line and the deck. A record and plot should be kept of the hog and sag, the time, and the state of the tide when it is measured.

BEGINNING:
DISPLACEMENT ____________ TONS (W)
KG ____________ FEET
LCG ____________ FEET FROM ________
CG (OFF CENTER) ____________ FEET TO ____________

	WEIGHT TONS	KG	VERTICAL MOMENT	LCG	LONG MOMENT	OFF CENTER	TRANSVERSE MOMENT
TOTAL		X		X		X	

NEW DISPLACEMENT = DISPLACEMENT + TOTAL WEIGHT=

NEW KG = [(WxKG) + VERT MOM] / NEW DISPLACEMENT =

NEW OFF CENTER POSITION OF G = [(WxGOC) + TRANS MOM] / NEW DISPLACEMENT

NEW LCG = [(WxLCG) + LONG MOM] / NEW DISPLACEMENT =

Figure 6-10. Weight Control Log.

Stress in the hull is the bending moment divided by the section modulus. Once the section modulus of the ship has been calculated, it is necessary to calculate only the changes in bending moment and divide by the fixed value of the section modulus to obtain the bending stress.

NOTE

If the ship is intact, the full section modulus may be used in calculating bending stress. If the ship's structure is damaged, the damage must be taken into account by omitting damaged structural components. Often damaged structural members will retain a portion of their strength. The strength remaining in damaged structure is best estimated by a salvage engineer. If a salvage engineer is not available to quantify the estimate, all damaged structure should be deleted in the strength analysis.

6-8 WEIGHT CONTROL IN STRANDED SHIPS.

Removal of weight from a stranded ship may make an important contribution to its refloating. Weight is often added temporarily to hold the ship in position until ready for refloating, and weight is brought aboard in the form of salvage equipment and material. Also, weight may be distributed in the ship to obtain a particular trim. The use of weight as a tool in refloating operations is discussed in Chapter 8: Ground Reaction Reduction and Pulling Systems. The weight aboard a stranded ship must be controlled carefully to ensure the desired effect is obtained and the center of gravity does not move upward, off the centerline, or fore and aft. If the position of the center of gravity is not controlled, the ship may be unstable when it refloats, or it may refloat with a dangerous list or trim. To control the weight, the following steps are taken:

a. All weight taken aboard, removed, or relocated on the ship is noted and logged in the Weight Control Log. Figure 6-10 is a typical Weight Control Log page.

b. The location of the weight above the keel, off the centerline, and fore and aft is noted and logged in the Weight Control Log.

c. The moments of the weight above the keel, off the centerline, and fore and aft are calculated.

d. The new position of the center of gravity and its effect on list, trim, and stability is calculated using the methods given in Chapter 4, Stability and Weight.

When the effect of weight changes on the list, trim, and stability of the stranded ship are known, an evaluation can be made and plans made to accept the existing situation or to take corrective action.

6-9 STRANDING CALCULATIONS SUMMARY.

The calculations described in this chapter provide information critical to the development of a salvage plan. Proposals for specific actions are adopted or discarded based on the predicted effects they will have on ground reaction, floating drafts, and stability aground and afloat. Similar calculations are, therefore, often repeated for a number of different actions, as part of the "what if" process. The condition of a stranded ship at any time is the result of the cumulative effects of salvors' actions and environmental forces. Salvage calculations must account for all these effects to provide an accurate picture of the ship's condition. Example 6-14 illustrates the repetitive and cumulative nature of salvage calculations.

EXAMPLE 6-14
COMPREHENSIVE STRANDING CALCULATION

An FFG-7 Class ship is stranded as described in Example 6-5. The following quantities are known or have been calculated:

Drafts before stranding = 14' 6" forward and aft

Drafts after stranding = 11' 5" forward, 16' 2" aft

$$TPI = 32.5$$

$$MT1 = 750$$

$$KG = 18 \text{ feet}$$

Center of flotation = 23 feet abaft midships

Center of pressure of ground reaction = 50 feet abaft the forward perpendicular = 154 feet forward of midships

$$dr = 154 + 23 = 177 \text{ feet}$$

Neutral loading point = 53 feet abaft the center of flotation = 76 feet abaft midships

Displacement before stranding = 3,475 tons

R is estimated at 230 tons (228 by change in draft forward, 242 by in trim method)

$KM_{aground}$ (from Curves of Form for 3,245 tons) = 22.47 feet

Virtual rise in center of gravity due to ground reaction = 1.28 feet

$$\frac{KG \times R}{W-R} = \frac{18 \times 230}{3475 - 230} = 1.28'$$

Salvors have calculated that flooding compartment 5-368-01-E will reduce ground reaction by 90 tons, while offloading 188 tons of diesel fuel from tanks 5-116-1-F, 5-116-2-F, 5-140-1-F, and 5-140-2-F will reduce ground reaction by 118 tons.

a. Calculate the effects of each of these actions on stability while aground.

(1) Flooding aft:

Compartment to be flooded: 5-368-01-E

Capacity, seawater = 200 tons (from flooding-effect diagram)

lcg = 180 feet aft of midships (estimated flooding arrangement plans)

kg = 15 feet (estimated from profile)

length and breadth = 47 feet long by 33 feet average width (from arrangement)

EXAMPLE 6-14 (CONTINUED)
COMPREHENSIVE STRANDING CALCULATION

Movement of G:

$$GG_1 = \frac{Gg \times w}{W + w}$$
$$GG_1 = \frac{(15-18) \times 200}{3,475 + 200}$$
$$GG_1 = -0.16 \text{ feet (lowering)}$$
$$KG_1 = 18 - 0.16 = 17.84 \text{ feet}$$

Virtual rise of G due to ground reaction:

The virtual rise of G due to ground reaction is reduced because R is reduced and W is increased:

$$GG_1 = \frac{(KG \times R)}{W - R}$$
$$R = 230 - 90 = 140 \text{ tons}$$
$$GG_1 = \frac{(17.84 \times 140)}{(3,675 - 140)}$$
$$GG_1 = 0.71 \text{ feet}$$

Virtual rise of G due to transient free surface while flooding compartment.

$$GG_1 = \frac{i}{V}$$
$$i = \frac{b^3 \times l}{12} = \frac{33^3 \times 47}{12} = 140,753$$
$$V = (3,475 - 230) \times 35 = 113,575$$
$$GG_1 = \frac{140,753}{113,575}$$
$$GG_1 = 1.24 \text{ feet}$$

Effective KG:

$$KG_{eff} = KG_1 + GG_{1Ground\,Reaction} + GG_{1Free\,Surface}$$
$$KG_{eff} = 17.84 + 0.71 + 1.24$$
$$KG_{eff} = 19.79 \text{ feet}$$

Effective GM:

$$GM_{eff} = KM_{aground} - KG_{eff}$$
$$GM_{eff} = 22.47 - 19.79$$
$$GM_{eff} = 2.68 \text{ feet}$$

(2) Removing fuel forward:

Tanks to be emptied: 5-116-1-F, 5-116-2-F, 5-140-1-F, 5-140-2-F

CONTINUED

EXAMPLE 6-14 (CONTINUED)
COMPREHENSIVE STRANDING CALCULATION

Combined capacity = 188 tons (diesel fuel)

Combined lcg = 68 feet forward of midships

Combined kg = 7.4 feet

length and breadth
5-140 tanks = 24 feet long by 19 feet average width
5-116 tanks = 24 feet long by 13 feet average width
(from effect diagram)

(Combined capacities and center of gravity calculated from taken from the FFG-7 Class Damage Control.)

Movement of G:

$$GG_1 = \frac{Gg \times w}{W + w}$$
$$GG_1 = \frac{(7.4 - 18) \times (-188)}{3,475 + (-188)}$$
$$GG_1 = 0.61 \text{ feet (rise)}$$
$$KG_1 = 18 + 0.61 = 18.61 \text{ feet}$$

Virtual rise of G due to ground reaction:

The virtual rise of G due to ground reaction is reduced because R is reduced:

$$GG_1 = \frac{(KG \times R)}{W - R}$$
$$R = 230 - 118 = 112 \text{ tons}$$
$$GG_1 = \frac{(18.61 \times 112)}{(3,287 - 112)}$$
$$GG_1 = 0.66 \text{ feet}$$

Virtual rise of G due to transient free surface while emptying tanks:

$$GG_1 = \frac{i}{V}$$
$$i = \frac{b^3 \times l}{12}$$
$$i_{\text{(for each 5-140 tank)}} = \frac{19^3 \times 24}{12} = 13,718$$
$$i_{\text{(for each 5-116 tank)}} = \frac{13^3 \times 24}{12} = 4,394$$
$$V = (3,475 - 230) \times 35 = 113,575$$
$$GG_{1\max} = \frac{13,718}{113,575} = 0.12 \text{ feet (tanks emptied one at a time)}$$
$$GG_{1\max} = \frac{2 \times 13,718}{113,575} = 0.24 \text{ feet (tanks emptied in pairs)}$$
$$GG_{1\max} = \frac{(2 \times 13,718) + (2 \times 4,394)}{113,575}$$
$$GG_{1\max} = 0.32 \text{ feet (all 4 tanks emptied simultaneously)}$$

CONTINUED ON NEXT PAGE

EXAMPLE 6-14 (CONTINUED)
COMPREHENSIVE STRANDING CALCULATION

Effective KG:

$$KG_{eff} = KG_1 + GG_{1Ground\ Reaction} + GG_{1Free\ Surface}$$
$$KG_{eff} = 18.61 + 0.66 + 0.32$$
$$KG_{eff} = 19.59 \text{ feet}$$

Effective GM:

$$GM_{eff} = KM_{aground} - KG_{eff}$$
$$GM_{eff} = 22.47 - 19.59$$
$$GM_{eff} = 2.88 \text{ feet}$$

b. Based on the above calculations, the ship will retain adequate stability for either course of action (flooding aft or defueling forward). Salvors elect to reduce ground reaction by emptying the four fuel tanks and attempt a retraction on a high tide that will rise 6 inches above tide level at the time of stranding. Calculate ground reaction and freeing force at high tide, with the fuel tanks emptied. Assume the ship is grounded on rock with a coefficient of friction (μ) of 1.1.

Reduction in Ground Reaction due to rise of tide:

$$\delta R = \frac{-t \times TPI \times MT1 \times L}{(TPI \times d^2) + (MT1 \times L)}$$
$$\text{tide} = 6 \text{ inches}$$
$$d = 177 \text{ feet}$$
$$\delta R = \frac{(6 \times 32.5 \times 750 \times 408)}{(32.5 \times 177^2) + (750 \times 408)}$$
$$\delta R = \frac{59{,}670{,}000}{1{,}324{,}192.5}$$
$$\delta R = 45.1 \text{ (or 45) tons}$$

Ground Reaction at high tide with fuel tanks empty:

$$R_{high\ tide} = R - \delta R_{tide} - \delta R_{defueling}$$
$$R_{high\ tide} = 230 - 45 - 118$$
$$R_{high\ tide} = 67 \text{ long tons}$$

Retracting force:

$$F = 1.12 \times \mu \times R$$
$$F = 1.12 \times 1.1 \times 67$$
$$F = 82.5 \text{ short tons}$$
$$F = 82.5 \times 2{,}000 = 165{,}000 \text{ pounds}$$

Assuming that this retracting force is within the capacity of the salvage forces on scene, the ship can be refloated on the high tide. If the available assets could not generate more than 165,000 pounds of pull, it would be necessary to further reduce ground reaction before pulling.

CONTINUED

EXAMPLE 6-14 (CONTINUED)
COMPREHENSIVE STRANDING CALCULATION

c. Calculate the forward and after drafts and GM after re-floating. Assume the fuel tanks are completely emptied with no free surface.

Change in floating drafts:

$$\delta T_m \text{ due to parallel rise } = \frac{w}{TPI}$$
$$\delta T_m = \frac{-188}{32.5}$$
$$\delta T_m = -5.8 \text{ inches (or 6 inches)(decrease)}$$

$$\text{Trimming moment} = w \times \text{trim lever (to } LCF)$$
$$\text{Trimming moment} = -188 \times (68 + 23)$$
$$\text{Trimming moment} = -17{,}108 \text{ foot-tons}$$

$$\delta t = \frac{\text{Trimming moment}}{MT1}$$
$$\delta t = \frac{17{,}108}{750}$$
$$\delta t = 23 \text{ inches by the stern}$$

$$\delta T_a = \text{Change due to parallel rise + change due to trim}$$
$$\delta T_a = -6 - \left(\delta t \times \frac{LCF \text{ to } AP}{L}\right)$$
$$\delta T_a = -6 - \left(-23 \times \frac{204 - 23}{408}\right)$$
$$\delta T_a = 4.2 \text{ inches (or 4 inches)(increase)}$$

$$\delta T_f = \text{Change due to parallel rise - change due to trim}$$
$$\delta T_f = -6 + \left(\delta t \times \frac{LCF \text{ to } FP}{L}\right)$$
$$\delta T_f = -6 + \left(-23 \times \frac{204 + 23}{408}\right)$$
$$\delta T_f = -18.8 \text{ inches (or -19 inches)}$$

New floating drafts:

$$T_a = 14 \text{ feet 6 inches + 4 inches}$$
$$T_a = 14 \text{ feet 10 inches}$$
$$T_f = 14 \text{ feet 6 inches - 19 inches}$$
$$T_f = 12 \text{ feet 11 inches}$$

GM afloat:

$$KM_{afloat} = 22.5 \text{ feet (for } W = 3287 \text{ tons)}$$
$$KG = 18.61 \text{ feet (calculated in part a. of this example)}$$
$$GM = KM - KG$$
$$GM = 22.5 - 18.61$$
$$GM = 3.89 \text{ feet}$$

CHAPTER 7
CAPSIZED SHIPS

7-1 INTRODUCTION.

As often as not, ships will capsize as they sink, and come to rest at a severe angle. Ships sunk in this condition present a more complex problem than those sunk upright. An entirely new dimension is added to the salvage operation because the vessel is usually righted before refloating. Ships are righted by developing a moment of force to overcome the moment of weight that holds the ship in her capsized position. There are basically only four methods of handling a capsized ship:

- Refloating the ship on its side and moving it to another location
- Rotating the ship until it is completely upside down and refloating the upside-down ship
- Righting the ship in place, then refloating it. (Simple in principle, the righting of capsized ships is a complex engineering task requiring careful and detailed analysis.)
- Wrecking in place or otherwise disposing of it *in situ*.

This chapter discusses the first three alternatives. Chapter 13 deals with disposal of ships by wrecking in place.

7-2 THE CAPSIZED SHIP.

Ships seldom capsize and sink in ways favorable to salvors, rarely allowing a convenient and comparatively straightforward righting operation. Taken overall, few ships capsize facing outward from wharves or piers as shown in Figure 7-1. Statistically, it is as probable that a ship may capsize:

- Effectively blocking an entrance channel or canal
- In the middle of a wide river or navigable waterway where she is a traffic hazard
- In comparatively deep water, but where she is still a dangerous obstruction to traffic
- In the middle of a harbor or bay some distance from the nearest shoreline or harbor installation.

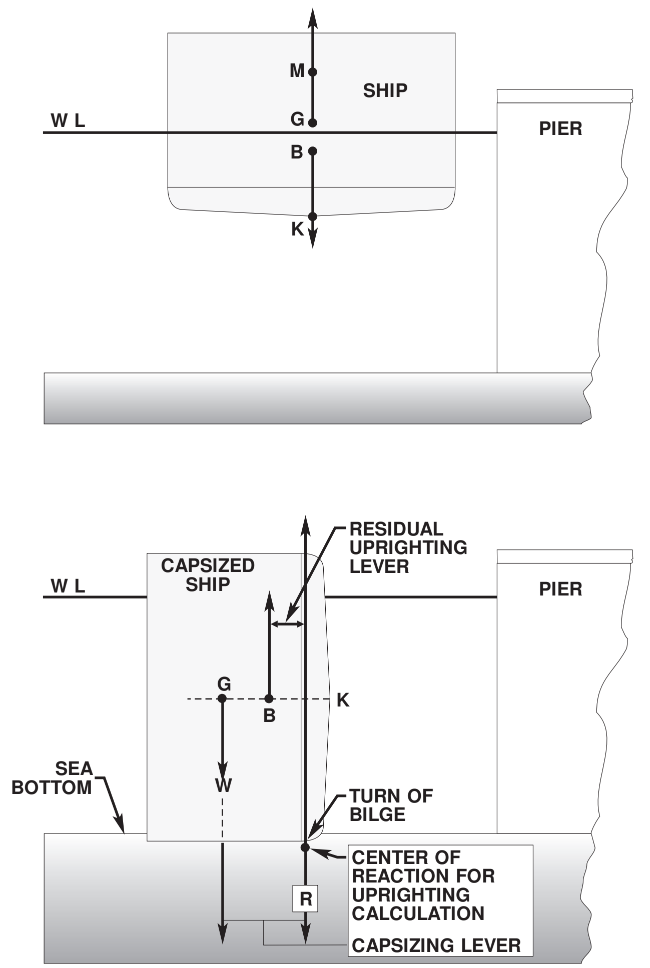


Figure 7-1. Measurement Points on Capsized Ship.

The ship that capsizes and sinks effectively blocking a channel or canal creates a difficult situation because working methods often are reversed. Normally, salvors right a sunken ship before trying to refloat her. A capsized ship that blocks or seriously obstructs an important channel or canal is treated differently. As an obstruction to maritime operations, such a wreck must be moved quickly. Sometimes the most effective method of moving the ship is to refloat it on its side, then haul or tow her away from the waterway. If the ship cannot be refloated completely, it may be practical to lighten or lift one end at a time, slewing or hauling the ship sideways to clear the channel. Under these circumstances, salvors have altered sunken ships' situations to their advantage by:

- Moving the ship, refloated on its side, to a more convenient righting location
- Swinging the refloated ship to face in the best direction for parbuckling
- Refloating the ship in such a way that it rotates so it is totally upside down and can be moved away immediately after refloating.

Without heavy lifting units that make wrecking in place (Chapter 13) an alternative, refloating first and righting later has many advantages. Where heavy lifting units are available, an analysis of both plans may show that refloating and moving away has both cost and time advantages over wrecking in place.

7-3 FACTORS INFLUENCING CAPSIZED SHIPS.

Influences on capsized ships arise from two principal sources:

- Condition in which the ship has capsized and sunk
- Environmental and physical working conditions.

7-3.1 The Capsized Condition. The position of a capsized ship relative to the sea bottom and water surface is one of the principal indicators of the complexity of righting and refloating the ship. Important aspects of the capsized condition include:

- The angle to which the ship has rotated
- Depth of water around and above the capsized ship
- Area of the hull plating in contact with the seafloor
- Amount of trim
- How far the ship has penetrated the seafloor
- Proximity to fixed installations, such as piers, wharves, or harbor installations
- Distance to sheltered or protected shallow water areas.

7-3.2 Environmental Effects. Environmental effects on capsized ships are as important as the physical ones. They include:

- Sinkage into seafloor as an initial and continuing problem
- Suction effects that may increase the difficulty of breaking the vessel free of the seafloor during initial rotation
- Scouring around the sunken ship, causing:
  - (1) Stress buildup and hull failure in the ship
  - (2) Further subsidence into the seafloor.
- Siltation, the condition where mud and silt enter the hull through every opening, adding more weight that must be removed or accounted for when righting the ship
- Seafloor slope and angle that cause large trim angles in the capsized ship
- Tide and tidal currents that may either help or hamper the refloating operation
- Waves and swell that affect the work of divers, support craft, and floating cranes.

7-4 ON-THE-SIDE REFLOATING.

Methods of restoring enough buoyancy to refloat a ship on its side include:

- Sealing off enough major spaces to allow dewatering by compressed air, pumping out, inducing buoyancy, or a combination of these methods
- Deploying enough lifting power to lift the ship bodily on its side
- A combination of lifting and restoration of buoyancy.

The transverse and longitudinal stability of a ship to be refloated on its side must be examined thoroughly by the salvage engineer. Figure 7-2 shows the relative positions of both the transverse and longitudinal metacenters in an on-the-side refloating.

Ships that capsize and sink in the middle of wide rivers or navigable waterways are traffic hazards. One-way traffic on one side of the sunken ship probably can continue, but two-way traffic may be either restricted or impossible. In such cases, refloating the sunken ship on its side before dragging it to the most suitable channel edge for righting is convenient. An operation of this type involves:

- Setting up hauling equipment on the selected channel bank or shoreline
- Preparing the ship for refloating on its side or at an acute angle to reduce ground reaction
- Rigging attachments and lifting points for the floating cranes, lift barges, or other lifting devices that will stabilize the ship
- Removing structure, top hamper or masts, stacks, or equipment that increases the capsizing moment.

It is important to complete all preparations and system tests before rigging hauling equipment that blocks a working channel or fairway. When there is no operational necessity for salvors to obstruct channel traffic, it is better to allow normal traffic to continue for as long as possible. Safe navigational practice dictates that channel traffic is either restricted or stopped while a sunken ship is hauled to shore.

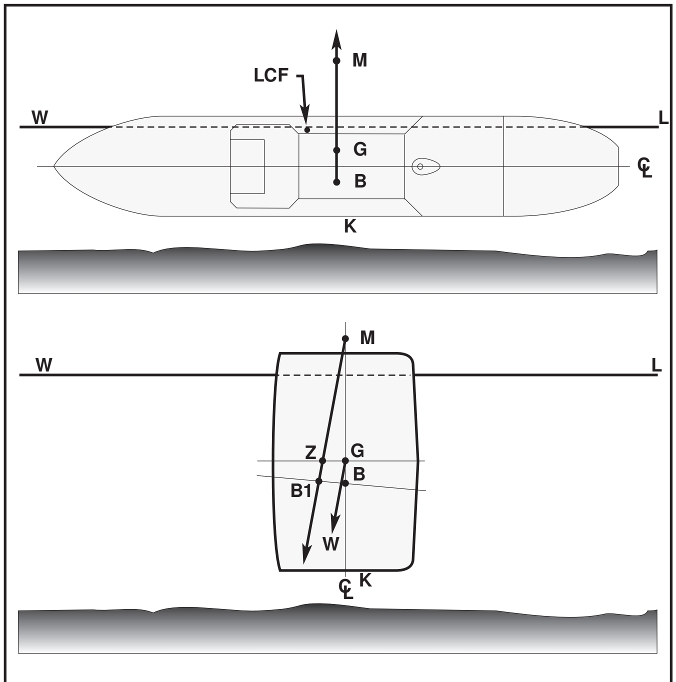


Figure 7-2. Stability of a Ship Refloated on Its Side.

7-5 UPSIDE-DOWN REFLOATING.

Ships may capsize and sink in water that is deeper than the beam of the ship. The sunken ship becomes an underwater obstruction and hazard to maritime traffic. Water depth around and over the ship at high water determines the extent and seriousness of the hazard and the urgency of removal. Refloating the ship upside down is sometimes suitable in such cases.

Floating a ship upside down is particularly suitable when:

- The ship is capsized to more than ninety degrees.
- The ship's bottom is relatively intact or can be made airtight.
- The top hamper, superstructure, and other items that will increase the navigational draft of the inverted ship can be removed easily.
- The channel to the ultimate destination is deep enough to allow the inverted ship to pass.
- The refloated ship is to be scuttled in deep water, scrapped in a drydock, or taken to a location that can accept the upside-down ship.

Ships are refloated upside down by restoring their buoyancy with compressed air. Therefore, it is important that the ship's bottom plating is intact or can be made airtight with minimal work. Rotation to the completely inverted position usually is accomplished by a combination of inducing buoyancy and applying a comparatively small amount of external buoyancy or rotational force to help the vessel to capsize completely. Figure 7-3 shows a ship capsized and sunk and the sequence of restoration of buoyancy, rotation, and upside-down refloating.

Transverse and longitudinal stability are calculated the same way for an upside-down ship as for the same ship floating normally. Normally, the stability characteristics of an upside-down ship differ from those of the same ship floating upright by having:

- Greater transverse stability
- Somewhat less longitudinal stability
- Greater initial stability
- Considerably greater resistance to external inclining forces.

Upside-down ships usually are very stable and handle easily when the waterline is about at tank top level. Ships without double bottoms should have a freeboard of about three feet.

Air leaks from ships under tow or sitting for long periods while they are upside down. If the air is not replenished, the ship will sink when sufficient buoyancy is lost. Compressors are provided on board or connected to the casualty for replacing lost air. This is particularly important when towing upside-down ships in harbors or on long coastal passages.

7-6 RIGHTING CAPSIZED SHIPS.

Righting a capsized ship is almost always an expensive and complex operation. It is usually done to remove a ship that is obstructing a berth, harbor area, or access channel, although increasingly wrecks are being salvaged for environmental or aesthetic reasons.

There is no guarantee that a righted and refloated ship can be returned to service. More often than not, the combined costs of righting, refloating, repairing, and refurbishing make returning the ship to service financially impractical. Almost every righting operation involves removal of considerable superstructure under less than optimum conditions. These removals increase repair costs considerably.

Before deciding what method, or combination of methods, is to be used to right a capsized ship, there are several important engineering and technical questions to be investigated and answered. These include:

- Calculations of righting moments to be developed to overcome the capsizing moment
- Investigations and, where appropriate, calculations to determine the physical point about which the ship will rotate, such as seafloor/soil load-bearing and shear calculations
- Investigation of local hull stresses in the ship during righting operations
- Determination of load-bearing abilities of hull areas critical to righting
- A detailed transverse and longitudinal stability analysis at selected stages of the parbuckling process (a parallel series of hull shear and bending moment analyses may be necessary)
- Weight reductions, additions of buoyancy, and other methods to reduce righting forces or lower the capsizing moment must be investigated and calculated.

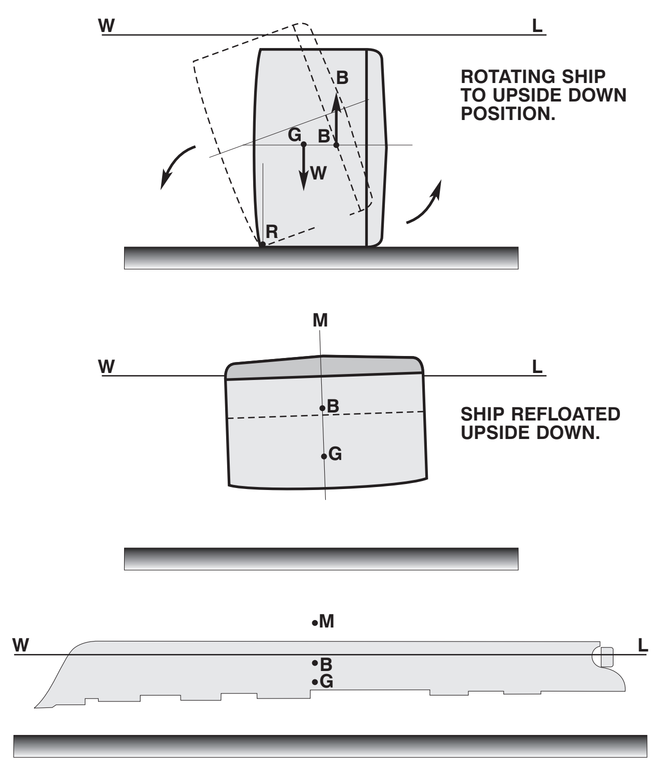
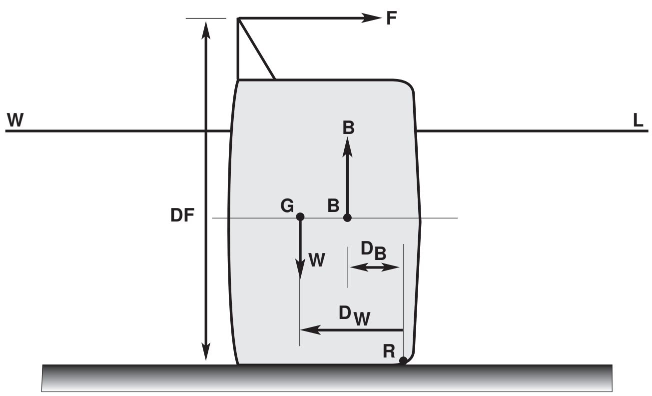


Figure 7-3. Refloating Ships Upside Down.



SHIP ASSUMED TO ROTATE ABOUT THE POINT R.

RIGHTING MOMENT (CLOCKWISE):

ANY REMAINING BUOYANCY ACTING THROUGH THE CENTER OF BUOYANCY.

FORCE F APPLIED AT 90 DEGREES TO HEADFRAMES TO ROTATE SHIP.

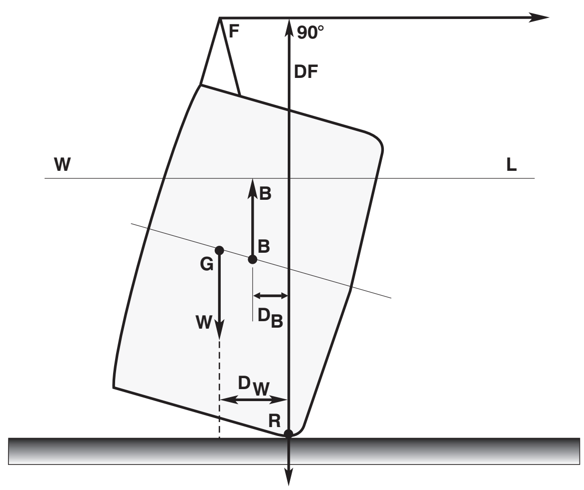
MOMENT = $B \times D_B$
MOMENT = $F \times D_F$

RESISTING MOMENT (COUNTERCLOCKWISE):

WEIGHT W ACTING THROUGH THE CENTER OF GRAVITY.

MOMENT = $W \times D_W$

Figure 7-4. Measurement Points for Calculation of Rotation Forces on Righting Ships.



SHIP ROTATES ABOUT THE POINT R.

RIGHTING MOMENT (CLOCKWISE):

ANY REMAINING BUOYANCY ACTING THROUGH THE CENTER OF BUOYANCY.

MOMENT = $B \times D_B$

FORCE F APPLIED TO HEADFRAMES.

MOMENT = $F \times D_F$

CAPSIZING MOMENT (COUNTERCLOCKWISE):

WEIGHT W ACTING THROUGH THE CENTER OF GRAVITY.

MOMENT = $W \times D_W$

Figure 7-5. Alteration in Moments as Ship Rotates.

7-6.1 Initial Calculations. Ships are righted by creating a moment with buoyancy, externally applied forces or both, that act around a pivot point to overcome the moment of weight, acting through the center of gravity, that is holding the ship capsized. The location of the pivot point lies at or near the turn of the bilge. Normally, a point near the turn of the bilge is selected for initial calculations. The pivot point may be moved farther up the hull by altering or dredging away the sea bottom supporting the ship. Moving the pivot point up the hull shortens the weight's moment arm. The righting force should be applied as far as possible from the pivot point.

Initial calculations on capsized ships establish the moment of weight to be overcome to right the ship. An order of magnitude of capsizing moment is obtained by arbitrarily basing calculations on a point of rotation at the bilge in contact with the seafloor. A lever arm is measured by projecting vertical lines from the free-floating center of gravity, *G*, to the seafloor.

The distance between the pivot point, *R*, and the intersection of the vertical through *G* with the seafloor, *W*, shown in Figure 7-4, is the arm for the moment of weight that resists righting.

Figure 7-5 shows the change in measurement points as force is applied.

NOTE

Salvors making righting calculations must be careful to keep their units straight. Ships' displacements and weights are given in long tons (2,240 pounds) while lifting and pulling systems are rated in short tons (2,000 pounds). Salvors in the field may find it easier to convert all units to pounds or kips 1,000 pounds).

EXAMPLE 7-1
MOMENT TO RIGHT VESSEL

Figure 7-1 shows a ship with a light displacement of 3,800 long tons at *KG* 19.0 feet floating alongside a wharf. Figure 7-1 also shows the same ship capsized 90 degrees and sunk on her port side some distance off the wharf. What is the total moment to be overcome to right this ship, assuming it was in a lightship condition when it capsized?

Ship's dimensions:

Length	420 feet
Breadth	60 feet
Depth	38 feet
Lightweight	3,800 (long) tons

Assume:

Distance between *R* and *W*: 19 feet
Assume *B* = 0 (Conservative)

Moment resisting righting:

$3,800 \times 19 = 72,200$ foot-tons
or $72,000 \times 2.24 = 161,728$ foot-kips

To right the ship, it is necessary to apply a moment in excess of 72,200 foot-long tons.

The initial moment is the greatest that is required during the righting. As shown in Figure 7-6, as the ship rotates her center of gravity gets closer to the pivot point, reducing the moment arm and the moment. The center of gravity final passes the pivot point so that the weight provides a moment that assists in the righting.

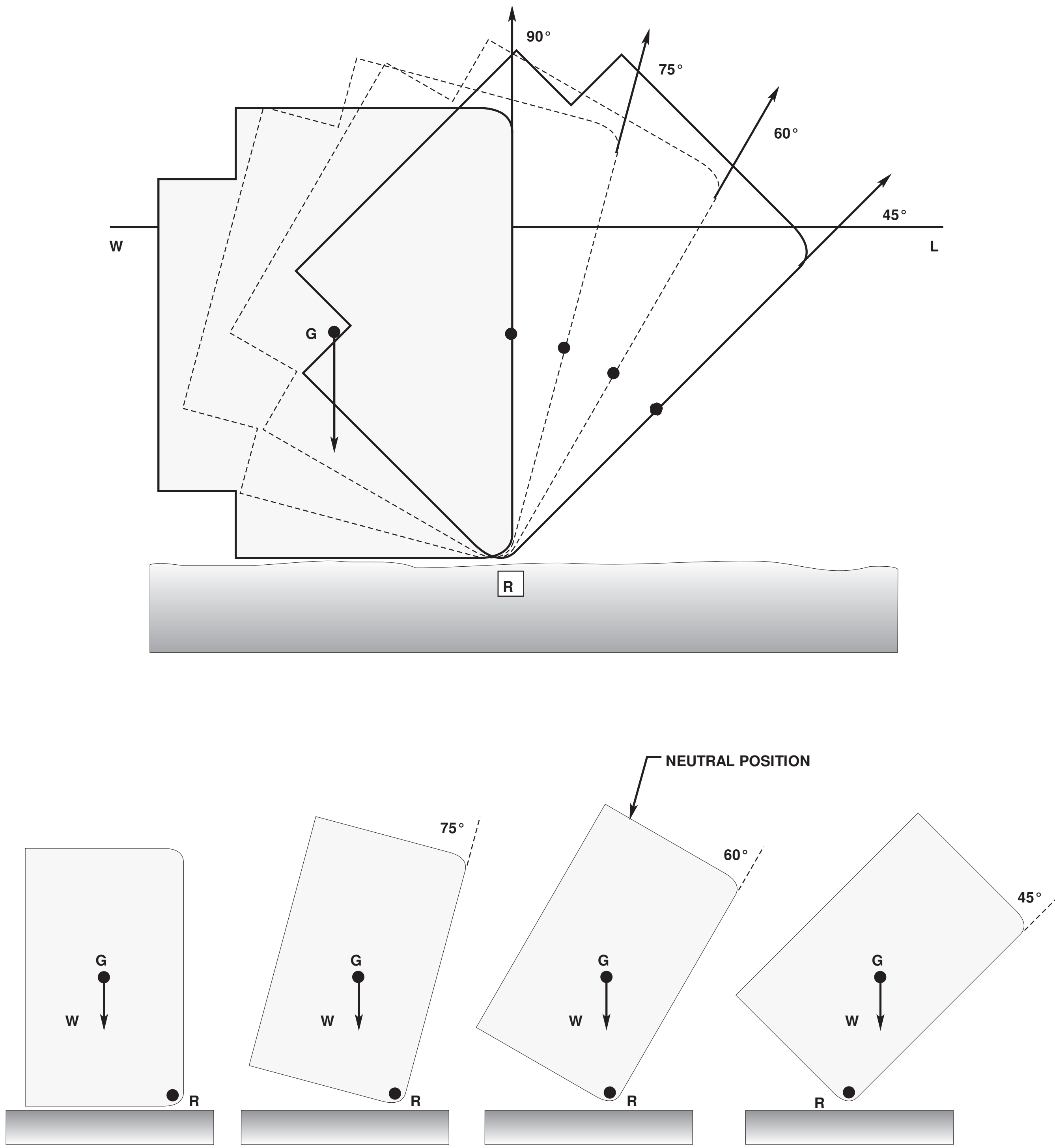


Figure 7-6. Movement of Center of Gravity and Effect of W as Ship is Rotated Upright.

7-6.2 Righting Methods. Figures 7-7 through 7-11 illustrate basic methods for righting capsized ships. Most of these methods involve righting the ship with the bilge firmly in contact with the seafloor, a static righting. There are circumstances when a static righting is not practical. If the ship is refloated in its capsized condition and then righted while in a floating condition, different criteria apply.

- Method 1 (Figure 7-7A). Selective sealing of major spaces in the ship allows controlled dewatering to restore buoyancy. Buoyancy, along with addition of ballast to the high side, produces a couple to right the ship.
- Method 2 (Figure 7-7B). Inducing buoyancy into selected spaces with compressed air, and adding water ballast to provide a couple. A small external force to provide the initial rotating moment is usually necessary. This system is a variation of Method 1, but usually involves compressed air dewatering.
- Method 3 (Figure 7-8A). Applying external static forces to lever arms mounted on the hull. This method is most often combined with Methods 1 and 2.
- Method 4 (Figure 7-8B). Applying external counterweights to the high side of the hull with buoyant lifting systems attached to the low side.
- Method 5 (Figure 7-9A). Applying a direct, external, rotational force or pull to the low side of the hull with external pulling or heaving systems. This is not a particularly common method because of the difficulty of generating enough righting moment unless the ship is made buoyant first.
- Method 6 (Figure 7-9B). Extending lever arms, or headframes, from the hull and applying righting forces at the head of this system. This is one of the most common righting or parbuckling methods involving external haulage.
- Method 7 (Figure 7-10A). Applying a combination of direct, dynamic lifts to the low side of the hull, and an external pull to the high side of the hull. This largely mechanical system is used when sufficient hauling/lifting power is readily available and sealing off the hull for induced buoyancy is not practical.
- Method 8 (Figure 7-10B). Constructing and fixing righting beams to the high side of the capsized ship, then applying a lifting force to these righting beams. This method is usually satisfactory in conjunction with large floating cranes or salvage sheer legs.
- Method 9 (Figure 7-11). A combination of methods including:
  - (1) Restoring buoyancy by dewatering selected spaces
  - (2) Adding rotational ballast to the high side
  - (3) Applying a dynamic pull to the high side of the ship, along with a mechanical lift on the low side.

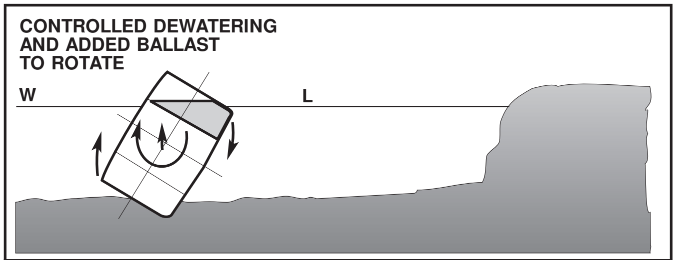


Figure 7-7A. Righting Method 1.

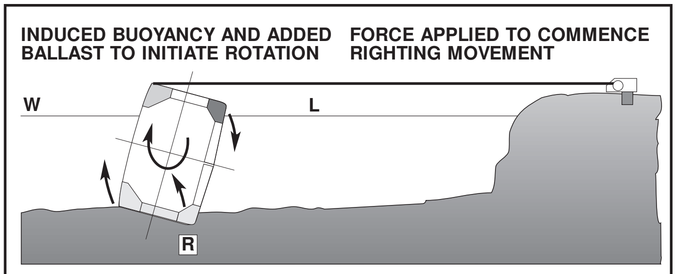


Figure 7-7B. Righting Method 2.

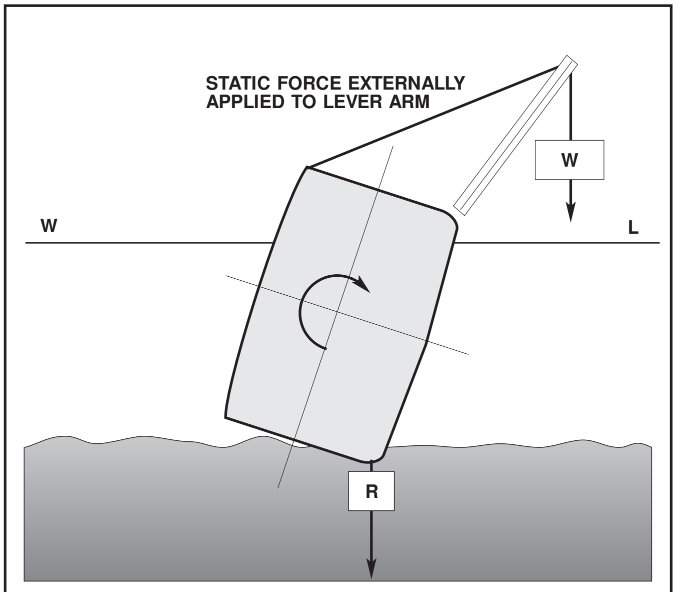


Figure 7-8A. Righting Method 3.

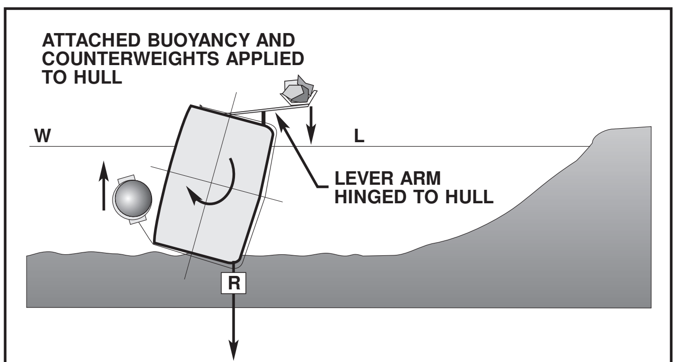


Figure 7-8B. Righting Method 4.

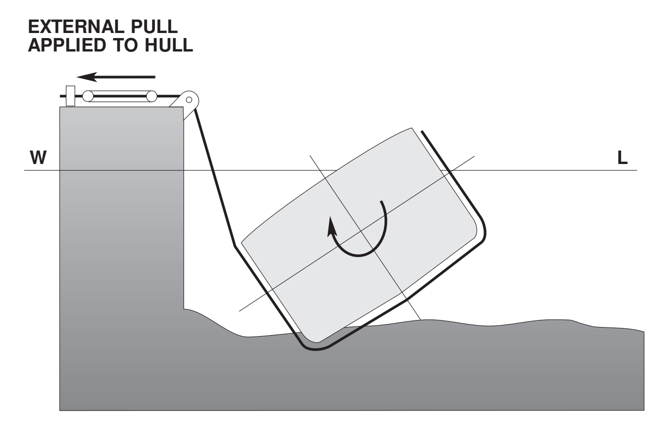


Figure 7-9A. Righting Method 5.

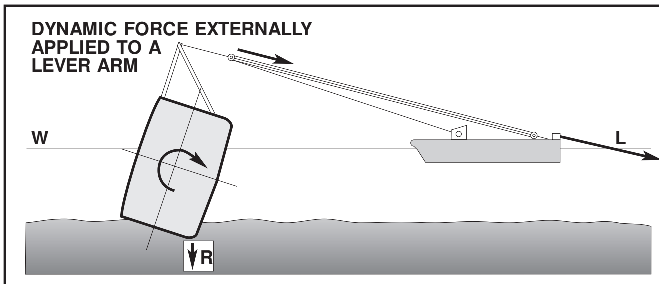


Figure 7-9B. Righting Method 6.

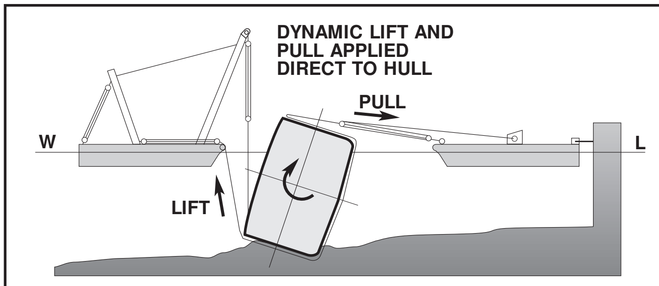


Figure 7-10A. Righting Method 7.

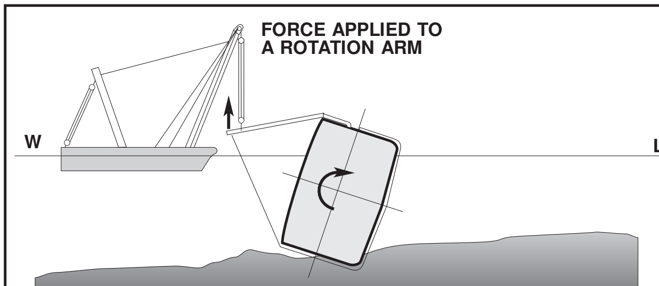


Figure 7-10B. Righting Method 8.

7-6.3 Variable Factors. The method or combination of methods selected will depend upon several variable factors that include, but are not limited to:

- Quantity of buoyancy that can be restored to the sunken ship
- Availability of heavy lifting and heavy hauling equipment in the casualty area
- Working considerations, including time and effort, required to restore buoyancy
- Factors that may prevent use of one or more obvious methods because the method will seriously disrupt port operations
- Environmental factors.

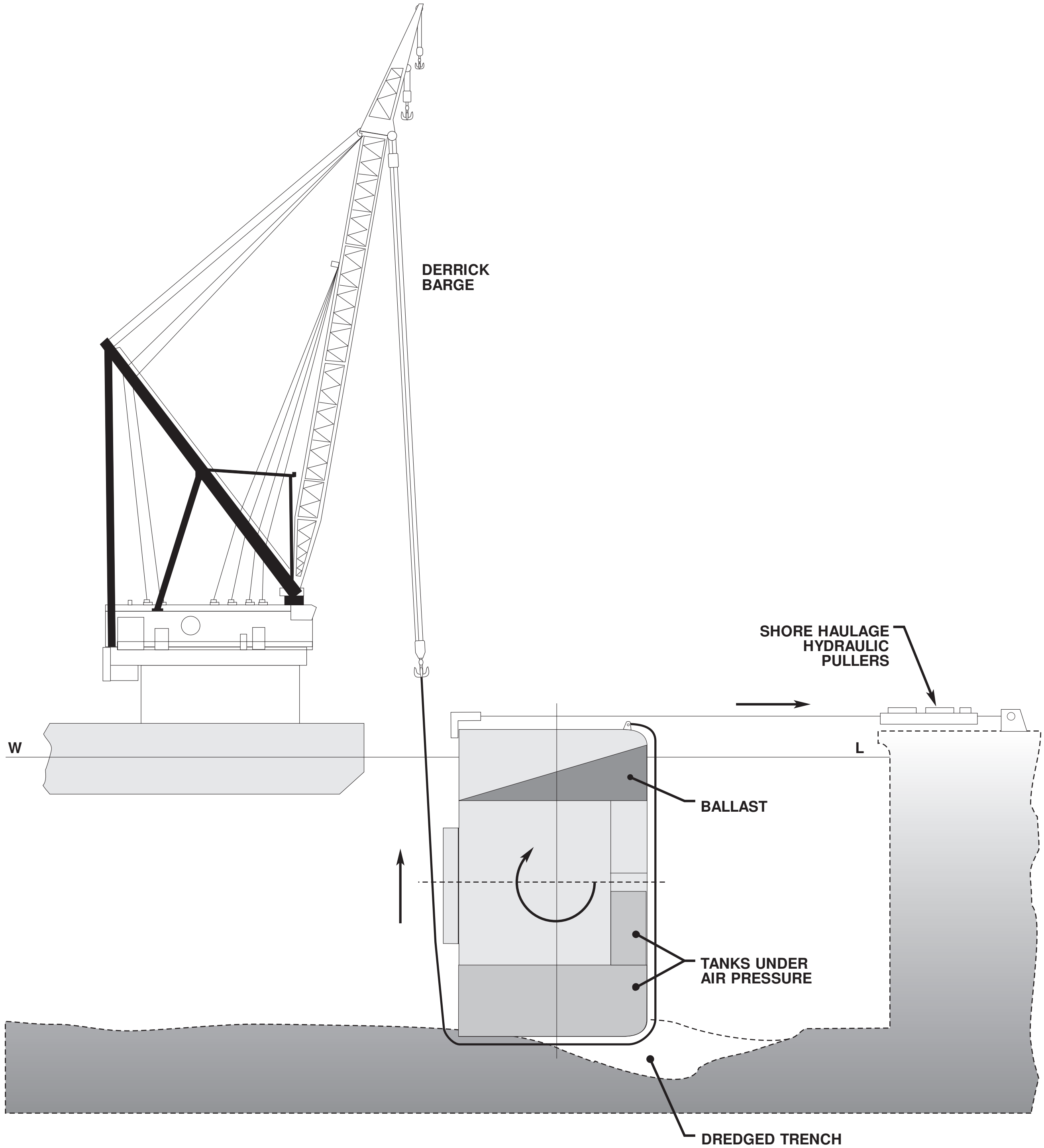


Figure 7-11. Combination of Methods Used to Upright a Capsized Ship.

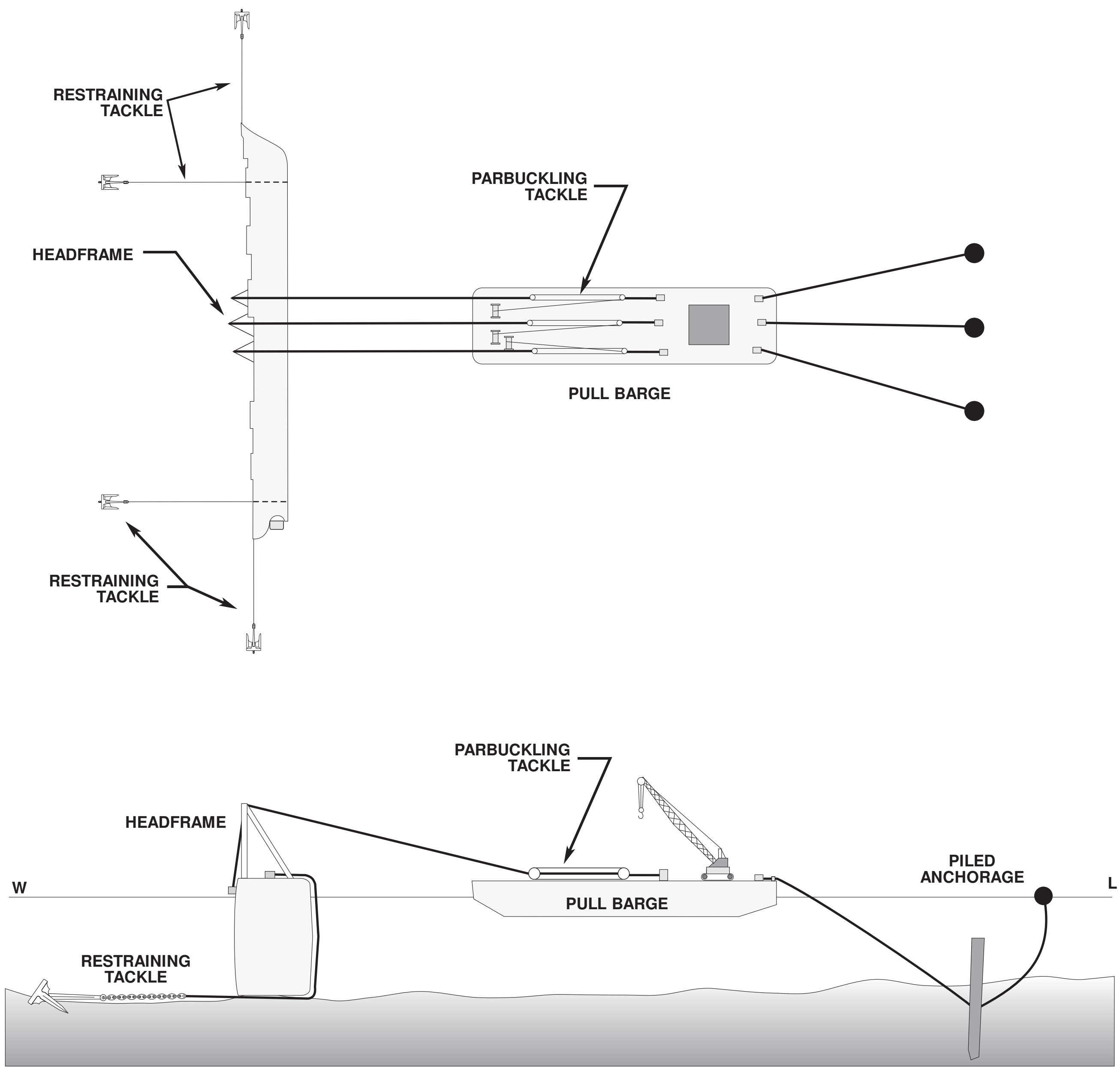


Figure 7-12. Offshore Parbuckling Operation.

7-6.4 Offshore Operations. A ship that is capsized and sunk a considerable distance offshore presents several problems. The problems are rarely insurmountable, but can add greatly to the cost and time of the operations. Some of the most common offshore or exposed-location righting difficulties are:

- Hauling and lifting systems usually are operated from barges or floating cranes that are subject to weather limitations. Parbuckling, lifting, or combined parbuckling and lifting can be done only in good weather.
- When righting forces are generated by barge-mounted hauling systems and holding ground is poor, it may be necessary to build piled anchorage systems or use propellant-embedment anchors. Piled anchorages normally must be removed or cut off at the mud line when the job is finished.

Figure 7-12 shows an exposed offshore area where a parbuckling operation is undertaken with a pulling barge.

7-7 RIGHTING PLANS.

With a proposed righting plan sketched out on paper, salvage officers and salvage engineers make a twofold analysis of the plan.

7-7.1 Calculations. Calculations are made to ascertain the following:

- Movement of the center of gravity at successive intervals (usually 5 or 10 degrees) of righting and applied pull required at each stage
- Stage of inclination at which ship reaches a neutral point and capsizing moment becomes the righting moment
- Changes, if any, at the assumed point of rotation and an accurate assessment of sinkage that may occur during rotation
- Soil load-bearing characteristics and, if necessary, arrangements for detailed soil analysis
- Existing quantities of siltation, residual stores, and cargo; in many instances, estimates will have to be made.
- Soil load-bearing characteristics of areas proposed for mounting the shore-based hauling systems (Design calculations for hauling anchorages are a special task in themselves.)
- Hull strength calculations to determine amount of local stiffening or reinforcement required where head frames are mounted
- Checks on pressure differentials created by dewatering major spaces, some of which may be partially submerged
- That the necessary pulling power can be developed by the proposed methods, and that any proposed mechanical system is suitable for the task
- Whether righting operations would be simplified by a trench dredged along the bilge
- Whether an air bubble introduced temporarily into selected compartments or further dewatering of major compartments would help to right the ship
- Whether a weight reduction program, including cutting down superstructure sections, masts, stacks and other structural members, is necessary and useful in the overall righting and refloating plan.

7-7.2 Site Investigations. Physical site investigations and detailed measurements are made to verify the assumptions for the proposed righting and refloating method. These investigations include:

- A diving survey of the capsized ship together with a seafloor inspection of the area around the casualty
- Measurements from all principal points on the hull to wharves or adjacent structures
- The amount of siltation and hull subsidence because silt or mud accumulations will either:

  (1) Increase the power needed to right the ship

  (2) Prove to be a major diving task to airlift, pump out, or otherwise remove

- Surveys of areas where it is proposed to set up purchase tackle or linear puller anchorages, considering:

  (1) Disruption of port activities by shoreside construction

  (2) Alignment between shore anchorages and hull-mounted hauling systems.

- Position and number of restraining anchors to prevent the ship from moving towards the parbuckling force because of the righting force's horizontal component
- Methods of stabilizing the ground under the ship by laying in gravel, crushed rock, shell, coral, or heavy sand in areas of high pressure
- Suitability and ability of the floating plant, mechanical equipment, or industrial activity to perform the operations.

7-7.3 Other Considerations. Combining site inspections, measurements, and physical examination of the capsized ship while the engineering analysis is in progress allows the salvors to coordinate the approach to righting and refloating. Often, a technique that has an engineering appeal and simplicity may be totally impractical for the capsized ship in question. Similarly, an apparently straightforward solution may introduce stresses that could lead to structural failures. Refloating a stranded ship is nearly always a time-critical operation, with the basic salvage plan being capable of rapid change. Righting and refloating a capsized ship is usually not time-critical in the same sense. All salvage operations are a combination of seamanship, applied mechanics, and engineering. In stranding salvage, the seamanship dominates; the salvage of capsized and sunken ships requires a greater proportion of applied mechanics, accurate engineering, and cost-consciousness.

7-7.4 Planning Approach. A tentative righting and refloating method for a capsized ship may emerge at a very early stage of site investigations and salvage survey. However, an apparently suitable early and tentative initial plan should never become the course of action until:

- All preliminary calculations and surveys verify that the initial plan has a sound basis
- It has been verified that all assets to accomplish the initial plan are available
- No other more logical or promising methods emerge from the calculating and debating sessions that are an essential part of planning for righting a capsized ship
- It is clear that following the initial plan to right the ship will not make later refloating operations more difficult or prolonged than necessary
- Cognizant and responsible authorities understand and accept the broad outlines of the initial plan and any downstream ramifications.

When selecting a righting system, salvors should remember there are many righting techniques and methods, some of which do not apply in every circumstance. In righting operations, because a proposed method, or combination of methods, has not been used before, does not mean that it is not suitable for a particular task. Similarly, a classic method used many times may be either wholly inappropriate or less than optimum because circumstances differ. All righting plans and ideas should be on the basis of merit and suitability to the particular circumstances. Some of the best evaluations and critiques are performed by salvage personnel who are familiar with the local conditions. Techniques of a righting plan may have serious or fatal flaws, overlooked by those unfamiliar with the method or the local conditions.

TABLE OF INCLINATION ANGLES			AS CAPSIZED			ANGLE OF INCLINATION OF VESSEL														
			89°			80°			70°			60°			50°			40°		
NO.	ITEMS	NOMINAL FORCE (TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)	FORCE (TONS)	LEVER (FT)	MOMENT (FT-TONS)
						ANGLE OF TRIPOD WIRE TO THE HORIZONTAL														
			4°			4-1/2°			5°			5-1/2°			5°			4-1/2°		
1.	16 TRIPODS EACH AT 100 TONS PULL (RESERVE OF 20 %)	1,600	1,596.2	101.0	161,216.0	1,595.04	107.75	171,865.6	1,593.92	112.20	178,837.8	1,592.64	113.3	180,466.1	1,593.9	112.0	178,519.0	1,595.04	107.3	171,147.8
2.	11 LIFTING PONTOONS A.S.P.(L) 80 TONS EACH	800	880.0	67.8	59,664.0	880.0	66.9	58,872.0	880.0	64.7	56,936.0	880.0	60.5	53,240.0	400.0	45.0	18,000.0	106.0	35.8	3,794.8
3.	6 COUNTER-WEIGHT PONTOONS A.S.P.(W) 115 TONS EACH	690	690.0	16.2	11,178.0	690.0	25.8	17,802.0	690.0	35.0	24,150.0	450.0	42.5	19,125.0	-	-	-	-	-	-
4.	8 COMPARTMENTS W/ INTERNAL BUOYANCY TO THE CENTER-LINE OF THE SHIP NOMINAL AIR PRESSURE 6-LBS. PER SQUARE INCH	4,700	4,700.0	30.6	143,820.0	1,819.4	24.0	43,665.6	-	-	-	-	-	-	-	-	-	-	-	-
5.	TOTAL UPRIGHTING MOMENT	-	-	-	375,878.0	-	-	292,205.2	-	-	259,924.0	-	-	252,811.1	-	-	196,519.0	-	-	174,942.6
6.	TOTAL UPSETTING MOMENT	14,500	14,500.0	-22.7	-329,150.0	14,500.0	-17.70	256,650.0	14,500.0	-12.3	-178,350.0	14,500.0	-6.7	-97,150	14,500.0	0.0	0.0	14,500.0	6.7	97,150.0
7.	EXCESS UPRIGHTING MOMENT	-	-	-	46,728.0	-	-	35,555.2	-	-	81,573.8	-	-	155,661.1	-	-	196,519.0	-	-	272,092.0
8.	PERCENTAGE EXCESS MOMENT OF MOMENT REQUIRED	-	-	-	14.2%	-	-	13.8%	-	-	45.7%	-	-	151.0%	-	-	∞	-	-	∞
9.	PERCENTAGE EXCESS MOMENT OF MOMENT AVAILABLE	-	-	-	12.4%	-	-	12.2%	-	-	31.4%	-	-	61.5%	-	-	100%	-	-	-

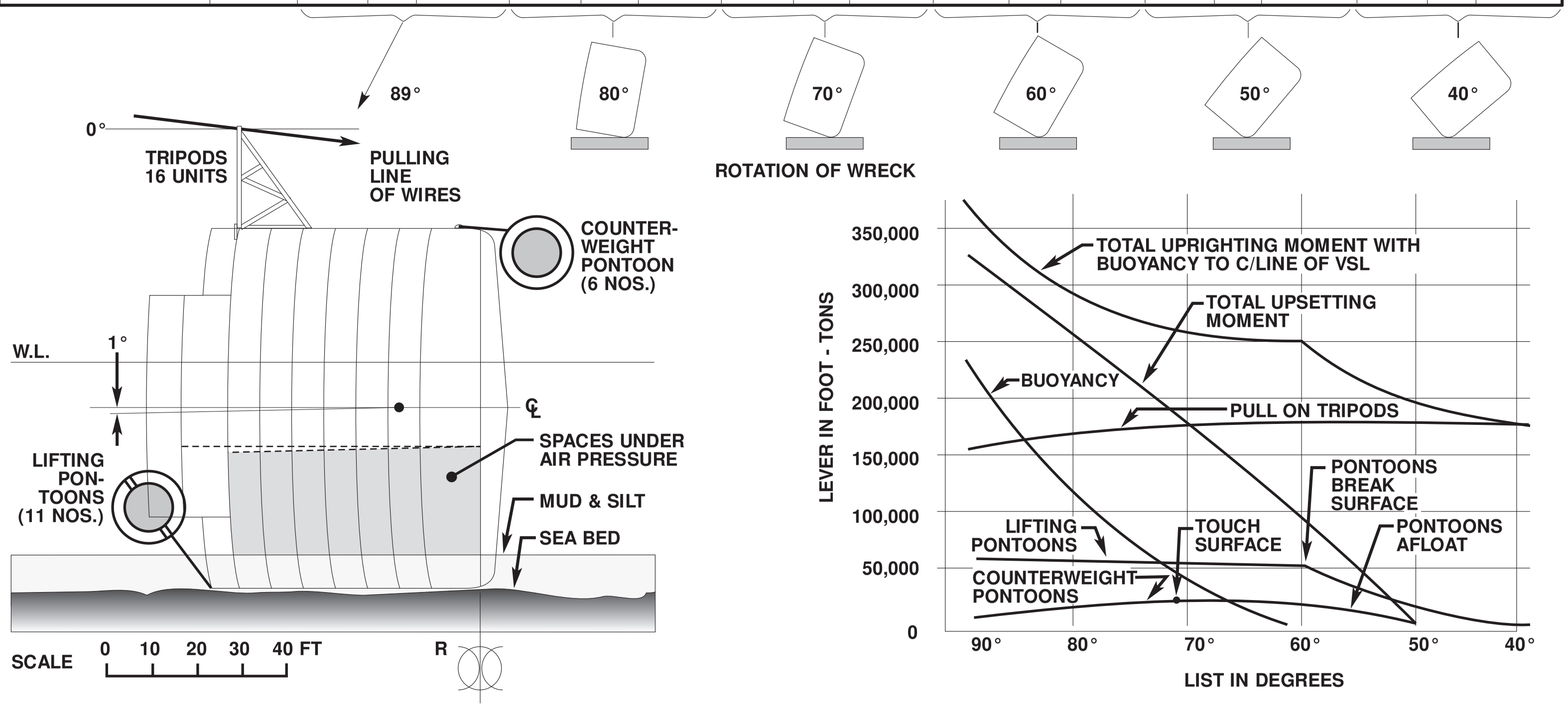


Figure 7-13. Presentation of Righting Data.

7-7.5 Plan Summary. In addition to procedural, environmental, and material elements, the basic righting and refloating plan contains a summary of calculation sequences. Figure 7-13 shows a useful format for presenting righting data, with moment plotted against angles of inclination. Large, complex righting operations may benefit from making a reasonably large scale model of the sunken ship. The model provides a convenient way to test theories and demonstrate practical matters. It also serves as a briefing aid that has more realism than computer-generated printouts or graphics.

7-8 RIGHTING, HAULING, AND ANCHORAGE DETAILS.

Where righting is done with remotely situated hauling systems, several factors are considered, including:

- Number of headframes
- Strength of each headframe to prevent distortion under load
- Method of attaching hauling wires to the ship and the local strength of the hull in way of attachment points

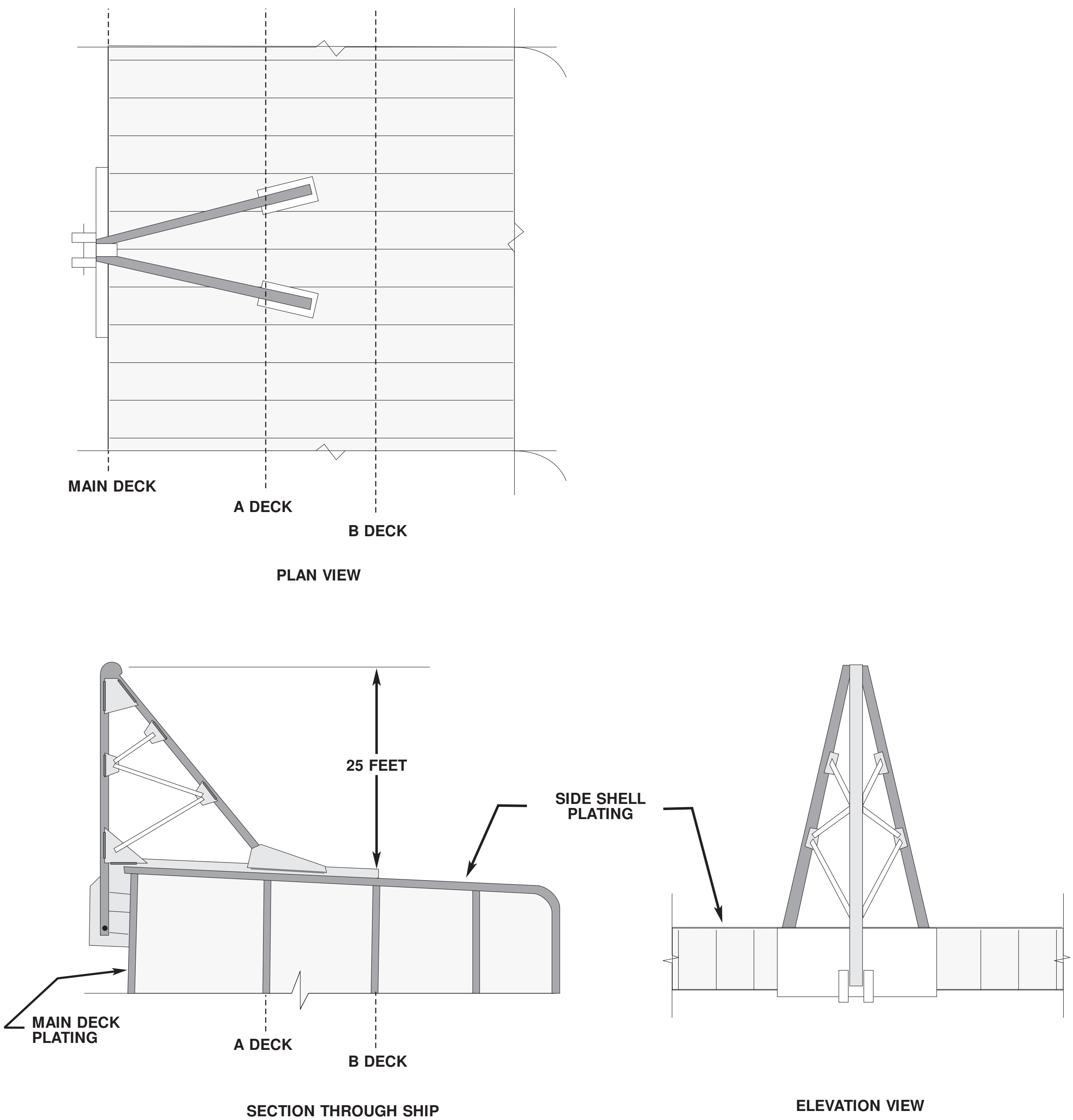


Figure 7-14. Braced-Girder Headframe.

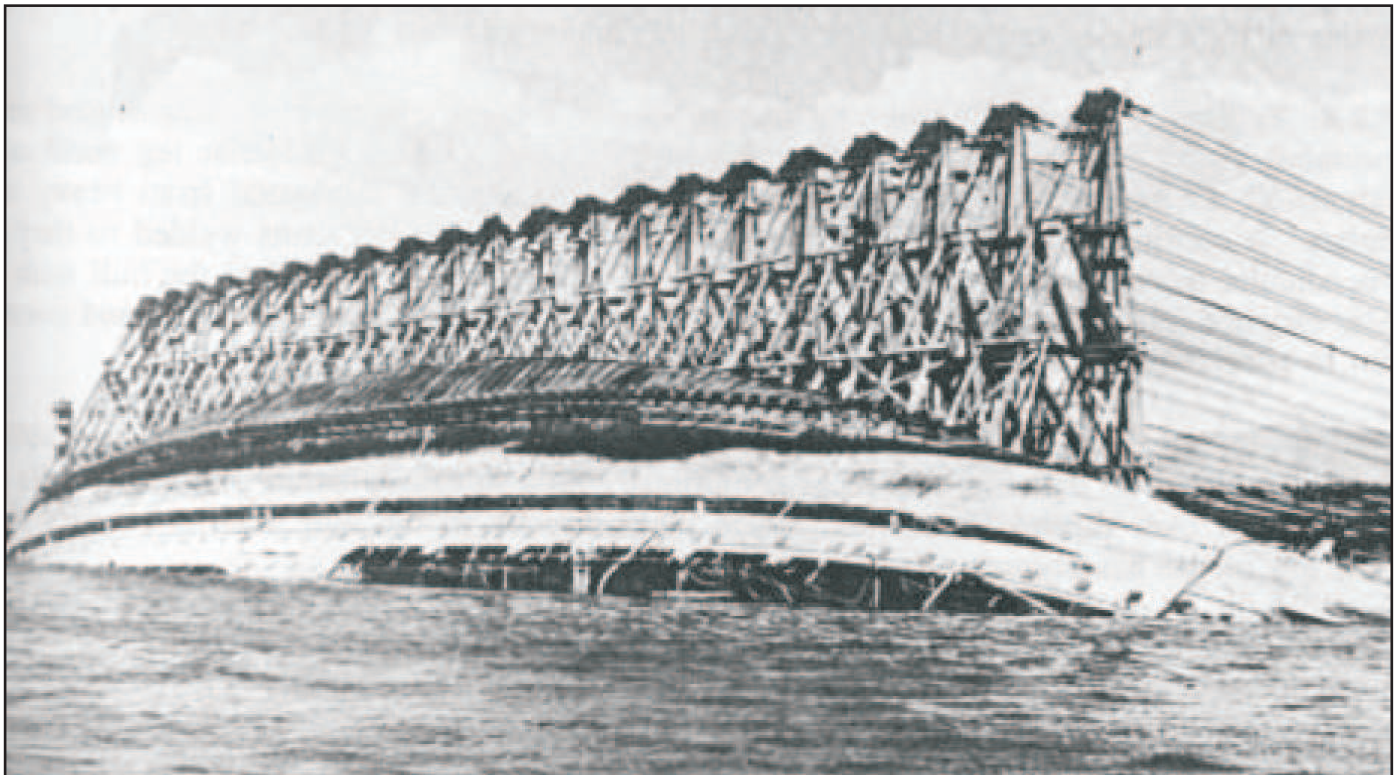


Figure 7-15. Braced-Girder Headframes on USS OKLAHOMA.

- Location and distances between hauling attachment points on the ship
- Restraining force required to prevent the ship from moving sideways with the parbuckling pull
- Number of fore-and-aft and athwartships restraining wires, types and holding power of restraining anchors
- Locations of individual shore-hauling anchorages (deadmen) and the distances from the capsized ship.

7-8.1 Headframes. Numbers and individual strengths of headframes are determined by a combination of rigging and engineering factors, including:

- Pull applied to each headframe, a function of the hauling system capacity. Headframes increase in size, strength, and foundation complexity with increasing pull.
- Whether wires pull directly from headframe tops or are connected to fittings on the ship's hull and led over shoes or guides set into headframe tops.
- Whether doubling sheaves are used.
- Availability of suitable structural steel to construct headframes.

7-8.2 Types of Headframes. Headframe construction usually follows one of four principal designs.

7-8.2.1 Braced Girder Design. In the braced girder design (Figure 7-14), the bracing leg or legs extend outward from the headframe tops toward the pull direction. The design is similar to a bipod or tripod mast and is connected rigidly to the ship's hull. Connections are made at main or strength deck level. Braced girders require more shoreside or shop fabrication than any other design. All fabrication can be monitored.

Installation is simplified to lifting, positioning, and welding each headframe to the hull. Braced-girder headframes were built and installed for parbuckling the battleship USS OKLAHOMA (BB37) at Pearl Harbor; the largest such job done by the U.S. Navy. Figure 7-15 shows these headframes and the twin hauling lines attached to each one. Note that the height of the headframe is adjusted to conform to the curvature of the hull and to keep the tops of the frames in the same plane.

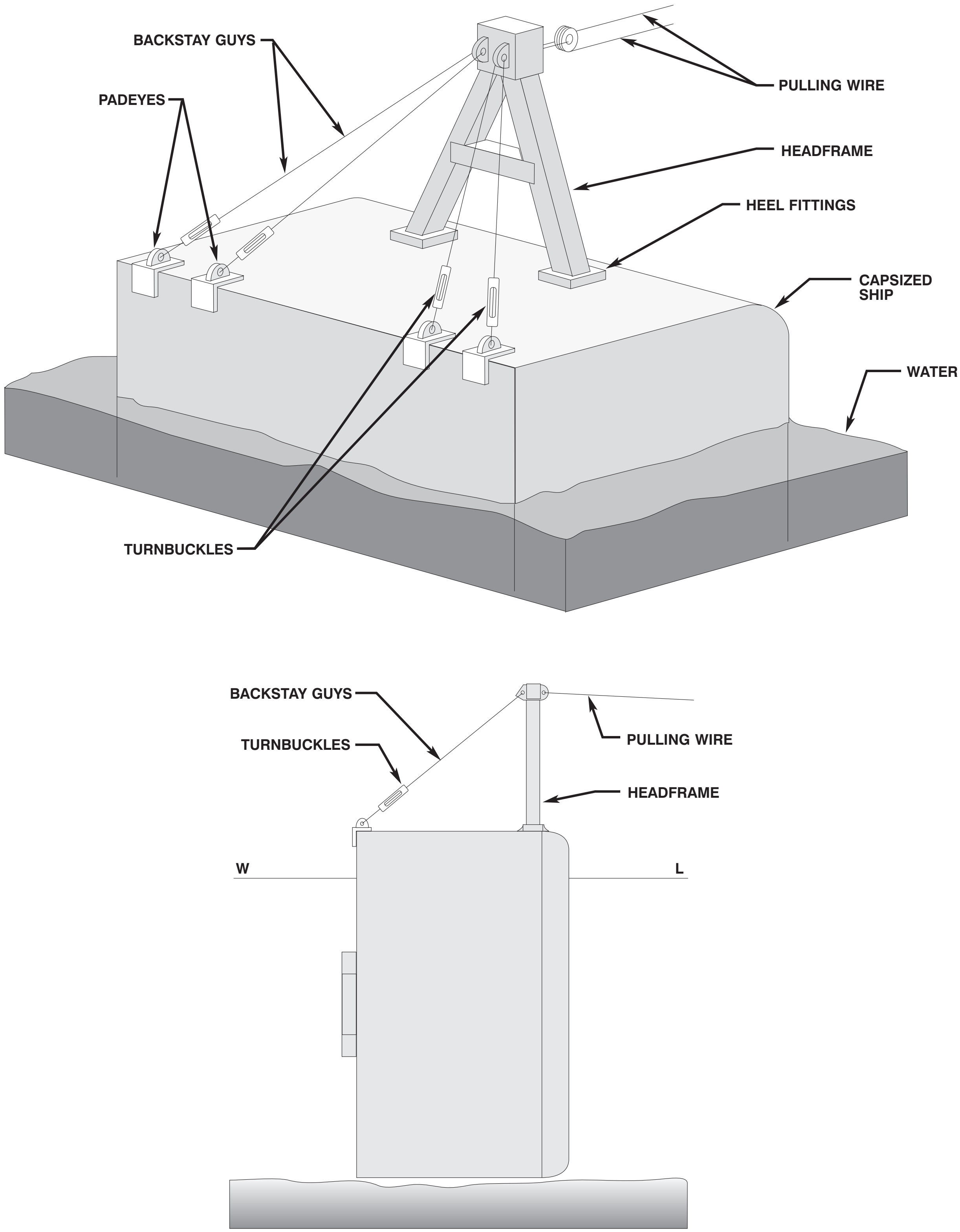


Figure 7-16. Stayed Girder Headframe.

7-8.2.2 Stayed Girder Design. In the stayed girder design (Figure 7-16), headframes are stayed back to hull connections on the sunken ship. This design is advantageous when there is a shortage of structural steel. Stayed girder designs require numerous wire backstays and more time-consuming and costly field rigging work than the braced girder design. It is difficult to achieve uniform stay-back tension and to control quality because of the number of anchorages, padeyes, and field connections.

7-8.2.3 Cantilevered Strut Design. In the cantilevered strut design (Figure 7-17), each headframe is a simple sheer leg braced to a horizontal strut or outrigger. The system is associated most commonly with wooden construction. In addition to difficulty in obtaining uniform strength with wooden spars or logs, this design requires a complex backstay rigging system. Backstay wire ropes are arranged from the headframe to the horizontal strut and from the horizontal strut to the ship. The principal advantage of this system is that when the hauling wire is led over the headframe and connected to the ship's hull, the righting pull remains at right angles to the hull throughout the operation.

7-8.2.4 Triangular Braced Semi-continuous Girder Design. In the triangular braced semi-continuous girder design (Figure 7-18), each headframe resembles triangular leg sections of offshore oil drilling rigs. The headframe structures usually are fabricated from heavy wall tubulars. A continuous length of pipe or girder has six- or eight-leg struts welded so they are perpendicular to one another at the pipe or girder. The struts are welded to the hull with the girder elevated. It is usual with this system to lead pulling wires over the girder and connect them to special brackets, bollards, or padeyes welded to the hull.

Variations of all four systems have been successful, depending upon material availability, specific problems on the ship, and local conditions. As a rule, it is better practice to pass the hauling wires over the headframe and attach them directly to the hull than to connect them to the top of the headframe. In Figure 7-18, Triangular Braced Semi-continuous Girder Headframe, one of the advantages of this system is the ability to share leg thrust between two decks, the main vehicle deck and the main strength deck.

7-8.3 Connection of Pulling Wire. Main hauling wires are connected to either headframes or the hull by several methods. Figure 7-19 shows connection methods.

7-8.3.1 Connection to Headframes. Main hauling wires are shackled directly, or made up to bolted or pinned connections at the tops of individual head frames. Direct attachment of main hauling wires to headframes is one of the more common connection methods. The headframes incorporate a heavy joining lug, padeye or plate shackle arrangement to which hauling wires are shackled or bolted. This method has the advantage that all connection components can be built to uniform specifications when headframes are fabricated. Headframe connection material and component requirements are analyzed by the salvage engineer as part of the overall analysis of the headframe design.

7-8.3.2 Connection to the Hull. Main hauling wires are bolted or shackled to specially fabricated anchorage points welded to strong points on the hull. In such cases, hauling wires are led *over* the top of each head frame to the hull anchorage point. Special anchorage points welded directly to the capsized ship's hull or deck are usually made for wires of between 2½- to 3½-inch diameter. Typically, such anchorage points consist of two heavy steel plates welded to plate foundations attached to the capsized ship's deck. Each anchorage point is located beneath and aligned with a parbuckling headframe or deck edge bolster serving a hauling wire. This connection has the added advantage that foundation plate designs pick up several frame stations or strong points where analysis indicates load spreading is necessary. In some respects, anchorage plate design resembles the Smit Towing Bracket described and illustrated in Chapter 3 of the *U.S. Navy Towing Manual* (SL740-AA-MAN-010).

7-8.3.3 Padeyes. Main hauling wires are attached to padeyes where enough local strength exists at wire connection points. Where analysis shows that not enough strength exists, it is usually not worth the time and effort to stiffen the structure for padeye connections. In such a situation, it is usually preferable to have purpose-built anchorage points (Paragraph 7-8.3.2) fabricated ashore. The eye opening must be large enough to accept the pin of a shackle of strength equal to that of the padeye. There must be enough metal around the eye to prevent failure in bearing or tension. Padeyes should be installed so that loads are in their own plane. Doubler plates and/or underdeck reinforcements spread the padeye loads through the ship's structure. Padeyes should be located to take advantage of existing stiffeners. Minimum padeye design requirements (Figure 4-7) can be found in the *U. S. Navy Towing Manual* (SL740-AA-MAN-010).

7-8.3.4 Special Bollards. Short, heavy-wall-thickness pipe bollards, welded to suitable long girders or structural steel sections, are a relatively efficient method of connecting multiple pulling wires to capsized ships. Each short bollard is fitted with a wide-top flange to prevent pulling wires from slipping off accidentally. Bollard-type connections are not suitable for all righting or hauling operations. This system is most often used with purpose-built pulling barges that deploy several wires to the capsized ship.

7-8.3.5 Chain Pigtails. Main hauling wires may be shackled to chain pigtails rove through specially cut holes or apertures in the capsized ship's hull. Chain pigtails rove through hull openings are most common when dragging partially submerged capsized ships out of channels. Decisions to use chair pigtail connectors are influenced by diving conditions and time required to prepare and weld special wire connection anchorages to the hull, especially if the attachment would otherwise require wet welding. Chain pigtails are not particularly effective unless the ship has an extremely heavy framing system to withstand the combined pulling and cutting effects of the chains. The method does not allow very detailed analysis of connection strength. Principles of chain reeving described and illustrated in Chapter 8 apply to this connection system.

7-8.4 Location of Both Hauling and Lifting Points on Hull. Several factors that act individually and in combination influence location of hauling and lifting points for mechanical righting. Hull construction and ship strength are considered along with the mechanical method to right the ship.

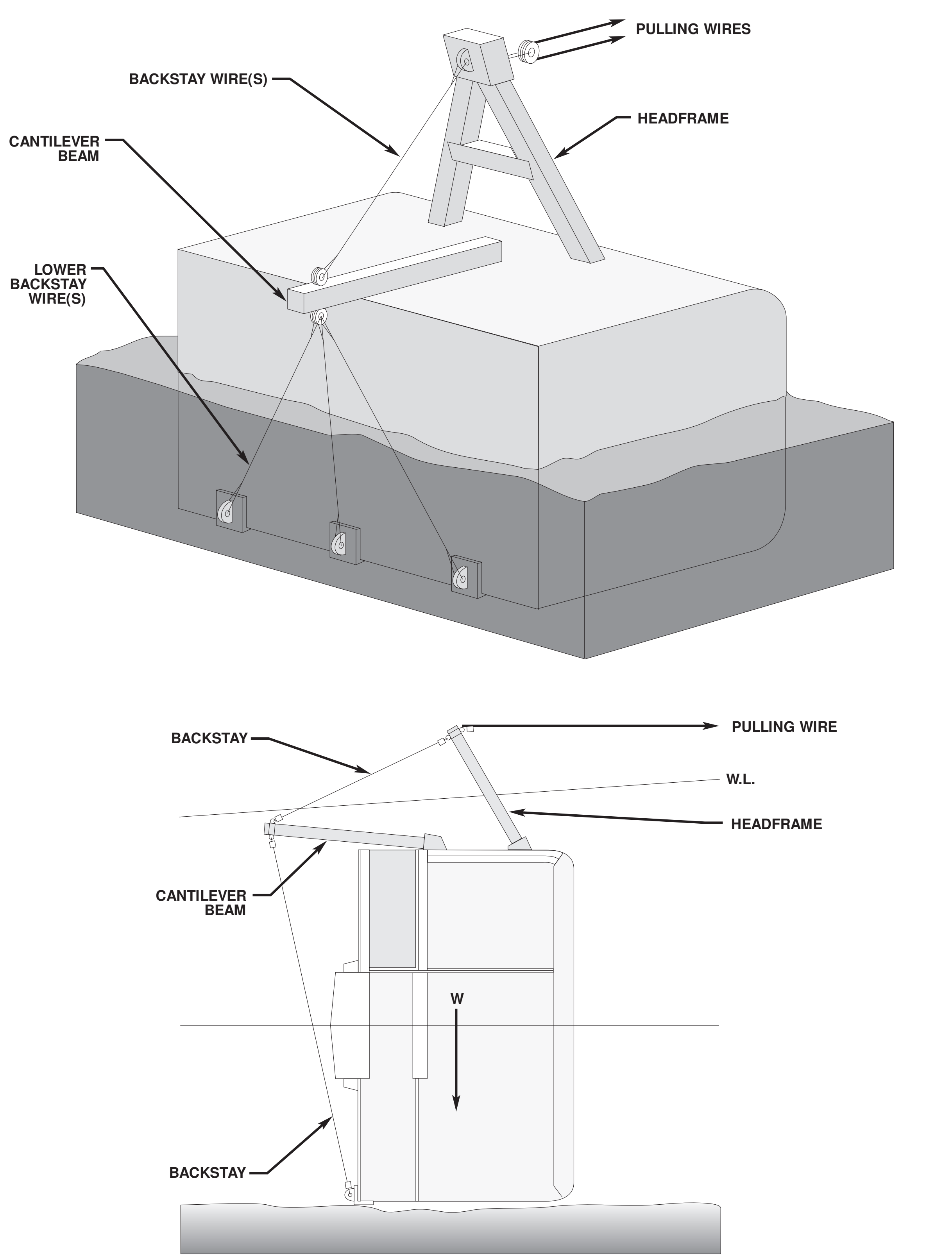


Figure 7-17. Cantilevered Strut Headframe.

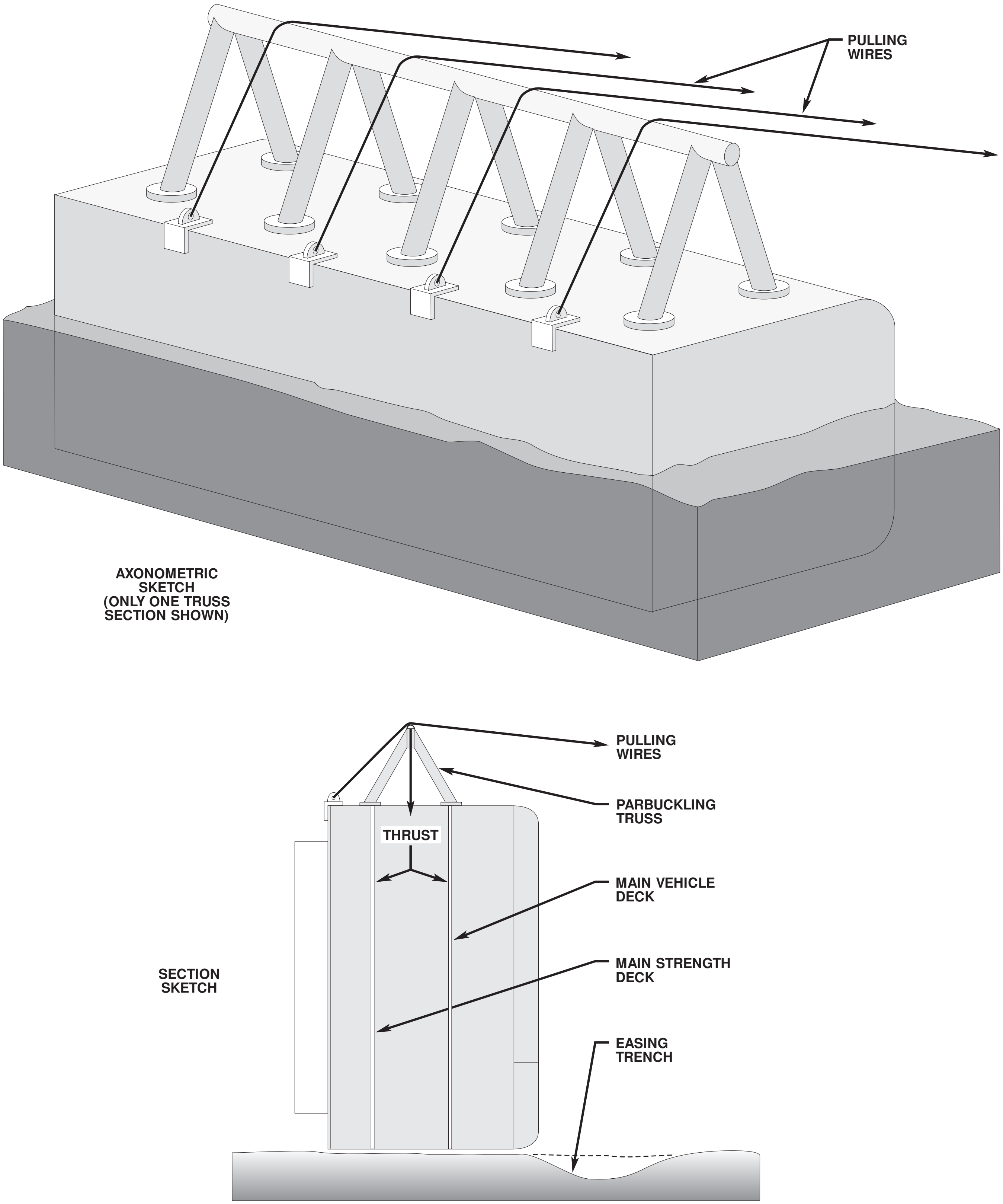


Figure 7-18. Triangular Braced Semi-continuous Girder Headframe.

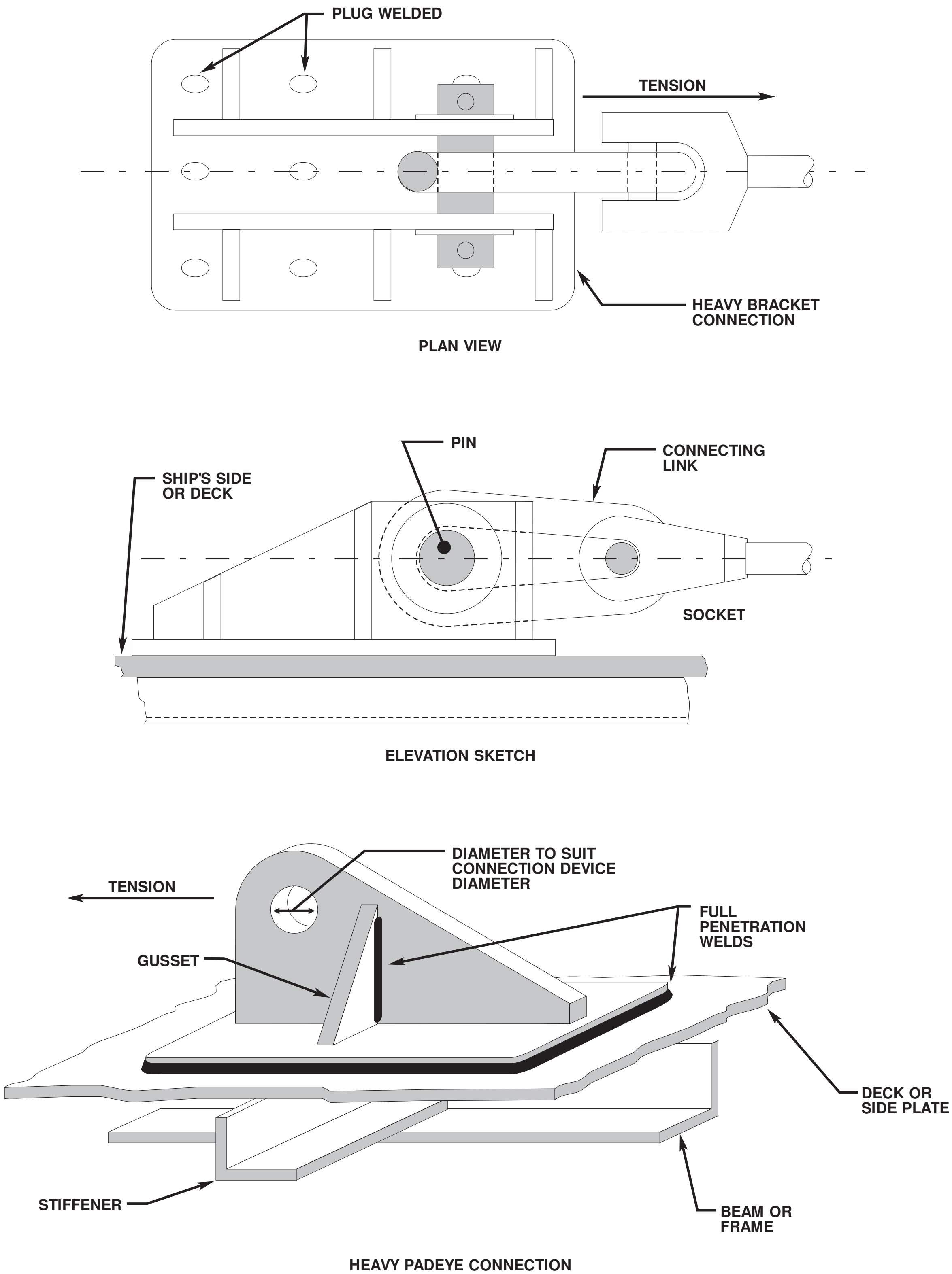


Figure 7-19. Typical Connection Points for Pulling and Restraining Wires.

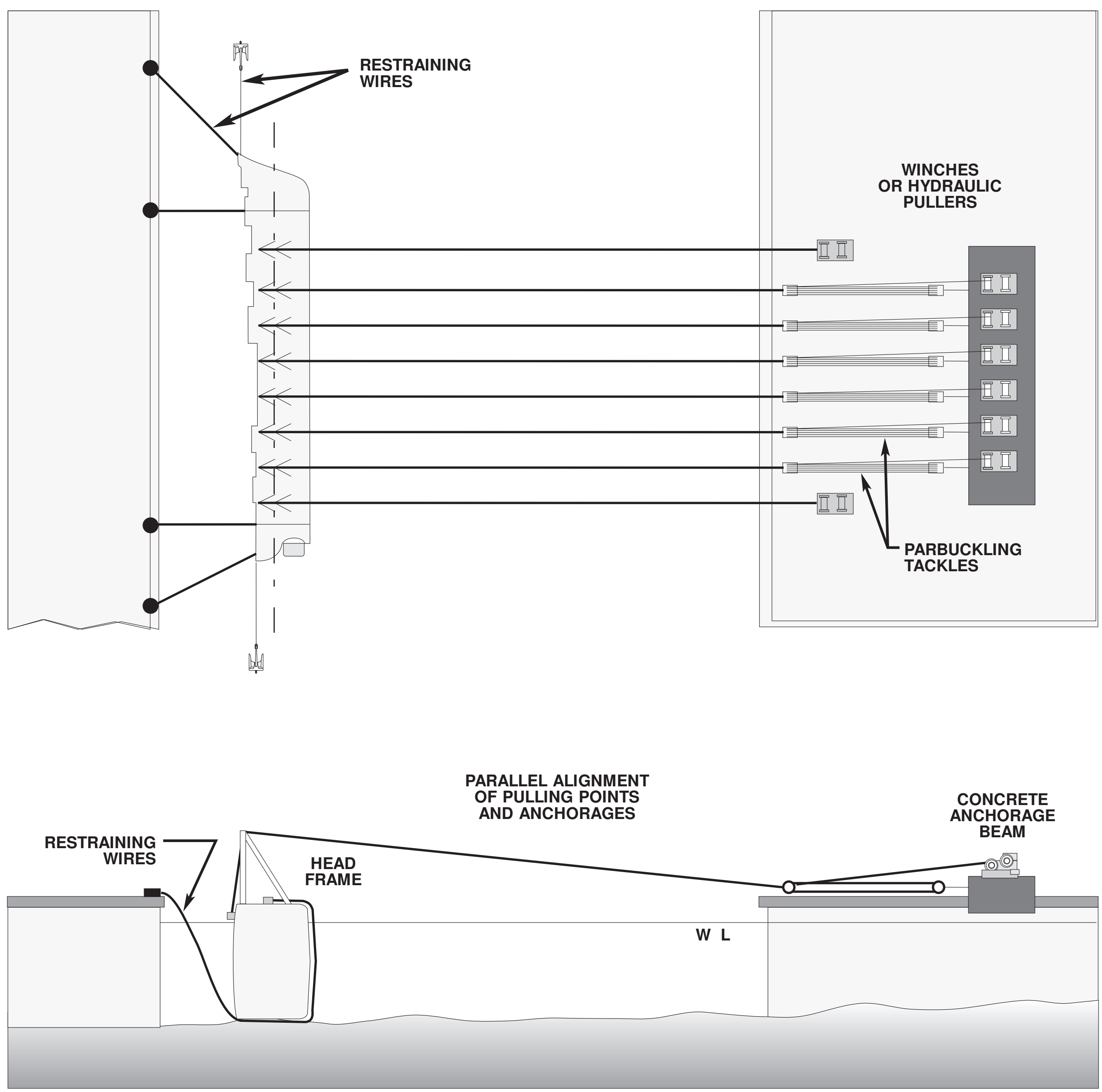


Figure 7-20. Parallel Alignment of Pulling Points and Tackle.

7-8.4.1 Headframe Attachment Position. To ensure that each purchase or pulling system develops almost identical righting moments, headframe top and hauling system anchorage point baselines must be in the same plane. To achieve this, it is customary to locate all headframe attachment positions on the capsized ship's parallel midbody.

Large areas of parallel midbody seldom exist on modern warships, so salvors may have to construct headframes of different heights to be sure headframe tops are in alignment. Larger fleet auxiliaries and most large merchant ships have long parallel midbodies that simplify headframe mounting arrangements.

Figure 7-20 shows this alignment.

Headframes must be set over strength decks to ensure that the strongest hull areas absorb the vertical thrust or pull. Salvors try to set headframes at junctions of sheer strake and weather deck plating, or junctions of main longitudinal strength deck and side shell plating. Where headframes cannot be set on hull junction points, salvors may have to install heavy stiffening. In modern warships the sheer strake is often HY-80 or another high-strength steel requiring special welding procedures. In these ships, headframe foundations can be bolted to the hull or the headframe relocated clear of the sheer strake.

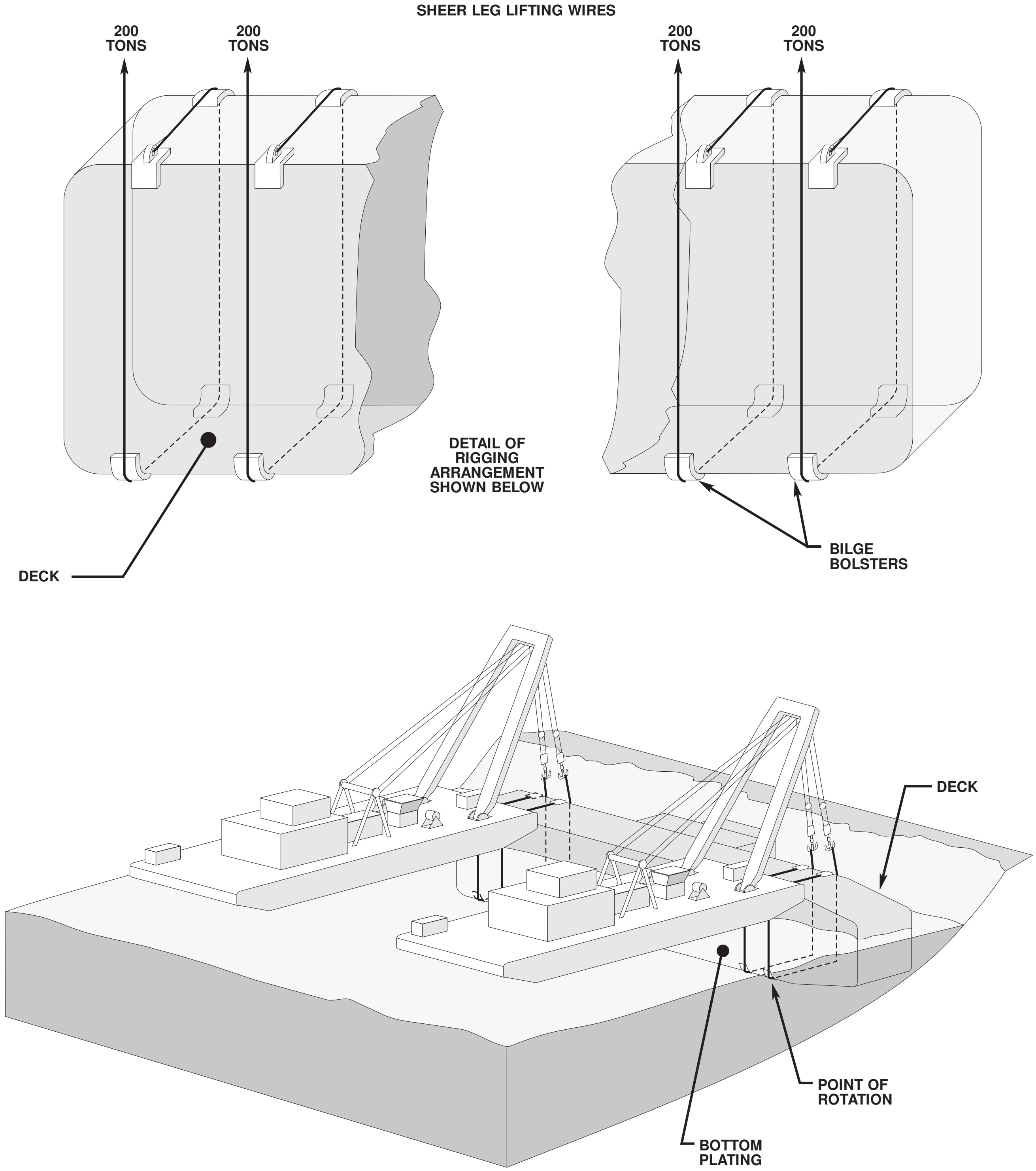


Figure 7-21. Sheer Legs Uprighting Capsized Ship.

Salvage engineers will advise what areas of the hull have enough strength and will devise stiffening for on-site or shop fabrication. In some cases, internal pillaring, local shoring, or comprehensive stiffening may be necessary.

7-8.4.2 Hull Attachment Points. Where a righting force is applied directly to the capsized ship's hull, attachment points usually are made at or near main strength decks. These attachment points may typically be:

- Large padeye and doubler plate combinations welded to side shell plating in way of major bulkheads or transverse frames.
- Large padeyes welded to deck plating in way of bulkheads or transverse frames. In such cases, main hauling wires are led vertically upwards from the padeyes and over specially built deck edge bolster. The bolsters serve the dual functions of preventing wire slicing damage to hull and edge junction plating, and providing properly radiused fairlead surfaces for the wires or chains.
- Chain pigtails rigged through apertures or openings cut in deck plating.
- Chain or wire rope pendants rigged around local strong points that include gun mounting rings, heavy hatch coamings, mooring bollards, hawse pipes, and propeller shaft brackets.

On some capsized ships where righting pull is applied at the deck edge, salvors rig chain or wire pendants right around the ship. This method is advantageous when refloating will be accomplished by mechanical lifting. After the ship is righted, parbuckling wire pendants can serve as lifting straps or as messengers to haul through main lift wires.

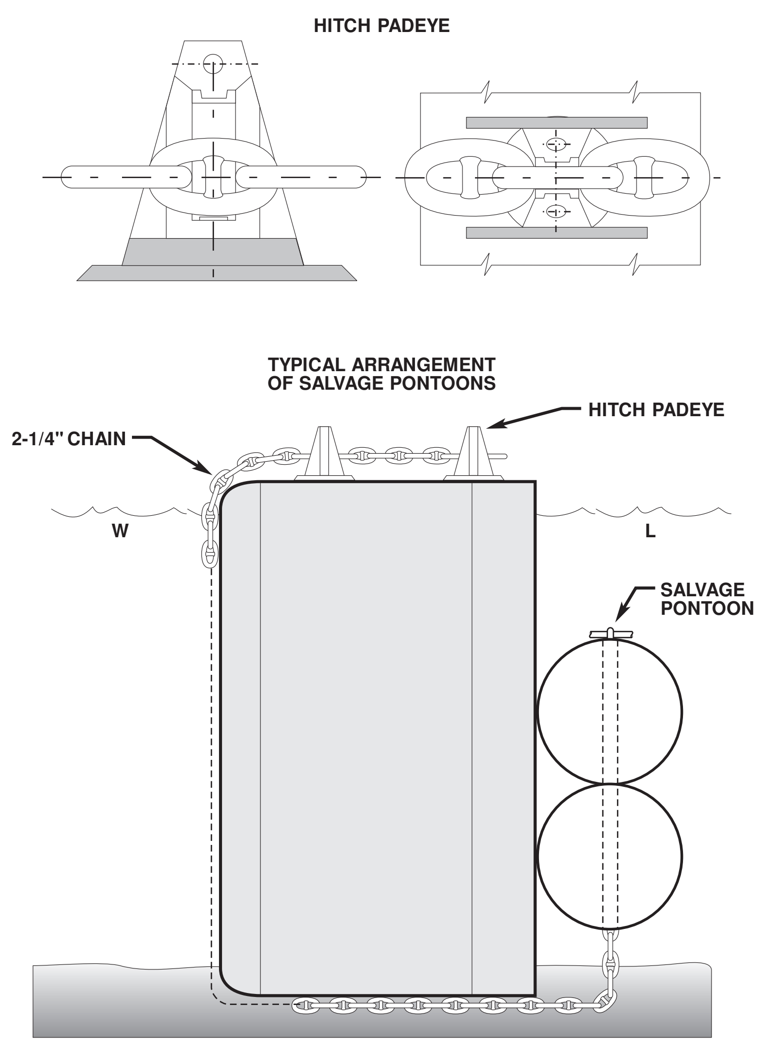


Figure 7-22. Pontoon Attachment for Righting.

7-8.4.3 Floating Cranes and Sheer Legs. Floating cranes and sheer legs in a righting role typically lift in the parallel midbody at the low or seafloor side of the capsized ship, opposite the bottom plating. Lifting slings or straps from cranes normally are passed underneath the capsized ship's hull, taken up along bottom plating, and then alongside shell plate. This may involve tunneling, sawing, or sweeping messenger wires under the capsized ship. The wires connect to padeyes or special side bolster fittings welded to the high side sheer strake. As large forces or pulls are applied in localized areas, bolsters are fitted to side shell and deck plate junction areas in way of lifting pendants. Figures 7-21 and 7-22 show sheer legs uprighting a capsized ship and a schematic of pontoon attachment for righting.

Salvage personnel and crane barge operators must establish close liaison and mutually agree on connection methods to ensure that crane barge shackles and associated rigging jewelry match bolster fittings or padeyes made by salvors. Some superstructure elements, masts, and other fittings may be removed from the capsized ship to prevent them from damaging the barges during rotation operations.

High-capacity, single main hook offshore derrick barges employed in parbuckling operations may require several under hull pendants and connecting points because of their lifting power.

Figure 7-21 shows typical righting arrangements with salvage sheer legs. The sheer legs have deployed both main lift hooks and deck tackles for maximum righting power.

7-8.4.4 Small-capacity Buoyant Lift Devices. Salvage pontoons and other small-capacity buoyant lifting devices are connected to capsized ships by fittings and rigging methods that support the buoyant force. Rigging for buoyant lift systems does not involve the degree of engineering or component strength required for large cranes or sheer legs. Figure 7-22 shows a typical salvage pontoon attachment for righting with external buoyancy.

7-8.5 Hauling System Anchorages. Mechanical hauling methods for righting capsized ships require an anchorage system to pull against. The engineering and building or laying of anchorage systems are two of the most important and time-consuming parts of preparing for a mechanical righting operation. Failure or drag of any individual hauling anchor point creates a situation that results in either an embarrassment or a catastrophic stoppage of righting operations. This section describes some of the more important practical matters in selecting and establishing strong points for hauling anchorages.

Anchorages are divided into two basic classes:

- Shore-based hauling foundations
- Marine-based pulling anchorage systems.

Anchorage or foundation systems for large righting systems require careful engineering and design analysis that consider:

- Total pulling force on the system
- Individual pull or reaction force on each anchorage
- Soil shear and strength characteristics, including the load-bearing capacity of the foundation area
- Methods of installing, removing and, where appropriate, demolishing and/or rehabilitating areas of foundation construction
- The relative merits and disadvantages of proposed anchorage systems and their cost in time and materials
- Effects in cost and time for construction of specially engineered anchorage systems compared to intelligent improvisations with locally available components.

7-8.5.1 Shore-based Anchorages. Anchorages for shore-mounted hauling systems cover a wide range of designs, depending on total pull exerted on each anchorage point and soil characteristics. Some systems designed to absorb 40 to 60 tons per point may use convenient materials of opportunity and involve simple excavations with backhoes. At the opposite end of the scale, major foundation works and site engineering are required with individual point pulls of 200 to 300 tons or more. For example, construction of the shore foundations excavated for righting the battleship USS OKLAHOMA required about 8,000 tons of reinforced concrete. An example of a shore based Anchorage appears in Figure 7-25, Guy Anchor System.

Basic designs for shore hauling foundations include:

- Simple deadman systems that consist of an excavated pit with its front, or pressure face, lined with vertical balks or logs of heavy timbers. A chain for the standing purchase block is secured around a horizontal beam laid behind the face timbers. The chain is laid up outside before the pit is filled with soil, crushed rock, or reinforced, ready-mixed concrete.

- Simple piled anchorages, driven or drilled into soil or bedrock, to which tail chains or heavy padeyes are connected. Basic piled anchorages of this type are suitable as attachment points for standard hydraulic pullers or standard beach gear purchase blocks.

- Individually excavated pits in which steel structural beams are placed as foundations for winches. After structural steel members are welded together, the pits are filled with concrete to complete each anchorage unit. Variations on this method are quite common; winch foundation blocks may also serve as anchor points for standing purchase blocks.

- Large, composite foundation blocks for mounting several winch or hydraulic puller systems. Typically, such foundations are deeply excavated, prismatic trenches incorporating raker piles and large quantities of reinforced concrete. Excavation, preparation, steel fixing, and concrete pours make such foundations major tasks that may best be subcontracted to military or civilian engineering organizations.

- On occasion, bulldozers, crawler cranes, and other heavy tracked vehicles, including tanks, packed in roughly excavated pits have served as satisfactory shore anchorage points.

Innovative salvors have constructed their own shore hauling system anchorages for smaller righting tasks. Simple and effective shore hauling foundations have been constructed by taking beach gear anchors and chain cables ashore, excavating suitable pits, and burying them. Other salvors have successfully used large concrete mooring clumps, discarded structural steel or other materials of opportunity as shore hauling foundations. Figure 7-23 shows such a system.

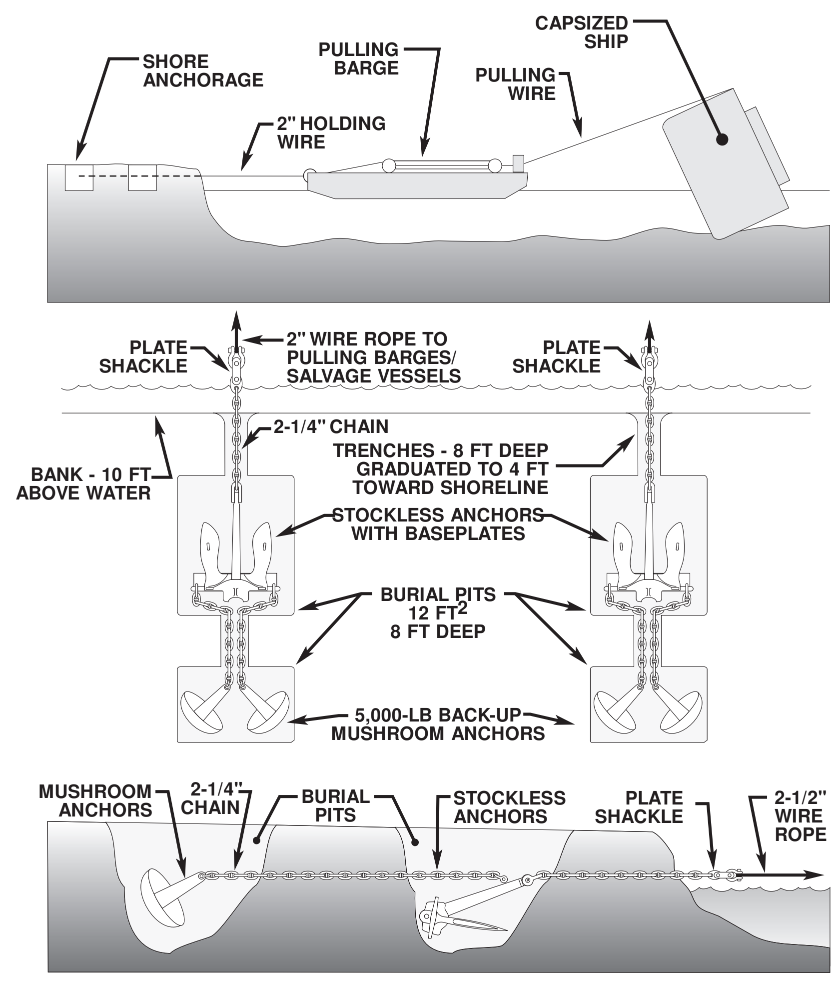


Figure 7-23. Anchorage for Small Righting Job.

NOTE

Chapter 6 and Appendix G describe characteristics and holding powers of anchors. This section assumes a knowledge of Navy salvage anchors and anchor-laying methods.

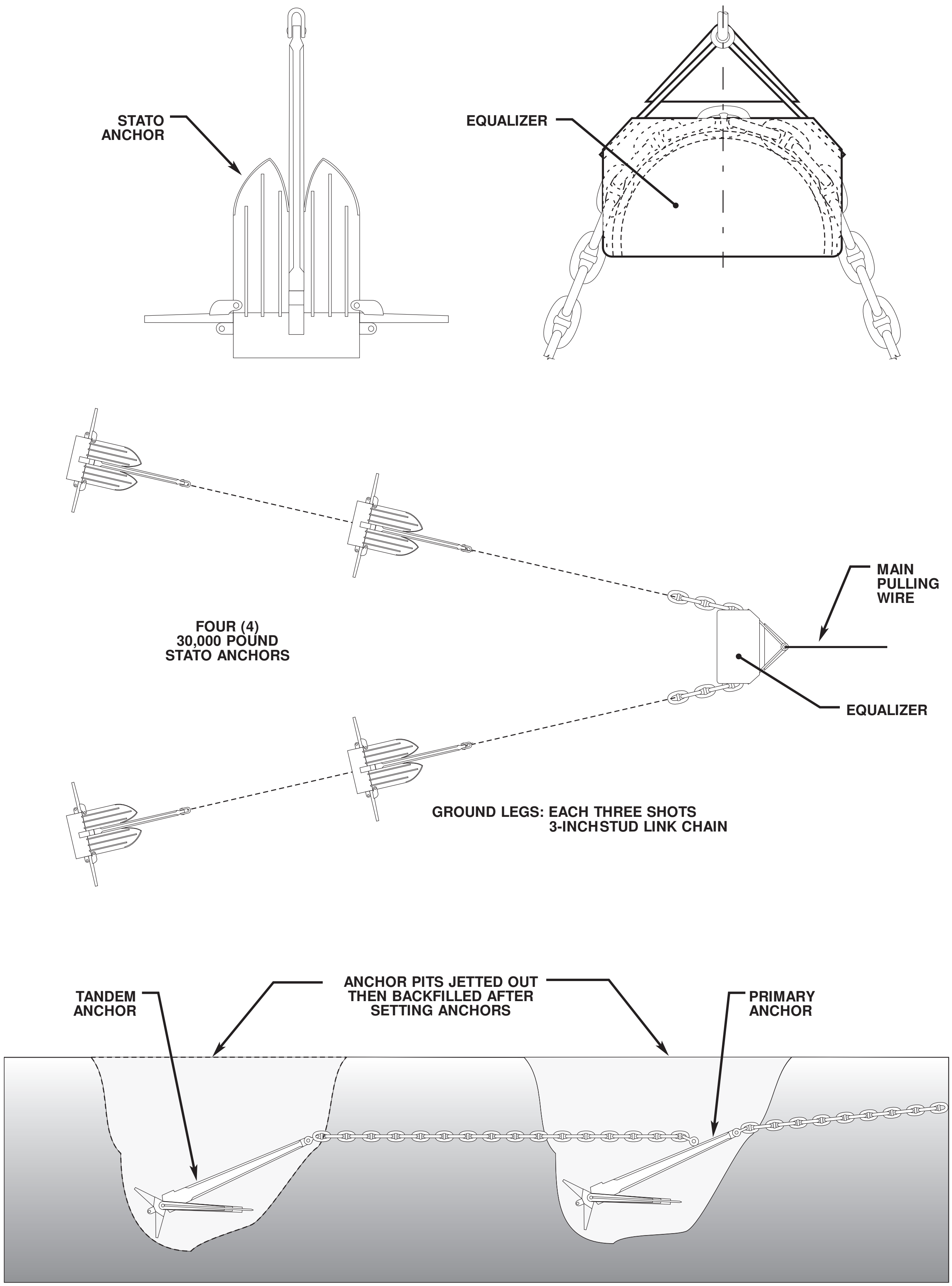


Figure 7-24. Yoked Anchor Placement Pattern.

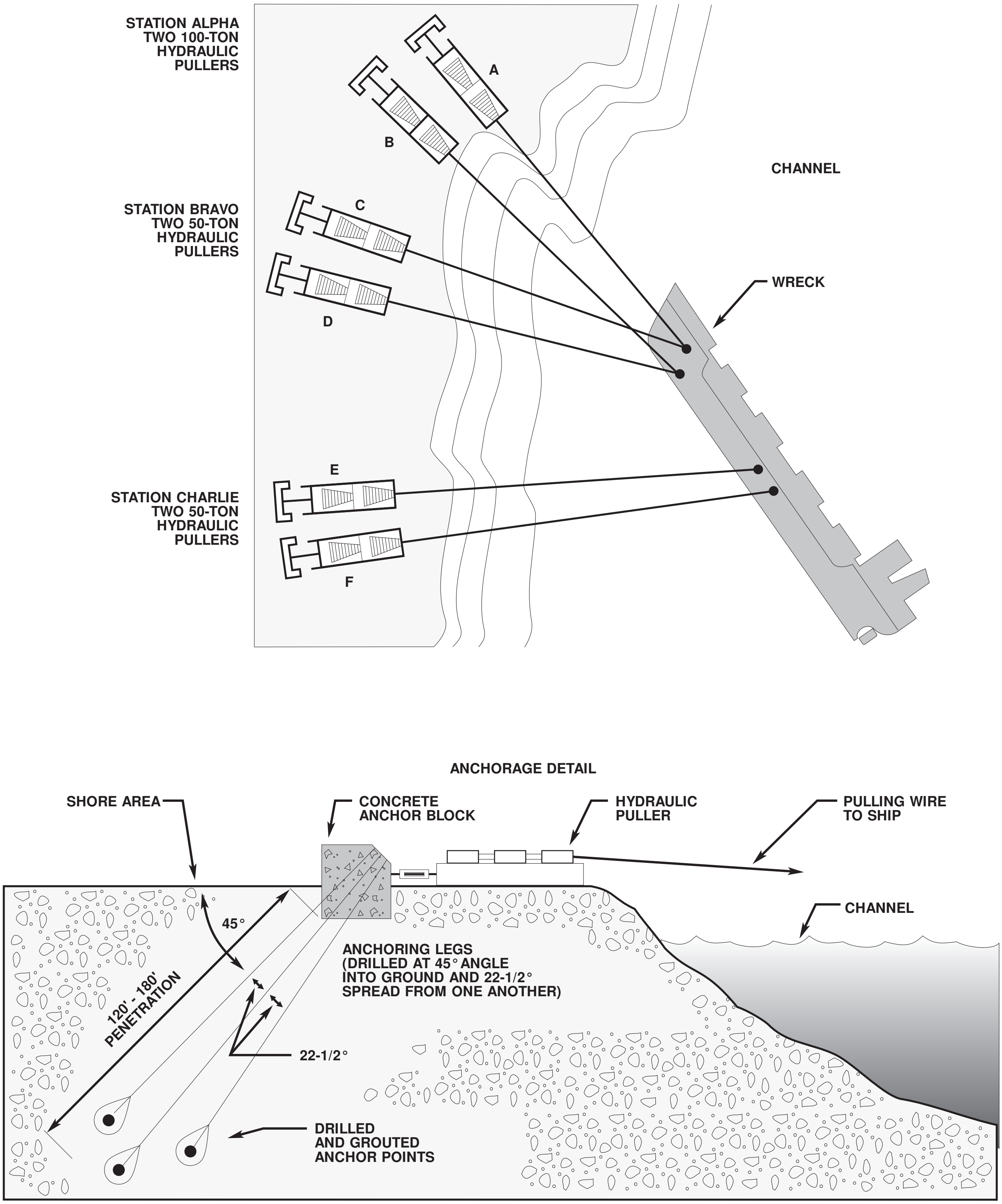


Figure 7-25. Guyed Anchor System.

Factors influencing anchor performance as ground tackle in a beach gear system are equally applicable to anchor performance in righting hauling systems.

Unfortunately, drag-embedment anchors have a history of dragging or failing to hold at maximum tensions developed by marine-based righting systems. Before a large conventional drag-embedment anchor is laid for a righting operation, several checks should be made, including:

- Confirmation of water depth
- Underwater inspection of proposed anchor pattern areas to confirm that no bottom obstructions exist
- Test-lay one anchor leg of the proposed system by tensioning to the maximum load obtainable from its pulling system.

Conventional drag embedment anchors may require extensive jetting and/or airlifting and pumping for burial to maximum penetration. When a test anchor leg either fails to hold or appears to have dragged excessively, a soil coring and analysis should be made. Conventional anchor systems in righting operations require careful planning of anchor patterns to ensure holding power is almost fail-safe. Anchor patterns and laying techniques are most successful if they are modeled on buoy mooring anchor patterns. Positioning and laying of anchors should follow mooring techniques. Dropping anchors will not produce very effective results. A better mooring system can be established when time is taken to conduct operations systematically. Figure 7-24 shows a yoked anchor placement pattern adopted for some righting moorings with heavy STATO or NAVMOOR anchors in tandem. The center of Figure 7-24 shows the layout of four 30,000 pound SATO anchors with an equalizer. Equalizers are typically used in anchoring situations with “doubled” anchors that are rigged in parallel. The second anchor added to the ground leg improves holding power and the equalizer offers equal support from each rigged anchor leg. This set up is used in situations where there is limited scope or poor holding ground.

7-8.5.2 Marine-based Anchorages. The following sections discuss marine-based anchorages.

7-8.5.2.1 Direct-embedment Anchors. Some anchorage areas are suitable for direct-embedment anchors. Such anchors include:

- Propellent-embedment anchors
- Vibratory-driven anchors
- Auger anchors
- Wire-guyed tension anchors
- Pins or rock bolts grouted into holes drilled into structurally competent rock.

The specific type of direct-embedment anchor is selected for the engineering properties of the soil, topography and strata thickness, and environmental and work area requirements. Salvage engineering personnel will arrange for soil tests and evaluation of direct-embedment anchors for parbuckling anchors. Figure 7-25 shows a typical guyed anchor pattern for a shore-hauling operation. This anchoring system can be considered both a shore based and a direct embedment anchorage.

7-8.5.2.2 Piled Anchorages. Piled anchorages are used when soil analysis, high pulling forces, or a combination of both, makes conventional anchoring systems unsuitable. Piled anchorages typically feature large-diameter, heavy-wall-thickness steel tubes, or wide flange sections (H-piles), driven to penetrations specified by engineers. Although salvage personnel may not be concerned actively with pile-driving operations, they must know:

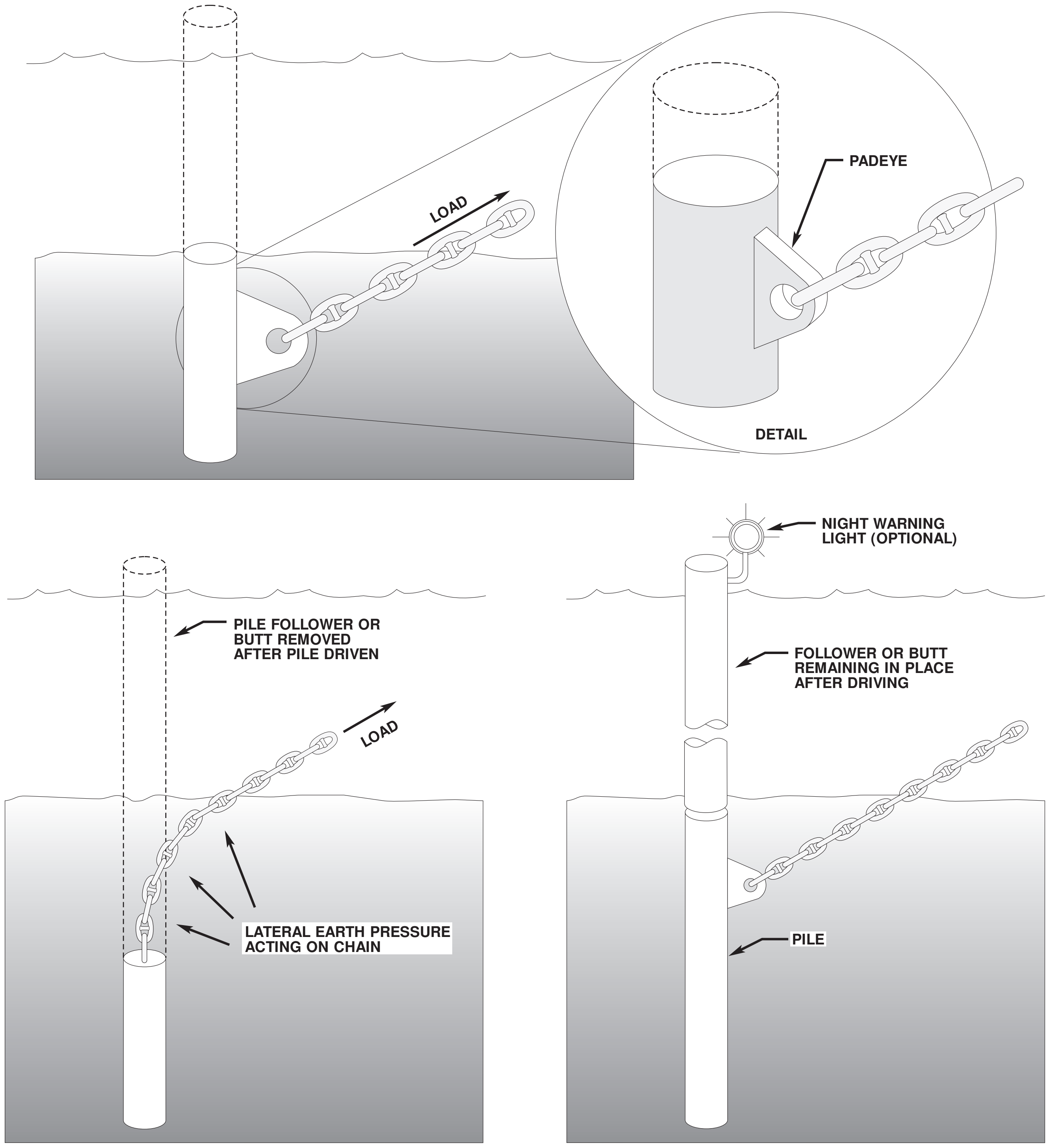
- Proposed method of attaching main anchorage hauling wires to piles
- That connections between tail chains or follower wires on piles are compatible with salvage hardware
- Whether piles will be cut off at seafloor level after driving, or pile followers (driving lengths) will remain above water (Pile butts or pile followers projecting above sea level are a navigation hazard, but the practice of allowing them to remain is not unusual.)
- Method of extracting piles, and whether salvors will be involved with pile removal.

Figure 7-26 shows a typical anchor pile arrangement and details of connection methods common for securing hauling anchor wires.

Small discarded or damaged, but floating casualties rigged with multiple-chain pigtails have been sunk at anchorage locations as large underwater deadman moorings.

7-8.6 Restraining Tackle. Restraining tackle must be placed to prevent the horizontal fore-and-aft and athwartships components from moving the ship toward the force. The force developed by the restraining tackle must equal the horizontal components of the righting force and act in the opposite direction.

Restraining tackle laid against athwartships movement usually consists of chain or wire rope attached to a connection point similar to those described in Paragraph 7-8.4.2. The connection point is on the high side of the hull. The chain or wire rope is led around the hull and to an anchorage point on the side opposite the pulling force. The anchorage may be any of the types described in Paragraph 7-8.5. Bulldozers, beach gear, or drag-embedment anchors are most often used as restraining gear; they are attached to the hull by chain or wire rope secured to a strong point and provide restraint against fore-and-aft movement. Typical layouts of restraining tackle during righting operations are illustrated in Figures 7-12 and 7-20.



(a) PILE HEAD DRIVEN BELOW SEAFLOOR

(b) PILE HEAD DRIVEN BELOW SEAFLOOR WITH FOLLOWER LEFT ON PILE

Figure 7-26. Typical Piled Anchorage Details.

7-9 WEIGHT REMOVAL.

In almost every case where ships capsize and sink, salvors must remove structure or steel weight before righting the ship. Structure most frequently removed includes:

- Masts, stacks, and cranes
- Superstructure
- Weapons mounts and weather deck fittings
- Large sections of hull structure below the main deck.

This section discusses some general aspects of weight removal in capsized ships. No two sunken, capsized ships exhibit identical characteristics to salvors, even when ships are of the same type. In stranding situations, no two casualties are exactly the same. In capsized ships, a weight that must be removed on one ship becomes a useful weight to retain on a sister ship capsized under different circumstances.

7-9.1 Weight Removal. Weight or structural sections of capsized ships are removed for one of four reasons:

- Structures that will prevent righting of the ship, or will cause damage to salvage vessels, are removed to allow operations to proceed.
- Total capacity of available righting forces cannot overcome the calculated capsizing moment unless weights are removed.
- Weight, such as mud, silt, or debris, that enters a capsized ship after it has sunk, usually is removed to reduce righting force as a matter of good salvage practice.
- The weight concerned is of a hazardous or pollutant nature, such as ordnance or fuel oil.

Weight removal plans consider several factors, including:

- Getting maximum reduction of capsizing moment with minimum possible surface and diver work
- Not compromising or making refloating operations more difficult as a result of structural removals
- Availability of lifting equipment, either mechanical or buoyant, that governs the size and weight of sections that can be handled safely.

7-9.2 Weight Removal Methods. Methods of removing weight from capsized ships depend upon the location of weight or structure relative to average high and low water levels. As a general rule, any structural elements that are out of water throughout the tidal cycle are wholly or partially removed by conventional surface burning and cutting. Structural sections or individual weight elements that are wholly underwater are cut away by divers. Subject to equipment availability, some major surface and underwater sections may be removed by mechanical or explosive cutting. Chapter 9, Wrecking in Place, discusses the practical applications of these methods.

7-9.3 Weight Removal Calculations. Weight removal calculations are performed in the same way that was discussed in Chapter 4. The center of gravity of any removed structure or weight should be either measured or estimated.

EXAMPLE 7-2
WEIGHT REMOVAL

A 3,800-ton (lightweight) ship, described in Example 7-1, is to be righted. Salvors have concluded that a large quantity of mud has entered the ship, and that the superstructure will seriously hamper righting operations with floating cranes. Measurements and locations are shown in Figure 7-27. When a ship is capsized, height and breadth can become confused. It is usual in salvage to refer to positions of the ship as though the ship were upright. Thus, a center of gravity is referred to as "above the keel" though it may actually lie alongside.

a. It is estimated there is a 4-foot layer of mud distributed from the double bottom to the main deck in two major spaces. Mud weight is about 100 pounds/ft^3 in water. Divers' surveys show that mud extends for 120 feet lengthwise, and about 36 feet in height, measured from tank top to main deck.

   Mud volume: 120 × 36 × 4
   = 4,320 x 4
   = 14,400 cubic feet

   Mud weight: 17,280 × 100
   = 1,728,000 pounds
   = 864 short tons or 771 long tons

   Center of gravity of mud: 20 feet above *R*

   Moment about *R* = 20 × 771 long tons
   = 15,420 foot-long tons

   Therefore, 771 long tons of mud have increased the righting moment requirement from 72,200 to 87,620 foot-long tons.

b. Superstructure to be removed has a total weight of 125 (long) tons, with a mean center of gravity located 12 feet above the main deck level, or 50 feet above the keel.

   Moment reduction = 125 x 50
   = 6,250 foot-long tons

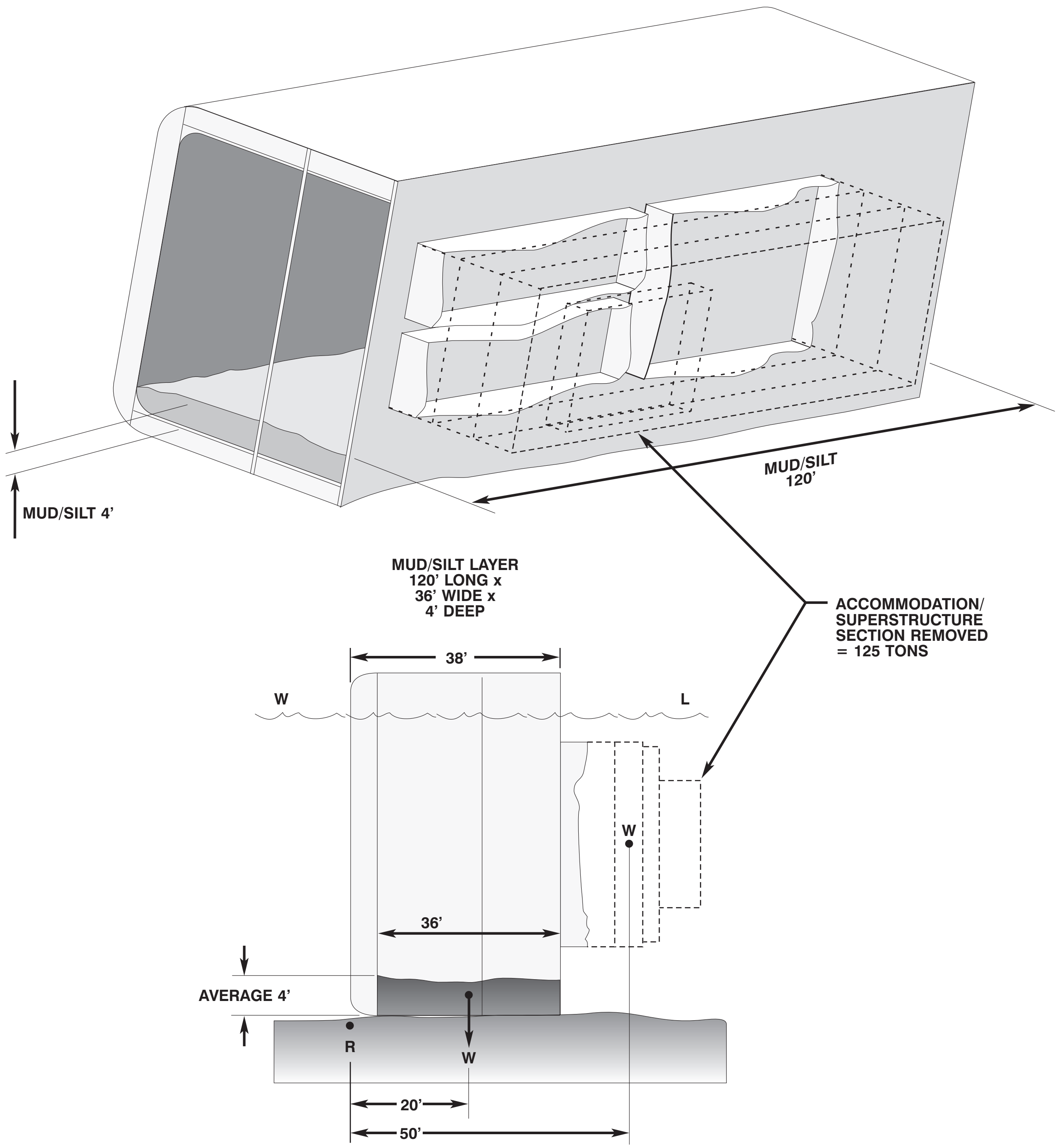


Figure 7-27. Measurements for Weight Removal.

7-10 RIGHTING CALCULATIONS.

This section demonstrates, with an example, the basic calculations and rationale that are essential parts of planning a righting operation.

EXAMPLE 7-3
RIGHTING CALCULATION

The ship described in Example 7-1 is capsized and almost completely submerged, lying on her port side about 150 feet from a wharf. Salvage efforts are to right, then refloat the ship. The calculations that follow are based on the following assumptions about the ship:

- She is capsized to an angle of 90° and lying on a uniformly hard seafloor of coral sand.
- Water depth varies only 1 foot between bow and stern, so the ship has no trim.
- The tidal range of 6 feet means the ship's starboard side is never submerged at high water.
- No siltation has occurred inside the hull.
- No cargo or ordnance was on board and all fuel oil and lubricants have been removed.
- Divers' survey shows there are no seafloor obstructions to damage the hull after rotation occurs.
- Rotation point will be at or close to the port bilge.
- Two ARS-50 class salvage ships are available.

Determine a method for uprighting the ship.

a. **First Calculation**. The first calculation is based on applying a righting pull directly to the starboard sheer strake of the unlightened ship with only mechanical forces, as illustrated in Figure 7-28A.

Given:	Light weight of 3,800 long tons, ship and condition as in Example 7-1
Moment to overcome:	72,200 foot-tons
Vertical distance between *R* and starboard sheer strake:	60 feet
Minimum force to equal capsizing moment:	$\frac{\text{Capsizing moment (foot-tons)}}{\text{Lever arm (feet)}}$ $F = \frac{72{,}200}{60}$
Minimum pull to equal capsizing moment:	1,203 long or 1,347 short tons

Since an allowance of 20 percent of the minimum pull would be a prudent margin for error, righting pull would be:

1,347 × 1.20 = 1,616 short tons

or

1,650 tons, for practical purposes

This is an unreasonably high pull equaling 33 sets of Navy standard beach gear with a pull of 50 short tons each; clearly impractical for this task.

CONTINUED

EXAMPLE 7-3 (CONTINUED)

b. **Second Calculation**. Apply the righting pull to headframes erected on the starboard side of the ship, as illustrated in Figure 7-28B. Allow headframes to be 25 feet above the starboard side of the ship.

Given:	
Moment to overcome:	72,200 foot-tons
Vertical distance between *R* and top of head frames:	85 feet
Minimum force to equal capsizing moment:	$\frac{\text{Capsizing moment (foot-tons)}}{\text{Lever arm (feet)}}$ $F = \frac{72{,}200}{85}$
Minimum pull to equal capsizing moment:	849 long or 951 short tons

Allowance of 20 percent of the minimum pull is retained as a prudent margin for error. Righting force requirement:

951 x 1.20 = 1,141 short tons

or

1,150 tons, for practical purposes

This force equates to the pull developed by 23 sets of Navy standard beach gear. Although more favorable than the result of the first calculation, further examination is required to reduce the amount of shore-based pull.

c. **Third Calculation**. Two ARS-50 class salvage ships with a bow lift capability of 150 tons each are available. If the salvage vessels make a combined lift of 300 tons on the port sheer strake, as illustrated in Figure 7-28C, what effect is there on the capsizing moment?

Horizontal distance from *R* to edge of port sheer strake (molded depth):	38 feet
Force exerted by 2 × ARS-50:	300 short tons
Reduction of capsizing moment:	300 x 38 = 11,400 foot-(short) tons or 10,179 foot-(long) tons

Percent total moment = 10,179/72,200

Percent total moment = 14.1

Therefore, the bowlifting ARSs overcome slightly less than 15 percent of the capsizing moment, and would be a valuable contribution to the righting effort.

NOTE

If there is enough sea room, the ARSs could wrap chains around the wreck and lay off and haul against beach gear to help rotate the wreck. This method requires additional work to pass the chains and carries the hazards of the beach gear dragging near maximum load and possible damage to the hull from the parbuckling chains.

CONTINUED ON NEXT PAGE

EXAMPLE 7-3 (CONTINUED)

d. **Fourth Calculation**. There are pairs of large fuel oil deep tanks forward and aft of the casualty's machinery spaces. Each pair of deep tanks has a salt water capacity of 500 tons, and each pair extends halfway across the ship. Both starboard tanks are accessible for dewatering with salvage pumps and both port side tanks can be dewatered with compressed air. Each pair of deep tanks has an effective *kg* of 19 feet.

The contribution to righting made by dewatering these tanks would be:

- Net weight to be righted:

  3,800 - 1,000 = 2,800 long tons

- A modified capsizing moment:

  2,800 tons x 19 = 53,200 foot-(long) tons

That when combined with:

- A moment created by the ARS on bow lift:

Gives:

300 × 38 = 11,400 foot-tons = 10,179 foot-long tons

- Residual moment to be overcome by pull on headframes:

  53,200 - 10,179 = 43,021 foot-(long)tons

CONTINUED

EXAMPLE 7-3 (CONTINUED)

SAMPLE TABULAR LAYOUT FOR ABOVE INFORMATION

	Force (long tons)	Lever (feet)	Moment (foot-long tons)
Light weight	3,800		
Regained buoyancy	1,000		
Weight to be rotated	2,800	19	53,200
ARS bow lift	268	38	10,184
Righting moment			43,016
Righting force	43,016/85'=506 long tons×1.2 = 607 short tons		
With Contingency	607 long tons × 1.2 = 680 short tons equivalent to 14 sets of Navy standard beach gear.		

Figure 7-28D shows the basis of these calculations.

Conclusions. Each assumption is tested by simple calculations based on a general plan that suits the casualty conditions. The result of these calculations is that a conventional righting operation can be based upon:

- 700 short tons of external pulling force applied through headframes 25 feet high by 14 sets of beach gear
- 300 short tons of external lift applied by two ARS-50 Class ships making 150-ton bow lifts

The proposed righting plan must be analyzed for both theoretical and practical difficulties. Failure to analyze the proposed righting plan may result in entirely avoidable lost time and wasted effort. Salvage engineers should make more complete calculations.

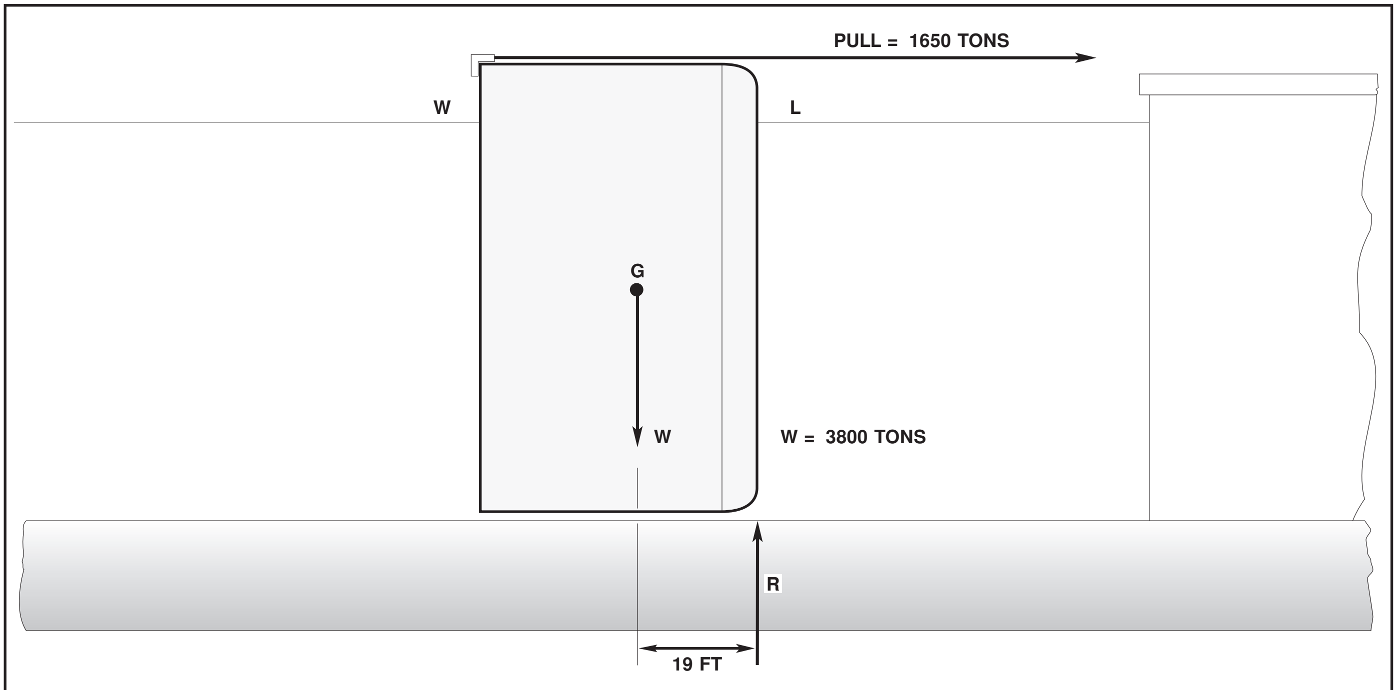


Figure 7-28A. Pulling on Sheer Strake.

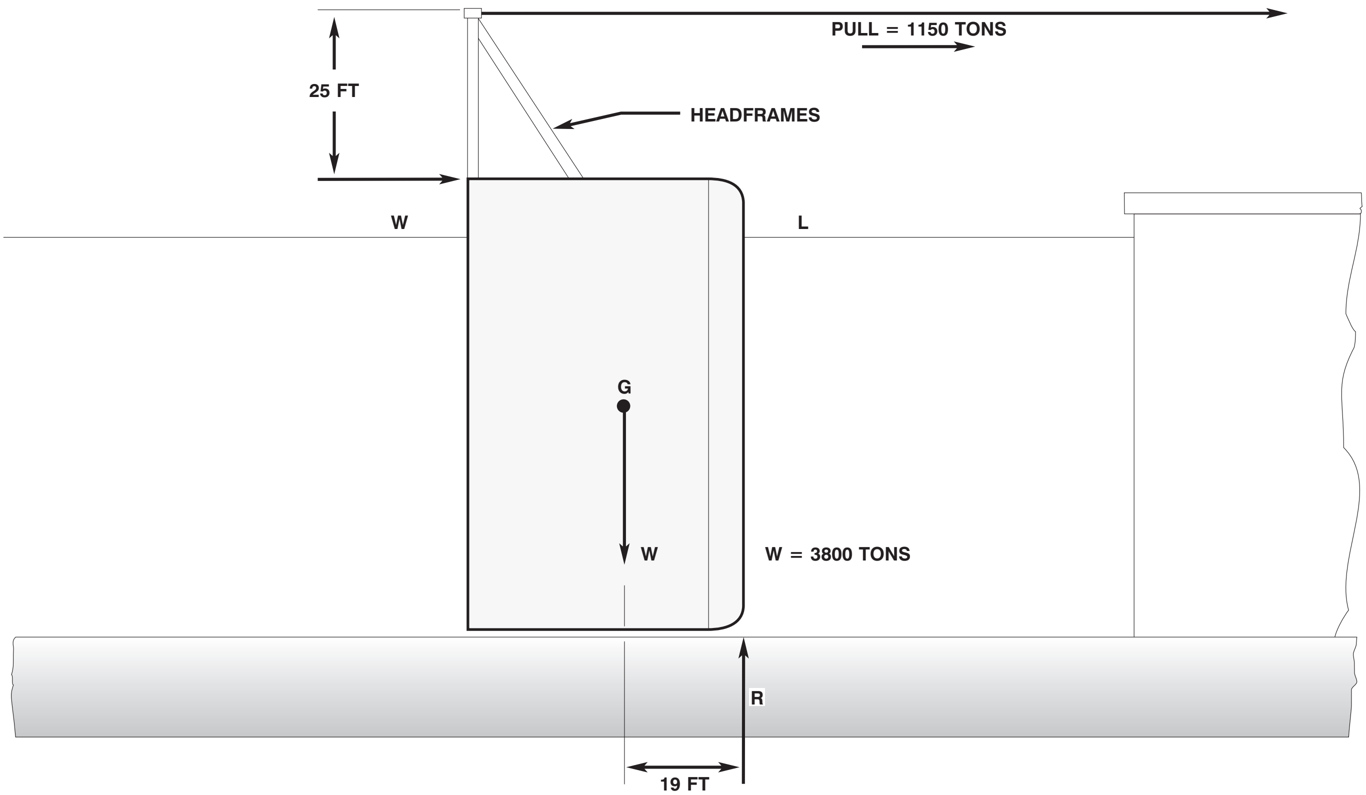


Figure 7-28B. Pulling on Headframes.

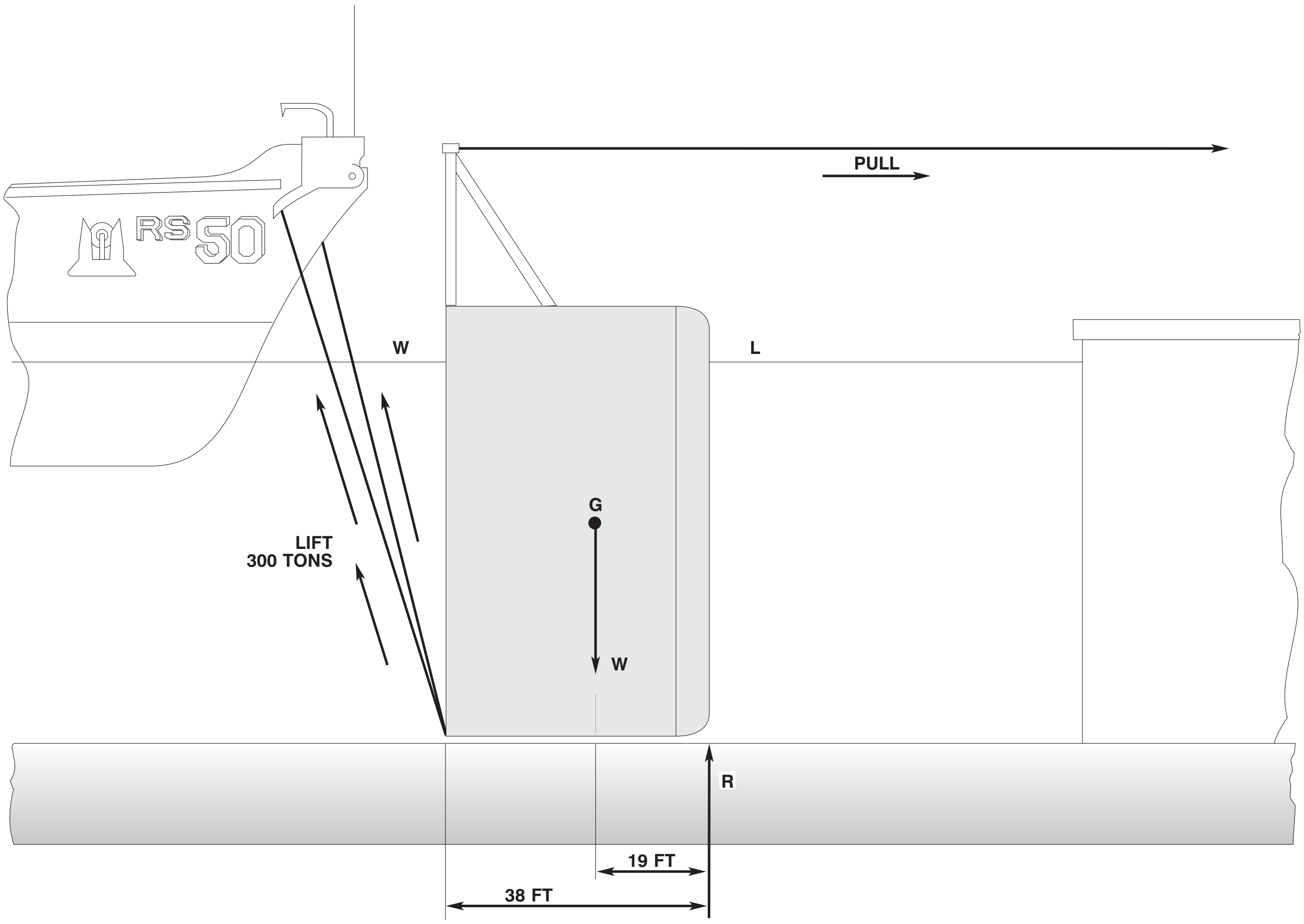


Figure 7-28C. ARS Bow Lift.

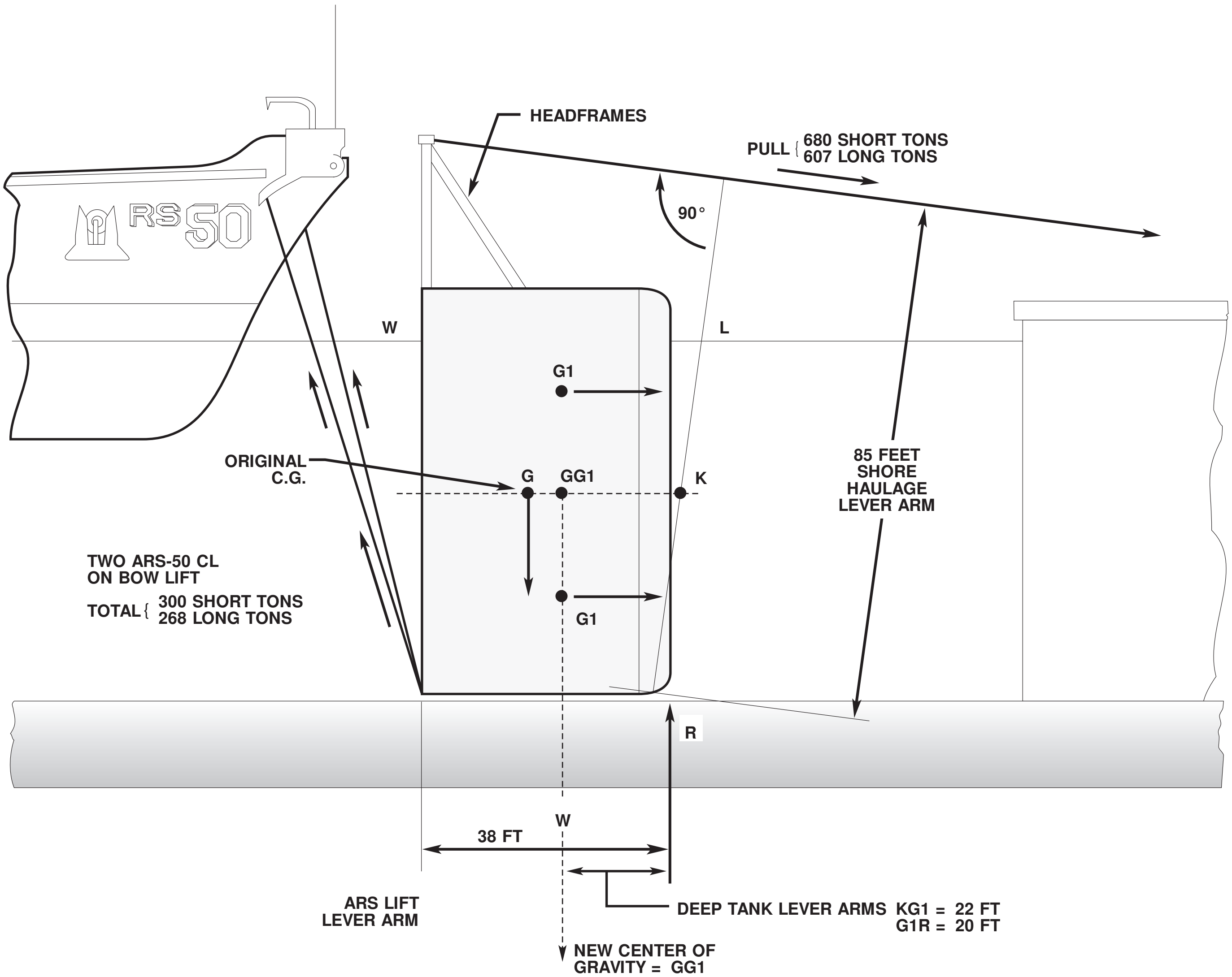


Figure 7-28D. Combined Pulling, Lifting, and Buoyancy.

CHAPTER 8
GROUND REACTION REDUCTION, PULLING SYSTEMS AND BEACH GEAR

8-1 INTRODUCTION TO GROUND REACTION REDUCTION AND PULLING SYSTEMS.

This chapter provides general information on ground reaction reduction and pulling systems, as well as information about Navy standard beach gear carried on Navy salvage ships and provided by ESSM. These systems are critical in refloating stranded ships. When a ship is stranded, it is the job of the salvors to refloat her quickly, safely, and economically. While each stranded ship presents a unique combination of problems, all have common elements and respond to time-tested techniques that have solid engineering bases. There are essentially three things that must be done with a stranded ship:

- Stabilize her upon her strand so that her condition does not deteriorate.
- Reduce the ground reaction to the point where it can be overcome.
- Move the ship into deeper, safer water.

Maintaining control of a casualty is key during the utilization of ground reaction reduction and pulling systems. If control of the casualty is lost, the stability of the vessel and the entire salvage operation may be jeopardized. Three ways in which the stability of a casualty can be enhanced with the help of pulling systems, specifically during refloating is:

- To physically constrain the casualty from capsizing by holding one end on the bottom while refloating the other.
- To increase the effective breadth of the waterline of the casualty by rigging barges, pontoons, or lift craft alongside.
- To apply additional forces through the pulling systems to counter the upsetting forces.

This chapter discusses methods for reducing ground reaction and pulling systems for moving the ship.

8-2 REDUCING GROUND REACTION.

To refloat most large ships and many small ones, it is necessary to reduce the ground reaction so that the freeing force will be within the capacity of the pulling systems that it is practical to employ. In some cases, such as those of laden tankers where the ground reaction may be sharply reduced by removing cargo, it is possible to refloat the ship by ground reaction reduction alone. In other cases, a combination of ground reaction reduction and pulling is used. Ground reaction should be reduced as much as practical to minimize damage from dragging the ship with her bottom in contact with the seafloor. In some cases it may be preferable to refloat (reducing ground reaction) than retract. The following paragraphs discuss five methods of reducing ground reaction to aid in refloating:

- Weight management (Paragraph 8-2.1)
- Induced Buoyancy (Paragraph 8-2.2)
- Ground Removal (Paragraph 8-2.3)
- Lifting (Paragraph 8-2.4)
- Temporary reductions (Paragraph 8-2.5).

8-2.1 Weight Management. Of the five means of reducing ground reaction, weight management is the most widely used because it applies to almost every stranding. Weight management includes determination of the effects of weight on stability and hull strength, removal or redistribution of weight to reduce ground reaction, and temporary replacement of weight to hold the ship on her strand until a refloating effort is ready. Weight changes must be carefully planned, and their effects determined before changes are made. In most strandings, the effects of weight changes on stability and hull strength will limit the changes that can be made.

Weight removal is the preferred method for reducing ground reaction.

- Weights added or removed at the center of ground reaction cause a change in ground reaction equal to the weight change. Buoyancy remains unchanged.
- Weights added or removed at the neutral loading point cause a change in buoyancy equal to the weight change. Ground reaction remains unchanged.
- Adding weight forward or removing weight aft of the neutral loading point will increase ground reaction
- Removing weight forward or adding weight aft of the neutral loading point will decrease ground reaction.

Weight changes must be coordinated with other salvage actions so that the maximum benefit of the weight management program will occur when other refloating actions are ready. Chapters 3 and 5 present means for determining the effects of weight changes on stability, strength, and ground reaction. The weight control log, described in Figure 6-10, should be used as a tool to control and coordinate weight changes as well as to maintain an accurate record.

8-2.1.1 Weight Changes. The choice of weight to be removed is usually dictated by the conditions of the stranding, the weight that can be removed, and the facilities for handling and receiving weight. The payload of a warship or the cargo of a naval auxiliary or commercial vessel, one of the largest quantities of weight in a ship, is a primary candidate for weight removal. Payload and cargo have military or commercial value and should be handled with care to reduce loss and damage. Jettisoning of cargo should be the last choice and should be undertaken only when there is no alternative. Jettisoning of cargo, even cargo that is environmentally benign, may be prevented by local authorities. Cargo handling is time consuming, generally labor intensive, and payload or cargo handled during salvage operations may be damaged. Cargo discharge should be carefully planned and limited to the minimum amount consistent with reducing the ground reaction to the point intended.

The variety of cargoes carried at sea is almost limitless. Many require special handling procedures and expertise; many are serious pollutants. A large percentage of modern cargo vessels have no facilities for either loading or discharging cargo. Removal of cargo from these ships at a salvage site may be a difficult problem. It is neither the purpose of this manual nor within its scope to discuss handling of military payload or cargo in detail. During salvage operations, advice and on-site expertise in procedures and requirements for handling payload or cargo may be obtained from the ship's operational commander or operator, the cargo owner or manufacturer, or the Coast Guard. This paragraph discusses basic considerations in handling cargo as removable weight during salvage operations.

Liquid cargoes and stores are the easiest to remove because they can be pumped into suitable receiving vessels. Handling of petroleum cargoes and ships' bunkers under emergency and salvage conditions is discussed in detail in the *U.S. Navy Salvage Manual, Volume 5* (S0300-A6-MAN-050). Other liquid cargoes may require special handling to preserve the cargo and prevent environmental damage. Expert assistance in handling these cargoes should be sought through the Supervisor of Salvage. Some bulk cargoes — ore concentrates, grains, and the like — may be slurried by mixing them with water and handling them as liquid cargoes by pumping them to suitable receivers. Others are best removed with vacuum devices.

Containers present a difficult problem when the ship has no unloading installation. Containers may be discharged by hand and the empty container jettisoned. The operation will be long and expensive. Container weight may be trimmed to the lifting capacity available and the partially loaded containers lifted off with helicopters.

In ships that strand without significant payload, cargo, or other easily removable weight on board, it may be necessary to remove and carry away rigging, masts, deck machinery, and superstructure in order to remove significant amounts of weight from the hull. Hull strength members must not be cut away or the strength of the hull itself impaired in any other way. Material removed from the ship should be protected and preserved so it may be reinstalled after refloating.

Sea conditions can limit weight removal operations, especially when the weight is being transferred to a vessel alongside. Helicopters are invaluable when weather permits their operation. Highlines between the ship and the salvage ship lying to seaward may be used to move cargo into a barge moored between them. *NWP-14* should be consulted for guidance in rigging highlines for transfer.

There is no limit to the ability to remove weight from a stranded ship other than the expertise and imagination of the salvor. Part of the expertise is knowing when to call in experts in cargo handling procedures and cargo characteristics. All weight removal operations must be carefully planned, and the effects of the removal on stability, strength, and ground reaction must be calculated prior to commencing the operation.

8-2.1.2 Temporary Weight Replacement. When weight is removed, the ground reaction is reduced, and the ship is in danger of being driven farther ashore. Prior to removing any weight, ground tackle should be laid and tensioned to prevent the ship from going farther ashore as weight is removed. If for any reason it is not practical or it is undesirable to lay and tension all the ground tackle necessary to hold the ship, the weight removed may be temporarily replaced with water to hold the vessel firmly on the strand until all preparations for refloating are complete. In temporary weight replacement, there are three things of importance:

- The effects of the replacement weight on stability
- The containment of the replacement weight
- Rapid removal of the replacement weight.

If the ship is firmly aground and in no danger of capsizing while stranded, the effect of the replacement weight on stability can safely be ignored because the weight will be added and removed before floating the ship. If, however, the ship is supported in such a way that there is a danger of capsizing or a negative metacentric height is developed, the replacement weight must be positioned to prevent the ship from becoming unstable. A full set of stability calculations is required.

Replacement weight can be contained in a number of ways. Water may be pumped into ship's tanks or compartments, bladders, or fabricated steel tanks temporarily mounted on deck.

Whatever containment system is used, the replacement weight must be removed quickly when a refloating attempt is made. Bladders and temporary tanks located above the waterline may be fitted with large valves for rapid drainage. Compartments above the waterline can be fitted with large valves to allow over-the-side drainage. Holds and tanks located below the waterline may be pumped using the ship's bilge and ballast system if the system is operative and of sufficient capacity; otherwise the spaces should be rigged with sufficient pumps to empty the tank rapidly. There should be enough pumps to remove the water even if a number of them become clogged or fail.

Removal of temporary weight should not begin until sufficient ground tackle has been tensioned to hold the ship securely. Completion of removal should occur when full tension is reached.

If the pulling attempt is unsuccessful, the weight must be replaced rapidly to hold the ship securely until the next pulling attempt.

8-2.2 Induced Buoyancy. Buoyancy is induced in a stranded vessel by removing the water from spaces that are flooded. The three most common means of doing this are by pumping, blowing with compressed air, and displacing the water with a buoyant material.

8-2.2.1 Pumping. Pumping may be used to remove flood water from a stranded ship after the portion of the ship below the waterline has been made watertight. A complete discussion of pumping — including the criteria for selecting spaces to pump, pumping equipment, and techniques is discussed in chapter 10.

8-2.2.2 Compressed Air. Compressed air is particularly suitable for removing water from double bottoms. It is also suited for removing water from tanks that are open to the sea in their lower part, where damage is in contact with the seafloor, or otherwise cannot be reached for patching. When compressed air is used, all portions of the compartment that are to be buoyant must be made airtight.

8-2.2.3 Water Displacement. Water may be displaced from a flooded compartment by filling the compartment with a buoyant material. The material may be buoyant objects such as drums or lift bags, chemical foam, or any of a number of water displacement systems. When water displacement systems are used, the compartment need not be as watertight as when the compartment is pumped or blown. The buoyancy gained is the buoyancy of the entire compartment less the weight of the water displacement material. Some materials — particularly chemical foam — are extremely expensive, difficult to use at a salvage site, or marginally effective.

8-2.3 Ground Removal. Removal of the ground under a ship allows the ship to sink deeper into the water and, thus, recover some of the buoyancy lost on grounding. In some cases, it will be necessary to remove ground to seaward of the ship to form a channel whereby the ship may reach deep water. The effectiveness of ground removal depends upon the nature of the seafloor under the ship. Sand and clay seafloors can be removed with relatively little effort and once removed will not fill in immediately. Hard seafloors cannot be removed easily, and very soft seafloors tend to fill in after initial removal. Rocks upon which the ship is impaled must be removed to allow the ship to move, but their removal provides little, if any, reduction in ground reaction.

8-2.3.1 Scouring. Scouring is the use of currents to remove ground from around a ship. Currents may be produced by the propeller wash of tugs alongside, the ship's propeller wash, or jetting pumps. Breakwaters, or groins, may be built perpendicular to the beach to set up currents that will prevent ground buildup around the ship or will scour away the ground. Scouring is most effective in sand or mud seafloors. The method of scouring chosen depends upon the assets available, the conditions at the site, and the amount of ground to be moved:

CAUTION

Tugs, trimmed by the stern to direct the propeller wash downward, can be moored alongside the casualty with their stern directed towards the area from which ground is to be removed. The tug lies alongside the stranded ship at an angle of about 50 degrees to her heading, then builds up to full power and gradually works her way aft. Lines from the stranded ship and the tug's towline may be slacked or hove taut to change the direction of the wash. The wash from the tug's propeller scours against the stranded ship's bilge, carrying seafloor material down the side and clear of the casualty. Tugs may also work from amidships forward and may scour both sides simultaneously. Scouring by tugs is most useful in easily scoured seafloors such as sand, and may be used to move moderate amounts of ground from under specific areas of the ship. Tugs with controllable-pitch propellers should not be used for scouring because sand and other abrasive material stirred up may damage the pitch-control mechanism. Scouring by tugs should be avoided if dredges are available and ground removal is necessary. Figure 8-1 shows scouring by a tug.

- The stranded ship's propeller may be run astern to wash the ground away from the after section of the ship. The effect will be limited to the area immediately in the way of the propeller. When the ship's propeller is used for scouring, high suctions should always be used to minimize the infusion of seafloor material into the ship's machinery. Scouring should not be attempted when the ship has controllable-pitch propellers or other under-water installations that may be damaged by sand.

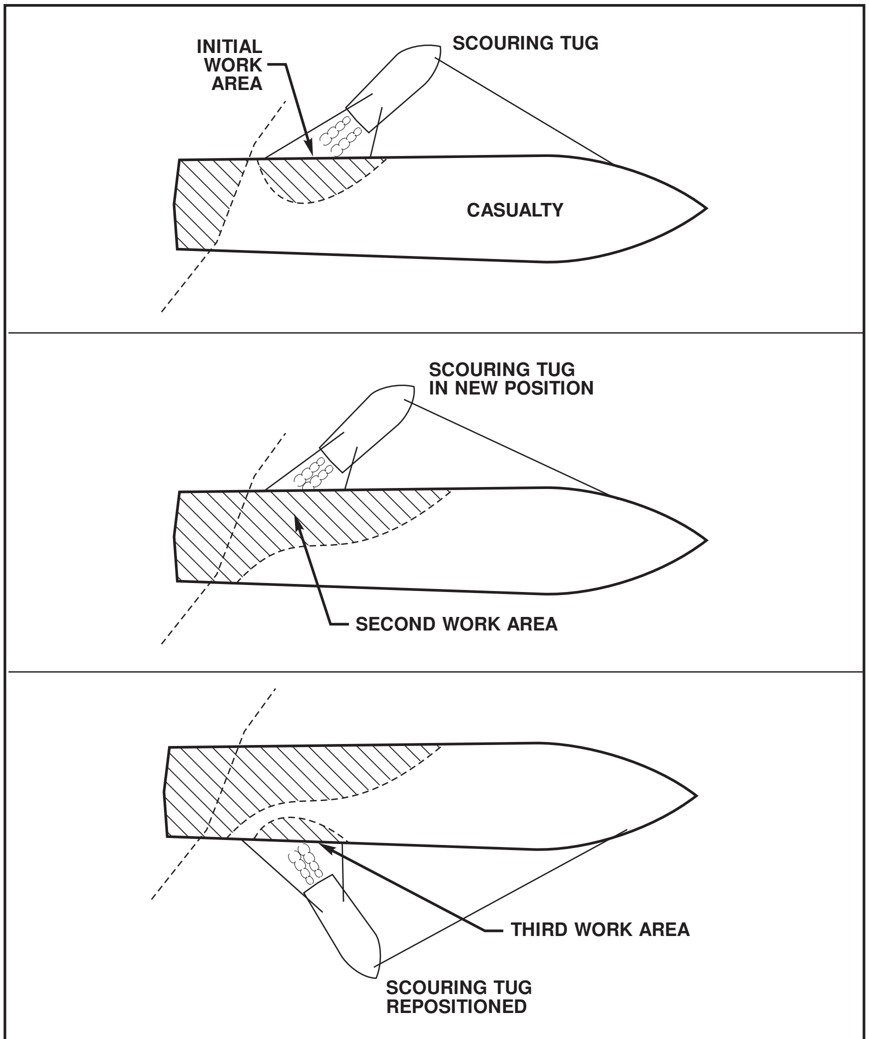


Figure 8-1. Salvage Tug Scouring Away Soft Material.

- Jetting pumps or other high-pressure pumps may be used to scour limited areas. Pumps may be operated from the stranded ship, but it is usually better to locate them on tugs or barges that are closer to the water and more mobile.

8-2.3.2 Dredging. Dredging is used to move large quantities of soft seafloor material from around and under a casualty and to dig channels to deep water. The equipment used for dredging depends upon the situation of the casualty.

When dredges cut trenches close alongside casualties in soft or fluid soils, soil from under the ship will flow into the hole, and the ship will sink correspondingly lower in the water. If a ship is high and dry, or nearly so, bulldozers followed by floating dredges may construct a pond in which the ship can be floated and may also dig a channel to deep water. When building a pond and lowering a ship into it, a good practice is to leave columns or ridges of the seafloor material under the ship to support her as blocks do on a drydock. The ship can be lowered into the pond under control by washing away the supports with jetting pumps.

Small quantities of dredging, particularly ground removal around the casualty's seaward end and bilges, can be undertaken by barge-mounted jet pumps (eductors) or diver-operated jet pumps and air lifts.

Dredging, in salvage, is a complicated operation requiring time, work, planning, and careful coordination with other work. The Army Corps of Engineers is the Department of Defense resident expert in dredging.

They use a variety of dredging equipment and techniques to keep navigation channels open, perform beach replenishment, perform environmental restoration as well as shore protection. They are an excellent source of information regarding dredging.

8-2.3.3 Rock Removal. Impaling rock or rock upon which the ship rests is the most difficult type of seafloor to remove. Impaling rock may sometimes be removed from inside the ship by chipping with jackhammers. Jackhammers and explosives may be used outside the ship. Explosives carry with them the risk of additional damage to the ship and should be used only by experienced personnel. Explosive standoff distances must be calculated and used to prevent damage to the ship's hull. Explosives may be used to cut channels in hard seafloors. *The Technical Manual for Use of Explosives in Underwater Salvage,* NAVSEA-SW061-AA-MMA-010, provides information on the employment of explosives in salvage work.

8-2.4 Lifting. Ground reaction may be reduced by physically lifting the ship. Methods of lifting the ship to reduce ground reaction include jacking, pontoons, helicopters, and cranes or sheer legs.

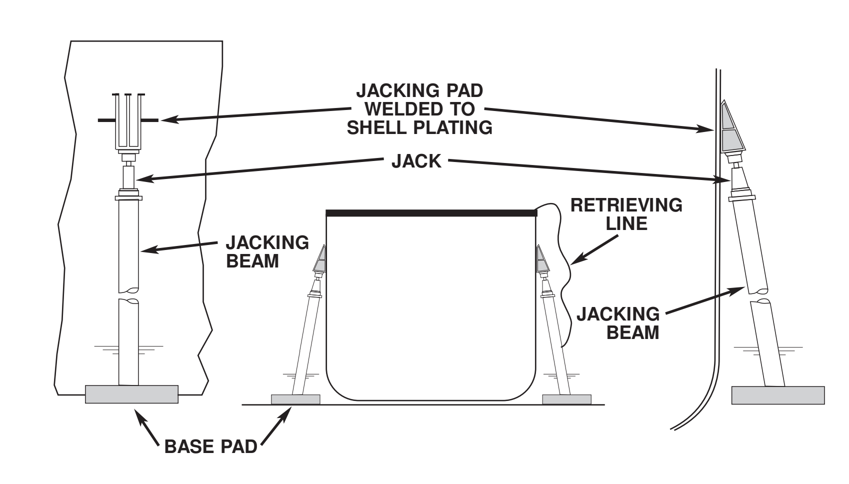


Figure 8-2. Jacking a Vessel as Part of Refloating Operations.

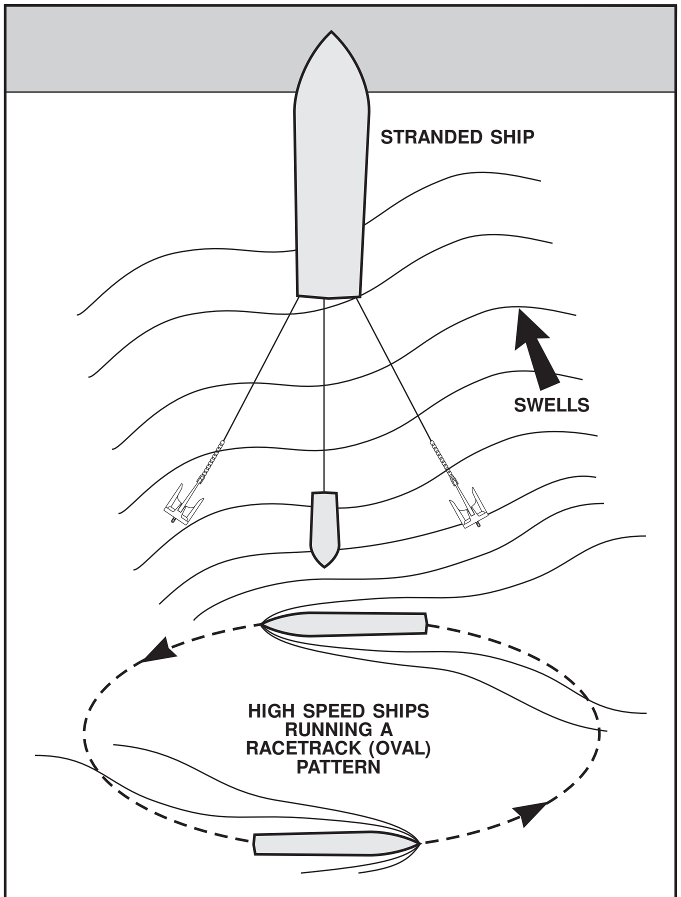


Figure 8-3. Ships Generating Swells.

8-2.4.1 Jacking. Hydraulic jacks of 60 tons or greater capacity are employed to temporarily lift stranded ships to allow them either to be refloated by pulling or to permit slipways to be constructed under them.

For jacking to be successful, the seafloor must be hard enough, or must be reinforced, to support the jacking forces. On rock seafloors, concrete rubble-filled beds or heavy timbers topped by steel plate are adequate foundations. Similarly, the hull of the ship must be protected from the jacking forces. If these forces are not spread out along the hull, they will cause local damage at the point of application and may even rupture the hull.

Steel weldments or heavy steel angles welded to the hull and padded with timbers are suitable jacking pads.

Jacks are placed symmetrically about the estimated position of the center of ground reaction and are secured with a retrieving line led to the deck. The jacks are raised to their maximum lift at the beginning of a pull. When the ship moves, the jacks will topple and must be reset for the next operation. Figure 8-2 shows jacks placed for lifting a ship.

Jacks may also be used to push the ship by placing them parallel to the seafloor between the ship and a deadman.

8-2.4.2 Pontoons. Pontoons of any description may be placed alongside the stranded ship and rigged either to the hull or with slings under the hull to provide lift and reduce ground reaction.

8-2.4.3 Cranes and Sheer Legs. Where space and water depths permit, cranes and sheer legs may be brought alongside and rigged to lift the stranded ship to reduce the ground reaction. When sheer legs and cranes are used, the refloating should be slow and controlled to prevent sudden high loading of the sheer leg tackle as the ship comes afloat and the center of buoyancy moves forward.

8-2.5 Temporary Reductions. A temporary reduction of ground reaction during a pulling attempt can either reduce ground reaction or reduce friction or both.

- Jetting pumps rigged to establish a flow of water under the casualty's hull wash away the ground under the ship and make the seafloor more fluid. Jetting hoses for fluidizing the seafloor are normally rigged over-the-side. In cases where there is bottom damage, they may be rigged through the damage to fluidize the seafloor in way of the damage. Hoses rigged through the bottom should be removed before refloating the ship.
- Air lances — pipes perforated with holes along their length and attached to a compressed air source by hoses — may also be used to fluidize the seafloor to reduce the coefficient of friction. Properly set air lances can reduce the coefficient of friction of hard sand seafloors to that of soft mud. Air lances should be driven or worked into the ground. Like jetting hoses, air lances may be worked through bottom damage.
- Swells moving on shore increase the buoyancy of the stranded ship and decrease the ground reaction as they pass. High seas or heavy swells during a retraction decrease the pulling force required to refloat the ship. When there are no natural swells, ships passing parallel to the beach at high speed create swells that act like the natural swell. Destroyers running a long racetrack pattern as close to the refloating operation as safety permits are ideal for this purpose. Figure 8-3 shows such an operation.

8-3 PULLING SYSTEMS.

Pulling systems are combinations of mechanical components that work together to apply a controlled, essentially horizontal force in a planned direction to a stranded ship. They hold the ship against the action of the sea or overcome the forces that keep the ship aground. Pulling systems are effective in refloating stranded ships because:

- They can provide large forces with relatively small amounts of equipment.
- They can be assembled quickly from common shipboard components.

- They are appropriate in almost all strandings.
- Different types of systems can be combined in the same operation.

Tugs and ground tackle are the pulling systems most commonly used in salvage. Tugs, attached to the stranded ship with a towline, develop pulling forces with their engines. Salvage ground tackle is a system of anchors, ground leg, and hauling gear rigged to pullers, purchases, or winches on a platform. The platform may be the stranded ship, an assisting ship, a barge, or the shore. In many salvage operations, the total pulling force is developed by a combination of ground tackle and tugs. Pulling systems are tailored to the particular stranding to gain maximum effect and minimize interference.

8-3.1 Tugs. ARS, T-ATF, and commercial salvage tugs are used to complete USN salvage operations. The need for enhanced tug capabilities continues to grow with the size and variability of modern day salvage jobs. Changes in hull design, propulsion systems, and maneuverability have provided towing industry and salvors with a variety of enhanced operational capabilities. Positional accuracy, automated deck machinery, and intuitive and sensitive bridge controls have contributed to today's unsurpassed tug performance. Following is a basic outline of the types of tugs and tug propulsion that can be found in the private sector.

8-3.1.1 Tug Propulsion. The most common engine used in tugs is the medium speed diesel engine. In some applications, tugs may be outfitted with a diesel-electric drive. Standard reduction/reversing gear is used in most towing applications. There are a variety of propeller configurations used with tugs. Kort nozzles provide tugs, trawlers, dredgers and offshore supply vessels with marked improvement in thrust at low speeds, allowing for a reduction in installed power for a given performance. Kort nozzles were originally introduced in the 1920s to the towing industry in Europe to reduce propeller wash and lessen erosion damage to the canals. The phenomenon that occurred as a result of their introduction was an increase in speed as well as greater thrust.

Fixed pitch propellers in kort nozzle develop maximum bollard pull and excellent low speed thrust, however, it reduces the running speed and efficiency. Following are a number of tug propulsion options used in various types of tugs:

- Fixed pitch propellers, open wheel or in kort nozzles
- Controllable pitch propellers, open wheel or in kort nozzles
- Azmuthing Stern Drive (excellent low speed thrust and bollard pull in direct and indirect towing, used in salvage tugs and escort/harbor assist tug designs)
- Cycloidal propulsion (maximum maneuverability, excellent bollard pull and thrust in both direct and indirect towing modes, used on escort/harbor assist tugs)

8-3.1.2 Types of Tugs. The tug and towing industry services four main user groups, these user groups define the types of tugs and tug capabilities. The four main types of tugs include:

- Anchor Handling Towing Supply (AHTS)
- Salvage/Rescue
- Offshore Towing
- Escort and Harbor Ship Assist.

a. Anchor Handling Towing Supply Tugs (AHTS). AHTS tugs are large, with a heavily reinforced aft deck for dealing with heavy gear. They are typically equipped with tuggers, capstan, stern rollers, and other devices used in decking large anchors, hauling cargo and long range towing operations. Many of the AHTS vessels are equipped with dynamic positioning equipment to aid in navigational accuracy. AHTS, salvage and rescue tugs as well as offshore towing tug propellers may be open, and include kort nozzles for improved thrust at low speeds. The pitch on the propellers may be fixed or variable. Some of the newer tug designs include Azmuthing Stern Drives (ASD) allowing for 360-degree maneuverability. Visibility from the bridge of the AHTS tug is excellent. These tugs are long range with moderate to fast running speeds. Due to their size, the AHTS tugs may not be as maneuverable in confined areas.

b. Salvage and Rescue Tugs. In general, salvage and rescue tugs are the largest tugs in the fleet. They are designed with deep V hulls to accommodate stability in harsh sea conditions and heavy salvage and rescue operations. With their size and capability, there is a trade off in speed and maneuverability. They have high bulwarks for protection with freeing ports for maximum drainage while operating in poor sea conditions. Most salvage tugs have large winches with "towing machines" allowing tow wire to slip if excessive pull is utilized. Salvage tugs may include controllable pitch propellers fitted in kort nozzles providing an excellent range of maneuverability and optimized bollard pull. They have large deck areas that can accommodate tugger winches and lifting devices. The deep V hull design limits shallow water operations. The high horsepower tow gear may not absorb power under all towing conditions.

Figure 8-4. Kort Nozzle.

c. Offshore Towing Tugs. The offshore towing industry may also perform anchor handling and movement of barges. Tugs designed for offshore towing typically have twin screws and high horsepower capabilities and are built with fuel, lubrication and water capacity for extended tows and other assignments. Double drum winches are normally found aboard offshore tugs for use in anchor handling and multiple barge tows. The fairleads and equipment onboard is placed to provide proper fleeting angels. The tow point is located forward to allow for maximum maneuverability. In order to handle barges alongside, the tugs are heavily fendered. Double drum winches and reinforced stern rollers allow for maximum anchor handling and multiple barge tows.

d. Escort and Harbor Assist Tugs. Escort and harbor assist tugs are designed to assist ships in docking and undocking operations in confined and potentially shallow waters. They are heavily fendered to allow for maximum contact with vessel hulls and to accommodate occasional barge movements. Some escort and harbor assist tugs utilize specialized synthetic lines with high breaking strength. In order to work under the large flares of ships the deckhouse and pilothouse can be located well inboard and have a low profile. These tugs provide precise control and maneuverability with winch controls in the pilot house. They typically have 360 degree visibility and external fire fighting capability

8-3.2 Use of Tugs on Strandings. On strandings near ports, tugs are often used to attempt an immediate refloating. Even low speed strandings usually result in ground reactions exceeding the pulling capacity of most tugs. Tugs, as the sole pulling system, normally free only lightly stranded ships. There are three steps in assessing the ability of tugs to refloat a stranded ship:

a. Determine the maximum bollard pull of each tug.

b. Estimate the reduction in pull caused by the conditions on site.

c. Determine the excess of expected bollard pull over the freeing force. Twenty-five to thirty percent is a desirable excess.

If the assessment shows there is a high probability of refloating the ship, an attempt should be made to pull with available tugs. Otherwise, the time is better spent in preparing for a more complex salvage operation wherein tugs augment ground tackle systems.

Additional information about the use of tugs on strandings is included in Chapter 9, Operations to Refloat Stranded Ships.

8-3.2.1 Bollard Pull. Bollard pull is the amount of static force a tug can exert on its towline under practical operating conditions. Bollard pull is related to engine power and other characteristics of the tug's propulsion system. Tugs with propeller shrouds (Kort nozzles) and controllable-pitch propellers produce greater bollard pull than tugs with fixed-pitch propellers for the same amount of horsepower.

CAUTION

The ship may be lost if pulling with tugs prevents completion of work to improve the stability and structural condition of the stranding. Stranded ships must be stabilized immediately.

Bollard pull is measured by a standardized trial conducted when the tug is new and after major modifications. The bollard pull of the ARS-50 Class Navy salvage ships has been measured by standard bollard pull tests. The maximum bollard pull achieved in these tests was 140,000 pounds for the ARS-50. Commercial tugs that have completed bollard pull trials carry a certificate of bollard pull. There is no requirement that tugs undergo such trials or carry a certificate; many do not have them. Appendix H provides bollard pull curves for U.S. Navy salvage ships and tugs.

8-3.2.2 Estimating Bollard Pull. If there is no bollard pull certificate, bollard pull must be estimated. The brake horsepower (BHP) or shaft horsepower (SHP) taken from the tug's documents is used to estimate bollard pull. Brake horsepower is the power developed by the engines, and shaft horsepower is the power delivered to the propeller. A quantity abbreviated IHP is often used to describe tug horsepower. This quantity may be either "indicated" or "installed" horsepower and is not a reliable indicator of the power available for propulsion. IHP should not be used in bollard pull calculations if possible. Formulae in Table 8-1 are used to calculate bollard pull from brake horsepower.

Table 8-1. Formulae to Estimate Bollard Pull from Brake Horsepower.

Open, fixed-pitch propeller	BP=0.011 × BHP
Open, controllable-pitch propeller	BP=0.012 × BHP
Shrouded, fixed-pitch propeller	BP=0.013 × BHP
Shrouded, controllable-pitch propeller	BP=0.016 × BHP

where:
BP = Bollard pull in short tons
BHP = Brake horsepower of the tug's main engines, or
BHP = 1.05 × SHP

EXAMPLE 8-1
ESTIMATE OF BOLLARD PULL

A tug has 6,000 shaft horsepower. Estimate the maximum bollard pull for:

a. An open, fixed-pitch propeller:

$$BP = 0.011 \times BHP$$
$$BHP = 1.05 \times SHP$$
$$BP = 0.011 \times (1.05 \times 6000)$$
$$BP = 69.3 \text{ tons}$$

b. An open, controllable-pitch propeller:

$$BP = 0.012 \times BHP$$
$$BHP = 1.05 \times SHP$$
$$BP = 0.012 \times (1.05 \times 6000)$$
$$BP = 75.6 \text{ tons}$$

c. A shrouded, fixed-pitch propeller:

$$BP = 0.013 \times BHP$$
$$BHP = 1.05 \times SHP$$
$$BP = 0.013 \times (1.05 \times 6000)$$
$$BP = 81.9 \text{ tons}$$

d. A shrouded, controllable-pitch propeller:

$$BP = 0.016 \times BHP$$
$$BHP = 1.05 \times SHP$$
$$BP = 0.016 \times (1.05 \times 6000)$$
$$BP = 100.8 \text{ tons}$$

If only shaft horsepower information is available, brake horsepower is calculated by multiplying the shaft horsepower (SHP) by 1.05.

$$BHP = 1.05 \times SHP$$

If only main engine indicated horsepower information is available, brake horsepower is estimated by multiplying the indicated horsepower (IHP) by .75.

$$BHP = 0.75 \times IHP$$

The bollard pull estimated by the method described above is the maximum pull that can be produced by the tug developing its full engine power in calm water. The effective bollard pull may be as little as fifty percent of the maximum if:

- The sea is rough
- Currents and sea conditions cause constant use of the tug's rudder to stay on course
- The towline is not leading directly astern.

8-3.2.3 <u>High Horsepower Tugs</u>. High horsepower tugs — those that have bollard pulls exceeding the pull of one or more legs of ground tackle — are particularly useful in pulling and wrenching. The most efficient use of these ships is to swing them slowly in an arc of sixty degrees or more while pulling. The combined action of wrenching and pulling is more effective in overcoming friction than either would be alone. In some conditions, particularly when there is a longshore current, it may be advantageous to use a small tug to hold the head of the high horsepower tug so the pull remains in the most effective direction.

The bollard pull of some of these ships is so great that, if applied fully, it may cause failure of single towlines or attachment points. High horsepower tugs may be connected to the stranded ship by two or more towlines connected to different attachment points. When more than one towline is attached, the tug must be equipped to control and measure the tension in each towline, otherwise one line will shirk the load and the bulk of the load will fall on the other towline. Alternatively, the tug may be operated at a reduced power or pitch setting to keep towline and attachment point loads at acceptable levels.

When high horsepower tugs are used in refloating operations, pendants of lower breaking strength than the main towline (weak links) are desirable to reduce the possibility of damage to the main towline if there is an overload.

8-3.3 <u>Ground Tackle Systems</u>. Ground tackle systems use a mechanical device to tension and haul against a ground leg consisting of an anchor or anchors, chain, and wire rope. These following paragraphs discuss two types of ground tackle systems and the way they are applied on a stranded ship, salvage ship, and pulling ship or barge. Ground tackle pulling systems are known in the Navy as "beach gear." The two types of beach gear used by the Navy are direct pull and purchase systems.

8-3.3.1 <u>Direct Pull Systems</u>. Direct pull systems employ a mechanical device to pull directly on the ground leg. Two such systems are used in salvage. The first and most common in Navy salvage ships is the direct linear pull system wherein forces are developed by linear pullers hauling the ground leg. The second system develops force by pulling with large winches.

8-3.3.2 <u>Linear Pullers</u>. Linear pullers are the primary beach gear heaving source on Navy salvage ships. Portable pullers can be used on board the salvage ship or, preferably, be transferred to pull from the stranded ship. Pullers may be mounted on pulling barges or other platforms. On a barge, large pulling forces may be developed by locating several pullers athwartships. The pullers can be located to pull against both the ground leg and wire ropes leading to the stranded ship.

A linear puller hauling a well-laid and set beach gear leg will net about 50 short tons of line pull.

8-3.3.3 <u>Winches</u>. Direct pull winches can be used on the stranded ship, on barges, or on salvage ships or pulling barges. These winches are more specialized equipment than the linear direct pullers and are not carried in Navy salvage ships. There are salvage ships and barges designed specifically for pulling that have permanently installed winches with line pulls of 100 short tons.

The pulling ship or barge moves to a planned position and lays the anchor by paying out the ground leg from the winch. The operation is repeated until the desired number of anchors are in place. The pulling ship then backs to the stranded ship and passes her towline(s) to complete the moor. The ground leg and towlines are hove taut. The winches pull against the ground leg or the towlines or both. A ship or barge pulling with winches can develop large forces with less effort than when standard beach gear systems are used. Since barges typically have large, open decks, several winches can be installed to give salvors high pulling forces.

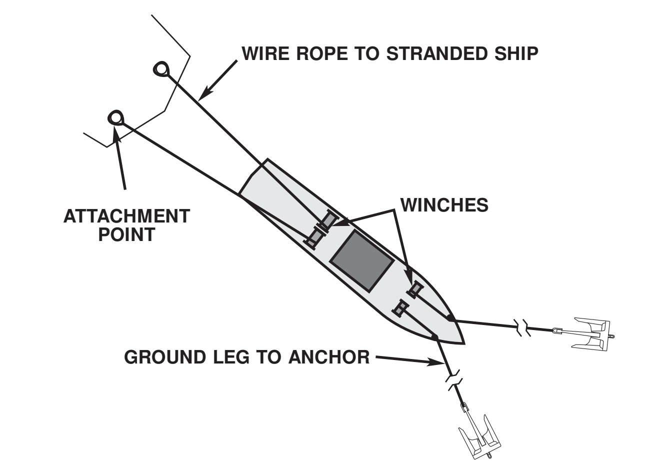


Figure 8-5. Pulling Ship with Direct Pull Winches.

Figure 8-5 shows how a pulling ship may pull with winches.

Direct pull winches may be placed aboard the stranded ship to pull the ground leg directly. This is seldom practical because of the difficulty in handling the large winches and placing them in suitable locations.

WARNING

All hands must stay clear of deck tackle purchases under strain. The design failure mode is first anchor drag and then ground wire parting. Undetected weaknesses in the purchase or the padeyes can cause other components to fail catastrophically.

8-3.3.4 Purchase Systems. In the most common ground tackle pulling system, winches haul purchases that are connected to the ground legs. Many salvage ships carry purchases for beach gear as well as linear pullers. The requirements to obtain maximum pull with purchase systems are:

- Long, clear areas for the traveling block to move along
- Winches or capstans with a line pull of 5 tons or more to heave on the purchase
- Attachment points strong enough to hold a 50-short-ton load.

Table 8-2. Advantages and Disadvantages of Pulling Ships and Barges.

Advantages	Disadvantages
Ground legs can be put in place rapidly.	All legs in operation must be recovered before the ship or barge can be moved.
The ground leg is always attached to winches, so the system is ready to pull as soon as the anchors are set.	There are few pulling barges or ships.
Minimum deck space is required compared to that required to lay out purchase systems.	Pulling barges must be towed to the salvage site.
Fewer personnel are needed to operate winches than purchase systems.	Tug may have to trip out in heavy weather.
The heaving operation does not have to stop to fleet out purchases.	
Pulling ships can hold or adjust position with the winches to compensate for increased seas and weather.	
By paying out on some winches and heaving on others, the ship can move about in the moor to reset anchors without having to disconnect her towlines.	
Ground legs and towlines can be slacked immediately if needed.	
LSTs, Icebreakers, mine warfare ships and tugs may have large winches installed suitable for direct pulling.	

8-3.3.5 Mechanics of Purchase. Purchases allow low-powered heaving equipment to develop high forces.

A purchase consists of one or more blocks with wire rope or line rove over the individual sheaves and between the blocks. Purchases used in ground tackle systems consist of three basic parts:

- One standing block secured to a padeye on deck
- One traveling block attached to the ground leg
- Wire rope rove between the sheaves of the two blocks.

Force is applied to the wire rope leading to the traveling block by pulling the wire rope in the same direction that the traveling block moves. The purchase multiplies the force originating at a winch or deck capstan to a much larger force in the ground leg. A force of 8 to 12 short tons applied to the wire rove through two four-fold blocks can produce forces from 40 to 60 short tons. The mechanical advantage of the purchase is the amount of multiplication of the force. By moving the traveling block, the purchase shortens the span between the stranded ship and the salvage anchor. The effect is movement of the ship from its strand.

A purchase gains an advantage (or multiplies a force) because each part of rope at the traveling block bears a portion of the load, acting in the same direction. The total force on the traveling block is the sum of the forces in each part of rope, or the product of the pulling force and number of parts of rope at the traveling block. A purchase rove so there are nine parts at the traveling block and hauled with five tons develops 9 × 5 or 45 tons of force at the traveling block.

The theoretical multiplication of force, or the theoretical mechanical advantage (TMA) of the purchase is the same as the ratio of the pull of the bitter end to the pull on the traveling block. For the purchase described above the TMA is 9.

The actual mechanical advantage (AMA) of a purchase is less than the TMA because there is friction in the system. Friction in a purchase is a function of the number and condition of the sheaves and the amount of rope in contact with the sheaves. Friction loss is determined by multiplying by a friction factor the number of sheaves in the entire purchase system. The friction factor must be included in any calculation of AMA. Generally:

- For ordinary sheaves in good condition with the wire bending 180 degrees on the sheave, the friction factor is 0.10.
- For low-friction blocks, such as those in heavy lift purchases, the friction factor may be reduced to 0.06.
- Conversely, the friction factor may increase to as much as 0.25 for poorly lubricated or non-standard blocks.

The friction of the sheave bearings, the rope moving over the sheaves, and the weight of the purchase is accounted for in the calculation:

$$AMA = \frac{TMA}{1 + (k \times N)}$$

where:

AMA	=	Actual mechanical advantage
TMA	=	Theoretical mechanical advantage
N	=	Number of sheaves in the purchase system
k	=	Friction factor

All sheaves in the moving, standing, and fairlead blocks must be included in the number (N) of sheaves in the purchase system.

In a purchase system, the blocks are designed to be stronger than the rope used to reeve them. Therefore, the safe working load of a purchase is the safe working load of the rope. The amount of pull applied to the purchase by the winch should never exceed the safe working load of the rope in the purchase.

EXAMPLE 8-2
CALCULATION OF ACTUAL MECHANICAL ADVANTAGE OF A PURCHASE

A purchase with two four-sheave blocks is rigged with the becket on the hauling block.

a. What is the theoretical mechanical advantage?

Since there are four sheaves, each with two parts and one part to the becket, then there are nine parts of wire at the traveling block.

The TMA is 9:1.

b. The blocks are well-lubricated and in good condition. What is the actual mechanical advantage?

Since the blocks are well-lubricated and in good condition the friction factor is 0.10.

$$AMA = \frac{TMA}{1 + (k \times N)} = \frac{9}{1 + (.10 \times 8)} = \frac{9}{1.80} = 5.0$$

c. If the purchase is hauled with a winch that has a line pull of 8 tons, what is the force on the ground leg?

The force at the block is the product of the force at the winch and the AMA:

$$\text{Force} = \text{Winch force} \times AMA$$
$$\text{Force} = 8 \times 5$$
$$\text{Force} = 40 \text{ tons}$$

CAUTION

Rigging purchases with components that are not matched can result in catastrophic failure of the system. Purchases are to be rigged only with wire rope and sheaves that are matched. Sheaves that are too small or have grooves that are too wide or too narrow for the wire rope being used can overload and damage the wire rope. Damaged wire rope will part at less than its design breaking strength.

8-3.3.6 Purchase Components. Components of a purchase system can vary in size and number of sheaves in the system, but the operating principle is the same. A purchase system generally includes the following components:

- A set of blocks or individual sheaves
- Fiber or wire rope to reeve through the blocks
- Devices, such as Carpenter stoppers, to grip the ground leg and the purchase rope
- Attachment points for the system
- Power to haul the purchase.

Substitutions for some items can be made if necessary. When substitutions are made, there may be a loss in the pulling power and the safe working load of the system.

Most ships carry purchase elements of varying sizes. In Navy purchases, the elements are standardized, so the weak link is the wire rope. When a purchase system is assembled from miscellaneous pieces, the system's safe working load is the safe working load of the weakest component.

NOTE

Appropriate safety factors must be used when calculating the forces that non-standard purchase systems can withstand. Chapter 613 of NSTM should be strictly adhered to. Chapter 4 of the *U.S. Navy Salvage Safety Manual* (S0400-AA-SAF-010) discusses safety factors in detail and should be consulted when in doubt.

8-3.3.7 Luff-on-Luff. Purchases rigged luff-on-luff are purchases rigged in series so that the traveling block of the purchase nearest the source of power pulls on the bitter end of a second purchase attached to the load. Luff-on-luff can be used when the winch does not have sufficient line pull, when there are not enough large, multiple-sheave blocks, or when the components of a purchase system are relatively small. The TMA is the product of the mechanical advantages of the individual purchases. The AMA is determined the same way as a single purchase system — by accounting for all sheaves in both purchases.

CAUTION

In luff-on-luff systems, forces developed by the purchase led to the source of power may be sufficient to part the wire rope leading to the second purchase.

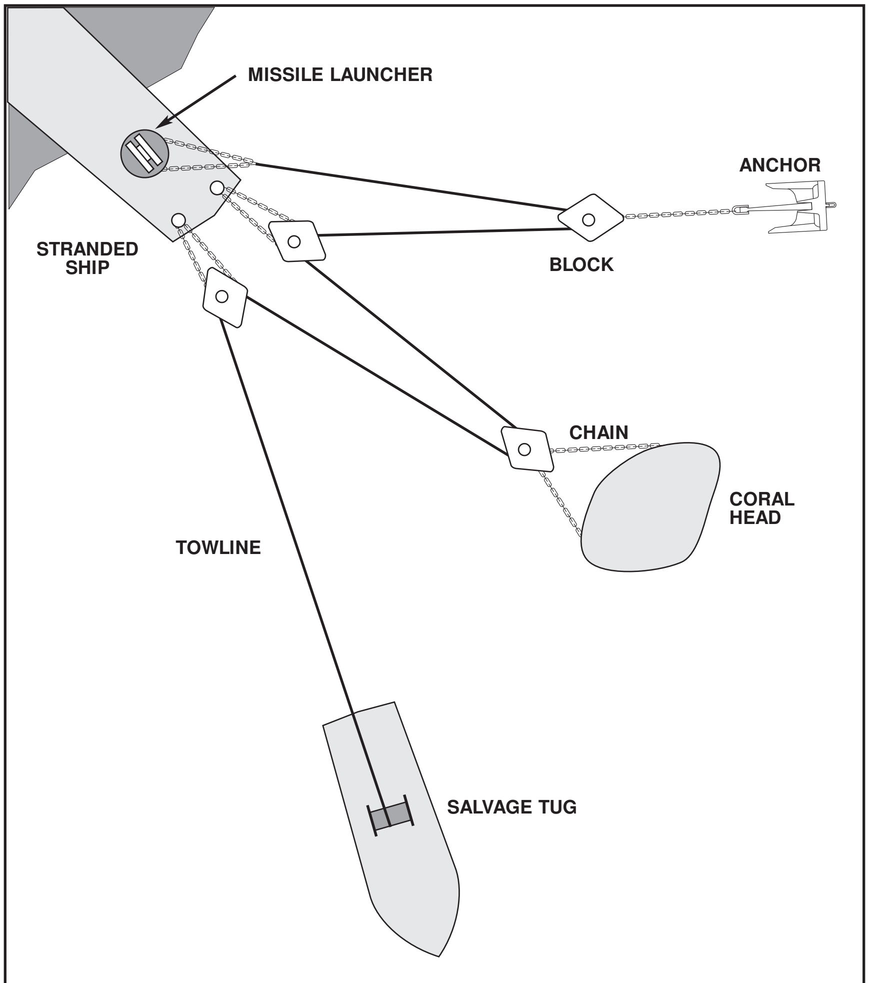


Figure 8-6. Dynamic Purchase Rigged Between Stranded Ship and Tug.

EXAMPLE 8-3
CALCULATING THE ACTUAL MECHANICAL ADVANTAGE OF A LUFF-ON-LUFF PURCHASE

Two purchases are rigged luff-on-luff purchase. Each purchase has four-sheave blocks with beckets on the traveling blocks and a friction factor of 0.10.

Purchase number one:

$$AMA = \frac{TMA}{1+(k \times N)}$$

$$AMA = \frac{9}{1+(.10 \times 8)}$$

$$AMA = \frac{9}{1.80}$$

$$AMA(1) = 5.0$$

Purchase number two: Since the purchases are identical, AMA is the same.

$$AMA(2) = 5.0$$

AMA of system is:

$$AMA(1) \times AMA(2) \text{ or } 5.0 \times 5.0 = 25$$

8-3.3.8 Dynamic Purchases. Purchases used in salvage vary from the traditional two-block arrangement rigged on ships' decks to purchases rigged between the stranding and an attachment on the seafloor. Purchases need not be located on board the stranded ship, barge, or salvage ship, nor do they require use of winches and capstans for the pulling forces.

In a dynamic purchase, the pulling forces through the blocks are provided by a salvage tug heaving on the wire. In one type of dynamic purchase, a series of large blocks through which the tug's towline is passed are rigged on the seafloor between the stranded ship and anchors. Another dynamic purchase uses the tug's towline rigged to an anchor through blocks located on the deck of the stranded ship. In both cases, the tug hauls the towline and gains a mechanical advantage on the bollard pull of the tug through the purchase. Figure 8-6 shows a type of dynamic purchase.

Dynamic purchase systems are subject to large dynamic loads caused by the seas and swells. Slack must be kept out of the purchase wire to prevent fouling. If the tug stops heaving, the leg cannot be stopped off to hold what had been gained. Heavy weather can prohibit the tug from pulling on this system. Dynamic purchases are seldom used in Navy salvage.

8-3.4 Ground Leg Design. A Navy standard beach gear ground leg is not suitable in all strandings. Differences in composition and slope of the seafloor require the ground leg to be tailored to the salvage site. If the ground leg is not properly configured, the anchor cannot develop its full holding power and may drag. A dragging anchor is of little use to the operation; time will be expended resetting it. Proper ground leg design is critical to the performance of beach gear. Ground leg design must be determined prior to rigging the ground leg for laying. Design should be based on the information gathered during the preliminary and hydrographic surveys.

8-3.4.1 General Ground Leg Components. The beach gear ground leg consists of an anchor, chain, wire rope, recovery pendants, and buoys. Like the deck tackles, the arrangement of the ground leg can be modified to suit the needs of the salvage operation. The functional description of general ground leg components follows:

- Anchors provide the solid attachment point for pulling systems to heave against. The anchor is the most critical part of a pulling system. If the anchor does not hold, the pulling system cannot exert its full force. Drag-embedment anchors are used in nearly all Navy ground tackle pulling systems. When seafloor conditions prohibit the use of conventional salvage anchors, anchoring systems such as chain around coral heads or propellent-embedment anchors can be used.

- The chain used in a ground leg serves three purposes. First, it provides weight to keep the anchor shank parallel to the seafloor for sufficient seafloor penetration and maximum holding power. Second, by its rugged construction, it minimizes ground leg chafing and fouling. Third, through its inertia, the chain assists in absorbing shock loads on the ground leg.

- The ground leg wire rope transmits the pulling force developed by the heaving source through the chain to the anchor. The wire rope also adds length to the ground leg to decrease the angle at which the rope leads aboard the stranded ship. Downward forces on the stranded ship that reduce the effectiveness of the pull are reduced by decreasing the angle of pull with the horizontal.

- Detachable links or plate shackles connect the wire rope, chain, and anchor.

- The crown pendant is used to move, reset, or recover the anchor.

- The retrieving pendant is used to recover the bitter end of the ground leg wire rope.

- Buoys keep the bitter ends of the crown and retrieving pendants on the surface, where they can be recovered by the salvage ship.

- When water depths are great, spring buoys are connected into the ground leg to keep the angle of pull nearly horizontal.

- Flotation cells are used to support pulling and ground leg wire ropes.

8-3.4.2 Minimum Ground Leg Scope. The ground leg must be at least a minimum scope to achieve maximum holding power. The minimum ground leg scope is determined by the:

- Depth of water in which the anchor is laid
- Expected depth of anchor embedment
- Height of the ship's deck above the water
- Drag necessary to set the anchor
- Distance the ship must move to float free
- Length of wire rope required on deck.

NOTE

The ground leg may be longer than the minimum scope. If it is less than the minimum, the holding power of the anchor and the effectiveness of the leg will be reduced. It should never be less than 690 feet.

Table 8-3. Basic Ground Leg Scope.

Anchor (D)	and One Shot of	and Two Shots of	and Three Shots of
60	1120 feet	787 feet	NA
72	1275	907	732 feet
84	1420	1022	823
96	1557	1133	912
108	1687	1240	998
120	1810	1345	1083
132	1929	1445	1166
144	2043	1543	1248
156	2153	1639	1328
168	2260	1732	1407
180		1822	1485
192		1904	1561
204		1998	1636
216		2082	1709
228		2166	1782
240		2247	1854
252			1924
264			1993
276			2062
288			2130
300			2197

EXAMPLE 8-4
CALCULATING MINIMUM GROUND LEG SCOPE

The deck of a stranded ship is thirty feet above the water; a beach gear leg with one shot of chain is to be laid in soft mud in 80 feet of water. The ship must travel 100 feet to refloat; there will be 50 feet of wire rope on deck. What is the minimum scope for the ground leg?

Determine the anchor depth:

Height of deck	30 feet
Depth of water	80 feet
Embedded depth (soft mud)	10 feet
Anchor depth	120 feet

Enter Table 8-4 with 120 feet, read up to the one shot column, then read across to the vertical axis. Read the basic ground leg scope as 1,810 feet.

Calculate the minimum ground leg scope:

Basic ground leg length	1,810 feet
Distance to travel	100 feet
Length on deck	50 feet
Minimum ground leg scope	1,960 feet

8-3.4.3 Determination of Minimum Ground Leg Scope. The minimum ground leg scope is determined in the following manner:

a. Determine the "anchor depth" by summing:

(1) The height of the deck upon which the heaving gear is rigged above the waterline (When spring buoys are used, the height of the deck above the water is not used.)

(2) The depth of water at the anchor

(3) The embedded depth which equals:

(a) 0 feet for firm sand or clay, coral, or rock

(b) 5 feet for medium density sand or clay

(c) 10 feet for soft mud.

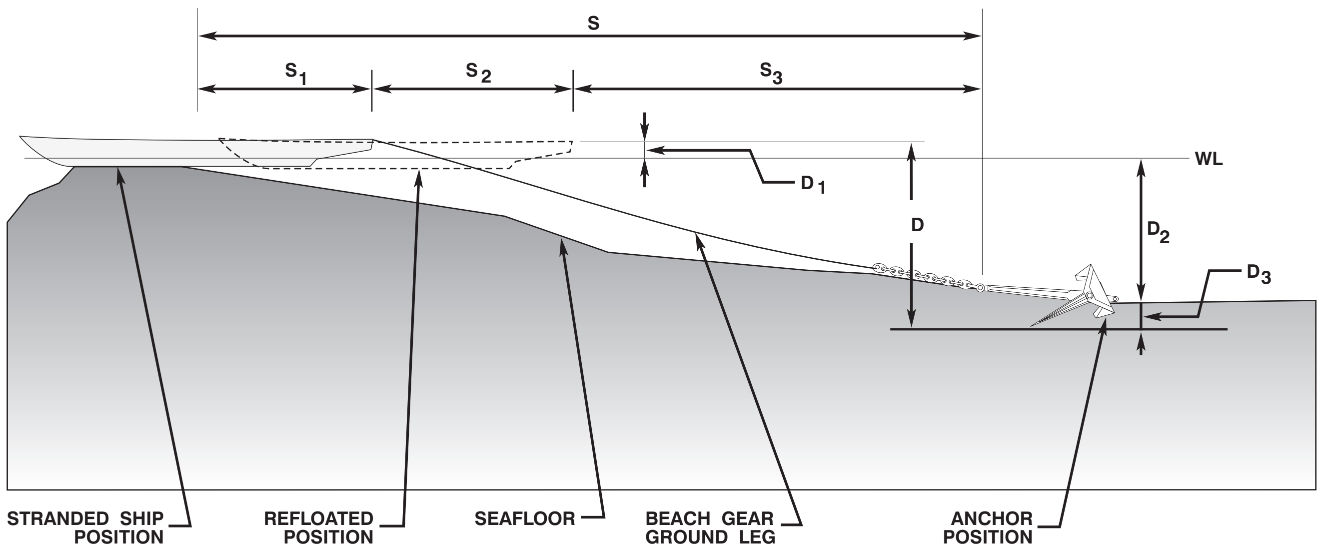
These depths are illustrated in Figure 8-7

b. Enter Table 8-3 with the anchor depth and read the basic ground leg scope. The basic ground leg scope includes the drag required to set the anchor properly.

c. To obtain the minimum ground leg scope, add the distance the ship must travel to refloat and the length of wire rope on deck to the basic ground leg scope. These distances are illustrated in Figure 8-7. When the beach gear is laid to a salvage ship or barge, the distance the ship must travel is omitted from the calculation.

d. The total length of components that make up the ground leg should equal or exceed the minimum ground leg scope. Shorter scopes will cause anchor drag.

e. As chain and wire rope come in standard lengths, the next longer scope that can be made up with the components on hand is used.



$D = D_1 + D_2 + D_3$ = "ANCHOR DEPTH"

D_1 = HEIGHT OF SHIP'S DECK ABOVE WATER

D_2 = WATER DEPTH AT ANCHOR LOCATION

D_3 = ANCHOR EMBEDDED DEPTH

$S = S_1 + S_2 + S_3$ = REQUIRED LENGTH OF GROUND LEG

S_1 = LENGTH OF WIRE ROPE NEEDED ON DECK

S_2 = DISTANCE TO MOVE SHIP FOR REFLOATING

S_3 = MINIMUM GROUND LEG SCOPE

Figure 8-7. Distances for Determining Ground Leg Scope.

8-3.4.4 Ground Leg Catenary. For an anchor to develop its maximum holding power, the shank of the anchor and the pull on the shank must be parallel to the seafloor when the maximum pulling force is applied. Even a slight angle will seriously reduce the anchor's holding power. A six-degree angle will reduce holding power by 15 percent, a twelve-degree angle by 38 percent, and a twenty-degree angle by 50 percent. Figure 8-8 shows the chain holding the anchor shank parallel to the seafloor.

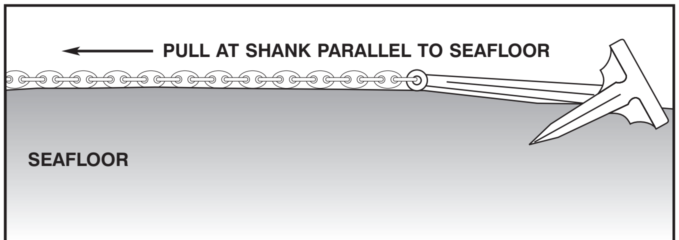


Figure 8-8. Chain Holding Anchor Shank Parallel to Seafloor.

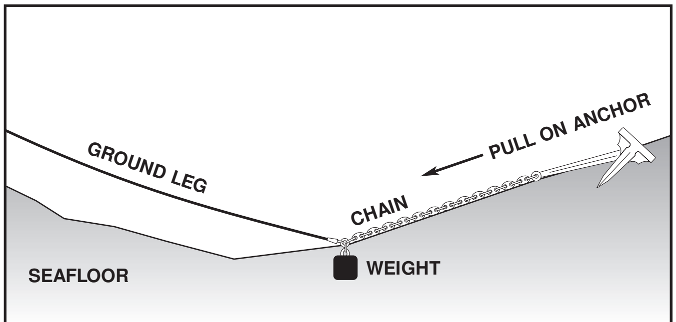


Figure 8-9. Ground Leg Configuration, Anchor on Up-Slope.

For the anchor shank and the pull to be parallel to the seafloor, the ground leg must have sufficient catenary so that the anchor always lies parallel to the seafloor. The ground leg lies in a catenary between the location where it passes over the ship's side and the anchor. Even when the ground leg is being hauled and appears to lead directly to the anchor, it lies in a catenary. The catenary is achieved by designing the ground leg for the conditions at the site.

The shape of the catenary is influenced by the weight of the ground leg. There are two factors that affect the weight: the size of the chain and wire rope in the leg and their length. One shot of 2¼-inch chain is placed immediately adjacent to the anchor. The chain deepens the catenary and keeps it parallel to the seafloor at the anchor. If the shot of chain must be omitted, it may be replaced with wire rope equal to the chain weight to develop a similar catenary.

The portion of the ground leg in contact with the seafloor improves the system holding power because of friction between the ground leg and the seafloor. Chain, because of a higher coefficient of friction and greater weight, contributes more than the same length of wire rope. When the holding power of a pulling system is computed, the contribution of the ground leg friction is ignored and taken as a bonus.

NOTE

Where another size of chain or wire rope replaces the standard 2¼-inch chain, it should weigh a minimum of 4,250 pounds (the weight of one shot of 2¼-inch Stud-Link chain).

The shot of 2¼-inch chain used next to the anchor is designed to keep the beach gear anchor shank parallel to the seafloor as long as the seafloor where the anchor lies is flat or slopes down away from the stranded ship.

Stud-Link chain is preferred for beach gear legs because Di-Lok is no longer manufactured and what remains in inventory is more effective as lift legs in heavy lift operations. Di-Lok is stronger, more resistant to kinking, and will withstand a smaller D/d than Stud-Link chain.

If the seafloor where the anchor lies slopes up away from the stranded ship, as shown in Figure 8-9, weight must be added to increase the depth of the catenary to hold the anchor shank parallel to the seafloor. The weight may be either additional chain or a clump between the chain and wire rope components of the ground leg. The distance between the clump and ground leg should be as short as possible.

NOTE

An anchor may be used in lieu of a clump for adding weight to increase the catenary. The anchor must be short coupled to the ground leg and preferably shackled directly to a Flounder plate or ring.

The following weights are suitable for the slopes indicated for ground legs determined by the method presented in Paragraph 8-3.3.3:

Slope (maximum)		Weight (minimum)
Degrees	Percent Grade	
10	17.6	4,000 pounds
14	24.9	6,000 pounds
19	34.4	8,000 pounds

Where the water is deep, close in to shore, or when operating space is limited, the ground leg may be shortened. Chain up to a total of three shots may be added to deepen the catenary and reduce the total scope of the ground leg.

Adding additional chain at the anchor end is generally not effective when the anchor depth is less than 60 feet. Chain may be added between any two lengths of wire rope in the ground leg to deepen the catenary. The addition of chain, particularly between wire rope lengths, makes handling, rigging, and recovering the ground leg more difficult and time-consuming than normal. Additional chain should be added only when conditions dictate using a short ground leg. Beach gear in water depth greater than fifty fathoms is not normally recommended because the effectiveness of the ground leg is diminished.

8-3.5 Anchors. The anchor is the critical component of salvage ground tackle. It must hold against the full pull of the leg or the entire leg becomes useless. Drag-embedment anchors are preferred for salvage. This type of anchor develops its holding power by digging into the seafloor and resisting the forces developed as the ground leg is hauled and the anchor dragged along the seafloor. These anchors are preferred because they are efficient, reusable, high in holding power, compact, and light enough to handle easily.

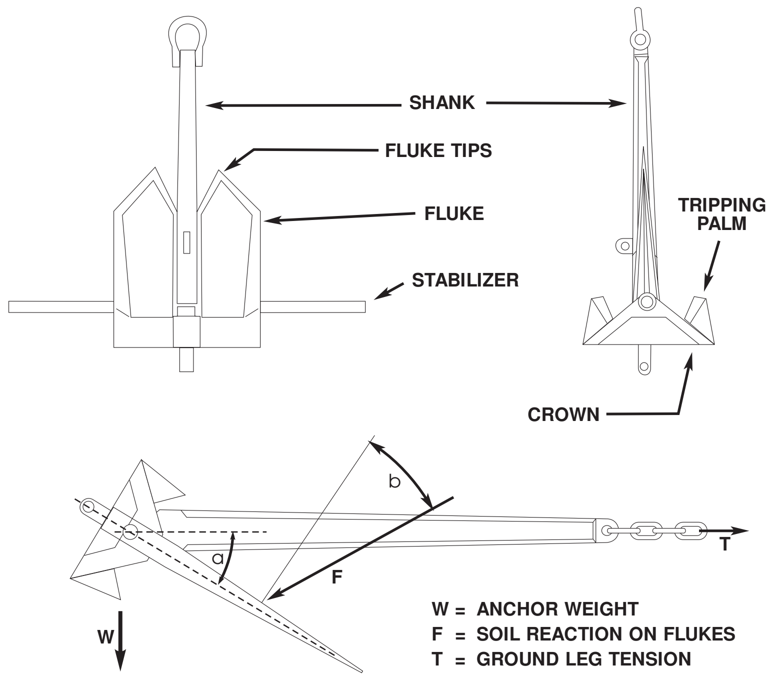


Figure 8-10. Drag-Embedment Anchor Suitable for Salvage.

Drag-embedment anchors are manufactured in a wide variety of sizes and shapes, but all have common characteristics. As shown in Figure 8-10, drag-embedment anchors suitable for salvage are made up of the following parts:

- The shank transmits pulling forces from the ground leg wire and chain from the bending shackle at the end of the shank to the crown.
- The crown connects the shank to the flukes so that the shank can align itself to the pull of the chain while the flukes dig in.
- The flukes cause the anchor to dig into the seafloor soil and provide surface area to resist pulling through the seafloor soil.
- The fluke tips are the biting edge of the fluke; they aid penetration.
- The tripping, or mud, palms assist in opening the flukes so they can dig into the seafloor as the anchor is pulled.
- The stabilizers provide rotational stability to prevent the anchor from upending or lying on its side.

Drag-embedment anchors may have either fixed or movable flukes. The crown and shank of fixed-fluke anchors have been manufactured in one piece or the flukes have been welded in one position so that there is no relative motion between the parts. Movable flukes are hinged at the crown and allow the flukes to lie parallel to the shank. When the anchor is dragged, the flukes rotate and dig into the seafloor because the hinge allows the flukes to open. Wedges can be installed to obtain the optimum opening for a particular soil.

Movable-fluke anchors are either unilateral or bilateral. The flukes of unilateral-fluke anchors open in one direction; if the anchor lands upside down, it will not dig into the seafloor. The flukes of bilateral-fluke anchors will open in either direction; thus, the anchor has a greater probability of landing in the correct position to dig into the seafloor.

Anchors suitable for use in hard soils have small sharp flukes set close to the shank and long stabilizers to keep the anchor from rotating. Soft soil anchors have large fluke areas and are streamlined to dig deeply into the seafloor.

8-3.5.1 Anchor Holding Power. The holding power of an anchor depends upon the weight and type of the anchor, how the anchor is laid, and the type and depth of soil. Table 8-4 gives the holding power in sand and mud for Navy salvage anchors.

Soil depth and consistency affect holding power. There must be sufficient soil over hard strata for the anchor to dig in deeply enough to set the flukes properly. To embed to the proper depth, the anchor must be dragged farther in mud and other soft soils than in stiffer, more resistant soils. In mud and soft soils, a greater soil depth is required above the hard strata to allow adequate penetration.

If a selection of anchors is available, the seafloor composition should be determined by sampling, and the anchor with the highest holding power in the prevalent soil should be used. Drag-embedment anchors may not be effective in some seafloors. Other anchor types, such as propellant-embedment anchors (PEA), may be more appropriate. Appendix G addresses relative advantages and performance of different anchor types. Table 8-5 shows the effect of seafloor soil types on anchor performance.

Table 8-4. Holding Power for Navy Salvage Anchors.

Anchor Type	Weight (Pounds)	Holding Power (Pounds)		Efficiency (Holding Power/Anchor Weight)	
		Sand	Mud	Sand	Mud
NAVMOOR	6,000	166,800	132,000	27.5	22.0
STATO	6,000	120,000	129,600	20.0	21.0
Eells	8,000	58,000	38,000	7.3	4.8
LWT	6,000	83,700	54,400	13.9	9.0
Danforth	6,000	83,700	54,400	13.9	9.0
Navy Stockless	6,000	29,400	15,000	4.9	2.5

Table 8-5. Seafloor Soil Types and Their Effects on Anchor Performance.

Firm Sand and Clay	The anchor can become firmly embedded and can develop its design holding power; the standard soil for determining the nominal holding power for anchors.
Sand and Clay of Medium Density	To develop its holding power, the anchor must penetrate deeper than in firm sand or clay. Depending upon depth of penetration and density of soil, the anchor holding power varies from 66 to 100 percent of the design holding power.
Soft Mud	The anchor must penetrate deeply to develop its holding power. Holding power may vary from 33 percent to near 100 percent of design holding power depending on the depth of penetration and type of sub-bottom.
Loose, Coarse Sand and Gravel with Large Rocks and Boulders	Anchor embedment and holding power cannot be predicted. Depending on depth of penetration or engagement of a large rock or boulder, the holding power may vary from 33 percent to far above the design holding power.
Hard Seafloors	Rock, shale, boulders, or coral. If the anchor cannot embed, the holding power of an anchor is less than the weight of the anchor. If the anchor fluke cannot fetch up on rocks or coral heads, propellent-embedment anchors may be required. If the anchor does fetch up, holding power can exceed system safe working load.

8-3.5.2 Anchor Drag. An anchor will drag when the force on the ground leg exceeds the holding power of the anchor. Anchor drag is the design mode of failure of a ground tackle system, because when the anchor drags, none of the components of the system fails and requires replacement. In salvage operations, where high loads are applied to ground legs and anchors, dragging is highly probable.

With tensiometers installed in the ground leg, the exact force developed by the pulling system can be measured. If the amount registered on the tensiometer is lower than expected or falls suddenly and remains low, anchor drag should be suspected.

If no tensiometers are installed in the system and the ground leg wire goes slack or begins to come home rapidly, dragging is indicated. Table 8-6 is a troubleshooting guide for anchor drag and should be consulted for assistance in eliminating dragging.

Table 8-6. Anchor Drag Troubleshooting Guide.

TROUBLESHOOTING PROCEDURES

PROBLEM	SYMPTOM	PROBABLE REASON	POSSIBLE SOLUTION(S)
Poor Mud Performance	1. Near constant line tension ½ to 2 times anchor weight	1. Flukes not tripping	1. Review setting procedures 2. Increase size of tripping palms 3. Fix flukes in open position 4. Jet flukes into seabed 5. Extend or add stabilizer
	2. Drop in tension during loading	1. Anchor rotating	1. Recover and clean; check for balling up 2. Extend or add stabilizers 3. Use different or larger anchor
		2. Soil firmer than expected	1. Reduce fluke angle to sand setting or 5-10^{o} less than sand setting
	3. Holding power too low	1. Soil softer than expected 2. Less sediment than needed over hard substrata	1. Reset and soak for 24 hours 2. Use larger anchor 3. Add chain 4. Use tandem or doubled anchors 5. Use different anchor
Poor Sand/Hard Soil Performance	1. Near constant line tension 1 to 3 times	1. Anchor not tripping	1. Sharpen fluke tips; add fluke tip barbs to break up soil 2. Reduce fluke angle to a minimum of 25^{o} 3. Extend or add stabilizer 4. Add barbs to tripping palms; extend crown with plate or pipe construction 5. Fix flukes in open position 6. Crush hardened surface soil with explosives; blast or jet anchor flukes in
	2. Variable tension 3 to 10 times anchor weight	1. Flukes not penetrating	1. Reduce fluke angle to a minimum of 25^{o} 2. Sharpen fluke tips 3. Extend or add stabilizer 4. Use larger or more stream-lined anchor
	3. Rapid drop in tension during loading	1. Anchor rotating	1. Extend or add stabilizers 2. Use larger or different anchor 3. Use tandem or doubled anchors
	4. Holding power too low	1. Less sediment than needed 2. Very hard seafloor	1. Use larger or different anchor 2. Use tandem or doubled anchors 3. Add chain

Once an anchor starts dragging, it will usually not reset itself. The pulling operation must be stopped and the anchor redeployed. The anchor is redeployed by hauling the anchor crown pendant in a direction away from the stranded ship along the axis of the ground leg, pulling the ground leg taut, and then releasing the crown pendant so the anchor can dig in when the ground leg is hauled.

8-3.5.3 <u>Improving Holding Power</u>. Holding power may be improved by rigging doubled or tandem anchors, modifying the fluke angle, or adding mud palms or stabilizers.

- Two anchors rigged in parallel in the same ground leg are "doubled." Doubling is used with anchors having shanks and fittings that are designed to carry the holding capacity of one anchor. Doubled rigging is accomplished by attaching both anchors to a Flounder plate with chain. Each anchor acts independently. One chain should be at least four fluke lengths longer than the other to keep the anchors from moving into each other and fouling. The holding power of doubled anchors is 15 to 20 percent greater than the sum of the individual anchor capacities. Figure 8-11 shows doubled anchors attached to a Flounder plate.

- Two anchors connected in series are "in tandem." In tandem, the two anchors are capable of developing more than double the rated holding power of a single anchor. As the backup or secondary anchor is pulled into the track of the primary anchor (the one attached to the ground leg), it is able to penetrate more deeply into the already broken ground and develops very high holding power. The weight of the primary anchor keeps the pull on the tandem anchor parallel to the seafloor but below the seabed. Figure 8-12(a) shows tandem anchors rigged shank-to-crown.

(1) Crown-to-shank rigging (attaching the secondary anchor pendant to the crown end of the primary anchor) is preferred for convenience in handling, rigging, and laying. There are three basic requirements for this rigging arrangement to function properly: 1) the primary anchor must be well stabilized, 2) the primary anchor flukes must be fixed open or able to rotate freely when the primary anchor is loaded by the secondary anchor, and 3) the primary anchor must be structurally suited to the tandem load.

(2) If the tandem anchor is connected to the crown of the primary anchor, the line tension from the tandem anchor will close and hold the flukes of the primary anchor parallel to the shank, unless the flukes are fixed in the open position. If this happens, the primary anchor will break out and slide along the seafloor, acting only as a clump. The primary anchor held at the seafloor surface will prevent the tandem anchor from penetrating deeply; system holding power may be less than that of a single anchor.

(3) Unstabilized (Stockless, Eells) or poorly stabilized (Danforth, LWT) anchors used as primary anchors in a tandem system rotate as soon as load is applied by the tandem anchor. The primary anchor breaks out and prevents the tandem anchor from penetrating. Less stable anchors can be used to back up more stable primary anchors, such as the NAVMOOR or STATO.

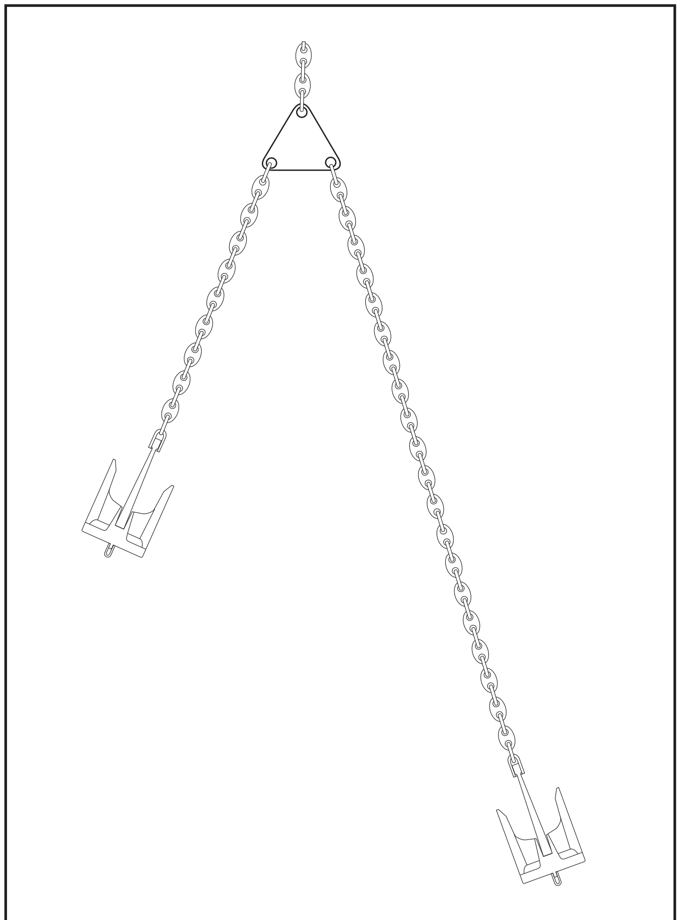


Figure 8-11. Doubled Anchor Arrangement.

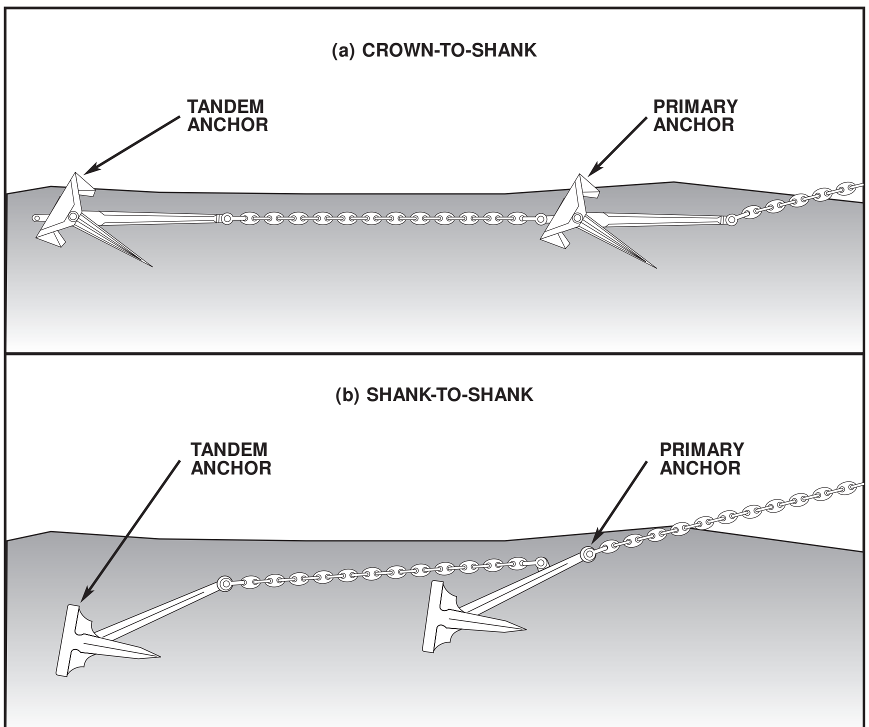


Figure 8-12. Tandem-Anchor Arrangements.

(4) When tandem anchors are rigged crown-to-shank, all of the forces pass through the primary anchor shank, shackle and connecting link; these parts must be strong enough to carry all the loads. Of Navy anchors, only the NAVMOOR is specifically designed for tandem rigging with anchor fittings designed to hold two and one-half times one anchor's design holding power and allow the flukes to rotate freely.

(5) Anchors not suitable for crown attachment of a tandem anchor because of insufficient strength (STATO) or stability (Eells, Stockless, LWT, Danforth) can be rigged shank-to-shank as shown in Figure 8-12(b). Model tests have shown that primary anchor stability will not be affected by this rigging arrangement, and the system holding power will equal the sum of the individual anchor holding powers. The tandem anchor pendant can be shackled to a padeye welded to the primary anchor shank or bent into the ground leg at or immediately before the primary anchor Jews Harp through a Flounder plate or mooring ring. This rigging arrangement should be used only with fixed-fluke anchors to minimize the potential for fouling the primary anchor with the tandem anchor pendant.

(6) When rigging anchors in tandem shank-to-crown, separation between anchors should be at least three times the length of one fluke. In practice, the distance should exceed the water depth to allow the primary anchor to set first. The second, or tandem, anchor is laid with the connecting chain or wire taut and the primary anchor on the seafloor.

(7) When tandem anchors are used, the weight of the primary anchor and the connecting chain keeps the pull on the tandem anchor parallel to the seafloor. Chain should be used between the primary anchor and the remainder of the ground leg.

- Modified Fluke Angle. Adjustments to the fluke angle will increase efficiency in particular soils. For instance, STATO anchor fluke movement should be constrained by wedges to 30 degrees +/- 2 degrees in stiff clay, sand and hard soil, and 50 degrees +/- 2 degrees in mud.

- Mud Palms and Stabilizers. Mud palms, or tripping palms, add drag resistance in soft soils and force the flukes downward. For instance, if the shank falls below the flukes, then larger mud palms will force the flukes down and permit them to dig in. Stabilizers prevent anchor rotation and breakout. Folding stabilizers must deploy fully to be effective.

8-4 INTRODUCTION TO BEACH GEAR.

This section provides general information on the Navy standard beach gear carried by Navy salvage ships and the ESSM system and discusses improvised beach gear. It also discusses operation of beach gear from stranded ships and from Navy salvage ships. For detailed information on the operation and maintenance of all equipment, the technical manual for specific equipment should be consulted. Similarly, the operating manual for ships should be used for detailed rigging instructions.

8-5 NAVY STANDARD BEACH GEAR.

Navy standard beach gear is a ground tackle system comprised of anchors, chain, wire rope, and heaving equipment. It is an engineered system designed to be used for developing a pulling force of up to 60 tons to retract stranded ships. Standardization simplifies procurement and inventory control for salvage units. The makeup of the set is not intended to limit the actual configuration of the beach gear system. The system is composed of two subsystems: the deck arrangement and the ground leg.

8-5.1 The Deck Arrangement. The deck arrangement consists of pulling equipment — either a linear puller or a four-fold purchase — and cable holding and tension-measuring devices. The individual components are of sufficient strength to carry the maximum load that can be developed by the system.

8-5.1.1 The Linear Puller System. The linear puller system for Navy standard beach gear consists of a linear hydraulically powered puller and its associated components as described below:

- Puller. The puller is a mechanical device that hauls the ground leg. The puller has two grips: a hauling grip and a fixed grip. The hauling grip moves backward and forward to heave in or pay out the wire rope. While the hauling grip is moving, the fixed grip is open. When the hauling grip reaches the limit of its travel, the fixed grip engages, and the hauling grip releases and re-positions for another pull. The hauling grip grasps the wire rope and the fixed grip releases. The hauling grip then makes another pull and the cycle repeats.

  Each grip is actuated by small hydraulic cylinders. The hauling grip rides on a carriage that is actuated by two hydraulic cylinders. The cylinders are controlled by a control manifold. The cable puller is specifically designed for 1⅝-inch wire rope.

  Each puller weighs about 5,500 pounds and has overall operational dimensions of 21×41×117 inches (141 inches extended). It is moved from stowage using the ship's handling equipment.

- Power Supplies. Power is supplied from either a hydraulic system installed in the ship or a portable hydraulic power supply. One portable hydraulic power supply is required for each puller. Each portable hydraulic power supply consists of a diesel engine, a hydraulic fluid pump, and other ancillary equipment. The portable power supply units weigh approximately 3,800 pounds.

- Control Block. A control block module and cable are connected to the puller and power supply. The control block is portable and can operate away from the puller location in the position that gives the best visibility and control of multiple pullers. The controls consist of three hydraulic valves, three hydraulic pressure gages, an accumulator bottle, flow limiting valves, supply and return hoses, control hoses to the cable puller, and an adjustable high pressure relief valve. A bleed-down valve on the right side of the control panel can be used to de-pressurize the system. The module weighs about 390 pounds.

- Tensiometer. A tensiometer can be installed in the system between the padeye and the puller bridle. The tensiometer provides a direct reading of the force developed by the pulling system.

- Attachment Point. The puller frame is secured to deck padeyes with a wire-rope bridle.

Table 8-7 presents the advantages and disadvantages of linear hydraulic pullers in beach gear.

8-5.1.2 The Deck Purchase System. The deck purchase system for Navy standard beach gear is made up of components similar to those listed in Paragraph 8-5.1.1 and are standard for all salvage ships or units. The standard Navy beach gear purchase includes these items:

a. Two ⅝-inch, four-sheave blocks. The traveling block has a becket for securing the hauling wire rope.

b. Wire rope. 1,200 feet of ⅝-inch, improved plow steel, IWRC, 6×37, uncoated wire rope for reeving the quadruple blocks. Four wire rope clips are used to attach the wire rope to the becket of the hauling block.

Table 8-7. Advantages and Disadvantages of Linear Hydraulic Pullers.

Advantages	Disadvantages
Fewer personnel are needed to operate puller than purchase systems.	Bad weather can make transfer of heavy portable systems difficult.
Puller controls can be positioned wherever advantageous.	The power source as well as the puller must be transferred to the stranded ship.
Continuous line pull gives positive control of the pulling operation. No holding stoppers are required for the purchase wires when heaving is stopped because the ground leg is held by grips integral to the pullers. Pulling can be resumed immediately.	Padeyes strong enough to attach pullers may have to be fabricated and installed aboard the stranded ship.
Pullers are portable.	Wire rope connections will not pass through the puller. The operation must stop and the connections hauled past the puller.
There is no loss of pulling force caused by sheaves with efficiency losses.	
The heaving operation can proceed continuously without stopping to fleet out purchases.	

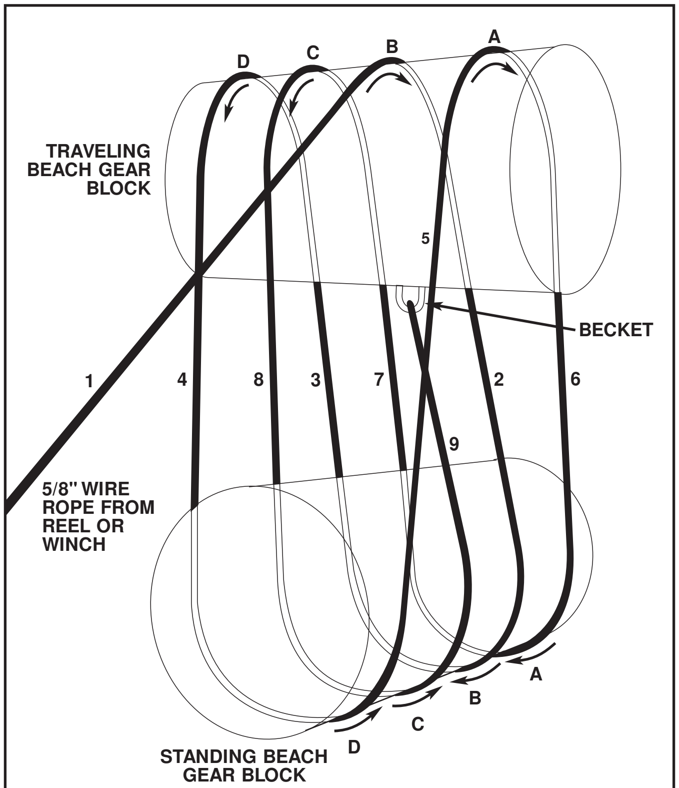


Figure 8-13. Center-to-Center Reeving.

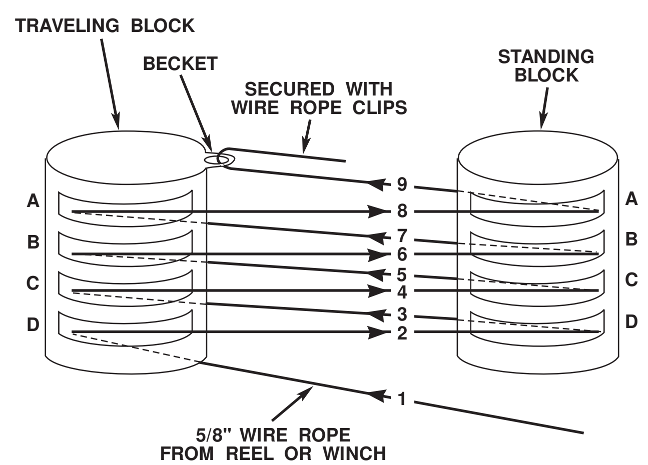


Figure 8-14. Round-Robin Reeving.

(1) Reeving sequence. Figure 8-13 illustrates the center-to-center method of reeving the blocks. The center-to-center method is preferred because it reduces the tendency of the ⅝-inch wire rope to turn the traveling block as load is applied. The round-robin method can also be used. Figure 8-14 shows the round-robin reeving sequence.

(2) Reducing twists. A timber or steel bar should be secured in the bridle of the hauling Carpenter stopper to reduce the twist placed on the purchase by the 1⅝-inch wire rope. Figure 8-15 shows a bar rigged to reduce twisting.

WARNING

Carpenter stopper and wire rope size must match. Otherwise, they will not hold well, and the wire will be damaged. Damaged wire rope can part at low loads and damage the purchase system and endanger personnel.

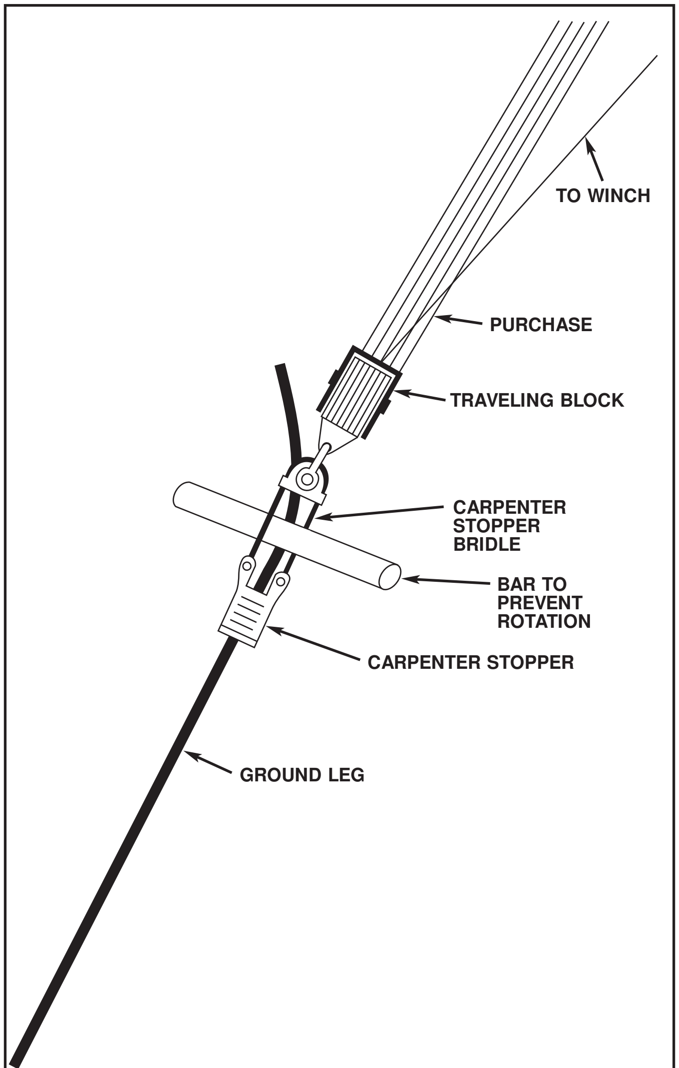


Figure 8-15. Bar in Purchase to Prevent Rotation.

c. Carpenter stoppers. Carpenter stoppers are sliding wedge block wire rope stoppers that hold wire rope without damage up to breaking strength. Four Carpenter stoppers are used in each purchase beach gear leg. Two ⅝-inch stoppers are used for hauling and holding the purchase rope, and two 1⅝-inch stoppers to haul on and hold the ground leg.

Lubrication and frequent inspection of Carpenter stoppers are essential for safe and efficient operation.

Carpenter stoppers are certified by the ESSM system during salvage ships' intermediate maintenance periods. On each stopper is stamped a serial number indicating the size and number of the stopper. For example, CS0158-1 identifies the carpenter stopper as 1⅝-inch and the first one certified. Carpenter stoppers not serialized by the ESSM system can be sized by reading the wire rope size stamped on the wedge.

Stoppers for 1⅝-inch wire rope come with a set of wedges for ropes of differing lay lengths. The lay length of the rope should be matched to the wedge, as shown in the technical manual for Carpenter stoppers. Figure 8-16 illustrates a Carpenter stopper.

Carpenter stoppers to be used in beach gear are those manufactured by Baldt in 1973 or later. All other Carpenter stoppers should be disposed of by cutting the hinges and surveying them.

d. Fairlead blocks. Fairlead blocks change the direction of lead of the rope. A fairlead block is used when there is no direct lead to the winch or capstan that will pull the ⅝-inch purchase rope. A fairlead block can be used with the 1⅝-inch ground leg to align the ground leg with the traveling block.

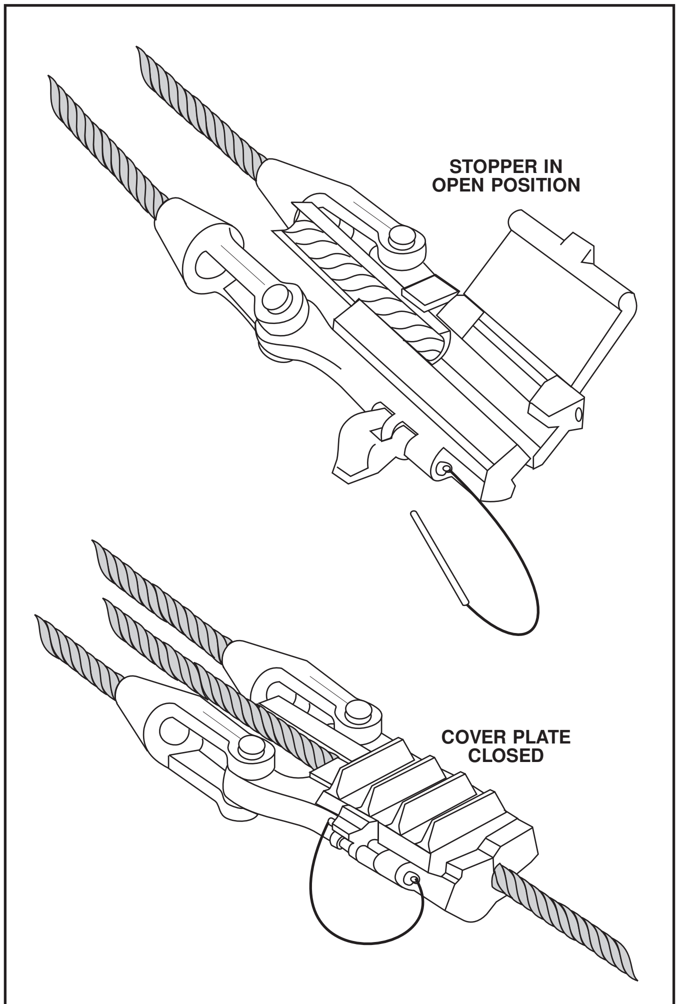


Figure 8-16. Carpenter Stopper.

Table 8-8. Advantages and Disadvantages of Purchase-hauled Pulling Systems.

Advantages	Disadvantages
Purchases are lightweight and easily portable.	Heaving operations must be interrupted frequently for overhauling the purchases.
Ground legs used in purchase systems can be rigged and laid from any ship or tug.	Standard purchase pulling systems have limited pulling power. The range is from 50 to 100 short tons.
No special salvage ships are required to use purchases.	Portable winches must be transferred to stranded ships that have no power.
Continuous strain is placed on the stranded ship. Once the ground leg is hauled taut, tension can be held regardless of the weather.	
The ground wire is always gripped by one of the Carpenter stoppers.	
Substitute components can be used to rig purchase systems.	
Adequate winch and capstan power to heave on the purchases is available on most ships.	

8-5.1.3 Tensiometers. Tensiometers measure the force developed by a pulling system. Two types of tensiometers are used by the Navy. The newest is a Hydraulic Tension Measuring System (HTMS). The older is the Type 516 Tension Measurement System. Figure 8-17 illustrates the hydraulic type of Navy tensiometers.

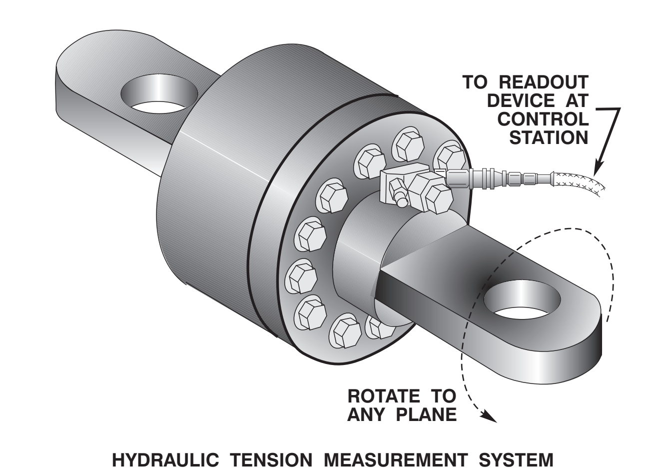


Figure 8-17. Tensiometer.

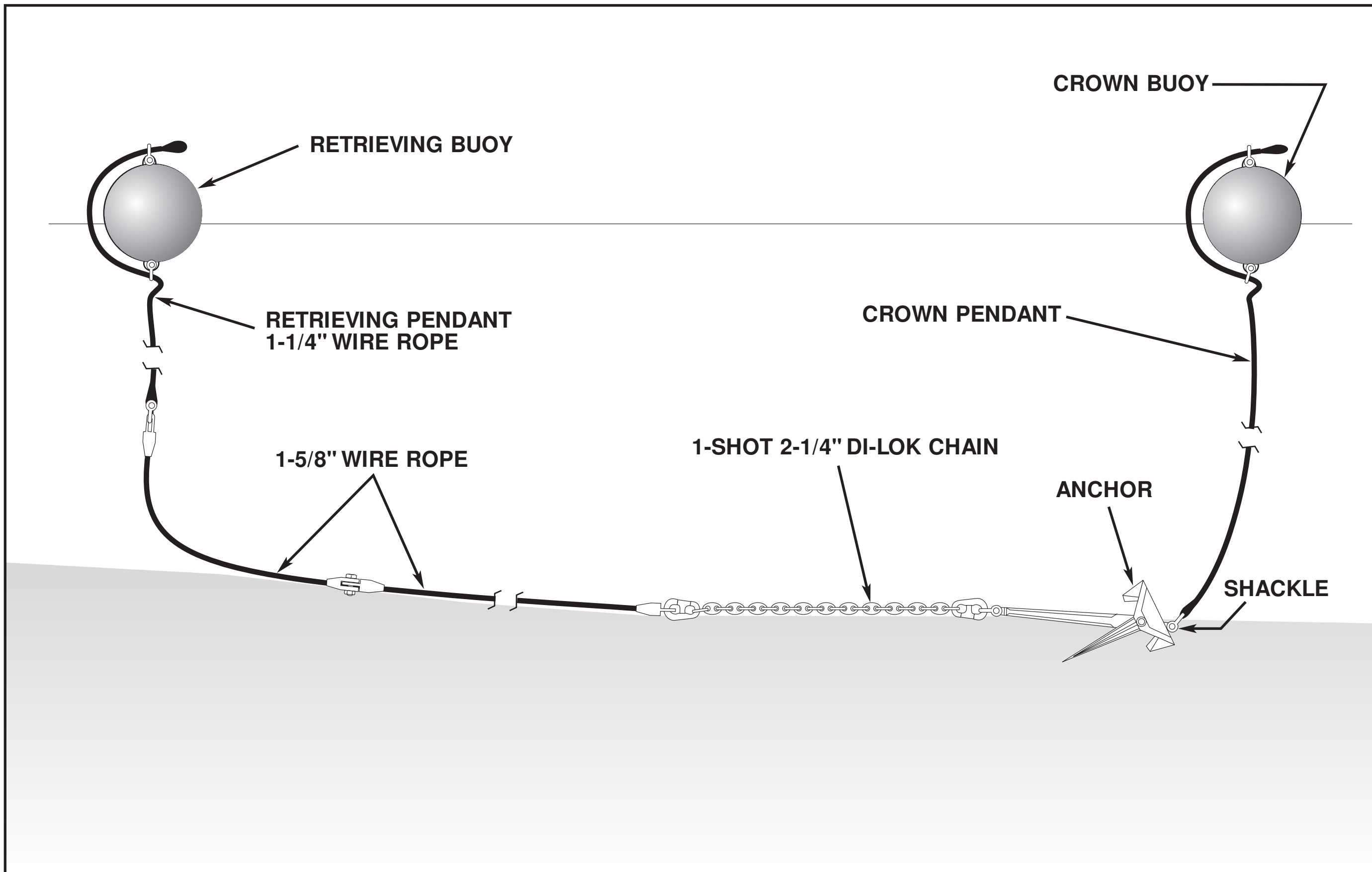


Figure 8-18. Navy Standard Beach Gear Ground Leg.

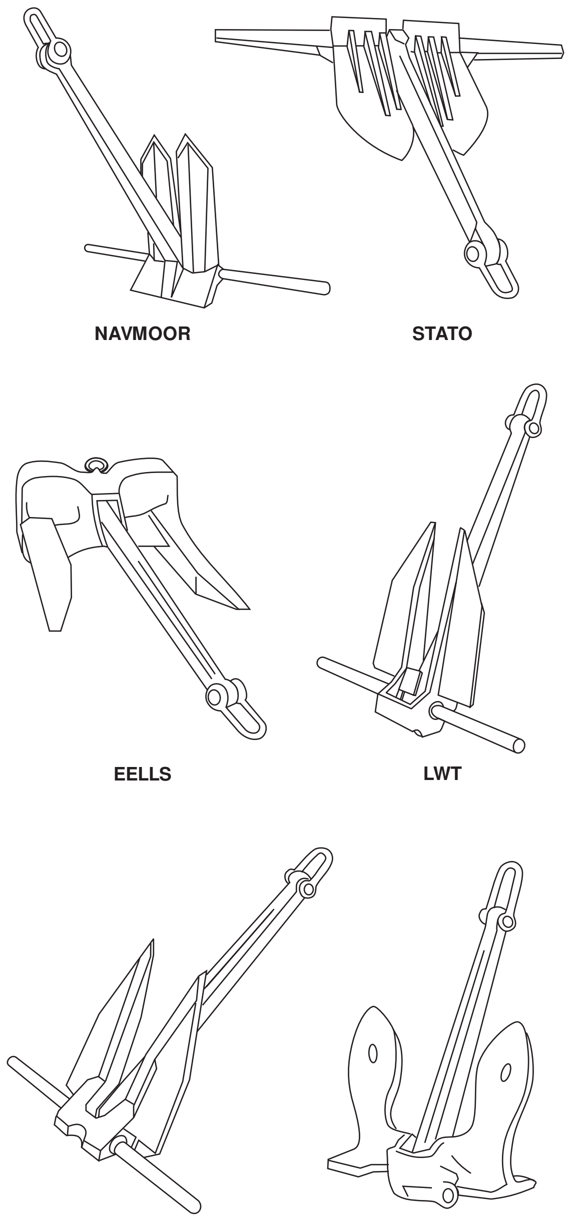


Figure 8-19. Anchors Used in Beach Gear.

8-5.2 <u>The Ground Leg</u>. The ground leg of Navy standard beach gear consists of an anchor, chain and wire rope combination, a retrieving pendant and buoy, and an anchor crown pendant and buoy. Like the deck arrangement, the ground leg can be modified to suit the needs of the salvage operation. Figure 8-18 shows the Navy standard beach gear ground leg. The ground leg includes the items described in the following paragraphs.

8-5.2.1 <u>Anchors</u>. Anchors provide the solid point for pulling systems to heave against. Nearly all Navy ground tackle pulling systems use drag embedment anchors. The anchor is the most critical component of a pulling system. If the anchor does not hold, the pulling system cannot develop its full force.

NOTE

In the anchor descriptions given below, the nominal weight is the weight of the anchor that is most appropriate with Navy standard beach gear. Other weights of the same type anchor will be found. If lighter weights are used, the anchor can be expected to drag at lower loads. If heavier weights are used, the expected failure mode may shift from anchor drag to ground leg wire rope failure.

Figure 8-19 shows the anchors used in beach gear. The primary anchors used for beach gear (carried on salvage ships, in the ESSM system, and in the Navy inventory) are:

- NAVMOOR. THE NAVMOOR drag embedment anchor was originally designed as a high-capacity fleet mooring anchor. It is similar to the STATO anchor. The 6,000-pound version has been modified specifically for salvage. It has bilateral flukes, tripping or mud palms, and folding stabilizers. The hollow flukes are streamlined and reinforced for good penetration and bending resistance. It is fitted with a tandem connecting shackle at the crown end of the shank that allows the load from a tandem anchor to be applied directly through the shank so the flukes can rotate freely. The anchor is ruggedly constructed and the shank and connecting shackles were designed to carry 2½ times the anchor's maximum rated capacity of 166,800 pounds. Fixed-fluke angles of 50 degrees for soft soil and 32 degrees for sand or hard soil can be set by tack welding wedges in the anchor. The NAVMOOR anchor is carried on some ARS-50 Class ships and in the ESSM system. It can be used by all salvage ships.

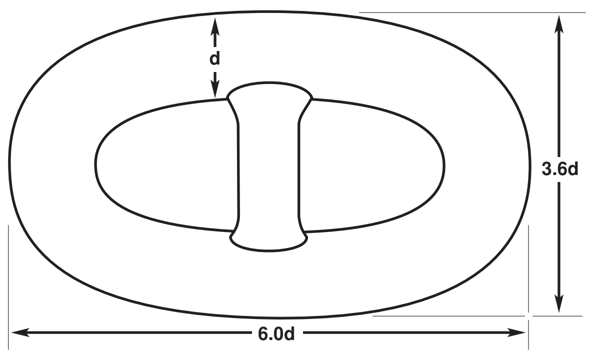
- STATO. The STATO anchor is a high performance drag embedment anchor originally designed for fleet moorings. Various sized STATO anchors are maintained in the ESSM system and by the Naval Facilities Engineering Command (NAVFAC); the 6,000-pound version is most suitable for use as a beach gear anchor. It has bilateral flukes, adjustable tripping or mud palms, and folding stabilizers. Fluke angles of 50 degrees for soft soil and 34 degrees for sand or hard soil are set by changing wedges. Because of its relatively light construction and crown shackle location, it is not suitable for use as the primary anchor in a tandem-anchor system unless rigged shank-to-shank. It can be rigged crown-to-shank as the tandem anchor with a NAVMOOR as the primary anchor. It is susceptible to damage in rock and coral bottoms, especially if the flukes are loaded unevenly.

- EELLS. The Eells is an 8,000-pound drag embedment anchor with bilateral flukes. The anchor is built with a 38½ degree fluke angle without any special provision to change fluke angle, however, wedges can be fabricated and tack welded in place to limit fluke angle. Fluke angle should be reduced to approximately 30 degrees for use in sand and hard soil. The holding power is not as great as with the STATO and NAVMOOR. The Eells anchor has good tripping and initial embedment performance because of its relatively sharp fluke tips. It can be rigged in tandem if the flukes are fixed open. The crown is a box design that enhances setting with minimum drag. Backing plates welded to the base of the box crown will improve tripping performance soft soils but will inhibit bottom penetration.

- LWT. The LWT is a movable bilateral fluke anchor equipped with tripping palms, a stabilizer, and removable wedges to obtain the optimum fluke angle for use in mud and sand. 6,000-pound LWT anchors are suitable as beach gear anchors. The LWT has lower holding power, is less stable, and trips less reliably than the STATO or NAVMOOR.

- DANFORTH. The Danforth anchor is similar in appearance to the LWT anchor but has no tripping palms or wedges. Its performance is approximately the same as the LWT. The Danforth anchor is not normally carried aboard salvage ships.

- NAVY STOCKLESS. The Navy stockless anchor has no stock or stabilizer and does not bury deeply, so it may be retrieved with relative ease. The Navy stockless anchor is widely used as a ship's bower anchor and for fleet moorings. It is built with a 45-degree fluke angle without provision for changing fluke angle. It does not develop a large holding power and is a poor salvage anchor. A stabilizer bar can be welded to the crown to prevent rotation of the anchor when setting. Because of its heavy construction, it is suitable for tandem rigging if modified by adding a suitably-sized crown padeye, a stabilizer and fixing the flukes open. If the flukes are fixed at 35 degrees, the holding power is approximately the same as an Eells anchor.



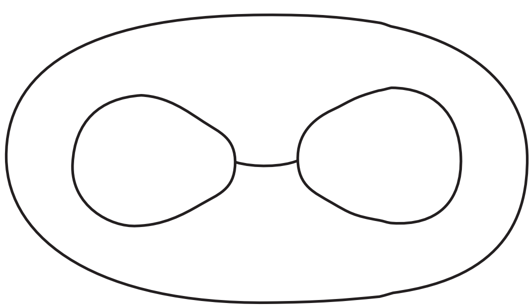


Figure 8-20. Aid to Identifying Chain.

8-5.2.2 Chain. Chain in the ground leg holds the anchor shank parallel to the sea floor, resists chafing, and increases the ability of the ground leg to carry dynamic loads. The weight of the chain holds the anchor shank parallel to the sea floor for the best anchor performance. Because of its construction, chain is more resistant to chafing and fouling than wire rope, and therefore is more suitable for contact with the sea floor. The weight of the chain provides inertia that allows the chain to absorb dynamic loads.

The chain used in beach gear is 2¼-inch welded stud-link chain that meets MIL-C-24633. Di-Lok chain may also be used if stud-link chain is unavailable. Other chain may be used, but its strength, weight, and the hardware to bend it to the ground leg can affect overall ground leg performance.

NOTE

> If the grade and type of chain is unknown, it should be treated as commercial Grade 1. Safe working loads and breaking strengths for Grade 1 chain are 2/3 of those for the same size Grade 2 chain.

Chain type can be identified visually. Figure 8-20 is an aid to identifying chain. One end of the Di-Lok chain link is slightly larger than the other and the stud is an integral part of the link. Welded stud-link chain has a separate stud pressed into the link. Most ship's anchor chain is Grade 2. Oil Rig Quality (ORQ) and Grade 4 chain have the stud seal-welded to the link at one end. Unless its grade is known, chain with seal-welded studs should be treated as Grade 2 chain.

Generally, a minimum of one shot (90 feet) of chain is used between the anchor and the ground leg wire rope. Additional chain placed at any other point in the ground leg can improve the spring effect and deepen the catenary.

Chain is designed to be used in tension. When chain is bent around a sharp corner, stresses are introduced into the chain that may cause failure at loads well below its design tensile load. When it is necessary to lead chain around a corner, the diameter of the bend must be at least 7 times the diameter of the bar that forms the chain. Thus, 2¼-inch chain should not be bent around a diameter of less than 15¾ inches. When chain is led over or around a curved surface at least three links of the chain should be in contact with the curved surface. Properly sized connectors between chain, wire rope, and the anchor must be used to ensure the overall strength of the system. Proper connectors in the order of preference are:

- Detachable links
- Plate shackles
- Joining shackles.

Chain is proof-tested at manufacture and the overall length recorded. After manufacture, the chain can be tested by measuring its elongation. A worn or stretched chain will exceed the manufacturer's specified length. The first step in testing is to count the links to ensure a full shot. The chain is hoisted so it hangs free, and the overall length measured and compared to allowable limits. A worn or stretched chain will exceed the upper limit. The entire length of chain is then gaged with calipers set to a six-link length. If any six-link segment exceeds the manufacturer's specified length, it indicates individual links are excessively worn or stretched.

There is seldom time or the facilities for these tests at a stranding site. A hammer can be used to identify cracked links. Each link is rung with a solid blow from a two-pound hammer. A sound link will sing with a clear, ringing tone. A bad link will have a dull, flat tone. Bad links can be cut out and replaced with a detachable link or joining shackle. Any chain from which links have been removed is suspect and should be used only where its strength is not critical. Characteristics of welded stud-link and Navy Di-Lok chain manufactured by Baldt are given in Appendix F.

8-5.2.3 Ground Leg Wire Rope. The wire rope transmits the pulling forces developed by the heaving source through the chain to the anchor. Wire rope adds length to the ground leg to decrease the angle of pull leading aboard the stranded ship.

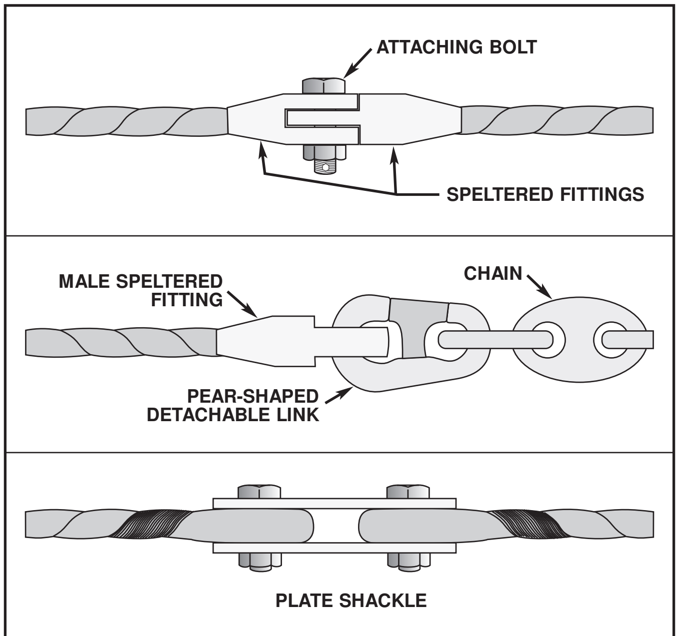


Figure 8-21. Connections for Ground Leg.

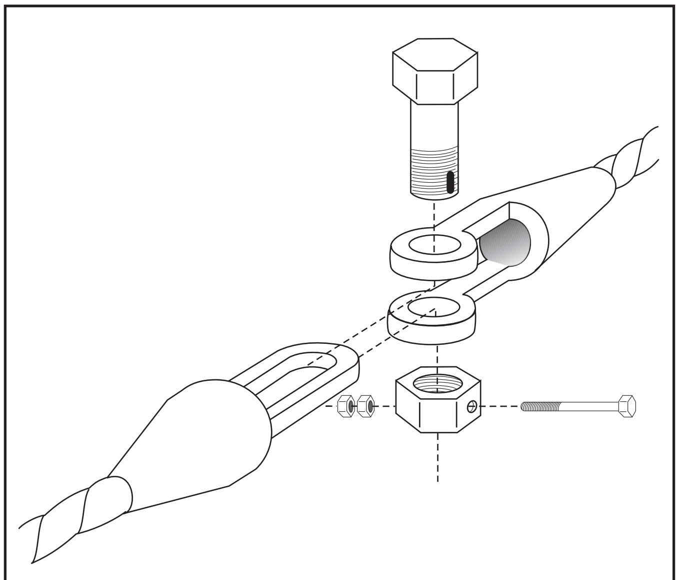


Figure 8-22. Speltered Fittings

Navy standard beach gear ground legs are 1⅝-inch diameter, improved plow steel (IPS), drawn, galvanized, preformed, right-hand lay, fiber core, Type 1, Class 3, 6×37, Warrington-Seale wire rope constructed in accordance with military standard RR-W-410. This wire rope has a breaking strength of 192,600 pounds; it is the weakest part of Navy standard beach gear.

The wire rope is normally made up of 50- and 100-fathom pendants with either speltered fittings or eyes for attachment. The pendants are connected with either specially designed safety bolts for the speltered fittings or plate shackles for the eyes. The wire rope attaches to the chain with 1⅝-inch detachable end links. Figure 8-21 shows the connections of a ground leg. If the ground leg fails, failure is in the wire rope, away from the ship, and thus is safer for personnel operating deck purchases, pullers, and associated equipment.

Male and female speltered fittings connect wire rope pendants and join the pendants into other ground leg components. These fittings are smaller than plate shackles and their smooth design helps prevent fouling. The fittings are connected by standard 3-inch bolts and special nuts. Figure 8-22 shows typical speltered fittings.

Detachable links connect chain, wire rope, and anchors in pulling systems. There are two basic types. The first is the standard link that connects chain of equal size. It is approximately the same size as the chain and has a breaking strength equal to that of the chain it connects. The second is a pear-shaped link that connects different-sized components, such as the anchor bending shackle and the chain. Detachable links have the same strength as the smallest chain size they were designed to connect. Only detachable links that accept a hairpin retainer should be used in salvage operations. Components of detachable links are not interchangeable and must not be mixed during use or maintenance.

Plate shackles connect components of the beach gear leg. The breaking strength of all plate shackles is greater than that of 1⅝-inch wire rope. Plate shackles are difficult to haul through chocks, over rollers, or through fairleads. They may foul and delay pulling operations. Navy standard beach gear leg uses two types of plate shackle:

- The small, or flat, plate shackle is used to connect 1⅝-inch wire rope pendants with eyes or to connect pendants to spring buoys.

- The large, or offset, plate shackle may be used to connect 1⅝-inch wire rope pendant to 2¼-inch chain. Plate shackles should be used to connect beach gear components when detachable links are not available. They can be fabricated on-site using NAVSEA drawing S8400-921610 or S8400-921602.

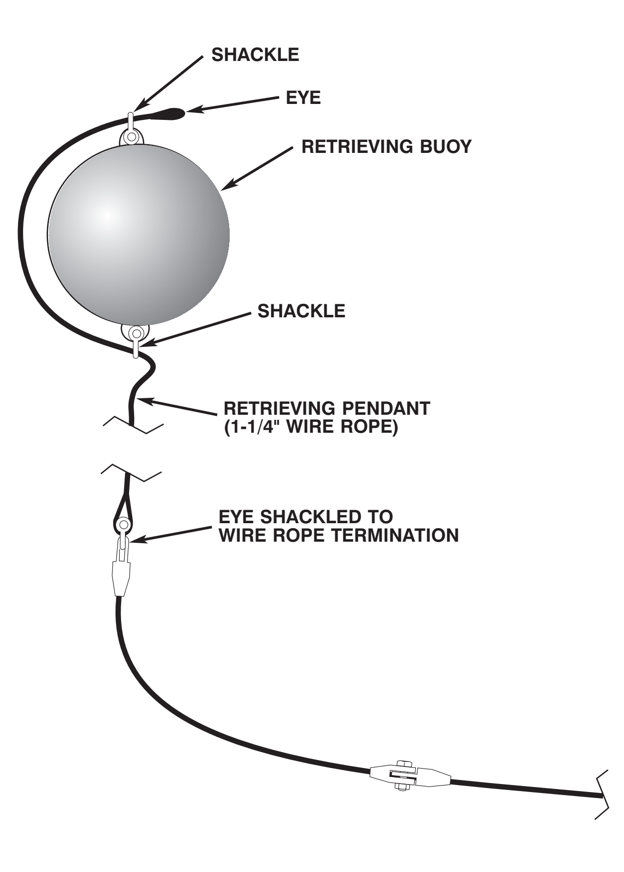


Figure 8-23. Retrieving Pendant Connections.

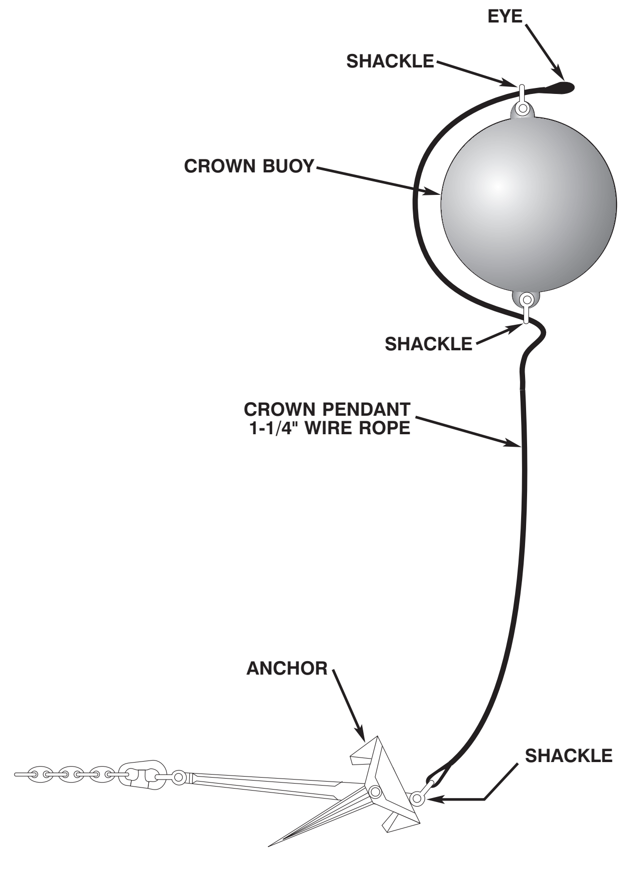


Figure 8-24. Crown Pendant Connections.

8-5.2.4 Retrieving Pendant. The retrieving pendant is a length of wire rope longer than the water depth used to retrieve the ground leg. One end of the retrieving pendant is connected to the shoreward end of the ground leg wire rope; the other end is suspended from a buoy.

Shipboard retrieving pendants are 100- and 200-foot lengths of 1¼-inch diameter, IPS, drawn, galvanized, preformed, right-hand lay, fiber core, Type-1, Class-3, 6×37 Warrington-Seale wire rope. The 113,200-pound breaking strength of the rope is sufficient for retrieving the ground leg.

The retrieving pendant is attached to the bitter end of the ground leg and dropped by the salvage ship along with the ground leg. When the ground leg is to be recovered, the buoy is picked up, and the bitter end of the retrieving pendant on the buoy is hauled aboard and used to heave in the bitter end of the ground leg.

The details of securing the retrieving pendant to the ground leg and buoy are shown in Figure 8-23. The retrieving pendant leads through shackles on the buoy and leaves the bitter end free.

8-5.2.5 Crown Pendant. The crown pendant is used to recover or reset the ground leg anchor.

Shipboard crown pendants are the same type of wire rope as are retrieving pendants. Heavier wire rope may be needed to break out tandem anchors and may be substituted when tandem anchors are rigged.

One end of the crown pendant is shackled directly to the crown of the anchor and the other to a buoy. The pendant is dropped with the beach gear. When the beach gear anchor is to be recovered or reset, the salvage ship recovers the crown pendant.

The details of securing the crown pendant to the anchor and crown buoy are shown in Figure 8-24. The pendant is passed through the shackles to make handling easier. The breaking strength is sufficient for breaking out and recovering the anchor. Heavier wire rope may be needed to break out tandem anchors.

8-5.2.6 Retrieving and Crown Buoys. The retrieving and crown buoys are used to support the retrieving and crown pendants.

CAUTION

In deep water, the weight of the crown and retrieving pendants can exceed the net buoyancy of the buoy. Additional buoys should be added to prevent loss of the pendants and buoys.

Table 8-9. Wire Rope Weights and Flotation Cell Spacing.

Wire Rope Size (Inches)	Approximate Weight (Pounds-per-Foot)	Flotation Cell Spacing (Feet)
1¼	2.67	90
1⅜	3.23	75
1½	3.84	60
1⅝	4.50	55
1¾	5.23	45
1⅞	6.00	40
2	6.82	35
2⅛	7.70	30
2¼	8.64	25
2½	9.61	23
2¾	12.90	18

Salvage ships carry two types of buoys. The older 42-inch steel buoys weigh 325 pounds and will support about 1,100 pounds of wire rope and fittings. The newer 40-inch nylon-covered, closed-cell foam buoys weigh 164 pounds and have a net buoyancy of about 1,000 pounds.

Each 100 feet of retrieving pendant and its connecting shackle weigh about 300 pounds. One buoy will support three 100-foot lengths of retrieving or crown pendant.

The buoys are used during the laying, heaving, and recovery of beach gear. After the beach gear ground leg is dropped, the crown buoy is used as a reference to mark the direction of pull on a particular ground leg. The retrieving buoy marks the bitter end of the ground leg when it is dropped and cast off.

8-5.2.7 Flotation Cells. Flotation cells are inflatable rubber bags used to help float heavy wires. They are called "strawberries." Each flotation cell, when fully inflated, has a net buoyancy of 275 pounds.

Flotation cells are most often used in passing the towline from the salvage ship to the stranded ship. The weight of the towline dictates the number and spacing of flotation cells. The net buoyancy, divided by the weight per foot of the towline, will give spacing of the flotation cells. The cells are secured to the towline by cross-tying small stuff, usually nine-thread, through the D-rings of the cells and bending all ends to the towline with either clove or constrictor hitches.

Flotation cells reduce the load on the messenger line, keep the wire rope from snagging on the seafloor, and make passing heavy wire rope easier. Table 8-9 gives the weights of commonly used wire rope sizes and the associated spacing for flotation cells.

Anything with buoyancy that is sturdy and can be attached to the towline can be used for flotation. Empty barrels make good floats. Their net buoyancy depends upon the volume and weight of the barrel. The weight of the barrel is subtracted from the gross buoyancy to give the net buoyancy.

EXAMPLE 8-5
CALCULATION OF NET BUOYANCY

A 55-gallon drum has a volume of 7.35 cubic feet and weighs 60 pounds. What is the net buoyancy?

a. Multiply the volume of the barrel by the weight per cubic foot of seawater to calculate the gross buoyancy:

$$\text{Gross Buoyancy} = \text{volume} \times \frac{\text{weight}}{\text{Cubic foot}}$$
$$\text{Gross Buoyancy} = 7.35 \times 64$$
$$\text{Gross Buoyancy} = 470 \text{ pounds}$$

b. Subtract the barrel's weight to calculate net buoyancy:

$$\text{Net Buoyancy} = 470 - 60$$
$$\text{Net Buoyancy} = 410 \text{ pounds}$$

8-5.2.8 Spring Buoys. Spring buoys are used where there is deep water directly astern of a stranded ship. The buoys are 10-foot-long, 6-foot-diameter, 3,100-pound, urethane-covered foam buoys with a net buoyancy of about 7.5 tons. The buoy attachment bails on each end are connected with a solid rod or chain running through the center of the buoy and can withstand about 125 tons of pull-through force.

Spring buoys are rigged into the ground leg to allow a nearly horizontal pull on the stranded ship. The buoy also reduces the effects of sea-induced dynamic loads on the ground leg. Spring buoys may be used on beach gear rigged to either the stranded ship or the salvage ship. Figure 8-25 shows a spring buoy rigged into a ground leg.

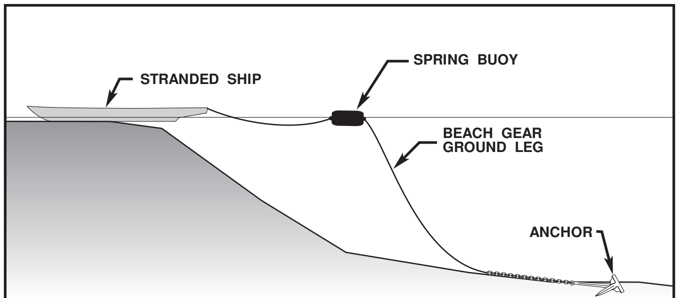


Figure 8-25. Spring Buoy Rigged into Ground Leg.

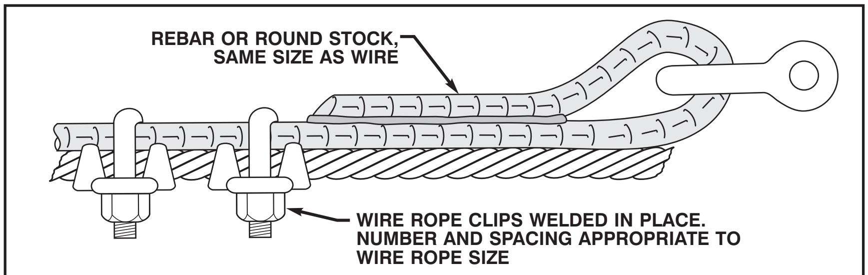


Figure 8-26. Improvised Wire Rope Stoppers.

8-5.2.9 Miscellaneous Beach Gear Equipment. In beach gear operations, it is prudent to have a supply of miscellaneous equipment and spares available. The items should include at least:

- An assortment of wire rope pendants of various lengths ranging in size from ⅝ inches to 1⅝ inches
- An assortment of safety shackles ranging from ¾-inch to 3-inch
- A set of reel rollers for handling the wire rope drum
- One drum of ¾-inch wire rope of the same quality as other wire rope in the system
- One wire rope cutter capable of cutting 1⅝-inch wire rope or a portable burning set or axe
- Six 1×12-inch jaw-and-jaw turnbuckles to be used in lashing
- One twofold purchase rove with 3-inch nylon line for fleeting out the deck purchase
- A variety of hand tools — including mauls, marlinespikes, crowbars, wrenches, and a long-handled (6- to 9-foot) knife to stand off while cutting manila stops that do not part
- Various sizes of small stuff — six-thread to 2½-inch fiber line
- A gin pole or similar equipment for handling heavy gear.

8-6 ESSM BEACH GEAR SYSTEMS.

The Emergency Ship Salvage Material (ESSM) system stocks beach gear systems in ready-for-issue condition. These systems are nearly identical to the Navy standard beach gear sets carried on salvage ships. Issue of beach gear sets may be requested from the ESSM system by forwarding NAVCOMPT Form 2276, Request for Contractual Procurement, to NAVSEA OOC via the appropriate chain of command. The beach gear sets can normally be delivered to the requesting unit by ESSM warehouse operators. One of the advantages of ESSM beach gear systems is the portability of many of the available beach gear components, such as the ESSM hydraulic 5 ton winch which is much more portable than the Clyde winch.

8-6.1 System Make-up. An ESSM beach gear set consists of one hydraulic puller, a power source and control panel, and a standard ground leg. Purchase-hauled sets can also be requested. In addition to the deck arrangements, each set has:

- A ground leg with the same basic components as carried on Navy salvage ships. The ground legs are the same for both types of pulling systems, but 2,000-foot continuous lengths of 1⅝-inch wire rope are available. STATO anchors are issued with the standard ESSM beach gear set.
- Retrieving wire rope — the same as used in the standard Navy beach gear. Beach gear sets drawn from the ESSM system contain eight 100-foot lengths of 1¼-inch wire rope on two-wire spools.
- The same 1¼-inch wire rope issued as the retrieving pendant in the ESSM system standard beach gear set is used for the crown pendant.

8-6.2 Ordering ESSM Beach Gear. When ordering beach gear from the ESSM system:

- The pulling power source — linear puller or purchase — must be specified.
- Portable winches must be drawn for purchase-hauled systems when required.
- Extra wire rope should be drawn if the ground legs must be longer than the standard leg. The ESSM system can supply 50- or 100-fathom and 2,000-foot lengths of 1⅝-inch wire rope.

8-7 IMPROVISED BEACH GEAR.

When there is no available Navy standard or ESSM beach gear, salvors can improvise beach gear from material found aboard the stranded ship or procured locally. Improvised beach gear may be extremely helpful in stabilizing and preventing broaching of a stranded ship.

WARNING

Use of nonstandard or unmatched components in a purchase pulling system can result in unforeseen failure and danger to personnel. When purchase pulling systems are assembled from nonstandard or unmatched components, all personnel should stay well clear when loads are applied.

8-7.1 Components. Commonly found rigging components and other equipment may be used to improvise beach gear.

- Blocks and wire rope from booms can be rigged into purchase pulling systems. The safe working loads and capacity of the boom and rigging are usually listed in the ship's papers.
- Improvised wire rope stoppers, as shown in Figure 8-26 can be made of rebar or round stock which is the same size as wire. Wire rope clips can be welded in place and spaced appropriately, based on wire rope size. Beach gear capacity will be reduced when using improvised stoppers.

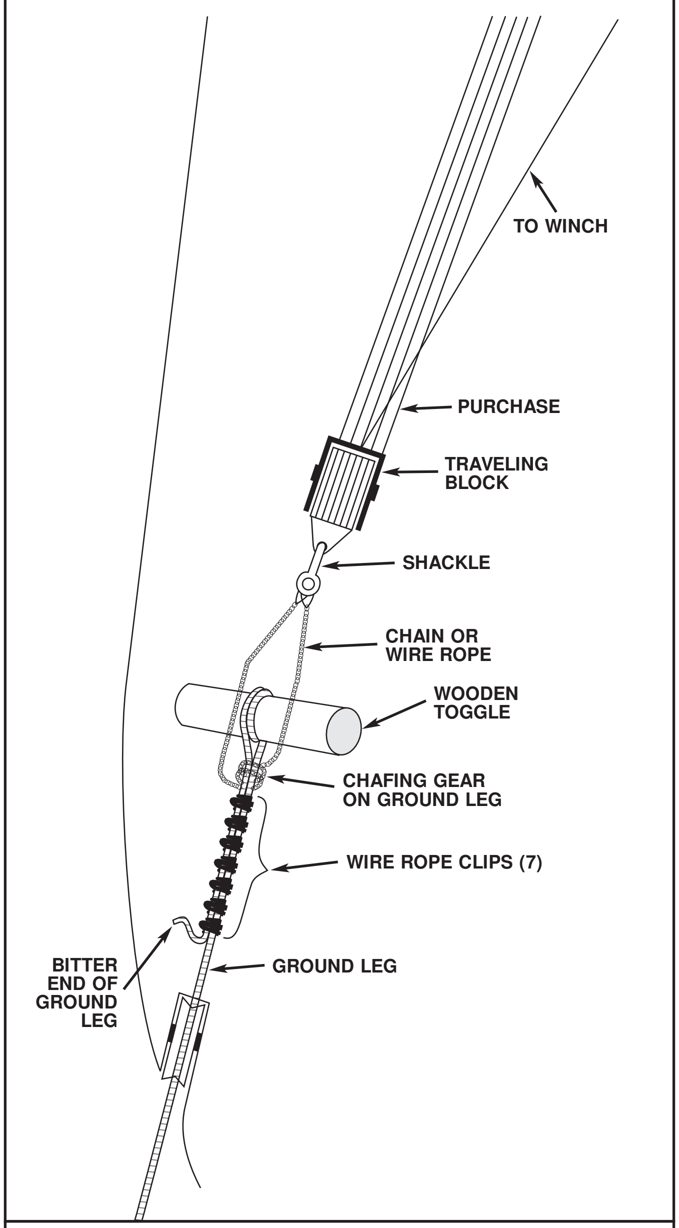


Figure 8-27. Toggle Bar Used as Stopper on Ground Leg.

- Toggles can be used with purchases in place of Carpenter stoppers. Toggles reduce the amount of pull that can be applied because they will damage wire under heavy strain. Figure 8-27 shows toggle rigging.
- Ships usually carry an assortment of chain, shackles, and wire rope that can be used to secure the purchases to pulling points.
- The deck machinery normally used to operate cranes and booms can be used to haul purchases. These same winches are normally used for operating Navy standard beach gear purchases when beach gear is rigged aboard the stranded ship.
- The stranded ship's anchor chain can be used in the ground leg if tugs or other craft are available to carry it seaward. The chain from both anchors can be joined for a longer leg. Wire rope or synthetic line ground legs can be made up when the material is available. It is good practice to check the ship's cargo manifest for wire rope, chain, or anchors that may be used.
- Usually the ship's anchors are the only ones available for the ground leg anchor. Moving these anchors from the ship seaward is difficult but possible even when tugs are not on scene.
- Anything with buoyancy, such as empty drums, life jackets, and small fenders, can be lashed to the ground leg and chain to make its movement easier.

WARNING

Carrying out anchors with lifeboats can be dangerous and should be avoided if other means are available.

8-7.2 Inspection of Improvised Beach Gear. All components of improvised beach gear should be inspected every time the system is loaded and the load removed. Items to look for:

- Elongated shackles and deck padeyes
- Bent shackle or sheave pins
- Distortion of any component
- Multiple-sheave blocks with sheaves that are no longer parallel
- Flattened wire rope
- Broken wire rope strands
- Buttered, elongated, or cracked chain links.

If any of the items listed is found, the component should be replaced or loads limited, and extreme care should be taken when loads are applied.

Wire rope preventers can be rigged to components to minimize damage caused by catastrophic failure. For instance, a wire rope preventer can stop a standing block from traveling down the deck and injuring personnel if the padeye or bridle holding the block parts.

8-8 BEACH GEAR OPERATIONS.

8-8.1 On Board the Stranded Ship. The first step in beach gear operations is to pass the bitter end of the beach gear leg to the stranded ship. This may be done by first passing a messenger line by helicopter, line-throwing gun, or boat, and hauling in and securing the bitter end. If there is power on the stranded ship, the line may be hauled aboard by power; otherwise, it must be passed back to the salvage ship for handling.

The most desirable way to secure the bitter end is with a Carpenter stopper that has been passed previously. If this cannot be done, the line may be figure-eighted on a set of bitts. Space must be left for passing a Carpenter stopper on the wire rope before it is taken off the bitts. Once the bitter end is aboard and secured, the salvage ship steams on a predetermined bearing, stretches the beach gear wire rope out to its full extent, and drops the remainder of the leg. Figure 8-28 shows typical beach gear arrangements on a stranded ship.

Either direct pull or purchase ground tackle can be used when pulling from the stranded ship. The beach gear purchase has traditionally been the fastest and most effective method for preparing a pulling system. The purchase is highly portable and can be transferred aboard with minimal effort. Numerous heaving sources are common on most ships.

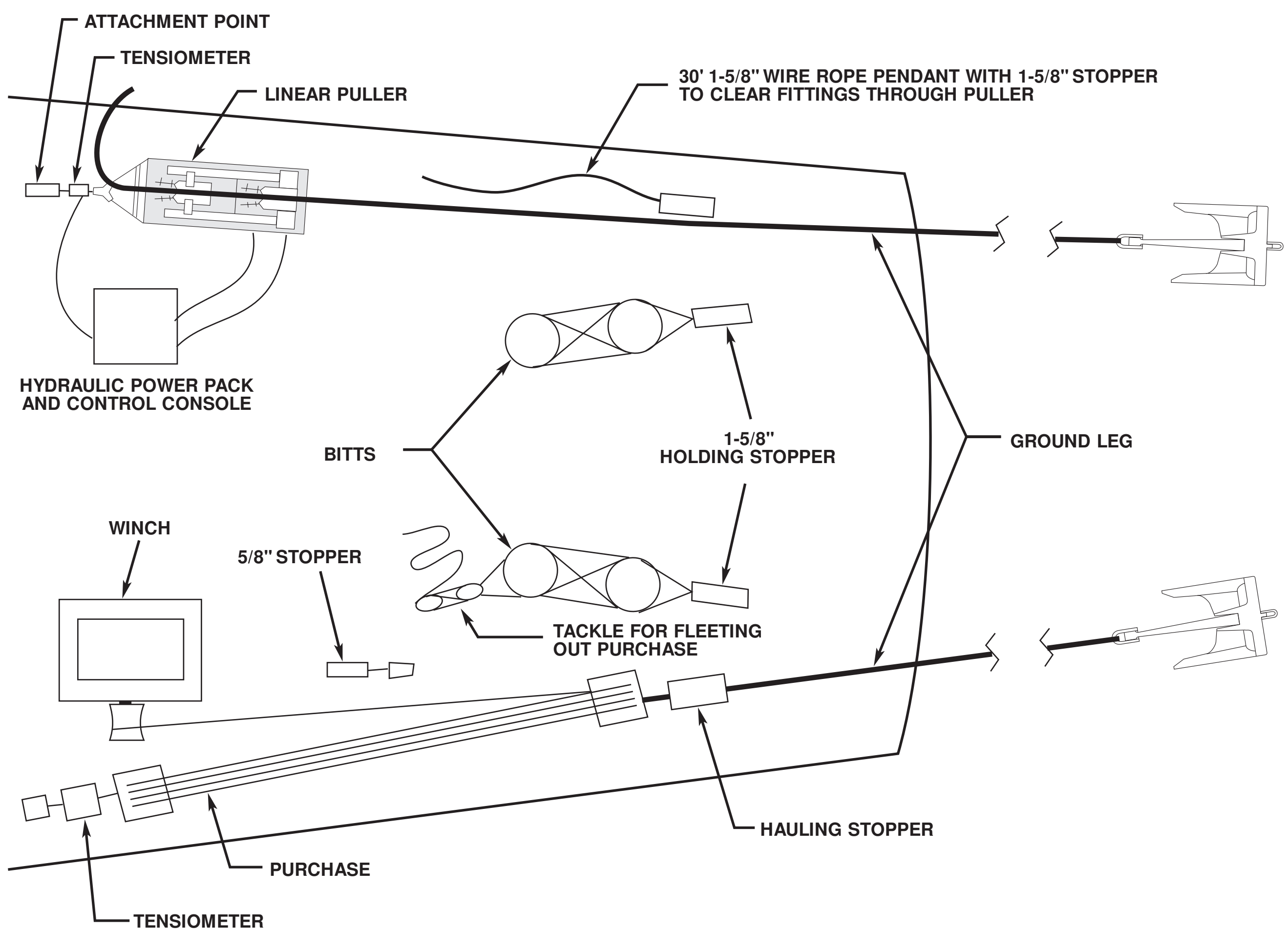


Figure 8-28. Beach Gear Arrangement on Stranded Ship.

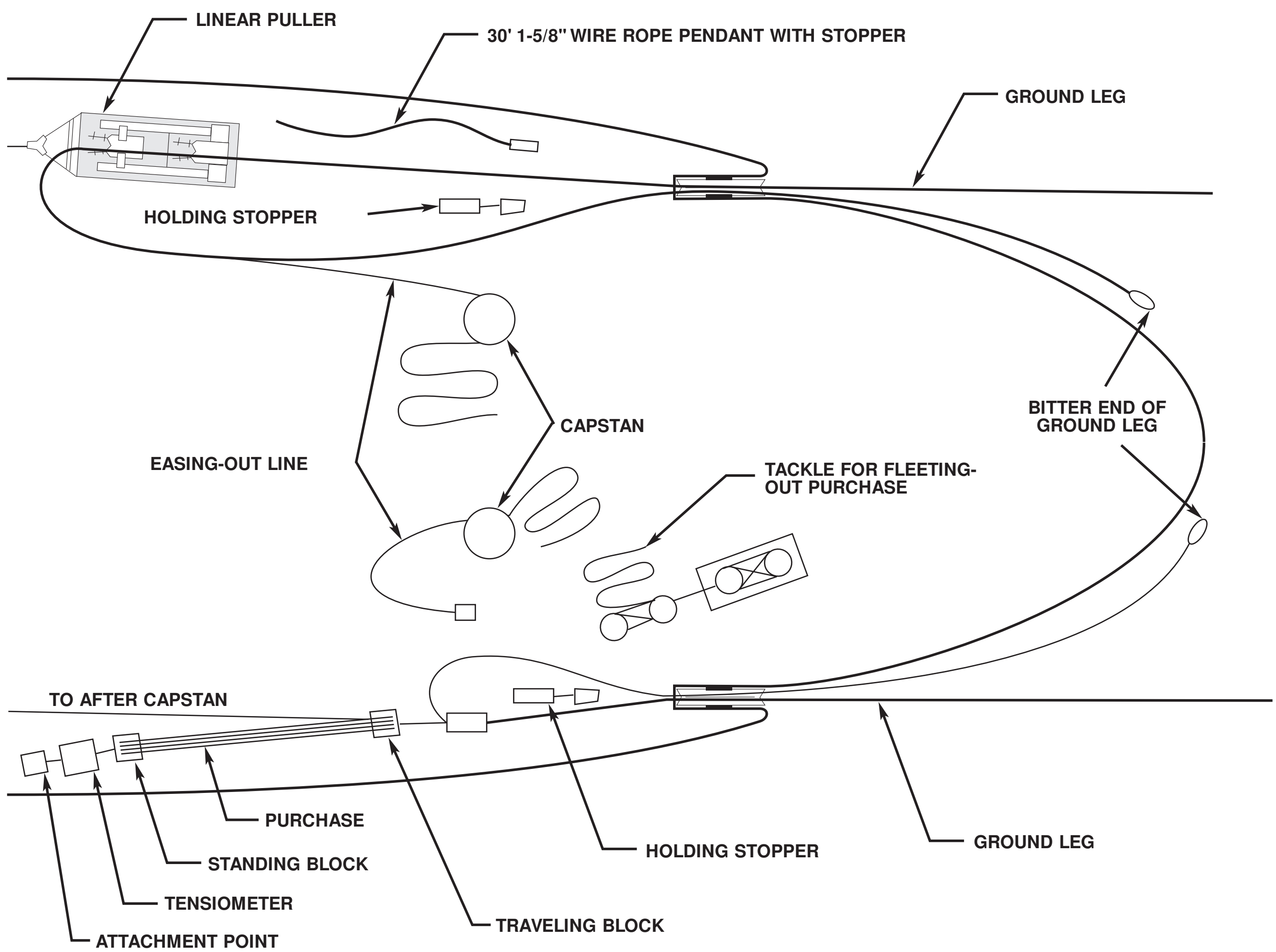


Figure 8-29. Beach Gear on ARS-50 Class.

Conversely, components of direct-pull ground tackle — such as the linear puller and power source — are heavy and difficult to move, particularly in bad weather. Pullers cannot be operated without a hydraulic power source. Such sources — unlike winches and capstans — are not found on most ships. Whichever system is used, it must be transported to the ship by helicopter or boat and hauled on board. When beach gear equipment is transferred to a stranded ship, all components for one leg should be packaged together in a cargo net. Similar components for several legs should never be packaged together; loss of a single cargo net during transfer could mean the loss of several legs.

A pull can be made or tension maintained from a stranded ship in weather that will drive off the hardiest salvage ship. Ground legs for beach gear are usually effectively run in the general direction of refloating. These legs cannot be used to wrench as effectively as legs leading sharply away from the stranding. Wrenching allows the ship to be swung to the optimum heading for refloating.

When rigging beach gear on a stranded ship:

- Beach gear is rigged as soon as possible to get control of the ship's movement.
- As many beach gear sets should be rigged as deck space allows.
- Purchases are rigged fore-and-aft where traveling blocks have the longest possible run.
- Elevated platforms may be built over operating purchases.
- If necessary, deck fittings and equipment may be removed or holes may be cut in the ship for fairleads and long runs of the purchase.
- All bitts, padeyes, and other securing points that will be used to anchor the standing blocks, holding stoppers, and fairleads should be inspected for structural soundness.
- If possible, each purchase should be led to its own heaving source.

The above guidelines are still applicable for hydraulic pullers. A long, clear deck area is not as important because pullers do not require as much operating area as purchases.

8-8.2 On Board the ARS-50 Class. This paragraph describes the general rigging, pulling and recovery procedures for beach gear on the ARS-50 Class. Figure 8-29 shows a purchase-and direct-pull ground tackle systems arrangement. The operations handbook for this class ship, NAVSEA SS500-AM-MMO-010, provides detailed drawings and procedures for all beach gear evolutions. The operations handbook should be the primary reference when putting the pulling systems into place.

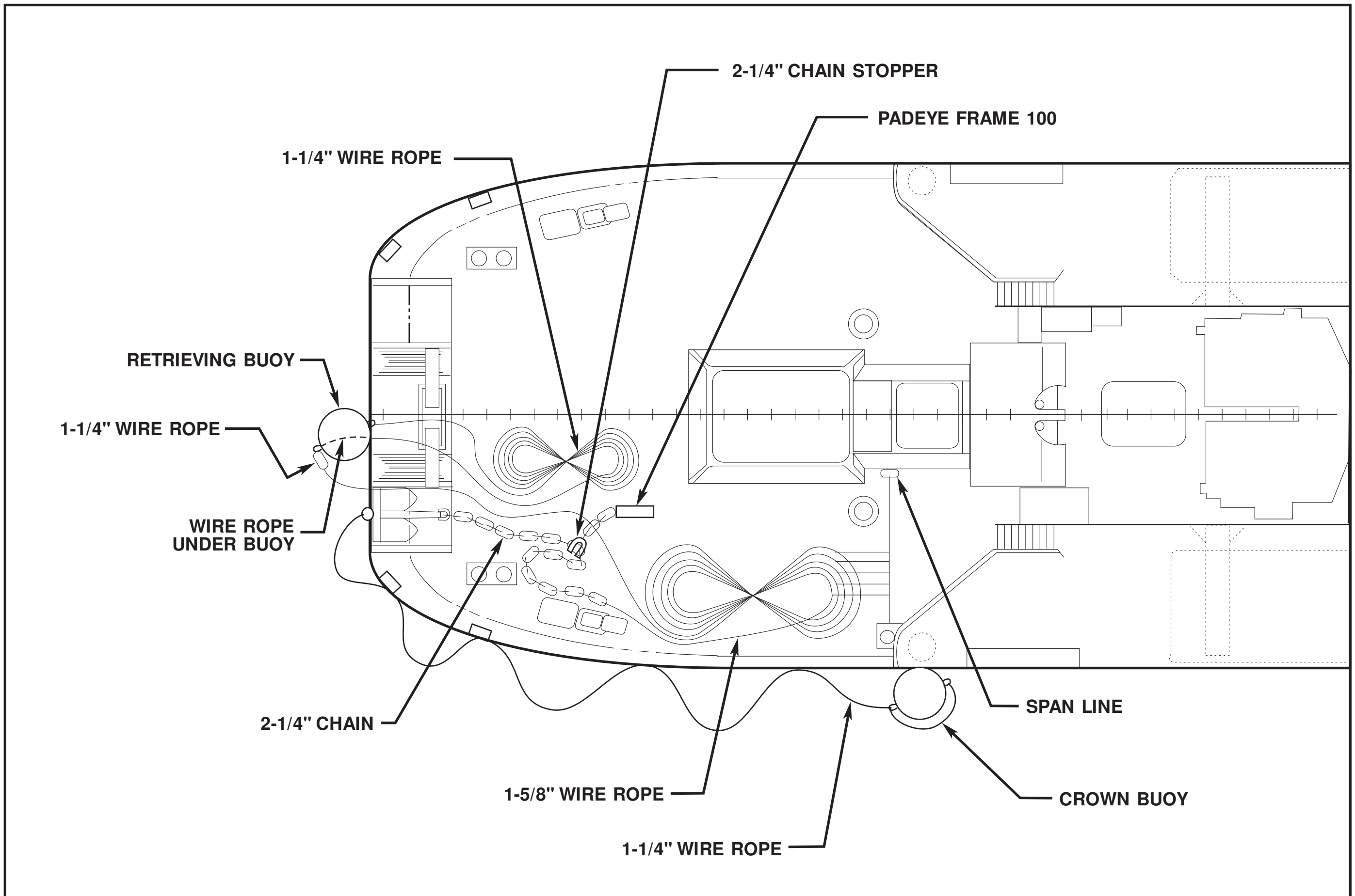


Figure 8-30. Beach Gear Rigged for Laying from ARS-50 Class.

Direct pull and purchase ground tackle systems are carried in the ARS-50 Class. The primary pulling system uses linear pullers. Two of the pullers are operated with installed hydraulic power units, and two, with portable power units.

Four purchase sets are carried for rigging on board or transferring to the stranded ship.

The ground tackle systems are supported by six STATO anchors.

Rigging the ground legs for laying is as shown in Figure 8-30. Although four anchors are permanently stowed in billboards, the recommended procedure is to lay anchors from the stern anchor chutes.

Tests have shown that anchors tripped from the stern chutes tend to set and hold better than those laid from the billboard. The anchors stowed in the after billboards can be moved to the stern chutes with the 40-ton boom. The forward anchors must be yard-and-stayed to the stern chutes.

The primary arrangement for beach gear operations is to heave on the ground leg wires with two hydraulic pullers located on the 01 level, port and starboard. One or both tow lines are led from the double-drum towing machine to the stranded ship.

Purchases can be used in lieu of the hydraulic pullers on either side on the 01 level. Purchases are hauled using capstans on the fantail.

In addition to the towlines leading to the stranded ship, pulling wires can be rigged. Two portable pullers can heave on wire ropes from the fantail directly to the stranded ship.

8-8.3 On Board the T-ATF-166 Class. These classes of ships do not carry beach gear but have deck fittings and operating instructions to rig and lay portable systems. Both can rig either puller or purchase-hauled systems.

Two standard beach gear sets are normally drawn from the ESSM system. Pullers will be delivered unless purchases are specifically requested.

With their large open decks, the T-ATF-166 Class ships can haul additional beach gear purchases. The request for additional purchases should include portable winches. Capstans on the T-ATF-166 Class have insufficient line pull to haul beach gear. The ships require portable T-bitts for rigging pulling systems on the fantail.

Like the ARS-50 Class, the T-ATF-166 Class can pull in both directions. Two sets of puller-hauled beach gear lead forward to ground legs, while the towlines and two purchase-hauled beach gear legs lead aft to the stranded ship.

CHAPTER 9
OPERATIONS TO REFLOAT STRANDED SHIPS

9-1 INTRODUCTION.

There is urgency in any stranding. No matter how secure a stranded ship may appear, she is in a dangerous position. A stranded ship generates great interest and a desire for action. In most cases, rapid refloating is desirable to remove the ship from a place of danger, to reduce stress in the hull, and to decrease the risk of pollution. Pressure for immediate action must not cloud good judgement. The fundamental goal is safe refloating of the stranded ship.

Action taken in haste can hazard the ship, complicate the refloating operation, or delay its completion. The refloating should be a cooperative effort between the stranded ship's crew, which has expertise in the ship, and the salvage crew, which is expert in salvage operations. The goals of both are to save life, the ship and its cargo, and to prevent pollution. It is almost impossible to overreact to a ship stranding. The arrival of salvors on-scene with insufficient material or personnel can doom a stranded ship; it is good business to arrive with more than needed.

Refloating operations have three phases:

- The Stabilization Phase — when steps are taken to prevent further damage and keep the ship from being driven harder aground or broaching. During this phase, information for the development of a salvage plan is gathered and organized, and the salvage plan is prepared.
- The Refloating Phase — when the salvage plan is executed and the ship is refloated.
- The Post-Refloating Phase — when the ship is secured and prepared for delivery to her operational commander or owner.

9-2 THE STABILIZATION PHASE.

Well-planned and thought-out efforts immediately after a ship strands can reduce damage and enhance salvage operations. The actions to prepare for the operation by the ship's crew and the salvors are equally important.

9-2.1 Immediate Actions by the Stranded Ship. There are few commanding officers or ship masters with much experience in the stranding of their ships. For most, it is an entirely new, ominous, and traumatic experience. None the less, the prudent commanding officer is as well-prepared for stranding as for fire and other ship-board emergencies. He must make decisions that may affect the fate of the ship and its crew under conditions of extreme stress. Proper action by the ship's company after a stranding can abate the effects of the casualty and make salvage easier and less costly. Improper or poorly thought-out action taken in haste can make the situation worse and may even lead to the loss of the ship.

Immediately upon stranding, the commanding officer should take the following actions to gain control over the situation and to reduce the hazard to life:

- Go to General Quarters or Emergency Stations.
- Set the material condition that gives the maximum degree of watertight integrity.
- Display proper signals.
- Notify the operational commander and other authorities.

When the immediate danger is past, the commanding officer must evaluate:

- Safety of personnel
- Weather and sea conditions, including any forecast changes
- Current and tide
- Nature of the seafloor, the shore line, and the depth of water around the ship
- Damage
- Risk of further damage
- Prospect of maintaining communications
- Pollution that has occurred and the risk of potential pollution
- The ground reaction
- The draft and trim after refloating.

Only when information about the damage has been obtained will it be possible to make a reasonable assessment of the situation and the necessity for salvage assistance. The ship must be surveyed completely for damage with special attention to flooding in compartments located in the area of grounding. While the loading of holds and compartments may make it difficult to ascertain the exact condition of a ship, every reasonable effort should be made. Particular care should be taken in opening sounding tubes, scuttles, hatches, and other accesses that may allow flooding to spread. Attention should be paid to deformed plating, twisted structural members, and other indications of hull damage.

Soundings should be made all around the ship to determine the extent of the stranding. If the sea is too rough for accurate soundings, it may be possible to measure the distance from the weather deck to the seafloor. The extent of the stranding may be determined by marking these distances on a profile of the ship.

The commanding officer must **not**:

- Jettison weight in an attempt to lighten ship preparatory to an attempt to back off. Jettisoning generally results in the lightened ship being driven farther ashore by weather. Stability may be impaired if low weights are removed and the center of gravity allowed to rise.
- Attempt to back off when the bottom is torn open. Attempting to back off if the ship has been rendered un-seaworthy by bottom damage, or unstable by off-center flooding, free surface, or free communication can cause additional bottom damage or sinking.
- Fail to take action to stabilize the ship or determine its condition.

If seafloor material is likely to clog sea suctions, secure as much machinery as possible. Shift to high sea suctions. Operate machinery only in spaces with the deepest water under them.

A request for salvage assistance should be made immediately and not delayed while a refloating attempt is made by the ship's force. Early mobilization and dispatch of salvage assistance may mean the difference between success and failure of the salvage operation.

If the damage assessment shows the ship will not broach, sink, or capsize, an attempt can be made to back clear using full engine power on the next high tide. If the ship does not clear her strand in a short time, the engines should be placed in standby, ready for immediate use, and the ship secured on her strand.

CAUTION

If seafloor material is likely to clog sea suctions, secure as much machinery as possible. Shift to high sea suctions. Operate machinery only in spaces with the deepest water under them.

CAUTION

If the stern is inshore of the surf line, or there is a strong longshore current, trying to back clear can result in broaching before the ship gathers enough sternway to clear the strand.

If the ship cannot retract, but the ship's head is swinging back and forth and the deck feels as though it is rising and falling with the swell, the ship is lively. A lively ship is in danger of broaching or being driven farther aground. If changes in the ship's head show that she is starting to broach and if the stern is clear to maneuver, judicious use of engines can help hold the head without driving the ship farther aground. Lines to rocks, coral heads, or by carrying anchors out for ground legs can help prevent broaching.

Boats and tugs can help keep the ship from broaching by pushing or pulling on her seaward end. Properly laid ground legs are the best method to secure the ship. If suitable boats are not available to carry the ships own anchors out, ship’s company may be able to slip and buoy bower anchors to which mooring lines can be passed.

Ballasting or flooding compartments weighs the ship down and prevents her from being driven farther inshore. A ship aground with one end floating may be ballasted to increase the bottom area in contact with the seafloor and distribute the ground reaction over a greater area. If the seaward end is moving with the sea and swells, ballasting will reduce the hinging action and ease bending stress on the hull girder.

9-2.2 Immediate Actions by Salvors. Upon being assigned responsibility for the casualty, salvors should establish communications with the stranded ship. In the initial contact with the ship, salvors should do three things:

- Advise the stranded ship that help is on the way and what the expected time of arrival is.
- Repeat the advice of Paragraph 9-2.1.
- Obtain specific information about the condition of the ship.

When information about the casualty has been obtained, salvors can evaluate the situation and plan specific immediate action.

Proper action in the early stages of a casualty can make a great difference to the outcome. If the casualty can be reached by air, it is good practice to fly a cadre of experienced salvors to the scene. They can evaluate the situation, advise and supervise the ship's crew in securing the ship and preparing it for salvage, obtain information that will allow the salvage ship to begin work immediately upon arrival, and pass pertinent information to interested parties. The composition of this crew will vary according to the location of, and access to, the casualty and the initial evaluation. The party should always be as self-sufficient as possible and should include the most experienced people available.

In the initial evaluation of a casualty, salvors must prepare recommendations as to whether or not the salvage should be attempted. Major factors for consideration are the technical feasibility of the operation, the probability of a successful return to a port for repairs, and the possibility of repairs. In making a recommendation, salvors must also realize that the decision to attempt the salvage will be made by higher authority. The decision-making authority may be influenced by financial and political considerations unknown to salvors in the field.

It is often practical to complete the salvage with a crew and specialized equipment that is flown in and augmented by tugs, barges, and other equipment hired locally. While the balance of this chapter is directed toward the classic case in which a salvage ship is the primary means of doing the job, it applies equally to "fly-away" operations.

9-2.2.1 Information to be Requested. Information to be requested from the salvage site includes:

- An accurate position of the stranding site giving latitude and longitude, along with applicable chart numbers and means of fixing the position
- Drafts on sailing from the last port and estimated at time of stranding
- Drafts forward, amidships, and aft, after stranding with the state of tide and the time taken
- Soundings alongside from forward to aft, corrected to the datum of the chart of the area
- Course and speed at time of stranding
- Ship's heading after stranding with details of changes
- Liveliness of the ship
- Weather conditions including: wind direction and velocity, current weather forecast, weather at the site
- Sea and current conditions including direction and height of seas and swells
- Extent and type of damage to the ship
- Location of grounding points and estimated ground reaction
- Type of seafloor at the site
- Status of ship's machinery
- Ship's cargo list or manifest
- Amount and location of known hazardous materials
- Help available on-scene or in the area, such as tugs, large boats, bulldozers, cranes, etc.

9-2.2.2 Initial Evaluation. An initial evaluation is made from the information received from the scene. The evaluation includes:

- Confirmation of the original estimates of ground reaction and freeing force
- Evaluation of reported damage to determine the stability afloat and residual strength

- Evaluation of the ship's machinery condition and on-scene help to estimate the retraction power available
- Evaluation of the ship's ability to proceed to a safe haven after refloating.

When the initial evaluation is complete, salvors are in a position to advise the ship on the wisdom of a refloating attempt.

9-2.3 Salvage Force Mobilization. Salvage force mobilization requires several actions, including:

- Determining personnel and material needs, including special skills such as salvage engineering or pollution control (either additional personnel and material should be loaded, or arrangements made for them to be transported to the site).
- Collecting information about the stranded ship. For naval ships, such information is available from sister ships, squadron material officers, the planning yard, and the Naval Sea Systems Command. Information on commercial vessels may be sought from the ship's owners or agents, the Coast Guard, or classification society registers (such as ABS or Lloyds). Satellite or high-altitude reconnaissance of the stranding site may provide excellent information about the casualty.
- Ensuring navigational material — including current charts, several copies of the largest-scale chart of the site, and tide and current tables — is on board.
- Starting the daily Salvage Situation Reports and all other records and reports required by current directives.

9-2.4 Salvage Ship Actions Enroute. While enroute to the salvage site, the salvage ship should prepare for the work ahead so that she is most effective upon arrival. Preparations include:

- Maintaining communications with the stranding to keep abreast of changing conditions and to keep advice to the casualty current
- Reviewing the stranded ship's information to determine capacities and working loads of deck equipment, such as booms, cranes, winches, capstans, and windlasses
- Laying out the survey plan, and briefing the survey and boarding teams
- Checking out workboats and rubber boats and outboard motors
- Staging equipment and material for transfer to the casualty
- Rigging two sets of beach gear for laying on arrival
- Checking the cargo manifest for hazardous materials and their locations
- Working up tidal and tidal current information
- Working up hydrostatic information
- Arranging daily and long-range weather forecasts.

9-2.5 Salvage Ship Actions Upon Arrival. Actions taken by the salvage ship upon arrival at the salvage site are divided into two categories: damage control and position stabilization.

Damage control action may range from augmentation of the ship's crew to total responsibility for all damage control. It may include fire fighting, patching, shoring, or any other action to prevent further damage.

CAUTION

Salvors should always conduct a hydrographic survey to locate and mark all dangers to navigation at the salvage site. Unmarked and unnoted hazards are dangers to salvage ships. In clear waters, observations from helicopters are useful for identifying shoals and channels.

Generally, two legs of beach gear to the stranded ship should be laid as soon as possible to secure the ship from broaching or being driven farther ashore. If broaching is imminent or has already occurred, the ship should be hauled around if at all possible until she lies end-on to the prevailing seas.

Once on the scene, a salvage survey should be conducted. The Salvage Survey is discussed in detail in Chapter 2, Surveys and Planning, of this manual.

9-3 REFLOATING PHASE.

The above mentioned section has described the stabilization phase. There is no clear separation between the stabilization and refloating phases. The stabilization effort changes gradually and smoothly into the refloating effort. The major portion of the refloating stage is devoted to preparation and rehearsal for the refloating effort. The preparation culminates in a relatively short, but highly concentrated effort to refloat the ship.

Rehearsals of key events and procedures are beneficial in identifying and finding solutions to problems, improving timing, ensuring equipment is operating, and sharpening teamwork. Rehearsals should be scheduled as early as possible in the operation to allow time to identify and implement solutions to problems.

Salvors must be able to apply pulling systems effectively and avoid interference between systems. Because of the importance of tugs and ground tackle to refloating efforts and the concentration of their use in the refloating phase, the remainder of this section is devoted to a discussion of the specialized seamanship required for their use in salvage.

9-3.1 Direction of Refloating. One of the principal factors governing the use of pulling systems is the direction in which the ship will be hauled to refloat. Where a ship has stranded perpendicularly, or nearly so, to the beach, and has not changed heading significantly, the best direction for refloating is usually along the reciprocal of her course at the time of stranding. The hydrographic survey should verify depths and the absence of underwater obstacles along the planned refloating route.

If the stranding broaches after grounding, the direction of refloating will probably also lie along the reciprocal of her course before grounding. In these cases, it will be necessary to rotate the ship to the proper heading prior to refloating her. Approximately one-third as much force is required to rotate the ship as to free her.

Where equal choices exist, it is usually better to refloat a ship stern first to prevent damaging the rudders, propellers, and other appendages by dragging them across the seafloor.

9-3.2 Connections to the Stranded Ship. Towlines and ground legs must be connected to the stranded ship at points strong enough to hold the largest forces the pulling system can develop. Acceptable connecting points are:

- Deck padeyes. Deck padeyes may have sufficient strength to carry pulling loads. Usually padeyes are load-rated and carry label plates with the rated load and test date. If there is no label plate or test data, the padeye and welds must be carefully inspected for cracks or deformation. If none is found, the padeye may be used with great care.
- Gun and winch foundations, deck houses and superstructure, masts, king posts, and sampson posts. Chain should be wrapped around these structures and the pulling line made up to the chain with a pelican hook. Sharp corners and small bending radii must be relieved to prevent the development of high bending stresses that can cause chain failure.
- Bitts and bollards. Wire rope or chain pendant bridles for pelican hooks can be figure-eighted on bitts and bollards. Loaded pendants should lead from the bottom of the bitts or bollards, otherwise the moment of the force on the pendant about the base of the bitts may cause failure. It is recommended that a preventer strap be installed on the bitts after the wire is made up to the bitts to prevent the wire rope turns from jumping off the bitts. Figure 9-1 illustrates the correct method of making up pendants on bitts.

If the eye of the towline is large enough, the pelican hook can be secured through it. If the termination of the towline is a socket, a safety shackle rated for the expected load can be attached to the socket. The pelican hook is secured through the shackle.

Turns should be made up tightly on bitts. Connections to bitts should be backed with wire rope or chain led to the next closest set of bitts, made up tightly, and hove taut. Figure 9-2 shows wire rope backed with chain to a second set of bitts.

It is not good practice to place the eye of a wire rope or the bridle of a Carpenter stopper directly over bitts or a bollard. Where space limitations dictate this must be done, a preventer should be rigged to ensure the bridle does not ride up.

When no pelican hook or quick-release chain stoppers are available, the wire rope of the ground leg may be figure-eighted around two or three sets of bitts. The ground leg is released by taking the turns off the furthermost bitts and working toward the direction of pull. The ground leg must be slack when it is being released. An easing-out line and preventers keep the wire rope from running out of control as it is eased over the side.

9-3.3 Tugs. Tugs pull directly on stranded ships, wrench them, and augment other pulling systems. Tugs may be used independently or in combination with ground tackle. The advantages and disadvantages of tugs in salvage and some considerations for their use were discussed in the previous Chapter. This section provides additional information on the use of tugs for refloating stranded ships.

9-3.3.1 Tug Approaches to the Stranding. Salvage ships and tugs are designed to work in-close in shoal water as part of their mission. Such work is dangerous. Tugs should maneuver near the stranded ship only after surrounding depths have been verified by a hydrographic survey. Depths should be recorded for all areas near the stranding where ships can be expected to work. Areas that present navigation hazards to ships working at the site should be clearly marked in red on navigational charts. Anchors should be ready for letting go at all times.

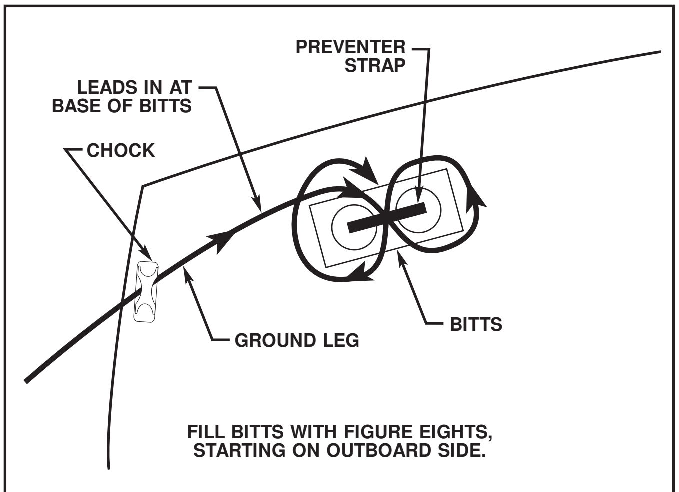


Figure 9-1. Making Up Pendants to Bitts Correctly.

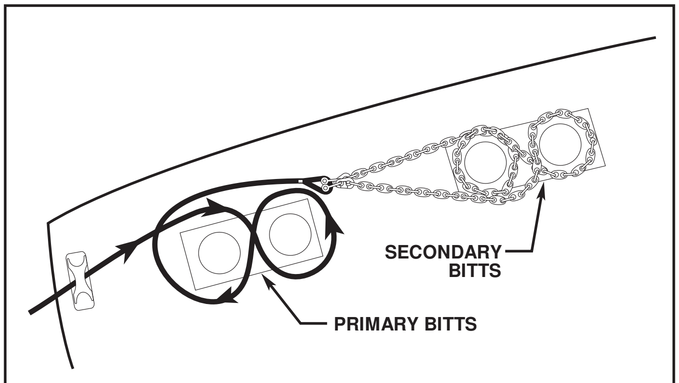


Figure 9-2. Wire Rope Backed Up by Chain on Secondary Bitts.

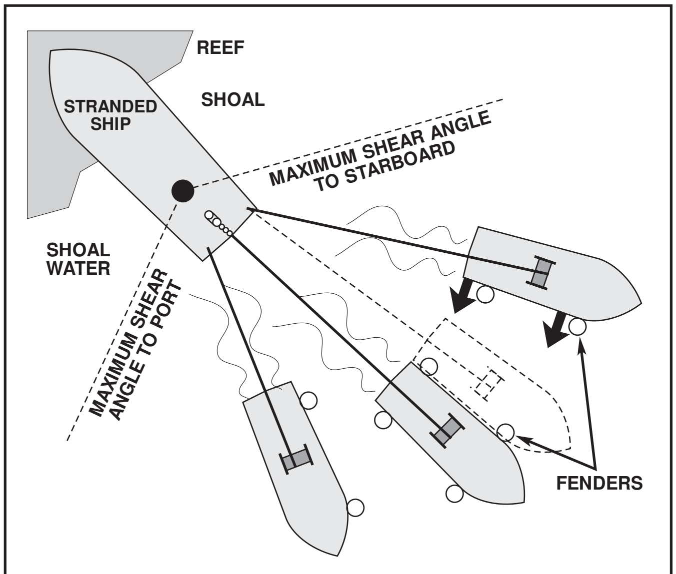


Figure 9-3. Pulling Arrangements for Several Tugs.

It is extremely useful for the salvage officer and tug commanding officers to fly over the salvage site by helicopter and closely observe the changes in color and other indications of shoal water. Helicopters can help guide salvage ships or tugs through shoal or rocky waters.

A salvage ship or tug can approach a stranded ship safely by anchoring to seaward of the stranded ship and backing towards it while veering anchor chain. The anchor holds the bow into the sea and holds the ship in position if propulsion is lost.

9-3.3.2 Location of Tugs and Length of Towlines. Tugs must be positioned to:

- Achieve the most effective pull
- Prevent mutual interference
- Avoid fouling beach gear ground legs.

To achieve the most effective pull, tugs usually pull independently from the seaward end of the stranded ship. Tugs can also pull both ends to wrench the ship's stern into the sea.

To prevent fouling of towlines and tugs, the towlines of all tugs should be approximately the same length. Towlines of the same length do not foul if one tug drifts down upon another. When towlines are the same length, the tugs may come together, but tugs cannot overrun and damage one another's towlines. Fenders should be rigged on each salvage ship or tug to absorb energy and prevent damage should the tugs drift together. Figure 9-3 shows a pulling arrangement with several tugs.

All towlines should be significantly longer than the beach gear ground legs leading from the stranding. The distance between the towlines and ground legs depends on the slope of the seafloor. The towline catenary must not be deep enough to foul the ground legs. Short distances are sufficient where the slope is great. Figure 9-4 shows pulling with a tug and beach gear combination.

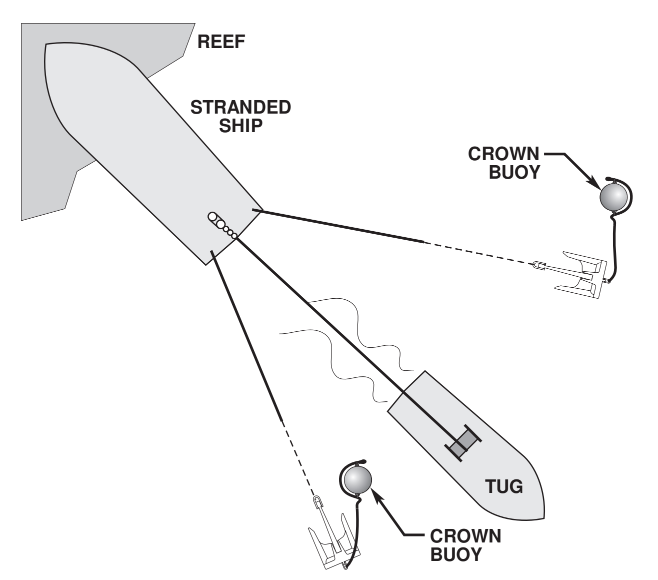


Figure 9-4. Pulling with Beach Gear and Tug Combination.

9-3.3.3 Tugs in Tandem. Where space is limited, tugs may be rigged to pull in tandem to maximize the pull on the stranded ship. When the inboard tug has no bow thruster, or the bow thruster cannot hold her head in the seas and currents, a second tug may be rigged in tandem. The tug in the lead position helps control the head of the inboard tug so that its pull is directed in the desired direction. Whenever tugs are rigged in tandem, their overall maneuverability is reduced. If the lead tug loses propulsion, the seas and wind may cause it to drag the other tug aground. Towlines should be rigged with pelican hooks, and cutting equipment should be at hand. Anchors on both tugs should be ready for letting go.

When tugs pull in tandem, the total bollard pull of both tugs is transmitted to the stranded ship through the inboard tug's towline. The total bollard pull must not exceed the breaking strength of this line, and if possible, should not exceed the safe working load (SWL). Appendix B of the *U.S. Navy Towing Manual* (SL740-AA-MAN-010) provides the characteristics of wire rope used for towing.

To keep the inboard tug on a particular heading, the lead tug will usually use her bow thruster to control her head. If she has no bow thruster, or the bow thruster is not powerful enough, she may rig a Liverpool Bridle. The Liverpool Bridle consists of a line rigged from the forward shoulder bitts to a Carpenter stopper. The Carpenter stopper is placed on the towline. The towline is slacked and the bridle takes the load. The Liverpool Bridle allows the tug to head into the winds and current by shifting the pivot point of the tug farther forward to make the rudder more effective. The bridle may be shifted from one side to the other as required by wind and current. Figure 9-5 shows how a Liverpool Bridle is rigged.

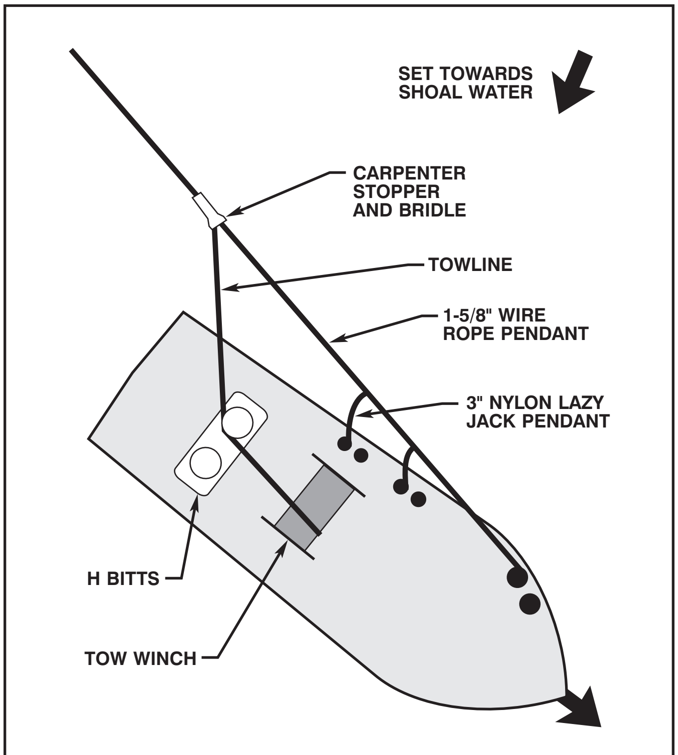


Figure 9-5. Liverpool Bridle Rigging.

9-3.3.4 Wrenching. One of the principal uses for tugs in salvage is to wrench or change the stranded ship's heading by pulling her from side to side. Wrenching helps break friction or rotates the stranding to the heading for refloating. To wrench, tugs swing in an arc while pulling. Stranded ships are wrenched more quickly by tugs than by beach gear. Tugs for wrenching should be positioned so that the arc through which they swing is centered about the planned refloating path. If there is sufficient room, wrenching tugs should swing through an arc of at least 60 degrees. When more than one tug is wrenching, the swing should be coordinated so that tugs pull in the same direction. When the stranded ship begins to move, the tugs should stop swinging and steady on the course that gives maximum pull along the refloating path.

Tugs and beach gear may be used together to wrench the stranding. The tug normally pulls against the seaward end of the ship. The beach gear wrenching legs can be rigged from both sides of the ship's grounded end. If the ship is bow on the beach, as the tug swings the stern in one direction, the purchases heave the bow in the opposite direction. Figure 9-6 shows the tug and beach gear wrenching combination.

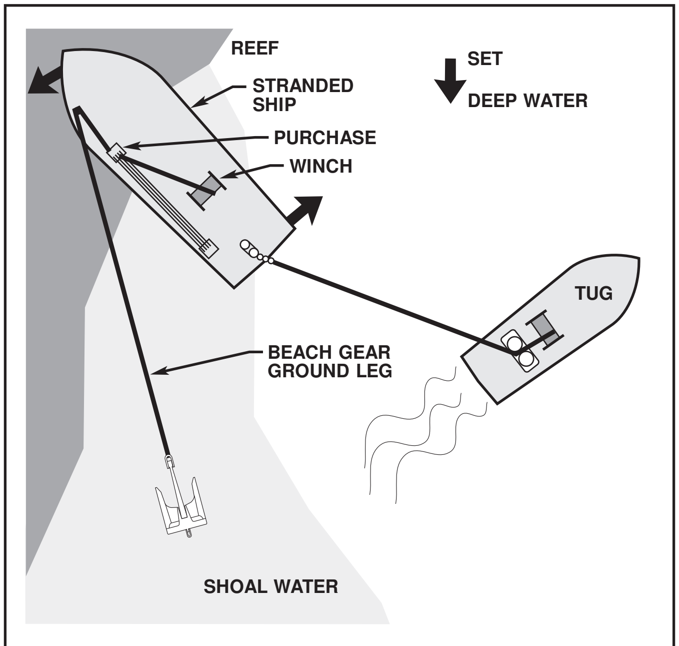


Figure 9-6. Wrenching with a Tug-and-Purchase Combination.

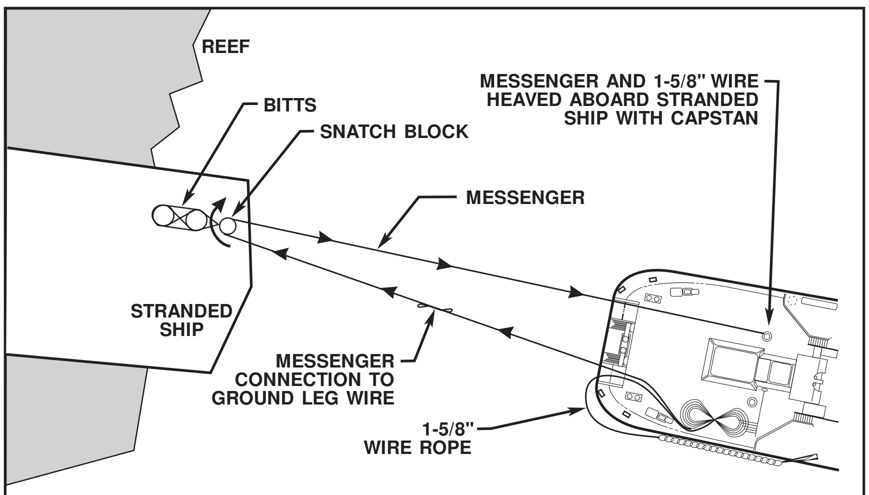


Figure 9-7. Hauling the Messenger to the Stranding.

9-3.3.5 Safety of the Salvage Tug. While every salvage operation involves risks to all participants, tugs must not be hazarded unnecessarily. Until the pull is terminated or the stranding moves, the tug's propellers will be turning over at or near full pitch or maximum revolutions. The tug will be nearly stationary, straining the endurance of her machinery and crew. Special care in navigation is required by the close waters. The commanding officer or master of the tug must be prepared to call for a break in the operation. A break should be called when it becomes apparent that the ship or the successful outcome of the stranding operation is jeopardized. Ground tackle rigged from the stranded ship allows the position to be held if a tug fails or must take a break.

9-3.4 Beach Gear Employment. There are four basic decisions to be made about beach gear:

- The number of legs required
- The platforms from which they should be rigged
- The direction for laying the ground tackle
- The use of each leg.

EXAMPLE 9-1
NUMBER OF BEACH GEAR LEGS REQUIRED

The force required to free a stranded ship is 276 short tons. How many legs of beach gear must be laid?

$$N = \frac{F}{50}$$
$$N = \frac{276}{50}$$
$$N = 5.52 \text{ legs (lay 6 legs of beach gear)}$$

EXAMPLE 9-2
EFFECTIVE FORCE

A leg of beach gear is laid at an angle of 20 degrees to the planned direction of retraction. What is the effective force of the leg?

$$\text{Effective force} = \text{Average pulling force} \times \text{cosine } \theta$$
$$\text{Effective force} = 50 \times \text{cosine } 20$$
$$\text{Effective force} = 50 \times 0.94$$
$$\text{Effective force} = 47 \text{ tons}$$

The decisions are interrelated and somewhat dependent upon one another as the supply of beach gear may be limited, and the geography of the salvage site may restrict some applications and dictate others. Since the purpose of the operation is to free the stranded ship, use of beach gear for pulling has priority.

Chapter 6 discusses the method of determining the freeing force required. To make a first estimate of the number of legs of beach gear needed, subtract the expected tug pull from the required freeing force and divide the remainder by the average pulling force of a leg of beach gear (50 short tons). The next largest whole number is the number of legs required to provide the freeing force. Once the initial estimate has been made, a diagram should be made of the proposed beach gear arrangement. Because each leg of beach gear occupies space, the legs must be laid as a spread rather than all in the direction of refloating. The effective force is the product of the force developed and the cosine of the angle between the beach gear leg and the direction of refloating. A second estimate is made to determine if the total effective force is enough to refloat the ship. If it is not, additional beach gear must be added, or the freeing force reduced by reducing ground reaction. When the beach gear can be pulled, actual pulling forces can be determined by tensiometer readings and the effectiveness of the beach gear arrangement evaluated.

To reduce loss of pulling force, beach gear should be laid as nearly parallel to the direction of refloating as possible.

The stranded ship is the preferred platform for beach gear. Generally, the salvage plan includes rigging beach gear from both the stranded ship and the salvage ships.

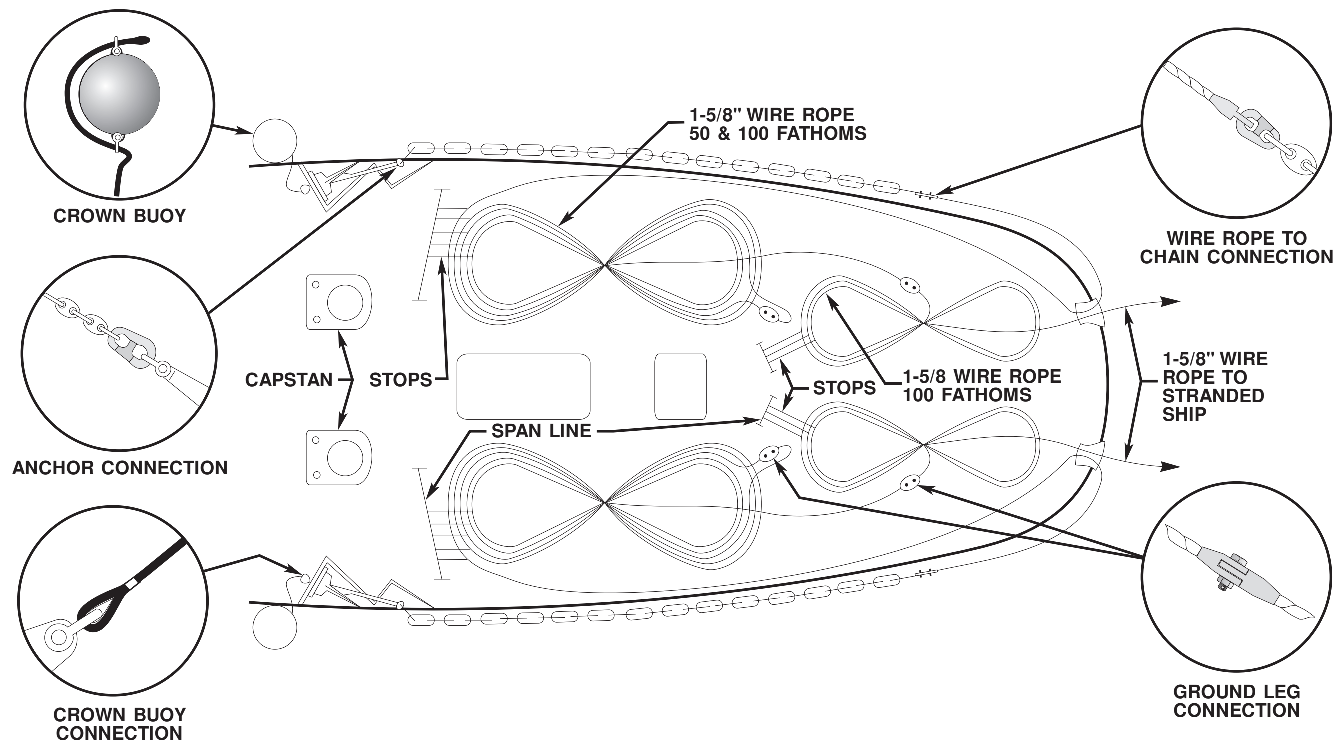


Figure 9-8. Arrangement for Laying the Ground Leg to Seaward Away from the Casualty.

Beach gear can be laid to assist in wrenching or in holding the ship perpendicular to the beach. Wrenching and holding legs may make a contribution to the pulling effort. They should be tensioned when maximum pull is applied and slacked when the ship begins to move.

9-3.4.1 Rigging Beach Gear. Rigging beach gear is a time-consuming and critical process. Beach gear must be properly rigged and laid if it is to develop its full pulling power. Rigging begins when the beach gear ground leg is broken out and assembled for laying. Usually this starts while the salvage ship is enroute to the stranding site. The deck arrangements are broken out, inspected, operated, and installed in place or prepared for transfer to the stranded ship.

CAUTION

Beach gear ground legs leading from a stranded ship should be slacked when a salvage ship or tug is maneuvering in-close. Failure to do so can result in the ship fouling or parting the ground leg. Slacking all ground legs at the same time exposes the ship to the full effect of environmental forces.

9-3.4.2 Laying the Ground Leg. There are two basic procedures for laying beach gear.

a. The preferred procedure is:

(1) The bitter end of the ground leg is passed from the salvage ship to the stranded ship. The salvage ship can transfer the ground leg by anchoring or maneuvering close in, passing a messenger by heaving line, line-throwing gun, helicopter or, floating it over. If the stranded ship is without power, the messenger can be taken around a convenient fairlead on the stranded ship and passed back to the salvage ship. The messenger is hauled in by the salvage ship to pull the ground leg to the stranded ship. Figure 9-7 shows this method. When the ground leg is aboard the stranded ship, it is secured with a Carpenter stopper as in Figure 9-10.

NOTE

Helicopters are extremely useful for passing lines in salvage operations. Messengers may be passed by helicopters of any size. Helicopters with sufficient lift may pass ground leg wire ropes and towlines directly.

(2) The salvage ship steams away from the stranded ship on the predetermined bearing for the beach gear leg. Marking the drop location and bearing with buoys or a range will improve the accuracy of the drop.

(3) The ground leg is payed out by cutting or parting the stops holding the wire rope as the distance to the stranded ship increases and the wire rope becomes taut. The wire rope is generally figure-eighted and stopped off, ready for running, on the fantail of the salvage ship. Figure 9-8 illustrates beach gear made up on the fantail of a salvage ship. If there is insufficient fantail space, the wire rope is hung off in bights over the side and stopped off.

(4) The anchor, crown pendant, and crown buoy are dropped after all of the ground leg is over the side and any slack is removed.

(5) On board the stranded ship, the hauling Carpenter stopper is passed on the ground leg, the standing Carpenter stopper removed, and the ground leg hauled to remove any remaining slack and set the anchor. The set-up should be satisfactory for the duration of the pulling phase.

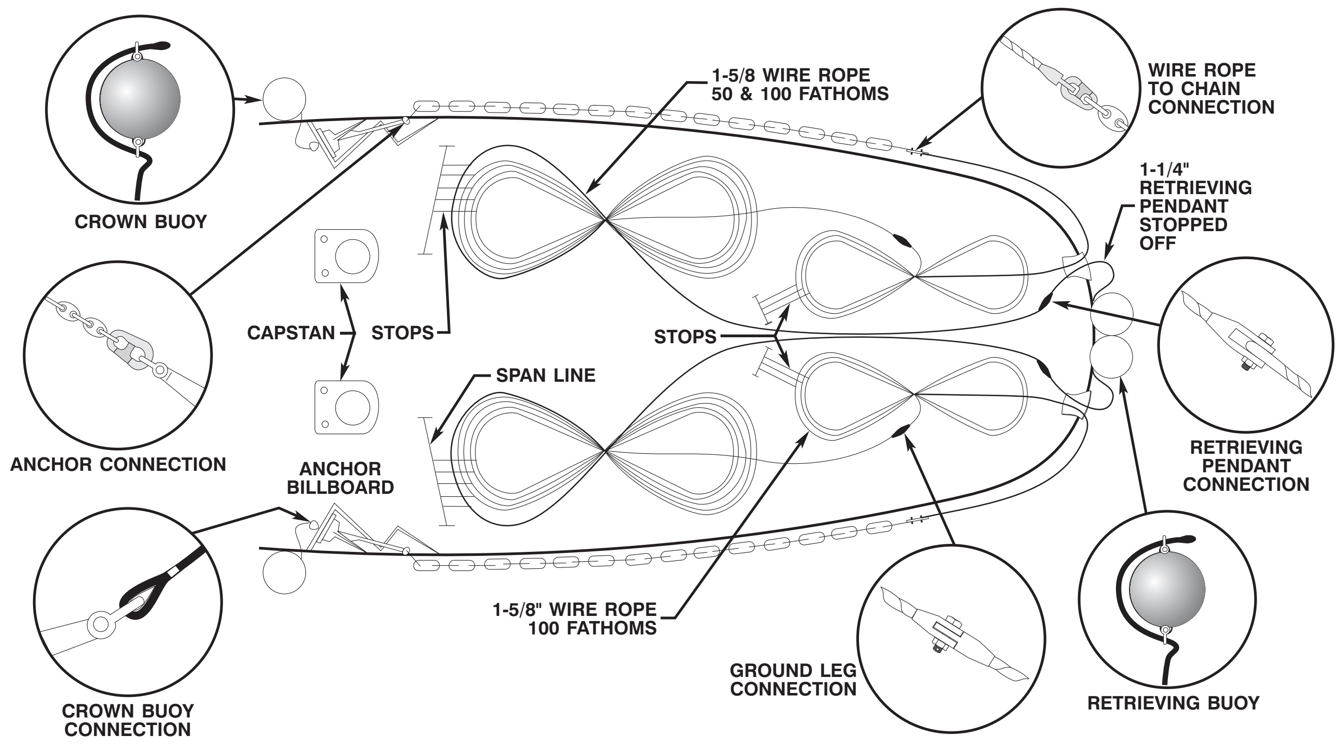


Figure 9-9. Arrangement for Laying the Ground Leg from Seaward Toward the Casualty.

b. The alternative procedure is:

(1) The salvage ship steams on a predetermined bearing toward the stranded ship. When she reaches a marked position the anchors are dropped, followed by the crown buoy and pendant, chain, ground leg wire rope, and retrieving pendant and buoy. The anchor may be dropped from a billboard or chute. Figure 9-9 shows the ground leg rigged for laying by the alternative procedure. When the salvage ship has neither billboards nor chutes, the anchor is stopped off over-the-side for laying as shown in Figure 9-10.

(2) To retrieve the bitter end of the ground leg, the salvage ship secures a messenger line to the bitter end of the pendant on the retrieving buoy. The retrieving pendant is taken aboard and used to retrieve the bitter end of the ground leg. The bitter end of the ground leg is hauled aboard the salvage ship.

(3) A messenger is attached to the bitter end of the ground leg if it is to be passed to another pulling platform. The messenger is passed to the pulling platform, then the ground leg is passed and led to the hauling stopper of the pulling equipment, and the remaining slack taken out of the ground leg.

(4) If the pulling platform is the salvage ship, it must be connected to the stranded ship. The salvage ship closes the stranded ship and passes the towline. The towline is hauled aboard the stranded ship and secured.

9-3.4.3 Testing Beach Gear. After all ground legs and lines to the stranded ship are connected, all legs are individually hauled to capacity to test their holding.

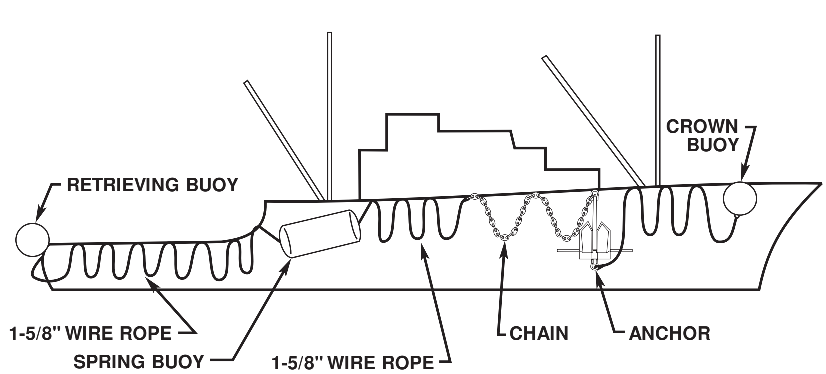


Figure 9-10. Ground Leg Rigged Over the Side.

9-3.5 Rigging the Stranded Ship for Towing. If the stranded ship is without propulsion or steering, lines are rigged over the side to assist tugs in making up alongside. These lines are left hanging lazy. If the stranded ship requires ocean towing after retraction, the towing bridle is rigged and made ready for pickup by the designated tug.

9-3.6 Pulling. In order to take advantage of the minimum ground reaction that accompanies high tides, pulling should coincide with high water. The pull is not a sudden application of power. Power is built up slowly and held until the ship either refloats or it becomes obvious that she will not. Full pulling power should be reached at least two hours before the scheduled high water and held through the high water until the water has dropped below its height when full pulling power was reached. Premature pulls — pulls made before all systems are ready and the ground reaction has been reduced to a planned point — are largely wastes of time and should be avoided.

Tensiometers in beach gear legs and towline tension meters on tugs should be monitored constantly and adjustments made to keep tension maximized. If the tension in a beach gear leg drops suddenly, it is usually an indication of anchor drag. It is probable that the leg is lost to the pull and that the anchor will have to be reset. The pull should be terminated if several beach gear legs drag and sufficient tension cannot be maintained on the stranded ship.

Salvors on the stranded ship should constantly monitor bearings and ranges ashore for signs of movement and report them to the salvage officer.

9-3.7 Anchor Drag. Because beach gear ground legs are highly loaded and anchor drag is the design failure mode of beach gear, beach gear anchors often drag during salvage operations. Anchor drag is a major operational problem. The anchor usually does not reset itself and the beach gear leg is ineffective. Resetting beach gear is a time-consuming operation that delays refloating.

When beach gear anchors drag, the cause of dragging should be determined and, if possible, corrected before resetting the anchor. Some of the more common causes of anchor drag in salvage operations are:

- Anchors improperly dug in
- Improper fluke angle for the soil
- Balling of soil on the flukes
- Rolling of the anchor caused by ineffective or improperly deployed stabilizers
- Chain fouled on the flukes.

The anchor can be inspected by divers in shallow water. Conditions likely to cause dragging can be identified and corrected before time and effort are spent setting the beach gear. In soft seafloors, divers using high pressure water jets can wash the soil from under the anchors and cause the flukes to drop into position and the anchor to be buried.

Unless a remotely-operated vehicle (ROV) or other deep water inspection and work system is present at the salvage site, anchors laid deeper than divers can work cannot be inspected.

9-3.8 Resetting the Anchors. To reset the anchor, the anchor is picked up, hauled to a new position, and set back down on the seafloor. The crown pendant is used to handle anchors for resetting as well as to retrieve the anchors. A salvage ship attaches a line to the crown pendant, hauls it on deck, and lifts the anchor clear of the seafloor. The pendant is made fast on deck and the salvage ship steams away from the stranded ship along the ground leg bearing. The ground leg may be slacked as the anchor is moved seaward. When the slack is out of the ground leg, the crown pendant and buoy are released, and the ground leg is ready to be pulled and set again.

Normally the anchor is reset by a ship other than the salvage ship hauling the leg that has dragged. If no other ships are on-scene to reset the anchors, the salvage ship must trip out of the pulling harness and reset her own anchors. Before tripping out, the retrieving buoys must be reattached to the bitter end of the ground leg. After being reattached, the retrieving pendants are tripped out and allowed to fall over the side. The towline to the stranded ship is recovered. When the salvage ship is no longer encumbered by its towline and beach gear, it maneuvers to reset the anchor.

9-3.9 Safety Considerations. Salvage is hard physical and mental work done under difficult conditions. Whenever possible, salvage operations are conducted around-the-clock. However, salvors must avoid fatigue and keep physically strong and mentally alert because overly-tired personnel can make mistakes and become careless. The schedule must include time for all hands to have sufficient rest. It is particularly important that supervisory personnel and decision-makers take advantage of opportunities to rest. Diet is also important in maintaining the stamina needed for salvage work. Meal hours must be adjusted to suit the work schedule and to ensure that all shifts have adequate quantities of hot food. Hot showers and clean clothes at the end of shifts help maintain the effectiveness of salvage crews. It is sometimes necessary to put salvage teams aboard the casualty and to leave them there under rough conditions. Their comfort and feeding requires particular attention if safety and effectiveness are to be maintained. The salvage officer must be alert to signs of excessive fatigue in himself, his supervisors, and his crew. He should not hesitate to call for rest breaks. Accidents or equipment damage caused by fatigue can be more costly than taking time for sufficient rest.

9-4 POST-REFLOATING PHASE.

The post-refloating phase of a stranding salvage operation begins as soon as the ship begins to move off her strand, and completes when:

- The ship has been redelivered to its operational commander or owner.
- All beach gear and other equipment has been recovered, cleaned and overhauled, and restowed.
- The salvage reports required by Commander, Naval Sea Systems Command Instruction 4740.8 (series) and other current directives have been prepared and submitted.

The most immediate action in the post-refloating phase of a salvage operation is controlling the refloated ship and stabilizing her afloat condition. Planning for the post-refloating phase must be completed prior to refloating and should encompass all possible options. It is particularly important that planning for the first stages of the post-refloating phase be thorough. When a stranded ship comes afloat — often in a rush — the situation can change quickly and decisions must be made rapidly. Thorough planning and consideration of the options provide a basis for sound decisions.

9-4.1 Control of the Ship. As soon as the ship comes afloat, the salvors must control it so that they can position it at will. In the simplest case, the ship has propulsion and steering and can simply cast off beach gear and towlines and control herself. In other cases, one of the salvage ships or tugs is designated to take the ship in tow. Preferably, a tug immediately astern of the stranded ship and pulling no beach gear is designated. The designated tug takes the refloated ship under tow to safe waters while her condition is evaluated and further decisions made. The first concern is assessment of damage and completion of necessary repairs so the refloated ship can proceed safely.

9-4.2 Slipping Beach Gear. As a ship is hauled off its strand, beach gear on the salvage and refloated ships must be slipped. The refloated ship must be entirely free from ground legs so that it can be taken in tow by the salvage ship. Salvage ships must be free from ground legs to prevent overrunning them, to maneuver clear of the retracted ship, and to tow it to safety. Slipping beach gear ground legs from both the salvage ship and stranded ship is done the same way.

The ground leg must be able to run freely when released. The bitter end of the ground leg is led through the same opening through which the pulling part of the ground leg comes aboard. An easing-out line is rigged around the ground leg and made up to bitts near the attachment point. The retrieving buoy is made up to the bitter end and prepared for letting go.

The gear is slipped by tripping the ground leg puller or Carpenter stopper and easing it overboard by slacking the easing-out line and allowing it to render around the bitts. Simultaneously, the retrieving buoy is let go.

9-4.3 Securing the Ship. When the ship is afloat and under control, the process of securing her for movement to a port begins.

If the refloated ship is seriously damaged, or presents a real or perceived pollution hazard, local authorities may resist the entry of the ship into their waters. As part of the securing process, salvors should define thoroughly the condition of the ship to cognizant authorities who will make the necessary arrangements for port entry.

The first step in securing the ship is to conduct a thorough survey to locate damage that may have occurred during refloating or was concealed by the way the ship lay upon her strand. Salvors should be prepared and equipped to take damage control action.

When the ship has been inspected, salvors must determine its immediate disposal. Ultimate disposition will normally have already been decided by higher authority. The options are:

- Steaming into port
- Towing to a safe haven
- Anchoring to make preparations for tow or to make temporary repairs to damage caused by grounding or refloating
- Beaching the ship if it is in danger of sinking
- Scuttling or sinking.

9-4.3.1 Steaming or Towing the Refloated Ship. The ship must be able to make the transit from the salvage site to a secure port safely. The ship may make the transit under her own power; under her own power, but escorted by the salvage ship; or under tow. The method chosen depends upon the condition of the ship, her danger to herself and the environment, and the tactical situation. If the ship has hull damage or critical stability, the transit should be made when the best possible weather is predicted. If good weather is some time away, the desirability of waiting for better weather must be balanced with the risk of the transit. In preparing for transit, at a minimum, the following items are checked:

- Overall seaworthiness
- The bottom for damage hidden when the ship was on her strand
- Piping systems and machinery
- All systems necessary to the transit
- Ship's stability, list, and trim (Weights should be loaded or shifted to ensure the ship is stable and at an acceptable trim.)
- Patches and pumping arrangements for compartments in way of damage
- The towing bridle, and day and night signals. If the ship is to proceed under her own power with an escort, the towing bridle should be rigged along with pick-up lines and buoys.

9-4.3.2 Anchoring the Refloated Ship. Prior to refloating the ship, anchors are made ready for letting go. If the towing ship's towline parts after refloating and the refloated ship is without propulsion, it should be anchored immediately to avoid regrounding.

Anchorages should be selected before the ship is refloated. Sites should provide a lee for salvors to complete repairs. There should be a minimum of current so that divers may work effectively and good underwater visibility for effective underwater video and photography.

9-4.3.3 Beaching a Ship. If upon refloating the ship is in danger of sinking, it may be beached for emergency repairs. Potential beaching areas should be selected before the ship is refloated. Suitable beaching areas are free of rocks and obstructions on the beach and in its approaches, and have a gentle slope with weak currents and no pounding or dumping surf.

In preparation for beaching, the ship should be trimmed to help prevent broaching. When she beaches, the seaward end should touch the seafloor first. If the trim is just greater than the seafloor slope, the remainder of the ship settles gently.

Beaching should be scheduled on the ebbing tide shortly before low water. The falling tide allows the ship to settle gently on the seafloor while the tidal rise will assist in refloating. If it is desired to expose areas of the ship's side for repairs, beaching near the top of the tide may be desirable. The ship should be nearly stopped when she touches bottom.

The ship may be beached with either the bow or stern toward the beach depending upon the situation. In either case, the ship's anchors should be dropped to seaward and the chain veered as the ship approaches the beach. Ground legs to seaward and shoreward hold the ship in place and allow a controlled refloating. Anchors or deadman moorings can be used ashore. When the ship is beached, a line from the ship's head to an anchoring point ashore can be used as a headline to haul the ship toward the beach.

9-4.3.4 Scuttling or Sinking. Often, when a ship has no remaining value, it will be scuttled following refloating to dispose of the wreck. Preparations for predetermined scuttling should be made before the ship is retracted.

The usual means of scuttling is to open the hull with explosive charges. Enough explosives must be used to ensure the ship sinks and does not become derelict. Returning to the severely damaged ship to set additional charges can be dangerous. As in other operations involving explosives, scuttling with explosives should be undertaken only by personnel trained and experienced in their use. All personnel should be well clear of the ship when scuttling charges are detonated.

Ships may also be scuttled by opening hull valves, breaking piping systems, venting if riding on a bubble, and otherwise opening the hull to the sea. Scuttling by these means is dangerous because scuttling crews must be on board to do the work and abandon the ship while she is sinking.

Ad hoc sinking with gunfire (as opposed to a formal SINKEX) is sometimes attempted. It is inefficient and often ineffective. Historically, ships have not behaved as expected and large quantities of ammunition have been expended without achieving the desired result.

9-4.4 Recovering Beach Gear. Recovery is the most tedious task involving beach gear. It is, nonetheless, very important. Too many ground legs of U.S. Navy beach gear are lost because of incorrect composition, improper placement, or other indicators of inattention to detail or ineptness on the part of the salvage crews. The procedures for recovery — similar for all ground legs — are:

a. The crown buoy is picked up and removed. A messenger is attached to the crown pendant and hauled until it can be taken to a capstan.

b. The anchor is broken out and brought to the surface by heaving on the crown pendant. Anchor breakout can be difficult in cohesive soils or with tandem anchors. In these cases, a chain chaser can assist in anchor breakout. The chaser is pulled down the chain to the base of the inboard anchor shank. The chaser pulls the shank up and rotates the flukes upward so they can dig out. Figure 9-11 shows a chain chaser breaking out an anchor.

c. A wire rope strap is passed around the anchor crown and connected to a boom or crane.

d. The anchor is lifted onto the deck. On the T-ATF-166 Class and other ships with stern rollers, the anchor can be hauled over the stern roller with the capstan. The chain and wire rope follow the anchor and are restowed as they come aboard.

e. When the ground leg components are on board, they are inspected, cleaned, lubricated, and restowed in readiness for the next job.

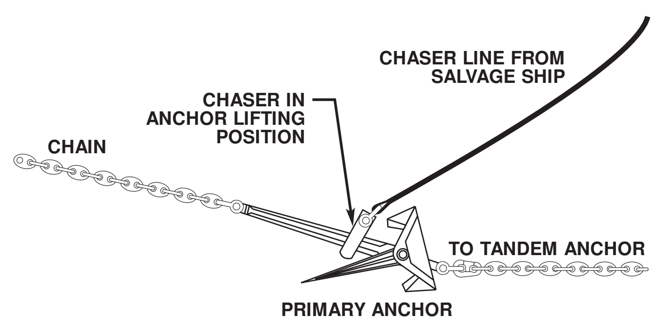


Figure 9-11. Chain Chaser Attached to Chain.

9-4.5 Delivery. The salvage operation is complete when the refloated ship is delivered to her operational commander or owner. Arrangements relative to the delivery of the ship should be made by the operational commander of the salvage unit during the salvage operation. Delivery should be reported by message in the final daily salvage situation report.

In the case of a ship other than a Navy ship, especially a commercial vessel, a delivery certificate similar to that provided in Commander, Naval Sea Systems Command Instruction 4740.8 (series) should be obtained.

CHAPTER 10
DEWATERING

10-1 INTRODUCTION.

Recovery of buoyancy is usually the most important salvage task undertaken as part of the refloating operation. Once the watertight envelope is restored, the buoyancy can be recovered. There are several clearly defined, basic methods of recovering buoyancy:

- Pumping out flooded spaces
- Blowing out flooded spaces with compressed air
- Combining sealing off/patching with both pumping and blowing with compressed air
- Inducing buoyancy with special flotation materials placed inside the hull. These materials include:
  (1) Collapsible buoyancy devices, such as salvage lifting pontoons
  (2) Cast-in-place polyurethane foam (Foam-in-Salvage)
  (3) Expanded polystyrene foam granules
  (4) Small buoyancy spheres.

10-2 PUMPS AND PUMPING.

When a ship sinks in shallow water, pumping is often the easiest, quickest, and most effective way of recovering buoyancy. Pumps move large quantities of water at a relatively high efficiency for the size and weight of the machinery employed. Pumping is a preferred method of dewatering because:

- Pumps are relatively easy to use.
- Pumps can be rigged rapidly.
- Large volumes of water can be moved with a high degree of efficiency with compact, portable equipment.
- Water levels and dewatering rates can be controlled with relative precision.
- Pumping requires less preparation and set-up time than other dewatering methods.

A ship that is pumped out usually comes afloat more slowly than the same vessel raised with compressed air. The slow refloating gives the salvor time to react to problems and allows for greater control of the ship.

10-2.1 Pump Theory and Terminology.

Pumping terminology is based on the concept of head pressure. "Head" is the measure of the pressure exerted by a column of liquid because of the weight of the liquid. Pumping head for salvage purposes is expressed in feet of seawater. In pumping, the following definitions, shown graphically in Figure 10-1, apply:

- Static Suction Head (H_s) is the vertical distance between the liquid surface and the pump suction inlet. A pump whose suction is located below the surface of the liquid has a positive suction head and a positive pressure at the pump suction. If the pump is located above the liquid surface, suction head is negative. Submersible pumps are considered to have zero suction head. A surface-mounted salvage pump will normally be working against a negative suction head or suction lift. A salvage pump working in this manner must create a vacuum at the pump suction so that the differential pressure between the liquid surface and pump suction will lift the liquid to the suction.

- In practice, the maximum achievable suction lift for pumping seawater at atmospheric pressure is about 25 feet for centrifugal pumps and slightly higher for positive-displacement pumps. In salvage, the suction line should be kept as short as possible and the suction lift as low as possible. Reduction in pumping capacity becomes noticeable at lifts in excess of 15 feet and is very pronounced at 25 feet.

- Static Discharge Head (H_d) is the vertical distance at which the point of free discharge, or the liquid surface of the discharge tank, lies above the pump. This quantity is also referred to as the "delivery head" in some technical publications.

- Friction Head (H_f) is the equivalent of the friction loss caused by pumping the liquid through pipes, hoses, valves and pump fittings. Friction head, sometimes called "pressure drop" or "head loss," is expressed as a function of flow rate and length of piping and hoses in the salvage pumping system. For most salvage applications, friction head can be estimated as being not more than twenty percent of the total length in feet of suction and discharge piping or hose.

- Total Head (H_t) is the sum of the static suction head, static discharge head, and friction head.

$$H_t = H_s + H_d + H_f$$

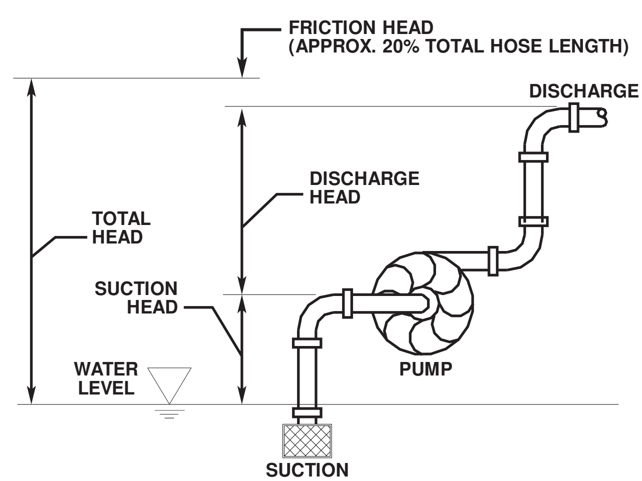


Figure 10-1. PUMPING HEADS

EXAMPLE 10-1
CALCULATION OF TOTAL HEAD

A 6-inch diesel salvage pump in the hold of a ship is located 10 feet above the surface of the flood water. The suction hose is 20 feet. The long discharge hose runs over a hatch coaming 20 feet above the pump, then 10 feet horizontally to the side of the ship. What is the total head?

$$H_t = H_s + H_d + H_f$$
$$H_s = 10 \text{ feet (height of the pump above the water surface)}$$
$$H_d = 20 \text{ feet (maximum height of the hose above the pump)}$$

The total length of hose is the length of the suction hose, 20 feet, plus the length of the discharge hose, 20 + 10 or 30 feet. The total length of hose is 50 feet. The friction head is then:

$$H_f = 0.20 \times \text{total length}$$
$$H_f = 0.20 \times 50$$
$$H_f = 10 \text{ feet}$$

Total head is:

$$H_t = H_s + H_d + H_f$$
$$H_t = 10 + 20 + 10$$
$$H_t = 40 \text{ feet}$$

EXAMPLE 10-2
USE OF PUMP PERFORMANCE CURVES

If the 6-inch salvage pump described in Example 10-1 is operated at 2,000 rpm, what output in gallons per minute can be expected?

Total head is 40 feet; suction head (lift) is 10 feet.

Enter the performance curve for the 6-inch diesel pump, Figure 10-2, along the vertical axis at 40 feet. Read across to the curve marked "optimum 2,000 rpm" and the branch marked "10 feet." Read the output on the horizontal scale as 1,540 gallons per minute.

If the suction head is increased to 20 feet while the total head and rpm remain the same, what is the output?

Enter the performance curve along the 40-foot total-head line and read horizontally to the 20-foot suction lift branch of the 2,000 rpm curve. Read the output from the horizontal axis as 1,080 gallon per minute.

If the pump with a 40-foot total head and 10-foot suction lift is run at 2,200 rpm, what is the output?

Enter the performance curve along the 40-foot total-head line and read horizontally to the 10-foot suction lift branch of the 2,200 rpm curve. Read the output on the horizontal scale as 1,600 gallons per minute.

10-2.2 Salvage Pumps. Salvage pumps are general-purpose, portable dewatering pumps especially adapted for marine salvage work. An efficient marine salvage pump must have the following:

- Rugged construction and protective framework or packaging to reduce the risk of accidental damage
- A high pumping-capacity-to-pump-weight ratio
- A discharge head greater than 60 feet
- The ability to pump a variety of contaminated liquids
- Comparatively simple construction for rapid routine maintenance and repair.

Other desirable features include the ability to self-prime and to handle a wide range of fluid viscosities and specific gravities. Special-purpose salvage pumps have been developed, or modified, from existing commercial designs to meet the requirements of a specific task—particularly, work involving moving hydrocarbon products or heavy slurries.

The following pumps are widely applied to salvage work:

- Electric or hydraulic-motor-driven, submersible centrifugal pumps (some pumps are axial flow or mixed flow pumps)
- Self-contained, heavy-duty, diesel- or gasoline-engine-driven centrifugal pumps
- Pneumatic diaphragm and centrifugal pumps
- Eductors and air lifts.

Salvage pumps are specified by type and discharge outlet diameter. Navy ships and units and the Emergency Ship Salvage Material (ESSM) System maintain the following types of salvage pumps as normal inventory:

- Self-contained, diesel-engine-driven, high-capacity, low-head centrifugal pumps with open, trash-type impellers in 10-inch, 6-inch, and 3-inch sizes
- Electrically driven submersible pumps in 4-inch and 1½-inch sizes
- 2½ inch electric submersible pumps (DC pumps carried by ships)
- Pneumatically driven 2½-inch trash pumps
- Hydraulically driven submersible pumps in 6-inch, 4-inch, and 1½-inch sizes
- 4-inch and 2½-inch water-driven eductors

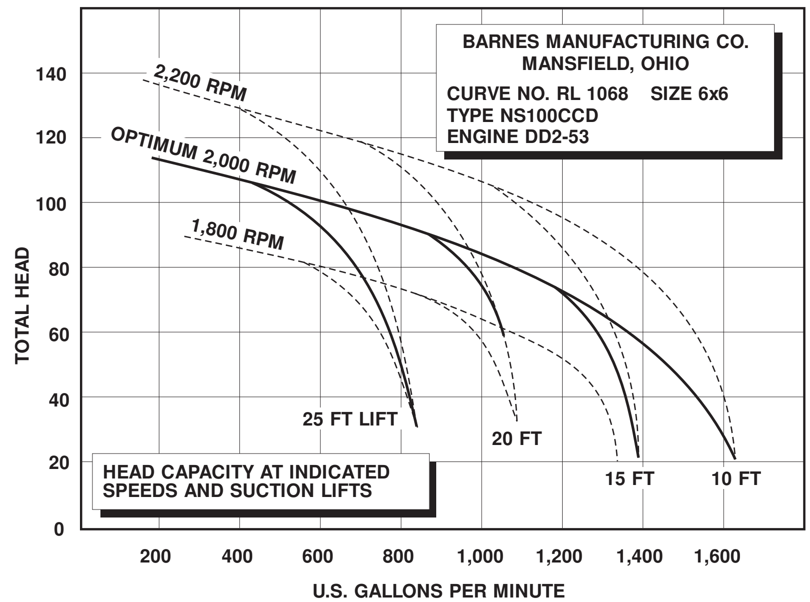


Figure 10-2. Performance Curve, 6-Inch Diesel Pump.

- 2½-inch self-contained, diesel-engine-driven, high-pressure, centrifugal jetting pumps
- 2½-inch self-contained, gasoline-engine-driven, high-pressure, centrifugal fire pumps (P-250-type pumps).

Figure 10-2 is a performance curve for a 6-inch, diesel salvage pump and is typical of the pump characteristic curves that are available for salvage pumps. U.S. Navy salvage and damage control pump characteristics and performance curves appear in Appendix G.

10-2.3 Alternative Portable Pumps. Under some circumstances, it may not be possible to obtain Navy salvage pumps of suitable size, output, or type for a planned dewatering operation. In these situations, portable pumps designed for agricultural, mining, heavy construction, or general use may be put into service as salvage pumps. Restrictions on size, output, ease of handling, and ability to withstand accidental rough handling may restrict the ease and speed of deployment of alternative salvage pumps.

The availability of Navy salvage pumps may cover only the theoretical pumping capacity to perform the task with no margin for overload, leakage, or pump redundancy. In such cases, it is prudent salvage practice to use alternative salvage pumps as part of the main or back-up pump battery rather than hazard the dewatering operation if the pumping capacity is unexpectedly reduced during the operation.

10-2.4 The Casualty's Installed Pumps. The pumps installed on the casualty can be of use to the salvor because:

- Work to transport and rig portable pumps may be reduced or, in some instances, avoided altogether.
- Dewatering can be controlled through the installed piping and manifold systems in the casualty.
- Pump rooms are located to minimize suction lift or maximize positive suction head.
- POL pumps are designed for the products carried.

Generally, the casualty's installed pumps and piping systems are used in conjunction with, or as a supplement to, the salvors' portable pumps. It is unwise to expect that major pumping operations will be greatly expedited by the casualty's installed pumps; however, the manifold systems may greatly assist to defuel many small fuel and lube oil tanks that would be difficult to access with portable salvage pumps.

For example, consider the dewatering of flooded machinery spaces in a major combatant. Fire rooms, engine rooms, and auxiliary machinery rooms are all flooded to the main deck level, and all electric distribution systems are disabled. Salvors would probably choose to pump the major flooded spaces with portable salvage pumps. However, fuel oil service and settling tanks, bulk lube oil, and hydraulic oil tanks could be most easily pumped out by connecting pneumatic diaphragm pumps to the piping manifold serving each group of tanks. This approach reduces the risk of additional oil spillage and takes maximum advantage of piping systems existing on the casualty without requiring repair and reactivation of the casualty's flooded pumping systems.

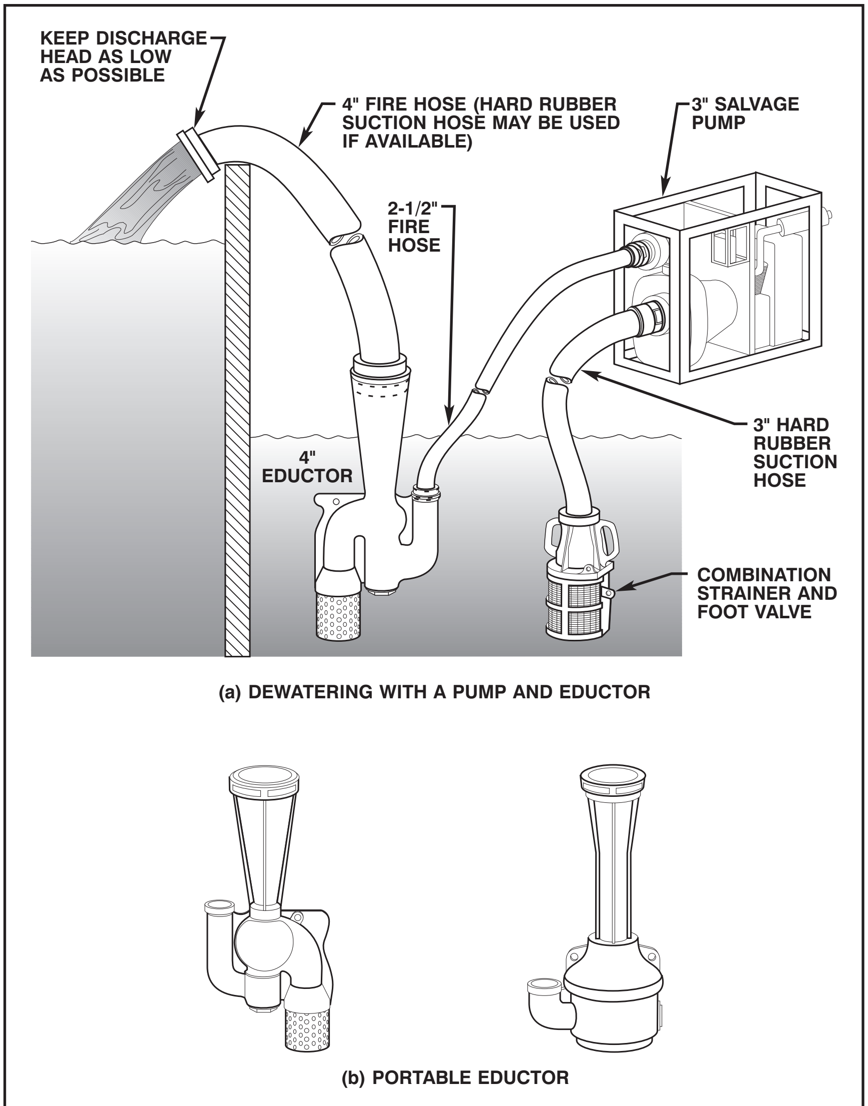


Figure 10-3. Standard Damage Control Eductor.

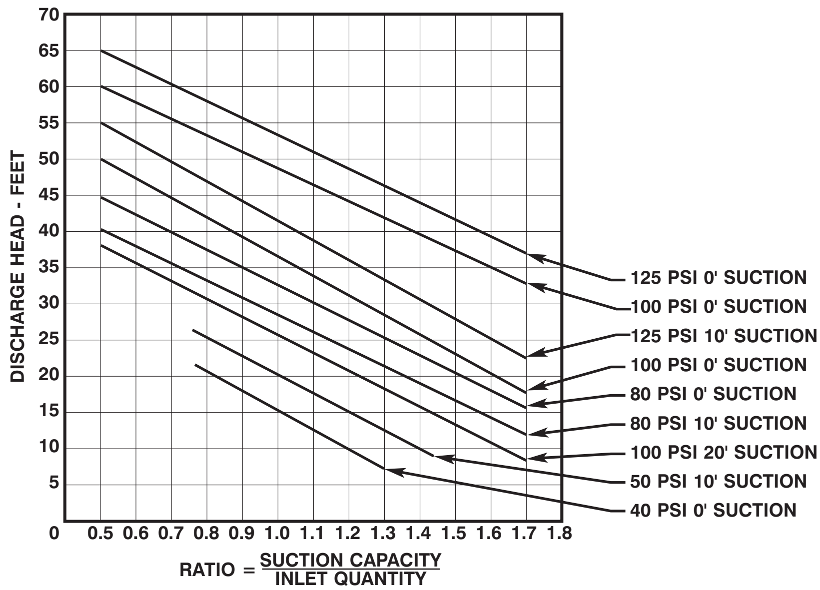
10-2.5 Eductors and Air Lifts. Eductors and air lifts are dynamic pumps that use a fluid—air or water—to move other fluids. Because of their simplicity and versatility, eductors and air lifts are widely used in salvage operations.

10-2.5.1 Eductors. An eductor is a practical application of water jets for dewatering. When a stream of water under pressure passes through a restricting orifice or nozzle, two important things occur:

- The water pressure is decreased
- The velocity of the water stream is increased.

In relative terms, a high-pressure, low-velocity stream is converted into a low-pressure, high-velocity stream by passing through the nozzle. If the nozzle is fitted inside a pipe that is open at each end, the discharged water jet creates a partial vacuum inside the pipe that will draw other fluids into the discharge stream. Efficient eductors can be constructed to pump liquids, slurries, or powdered solids. The eductors seen most often in salvage operations are the same as those supplied to ships for damage control. These eductors have a 4-inch or (2½-inch) suction and discharge and are driven by a 2½-inch fire hose supplying water at 50 to 150 psi. They weigh approximately 58 pounds. A standard damage control eductor is shown in Figure 10-3.

The capacity of an eductor depends upon the pressure and flow rate of the water supplied to it, the suction lift, and the discharge head. In general, the total discharge quantity will be between 1.5 and 2.0 times the quantity supplied. The Peri-Jet damage control eductor will discharge about 330 gallons per minute when 180 gallons are supplied from a fire main at 100 psi. Figure 10-4 is a typical eductor performance curve.



EXAMPLE

TO FIND CAPACITY OF EDUCTOR WHEN:

INLET QUALITY	90 GPM
SUCTION LIFT	20 FT.
DISCHARGE HD.	10 FT.
INLET PRESS.	100 PSI

FIND 10-FT. LINE AT LEFT HAND, FOLLOW IT HORIZONTALLY UNTIL IT INTERSECTS CURVE MARKED "100 PSI-20 FT. SUCTION." GO VERTICALLY DOWN TO RATIO WHICH IS 1.65 AND INDICATES THE EDUCTOR WILL HAVE A CAPACITY EQUAL TO 1.65 GALLONS FOR EVERY GALLON OF INLET LIQUID. CAPACITY = 90 GPM x 1.65 = 150 GPM.

Figure 10-4. Eductor Perfomance Curve.

All eductors have a minimum pressure and flow rate below which they will not function. Proper functioning of the eductor will be obvious by the quantity of the discharge.

Eductors have several advantages for small salvage dewatering jobs. Eductors:

- Are small, relatively compact, and have no moving or mechanical parts
- Can be driven from any convenient medium-pressure water supply
- Are convenient and safe in small, enclosed compartments containing fuel or POL residues floating on top of the flood water
- Are suitable for moving flood water with quantities of slurry or abrasive solids in suspension
- Can be driven from the fire main during firefighting operations, thereby avoiding an additional power source for pumping.

10-2.5.2 Air Lifts. In an air lift, compressed air is introduced into the lower end of a submerged or partially submerged pipe. The combination of the air and the liquid in the pipe forms a mixture that is less dense than the liquid outside the pipe. The reduction in density results in less head pressure in the pipe. The mixture rises and creates a differential pressure that lifts water, or semisolid material, up the pipe.

The efficiency of an air lift is governed by the:

- Volume and pressure of the air supply relative to the depth of water
- Ratio of the immersed pipe length to the emerged length
- Depth of water
- Position of the air inlet relative to the lower end of the air lift
- Nature of the material being lifted.

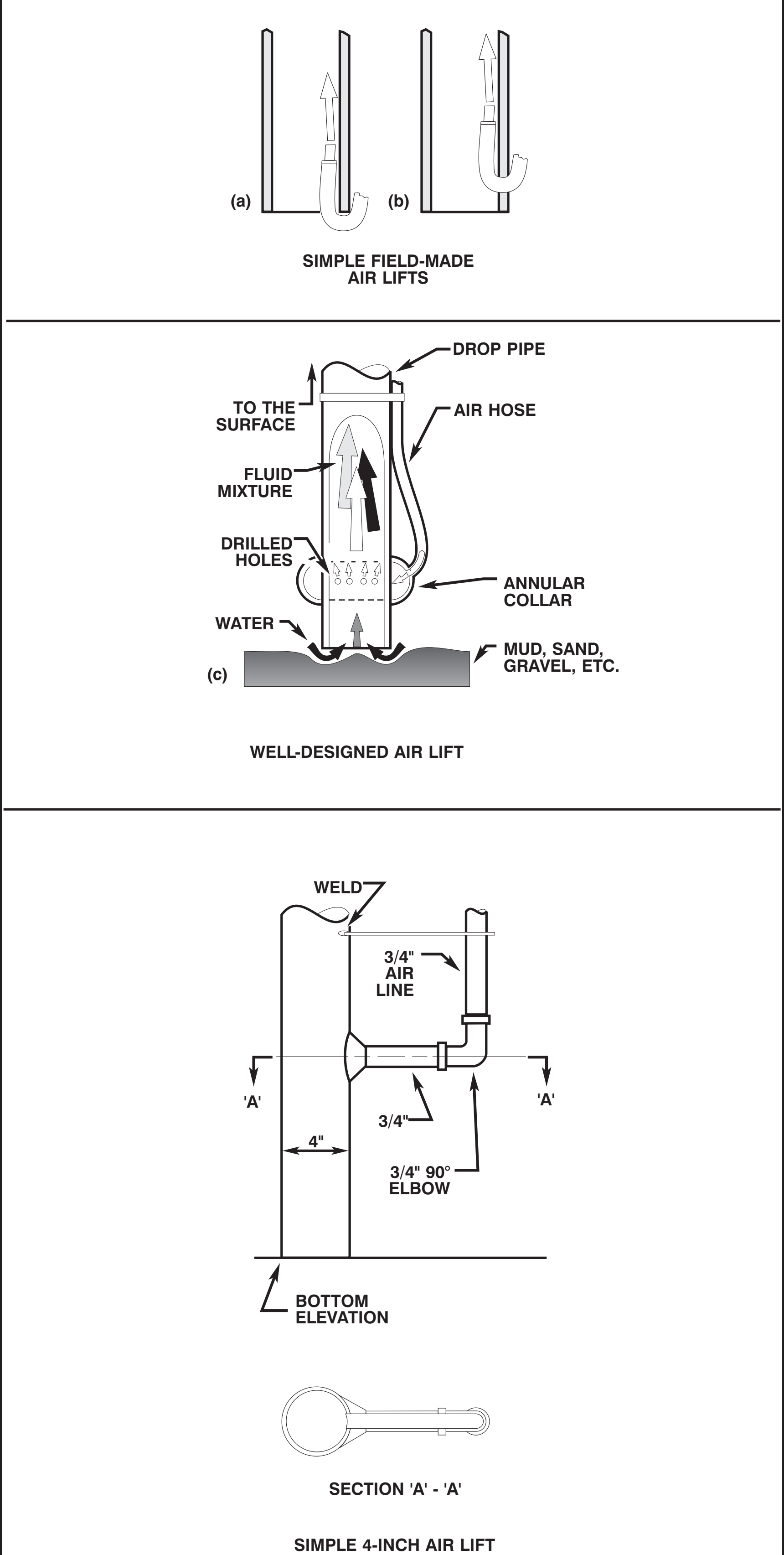


Figure 10-5. Typical Air Lift Configurations.

Air lifts are frequently used to clear mud and loose silt from diver working areas around wrecks and to remove silt and trapped mud from spaces inside sunken wrecks. Air lifts will normally lift loose material only in the immediate vicinity of the lower end. Water jetting in the immediate vicinity of an air lift will break up heavy or hard-packed material and increase the efficiency of air lifts. Clay, paper pulp, and similar materials will tend to choke air lifts. While air lifts are not particularly as efficient as pumps, they are easy to build in the field, simple to operate, and remove semisolid or slurried materials continuously. Figure 10-5 illustrates typical air lift configurations. Appendix J provides detailed information on the design and construction of air lifts.

10-2.6 Pump Selection. The pumps selected for any casualty are the result of two important decisions:

- Whether or not to use the casualty's installed pumps
- The number and type of portable pumps to use.

Most salvage pumping work is done with portable pumps. The following paragraphs describe specific considerations that govern pump selection.

10-2.6.1 Capacity. The greater the pumping capacity, the less time will be required to dewater a given compartment or ship. In cases where dewatering must start and finish in one tidal cycle, pumping capacity is of critical importance. In other circumstances, the time to dewater may be a matter of convenience and coordination with other evolutions in the overall salvage operation.

Operational safety is affected by pumping capacity. There must be sufficient pumping capacity on the casualty to overcome any leakage with an adequate margin for safety and redundancy. Generally, it is essential to have the entire available portable salvage pump inventory aboard the casualty before pumping operations begin. Even if only a portion of the available capacity is used during the operation, there is no substitute for having extra equipment on-site and ready to operate. Leakage, prime mover breakdowns, clogged suctions, pump breakage, and other unforeseen emergencies have the unfortunate habit of occurring at the worst possible time on even the best planned salvage operation.

Pump numbers and capacity should be such that if one or more pumps fail, the spare pump capacity is sufficient to complete the operation. Reserve or backup pumping capacity must be aboard the casualty, ready to immediately deploy into spaces being pumped. There is no rule of thumb for the minimum redundant pump capacity that should be available; one hundred percent of required capacity is not excessive.

10-2.6.2 Size. The size, weight, and type of portable pump available will affect where the pump can be most usefully deployed and the time required to put it into operation. Where access is limited, it may be neither practical nor safe to rig in large diesel-powered pumps.

As a general rule, hydraulic or electric submersible pumps are preferred for dewatering cramped, confined or difficult to access spaces (e.g., machinery spaces, fire rooms, magazines, shaft alleys, and storerooms).

Large diesel centrifugal pumps, because of their size, weight and exhaust emissions, are best suited for pumping out large spaces, such as cargo holds that have wide direct access to the deck.

Rigging time is also influenced by the type of pump deployed. Generally, it is quicker to rig and prepare a 6-inch hydraulic submersible pump than a 6-inch diesel salvage pump.

10-2.6.3 Liquid to be Pumped. Dewatering flooded spaces almost always involves handling contaminated water and, to a lesser extent, slurried material. Standard Navy salvage pump impellers will tolerate a moderate amount of slurry or abrasive material, but are not suitable for prolonged pumping of such materials. When large amounts of abrasive material must be pumped, special trash or slurry pumps may be required.

Corrosive or reactive liquids should be handled using pumps made with materials that are resistant to the liquid being pumped. In the case of some hydrocarbons and petrochemicals, specialized pumps, hoses and fittings must be used. These fittings are not usually available in the Navy. The Supervisor of Salvage should be contacted for assistance in acquiring such specialized equipment.

WARNING

POL products should be pumped only with hydraulic or electric submersible pumps, pneumatic diaphragm pumps, or other pumps marked "intrinsically safe" by the U.S. Coast Guard. POL products must NEVER be pumped with diesel- or gasoline-engine-driven pumps.

CAUTION

The Navy standard 4-inch electric submersible pump is available in two models. Model number 9-26035-131 has been modified for pumping POL and may be used safely for this service. Pump model 25034B has not been modified and should not be used for pumping POL.

NOTE

Detailed guidelines and operating procedures for transfer of POL products under salvage conditions may be found in the *U.S. Navy Salvage Manual, Volume 5* (S0300-A6-MAN-050).

POL products are volatile and produce fumes that are heavier than air and lie close to weather decks and collect in low spaces. These fumes can cause explosions if they reach hot surfaces or other sources of ignition or may cause engines to overspeed dangerously if taken into the engine. For these reasons, engine-driven pumps should never be used aboard tankships or where large quantities of POL are being handled. Only hydraulic or electric submersible pumps, pneumatic diaphragm pumps, or other pumps designated as intrinsically safe by the U.S. Coast Guard should pump POL. Engine-driven hydraulic pumps or generators should be located in well-ventilated areas as far as possible from areas where collections of explosive fumes are probable. Engine-driven equipment should not be operated on or adjacent to the tank deck of tankships carrying volatile fuels.

10-2.7 Salvage Pumping Calculations. Pumping calculations undertaken by the salvor generally answer one of three questions:

- How many pumps will be required to pump a flooded space in a given time (such as one-tide cycle)?
- How much time will be required to pump a flooded space with a particular number of pumps?
- At what rate will the water surface be lowered?

To make these calculations, the salvor needs only the performance curves of the pumps being worked with, the static suction head (Hs), static discharge head (Hd), and an estimate of the friction head (Hf) along with the volume of the water to be pumped and the geometry of the flooded compartment.

The salvor should be aware that in a pumping operation, the suction head and total head may not remain constant but will change throughout the operation. If the position of a surface-mounted pump is fixed, the suction head will increase as the water level drops. If the pump is lowered to keep the suction head constant, the discharge head will increase. The positive suction head of a submersible pump will be decreased as the water level lowers, but the discharge head will remain constant.

10-2.7.1 Number of Pumps Required. To calculate the minimum number of pumps required to dewater a space in a given period of time:

a. Determine the capacity of each type of pump in gallons per minute.

b. Multiply the capacity of each pump by the number of minutes available for pumping to determine the quantity that one pump will remove during the pumping period.

c. Calculate the total amount of water to be removed in gallons.

d. Divide the total amount of water by the quantity one pump can remove to determine the minimum number of pumps required.

The prudent salvor will use more than the minimum number of pumps to allow for inaccuracies in the calculation, leakage, or poor pump performance.

EXAMPLE 10-3
CALCULATION OF THE MINIMUM NUMBER OF PUMPS

What is the minimum number of 6-inch diesel-driven salvage pumps that can dewater a space 70 feet long by 70 feet wide and 30 feet deep in 6 hours if the pumps are to operate at 2,000 rpm with a constant suction lift of 10 feet and a total head held at 80 feet? What is the recommended number of pumps on board?

a. Determine the capacity of each pump:

From the performance curve (Figure 10-2) with a 10-foot suction lift and an 80-foot total head, each pump will have a capacity of 1,100 gallons per minute.

b. Total quantity each pump will remove:

$$Q = \text{Capacity of each pump} \times \text{total time}$$
$$Q = 1{,}100 \times (6 \times 60)$$
$$Q = 396{,}000 \text{ gallons}$$

c. Total quantity in space:

$$\text{Volume} = l(\text{ft}) \times b(\text{ft}) \times d(\text{ft}) \times 7.48 \text{ gallons/foot}^3$$
$$\text{Volume} = (70 \times 70 \times 30) \times 7.48$$
$$\text{Volume} = 1{,}099{,}560 \text{ gallons}$$

d. Minimum number of pumps required:

$$n = \frac{Vol}{Q}$$
$$n = \frac{1{,}099{,}560}{396{,}000}$$
$$n = 2.77 \text{ or } 3 \text{ six - inch diesel salvage pumps}$$

e. Recommended number of pumps = 2 x 3 = 6

10-2.7.2 <u>Dewatering Time</u>. To calculate the time required to de-water a space with a given battery of pumps:

a. Determine the total capacity of the battery of pumps in gallons per minute.

b. Calculate the total amount of water to be removed in gallons.

c. Divide the volume of water to be removed by the capacity of the battery to determine the time required to pump out the space.

10-2.7.3 <u>Rate of Fall of the Surface</u>. To calculate the rate of fall of the surface:

a. Determine the total capacity of the battery of pumps in gallons per minute.

b. Determine the volume of a 1-inch layer of water.

c. Divide the volume of the 1-inch layer by the capacity of the pumping battery to determine the time required in minutes for the level to fall one inch.

EXAMPLE 10-4
DEWATERING TIME

A battery of three 6-inch diesel pumps is rigged to pump out a space 70 feet long by 70 feet wide by 30 feet deep. The pumps are to be operated at 2,000 rpm with a constant suction lift of 10 feet and constant total head of 80 feet. How long will it take to dewater the compartment?

a. Total capacity of the pump battery:

From the performance curve (Figure 10-2) each pump will have a capacity of 1,100 gallons per minute. The capacity of the battery is then:

$$Q = 3 \times 1{,}100$$
$$Q = 3{,}300 \text{ gpm}$$

b. Total quantity in space:

$$\text{Volume} = l \times b \times d \times 7.48 \text{ gallons}$$
$$\text{Volume} = (70 \times 70 \times 30) \times 7.48$$
$$\text{Volume} = 1{,}099{,}560 \text{ gallons}$$

c. Total time required:

$$t = \frac{Vol}{Q}$$
$$t = \frac{1{,}099{,}560}{3{,}300}$$
$$t = 333 \text{ or 5 hours 33 minutes}$$

EXAMPLE 10-5
RATE OF FALL OF THE SURFACE

A battery of three 6-inch diesel pumps is rigged to pump out a space 70 feet long by 70 feet wide by 30 feet deep. The pumps are to be operated at 2,000 rpm with a constant suction lift of 10 feet and constant total head of 80 feet. How long will it take for the surface to drop one inch? One foot?

a. Total capacity of the pump battery:

From the performance curve (Figure 10-2) each pump will have a capacity of 1,100 gallons per minute. The capacity of the battery is then:

$$Q = 3 \times 1{,}100$$
$$Q = 3{,}300 \text{ gpm}$$

b. Volume in one-inch layer:

$$\text{Volume} = l \times b \times \tfrac{1}{12} \times 7.48 \text{ gallons}$$
$$\text{Volume} = (70 \times 70 \times \tfrac{1}{12}) \times 7.48$$
$$\text{Volume} = 3{,}054.3 \text{ gallons}$$

c. Time to pump space one inch:

$$t = \frac{\text{Volume}}{\text{pumping rate}}$$
$$t = \frac{3{,}054.3}{3{,}300}$$
$$t = 0 \text{ minutes 56 seconds}$$

d. Time to pump down one foot:

$$t = 12 \times \frac{3{,}054.3}{3{,}300}$$
$$t = 11 \text{ minutes 6 seconds}$$

10-2.8 Pumping Operations. In setting up for pumping operations, great attention to detail is required to determine what has to be done, as well as ensure it is done effectively. The following paragraphs, although not all-inclusive, delineate some important aspects of pumping operations. The salvor must be continually alert to the particular situation and keep a weather eye out for the many small details that spell success for salvage pumping operations. During salvage pumping operations, as during all salvage operations, salvors must keep their eyes open and their brains in gear.

10-2.8.1 Limiting Suction and Total Head. It is most important to limit the negative suction head or suction lift on any centrifugal salvage pump by placing the pump suction as close as possible to the liquid being pumped. Suction hoses should not be led over obstructions higher than the pump inlet, as an air pocket may form at the high point and cause the pump to lose suction.

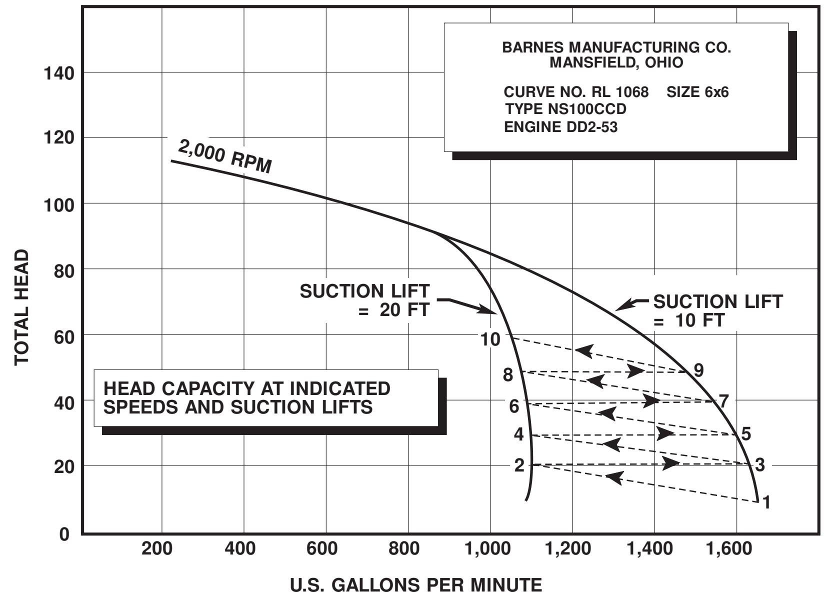


Figure 10-6. Curve for Example 10-6.

EXAMPLE 10-6
PUMPING WITH HEAD CHANGES

A cargo hold to be pumped out is 100 feet long, 85 feet wide, and 60 feet deep. The compartment is flooded to within eight feet of the main deck; it contains some cargo, so that its permeability is 0.80. Two 6-inch Navy diesel-driven salvage pumps are available for pumping. How can the compartment be pumped out? How long will it take?

By consulting and extrapolating the performance curve for the 6-inch, diesel-driven pump (Figure 10-2), it can be seen that if the pumps are mounted on the main deck and operated at 2,000 rpm, the initial pumping rate will be in excess of 1,600 gpm, but the rate will fall to about 850 gpm when the suction head rises to 25 feet. The pump will lose suction completely as the suction head increases, and the pump will not be able to pump out the space.

If the pumps are placed on a movable platform and lowered with the water level so that the suction lift remains constant at 10 feet, the total head will gradually increase from 10 feet to 50 feet and the pumping rate would decrease as the discharge head rose from 0 to 50 feet. From the performance curve, it can be seen that the discharge would fall only from about 1,650 gpm to about 1,500 gpm. This is acceptable and would result in the pump keeping the space dry. Keeping the pump a constant distance above the surface would require it to be continuously lowered. This rigger's nightmare is not a reasonable salvage evolution.

If the pumps are placed on a platform and lowered 10 feet each time the water level drops that amount, then the pumping rate:

- Decreases as the suction head increases from 10 to 20 feet
- Increases as the suction head is again decreased
- Decreases with increases in discharge head and total head as the pump is lowered.

The pumping rate can be tracked along the path from point 1 to point 10 in Figure 10-6. Each 10-foot layer in the space contains:

$$vol = \mu \times l \times b \times d \times 7.48$$
$$vol = 0.8 \times 100 \times 85 \times 10 \times 7.48$$
$$vol = 508{,}640 \text{ gallons}$$

CONTINUED

EXAMPLE 10-6 (CONTINUED)
PUMPING WITH HEAD CHANGES

Pumping Rate (each pump)		Quantity	Time
point 1	1,650.0 gpm		
point 2	1,100.0 gpm		
average	1,375.0 gpm		
total (2 pumps)	**2,750.0 gpm**	**508,640 gallons**	**185 min**
point 3	1,625.0 gpm		
point 4	1,100.0 gpm		
average	1,362.5 gpm		
total	**2,725.0 gpm**	**508,640 gallons**	**187 min**
point 5	1,590.0 gpm		
point 6	1,100.0 gpm		
average	1,345.0 gpm		
total	**2,690.0 gpm**	**508,640 gallons**	**189 min**
point 7	1,540.0 gpm		
point 8	1,080.0 gpm		
average	1,310.0 gpm		
total	**2,620.0 gpm**	**508,640 gallons**	**194 min**
point 9	1,450.0 gpm		
point 10	1,060.0 gpm		
average	1,255.0 gpm		
total	**2,510.0 gpm**	**610,368 gallons**	**243 min**
		Total	**16 hrs 38 ,min**

The increased accuracy of this calculation over simple averaging is shown by:

$$\frac{\text{quantity at point 1} + \text{quantity at point 10}}{2} = \text{Average quantity}$$

$$\frac{1{,}650 + 1{,}060}{2} = 1{,}355 \text{ gpm}$$

$$\text{Total pumping capacity} = 1{,}355 \times 2 = 2{,}710 \text{ gpm}$$

$$\text{Time} = \frac{\text{total volume}}{\text{total pumping capacity}}$$

$$\text{Time} = \frac{2{,}644{,}928}{2{,}710}$$

$$\text{Time} = 976 \text{ min or 16 hours 16 minutes}$$

While the detailed calculations are slightly more accurate, they are generally not warranted in salvage calculations.

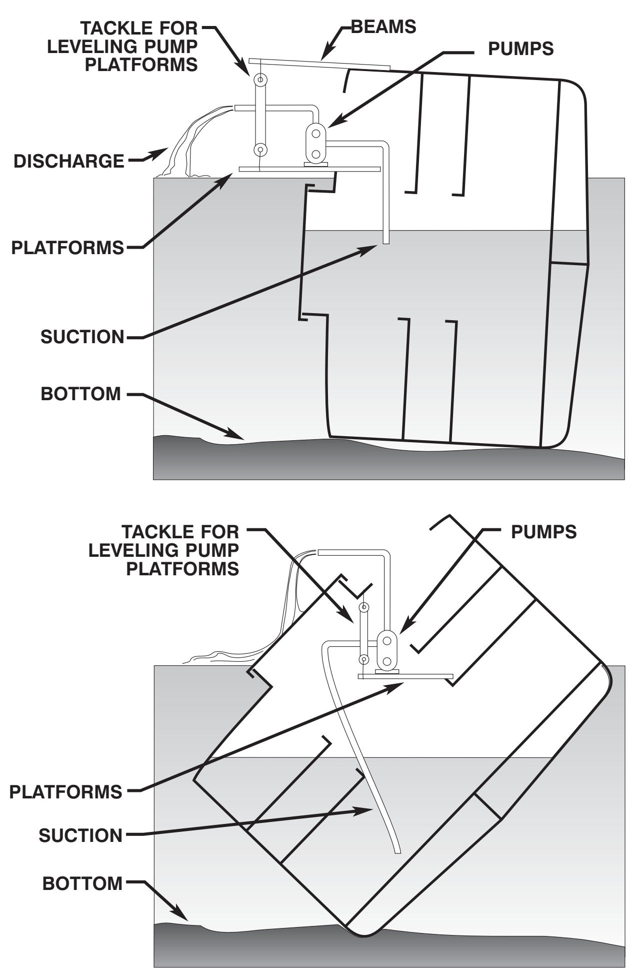


Figure 10-7. Pump Leveling Platforms.

Table 10-1. Pumps Rigged in Parallel.

PUMP SIZE	HOSE OR PIPE SIZE	MAXIMUM NUMBER OF PUMPS
1½-inch	2½-inch	2
	3-inch	3
	4-inch	6
	6-inch	15
2½-inch	4-inch	2
	6-inch	5
	10-inch	15
3-inch	4-inch	1
	6-inch	3
	10-inch	10
4-inch	6-inch	2
	10-inch	5
6-inch	10-inch	2

Access holes for suction lines may have to be cut through bulkheads or the sides of flooded compartments to shorten suction hose runs. Discharge hoses should be run along the lowest possible deck to avoid creating unnecessary discharge head pressures. When necessary, discharge hoses should be led outboard through holes cut in bulkheads or shell plating. No more hose than necessary should be used in order to limit friction loss.

Engine-driven pumps may be suspended on "jury-rigged" platforms hung over large spaces so pumps may be lowered and kept as close to the water surface as practical. Self-contained engine-driven pumps, generators, and hydraulic power units should be kept level at all times during operation. In some cases, special leveling platforms, such as those shown in Figure 10-7, must be built to ensure the machinery remains level.

It may be necessary in deep ships to accept large discharge heads that can reduce the output of centrifugal or diaphragm pumps. The effectiveness of the pumps may be increased by "staging" or "pumping in series." This is done by leading the discharge of one pump to the suction of a second located on a higher level as shown in Figure 10-8. The pumps should be of nearly equal capacities to avoid pump damage and cavitation effects in the upper pump.

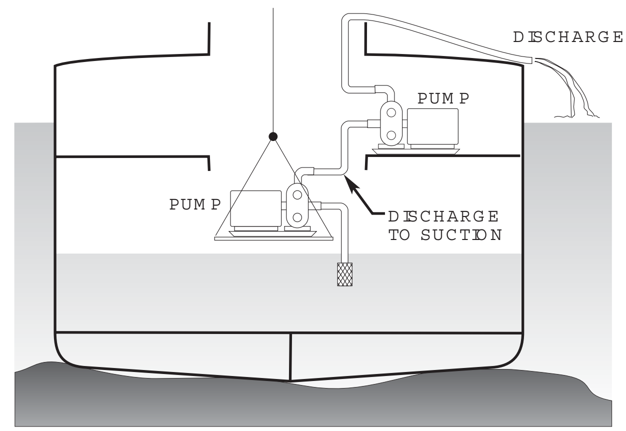


Figure 10-8. Pumping in Series.

"Pumping in parallel" may be used to reduce friction losses in the discharge pipe, as well as to reduce the work in rigging discharge hoses. As shown in Figure 10-9, two or more hoses are rigged into a single discharge hose or pipe. For instance, two 6-inch pump discharges may be rigged into a single 10-inch discharge pipe.

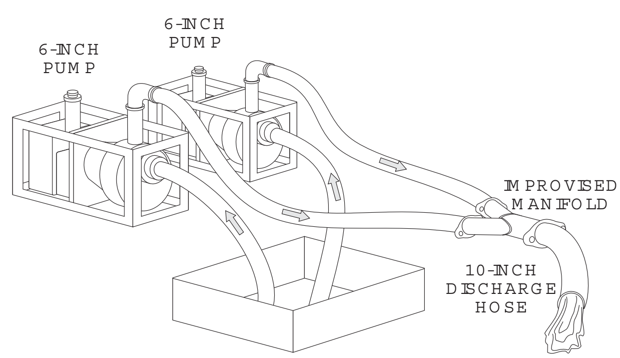


Figure 10-9. Pumping in Parallel.

It is important that the largest discharge hose be large enough to accommodate the combined flow from the pumps. Table 10-1 is a guide to the maximum number of pumps that may be rigged in parallel with standard Navy discharge hose and pipe.

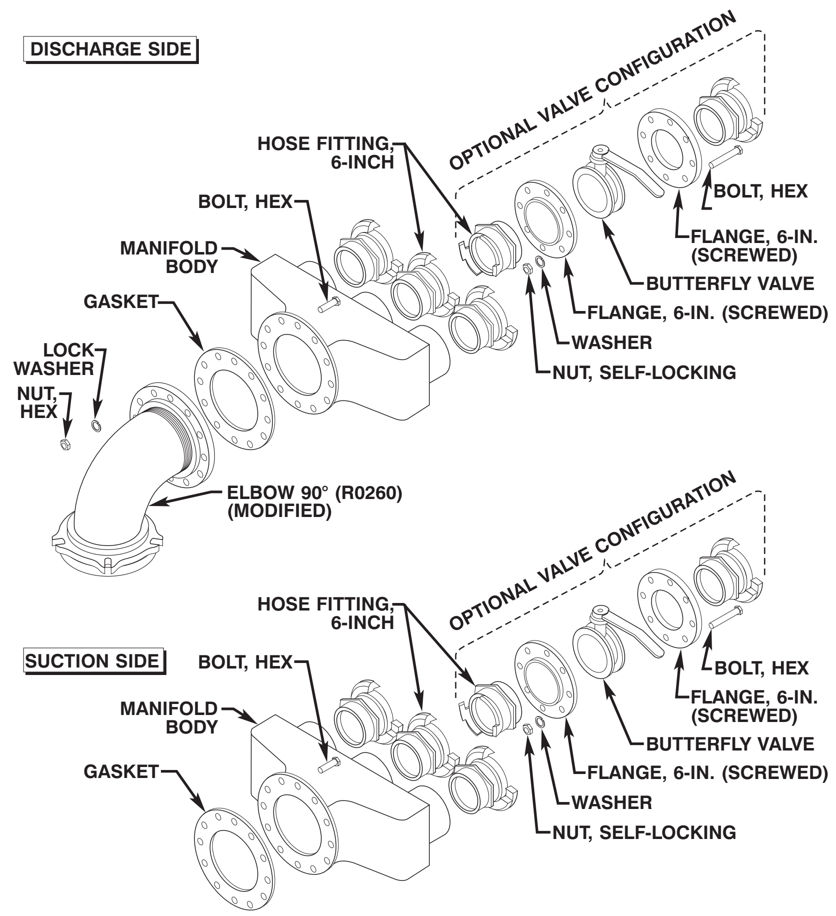


Figure 10-10. Manifold, 10-Inch to 6-Inch Hose, Discharge/Suction Connections, 10-Inch Diesel Pump.

10-2.8.2 Miscellaneous Operational Notes. The collection of miscellaneous notes in this paragraph has proved their practical value in numerous salvage operations.

A variation of the pumping-in-parallel system, described in the preceding section, is used with the 10-inch diesel salvage pump. A standard manifold, shown in Figure 10-10, is available on salvage ships and in the ESSM system to allow three 6-inch, lightweight plastic hoses to be rigged into the 10-inch pump suction rather than the heavy 10-inch hard rubber suction hose. The lightweight hose is much quicker and easier to rig than the heavy steel pipe. The suctions may be taken into separate compartments. The manifolds may also be rigged on the discharge of the 10-inch pumps. When 6-inch suctions from 10-inch pumps are led to different compartments, and one six-inch hose looses suction, then all hoses will loose suction. A valve in each suction line will permit the line to be closed off to prevent the loss of suction and the need to re-rig the wet compartment.

Organic materials, such as grain, will ferment when immersed in water, especially in warm climates. Other porous materials will absorb water, changing their density as suspended particles in a slurry mix. Chemical fermentation and molecular breakdown can significantly reduce pump capacity and suction lift ability. These effects are difficult to predict and must be dealt with by trial and error.

Air leaks in suction hoses greatly reduce efficiency and may seriously limit the ability of pumps to take suction. Hose couplings should always be sound. Hose sections that tend to leak should be placed in discharge strings where minor leakage is not critical. If leakage cannot be stopped, varnish or a sealing compound applied to pump couplings and unions where the hoses join the couplings will help seal them.

Operating centrifugal pumps at very high speeds may be harmful to the prime mover. Optimum speeds for standard Navy salvage pumps are given in the performance curves. If the optimum speed for engine-driven pumps is not available, the pump should be operated at about two-thirds of its rated speed. By keeping the speed down, the engine will operate most economically and efficiently.

A hold clogged with cargo or a debris-filled small space that cannot be accessed easily may be dewatered through the bilge suction manifold in the machinery space. Portable pumps may be connected directly to the manifold. This method avoids the effort of clearing and maintaining a suction access through the accumulated contents or debris in the space but may be extremely slow if the bilge piping is small. In some ships, it will be possible to drain flooded holds and tanks into adjacent shaft alleys through access holes cut or punched through from the shaft alley side plating. The flooded space will drain into the shaft alley where portable salvage pumps can remove the relatively clear water.

When engine-driven pumps are operated in confined spaces or below decks, there must be adequate provision for the removal of exhaust gases to the open atmosphere.

Power cables and switch boxes for electric submersible pumps and power hoses for hydraulic submersible pumps, though designed for the salvage environment, must be treated with reasonable care. Electric leads and hydraulic leads must be secured and led where they are not likely to be damaged. Power leads should be rigged clear of decks where they may become fouled, damage equipment, or present a danger to personnel.

A casualty may seem rock-steady; she is not—especially when she starts to come afloat. Pumps should be secured against shifting as the ship begins to move and her attitude changes. Pump suction, and especially discharge hoses, must be lashed so they do not flail about when flow commences.

Prior to commencing the pumping operation, it is prudent practice to conduct a test-pumping during which each pump is operated to ensure that it will work and actually pump water. The test-pumping should last long enough to demonstrate that the pump battery will, in fact, lower the level of water in the flooded space at roughly the expected rate. During test-pumpings, divers with bags of sawdust and marking crayons should be in the water locating and marking areas where patches are leaking. Problems defined during the test-pumping, especially excessive leakage, should be corrected before trying to pump the space.

Where clearing the wreck from its location is of primary importance, and the wreck will be disposed of, salvors have considerable latitude in the quality of their work. In these cases, it is acceptable, even good, practice to expedite the work by accepting relatively large amounts of leakage around patches and overcoming the leakage with a larger-than-required battery of pumps. The battery of pumps must be large enough to ensure the wreck does not sink enroute to its beaching or disposal site should there be pump failures.

Appendix G of this volume contains specifications and technical data for Navy standard salvage pumps. Additional information appears in the *U.S. Navy Emergency Ship Salvage Material Catalog* (NAVSEA 0995-LP-017-3010). When alternative pumps or pumps of opportunity are deployed on salvage operations, the manufacturer's handbook or instruction manual should accompany them.

10-3 COMPRESSED AIR DEWATERING.

Dewatering flooded spaces with portable pumps is probably the most common method of removing floodwater and recovering buoyancy in salvage. The use of compressed air dewatering is also a very common technique. Compressed air dewatering methods have greatly improved in the last forty years. The primary reasons for the improvement have been developments in underwater welding and air compressor technology and techniques. Better underwater welding allows salvors to obtain better airtightness in preparation for compressed air operations; larger capacity, more reliable air compressors are available now than were in the past.

Compressed air is best used in salvage for:

- Dewatering large tanks, hold spaces, or machinery spaces in ships that have bottom damage from underwater weapons, stranding, or other causes
- Dewatering flooded double-bottom tanks and deep tanks that are open to the sea
- Dewatering cargo tanks in tankers and large bulk liquid tanks in other ships
- Assisting certain types of pumping operations where controlled air blowing will reduce the pressure differential across decks or bulkheads.
- Regaining sufficient buoyancy to refloat ships that are sunk either on their sides or completely upside down.

Compressed air dewatering, like any other salvage method, has advantages and disadvantages that must be evaluated in the context of the overall salvage and dewatering plan.

10-3.1 Principles of Compressed Air Dewatering. The principles of compressed air dewatering for buoyancy recovery are:

- Air under pressure greater than the surrounding seawater is forced into the space.
- Floodwater is forced out by the pressure either through the bottom damage or up specially installed standpipes.

CAUTION

> Compartments must never be filled with compressed air unless fitted with a gage that can be easily monitored. Serious structural failure may occur if the compartment is over-pressurized.

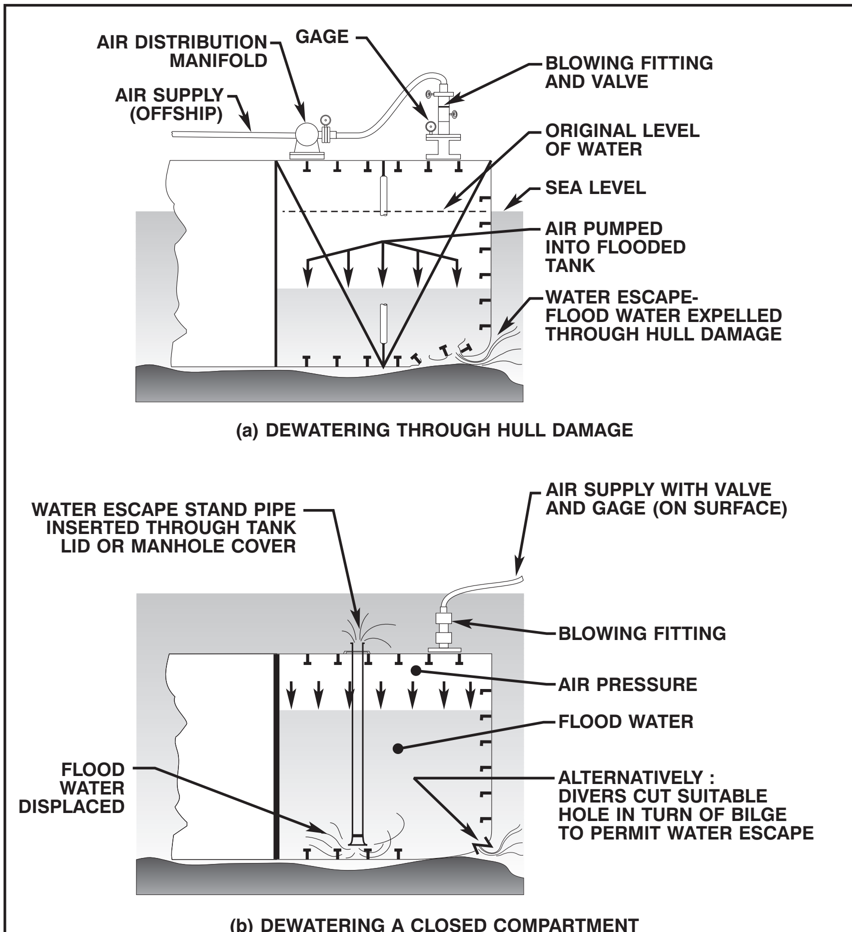


Figure 10-11. Compressed Air System.

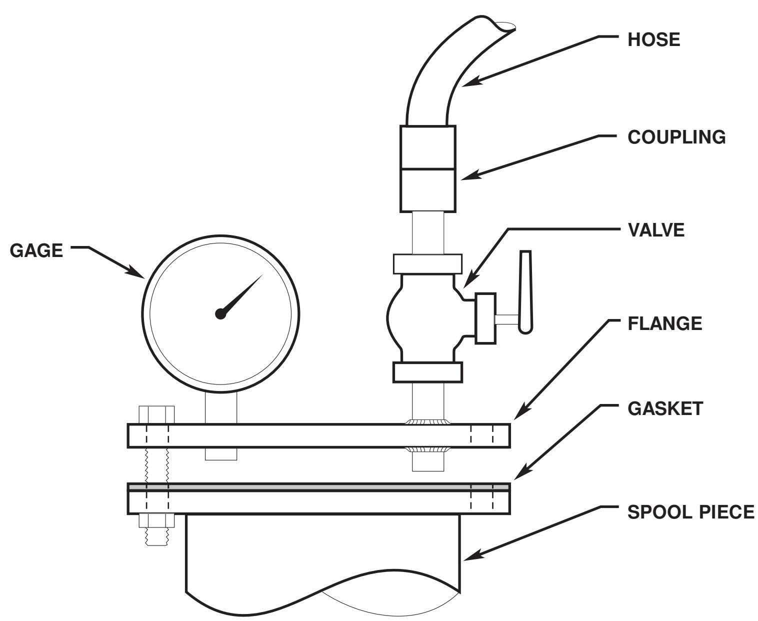


Figure 10-12. Blowing Fitting.

Dewatering a space with compressed air requires:

- The compartment must be watertight or capable of being made watertight at its top.
- The vertical sides of the compartment's boundaries must be airtight or capable of being made airtight.
- A damaged compartment must have damage either at its bottom or very low down on its side through which the flood water can be forced out.
- Where the compartment to be dewatered is undamaged, a standpipe to carry the water out must be fitted into the space.
- Suitable high-capacity air compressors, hoses, manifolds and gages.
- In some cases, special over-pressure (relief) valves may be installed on the compartments being dewatered.

Figure 10-11 shows the general features of a compressed air system being used to dewater a casualty. The basic items in the dewatering system include the:

- Air supply
- Blowing fitting and valve
- Compartment gage
- Means of escape for the air near the bottom of the compartment.

Figure 10-12 illustrates a typical fitting attached to a space for blowing.

10-3.2 <u>Compressed Air Dewatering Situations</u>. Compressed air is the appropriate dewatering method in a variety of situations involving stranded, beached, or sunken ships.

10-3.2.1 <u>Compressed Air Dewatering of Stranded or Beached Ships</u>. Experienced salvors dewater damaged double bottoms and deep tanks in stranded and beached ships almost automatically as a standard operating procedure. Dewatering with compressed air is often the quickest, easiest, and most efficient method of completely removing floodwater, restoring buoyancy, and reducing the ground reaction in stranded or beached casualties. Compressed air dewatering is practical for stranded or beached ships when:

- The casualty is hard upon, or close to the ground, so that divers cannot reach hull damage to patch it.
- The diving conditions at the casualty—current, surf, surge, ground swell, etc.—make it impossible or impractical for divers to work near the casualty.
- The casualty has such serious bottom damage that patching is impractical.
- Military payload, cargo, stores, or other heavy material prevent access for installation of pumping systems.
- A combination of damage to the casualty's pumps and impeded access to sound, full tanks make dewatering through standpipes attractive.
- Massive bottom damage to major compartments make temporary sealing off and blowing with compressed air a last resort; thus, employing a quick-and-dirty solution may prevent loss of the ship.

10-3.2.2 <u>Compressed Air Dewatering of Sunken or Partially Sunken Ships</u>. Compressed air dewatering is practical for sunken or partially sunken ships when:

- The ship has sustained such serious bottom damage that it is not practical to repair the damage.
- Divers cannot gain access to the damage.
- The ship is of a design that has few large deck openings so the deck may be made tight with relative ease.

NOTE

The design and construction of large submarines of all types makes a wholly or partially sunken submarine very suitable for raising by compressed air dewatering. The Supervisor of Salvage maintains comprehensive empirical and historical data concerning submarine salvage operations. The *U.S. Navy Salvage Manual, Volume 4* (S0300-A6-MAN-040) discusses submarine salvage in detail.

- It will avoid having to bring large cranes, sheer legs, and other floating plants from distant locations.
- The ship is lying at an angle—up to 90 degrees—and has sufficient intact volume that she may be floated on her side.
- The ship is inclined beyond 90 degrees so that most compartments can be dewatered with compressed air, and the position and planned disposal of the wreck indicate that upside-down refloating is the most time- and cost-effective method.

10-3.3 <u>Recoverable Buoyancy</u>. The amount of buoyancy that can be recovered from any compartment is a function of the volume of water in the compartment that can be blown down without air leaking from the compartment. If the compartment has damage that is limited to the bottom of the tank, almost all the buoyancy can be recovered. If the damage is part of the way up the tank, only the volume above the damage is recoverable buoyancy.

EXAMPLE 10-7
RECOVERABLE BUOYANCY

A flooded tank has the following dimensions: *l* = 40, *w* = 40, *d* = 30 feet. What is the recoverable buoyancy if:

a. The damage to the tank is on the bottom?

b. Damage extends one foot up the side of the tank?

c. Damage extends fifteen feet up the side of the tank?

Solution:

a. The recoverable buoyancy is the entire volume of the tank:

$$b = \frac{(l \times w \times d)}{35}$$
$$b = \frac{(40 \times 40 \times 30)}{35}$$
$$b = 1{,}371 \text{ tons}$$

b. The recoverable buoyancy of the tank is the volume less a 1-foot layer on the bottom from which the water cannot be blown:

$$b = \frac{[l \times w \times (d-1)]}{35}$$
$$b = \frac{40 \times 40 \times 29}{35}$$
$$b = 1{,}326 \text{ tons}$$

c. The recoverable buoyancy of the tank is the volume less a 15-foot layer on the bottom from which the water cannot be blown.

$$b = \frac{[l \times w \times (d-15)]}{35}$$
$$b = \frac{(40 \times 40 \times 15)}{35}$$
$$b = 686 \text{ tons}$$

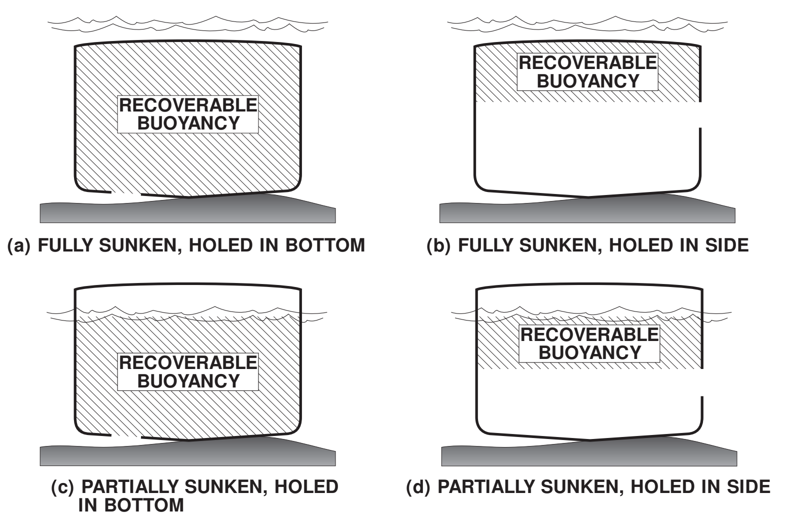


Figure 10-13. Recoverable Buoyancy.

Figure 10-13 illustrates recoverable buoyancy.

10-3.4 Free Surface. When only a small number of double-bottom tanks are blown almost dry, the only free surface to be considered is in the tanks blown. It is generally small; however, when a vessel with a considerable number of large tanks, such as a tanker, is refloated with compressed air, free floating trim, list, and stability must be carefully analyzed before the refloating. Particular attention must be paid to free surface.

10-3.5 Air Migration. The pressure of compressed air acts equally throughout the space. Compressed air has the disturbing and characteristic habit of migrating to the high side of the casualty. Migration of compressed air occurs through small holes or breaches in the internal structure. Even a ship with a slight list can quickly develop a major list resulting from a transverse shift of the compressed air mass through longitudinal bulkheads.

Migration of air may also cause the same problems with longitudinal stability, particularly in ships with long, narrow side tanks.

10-3.6 Salvage Compressed Air Theory and Terminology. Air compressors are rated in terms of discharge pressure in pounds per square inch gage and flow rate in standard cubic feet per minute. A standard cubic foot is the quantity of air that occupies one cubic foot at a standard set of conditions. These conditions are:

- Pressure – one atmosphere, 14.7 psi
- Temperature – 68 degrees Fahrenheit
- Relative humidity – 36 percent
- Density – 0.0750 pounds/cubic foot.

The volume occupied by air varies inversely with the pressure and directly with the temperature. This means that at the same temperature, the volume occupied by air:

- Decreases as the pressure rises
- Increases as pressure falls.

And that when the pressure is constant, the volume occupied by air:

- Increases as the temperature rises
- Decreases as the temperature decreases.

The standard cubic feet (*SCF*) required to fill a space whose volume in actual cubic feet (*ACF*) is:

$$SCF = (ACF) \times \left[\frac{(D+33)}{33}\right] \times \left[\frac{(T_a+460)}{(T_w+460)}\right]$$

where:

SCF	=	standard cubic feet of air required to fill the space
ACF	=	volume of the space in cubic feet
D	=	depth of water in feet
T_a	=	temperature of the air in degrees Fahrenheit
T_w	=	temperature of the water in degrees Fahrenheit
460	=	correction factor to convert to absolute temperature

The minimum pressure required to blow a compartment is the pressure at the hole through which the water will be blown, plus an allowance for air line losses and friction, normally taken as 2 psi.

$$P_b = 0.445 \times D + P_1$$

where:

P_b	=	blowing pressure, psig
D	=	depth of vent holes or standpipe in feet
P_1	=	pressure loss in psi (taken as 2)

EXAMPLE 10-8
CALCULATION PUMPING WITH HEAD CHANGES

A ship is sunk in 30 feet of water. A compartment to be blown dry is holed at the bottom. The compartment dimensions are *l* = 40 feet, *w* = 40 feet, and *d* = 25 feet. Air temperature is 50° F, water temperature is 36° F. How many standard cubic feet are required to dewater the compartment?

$$SCF = (ACF) \times \left[\frac{(D+33)}{33}\right] \times \left[\frac{(T_a+460)}{(T_w+460)}\right]$$

$$SCF = (40 \times 40 \times 25) \times \left[\frac{(30+33)}{33}\right] \times \left[\frac{(50+460)}{(36+460)}\right]$$

$$SCF = 40{,}000 \times 1.91 \times \left(\frac{510}{496}\right)$$

$$SCF = 78{,}556 \text{ cubic feet}$$

Note that the temperature difference contributes only a small amount to the accuracy of the calculation. In most salvage calculations, it can be ignored safely.

EXAMPLE 10-9
CALCULATION OF BLOWING PRESSURE

What minimum pressure is required to dewater a compartment holed at 25 feet?

$$P_b = 0.445 \times D + P_1$$
$$P_b = 0.445 \times 25 + 2$$
$$P_b = 13.125 \text{ psig}$$

10-3.7 Compressed Air Salvage Calculations. Compressed air calculations undertaken by the salvor are generally used to answer one of two questions:

- How many compressors will be required to blow a space in a given time?
- How long will it take to blow a compartment with a given compressor battery?

To make these calculations, the salvor need only know the rating of the compressors to be used, the geometry of the situation, and the temperature of the air and water in the space to be dewatered. As previously stated, the temperature correction can often be ignored in salvage calculations.

10-3.7.1 Number of Compressors. To calculate the minimum number of compressors required to dewater a space in a given time:

a. Determine the number of standard cubic feet required to dewater the space.

b. Divide the SCF required by the time required to determine the total number of cubic feet required per minute.

EXAMPLE 10-10
CALCULATION OF MINIMUM NUMBER OF COMPRESSORS

A ship is sunk in 30 feet of water. A compartment to be blown dry is holed at the bottom. The compartment dimensions are *l* = 40 feet, *w* = 40 feet, and *d* = 25 feet. Air temperature is 50° F, water temperature is 36° F. How many 125-cfm compressors are required to dewater the space in 3 hours?

a. Standard cubic feet required:

$$SCF = (ACF) \times \left[\frac{(D+33)}{33}\right] \times \left[\frac{(T_a+460)}{(T_w+460)}\right]$$

$$SCF = (40 \times 40 \times 25) \times \left[\frac{(30+33)}{33}\right] \times \left[\frac{(50+460)}{(36+460)}\right]$$

$$SCF = 40{,}000 \times 1.91 \times \left(\frac{510}{496}\right)$$

$$SCF = 78{,}556 \text{ cubic feet}$$

If the temperature correction is ignored:

$$SCF = \left[\frac{(D+33)}{33}\right] \times ACF = \left[\frac{(30+33)}{33}\right] \times 40{,}000$$

$$SCF = 1.91 \times 40{,}000$$

$$SCF = 76{,}400 \text{ feet}^3$$

b. Standard cubic feet per minute required:

$$SCFM = \frac{SCF}{\text{minutes}} = \frac{76{,}400}{180}$$

$$SCFM = 424\ SCFM$$

c. Number of compressors required:

$$n = \frac{SCFM}{\text{rating}} = \frac{424}{125}$$

$$n = 3.4 \text{ or four 125-}CFM \text{ compressors}$$

c. Divide the SCF required per minute by the rating of the compressors to determine the minimum number required.

10-3.7.2 Dewatering Time. To calculate the time required to dewater a space with a particular battery of compressors:

a. Determine the standard cubic feet required to dewater the space.

b. Determine the total capacity of the compressor battery in SCFM.

c. Divide the SC required by the compressor battery capacity to determine the dewatering time.

EXAMPLE 10-11
DEWATERING TIME

A ship is sunk in 25 feet of water. A compartment to be blown dry is holed at the bottom. The compartment dimensions are *l* = 40 feet, *w* = 40 feet, and *d* = 25 feet. Air temperature is 50 °F, water temperature is 36° F. How long will be required for 5 125-SCFM compressors to dewater the space?

a. Standard cubic feet required:

$$SCF = (ACF) \times \left[\frac{(D+33)}{33}\right] \times \left[\frac{(T_a+460)}{(T_w+460)}\right]$$

$$SCF = (40 \times 40 \times 25) \times \left[\frac{(25+33)}{33}\right] \times \left[\frac{(50+460)}{(36+460)}\right]$$

$$SCF = 40{,}000 \times 1.76 \times \left(\frac{510}{496}\right)$$

$$SCF = 72{,}387 \text{ standard cubic feet}$$

b. Total compressor battery capacity:

$$SCFM = \text{Number of compressors} \times \text{individual compressor capacity}$$

$$SCFM = 5 \times 125$$

$$SCFM = 625$$

c. Dewatering time:

$$t = \frac{SCF}{SCFM}$$

$$t = \frac{72{,}387}{625}$$

$$t = 116 \text{ minutes}$$

10-3.8 <u>The Decision to Dewater with Compressed Air</u>. On many occasions, compressed air dewatering is such an obvious choice, both technically and logistically, that no purpose is served by investigating other refloating methods. At other times, compressed air refloating presents so many technical and preparation problems that the concept is in doubt from the first survey.

Whether the method is the obvious choice from the beginning or a doubtful starter at best, the proposal for refloating with compressed air deserves thorough and detailed engineering analysis to establish the:

- Ship's ability to withstand internal air pressure and the amount of reinforcement required, if any
- Pressure curve for the refloating sequence, and possible requirement for pressure relief valves
- Transverse and longitudinal stability and trim characteristics at each stage of the refloating
- Weights, counterweights, or restraining forces necessary to control list and trim
- Extent of watertight and airtight compartmentation required to control list and trim
- Compressor plant capacity.

The proposed salvage plan must be reviewed in detail by the salvage officer and senior divers for practicality at each stage. The review includes:

- Availability of material to make necessary repairs, modifications, and closures
- Availability of the required compressor plant, manifolding, hoses, and gages
- Estimates of the diving time required and the time required for topside work
- Effects of moving the ship on its side, upside down, or partially submerged to the next area of operations.

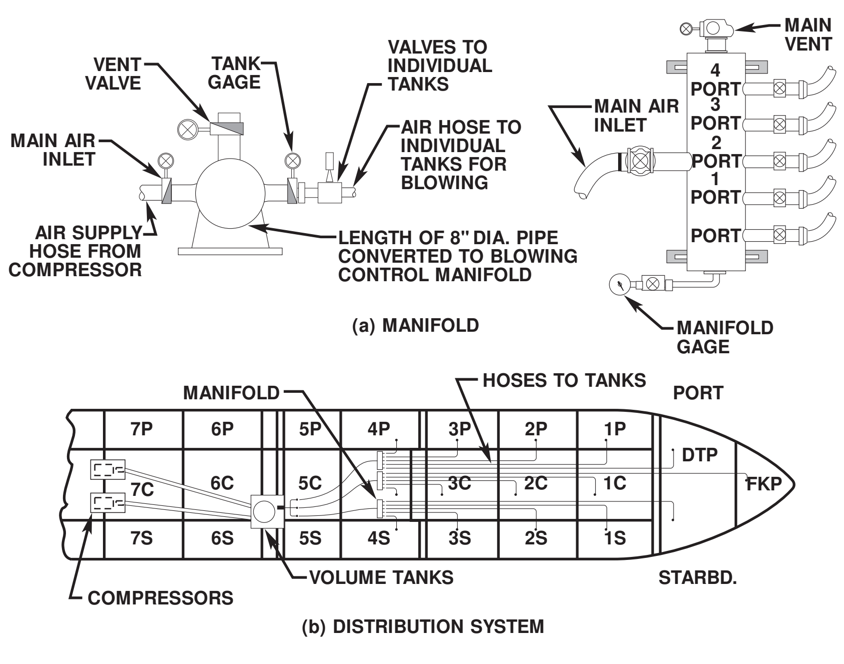


Figure 10-14. Compressed Air Manifolds and Distribution System.

10-3.9 <u>Miscellaneous Operational Notes</u>. The collection of miscellaneous notes in this paragraph has proved their practical value in numerous salvage operations.

Air compressors should not usually be mounted on the ship being raised, but on a barge or other work platform alongside. If the ship is lost, compressors and equipment on it will also be lost. Salvage compressors should be secured to the deck in such a manner that the hose will part or a fitting will carry away before the compressor comes adrift.

The work necessary to obtain a high degree of air tightness is frequently very time-consuming and labor-intensive. If the work is to be done by divers, large diving teams will be required.

A high-driving pressure will not necessarily ensure more rapid dewatering. Dewatering rate is dependent upon volume flow; the compartment will not be dewatered until a sufficient volume of air has been delivered.

Compressed air delivery systems must be carefully thought-out. Delivery via one or more compressed air manifolds is an excellent method of organizing air compressed air and distribution systems. Figure 10-14 shows a typical compressed air manifold and distribution system.

Hoses rigged to underwater connections should be individually tagged with plastic or metal identification tags matching a tag previously placed on the connection. By running each hose individually and ensuring the divers compare the air hose tag to the tag on the connection, a simple cross-check is provided.

When the ship is wholly or partially submerged, pneumofathometers (Kluge gages) will assist in monitoring and detecting movement or changes in attitude. Typically, Kluges are fitted forward and on both sides amidships and led to a central monitoring point.

Installed piping systems can be used as air distribution systems. Auxiliary steam systems with the boiler as a volume tank and tanker inert gas systems are particularly suitable.

Compressed air escapes between four and six times as fast as water from the same hole. Minor leaks that would otherwise safely be ignored must be sealed for compressed air dewatering.

Compressed air, leaking out of small holes and splits, will transfer to compartments where it is not wanted, resulting in a continuous loss of buoyancy or an increase in buoyancy where it is not desired.

Crude oil tanks should always be inerted during cargo transfer. Hydrocarbon gasses encountered in tanks cannot burn in atmospheres containing less than 11 percent oxygen. Pumping inert gas in the tanks decreases the risk of fires. The gas can be delivered at a maximum pressure of 3.5 psig. Inert gas can, however, present a hazard to personnel because it does not smell and can suffocate anyone entering an inerted space. Best practices include checking the oxygen content of inert gas at both the outlet of the tank as well as in the inerted tank.

Ships sunk in even moderate depths are usually refloated so that one end surfaces first, and the other end is then brought afloat. If refloating trim is excessive, air will spill from the high end compartments at such a rate that all buoyancy may be lost and the ship will sink again.

When raising ships with long compartments upside down or on their sides, spill pipes should be fitted in the centerline—relative to the ship's final position—to prevent large air bubbles from developing in the hold. Large air bubbles will move from end to end of the hold and develop large undesirable trimming forces.

Ships raised upside down can usually be brought very high out of the water; however, they should not be raised more than the height of the double bottom as they are very stable in this condition.

Inclining experiments conducted on ships floating upside down have shown this to be a very stable condition with metacentric heights up to two and one-half times that of the same ship floating upright. Longitudinal stability is somewhat less than for the upright ship because the ship floating with a low freeboard loses waterplane quickly when pitching, and air tends to migrate to the high end.

Buoyancy can be limited by securing from blowing before the water level reaches the vent holes or standpipe. This method is satisfactory for ships sunk in shallow water, but should not be used on deeply submerged ships because the air will expand as the ship rises, adding buoyancy in an uncontrolled manner.

If the standpipe or the hull openings are too small, water will flow out of the compartment slower than air flows in and cause pressure to build up. If pressure rises in the compartment, blowing should be secured until it falls.

Patches should be ready for installation on vent holes when the ship is afloat. If bottom damage can be repaired, additional buoyancy may be regained and the ship will be more secure during tow.

When a ship is substantially afloat on compressed air (on a bubble) and being towed in the open sea, it will roll and pitch, spilling air and losing buoyancy. Compressors must be provided on board or connected to the casualty for replacing lost air.

Compressed air expands as water depth decreases and can cause major structural damage or loss due to catastrophic bulkhead or hull failure. Figure 10-15 illustrates the expansion of air with decreasing depth. When a sunken ship is to be raised from any significant depth with compressed air, there must be either sufficient hull openings or adequate pressure relief valves for venting out surplus air.

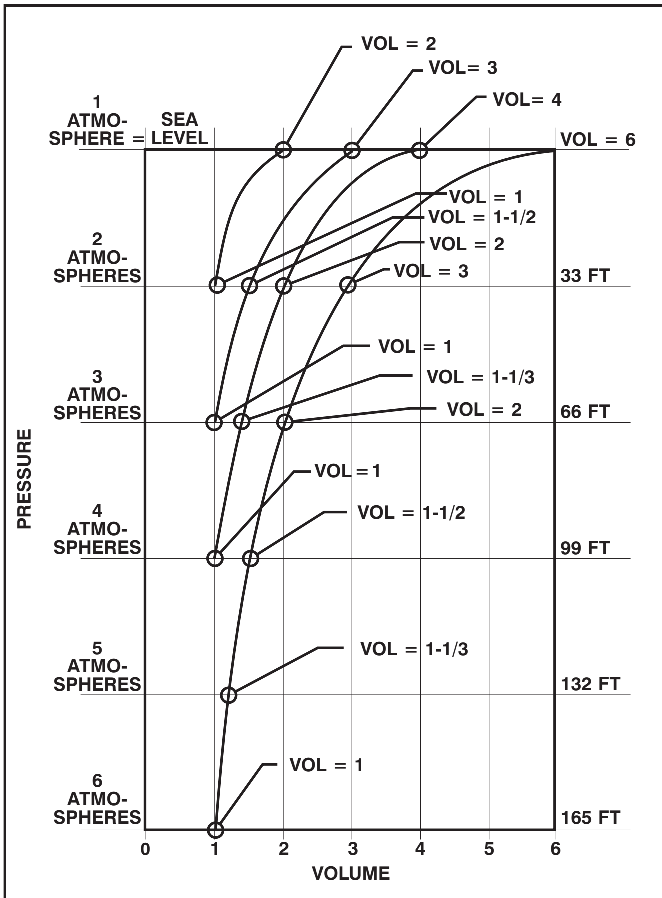


Figure 10-15. Expansion of Air with Decreasing Depth.

The appearance of numerous bubbles that approximate the outline of the vessel is an indication that the ship is about to rise.

A sunken ship being raised on compressed air tends to move off the bottom quickly without warning and accelerate as it rises. The rising ship presents a danger to surface craft. All salvage ships and craft should be pulled back as far as practical to avoid collision with the rising ship.

Like any other salvage system, compressed air has its limitations and problems. Salvors should be fully aware of these limitations, some of which have been delineated here, and evaluate them in the context of the operation at hand. Knowledge of limitations and problems should not prevent salvors from using compressed air when it is appropriate, but should give them a basis for devising solutions well in advance.

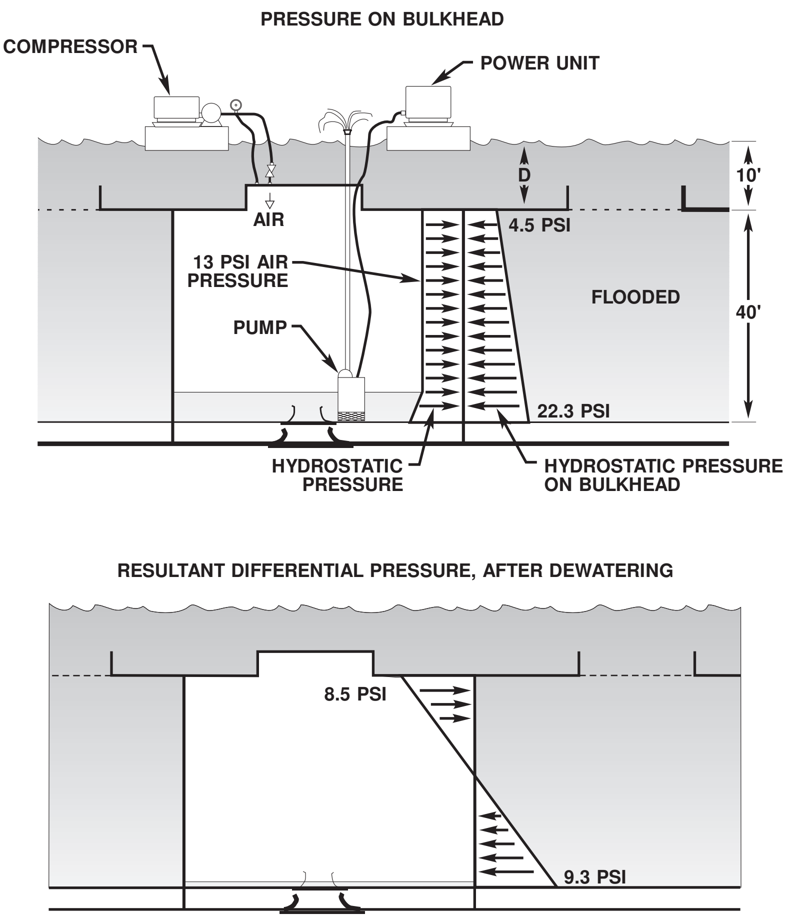


Figure 10-16. Combined Pumping and Blowing to Limit Differential Pressure.

10-4 COMBINED PUMPING AND BLOWING.

Sometimes it is advantageous to pressurize a compartment while pumping it. The most common use of combined pumping and blowing is to keep the pressure differential across bulkheads, decks, or shell plating within acceptable limits. Excessive pressure differentials can result from either of two conditions:

- When a compartment is dewatered by pumping, the inside of bulkheads, shell, and decks see atmospheric pressure. The outer sides see an opposing hydrostatic pressure that varies with depth. If the water depth is great enough, hydrostatic pressure will cause structural failure.
- To completely dewater a space with compressed air, the pressure in the compartment must be greater than the hydrostatic pressure at the bottom of the space. When blowing deep compartments, the blowing pressure can cause an excessive pressure near the top of the compartment. Combined pumping and blowing can be used to advantage in situations where the work and time required to seal the compartment are less than what would be required to shore or strengthen the casualty's structure against excessive pressures.

Figure 10-16 illustrates how the introduction of compressed air can lower differential pressure across the bulkhead of a compartment being dewatered between a compartment being dewatered and one open to the sea.

Combined pumping and blowing can be a difficult technique to apply because all the problems of both methods are present:

- Compartments must be sealed for blowing with special attention paid to pump suctions, discharges, power lines, hydraulic hoses, etc.
- Pressure on each compartment must be monitored carefully to ensure that the maximum blowing pressure is not exceeded.
- The air flow rate must be matched to total pumping capacity and monitored by watching the gages to avoid over-pressurization.
- Holes must be double-patched.

When combined pumping and blowing is used to dewater a compartment, the internal pressure must be controlled to ensure that the internal pressure:

- Never rises so high that the compartment cannot hold it
- Does not fall so low that the structure is collapsed by hydrostatic pressure.

Air flow is controlled by throttling the air inlet, varying compressor speed, or intermittently admitting air.

Pump performance may be improved by keeping a pressure above the fluid being pumped to produce a positive suction head. When pumping flammable liquids with the ship's pumps, pressurizing tanks with inert gas improves pump performance and reduces the danger of ignition. Many tanker pumps are designed for optimum operation with a 5- to 10-psi inert gas pressure.

When some compartments are being dewatered by compressed air and others by pumping, each may be handled independently as shown in Figure 10-17. The pressure differential across bulkheads separating compartments to be blown from those to be pumped must not exceed the bulkhead design pressure.

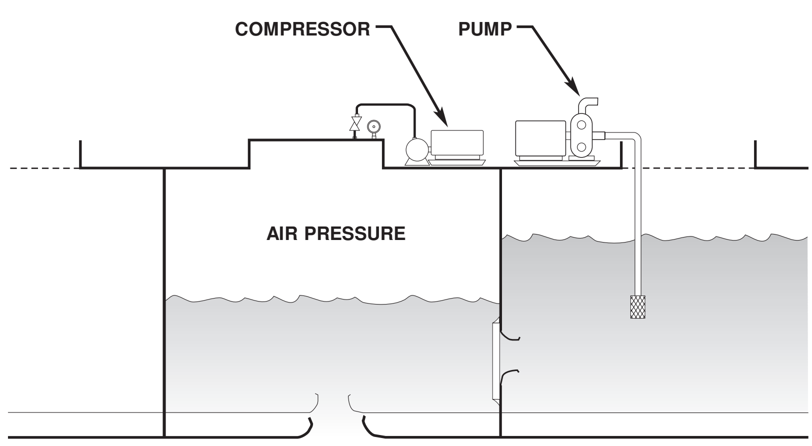


Figure 10-17. Combined Pumping and Blowing as the Most Appropriate Method for the Space Being Dewatered.

Combined pumping and blowing operations are tedious and must be undertaken only with a full appreciation of the problems involved in situations where they are clearly called for and the alternatives are unacceptable.

10-5 INDUCED BUOYANCY.

Buoyancy may be induced in a hull by placing buoyant objects inside the hull or by inserting a large buoyant mass. Inducing buoyancy is most attractive when the hull is so badly damaged or deteriorated that it cannot be made sufficiently watertight for pumping or blowing.

Whenever buoyancy is induced in a hull, the net buoyancy gained is the buoyancy of the object less its weight in water. If the buoyant object is heavy relative to its buoyancy, the overall gain may be quite small.

Buoyant objects, such as sealed empty drums, lift bags or collapsible pontoons, rigid pontoons, or any buoyant material, can be placed in the space. Buoyant objects must be contained or secured so as not to float out of the compartment. Inducing buoyancy by putting buoyant objects internally is likely to be labor-intensive and to consume large amounts of diving time.

Several systems for inducing large amounts of buoyancy in hulls have been developed and used with varying degrees of success. All are either technically complex, expensive, or require large amounts of equipment on-scene. These systems include:

- Foam-in-Salvage – a buoyant polyurethane foam formed when liquid components are combined and pumped into a space. The foam hardens into a buoyant mass. The foam is rigid, easy to contain, and difficult to apply and remove. Applying the foam, even in limited quantities, is an expensive, major operation requiring considerable technical expertise and involving serious safety and fire hazards.

  Foam-in-Salvage has the additional benefit of contributing some strength to the hull girder. The hardened foam has some compressive strength that contributes to the overall compressive strength. In addition, the foam covering the structure restrains the structure much in the same way as sand filling a pipe restrains failure. The contribution of foam to hull strength varies with the quality of the foam and the thoroughness of its application. Accordingly, it cannot be quantified. Foam installed in the hull may allow the salvor to accept a reduced factor of safety in compressive hull loading.

- The Pressurized Sphere Injection System injects spheres made of a petrochemical material into the hull. The spheres are pressurized to ambient levels to withstand the hydrostatic pressure at depth and are fitted with relief valves to allow the pressure to equalize as the ship rises. This system requires a large volume and considerable equipment for storing and handling the spheres.

- The Karl Kroyer A/S (Denmark) system uses polystyrene granules that are expanded by steam into small buoyant spheres. The spheres must be stored for drying and air diffusion before being pumped into the casualty as slurry. The buoyant mass is not rigid; there is a pronounced free surface effect. European salvors have used the system with some success.

Induced buoyancy systems are not "the answer to a maiden's prayer." They are both expensive and difficult to use and have drawbacks that limit their utility. They can be an appropriate tool for specific jobs, but should not be used when simpler, less complex, and less costly methods will do the job.

The Foam-in-Salvage system is readily available to the Navy but as a product that is under development. While foam is a viable system, it is not an easy one and should be used only when it is clearly the best alternative. When foam appears be a suitable solution to a salvage problem, the Supervisor of Salvage should be contacted for technical advice and for making arrangements to obtain foam.

CHAPTER 11
HEAVY SALVAGE RIGGING

11-1 INTRODUCTION.

Most harbor clearance and wreck removal operations involve heavy and powerful pulling and lifting systems to raise, upright, or move sunken ships. These heavy rigging systems:

- Develop the mechanical power to lift, rotate, move, or stabilize sunken ships
- Transmit forces developed by tidal and buoyant lifting to the ship being stabilized or lifted
- Connect lifting or pulling systems to sunken or capsized ships.

Mechanically hauled purchases or hydraulically powered linear pullers power heavy pulling and lifting systems. Many sets may be needed to develop the required force.

Heavy rigging systems for harbor salvage, harbor clearance, and wreck removal are developed from the Navy standard beach gear system. Unlike Navy standard beach gear, the heavy systems are not easily portable. The heavy rigging systems are characterized as:

- Permanently rigged, integral lifting systems incorporated in the design of heavy lift cranes and purpose-built salvage barges
- Systems specifically designed and assembled for a particular operation; preferably, such systems are assembled from standard, matched components.

This chapter describes applications of both Navy standard and heavy rigging systems. Hydraulic pullers are the preferred power equipment for Navy pulling systems, however, these are not always available. In every salvage operation, there is a possibility that the salvors will have to go back to basic principles when developing their methods. Because of that possibility, this chapter discusses heavy purchase rigging in detail and describes the more common salvage rigging practices.

Passage of lifting and hauling wires under and around sunken ships is an integral part of salvage rigging. This chapter discusses, in outline, methods of passing lift wires. It also discusses methods of calculating lift wire tension in tidal lifting and methods of predicting and preventing damage by lift wires to the vessel being raised.

A knowledge of heavy salvage rigging is necessary to understanding the practical application of the salvage methods described in Chapters 7 through 9. There are no hard and fast rules for choosing pulling and lifting systems. Only detailed on-site surveys and investigations, combined with engineering and rigging evaluations and determination of equipment availability, will allow assembly of the most practicable system.

11-2 HEAVY RIGGING AND PULLING SYSTEMS.

Heavy rigging and pulling systems are combinations of mechanical components that work together to apply a controlled force—either vertical or horizontal—to raise, rotate, or move ships. The basic pulling systems in Navy salvage operations are:

- The linear puller system
- The deck purchase system.

Both systems were specifically designed for beach gear for refloating stranded ships. Under some conditions, both systems can be used for raising and uprighting sunken ships. Both systems are portable and have rated capacities of 50 short tons. The systems must be employed within their designed operating envelope. Operational requirements sometimes lie outside this envelope.

11-2.1 Heavy Purchase Systems. Many harbor salvage, harbor clearance, and wreck removal operations require pulling and lifting forces that can be developed only by many standard pullers or purchases. In the interest of safety, simplicity, workability, and ease of control the minimum number of systems possible should be used on any task. Space aboard ships and barges and in many land-based applications is at a premium. A system that increases pulling power without a concomitant exponential increase in complexity and ancillary equipment is an advantage in salvage or clearance.

Heavy salvage pulling and lifting require a more flexible approach to rigging than normally is found in stranding salvage. The criteria that influence decisions to use particular lifting and pulling systems are:

- Simplicity of coordination and control
- Ease of setting up the system to include rigging, constructing anchor points, and establishing pulling points on the ship
- Time required to set up the system
- Safety.

Simple, easy-to-control systems are operationally safe systems. Simplicity enhances safety because there are fewer purchases and prime movers in the system.

11-3 PURCHASE SYSTEM COMPONENTS.

11-3.1 Basic Components. The basic components of any conventional purchase system are:

- A pair of multi-sheave blocks
- Wire rope to reeve the purchase
- A securing system to secure the traveling block to the main hauling or lifting wire
- Guide systems to fairlead the main hauling or lifting wire to the blocks.

Figure 11-1 shows the components of a Navy standard beach gear system. These components are:

- Two four-sheave blocks designed for ⅝-inch wire rope
- 1,200 feet of ⅝-inch EIPS FC wire rope to reeve the purchase
- Carpenter stoppers, sliding wedge block-type stoppers, that hold wire rope without damage up to the rope's breaking strength (a 1⅝-inch stopper secures the traveling block to the main wire rope)
- Fairlead blocks.

These standard components have been tested exhaustively, analyzed, and improved over the years to produce a system that has a 50-ton general working rating.

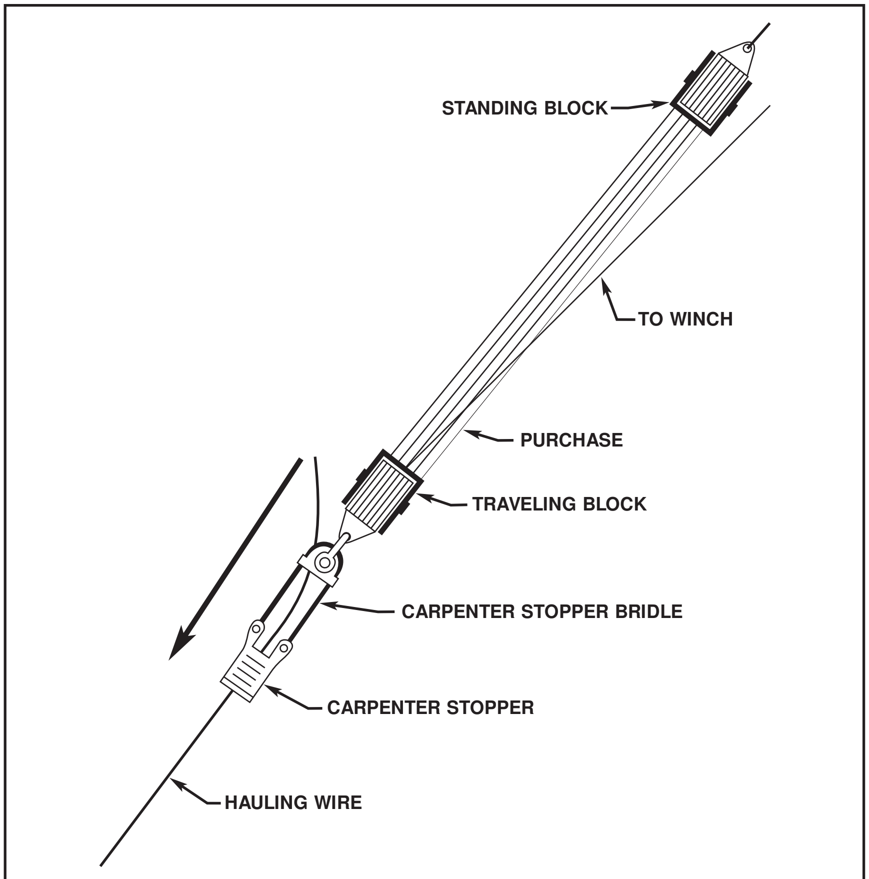


Figure 11-1. Navy Standard Beach Gear Purchase

11-3.2 Heavy Purchase Systems. Components of heavy purchase systems perform the same functions as those of Navy standard beach gear but differ in design, strength, and rigging techniques. Differences include:

- The number of sheaves in purchase blocks increases from four to six or eight. There may be as many as sixteen or eighteen sheaves in blocks used for special applications.
- Depending upon power requirements and sheave diameter, purchase block wire sizes increase from ⅝-inch up to ⅞- to 1⅜-inch.
- Hauling wire sizes of 2½, 3, and 3½ inches are common in heavy salvage systems.
- Carpenter stoppers are replaced by either wires of predetermined lengths connected directly to the traveling block, or specially designed clamping devices, usually based on the Bullivant clamp.
- Fairlead rollers or blocks are specially constructed to suit the main lifting wires.

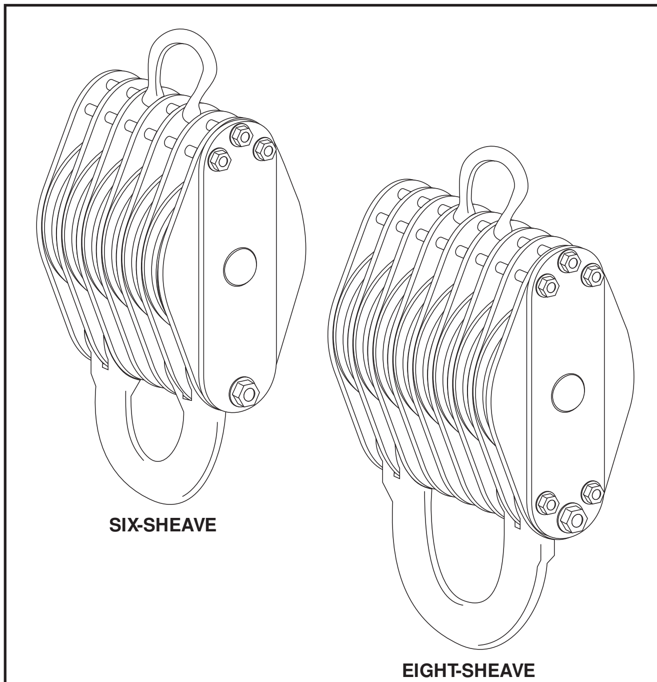
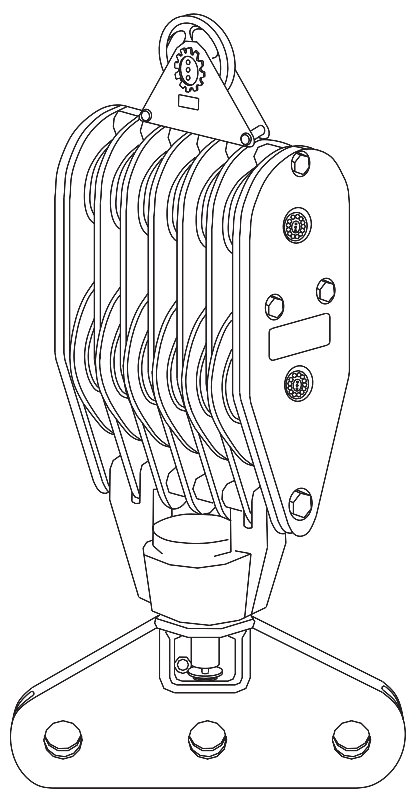


Figure 11-2. Six- and Eight-Sheave Construction Blocks.

11-3.3 Blocks. Six- and eight-sheave construction blocks, illustrated in Figure 11-2, often fill salvage purchase block requirements. A typical six-sheave construction block with a safe working load of 120 tons has 20-inch diameter sheaves, weighs 1,000 pounds, and is rove with 1-inch diameter wire rope. An eight-sheave construction block with a safe working load of 160 tons has 20-inch diameter sheaves, weighs 1,200 pounds, and is rove with 1-inch diameter wire rope. Larger six-sheave and eight-sheave blocks are rated at 140 tons and 180 tons, have 24-inch diameter sheaves, weigh 1,900 and 2,600 pounds respectively, and are rove with 1¼-inch wire rope. The larger blocks are used in salvage operations only as permanent rigging on salvage sheer legs, crane barges, or pulling barges.

The rated safe working load of construction blocks is usually three-fourths of the ultimate strength of the block. For salvage, the blocks are derated to a safe working load of foure-fifths of the ultimate strength. The safe working load of a 120-ton construction block in salvage becomes 96 tons; that of a 160-ton block becomes 128 tons. In field applications, these blocks would be rated at 100 tons and 125 tons, respectively.

Tandem-sheave blocks are sometimes used for parbuckling very large vessels with shore-based hauling systems. Tandem-sheave blocks, illustrated in Figure 11-3, have two rows of sheaves. The lower sheaves have a larger diameter than the upper sheaves. Such blocks often have an equalizing sheave and have two hauling parts on the purchase wire.



30” AND 24” 250-TON TWELVE-SHEAVE TANDEM SHEAVE BLOCK WITH EQUALIZER AND LOCKING HANGER

Figure 11-3. Tandem Sheave Block.

One of the largest righting operations undertaken by the Navy, the refloating of the battleship USS OKLAHOMA, sunk at Pearl Harbor in the December 1941 attack, used tandem-sheave blocks—twenty-one sets of purchase gear consisting of two tandem-sheave blocks, each with eight 28-inch sheaves, eight 24-inch sheaves, and an equalizing sheave. Each set of purchase blocks were rove with 9,500 feet of 1-inch wire rope. These purchase tackles could exert a pull of between 324 and 361 tons at a efficiency of about 65 percent. Pulls of between 6,800 and 7,900 tons were made.

The USS OKLAHOMA operation is an example of what a large, sophisticated purchase system can achieve. The design and engineering of such a system is beyond the scope of this manual. The Supervisor of Salvage provides guidance and engineering support for salvage operations requiring elaborate rigging systems.

11-3.4 Reeving. Figures 11-4 and 11-5 show reeving of Navy standard beach gear purchases. Reeving of large six- and eight-sheave blocks differs from that of the four-sheave blocks. Large purchases usually operate in a horizontal plane. The round-robin reeving system is not particularly efficient because the purchase develops a twisting moment that capsizes the traveling block. Round-robin reeving is used only for large purchases that operate on a track or have restraining systems.

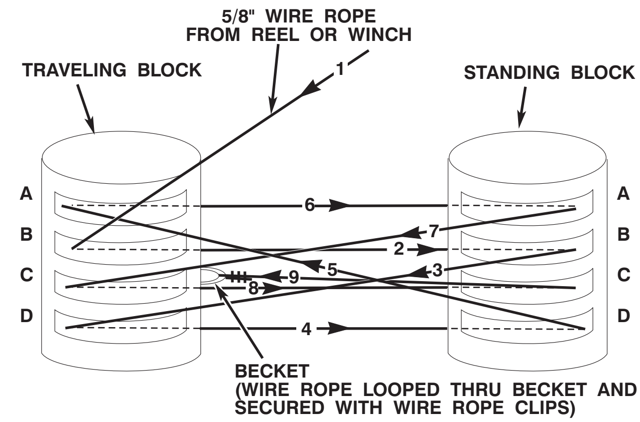


Figure 11-4. Navy Standard Beach Gear Blocks - Center to Center Reeving.

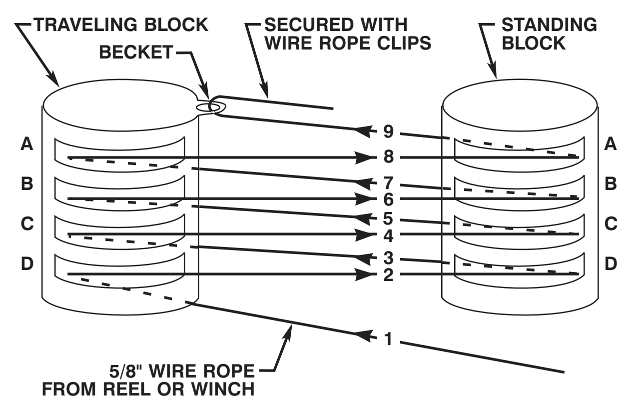


Figure 11-5. Navy Standard Beach Gear Blocks - Round-Robin Reeving.

Large horizontal purchases usually are rove with reverse bends to counter the torque that twists the purchase and capsizes the traveling blocks. Figures 11-6 and 11-7 illustrate common reeving systems for six- and eight-sheave blocks. Both systems incorporate two reverse bends and have the bitter end of the purchase wire dead-ended to the traveling block.

There are no hard-and-fast rules for reeving large purchase blocks that operate in a horizontal plane. The following procedures, however, are good rigging practice:

a. The standing block is placed in its correct operating position and connected to its deadman or anchorage.

b. The traveling block is placed approximately two block lengths away and secured with straps shackled to a convenient strong point.

c. Sheaves of purchase blocks are numbered for reeving. The sheaves of the standing block have even numbers, those of the traveling block, odd numbers.

d. Each sheave of both blocks is marked clearly or painted with its number.

e. A dummy reeve is made with light, synthetic, fiber line rove through the sheaves.

f. After the dummy reeve is checked and approved, a length of ⅝-inch diameter wire rope is attached to the dummy reeve line and rove through the purchase. The ⅝-inch wire serves as a gantline for reeving the main purchase wire.

g. The reels with the purchase wire are set upon stools or rollers in suitable positions. Purchases may be rove after all the wire except for a short end for reeving the blocks has been spooled onto the winch drum; or, they may be rove directly from the reel. In the latter method, the traveling block is fully fleeted to its operating position, and the entire length of the purchase wire unspooled before the bitter end is taken to the winch.

h. The free end of the gantline is short-spliced or welded to the bitter end of the main purchase wire. The ⅝-inch wire is taken to power and hauled slowly through the purchase until the end of the main purchase wire emerges from the last sheave.

i. The gantline is removed and the main purchase wire made up to its becket. The reeve is complete.

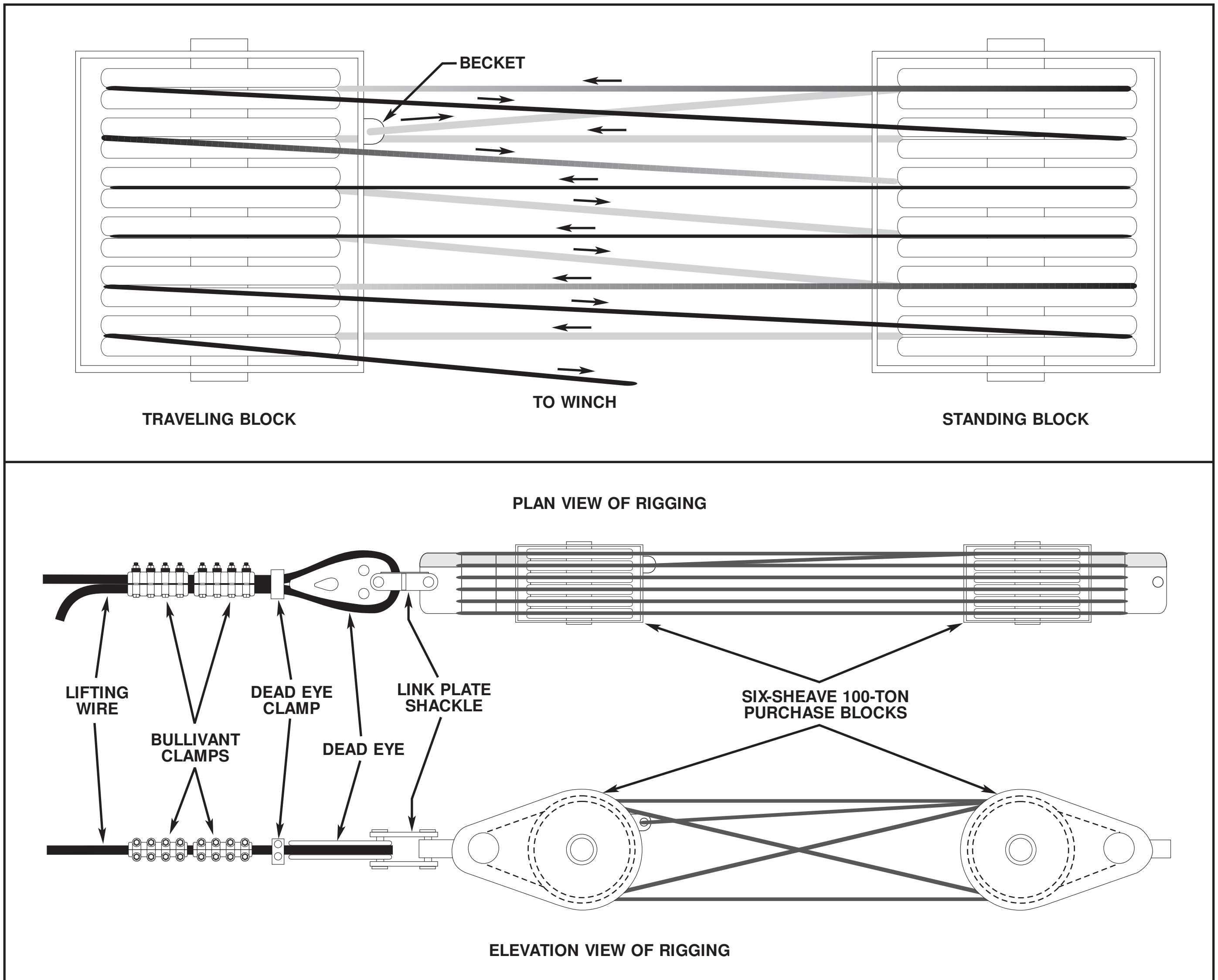


Figure 11-6. Reeving Six-Sheave Blocks.

After the purchases have been rove, the traveling blocks are moved to their initial operating position. Because of the system weights and relative inertias, it is unwise and dangerous simply to attach a wire and start hauling the traveling block. The block must be moved slowly under positive control. On a land-based system, a crawler crane, large fork lift or bulldozer can tow the block into place. On a salvage barge, where vehicles are impractical, Navy standard beach gear purchases are used as overhauling tackle.

The deck area, over which the purchase operates, must be clean and free of trash that can foul the purchase or damage the purchase wires. In a shore-based system, a plank or plate skidway may be desirable.

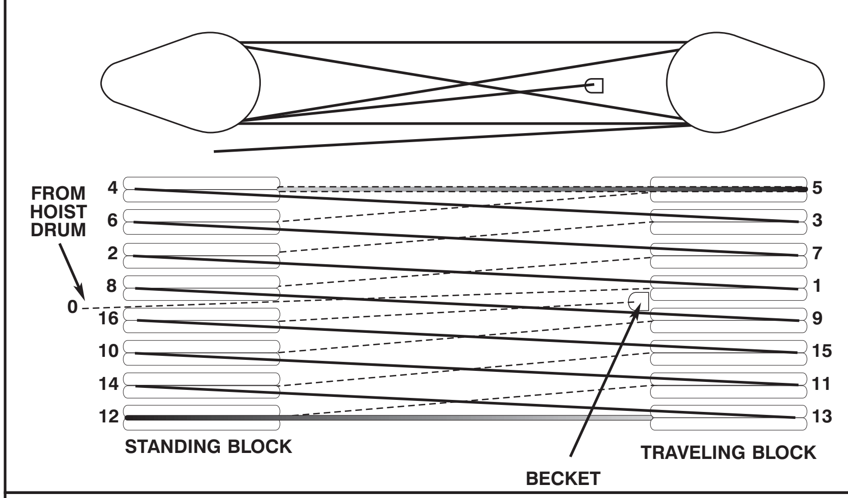


Figure 11-7. Reeving Eight-Sheave Blocks.

11-3.5 Fleet Length. The total scope, or fleet length, of a heavy purchase system depends upon several factors, including:

- The storage and handling capacity of the winches
- The distance the vessel must be lifted or hauled
- The space available for rigging.

For heavy purchases powered by large diesel winches, the primary limit on tackle fleet length is usually winch drum capacity. Fleet length can be calculated by dividing the drum capacity by the number of parts in the purchase and adding two.

11-3.6 Continuous Fleet System. When the winch drums will not hold the entire length of purchase wire, a long fleet is required; when no part of the load can be slacked, a continuous fleet system may be used. The full length of the purchase wire is rove into the purchase, and the winches run until their drums are full. When the winch drums are full:

a. Heaving stops, and the wires are stoppered off under load one at a time with Carpenter stoppers.

b. The purchase wire is slacked until the load comes on the Carpenter stopper.

c. The wire is cut.

d. The remaining wire is spooled off the drum and stowed.

e. The end of the wire remaining on the purchase is resecured to the drum, six or eight wraps taken, the load is taken, and the stopper is released.

When the operation is completed on all purchases, heaving begins again.

Continuous fleet systems are seldom used on barges, but are often advantageous in shore-based systems.

Other factors that affect the planning and operation of large purchase tackle systems in shore-based and afloat heavy lifting and hauling are discussed in Chapter 8.

11-4 PURCHASE CONNECTION SYSTEMS.

The method of connecting the traveling block to the hauling or lifting wire depends upon the size of the wire and the nature of the load being handled. The traveling blocks of Navy standard beach gear purchases are connected to lifting or pulling wires by either:

- Carpenter stoppers passed onto the lifting or hauling wire as shown in Figure 11-1
- Plate or safety shackles connected to socketed or swaged eyes in the pulling or lifting wires.

These connecting systems are safe, suitable, and practical for loads of up to 75 tons per purchase system. Beyond 75-ton loads and 2½-inch wire diameter, there are no U.S. Navy-approved Carpenter stoppers in production.

Larger and more powerful purchase systems require a high degree of safety and reliability in the connection between the traveling blocks and the hauling or lifting wires. Shore-based purchase systems for parbuckling are usually deployed from fixed anchorages or deadmen. The distance from the pulling point on the hull to the fully fleeted traveling block is known with reasonable accuracy. Hauling wires may be cut to these lengths. Wires of up to 3½-inch diameter can be fitted with thimbles, sockets or swaged eyes for attachment to the traveling block. The connection between blocks and pendant wires is made with:

- Large plate shackles, specially designed and built for the purpose
- Open sockets, with an appropriate bolt to suit the end beckets or adaptor plates of the blocks
- Heavy-duty safety anchor shackles.

NOTE

The use of wire rope clips to form eyes in heavy pulling wires is not recommended. There is usually enough time available to have all wire ends fitted with swaged, socketed or spliced end fittings.

Salvage heavy lifting operations with large purchase systems frequently involve a series of lifts with comparatively long main lifting wires. For both efficiency and economy, heavy lift wires do not usually have hard eyes at both ends. A wire is normally issued with a hard or soft eye at one end and a plain or tapered finish at the other end. Alternatively, the wire may be supplied without a termination. Where wires for heavy purchase tackles have been supplied with plain ends, a special multi-bolt, split-shell wire rope clamp is fitted on the wire to make a temporary eye in the wire. These large multi-bolt clamps are Bullivant clamps. They are manufactured to fit 2½-, 2¾- and 3-inch diameter wire rope. Figure 11-8 shows a Bullivant clamp for 2¾-inch diameter wire. They have been used since the U.S. Navy leased YMLCs in the mid-1960s. Subsequently, they were used in lift operations during the Suez clearance, and in other improvised lift barge operations.

A Bullivant clamp consists of two cast steel shells that are joined with eight bolts, each approximately 14 inches long and 1¾ inches in diameter. Clamps for 2¾-inch wire are 24 inches long. Bullivant clamps have 8 bolts, 16 washers, and 8 hexagonal head nuts with approximately a dozen spacing washers per bolt. The hexagonal heads of the bolts draw hard up into a shaped recess that has two sides cast to take the hexagonal heads of the bolts and prevent them from turning when the nuts are being run up. To secure two parts of a wire, or secure two wires together:

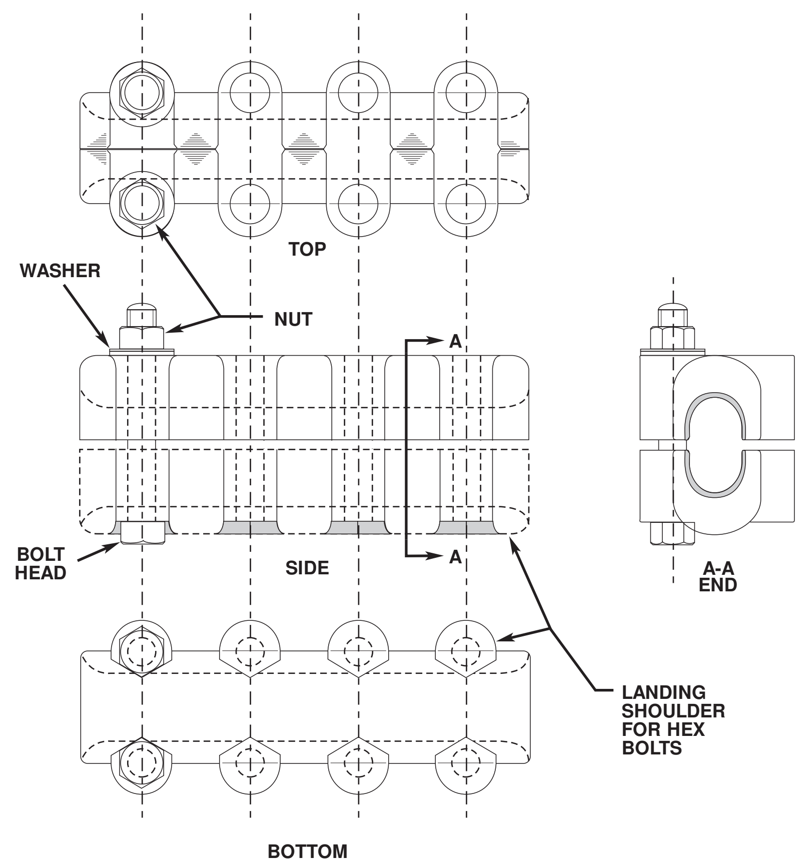


Figure 11-8. Bullivant Clamp.

a. The two sections of wire are frapped together, and the shells of the Bullivant clamp laid adjacent to the wires.

b. The eight bolts are fitted through the bottom section of the clamp. This section is then moved under the two wires so that the wires lie between the two rows of bolts.

c. The inside of the clamp is covered with rope yarns, preferably unlaid manila.

d. The clamp is wedged up against the low wire, more yarns are placed on the wires, and the top shell of the clamp is fitted onto the bolts.

e. The nuts are run up with an impact wrench, adding spacer washers as appropriate, until the wires are clamped tightly together. Bullivant clamps are normally applied in pairs.

Although heavy and cumbersome, Bullivant clamps are very strong, do little or no damage to the wires, and hold to the breaking strength of the wire. Figure 11-9 illustrates the sequence of fitting and bolting up Bullivant clamps. Bullivant clamps can be obtained through the Supervisor of Salvage or the Bullivant Division of Australian Wire Industries PTY LTD, NSW, Australia.

To avoid crimping or nipping large-diameter wires made up with temporary eyes, it is normal rigging practice to bend the temporary eye around a steel deadeye plate. Figure 11-10 shows a deadeye plate incorporated in the eye of a 3-inch diameter lift wire made up to a six-sheave block.

Larger, semi-permanent deck purchase tackles, installed on some salvage sheer legs and the YHLC Class lifting ships, have modified deadeyes. These deadeyes incorporate the traveling block sheaves in their construction. The combined traveling block/ deadeye, illustrated in Figure 11-11, has provision for two 3-inch diameter lifting wires to be made up around the deadeyes.

11-5 LARGE HYDRAULIC LINEAR PULLERS.

The linear puller system for Navy standard beach gear, as described in Paragraph 8-5.1.1, exerts a pull of 50 short tons on 1⅝-inch diameter wire rope.

For greater pulling power, large hydraulic pullers are available from commercial sources. These pullers are manufactured on the same general principles as the Navy's linear pullers. Standard capacities of very large commercial hydraulic pullers are:

Pull Rating (Short Tons)	(Diameter)
100	2½-inch
150	3-inch
250	4 -inch

Machines with these outputs have applications in salvage heavy hauling and pulling. The working principles are the same as the Navy's machines.

Large hydraulic pullers have distinct advantages over conventional heavy purchase systems for salvage hauling and pulling. These advantages include:

- There is no loss of pulling force from the sheave friction of a purchase system.
- The pullers can be set up in a limited space because long fleets are not required.
- Heaving or pulling operations can proceed continuously without stopping to fleet out purchases.
- Puller controls can be centralized in one area, allowing precise control over each unit in the system.
- Fewer personnel are required to rig and operate pullers than purchase systems, reducing the need for skilled and experienced riggers.

The decision to use large hydraulic pullers on a salvage or harbor clearance hauling task is governed by several factors, including:

- Availability of sufficient numbers of compatible hydraulic pullers to do the job. Standardization of machine and wire characteristics is very important in large operations.
- Availability of suitable wire in adequate lengths to allow continuous feed to the pulling machines. Wire rope connections will not pass through pullers. Passing connections can create difficulties during parbuckling or uprighting operations, although rigging solutions may be found.
- Availability of enough space to install machine anchorages, pulling machines, wire take-up spools, and the prime movers.

Figure 11-12 gives the general characteristics of large hydraulic pulling machines.

Winches with pulling capacities of 100 to 200 tons may be used in lieu of pullers.

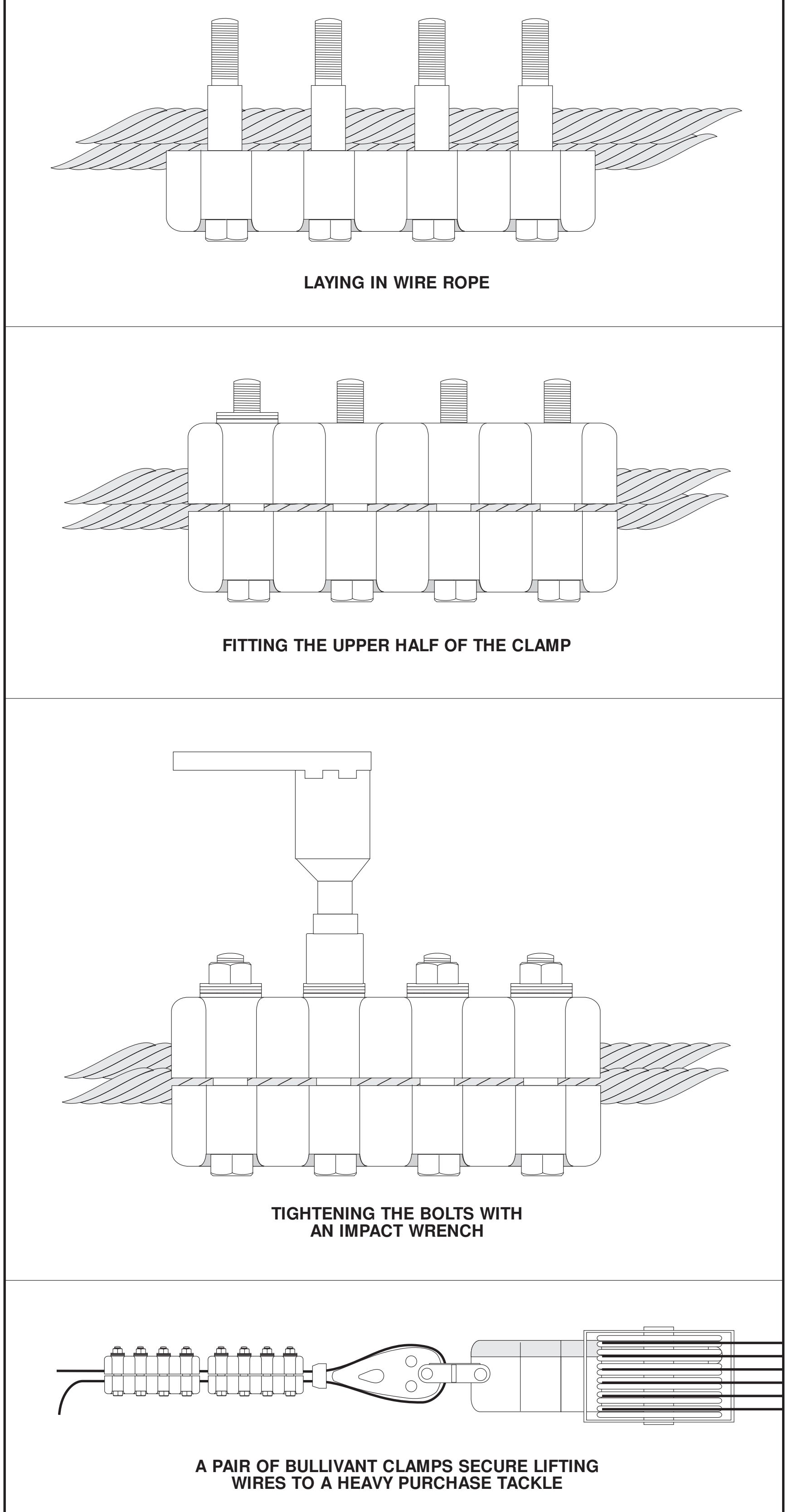


Figure 11-9. Fitting Up a Bullivant Clamp.

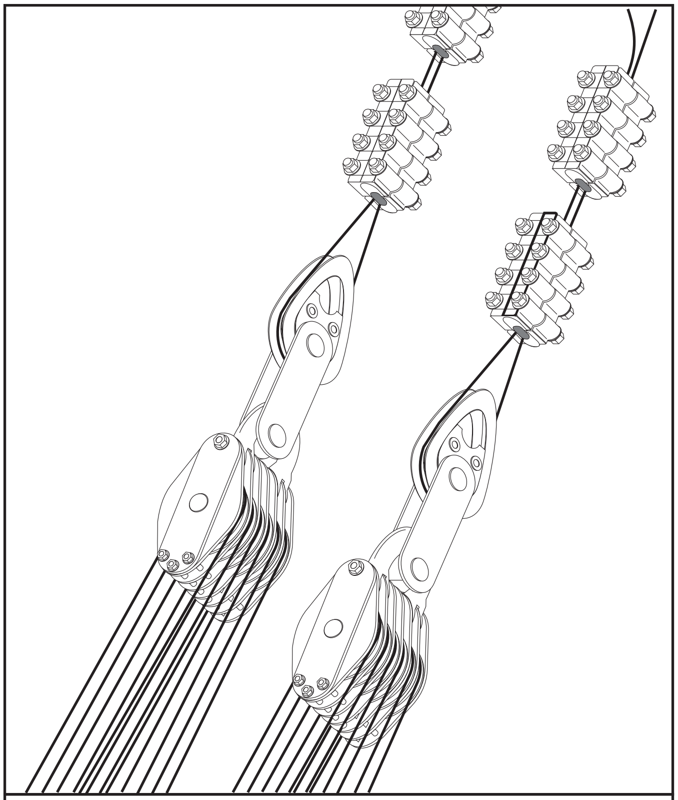


Figure 11-10. Lift Wires Made Up with Bullivant Clamps.

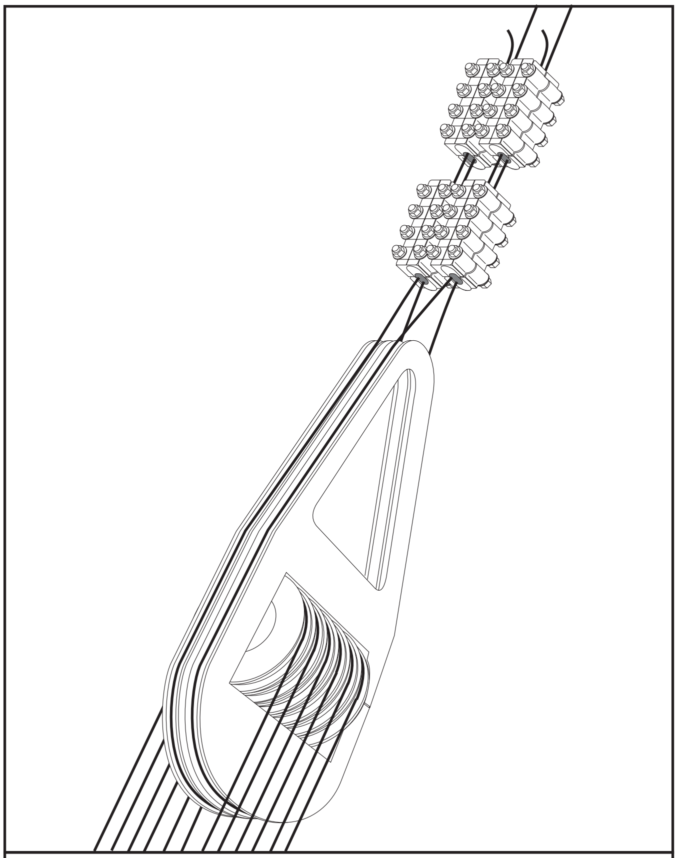
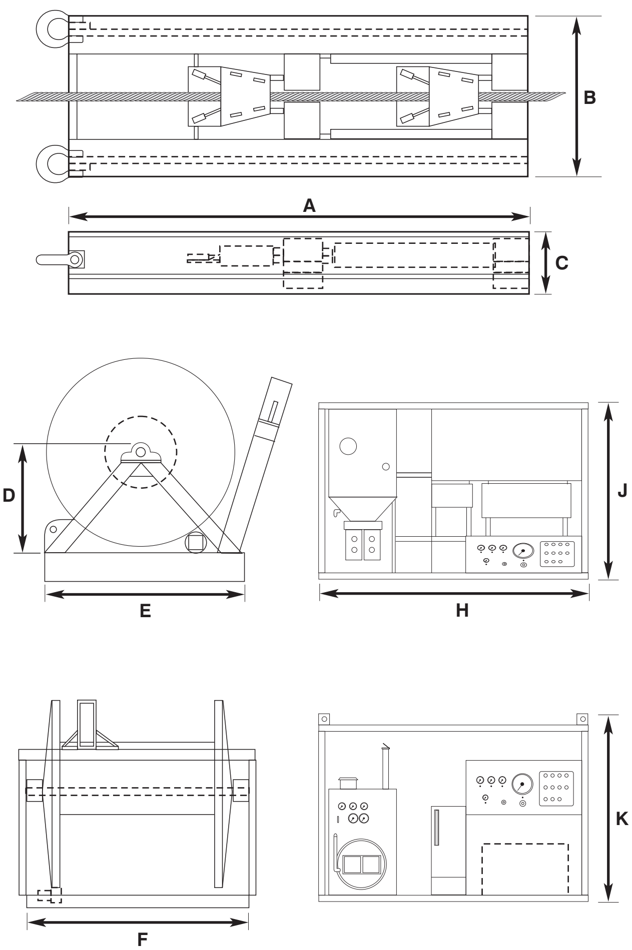


Figure 11-11. Combined Traveling Block and Deadeye.



MODEL	IPM 200	IPM 300	IPM 500
PULL IN POUNDS	200,000	300,000	500,000
NORMAL SPEED FPM	15	10	7
PULLER: DIMENSION A	17'	18'	19'
PULLER: DIMENSION B	66"	66"	90"
PULLER: DIMENSION C	24"	30"	30"
REEL UNIT: DIMENSION D	108"	108"	108"
REEL UNIT: DIMENSION E	96"	96"	96"
REEL UNIT: DIMENSION F	132"	132"	138"
WEIGHT OF PULLER	8,000 LBS	10,850 LBS	23,000 LBS
WEIGHT OF POWER UNIT	4,400 LBS	4,750 LBS	4,900 LBS
WEIGHT OF REEL UNIT	4,200 LBS	4,900 LBS	5,200 LBS
WIRE ROPE DIAMETER (SUGGESTED)	2-1/2"	3"	4"
ROPE LENGTH	3,300 FT	2,200 FT	2,000 FT
WEIGHT OF ROPE	38,280 LBS	36,520 LBS	59,200 LBS
LAY IN ROPE	YES	OPTIONAL	OPTIONAL
THREAD ROPE	YES	YES	YES
POWER UNIT: DIMENSION H	84"	96"	96"
POWER UNIT: DIMENSION J	72"	72"	84"
POWER UNIT: DIMENSION K	66"	66"	72"

Figure 11-12. Hydraulic Puller Characteristics.

11-6 SPECIAL WINCH SYSTEMS.

The offshore oilfield construction industry has developed special high-capacity line pull winches encased in truss structures to form transportable lifting or pulling packages. Frequently, a number of these units are mounted on large barges to lower oil field platform structures. The truss structures containing the winch system have a cantilevered design incorporating a special swiveling fairlead head to allow the winch to lead either horizontally or vertically. The diesel-driven hydraulic pump unit, hydraulic winch control units, and fairleads are usually mounted inside the truss structure. Winch packages may measure 75 feet long by 20 feet wide by 19 feet high, and weigh between 300 and 400 tons per unit.

Wires used with truss winches measure between 2⅞ inches and 3½ inches in diameter. The units have pull rating from 250 to 400 tons depending on wire size. The same factors governing the use of pullers govern the use of truss winches.

Figure 11-13 shows a typical truss winch and an arrangement for four truss winches on a salvage barge.

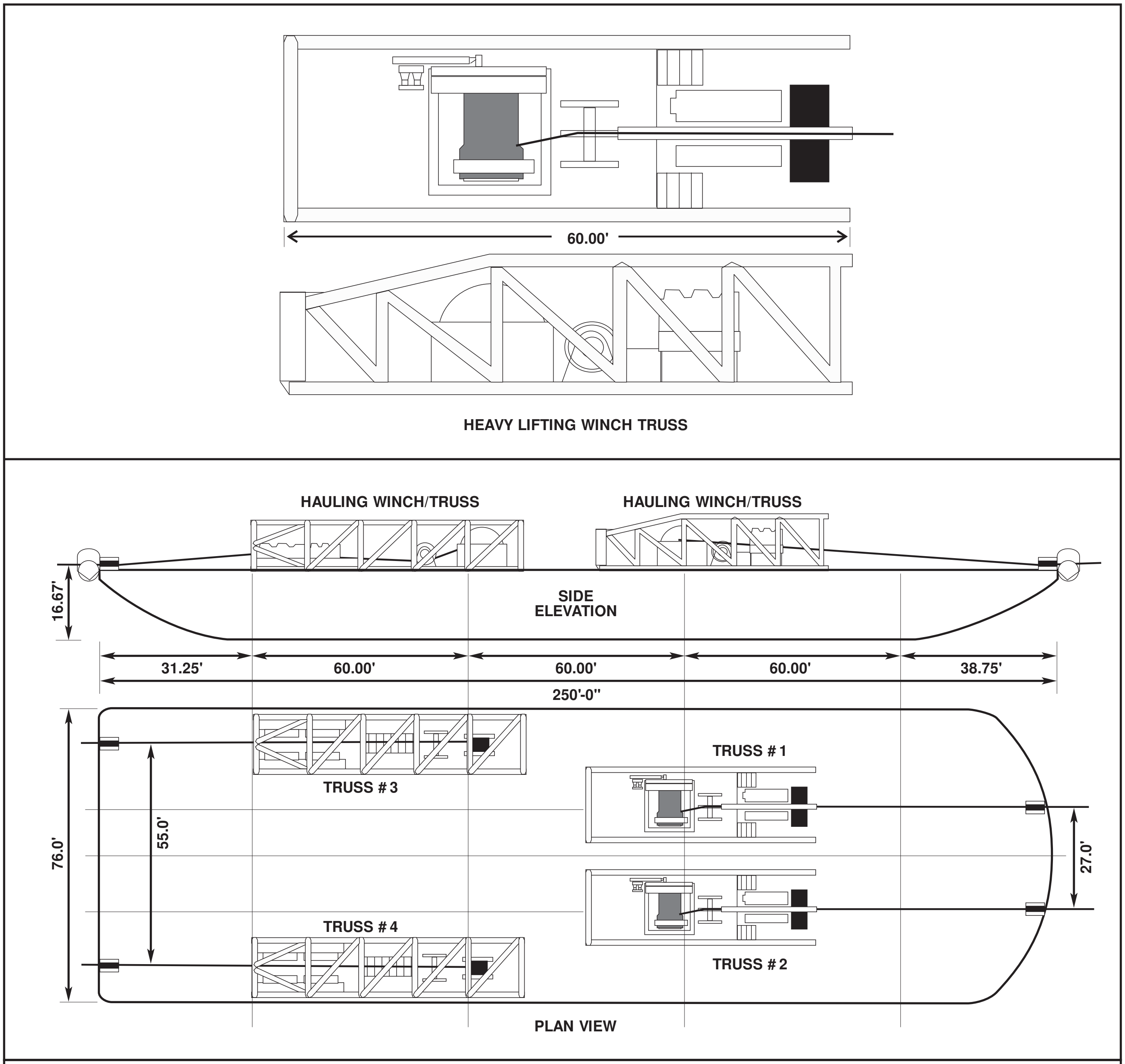


Figure 11-13. Truss Winches on a Salvage Barge.

11-7 DOUBLING SHEAVE SYSTEMS.

Pulling power in certain types of hauling operations is increased by between 50 and 75 percent if a doubling sheave or roller is rigged into the system. Doubling sheaves are rigged when there is not enough power available in the purchases or pulling machinery to do the job and to cope with contingencies. Doubling sheaves should not be used with Navy standard beach gear or lighter purchases hauling 1⅝-inch wire rope.

11-7.1 The Doubling System. In a doubling sheave system, the hauling wire's standing end is secured to an anchorage. The free end is taken to the sunken ship, fairled through a very heavy single-sheave block, and taken back and secured to the hauling gear. When the system is hauled, the force at the ship is nominally double that of the hauling force. The principle of a doubling sheave system is illustrated in Figure 11-14.

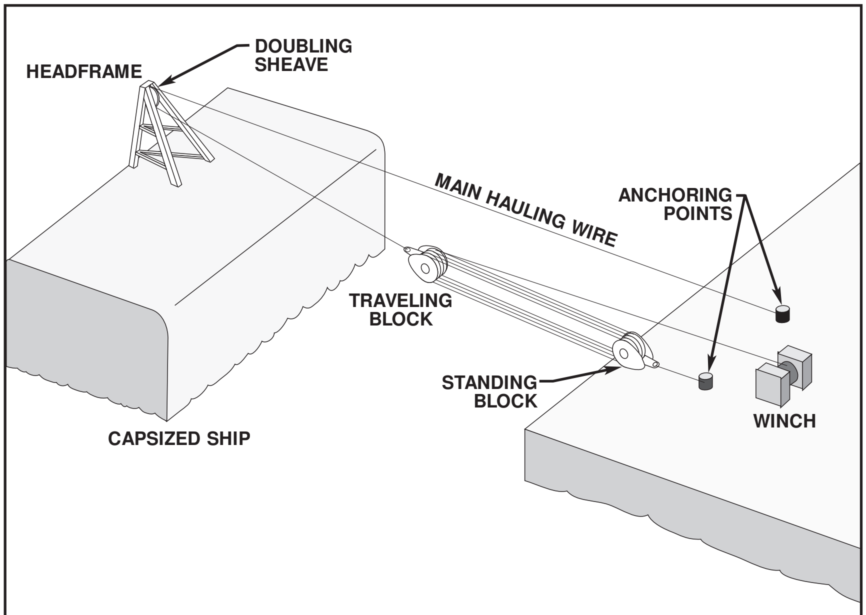


Figure 11-14. Parbuckling with Doubling Sheaves.

Doubling sheaves do not actually double the pulling power applied to the ship. The power increase is from 50 to 75 percent of the pull applied. Doubling sheaves are an application of a special type of purchase—the velocity purchase.

11-7.2 Utility of Doubling Sheave Systems. Doubling sheave systems produce an increase in power that is useful where:

- Not enough purchases, pullers, or large winches are available to develop all the power required and have enough margin for contingencies.
- Heavy wires long enough to rig the system are available.
- Large, heavy-duty, single-sheave blocks sized for the wire can be obtained easily.
- Arrangements can be made to avoid twisting of both parts of the hauling wire.
- Anchorages or deadmen of sufficient strength can be established without great cost in time, labor, material, and money.

11-7.3 Disadvantages of Doubling Sheave Systems. Practically, there are several disadvantages to doubling that must be balanced against the advantages:

- Hauling wires must be both larger and stronger than the 1⅝-inch wire of Navy standard beach gear.
- Anchorages must provide adequate securing points for both the pulling system and hauling wires.
- Additional strengthening may be required on board the ship to absorb the pulling loads.
- Special arrangements must be made to prevent the hauling wires from twisting and fouling under load.
- A rigorous engineering analysis of the entire system must be carried out to ensure acceptable safety standards are maintained.

11-7.4 Preventing Twisting. The tendency of the traveling blocks to twist under load causes a problem with doubling blocks. Twisting is amplified if the blocks are in the air when under load. Twisting can be prevented by:

- Connecting each pair of twisting blocks rigidly with a length of Schedule 80 or 120 pipe or railroad track
- Attaching a heavy weight rigidly to the becket of each traveling block; the weight hangs vertically below the block and counters the twisting moment.

11-8 WIRE TENSION CALCULATIONS.

11-8.1 Load Measurement. Accurate knowledge of the weights being lifted or the power being applied to a pulling wire is an essential engineering and safety requirement on salvage operations. The pulling force applied to Navy standard beach gear systems is measured by direct readout tensiometers that are available in hydraulic or electric types:

Offshore derrick barges, purpose-built salvage sheer legs, and most other specialized marine lifting vessels have remote-reading load cell or strain gage systems to give precise readouts of loads handled at the central lift control stations.

Large purchase or hydraulic pulling systems for specialized salvage, wreck removal, or harbor clearance operations must be fitted with load measurement systems. For most cases, suitable commercial strain gage, load cell or hydraulic tensiometers can be obtained at short notice or off-the-shelf. Load measuring systems are an integral part of heavy lift purchase or pulling system rigs. All measuring devices should be calibrated or load tested before installation.

Remote reading load gages should be installed at the central control position and at local operator stations.

11-8.2 Loads in Tidal Lifting. Salvors have traditionally had difficulty measuring lifting wire tension during tidal lifts. A detailed description of tidal lifting methods can be found in Chapter 12.

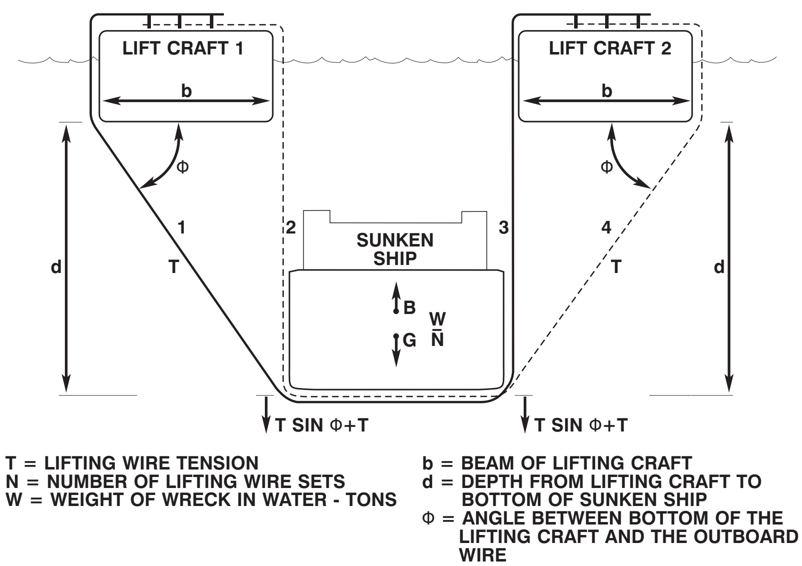


Figure 11-15. Lifting Wire Tension Sketch.

Figure 11-15 shows a typical lift configuration. Each wire is rigged from one lift craft under the wreck to the other lift craft. There is a pair of wires at each transverse location. Each pair of wires has four lifting parts. The total of the vertical components equals the wreck's weight in water. The wire tension may be calculated by:

$$T \text{ Sin } \Phi + T + T + T \text{ Sin } \Phi = \frac{W}{N}$$

$$2T \text{ Sin } \Phi + 2T = \frac{W}{N}$$

$$2T(\text{Sin } \Phi + 1) = \frac{W}{N}$$

or

$$T = \frac{W}{2N(1+\text{Sin } \Phi)}$$

where:

N = number of lift wire sets
W = weight of wreck in water
T = lift wire tension
Φ = angle between bottom of lift craft and the outboard wire

EXAMPLE 11-1

A sunken ship with a displacement (lifting weight) of 2,450 tons is to be raised with two tidal lifting craft. It is proposed to use 11 sets of lifting wires (22 wires). What is the tension in the lift wires, given:

Beam of Lift Craft *(b)*	= 36 feet
Maximum Depth of wreck at Low Water	= 25 feet
Maximum draft of Lift Craft	= 15 feet

Solving for wire tension *T*:

$$d = 25' - 15' = 10'$$

$$\frac{d}{b} = \frac{10}{36} = 0.278$$

From Figure 11-15: Φ = arctan (0.278) = 15.5 °

$$\frac{1}{2(1+\text{Sin } \Phi)} = 0.39$$

$$T = \frac{W(0.39)}{N}$$

$$T = \frac{2{,}450(0.390)}{11}$$

$$T = 87 \text{ tons}$$

The angle Φ has a tangent of *d/b*, where *b* is the beam of the lift craft, and *d* is the vertical distance between the bottom of the lift craft and the bottom of the object being lifted. In general, *d* is calculated by subtracting the lift craft maximum draft from the low water depth, because at the start of a lift, the lift craft are fully ballasted.

Soundings are taken to establish the low water depth when the lift craft are positioned adjacent to the sunken ship. Figure 11-16 is a plot of the *d/b* ratio and:

$$\frac{1}{\left(2(1+\text{Sin } \Phi)\right)}$$

The product of the quantity obtained from the curve and *W/N* is the tension in the wire.

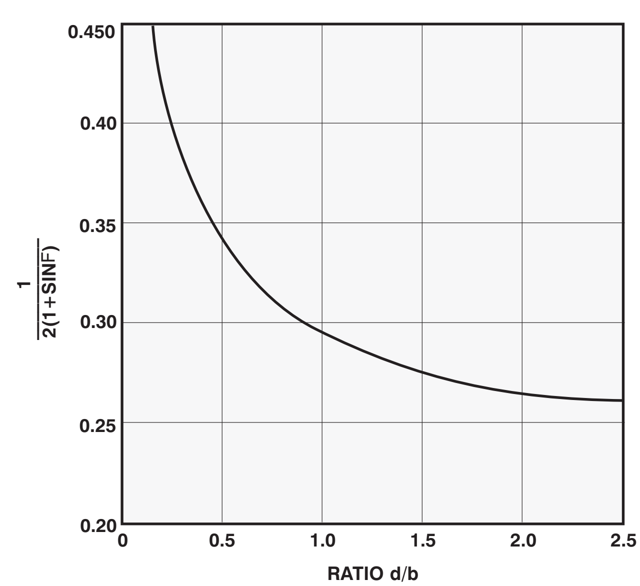


Figure 11-16. Wire Tension Factor.

11-9 PREVENTION OF DAMAGE BY LIFTING WIRES.

Accidental damage caused by lifting or pulling wires during the salvage of sunken ships, removal of wrecks, or lifting of sections is the bane of salvors' working lives. Typical examples of accidental damage are:

- Lifting wires cut or slice through bilge sections of the hull being lifted. Slicing usually occurs because the hull or bilge section is not strong enough to resist slicing stresses developed by lifting wires.
- Lifting wires fray, jam or are otherwise damaged on hull projections, or fail as a result of slicing into the hull.
- Lifting wires are rove through hull sections that do not have adequate strength to carry the weight of the lifts being attempted.
- Lifting sling arrangements are deficient, allowing the slings to set up cutting forces in the section being handled.

The possibility of lifting wire slicing, particularly at bilges, can be estimated with the empirical data presented in Table 11-1 and Figure 11-17. Table 11-1 lists the stress factor *K* for bilge radii from 6 to 24 inches, and hull plating thickness from ¼-inch to 1-inch. Figure 11-17 is a nomogram for the values of lift wire tension between 5 tons and 200 tons.

To estimate the possibility of bilge slicing occurring, with Table 11-1 and Figure 11-17:

a. Calculate the lift wire tension *T* by either the procedure described in Paragraph 11-8.2 or by taking direct readings from the hook, puller, or purchase readout gages.

b. Enter the *K* stress factor table with bilge radius and hull plating thickness to get *K*.

c. Draw a line connecting *K* and *T;* the estimated hull stress in way of each lifting wire is shown where the line crosses the Principal Stress line *Z*.

For a factor of safety of 1.5, the allowable stress for steel should be taken at 22,000 psi.

In many salvage and wreck removal situations, limitations imposed by the numbers of hooks or lifting slings requires that average hull yield stress be exceeded. Sling loads are spread over larger hull plating areas by bilge bolsters inserted between lifting wires and the hull. Bilge bolsters vary in size and sophistication from a series of lumber balks stapled together with wires to heavy, curved steel radius plates fitted with shaped wooden chocks on their inner faces.

EXAMPLE 11-2

For a tidal lift, the bilge radius is 21 inches, the plating thickness is ¾-inch and the lift wire tension 87 tons. What is the stress in the hull caused by the lift wires?

From Table 11-1 for bilge radius 21 inches and hull plate thickness ¾-inch: *K* = 56

On Figure 11-17, a line between *K*(56) and *T*(87) on the nomogram intersects Z at 10,000 psi, an acceptable stress for mild steel.

Table 11-1. Stress Factor *K* in^{-2} × 1,000.

r Bilge Radius (inches)	*h* Hull Plating Thickness (inches)						
	¼	⅜	½	⅝	¾	⅞	1
6	625	483	405	355	320	293	272
12	252	189	156	135	121	110	101
15	190	142	116	100	89	81	74
18	152	112	91	78	69	63	58
21	126	92	75	64	56	51	47
24	107	78	63	54	47	43	39

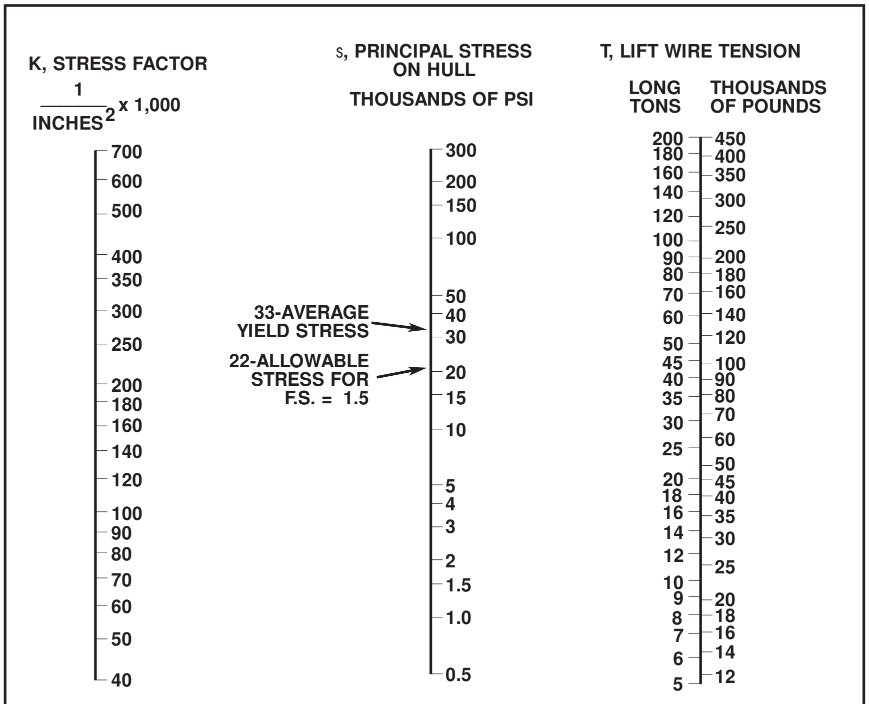


Figure 11-17. Hull Stress Nomogram.

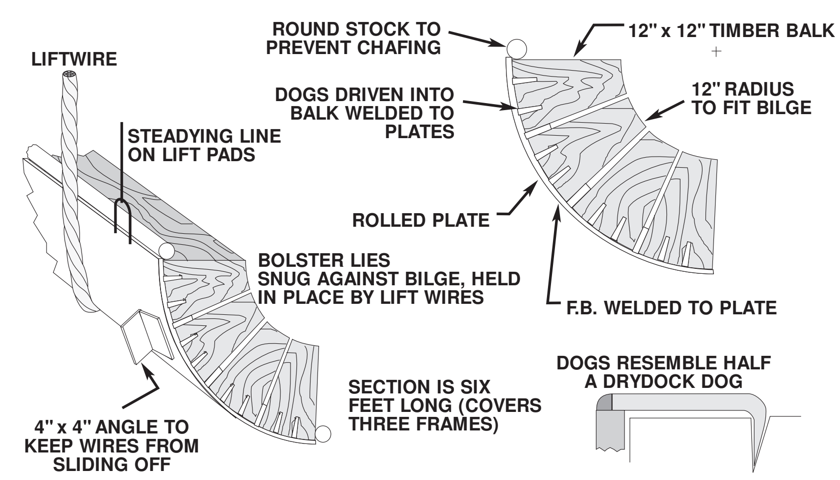


Figure 11-18A. Bilge Bolster.

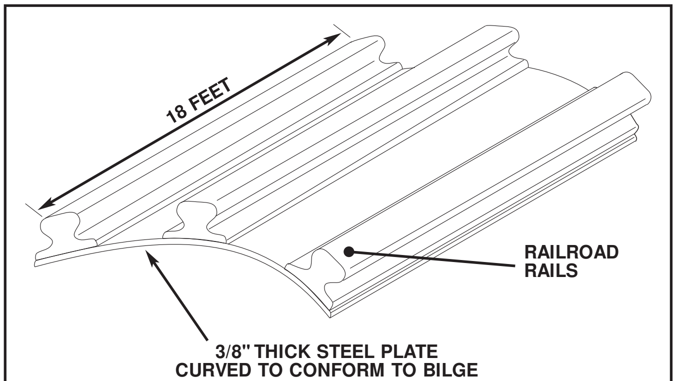


Figure 11-18B. Bilge Bolster.

Figure 11-18A shows a bilge bolster with a series of roughly shaped 12×12-inch timbers. This type of bolster is made from plate of between ½-inch and 1-inch thickness, rolled to a radius that varies between 24 and 36 inches, depending upon the chine configuration of the vessel being lifted. Figure 11-18B shows a field-fabricated bilge bolster, with a series of railroad rails welded to a curved steel plate—not artistic, but effective and suitable for the purpose. As this volume of the Salvage Manual stresses, intelligent on-site improvisation is a desirable salvage virtue.

11-10 PASSING LIFT WIRES AND CHAINS.

Passing lift wires and chains under sunken ships can be the single most difficult and time-consuming part of an underwater lifting operation. Passing wires may become a crucial and delaying phase of the work, particularly when tidal currents or depth limit the work that can be done by divers. Over the years, several techniques have been developed to overcome difficulties and simplify the process of passing the lift wires. These techniques include:

- Direct reeving
- Sweeping and sawing
- Lancing
- Tunneling
- Profile dredging.

After the number and spacing of lift wires has been determined, one or more of these methods may be used to pass the lift wires. The choice of method depends upon the particular circumstances of the casualty, specifically:

- The nature of the seafloor under the sunken ship (mud, sand, coral, rock, etc.)
- The attitude of the sunken ship (upright, heavily listed, capsized)
- Subsidence into the seafloor
- Proximity of other objects, such as wrecks, piers and structures to the sunken ship
- Direction and velocity of tidal currents in the working area
- Number and configuration of lift wires.

NOTE

In the following paragraphs, "messenger wire" or "messenger" refer to a moderately heavy wire rope capable of withstanding abrasion and rough handling. In salvage and harbor clearance operations, there are distinct types of messengers. The light messenger, or pilot wire, may be a ¾-inch wire rope. The working messenger should be approximately one-half the diameter of the main lift wire.

11-10.1 Direct Reeving.

Direct reeving means rigging lift wires or chains through existing openings in the sunken ship or through areas where the ship's bottom is clear of the seafloor.

Typical direct reeving points are hawses and stern apertures. Both these points are used for rigging mechanical lifts of smaller ships and for lift control points when buoyancy restoration is the primary means of refloating. Lift wires can be rove directly underneath the sunken ship where gaps between the seafloor and hull have left suitable passages or tunnels for messengers. Figure 11-19 shows lift wires and chains rigged on a sunken ship through the hawse, stern aperture, and through a passage under the ship.

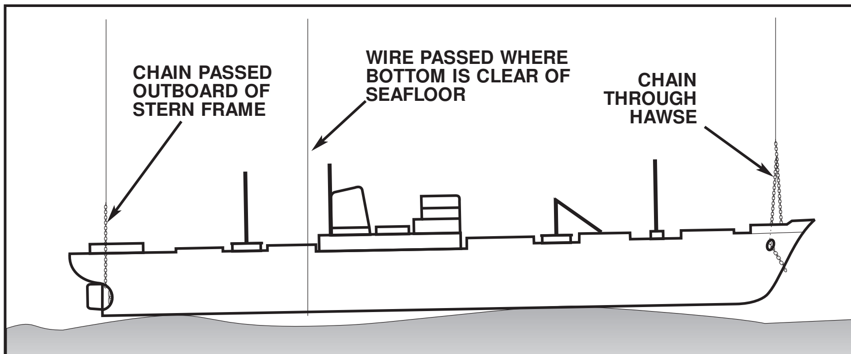


Figure 11-19. Directly Rove Lift Wires and Chains.

Cranes, bridges, and other sunken structures often encountered in harbor clearance operations are frequently directly rove. The open lattice and chord construction, and the inherent strength of crane and bridge sections, make them especially suitable for this method.

A direct reeving method used in piecemeal demolition of wrecks is to cut lifting holes in the shell or deck several frame spaces apart and to pass lifting chains through them as shown in Figure 11-20. It is very important to pass the chain around several structure members; when lift forces are applied, the chain will tear through the shell plating.

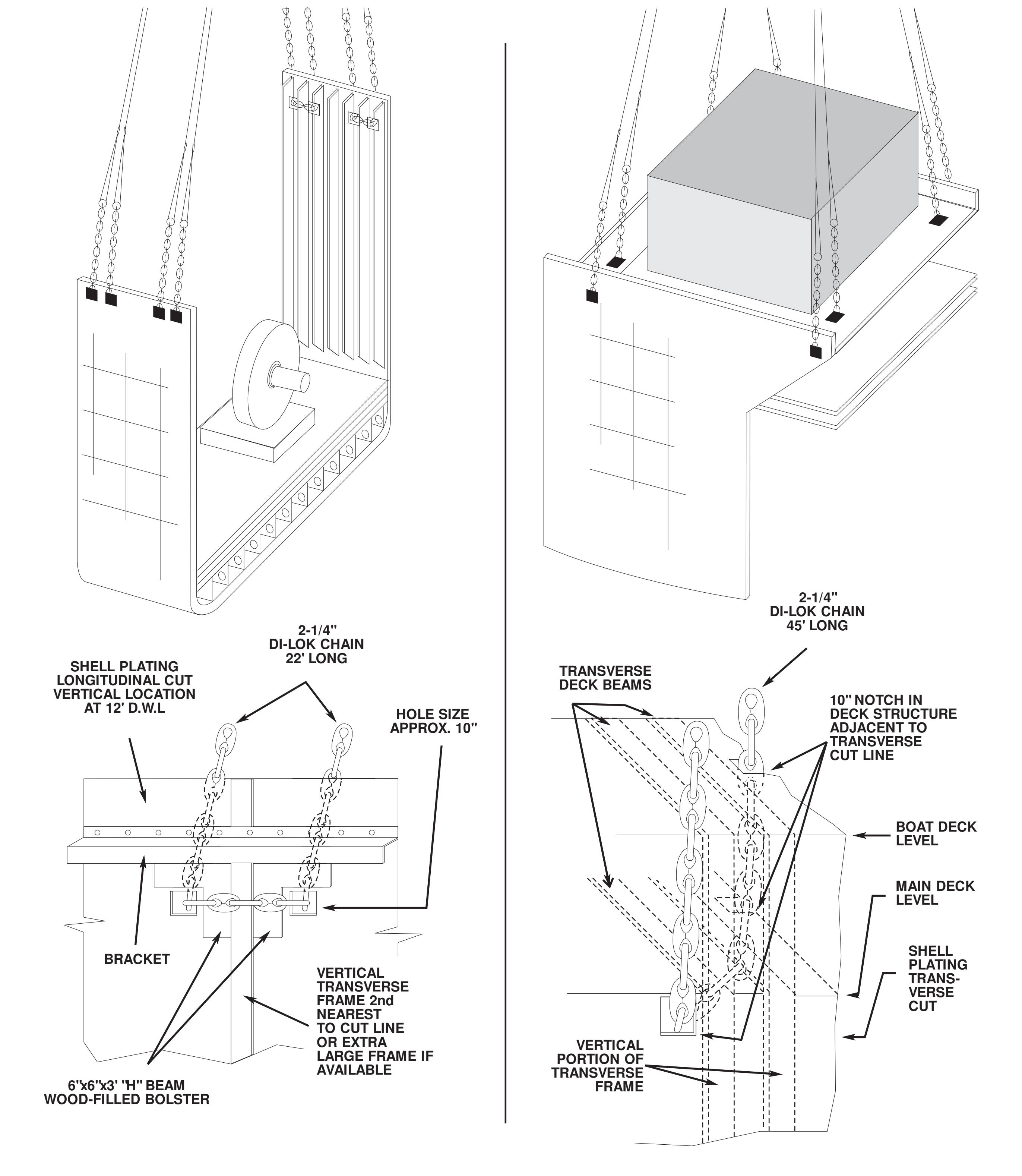


Figure 11-20. Chains Directly Rove Through Cut Holes.

In harbor clearance operations, it may be necessary to cut holes and rig lift chains into the plating of small sunken ships or wrecks to be moved urgently.

The method should be restricted to small vessels unless other lifting methods are available to keep loads on individual lifting points low. Even with the load well-distributed, there is a risk that shell or deck plating may tear or fracture because of uneven load sharing.

Chains are rigged through holes cut in plating. Rough-cut plate edges will cut wire rope. The chain pigtails are, in effect, static chain slings that will not be damaged seriously by the sharp edges of the lifting access holes.

Direct reeving is a simple and rapid method of passing a lift wire or chain. Usually, a diver can haul a pilot wire to the lift wire or chain and shackle them together. The lift wire or chain is hauled through with the pilot wire without a working messenger.

11-10.2 Sweeping and Sawing. Sweeping is a method of passing lift wires in which working messenger wires are dragged or swept underneath the sunken ship by towing or winching with surface vessels. For sweeping operations to be successful, the following conditions are necessary:

- The seafloor is relatively soft material, such as mud, sand, or shingle.
- There is no extensive damage to the sunken ship that will foul the sweep.
- The sunken ship is reasonably upright, with either its bow or stern clear of the seafloor.

There are two conventional sequences of sweeping wires under a sunken ship. Both begin after divers have marked the bow and stern of the sunken ship with conspicuous reference buoys.

11-10.2.1 Method 1. The steps in Method 1 are:

a. The bight of a working messenger wire is passed under the end of the ship that is clear of the seafloor.

b. Each free end of the messenger is secured to a small, powerful tug or workboat positioned on either side of the sunken ship.

c. The towing vessels shackle another wire to the messenger to allow a good bight or catenary before towing the wire at full power under the ship.

d. Both vessels tow until they come to a screaming halt. They then begin to seesaw the messenger by going ahead alternately.

e. The process is repeated with each successive messenger until all the working messengers are in position at the lifting stations.

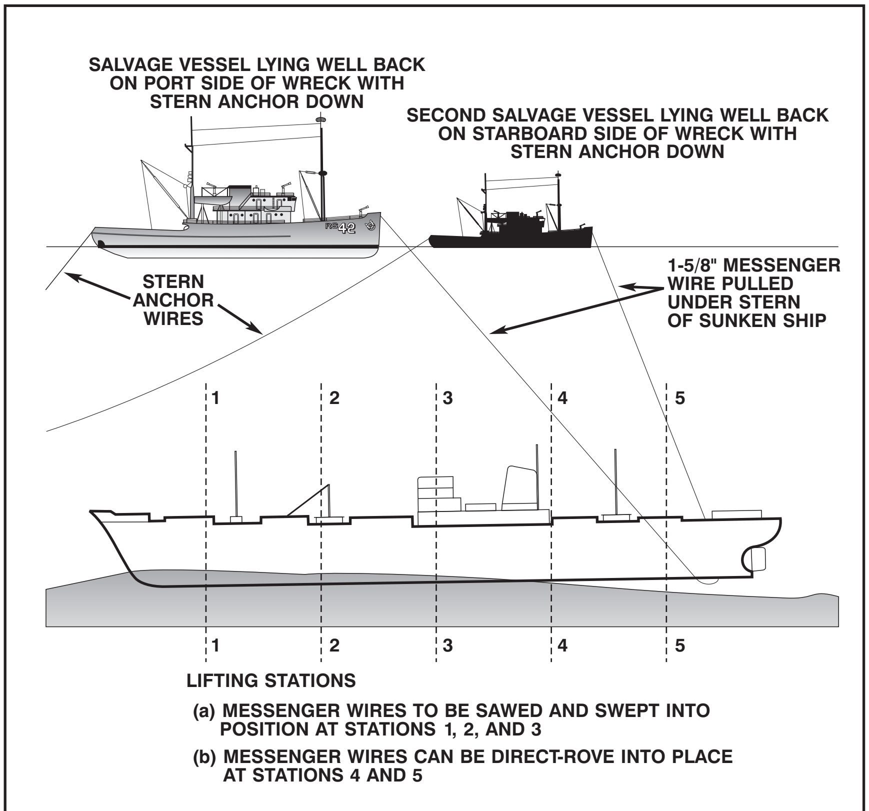


Figure 11-21. Sawing Wires with Salvage Ships.

11-10.2.2 Method 2. The steps in Method 2 are:

a. Two salvage vessels moor, one on each side of the sunken ship, lying well away from and at a broad angle to the casualty.

b. A light messenger is passed between the two vessels and positioned under the accessible end of the sunken ship by divers.

c. A working messenger, usually incorporating one or two shots of 2¼-inch chain at its mid-length, is then passed under the sunken ship.

d. The two salvage vessels alternately heave and slack the messenger, working the chain along the sunken ship in a sawing action.

e. When the working messenger is in the final position, one ship shackles a new working messenger to it. This messenger acts as the messenger for the lift wire. It is very important that the messenger used for sweeping not be used for passing the lift wire, as sweeping damages it so it no longer has its full strength.

f. The second vessel hauls the complete working messenger on board, and in the process, passes the lift wire messenger. Figure 11-21 illustrates sawing wires with salvage vessels.

11-10.3 Tunneling and Lancing. When lift wires or chains cannot be directly rove or swept under a sunken vessel, it is necessary to dig a tunnel through which to pass messenger wires. Where tunnels are washed or jetted through hard clay or mud, a reaction nozzle with balancing jets enables divers to control the system. Figure 11-22 shows such a nozzle. When there is a danger of tunnels collapsing on divers, it is sometimes practical to push a self-propelled lance underneath the hull of the sunken ship.

Tunneling underneath sunken ships is not simply a matter of sending a diver down to the seafloor with a hose and reaction nozzle. On rare occasions, divers may encounter favorable soil structure and current conditions that allow them to:

- Jet in their initial access point or tunnel sump, from which a tunnel is driven underneath the sunken ship
- Jet a tunnel underneath the ship through which messenger wires can be passed.

Unfortunately, in the unforgiving and ordinarily uncooperative real world of salvage, these ideal conditions seldom occur. Divers find their work is often frustrated and much-delayed by collapsing and siltation of the access shaft. Their efforts are directed as much at maintaining their access shaft as at actually excavating a tunnel underneath the sunken ship. When poor conditions are suspected, it is prudent to plan for the worst from the outset and attack the tunneling operations in a systematic manner. The steps in a tunneling operation are:

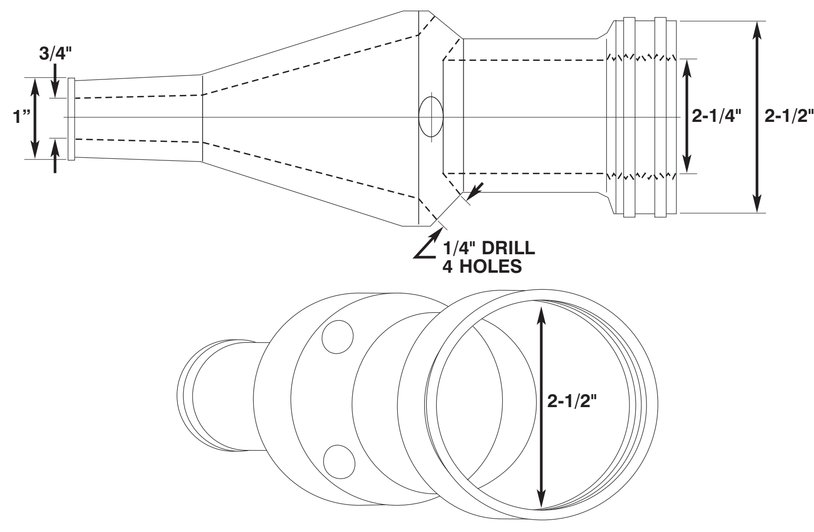


Figure 11-22. Jetting Nozzle.

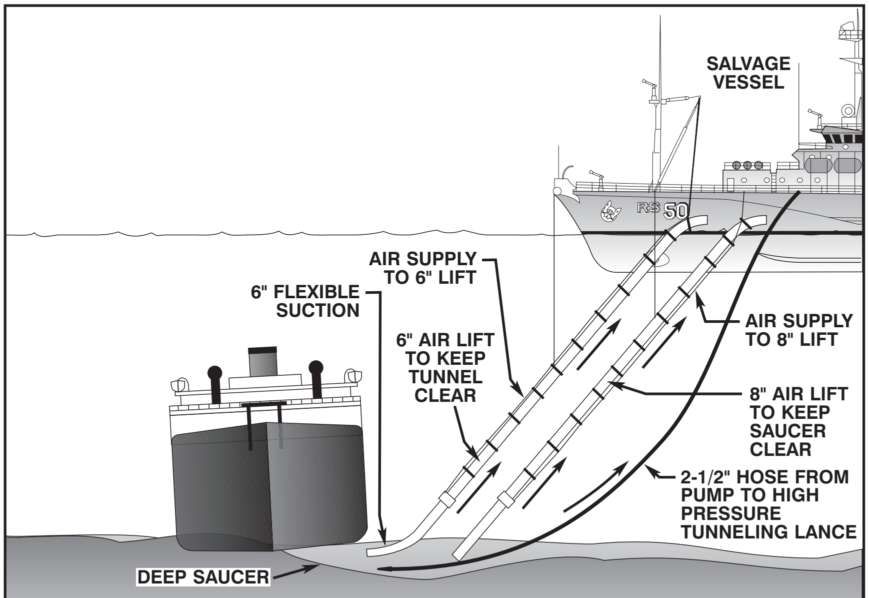


Figure 11-23. Tunneling to Pass Lift Wires.

a. Excavate a well or deep saucer alongside the sunken ship with a reaction nozzle to cut away the seafloor and a pump or airlift to take away the excavated silt. The width and depth of the saucer and the slope of its sides depends upon the seafloor material. In hardpan or clay, the sides can be relatively steep and the width of the saucer much less than in mud or sand. The saucer, or well, is dug to about 7 feet below the mean bottom line of the sunken ship.

b. When the saucer excavation is complete, a working face is made on the side next to the sunken ship, and tunneling operations begin. In soft material, a reaction nozzle washes away material without much trouble; in hard ground, a mining technique should be adopted. The tunnel face is cut away first to undermine the remainder, which then breaks down into the cavity created by the undermining. Correct slope on tunnel walls must be maintained to avoid slippage of the sides.

c. All soils washed out of the tunneling area are fed to a diver-tended pump or airlift suction operating continuously in the saucer area. This procedure keeps the work area free of soil and silt buildup and expedites work by the diver.

d. Tunnels are driven through directly underneath the sunken ship using the ship's bottom plating as a tunnel roof and guide for the excavation. By forming the tunnel roof with the bottom plating, risks of tunnel cave-ins are reduced.

e. As tunneling progresses, a second pump suction hose or airlift in the tunnel assists with removing excavated material.

f. Where the seafloor is reasonably soft, it may not be necessary to drive the tunnel right through to the far side of the wreck. Sometimes, the last 10 to 12 feet can be penetrated by a reaction nozzle screwed to several short lengths of steel pipe. This jet digs its way through the last few feet to clear the far side of the wreck. An air hose is clamped to the steel pipe and compressed air is blasted through the pipe.

g. A diver on the wreck's far side can locate these air bubbles easily, and jet or airlift a sump to dig out the reaction nozzle. The diver can pull the reaction nozzle through and remove the pilot wire. With the pilot wire in hand, the process of passing messenger wires can begin.

Figure 11-23 shows the general principles of this method.

11-10.4 Tunneling Lances. As was done during the SQUALUS salvage, it may be more practical to pass a messenger wire with a tunneling lance than to excavate a conventional tunnel under the sunken ship. Figure 11-24 shows the basic principle of tunneling lances. Figure 11-25 shows the general sequence of a lancing operation. Tunneling lances consist of several pipe sections joined together as the reaction nozzle works its way underneath or around the sunken ship. The number and length of pipe sections making up a tunneling lance depends upon the distance to be traversed to pass the first messenger. It is difficult to lay down specific procedures for any tunneling lance operation, because a system that works efficiently at the bow of a sunken ship may require total reorganization to work effectively at the stern. Basic components of a tunneling lance are:

- A high-pressure jetting pump with a length of hose to deliver water to divers operating the lance
- A reaction nozzle screwed to the first, or leader, pipe section of the lance
- A series of extension pipes fitted with threaded couplings
- A small-diameter messenger wire that is spliced or shackled to the outside of the leading pipe section.

Divers guide the reaction nozzle and leading pipe section into position, then apply jetting pressure. Divers push or steady the leading pipe into the tunnel made by reaction jetting. When the leading pipe is fully entered, water jetting stops and divers disconnect the jetting hose from the leading pipe coupling. They screw another section of tunneling lance pipe onto the leader pipe, and connect a jetting hose to the extension's outboard end. Jetting operations resume, with divers adding extensions as the lance progresses. After the lance clears the far side of the ship, divers remove the reaction nozzle to gain access to the messenger wire.

NOTE

Passing messenger wires with tunneling lances is not always a straightforward matter. To some extent, divers manipulating the lance are operating blind. They cannot see obstructions, hull damage or seafloor features that the lance may encounter as it passes underneath the hull. Some measure of luck and a generous amount of patience are required during a lancing operation.

11-10.5 Dredging. The Army Corps of Engineers is the DoD resident expert on dredging. USACE operates dredges and has contracts with commercial dredgers.

Under some circumstances, a floating, portable suction cutter dredge is the most efficient and fastest method of tunneling underneath sunken ships. Dredging to cut profile trenches and other

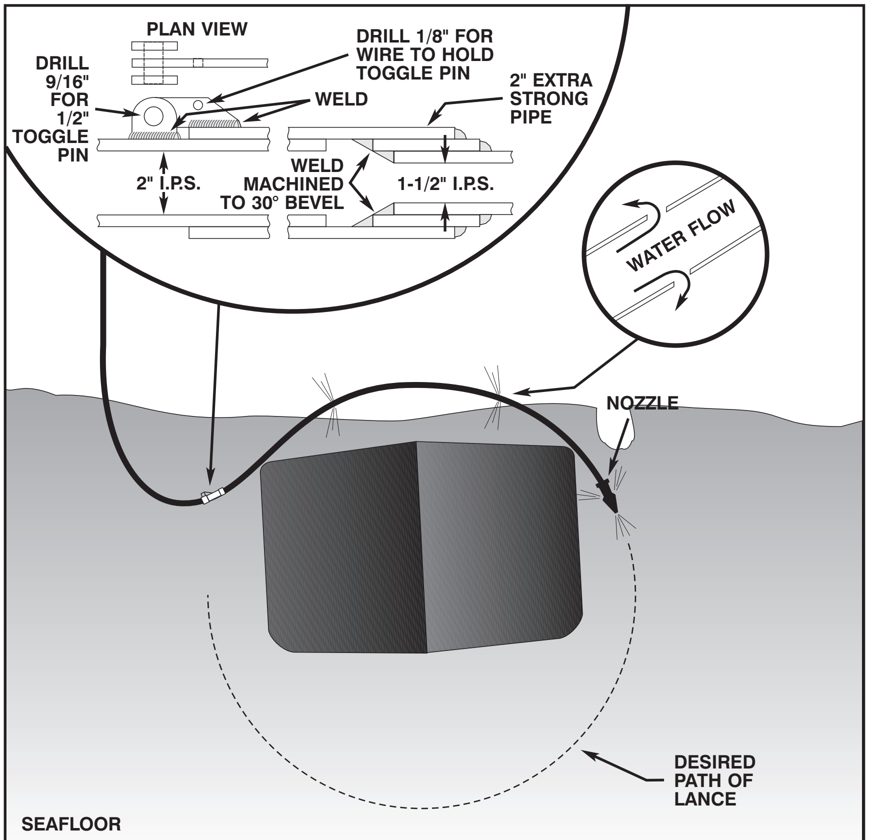


Figure 11-24. Tunneling Lance Operations.

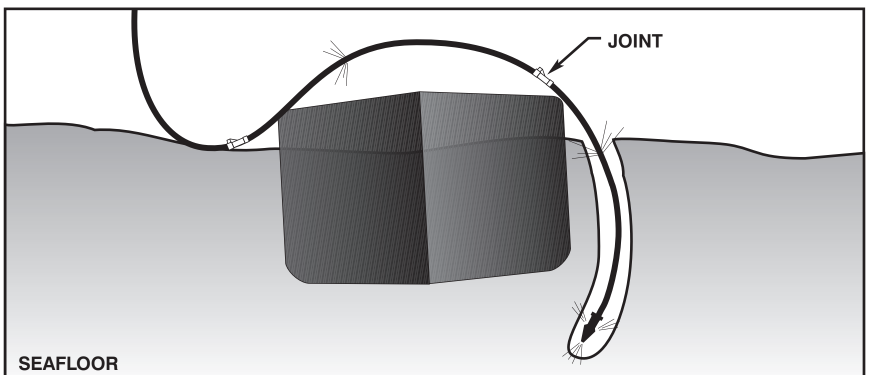


Figure 11-25A. Tunneling Lance Operations.

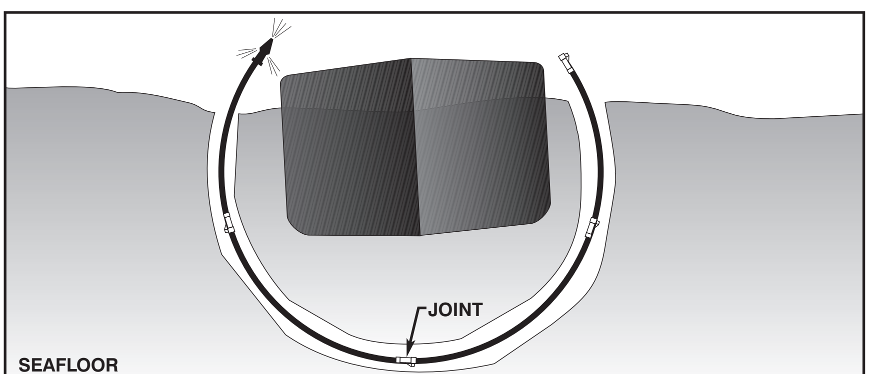


Figure 11-25B. Tunneling Lance Operations.

narrow defiles has considerable value for some salvage operations. Salvors have used dredges to cut and excavate lift and pulling wire tunnels on many occasions; the method should not be ignored if suitable dredging equipment is available.

11-10.6 Passing Lifting Wires. After messenger wires are passed through their tunnels, main lifting wires are pulled under the ship. There are three common methods of passing main lifting wires:

- A single main lift wire is shackled to the messenger wire with a Baldt pear-shaped detachable link as shown in Figure 11-26.
- A single heavy messenger wire is shackled to a triangular reeving plate (flounder plate). Two main lifting wires are connected to the reeving plate's trailing edge. The reeving plate is hauled through the tunnel previously driven under the sunken ship. Although in theory, both main lift wires should come through in their correct relative positions, there is a tendency for the main wires to twist once or twice about each other. Figure 11-27A shows this arrangement. Figure 11-27B shows an alternative system that has a triangular plate fitted with three trailing lugs.
- A reduced or passing eye is spliced into the main lifting wire, and the messenger wire is spliced into the reduced eye.

The sequence of making a reduced eye in a 3-inch diameter lifting wire, shown in Figure 11-28, is:

a. The wire is seized at a point from the end equal to forty-five times its circumference, plus the length of the eye.

b. Three alternate strands are unlaid leaving the other three strands standing as a three-stranded rope.

c. The core is cut out, and another seizing secured on the three standing strands at point 2.

d. The three-stranded rope is unstranded back to seizing 2.

e. The wire is bent into an eye and three strands married into the three unlaid strands on the main wire.

f. A seizing is secured on this marry at point 3, and a fourth seizing placed below 3 at point 4.

g. Seizing No. 1 is cut off and removed, and the splice proceeds as if it were a long splice. Each strand from the wire's eye follows down one of the three stands originally unlaid for distances of 36, 24, and 12 times the wire's circumference.

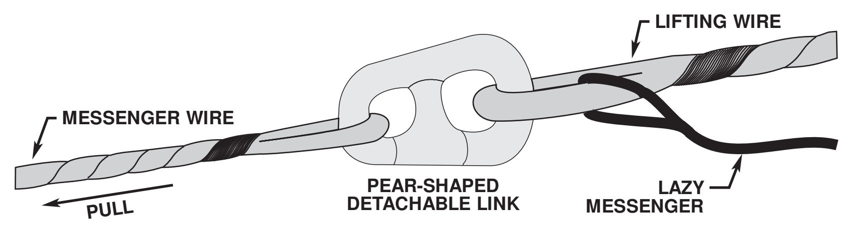


Figure 11-26. Wire Messengers Connected with Detachable Link.

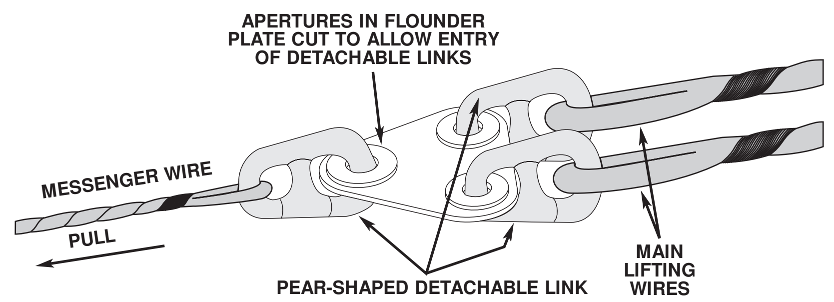


Figure 11-27A. Wire Rigged to Flounder Plate for Passing.

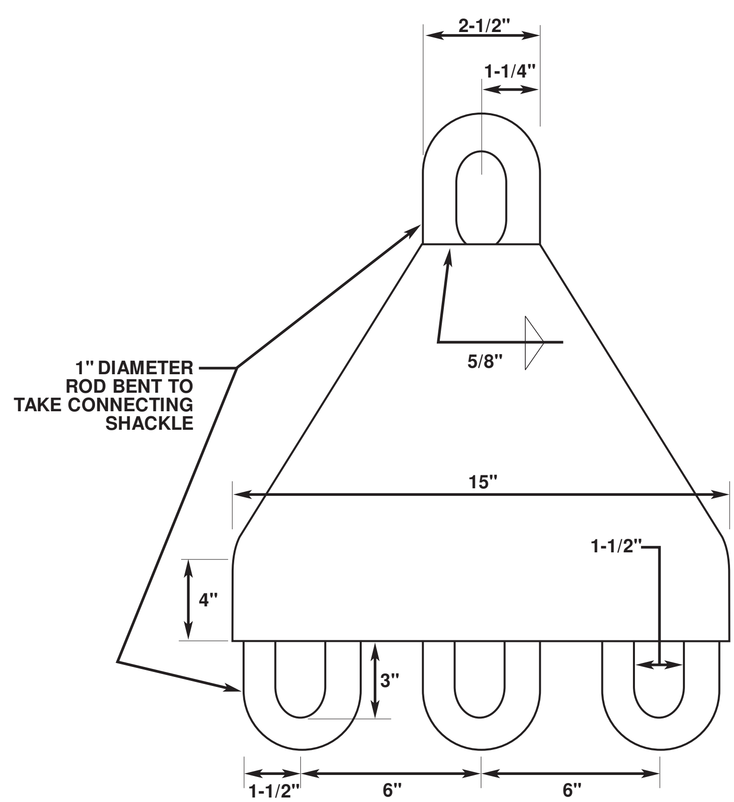


Figure 11-27B. Reeving Plate.

Reduced eyes are used frequently in the lifting wires of tidal lifting craft, where up to twenty pairs of wires may be passed underneath a sunken ship. Reduced eyes are comparatively quick and easy to make and, because of their tapered shape, easy to pass. As the strength of a reduced eye is not greater than 75 percent of the wire from which it is made, this method is not suitable for lift wires that accept maximum working loads at their termination.

11-11 ENGINEERING OF IMPROVISED SYSTEMS.

Heavy salvage rigging systems are often improvised from off-the-shelf components. Improvised systems must be carefully and thoroughly engineered to ensure that each and every component can take the loads applied during the particular application. Both the equipment manufacturers and the salvage engineer should be consulted to ensure the systems are assembled properly and will not fail catastrophically.

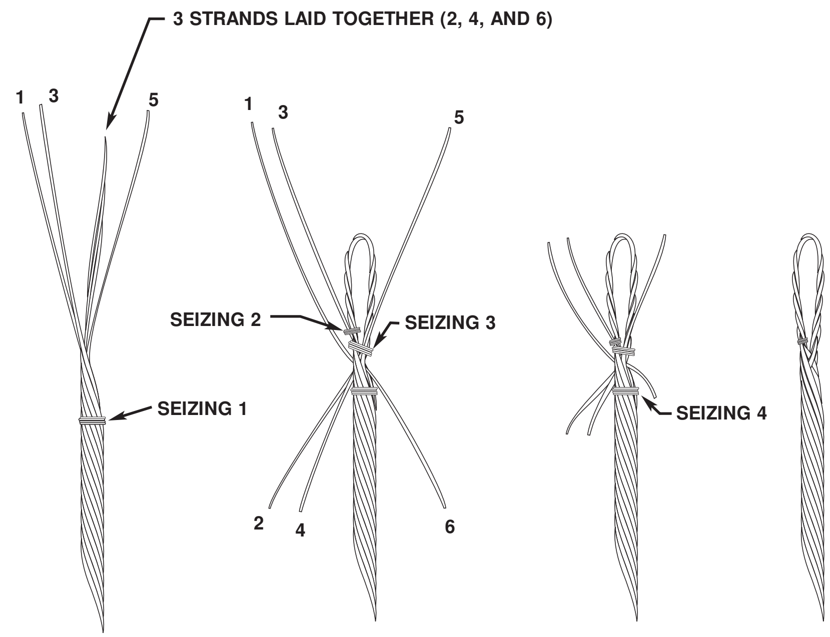


Figure 11-28. Making a Reduced Eye in a Wire.

CHAPTER 12
LIFTING

12-1 INTRODUCTION.

Almost every harbor clearance, harbor salvage, or wreck removal job involves lifting, whether it be handling materials or bodily lifting sunken ships from the seafloor. There are a number of lifting methods that have been used in salvage:

- Pontoons for submarine salvage were developed in the U.S. Navy early in the twentieth century and have been used in a variety of salvage jobs. The purpose-built submarine salvage pontoons have disappeared from the Navy inventory, but other types of pontoons—both rigid and collapsible—have been used in a wide variety of salvage work.

- U.S. Navy salvors first became acquainted with purpose-built lift craft when working with their British counterparts in World War II. While barges and other craft have been converted for lifting, the Navy has never built specialized lifting craft. During the Vietnam War, World War II vintage lift craft were leased from the British and used throughout the rivers and coastal regions of Vietnam. Contemporaneously, two German lift craft were purchased. These craft were used in Vietnam, later in the 1974 clearance of the Suez Canal, and are now in the Reserve Fleet.

- Almost all Navy salvage ships since the early days of World War II have been equipped with special purchases for dynamic lifting.

- Cranes have always had a major role in harbor clearance. It is in lifting with cranes and their application to salvage that the most spectacular changes in harbor clearance have occurred. Because of advances in welding technology, the construction of sheer legs and other types of floating cranes with capacities of many thousands of tons has become possible. Large cranes, specifically built to support the offshore oil industry, are finding increasing employment in salvage operations.

External lift expedites salvage and sunken ship removal operations when the aggregate external lift is an appreciable percentage of the sunken ship's displacement. If the external lifting force is a small percentage of the sunken ship's weight, external lifting assumes a relatively minor role in the overall effort. External lift for stabilizing and providing secondary lift forces has been discussed in Chapter 3. When sufficient lift force is available, it is often easier to raise the entire ship with external lift than to recover buoyancy.

Compared to recovering buoyancy, external lifting:

- Converts underwater work to rigging work because it:

  (1) Requires less preparation time and materials devoted to the sunken ship itself

  (2) Minimizes the time divers spend doing internal construction in the sunken ship to establish watertightness.

- Allows a high degree of lift control because the lift units can be individually synchronized to achieve the desired lift throughout the operation

- Provides more transverse and longitudinal stability compared to recovery of buoyancy

- Is usually quicker.

12-2 CATEGORIES OF LIFTS.

External lifting methods can be divided into three categories:

- Buoyant lifts
- Tidal lifts
- Mechanical lifts.

12-2.1 Buoyant Lifts. Buoyant lifts are made by rigging fixed- or variable-volume lift devices externally, and securing them by wire rope or chain passed under or attached to the sunken ship. When the lift device is blown with compressed air, it provides a lift equal to its internal volume less its weight. Figure 12-1 illustrates a buoyant lift.

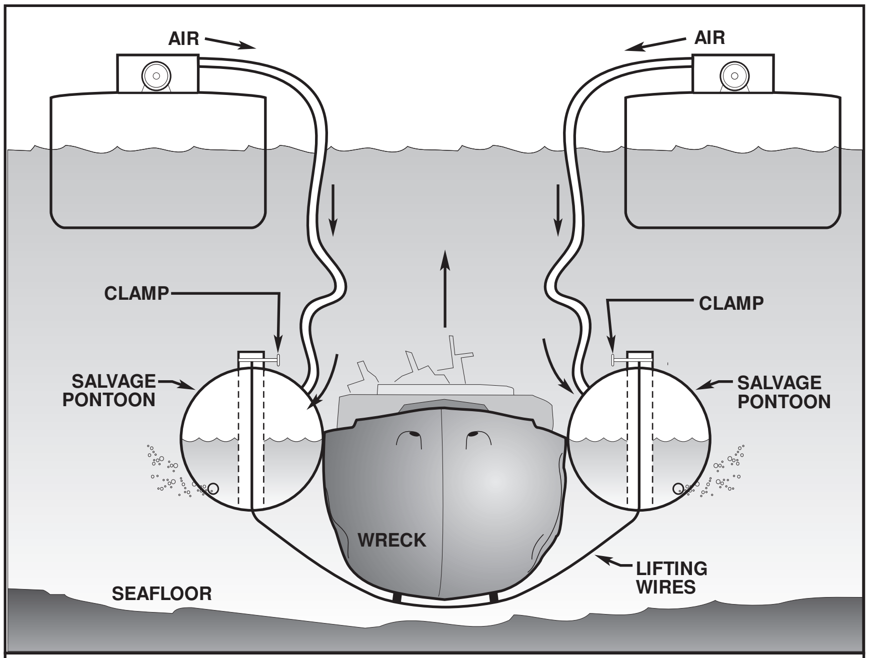


Figure 12-1. Buoyant Lift.

Collapsible, inflatable lift bags (variable-volume devices) and rigid-steel pontoons (fixed-volume devices) are the only buoyant lift devices that have been consistently successful in salvage.

The Navy developed and employed 80-ton, rigid-steel pontoons for submarine salvage. Large, rigid salvage pontoons are still maintained and used by other navies and some commercial organizations. The Navy maintains 8.4-ton lift capacity, inflatable salvage pontoons as standard salvage equipment.

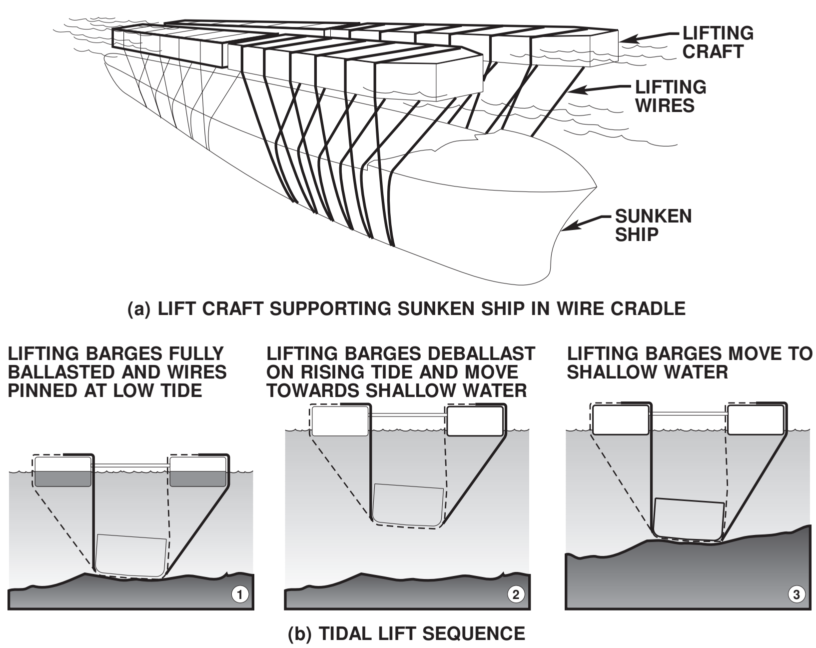


Figure 12-2. Tidal Lift.

12-2.2 Tidal Lifts. Tidal lifts are made with lifting craft that obtain their lift from the rise of the tide. The lift craft are moored above or beside the sunken ship. A network of heavy wire ropes is passed under the ship. The lift craft are ballasted to their deepest safe working draft at low water. The lift wires are hauled tight and stopped off. As the tide rises, the lift vessels' buoyancy lifts the sunken ship; further lift is obtained by deballasting the lift craft. When the sunken ship has been lifted, it is moved into shallow water still supported by the lift craft, and the process repeated. Figure 12-2 illustrates a tidal lift.

Tidal lift craft normally operate in pairs—one on each side of the sunken ship. Tidal lifts have been made with up to four lift craft. Single lift craft may make belly lifts as illustrated in Figure 12-3.

Tidal lifts are most effective in areas with a substantial tidal range.

12-2.3 Mechanical Lifts. In making mechanical lifts, the salvage units apply their lifting power to the sunken ship by heaving on wire ropes rigged around and underneath the sunken ship. Lifting power is obtained from vertical lift tackles rigged from A-frames, cranes or sheer legs, or from horizontal tackles rigged on deck. Mechanical lifting operations are independent of the tide or any form of induced buoyancy to obtain their lifting forces. Tidal heights and clearances may restrict their operation.

ARS-50 type salvage ships are capable of exerting a pull of nearly 200 tons on a stranded ship using tow wires, propulsion engines and two legs of beach gear.

Commercial seagoing cranes with lift capacities in excess of 7,500 tons and seagoing salvage sheer legs with lift capacities exceeding 1,600 tons are in regular service. Figure 12-4 illustrates a salvage sheer leg.

Commercial salvors also have seagoing salvage barges with 3,000-ton bow lifting (and pulling) capacities in service and have improvised 2,500-ton bow lifting barges when additional power was required.

12-2.4 Combination Lifts. In many salvage situations, the availability of lifting equipment and the circumstances of the sunken ship dictate a refloating method that combines recovering buoyancy with one or all of the basic lifting methods. Typical combination lifts on partially or completely sunken ships include:

- Compressed air buoyancy in several compartments, combined with several pairs of steel pontoons to provide buoyant lift, and bow lift craft at each end providing mechanical lift
- Dewatering of several compartments combined with one or more pairs of side lifting craft providing tidal lift
- Compressed air in some compartments, pumping in others, with sheer legs or derricks providing a stabilizing mechanical lift at each end of the sunken vessel.

Figure 12-5 illustrates a combined lift.

In situations where the lifting capacity is a small percentage of the actual weight of the ship being salvaged—20 to 25 percent or less—the lift force acts primarily as stabilizing or controlling forces to:

- Provide transverse stability by cradling the sunken ship between several pairs of pontoons, or in the lifting slings of cranes or bow lift ships
- Provide control over the refloating operation by having the lifting unit apply the final few percent of the buoyant force required to commence or maintain the lifting operation.

In situations where the lifting capacity is a large percentage—75 to 80 percent or more—the recovered buoyancy supplements lifting by:

- Providing more than the minimum lift required by recovering buoyancy by the most suitable and, where possible, the least labor-intensive method
- Reducing the lift force required, as a net percentage of the weight to be lifted, giving a greater margin of safety and control.

In planning any job that combines recovered buoyancy with external lift, there is only one consistently applied standard operating procedure:

- Buoyancy is recovered as the *FIRST* stage of the operation.
- External lift is applied incrementally as the *SECOND* and controlling stage.

Combination lifts are also advantageous where mud suction is a factor. Mechanical or tidal lift can provide the last few percent of “no suction” lift required and the excess lift required to break the suction, where recovered buoyancy provides the main lift. When the suction breaks, the tidal lift stops in short order. At this point the mechanical lift proceeds at a controlled rate and the casualty does not rocket to the surface on internal buoyancy.

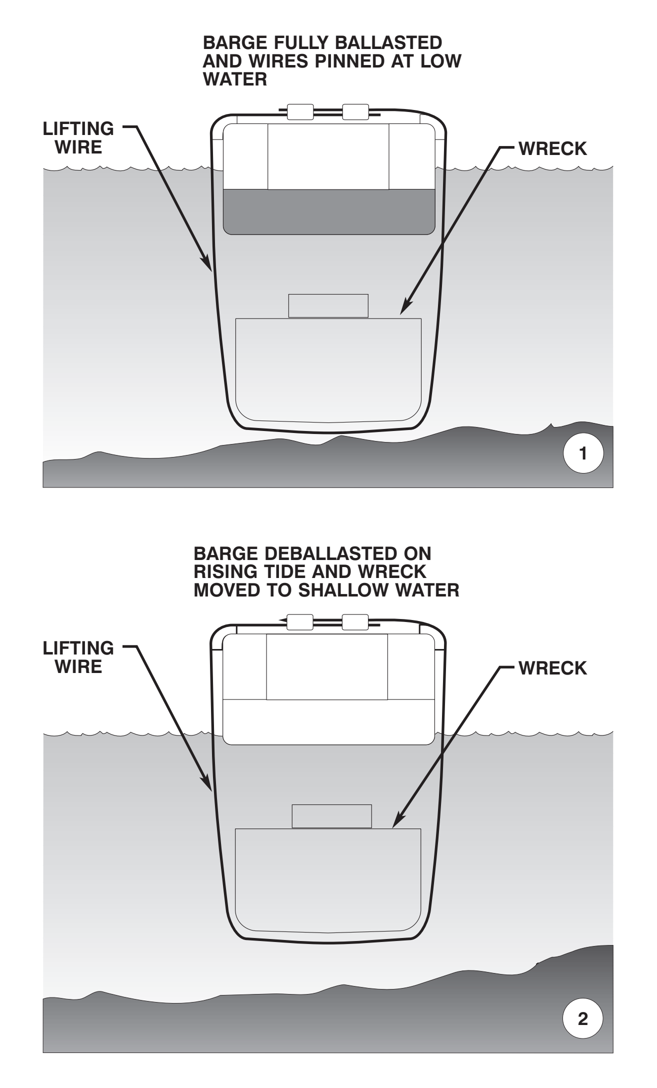


Figure 12-3. Belly Lift with Single Lift Craft.

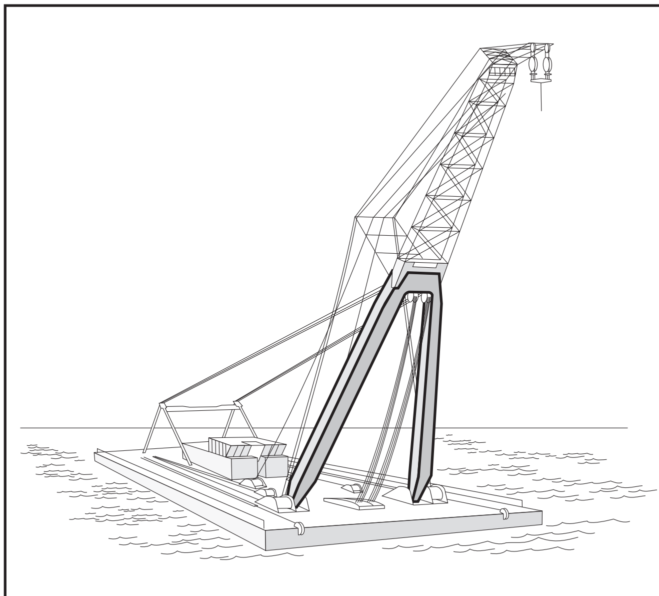


Figure 12-4. Sheer Leg Crane.

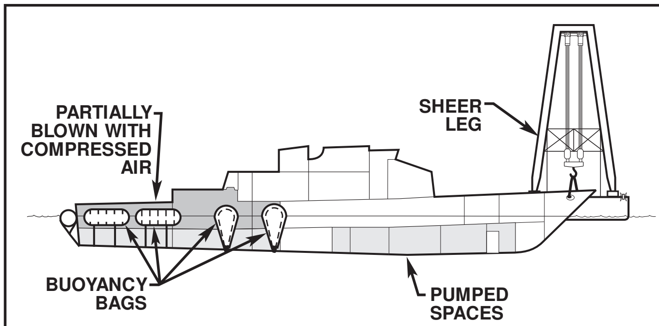
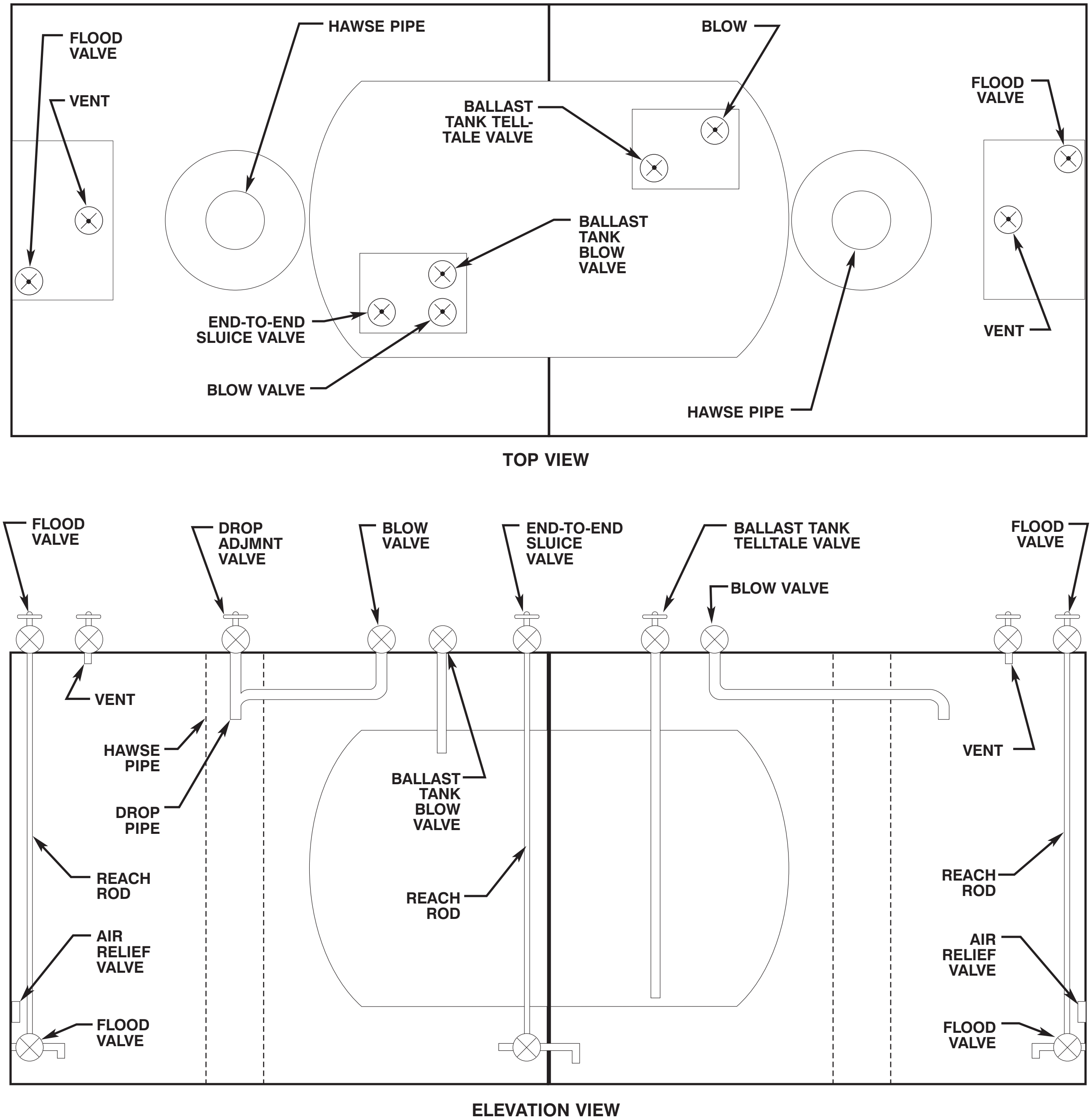


Figure 12-5. Combined Lift.

Successful operations utilizing recovered buoyancy and lifting have occasionally combined some unusual (and unlikely) methods. When conventional salvage equipment is nonexistent, innovative and opportunistic salvage personnel have exercised their imaginations and creative procurement abilities to get the job done.

12-3 SALVAGE PONTOONS AND LIFT BAGS.

Salvage pontoons and inflatable lift bags are used extensively to refloat small ships and to stabilize the refloating process when larger ships are being raised—particularly in combined lifting operations. As buoyant lift devices, salvage pontoons and lift bags are rigged onto the sunken ship in either a flooded or collapsed condition. Compressed air is blown into the pontoons or lift bags to make them buoyant. As the pontoons rise through the water, the air in them expands as hydrostatic pressure decreases. If the pontoons are not properly vented, there is a serious danger of structural failure or explosion from over-pressurization. Purpose-designed pontoons and lift bags have built-in relief valves. The design and construction of improvised buoyant lift devices should be examined carefully to ensure there are adequate pressure relief arrangements.



MAX PRESSURE, END COMPARTMENTS - 30 PSI MAX PRESSURE, CENTER COMPARTMENT - 75 PSI

- LENGTH - 32'-0"
- DIAMETER - 12'-6"
- LIFTING CAPACITY - 80 TONS
- WEIGHT, DRY - 35-40 TONS
- NEGATIVE BUOYANCY, WITH END COMPARTMENTS
- FLOODED TO END OF BLOW PIPES - ABOUT 35 TONS

VALVE HANDWHEELS

- ROUND
  - TELLTALE AIR VENT, CENTER COMPARTMENT
  - AIR VENT, END COMPARTMENT
- SQUARE
  - BLOW VALVES, END COMPARTMENT
- TRIANGULAR
  - BLOW, CENTER COMPARTMENT
- T-WRENCH, PORTABLE
  - OPERATING RODS TO:
    - SLUICE VALVE
    - FLOOD VALVES, END COMPARTMENT

Figure 12-6. 80-ton Rigid Salvage Pontoon.

12-3.1 Salvage Pontoons. The steel salvage pontoon (called a *camel* overseas) can be employed in both deep and shallow water, as well as in the presence or absence of tide. The most common general-purpose salvage pontoon is about 32 feet 6 inches long, 12 feet 6 inches in diameter, and has a lifting capacity of 80 to 90 tons per unit, depending upon the internal configuration. Some foreign military and commercial organizations have steel salvage pontoons that are 55 feet long, 23 feet in diameter, and lift 500 tons per unit. Figure 12-6 illustrates an 80-ton rigid pontoon.

The Navy no longer maintains steel salvage pontoons; however, it is quite possible that harbor clearance teams will have to use foreign military, commercial, or improvised pontoons under certain circumstances. The general principles of the 80-ton units, formerly operated by the Navy and still common overseas, are presented below. Their principles are applicable to all steel salvage pontoons.

The pontoons are steel cylinders, sheathed with wooden fendering. The pontoon is divided into three watertight compartments to permit better control of the pontoon through control of reserve buoyancy and ballast. Free surface and surging of the water from one end to the other are reduced. Each compartment of the pontoon has vent, flood, and relief valves:

- The vent valve is the air supply valve.
- The flood valve admits water and discharges it during blowing.
- The relief valve allows air to escape while the pontoon is rising.

The end compartments contain hawse pipes through which lifting chains are passed. The lifting chains are attached to or form a cradle under the sunken ship. The controls to each compartment are usually painted different colors for easy identification.

All valves are operated by reach rods. The pontoon is sunk by flooding the two end compartments and is raised by blowing them down with compressed air. Figure 12-7 shows an isometric of a partially flooded pontoon.

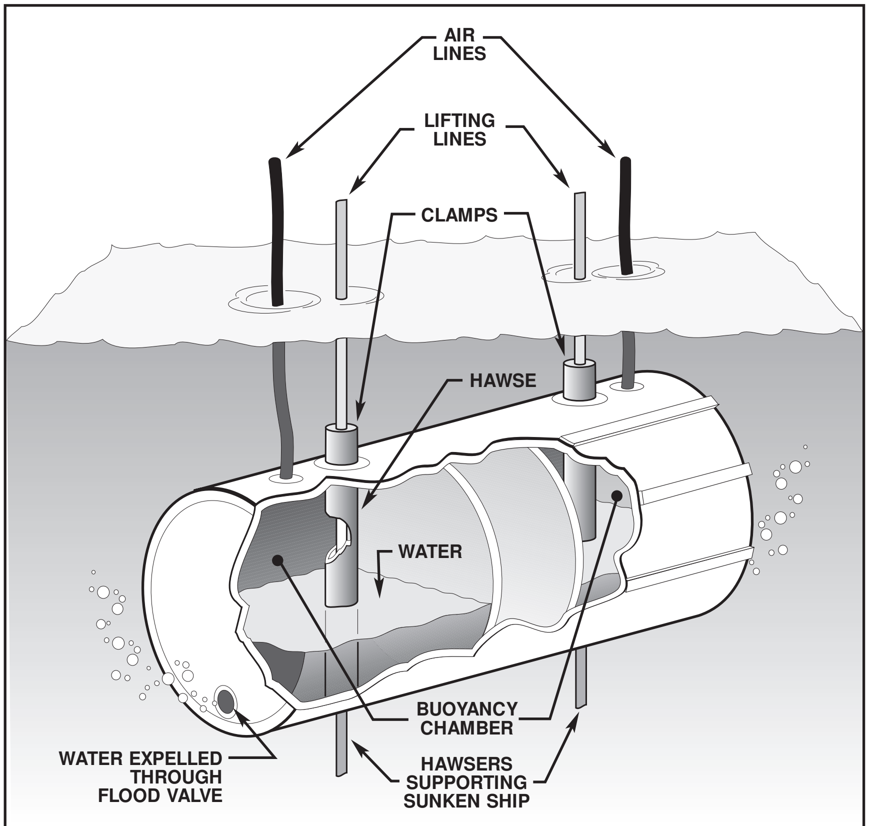


Figure 12-7. Partially Flooded Salvage Pontoon.

12-3.2 Pontoon Operational Notes. There are numerous methods and variations of the procedure for operating salvage pontoons. The following points are derived from operational experience.

Salvage pontoons are secured to the sunken ship by:

- Chains
- Wire ropes
- Specially constructed welded shocks or gusset plates that hold the pontoons in position on the sunken ship.

CAUTION

Burning the stud link chain reduces its proof strength to that of the next lower grade of the same size. In the case of Grade 1 chain, the proof strength should be considered to be reduced by 30 percent. Do not cut the stud from Di-Lok or cast chain.

When pontoons are secured to the sunken ship with stud link chain and are in position, the chains are hauled up very tight. Studs are burned out of the links just above the hawse pipes and toggle bars are inserted in the links.

Five-inch or larger nylon lowering lines should be provided at each end of each pontoon. The lines should be marked in feet to indicate the trim of the pontoon during descent.

Occasionally, pontoons may be very slow to submerge. This is usually due to the formation of air pockets at the top of the end compartments. If this occurs, the vent pipes should be blown through and the pontoons rocked by alternately raising and lowering each end.

Salvage pontoons are heavy; an 80-ton lift capacity pontoon may weigh as much as 40 tons. The pontoons are difficult to handle on the surface.

Salvage pontoons produce 80 tons of lift for 40 tons of weight, while the standard Navy salvage pontoons produce 8.4 tons of lift for 750 pounds of weight. A team of salvage divers should be able to set up ten 8.4-ton pontoons about as fast as a single 80-ton rigid pontoon.

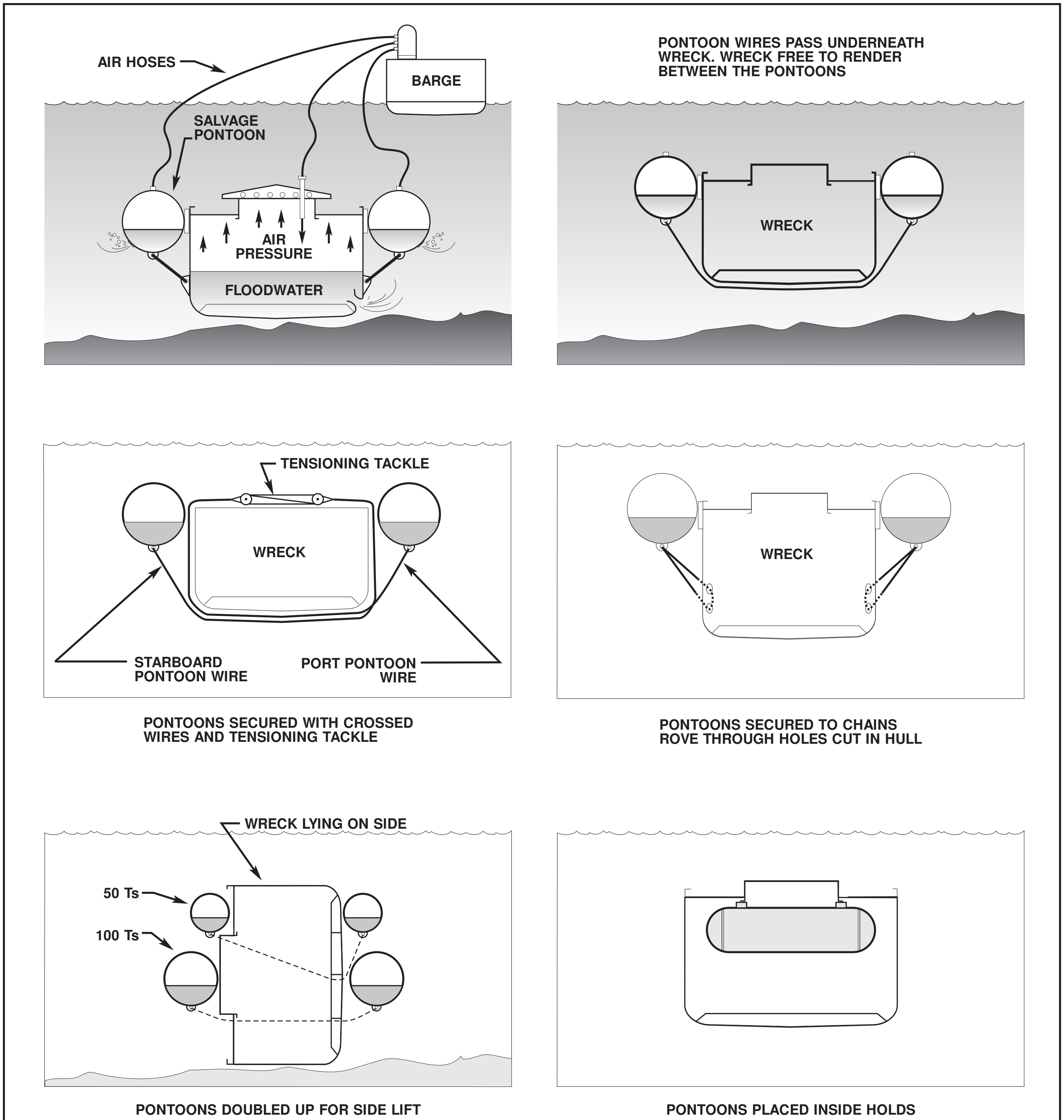


Figure 12-8. Methods of Rigging Salvage Pontoons.

For strength and lift balance reasons, pontoons are best rigged in pairs. Each pair should be connected by chains or wire ropes passing, under, through, or attached to the sunken ship. Figure 12-8 shows some typical ways of rigging pontoons to sunken ships.

Improvised salvage pontoons have been successfully adapted from old oil field storage tanks, large compressed gas cylinders or pressure receivers, as well as purpose-built steel boxes fitted with lifting connections. The hardware and rigging for improvised salvage pontoons tends to be unorthodox and depend greatly on the skill and ingenuity of the salvage personnel for safe operation.

Salvage pontoons are not always the easiest salvage tool to use. The term camel, used overseas for pontoons, is apt. Like those beasts, salvage pontoons can be docile or develop a perversity all out of proportion to their utility. However, the advantage of the steel salvage pontoon in most salvage operations is that it can absorb a great deal of mistreatment, contact, and minor damage that would seriously damage or destroy inflatable lift bags.

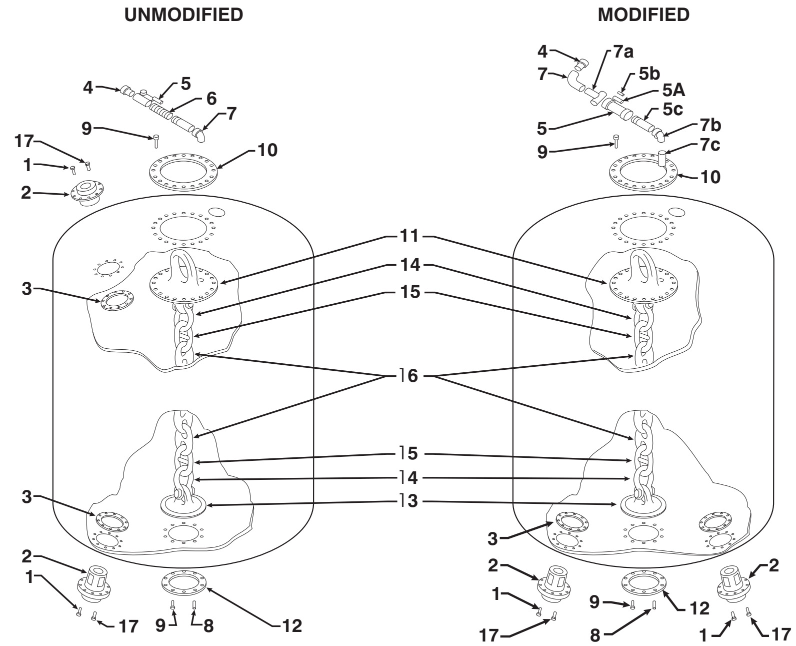
12-3.3 Inflatable Pontoons and Lift Bags. The development and ready availability of inflatable lift bags and pontoons has led to the widespread use of these devices in salvage operations. The standard Navy lift bag is the 8.4-ton inflatable salvage pontoon. A wide variety of open and enclosed lift bags are available commercially.

Typical salvage uses for inflatable salvage pontoons and lift bags are:

- Lifting and recovery of aircraft, helicopters, torpedoes, missiles, and other ordnance components
- Lifting small combatants, yard craft, and auxiliaries sunk in shallow to moderate depths
- Lifting and moving underwater obstructions during harbor clearance operations
- Providing additional buoyancy and longitudinal stability to larger ships, particularly fine-lined combatants up to about 5,000 tons displacement.

CAUTION

When 8.4-ton pontoons are rigged in series, or when more than one pontoon is rigged to the same attachment point, the attachment point must be capable of carrying the lift of all the pontoons in series or rigged to it individually.



1. CAP SCREW
2. RELIEF VALVE
3. CLAMPING REING
4. QUICK DISCONNECT NIPPLE, (ROYLYN 1022-20B)
5. BALL VALVE
5a. HANDLE VALVE (FABRICATED)
5b. NUT, VALVE, HANDLE
5c. NIPPLE
6. HOSE ASSEMBLY
7. STREET ELBOW
7a. BRACKET (FABRICATED)
7b. ELBOW
7c. NIPPLE
8. PIPE PLUG
9. CAP SCREW
10. CLOSURE RING
11. END PLATE
12. CLOSURE PLATE
13. END PLATE
14. BENDING SHACKLE
15. END LINK
16. DI-LOK LINK
17. SCREW HEX, HEAD

Figure 12-9. 8.4-ton Inflatable Salvage Pontoon.

12-3.3.1 The 8.4-ton Salvage Pontoon. The 8.4-ton salvage pontoon, illustrated in Figure 12-9, is used for lifting objects at sea. It is built for extended operations in seawater and for prolonged storage when deflated. The 8.4-ton pontoon is a closed-bag design, fitted with relief valves to vent excess air as the bag ascends. The pontoons may be used in the following configurations:

- Singly, on small lifting or recovery jobs
- Rigged vertically in series of up to three pontoons for lifting and supporting larger objects
- Rigged in groups around small sunken vessels.

The physical characteristics of the 8.4-ton salvage pontoon are:

- Net buoyancy in seawater - 8.4 tons
- Diameter - 86 inches
- Length - 121 inches
- Cubic capacity (inflated) - 406.75 cubic feet
- Dry weight - 750 pounds.

The relief valve cracks between 3 and 8 psi, depending upon the model of the pontoon. Complete details for the 8.4-ton salvage pontoon are contained in the *Manual for Salvage Pontoons* (NAVSHIPS 0994-011-2010).

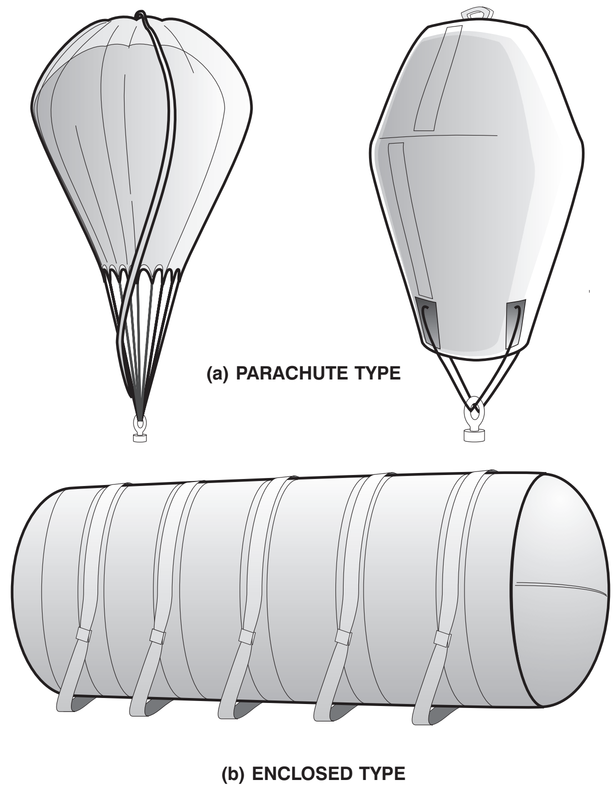


Figure 12-10. Commercial Inflatable Lift Bags.

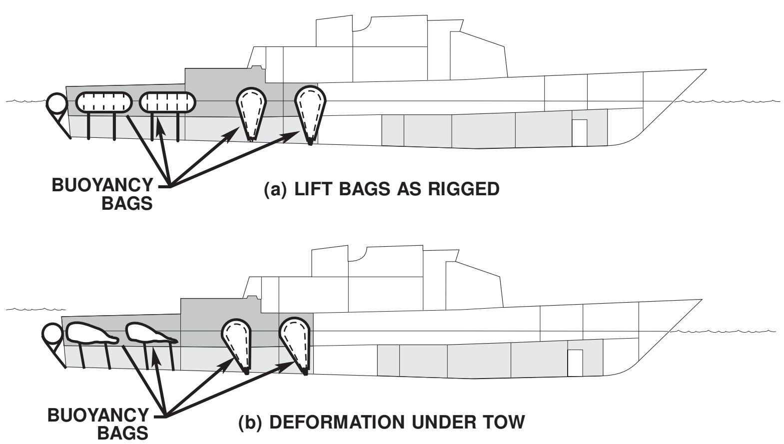


Figure 12-11. Deformation of Enclosed Lift Bags Under Tow.

12-3.3.2 Commercial Pontoons and Lift Bags. Commercial inflatable pontoons and lift bags are produced in two basic designs: the parachute-type and the totally enclosed type. Figure 12-10 illustrates the two types of commercial inflatable lift bags.

WARNING

Divers should be clear of all shrouds before inflating the lift bag to preclude uncontrolled rapid ascent and possible embolism or decompression sickness.

The parachute-type lift bag is available in a variety of sizes for salvage. Obtainable sizes give lifts from 5 to 35 tons. Parachute bags are rubberized fabric bags that have lifting straps bonded to them. Air from the surface is admitted to the top of the bag through a diver-operated air control valve. The diver regulates the rate of ascent and has greater control than can be achieved by regulating the air from the surface. As the bag has an open bottom, it will spill air. The open bottom both limits the parachute bag to vertical lifts and eliminates the need for a relief valve.

The enclosed-type lift bag is similar to the parachute-type except that the bag is totally enclosed and fitted with a relief valve. Bags with buoyant lifts from 5 to 35 tons are available. The valve assembly is built into the top of the bag. Different air pressure settings can be obtained by changing the pressure switch. Bag inflation and ascent are diver-controlled, as with the parachute-type bag.

12-3.3.3 Lift Bag Calculations. Calculations of the amount of air and time required to fill lift bags are the same as those calculations for dewatering a compartment. In lift bag calculations, an extra thirty percent compressor output should be allowed for air line and other losses.

12-3.3.4 Lift Bag Operational Notes. The following operational notes have been derived from experience with lift bags.

Lift bags are not as rugged, nor as salvor-proof, as other compressed air lifting devices. Inflatable pontoons and lift bags must be handled carefully to avoid snags, tears, and punctures. The following precautions should be taken to ensure the pontoons and lift bags remain intact and effective:

- When laying out pontoons or lift bags, the deck or layout area must be clear of objects that might cause damage.
- Pontoons must not be dragged over or against sharp objects when they are being rigged.
- Pontoons should not be rigged underwater where they are likely to foul, snag, or tear on sharp objects, pier pilings, or damaged or torn plating.
- Inflatable pontoons should not be rigged into totally enclosed flooded spaces, except when there is no other choice. For example, inflating pontoons in machinery spaces will usually result in damage to the pontoon and total loss of lift.

To avoid excessive ascent rates, the lift should be the minimum required for the job. Excessive ascent rates produce forces that distort the bags and induce instability. In extreme cases, air will be dumped and buoyancy lost.

Totally enclosed commercial bags must be secured so that they remain horizontal throughout the lifting operation. If they deviate from the horizontal, air will migrate to one end, causing deformation and loss of efficiency.

Parachute-type bags will be stable when rigged in pairs on opposite sides of the sunken vessel with a single line. Because of the difficulty in getting two lines to carry equal loads with a deformable bag, enclosed lift bags are best rigged to the object being lifted. If enclosed bags are rigged together, the imbalance in forces will cause them to trim, distort, and lose efficiency.

Parachute-type bags are preferable for a tow because they are more stable. Enclosed-type bags distort under tow as shown in Figure 12-11.

After being completely attached, bags should be partially inflated to ensure all straps are properly positioned and the bags have assumed the correct shape. After the bags have been thoroughly checked out, they are fully inflated for the ascent.

12-3.4 Control Pontoons. Ships sunk in such depths that one end can be surfaced and brought under control while the other end is stabilized by bottom contact can be raised in one two-phased step with pontoons or lift bags as shown in Figure 12-12.

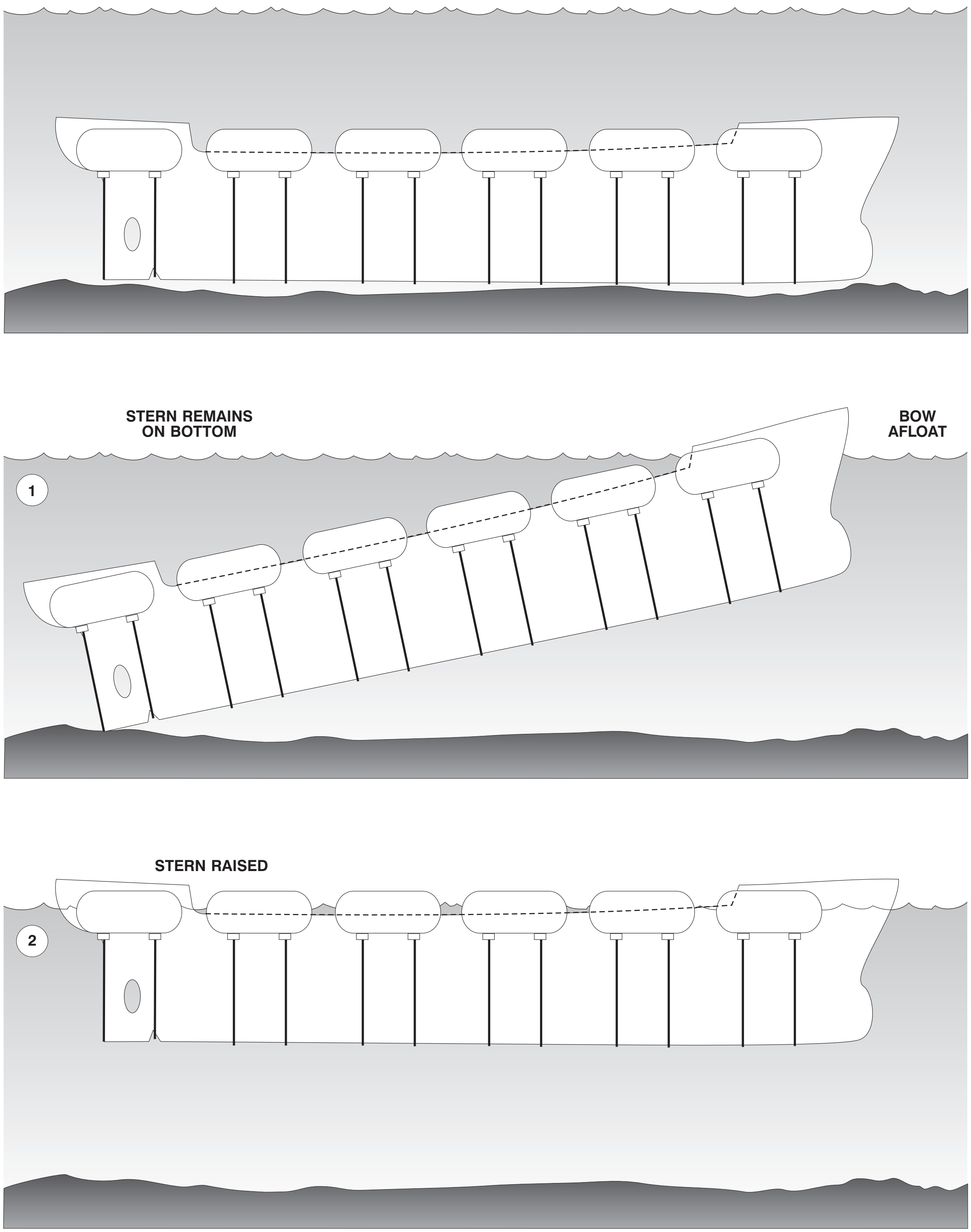


Figure 12-12. Pontoons Raising a Ship Sunk in Shallow Water.

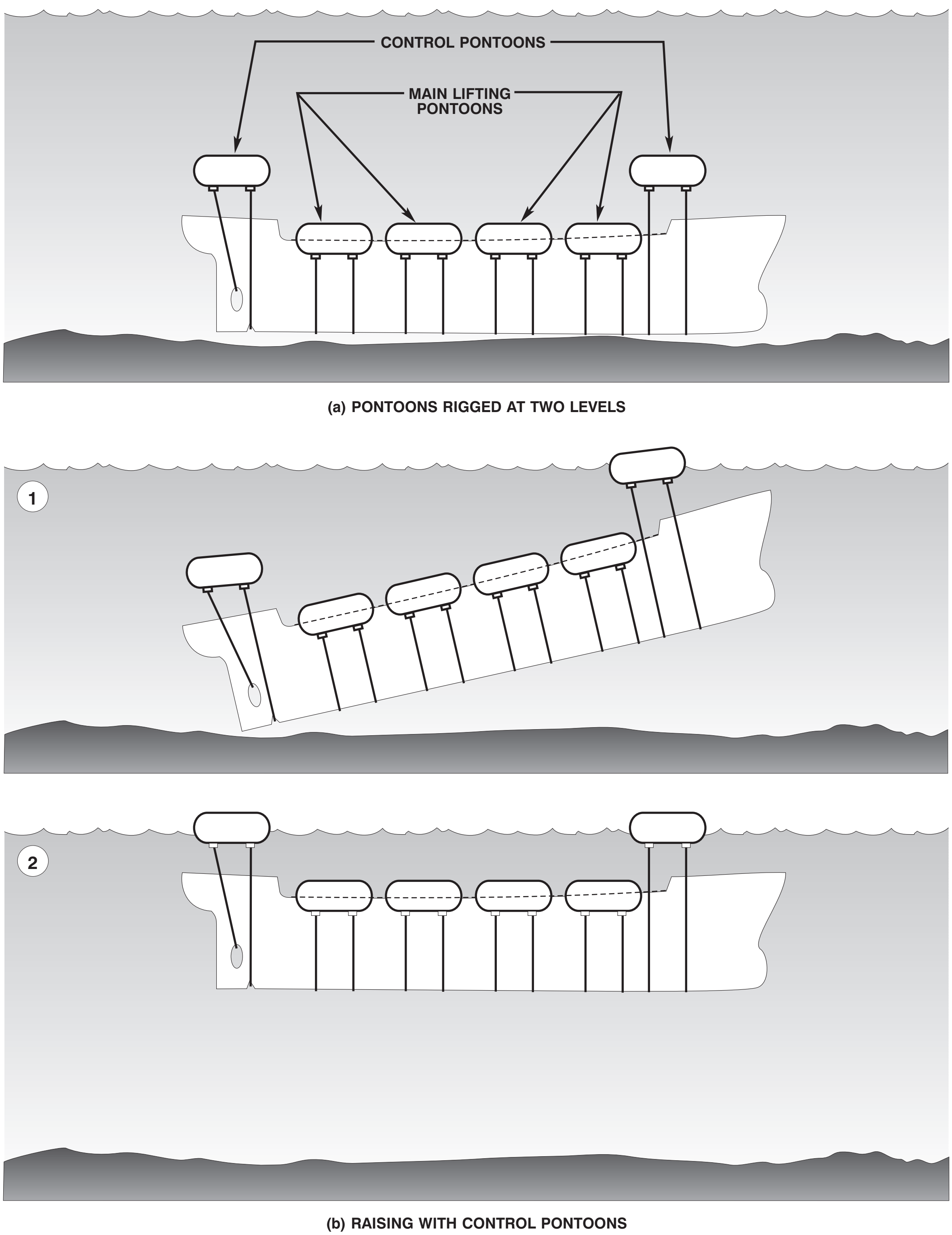


Figure 12-13. Pontoons Raising a Ship Sunk in Deep Water.

Deeply sunken ships raised with pontoons in one step accelerate as they rise and trim, despite the best efforts of salvors to balance the lift. Lack of control in such a raising often leads to damage to the ship or pontoons. Sometimes such an evolution results in the ship's surfacing only briefly before sinking again in a tangle of lift gear.

Deep lifts are best made in stages. The sunken ship is lifted part of the way to the surface, moved to a beaching ground, beached, and rerigged. The process is repeated until a stable lift can be made in relatively shallow water. To lift in stages, pontoons are rigged at two different levels, as shown in Figure 12-13(a). The pontoons near the sunken ship are the main lifting pontoons; those at a shallower depth are the control pontoons. The total lift of all pontoons is slightly greater than the weight to be lifted. The total lift of the main lifting pontoons is less than the weight to be lifted. As the ship rises, the control pontoons break the surface first as shown in Figure 12-13(b). With the control pontoons on the surface, the total buoyancy of the control and main lifting pontoons is equal to the weight being lifted. The sunken ship is supported at an intermediate depth and may then be towed to the beaching ground, beached, and rigged for another lift.

12-4 TIDAL LIFTS.

Tidal lifts are made with lift craft that are not submersible and that rely mainly on the rise of tide for their lift capability. Tidal lifts are seldom made in modern salvage. It is, however, a technique that uses natural forces, and equipment may be improvised from quite ordinary marine equipment. A knowledge of tidal lifting has its place in every salvor's bag of tricks as a technique to be called upon for use in an emergency. Tidal lift craft normally work in pairs, with the sunken ship slung between them.

12-4.1 Tidal Lifting Procedures.

The following are typical tidal lifting procedures:

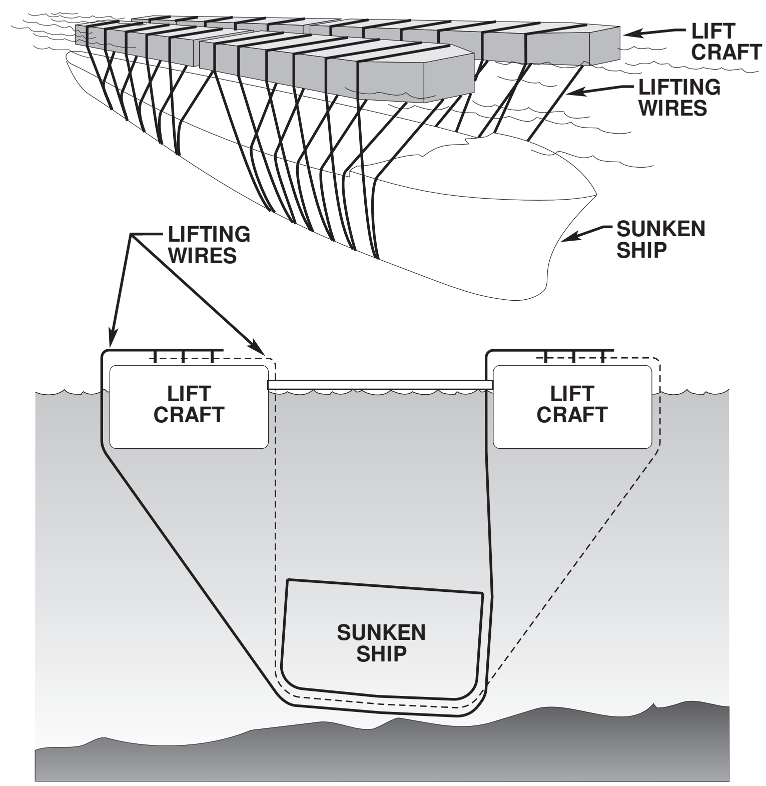


Figure 12-14. Lift Wire Rigging.

a. The two lift craft are securely moored parallel to the centerline of the sunken ship on heavy moorings that have been previously laid.

b. Moorings are adjusted so that the lift craft lie about as far apart as the breadth of the sunken ship.

c. When the lift craft are in position, they are ballasted—*flooded down* in salvage terminology—to their deepest safe operating draft.

d. The ends of previously swept and buoyed-off lift wires are recovered aboard the lift craft at predetermined positions.

e. The lift wires, up to 3-inch diameter, are passed in pairs. One wire leads from the inboard side of one lift craft, under the sunken ship, and up the outboard side of the second craft. The second wire leads from the outboard side of the first craft, under the sunken ship, and up the inboard side of the second. Figure 12-14 illustrates how the wires are rigged. Section 11-8.2 previously addressed wire tension calculations.

f. At low water, the lift wires are hauled taut and secured tight—but not hard down. The craft are now said to be *pinned*, or *pinned down*.

   (1) The wires are clamped together on the deck in specially designed clamps. Lift craft rigged in this manner are not connected to the wire and are free to render in the bight of the wire and remain essentially upright throughout the lift.

g. As the tide rises, the lift craft, cradling the sunken ship between them, begin to deballast slowly. As the load comes on the lift wires, they will begin to surge in their clamps. As soon as the wires begin to surge, they are clamped hard down. This procedure assists in equalizing the load on the wires.

h. As the tide rises, the lift craft and sunken ship rise. During the last part of the tide rise, the lift craft deballast simultaneously. The additional lift gained is the tons of ballast discharged divided by the TPI of the lift craft. If the tide rise is twelve feet and the lift craft can discharge enough ballast to gain another 6 feet of lift, the sunken ship can be raised to a total of 18 feet.

i. At high water, the lift craft slip their moorings and are towed into shallow water carrying the sunken ship. Movement continues until the sunken ship touches bottom. Preferably, the lift craft and sunken ship are aligned with the tidal flow before remooring.

j. As the tide falls, the lift craft flood down and recover slack in all pairs of lift wires. All wires must be:

   (1) Unclamped from the secured position

   (2) Adjusted or rendered prior to being clamped for the next lift.

k. On the rising tide, the lift craft again deballast and repeat the lifting, deballasting, moving, and beaching procedure until the ship reaches a position where it can be patched, pumped and refloated, or abandoned.

12-4.2 Available Lift. There are two critical physical quantities in tidal lifting:

- The lift capacity of the lift craft relative to the weight to be lifted
- The height that the sunken ship can be lifted.

The lifting capacity must exceed the weight to be lifted. The amount of excess is a matter of judgement based on the conditions of the particular operation. Twenty percent of the weight to be lifted is a reasonable minimum excess of lift capacity.

The height the sunken ship can be lifted depends primarily on the rise of the tide. Tidal lifts are effective only when there is a good range of tide, otherwise they can be long and unproductive operations.

The fundamental rule in tidal lifting is to start the lift at low water and to move the sunken ship as far as possible into shallow water before she beaches at high tide in order to minimize the number of lifts that must be made to complete the operation.

A hydrographic survey is an integral part of the planning of any tidal lifting operation. The purposes of the survey are to establish:

- How far the ship has subsided into the seafloor (Sunken ships have scoured or worked themselves into holes or depressions that are deeper than the total lift that can be expected from the lift of the tide and deballasting the lift craft.)
- If there are any obstacles along the route to the beaching ground that may interfere with the movement of the sunken ship.

After the depth of subsidence has been determined, the feasibility of the operation is determined by:

a. Calculating the maximum rise of tide

b. Calculating the gain by deballasting—tons of ballast divided by *TPI* of the lift craft

c. Adding the two quantities and subtracting an allowance for loss of time and lift in making up wires as the tide rises (Three feet is a good estimate for a trained crew, up to six feet with a less well-trained crew.)

d. Subtracting the subsidence, or depth of the hole, from which the sunken ship must be lifted from the above.

In cases where the sunken ship cannot be lifted clear of the hole, the best solution is usually to call in a dredge to dredge a step lower than the top of the hole to which the ship can be lifted and to make a second lift to clear the hole.

12-4.3 Tidal Lifting with the ARS-50 Class. Although it is considered an abnormal condition, the ARS-50 Class ships may make tidal lifts of 350 long tons under the following conditions:

- Load is evenly distributed on four lift wires rigged over the bow and stern rollers
- Swell is 6 feet or less
- Ship's displacement is between Full Load Condition and Minimum Operating Condition.

Detailed Instructions for making such a lift are found in the *ARS-50 Operating Manual* (NAVSEA SS5500-AM-MMO-010).

EXAMPLE 12-1
CALCULATION OF LIFT HEIGHT

A ship is to be lifted by lift craft of adequate capacity, manned by well-trained crews. The tidal range is 12 feet and the craft can gain another 6 feet by deballasting. How much margin is there if the ship has (a) subsided uniformly 10 feet? (b) subsided 12 feet at the bow and 18 feet at the stern?

Available lift distance:

Rise of tide	12 feet
Deballast rise	6 feet
Loss allowance	-3 feet (well-trained crew)
Available lift	15 feet

a. 10-foot uniform subsidence:

Available lift	15 feet
Subsidence	-10 feet
Margin	5 feet

The sunken ship can be lifted clear of the hole.

b. 12-foot bow subsidence, 18-foot stern subsidence:

Bow		Stern	
Available lift	15 feet	Available lift	15 feet
Subsidence	-12 feet	Subsidence	-18 feet
Margin	3 feet	Margin	-3 feet

The bow can be lifted clear of the hole; the stern cannot.

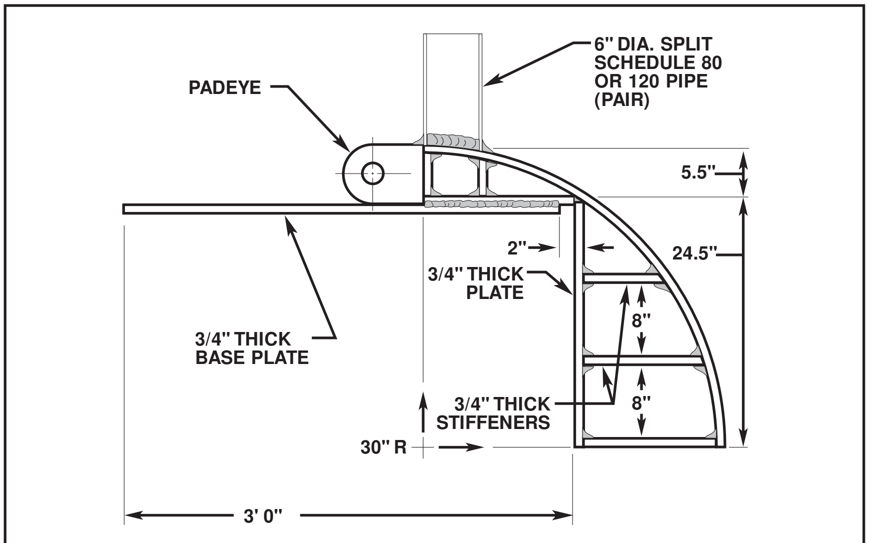


Figure 12-15. Deck-Edge Bolster.

12-4.4 Conversion of Barges for Tidal Lifts. Suitable barges may be converted to tidal lifting craft. Barges so converted should be tank barges with:

- Tanks, three across
- A beam that does not exceed 60 feet
- An efficient installed pumping system
- Very sound structure—shoring of even sound structure may be required.

The following equipment must be installed:

- Deck-edge bolsters with a radius of at least 60 inches in diameter and high enough to hold the wire clamps clear of the deck when the wires are under tension (Figure 12-15)
- Winches and deck fittings for at least a four-point moor
- A winch and fittings for hauling lift wires
- A crawler crane
- Air compressors for pneumatic tools and general service
- A central control station from where the entire deck can be seen.

If portable pumps are to be fitted, they should be rigged through pumping plates to minimize the number of deck edge openings. A diving station on board is in the "nice to have" category. A boat alongside usually makes a satisfactory diving platform.

Field conversion of a barge to a tidal lift barge requires the assistance of a naval architect and salvage engineer.

12-4.5 Miscellaneous Operational Notes. Efficient operation of lift craft requires considerable operator familiarity and experience. Only practical, hands-on experience will give the familiarity required to develop a high degree of operational experience. This experience cannot be provided by any manual. The following operational notes—developed from hard experience with tidal lifting—are provided as guidance and reminders for both the neophyte and old hand in tidal lifting.

Ideally, lift craft that are free to render will remain upright during lift operations. Actually, the loads on the wires cause all lift craft to list inboard toward the sunken ship. In heavy lifts, the list can become extreme. To counter the list, it is usual to produce a moment that lists the vessel outboard by not completely deballasting one outboard tank. While lift craft lift combinations are inherently very stable, limiting ballast to one tank reduces the free surface effect.

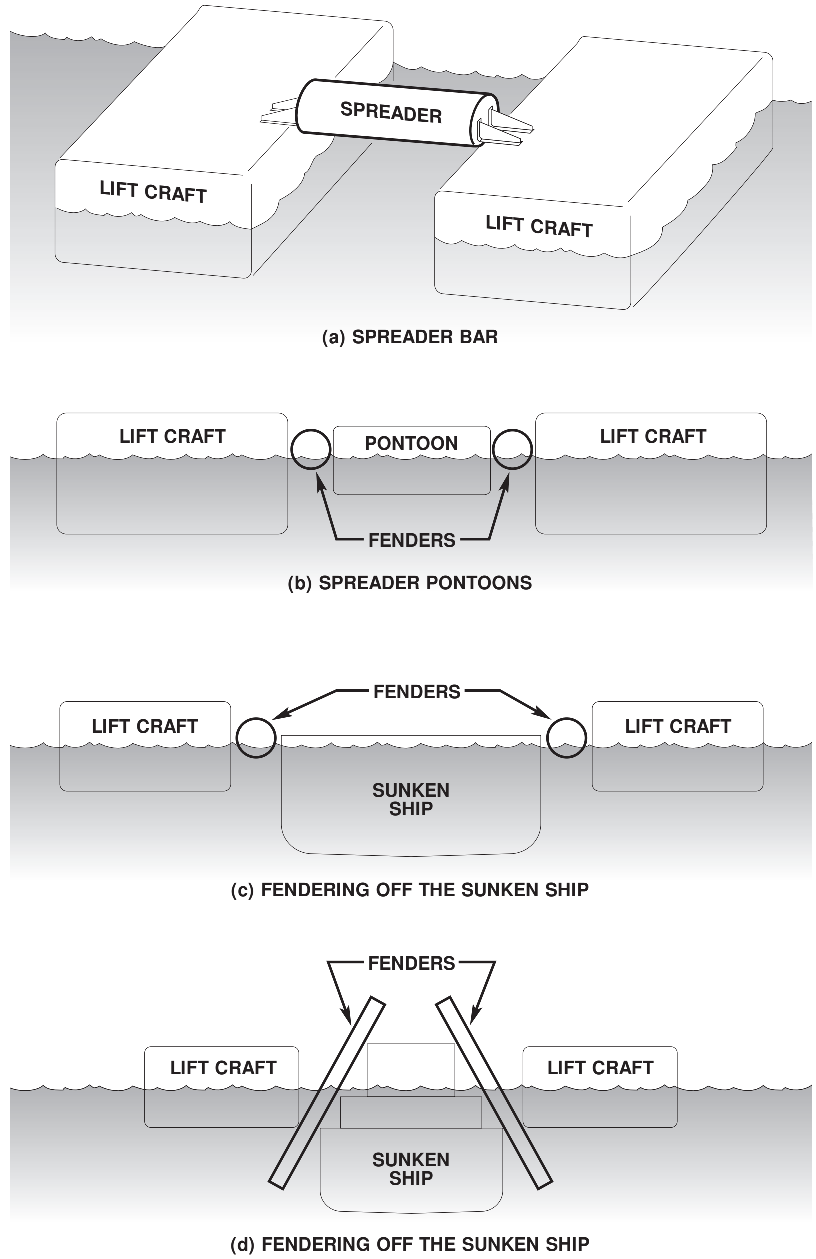


Figure 12-16. Spreaders and Fenders.

Lift forces cause the lift craft to move toward one another. Craft are kept separated by placing spreader bars rigged to the deck of the craft or spreader pontoons floating between the craft as shown in Figure 12-16. When the sunken ship is above the surface, fenders must be rigged to prevent the lift craft from riding hard against the ship or riding over submerged decks.

Crew training in all aspects of rigging is essential to reduce pinning time to the minimum. Speed and teamwork by the crews of both lift craft are vital to successful tidal lifting. In areas with a large tidal range, the low water tide stand is usually relatively short. Rigging must be especially rapid and coordinated.

Prior to pinning lift craft, an accurately timed deballasting should be performed to develop accurate information for scheduling and sequencing the operation. Unless the lift craft are rigged as stabilizing pontoons alongside a floating casualty, the total tension in the lifting wires will equal the weight being lifted. Ideally, the total tension is divided equally among the wires. Uneven wire tensions can be caused by incorrect trim of the lift craft or poor coordination during deballasting.

A good deal of tide rise and effective lifting height can be lost because lift wires were too slack during pin-down of the craft. It is good practice to make a test-pin on the sunken ship to review techniques and coordinate the crews.

Operating lift craft in the strong tidal currents normally associated with large tide ranges requires careful planning and preparation of moors. When the sunken ship lies athwart the main tidal current, heavy loads are imposed on the moors. Moorings must be designed for the worst conditions and must include those stages of lifting where the sunken ship is suspended between the lift craft and the bottom.

Operational planning for the lift should include a dedicated ship to run out, lay, recover, and shift anchors. The mooring vessel should carry at least twice the number of anchors and amount of chain, wire rope, and fittings required. One hundred percent redundancy allows the mooring vessel to accompany the lift to the next beaching ground, lay a moor after beaching, then return to pick up the old moor and prepare it for relaying at the next beaching ground.

In addition to the mooring vessel, a major lift requires powerful tugs and workboats to move the lift units and suspended ship safely and efficiently. Large ocean tugs are not suitable for this work, particularly where the passage is through confined waters.

Tidal lifting craft should not make side lifts in appreciable swell. Lift ships with the lift wires independently pinned on heavy bitts cannot render, and will part lift wires in heavy swell.

Side lift craft, in which the pairs of lift wires are clamped together, are free to render and are more tolerant of swell. The lift craft rolling inside the wire bight hazards the clamping system.

Operations will be expedited by providing a deck barge with a crawler crane aboard alongside the lift craft. Handling long bights of heavy wire with deck capstans and winches is time-consuming, labor-intensive, and physically exhausting. A crane with a long boom can handle the wires more efficiently than a large team of men.

The old expression "Time and Tide Wait for No Man" (and no lift craft) was clear to the first salvor who made a tidal lift—and every one since.

12-5 MECHANICAL LIFTS.

To make mechanical lifts, salvage units heave on wire ropes or chain rigged around, through, or underneath a sunken ship or object. Mechanical lifting in salvage has the following advantages:

- Independence of tidal rise and fall
- Positive control of lift and lift rates
- Smaller crews than required for tidal lifting
- Ability to make lifts in moderate swells and in open waters.

The following types of mechanical lifts are made in salvage:

- Bow lifts by ARS- and ATS-type ships
- Stern lifts by ARS-50 Class ships
- Combined bow and stern lifts using both the bow and stern rollers on board the ARS-50 Class ships
- Bow and stern lifts by purpose-built salvage ships or lift craft
- Bow lifts by converted barges of opportunity
- Stern lifts by seagoing derrick barges with fully revolving (whirley) cranes
- Lifts by seagoing salvage sheer legs
- Combined lifts by purpose-built salvage lifting equipment using either derricks or sheer legs and deck tackles.

Combined lifts usually double the lift capacity that can be obtained from a single salvage lifting unit; however, there is a correspondingly higher degree of skill and coordination required. Lifts may be made with several lifting units employing different techniques. In these cases, lift positions and underway movement require careful planning and coordination.

12-5.1 Salvage Ship Lifts. ARS salvage ships have bow lift systems that can be used to supply all or part of the lift force needed to recover a ship or other object. These bow lifting systems may also be used to provide a parbuckling, or uprighting, force and for chain cutting and demolition operations. All Navy salvage ships are limited to a maximum bow lifting capacity of 150 tons.

CAUTION

The standard beach gear purchase rigged luff-on-luff to haul the ⅞-inch bow lifting purchase may part the heavier wire if overloading is permitted. The load on the bow lifting purchase should be monitored with a dynamometer or by the *MT1* method.

12-5.1.1 The ARS-50 Class Heavy Lift Systems. The ARS-50 Class ships can make heavy lifts at either the bow or stern and may make a combination lift by using the bow and stern lifts together. In a bow lift, the two main bow rollers are used to make a maximum lift of 150 tons. When the bow rollers are used in conjunction with the stern rollers, a total lift of 300 tons may be made on four wires.

Figure 12-17 shows the general arrangement of equipment aboard ARS-50 Class ships for making a 150-ton lift with conventional tackle over the bow rollers.

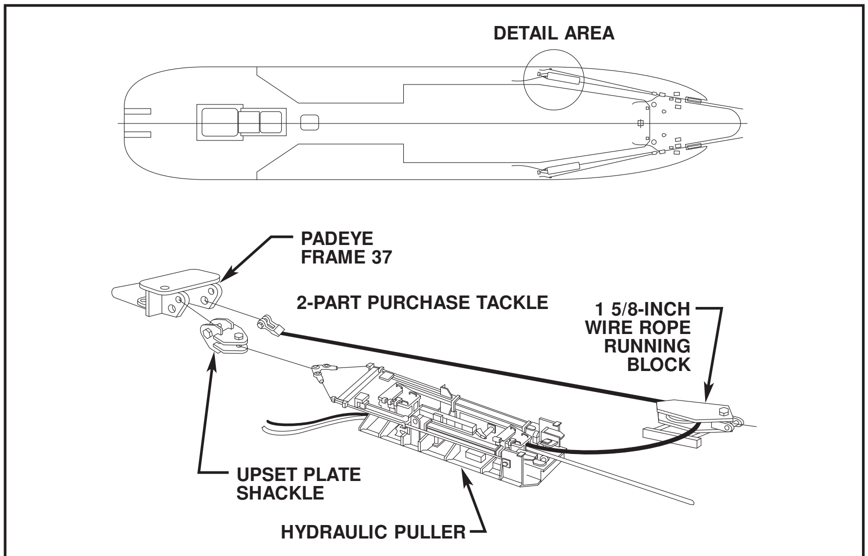


Figure 12-17. General Arrangement for ARS-50 Class Bow Lift.

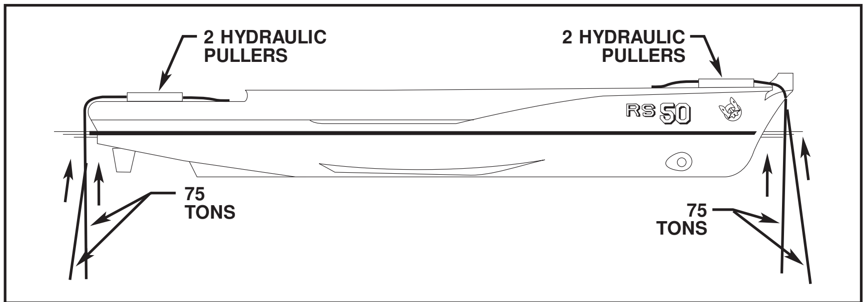


Figure 12-18A. ARS-50 Bow and Stern Lift Configurations.

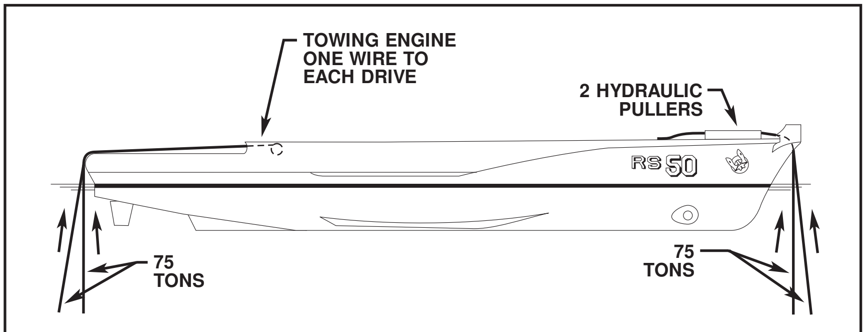


Figure 12-18B. ARS-50 Bow and Stern Lift Configurations.

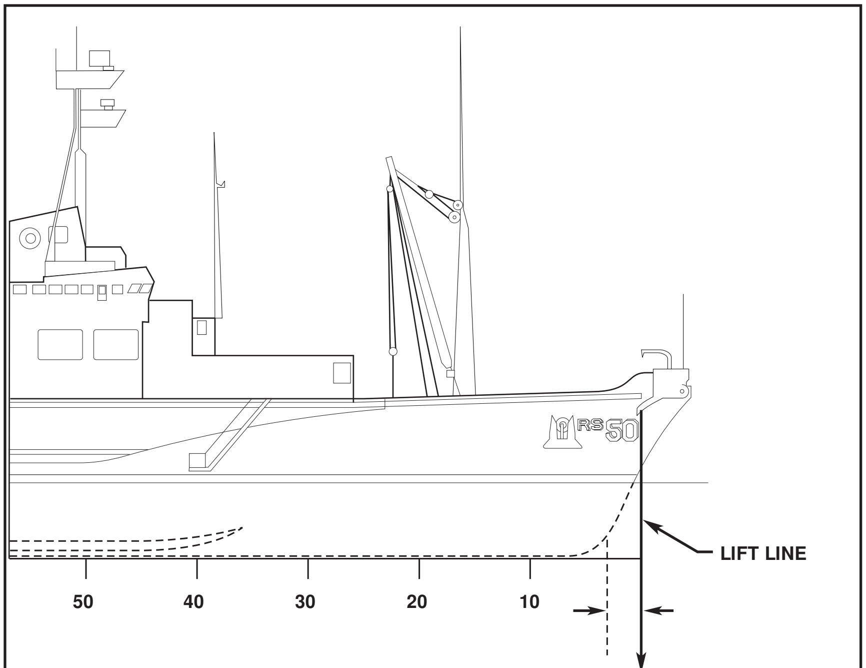


Figure 12-19. Plumb Line ARS-50 Bow Lift.

With two combinations of deck machinery, the ARS-50 Class ships can make bow and stern lifts of 75 tons per wire. These arrangements include:

- Main bow roller lift of 75 tons per wire with deck purchases made in conjunction with a pair of hydraulically powered linear pullers, each pulling 75 tons over the stern rollers
- Main bow roller lift of 75 tons per wire with hydraulically powered linear pullers in conjunction with both drums of the towing machine lifting 75 tons over each of the stern rollers.

Figure 12-18 illustrates these lifting combinations.

As shown in Figure 12-19, the ARS-50 Class has a clipper bow that extends the main bow roller lift plumb line outboard of the forward perpendicular. Despite this arrangement, care must be taken to prevent fouling the surfaced lift on the bow structure.

12-5.1.2 <u>Bow Lifting Salvage Ships</u>. Purpose-built bow lifting salvage ships are operated by some foreign commercial and military salvage organizations. These ships are capable of making bow lifts of between 200 and 300 tons each. Many of the craft are multi-functional, although their bow-lifting role in salvage, net tending, and mooring work dominates. The design of these vessels is typically characterized by:

- A broad-beamed, open forward deck with a pair of heavy lifting horns projecting forward of the bow
- Powerful winches placed to service the forward deck and to haul the heavy bow lifting purchases
- A variety of heavy purchase anchoring points near amidships for securing the standing purchase blocks
- A bow design that allows heavy objects to be brought to the surface without great concern that they will contact the ship's structure.

Generally, these ships get their bow lifting power through sets of 125-ton, sixfold purchases rigged with 1⅛- or 1¼-inch wire rope. Two purchases are used—one for each bow horn roller or lifting sheave. Because the bow lifting role is dominant in these ships' purchases, fleet lengths of 90 to 100 feet are common. The ships have great flexibility in their lift capability.

Figure 12-20 shows the bow lifting arrangement of the Royal Navy's SAL-Class Mooring and Salvage Vessel.

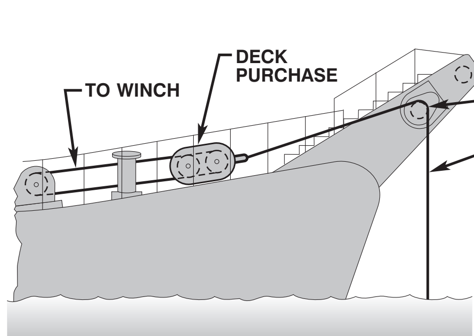
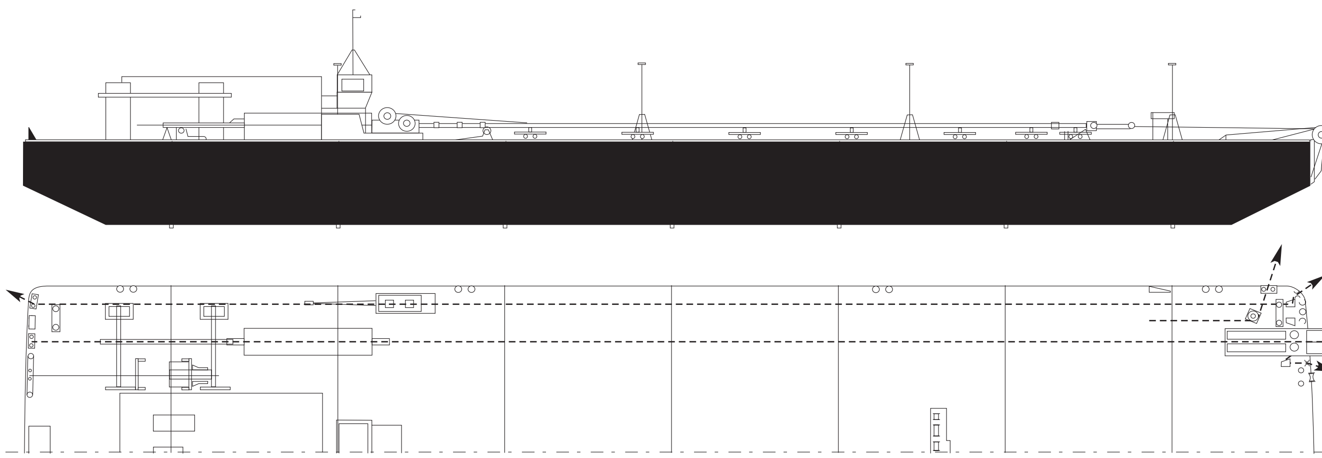


Figure 12-20. Elevation, Royal Navy SAL Class Salvage Ships.

12-5.2 Specialized Lift Craft. Specialized craft designed for making mechanical lifts in salvage are operated by commercial and military salvors throughout the world. These craft are generally highly specialized and of unique design.

12-5.2.1 Bow-lifting Salvage Barges. Commercially operated bow-lifting salvage barges with lift ratings up to 3,000 tons are in service. These barges have been used successfully for bow lifting and direct pulling in refloating and parbuckling operations.

The barge illustrated in Figure 12-21 is fitted with two independently controlled electro-hydraulic pulling units, each capable of exerting a maximum force of 1,500 tons. The hydraulic pulling units apply their power through a sectional, collared pulling shaft connected to a yoke plate. The yoke plate incorporates a complex, equalizing purchase sheave assembly. A series of wire slings with equalizing roller shackles leads underneath the ship or wreck section to be lifted.



DIMENSIONS : LENGTH 316 FEET
BREADTH 84.36 FEET
DEPTH 19.84 FEET
LIFTING CAPACITY 3,000 TONS

DESCRIPTION OF EQUIPMENT

PULLING UNITS : THE PONTOONS ARE SEPARATELY FILLED WITH 2 INDEPENDENTLY CONTROLLED ELECTRO-HYDRAULIC PULLING UNITS EACH CAPABLE OF EXERTING A FORCE UP TO 1500 TONS.

COLLARED PULLING SHAFT : TWO ON EACH PONTOON. EACH SHAFT CONSISTS OF SEVEN SECTIONS OF EIGHT METERS IN LENGTH.

TRAVELING DISTANCE : 157 FEET

TRAVELING SPEED : 6.6 INCHES PER MINUTE IN STOPS OF 6.6 FEET

REVERSE SPEED : 3 MINUTES PER 6.6 FEET

CONTROL ROOM : THE HYDRAULIC UNITS ARE ELECTRICALLY CONTROLLED AND MONITORED FROM INSIDE A RAISED CONTROL ROOM FROM WHICH THERE IS AN UNINTERRUPTED VIEW OF THE WORKING AREA.

BOW ROLLERS : BOW ROLLERS OF EACH SYSTEM ARE DESIGNED TO OPERATE UNDER FULL LOAD.

MOORING SYSTEM : EACH PONTOON IS EQUIPPED WITH AN INDEPENDENT 4-POINT MOORING SYSTEM THAT PROVIDES A HIGH DEGREE OF MANUVERABILITY ON EACH LOCATION.

ELECTRICAL POWER : MAIN ELECTRICAL POWER FOR THE HYDRAULIC UNITS, DECK FLOOD-LIGHTING, AND NUMEROUS POWER UNITS THROUGHOUT EACH PONTOON IS PROVIDED BY A 250-Kva,

440-V, 60-CYCLE DIESEL GENERATOR AS BACKUP. FOR IN-PORT AND LOW CONSUMPTION PURPOSES THERE IS A 15-Kva, 220-V, 60-CYCLE UNIT.

STANDARD EQUIPMENT : EACH PONTOON IS FITTED WITH A WORKSHOP AND SALVAGE STORE EQUIPPED WITH COMPREHENSIVE RANGE OF HAND TOOLS, ELECTRIC SUBMERSIBLE PUMPS, ROPES, SLINGS, SHACKLES, ETC. TO PROVIDE ALL THE NECESSARY AUXILIARY EQUIPMENT FOR A MAJOR OPERATION.

WRECK POSITION INDICATED : A COMPUTER MONITORS SENSORS PLACED ON THE WRECK AND PROVIDES A REAL-TIME DIGITAL READOUT OF DEPTH, TRIM, AND HEEL.

Figure 12-21. Pull and Lift Barge.

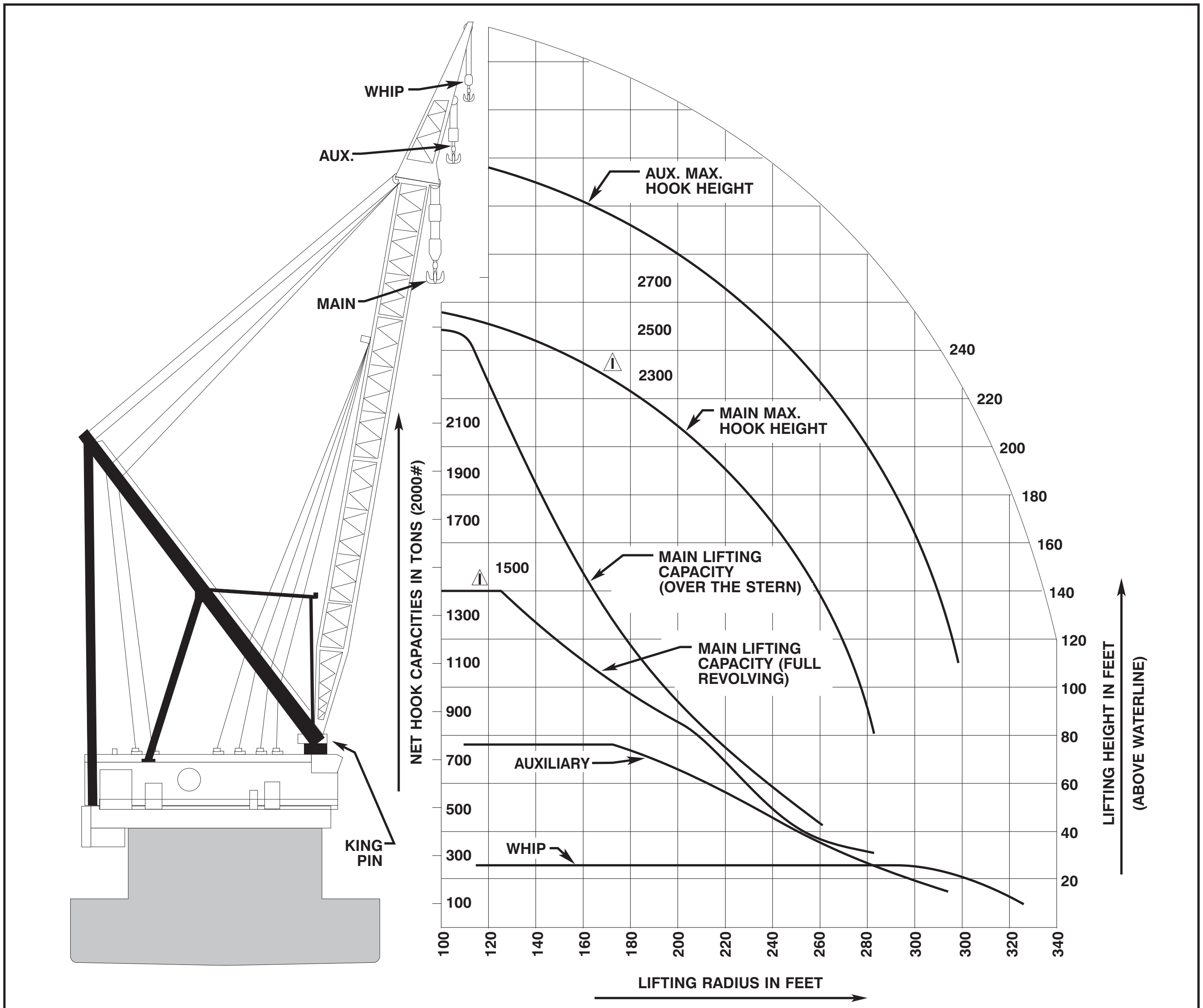


Figure 12-22. Typical Offshore Derrick with Lift and Lift Curves.

The collared pulling shaft consists of seven sections, each about 26 feet 3 inches long, configured to fit the stroke of the hydraulic pullers. The nominal travel distance for the shaft is 157 feet at a pulling rate of 8 feet per minute. Stops are located 80 inches apart.

The design and lifting configuration of these barges are such that the barges may be operated only in matched pairs to lift sunken ships. They may be operated singly for parbuckling capsized vessels.

Barges may be converted for bow lifting using conventional purchase systems such as the standard beach gear purchases and hauling equipment available in the ESSM System. Technical information and specifications for such conversions may be obtained through the Supervisor of Salvage.

12-5.3 Derricks and Sheer Legs. The development of welding technology, coupled with the commercial requirement for heavy offshore lifts associated with oil field construction, has resulted in numerous offshore construction derricks suitable for salvage. Large-capacity sheer legs, many specialized for salvage lifting, have also been built. These devices give the salvor more options than previously available for heavy lifting in harbor clearance and wreck removal.

12-5.3.1 Derricks. Seagoing derrick barges are available with lift capacities of 600 to 3,000 tons in conventional monohulls, and larger capacities in catamaran and semi-submersible hulls. The largest known capacity at this writing is 14,000 tons. Most offshore derrick barges are multi-functional craft that combine fabrication, construction, and accommodation facilities in a single hull. The fact that the vessels are large, integrated, self-contained industrial complexes sometimes militates against their integration into a salvage effort. Their size and complexity works against them; smaller, single-purpose tools can sometimes do the job better and less expensively.

The derrick or whirley crane is usually positioned near the barge's stern on a substantial structure known as a *crane tub*. The crane usually has three lifting systems: a main hook of the rated capacity at a relatively short radius, and an auxiliary hook and a whip hook that have substantially smaller capacities at greater radii. Figure 12-22 shows a typical offshore derrick and its lift curves. It should be noted that the radius for lifts is measured from the crane kingpin and is quite close to the barge. The proximity of the main lift to the barge is often a limitation in salvage.

The lift on the main hook may be substantially increased (15 to 20 percent) in what is known as a *tied-down* or *guyed* lift. This type of lift is made with the derrick pointing directly aft over the stern and secured so that it cannot rotate. When a tied-down lift is made, moving the suspended lift means repositioning the derrick barge. As the derrick barge is usually placed in an 8- to 12-point moor, repositioning beyond the limits of the moor is a major evolution.

Derrick barge employment for heavy lifts in harbor salvage and wreck removal is limited by the costs and characteristics of the units. These factors must be balanced against the advantages to determine the viability of this type of unit in a particular operation. Limitations on the effectiveness of offshore derricks in salvage operations include:

- The physical size of the barge on which the derrick is mounted limits its effectiveness. Sometimes it is physically impossible to position the large barge for lifting operations. If the barge must be positioned too far from the object to be lifted, the lift capacity may be unacceptably reduced, or the lift system may be overloaded.

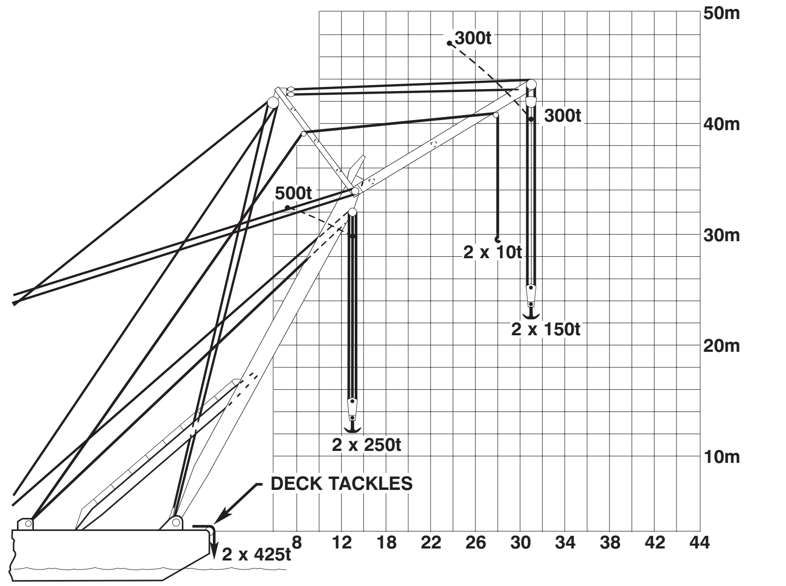


Figure 12-23. Typical Outreach and Lift Diagram, for Salvage Sheer Legs.

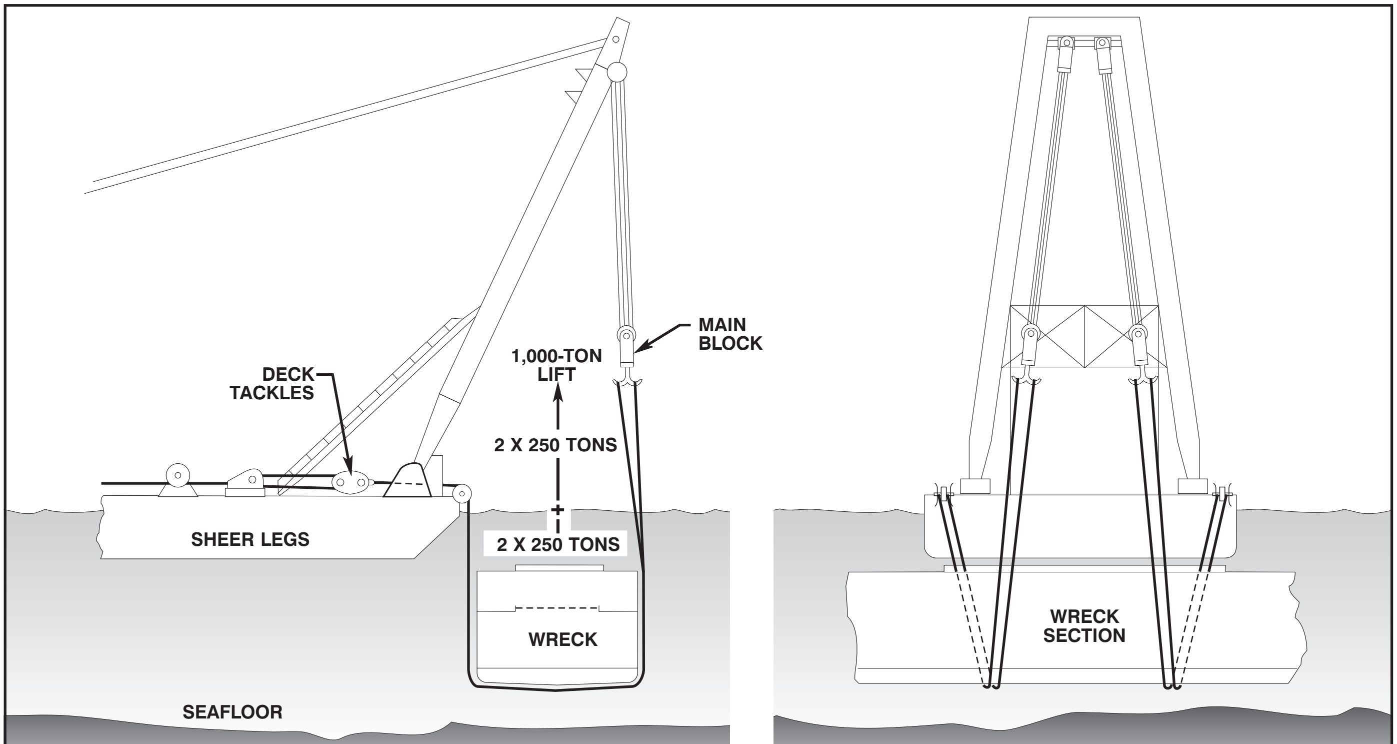


Figure 12-24. Typical Working Arrangements on Salvage Sheer Legs.

- The mooring of a derrick barge is usually very complex and requires specially equipped, powerful anchor handling workboats to lay, pick up, and reposition anchors and associated mooring equipment.

- Offshore derrick barges' lift capacities are governed by strict limits on list, trim, and sea state. All of these limitations can be exceeded easily in salvage.

- When derrick barges make lifts that are acted upon by currents, the lifting system can be overloaded. Wires rigged to the object to hold it into the derrick barge have limited effectiveness in salvage lifting.

- Some hulls, especially semi-submersible types, may draw so much water that they cannot be brought close to the wreck.

- Offshore derrick barges are generally used in carefully planned and engineered operations that bear little resemblance to *ad hoc* salvage operations. When offshore derricks are used in salvage operations, the salvors must carefully and thoroughly coordinate the operation with the derrick operators.

The high cost of derrick barges may dictate that they be brought into operations for short periods and specific purposes. Employment of such high-cost assets must be balanced against their effectiveness and the benefit gained from them. Because of their size and variety of on-board facilities, derrick barges make good bases for harbor clearance operations. In addition, they may serve as a floating accommodation complex and provide fabrication facilities and logistic support for the entire operation.

12-5.3.2 Sheer Legs. Sheer legs mounted on seagoing barges, as illustrated in Figure 12-4, have performed effectively in many salvage, wreck removal, and harbor clearance operations. Tasks performed by sheer legs include:

- Lifting entire ships or sections of wrecks to remove obstructions from harbors and channels
- Cutting sunken ships and wreckage into manageable lift sections by chain-cutting, wreck grabs, or tearing
- Removing partially buried wrecks by demolishing hull sections with wreck grabs
- Making additional or stabilizing lifts on sunken ships that are being raised by a combination of restoration of buoyancy and external lift
- Providing forces to parbuckle, or right, capsized ships.

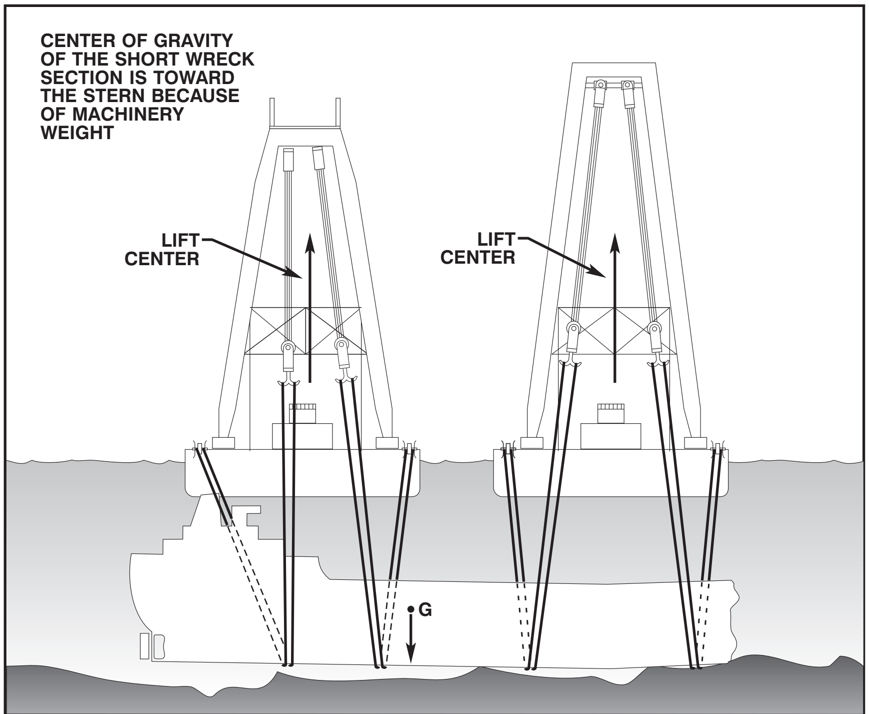


Figure 12-25. Lift of Short, Heavy Section with Two Sheer Legs.

Salvage sheer legs lift by means of heavy lift tackles hung from heavy fixed or luffing A-frame structures (sheer legs) normally mounted on the forward end of the pontoon. Purchases usually have a capacity of between 200 and 300 tons per set. Additional purchases of comparable capacity may be rigged on deck to double the lift capacity. Figure 12-23 shows a typical outreach and lift diagram for a typical 500-ton capacity sheer leg equipped with two deck tackles. Figure 12-24 shows typical working arrangements on salvage sheer legs.

Salvage sheer legs have several advantages for lifting:

- They can make lifts on their sheer leg tackles on either two, three, or four hooks—depending on the configuration of the particular A-frame.
- They are not constrained by tide and are not dependent upon tidal buoyancy.
- The sheer legs are short and heavily constructed compared to the booms of derrick barges. By design, sheer legs can accept and withstand some amount of the racking and misalignment that develops in open sea lifting operations.
- With several main lift hooks, salvage sheer legs can accept varying sling lengths and lift angle irregularities that would not be acceptable for derricks with a single hook.
- Sheer legs are physically smaller, requiring less elaborate moors than derrick barges.
- Most units are self-propelled and thereby have considerable independence on-site. The propulsion and maneuvering systems are generally sufficient for close work around wrecks and in harbors. Salvage sheer legs require tug assistance when moving large lifts.
- Most salvage sheer legs are designed so that their A-frames may be rigged down for tow. The A-frame is self-erecting.

Despite being designed specifically for salvage, sheer legs have some limitations in these operations:

- Several sheer legs may be required to accomplish the same lift that could be made by only two lift craft. This disadvantage is somewhat balanced by the sheer legs' ease of rigging and independence from the tide. The choice depends upon the condition of the particular casualty.
- Few salvage sheer legs are able to match the lifting heights or outreach spotting ability of derrick barges. This is a serious limitation only when wreckage is to be lifted clear of the surface and placed on a dry dump site.
- Unlike the derrick barge incorporating a whirley crane, sheer legs cannot reposition a lift without moving the pontoon. When more than one sheer leg makes the lift, the entire lifting unit must be maneuvered together.
- As illustrated in Figure 12-25, when two or more sheer legs are used alongside one another, and a short, heavy section is to be lifted, the lift may be difficult to balance because of the distance between effective lift centers necessitated by the breadth of the sheer legs' pontoons.

12-6 MISCELLANEOUS LIFTS.

The salvor should always be alert to facilities for making lifts that are not conventional. Floating drydocks, designed to lift by deballasting, have been used in salvage as belly lift vessels and have been cut down and rigged as paired lift craft. The submersible heavy-lift ship in general maritime service offers interesting possibilities for salvage lifting. Industrial equipment and machinery used in a variety of industries—construction, logging, and heavy metal fabrication—may be used for salvage. The only limit on the tools that can be used for salvage lifting is the imagination of the salvor.

CHAPTER 13
WRECKING IN PLACE

13-1 INTRODUCTION.

Preceding chapters have discussed techniques for raising, refloating, or moving intact sunken ships from locations where the casualties occurred. Sometimes the condition of a sunken or stranded ship is so poor that the ship can be classified only as a "wreck" that cannot be returned to service. Where wrecks are a navigational or environmental hazard, or an obstruction to port operations, salvors must remove them. As it may be possible to refloat only a section, salvors must dismantle some or all of the wreck. Dismantling is called *wrecking in place*. This chapter discusses some principles and techniques applicable to wrecking in place. Some techniques—such as flattening wrecks below an acceptable navigational datum or burying wrecks beneath the mean seafloor line—may be confined solely to wrecking operations. Other techniques, such as partial hull demolition, may be applied to one section of a wreck, while the remaining section of that wreck is refloated by conventional means. Salvors should approach wreck removal tasks with an open mind, and be prepared to combine wrecking in place with conventional refloating. All wreck removal operations require close attention to cost and schedule.

Wrecking in place is also called *piecemeal demolition*. To some extent, the terms are interchangeable, although piecemeal demolition implies the entire wreck will literally be dismantled *in situ*.

13-2 GENERAL PRINCIPLES.

13-2.1 Reasons for Wrecking in Place. Badly damaged sunken or stranded ships that create navigation or environmental hazards or obstruct port operations are often partially or entirely wrecked in place. Reasons for wrecking ships in place include:

- Damage sustained by ships is so severe that the repairs necessary for conventional refloating are a waste of labor and material. If it would take longer to patch, pump, and prepare a ship for refloating than it would to demolish the ship, wrecking in place is a viable option.
- Tactical, logistic, or operational situations may not allow salvors time to prepare for conventional refloating. This is particularly true in harbor clearance following combat casualties or natural disasters. Military requirements to clear deliberately blocked harbors often require elements of wrecking in place to allow access to ports and berths.
- Environmental considerations—particularly relative to removal of wrecks that create potential hazards to animal and plant life. Sometimes, wrecking-in-place techniques that do not cause further environmental damage can overcome the environmental problems posed by the wreck.
- Comparatively low priority of a wreck-removal task, combined with shortages of heavy lifting equipment and skilled salvors, may influence decisions in favor of wrecking in place. Some nonurgent wreck removal tasks are suitable for training salvage and diving personnel and may be held in reserve for that purpose.

13-2.2 Wrecking-in-place Methods and Techniques. Wrecking-in-place operations employ several specialized methods in addition to normal salvage techniques. These methods can be classified very broadly as:

- Manual cutting by divers and surface workers
- Mechanical demolition using heavy lift cranes
- Explosive sectioning, dispersal, or flattening
- Burial or settling by hydraulic dredging.

Each method has its own particular equipment requirements, operational techniques, and specific advantages and disadvantages. A method that is operationally suitable and acceptable for one wreck may be technically impractical or environmentally unacceptable under different circumstances. Salvors must determine what method, or combination of methods, is most suitable for their wreck and if appropriate equipment is available. Where the opportunity exists, salvors may combine wrecking in place with conventional salvage techniques.

An example of combining both wrecking-in-place methods with conventional salvage occurs when salvors deliberately cut a wreck into two sections. The buoyant section is floated away, leaving the heavily damaged hull section to be wrecked in place. Wrecking in place tends to be both labor- and diver-intensive when heavy mechanical methods are not available. Explosives are often used for underwater cutting to reduce diving time and expedite operations. In other circumstances, salvors may combine several wrecking-in-place methods to remove a ship.

13-2.2.1 Manual Cutting. Manual cutting by divers and surface crews is the most common method of performing small wrecking-in-place jobs and is used extensively on large wrecking operations. Topside crews cut with conventional oxy-acetylene or oxy-arc burning gear, or semiautomatic cutting machines. Divers make underwater cuts with underwater cutting equipment. Topside manual cutting is the most precise wrecking-in-place method, but it is also labor-intensive. Many environmental and wreck-related conditions influence underwater cutting speed and precision.

13-2.2.2 Mechanical Demolition. Mechanical demolition is usually performed by heavy lifting and hauling equipment mounted on floating cranes, salvage sheer legs, salvage vessels, or improvised salvage barges. Mechanical demolition methods include:

- Chain and wire cutting or sawing
- Direct ripping or stressing of weakened steel structures
- Tearing wrecks apart with heavyweight dredging grabs or specially designed wreck grabs
- Smashing wreck sections with wrecking chisels

13-2.2.3 Explosive Sectioning. Explosives are an important wrecking-in-place tool that can be effective in both wreck removal and wreck dispersal operations. Explosive uses include:

- Cutting or breaking hull and superstructure sections
- Pounding or flattening wrecks into the seafloor
- Breaking wreck sections that cannot be handled by other methods
- Dispersing wreck sections or entire wrecks as part of channel clearing operations.

13-2.2.4 Burying or Settling Wrecks. Where seafloor conditions are suitable, and sufficient depth of water exists, it may be possible to dredge a trench, or a series of trenches, for the wreck to settle or skid into as the surrounding soil collapses. To reduce the amount of dredging work, divers cut away the wreck's superstructure, masts, and stacks before dredging begins. Before a wreck is buried, a soil analysis should be made to determine if the soil is suitable for this technique. Excavation for wreck settling or burial operations is done in three principal ways, either singly or in combination:

- Mechanical or profile dredging with clamshell or hydraulic cutter dredges
- Explosives
- High-pressure water jetting or sluice pumping.

In peacetime, wreck burial normally is the least favored method of wreck disposal. While the problem of obstruction of a waterway or berth may be dealt with by burying a wreck, the wreck remains at the site where it may become an obstruction to future dredging or construction. Buried wrecks have been known to work their way back to the surface. Peacetime wreck burials should not be attempted without a thorough civil engineering investigation, consultation with long-term planning authorities, and approval from cognizant or governing environmental agencies.

13-2.3 Problems in Wrecking in Place. There are problems in all types of salvage operations. Weather, tide, surf, and natural phenomena delay or increase the difficulty of the job. Wreck removal and wrecking-in-place operations are subject to all the difficulties of other salvage operations plus:

- A large quantity of unknowns about contents of and extent of damage to the ship
- Stringent safety and accident prevention policies and procedures
- Siltation and subsidence into the seafloor
- The physical working environment relative to port activities
- Removal and disposal of remaining cargo, stores, ordnance, and provisions
- Environmental regulations and restraints
- Acceptable and realistic work plans and schedules
- Equipment, manpower, logistics, and funding limits
- Postoperation cleanup and rehabilitation.

13-2.3.1 Unknowns About the Wreck and Its Contents. Salvage operations to refloat a stranded or sunken ship usually start soon after the casualty occurs. The early start allows salvage personnel to get near-contemporary information about the casualty and its pre-accident condition from operators, ship's personnel, and local officials. Wrecking in place may occur weeks, months, or years after the casualty occurs. The ship's operators, officers, and personnel may have dispersed, or may otherwise be unable to provide information to salvage personnel.

When a wreck has been caused by a catastrophic occurrence, such as a major explosion or fire, it is unlikely that the remaining wreck will be intact. Wrecks caused by major combat damage may contain unexploded ordnance or dangerous cargoes. Those intentionally scuttled by enemy forces may be mined or booby-trapped to hinder salvage or removal. Salvors must survey the wrecks with special care, taking nothing for granted, and making no assumptions about the safety of the wreck and its contents until a thorough investigation is complete. During these surveys, particular attention is paid to fuel, ammunition, cargo, explosives, stores, organic materials, and other items that may be either hazardous or polluting.

Plans must be made and procedures set up, often with the aid of experts, to remove unexploded ordnance and dangerous or hazardous materials before beginning wrecking. Methods of removal must be structured to fully consider safety and pollution control.

13-2.3.2 Safety. Any marine salvage project is hazardous; safety is a major consideration. Wrecking-in-place operations usually take longer to complete than other types of salvage and often combine a long job with tedious, repetitious work. The work force often contains numbers of subcontractor or other personnel who are not trained as salvors. The workplace (the wreck) is gradually being demolished in a heavy industrial environment. With several burning crews working, the fire danger is great and ever-present. It is very easy to have serious accidents; fire prevention is critical. Noxious or hazardous substances are often encountered. Older ships may be laden with asbestos lagging and insulation. Safety must be addressed and reviewed constantly. Detailed safe working practices, fire protection, and fire fighting practice must be the subject of a separate annex to the salvage plan. Safety does not just happen—it must be planned, explained, monitored, and enforced to prevent injuries, deaths, serious failures, equipment destruction, and serious work disruption.

13-2.3.3 Siltation and Subsidence. Earlier chapters of this manual discuss difficulties associated with mud and silt accumulations in sunken and capsized ships. Mud and silt buildup can seriously hamper manual, mechanical, or explosive cutting operations. Where divers are cutting manually, clearing silt or mud away from the cut line and keeping the cut line clear during cutting operations saves much time. Mud and silt increase lifting weights, sometimes to the point where cranes and lifting equipment are overloaded. It is difficult to pass lifting slings or cutting chains around wrecks that have subsided deeply into the bottom.

Mud, silt, and overburden removal may create a messy visual pollution problem that may be unwelcome in some localities. Salvors should make contingency plans for dealing with complaints. Large quantities of mud and silt pumped into the water column by *demudding* operations can clog or foul cooling water or other inlets. Mud and silt accumulations in wrecks can entrap other offensive or hazardous materials and garbage that can create hazardous working conditions. Sections of wreckage containing mud landed ashore for sectioning or dry cutting usually are demudded with high-pressure water hoses before they are cut or sheared. A filthy, muddy, slippery work area will result if housekeeping and trash disposal plans are not made in advance and carried out meticulously.

13-2.3.4 Removal and Disposal of Ships' Contents. Plans for wrecking in place must consider problems that occur because payload, stores, and provisions usually remain in wrecks. In this context "payload" means: cargo, ordnance, explosives, and other items of military importance. Ships load, stow, carry, and offload payload while basically upright and intact. The designed access, discharge, and delivery systems of sunken or damaged wrecks may be destroyed or inaccessible by conventional methods.

Wrecking-in-place crews must determine how payload, stores, and provisions will be removed from the wreck or from each section of the wreck. Removal of ordnance, weapons, explosives, and pyrotechnics normally takes first priority. Following closely is the removal of organic material that forms noxious or dangerous decay products. The possibility of finding unexploded ordnance, including missile propellants, at all stages of the demolition must be kept in mind when wrecking warships, combat casualties, and intentionally scuttled ships. Dry cargo and stores, normally stowed horizontally or vertically, can be displaced or jammed into very strange attitudes in wrecks caused by combat, scuttling, or natural disasters.

Access to and removal of cargo to permit wrecking to continue can be a major clearance and rigging evolution requiring careful planning. Recovered cargo, stores, and debris may occupy large amounts of barge or shore storage space. Handling, protection, and disposal of the material may be a major logistical and environmental operation. Heavy mechanical wrecking-in-place methods, like sawing with chains, can overcome many cargo obstructions. These same operations create other problems because mangled and cut cargo falls out of wreck sections when they are being lifted.

13-2.3.5 Environmental Regulation and Constraint. In all but purely military operations in wartime, wrecking-in-place operations are usually subject to the same environmental protection rules, regulations, and guidelines as other marine or harbor industrial activity. Salvors performing harbor or coastal wrecking operations often believe that environmental protection rules hinder their work. The rules are seldom waived because of the special circumstances of the work. While local regulations concerning matters such as explosives storage and handling and permissible charge rates may be negotiable, wrecking plans should not be based on any exceptions to environmental rules. Navy salvors should **never** expect environmental protection rules to be waived for them. They should set an example of efficient, effective work within the rules.

Wrecking in place invariably generates pollution in the form of:

- Unintentionally liberated cargo and debris
- Mud, silt, and solids in the water column
- Offensive garbage and trash liberated during the work
- Accidental spills of residual oil.

Control of these forms of pollution is an essential part of wrecking-in-place work and should be addressed thoroughly in an annex to the salvage plan.

Some wreck removal or wrecking-in-place operations are conducted solely for environmental or rehabilitation reasons. Extra restraints may be placed on these operations. Garbage disposal, water cleanliness, and protection of flora, fauna, and coastal areas are all matters that come under environmental protection in wrecking-in-place operations.

13-2.3.6 Realistic Plans and Schedules. The nature of casualty operations is such that plans develop around available assets and personnel on an *ad hoc* basis. These plans are subject to rapid change as weather and casualty circumstances change. Delays and postponements are the rule rather than the exception. Although casualty salvage operations are time-critical, some delays, however unwelcome, are acceptable because the operational purpose is to refloat and redeliver the casualty for further service.

Equipment and personnel provided by naval activities or from third party sources often are committed to other work at the end of the wreck removal. When wrecking-in-place plans are deficient and the project schedule slips badly, equipment and personnel continuity is jeopardized, and costs escalate.

Port and area planning and operations authority usually has broader responsibilities than the one wrecking job. Authorities structure other port operations and priorities around the schedules they are given for the wreck removal. Cargo movements into the port may be scheduled on specialized shipping while the wreck removal is in progress or delayed until the operation completes. Wrecking-in-place operations delayed because of poor planning and task evaluation may disrupt broader operational plans and embarrass salvors. Salvors should remember that the port user is the ultimate customer, to whom they owe a job professionally planned, scheduled, and executed. Some delays are often inevitable because of unforeseen circumstances. Gross delays caused by failure of the wreck removal plan to recognize problems detected during surveys are not acceptable.

Overly optimistic wrecking-in-place plans that do not address all aspects of a job have a habit of backfiring. Pessimistic plans, based on simply doubling or tripling times for each operational evolution are equally unacceptable. Both types of unrealistic plans must be avoided. Plans for wrecking in place must be realistic in timetable, labor requirements, logistics support, and equipment schedules.

Frequently, the single most detrimental effect of schedule slippage is cost escalation. Unless being performed exclusively using DOD resources (which is seldom the case), the operation will incur a very high daily operating cost, especially if large commercial lifting platforms are on hire. Because salvage operations are seldom budgeted, the activity or command funding the operation will have already degraded mission-related programs to fund the salvors' initial estimate. Major cost overruns are therefore not favorably received.

Affected commands and port operating authorities should be briefed thoroughly on the wreck removal schedule and any areas of prospective technical or logistic uncertainty. Operations staffs do not like problems that cannot be quantified readily in "delay days." They prefer warnings before an operation starts and regular updates on how particular problems are being handled.

13-2.3.7 Post-operation Cleanup and Rehabilitation. Combat casualties and catastrophic accidents, such as large explosions, usually result in ships' structural debris and contents being scattered on the seafloor around the wreck. Experience with ammunition ship explosions has shown that all the cargo munitions do not detonate in a massive explosion, but are scattered around the wreck where they present an unexploded ordnance hazard. Wrecking-in-place operations drop debris in the immediate vicinity of the work areas and en route to dumping or disposal sites. Ordnance, debris, and other material from casualties and wreck removals may present a hazard to navigation that port authorities will not tolerate. In most wreck removals, salvors are responsible for locating, identifying, and removing all underwater debris during or after operations. Salvors may utilize side scan sonars, underwater television systems, and/or divers to identify and buoy off debris before removing it. In peacetime, port authorities make final "site clearance" surveys after salvors have completed debris recovery. In some locations, local authorities may require drag bar or wire sweeps in addition to side scan and echo sounder surveys.

Cleaning up shore sites may or may not be the responsibility of the salvors. When salvors are responsible, they must carry out the operations required by local authorities and regulations. In environmentally sensitive areas, salvors may have to make special arrangements to dispose of domestic garbage and the trash generated by wrecking-in-place operations.

13-3 PLANNING WRECKING-IN-PLACE OPERATIONS.

Paragraph 13-2.3.6 discussed the basic rationale underlying development of wreck removal and wrecking-in-place plans and schedules. This section outlines practical matters that must be evaluated as part of the general formulation and implementation of wrecking-in-place plans.

13-3.1 Wrecking-in-place Plans. Wrecking-in-place plans are developed from the wreck survey, the area or port authorities' requirements, and an analysis of the salvage and wrecking assets available.

13-3.1.1 Port Authority Requirements. Wrecking plans must address the requirements of the area or port operating authority. Removal requirements may include:

- The priority of the wreck removal operation based on the degree of obstruction or disruption to port operations that the wreck causes
- The partial or total removal of a wreck from its location, or reduction of the wreck to a predetermined depth below low water
- Prevention of pollution during wreck removal
- Restrictions on the wrecking work caused by port operations, vessel movements, and environmental matters
- Specification of the location to which the wreck or wreck sections are to be delivered, or instructions for final disposal of the wreck
- Removal from the seafloor of all wreckage, debris, and casualty-related obstructions
- Verification that wreckage has been removed and the area cleared as required.

13-3.1.2 Basic Wrecking Factors. Basic wrecking methods usually are determined by several factors, including:

- The condition of the wreck, as determined by salvage surveys and from relevant information provided by local authorities. The age of the wreck, nature of the damage, and degree of embedment or sinkage into seafloor influence the wreck removal plan.
- Local environmental factors. Tidal currents, swell, surge, and prevailing sea and swell conditions all affect divers' abilities to work effectively and may limit the salvors' options.
- Ability to obtain suitable floating equipment, particularly when the wreck must be totally removed. When the wreck is to be sectioned, availability and capacities of cranes or sheer legs are the controlling factors. The weight and geometry of each section must be compatible with the lifting equipment.
- Value of the wreck and its disposition.
- Availability of personnel with the proper skills and equipment. All wrecking-in-place operations do not require the same mix of skills or the same sequence of applied skills. The wrecking crew must be tailored to the job. Early phases of the wrecking operation may start with local personnel assets, while full crews and equipment are assembled from units in other areas.
- Priority of the wrecking operation. A very high priority expedites equipment and personnel procurement. High priorities may enable salvors to bring in heavier lift equipment and thereby reduce the number of cuts that must be made.
- Funding available – usually the most cost-effective approach is taken.
- Safety of the operation and a safe working environment in and about the wreck.

13-3.1.3 Other Planning Factors. Other factors may influence wrecking-in place planning. These include:

- Survey findings that allow salvors to suggest variations to the original work scope. For instance, salvors may suggest that the objective of the removal could be attained by removal of only the portions of a wreck that obstruct immediate port operations rather than the entire wreck.
- Wreck condition that allows salvors to accomplish complete wreck removal by partial wrecking in place one or more lightened hull sections before refloating. This solution is particularly efficient when enough high weight can be removed by manual cutting.
- Permission to cut explosively. In wartime, particularly in forward areas, permission to use explosives is seldom a problem. In peacetime, local circumstances and regulations may prevent explosive cutting entirely, restrict the size of charges to the point that cutting with explosives is inefficient, or impose severe restrictions on the handling and storage of explosives.
- Degree of practical difficulty in complying with area pollution prevention and environmental protection requirements. Environment-related matters can severely test salvors' patience, work practices, and logistic arrangements, as well as increase costs.
- The ability of salvage equipment to reach the designated disposal site and to land the wreckage ashore safely.
- Safety requirements peculiar to the type of work. Wrecking in place with manual or automatic surface cutting always carries a fire risk. Underwater cutting can generate large quantities of gaseous hydrogen from the dissociation of water. The hydrogen must be vented to the surface to prevent pocketing within the wreck and an explosion hazard. Safety plans must be tailored to the particular operation, have strong fire prevention and control sections, and be enforced rigidly.

13-3.2 Planning a Wrecking-in-place Operation. Wrecking-in-place operations are usually planned on the basis of reducing the wreck to hull sections that can be removed and taken to a disposal site individually. The size and weight of each section is determined by several factors including:

- Construction and weight-per-unit length of the hull section to be lifted
- Lifting capacity and outreach of cranes and sheer legs supporting the work
- Ability of each hull section to withstand lift stresses without collapsing
- Hull damage (A badly damaged wreck may require more subdivision than a relatively undamaged wreck.)
- Amount of entrapped debris, cargo, or silt expected in the wreck
- Allowances for imprecise cutting (The precision of cuts is, to some extent, a function of the methods used to make the cut.)
- Sea and swell conditions that may require allowances for dynamic loads on lift equipment or require delaying lifts
- Cost and potential cost escalation.

13-3.2.1 Effect of Ship Construction. Wrecking in place can be slowed or disrupted by features of the ship's construction. Ships are built to withstand a variety of environmental and man-made forces. Resistance to bending, racking, and collapsing forces is integral to ship design and construction. Construction features that resist shock and vibration add to the strength and structural complexity of the hull. Structural continuity is achieved by long assemblies of steel plates and structural shapes. As shown by the typical double-bottom sections in Figure 13-1, ships' structures are complex. In addition to the structure shown in Figure 13-1, there is piping, cabling, and other fittings. The structural complexity that gives the ship its strength makes wrecking in place difficult. A wreck contains most, if not all, of the structural members of the floating ship. When the ship is sectioned, all of these must be cut completely free to allow the section to be lifted. If a lift is made while structure remains uncut, the crane or its rigging may be overloaded and damaged.

It is relatively easy to confirm that cuts made manually above water are complete and clear. Underwater cutting takes significantly longer than topside cutting. Underwater cuts must be checked, double-checked, and checked again to ensure every structural member, pipe, and cable along the cutline is truly severed and free. Even mechanical cutting by chain sawing and wrecking grabs can be delayed by structural members that do not rip or tear away easily. Allowances should be made in the schedule for the difficulty of making underwater cuts and for ensuring the cuts are complete. Underwater cuts should be made clear of complex machinery and tank spaces whenever possible. Complex spaces may be subdivided into several cuts. It is often more efficient to make several small lifts than to expend the time necessary to cut complex structure and ensure it is completely free for lifting.

13-3.2.2 Weight Estimates. The weight of each section of the ship must be estimated to ensure that its weight is within the capacity of the available lifting equipment. In general, weight estimating is done by scaling the section from the ship's plans and cross-checking against the weight distribution curves. Where accurate plans are not available, careful surveys and measurements must be made. If weight curves are unavailable, salvage engineers must estimate weights from the best available data.

NOTE

Weight curves and their importance are discussed in Chapter 5.

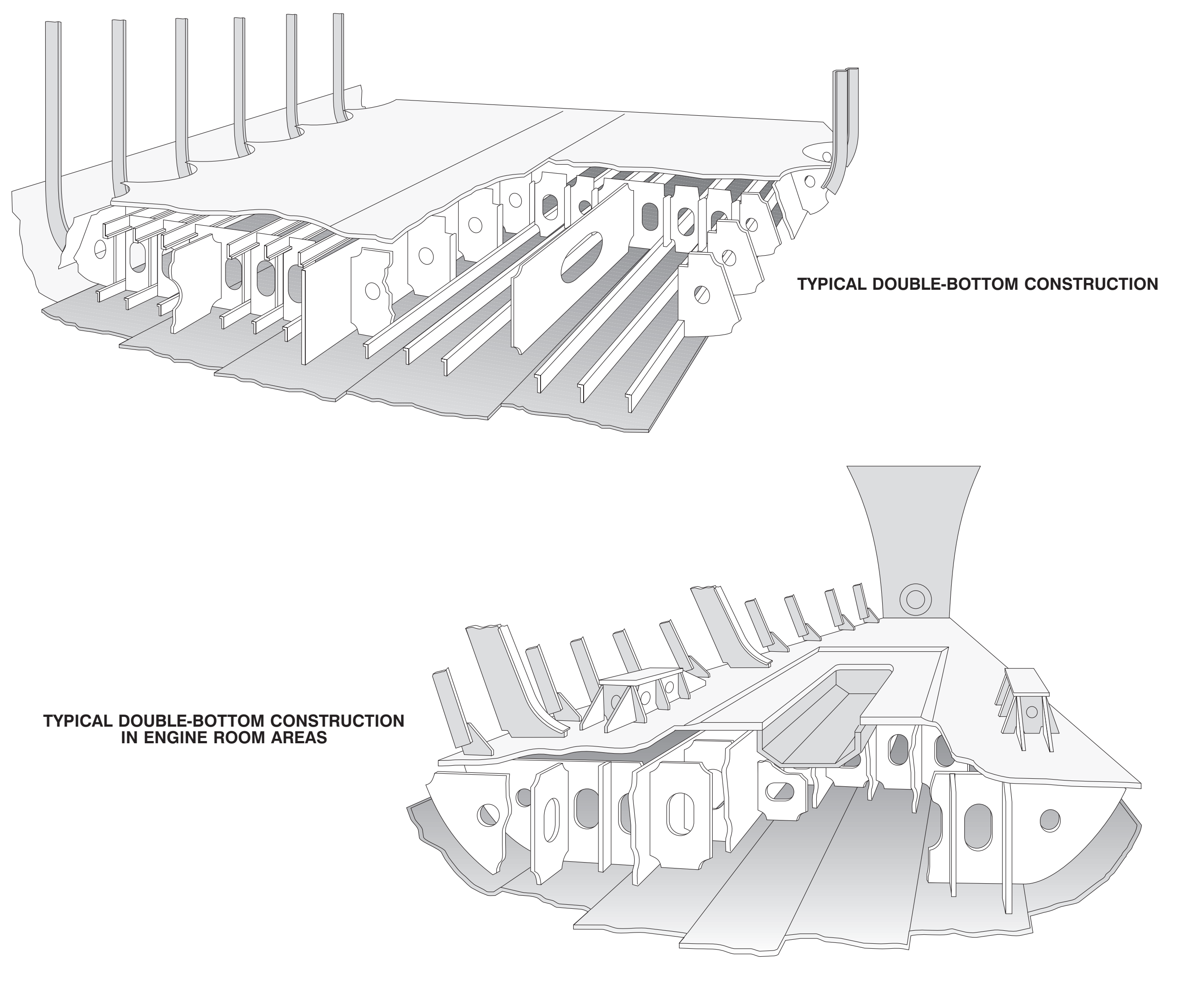


Figure 13-1. Double-Bottom Construction for a Large Tanker.

Figures 13-2 and 13-3 are representative weight curves. Figure 13-2 is for a frigate; Figure 13-3 for a large tanker. For many merchant ships and some foreign warships, the Weight Curve is known as:

- (Builders) Weight Distribution Curve, or
- Construction Weight Curve.

Before reviewing the structural geometry of the section, proposed cut lines for each section are compared with the Weight Curve to approximate the section weight. Cutting may be expedited by moving cutlines short distances to avoid major structural members. Weight estimates must be reviewed to ensure that weights remain within the capacity of lifting devices. Cranes must be able to surface each section without overloading or fouling wreck sections on crane barge hulls.

13-3.2.3 Lift Margins. Because the weight to be lifted is, at best, a careful approximation, an adequate margin between crane capacity and weight lift must be allowed. As a rule of thumb, the maximum planned lift, including cargo, stores, mud, and other entrapped material, should not exceed fifty percent of the rated crane capacity at the outreach required for the job. Crane superintendents may place more severe limits on the lift depending upon the particular circumstances of the work.

Purpose-built salvage sheer legs are more robust and accept dynamic loadings better than offshore construction derricks with single, fully revolving booms. Section geometry and lifting height limit salvage sheer legs.

13-3.2.4 Wrecking-in-Place and Ship Breaking. Wrecking in place is a form of shipbreaking. Salvors are not always able to conduct their operations under the semi-ideal conditions that professional shipbreakers enjoy, but they may be able to borrow shipbreakers' techniques for their work. Large amounts of dry cutting and topside demolition may be expedited with shipbreaking hydraulic shears, semiautomatic cutting, and bulk gas piped to work areas. Any technique that reduces surface or underwater cutting time should be investigated during wrecking-in-place planning.

13-3.3 Examples of Wrecking-in-place Planning. The following hypothetical examples of wrecking-in-place planning address two basic situations. In the first, a badly damaged tanker is removed by a combination of refloating lightly damaged sections and wrecking the most severely damaged section in place. The second example describes the planning for total wrecking in place of a medium-sized dredge. Both examples develop the rationale behind the choice of techniques and are patterned after actual wrecking-in-place operations. Additional reading may be found in the salvage report of the CORINTHOS or the dredge MACKENZIE.

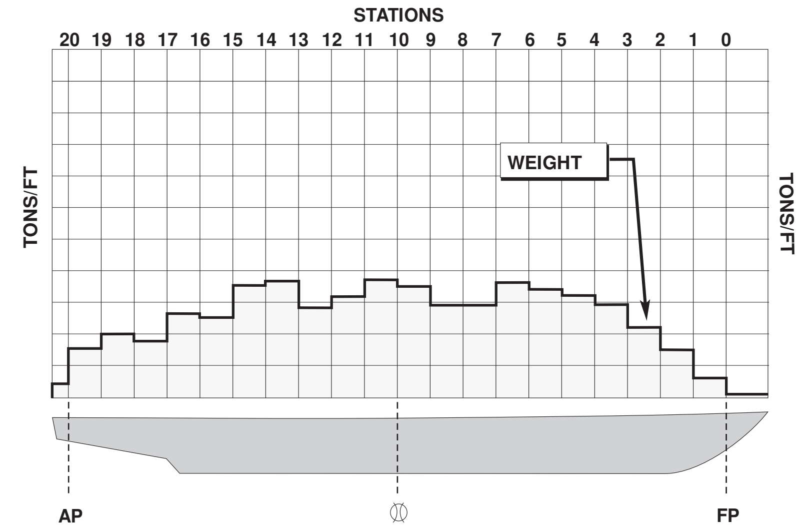


Figure 13-2. Weight Curve for Frigate.

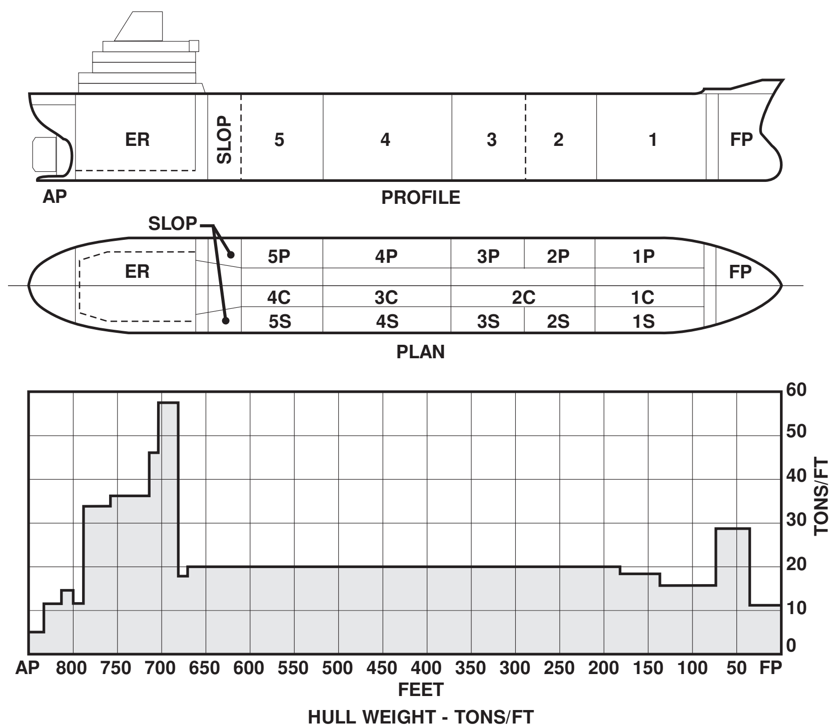


Figure 13-3. Weight Distribution Curve for a Large Tanker.

Logistics management is a crucial element in successful wrecking-in-place operations. Logistics require detailed planning and dedicated, persistent follow-up by project management. A key element in logistics and cost control is scheduling floating equipment—especially the more expensive units such as the heavy lift crane.

EXAMPLE 13-1
REMOVALOF A TANKER

Catastrophic explosions in tankers caused by hostile action, collisions, hull failure, or fires have resulted in badly damaged ships sinking in harbors and at terminals. Almost inevitably, such casualties result in obstruction or blockage of port facilities. The ships are often candidates for removal by refloating relatively undamaged sections and wrecking the badly damaged sections in place. This technique is particularly applicable to modern tankers because the design and construction of these ships allows them to sustain great damage while retaining buoyancy in some parts of their hulls.

Figure 13-4 shows a large, foreign-built tanker that has exploded and sunk alongside an oil terminal. The tanker had a major fire that severely damaged the amidships internal and external structure. From wreck surveys, salvors have established that the wreck can be divided into three distinct sections:

- The stern section - From frames 0 to 60, consisting of the engine room, slop tanks Number 4 center and Number 5 port and starboard tanks
- The midships section - From frames 60 to 75, consisting of Numbers 3 and 4 port and starboard tanks, Number 3 center tank, and part of Number 2 center tank
- The forward section - From frames 75 to the Forward Perpendicular, consisting of Numbers 1 and 2 port and starboard tanks, Number 1 and part of Number 2 center tanks, and the Fore Peak Tank.

Salvage engineering calculations have shown that there is insufficient strength remaining between Frames 60 and 75 to refloat the ship in one piece.

Wreck removal plans develop on the basis of:

- Aft section - Refloat by dewatering all flooded spaces aft of the port and starboard slop tanks. Separate from midships section at Frame 58/59 by a combination of oxy-arc and explosive cutting. Leave Number 4 center and Number 5 port and starboard tanks open to the sea. Lift with cranes at Frame 56-57 to stabilize the stern during towing.
- Repair local blast damage in Number 2 starboard wing tank in way of the bulkhead at Frame 75. Separate from the midships section at Frame 74, leaving Number 2 center tank open to the sea. Cut the hull with explosives and oxy-arc. Forward section does not require external stabilization.
- Wreck the midships section in place following removal of the after and forward sections.

CONTINUED

EXAMPLE 13-1 (CONTINUED)
REMOVALOF A TANKER

Figure 13-5 shows the first two phases of wreck removal. Proven salvage methods have converted the tanker into two floating sections and one sunken section that is too badly damaged to be removed by any method other than wrecking in place.

From the weight curve for the tanker, Figure 13-3, it can be seen that the midships section weighs approximately 20 long tons per foot, giving a total weight for the section of 5,500 tons. If the crane whose lifting characteristics are given in Figure 12-24 is available, lifts of 1,400 tons may be made at a maximum outreach of 115 feet. Following the rule of thumb given in Paragraph 9.2.2.3 that planned lifts should not exceed fifty percent of lift capacity, a maximum lift of 700 tons is permissible. Examination of the ship's structural plans and laying out cuts to avoid transverse bulkheads and deep web frames shows that it is convenient to divide the ship's midships section into approximately equal transverse sections, then divide each transverse section horizontally into sections of approximately 500 tons each. Retaining the bulkheads and deep webs in the sections gives them sufficient strength and rigidity for lifting without reinforcement. Figure 13-6 shows the cutting plan for the midships section.

A wrecking-in-place operation of this type is largely an underwater cutting operation requiring a great deal of skill and patience by divers, their supervisors, and topside support crews. The construction of the cargo tanks lends itself to explosive cutting with linear shaped charges, but a large amount of manual cutting is required. Debris and damaged structure resulting from the original explosion must be cut away and each cut line made safe for divers to work through.

A large (e.g., 240×70×16) support barge fitted with a multipoint mooring system and a 200- to 300-ton crawler crane with a 150- to 180-foot boom would be required along with barges to haul away minor debris. Barges will also be required to carry away the major hull sections. Tugs and workboats are needed to support the operation.

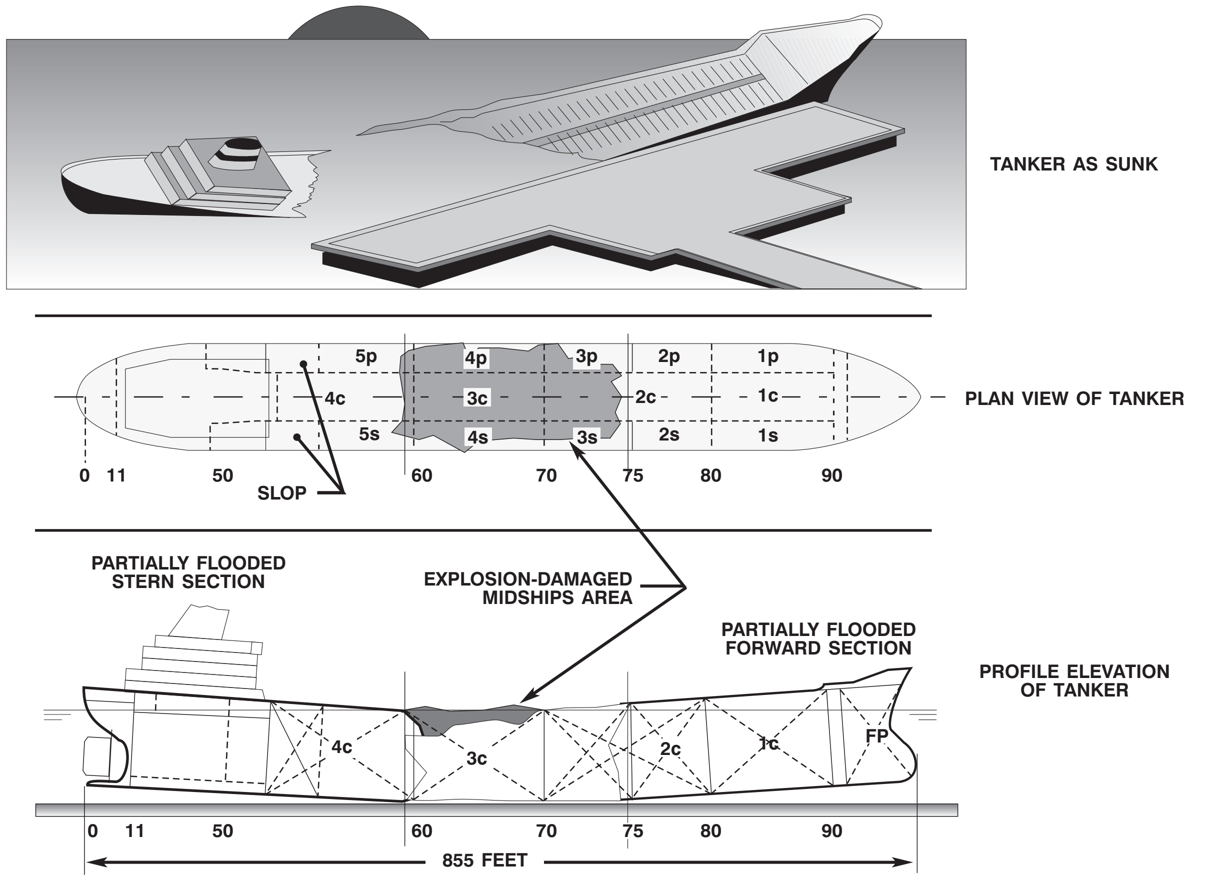


Figure 13-4. Tanker Wreck as Surveyed.

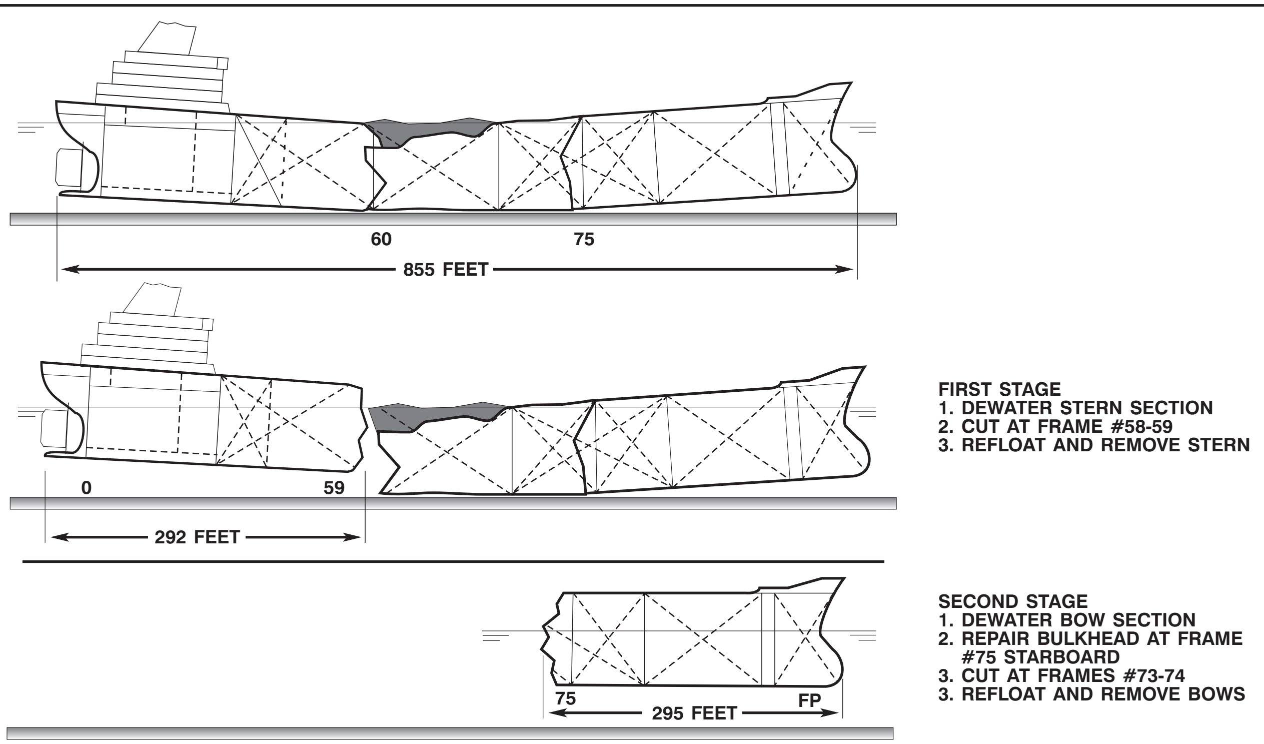


Figure 13-5. Removal of Bow and Stern Sections of Wreck.

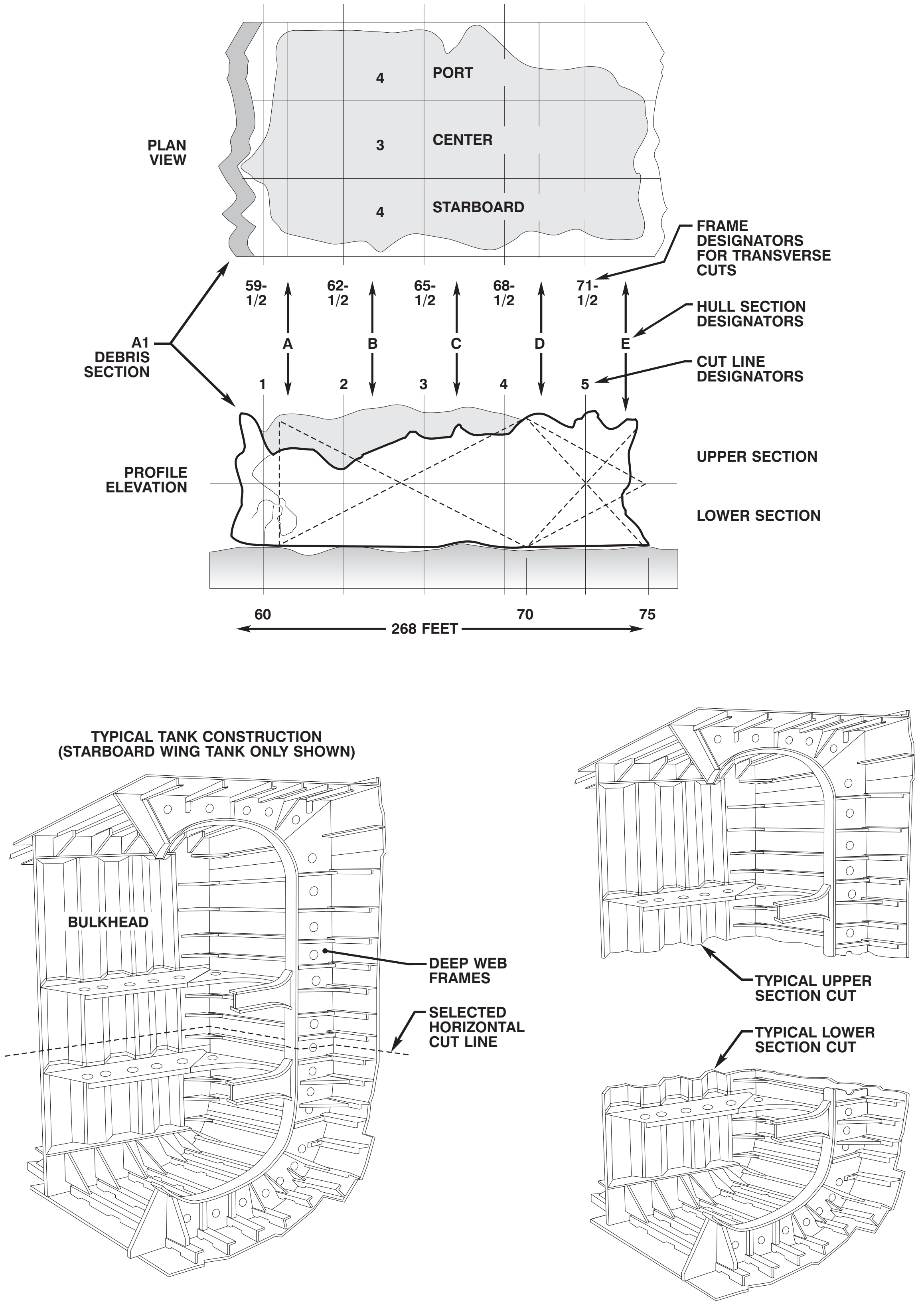


Figure 13-6. Transverse Cutting Plan for Midships Section.

EXAMPLE 13-2
TOTAL WRECKING IN PLACE OF A DREDGE

Some wrecks do not lend themselves to refloating or removal in one piece, or to the partial refloating-partial wrecking described in Example 13-1. Small- to medium-sized wrecks are often suited for total wrecking in place by cutting into sections so planned that they can be lifted safely by cranes of opportunity that are on site only when sections are ready for removal.

Figure 13-7 is a perspective sketch of a sunken medium-sized dredge partially blocking a navigational channel. Logistics, risk assessment, and economics have decreed that the dredge be wrecked in place. Lift sections weighing not more than 400 tons have been planned to remain within the capacity of locally available equipment. A flat-top support barge with a mooring system and a 100-ton crawler crane on board provided base support, served as a diving station and hauled out debris.

Figure 13-7 also shows the dredge's configuration after removal of principal upper deckhouses, some upper works, and masts. The hull is divided into eight transverse sections by seven cuts. To allow a safe margin between the expected lift weights and the capacity of lifting equipment, five of the sections are subdivided by horizontal cuts. A final cutting and lifting plan is shown on the lower profile in Figure 13-7.

As was the case with the tanker described in Example 13-1, cutting is a combination of manual oxy-arc cutting by divers and explosive cutting with shaped charges. Sections are cut and removed in a sequence that allows divers to work progressively along the wreck from the extremities.

Conventional methods aim to remove all major single section lifts before horizontal cuts are made. Figure 13-8 shows the wreck after the end sections have been lifted out and before horizontal cuts are made in the midships section. Figure 13-8 also shows the approximate configuration of two upper sections. The horizontal cuts provide sections of acceptable lift weights without the difficulty of additional transverse cuts through complex double bottom structure. Typical lift configurations for lower sections containing heavy dredging machinery are shown in Figure 13-9.

13-3.4 Schedules and Schedule Adherence. On wrecking-in-place operations, some events may progress more rapidly than expected while others will be slowed by unforeseen difficulties. Wrecking-in-place operations must be planned and scheduled as thoroughly as possible, but the ability to vary from plans and schedules should be inherent in any operation. The successful wrecking plan analyzes and addresses:

- Technical methods
- Availability of assets and personnel
- Logistics
- Safety requirements
- Time and scheduling criteria
- Cost effectiveness.

Realistic schedules, adherence to them, and improvement where events permit are major factors in employing equipment efficiently and in controlling costs.

13-4 MANUAL CUTTING.

WARNING

Stringent safety precautions are necessary where any type of underwater cutting is performed during salvage operations. The mixture of acetylene with air is highly explosive. At greater depths, greater pressures of acetylene are required for cutting. Hydrogen is used in preference to acetylene in some instances due to the fact that, by comparison to acetylene, it is less flammable. Accumulations of hydrogen and other flammable gasses with oxygen can produce gas explosions. Gas explosions are hard to predict as they depend on the gas mixture and the distribution of gases. Comprehensive safety requirements and precautions are listed in *Underwater Cutting and Welding Manual, Change B June 2002*. This manual can be downloaded from the NAVSEA 00C website.

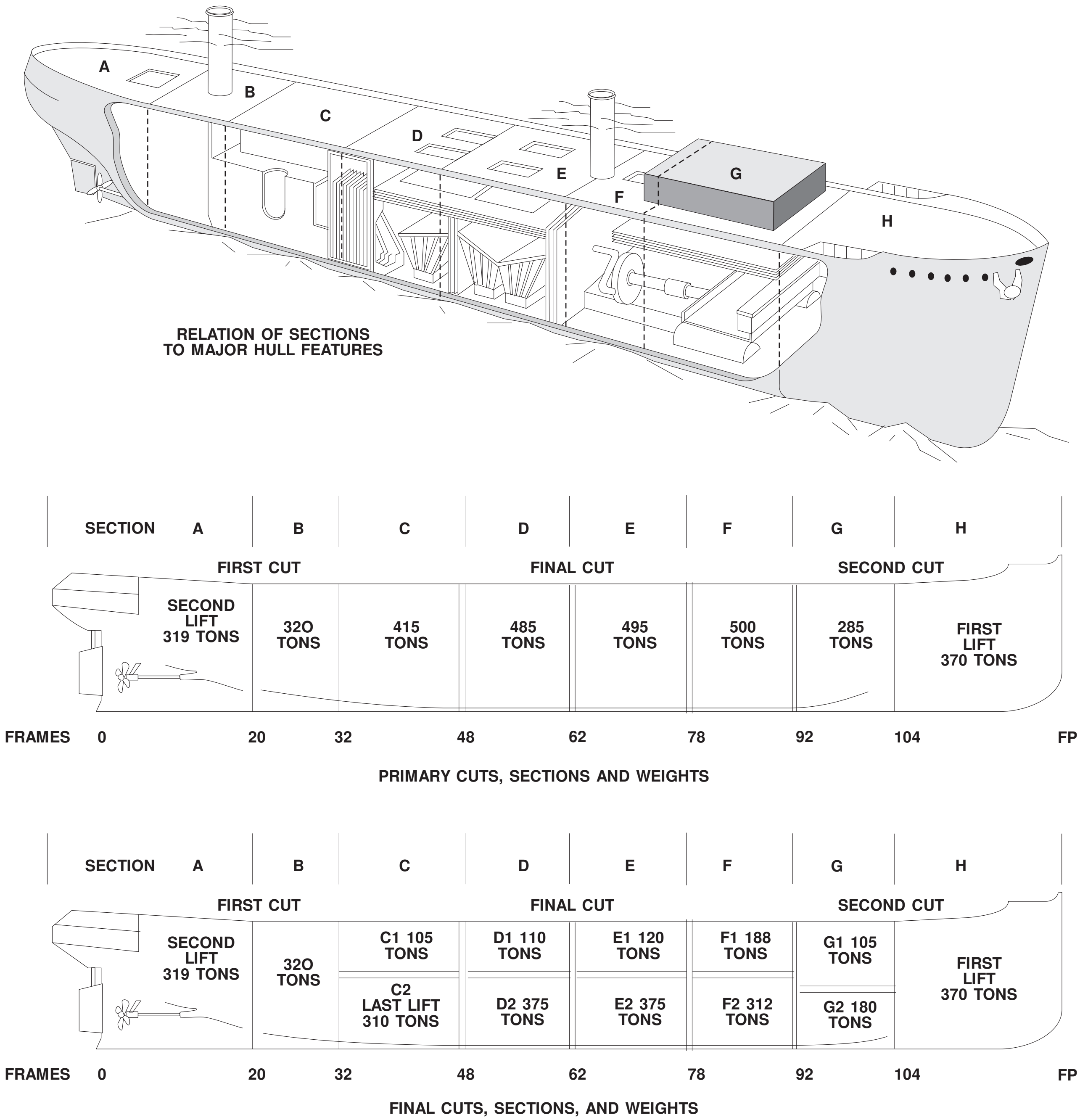
Manual cutting is surface or underwater cutting operations performed with man-portable cutting gear or tools including:

- Oxy-fuel gas cutting torches employed on the surface or underwater
- Electric or hydraulic cutting, grinding, or shearing
- Diver-operated cutting equipment such as oxy-arc, thermic lance, and Kerie cable.

Wrecking in place often requires extensive surface and underwater cutting. Numerous minor operations are best performed by surface workers or divers cutting steel structural members, piping, and internal fittings with basic flame or oxy-arc techniques. Manual cutting is deployed for large-scale wrecking-in-place operations when:

- Mechanical wrecking systems are unavailable or unsuitable
- Large portions of the superstructure or hull is above the surface
- Debris or wreckage obstructing main working areas or cut lines must be removed for access.

Manual cutting supplements other wrecking-in-place techniques. Preliminary phases of mechanical and explosive cutting operations may require preparatory manual cutting to ensure efficiency.



NOTE: ALL WEIGHTS IN SHORT TONS OF 2000 POUNDS

Figure 13-7. Wrecking in Place Planning Sections.

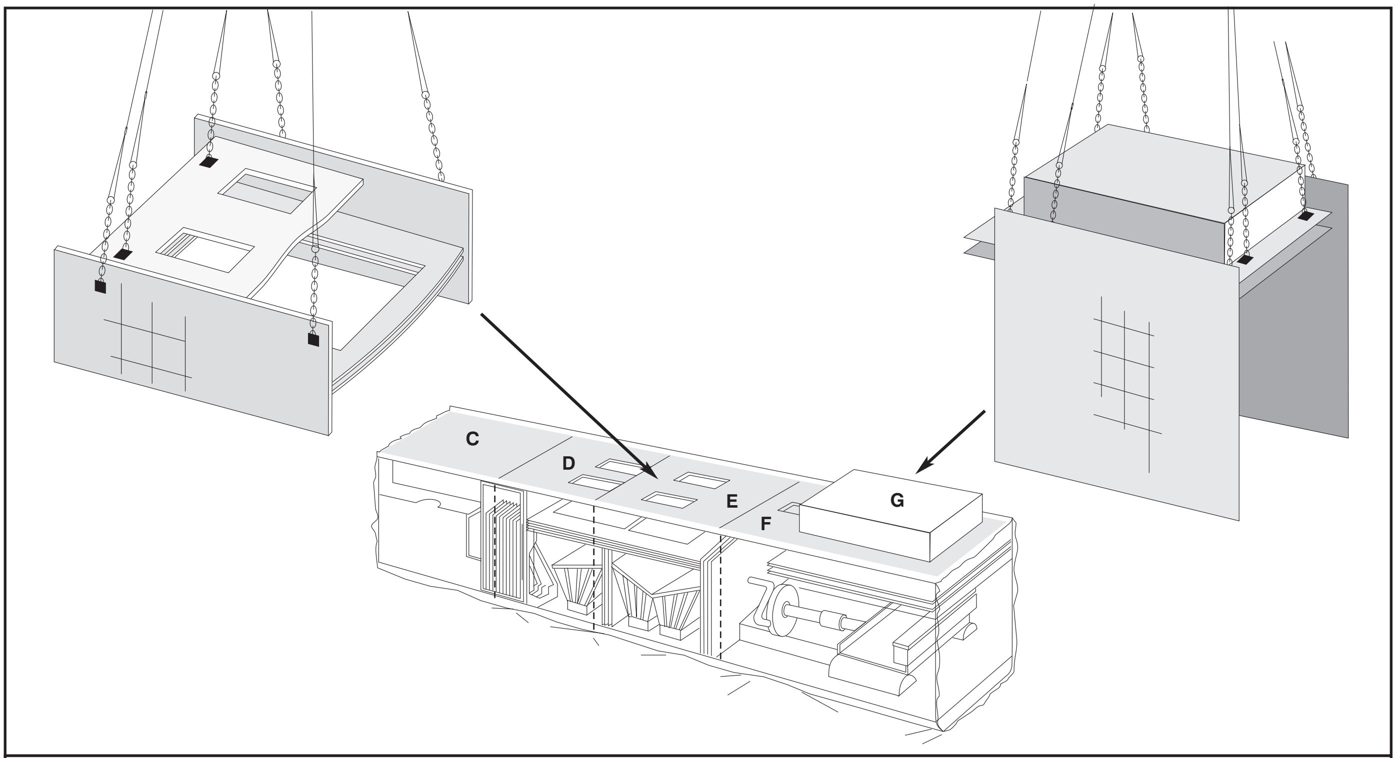


Figure 13-8. Status of a Wreck Before Horizontal Cuts Commence.

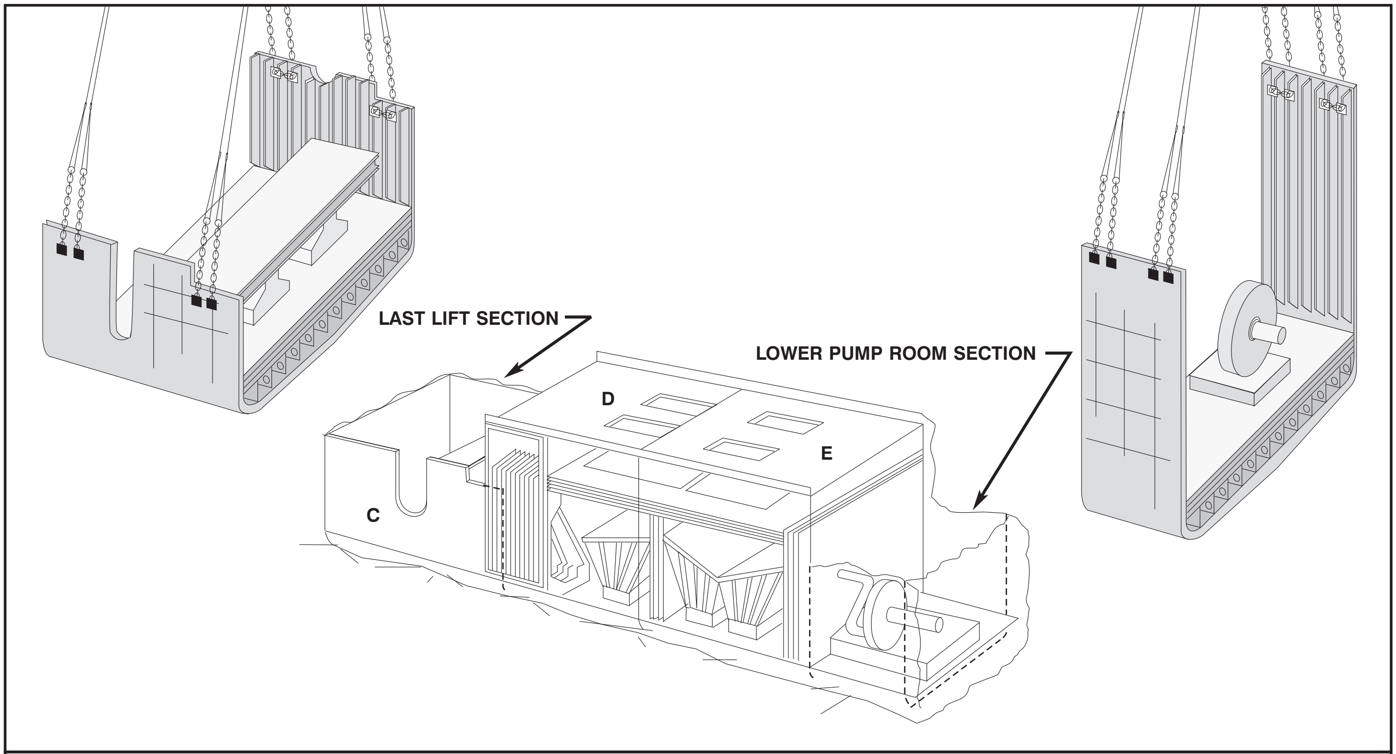


Figure 13-9. Wreck at Intermediate Stage of Demolition.

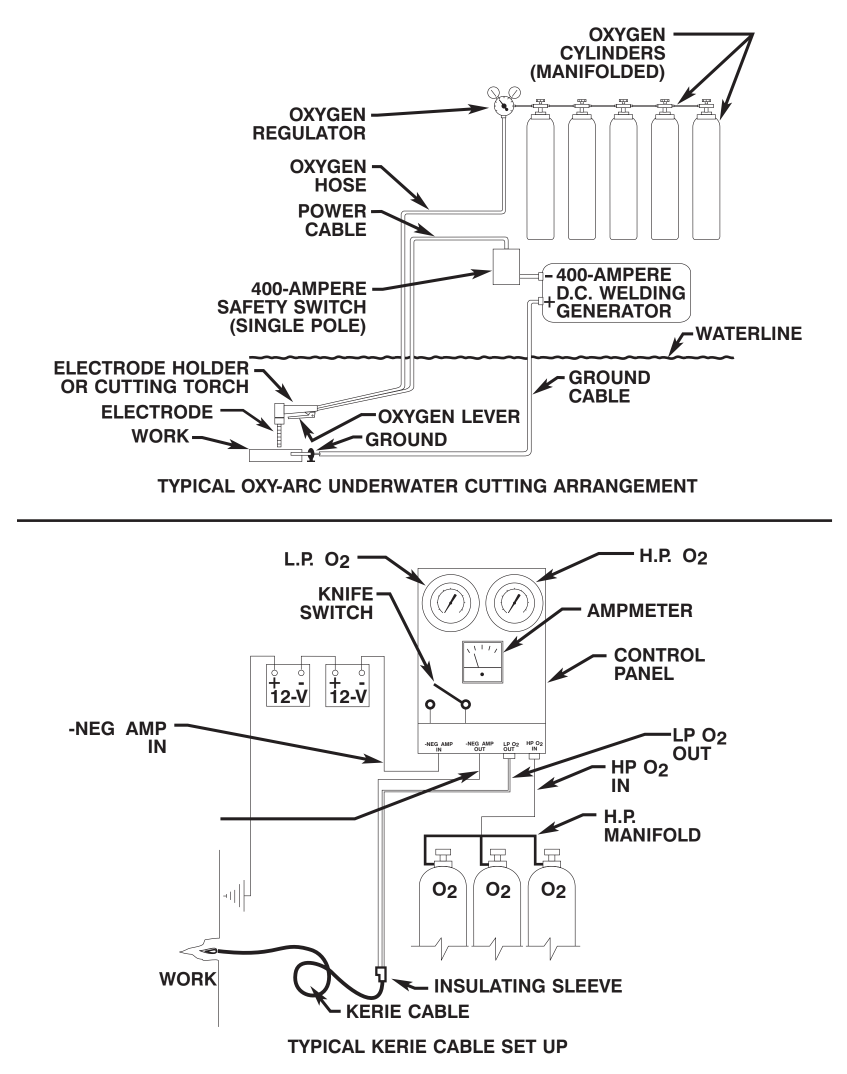


Figure 13-10. Typical Underwater Cutting Systems.

13-4.1 Underwater Manual Cutting. Diver-operated manual cutting systems are used on almost every wrecking-in-place operation. Work assigned to underwater cutting teams ranges from cutting hull-section slinging holes to cutting entire hulls. The success and speed of underwater cutting depends upon several factors including:

- Experience and skill of the divers
- Limitations imposed on divers by diving conditions, current, wreck attitude, and depth
- Location of cut lines relative to hull structural features, machinery, piping, and internal fittings
- Access to the cut line.

13-4.1.1 Underwater Cutting Processes. The Navy employs two underwater cutting processes:

- Oxy-arc cutting with exothermic electrodes, steel-tubular electrodes, and exothermic cable
- Shielded metal-arc cutting (cutting with ordinary welding leads and rods)

Oxy-arc is preferred because of its ease of use. There are two types of electrodes (rods) for oxy-arc cutting: exothermic and steel-tubular. The exothermic is preferred because it burns independently after an arc is struck and oxygen is flowing.

In shielded metal arc cutting, the metal is cut by the intense heat without the oxygen. Shielded metal arc cutting is particularly suitable for cutting steel ¼-inch or less thick, and nonferrous metals or corrosion-resistant metal of any thickness.

Figure 13-10 shows typical arrangements for underwater cutting with oxy-arc and Kerie cable systems.

13-4.1.2 Reference Material. Comprehensive information on conventional underwater cutting is contained in the *U.S. Navy Underwater Cutting and Welding Manual* (S0300-BB-MAN-010). The *Underwater Cutting and Welding Manual* collects fleet and commercial experience with both state-of-the-art and tried-and-proven underwater welding and cutting techniques. The *Underwater Cutting and Welding Manual* is the basic reference for these processes. This volume of the *U.S. Navy Salvage Manual* assumes basic knowledge of underwater cutting and confines its discussions to aspects of underwater cutting specifically related to harbor clearance and wrecking-in-place operations.

13-4.1.3 Operational Notes. Before commencing any underwater cutting on a wrecking-in-place operation, a thorough inspection of the wreck should be made to determine hazards to personnel, equipment, and the wreck. Hazards should be minimized or eliminated. Items of particular concern are:

- Tanks that contain oil, oil residues, or combustible gases
- Piping containing oil fuels, cargo oils, or combustible gases
- Overhanging wreckage or unsecured debris or cargo that can fall upon or trap divers
- Areas that may accumulate gases liberated during cutting and create explosion hazards.

Dangers associated with oil tank contents are usually most serious on wrecks caused by combat action or deliberate scuttling. In such cases, there seldom is time or the inclination to remove fuel after the sinking. The problem remains until the harbor clearance or wreck removal operation is undertaken sometime later. By the time removal operations are planned, information on fuels and explosives aboard the casualty may be lost. Operations may be delayed until the hazardous materials are removed.

Total removal of a large sunken wreck solely by manual underwater cutting would be unusual unless:

- There is a total prohibition on explosives or explosives are not available
- No mechanical wrecking systems are available
- There is no particular urgency attached to the wreck removal and the work is to be done by a small team.

Figure 13-11 shows an oxy-arc cutting plan for a comparatively small wreck. The sequence of work is:

a. Cut free and remove the superstructure.

b. Make the first transverse hull cut forward of the bulkhead between Holds Numbers 1 and 2.

c. Make the second transverse hull cut forward of the engine room.

d. Make the third transverse hull cut abaft the engine room.

e. Make the fourth and final hull cut at the after end of Hold Number 3.

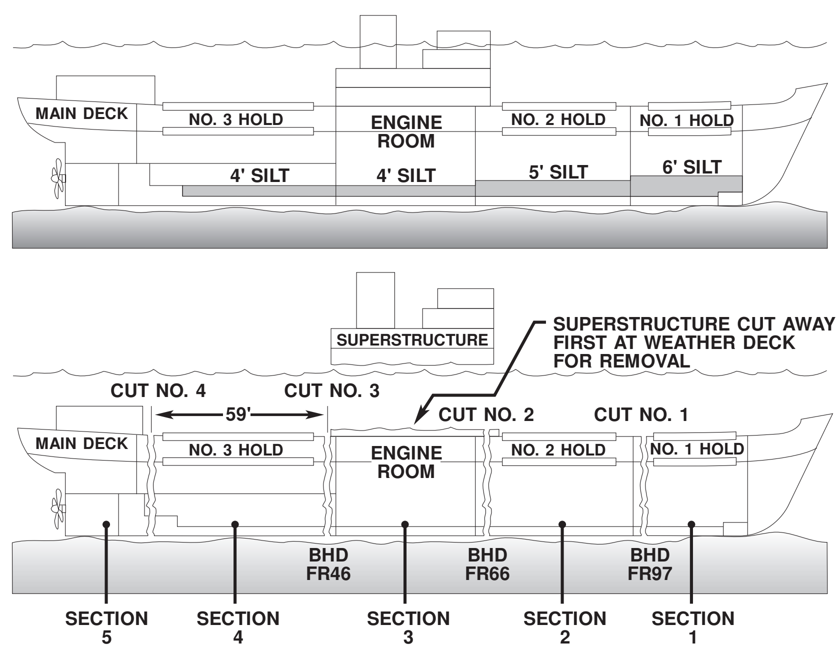


Figure 13-11. Cutting Plan for a Small Wreck.

Oxy-arc cutting is normally used in conjunction with explosive and mechanical cutting and for secondary tasks including:

- Cutting access openings
- Cutting away easily accessible sections in shallow water
- Cutting holes for lifting slings and chains
- Scoring plating in preparation for explosive cutting
- Cutting holes for securing explosive charges in place.

Conditions that make underwater oxy-arc cutting of wrecks dangerous and work difficult include:

- Adverse currents
- Unstable footing
- Poor visibility
- Unusual wreck attitudes
- Badly damaged work areas
- Mud and silt accumulations in work areas
- Falling or rolling away of cut off pieces.
- Peculiarities of compartmentalizing or other conditions that favor the accumulation of flammable gasses and oxygen resulting from the cutting process in confined spaces.

Planners and supervisors must be aware of their responsibilities to divers cutting underwater. It is seldom, if ever, practical to concentrate surface and underwater cutting in close proximity to one another. Distraction of and disruption to divers and tenders must be kept to a minimum to avoid accidents. It is very difficult for the diving team to concentrate on assigned tasks and to dive safely when the diving station is surrounded by other wrecking activities. Whenever practical, diving operations should be located well away from surface operations. Surface flame cutting crews must not be permitted to tap into manifolded oxygen quads being used by divers for oxy-arc cutting. Aviators' breathing (high purity) oxygen is required for efficient oxy-arc cutting. Divers' cutting oxygen should be kept separate from the industrial grade oxygen that is satisfactory for surface flame cutting.

If two or more diving teams are cutting underwater, they should be as widely separated as possible to avoid confusion and misinterpretation of orders.

When cutting is done in virtually zero underwater visibility, much of the divers' work is done by touch. Diver safety and efficiency is improved by assigning the same team to a series of tasks in the same area. Divers require time to familiarize themselves with a section of a wreck, particularly when working inside a damaged hull or a machinery space. Overall performance is improved when each diving team works a section or cut line through to completion. If two or three shifts of divers are cutting, each team should work a single area from start to completion.

Lifts of any size should **never** be swung over diving stations or areas where divers are cutting underwater.

Messing and berthing areas are particularly difficult to cut underwater because of the extensive joiner work, furniture, bulkhead linings, piping, mattresses, etc. Clearing debris away from cut lines in messing and berthing areas may be as necessary and as time-consuming as airlifting silt or demudding.

Oxy-arc cutting of decks that are covered with concrete, heavy tiles, or composition is slow and relatively ineffective, however, cutting is usually more efficient than manual removal of the deck coverings.

Underwater cutting by divers is more productive and safer when cut lines:

- Are laid out as simply as possible (Deliberate efforts should be made to avoid cutting through heavy structure.)
- Are positioned between transverse frames so the frames may serve as reference lines for divers
- Avoid or minimize overhead cuts
- Minimize cutting in berthing, messing, and machinery spaces.

Additional things that enhance safety are:

- Allowing safety or buffer zones between topside demolition areas and areas where underwater cutting is being done
- Ensuring that sections are completely separated and all cuts are completed.

13-4.2 Surface Manual Cutting. Surface cutting is often an important part of wrecking-in-place work. Cutting tasks vary from cutting holes for slings or access to demolition and removal of major hull sections above the waterline. Topside flame cutting teams range from one man with a portable cutting torch to several gangs of burners distributed all over the wreck. Most flame cutting is done with oxy-acetylene or oxy-propane gas mixtures. Cutting gases are compressed flammable and explosive substances that carry with them fire and explosion hazards. Wrecking operations with gas cutting systems require stringent safety programs to prevent accidents.

13-4.2.1 Preparations for Large-scale Manual Cutting. Preparations for large-scale manual cutting operations vary with the wreck's position and the amount of the wreck above the waterline. A wreck capsized on its side may present a large area of the ship plating to surface cutters. Cutting concentrates on removal of side plating, some transverse bulkheads, and messing, berthing, and machinery areas. If the same wreck is sunk upright, most surface cutting would concentrate on removal of masts and other top hamper, superstructure, and deck fittings. In addition to safety and firefighting, preparations for large-scale cutting must take into account:

- Work sequence
- Materials handling
- Automation of cutting.

Figure 13-12, patterned after the ex-USS TORTUGA (LSD 26) salvage, shows cutting sequences for a vessel being partially wrecked in place by surface manual cutting.

13-4.2.2 Work Sequence. The first priority in any wrecking-in-place operation is to remove all potentially or actually dangerous polluting or toxic material. Dangerous cargo, stores, ordnance, fuel oil, lubricants, and similar materials should be removed before wrecking begins. Where access cannot be gained to tanks immediately, precautions must be taken to prevent igniting or freeing the contents of the tanks. After the wreck is safe for hot work, wrecking usually begins from the top down.

Intact superstructures require:

- Stripping out combustibles, furnishings, joiner work, and equipment that obstructs cut lines
- Cutting piping, electrical cables, ventilation ducting, and other service conduits in way of cut lines. Hydraulic cutters are useful for cutting small pipes, cables, and ventilation ducts.

Insulation materials in old ships may contain asbestos. Materials suspected of containing asbestos must be analyzed before they are removed. Where asbestos is present, appropriate safety precautions must be taken. The *U.S. Navy Salvage Manual, Volume 1* (S0400-AA-SAF-010) provides information on limits for asbestos exposure and appropriate safety precautions.

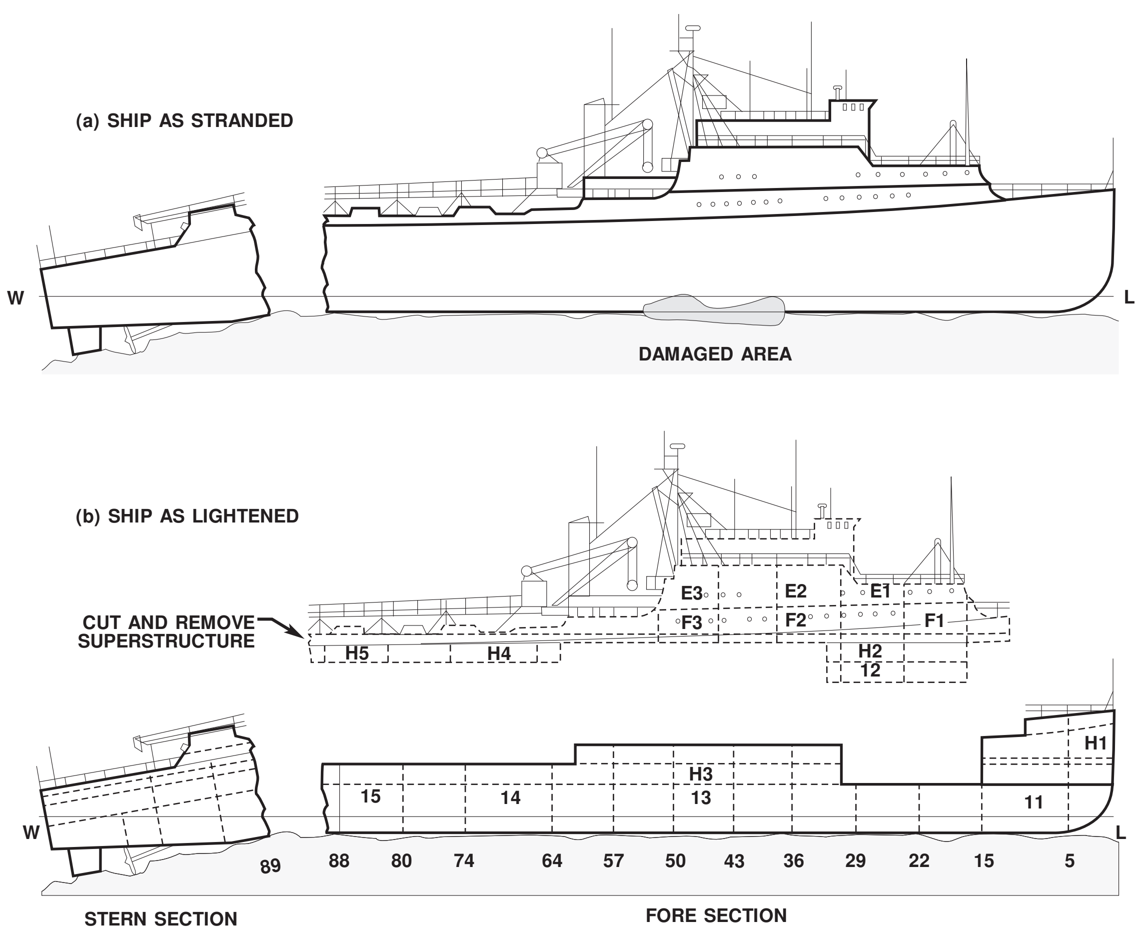


Figure 13-12. Surface Cutting Plan to Lighten a Wreck.

As each area is stripped and prepared for cutting, preparation teams move down in the wreck until they reach the water line. Final dry cut lines are set at either the high or low water mark, depending upon the tide range and the wreck location.

Attempts to expedite removal of combustibles by *in situ* smashing and demolition are usually counterproductive. Where permissible, burning out superstructure may save time and labor-intensive clearing work. Pollution regulations and the possibility of the fire becoming uncontrolled do not favor this method of removal.

13-4.2.3 Materials Handling. Partial demolition of wrecks by manual surface cutting generates large volumes of debris and trash. As this debris is a safety and fire hazard and a potential pollutant it has to be removed from the wreck. The attitude of some wrecks allows some mechanical handling of the debris. Small tracked Bobcat and forklift vehicles can expedite material handling greatly. Bobcats fitted with bucket scoops and hydraulic manipulators have been successful on wrecking operations.

Trash clearance and site housekeeping requires an ongoing commitment of personnel and equipment. Handling trash and debris is labor-intensive and time-consuming, but absolutely necessary for fire prevention and safety. Debris storage is simplified if proper trash receptacles are available and are emptied and replenished regularly. Salvors can improvise trash receptacles from sections of deckhouses turned upside down. Steel plate trimmed from the wreck can be trimmed and fitted as covers for improvised containers. Small debris can be handled manually, but large sections must be removed by cranes or derricks.

13-4.2.4 Automation of Cutting Operations. The amount of automation that is practical largely depends on the wreck's attitude. For automation to be practical at all, there must be large amounts of relatively level structure. Manual wrecking with gas flame cutting does not lend itself to a high degree of automation. Sometimes motor-driven gang cutters or hand-driven cutting machines may be used successfully. Small tracked hydraulic shearing machines have had some success where there is sufficient side or deck area for the machine to operate safely. Increased cutting speeds gained by Kerie cable or semiautomatic machines are not of great benefit when clearance of combustible materials is largely a manual process.

13-4.3 Safety Planning. Comprehensive guidance on safety in salvage is contained in the *U.S. Navy Salvage Safety Manual* (S0400-AA-SAF-010). The discussions relative to fire, explosions, lifting, and personnel accidents in the following paragraphs address specific problems that occur in wrecking-in-place operations. Effective accident prevention during wrecking-in-place operations is based upon:

- Awareness of the safety hazards
- Knowledge of the nature of threats
- A positive commitment to accident prevention.

Salvage personnel who plan, supervise, and work on salvage operations that employ any element of manual cutting must recognize that safety is a major planning and supervisory responsibility. Serious, sometimes fatal, accidents that occur during wrecking operations fall into four categories:

- Fire
- Explosion
- Lifting
- Personnel.

Wrecking-in-place operations often take longer to complete than other types of salvage work. The work is frequently repetitious and boring, particularly when large areas of hull or superstructure are demolished by manual cutting. Because the work is demolition rather than salvage, lax or casual attitudes may develop. Such attitudes are most common among people who are not truly salvage personnel and who do not have the same safety training and sense of self-preservation of salvors. Nonsalvage personnel working on wrecking jobs must be given safety indoctrination and provided with simple, easily understood safety guidelines. A positive safety attitude must be maintained for the duration of the work—not always an easy task. Time pressure as work progresses leads to tendencies to modify or ignore safety in the interest of expediting work. It is an immutable salvage law that serious and sometimes fatal accidents occur when safety standards are degraded or abandoned. There is little margin for error in salvage safety; none at all for laxity.

13-4.3.1 Fire. Most fires on wrecking-in-place operations are caused by flame cutting torches igniting combustibles in the ship's outfit or cargo. A cutting flame has two sides; one is clearly visible to the operator as the flame moves along a cut line. The operator cannot always see the reverse side of the flame where sparks, molten slag, and hot metal fragments are landing. Minor fires are not unusual as paintwork and steel coating burn readily when heat is applied. These small fires are usually detected and extinguished quickly by cutting torch operators or their Fire Watch. When numerous torches are operating, the large quantity of combustion by-products deadens operators' and Fire Watches' sense of smell, disabling an important human early warning system. Fire prevention in wrecking operations has four major elements:

- Inspection of cutting areas before cutting begins and removal of combustibles
- Efficient housekeeping and removal of flammable trash and debris as the operation progresses
- Providing each burner with a Fire Watch equipped with an extinguisher. The Fire Watch should be stationed on the opposite side of the plate the burner is cutting. Such stationing may not always be practical because of the geometry of the section being cut.
- Mandatory fire and safety patrolling by a core of senior salvage personnel.

13-4.3.2 Explosion. Explosions are usually caused by accidental cutting into fuel tanks, piping, or spaces containing explosive vapors. Leaking cutting gas hoses and cylinders may cause a buildup of explosive gases. Decomposition of payload, cargo, provisions, or organic materials can generate potentially explosive or life-threatening gases. Hydrogen and oxygen from the dissociation of water in the vicinity of underwater cutting or welding may create explosive atmospheres if they pocket in compartments underwater, or if they rise to the surface where they can be trapped by overhanging structure.

Explosion prevention is largely a matter of diligent investigation, applied safety, and constant monitoring of spaces that present an explosive hazard. Certain basic precautions must be taken with any space known or suspected to contain fuel or flammable materials. These precautions include:

- Removing fuel at the earliest opportunity and subsequently gas-freeing and purging of the tanks or spaces before cutting
- Providing fans to ventilate spaces where gas buildup may occur
- Removing material that may generate explosive gases
- Enforcing a rigorous program of monitoring all spaces regularly for potentially hazardous gas buildup.

13-4.3.3 Lifting. Accidents during lifting operations occur easily when untrained personnel are allowed to rig, sling, or break out even small lifts. Most wrecking-in-place operations employ barge-mounted crawler or revolving cranes for general-purpose lifting. Crane operators are not always able to see lift areas and depend upon signals from the wreck. Many lifting accidents occur because:

- The lift area is not cleared of personnel before lifting
- Incorrect or misleading signals are given to the crane operators
- Adequacy of attachment lifting points
- The sling is inadequate or incorrect for the weight, geometry, or behavior of the lift
- Movements of the barge-mounted crane in the sea and swell is not taken into account.

Most lifting accidents can be avoided by assigning a small group of qualified salvage personnel as a rigging team. Because lifts take place from different areas, the rigging team moves from site to site. The team's duties include:

- Providing and rigging lifting gear to each section or component structure as it is ready to lift
- Checking that each piece is cut free and ready for lifting
- Planning and directing any final cuts necessary to break out difficult lifts
- Ensuring all hands and their equipment are clear of the working area before lifting begins
- Directing the crane operator by hand signals, whistle, or radio to make lifts
- Controlling lifts until the crane operator slews the lifts away from the wreck.

13-4.3.4 Personnel Injuries. Accidents to personnel, particularly those involving workers falling into or from unfenced areas, are a frequent source of injuries and fatalities. Large manual cutting operations are labor-intensive in a potentially dangerous environment, and many of the wrecking crew will probably not be trained salvors. Lacking salvage training, the wrecking crew will not have developed the instinctive attitude of salvors toward safety. Further difficulties arise because the wrecking crews are gradually demolishing their workplace. Wrecks that are sunk or capsized at severe angles also create problems for wrecking crews. The activities of wrecking crews must be supervised carefully by experienced salvors. Other important safety planning factors for preventing personnel injuries include:

- Safety briefings that concentrate on matters relevant to the wrecking crews' needs. Concise, easily understood safety rules and procedures must be explained and personnel motivated to adhere to safety rules.
- Each group of wreckers should be supervised by an experienced salvor whose task includes arranging temporary safety rails and coordinating safety procedures. This salvor maintains contact with the roving Fire and Safety Patrol, seeking their advice and assistance when required.
- All wrecking crew members must be given both firefighting and emergency evacuation training. Although wreckers should not be designated as firefighters, they should have some understanding of how salvors will attack and control fires.
- Wrecking crew movements should be controlled carefully so that wreckers do not wander off into unsafe or irregularly patrolled areas.

13-4.3.5 Safety Summary. The procedures delineated in the preceding paragraphs enhance safety in what is inherently dangerous work. The system enables constant monitoring of wrecking by assigning senior salvage supervisors to supervisory roles in a roving Fire and Safety Patrol. Direct supervision of each burning or wrecking area is assigned to an experienced salvor. All rigging and lifting is supervised or carried out by the rigging team. With this system, each area of risk is overseen by experienced salvors. A daily briefing of all salvage personnel is an essential management tool to maintain a flow of information and identify problem areas quickly.

13-4.4 Firefighting Arrangements. Large-scale wrecking in place by surface manual cutting carries a high fire risk, and requires efficient fire control methods. Dedicated fire pumps, fire main piping, and adequate numbers of fire hoses and nozzles are essential to major fire control plans. Portable fire extinguishers, fire axes, and wrecking bars are also necessary firefighting equipment. Firefighting and personnel rescue teams must back up the Fire and Safety Patrol team in a major fire. Where a freely floating ship can be maneuvered to an optimum position relative to prevailing winds for firefighting, wrecks are usually fixed in one position. Under some conditions crosswinds may seriously hamper on-board firefighters. For this reason, a secondary fire control station must be available on board the site's work barge or ashore.

Wreck removal planning should allow for a dedicated fire pump aboard the wreck and a dedicated fire main. As a general guide, primary fire pumps on the wreck should be located at the opposite end from major cutting work. Where principal cutting activities are taking place forward, the fire pump should be located towards wreck's stern. A self-contained, diesel-powered pump, such as the 3-inch Barnes unit, is suitable as a fire pump provided suction lift is kept low. Where possible, suction hoses should be run inside the wreck to prevent damage by sea swell or vessels coming alongside. Electric centrifugal submersible pumps, such as the 4-inch Prosser, are good backup fire pumps. Fire pumps should be connected to a manifold that serves a fire main system. A well-designed, improvised fire manifold has connections for the primary diesel pump, a 4-inch connection to adapt to either Prosser or externally supplied water, and one or two connections to suit P-250 fire pumps.

Experience has shown that steel pipe is the recommended and only suitable material for fire mains. Wreckage will inevitably be dropped on the fire main or equipment will be dragged across them. The fire main should be arranged along the wreck's deck or side plating and should extend into the demolition area. Adequate 2½-inch and 1½-inch hose connections should be arranged at intervals along the fire main. Hose stands or hose boxes should be located at each hose outlet. On some occasions, salvors may be able to adapt, cannibalize, or otherwise improvise a fire main system from the wreck's water service piping. Where a system cannot be made, salvors will have to provide materials and install the system.

Firefighting equipment should be tailored to the probable fire risk that exists on board the wreck as cutting-down progresses. Threat levels are normally lowest where demolition involves only removal of masts and above deck structures. Levels of fire risk increase as cutting crews demolish berthing and messing areas, and reach a maximum threat when surface cutting teams work in machinery spaces and fuel tank areas. Consequently, firefighting equipment must be planned for most classes of fires. Ideally, there should be a first-response and a backup team of experienced salvage personnel with sufficient equipment to deal with a large fire. It is not practical to specify fire team compositions because each wrecking task differs. A probable worst scenario would be a major berthing and messing area fire, with additional fire fuel load being generated in machinery spaces.

Firefighting station bills must include evacuation of nonsalvage personnel. Plans should include evacuation of these personnel to support craft, the site work barge, or ashore early in the firefighting. The possibility of rigging additional standby firefighting equipment on board the site work or crane barge should not be ignored. Where applicable, cognizant port and area authorities should be briefed about salvors' in-house firefighting plans. The extent of assistance and cooperation from shore or port-based firefighters should be determined as part of overall wreck removal plans.

In addition to establishing and maintaining a roving Fire and Safety Patrol throughout working hours, there should be a regular after hours inspection of areas where hot work has been conducted. Frequently, hot embers or slag will cause small smoldering fires that do not burst into flame immediately. The after hours patrol makes checks after dayworkers and burning crews had left the wreck. Night crews must maintain vigilant fire patrol activity, although large-scale surface gas cutting operations at night are more an exception than a rule of wrecking operations. Safety controls are difficult to maintain over large-scale burning and cutting operations at night. Most surface cutting work at night consists of salvage personnel sectioning recovered wreckage, welding tie-downs, and generally preparing for the next day's work.

13-5 MECHANICAL DEMOLITION.

Mechanical demolition describes cutting with heavy lifting and hauling equipment. Such systems reduce the amount of diving and surface labor time required for wrecking in place operations. Mechanical cutting can be very effective, either in conjunction with explosive cutting or as a stand-alone technique, provided suitable heavy lifting and hauling equipment is available.

Mechanical demolition methods include:

- Chain and wire cutting or sawing wrecks into sections suitable for lifting
- Tearing wrecks apart with specially designed wrecking grabs or heavy dredging grabs
- Direct impact cutting and smashing with wrecking chisels or wreck punches
- Stressing weakened steel structures to breaking point by direct ripping.

Mechanical cutting is usually performed by heavy lifting and hauling equipment mounted on floating cranes, salvage sheer legs, salvage vessels, or improvised salvage barges. Under certain circumstances, some mechanical cutting systems can be operated by shore-based lifting or hauling systems.

13-5.1 Chain Cutting. The practice of mechanically cutting wrecks is over a century old. Somewhere, many years ago, an innovative, and probably very frustrated salvor decided that the problem caused by lift wires and chains slicing, or *cheesing*, into wrecks could be turned to his advantage.

Salvors realized that by continuously heaving and veering on a lift wire, they could cut through a hull, dividing it into two sections. By a logical progression of reasoning and experiment, it was found that good-quality steel chain was an even better cutting medium. The process is referred to as *chain cutting*, *chain sawing*, or *using saw chains*. Whatever the term, to all salvors it means a combined ripping, tearing, and crushing system that cuts a wreck into sections.

Chain cutting sections wrecks to suit lift capacity and local circumstances. Chain cutting does not have precise guidelines to suit every wreck situation. Wrecks may be cut into sections either vertically or horizontally, depending upon wreck attitude and availability of suitable hauling or lifting equipment. Chain cutting is more efficient than wire cutting and is advantageous when:

- Suitable heavy-lift salvage sheer legs or cranes to operate cutting system are available.
- Tidal or river currents severely restrict diving operations.
- Cut lines with oxy-arc or explosives have not been completely successful.
- Damage to the wreck makes precision cutting difficult and dangerous, particularly where wreck sections are partially buoyant and hinged.
- Large quantities of cargo or debris create serious obstructions to clearing away and maintaining access to cut lines.

Figure 13-13 shows heavy salvage sheer legs with a cutting chain rigged into position underneath a wreck.

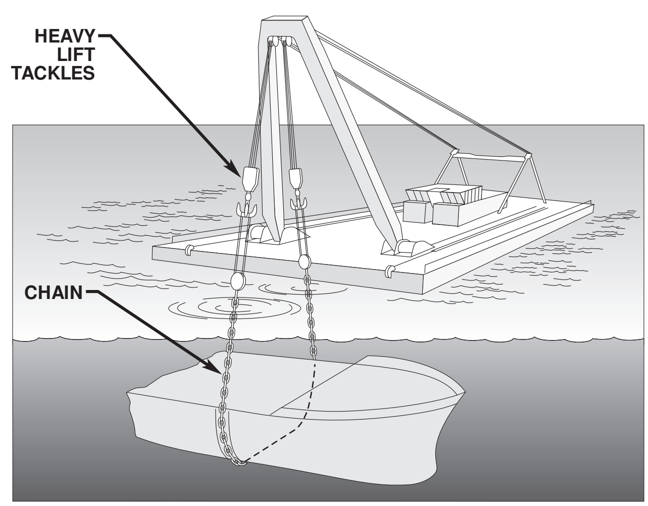


Figure 13-13. Chain Cutting Rig.

13-5.1.1 Advantages and Disadvantages of Chain Cutting. Chain cutting of wrecks has advantages and disadvantages. The advantages include:

- The system is basically independent of divers after the cutting chain has settled into its starting notches.
- Chain sawing usually cuts any given section faster than any diver-operated underwater methods.
- Chains are not hampered by mud, poor underwater visibility, or bottom time limitations.
- Buoyancy exerted by salvage cranes operating chain cutting systems usually has positive effects on cutting speed by increasing tearing and breaking action.

Disadvantages of chain cutting systems include:

- It is difficult, and frequently dangerous for divers to examine progress of cutting due to jagged and torn metal edges along cut lines. Visual monitoring of progress can be difficult, if not impossible, even with underwater TV systems.
- Cutting delays may be encountered where chains deflect from planned cut lines and unintentionally cut into heavy beams and girders.
- Chains sometimes break inside the cut line. Extracting broken chain ends and re-rigging a new length of chain into cut lines can be time-consuming and difficult.
- Large salvage sheer legs perform the most efficient chain cutting work. These craft are not always available. None of adequate size are used by the Navy.

13-5.1.2 Cutting Chains. Chain cutting requires high-grade chain, such as Di-Lok or near equivalent flash-butt-welded, stud link chain. Cutting chains must be free of flaws, loose studs, and structural distortion. Scrap chain is rarely suitable for cutting. Heavy, good quality, used Oil Rig Quality (ORQ) chain of 2¾- to 3½-inch diameter has been successful in chain cutting. As a general rule, chain cutting should not be attempted with chain of less than 2¼-inch diameter. Di-Lok chain should be reserved for this type work and lifting operations.

13-5.1.3 Preparation for Chain Cutting. The effectiveness and speed of chain cutting depends on the lifting capacity and outreach of the cranes available to salvors. Chain cuts are most efficiently performed by salvage sheer legs or heavy lift cranes rigged with two or more lift purchases of equal capacity. Lifting capacity of 150 to 200 tons per lift purchase appears to be the lowest acceptable level of lifting power for cutting large ship sections. Salvage sheer legs with several 300-ton lift capacity purchases are more suitable, but not always available. Preparatory steps for making chain cuts are:

a. Suitable messenger wires are passed, swept, or sawn under the wreck at each cut station.

b. Cutting chains are passed or dragged underneath the wreck and connected to crane lift purchase hooks with heavy wire slings.

c. Both lift purchases are lightly tensioned to bring the cutting chain into contact with wreck hull. Both contact points are marked and chain slacked off to allow divers to cut *starting notches* with oxy-arc equipment or shaped charges.

d. The size and depth of starting notches depends upon the aspect of the wreck and the diameter of the cutting chain. As a general rule of thumb, at least three or four links of chain should bury themselves in each starting notch.

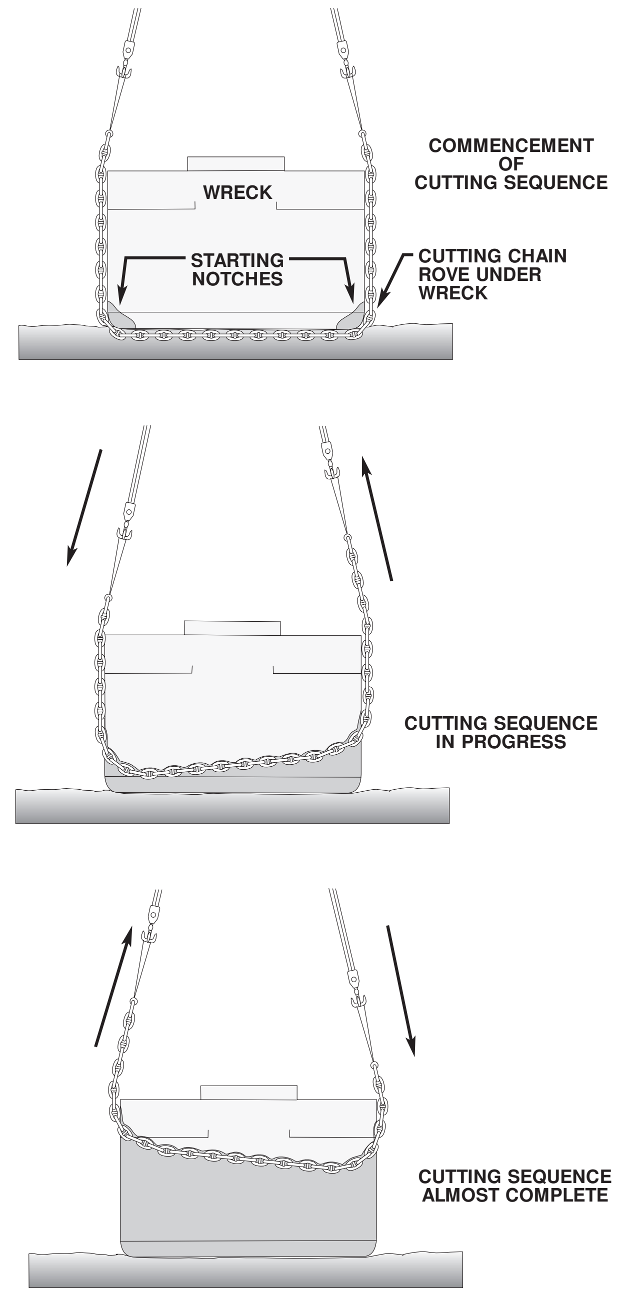


Figure 13-14. Chain Cutting Sequence.

In some cases, starting notches may have been pre-cut by an advance team so crane barge crews and divers rig cutting chains into pre-cut notches or a previously attempted cut line. Some pre-cutting of heavy structural section, such as propeller shafts and machinery foundations, may be necessary and advisable if hull cuts are to be made in such areas. Chain cutting through machinery spaces should be avoided whenever possible.

Figure 13-14 shows two starting notches cut into bilge radius plates of a wreck and the general progress of a chain cut.

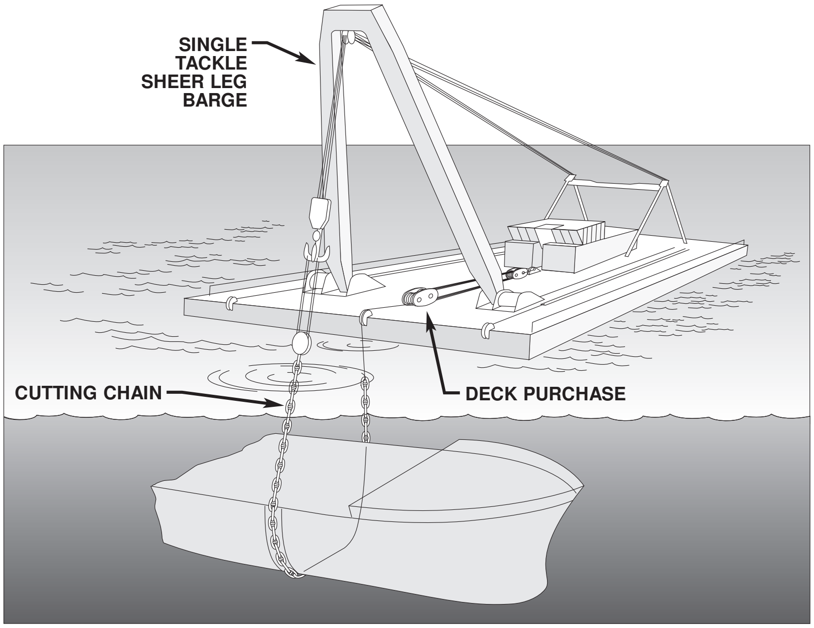


Figure 13-15. Improvised Chain Cutting System with A-Frame and Deck Tackle.

Figure 13-15 shows an improvised chain sawing system rigged on a single-hook sheer legs crane. This system operates with a deck purchase leading over a bow fairlead, working in conjunction with the sheer leg purchase tackle. In this system, the main cutting and tearing load is applied by the A-frame purchase, with the deck purchase back-hauling cutting chain after each tension cycle.

Successful chain cuts can be made by pairs of single-hook floating cranes or sheer legs. One derrick is located on each side of the wreck or section to be cut, and the chain sawn steadily between both cranes. This method is technically relatively efficient, but requires two floating cranes or sheer legs that should be fairly well matched in size and capacity. Because the operation is performed from two separate vessels, coordination and control between crane operators is a critical factor in a safe and successful operation. Startup is characterized by some degree of trial and error as crane operators and salvors adapt themselves and their craft to the method. A strong mooring system for each crane and between the crane barges is essential to operate the system effectively. Figure 13-16 shows a chain sawing arrangement operated by two floating cranes.

13-5.1.4 Chain Cutting Operations. Cutting chains are sawn alternately backwards and forwards through the wreck's hull and superstructure. Cutting is achieved by stressing, shearing, and tearing of steelwork by controlled lifting forces. Each link of the cutting chain acts like a blade on a chain saw. Steel plate and structural sections are crushed or distorted to their failure point as successive chain links wear and rip at the metal.

After a cutting chain is settled in its starting notch, operations usually proceed as follows:

a. A heaving or lifting strain of 150 to 200 tons is put on one end of chain, while the other purchase system slacks away slowly at about half that tension.

b. Several cycles, alternating each purchase between heaving and slacking, are usually necessary before the chain cuts or breaks into the wreck's hull.

c. Cutting rate is monitored by both hook weight readouts from strain gages and observing travel lengths of purchase tackles. Successively shorter purchase fleets indicate that a cut is proceeding efficiently.

d. When purchase fleet lengths become unworkably short, the long wire slings connecting each lift hook to the cutting chain ends must be replaced by shorter wire slings.

e. Cutting is completed when the cutting chain's bight is torn free of the wreck and recovered to the salvage crane.

13-5.1.5 Improvising Chain Cutting Systems. Chain cutting systems can be improvised from assets of opportunity, with varying degrees of success, depending upon knowledge, experience, and skill of salvors. Extremely powerful winches, such as the oilfield truss winches are suitable for chain cutting in either barge- or shore-mounted configurations.

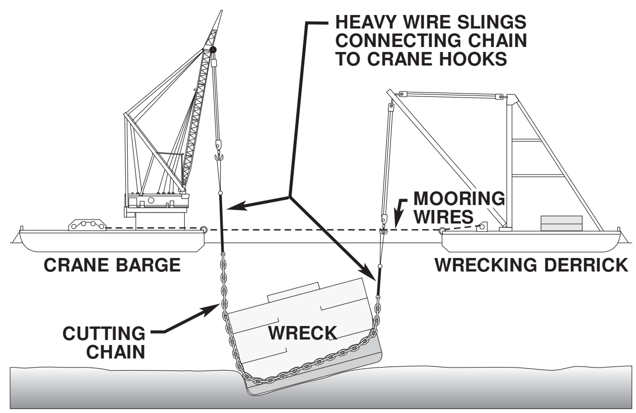


Figure 13-16. Two Crane Barges Operating a Sawing Chain.

CAUTION

Single kingpin mobile or tracked cranes such as barge-mounted crawler cranes are not designed or constructed to operate chain cutting systems. Improvised chain cutting systems with lattice boom rotating cranes may result in boom or pivot systems being unacceptably overloaded.

13-5.1.6 Horizontal Chain Cutting. Heavy deck tackles mounted on barges can make horizontal chain cuts. The anchorages or moorings against which salvage vessels pull are crucial when horizontal chain cuts are made on steel-hulled ships. Experience with barge-mounted horizontal cutting systems shows that barges must be moored to substantial anchorages, or to the wreck, because conventional mooring anchors usually drag under the high loading that develops.

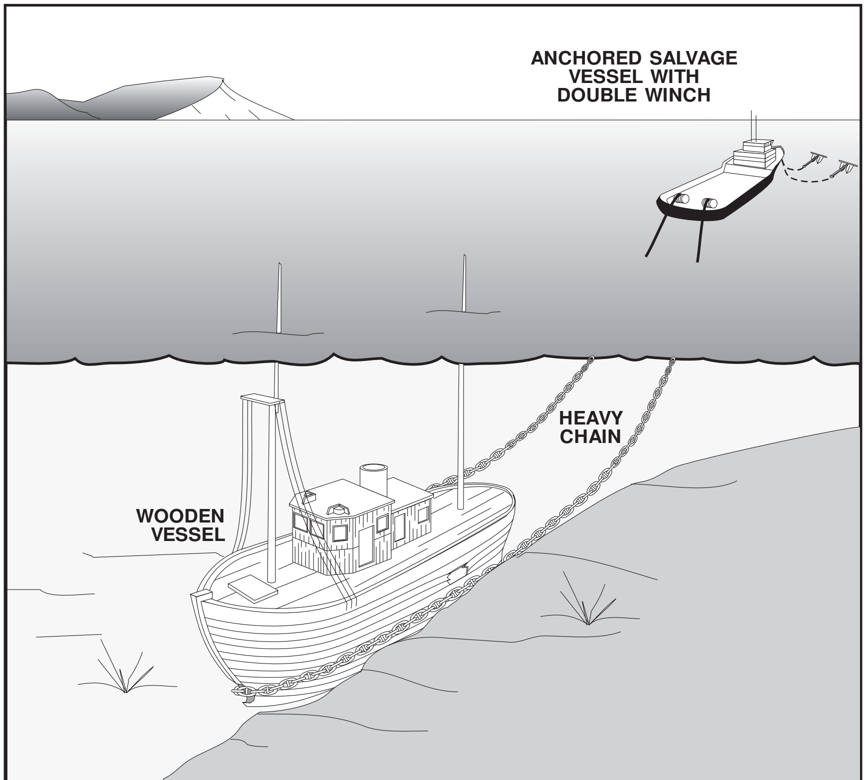


Figure 13-17. Use of Saw Chains for Horizontal Cutting of a Wooden Vessel.

In conventional (vertical) chain cutting, salvage cranes exert lifting and tearing forces against their own buoyancy as in normal lifting operations. The cranes are usually designed to lift 400 to 1,000 tons on their main tackles. Total vertical component pulls of 300 to 400 tons for chain cutting do not materially affect the barge or require special anchorages.

Figure 13-17 shows a horizontal chain cutting system operated from an anchored salvage vessel demolishing a small wooden ship. Figure 13-18 shows a horizontal chain cutting system rigged on deck of a barge cutting a sunken wreck into sections. The method shown in Figure 13-18 could also operate from suitable strong points sunk into a pier apron.

Chain sawing or cutting is not a particularly scientific method of wreck sectioning. Systems and operational guidelines in this section are described in general terms. Salvors have improvised various chain cutting methods and systems to suit particular circumstances applicable to locally available assets and the wreck. Chain cutting can be successful in conjunction with explosives.

13-5.2 Wreck Grabs. Wrecks that lie partially or wholly buried in the seafloor, that have deteriorated with age, or that are seriously damaged, present a difficult wreck removal problem. Diving operations on such wrecks are usually hindered by strong currents, poor visibility, and a high degree of risk. Without mechanical systems, attempts to demolish or remove seriously damaged or partially destroyed sunken wrecks are usually time-consuming and very often extremely costly.

In an effort to overcome problems caused by partially embedded, heavily damaged wrecks, commercial salvors attempted first to destroy, then to lift wrecks with heavy rock dredging grabs. These grabs could grip wreckage and tear it away under some conditions. Dredging grabs are usually unable to crush steel effectively, and do not withstand the heavy stresses of wrecking. However, in the course of deep water cargo recovery, salvors discovered that modified *cactus grabs* were extremely useful for gripping and tearing away weakened steel plates. These cactus grabs, also known as *orange peel grabs*, successfully tore away steel structure previously weakened or partially cut by explosives.

Cactus grabs are strongly built, but do not have a wide total jaw opening. The grabs were successful on wrecking operations and are suitable for demolition and wreckage purposes because they:

- Are strongly built, and relatively simple to operate
- Can be operated independently of divers, reducing risks to personnel
- Have the ability to grip even badly distorted steel structures.

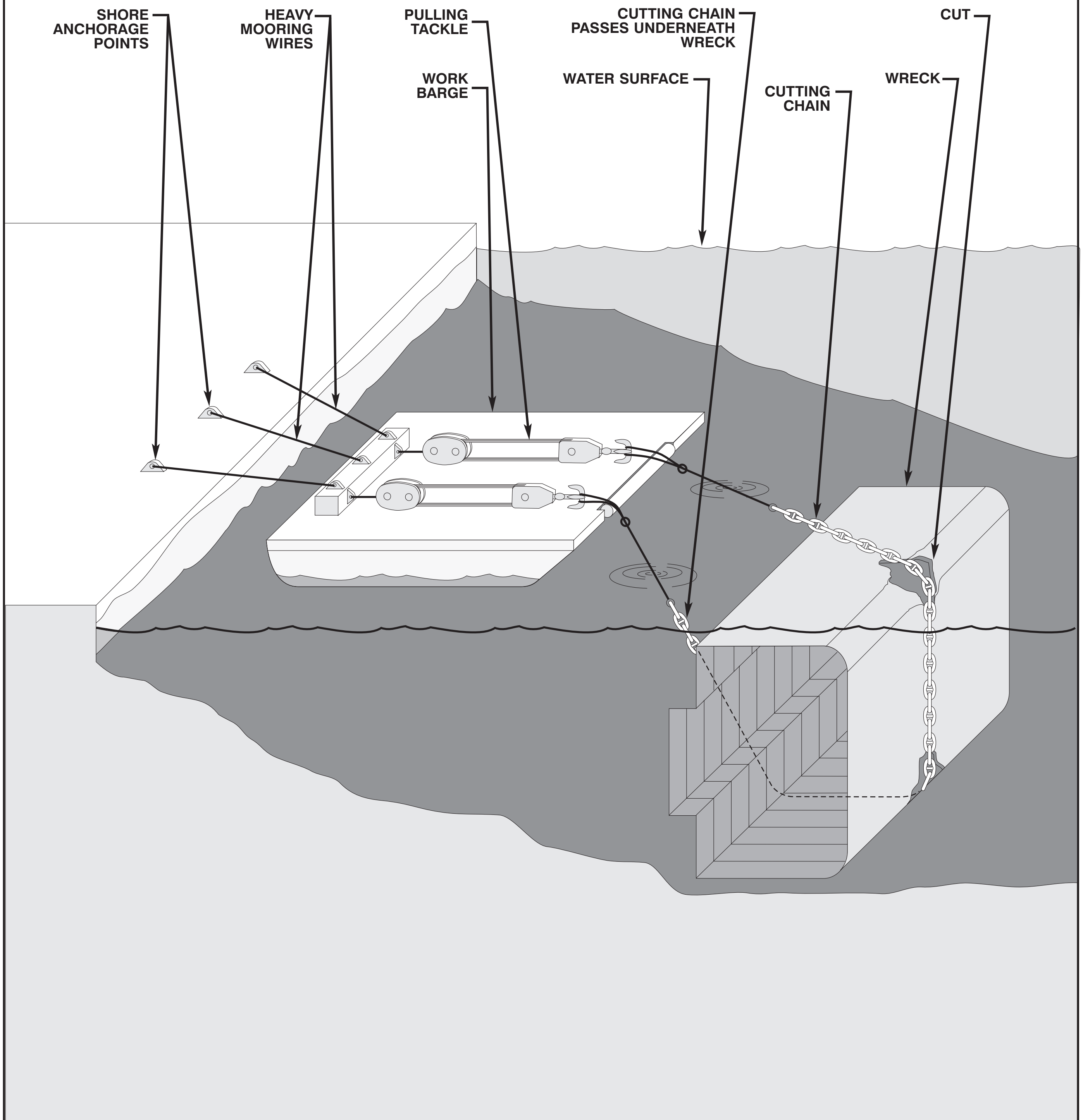


Figure 13-18. Horizontal Chain Cutting System.

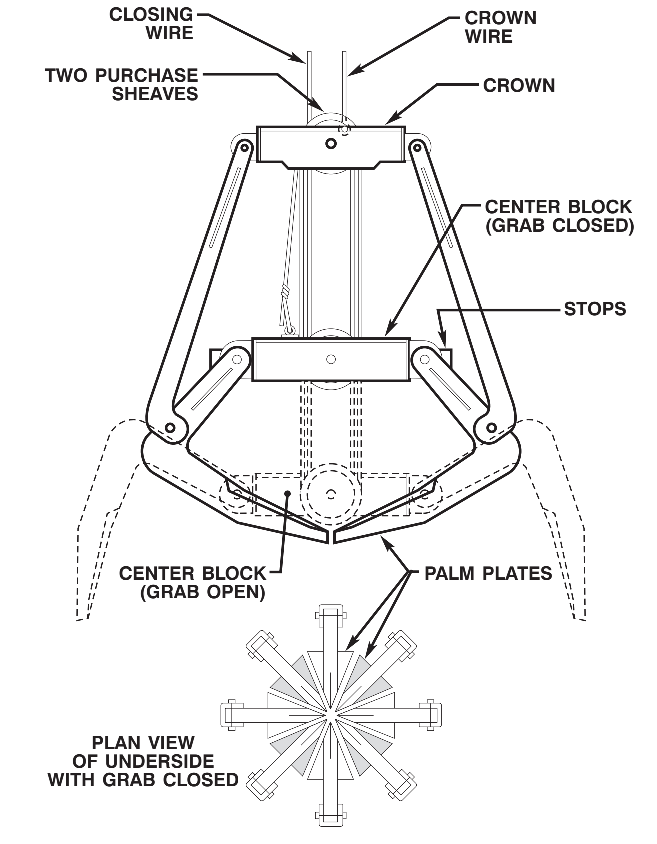


Figure 13-19A. Typical Cactus Grab.

A typical cactus grab is shown is Figure 13-19A. This type of grab is useful on small wrecking-in-place projects and as an all-purpose rehandling grab on large wrecking projects. Orange peel grabs may have a different arrangement of grab leaves and tine points depending upon their design and origin.

Figure 13-19B shows an example of the configuration and size of a Cactus Grab from Europe.

Figure 13-19B. Cactus Grab from the United Kingdom.

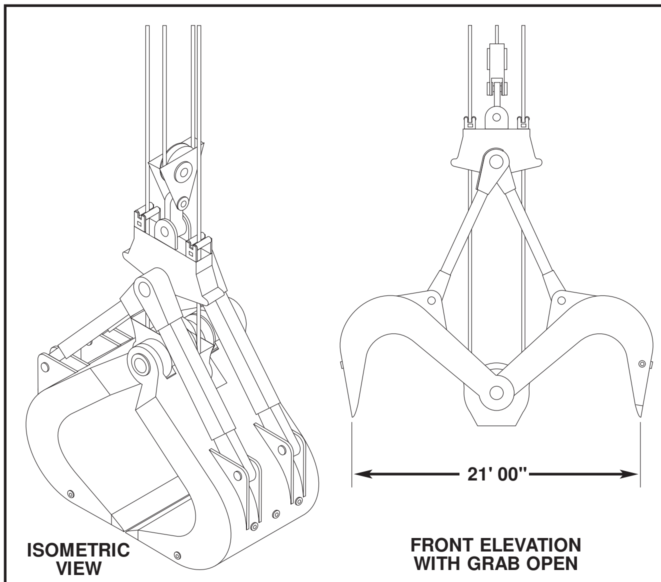


Figure 13-20. 150-Ton Wreck Grab.

Many World War Two casualties occurred in narrow coastal traffic lanes, swept channels through minefields, and in major rivers of Europe. Faced with wartime pressure to keep navigable channels clear, a practice developed of clearing or dispersing wrecks with massive explosive charges. Effects of such demolition or wreck flattening left many wrecks only partially destroyed or damaged. Many dispersed wrecks subsequently became serious navigational hazards as larger, deeper draft ships came into service.

Diving on any ship that has been partially destroyed with explosives is dangerous. Difficulties are compounded as wrecks settle into the seafloor. Strong currents and poor visibility make diving operations time-consuming and unproductive.

Addressing the problem from both salvage and dredging viewpoints, European salvors and grab designers combined rock dredging and cactus grab features into a massive grab that has become known as a *wreck grab*. Early wreck grabs typically had an open width of 24 feet, a jaw grip or breadth of 8 feet, and an empty weight of between 60 and 80 tons in air. These grabs were intended for operation by large salvage sheer legs. Nominally rated at 150- to 200-ton lift capacity, early wreck grabs required at least two heavy tackle systems of 150 to 200 tons lifting capacity on each tackle to operate. Grab closing forces of between 300 and 500 tons develop powerful crushing forces on steel structures. Most wreck grabs are fitted with specially hardened teeth or edge plates to assist in crushing and punching through steel.

Further developments based on operational experience have seen wreck grabs of 600 tons capacity constructed. Some earlier grabs have been modified to work from fully rotating cranes, producing a versatile and flexible wrecking tool. Figure 13-20 shows a wreck grab with a nominal 150-ton capacity designed to be operated by conventional salvage sheer legs.

Wreck grabs are very effective on wrecks where steel structure has deteriorated with age and corrosion, and on wrecks that have been heavily damaged or distorted by explosions. Total and partial removals of wrecks in depths of up to 125 feet of seawater have been accomplished with wreck grabs. Commercial salvors have made extensive use of wreck grabs operated from heavy sheer legs in large harbor and river clearances. As a rule, the extra time a wreck grab takes to tear away relatively new steelwork is compensated for by large savings in diving time. Clearance by grabs is the most efficient method of removing wrecks that are heavily embedded in mud and silt.

The basic procedure for demolition and removal of sunken wrecks by wreck grabs is:

a. After completion of wreck survey, a decision is made on which end of the wreck will be demolished first. Grabbing operations usually commence at wreck's shallowest end and work steadily towards the more deeply buried section.

b. Heavy moorings are laid out around the wreck, and the sheer legs or salvage crane are aligned facing, or on the same heading as the wreck. Alignment of the crane is determined by the current and the basic demolition sequence.

c. The grab is lowered in the fully open position until it contacts the wreck. Closing tackles are hove up slowly to bite grab jaws into hull wreckage. As the grab jaws close, they penetrate steelwork and begin crushing and tearing.

d. When the grab will not close any more, its lifting tackles are hove up to lift the grab and the wreckage gripped in its jaws. Breaking out a closed grab is a contest of strength between the sheer legs and the wreck.

e. Wreck structure held by grab jaws is torn, crushed, and sheared away from the wreck as the sheer legs heaves up its grab. A combination of brute force and the buoyant upthrust of the sheer legs hull breaks overstressed and damaged steelwork.

f. The wreck grab is brought to surface where recovered wreckage is lowered onto a barge. Bites of 60 to 80 tons of wreckage can be taken under ideal conditions.

When a wreck grab is working on a totally submerged wreck, it is very difficult to see where the grab is operating or what it is doing. Large clouds of mud, silt and marine growth disturbed by the grab swirl around the working area. After grabbing commences, it is usually dangerous for divers to make wreck inspections. Progress is judged by wreckage accumulated on storage barges and the skill of salvage personnel in identifying structural components. When operating a wreck grab from a salvage sheer legs some delays occur as tugs move the scrap barge underneath the grab to receive wreckage as each cycle ends.

Demolition by diver or explosive cutting systems usually produces fairly regularly shaped wreck sections. Barge stowage and wreckage handling is simplified because section cuts follow a planned sequence. Demolition by wreck grab produces very irregular-sized and -shaped wreckage. Wreckage recovered by a wreck grab grows to resemble a gigantic junk pile. Mud, oil, and sludge create safety hazards on barges. High-pressure hoses used for housekeeping spread the pollutants that are inherent in the mud, oil and sludge, contaminating the work area.

Sometimes manual gas cutting of recovered wreckage is necessary to create better or safer stowage on board debris barges. On large projects, scheduling and dispatch of debris barges and unloading and turnaround times of scrap unloading become critical factors in the operation.

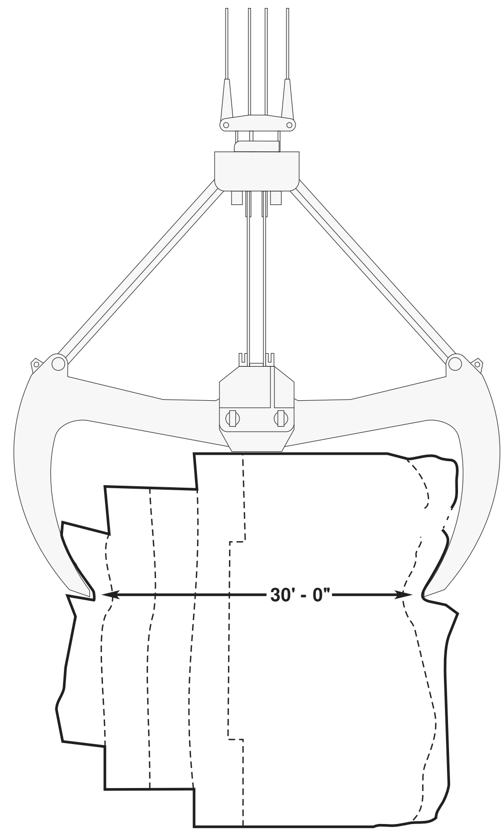


Figure 13-21. Large 600-Ton Wreck Grab Holding Section of Small Wreck.

Most commercial wreck demolition experience with wreck grabs has been gained by operating grabs from large, heavy-lift sheer legs. Grabs have been successfully operated on lighter duty work from fully revolving derricks that have two hooks operating simultaneously and independently from one other. Wreck grabs also sometimes:

- Hoist and handle wreck sections (cut by other means) to avoid difficult slinging preparations.
- Remove small wrecks or sections of small ships by picking them up bodily with the wreck grab.
- Demolish steel pier and harbor installations.

Other uses for wreck grabs include some special dredging and debris recovery associated with harbor clearance and port rehabilitation operations. Figure 13-21 shows a large wreck grab holding a hull section of a comparatively small wreck.

CAUTION

Operation of wreck grabs from floating cranes of opportunity should not be attempted without the agreement of both the grab owner and crane operator. Wreck grabs must not be operated with barge-mounted crawler cranes.

CAUTION

Cactus grabs are designed as double wire grabs to be operated from cranes fitted with two independently operated winch drums. Attempting to work a cactus grab by a barge-mounted crawler crane may be dangerous if the crane concerned is not rated for dredging duty or grabbing work.

13-5.3 Wreck Punches and Chisels. A wreck punch or wreck chisel is a steel I-beam section cut to a chisel-shaped point at its lower end. Wreck punches smash steel hulls that have not been completely cut by explosive, oxy-arc, or surface cutting techniques. Under some circumstances, wreck punches cut hulls into sections.

Wreck punches are usually made up from heavy I-beams that are stiffened and sometimes boxed in with thick plates welded to beam flanges. Lead billets can be arranged inside beam flanges to add extra weight. Wreck punches are typically made up about 40 feet long, with a weight of between 10 and 15 tons. Wreck punches are operated by cranes. The punch is lifted above the wreck and then dropped repeatedly on the area to be cut. A heavily constructed punch, dropped from sufficient height, obtains enough energy to cut or break plate sections and frames on impact. Figure 13-22 shows typical wreck punches constructed from locally available materials.

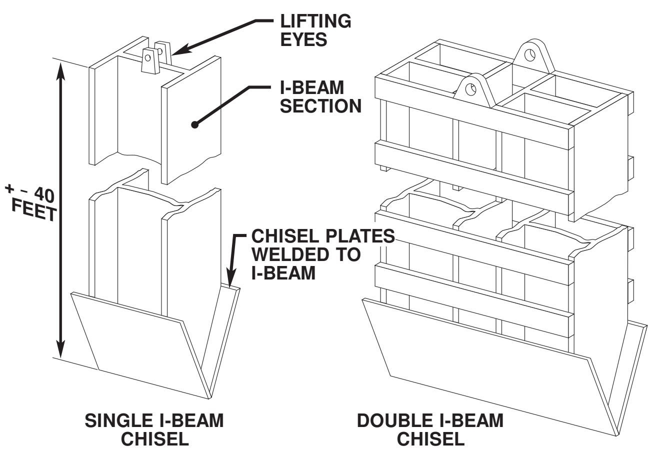


Figure 13-22. Field Fabricated Wreck Chisels.

Where chain cutting is not practical and wreck grabs are not available, wreck punches are comparatively effective mechanical cutting devices. Most large barge-mounted crawler cranes are capable of operating wreck punches. Heavy oilfield construction cranes can operate very large wreck punches.

Improvised heavy wreck punches have been constructed from:

- Large dredge spuds, on which the pointed end was covered with welded steel plate to form a chisel end. Some of these converted spuds weigh 35 to 40 tons.
- Pairs of large section I-beams welded together and weighted with railroad track and scrap billets.

Not all cranes or derricks are suitable for operating wreck punches. Free-fall capability of the main crane hook is essential for wreck punching. When evaluating potential cranes, salvors must insist upon a free-fall test of the main or auxiliary hook with a realistic weight simulating the wreck punch. Candidate cranes must be able to release and free-fall a heavy weight from a high boom elevation. Any crane that cannot demonstrate efficient free-fall capability is unsuitable for operating a wreck punch. Successful wreck punching depends upon a combination of punch weight and drop velocity. Cranes designed or specially adapted for marine clamshell dredging are almost always suitable for operating wreck punches. Auxiliary hooks on large offshore derricks have designed free-fall capability and sufficient lift combined with suitably long booms to handle wreck punches quickly and safely.

13-6 EXPLOSIVE CUTTING.

Explosives are an important salvage tool in wreck removal, harbor clearance, and wreck dispersal operations. Principal salvage and harbor clearance related explosive uses are:

- Cutting and breaking hull and superstructure sections
- Pounding down, flattening, or burying wrecks into the seafloor
- Dispersing wrecks or wreck sections as part of harbor or channel clearances
- Widening, deepening, and straightening channels
- Demolishing concrete masonry and steel harbor installations that obstruct port or salvage operations.

The discussion in this section is directed principally towards cutting and breaking of hull and superstructure sections in wrecking-in-place operations.

The publication *Technical Manual for Use of Explosives in Underwater Salvage* (SWO61-AA-MMA-010) describes demolition devices in underwater salvage and wreck clearance and provides instructions for their safe and effective use, but is not fully detailed in explaining specific cutting techniques. This chapter of the *Salvage Manual* therefore supplements, but does not supersede *Technical Manual for Use of Explosives in Underwater Salvage* (SWO61-AA-MMA-010).

WARNING

Stringent safety precautions are necessary where any types of explosives or detonators are handled during salvage operations. Comprehensive safety requirements and precautions are listed in *Technical Manual for Use of Explosives in Underwater Salvage* (NAVSEA SWO61-AA-MMA-010) under the headings: "Safety Summary" and "Safety Requirements and Precautions" - Chapter 3. All those warnings are applicable to this section of this manual.

WARNING

All personnel who place or use explosives for underwater cutting operations must be specially trained for such work. They must be fully acquainted with types of explosives used. Explosive cutting systems must be in compliance with approved demolition practices and techniques.

NOTE

Environmental protection considerations may require a detailed impact statement prior to the use of explosive cutting.

13-6.1 Explosive Cutting Principles. The primary reason for underwater cutting with explosives in wrecking-in-place work is the extreme speed at which explosives release energy and the fact that the activity is remote, creating an extra measure of safety. No personnel have to be present when a cut piece or section comes free of its last support. Explosive cutting is a method that reduces diving time and expedites underwater sectioning because explosives can be placed quickly and detonated rapidly. Efficient use of explosives gets the same work out of less explosive material, thereby limited unwanted collateral effects. Many people, including some salvors, have a poor understanding of how to obtain best results from explosives in ship cutting operations. Ship structures are complex girders, designed to withstand combined effects of a variety of loads and stresses. Steel ships just do not break up and blow apart into scattered pieces under the loads imposed by detonation of small to moderate charge weights.

Wreck sectioning with explosives requires a thorough understanding of the uses and limitations of explosives. Explosives are most useful to salvors when detonation energy produces a directionalized force to cut and break ship structures along predetermined cut lines. Salvors must address two specific problems to gain maximum underwater cutting effects from explosives:

- Explosives must be correctly placed in direct contact with the steel plating sections to be cut.
- Frames and longitudinal girders that support plating may be cut simultaneously with their attached plate, or deliberately cut independently of main plating.

Simultaneous explosive cutting of plating and framing is not particularly difficult to achieve in a dry or surface environment. The situation underwater is different. It is frequently necessary to combine oxy-arc and explosive cutting to gain the maximum benefits from the explosives. On many wrecking-in-place operations, divers cut frames and longitudinals with oxy-arc while hull plating and web frames are cut explosively afterwards.

Poor results with explosive cutting usually arise from one or a combination of the following:

- Failure to make proper plans and preparations for explosives as underwater cutting tools
- Lack of understanding of basic explosive cutting principles that produces inefficient work
- Incorrectly designed charges
- So much explosive that cutting efforts are wasted or lost amongst secondary blast effects and debris
- Secondary blast effect is so great that divers must waste time reorienting themselves at the worksite.

Misuse of explosives causes wasted time and effort because of confusion between the roles of explosives in dispersal or explosive clearance of wrecks as contrasted to cutting or sectioning of wrecks.

Dispersing or clearing of wrecks by explosive methods is not the same as cutting wrecks into moveable sections with explosives. Dispersal destroys wrecks quickly with the brute force effect of heavy explosive charges. In wrecking-in-place operations, explosives cut steel structures with relative precision. There is a great difference between the two tasks in terms of charge weights, placement, and basic techniques. Salvors using explosive cutting methods always try to minimize charge weights consistent with achieving regular, quality cuts.

13-6.2 Explosive Cutting Effects. The work of an explosive charge is performed by high instantaneous pressure, intense heat, and gas expansion generated at detonation. Initial blast releases these forces equally in all directions. This characteristic is an advantage when the desired effect is to demolish some structures, disperse wrecks, or move solid materials. In explosive ship-cutting this characteristic is a definite disadvantage. Explosive forces must be concentrated and directed into the work area to obtain maximum effectiveness from charges. Several methods control, channel, and concentrate detonation forces onto the work area, but few promote efficient steel cutting. For most underwater wrecking-in-place operations, *shaped charges* give the best cutting effects.

A hollowed-out or shaped charge detonated against steel produces a cratering effect that is approximately a mirror image of the charge cavity or air space. This cratering action is known as *Munroe Effect* after its 19th century discoverer. A flat-ended explosive charge detonated directly against a steel plate usually only dents or bends the plate; a cavity charge does much more cutting. Research into charge behavior found that when surface of the cavity is covered with a liner, much better cutting results are obtained.

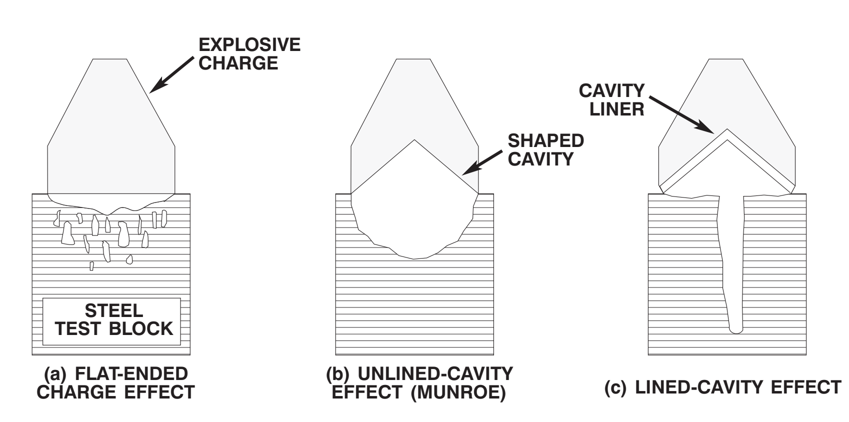


Figure 13-23A. Explosive Cutting Charge Configuration - Effect of Charge Configurations.

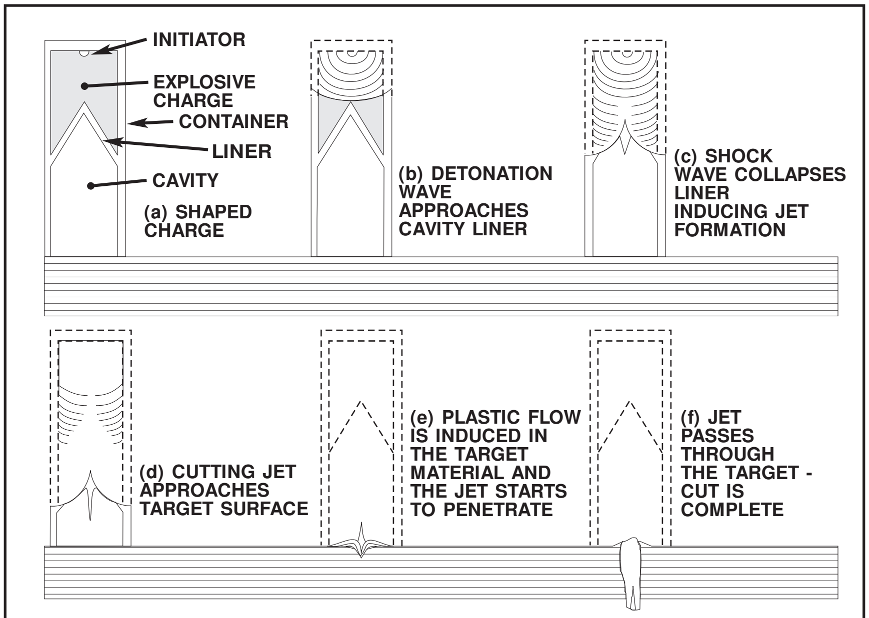


Figure 13-23B. Explosive Cutting Charge Configuration - Lined-Cavity Charge Cutting Sequence.

Figure 13-23A shows differences in explosive cutting behavior of flat-ended charges, unlined-cavity charges, and lined-cavity charges.

Modern shaped charges incorporate various designs of liner and liner materials to improve cutting performance. When a lined-cavity-shaped charge is detonated, its product gases expand omni-directionally from the charge center or axis. Detonation waves converge on a plane at the cavity of a shaped charge. This confluence of energy produces a magnified force that is deflected onto the target surface. Liner material collapses under explosive pressure converting into minute fragments that impact on the target surface in a heated mass or jet of heat and metallic fragments. Wave pressure is directed against target surface at a 90-degree angle so the cutting jet attacks a small cross-sectional area. As the cutting jet penetrates, it may also create a spalling effect to assist cutting action on the opposite side of the target plate.

Enclosed cavities or shaped charges will collapse if submerged too deeply. Some blasters have successfully filled cavities with foam, or pressurized gas to extend depth range. Figure 13-23B shows the behavior of a lined-cavity-shaped cutting charge under ideal conditions.

Cavity spaces of lined-shaped charges must not contain any material that prevents the penetration jet from forming completely before it reaches target steel. Underwater, the cavity **must be watertight**. Basic underwater shaped charges consist of containers with explosive compartments and watertight cavity spaces. Penetration and cutting power of a shaped charge are directly proportional to detonation pressure, a function of the type and density of the explosive in the charges.

Military shaped-charge containers are available in a variety of precisely engineered configurations including linear charges of several sizes suitable for cutting steel plate and hull girders. Most of these containers must be wound with waterproof tape to seal in the explosive charge and seal the cavity area. Linear shaped charges are precision cutting tools that cannot achieve their full potential unless they are in close contact with the material to be cut. Linear charges can be made up in a variety of special cutters by commercial vendors. Custom-made cutters for a particular underwater cutting project may be obtained through the Supervisor of Salvage.

Figure 13-24 shows the difference in cut results on two identical steel tower support legs obtained with conventional blasting using C-4 explosive and with specially designed linear-shaped charges.

Where linear-shaped cutting charges are not available and it is not possible to fabricate shaped cutters, hose charges may be substituted. A basic hose charge consists of a length of 2½-inch fire hose packed with C-4 or other suitable plastic explosive. The fire hose is split open, packed with explosive at about 3 pounds per foot of hose, and sealed with heavy waterproof tape. Various configurations of hose charges can be made up to fit onto flat, concave, or convex plate constructions. Generally, an elliptical section is suitable for steel cutting work with the charge initiated from midlength.

Hose charges are not as efficient as shaped charges. Their cutting effects can be improved by scoring cut lines with an oxy-arc cutters. Charges are placed along the score lines. The score lines both assist divers in positioning charges and improve cutting effects. Hose charges are a poor substitute for well-designed shaped charges. To obtain sufficient penetration, relatively large amounts of explosives are required with all the attendant and undesirable results of large secondary effects. Figure 13-25 shows a field-fabricated hose cutting charge of a type sometimes used in steel plate sectioning.

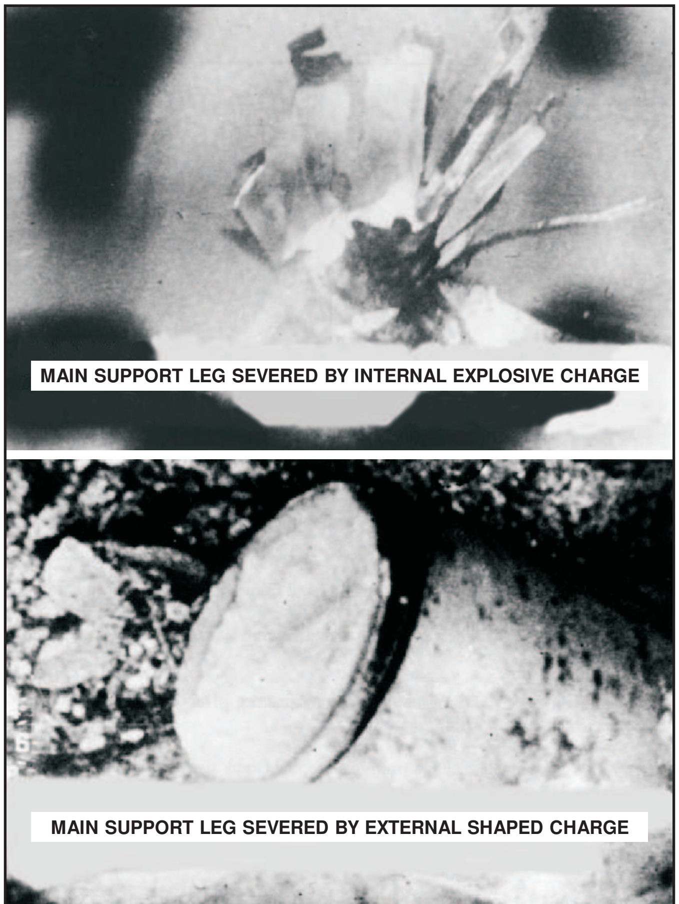


Figure 13-24. Effects of Controlled and Uncontrolled Explosive Cutting.

13-6.3 Charge Placement. Weight and placement of underwater explosive cutting charges must be planned to:

- Obtain a continuous cut of hull plating and frames along the selected cut line
- Avoid serious distortion of plating and structurals adjacent to the cut line that would hinder divers
- Maintain basic wrecking-in-place cutting practice of not cutting main hull strength areas wherever possible.
- Avoid undesirable damage from inappropriate explosive stand-off distances.

To obtain the best underwater explosive cutting effects, charges must be placed to cut against, or very close to strength girders. Explosive cutting of steel plates is most effective when charges are detonated adjacent to, but slightly offset from, frames.

Charges must be placed hard against the steel to be cut for maximum efficiency. Explosive charges on all vertical and many horizontal or angled surfaces must be positively secured to the cut line. Methods of securing charges in position include:

- Firing a series of studs into steel each side of the cut line and bolting charges into position with light metal straps
- Oxy-arc cutting small holes through shell plating and frames through which tie-down wires or short lengths of bongee cord are inserted to hold charges in position
- Placing weights on charges on horizontal surfaces
- Holding charges with magnetic clamps and small suction pads. These devices have had limited success.

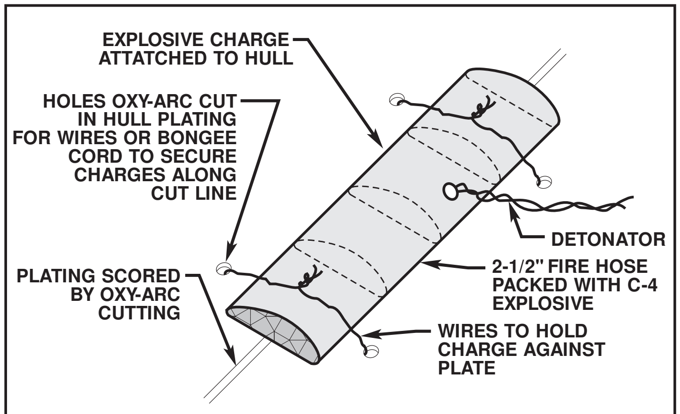
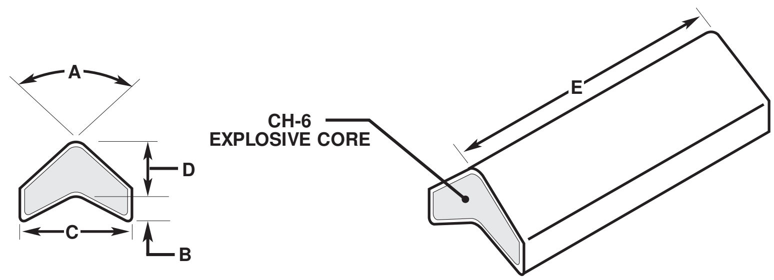


Figure 13-25. Hose-Type Cutting Charge.

The weight of explosive per linear foot of cutting charge should be established from the appropriate tables in *Technical Manual for Use of Explosives in Underwater Salvage* (SWO61-AA-MMA-010) or from data provided by explosive manufacturers (Figure 13-26 is representative). Test shots should be made up and fired against selected areas of plate and structurals on each cut line. These test shots verify the suitability of cutters and loading weights before the main cutting begins. Overly large charges usually result in distortion adjacent to cut lines and excessive disruption of compartment structural components. These factors create serious and time-consuming re-orientation difficulties for divers returning to check on cutting progress or place the next series of charges.

Conditions on most wrecking operations are unfavorable for placing very long strings of charges for simultaneous detonation. Although slower at first glance, explosive cutting of steel for wrecking-in-place operations is best performed a few feet per shot to better ensure the quality of cutting.



PENETRATION			ANGLE	DIMENSIONS (INCHES)			
ALUMINUM	STEEL	DESIGNATION (gpf)	A	B	C	D	E
(0.209 IN.)	(0.126 IN.)	125	90°	0.130	0.280	0.410	48.00
(0.457 IN.)	(0.262 IN.)	600	90°	0.330	0.665	0.670	48.00

Figure 13-26. Flexible Linear Shaped Charge (125 & 600 Gr Ft).

13-7 BURIAL, FLATTENING, AND REDUCTION OF WRECKS.

In some situations, the combination of time, cost, and physical conditions make total wreck removal uneconomical or impractical. Under those conditions, the hazards of sunken wrecks may be sufficiently reduced without physically removing major portions of the wrecks. Three common techniques of wreck reduction are:

- Wreck burial
- Flattening wrecks
- Cutting down wrecks.

Wreck burial may be conducted as a wartime military operation with heavy explosive charges or as a peacetime task involving special dredging techniques. It should be noted that military engineering practice considers explosive burial or settling of wrecks and flattening of wrecks as two distinctly different operations. This manual addresses both methods of explosive wreck reduction under the heading *Flattening Wrecks*. In the past, cutting down wrecks was a common method of increasing navigational depths over sunken wrecks. Military circumstances may still require salvors to cut down wrecks, but civilian port authorities do not encourage the practice. Each method described in this section results in hull structures remaining at or close to wreck sites, potentially creating future navigation, construction, or environmental hazards.

13-7.1 Burial of Wrecks. Wreck burial is usually the least favored and most infrequent peacetime method of wreck reduction. Burial of a wreck minimizes a navigational hazard, but does not remove a potential obstruction. Buried wrecks have changed their position because of scouring, and in the worst cases, have worked their way back towards the surface. Peacetime wreck burials should not be attempted without detailed consultation and approval of port operating, navigational, and environmental authorities. Detailed engineering investigations and dredging expertise are key elements in peacetime wreck burial tasks. Combination of careful profile dredging and explosive or gravity induced skidding undercut and settle wrecks into burial trenches.

Site conditions and lack or cost of wreck removal equipment may combine with suitable soil conditions to permit wreck burial. Seafloor soil characteristics are critical in the decision process. Detailed seafloor investigations and tests are necessary to:

- Establish the level below the seafloor and navigational datums where the bedrock or undredgable material strata is located.
- Confirm that the wreck can be lowered or buried to the clearance depth required by authorities. Clearance depths over the buried wreck are critical to the operation.
- Estimate rates of current-induced soil deposit or back filling that will occur during dredging operations.
- Establish soil characteristics for calculation of trench profiles and skidding angles.
- Decide a suitable method of dredging or combination of dredging and blasting necessary to excavate the burial trench.

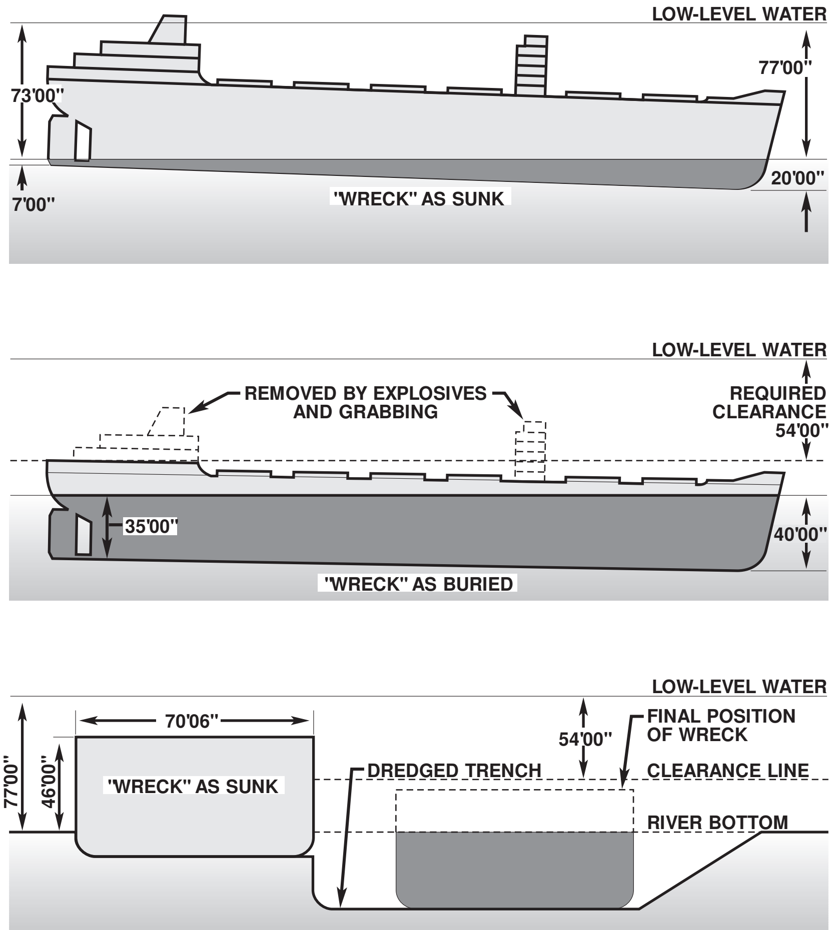


Figure 13-27. Wreck Burial Plan.

Figure 13-27 shows a profile of a sunken wreck as sunk and final position of the wreck after trenching and burial operations.

Salvage engineering studies of wreck movement are conducted in conjunction with soil engineering and excavation investigations. These studies combine to produce a wreck burial and excavation plan based on either dredging or combined dredging and explosive trenching. Dredging methods include:

- Undercutting one side of the wreck so that it capsizes into a pre-excavated trench or burial area
- Alternately dredging and undercutting on each side of wreck so that it subsides in a rocking motion from port to starboard
- Dredging a deep trench near the wreck, then profile dredging a sloping skidway from that trench to wreck.

Figure 13-28 shows a diagrammatic sequence of alternate side trenching system suitable for some wreck burial tasks.

Most work in a conventional wreck burial task is performed by dredging and civil engineering personnel. Salvage aspects of the work in terms of utilizing salvors' skills include:

- Detailed wreck surveys and assistance with moorings and seamanship aspects of soil investigations
- Underwater cutting and removal of masts, stacks, superstructure, and other wreckage that may project above cut line
- Monitoring project and providing technical advice and assistance with explosive charge placement, if required.

The primarily civil engineering nature of wreck burial may cause contractors to use drill and blast explosive systems that may not be familiar to Navy salvage personnel.

Wreck burial by dredging methods is a specialized and infrequently attempted method of wreck reduction. Comprehensive data on past wreck burial methods and specialist advice can be obtained through the Navy Civil Engineering Laboratory and U.S. Army Corps of Engineers.

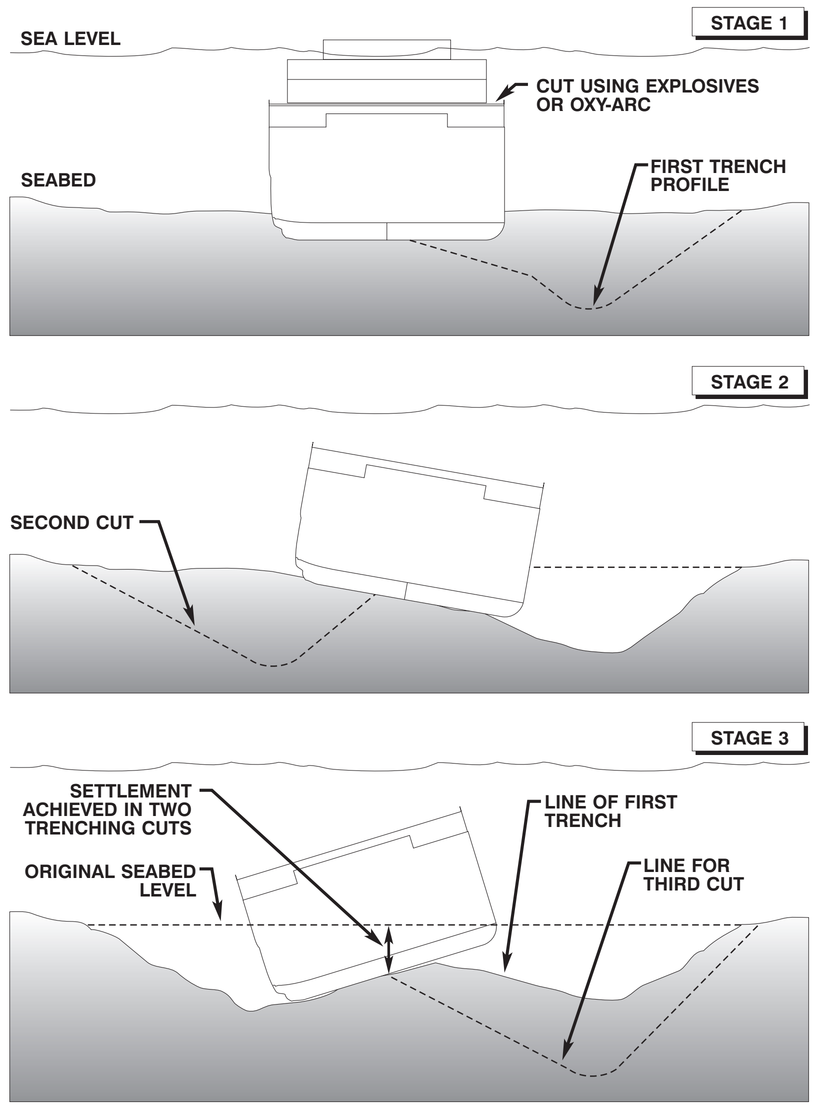


Figure 13-28. Alternate Trench Method of Wreck Burial.

13-7.2 Flattening Wrecks. In this manual, *Flattening Wrecks* encompasses practices that are more specifically known and referred to as:

- Ship settling
- Ship flattening
- Wreck dispersal.

These three practices, grouped together because they have similar end results, employ different techniques, but all have common features including:

- The primary intention of destroying wrecks is to disperse navigational hazards or increase navigable depths.
- Time and usually military circumstances do not permit wrecks to be removed conventionally.
- Wrecks are settled, flattened, or dispersed by explosive demolition.
- Most major wreck components and structures are left *in situ* as shattered debris.

Ship flattening or settling is usually only performed in peacetime as an emergency means of channel or harbor clearance, or as a training exercise. Peacetime explosive wreck dispersal may be conducted before follow-up clearance with wreck grabs.

Detailed procedures for explosive ship flattening and settling are described in the *Technical Manual for Use of Explosives in Underwater Salvage* (SWO61-AA-MMA-010).

13-7.2.1 Ship Settling. Ship settling is making a sunken wreck entrench itself deeper into the seafloor. Ship settling may be the sole method of lowering a wreck to increase depth over it, or may be done in conjunction with ship flattening or wreck dispersal. Suitable soil conditions must exist for explosive ship settling to be successful. Soft sand or muddy seafloors permit settling, but hard clay soil may present some difficulties. Wreck settlement is done by:

- Placing heavy charges inside the hull and blowing holes along the bottom or side of the wreck where it is in contact with the seafloor. Damage to hull plating and reduction of bearing surface area causes the hull to sink. Seafloor material oozes into the hull through the holes blasted by the charges.
- Charges placed around the hull and simultaneously detonated to excavate a rough trench around the wreck. In strong current areas scouring occurs and expedites settling.

These methods may be sequential; first the wreck's side or bottom plating is blasted out, followed by detonation of trenching charges around the wreck.

Figure 13-29 shows internal placement for settlement of an upright wreck.

13-7.2.2 Ship Flattening. Flattening procedures depend upon how the ship is sunk relative to the seafloor. A wreck lying on its side presents a different problem from one that is substantially upright on the bottom. Upright wrecks are flattened from top downwards. Masts, stacks, and superstructure may be cut away with oxy-arc or explosive cutting methods and removed or blasted and allowed to scatter on the seafloor. Some methods of explosive hull flattening follow a combination of pounding down and linear cutting along deck edges to collapse the hull. Combined explosive heavy linear cutting and pounding often results in the wreck collapsing in on itself as a distorted scrapheap.

Another explosive wreck flattening method, more commonly associated with wreck dispersal, places a series of very heavy charges internally. Charges are located inside the wreck's hull with the most powerful charges sited amidships. When the forward, midships, and after end charges are simultaneously detonated, very heavy and opposing pressure surges occur. Internal over-pressure causes side plating and bulkheads to rupture and decks to collapse. Blast and over-pressure effects from very heavy explosive charges detonated inside or against wrecks cannot be easily controlled and result in a shattered and distorted wreck.

Diving activities around such wrecks are hazardous and must be conducted with extreme caution. Wrecks that have been flattened or dispersed with heavy explosive charges usually make subsequent wreck removals difficult.

13-7.2.3 Wreck Dispersal. Wreck dispersal describes a method of flattening or destroying wrecks by heavy explosive charges that are laid on or around wrecks without diver assistance. Wreck dispersal is associated with urgent wartime operations where time does not permit conventional wreck removal. Divers are usually not employed in wreck dispersal work except for initial surveys, and then only if it is safe for divers to enter the water. Wreck dispersal work may be performed near minefields and mine clearance operations that would be dangerous to diving activities. Wreck dispersal operations are characterized by simultaneous detonations of multiple heavy charges. Methods of calculating charge weight and placement for wreck dispersal operations are beyond the scope of this manual.

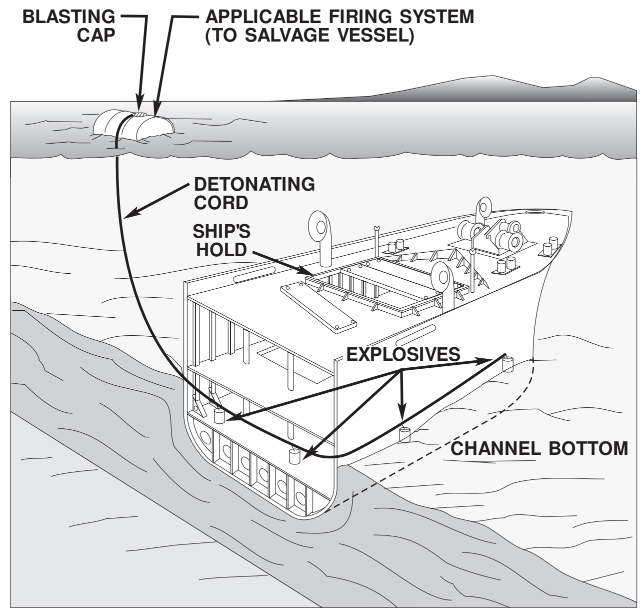


Figure 13-29. Charge Placement for Wreck Settling.

13-7.3 Cutting Down Wrecks. Sometimes navigational obstructions can be reduced by cutting a wreck down to a specified depth below a specified water level. Clearance levels over wrecks are established by port or area operating authorities with regard to present and future traffic.

Wrecks can be cut down to specified levels by various wrecking techniques including:

- Oxy-arc cutting
- Explosive cutting
- A combination of oxy-arc and explosives
- Wreck grabbing.

Manual and explosive cutting methods are most common for this type of wreck reduction. Where cost and lack of suitable floating equipment influences wreck removal plans, partial reduction of wrecks is a short- to medium-term solution to a wreck removal problem.

Figure 13-30 shows a typical planning sequence for cutting down to sea level with oxy-arc and explosive cutting.

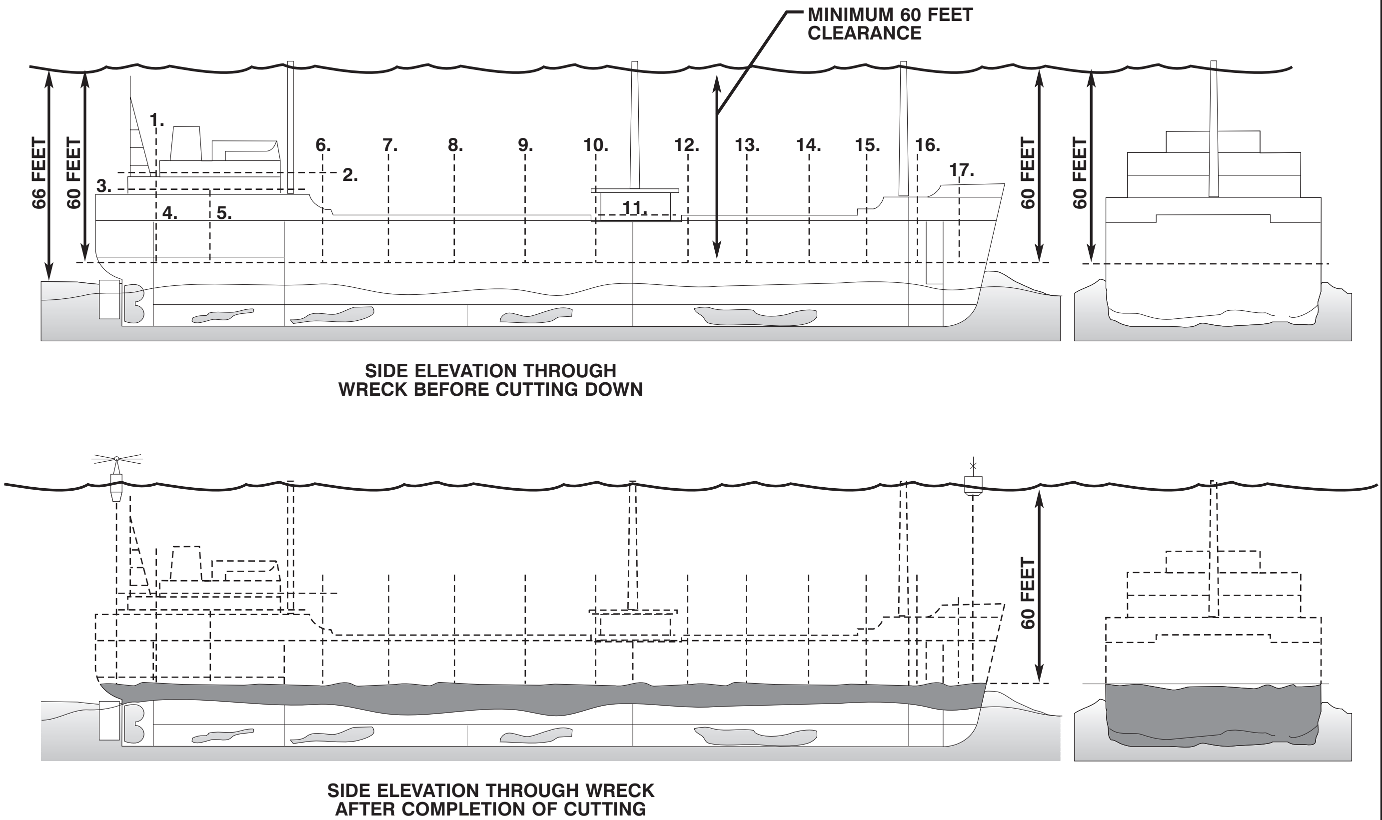


Figure 13-30. Cutting-Down of Wreck to Specified Depth.

APPENDIX A
DOCUMENTATION MATRIX

A-1 PURPOSE.

The purpose of this matrix is to provide the user of this manual with a listing of additional reference documentation. This is given by reference manual and topic area.

A-2 REFERENCE DOCUMENTS.

The following manuals/publications are referenced on the matrix (Table A-1):

- SAFETY MANUAL - U.S. Navy Ship Salvage Safety Manual (S0400-AA-SAF-010)
- SALVAGE MANUAL - U.S. Navy Salvage Manual

  Volume 1 Stranding and Harbor Clearance (S0300-A6-MAN-010)

  Volume 2 Harbor Clearance (S0300-A6-MAN-020); Cancelled (incorporated into Volume 1)

  Volume 3 Fire Fighting and Battle Damage (S0300-A6-MAN-030/2K175); Under Revision

  Volume 4 Deep Ocean (S0300-A6-MAN-040/2K175); Under Revision

  Volume 5 POL Offloading (S0300-A6-MAN-050/2K175); Under Revision

  Volume 6 POL Spill Response (S0300-A6-MAN-060/2K175); Under Revision
- SALVOR'S HANDBOOK - U.S. Navy Salvor's Handbook (S0300-A7-HBK-010/2K175)
- UNDERWATER CUT & WELD - U.S. Navy Underwater Cutting and Welding Manual (S0300-BB-MAN-010)
- ENGINEER'S HANDBOOK - U.S. Navy Salvage Engineer's Handbook

  Volume 1 (S0300-A8-HBK-010)

  Volume 2 (S0300-A8-HBK-020)
- TOWING MANUAL - U.S. Navy Towing Manual (SL740-AA-MAN-010)
- ESSM MANUAL - Emergency Ship Salvage Material Catalog (NAVSEA 0994-LP-017-3010)
- EXPLOSIVES MANUAL - Technical Manual for Use of Explosives in Underwater Salvage (NAVSEA SW061-AA-MMA-010)

Table A-1. Salvage Documentation Matrix.

TOPIC AREA	SAFETY MANUAL	SALVAGE MANUAL: VOLUME 1 - STRANDINGS & HARBOR CLEARANCE	SALVAGE MANUAL: VOLUME 2 - (Canceled)	SALVAGE MANUAL: VOLUME 3 - FIRE FIGHTING & DAMAGE CONTROL	SALVAGE MANUAL: VOLUME 4 - DEEP OCEAN	SALVAGE MANUAL: VOLUME 5 - POL OFFLOADING	SALVAGE MANUAL: VOLUME 6 - OIL SPILL RESPONSE	SALVOR'S HANDBOOK	UNDERWATER CUT & WELD	ENGINEER'S HANDBOOK: VOLUME 1	ENGINEER'S HANDBOOK: VOLUME 2 - POSSE USER'S MANUAL	TOWING MANUAL	EXPLOSIVES MANUAL	ESSM MATERIAL CATALOG: VOLUME 1 - SALVAGE EQUIPMENT	ESSM MATERIAL CATALOG: VOLUME 2 - POLLUTION EQUIPMENT
DAMAGE CONTROL				●				●		●					
STABILITY		●				●		●		●	●				
SHIP STRENGTH		●				●		●		●	●				
RIGGING	●	●			●	●	●	●		●		●			
ANCHORS	●	●					●	●		●				●	
STRANDING		●				●		●		●	●				
PULLING SYSTEMS	●	●						●		●				●	
SAFETY	●	●		●	●	●	●	●	●	●		●	●		
MACHINERY	●							●		●		●		●	●
EXPLOSIVES		●						●		●	●		●		
HAZMAT	●					●	●	●		●					●
POL	●					●	●	●		●					
OFFSHIP FIREFIGHTING	●			●		●		●						●	
TOWING: POINT-TO-POINT						●						●			
RESCUE				●				●				●			
PATCHING		●						●		●					
COFFERDAMS								●		●					
LIFTING SYSTEMS	●	●			●			●		●				●	
POLLUTION CONTROL	●					●	●	●		●					●
PONTOONS		●			●			●		●				●	
SALVAGE PLANNING	●	●			●	●	●	●		●			●		
PROPERTIES OF MATERIALS		●				●		●		●		●	●		
CONVERSION FACTORS		●						●	●	●					
COMPUTER PROGRAMS											●	●			
DEEP WATER RECOVERY					●			●						●	
CUTTING	●	●							●				●		
WELDING	●								●						
CARGO OFFLOAD	●	●				●	●	●		●					

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APPENDIX B
WEIGHTS AND MEASURES

Table B-1. Systems of Measures.

ENGLISH SYSTEM

The English system, in common use in the United States, uses base units of length, force, and time to derive all other units. The system is sometimes called the foot-pound-second system because these are the fundamental units. The word "pound" is used for unit of both force and mass, the pound mass defined as the mass that weighs (produces a downward force) of one pound force in a standard gravitational field, i.e., sea level, with the acceleration due to gravity, g, equal to 32.2 ft/s^2. Since the variation in the earth's gravitational field is small, using units of force to describe mass and vice versa will produce negligible errors in ordinary situations.

LENGTH

1,000 mils	= 1 inch (in)	
12 inches	= 1 foot (ft)	
3 feet	= 1 yard (yd)	
6 feet	= 1 fathom (fm)	
15 fathoms	= 1 shot of chain	= 90 feet
120 fathoms	= 1 cable's length	= 720 feet
5,280 feet	= 1 statute mile (mi)	= 1,760 yards
6,080 feet	= 1 nautical mile (NM)	= 2,027 yards

AREA

144 square inches (in^2)	= 1 square foot (ft^2)
9 square feet (ft^2)	= 1 square yard (yd^2)
43,560 square feet	= 1 acre
640 acres	= 1 square statute mile (mi^2)
	= 27,878,400 ft^2
1 square nautical mile	= 849 acres
	= 36,966,400 ft^2

VOLUME

1,728 cubic inches (in^3)	= 1 cubic foot (ft^3)
27 cubic feet (ft^3)	= 1 cubic yard (yd^3)
231 cubic inches	= 1 U.S. gallon (gal)
277.27 cubic inches	= 1 Imperial gallon
42 U.S. gallons	= 1 barrel = 5.615 cubic feet
1 cubic foot	= 7.48 U.S. gallons
	= 6.23 Imperial gallons
1 cord of wood	= 128 cubic ft (4 ft × 4 ft × 8 ft)
1 acre foot	= 1 acre covered to one foot depth of water
	= 43,560 cubic feet

BOARD MEASURE

board feet	= Length in feet × width in feet × thickness in inches; therefore:
12 board feet	= 1 cubic foot

DRY MEASURE

2 pints	= 1 quart
8 quarts	= 1 peck
4 pecks	= 1 bushel

Table B-1 (continued). Systems of Measures.

LIQUID MEASURE

4 ounces	= 1 gill
4 gills	= 1 pint
2 pints	= 1 quart
4 quarts	= 1 gallon

Note: English system dry measure and liquid measure quarts and pints are not equivalent volumes.

The U.S. gallon and Imperial gallon are subdivided in the same manner, i.e., 4 quarts to the gallon, etc. All Imperial liquid measures are therefore larger than the corresponding U.S. measure by a factor of 277/231, or 1.2.

FORCE AND WEIGHT

7,000 grains (gr)	= 1 pound (lb)
16 ounces (oz)	= 1 pound
2,000 pounds	= 1 short ton
2,240 pounds	= 1 long ton

The metric, or SI *(Systeme Internationale)* system is based on units of length, mass, and, time. Because the fundamental units are the meter, kilogram, and second, the system is sometimes called the MKS system. The units of length and mass are related by the properties of water; a kilogram is the mass of 1,000 cubic centimeters, or one liter. All metric units are decimal subdivisions or multiples of the meter, gram, and liter. The names of the units are formed by combining the basic unit name with one of the Greek prefixes listed in Table B-2. Metric mass units are commonly used to describe weights and forces, with a kilogram (force) equal to the weight, or downward force, of a one kilogram mass in a standard gravitational field (i.e., sea level, with the acceleration due to gravity, g, equal to 9.807 m/s^2 = 32.2 ft/s^2). The more proper force unit in the SI system is the newton, defined as the force required to accelerate a one-kilogram mass at 1 m/s2, and equivalent to 0.102 kgf.

LENGTH

1 meter (m)	= 10 decimeter (dm)
	= 100 centimeters (cm)
	= 1,000 millimeters (mm)
10 meters	= 1 decameter (dam)
100 meters	= 1 hectometer (hm)
1,000 meters	= 1 kilometer (km)

AREA

1 square meter (m^2)	= 1,000,000 square millimeters (mm^2)
	= 10,000 square centimeters (cm^2)
	= 100 square decimeters (dm^2)
1 hectare	= 10,000 square meters
1 square kilometer	= 1,000,000 square meters

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Table B-1 (continued). Systems of Measures.

VOLUME		
1 liter (l)	=	10 deciliters (dl)
	=	100 centiliters (cl)
	=	1,000 milliliters (ml)
	=	1 cubic decimeter (dm3)
1 kiloliter (kl)	=	1,000 liters
	=	1 cubic meter (m3)
1 milliliter (ml)	=	1 cubic centimeter (cc)
MASS		
1 kilogram (kg)	=	1,000 grams (g)
1 gram (g)	=	1,000,000 micrograms (μg)
	=	1,000 milligrams (mg)
	=	100 centigrams (cg)
100 kilograms	=	1 quintal (q)
1,000 kilograms	=	1 metric ton (tonne)
FORCE		
1 kilogram force (kgf)	=	9.807 newtons (N)
1 newton (N)	=	0.102 kgf
1 kilonewton (kN)	=	1,000 newtons
	=	102 kgf
1 meganewton (MN)	=	1,000,000 newtons
	=	102,000 kgf
	=	102 tonnes force (tonnef)

CIRCULAR OR ANGULAR MEASURE

60 seconds	=	1 minute of arc
60 minutes	=	1 degree
90 degrees	=	1 quadrant or right angle
4 quadrants	=	1 circumference = 360 degrees
2π radians	=	1 circumference
1 radian	=	$180/\pi \approx 57.3$ degrees
1,000 mils	=	1 radian

Table B-2. Prefixes.

Prefix	Symbol	Factor by which unit is multiplied	
exa	E	1,000,000,000,000,000,000	= 10^{18}
peta	P	1,000,000,000,000,000	= 10^{15}
tera	T	1,000,000,000,000	= 10^{12}
giga	G	1,000,000,000	= 10^{9}
mega	M	1,000,000	= 10^{6}
kilo	k	1,000	= 10^{3}
hecto	h	100	= 10^{2}
deca	da	10	= 10^{1}
deci	d	0.1	= 10^{-1}
centi	c	0.01	= 10^{-2}
milli	m	0.001	= 10^{-3}
micro	μ	0.000 001	= 10^{-6}
nano	n	0.000 000 001	= 10^{-9}
pico	p	0.000 000 000 001	= 10^{-12}
femto	f	0.000 000 000 000 001	= 10^{-15}
atto	a	0.000 000 000 000 000 001	= 10^{-18}

The Greek prefixes and symbols are most often associated with the metric (SI) system, but can be used with other units or by themselves as a convenient shorthand, e.g., "kilopound" (kp), "K" for 1000, M for 1,000,000, etc.

Table B-3. Basic Metric/English Equivalents.

MEASURES OF LENGTH

1 millimeter	=	0.03937 inch	1 inch	=	25.4 millimeters
1 centimeter	=	0.3937 inch	1 inch	=	2.54 centimeters
1 meter	=	39.37 inches	1 inch	=	0.0254 meter
1 meter	=	3.281 feet	1 foot	=	0.3048 meter
1 kilometer	=	0.62 mile	1 mile	=	1.6 kilometers
1 kilometer	=	0.54 nautical mile	1 NM	=	1.85 kilometers
1 kilometer	=	1,094 yards	1 mile	=	1609 meters
1 kilometer	=	3,281 feet	1 nm	=	1853 meters

MEASURES OF AREA

1 square mm (mm^2)	=	0.0155 square inch	1 square inch	=	645.2 square millimeters
1 square cm (cm^2)	=	0.155 square inch	1 square inch	=	6.452 square centimeters
1 square meter	=	10.76 square feet	1 square foot	=	0.0929 square meter
1 square meter	=	1.196 square yards	1 square yard	=	0.836 square meter
1 hectare	=	2.471 acres	1 acre	=	0.405 hectare
1 hectare	=	107,637 square feet	1 acre	=	4,047 square meters
1 hectare	=	0.00386 square mile	1 square mile	=	259 hectare
1 square kilometer	=	0.386 square mile	1 square mile	=	2.59 square kilometers

MEASURES OF VOLUME

1 cc or ml	=	0.061 cubic inch	1 cubic inch (in^3)	=	16.39 cc or ml
1 cubic meter (m^3)	=	35.3 cubic feet	1 cubic foot (ft^3)	=	0.0283 cubic meter
1 cubic meter	=	1.31 cubic yards	1 cubic yard (yd^3)	=	0.764 cubic meter
1 liter	=	61 .023 cubic inches	1 cubic foot (ft^3)	=	28.32 liters
1 liter	=	0.0353 cubic foot			

LIQUID MEASURE

1 liter (l)	=	1.057 U.S. quarts	1 U.S. quart (qt)	=	0.946 liter
1 liter (l)	=	0.264 U.S. gallons	1 U.S. gallon (gal)	=	3.79 liters
1 cubic meter	=	264.17 gallons	1 U.S. gallon	=	0.0038 cubic meter

DRY MEASURE

1 liter (l)	=	0.908 dry quarts	1 dry quart	=	1.101 liters
1 hectoliter (hl)	=	2.8375 bushels	1 bushel	=	0.353 hectoliter

MEASURES OF WEIGHT AND MASS

1 kilogram (kg)	=	2.205 pounds force	1 pound force (lbm)	=	0.454 kilograms
				=	454 grams
1 tonne	=	1.1023 short tons	1 short ton	=	0.9072 tonne
	=	2205 pounds		=	907.2 pounds
1 tonne	=	0.9842 long tons	1 long ton	=	1.016 tonne
	=	1016 pounds			
1 milligram	=	0.154 grain	1 grain	=	64.8 milligrams
1 gram	=	15.432 grains		=	0.0648 gram
1 newton	=	0.225 pounds force	1 pound force (lbf)	=	4.448 newtons
1 meganewton	=	100.4 long tons	1 long ton	=	0.009964 MN
	=	112.4 short tons	1 short ton	=	0.008897 MN
	=	224,799 pounds			

Table B-4. Common (Approximate) Pressure Conversions.

Multiply	By	To Obtain
Inches of seawater	0.037	psi
Feet of seawater	0.445	psi
Inches of fresh water	0.036	psi
Feet of fresh water	0.434	psi
Psi	2.25	feet of seawater
Psi	2.3	feet of fresh water
Inches of mercury	0.49	lb/in^2
Lb/in^2	2.04	inches of mercury
Atmospheres	14.7	lb/in^2
Lb/in^2	0.07	atmospheres
Atmospheres	10.0	meters of seawater

Table B-5. Common Density Conversions.

Multiply	By	To Obtain
Lb/ft^3	16.02	kg/m^3
	0.01602	g/cc
Kg/m3	0.0624	lb/ft^3
	1,000	g/cc
m^3/tonne	35.87	ft^3/lton
ft^3/lton	0.0279	m^3/tonne

Table B-6. General Conversion Factors.

Multiply	By	To Obtain
Atmospheres	760	mm of mercury (mm Hg)
	76.0	cm of mercury (cm Hg)
	33.9	feet of fresh water (ffw)
	34	approximate ffw
	33.1	feet of seawater (fsw)
	10	approximate meters of seawater
	33	approximate fsw
	29.92	inches of mercury (in Hg)
	1.033	kg/cm^2
	10,332	kg/m^2
	14.7	lb/in^2 (psi)
	1.06	tons/ft^2
Bars	0.987	atmospheres
	10200	kg/m^2
	1.02	kg/cm^2
	14.5	lb/in^2 (psi)
Barrels	5.615	cubic feet (ft^3)
	42	U.S. gallons (gal)
	0.159	kiloliters, cubic meters
	159	liters
Centimeters	0.394	inches (in)
	0.0328	feet (ft)
	0.0109	yards (yd)

Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Centimeters/second	1.969	feet/min
	0.0328	feet/sec
	0.036	km/hour
	0.0194	knots
	0.6	meters/min
	0.0224	miles/hour
Cubic centimeters	0.061	cubic inches (in^3)
	0.00003531	cubic feet (ft^3)
	0.000001308	cubic yards (yd^3)
	0.0002642	gallons (U.S.)
	0.0338	ounces
Cubic feet	28,320	cubic cm (cc)
	1,728	cubic inches (in^3)
	0.02832	cubic meters (m^3)
	0.03704	cubic yards (yd^3)
	7.48	U.S. gallons (gal)
	7.5	approximate U.S. gallons
	28.32	liters
	0.178	barrels (bbl)
Cubic feet/minute	472	cubic cm/sec (cc/sec)
	35.31	cubic meter/min (m^3/min)
	7.48	U.S. gallons/min (gpm)
	7.5	approximate gpm
	0.1247	U.S. gallons/sec
	60	cubic feet/hour (ft^3/hour)
	449	gal/hour
	1.43	bbl/hour
Cubic feet/second	448.8	U.S. gallons/min
Cubic inches	16.39	cubic cm (cc)
	0.0005787	cubic feet (ft^3)
	0.00001639	cubic meters (m^3)
	0.00002143	cubic yards (yd^3)
	0.004329	U.S. gallons (gal)
	0.01639	liters (l)
Cubic meters	61,023	cubic inches (in^3)
	35.31	cubic feet (ft^3)
	1.308	cubic yards (yd^3)
	264.2	U.S. gallons (gal)
	6.29	barrels
	1,000	liters (l)
	1	kiloliters (kl)
Cubic meters/minute	35.31	ft^3/min
	0.5885	ft^3/sec
Feet	304.8	millimeters
	30.48	centimeters
	0.3048	meters
	0.0001645	miles (nautical)
	0.0001894	miles (statute)
Feet of fresh water	.0295	atmospheres
	0.8827	in Hg
	0.0305	kg/cm^2
	304.77	kg/m^2
	62.4	lb/ft^2
	0.434	lb/in^2

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Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Feet of seawater	0.0303	atmospheres
	0.9048	in Hg
	0.03124	kg/cm^2
	312.46	kg/m^2
	64.0	lb/ft^2
	0.445	lb/in^2 (psi)
Feet/minute	0.5080	cm/sec
	0.01667	feet/sec
	0.01829	km/hour
	0.3048	meters/min
	0.01136	miles/hour
Feet/second	30.48	cm/sec
	1.097	km/hour
	0.5921	knots
	18.29	meters/min
	0.6818	miles/hour
	0.01136	miles/min
Foot-lbs	1.355	newton-meters
	0.1383	kilogram-meters
	13830	gram-centimeters
Foot tons (long tons)	3,035.2	newton-meters
	0.00303	meganewton-meters
	0.3	meter-tonne
Foot-tons (short tons)	2,710	newton-meters
	0.00271	meganewton-meters
	0.336	meter-tonne
Gallons (U.S.)	3,785	cubic cm (cc)
	0.1337	cubic feet (ft^3)
	231	cubic inches (in^3)
	0.003785	cubic meters (m^3)
	0.004951	cubic yards (yd^3)
	3.785	liters (l)
	1.2	Imperial gallons
	0.0238	barrels (bbl)
Gallons (Imperial)	0.833	U.S. gallons (gal)
gram/centimeter	0.0056	lb/in
Inches	25.4	millimeters
	2.54	centimeters
	0.08333	feet
	0.0254	meters
	0.02778	yards
Inch-pounds	0.113	newton-meters
	1153	gram-centimeters
Kilograms	2.205	pounds
	0.0009842	tons (long)
	0.001102	tons (short)
Kilograms/meter	0.672	lb/ft
Kilograms/m^2	0.2048	lb/ft^2
	0.00142	lb/in^2 (psi)
Kilgrams/m^3	0.0624	lb/ft^3
Kilogram-meter	7.233	ft-lbs
	87.53	inch-lbs
Kilograms/cm^2	14.223	lb/in^2 (psi)

Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Kiloliters	1	cubic meters (m^3)
	6.29	barrels (bbl)
	264.2	U.S. gallons
	220.1	Imperial gallons
	35.31	cubic feet (ft^3)
	1.308	cubic yards (yd^3)
Kilometers	3,281	feet
	0.6214	miles (statute)
	0.534	miles (nautical)
	0194	yards
Kilometers/hour	27.78	cm/sec
	54.68	feet/min
	0.9113	feet/sec
	0.5396	knots
	16.67	meters/min
	0.6214	miles/hour
Knots	6,080.2	feet/hour
	1.8532	kilometers/hour
	0.5144	meters/sec
	1.1516	statute miles/hour
	1.689	feet/sec
Liters	61.02	cubic inches (in^3)
	0.0353	cubic feet (ft^3)
	0.001308	cubic yards (yd^3)
	0.2642	U.S. gallons (gal)
	0.2201	Imperial gallons
	0.00629	barrels (bbl)
Meganewtons	100.4	long tons (lton)
	112.4	short tons
	102	tonne
	101,968	kilograms (kg)
	224,799	pounds (lb)
Meganewton-meters	329.3	foot-tons (long tons)
	368.8	foot-tons (short tons)
	101.97	meter-tonne
Meganewtons/meter	30.6	lton/ft
	34.3	short tons/ft
	102	tonne
Meters	39.37	inches
	3.281	feet
	0.0005396	miles (nautical)
	0.0006214	miles (statute)
	1.094	yards
Meters/minute	1.667	cm/sec
	3.281	feet/min
	0.05468	feet/sec
	0.06	km/hour
	0.03238	knots
	0.03728	mile/hour
Meters/second	1.934	knots
	196.8	feet/min (fpm)
	3.281	feet/sec
	3.6	km/hour
	0.06	km/min
	2.237	miles/hour (statute)
	0.03728	miles/min

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Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Miles (nautical)	1,853.25	meters (m)
	1.853	kilometers (km)
	6,080	feet (ft)
	2,027	yards (yd)
	1.1516	miles (statute)
Miles (statute)	1609	meters (m)
	1.61	kilometers (km)
	5,280	feet (ft)
	1,760	yards (yd)
	0.8684	nautical miles
Miles/hour	44.7	cm/sec
	88	feet/min
	1.467	feet/sec
	0.0167	miles/min
	1.609	km/hour
	0.02682	km/min
	0.8684	knots
	26.82	meters/min
	0.447	meters/sec
Millimeters	0.03937	inches (in)
	0.00328	feet (ft)
	0.001094	yards (yd)
Millimeters of mercury	0.00132	atmospheres
	0.00435	feet of seawater (fsw)
	0.00446	feet of fresh water (ffw)
	13.6	kg/m^2
	2.785	lb/ft^2
	0.0193	lb/in^2 (psi)
Newtons	0.225	pounds (lb)
Newtons/meter	0.102	kg/m
	1.356	lb/ft
Ounces	0.0625	pounds (lb)
Ounces (fluid)	1.805	cubic inches (in^3)
	0.02957	liters (l)
	0.0313	quarts, liquid (qt)
	0.0078	U.S. gallons (gal)
$Ounces/in^2$	0.0625	lb/in^2
Pounds	0.454	kilograms
	16	ounces
	4.448	newtons (N)
$Pounds/ft^3$	16.02	kg/m^3
	1,728	$pounds/in^3$
Pounds/ft	1.488	kg/m
Pounds/in	178.6	gm/cm
$Pounds/ft^2$	0.0004725	atmospheres
	4.882	kg/m^2
	0.006944	$pounds/in^2$ (psi)
$Pounds/in^2$	0.068	atmospheres
	2.25	feet of seawater (fsw)
	2.3	feet of fresh water (ffw)
	703.1	kg/m^2
	144	lb/ft^2
	0.0005	short $tons/in^2$
	0.000464	long $tons/in^2$

Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Quarts, U.S. liquid	0.946	liters (l)
	0.0334	cubic ft (ft^3)
	57.75	cubic inches (in^3)
	32	fluid ounces
	4	gallons
Square feet	92,900	square mm (mm^2)
	929	square cm (cm^2)
	0.0929	square meters (m^2)
	144	square inches (in^2)
	0.111	square yards (yd^2)
	0.00002296	acres
Square inches	645.2	square mm (mm^2)
	6.452	square cm (cm^2)
	0.006944	square feet (ft^2)
Square kilometers	0.3861	square miles
	0.29155	square nautical miles
Square meters	10.76	square feet (ft^2)
	1,550	square inches (in^2)
	1.196	square yards (yd^2)
Square miles	2.590	square kilometers
	640	acres
	27,878,400	square ft
Square millimeters (mm^2)	0.00155	square inches
Square yards	0.8361	square meters (m^2)
Tons (long)	1,016	kilograms
	2,240	pounds
	1.12	tons (short)
	1.016	tonne (metric)
	0.009964	meganewtons (MN)
Long tons/square inch	2,240	lbs/in^2 (psi)
	1,574,889	kg/m^2
	1,574.9	tonne/m2
	157.5	kg/cm^2
	15.44	$meganewtons/m^2$
Long tons/foot	1.12	short tons/foot
	3.33	tonne/meter
	3,333.7	kg/m
	32,693.6	newtons/meter (N/m)
	0.0327	meganewtons/meter (MN/m)
Tons (short)	907.2	kilograms
	2,000	pounds
	0.8929	tons (long)
	0.9072	tonnes (metric)
	0.008897	meganewtons (MN)
Short tons/square inch	2,000	lb/in^2
	1,406,151	kg/m^2
	1,406.15	$tonne/m^2$
	140.62	kg/cm^2
	13.79	MN/m^2

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Table B-6 (continued). General Conversion Factors.

Multiply	By	To Obtain
Short tons/foot	0.8929	lton/ft
	2.977	tonne/meter
	2,976.5	kg/m
	29,190.6	newton/meter (N/m)
	0.0292	MN/m
Tonne (metric)	0.984	long tons (lton)
	1.1023	short tons
	2,205	pounds (lbs)
	1,000	kilograms
	0.009807	meganewtons (MN)
Tonne/meter	0.3	lton/ft
	0.276	short tons/f
	672	lb/ft
	9,807	newtons/meter
Yards	91.44	centimeters
	0.9144	meters

Table B-7. Power Conversion.

Multiply	By	To Obtain
Horsepower	0.746	kilowatts
Kilowatts	1.3404	horsepower
Btu	778.3	foot-pounds
Foot-pounds	0.001285	Btu
Btu	0.0003927	horsepower hours
Horsepower hours	2,554.1	Btu
Btu	0.0002928	kilowatt hours
Kilowatt hours	3,412.75	Btu

Table B-8. Temperature Conversion.

Degrees Fahrenheit (^oF) = (9/5 × degrees Celsius) + 32

Degrees Celsius (^oC) = (5/9 × degrees Fahrenheit) - 32)

ABSOLUTE TEMPERATURE

Rankine (R) = Degrees Fahrenheit + 460

Kelvin (K) = Degrees Celsius + 273

Table B-9. Common Flow Rate Conversion.

Multiply	By	To Obtain
Liters per second (lps)	15.83	gpm
	0.12	cfm
Liters per minute (lpm)	0.26	gpm
	0.0353	cfm
Tons seawater per hour	261.8	gal/hour
	4.36	gpm
	0.583	cfm
	0.276	lps
	0.995	m^3/hour
Tonnes seawater per hour	4.295	gpm
	0.574	cfm
	0.271	lps
	0.976	m^3/hour
Tons fresh water per hour	4.475	gpm
	0.598	cfm
	0.282	lps
	1.016	m^3/hour
M^3/hour	4.4	gpm
	0.588	cfm
	0.278	lps
	1.01	tons seawater/hour
	0.98	tons fresh water/hour
	1.025	tonnes seawater/hour
M^3/sec	15850.2	gpm
	2118	cfm
Ft^3/min (cfm)	7.48	gpm
	0.472	lps
	28.32	lpm
	1.714	tons seawater/hour
	1.671	tons fresh water/hour
	1.741	tonnes seawater/hour
	0.00047	m^3/sec
	1.7	m^3/hour
U.S. gallons per minute (gpm)	0.134	cfm
	0.063	lps
	3.79	lpm
	0.229	tons seawater/hour
	0.223	tons fresh water/hour
	0.233	tonnes seawater/hour
	0.00006	m^3/sec
	0.228	m^3/hour

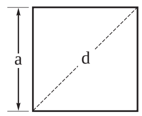
APPENDIX C
MISCELLANEOUS FORMULAE

The following formulae are used during salvage operations. They have been compiled from this manual and other references.

C-1 PLAN SURFACES.

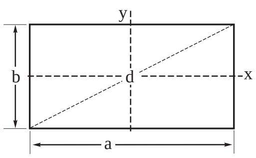
C-1.1 Square.

$$A = a^2$$
$$a = \sqrt{A}$$
$$d = a\sqrt{2}$$



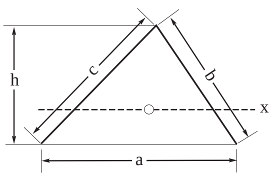
C-1.2 Rectangle.

$$A = ab$$
$$d = \sqrt{a^2 + b^2}$$
$$Ix = \frac{a^3 b}{12}$$
$$Iy = \frac{ab^3}{12}$$



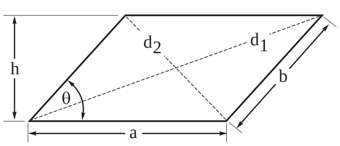
C-1.3 Triangle.

$$A = \frac{ah}{2}$$
$$s = \frac{a+b+c}{2}$$
$$A = \sqrt{s(s-a)(s-b)(s-c)}$$
$$I = \frac{ah^3}{36}$$



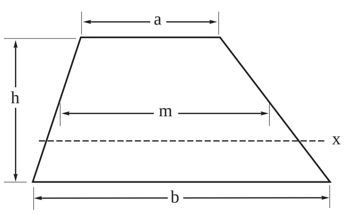
C-1.4 Parallelogram.

$$A = ah = ab\sin\theta$$
$$d_1 = \sqrt{(a + h\cot\theta)^2 + h^2}$$
$$d_2 = \sqrt{(a - h\cot\theta)^2 + h^2}$$



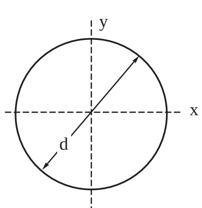
C-1.5 Trapezoid.

$$A = \frac{a+b}{2}h$$
$$I_x = \frac{h^3(a^2 + 4ab + b^2)}{36(a+b)}$$



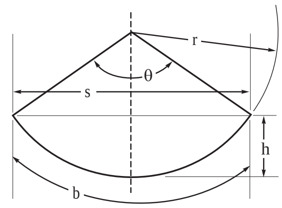
C-1.6 Circle.

$$A = \frac{\pi d^2}{4}$$
$$A = .785d^2$$
$$C = \pi d$$
$$I_x = I_y = \frac{\pi d^2}{64}$$



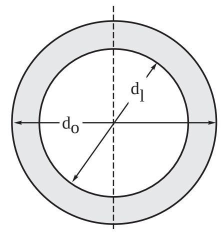
C-1.7 Segment of a Circle.

$$s = 2r\sin\frac{\theta}{2}$$
$$A = \frac{h}{6s}(3h^2 + 4s^2) = \frac{r^2}{2}(\theta - \sin\theta)$$
$$r = \frac{h}{2} + \frac{s^2}{8h}$$
$$h = r\left(1 - \cos\frac{\theta}{2}\right)$$
$$b = r\left(\frac{\theta}{57.29}\right)$$



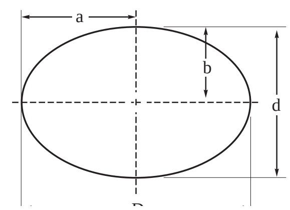
C-1.8 Hollow Ring.

$$A = \frac{\pi}{4}\left(d_0^{\,2} - d_1^{\,2}\right)$$



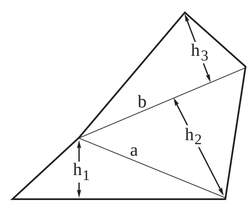
C-1.9 Ellipse.

$$A = \pi\frac{Dd}{4} = \pi ab$$
$$C = \pi\frac{D+d}{2}$$



C-1.10 Polygon.

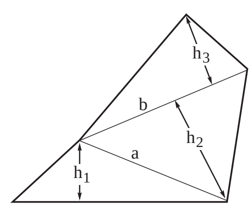
$$A = \frac{ah_1 + bh_2 + bh_3}{2}$$



C-1.11 Irregular Surfaces.

Divide length into parallel strips of equal width.

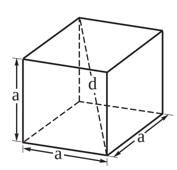
$$A = b\frac{h_1 + h_2 + h_3 + \ldots\ldots\ldots\ldots h_n}{n}$$



C-2 SOLID BODIES.

C-2.1 Cube.

$$V = a^3$$
$$A_o = 6a_2$$
$$d = a\sqrt{3}$$

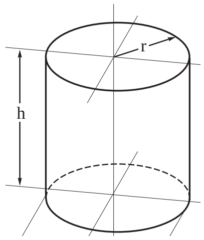


C-2.2 Cylinder.

$$V = \frac{\pi d^2}{4}$$

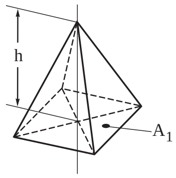
$$\text{Area of sides} = \pi dh$$

$$\text{Total Area} = \pi d\left(h + \frac{d}{2}\right)$$



C-2.3 Pyramid.

$$V = \frac{A_1 h}{3}$$

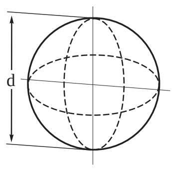


C-2.4 Sphere.

$$V = \frac{\pi d^3}{6}$$

$$V = .524d^3$$

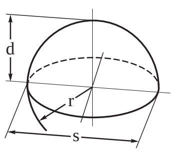
$$A = \pi d^2$$



C-2.5 Sphere segment.

$$V = \frac{\pi h}{6}\left(\frac{3}{4}s^3 + h^2\right) = \pi h^2\left(r - \frac{h}{3}\right)$$

$$A_m = 2\pi rh = \frac{\pi}{4}\left(s^2 + 4h^2\right)$$

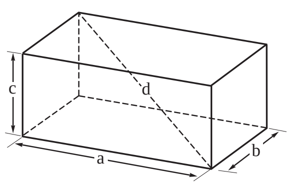


C-2.6 Cuboid.

$$V = abc$$

$$A_O = 2(ab + ac + bc)$$

$$d = \sqrt{a^2 + b^2 + c^2}$$



C-2.7 Cone.

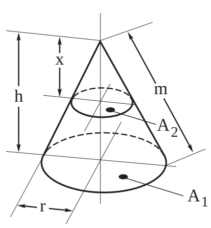
$$V = \frac{\pi r^2 h}{3}$$

$$A_M = \pi rm$$

$$A_O = \pi r(r + m)$$

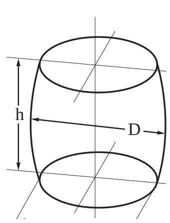
$$m = \sqrt{h^2 + h^2}$$

$$A_2 : A_1 = x^2 : h^2$$



C-2.8 Barrel.

$$V = \frac{\pi h}{12}\left(2D^2 + d^2\right)$$



C-3 NAVAL ARCHITECTURE.

C-3.1 Coefficients of Form.

C-3.1.1 Block Coefficient.

$$C_B = \frac{V}{L \times B \times T}$$

C-3.1.2 Midships Coefficient.

$$C_M = \frac{A_m}{B \times T}$$

C-3.1.3 Waterplane Coefficient.

$$C_{WP} = \frac{A_{WP}}{L \times B}$$

C-3.2 Displacement.

$$W = \frac{G_B \times L \times B \times T}{35}$$

C-3.2.1 Trim Correction to Displacement.

$$TC = \frac{d \times t}{L}$$

C-3.2.2 Tons Per Inch Immersion.

$$TPI = \frac{C_{WP} \times L \times B}{420}$$

C-3.3 Height of the Center of Gravity.

$$KG = \frac{\left[(KG \times W) \pm (kg_1 \times w_1) \pm (kg_2 \times w_2) \pm \ldots (kg_n \times w_n)\right]}{(w_1 \pm w_2 \pm \ldots w_n)}$$

C-3.3.1 Movement of the Center of Gravity.

$$GG_1 = \frac{Gg \times w}{W \pm w}$$

C-3.4 Height of the Center of Buoyancy.

$KB = .55T$ (approximate)

C-3.5 Transverse Metacentric Radius.

$$BM = \frac{I}{V}$$

C-3.6 Height of the Metacenter.

$$KM = KB + BM$$

C-3.7 Metacentric Height.

$$GM = KM + KG$$

C-3.8 Righting Arm.

$$GZ = GM \times \sin\theta$$

C-3.8.1 Righting Moment.

$$RM = W \times GZ$$

C-3.9 List.

$$\theta = \tan^{-1} \frac{w \times Gg}{W \times GM} \text{ (where } W \text{ includes } w)$$

C-3.9.1 Angle of Loll (Negative GM).

$$\theta = \tan^{-1} \frac{2 \times GM}{BM^{1/2}} \text{ (where } W \text{ includes } w)$$

C-3.10 Moment to Trim One Inch.

$$MT1 = \frac{(GM_L \times W)}{(12 \times L)}$$

C-3.11 Approximate Moment to Trim One Inch.

$$MT1 = \frac{(BM_L \times W)}{(12 \times L)}$$

C-3.11.1 Additional Methods to Determine Approximate Moment to Trim One Inch.

$$MT1 = \frac{30 \times (TPI)^2}{B}$$

$$MT1 = \frac{L^2 \times B}{10{,}000}$$

C-3.12 Trim.

$$\delta\text{trim} = \frac{\text{trimming moment}}{MT1}$$

C-3.12.1 Final Drafts.

$$\delta T_f = \frac{\delta \text{ trim} \times (\text{FP to LCF})}{L}$$

$$\delta T_a = \frac{\delta \text{ trim} \times (\text{AP to LCF})}{L}$$

C-3.13 Free-Surface Effect.

$$GG_1 = \frac{i}{V}$$

C-3.14 Free-Communication Effect.

$$GG_1 = \frac{(a \times y^2)}{V}$$

C-3.15 Ground Reaction. There are four primary methods of determining ground reaction. These methods are change in displacement, TPI, change in draft forward, and change in trim.

C-3.15.1 Change in Displacement Method.

$$R = W_b - W_s$$

C-3.15.2 TPI Method.

$$R = (T_{mbs} - T_{mas}) \times TPI$$

C-3.15.3 Change in Draft Forward Method.

$$R = \frac{TPI \times MT1 \times L \times (T_{fbs} - T_{fas})}{[(MT1 \times L) + (TPI \times d_r \times d_f)]}$$

C-3.15.4 Change in Trim Method.

$$R = \frac{MT1 \times t}{d}$$

C-3.16 Effect of Tides on Ground Reaction.

$$\delta R = \frac{t \times TPI \times MT1 \times L}{[(TPI \times d^2) + (MT1 \times L)]} \quad \text{(If ship can trim)}$$

$$\delta R = h \times TPI \quad \text{(If ship not free to trim)}$$

h = Tide fall

C-3.17 Neutral Loading Point.

$$d_n = \frac{(MT1 \times L)}{(TPI \times d_r)}$$

C-3.18 Freeing Force.

$$F = 1.12 \times \mu \times R$$

C-4 FLOODING RATES AND HYDROSTATIC PRESSURE.

C-4.1 Flooding Rate.

Theoretical flow through a hole is, in general terms:

$$Q = K_1 \times C_d \times A \times \sqrt{D}$$

where:

- Q = flow rate in various units
- K_1 = a constant depending upon the units of Q (see Table C-1, Values of K_1)
- C_d = discharge coefficient
- A = outlet area of the hole in ft^2 or meters
- D = depth of the center of area of the hole below the surface

Table C-1. Values of K_1.

Values of K_1			
A in square feet D in feet			
Volume units	*Second*	*Minute*	*Hour*
Cubic Feet	8.02	481	28,890
Tons (seawater)	0.229	13.74	825
Gallons	60	3,600	216,000
A in square meters D in meters			
Cubic meters	4.43	266	15,960
Tonnes (seawater)	4.32	259	25,570

Formulae for flow rate of water in gallons per minute:

$$Q = 3{,}600 \times A \times \sqrt{D}$$

where:
- Q = Quantity of water in gallons per minute
- A = Area of the hole in square feet
- D = Depth of the center of the area of the hole below the surface

Formulae for water flow rate in ft^3 / sec:

water flow rate, $ft^3/sec = Q = C_d A \sqrt{2gh}$

Outlet Area $A = Q / \; C_d \sqrt{2gh}$

where:
- A = outlet area ft^2
- Q = water flow rate in ft^3/sec
- C_d = discharge coefficient (from figure below)
- P_d = maximum acceptable differential pressure, psig
- g = acceleration due to gravity = 32.2 ft/sec^2
- h = blowing pressure, expressed as an equivalent head of seawater, feet = $P_d / 0.445$

C-4.1.1 Air Flow Requirements. The standard volume of air (V_s) required to completely dewater a space is based on the pressure at the opening of bottom of standpipe:

$$V_S = \frac{(D+33)}{33}(V_a)\left(\frac{T_a}{T_w}\right)$$

$$\text{Time to dewater} = \frac{V_s}{Q_s}$$

$$\text{Actual air flow rate} = Q_a = \frac{Q_s}{ATA}$$

$$\text{Required outlet area} = Q = \frac{Q}{C_d} 2gh$$

where:
- D = depth to the vent or bottom of the standpipe, feet
- V_a = water volume, actual cubic feet = space volume X permeability
- T_w = water temperature at depth, absolute
- T_a = air temperature, absolute
- Q_s = air delivery rate
- Q_a = actual air flow rate into the compartment
- V_s = standard volume of air

C-4.2 Hydrostatic Pressure. Pressure at any point on a submerged object:

$$P = .445 \times H \text{ (pounds per square inch)}$$

$$P = 64 \times H \text{ (pounds per square foot)}$$

where:
- H = Height in feet of seawater over the point where the pressure is desired

C-4.3 Hydrostatic Force.

$$F = 64 \times A \times d$$

where:
- F = Force in pounds
- A = Area in square feet
- d = Average depth of water in feet

If a liquid other than water is in the space, its weight per cubic foot should be substituted in the formula.

Average force on a bulkhead in an intact space:

$$F = 64 \times A \times \frac{d}{2}$$

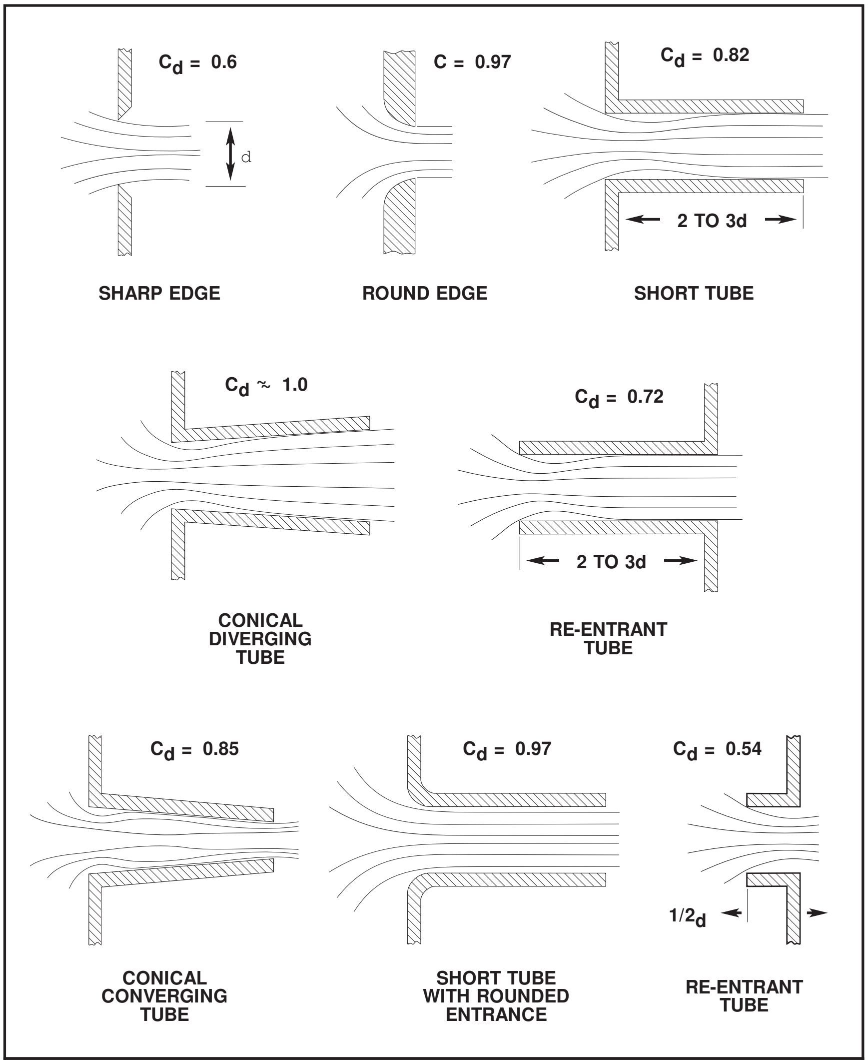


Figure C-1. Discharge Coefficients.

APPENDIX D
MATERIAL PROPERTIES

The following tables provide density and related properties for materials. Most of the referenced substances have no well-defined density. The values given are typical or average, and are therefore only approximations for any given sample of the material. A range of values is given for those materials with very large density variations. If more accurate values are available from vessel documents or crew, those values should be used.

Table D-1. Material Densities, Volume per Ton, and Underwater Weight.

SUBSTANCE	Average Density LB/FT^3	U/W WT Seawater LB/FT^3	Volume FT^3/LTon
METALS AND ORES			
Aluminum, cast-hammered	165	101	13.6
Aluminum alloy	173	109	12.9
Antimony	415	351	5.4
Brass, cast-rolled	534	470	4.2
Bronze, aluminum	481	417	4.7
Bronze, 8 - 14% tin	509	445	4.4
Bronze, phosphor	554	490	4.0
Copper, cast-rolled	556	492	4.0
Copper ore, pyrites	262	198	8.5
Gold, cast-hammered	1,205	1,141	1.9
Iron, gray cast	442	378	5.1
Iron, pig	450	386	5.0
Iron, wrought	485	421	4.6
Iron, ferrosilicon	437	373	5.1
Iron ore, hematite	325	261	6.9
Iron ore, limonite	237	173	9.5
Iron ore, magnetite	315	251	7.1
Iron slag	172	108	13.0
Lead	710	646	3.2
Lead ore, galena	465	401	4.8
Magnesium	109	45	20.6
Magnesium alloy	112	48	20.0
Manganese	475	411	4.7
Manganese ore, pyrolusite	259	195	8.6
Mercury	847	783	2.6
Monel, rolled	555	491	4.0
Molybdenum, wrought	643	579	3.5
Nickel	537	473	4.2
Plutonium	1,211	1,147	1.8
Silver, cast-hammered	656	592	3.4
Steel	489	425	4.6
Tin, cast hammered	459	395	4.9
Tin ore, cassiterite	418	354	5.4
Titanium alloy	282-302	218-238	7.9-7.4
Tungsten	1,200	1,136	1.9
Uranium	1,184	1,120	1.9
Zinc, cast-hammered	440	376	5.1
Zinc ore, blende	253	189	8.9

SUBSTANCE	Average Density LB/FT^3	U/W WT Seawater LB/FT^3	Dry Volume FT^3/LTon
OTHER NON-BUOYANT SOLIDS			
Brick			
common	112	48	20.0
fire	150	86	14.9
Chalk	137	73	16.4
Concrete,			
cement w/sand, stone	144	80	15.6
cement w/slag	130	66	17.2
cement w/cinder	100	36	22.4
reinforced	150	86	14.9
Cotton, flax, hemp	93	29	24.1
Glass	162	98	13.8
Glass reinforced plastic (GRP)			
linear layup, 30% fiber	117	53	19.1
linear layup, 65% fiber	124	60	18.1
Gypsum, alabaster	159	95	14.1
Limestone	169	105	13.3
Marble	160-177	96-113	14.0-12.7
Mortar, lime, set	103	39	21.7
Mortar, cement, set	135	71	16.6
Pitch	72	8	31.1
Plastics			
Polystyrene	66	2	33.9
Polyvinyl Chloride (PVC)	86	22	26.0
Polycarbonate	75	11	29.9
Nylon	71	7	31.5
Teflon	136	72	16.5
Quartzite	170	106	13.2
Resin, rosin	67	3	33.4
Rubber goods	94	30	23.8
Slate, shale	162-205	98-141	13.8-10.9
Soapstone, talc	169	105	13.3
Sulphur	125	61	17.9
Tar	75	11	29.9
Wool	82	18	27.3

Table D-1 (continued). Material Densities, Volume per Ton, and Underwater Weight.

SUBSTANCE	Average Density LB/FT^3	U/W Buoyancy Seawater LB/FT^3	Dry Volume FT^3/LTon	SUBSTANCE	Average Density LB/FT^3	U/W Buoyancy Seawater LB/FT^3	Dry Volume FT^3/LTon
BUOYANT SOLIDS				**TIMBER**			
Cork	15	49	149	Ash, white	42	22	53
Ice	56	8	40	Cedar, white, red	22	42	102
Leather	59	5	38	Chestnut	30	34	75
Paper	58	6	39	Cypress	29	35	77
Paraffin	56	8	40	Douglas fir	32	32	70
Plastics				Eastern fir	25	39	90
Polyethylene	57-60	4-7	39-37	Elm	35	29	64
Polypropylene	56	8	40	Hemlock	29	35	77
Plastic Foams				Hickory	48	16	47
Rigid Urethane Foam	1.4-2.0	62-62.6	1,600-1,120	Locust	45	19	50
Semi-rigid, MDI Urethane foam	8	56	280	Mahogany	44	20	51
Polystyrene	1.8-3.3	60.7-62.2	1,244-679	Maple, sugar	43	21	52
PVC flotation foam (PFD's, buoys)	4	60	560	Maple, white	33	31	68
PVC insulation foam	6	58	373	Oak, red, black	42	22	53
PVC shock-absorbent foam (athletic mats)	7	57	320	Oak, white	48	16	47
Latex/sponge rubber slabs (furniture padding)	6.5	57.5	345	Pine, Oregon	32	32	70
Syntactic foam	40-47	17-24	56-47	Pine, red	30	34	75
Tallow	58	6	39	Pine, white	27	37	83
Wax	60	4	37	Pine, yellow (southern)	40	24	56
				Pine, Norway	34	30	66
				Poplar	27	37	83
				Redwood	26	38	86
				Spruce, white, red	28	36	80
				Teak, African	48	16	47
				Teak, Indian	37	27	61
				Walnut	37	27	61
				Willow	28	36	80

Notes on the use of Table D-2

A stowage factor is the volume occupied by a specified weight of a material. Stowage factors are used to estimate the weight of cargo in a ship's hold and are therefore usually given in cubic ft/long ton, or cubic meter/tonne. Cargo density in lbs/cubic ft can be found by dividing the stowage factor into the number of pounds in a long ton, 2,240. It is important to remember that stowage factors and cargo densities account for the empty space between individual pieces of the cargo (stones, grains, beans, etc.) and are therefore not directly related to the material density. Cargo density can never be greater than the material density, and is usually significantly less. Stowage factors also account for empty space between containers; the stowage factor for bulk wheat is thus different from the stowage factor for bagged wheat.

The added weight due to flood water in a space can be calculated accurately if both the material density and cargo density or stowage factor are known for the contents of the space, as shown in the following examples.

Table D-2. Stowage Factors and Cargo Densities.

	Stowage Factor FT^3/Lton	Stowage Factor M^3/MT	Cargo Density LB/FT^3		Stowage Factor FT^3/Lton	Stowage Factor M^3/MT	Cargo Density LB/FT^3
BULK ITEMS				**BULK ITEMS (continued)**			
Alumina	33-46	0.92-1.28	49-68	Iron sponge, spent	16	0.45	139
Alumina, calcined	22	0.61	102	Iron pyrites	14	0.40	156
Alumina silica	25	0.70	89	Ironstone	14	0.39	160
Alumina silica, pellets	29	0.81	77	Labradorite	22	0.60	104
Aluminum dross	36	1.00	62	Lead ore	9-24	0.24-0.67	93-260
Aluminum nitrate fertilizers	36	1.00	62	Lime, loose	41	1.16	54
Ammonium nitrate ferilizers	34	0.96	65	Limestone	27	0.75	83
Ammonium sulphate	36	1.01	62	Magnesite	14-30	0.39-0.84	74-160
Antimony ore and residue	14	0.38	164	Manganese ore	11-25	0.32-0.70	89-195
Asphalt	24-32	0.66-0.91	69-94	Milorganite	55	1.53	41
Ashes & cinders, packed	53	1.49	42	Mineral concentrates	12-20	0.33-0.57	110-189
Barley	57	1.60	39	Monammonium phosphate	43	1.21	52
Barytes	12	0.34	184	Muriate of Potash	29-40	0.81-1.12	56-77
Basalt, piled	23	0.65	96	Peanuts (in shell)	118	3.29	19
Bauxite (aluminum ore)	28	0.78	80	Pebbles (rounded, 1 - 4 in)	21	0.59	106
Borax, anhydrous	28	0.78	80	Pellets, concentrates	17	0.47	133
Borax, pentahydryte (crude, "Rasorite 46")	33	0.92	68	Perlite (rock)	37	1.02	61
Calcium nitrate fertilzer	33	0.93	67	Petroleum coke, pitch prill, prilled coal tar, pencil pitch	45-60	1.25-1.67	37-50
Carborundum	20	0.56	111	Phosphate, deflourinated	40	1.12	56
Cement, Portland, loose	24-36	0.67-1.00	62-94	Phosphate rock, calcined	23-45	0.64-1.26	50-98
Cement clinkers	22-30	0.61-0.84	74-102	Phosphate rock, uncalcined	25	0.70	89
Cereals, barley	57	1.60	39	Pig iron, neatly stowed	11	0.30	208
Cereals, corn, rye	50	1.39	45	Portland cement, loose	24	0.67	94
Cereals, oats	86	2.40	26	Potash	32	0.90	69
Cereals, wheat	47	1.30	48	Potassium nitrate (saltpeter	32	0.88	71
Charcoal	60-224	4.46-6.24	10-14	Potassium sulphate	32	0.90	69
Chamotte (burned clay)	54	1.50	42	Potatoes, piled	51	1.42	44
Chrome ore	14	0.39	160	Pumice	68-117	1.90-3.25	19-33
Chrome pellets	22	0.60	104	Pyrite (containing copper and iron)	15	0.41	152
Clay	24-48	0.66-1.34	47-95	Pyrophylite	18	0.50	125
Coal				Quartz	22	0.60	104
anthracite	39-48	1.08-1.33	47-58	Quartzite	23	0.64	98
bituminus, lignite	41-56	1.16-1.16	40-54	Sand, rutile	14	0.39	160
peat	86-112	2.40-3.12	20-26	Sand, ilmenite	13	0.36	173
Cocoanuts	140	3.90	16	Sand, foundry (quartz)	18	0.50	125
Coke	45-105	1.25-2.93	21-50	Sand foundry (silica, feldspar)	35	0.98	64
Colemanite	22	0.61	102	Sand, zircon	13	0.36	173
Copper granules	9	0.24	260	Salt	29-40	0.81-1.12	56-77
Copper matte	11	0.30	208	Salt rock	37	1.02	61
Cryolite	25	0.70	89	Saltcake (sodium sulphate)	33	0.92	68
Diammonium phosphate	43	1.20	52	Seedcake	50-75	1.39-2.09	30-45
Direct reduced iron (DRI)	18	0.50	125	Silicamanganese	8	0.22	284
DRI briquettes	13	0.35	178	Soda ash	37-60	1.03-1.67	37-61
Dolomite	22	0.60	104	Sodium nitrate	32	0.88	71
Feldspar lump	22	0.60	104	Stainless steel grinding dust	15	0.42	149
Ferrochrome	8	0.22	284	Stone chippings	25	0.71	88
Ferromanganese	8	0.23	271	Sugar (raw, brown, white)	36-57	1.00-1.60	39-62
Ferrosilicon	17-26	0.48-0.72	87-130	Sulphate of potash and magnesium	34	0.95	66
Fertilizers, non-nitrate	32-50	0.90-1.40	45-69	Sulphur, lump or coarse	27	0.74	84
Fly ash	45	1.26	50	Superphosphate	33	0.93	67
Flourspar (calcium flouride)				Superphosphate, triple granular	43	1.20	52
dry	22	0.62	101	Taconite pellets	57	1.60	39
wet	18	0.51	122	Talc	25	0.69	90
Granulated slag	32	0.90	69	Urea	42-56	1.17-1.56	40-53
Gypsum	26	0.73	86	Vermiculite	49	1.37	46
Iron ore	10-29	0.29-0.80	78-215	Wheat	47	1.31	48
Iron ore pellets	9-91	0.24-2.53	25-260	Wood chips	110	3.07	20
Iron ore, taconite pellets	57	1.60	39	Wood pulp pellets	110	3.07	20
Iron oxide, spent	16	0.45	139	Zircon sand	13	0.36	173

Table D-2. Stowage Factors and Cargo Densities.

	Stowage Factor FT^3/Lton	Stowage Factor M^3/MT	Cargo Density LB/FT^3
EVACUATED EARTH, ETC.			
Clay, dry	34	0.95	65
Clay, damp	20	0.56	110
Clay and gravel, dry	22	0.61	100
Clay, stiff or compacted	11-19	0.31-0.52	120-195
Earth, dry, loose	29	0.81	76
Earth, dry, packed	24	0.67	95
Earth, moist, loose	29	0.81	78
Earth, moist, packed	23	0.64	96
Earth, mud, flowing	21	0.58	108
Earth, mud, packed	19	0.53	115
Marble, quarried, loose pile	24	0.67	95
Nitrates, loosely piled	22	0.61	100
Quartz, quarried, loose pile	24	0.67	95
Riprap, limestone	26-28	0.72-0.78	80-85
Riprap, sandstone	25	0.70	90
Riprap, shale	21	0.58	105
Sand, gravel, dry, loose	21-25	0.59-0.70	90-105
Sand, gravel, dry, packed	19-22	0.52-0.61	100-120
Sand, gravel, wet	18	0.50	126
Shale, loosely piled	24	0.67	92
Snow, loosely piled	64	1.78	35
Stone, loosely piled	30	0.84	75
PACKAGED ITEMS			
Acid, drums	45	1.25	50
Apples, boxes	80	2.23	28
Autos, diassembled, crated	110	3.07	20
Autos, assembled	270	7.53	8
Auto parts, cases	90	2.51	25
Barbed wire, rolls	55	1.53	41
Beans, bags	60	1.67	37
Beer, bottles in cases	80	2.23	28
Biscuits, cases	142	3.96	16
Blankets, bales	153	4.27	15
Burlap, bales	52	1.45	43
Butter, cases	60	1.67	37
Canned goods, cases	38-50	1.06-1.39	47-59
Cable, reels	31	0.86	72
Cardboard, bundles	210	5.85	11
Carpets/rugs	75	2.08	30
Carpets/rugs, bales	140	3.90	16
Cartridges, boxes	30	0.84	75
Castings, boxes	22	0.61	102
Cement, bags	35	0.98	64
Cheese, boxes	45	1.25	50
Coffee, bags	58	1.62	39
Conduits, boxes	31	0.86	72
Copper, slabs	7	0.20	320
Copper, bars	10	0.28	224
Cork, bales	187	5.21	12
Corn, bags	55	1.53	41
Cotton, bales	90	2.50	25
Dried fruit, boxes	45	1.25	50
Dry goods, boxes	100	2.79	22
Earth, bags	56	1.56	40
Eggs, cases	100	2.79	22
Electric motors, boxes	50	1.39	45
Engines, gasoline, cases	100	2.79	22
Excelsior, bales, compressed	118	3.29	19
PACKAGED ITEMS (continued)			
Fish, barrels, iced	50	1.39	45
Fish, boxes	65	1.81	34
Flour, bags	48	1.34	47
Flour, barrels	73	2.04	31
Fruit juice, bottles in case	70	1.95	32
Furniture, crated	156	4.35	14
Gasoline, drums	61	1.70	37
Glass, crated	130	3.62	17
Grapefruit, boxes	70	1.95	32
Hardware, boxes	50	1.39	45
Hay, bales	112	3.12	20
Hemp, bales, compressed	97	2.72	23
Hides, raw, bales	102	2.84	22
Hides, bales, compressed	80	2.23	28
Iron pigs, neatly stowed	10	0.28	207
Jute, bales, compressed	55	1.52	41
Lanterns, cases	375	10.45	6
Lard, boxes	45	1.25	50
Laths, bundles	107	2.98	21
Lead pigs, neatly stowed	8	0.22	280
Leather, bales	80	2.23	28
Lime, bags	52	1.45	43
Linen, cotton goods, boxes	45-64	1.25-1.78	35-50
Linoleum, rolls	70	1.95	32
Linseed, bags	60	1.67	37
Machinery, crated	46-50	1.28-1.39	45-49
Magazines, bundles	75	2.09	30
Mail, 55 lb bags	180	5.02	12
Meat, cold storage	95	2.65	24
Molasses, barrels	47	1.30	48
Newspapers, bales	120	3.35	19
Nitrate, bags	26	0.72	86
Nuts, bags	70	1.95	32
Oats, bags	77	2.15	29
Oil, drums	45	1.25	50
Oil, cases	50	1.39	45
Onions, bags	78	2.17	29
Oranges, boxes	78	2.17	29
Oysters, barrels	60	1.67	37
Paint, cans	36	1.00	62
Paint, drums	24	0.67	93
Paper, rolls	80	2.23	28
Paper, bales	80	2.23	28
Paper, boxes	60	1.67	37
Peas, bags	55	1.53	41
Potatoes, bags	60	1.67	37
Poultry, boxes	95	2.65	24
Plumbing fixtures, crates	100	2.79	22
R.R rails, neatly stowed	15	0.42	149
Rags, bales	118	3.29	19
Raisins, boxes	54	1.51	41
Rice, bags	58	1.62	39
Roofing paper, rolls	80	2.23	28
Rope, coils	72-90	2.01-2.51	25-31
Rubber, bundles	140	3.90	16
Rum, casks	60	1.67	37
Salt, barrels	52	1.45	43
Silk, bales	110	3.07	20
Silk, bolts	80	2.23	28

Table D-2. Stowage Factors and Cargo Densities.

	Stowage Factor FT^3/Lton	Stowage Factor M^3/MT	Cargo Density LB/FT^3		Stowage Factor FT^3/Lton	Stowage Factor M^3/MT	Cargo Density LB/FT^3
PACKAGED ITEMS (continued)				**PACKAGED ITEMS (continued)**			
Soap, boxes	45	1.25	50	Tile, boxes	50	1.39	45
Soap powder, boxes	90	2.51	25	Timber, oak	39	1.09	57
Starch, boxes	59	1.64	38	Timber, fir	65	1.81	34
Steel bolts, kegs	21	0.59	107	Tin, sheets	7	0.20	320
Steel rods, neatly stowed	12	0.33	187	Tires, bundles	168	4.68	13
Steel sheets, crated	36	1.00	62	Tobacco, boxes	134	3.74	17
Straw, bales	118	3.29	19	Transformers, cases	30	0.84	75
Sugar, bags	47	1.31	48	Typewriters, cases	110	3.07	20
Tallow, barrels	66	1.84	34	Waste, cotton, bales	175	4.88	13
Tar, barrels	54	1.51	41	Wax, vegetable, bags	50	1.39	45
Tea, cases	95	2.65	22	Wax, barrels	70	1.95	32
Thread, cases	60	1.67	37	Wheat, bags	52	1.45	43

EXAMPLE D-1

The number 2 hold of an ore carrier is filled with lead ore. The hold is approximately rectangular, measuring 60 feet long, 50 feet wide, and 20 feet deep. The ship suffers damage that completely floods the number 2 hold. Calculate the weight of the flood water.

Solution:

From Table D-2, the stowage factor for lead ore is 9.0 ft3/lton. The volume of the hold is:

$$V = L \times W \times D = 60 \text{ feet} \times 50 \text{ feet} \times 20 \text{ feet}$$
$$V = 60{,}000 \text{ feet}^3$$

The weight of the ore is the volume divided by the stowage factor:

$$W_{\text{cargo}} = \frac{V}{SF} = \frac{60{,}000 \text{ ft}^3}{9 \text{ ft}^3/\text{lton}} = 6{,}667 \text{ lton}$$

The volume actually occupied by individual lead ore particles, V_{cargo} is found by dividing the weight of the ore by the material density. From Table D-1, the material density for lead ore is 465 lb/cu ft, and:

$$W_{\text{cargo}} = \frac{W_{\text{cargo}}}{density} = \frac{6{,}667 \text{ lton} \times 2{,}240 \text{ lb/lton}}{465 \text{ lb/ft}^3} = 32{,}116 \text{ ft}^3$$

The volume not occupied by ore can be occupied by water. The space available for flood water to occupy, V_{flood}, is:

$$V_{\text{flood}} = \text{V-V}_{\text{cargo}} = 60{,}000 - 32{,}116 = 27{,}884 \text{ ft}^3$$

CONTINUED

EXAMPLE D-1 (CONTINUED)

The weight of 27,884 ft^3 of sea water is found by dividing by 35 ft^3/lton:

$$W_{\text{flood}} = \frac{V_{\text{flood}}}{\frac{35 \text{ ft}^3}{\text{lton}}} = \frac{27{,}884 \text{ ft}^3}{\frac{35 \text{ ft}^3}{\text{lton}}} = 797 \text{ tons}$$

Alternate solution:

Using the cargo density and material density of the lead ore, a permeability factor can be calculated for the hold. From Table D-2, cargo density is 250 lb/ft^3. From Table D-1, material density is 465 lb/ft^3. The ratio of cargo density to material density is the proportion of the hold occupied by solid, impermeable objects. Subtracting this ratio from 1 gives the proportion of the hold that is available to be flooded. This proportion is, by definition, the permeability factor, μ:

$$\mu = 1 - \left(\frac{\text{cargo density}}{\text{material density}}\right) = 1 - \left(\frac{250}{465}\right) = 1 - 0.54 = 0.46$$

The volume of flood water admitted is found by multiplying the permeability factor by the space volume:

$$V_{\text{flood}} = \mu \times V = 0.46 \times 60{,}000 \text{ ft}^3 = 27{,}600 \text{ ft}^3$$

The weight of flood water is found by dividing by 35 ft^3/lton, as before:

$$W_{\text{flood}} = \frac{27{,}600 \text{ ft}^3}{\frac{35 \text{ ft}^3}{\text{lton}}} = 789 \text{ tons}$$

Table D-3. Liquid Densities.

	Density LB/FT^3	Density LB/Gal	Volume FT^3/Ton	Volume Gal/Ton
Alcohol, ethyl (100%)	49	6.6	45.7	342
Alcohol, methyl (100%)	50	6.7	44.8	335
Acid, muriatic (40%)	75	10.0	29.9	223
Acid, nitric (91%)	94	12.6	23.8	178
Acid, sulphuric (87%)	112	15.0	20.0	150
Acid, hydrochloric (37%)	75	10.0	29.9	224
Battery electrolyte				
fully charged	81	10.8	27.6	207
discharged	69	9.2	32.6	244
Beer	63	8.4	35.5	266
Ammonia @ 32°F	39	5.2	57.6	431
Chloroform	95	12.7	23.6	176
Diesel fuel (DFM, Nato F-76)	52	7.0	42.7	320
Ether	46	6.2	48.7	364
Ethylene Glycol (anti-freeze)	70	9.4	31.9	239
Fuel oil, No 6	60	8.1	37.1	278
Fuel oil, No 5	58	7.8	38.4	287
Fuel oil, No 2	55	7.3	40.9	306
Fuel oil, No 1	51	6.8	44.3	332
Gasoline	44	5.9	50.6	379
Jet fuel (JP5)	51	6.9	43.5	326
Kerosene	50	6.7	44.9	336
Milk	64	8.6	34.8	260
Linseed oil	59	7.8	38.3	286
Lye, soda (66%)	106	14.2	21.1	158
Oil, vegetable	58	7.8	38.6	289
Oil, lubricating	56	7.5	39.9	298
Olive oil	57	7.6	39.2	293
Petroleum, crude	44	5.8	51.3	383
Sugar-in-water solution				
20% @ 68°F	67	9.0	33.2	248
40% @ 68°F	73	9.8	30.5	228
60% @ 68°F	80	10.7	27.9	209
Turpentine	54	7.2	41.5	310
Vinegar	67	9.0	33.2	249
Water, pure, @ 39°F	62	8.3	35.9	269
Water, seawater	64	8.6	35.0	262
Water, ice	56	7.5	40.0	299

Note: Liquids consisting of a mixture of compounds, such as petroleum products and vegetable derivatives, may vary in density from sample to sample. The densities given in this table are average or typical values. Liquid densities, especially those of petroleum products, can also vary significantly with temperature. The values given in this table should be used for rough approximations only. If more precise calculations are necessary, values for density should be obtained from ship's documents or personnel, or by test.

APPENDIX E
RIGGING

E-1 SALVAGE RIGGING.

Salvage operations normally involve extensive rigging of pulling, lifting, and material handling systems. The following information is provided to assist the salvor in selecting the proper equipment to complete the operation expeditiously and safely.

E-1.1 Fiber Rope. The factor of safety is the ratio between the breaking strength of a fiber rope and the applied load. The working load, or safe working load, is the breaking strength divided by the factor of safety that has been found to be appropriate for the material and application.

Table E-1. Breaking Strength of Plain-Laid Fiber Rope (in Pounds).

Circumference (inches)	Sisal	Manila	Polypropylene	Nylon*	Polyester
⅝	360	405	700	950	800
¾	480	540	1,000	1,500	1,200
1	800	900	1,700	2,600	2,000
1⅛	1,080	1,215	2,150	3,300	2,800
1¼	1,400	1,575	2,500	4,800	3,800
1½	2,120	2,385	3,700	5,800	5,000
1¾	2,760	3,105	4,800	7,600	6,500
2	3,520	3,960	6,000	9,800	8,000
2¼	4,320	4,860	7,000	13,200	10,000
2½	5,200	5,850	9,000	15,300	13,000
2¾	-----	6,930	11,000	19,000	15,000
3	-----	8,100	13,000	23,200	18,500
3½	-----	10,800	16,500	32,000	25,000
3¾	-----	12,150	19,500	36,500	-----
4	-----	13,500	21,500	41,300	31,000
4½	-----	16,650	26,000	50,000	-----
5	-----	20,250	32,000	60,000	48,000
5½	-----	23,850	38,000	72,000	-----
6	-----	27,900	44,000	90,000	68,000
6½	-----	-----	50,000	100,000	-----
7	-----	36,900	60,000	127,000	88,000
8	-----	46,800	75,000	164,000	110,000
9	-----	57,600	94,000	209,000	140,000
10	-----	69,300	115,000	265,000	165,000
11	-----	81,900	-----	316,000	240,000
12	-----	94,500	-----	375,000	285,000

*Figures are for new, dry nylon. Wet nylon experiences a 15% loss in strength while the other materials exhibit essentially no loss in wet strength.

The following factors of safety are recommended for use with all types of fiber rope.

General Use 6

Critical Loads (personnel, munitions, hazardous materials, etc.)... 10

Table E-2. Breaking Strength of Braided Rope (in Pounds).

Circumference (inches)	Double-Braid* Nylon	Double-Braid Polyester	Plaited* Nylon
¾	1,700	1,730	1,500
1	2,700	2,670	2,500
1⅛	3,900	3,860	3,700
1¼	5,100	5,210	5,000
1½	6,900	6,820	6,400
1¾	9,000	8,590	8,000
2	12,000	10,600	11,000
2¼	15,000	15,100	17,000
2½	18,400	17,800	20,000
2¾	22,500	20,600	24,000
3	26,500	26,800	31,000
3½	36,000	33,900	38,000
3¾	42,000	41,700	46,000
4	48,000	46,000	53,000
4½	60,000	59,900	63,000
5	73,000	69,900	73,000
5½	90,000	81,200	78,000
6	102,500	106,000	95,000
6½	123,000	119,000	106,000
7	140,000	133,000	125,000
7½	160,000	164,000	137,000
8	180,000	181,000	165,000
9	225,000	236,000	200,000
10	273,000	277,000	250,000
11	325,000	343,000	300,000
12	385,000	417,000	360,000
13	440,000	470,000	380,000
14	508,000	527,000	441,000
15	576,000	649,000	507,000
16	650,000	715,000	572,000
17	726,000	784,000	-----
18	808,000	931,000	-----
19	893,000	1,012,000	-----
20	980,000	1,091,000	-----
21	1,070,000	1,263,000	-----

*Figures are for new, dry nylon. Wet nylon experiences a 15% loss in strength while the other materials exhibit essentially no loss in wet strength.

EXAMPLE E-1
CALCULATING SAFE WORKING LOAD OF FIBER ROPE

What is the safe working load of 3-inch circumference, plain-laid polypropylene rope (a) In general use? (b) For critical loads?

From Table E-1: Breaking strength = 13,000 pounds

a. For general use:

$$SWL = \frac{13{,}000}{6}$$

$$SWL = 2{,}167 \text{ pounds}$$

b. For critical loads:

$$SWL = \frac{13{,}000}{10}$$

$$SWL = 1{,}300 \text{ pounds}$$

CAUTION

When fiber ropes are subjected to dynamic loads, safe working loads are much lower. Whenever a load is picked up, stopped, moved, or swung, the force on the rope is increased by dynamic loading. Quickly occurring actions cause greater increases. Dynamic effects are greater on short ropes than on long ones and greater on low-elongation ropes than on high-elongation ropes such as nylon. In extreme cases, the force on the rope may be two or three times the normal force. Safe working loads include only small allowances for dynamic loads. When dynamic loads are expected, the factor of safety must be increased by an amount appropriate to the size of the dynamic load and the load handled as smoothly as possible.

E-1.2 Wire Rope. Salvage rigging requires large quantities of wire rope for beach gear ground legs, four-fold purchases, lifting straps, and bow lift operations.

E-1.2.1 Construction. Wire rope for salvage operations is generally 6×37 improved plow steel (IPS) galvanized with either a fiber core (FC) or an independent wire rope core (IWRC). The difference between fiber core and independent wire rope core is that the axial member of fiber core wire rope is vegetative or synthetic material which provides little or no strength, whereas in independent wire rope core construction the axial member is a wire rope and provides significant reserve strength.

CAUTION

When wire ropes are subjected to dynamic loads, safe working loads are much lower. Whenever a load is picked up, stopped, moved, or swung, the force on the wire rope is increased by dynamic loading. Quickly occurring actions cause greater increases; dynamic effects are greater on short wire ropes than on long ones. In extreme cases, the force on the wire rope may be two or three times the normal force. Safe working loads include only small allowances for dynamic loads. When dynamic loads are expected, the factor of safety must be increased by an amount appropriate to the size of the dynamic load and the load handled as smoothly as possible.

E-1.2.2 Factors of Safety. Factors of safety are established to ensure adequate protection of personnel when operating equipment.

E-1.2.3 Beach Gear. Factors of safety for beach gear components are relative to the breaking strength of the 1⅝-inch wire rope in the ground leg. All other components are designed to withstand a greater force than the ground leg wire. The next weakest assembly is the ⅝-inch purchase which had a factor of safety of 1.31 based on the early high grade plow steel (HGPS) 1⅝-inch wire rope breaking strength of 185,000 pounds. The introduction of improved plow steel (IPS) wire rope construction reduced the factor of safety of the purchase assembly to 1.13 — acceptable for beach gear applications. The use of 6×37, 1⅝-inch IPS IWRC is not recommended for beach gear ground legs when purchases are employed, as the increased breaking strength of 230,000 pounds reduces the purchase factor of safety to 1.05

Table E-3. Characteristics of Wire Rope.

Type	Wire Rope Size in Inches, Breaking Strength in Pounds												
	½	⅝	¾	1	1¼	1½	1⅝	1¾	2	2¼	2½	2¾	3
6×9 IPS /FC	20,600	31,800	45,400	79,400	----	----	----	----	----	----	----	----	----
6×19 IPS /FC[a]	21,400	33,400	47,600	83,600	129,200	184,000	214,000	248,000	320,000	400,000	488,000	584,000	----
6×19 IPS/WSC or IWRC	23,000	35,800	51,200	89,800	138,800	197,800	230,000	266,000	344,000	430,000	524,000	628,000	----
6×19 EIPS/WSC or IWRC	26,600	41,200	58,800	103,400	159,800	228,000	----	306,000	396,000	494,000	604,000	722,000	----
6×19 CRS/IWRC	22,800	35,000	49,600	85,400	129,400	180,500	----	----	----	----	----	----	----
6×37 IPS/FC[a]	21,400	33,400	47,600	83,600	129,200	184,000	214,000	248,000	320,000	400,000	488,000	584,000	----
6×37 & 6×61 IPS/WSC[b] or IWRC[c]	22,000	34,000	48,600	85,600	132,200	189,000	230,000	256,000	330,000	414,000	508,000	610,000	720,000
6×37 CRS/IWRC	20,400	31,300	44,400	77,300	118,300	166,000	----	----	----	----	----	----	----
8×19 IPS/FC	18,460	28,600	41,000	72,000	111,400	158,800	----	----	----	----	----	----	----
6×37 & 6×61 IPS/WSC or IWRC	25,200	39,200	55,800	98,200	152,200	216,000	264,000	----	----	----	----	----	----
6×91 EIPS/IWRC	----	----	----	----	----	----	----	----	----	----	554,000	666,000	786,000

[a] MIL-STD-R-W-410D
[b] Subtract 10 percent for zinc-coated (galvanized) wire rope.
[c] 6×61 wire rope is available in sizes 2-inch and above and only in regular lay.

IPS = Improved Plow Steel
EIPS = Extra Improved Plow Steel
CRS = Corrosion-Resistant Steel
FC = Fiber Core
WSC = Wire Strand Core
IWRC = Independent Wire Rope Core

E-1.2.4 General Rigging. Salvage operations require general purpose rigging for offloading cargo, loading salvage equipment, and securing gear in place. When wire rope is employed in this manner, a factor of safety of five should be used to determine the safe working load.

EXAMPLE E-2
CALCULATING THE SAFE WORKING LOAD OF WIRE ROPE

What is the safe working load of 1-inch 6×37 IPS/FC wire rope?

From Table E-3: Breaking strength = 83,600 pounds

$$SWL = \frac{83,600}{5}$$

$$SWL = 16,720 \text{ pounds}$$

E-1.3 General-Purpose Alloy Steel Chain.

Table E-4. Characteristics of General-Purpose Alloy Steel Chain.

Nominal Diameter (inches)	Minimum Breaking Strength (pounds)		Weight per 100 ft	Length per 100 links (max) (inches)
	Grade 63			
7/32	6,900	8,700	50	76
9/32	11,400	14,400	84	98
5/16	14,000	17,800	120	110
⅜	20,200	25,600	176	134
½	35,900	45,600	300	160
⅝	56,100	71,200	453	200
¾	80,800	102,600	655	235
⅞	110,000	139,600	910	270
1	143,600	182,400	1,170	280
1¼	224,400	285,000	1,765	371

The factor of safety is the ratio between the breaking load of the chain and the load applied. The minimum factor of safety for alloy steel chain used in general-purpose rigging is 4 (reference ASTM Standard A 391-86).

EXAMPLE E-3
CALCULATING THE SAFE WORKING LOAD OF ALLOY STEEL CHAIN

What is the safe working load of ⅜-inch grade 63 chain used to tie down equipment?

From Table E-4: Breaking strength = 20,200 pounds

$$SWL = \frac{20,200}{4}$$

$$SWL = 5,050 \text{ pounds}$$

E-1.4 Connecting Devices. Devices such as hooks, turnbuckles, rings, etc., are used to connect rigging systems. The following tables provide the safe working load of connecting devices.

Table E-5. SWL (Pounds) of Connecting Devices.

Diameter (inches)	End Links	Eye Bolts	Swivels	Hooks	Turn-buckles
¼	---	500	850	---	400
5/16	2,500	800	1,500	---	700
⅜	3,800	1,200	2,250	---	1,000
7/16	5,100	---	2,900	---	1,250
½	6,500	2,200	3,600	---	1,500
⅝	9,300	3,500	5,200	---	2,250
¾	12,000	5,200	7,200	1,400	3,000
⅞	14,000	7,200	10,000	2,400	4,000
1	15,200	10,000	12,500	3,400	5,000
1⅛	20,800	12,600	15,200	4,200	5,000
1¼	26,400	15,200	18,000	5,000	7,500
1⅜	30,000	18,300	31,600	6,000	---
1½	34,000	21,400	45,200	8,000	---
1⅝	---	---	---	9,400	---

CAUTION

The safe working load for eye bolts in Table E-5 is for direct vertical pull loads only. When using slings to lift an object with multiple eye bolts, a spreader bar is used to keep the lifting force on a vertical line with the shank of the eye bolt. In some cases, lifting at an angle is unavoidable. Table E-6 gives the safe working load of eye bolts with angular loads applied.

Table E-6. SWL (Pounds) of Eye Bolts with Angular Loading.

Diameter (inches)	Plain Pattern			Shoulder Pattern		
	30º	45º	90º	30º	45º	90º
¼	120	80	60	140	100	80
c	240	160	120	280	200	160
⅜	420	280	210	490	350	280
v	600	400	300	700	500	400
½	780	520	390	910	650	520
b	900	600	450	1,050	750	600
⅝	1,200	800	600	1.400	1,000	800
¾	1,800	1,200	900	2,100	1,500	1,200
⅞	2,100	1,400	1,050	2,450	1,750	1,400
1	2,400	1,600	1,200	2,800	2,000	1,600
1⅛	3,000	2,000	1,500	3,500	2,500	2,000
1¼	4,500	3,000	2,250	5,250	3,750	3,000
1½	5,400	3,600	2,700	6,300	4,500	3,600
1¾	6,600	4,400	3,300	7,700	5,500	4,400
2	7,800	5,200	3,900	9,100	6,500	5,200

Table E-7. SWL of Safety Shackles.

Size D Inches	Recommended Safe Working Load (Maximum) (Pounds)		Proof Load (Minimum) (Pounds)		Breaking Load (Minimum) (Pounds)	
	Grade A	Grade B	Grade A	Grade B	Grade A	Grade B
3/16	520	900	1,040	2,250	2,600	4,500
¼	710	2,000	1,420	5,000	3,550	10,000
5/16	1,060	3,120	2,120	7,800	5,300	15,600
⅜	1,590	3,800	3,180	9,500	7,950	19,000
7/16	2,170	5,180	4,340	12,950	10,850	25,900
½	2,830	6,500	5,660	16,250	14,150	32,500
⅝	4,420	10,000	8,840	25,000	22,100	50,000
¾	6,360	13,800	12,720	34,500	31,800	69,000
⅞	8,650	18,700	17,300	46,750	43,250	93,500
1	11,310	24,400	22,620	61,000	56,550	122,000
1⅛	13,360	28,600	26,720	71,500	66,800	143,000
1¼	16,500	36,000	33,000	90,000	82,500	180,000
1⅜	19,800	41,400	39,600	103,500	99,800	207,000
1½	23,740	48,800	47,480	122,000	118,700	244,000
1⅝	27,900	57,400	55,800	143,500	139,500	287,000
1¾	32,320	65,000	64,640	162,500	161,600	325,000
2	42,220	85,040	84,440	212,600	211,100	425,200
2¼	54,000	----	108,000	----	270,000	----
2½	67,600	121,400	135,200	303,500	338,000	607,000
3	96,200	150,000	192,400	375,000	481,000	750,000
3½	131,100	200,000	262,200	500,000	655,500	1000,000
4	171,140	260,000	342,280	650,000	855,700	1300,000

The diameter of a shackle is measured at the bow or side.

SWL of Grade A and B shackles are marked with embossed or raised letters. Pins of Grade B shackles are marked "HS" while Grade A pins are unmarked. Shackles with no markings are older types and their safe working load is lower. To determine the safe working load of older shackles:

$$SWL = 3D^2 \times 2{,}000 \text{ pounds}$$

where:
SWL = Safe working load in pounds
D = Diameter of the shackle in inches

This is a conservative safe working load.

E-1.5 Slings. Lifting slings are essential in salvage rigging. The slings may be specialized single-purpose slings, general-purpose, prefabricated, or made up on the job. The weight that can be lifted with a sling depends upon the material of the sling, the end fittings, the method of attachment, and the angle of the sling. Slings exert force on the container to which they are attached and may crush the container with these forces. Spreader bars installed between the sling legs will prevent this. Multiple-part slings have a greater load-carrying capacity because the load is divided among the parts. When the legs of the slings are vertical, each leg carries load divided by the number of parts. When the angle between the legs increases, the tension in each leg increases. Figure E-1 shows the tension in the legs with angular loading.

The safe working load of multiple slings is:

$$SWL = \frac{S \times N \times \text{Sin}\theta}{F_S}$$

where:
SWL = Safe working load
S = Breaking strength of sling material
N = Number of sling legs
Sinθ = The angle between the horizontal axis of the load and the sling at the attachment point on the load
Fs = The desired safety factor

EXAMPLE E-4
CALCULATION OF SAFE WORKING LOAD OF MULTIPLE-LEG SLINGS.

Determine the safe working load of four-leg, ½-inch, 6×37 IPS/IWRC slings used to lift a load when the angle between the legs and the horizontal axis of the load is 30°.

From Table E-3: Breaking strength = 22,000 pounds

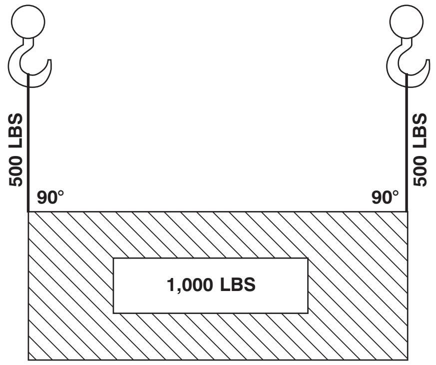
The desired safety factor = 5

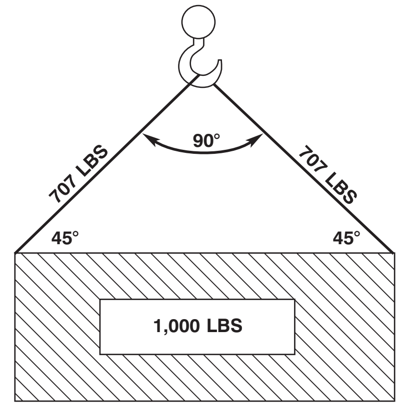
$$SWL = \frac{S \times N \times \text{Sin } \theta}{F_S}$$

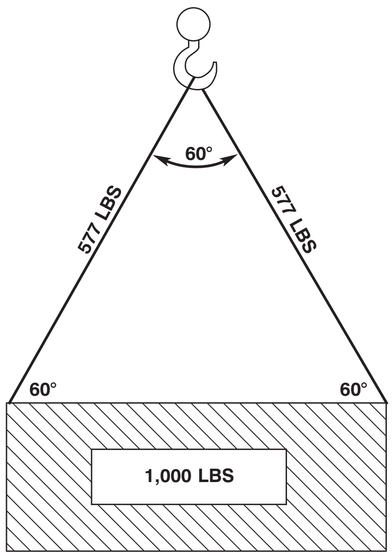
$$SWL = \frac{22{,}000 \times 4 \times 0.500}{5}$$

$$SWL = \frac{44{,}000}{5}$$

$$SWL = 8{,}800 \text{ pounds}$$







INCLUDED ANGLE ^	STRESSES PER SLING LEG PER 1,000 LBS. TOTAL LOAD
0	500
10	502
20	508
30	518
40	532
45	541
50	552
60	577
70	610
80	653
90	707
100	778
110	872
120	1,000
130	1,183
140	1,462
150	1,932
160	2,880
170	5,734
180	¥

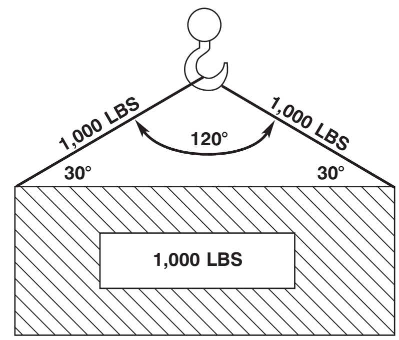


Figure E-1. Tension on Legs of Slings with Angular Loading.

Table E-8. Characteristics of Navy Stud-Link Chain (MIL-C-24633).

Size (in)	Number of links per shot	Length of six consecutive links (inches)			Proof load (pounds)	Minimum Breaking strength (pounds)	Weight per shot (pounds)
		Minimum	Nominal	Maximum			
¾	359	19⅜	19½	19 13/16	48,000	75,000	480
⅞	305	22⅝	22¾	23 1/16	64,400	98,000	660
1	267	25⅞	26	26⅜	84,000	129,000	860
1⅛	237	29 1/16	29¼	29⅝	106,000	161,000	1,080
1¼	213	32 5/16	32½	32 5/16	130,000	198,000	1,350
1⅜	193	35 9/16	35¾	36¼	157,000	235,000	1,630
1½	177	38 13/16	39	39½	185,000	280,000	1,940
1⅝	165	42	42¼	42⅞	216,000	325,000	2,240
1¾	153	45¼	45½	46⅛	249,000	380,000	2,590
1⅞	143	48½	48¾	49½	285,000	432,000	2,980
2	135	51 11/16	52	52¾	318,000	454,000	3,360
2⅛	125	54,	55¼	56⅛	357,000	510,000	3,790
2¼	119	58 3/16	58½	59⅜	396,000	570,000	4,250
2⅜	113	61 7/16	61¾	62¾	440,000	628,000	4,730
2½	107	64 11/16	65	66	484,000	692,000	5,270
2⅝	101	67⅞	68¼	69¼	530,000	758,000	5,820
2¾	97	71⅛	71½	72 9/16	578,000	826,000	6,410
2⅞	93	74⅜	74¾	75⅞	628,000	897,000	7,020
3	89	77⅝	78	79 3/16	679,000	970,000	7,650
3⅛	87	80 13/16	81¼	82½	732,000	1,046,000	8,320
3¼	83	84 1/16	84½	85¾	787,000	1,124,000	9,010
3⅜	79	87 5/16	87¾	89	843,000	1,204,000	9,730
3½	77	90 9/16	91	92 5/16	900,000	1,285,000	10,500
3⅝	73	93 13/16	94¼	95⅝	958,000	1,369,000	11,300
3¾	71	97 1/16	97½	98⅞	1,019,000	1,455,000	12,000
3⅞	69	100¼	100¾	102 3/16	1,080,000	1,543,000	12,900
4	67	103½	104	105½	1,143,000	1,632,000	13,700
4¾	57	122 5/16	123½	125 5/16	1,700,000	2,550,000	18,900

Table E-9. Characteristics of Di-Lok Chain (MIL-C-19444).

Size (in)	Number of links per shot	Length of six consecutive links (inches)			Proof load (pounds)	Minimum breaking strength (pounds)	Weight per shot (pounds)
		Minimum		Maximum			
¾	359	$19^{13}/_{32}$	19½	$19^{25}/_{32}$	48,000	75,000	490
⅞	305	$22^{41}/_{64}$	22¾	$23^{5}/_{64}$	64,000	98,000	680
1	267	25⅞	26	26⅜	84,000	129,000	890
1⅛	237	$29^{7}/_{64}$	29¼	$29^{43}/_{64}$	106,000	161,000	1,130
1¼	213	$32^{11}/_{32}$	32½	$32^{31}/_{32}$	130,000	198,000	1,400
1⅜	193	$35^{37}/_{64}$	35¾	$36^{17}/_{64}$	157,000	235,000	1,690
1½	177	$38^{13}/_{16}$	39	$39^{9}/_{16}$	185,000	280,000	2,010
1⅝	165	$42^{3}/_{64}$	42¼	$42^{55}/_{64}$	216,000	325,000	2,325
1¾	153	$45^{9}/_{32}$	45½	$46^{5}/_{32}$	249,000	380,000	2,695
1⅞	143	$48^{33}/_{64}$	48¾	$49^{29}/_{64}$	285,000	432,000	3,095
2	135	51¾	52	52¾	289,800	439,200	3,490
2⅛	125	$54^{63}/_{64}$	55¼	$56^{3}/_{64}$	325,800	493,200	3,935
2¼	119	$58^{7}/_{32}$	58½	$59^{11}/_{32}$	362,700	549,000	4,415
2⅜	113	$61^{29}/_{64}$	61¾	$62^{41}/_{64}$	402,300	607,500	4,915
2½	107	$64^{11}/_{16}$	65	$65^{15}/_{16}$	442,800	669,600	5,475
2⅝	101	$67^{59}/_{64}$	68¼	$69^{15}/_{64}$	486,000	731,700	6,050
2¾	97	$71^{5}/_{32}$	71½	$72^{17}/_{32}$	531,000	796,500	6,660
2⅞	93	$74^{25}/_{64}$	74¾	$75^{53}/_{64}$	576,000	868,500	7,295
3	89	77⅝	78	79⅛	623,700	940,500	7,955
3⅛	87	$80^{55}/_{64}$	81¼	$82^{27}/_{64}$	673,200	1,015,200	8,700
3¼	83	$84^{3}/_{32}$	84½	$85^{23}/_{32}$	723,700	1,089,000	9,410
3⅜	79	$87^{21}/_{64}$	87¾	$89^{1}/_{64}$	776,000	1,166,400	10,112
3½	77	$90^{9}/_{16}$	91	$92^{5}/_{16}$	829,800	1,244,800	10,900
3¾	71	$97^{1}/_{32}$	97½	$98^{29}/_{32}$	1,008,000	1,575,000	12,500
4¾	57	$121^{29}/_{32}$	122½	$124^{9}/_{32}$	1,700,000	2,550,000	20,500

Size (in)	Number of links per shot	Length of six consecutive links (inches)			Proof load (pounds)	Minimum breaking strength (pounds)	Weight per shot (pounds)
		Minimum		Maximum			
2¾	97	$71^{5}/_{32}$	71½	$72^{17}/_{32}$	584,100	882,900	7,000
3	89	77⅝	78	79⅛	685,800	1,035,000	8,100
3½	77	$90^{9}/_{16}$	91	$92^{5}/_{16}$	972,000	1,530,000	12,000

Size (in)	Number of links per shot	Length of six consecutive links (inches)			Proof load (pounds)	Minimum breaking strength (pounds)	Weight per shot (pounds)
		Minimum		Maximum			
¾	359	$19^{13}/_{32}$	19½	$19^{25}/_{32}$	67,500	91,100	550
1	267	25⅞	26	26⅜	116,100	156,700	1,000
1⅛	237	$29^{7}/_{64}$	29¼	$29^{43}/_{64}$	145,000	195,000	1,270
1⅜	193	$35^{37}/_{64}$	35¾	$36^{17}/_{64}$	211,500	285,500	1,900
1½	177	$38^{13}/_{16}$	39	$39^{9}/_{16}$	252,000	340,200	2,260
1⅝	165	$42^{3}/_{64}$	42¼	$42^{55}/_{64}$	292,500	395,000	2,620

Table E-10. Characteristics of Commercial Stud-Link Chain (ABS).

		Normal Strength Grade 1		High Strength Grade 2		Extra High Strength Grade 3			Oil Rig Quality[1]	
Chain Diameter	**Length of Five Links**	**Proof Load**	**Breaking Load**	**Proof Load**	**Breaking Load**	**Proof Load**	**Breaking Load**	**Weight in Pounds per 15 Fathoms**	**Proof Load**	**Breaking Load**
Inches	**Inches**		**Pounds**	**Pounds**	**Pounds**	**Pounds**	**Pounds**	**Pounds**	**Pounds**	**Pounds**
½	11	10700	15300	15300	21400	21400	30600	230		
9/16	12⅜	13500	19300	19300	27000	27000	38600	290		
⅝	13¾	16600	23700	23700	33200	33200	47500	370		
11/16	15⅛	20100	28600	28600	40100	40100	57300	410		
¾	16½	23800	34000	34000	47600	47600	68000	480		
13/16	17⅞	27800	39800	39800	55700	55700	79500	570		
⅞	19¼	32200	46000	46000	64400	64400	91800	660		
15/16	20⅝	36800	52600	52600	73700	73700	105000	760		
1	22	41800	59700	59700	83600	83600	119500	860	84000	129000
1 1/16	23⅜	47000	67200	67200	94100	94100	135000	970		
1⅛	24¾	52600	75000	75000	105000	105000	150000	1080	106000	161000
1 3/16	26⅛	58400	83400	83400	116500	116500	167000	1220		
1¼	27½	64500	92200	92200	129000	129000	184000	1350	130000	198000
1 5/16	28⅞	70900	101500	101500	142000	142000	203000	1490		
1⅜	30¼	77500	111000	111000	155000	155000	222000	1630	157000	235000
1 7/16	31⅝	84500	120500	120500	169000	169000	241000	1780		
1½	33	91700	131000	131000	183500	183500	262000	1940	185000	280000
1 9/16	34⅜	99200	142000	142000	198500	198500	284000	2090		
1⅝	35¾	108000	153000	153000	214000	214000	306000	2240	216000	325000
1 11/16	37⅛	115000	166500	166500	229000	229000	327000	2410		
1¾	38½	123500	176000	176000	247000	247000	352000	2590	249000	380000
1 13/16	39⅞	132000	188500	188500	264000	264000	377000	2790		
1⅞	41¼	140500	201000	201000	281000	281000	402000	2980	285000	432000
1 15/16	42⅝	149500	214000	214000	299000	299000	427000	3180		
2	44	159000	227000	227000	318000	318000	454000	3360	322000	488000
2 1/16	45⅜	168500	241000	241000	337000	337000	482000	3570	342000	518000
2⅛	46¾	178500	255000	255000	357000	357000	510000	3790	362000	548000
2 3/16	48⅛	188500	269000	269000	377000	377000	538000	4020	382500	579100
2¼	49½	198500	284000	284000	396000	396000	570000	4250	403000	610000
2 5/16	50⅞	209000	299000	299000	418000	418000	598000	4490	425000	642500
2⅜	52¼	212000	314000	314000	440000	440000	628000	4730	447000	675000
2 7/16	53⅝	231000	330000	330000	462000	462000	660000	4960	469500	709500
2½	55	242000	346000	346000	484000	484000	692000	5270	492000	744000
2 9/16	56⅜	254000	363000	363000	507000	507000	726000	5540	516000	778500
2⅝	57¾	265000	379000	379000	530000	530000	758000	5820	540000	813000
2 11/16	59⅛	277000	396000	396000	554000	554000	792000	6110	565000	849000
2¾	60½	289000	413000	413000	578000	578000	826000	6410	590000	885000
2 13/16	61⅞	301000	431000	431000	603000	603000	861000	6710	615000	925000
2⅞	63¼	314000	449000	449000	628000	628000	897000	7020	640000	965000
2 15/16	64⅝	327000	467000	467000	654000	654000	934000	7330	666500	1005000
3	66	340000	485000	485000	679000	679000	970000	7650	693000	1045000
3 1/16	67⅜	353000	504000	504000	705000	705000	1008000	7980	720500	1086500
3⅛	68¾	366000	523000	523000	732000	732000	1046000	8320	748000	1128000
3 3/16	70⅛	380000	542000	542000	759000	759000	1084000	8660	776050	1169000
3¼	71½	393000	562000	562000	787000	787000	1124000	9010	804100	1210000
3 5/16	72⅞	407000	582000	582000	814000	814000	1163000	9360	833150	1253000
3⅜	74¼	421000	602000	602000	843000	843000	1204000	9730	862200	1296000
3 7/16	75⅝	435000	622000	622000	871000	871000	1244000	10100	892100	1339550
3½	77	450000	643000	643000	900000	900000	1285000	10500	922000	1383100
3 9/16	78⅜	465000	664000	664000	929000	929000	1327000	10900		
3⅝	79¾	479000	685000	685000	958000	958000	1369000	11300	1021000	1566000
3¾	82½	509000	728000	728000	1019000	1019000	1455000	12000	1120000	1750000
3⅞	85¼	540000	772000	772000	1080000	1080000	1543000	12900	1205000	1863000
3 15/16	86⅝	556000	794000	794000	111000	1111000	1587000	13300		
4	88	571000	816000	816000	143000	1143000	1632000	13700	1298000	1996500

[1] Oil rig quality information from commercial vendor.

Table E-11. Characteristics of Commercial Stud-Link Chain (ABS) in Metric Units.

		Normal Strength Grade 1		High Strength Grade 2		Extra High Strength Grade 3		
Chain Diameter	Length of Five Links	Proof Load	Breaking Load	Proof Load	Breaking Load	Proof Load	Breaking Load	Weight Kilograms per Shot
mm	mm		kg	kg	kg	kg	kg	kg
12.5	275	4700	6700	6700	9400	9400	13500	110
14	308	5900	8400	8400	11800	11800	16800	130
16	352	7700	10900	10900	15300	15300	22000	170
17.5	385	9100	13000	13000	18300	18300	26100	180
19	418	10700	15300	15300	21500	21500	30700	220
20.5	451	12500	17800	17800	24900	24900	35600	260
22	484	14300	20400	20400	28600	28600	40900	300
24	528	17000	24200	24200	33900	33900	48500	340
26	572	19800	28300	28300	39700	39700	56700	420
28	616	22900	32700	32700	45800	45800	65500	480
30	660	26200	37500	37500	52400	52400	74900	550
32	704	29700	42500	42500	59400	59400	84900	610
34	748	33400	47700	47700	66800	66800	95500	700
36	792	37300	53300	53300	74600	74600	107000	790
38	836	41400	59200	59200	82800	82800	118000	880
40	880	45700	65300	65300	91400	91400	131000	970
42	924	50200	71700	71700	100000	100000	143000	1070
44	968	54900	78400	78400	110000	110000	157000	1170
46	1012	59700	85300	85300	119000	119000	171000	1270
48	1056	64800	92600	92600	130000	130000	185000	1380
50	1100	70000	100000	100000	140000	140000	200000	1480
52	1144	75400	108000	108000	151000	151000	215000	1600
54	1188	81000	116000	116000	162000	162000	231000	1720
56	1232	86800	124000	124000	174000	174000	248000	1850
58	1276	92700	132000	132000	185000	185000	265000	1990
60	1320	98800	141000	141000	198000	198000	282000	2120
62	1364	105000	150000	150000	210000	210000	300000	2250
64	1408	112000	159000	159000	223000	223000	319000	2440
66	1452	118000	169000	169000	236000	236000	337000	2590
68	1496	125000	178000	178000	250000	250000	357000	2750
70	1540	132000	188000	188000	263000	263000	376000	2910
73	1606	142000	203000	203000	285000	285000	407000	3180
76	1672	153000	219000	219000	307000	307000	438000	3470
78	1716	161000	230000	230000	322000	322000	459000	3650
81	1782	172000	246000	246000	345000	345000	492000	3930
84	1848	184000	263000	263000	368000	368000	526000	4250
87	1914	196000	280000	280000	393000	393000	561000	4560
90	1980	209000	298000	298000	417000	417000	596000	4860
92	2024	217000	310000	310000	434000	434000	620000	5100
95	2090	230000	329000	329000	460000	460000	657000	5400
97	2134	239000	341000	341000	477000	477000	682000	5670
98	2156	243000	347000	347000	486000	486000	695000	5750

Table E-11 (continued). Characteristics of Commercial Stud-Link Chain (ABS) in Metric Units.

		Normal Strength Grade 1		High Strength Grade 2		Extra High Strength Grade 3		
Chain Diameter	Length of Five Links	Proof Load	Breaking Load	Proof Load	Breaking Load	Proof Load	Breaking Load	Weight Kilograms per Shot
mm	mm		kg	kg	kg	kg	kg	kg
100	2200	252000	360000	360000	504000	504000	720000	6010
102	2244	261000	373000	373000	522000	522000	746000	6250
105	2310	275000	393000	393000	550000	550000	785000	6600
107	2354	284000	406000	406000	568000	568000	812000	6820
108	2376	289000	412000	412000	577000	577000	825000	6950
111	2442	303000	433000	433000	606000	606000	865000	7290
114	2508	317000	453000	453000	635000	635000	907000	7640
117	2574	332000	474000	474000	664000	664000	948000	7980
120	2640	347000	495000	495000	694000	694000	991000	8310
122	2684	357000	510000	510000	714000	714000	1019000	8620
124	2728	367000	524000	524000	734000	734000	1048000	8920
127	2794	382000	546000	546000	764000	764000	1092000	9380
130	2860	398000	568000	568000	795000	795000	1136000	9840
132	2904	408000	583000	583000	816000	816000	1165000	10140
137	3014	434000	620000	620000	868000	868000	1240000	10910
142	3124	461000	658000	658000	921000	921000	1316000	11670
147	3234	488000	697000	697000	975000	975000	1393000	12440
152	3344	515000	736000	736000	1030000	1030000	1471000	13200
157	3454	543000	775000	775000	1085000	1085000	1550000	14000
162	3564	571000	816000	816000	1142000	1142000	1631000	14700

APPENDIX F
ANCHOR PERFORMANCE

F-1 ANCHOR TYPES.

Marine anchors can be roughly divided into the following 5 types:

- Drag-embedment anchors
- Deadweight anchors or clumps
- Grappling devices
- Direct-embedment anchors
- Pile anchors.

The five anchor types are described in the following paragraphs. Figure F-1 shows the different types of anchors in use; Table F-1 summarizes their features and comparative advantages.

Detailed information on performance, applicability, and use of various anchor types can be obtained from the Naval Facilities Engineering Service Center, (ESC 00), Port Hueneme, California, telephone (805) 982-1393 or DSN 551-1393. Specialty anchors, such as propellant-embedment anchors or large drag-embedment anchors, can be procured through the Ocean Construction Division of the Chesapeake Division of the Naval Facilities Engineering Command (NAVFAC), (CODE ESC 55), telephone (202) 433-5166 or DSN 288-5166.

F-1.1 Drag-Embedment Anchors. Drag-embedment anchors, also called burial anchors or drag anchors, are designed to dig into the bottom when the ground leg is tensioned. Holding power results from the increasing resistance to lateral motion as the anchor reaches deeper, denser soil layers. Drag-embedment anchors suitable for salvage work are described in Paragraphs 6-3.4 and 7-2.2.1.

Drag-embedment anchors are the most commonly used anchor type because of their relative compactness and ease of stowage, handling, and deployment. The other types of anchors have limited salvage application and will be discussed only briefly, with the remainder of the appendix (Paragraph F-2) devoted to drag-embedment anchors.

F-1.2 Deadweight Anchors. Any heavy object that can be placed on the seafloor can b used as a deadweight anchor. Concrete, steel, and ferro-cement clumps are commonly used Figure F-2 shows some types of deadweight anchors. Deadweight anchors can rest on the seafloor or be partially or completely buried.

Table F-1. Comparison of Anchor Types.

Item	Deadweight	Pile-Embedment	Direct-Embedment	Drag-Embedment
Seafloor Material				
Soft clay, mud	++	+	++	++
Soft clay layer (0-20 ft) over hard layer	++	++	o	+
Stiff clay	++	++	++	++
Sand	++	++	++	++
Hard glacial till	++	++	++	+
Boulders	++	o	o	o
Soft rock or coral	++	++	++	+
Hard, massive rock	++	+	+	o
Seafloor Topography				
Slope ~ 10 deg	++	++	++	++
Slope > 10 deg	o	++	++	o
Loading Direction				
Omnidirectional	++	++	++	o
Unidirectional	++	++	++	++
Large uplift	++	++	++	o
Lateral Load Range				
To 100,000 lb	++	+	++	++
100,000 to 1,000,000 lb	+	++	+	++
Over 1,000,000 lb	o	++	o	o

++ Functions well
+ Functions, but not normally the best choice
o Does not function well

Some specially shaped deadweight anchors, such as d and e in Figure F-2, are designed to dig into the soil to a limited extent as the anchor is dragged.

The holding power of a deadweight anchor is the force required to lift or drag the large weight over the ocean bottom. Resistance to uplift, or vertical force is simply the submerged weight of the anchor, plus suction effects in soft bottoms.

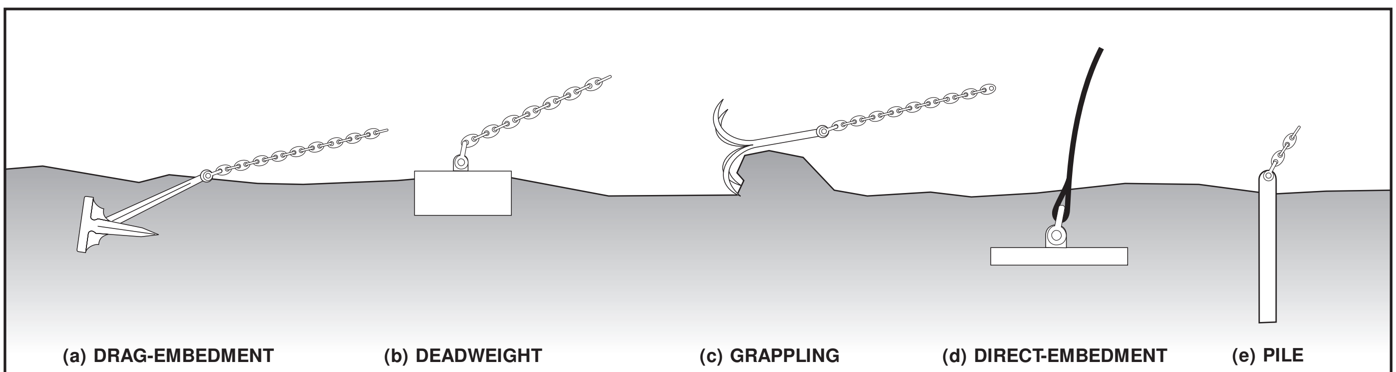


Figure F-1. Simplified Anchor Types.

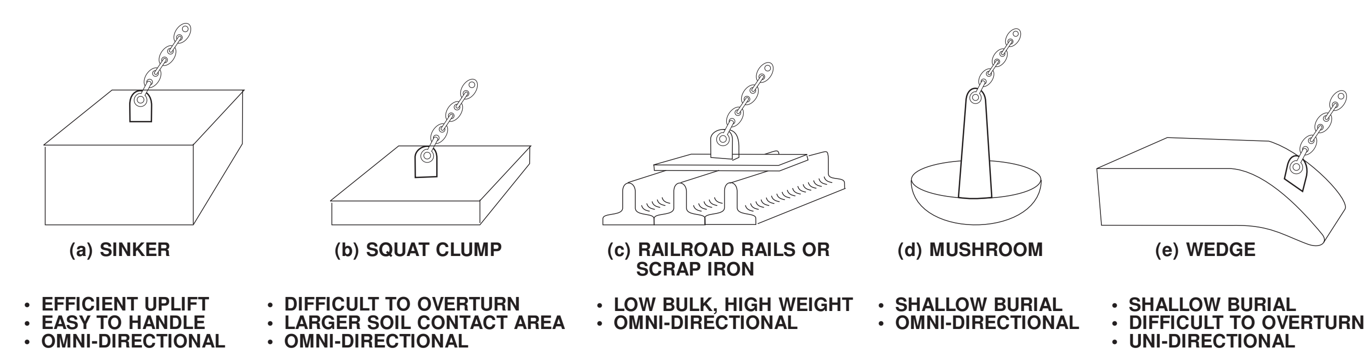


Figure F-2. Deadweight Anchors.

Resistance to dragging can be estimated in the same manner as the force required to free a stranded ship, that is, by multiplying the submerged weight by an appropriate coefficient of friction (μ). Table F-2 gives μ values for typical anchor and sea bed materials. Partial or complete burial will increase resistance to dragging. In practice, deadweight anchors are seldom used as beach gear anchors because of the difficulties in handling the very large weights that would be required to develop sufficient holding power.

F-1.3 Grappling Devices. Grappling devices are used to engage and hold against solid massive seafloor features, such as coral heads, rock outcroppings, or crevices and ledges in rock or coral bottoms. Grapnels, old fashioned Admiralty anchors, or other fluked anchors can be used to fetch up against seafloor features. Holding power depends on the strength of the anchor and the bottom formation and should be determined by a salvage or marine geotechnical engineer.

F-1.4 Direct-Embedment Anchors. Direct-embedment anchors, for use in most soils, are large plates that resist extraction when buried to a sufficient depth. Most direct-embedment anchors are installed by driving the anchor member or fluke vertically into the seafloor by explosive or mechanical means and then expanding or reorienting the fluke to increase pullout resistance. There are five major types of direct-embedment anchors: propellant-driven, impact-driven, jetted-in, vibratory-driven, and augured-in anchors. Mushroom anchors, or deadmen, buried in excavated pits or by jetting are also direct-embedment anchors. Holding power varies with the configuration of the anchor and seafloor composition and can be obtained from the manufacturer's technical data. Direct-embedment anchors can resist large uplift forces and therefore do not require long ground leg scopes to be effective. Propellant-embedment anchors (PEAs) and certain other direct-embedment anchors can develop reliable holding power in bottom types nor suitable for drag-embedment anchors. Propellant-embedment anchors with holding capacities of up to 200,000 pounds are maintained by the Naval Facilities Engineering Command (NAVFAC). Arrangements for the use or installation of propellant-embedment anchors can be made through the Supervisor of Salvage (NAVSEA OOC) or directly through NAVFAC. Figure F-3 illustrates the operation of propellant-embedment anchors.

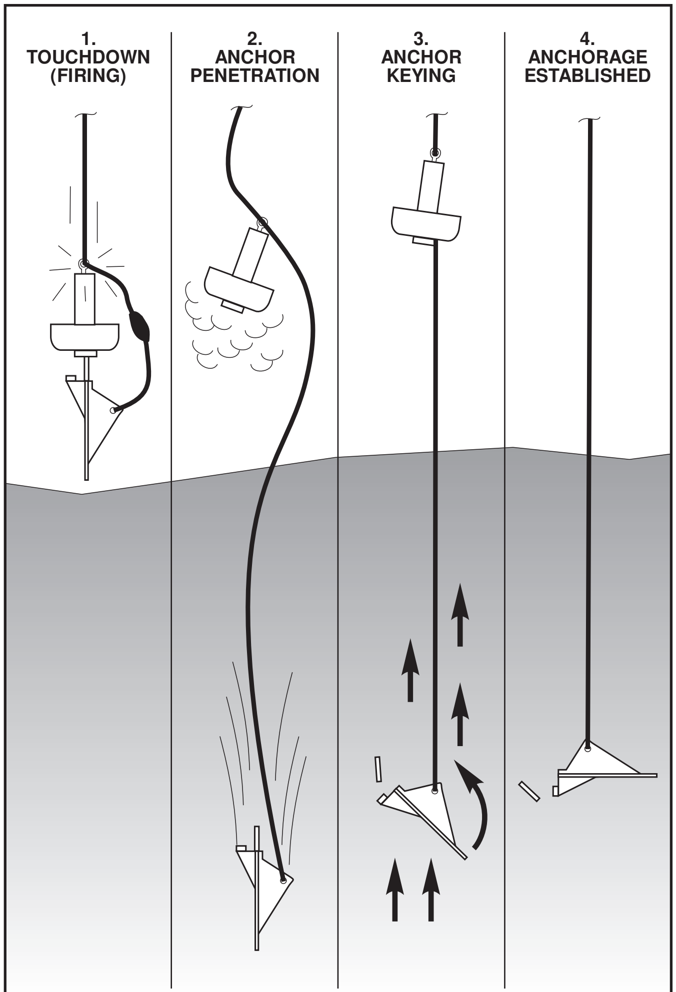


Figure F-3. Installation Sequence for a Propellant-Embedment Anchor.

Table F-2. Friction Coefficients, μ.

Soil	Smooth Steel	Rough Steel	Smooth Concrete	Rough Concrete
Quartz	0.27	0.60	0.60	0.69
Coralline Sand	0.20	0.63	0.63	0.66
Sand/silt	0.40	0.66	0.67	---

F-1.5 Pile Anchors. Pile anchors are piles or similar structures installed in the seafloor b, driving, by drilling and grouting, or by other under water construction methods. Like direct-embedment anchors, pile anchors can resist large uplift forces or horizontal forces from various directions. They can be installed in seafloors of any slope, including vertical cliff walls. Pile anchors are permanent structures and are not often used for salvage moorings or beach gear legs unless they have been coincidentally installed in the area or no other anchor type can provide the required holding power. Pile anchors should be considered when anchors must be used in the following situations:

- Coral bottoms
- Exposed or thinly covered rock bottoms
- Steeply sloping bottoms
- The anchor must resist large uplift forces, such as when scope is severely limited or anchoring parbuckling legs
- The anchor must resist lateral loads from more than one direction.

Design and installation, or evaluation of existing pile anchors, should be accomplished by a salvage or marine geotechnical engineer.

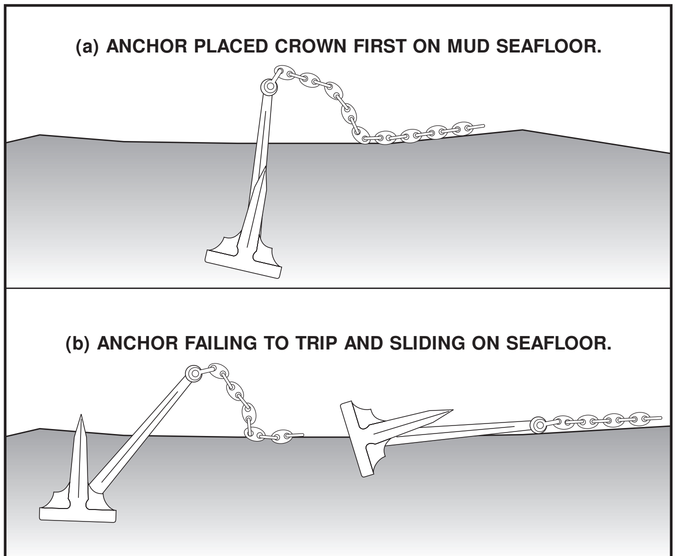


Figure F-4. Tripping Problem in Soft Seafloors with an Improperly Set Anchor.

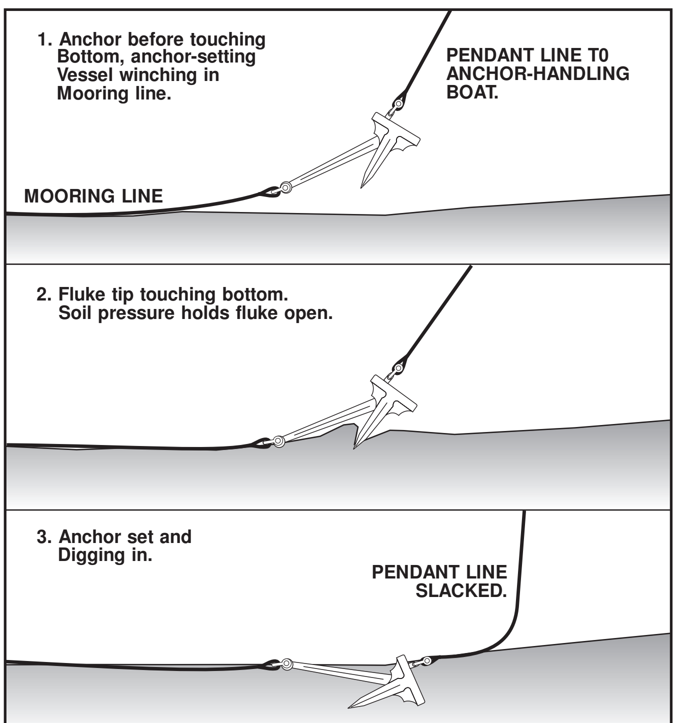


Figure F-5. Anchor-Setting Sequence Using Two Platforms.

F-2 DRAG-EMBEDMENT ANCHOR PERFORMANCE.

F-2.1 Anchor Function. A drag anchor can be likened to an inverted kite made to "fly" downward into the seafloor. The shank acts as the kite bridle, maintaining an angle of attack between the fluke and the soil that will cause the greatest resistance to horizontal movement. To function, the anchor must be pulled along the seafloor until it trips, or begins to dig in. Tripping palms assist by causing movable flukes to assume a downward angle and begin digging in when the anchor is dragged. The flukes bite into the bottom due to their ploughing effect; further dragging will cause a properly functioning anchor to penetrate the seafloor on an inclined path, because the resistance to travel in a direction parallel to the flukes is much less than the resistance to horizontal movement. Stabilizer bars, or stocks, help the anchor to dig and maintain consistent holding power by holding the anchor in a horizontal position.

After digging in, the anchor resists horizontal movement partly because of the drag caused by the projected fluke area, and partly because of the tendency of the anchor to move downward as anchor line tension is increased. Resistance to horizontal movement, or anchor holding power, increases with penetration depth because the deeper soil is normally "stronger," that is, it is denser and has greater resistance to the anchor moving through it. As line tension is increased, a properly functioning anchor will penetrate to some depth where maximum holding power is reached. The embedment depth for maximum holding power—and the drag distance to reach that depth—depend on the fluke angle, soil type, degree of anchor streamlining, and smoothness of the flukes. Fluke angles for optimum penetration and holding power differ for cohesionless soils (sands) and cohesive soils (clays and muds). Further increases in line tension will cause the anchor to move through the bottom, or drag. If the dragging anchor remains stable, that is, does not rotate or break out of the seafloor, it will continue to present a constant resistance equal to its maximum holding power. If the anchor breaks out or rotates, holding power will drop to a small fraction of the maximum value.

An anchor that is not functioning properly will not embed as deeply, and therefore will develop less holding power, or it may not embed at all. To develop maximum holding power, anchor line tension must be applied in a direction parallel to the seafloor.

For each anchor and soil type, there is a critical fluke angle that will optimize holding power. If the fluke angle is greater than critical, the standing anchor will penetrate only slightly and will slide in a standing or tipped position at a very small holding power. If the fluke angle is less than critical, anchor embedment depth will be reduced, and the anchor will develop less than its maximum potential holding power for that particular environment. For most anchors, a 50-degree fluke angle is optimum for soft bottoms (mud, soft clay, silt), while the optimum fluke angle for hard bottoms (firm sand, stiff clay) varies from 25 to 35 degrees. Most anchors are constructed with a fluke angle of about 50 degrees. Bolted or welded inserts or wedges are used to reduce the fluke angle for use in hard bottoms. Paragraph 8-5.2.1 gives the optimum fluke angle settings for Navy salvage anchors.

F-2.1.1 Tripping. On soft seafloors, such as soft clays and muds, anchors with very heavy crowns (stockless), small tripping palms (LWT, Danforth), or with the shank-to-fluke hinge far back on the fluke, often have tripping problems. This is especially true if the anchor is lowered or lands crown-first as shown in Figure F-4. When dragged, the anchor often does not dig into the seafloor, but slides along the mud surface with the flukes parallel to the shank and develops no more holding power than a similar sized deadweight anchor.

Proper tripping can be ensured in soft bottoms by lowering the anchor in the open position while heaving in on the ground leg as shown in Figure F-5.

In very hard soils, the fluke tips may not be able to start digging in, even when the anchor is laid as shown in Figure F-5. On hard bottoms, the anchor may slide without tripping, or dig in enough to cause the anchor to stand up and then fall over on its side and drag, as shown in Figure F-6. Anchors with heavy crowns and shank connections well back of the center of fluke area are susceptible to this kind of tripping problem. Hardsoil tripping performance can be improved by sharpening the fluke tips to improve digging capability, by welding barbs or extensions onto the tripping palms to increase the tripping moment, and by reducing the fluke angle several degrees below the sand setting.

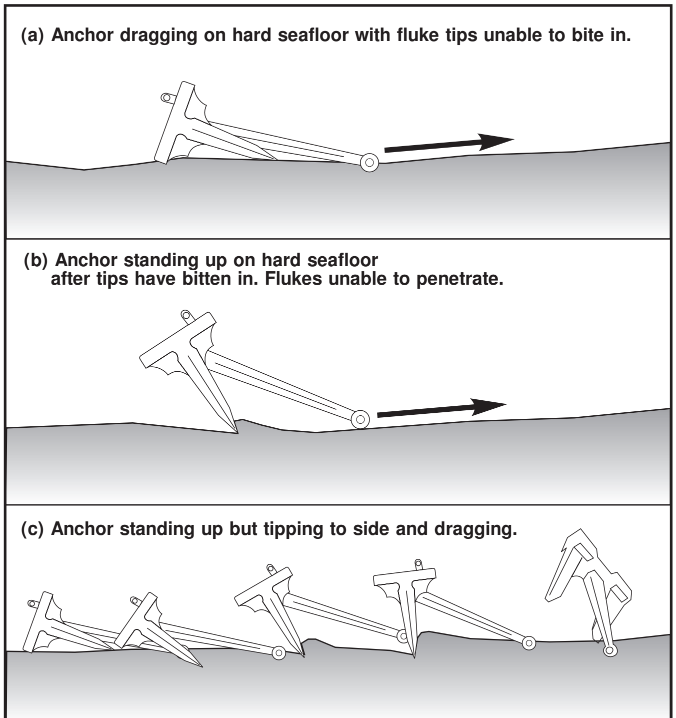


Figure F-6. Tripping Problem in Hard Seafloors.

F-2.1.2 Embedment. Penetration into the seafloor is influenced by anchor streamlining. Broad, square or flat shanks, and sharply angled tripping palms resist being dragged into the bottom and limit penetration. Fluke surface roughness also retards anchor penetration and thereby reduces holding power. Newer anchor designs, such as the NAVMOOR, with tapered and sharpened flukes, narrowed and chamfered shanks, and open or angled tripping palms, embed deeply in the bottom, and can reach stronger soils.

Anchors embed to a much shallower depth in hard soils than in soft soils. The crown of less-streamlined anchors, such as the STATO and stockless, may remain above the seafloor surface, while more streamlined anchors penetrate only a few feet. Conversely, high-performance anchors, such as the STATO and NAVMOOR, may penetrate 45 to 60 feet into mud bottoms before reaching maximum holding power.

Table F-3. Fluke Tip Penetration in Mud.

	(fluke lengths)
Stockless	2
Stockless, Stabilized with flukes	3
Eels	2
Danforth	4½
LWT	4½
STATO	4½
NAVMOOR	4½

For an anchor to achieve its maximum holding power, a minimum embedment depth much be achieved. If the depth of sediment over hard layers, such as rock, is not sufficient to allow this embedment depth, anchor holding power will be reduced. Anchor holding power is approximately proportional to the embedment depth in mud, and to the embedment depth squared in sand. Most drag anchors will penetrate about one fluke length in sand, about half a fluke length in very hard soil, and to varying depths in mud as shown in Table F-3.

Since the anchor embeds itself as it is dragged across the bottom, embedment depth, and therefore holding power, can be related to drag distance. Holding power as a function of drag distance is an important parameter when moorings or beach gear legs are laid where drag distance must be minimized. In sand, maximum holding power is reached in less than 10 fluke lengths of drag. The curves in Figure F-7 will help the salvor predict anchor drag distances in mud and select an anchor that will develop the required holding power in an acceptable drag distance, or estimate the holding power that can be obtained from an anchor dragged less than the distance required to develop their maximum holding power. In general, the higher performance anchors require greater drag distances to penetrate to their equilibrium depth and develop their maximum holding power than do the conventional heavy anchors.

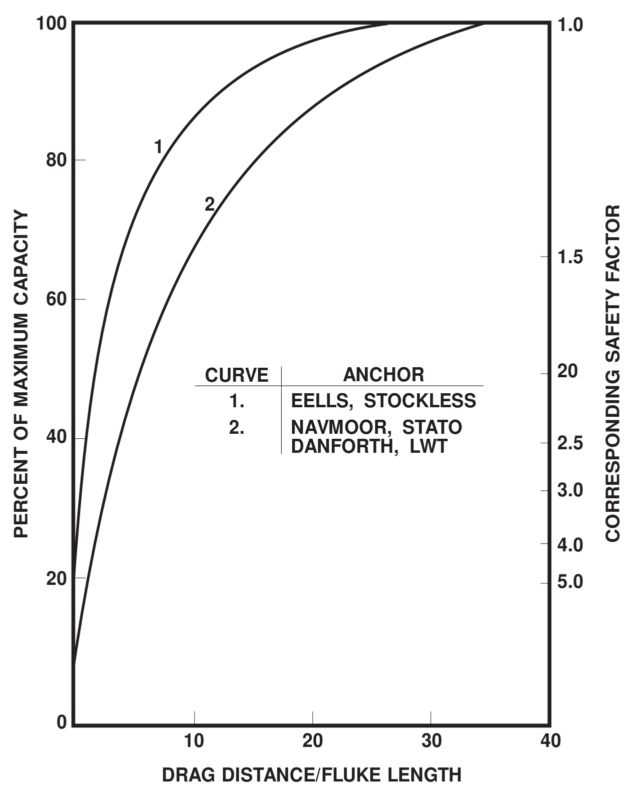


Figure F-7. Percent Holding Capacity Versus Drag Distance in Mud.

F-2.1.3 Stability. A drag anchor may become unstable and rotate after initially digging in, because of differences in the soil resistance on the two flukes, initial differences in the fluke penetration depths, or a change in direction of anchor line pull. Drag anchors often become unstable and roll after only a few feet of drag in sand. Stocks and stabilizers are designed to develop a countering force to resist anchor roll. In soft soils, the stabilizer influence is probably insignificant after both stabilizers have passed beneath the mudline. Even when fully embedded, every drag anchor is potentially

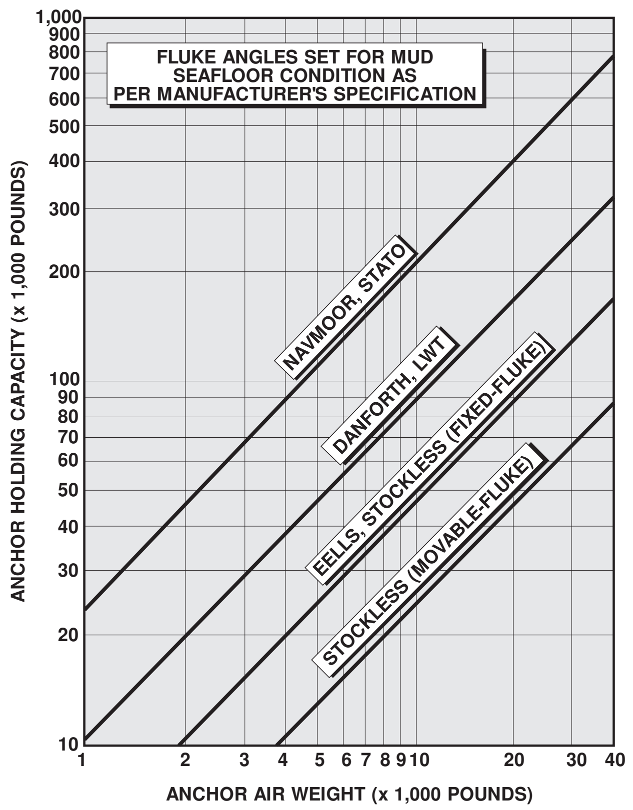


Figure F-8. Anchor-Holding Capacity in Mud.

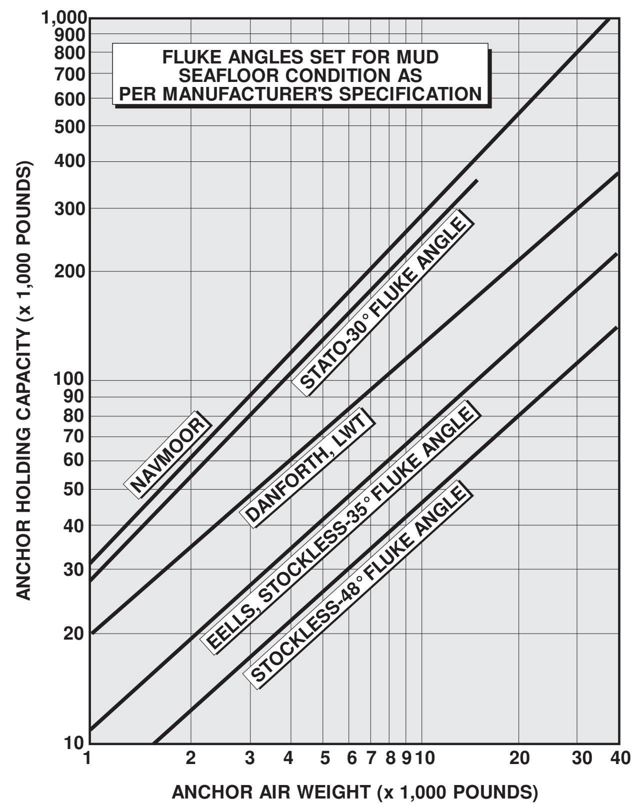


Figure F-9. Anchor-Holding Capacity in Sand.

unstable. Single-fluke anchors and double-fluke anchors with a large percentage of the fluke area near the shank, such as the NAVMOOR, have the greatest inherent stability. After penetrating a soft bottom, anchor stability is primarily a function of variation in direction of anchor line pull and uniformity of the soil.

Holding power is greatly reduced when an anchor turns on its side. The anchor no longer tends to bury itself when dragged, and may even pull out of the bottom, particularly if it begins to roll while only partially embedded or at a shallow depth of penetration. Once broken out, the anchor may or may not re-embed itself with further dragging.

Anchors can also "ball up" and pull out. "Balling up" refers to the formation of a large ball of soil covering the fluke and crown assembly, that can form after dragging 50 to 200 feet in soft soils. This ball of soil travels with the anchor, limiting penetration ability and stability. A "balled up" anchor that pulls out of the bottom will not re-embed with further dragging, but must be cleaned before it can be reset.

Strearnlined anchors, such as the NAVMOOR, are less susceptible to balling up than the less-streamlined anchors such as the STATO, LWT, and Navy stockless. This is due to the differences in frontal area presented by the anchor as it travels through the bottom soil. The greater the angle between the flukes and the anchor trajectory, the larger the tripping palms, and the greater the frontal area, the more likely the anchor is to ball up in soft soils.

F-2.1.4 Soaking. If possible, an anchor should be allowed to "soak," that is, lie undisturbed for a period of 24 hours or more after initial setting. This allows the disturbed soil around and above the anchor to settle and consolidate into firmer, denser layers. The soil strength is increased, thereby increasing holding power. Sandy soils consolidate more quickly than mud or clay.

F-2.1.5 Holding Power. Although holding power of embedment anchors is often given in terms of the anchor's weight, holding power depends mostly on the mass of the seabed soil that is displaced by the anchor. An anchor with large fluke area and features that enhance penetration (streamlined shank, smooth, sharp flukes, etc.) will have greater holding power than a heavier anchor without these features. Holding power is directly proportional to fluke area and soi1 shear strength, and inversely proportional to the anchor's resistance to penetration.

Holding power for a given anchor can be calculated by multiplying the anchor's weight by its efficiency (also called holding power factor):

$$H = W \times e$$

where:
H = Holding power, pounds
W= Anchor dry weight, pounds
e = Anchor efficiency, dimensionless

Table 8-5 provides anchor efficiencies for common salvage anchors. Anchor holding power is not a linear function of anchor weight. Anchor efficiencies are therefore valid only for the specified anchor weight. If the efficiency of a specific anchor is used to predict performance of a larger anchor of the same type, holding power will be overestimated. Using the same efficiency for smaller anchors would predict less than the actual holding power of the anchor. The anchor performance charts in Figures F-8 and F-9 should be used to predict holding power of anchor sizes other than those listed in Table 8-5. Anchor line pull must be parallel with the seafloor to achieve the predicted holding power.

F-2.1.6 Reliability. Reliability of an anchor is a subjective evaluation of its ability to trip, embed itself, resist rotating and balling up and maintain the desired holding power on a given bottom. Table F-4 is a general comparison of anchors commonly used in salvage.

The larger fluke area-to-weight ratio of high-performance anchors results in their being constructed more lightly than more conventional anchor types of the same weight. Fouling by wire rope and other sea-floor debris can prevent some of the higher performance anchors from properly embedding. Because of their heavier, simple construction, anchors such as the Eells and stockless types are more resistant to damage from nearby explosions and harsh use on rock and coral bottoms.

F-2.1.7 Improving Anchor Performance. Performance of a given anchor can be improved by one or more of the following actions:

- Adding or lengthening stabilizers
- Pre-deploying and locking folding stabilizers in position
- Sharpening fluke tips and smoothing fluke surfaces
- Adding barbs to the tripping palms
- Fixing flukes at the optimum angle for the bottom conditions
- Placing the anchor on the bottom in the correct orientation to embed, rather than simply dropping the anchor
- Inspecting the anchor to make sure that it is properly oriented, stabilizers are deployed, and that it is not fouled before attempting to set the anchor
- Washing or blasting the anchor into the bottom
- Using multiple anchors as discussed in Chapter 8
- Adding additional chain to improve the ground leg catenary and add frictional resistance allowing the anchor to "soak" before attempting a maximum line pull. Table 8-7 lists methods for correcting specific performance problems.

Table F-4. Drag Anchor Comparison.

	Cohesive Soils (Clays and Silts)			Cohesionless Soils (Sands)		
	Tripping Dig-In	Stability	Holding Power	Tripping Dig-In	Stability	Holding Power
Stockless (movable fluke)	Low	Med	Low	High	Med	Low
Stockless (fixed fluke)	High	Mod	Low	High	High	Low
Eells (w/o mudplates)	Low	Med	Low	High	High	Med
Eells (with mudplates)	High	Med	Low	High	High	Med
Danforth	Med	Low	Med	High	Med	Med
LWT	Low	Low	Low	High	Med	Med
STATO/NAVMOOR	High	Med	High	High	High	High

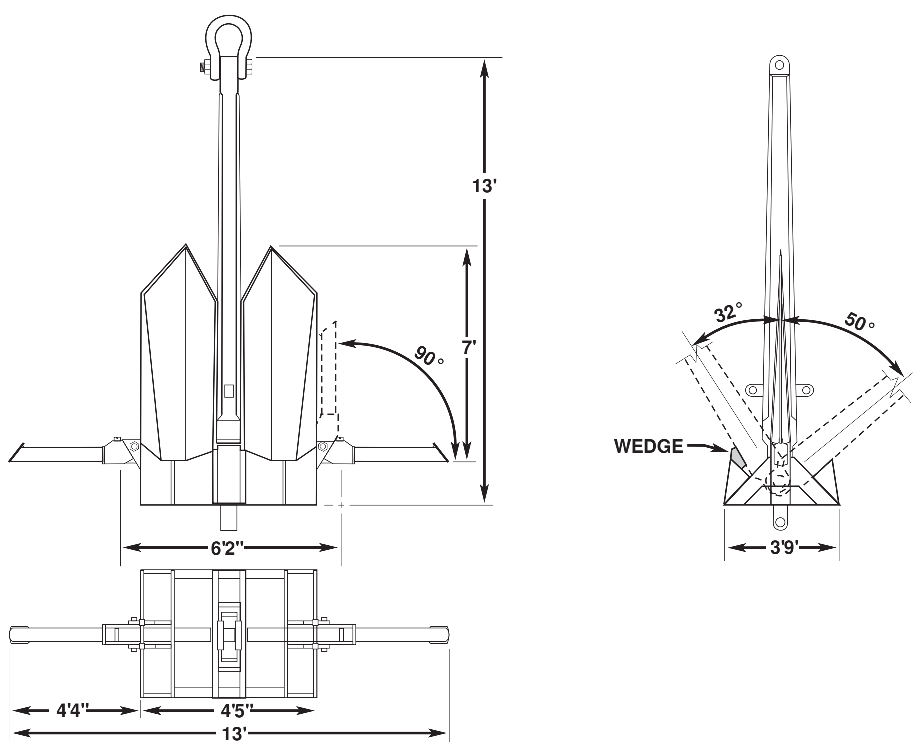
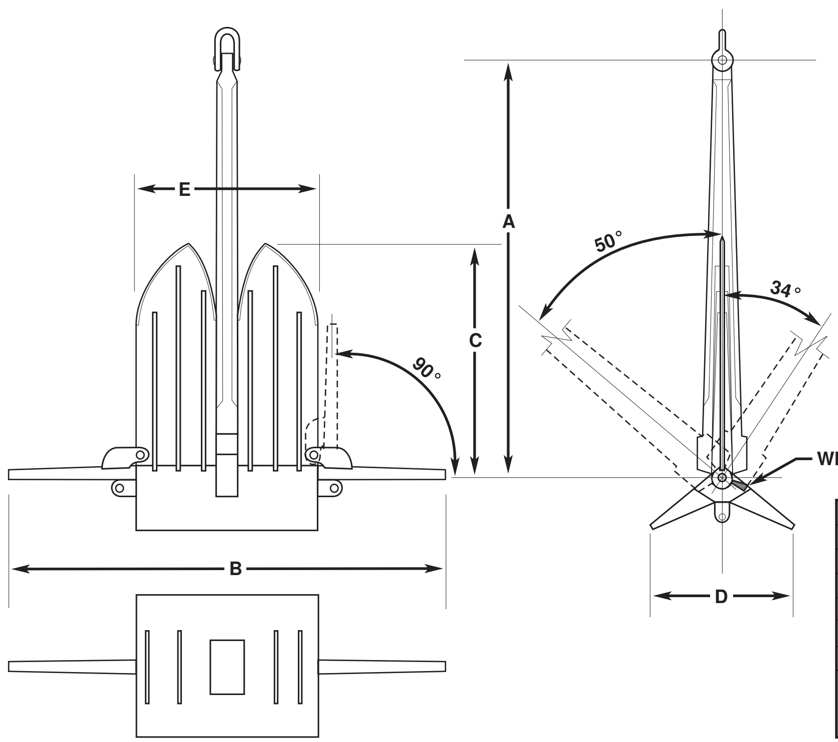


Figure F-10. 6,000-Pound NAVMOOR Anchor Dimensions.

F-3 DIMENSIONED ANCHOR DRAWINGS.

Dimensions and configurations for anchors typically available to Navy salvors are shown in the following drawings:

Figure	Description
F-10	6,000-Pound NAVMOOR
F-11	200-, 500-, 3,000-, 6,000-, 9,000-, 12,000-, and 15,000-Pound STATO
F-12	8,000-Pound Eells
F-13	1,500-, 4,000-, 6,000-, 10,000-, 15,000-, 20,000-, and 30,000-Pound LWT
F-14	200-, 1,000-, 4,000-, 6,000-, 10,000-, 16,000-, and 30,000-Pound Danforth
F-15	4,000-, 6,000-, 8,000-, 10,000-, 15,000-, 20,000-, and 30,000-Pound Navy Stockless



NOMINAL WEIGHT OF ANCHOR IN POUNDS	A	B	C	D	E
	DIMENSIONS (INCHES)				
15,000	204	224	126	60	72
12,000	186	197	113	55	67
9,000	160	143	92	44	53
6,000	144	143	92	44	53
3,000	129	109	72	35	42
500	71	60	40	19	23
200	42	59	26	14	17

Figure F-11. STATO Anchor Dimensions.

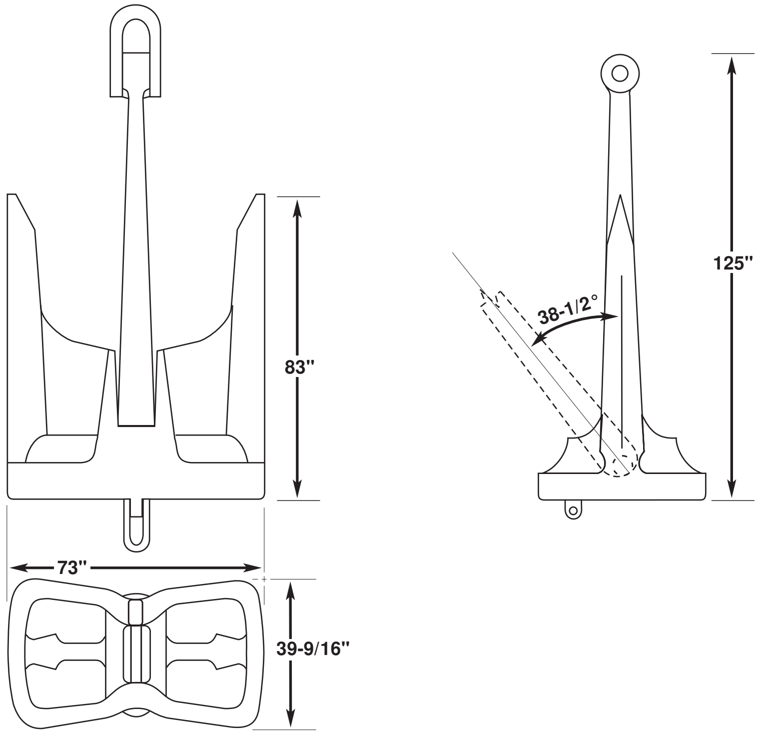
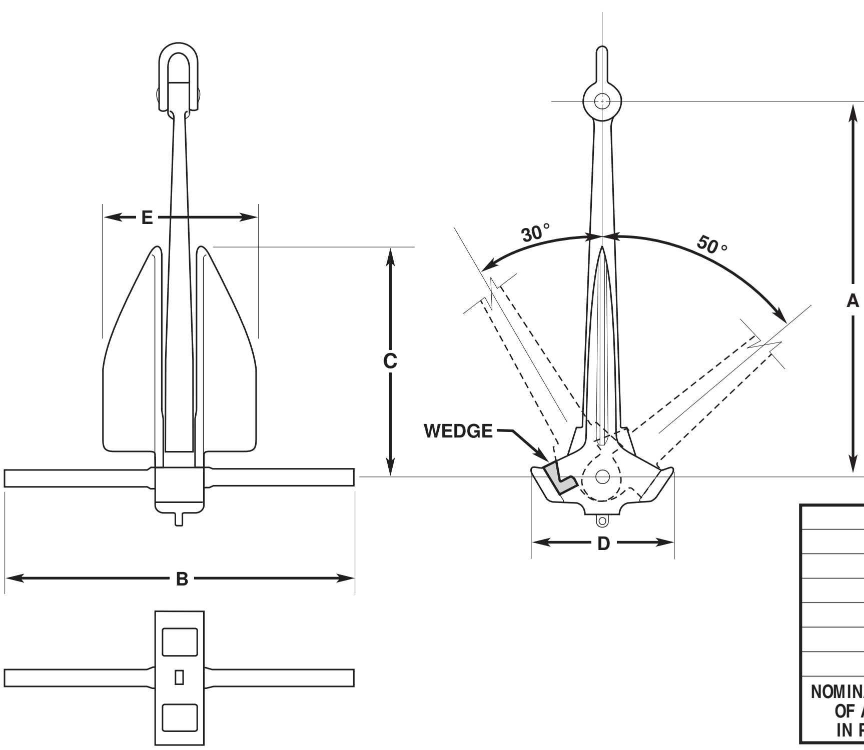
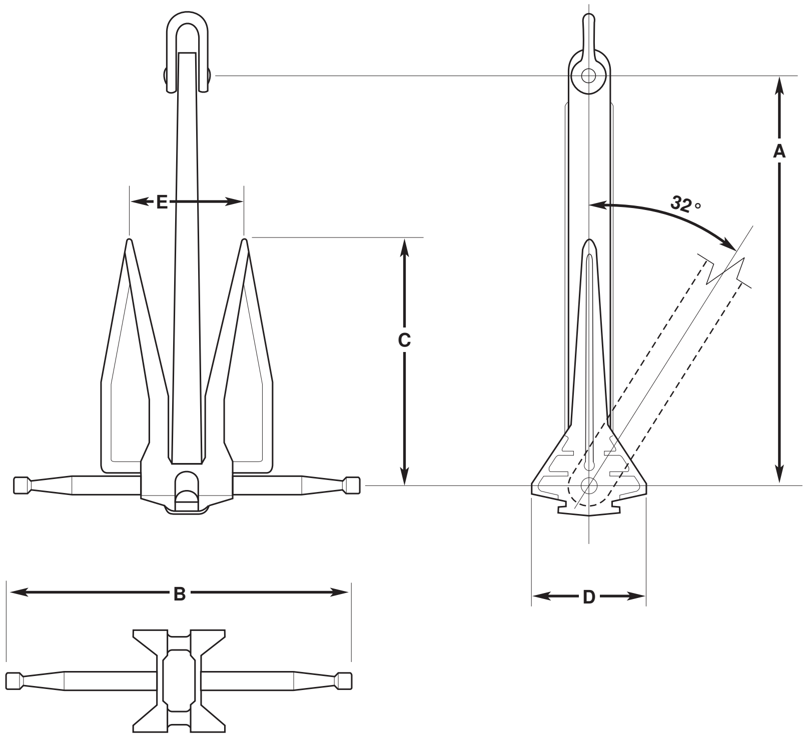


Figure F-12. 8,000-Pound Eells Anchor Dimensions.



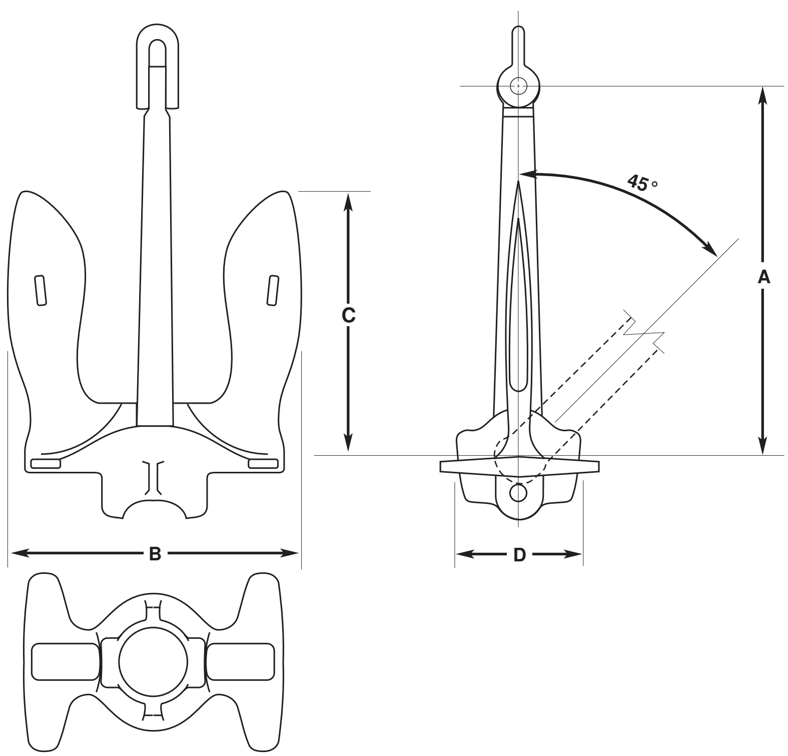
NOMINAL WEIGHT OF ANCHOR IN POUNDS	A	B	C	D	E
	DIMENSIONS (INCHES)				
30,000	198	220	121	68	78
20,000	173	190	106	59	68
15,000	157	150	96	54	62
10,000	144	137	88	49	55
6,000	124	118	76	41	47
4,000	116	110	71	38	44
1,500	87	59	53	28	32

Figure F-13. LWT Anchor Dimensions.



NOMINAL WEIGHT OF ANCHOR IN POUNDS	A	B	C	D	E
	DIMENSIONS (INCHES)				
30,000	197	187	112	51	31
16,000	160	160	107	42	25
10,000	138	131	87	36	22
6,000	118	112	74	30	19
4,000	104	99	66	26	15
1,000	72	62	45	17	19
200	53	46	33	10	6

Figure F-14. Danforth Anchor Dimensions.



NOMINAL WEIGHT OF ANCHOR IN POUNDS	A	B	C	D
	DIMENSIONS (INCHES)			
30,000	133	103	94	64
20,000	116	90	82	56
15,000	106	82	73	51
10,000	92	71	65	44
8,000	86	66	61	41
6,000	78	60	52	37
4,000	68	53	49	33

Figure F-15. Navy Stockless Anchor Dimensions.

APPENDIX G
ESSM AND FLEET SALVAGE ASSET INVENTORY

G-1 INTRODUCTION.

This Appendix G includes information about the location and type of salvage equipment and platforms that are available to Navy salvors worldwide. This equipment includes Vessels, ROVs, Side-Scan Sonars, and Salvage Equipment. There are four tables in this Appendix.

- Table G-1, ESSM Facility Locations and Abbreviations, lists the location of the eight ESSM facilities and the abbreviations that are used for them in Table G-4: ESSM Salvage Inventory and Shipping Characteristics.
- Table G-2, Fleet Salvage Inventory, lists the Fleet Salvage assets including vessels, ROVs, and side scan sonar equipment that are located throughout the fleet and are not accounted for in the ESSM salvage inventory.
- Table G-3, Aircraft Dimensions for Shipping, includes the payload, runway length and compartment dimensions of typical aircraft for shipping salvage equipment.

Table: G-1. ESSM Facility Locations and Abbreviations.

LOCATION	ABBREVIATION
Alaska	ALK
Bahrain	BH
Hawaii	HII
Italy	ITY
Japan	JAP
Port Hueneme, CA	PHE
Singapore	SIG
Williamsburg, VA	CAX

- Table G-4, ESSM Salvage Inventory and Shipping Characteristics, summarizes Navy-owned salvage equipment that are located in one or multiple ESSM facility locations.

There are eight ESSM facilities strategically located worldwide to support salvage operations. The locations and associated abbreviations are located in Table G-1, ESSM Facility Locations and Abbreviations.

The U.S. Navy owns fleet salvage, towing, ocean search and recovery assets that are used in worldwide salvage efforts. They consist of:

- Salvage and Towing Assets:

  (1) ARS-50 Class ships
  (2) T-ATF-166 Class ships

- Ocean Search and Recovery Assets:

  (1) Curv III ROV
  (2) Deep Drone 7200 ROV
  (3) Magnum ROV
  (4) MINIROVs
  (5) Orion Search System
  (6) Shallow Water Intermediate Search System (SWISS)

A brief description of the fleet salvage assets is located in Table G-2 Fleet Salvage Inventory, below. A full description of ocean search and recovery assets can be found in U.S. Navy Salvage Manual 4: Deep Ocean Operations. All of the above mentioned salvage, towing and ocean search and recovery assets can be located on the following website: http://www.supsalv.org/00c2_assets.asp?destpage=00c2.

Table G-2. Fleet Salvage Inventory.

Equipment Description		Length FT/IN	Width FT/IN	Height FT/IN	Weight	Description
ARS-50 Safeguard Class Salvage Vessel	Sasebo, JA Littlecreek Hawaii Norfolk	255’	50’	Draft 15.5	3,200 tons	Salvage vessels include USS SAFEGUARD, USS GRASP, USS SALVOR, and USS GRAPPLE. They operate as a dive platform, ROV platform, and salvage support vessel.
T-ATF-66 Pawhatan Class Fleet Ocean Tug	Various	226’	42’		2,260 tons	Fleet Ocean Tug operated by Military Sealift Command. Capable of towing, firefighting and heavy lift, used as a platform for MDSU divers. Max lift 100 Tons over stern.
Magnum ROV	SUPSALV WASH DC					8,200 depth rated, camera sonar, manipulators, lift capacity 8,000 lbs.
CURV III ROV	SUPSALV WASH DC				13,000	20,000’ depth rated, video, still camera, sonar, nav systems, manipulators, lift capacity 2,500 lbs, payload 300 lbs.
Deep Drone 7200 ROV	SUPSALV WASH DC	9’3”	4’7”	6’2”		7200 depth rated, can be transported on military aircraft. Still and video cameras, tool package, 3kts speed, 3 ea manipulators.
Mini ROV	SUPSALV WASH DC	MR14’8” MR24’2”	2’3” 2’4”	2’1” 2’4”	200 lbs 325 lbs	1,000’ depth rated, shallow water survey capabilities, used in photo documentation, high resolution sonar, 3kts speed, 300 lb payload MR1, 90 lb payload MR2, navigation package.
Shallow Water Intermediate Side Scan		3’	6”		<50 lbs	Operating speed 1-5kts, operating depth 0-5,000’, 100 khz, 500 khz.
Orion Search System Side Scan Sonar						20,000 depth rated, dual 56 khz for long range, 250 khz for targets, Intensified Charged Coupled Device video camera, fiber optic cable, long baseline shipboard DGPS and seafloor nav system.

The inventory of salvage assets includes dimensions of most of the equipment listed. Table G-3, Aircraft Dimensions for Shipping, shows the compartment dimensions and maximum allowable payload for typical military aircraft use in shipping the salvage equipment.

Table G-4: ESSM Salvage Inventory and Shipping Characteristics summarize the equipment type, size, location and characteristics of salvage equipment at each of eight ESSM locations. In addition to the ESSM salvage equipment inventory, an inventory of pollution equipment is also maintained by ESSM. Volume 6: Oil Spill

Response of the Salvage Operations Manuals includes a listing of the pollution inventory. An up to date listing of both the ESSM salvage and pollution equipment inventories can be located on the Naval Sea Systems Command Website under the key word, ESSM or at the following web addresses:

- http://www.essmnavy.net/new_page_13.htm for the salvage equipment inventory and
- http://www.essmnavy.net/new_page_10.htm for the pollution equipment inventory.

Both of the ESSM websites mentioned above are updated several times per year and represent the most accurate depiction of the equipment available. Tables G-2 and G-3 represent a snapshot of the salvage inventory.

Other sources of machinery suitable for salvage work include:

- Public Works Centers
- Naval Mobile Construction Battalions,
- Naval Underwater Construction Teams
- Engineering Maintenance
- Facilities Support
- Supply Units of the Navy or other armed forces
- Construction and Underwater construction contractors
- Commercial salvage equipment rental service
- Agricultural equipment suppliers

Table G-3. Aircraft Dimensions for Shipping.

Aircraft Type	C-5 Galaxy	C-17 Globe Master III	C-130J Hercules	C-141B Starlifter
Compartment Dimensions L × W × H (Ft)	143’9” × 19’ × 13’5”	88’ × 18’ × 12’4”	40’ × 9’9” × 9’	93’ × 10’3” × 9’1”
Maximum Allowable Payload (Lbs)	270,000	170,900	46,631	72,000
Maximum Normal Payload (Lbs)	270,000	160, 000	38,301	68,725
Range with Maximum Normal Payload w/o refueling (Nm)	2,650	2,400	2,371	2,174
Minimum Runway Length for Takeoff/Landing (Ft)	8,300/4,900	3000/3000	3000/3000	6000/6000
Minimum Runway Width (Ft)	148’	90’	80’	98’

Information supplied by USAF http://www.af.mil/factsheets/

Table G-4. ESSM Salvage Inventory and Shipping Characteristics.

This inventory is subject to change without notice.
Revised November 8, 2002 (Blue font indicates additional information on item available from the ESSM website: www.essm.navy.net)

Equipment Description	SYS #	ESSM #	CAX	PHI	LK	HII	SIG	JAP	ITY	BH	Length Feet/ inches	Width Feet/ Inches	Height Feet/ Inches	Cubic Feet	Lbs
Air Compressor System Portable, 175-CFM	S01100	AC0330	31	25	3	3	5	2	7	4	7’4”	3’9”	4’8”	129	2632
Air Compressor System Portable, 600-CFM	S01200	AC0301 AC0317	8	2	0	2	0	0	0	0	14’ 7”	6’ 5”	7’ 8”	717.4	6680
Air Compressor System Sub Salvage, 900-SCFM, 500-PSI	S01300	AC0244 AC0245	5	0	0	0	0	0	0	0	20’	8’	8’	1280	24,960
Hose, Air Sub Salvage	S20100	RL0600	23	97	0	3	0	0	5	2		2’ 4”	4’ 7”	49	490
Anchor System Spare	S03100	AN0001 AN1057 AN2006 AN2036 AN2140	23	26	0	0	0	0	0	0	10’10” 13’7” 14’ 14’ 12’11”	6’ 4” 6’11” 6’10” 6’10” 6’5”	3’ 6” 1’ 11” 3’1” 3’11” 3’8”	260 179 375 375 304	8200 6000 6200 6000 7200
Beach Gear Ground Leg	S05100	BG0100 BG0200	25	1	4	4	8	4	10	3	10’10” 14’0” 12’11”	6’ 4” 6’10” 6’5”	3’ 6” 3’11” 3’8”	260 375 304	8200 6200 7200
Wire Rope, 1⅝" × 300-Ft Spares	S05400	WR0150	59	14	0	2	0	0	0	0		4’	3’9”	60	2328
Wire Rope, 1⅝" × 600-Ft Spares	S05500	WR0151	136	26	0	2	0	0	0	0		4’	3’ 9”	60	2328
Wire Rope, 1⅝" × 2,000'	S05600	WR0156	10	0	0	0	0	0	0	0		6’	3’ 6”	132	9440
Carpenter Stopper System ⅝-Inch	S06000	ST0010	133	80	0	10	3	4	4	0	8”	6”	4”	1	12
Carpenter Stopper System ⅞-Inch	S06100	ST0020	17	0	0	0	0	0	0	0	1”	8”	5”	1	28
Carpenter Stopper System 1¼-Inch	S06200	ST0031	2	0	0	0	0	0	0	0	1’ 2”	9”	6”	1	54
Carpenter Stopper System 1⅝-Inch	S06300	ST0050	123	0	0	0	0	0	0	0	1’ 7”	1’ 1”	9”	1	150
Carpenter Stopper System 2¼-Inch	S06500	ST0071	22	0	0	3	0	0	0	0	2’	16”	11”	2.5	348
Carpenter Stopper System 2½-Inch	S06600	ST0081	50	0	0	0	0	0	0	0	2’ 4”	1’ 4”	11”	3	434
Capstan, Deck, Portable	S07100	CP2079	12	2	0	0	0	0	0	0	4’	4’	4’	64	2162
Chain, 2¼-Inch	S08100	CH0040 CH1093	5	16	0	0	0	0	0	0	5’ 2”	3’	3’ 6”	54	4460
Generator, 5-Kw, Dsl 120/240 Vac, Single-Phase	12200	GE0401 GE0404	26	14	2	4	4	2	6	2	3’	1’ 10”	3’	16.5	680
Generator, 30-Kw, Diesel	S12300	GE0410 GE0450 GE0460	15	7	2	6	5	3	6	4	7’ 1”	2’ 10”	4’ 9”	117	4030
Generator, 20-Kw, Dsl 120/240/440 Vac, 1 Phase / 3 Phase	S12400	GE0500	7	7	0	3	0	0	0	0					
Heavy Lift System	S13100		0	0	0	0	0	0	0	0	4’	2’ 3”	11”	8.5	825
Light Tower System W/5-Kw Dsl Generator	S14100	LT0430	11	2	3	2	4	2	6	1		4’ 8”	4’ 9”	142	2100
Light Tower, W/O Dsl Generator	S14200	LT0440	1	0	0	0	0	0	0	0	Under Development				
Lighting Kit (120-Volt)	S15100	LI0440	1	4	1	1	3	2	4	2					
Hydraulic Power Unit System Model 6	S16100	PW0045	1	4	2	3	1	1	2	2	8’	2’ 10”	4’ 10”	110	3840 dry 4400 wet
Puller System, Hydraulic Cable	S17100	HC0012	13	7	2	2	4	2	6	2	3’ 11”	2’ 8”	4’ 1”	42	730
Pumping System, Submersible Salvage, 6-Inch	S18000	PW0200	6	4	0	2	2	2	2	2		39”	12”	2.55	268
Pumping System, 350-Gpm 3-Inch Diesel	S18100	PU0201	5	7	2	6	8	4	8	4	3’	1’11”	3’	17.25	680
Pumping System, Trash 3-Inch Diesel	S18200	PU0234	24	13	2	2	5	2	7	2	3’ 0” 5’ 2” (pump vs pump and cage)	1’ 8” 3’	2’ 5” 3’ 6”	11.7 55	217 890

Table G-4 (continued). ESSM Salvage Inventory and Shipping Characteristics.

This inventory is subject to change without notice.
Revised November 8, 2002 (Blue font indicates additional information on item available from the ESSM website: www.essm.navy.net)

Equipment Description	SYS #	ESSM #	CAX	PHI	LK	HII	SIG	JAP	ITY	BH	Length Feet/ inches	Width Feet/ Inches	Height Feet/ Inches	Cubic Feet	Lbs
Pumping System, 1500-Gpm 6-Inch Diesel	18300	PU0210	9	10	2	4	6	2	7	2	5' 5"	2' 6"	4' 0"	54	2360
Pumping System, 3000-Gpm 10-Inch Diesel	S18400	PU0220	3	5	0	1	1	1	2	0	6' 11"	2' 9"	4' 4"	82.5	3200
Pumping System, Jetting 2 1/2-Inch	S18500	PU0228 PU0229 PU0230	11	6	1	1	1	2	2	1	9'2"	3'4"	6' 6"	199	4276
Pumping System, Submersible 1½-Inch	S18600	PU0250	4	1	2	0	3	2	5	2	1' 6" 1' 9"	6" 11"	6" 1' 4"	.05 2.5	32 52
Pumping System, Submersible 4-Inch Electric	S18700	PU0239 PU0240	9	9	0	4	1	2	7	2	5' 7" 6' 0"	1' 8" 2' 5"	1' 9" 4' 5"	17 64	639 1560
Pumping System, Submersible 4-Inch Hydraulic	S18800	PU0208	17	3	2	2	2	0	2	2		1' 10"	1' 7"	4.5	95
Pumping System, Submersible 6-Inch Hydraulic	S18900	PU0290	6	3	0	2	2	2	2	2	3' 11"	2' 8"	4' 1"	42	730
Reverse Osmosis Water Purification Unit (Rowpu), Marine	S19100	WP0903	5	0	0	0	0	0	0	1	15'	8'	8'	960	13690
Salvage Pontoons	S21100	PN0049 PN0050 PN0060	27	1	0	4	0	0	0	4	NA 5' 2"	NA 3'	13' 3' 5"	8' 6" NA	354 85
Spooling System	S22100	WR0001	3	2	0	1	0	0	0	0					
Tension Meter	24100	TE0051	9	3	0	4	4	2	4	3	2' 2"	1' 4"	1' 2"	3	264
Underwater Cutting Kit	26100	KT0558	3	3	0	2	3	2	3	2	4' 1"	3'	2' 4"	500	29
Welder, Diesel, 400-Amp	29100	WL0470	15	2	2	2	6	2	6	2	6' 10"	2' 8"	4' 11"	3250	90
Welder, Kit	29200	WL0472	7	2	2	2	6	2	6	2	3' 6"	1' 11"	1' 3"	7.66	250
Winch, 8-Ton Diesel	30100	WN0010	11	4	0	2	2	1	2	1	8' 2"	5' 0"	5' 1"	208	7080
Oxygen Acetylene Cutting & Welding Kit	31000	KT0557	6	2	0	2	2	2	5	2	2' 1"	2' 2"	1' 7"	7	84
Fly Away Deep Ocean Salvage System (Fadoss) 15-KIP (1st GEN)	DS0100	TU0101	1	0	0	0	0	0	0	0	5' 10"	2' 10"	3' 3"	54	1748
Fly Away Deep Ocean Salvage SYSTEM (FADOSS) 15-KIP (2nd GEN)	DS0101	TU0101	0	1	0	0	0	0	0	0	5' 10"	2' 10"	3' 3"	54	1748
Fly Away Deep Ocean Salvage System (Fadoss)30-KIP (1st GEN)	DS0110	TU0330	0	0	0	1	0	0	0	0	5' 10"	2' 10"	3' 3"	54	1748
Fly Away Deep Ocean Salvage System (Fadoss)30-KIP (2nd GEN)	DS0111	TU0331	0	0	0	1	0	0	0	0					
Fly Away Deep Ocean Salvage System (Fadoss) 60-KIP (1st GEN)	DS0120	MC0806	1	0	0	0	0	0	0	0	5' 10"	2' 10"	3' 3"	54	1748
Fly Away Deep Ocean Salvage System (Fadoss) 60-KIP (2nd GEN)	DS0121	MC0806	1	0	0	0	0	0	0	0	5' 10"	2' 10"	3' 3"	54	1748
Mooring System, Four Point	DS0200	CH2017	0	0	0	0	0	0	0	0	12'11"	6' 5"	3' 8"	304	6000 7000

Table G-5. Synthetic Line System.

TYPE OF LINE	SYS #	ESSM #	CAX	PHE	ALK	AII	SIG	JAP	ITY	BH
Line, Aramid Fiber, 2" × 3,800'	DS0300	LN0012	1	0	0	0	0	0	0	0
Line, Aramid Fiber, ⅜" × 24,000'	DS0300	LN0028	2	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 5,000'	DS0300	LN0029	1	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 4,850'	DS0300	LN0030	2	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 6,500'	DS0300	LN0031	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 4,000'	DS0300	LN2100	4	0	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 7,496'	DS0300	LN2103	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 24,000'	DS0300	LN2105	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 14,000'	DS0300	LN2106	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" ×10,000'	DS0300	LN2109	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 415'	DS0300	LN2110	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 1,405'	DS0300	LN2111	1	0	0	0	0	0	0	0
Line, Aramid Fiber 1½" × 5,975'	DS0300	LN2113	1	0	0	0	0	0	0	0
Line, Aramid Fiber 1½" ×780'	DS0300	LN2114	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 6,000' Spliced To 1" × 8,000'	DS0300	LN2119	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 4,000'	DS0300	LN2122	1	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 3,200'	DS0300	LN2123	5	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 10,000'	DS0300	LN2124	2	0	0	0	0	0	0	0
Line, Aramid Fiber, 2" × 8,000'	DS0300	LN2127	1	2	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 10,000'	DS0300	LN2128	0	1	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 4,000'	DS0300	LN2129	0	1	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 8,000'	DS0300	LN2130	3	2	0	0	0	0	0	0
Line, Aramid Fiber, 1" × 8,000'	DS0300	LN2131	0	3	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 4,000'	DS0300	LN2132	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 8,000'	DS0300	LN2133	0	2	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 10,000'	DS0300	LN2134	2	1	0	0	0	0	0	0
Line, Aramid Fiber, 2" × 4,000'	DS0300	LN2135	1	1	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 7,500'	DS0300	LN2136	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 4¾" × 1,200'	DS0300	LN2145	8	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 24,000'	DS0300	LN2146	1	1	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 6,800'	DS0300	LN2150	3	0	0	0	0	0	0	0
Line, Aramid Fiber, ¾" × 7,000'	DS0300	LN2151	1	0	0	0	0	0	0	0
Line, Aramid Fiber, 1½" × 2,500'	DS0300	LN2200	0	0	0	3	0	0	0	0
Line, Aramid Fiber, 1½" × 2,000'	DS0300	LN2205	0	0	0	1	0	0	0	0
Line, Aramid Fiber, 2½" × 150'	DS0300	LN2210	0	0	0	2	0	0	0	0
Line, Aramid Fiber, 2½" × 500'	DS0300	LN2211	0	0	0	2	0	0	0	0
Line, Nylon, Dbl Brd, 6" × 500'	DS0300	LN0107	1	1	0	0	0	0	0	0
Line, Nylon, Dbl Brd, 7" × 500'	DS0300	LN0130	0	1	0	0	0	0	0	0
Line, Nylon, 7" × 1000'	DS0300	LN0131	2	2	0	0	0	0	0	0
Line, Nylon, 8½" × 600'	DS0300	LN0136	1	0	0	0	0	0	0	0
Line, Nylon, 6" × 100'	DS0300	LN1064	74	0	0	0	0	0	0	0
Line, Nylon, 8" × 6,000'	DS0300	LN1920	0	1	0	0	0	0	0	0
Line, Nylon, Dbl Brd, 3½" × 4000'	DS0300	LN2034	1	0	0	0	0	0	0	0
Line, Nylon, Dbl Brd, 6" × 300'	DS0300	LN2064	1	0	0	0	0	0	0	0
Line, Nylon, Dbl Brd, 6" × 600'	DS0300	LN2065	1	0	0	0	0	0	0	0
Line, Stbl Brd, 8½" × 2,000'	DS0300	LN1989	1	0	0	0	0	0	0	0
Line, Stbl Brd, 6½" × 1,000'	DS0300	LN1990	7	0	0	0	0	0	0	0
Line, Duron, Stbl Brd, 4½" × 6,000'	DS0300	LN2086	3	0	0	0	0	0	0	0
Line, Duron, Stbl Brd, 4½" × 8,000'	DS0300	LN2087	1	0	0	0	0	0	0	0
Line, Duron, Stbl Brd, 8½" × 7,000'	DS0300	LN2088	3	0	0	0	0	0	0	0
Line, Duron, Stbl Brd, 4½" × 4,700'	DS0300	LN2090	1	0	0	0	0	0	0	0
Tow Hawser System	DS0400									
Line, Polyester Sgl Brd 8" × 1800'	DS0400	LN2139	1	0	0	0	0	0	0	0
Line, Polyester Dbl Brd 8" × 1800'	DS0400	LN2140	3	5	0	3	0	0	0	0
Line, Polyester Dbl Brd 10" × 2400'	DS0400	LN2141	4	5	0	2	0	0	0	0

Table G-5 (continued). Synthetic Line System.

TYPE OF LINE	SYS #	ESSM #	CAX	PHE	ALK	AII	SIG	JAP	ITY	BH
Line, Polyester Sgl Brd 10" × 2400'	DS0400	LN2142	1	1	0	0	0	0	0	0
Line, Polyester Dbl Brd 14" × 2400'	DS0400	LN2143	12	1	0	0	0	0	0	0
Line, Polyester Sgl Brd 14" × 2400'	DS0400	LN2144	2	0	0	0	0	0	0	0
Line, Polyester, Dbl Brd, 10" × 300'	DS0400	LN2161	3	0	0	0	0	0	0	0
Towing Vessel Fire/Flooding Alarm System	DS0501	AL0020	3	1	0	0	0	0	0	0
Towing Alarm System (Emergency)	DS0510	AL0100	1	0	0	0	0	0	0	0
Primary Towing Bridle Assembly System	DS0600	CH2121	1	0	0	0	0	0	0	0
Secondary Towing Bridle Assembly System	DS0605	WR0070	1	0	0	0	0	0	0	0
Emergency Towing Anchor System	DS0620	AN2140	1	0	0	0	0	0	0	0

G-2 OPERATING CHARACTERISTICS.

Performance curves or tables for salvage pumps are presented below.

G-2.1 3" Diesel Pump. See Figure G-1.

G-2.2 6" Diesel Pump. See Figure G-2.

G-2.3 10" Diesel Pump. See Figure G-3.

G-2.4 1½" Submersible Pump. The 1½" submersible pump is rated at 60 gallons per minute with a head of eight feet.

G-2.5 2½" Submersible Pump. See Figure G-4.

G-2.6 4" Electric Submersible Pump. See Figures G-5 through G-8.

G-2.7 4" Hydraulic Submersible Pump. See Figure G-9.

G-2.8 6" POL Hydraulic Submersible Pump.

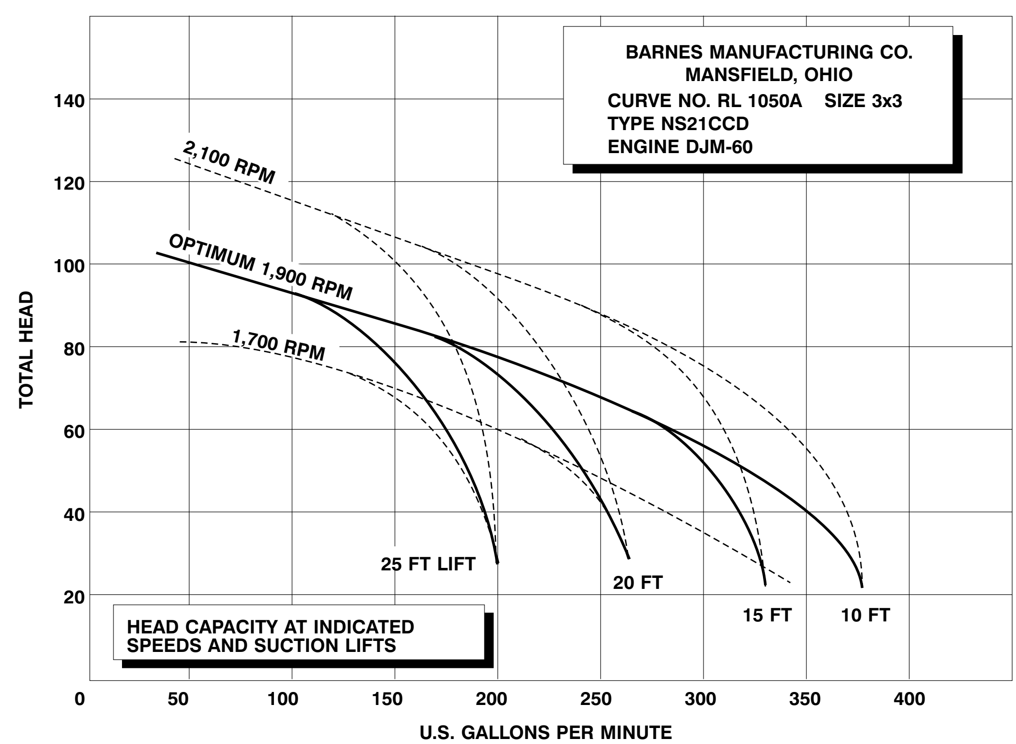


Figure G-1. Performance Curve, 3-Inch Diesel Pump.

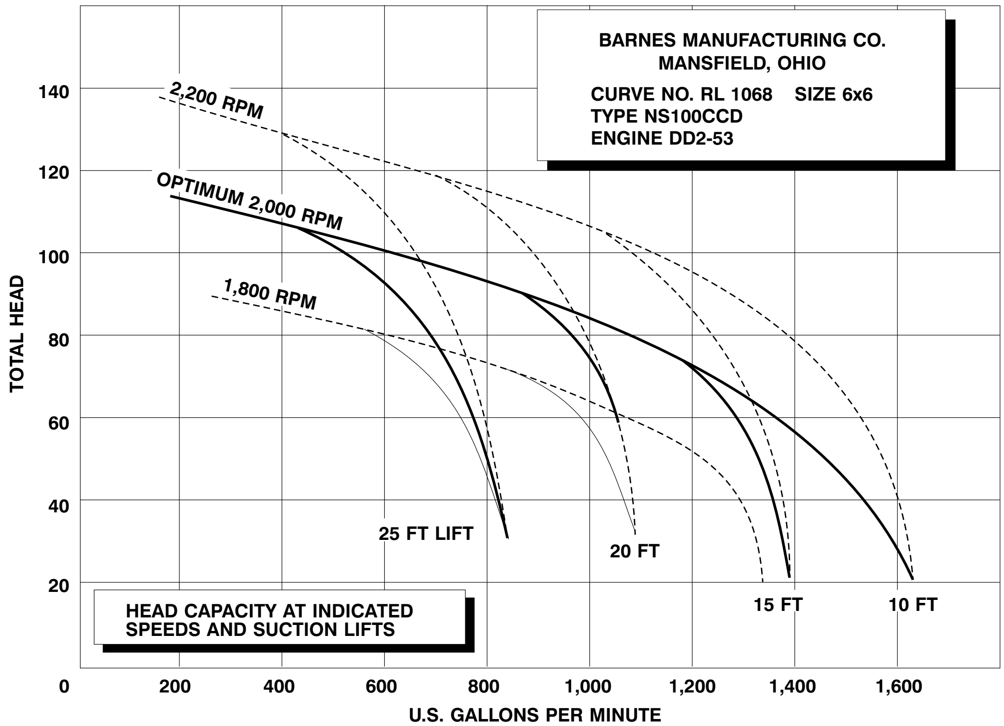


Figure G-2. Performance Curve, 6-Inch Diesel Pump.

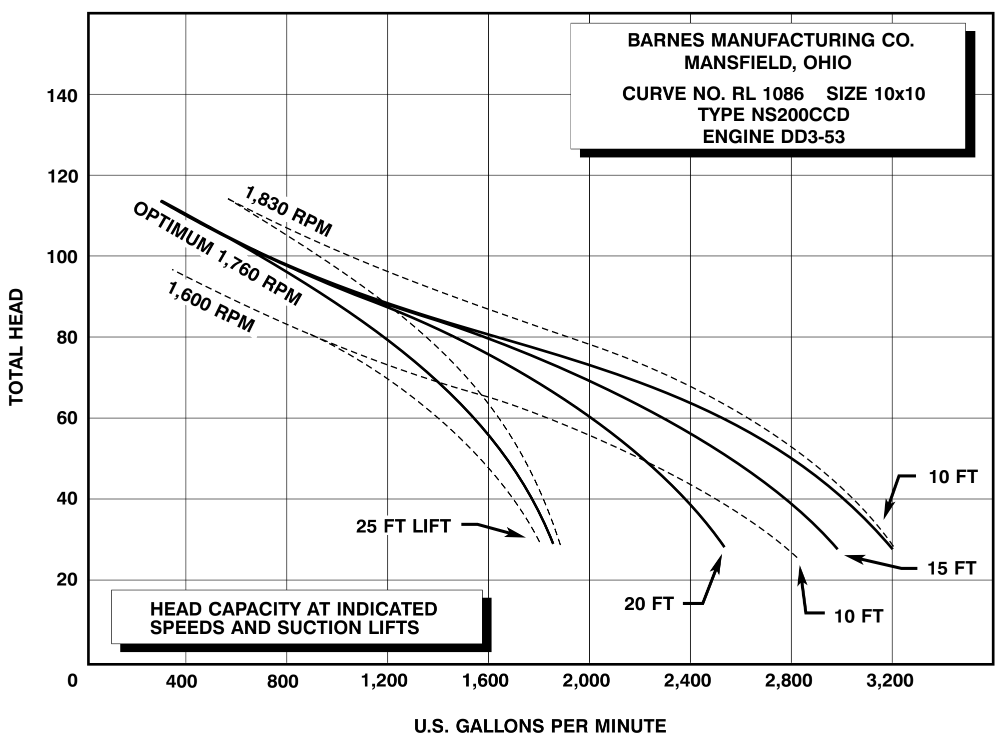


Figure G-3. Performance Curve, 10-Inch Diesel Pump.

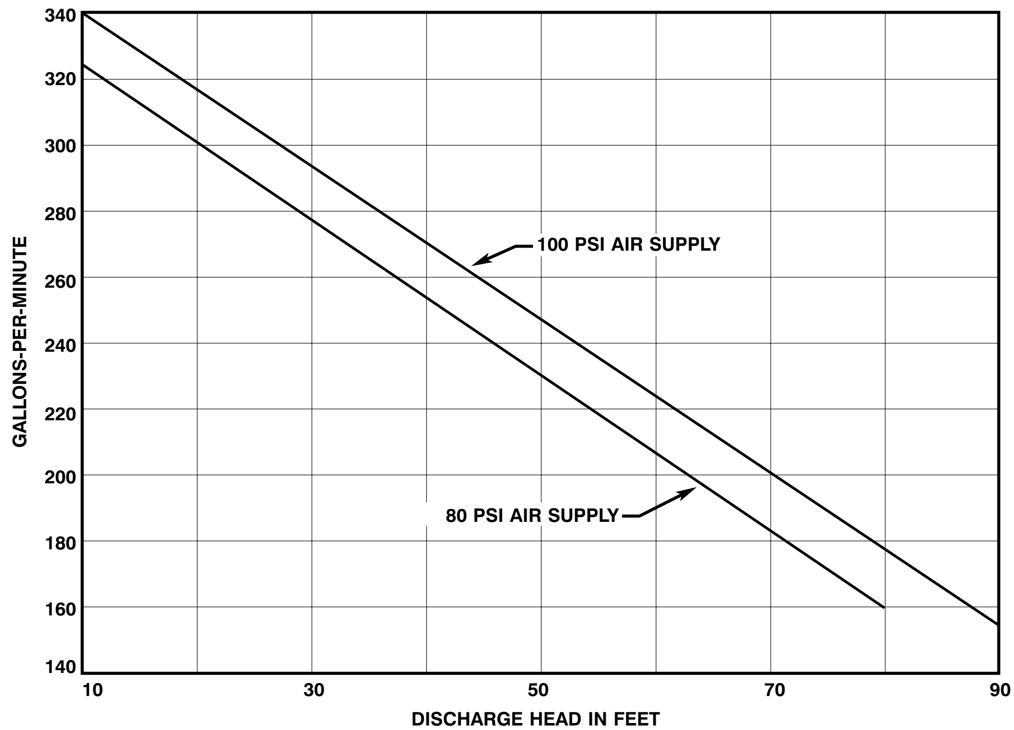


Figure G-4. 2 1/2-Inch Pneumatic Submersible Pump Performance Curves.

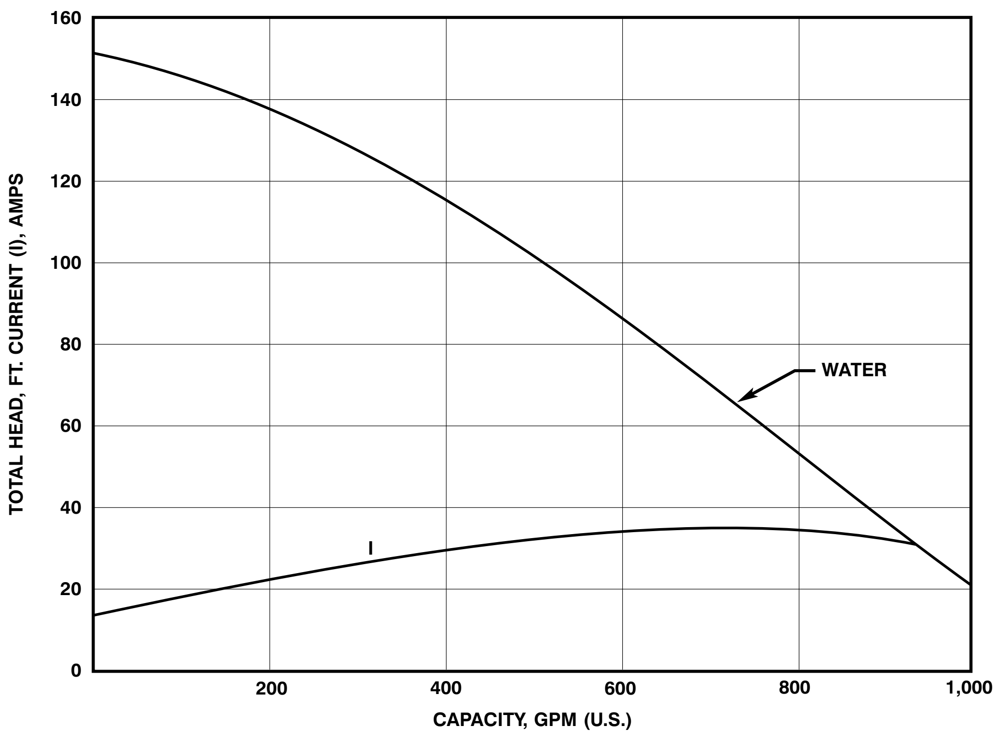


Figure G-5. U.S. Navy 4-Inch Electric Submersible Pump Performance With Impeller No. 1.

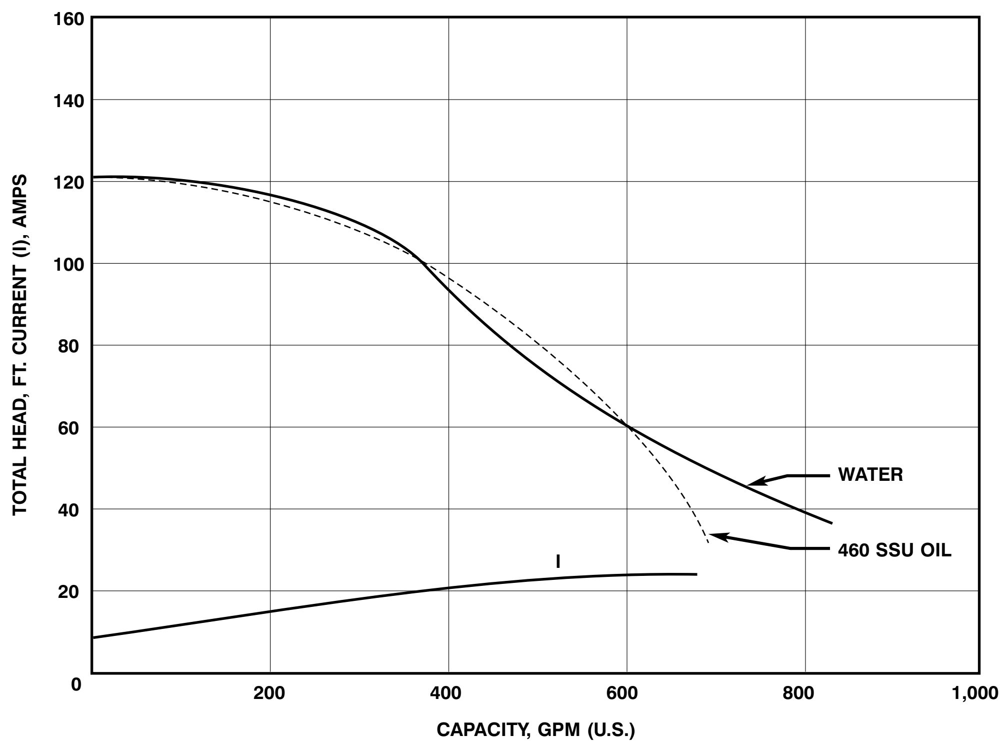


Figure G-6. U.S. Navy 4-Inch Electric Submersible Pump Performance With Impeller No. 2.

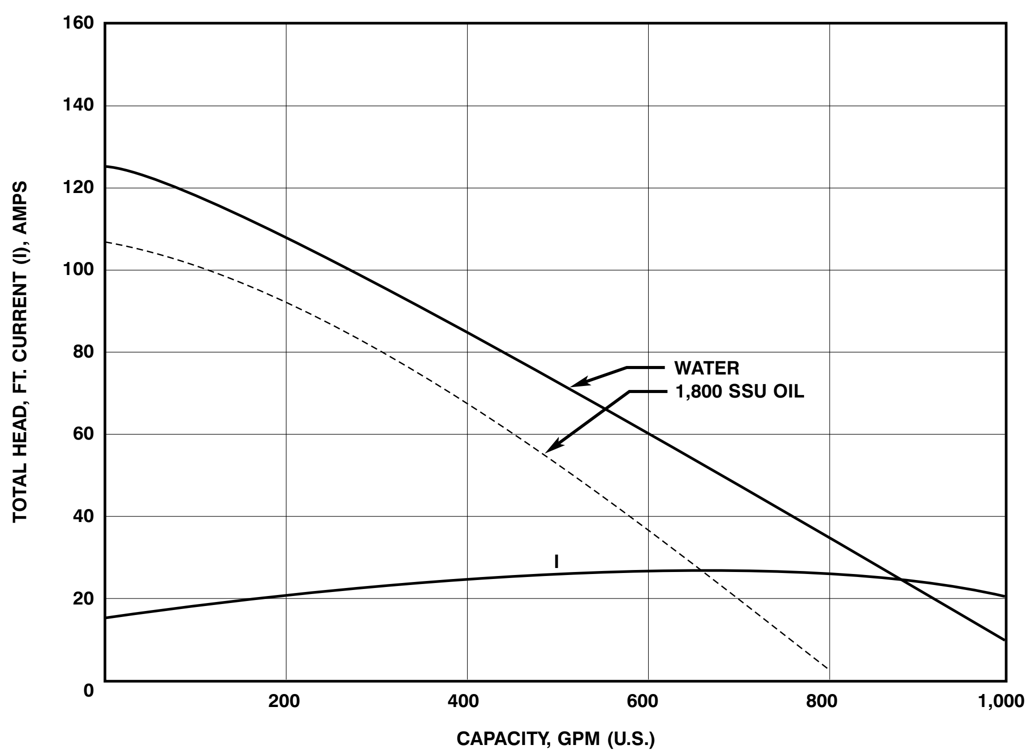


Figure G-7. U.S. Navy 4-Inch Electric Submersible Pump Performance With Impeller No. 3

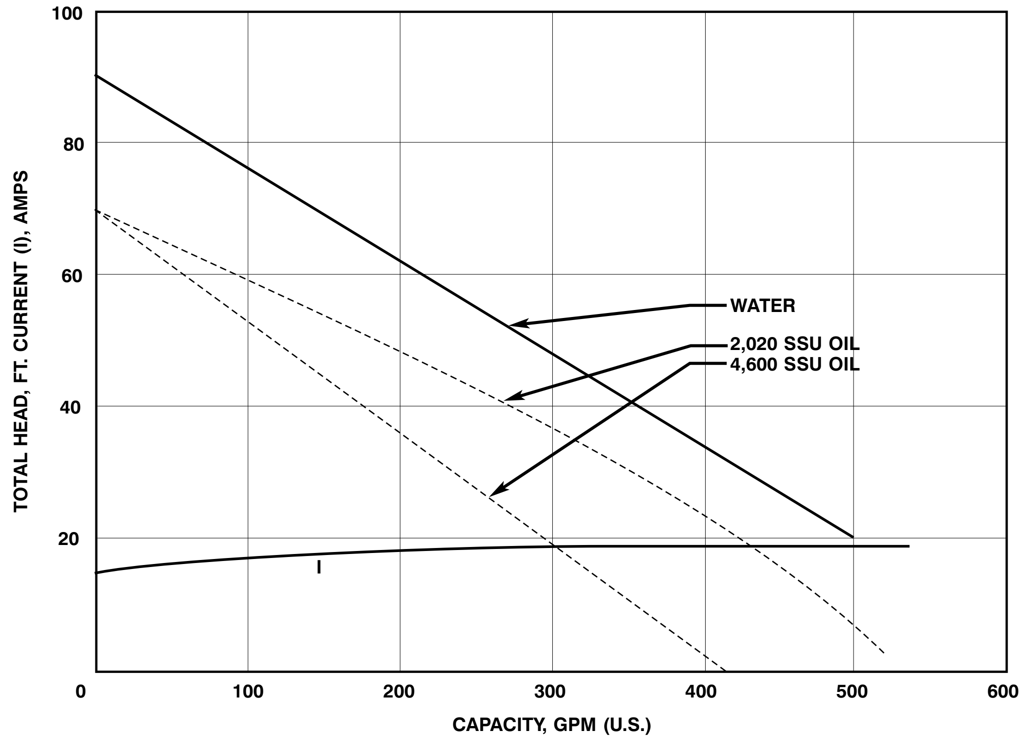


Figure G-8. U.S. Navy 4-Inch Electric Submersible Pump Performance With Impeller No. 4.

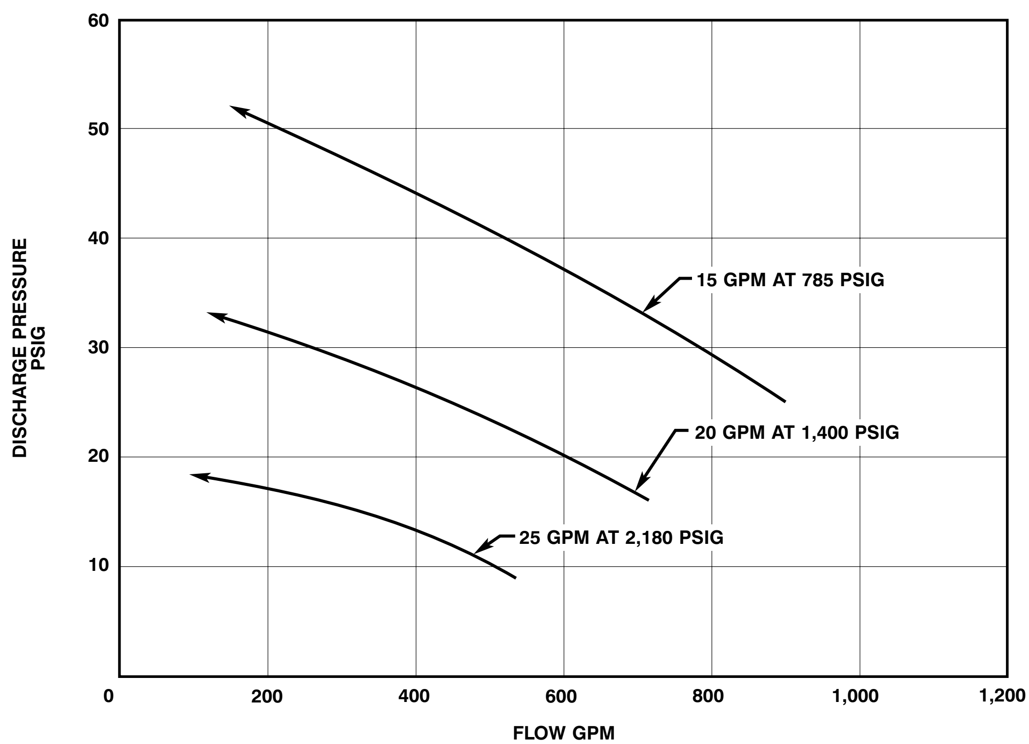


Figure G-9. 4-Inch Hydraulic Submersible Pump Performance Curves.

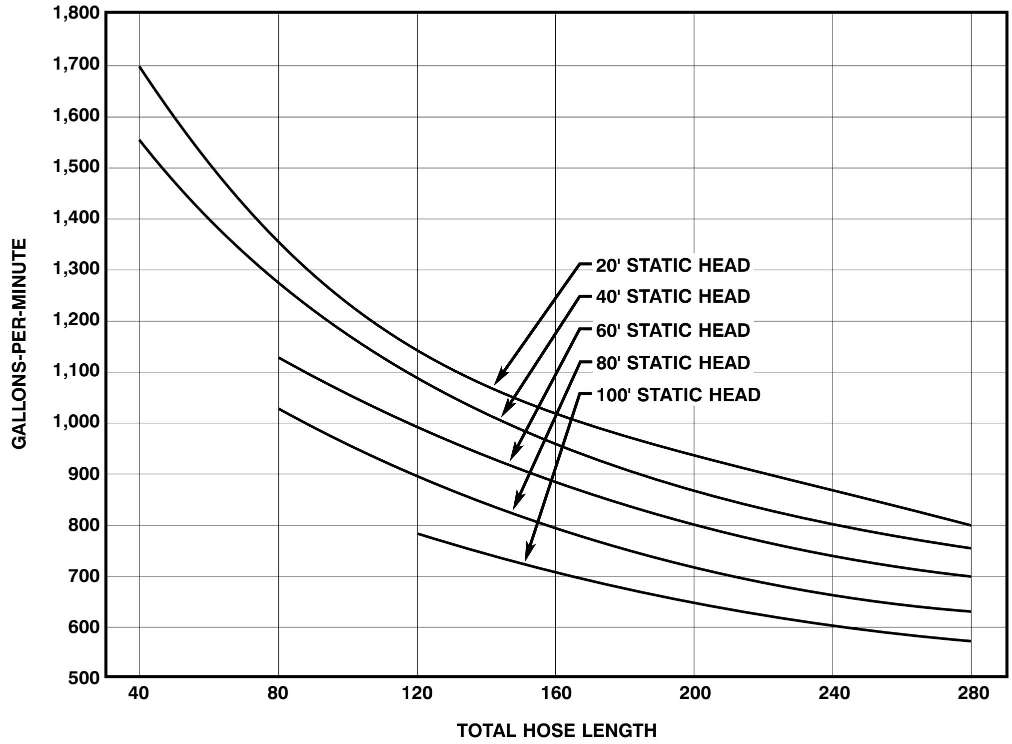


Figure G-10. CCN-150 Flow Rates - Water, 4" Hose.

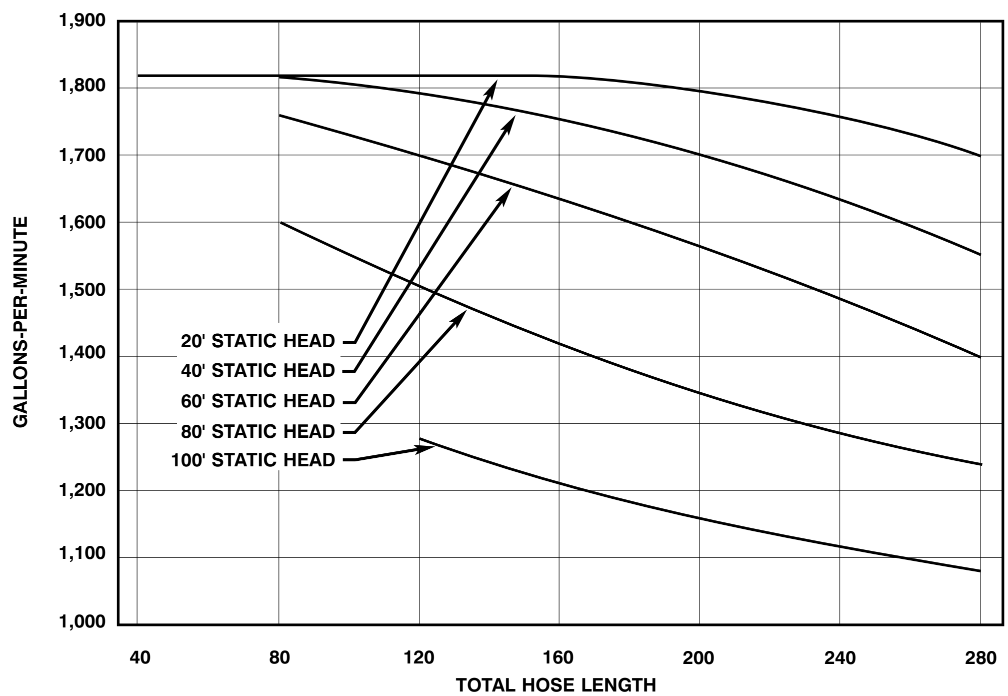


Figure G-11. CCN-150 Flow Rates - Water, 6" Hose.

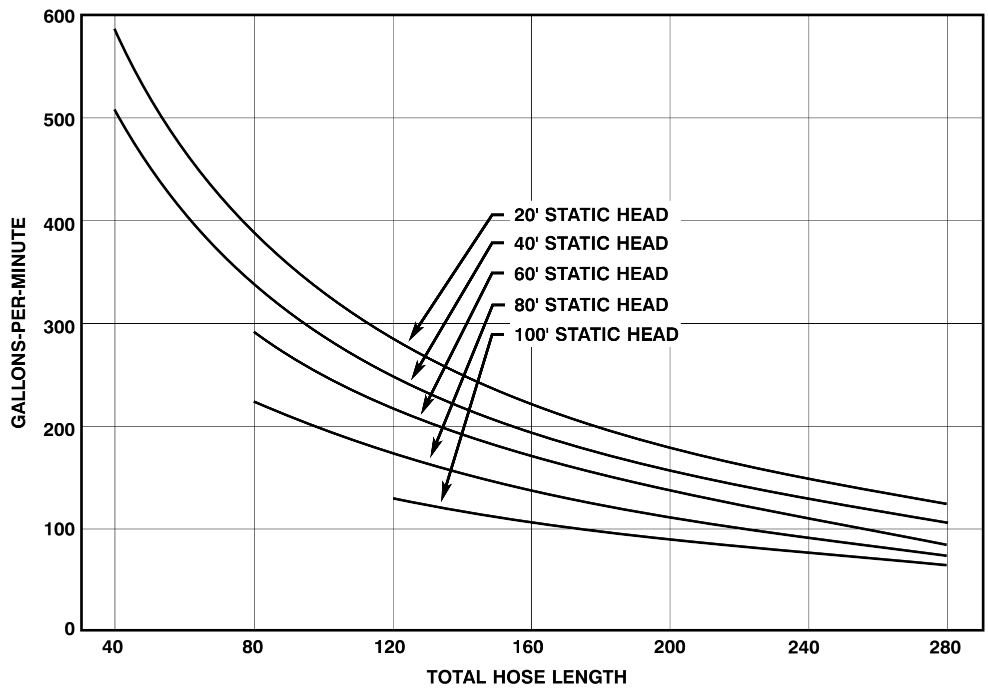


Figure G-12. CCN-150 Flow Rates - Warm #6 Fuel, 4" Hose.

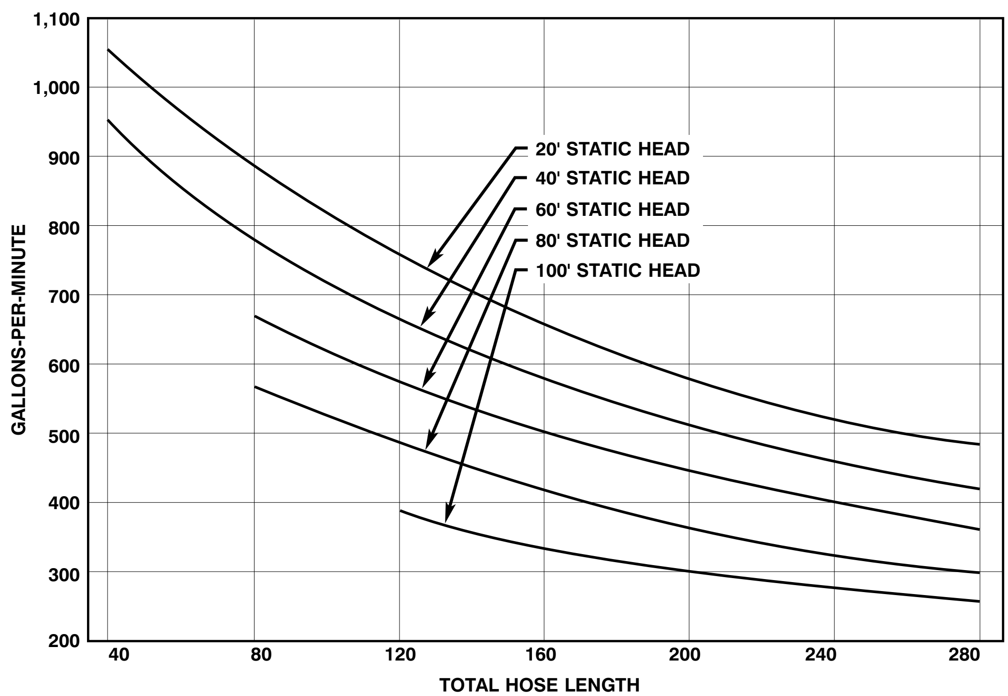


Figure G-13. CCN-150 Flow Rates - Warm #6 Fuel, 6" Hose.

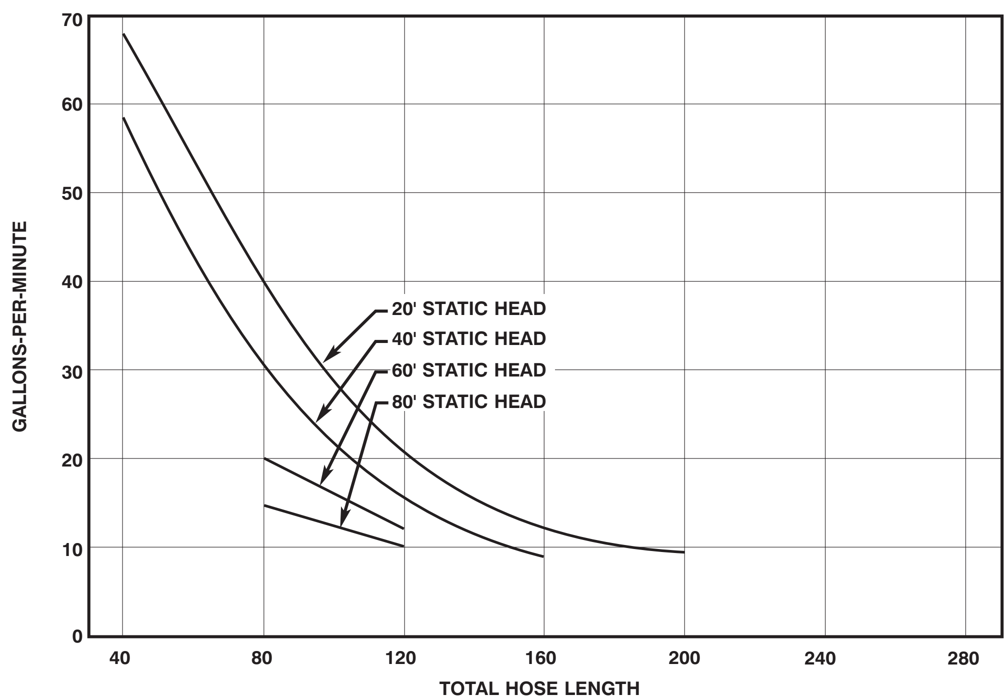


Figure G-14. CCN-150 Flow Rates - Cold #6 Fuel, 4" Hose.

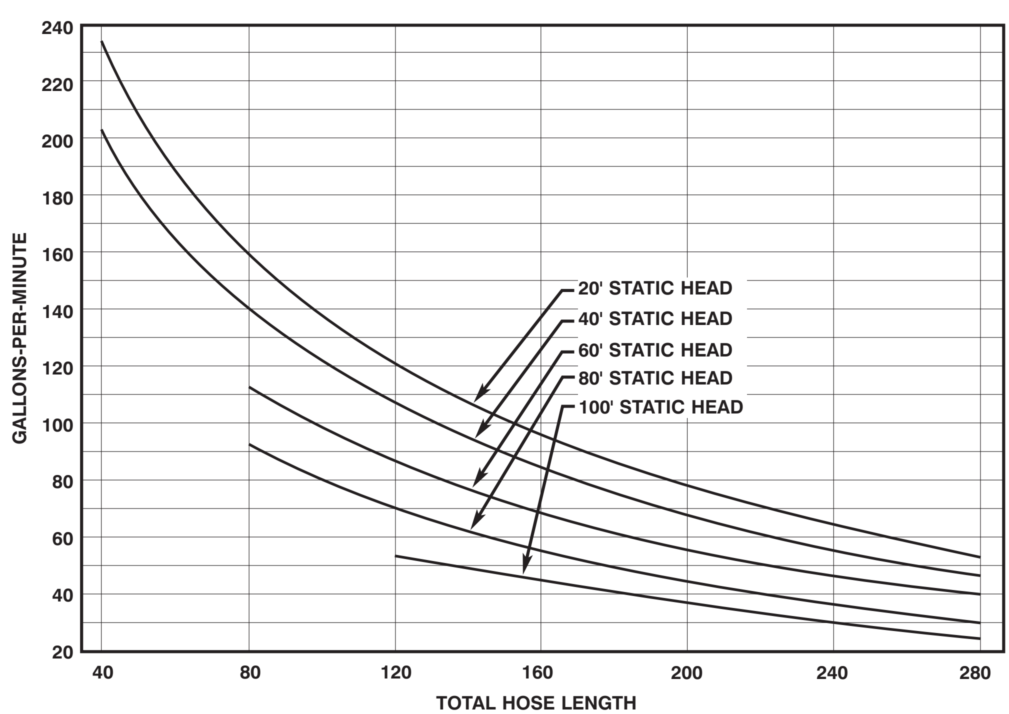


Figure G-15. CCN-150 Flow Rates - Cold #6 Fuel, 6" Hose.

APPENDIX H
BOLLARD PULL CURVES

H-1 BOLLARD PULL CURVES.

Bollard pull is plotted as a function of shaft RPM (and propeller pitch for CPP ships) for ARS-38, ARS-50, and T-ATF-166 Class ships in the following figures. Curves for other ship types will be provided as bollard pull tests are performed.

NOTE

These performance curves are not typical of all T-ATF-166 Class tugs. Some ships of this class are fitted with Kort nozzles

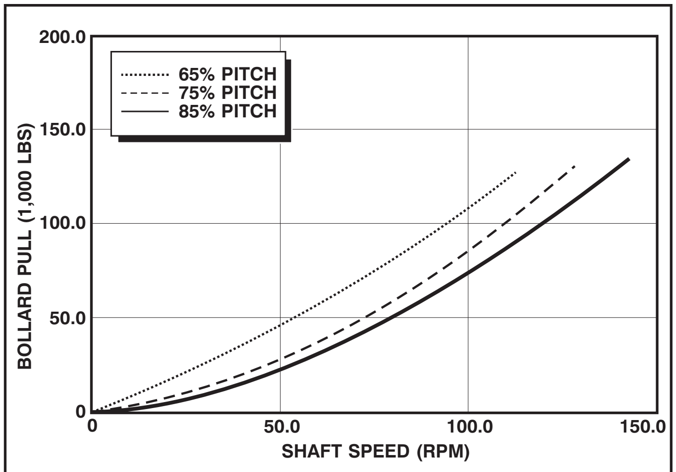


Figure H-1. Variation of Bollard Pull with Shaft Speed and Propeller Pitch for ARS-50 Class Ships.

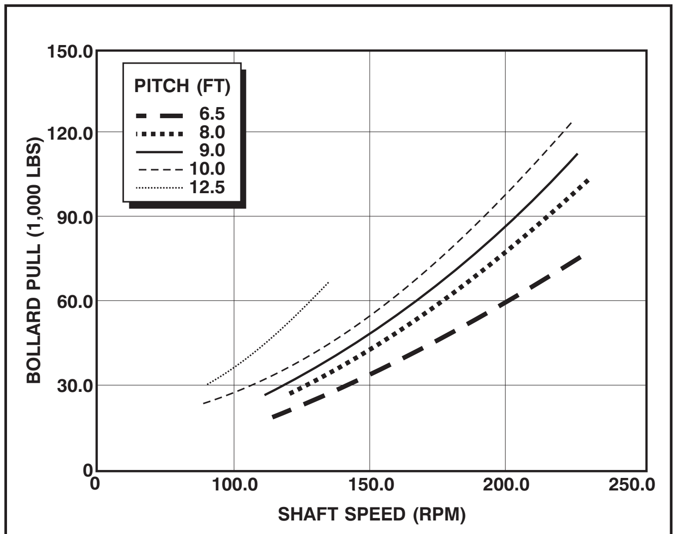


Figure H-2. Bollard Pull vs. Shaft Speed and Propeller Pitch for T-ATF-166 Class Ship Without Kort Nozzle.

APPENDIX I
OPERATION OF EQUIPMENT IN EXTREME COLD

I-1 INTRODUCTION.

Salvage operations in extreme cold weather environments require special preparation of salvage machinery. Very low temperatures cause difficulties in operating and maintaining diesel engines, pumps, compressors, winches, and other salvage gear. Some effects of low temperatures on salvage machinery are:

- High cranking resistance due to increased viscosity of lubricating and hydraulic oils
- Icing of fuel because of condensation
- Insufficient atomization of fuel
- Failure of equipment to reach recommended operating temperature
- Poor battery performance
- Freezing of pump discharge lines
- Icing of compressor discharges
- Brittleness of steel casings and components.

Machinery can be winterized to operate in temperatures as low as -65 °F. Table I-1 gives recommended operational limits for ESSM salvage equipment.

Table I-1. Recommended Operational Limits of ESSM Equipment.

Equipment	Nominal Operational Limit	Operational Limit with Winterizing
8-Ton Diesel Winch	-10 °F	-60 °F
3-Inch Diesel Pump	-10 °F	-60 °F
6-Inch Diesel Pump	-10 °F	-60 °F
10-Inch Diesel Pump	-10 °F	-60 °F
4-Inch Electric Submersible Pump	-10 °F	-60 °F
4-CFM HP Gasoline Air Compressor	-10 °F	N/A
125-CFM HP Diesel Air Compressor	-10 °F	-60 °F
5-KW Diesel Generator	-10 °F	-60 °F
30-KW Diesel Generator	-10 °F	-60 °F
5-KW Diesel Light Tower	-10 °F	-60 °F
400-Amp Diesel Welder	-10 °F	-60 °F
Beach Gear	0 °F	-60 °F
Inflatable 8.4-ton Pontoon	32 °F	-60 °F
Polyurethane Foam	32 °F	32 °F

WARNING

Flesh freezes to cold metal almost instantly. Grab handles, handrails, door handles, tools, etc. must be covered. Some dip- and cook-type plastics work well. Gloves must be worn when handling all metal so access openings to machinery controls should be extra large.

I-2 DIESEL ENGINES.

Onan DJM 60 series engines and Detroit Diesel 2-53, 3-53, and 8V71 series engines power most salvage machinery. Diesel engine starting becomes difficult as the ambient air temperature drops below 40 °F. Internal combustion engines are started by motoring from some external source of power until conditions have been established to allow the engine to run under its own power. Cranking power requirements are higher for diesel engines because of increased compression pressures and cranking speeds. Gasoline engines normally require speeds from 50 to 150 rpm, while diesel engines require speeds from 100 to 200 rpm.

Insufficient cranking speeds result in inadequate compression pressures and temperatures. At low temperatures, the compression temperature in diesel engines is reduced because of the lower compression pressures resulting from increased blow by caused by larger clearance and lower cranking speed. Cranking time must be limited as much as possible. When no firing occurs, the excess fuel washes the lubricating oil out of the cylinders, increasing wear of the cylinder walls. Dilution of the lubricant also has an adverse effect on the other moving parts of the engine. The battery cannot recover well. The starter can overheat causing damage to the windings.

It is desirable to start diesel engines as near idle speed as possible to prevent washing of the cylinder walls. If necessary, diesel engines can be started with the throttle at or near the full open position to ensure an adequate supply of fuel. The fuel is generally well-atomized by the injector nozzle, but when it is introduced into a cold cylinder wall, condensation occurs. The prevention of condensation or re-evaporation of the fuel is primarily an ignition problem. In some engines, this condensing action is employed to control burning rates.

Ignition of the charge is the major problem encountered with diesel engines in low-temperature starting. Ignition depends upon raising the temperature of the fuel vapor to its self-ignition point, approximately 750 °F, during the compression stroke

I-2.1 Diesel Engine Winterization. Winterization overcomes the inability of engines to start and operate under extremely cold conditions. The degree of winterization depends on the capability of the engine and the ambient operating temperature. The basic objective is to provide a reasonable starting environment followed by a dependable warm up of the engine and equipment. The winterization unit installation must maintain satisfactory operating temperatures with a minimum increase in maintenance of equipment and accessories.

Basic winterization of an engine or components for starting and operation in the lowest temperatures to be encountered requires:

Basic winterization of an engine or components for starting and operation in the lowest temperatures to be encountered requires:

- Correct accessories
- Proper lubrication
- Protection from low-temperature air blast (the metal temperature does not change but the rate of heat dissipation is affected)

- Fuel of proper grade for lowest temperatures
- Heating to increase engine coolant temperature to a minimum of 80 °F for starting in lower temperatures
- Low-temperature lubricating oil
- Cranking motor equipment capable of operating in the lowest expected temperature.

Satisfactory performance calls for modification to the engine, surrounding equipment, operating practices, and maintenance procedures. Low engine startup and operating temperatures cause formation of excessive carbon, varnish, and other deposits resulting in higher maintenance costs, increased engine wear, and poor performance. The colder the temperature, the greater the amount of required accessory modifications. Modifications must still permit operation in warmer climates. Accessory design should provide for simple disconnection when not required without affecting normal engine operation.

WARNING

The operation of fuel combustion space heaters in confined areas can create dangerous levels of carbon monoxide for attending personnel. Provide adequate ventilation.

I-2.1.1 Engine Heaters. Heat must be introduced to maintain proper viscosity for adequate oil flow for a non-operating engine. Electronic or fuel-fired coolant heaters are an excellent starting aid. Warm coolant creates a more satisfactory starting condition by reducing cylinder-to-piston friction where most cold weather cranking resistance occurs. More complete combustion occurs when the combustion chamber is warmed. External-type coolant heaters are available commercially. Forced draft, electronically ignited, diesel fuel or gasoline burning heaters of the capacity required can be operated from 24-volt storage batteries. One type is the Herman Nelson model manufactured by the American Air Filter Company, Louisville, Kentucky. These heaters range in size from 75,000 to 450,000 BTU.

Engine heaters can be either the coolant-circulation (thermo-syphon or pump) or hot air type. They are provided with an automatic shut-off feature in the event of lack of fuel or flame extinguishment during operation, and equipped with a metering device to ensure that rate of fuel flow to the burner is constant within acceptable tolerances. Combustion air is normally furnished by a DC, low-ampere, electric-motor-driven blower. Coolant heaters generally have a high heat output (to the coolant) rating of 12,000 to 16,000 BTU/hour and are available in 30,000 to 60,000 BTU/hour sizes. Hot air heaters are effective down to 0 °F when used alone, and down to -10 °F when a temporary enclosure is installed. Below -10 °F, an engine coolant heater, MIL-H-171538 (SHIPS) or equivalent, is required.

A pulsating heater that operates on the detonation principle requires electrical power only for starting the unit. The heater provides heated air to the engine coolant through appropriate heat exchangers. The heated air is either ducted toward the engine and blown directly on it, or circulated through a coolant jacket, which in turn heats the coolant of the engine. Air-cooled engines utilize these types of hot air heaters.

I-2.1.2 Engine Front Covers. A winter front cover alone or used with radiator shutters is necessary to seal the engine compartment and radiator at 0 °F or lower temperatures. Winter front covers are available at most automotive supply houses or can be custom made to fit the application. Oil pan covers, made of metal or from a waterproof, insulated heavy canvas blanket, may be suspended under the engine. These parts should be fabricated and custom-fit.

I-2.1.3 Enclosures. Wooden or fiberglass boxes are frequently used as temporary enclosures in cold weather operations. The engine exhaust discharged into the box keeps the engine operating temperature at the proper level. Care must be taken to prevent the entry of fine snow during shutdown periods. These enclosures can be completely filled by snow of talcum powder consistency entering through a BB-sized hole. Subsequent thawing and refreezing of the snow encases the engine solidly in ice.

I-2.1.4 Lube Oil Heaters. Lube oil heating can be accomplished with immersion-type electrically powered heaters. If the element is in contact with the oil, the maximum temperature of the elements must be held under 300 °F to prevent formation of hard carbon. If the temperature cannot be controlled, the element should be shielded.

I-2.1.5 Engine Cooling Systems. Temperature-modulated fan controls are desirable. All cooling systems should have a solution of permanent anti-rust, ethylene glycol-base antifreeze and water. Maximum protection at down to -75 °F can be obtained with a mixture of 63 percent antifreeze and 37 percent distilled water (clean potable water is acceptable). A 100 percent solution of antifreeze will freeze at -8 °F. Antifreeze solutions should be run through machinery before shipment to cold weather environments to ensure complete mixing of the antifreeze solution. The use of silicone hoses for radiators avoids premature cracking. Radiators should be equipped with thermostatically controlled shutters of the snap-action type, that can be either open or closed, to maintain an engine coolant temperature of about 160 °F. Slow moving shutters seem to freeze in position more easily. Shutter stops should be set 10 °F above the engine thermostat opening temperature.

Engine shrouds consist of canvas and metal grill covers, radiator covers, and engine compartment blankets designed to reduce the heat losses during preheat, warm up, standby, or shutdown, and to prevent entry of ice and snow.

I-2.1.6 Intake Air Preheaters. Some diesel and multi-fuel engines provide a means to heat the intake air and provide burning particles of fuel to the cylinders during cold weather starting. The system, commonly known as the air box heater or manifold heater, consists of an air-aspirated, nozzle-type unit with a spark plug for igniting the fuel/air mixture. An air pump delivers compressed air through the nozzle, aspirating and spraying fuel into the air box. The fuel vapor is ignited by the spark plug and burns, heating the air in the air box before entering the combustion chamber. Fuel flow is generally controlled by a solenoid valve. The heater can also be of the type that meters only the fuel and uses combustion air from the manifold. These heaters are sometimes less effective because of oxygen starvation in the heated mixture inducted into the cylinders. The intake air heater is designed for use below 32 °F and is sometimes provided as part of the standard engine.

I-2.1.7 Fuel System Heaters. Heat provided to fuel filters facilitates fuel flow. The heat prevents icing in the filter and helps alleviate waxing which might occur with diesel fuels. Waxing problems are reduced until temperatures of -55 °F and below are reached when using arctic-grade diesel fuel (DF-A). The amount of heat supplied to the fuel is relatively low, so that little actual temperature rise occurs across the filters when fuel is flowing.

I-2.1.8 Electrical Systems. A properly functioning electrical system is essential to engine operation at low temperatures. This is the most severe service condition for the electrical system. Special attention must be given to the components if they are to perform their function properly and to ensure that the system is in good condition at all times. Wire covering must be flexible at -65 °F. Normal plastic covering cracks and causes shocks. Connectors must be waterproof and dried with alcohol or sprayed with electrical contact cleaning solution at time of installation. Wire bundles must be securely tied to prevent tearing loose during ice buildup. Circuit breakers eliminate the need to carry and store fuses.

Engines used at -40 °F and below should be equipped with specially engineered cold weather wiring. This equipment can be obtained from diesel dealers or several large wire and cable companies who provide wires meeting military specifications or comparable commercial standards. Starting cables should conform to Spec MIL-C-13486B Type l Class A. All other wiring should conform to MIL-W-81044. Wire fabricated to these specifications provides protection to -65 °F.

MIL-C-13486B wire is fabricated with a conductor of sufficient gage to carry the anticipated electrical load. The conductor is insulated with a rubber material covered with a cloth braid and then encased in a jacket of neoprene or polychloroprene to resist cracking and withstand the high temperatures encountered inside engine covers. The SAE cable type is HTS.

MIL-W-81044 wire consists of a nickel-coated copper conductor with a cross-link polyalkene, alkene imide, or polyarylene insulation. These insulation compounds are capable of withstanding operating temperatures between 300 °F and 500 °F while remaining flexible down to -60 °F. The SAE cable type is HTE.

NOTE

The construction of HTS- and HTE-type cables is very expensive and normally will not be immediately available from local vendors. Spare wire should be taken to remote sites to preclude unnecessary delays while waiting for replacement material required for maintenance.

CAUTION

Provide adequate ventilation when charging batteries. Hydrogen gas generated during charging is extremely explosive in small concentrations.

Battery performance is reduced at low temperatures. Increased viscosity of the electrolyte slows diffusion of the electrolyte through the plate material. This increased resistance in the battery reduces voltage and available energy. The discharge time of the high-rate current is severely reduced with low temperatures. At 15 °F, a fully charged lead-acid battery will put out only 50 percent of normal capacity; at -30 °F, only 10 percent; and at -40 °F, the output is zero. A discharged battery will freeze at 19 °F. The freezing point varies with charge. Electrolyte below 35 °F will reject a charge. It must be warmed to recharge.

If the battery is not completely run down after one high-rate discharge, it will recuperate after a rest. The recuperative power is present, to a degree, in all batteries. In wet-cell batteries, this recuperation results from diffusion of fresh electrolyte into pores of the plates. It is most pronounced under high-discharge conditions, such as during cranking.

Two types of batteries are standard for engine starting. They are lead-acid and nickel-cadmium cells. The low-temperature power output and ability to accept charge of the nickel-cadmium battery are superior to lead-acid battery. The other advantages of nickel-cadmium batteries are:

- Holds a charge longer when idle
- Does not corrode
- Has a longer life
- Accepts a charge at temperatures as low as -40 °F
- Freezing point remains constant at -90 °F (since specific gravity is not reduced with battery discharge).

The high cost of the nickel-cadmium batteries restrict their general use. The two standard sizes of 12-volt lead-acid batteries are 2HN (45 ampere hour) and 6TN (100 ampere hour). Two batteries are connected in series for 24-volt systems.

A battery's state-of-charge is normally determined by measuring the specific gravity with a hydrometer. Since the specific gravity is affected by temperature, a correction must be applied. A value of .004 must be subtracted from the reading for each 10 °F below 80 °F. Battery condition and state-of-charge should be determined by a combination of observed specific gravity, no-load voltage, and initial cranking voltage.

Freezing of the battery electrolyte can damage the plates and battery case through expansion. The freezing temperature of the electrolyte is a function of the battery's state-of-charge and will occur at higher temperatures as the battery is discharged.

CAUTION

Electrolyte used in batteries is extremely caustic. Wear appropriate clothing and eye protection when servicing batteries.

Batteries should be maintained at or near the fully charged condition. Cold weather experience has shown that only battery acid, not water, should be added when restoring the electrolyte level.

The rates of charge acceptance and efficiency of charging are affected by temperature. Both charge acceptance and efficiency of charge decrease as temperatures decline. The battery must be warmed to a temperature of approximately 35 °F to 40 °F for effective recharging.

A battery heater should be part of an arctic adaptation kit to warm the battery to a temperature at which it will accept a charge (40 °F). For best operation, it should maintain the temperature at 80 °F, and avoid overheating (maximum case temperature of 150 °F). The design of the heater also reduces heat loss during cold soaks. The heaters can be either the coolant type or hot air. The coolant types generally use the engine coolant and circulate it through a plate on which the battery rests with the heat being transferred from the coolant through the plate to the battery during preheat and standby conditions. During equipment operation, the heater is not operated, but the heated coolant from the engine is allowed to circulate through the battery plate. In an alternate method, heated air is directed to the battery from the heater. The battery is normally enclosed in an insulated box with either method. Regardless of the heat source, the battery should be heated slowly, raising the temperature from 0 - 60 °F in one hour. An effective means of heating the battery is to conduct the heat through the battery posts by use of heated air impinging on finned cable connectors.

NOTE

When not in use for extended periods of time, batteries should be disconnected and stored fully charged.

While the starter is not normally affected by low temperatures, its performance is directly affected by the characteristics of the battery and engine cranking characteristics, both of which are adversely affected by temperature. As extreme cold weather is a severe condition of use of the starter, its adequacy deserves particular attention in arctic use.

The cranking speed decreases with a decrease in temperature as a result of two factors. As temperature decreases, the engine cranking torque increases. This increase in torque is primarily caused by increased viscosity of the lubricants. The battery voltage is reduced at lower temperatures, further lowering the speed.

Frequent exceptions are noted that are thought to be due to the warming of the engine's friction surfaces and oil film as a result of cranking, and the heating of the battery plates due to rapid discharge.

The consequence of reduced cranking speed and voltage is an increase in cranking current. A practical limit is placed on the sustained cranking current by the available battery power. A limitation may be met in the horsepower rating of the starter design, which is a function primarily of the internal resistance of the starter.

Starters should be connected to the battery through a series-parallel solenoid for 24-volt start, 12-volt run, wherever possible. Equipment should be outfitted with battery jumper cables on an external starting receptacle to receive auxiliary power.

Hydraulic starters are common on larger pieces of salvage machinery. The hydraulic system can be recharged by means of an installed hand pump between starting attempts. Once operating, the system is charged by a gear-driven pump located on the engine. The recommended starting pressure at different temperatures is listed in Table I-2.

Table I-2. Recommended Hydraulic Starting System Pressures.

Temperature	Pressure
Above 40 ºF	1,500 psi
0 ºF to 40 ºF	2,500 psi
Below 0 ºF	3,300 psi

I-2.1.9 Starting Aids. Starting aids are recommended for low temperatures. One method of bringing the air-fuel mixture up to the auto-ignition temperature for starting is to preheat the combustion chamber.

Diesels can be preheated by a resistance-type glow plug installed in each pre-combustion chamber. Glow plugs are high-resistance wires encased in tightly sealed metal tubes filled with magnesium oxide—a good electrical insulator and a fairly good heat conductor. A full-voltage plug draws 5 amps from a 24-volt supply. When the current is applied, the plug tip reaches a temperature of 1,600 °F to l,800 °F in approximately 30 seconds. This warms the entire pre-combustion chamber and decreases the time needed to start the engine in cold weather. When the ambient air is less than 60 °F, glow plugs are recommended for all starting systems.

Glow plugs are available for operation on 12-volt, 24-volt, and 30-35-volt systems. They can also be used with either 120-volt or 240-volt electrical systems with an appropriate transformer. Occasionally, standby installations have continuously energized glow plugs for reliable quick starting. After the engine starts, the glow plugs are automatically disconnected until the engine is shut down again.

CAUTION

Ether, as a starting aid for internal combustion engines, is toxic and highly combustible. Avoid use in enclosed spaces and in the vicinity of open flames.

Ether facilitates starting because it is a highly volatile fluid with a low-ignition point. When ether is introduced into the diesel air-fuel mixture, compression ignition will occur at a lower temperature. The recommended ether aid for diesel engines includes a high pressure (250 psi) metallic capsule, which when placed in an injection device and pierced, allows ether to enter the air intake manifold. The high-pressure capsule has proven to be a safe and positive system for ether injection. The metallic capsule has a bursting point that exceeds 6,000 psi and 600 °F, and requires no special precaution for handling, shipping, and storage. The pressurized tank-type ether system can be used instead of the capsule type. Care should be exercised by the operator to ensure the proper quantity of ether is injected.

A jacket water heater pre-conditions the engine for quick starting by maintaining jacket water temperature at a high level during periods of shut down. The heater operates on the principal of natural circulation due to the density differential between hot and cold water. Cold water from the engine jacket water system enters at the bottom of the heater, rises as it is heated, and flows into the top of the engine. Water temperature in the heater is controlled by an adjustable thermostat. The proper heater for a particular installation should maintain water temperature near 90 °F. Heaters are available in 1- to 9-kw sizes. Voltage of 120, 240, or 480, three-phase versions are available. Installation of jacket water heaters is relatively simple, since openings can be provided on the engine block and cylinder head for hose connections.

I-2.2 Fuel. Arctic diesel fuel should be used with a minimum cetane number of 40 and slush point of -70 °F. All other diesel fuels must be drained from tanks, filters, and lines before shipment to the arctic. Water-absorbing substances, such as isopropyl alcohol, should be added to tanks on every fill. Fuel hoses must have -65 °F flexibility. Fuel tanks should not be insulated with urethane foam, as it soaks up fuel and chips off easily. Engine coolants piped through tanks have worked well in Federally approved systems. Hoses should be insulated with closed-cell foam rubber tubing. Regular grade gasoline can be used but also requires addition of water-absorption chemicals at every fill because of condensation inside tanks.

The best diesel fuels for low-temperature operation are kerosene-type distillates of 550 °F to 600 °F distillation-end-point temperature. Fuel with a low sulfur content, (less than 0.5 percent), is necessary to minimize fire ring face wear. Distillate fuels meeting the military specifications contained in Table I-3 provide desired low-temperature properties in extreme cold (to -60 °F).

Most North American manufacturers of automotive diesel engines recommend the use of ASTM-D-975, Grade No. 2-D fuel at ambient temperatures above 20 °F. At very low temperatures, they recommend No. 1-D fuel, if available, or winterized or climatized No. 2-D fuel. Winterized or climatized fuels are made by diluting No. 2-D fuel with either No. 1-D fuel or kerosene to lower the cloud and pour points as required for the ambient operating temperature.

No 1-D fuel can be blended by the manufacturer to achieve a cloud point—the point at which paraffin crystals "cloud" the fuel and are too large to pass through a filter—as low as -72 °F upon request. When ordering fuel, the supplier should be informed of the region, ambient temperature anticipated, and the cloud point required for the temperature conditions.

These fuels are lighter than No. 2 grades. Even though not required by all specifications, the minimum cetane number should be 40, and the minimum cloud point, -70 °F. Incomplete fuel combustion is indicated by appearance of white, gray, or bluish exhaust smoke.

Table I-3. Diesel Fuels Suitable for Extreme Cold Weather.

Specification Number	Grade
VV-F-800D	DF-A
MIL-T-5624	JP-5
ASTM-D-1655	Jet A-1

White or gray smoke is a sign of misfiring cylinders and may be counteracted on the fuel side by an increase in cetane. Blue smoke is indicative of insufficient fuel vaporization and can be corrected by an increase of fuel volatility or by increasing the cylinder combustion temperature.

WARNING

Static electricity can form in the layers of clothing worn by personnel and in liquids being transported. Extreme caution must be exercised when refueling vehicles, stoves, lanterns, etc., because the spontaneous discharge of static electricity may ignite these inflammable fuels. Static electricity should be drained off by grounding vehicles or fuel containers prior to starting refueling operations. Personnel should ground themselves by touching a vehicle or container away from the vapor openings with the hand.

Fuel containers should be sealed tightly to prevent snow and ice moisture from entering. Diesel fuel should be strained to remove paraffin (2 to 2½ pounds per 55-gallon drum), using a chamois or felt. Funnels should have a copper screen to help filter out ice particles and foreign debris.

Condensation of moisture inside fuel tanks can be minimized by keeping the tank topped off. Adding ½ pint of denatured alcohol to each ten gallons of fuel at the time of filling will also improve performance.

I-2.3 Lubricating Oil. Recommended lubrications for use at low starting temperatures are given in Table I-4.

Table I-4. Recommended Lubricating Oils for Cold Weather.

Temperature Range	Lubricating Oil
+10 °F to -10 °F	MIL-L-2104E (SAE 10W)
	Series 3 SAE 10W
-10 °F to -65 °F	Series 3 SAE 10W
	SAE 5W/30,
	SAE 5W/20,
	MIL-L-46167 (SAE 0W/20)

NOTE

MIL-L-46167 should be used only as a last resort when cranking is a severe problem and auxiliary heating aids are not available.

The recommendation for the -10 °F to -65 °F temperature range covers prevailing operating temperatures, and in many instances, arctic applications. Where the upper portion of the range is encountered for only a few days in a season or only during early morning startup time, it may be more practical to consider use of those lubricants normally recommended for the +10 °F to -10 °F range. Maximum pour point for the MIL-L-2104E-type oils must be -40 °F. MIL-L-2104E, SAE 30 lube oil is recommended for year-round use for longer engine service life when it is possible to supply heat to the engine during both cranking and running under low-temperature conditions.

The engine oil change period should be reduced to one-half the normal change period if MIL-L-2104E-type oils are used. If the sulfur content exceeds 0.4 percent, the engine oil change period should be reduced to one-fourth the normal period. A complete change of engine or gear oil should be made instead of mixing various grades. Detroit Diesel recommends lubricating oils with an API service rating of CD or CD-II to provide sufficient additives for prevention of excess deposits that are harmful to the engine.

I-2.4 Miscellaneous Lubricants. Lubrication of gear cases and bearings for operation in extreme cold weather must be accomplished prior to shipment with suitable grease and oil. Ordinary lubricants thicken too much to be effective and create excessive drag on the equipment. The recommended gear oil for enclosed worm gears is SAE 90, MIL-L-2105D and SAE 30, MIL-L-2105D for enclosed gear drives. All bearings and bushings should be serviced with grease conforming to MIL-G-0010924E(ME), NATO code G-403. Table I-5 gives the recommended gear oil type for various temperature conditions. Lubricants for normal service should be removed when winterizing machinery, as they are not always completely compatible with the extreme cold weather lubricant grades.

Table I-5. Recommended Gear Oil Types at Various Temperatures.

Expected Temperature Range	MIL-2105D Classification	SAE Grade Equivalent	NATO Code
-70 °F to 50 °F	GO 75	SAE 75W	O-186
-20 °F to 120 °F	GO 80/90	SAE 80W/90	O-226
5 °F to 120 °F	GO 85/140	SAE 85W/140	O-228

Hydraulic oil should conform to MIL-O-5606. A suitable commercial substitute is CHEVRON SUB ZERO, SAE 5W 20 hydraulic oil.

Hydraulic transmissions use hydraulic transmission fluid, type C-1 for temperatures above -10 °F and automatic transmission fluid, type A, suffix A from -10 °F to -25 °F. In temperatures below -25 °F, either grade of transmission fluid can be used with auxiliary preheating to raise the temperature in pumps and external circuits to the appropriate temperature.

I-3 GASOLINE ENGINES.

The main problem in cold starting gasoline engines lies in vaporizing enough gasoline to form a combustible mixture. At a temperature of 65 °F, less than 5 percent of the fuel will be vaporized when it enters the cylinder. Since only that portion of the fuel which is in vapor form is effective in forming the air/fuel ratio for a combustible mixture, an excess of fuel must be supplied to compensate for the loss in volatility of the fuel at low temperatures. The fuel is atomized in the carburetor or at the injection nozzle in the form of fine droplets which presents a large total surface area for vapor formation. However, as these droplets pass through the manifold and over the piston surfaces, the fuel may condense into a liquid film with a small evaporation surface.

The two general methods of obtaining the desired air/fuel ratios in gasoline engines are (1) increasing the fuel quantity by use of chokes and primers and (2) heating the air, fuel, air/fuel mixture and manifold or cylinder walls. The ignition of the charge in the gasoline engine is not a serious problem, providing a combustible mixture is available and the spark plug is not fouled. The most frequent difficulty encountered in these engines is fouling of the plugs from condensed moisture or liquid fuel as a result of the excess fuel supplied. In both gasoline and diesel engines, excess fuel will dilute the lubricating oil in the engine cylinders, resulting in a lack of lubrication. A generally accepted quality of military engines is that they should be capable of being started after a maximum of one hour preheating after being cold-soaked to -25 °F or lower. Accordingly, a heating system is commonly required to maintain the engine and battery component temperatures at a standby level sufficient to permit the engine to be started on short notice after a maximum of 24 hours standby operation in ambient air temperatures of -25 °F and below.

I-3.1 Gasoline. Highly volatile, arctic, combat type-C gasoline, MIL-G-3056, with a Reid Vapor Pressure of 12 to 14 pounds at manufacture materially aids in starting gasoline engines to about -30 °F. Its volatile fractions make it difficult to keep at high temperatures, and it should be carefully stored and sealed. It is similar in composition to winter grade gasolines sold in the colder parts of the United States during the winter months. Storing gasoline for long periods before use results in gums settling out and the more volatile components evaporating. All gasoline should be filtered through felt. Felt will soak up water which will freeze in the material and can be shaken out so the filter can be reused. If felt is not available, a chamois can be used.

I-4 PUMPS.

Pumps can be successfully operated in temperatures down to -60 °F, providing the pumps are contained within the heated engine enclosure and heat is supplied to joints, elbows, and suction inlets. Genline hose, while stiff before water flow begins, retains its strength to -60 °F. It is important to keep water flowing through the hose and to drain lines and casing when pumping is finished.

I-5 AIR COMPRESSORS.

With the exception of the gasoline-driven air compressor, which has a limit of 0 °F, ESSM air compressors can be successfully operated down to -60 °F by the addition of alcohol injectors in the compression chamber.

I-6 WELDING MACHINES.

Welding machines can be successfully operated down to -60 °F without special winterization of the welding machine itself.

I-7 DIESEL GENERATORS.

Operation of ESSM generators down to -60 °F is feasible without modification of the generator itself.

I-8 BEACH GEAR.

Beach gear wire exhibits satisfactory strength down to -60 °F. Beach gear chain is satisfactory when immersed and allowed to come to the ambient water temperature. Shackles and other metal components must be constructed of alloy steel since carbon steel is brittle at about -20 °F. Wire rope is derated by 20 percent below 20 degrees F (-20 degrees C) because of its stiffness Special considerations should be made when using carbon steel shackles and fittings below -20 degrees F (-29 degrees C) as they can become brittle as well. Rubber equipment should be raised to a minimum temperature of 32 degrees F (0 degrees C) due to the tendency towards cracking at low temperatures. Keeping rubber equipment in below freezing temperature environments is not recommended due to the potential a reduced life-span.

I-9 INFLATABLE 8.4-TON PONTOONS.

Because of a loss of flexibility, inflatable 8.4-ton pontoons are not satisfactory unless warmed to 32 °F prior to inflation.

I-10 CRANES.

A reduction of 20 percent in lifting capacity of cranes has been encountered in extreme cold weather operations because of brittleness in the boom and stiffness of the wire rope. This reduction occurs as the temperature drops from 20 °F to -20 °F and does not change as the temperature decreases to -60 °F.

APPENDIX J
UNDERWATER TOOLS

J-1 INTRODUCTION.

Development of equipment for ship husbandry, offshore exploration, and underwater construction has produced a broad range of underwater power tools suitable for salvage operations. Power tools, when properly employed, enable underwater work to be performed more quickly and efficiently than similar tasks performed with simple hand tools alone. Table J-2 contains the underwater tools and photographic equipment that are authorized for Navy use in accordance with NAVSEAINST 10560.2 (series)

J-1.1 Hand Tools. Nearly every simple hand tool can be used satisfactorily underwater. Tasks that are simple on the surface, such as sawing, drilling, nailing, and tightening of bolts, are more difficult underwater because of the increased resistance to motion caused by the water and the apparent weightlessness of the diver. These adverse effects can be partially overcome by selection of appropriate diving equipment and tools. The diving equipment should meet the diver's stability and mobility requirements for the task. Tools should be compact. Hammers must be heavier to overcome the water resistance and must have relatively short handles to give the diver better control. Saws should be as short as possible. The blade should cut with either a pushing or pulling force to accommodate diver preference. All cutting tools must be sharp. Dull tools slip away from the work, creating a hazard, causing delay, and increasing the difficulty of the task. Taps and dies can be used underwater; the surrounding water acts as the lubricant. The technique for chip removal is similar to topside operations.

J-1.2 Pneumatic Tools. Most pneumatic tools designed for shipboard and industrial application can achieve satisfactory results underwater. Pneumatic tools exposed to saltwater should be soaked in diesel fuel or another light oil before being placed into service to protect the internal parts from contamination. Tools should be thoroughly washed with warm, soapy fresh water and placed back into an oil bath immediately after return to the surface or completion of the work.

An air supply, sufficient to overcome bottom pressure, must be provided. The supply hose must be able to withstand the increased pressure and provide adequate volume to operate the tool. The tool whip should be short (8 to 12 feet) and have a greater inside diameter to reduce line loss at the tool. Pneumatic tools exhaust directly into the surrounding atmosphere. Exhaust bubbles may reduce visibility by stirring up bottom sediments or marine growth in the vicinity of the tool. Pneumatic hammers require a non-collapsible exhaust line to be fed back to the surface in order to perform at their maximum capacity.

J-1.3 Hydraulic Tools.

WARNING

Some hydraulic tools require special operator training before they may be operated safely. Failure to follow recommended operating procedures contained in the technical manual for the specified tool can result in severe injury or death.

CAUTION

Hydraulically actuated tools shall be equipped with a Dead Man Switch to protect the diver in event of loss of control of the tool.

A comprehensive hydraulic tool package has been developed for underwater use. All of these tools can assist the salvor in making temporary repairs and clearing debris at the salvage site. The major advantage of hydraulic tools over pneumatic tools is durability. Since the tool has a closed system, corrosive seawater cannot enter the internals of the tool, reducing wear and maintenance time. Although the hydraulic supply and return hoses are neutrally buoyant in water, the size of the umbilical creates additional drag for the diver, requiring considerable effort on the divers' part when using SCUBA or lightweight diving gear. Some umbilical drag can be overcome by tying off the umbilical near the work site.

J-1.4 Explosive-propellant Tools.

WARNING

The explosive charge contained in the load is predetermined for the type and thickness of the material into which a fastening device is to be driven. Larger charges can cause the fastening device to pass completely through the material and injure unsuspecting personnel in the line of fire.

Explosive-propellant tools can save hours of drilling and tapping to install studs when attaching temporary patches, padeyes, and other devices to the underwater ship's hull. Their operation is simple and requires a minimum of maintenance.

J-1.5 Weight Handling Devices. Conventional chain falls and comealongs allow precise positioning of heavy objects underwater. The safe working load of these devices should be reduced to eighty percent of their rated load, as the clutches tend to slip when wet and loss of lubricant increases internal friction.

J-1.6 Underwater Video Equipment. Underwater video equipment can be hand-carried by the diver or affixed to the diver's helmet. It provides the salvage officer and salvage engineer with a detailed observation of internal spaces, underwater appendages, and damage without having to make an inspection dive. This advantage alone may be worth the cost of the equipment in time saved, particularly when diving to depths that may require lengthy decompression. Another significant advantage is that underwater video equipment provides the engineer with knowledge of the surrounding environment in which the diver is required to perform. This information can assist the engineer in selecting appropriate methods to solve the problem.

As a result of better technology in low-light photography and video equipment and computer enhancement, the engineer may actually "see" better than the diver operating the equipment. Stereoscopic video provides a panoramic view of the surrounding structure, and the area in question. It also allows the viewer three-dimensional analyses of surface conditions, since direct measurement of surface defects and such things as corrosion pitting can be determined. Still photography is an excellent supplement to video recording. The permanent video record is useful when briefing other members of the salvage team and for quality control of underwater work. Review of the video tapes will also assist in developing an accurate final salvage report by refreshing the salvage officer's memory of problems encountered and material expended. Video tapes may also provide invaluable training aids.

J-1.7 Air Lifts. Air lifts are used to remove mud and materials that may be pumped as slurry. Their use depends on the density differential between the air mixture in the tube and that at its mouth. This density differential causes an upward flow. Air lifts are relatively inefficient but are easily fabricated in the field. The general configuration of airlifts is shown in Figure J-1. Specific characteristics of air lifts are given in Table J-1.

When fabricating air lifts, the following points should be considered:

- A relatively fine mesh of holes allows the air and material being pumped to mix well and increases efficiency.
- Holes should be drilled at a 45° angle to the pipe axis with the high ends inside; holes drilled perpendicular to the pipe axis will reduce efficiency.
- For best operation, the discharge rate in gallons per minute should be between 12 and 15 times the pipe area in square inches.

J-1.7.1 Air Requirements. The volume of air required is a function of:

- Volume of water pumped
- Efficiency
- Pressure
- Submergence
- Lift.

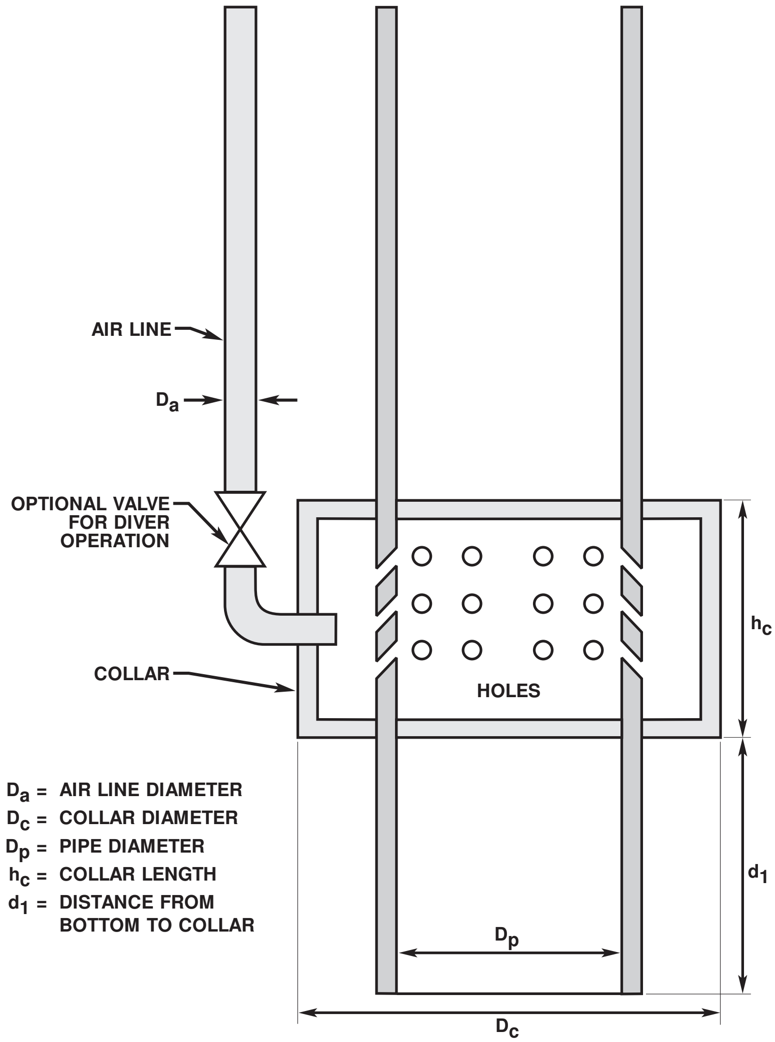


Figure J-1. Typical Air Lift Construction.

To ensure a steady flow, the compressor capacity should be twice the calculated air requirement. Pressure can be any over-bottom pressure.

Table J-1. Construction Dimensions for Fabricating Air Lifts.

D_p	D_c	D_a	h_c	d_1	Output	Rows	Num	Holes Dia	Dist on Center (in)	
(in)	(in)	(in)	(in)	(in)	(gpm) per Row		Holes	(in)	Vert	Hor
3	5	½	6	16	85-105	3	8	¼	1.00	1.17
4	6	¾	6	18	150-190	3	8	¼	1.00	1.57
6	8	1¼	7	20	335-400	3	16	⅜	1.00	1.17
						1	8	⅜	1.00	2.35
8	10	1½	9	23	600-725	6	16	⅜	1.00	1.57
10	12	2	10	25	900-1150	5	24	½	1.25	1.96
12	14	2	10	28	1350-1650	5	24	½	1.25	1.57
14	16	2	12	30	1800-2500	7	24	½	1.25	1.83

For a typical efficiency of 0.33:

$$V = \left(\frac{L}{B \times \log\left(1 + \frac{S}{B}\right)} \right)$$

where:

V	= air volume – ft^3 of free air per ft^3 of water
L	= total lift in feet
B	= absolute pressure in feet of water, at sea level, $B = D+33$
S	= depth of air entrance in feet, $S = D-d_1$
submergence ratio m	= D/L is optimum about 0.70

J-2 LUBRICANTS AND SEALANTS.

Lubricants and sealants are as essential in underwater work as they are in topside operations. Practically all of these compounds can be successfully used underwater by simply keeping the water exposure time to a minimum. Small fittings can have the compounds applied topside, placed in waterproof bags, and sent to the diver as needed. Where large quantities of these compounds are required to be applied underwater, vented containers and applicators can be lowered to the diver as needed.

J-2.1 Lubricants. Threaded fittings require lubrication to reduce corrosion and make nuts or bolts easier to install. White lead compounds are highly efficient in the underwater environment as lubricants, but the toxic effect on marine life prohibits use of large quantities of this substance. Petroleum-based products have been developed for use in the marine environment and are available through the supply system and at commercial marine supply outlets. High-grade gear grease is suitable for most underwater applications, since it displaces water and has a high cohesive quality. Many newer products have additives, such as Teflon, suspended in the compound to improve the lubricating and durability quality.

WARNING

Preparation of Bintuske can be hazardous. The waxy mixture is cooked at temperatures greater than 212 °F. If spilled or splashed on bare skin, it will stick causing third-degree burns. Wear protective clothing and exercise extreme care when preparing Bintuske.

J-2.2 Sealants. Common caulking compounds work well underwater for sealing small patches. Large patches can be backed up with a cement mixture to seal gross leakage. Sealing of cracks that are too large for liquid caulking and too small for cement are filled with Bintuske, a locally prepared sealant. The following materials are required to prepare Bintuske:

Ingredient	Unit of Issue
Cooking Oil, Soybean	Gallon
Resin	Drum
Bee's Wax	Pound
Tallow	Pound
Paraffin	Pound
Cheese cloth	Yard

EXAMPLE J-1
CALCULATING AIR LIFT REQUIREMENTS

A four-inch air lift is to be operated in thirty feet of water with a total lift of forty feet. Calculate:

- Output in gallons per minute
- Submergence ratio
- Air requirement
- Compressor capacity
- Compressor pressure.

Output:

Optimum output is 12 to 15 times the pipe area in square inches; 15 is used.

$$GPM = \frac{15 \times \pi \times D_p^2}{4}$$

$$GPM = \frac{15 \times \pi \times 4^2}{4}$$

$$GPM = 188.4$$

Submergence ratio:

$$m = \frac{D}{L}$$

$$m = \frac{30}{40}$$

$$m = 0.75$$

Air required:

$$V = \left(\frac{L}{B \times \log\left(1 + \frac{S}{B}\right)} \right)$$

$$B = D + 33 = 30 + 33 = 63$$

$$S = D - d_1 = 30 - \frac{18}{12} = 28.5$$

$$V = \left(\frac{40}{63 \times \log\left(1 + \frac{28.5}{63}\right)} \right)$$

$$V = 3.917 \text{ ft}^3 \text{ air/ft}^3 \text{ water}$$

$$V = 3.917 \times 0.1337$$

$$V = 0.524 \text{ ft}^3 \text{ air/gallon of water}$$

Air required = GPM x V
Air required = 188.4 x 0.524
Air required = 98.77 ft^3/min

Compressor capacity:

Capacity = 2 x Air required
Capacity = 2 x 98.77
Capacity = 197.54 ft^3/min

Pressure:

Pressure = Any pressure > 0.445 x D
Pressure = > 0.445 x 30
Pressure = > 13.35 psig

The amount of ingredients used depends upon whether it is summer or winter to ensure proper consistency. The summer formula is:

- 5 gallons of soybean cooking oil
- 25 pounds of resin
- 25 pounds of bee's wax
- 2 pounds of tallow
- 2 pounds of paraffin
- 70-80 six-foot strips of cheese cloth

The winter formula is:

- 5 gallons of soybean cooking oil
- 30 pounds of resin
- 25 pounds of bee's wax
- 3 pounds of tallow
- 2 pounds of paraffin
- 70-80 six-foot strips of cheese cloth

The preparation is as follows:

a. Heat soybean cooking oil to boiling.

b. Add resin—wait until completely melted.

c. Add bee's wax and tallow—stir until thoroughly mixed.

d. Cool to 150 °F and add paraffin—allow to melt, then mix thoroughly.

e. Add cheese cloth strip by strip as soon as the mixture cools enough so it doesn't burn the cheese cloth (some strips may be cut to give an assortment of 2' × 6' and 1' × 6' pieces)

f. Let stand until cool—remove for immediate use or storage.

NOTE

Bintuske becomes stiff when stored. It will become flexible again when worked by hand.

NOTE

The bottom half of a 55-gallon drum makes an excellent cauldron for Bintuske preparation.

APPENDIX K
FORMATS FOR SALVAGE SURVEY FORMS – SINKING

Table K-1. Salvage Survey Checklist, General.

Type of Casualty:			
Date/time of Casualty:			
Ship's Name:			
Hull Type:			
Builder:			
Flag:		Year:	
Hull or Pennant # (Naval)/Official # and Builder's # (merchant):			
Homeport:			
Planning Yard (USN):			
Owner:			
ISIC (Naval)/Agent (Merchant):			
Local Contact:			
Location (area name):			
(coordinates):			
Nearest Port:		Distance:	
Nearest U.S. or Allied Naval facility:			
Nearest major U.S. or Allied Naval station or repair facility:			
Crew status:			
Hazardous Cargo?		Spill?	
Oil spill or other pollution occurred or likely?			

Table K-1 (continued). Salvage Survey Checklist, General.

Principal Characteristics of Casualty:

LBP: ____________ LOA: ____________

Beam: ____________ Normal Service Draft: ____________

Displacement: ____________ Light ship/Full load

Number of Tanks/Holds: ____________

Deadweight: ____________

Propulsion: ____________

Framing system/significant structure details: ____________

Brief description of casualty, pre-casualty condition, cargo load, major damage, and ship's overall condition:

____
____
____
____

Damage (hull/structural) ____________
____
____
____

Machinery (condition/status): ____________
____
____
____

Flooding: ____________
____
____
____

Fire: ____________
____
____
____

Aim of Salvage Operation:

____
____
____
____

Table K-1 (continued). Salvage Survey Checklist, General.

Available Assets:

On-scene: ____________________

____

____

____

In-area: ____________________

____

____

Other assets (with estimated transit time): ____________________

____

____

Drawings and documents available:

General Arrangement:	______	Lines:	______
Section Scantlings:	______	Shell Expansion:	______
Offsets:	______	Curves of Form:	______
DC Book:	______	DC Plates:	______
Liquid Load Diagram:	______	Flooding Effect Diagram:	______
Draft Diagram:	______	Ship's Information Book:	______
Bonjean's Curves:	______	Structural Plans:	______
Sounding/Ullage Tables:	______	Capacity Plan:	______
Deadweight Scale:	______	Trim and Stability Book:	______
Stowage/Load Plan:	______	Cargo Manifest:	______
Deck Log:	______	Engineer's Log:	______

Pre-casualty stability information known or available from plans/documents:

KG:	______	TPI:	______
KM:	______	MT1:	______

Comments: ____________________

____

____

____

____

____

____

Table K-2. Salvage Survey Checklist, Sinking.

Capsized? ______________________________ To what angle? ______________________________

Main deck submerged?

		High tide	Low tide
Water depth	fwd:	__________	__________
	aft:	__________	__________

Portions of main deck exposed:

Length: ______________________________

Still water freeboard: __________ __________

Deck machinery/boats accessible/usable? __________
(If yes, complete deck machinery/boat summary sheets)

List any dry compartments

__________	__________	__________
__________	__________	__________

If machinery spaces are dry, complete auxiliary machinery summary sheet

Action taken to date

Action	Date	Accomplished by
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________
__________	__________	__________

Table K-2 (continued). Salvage Survey Checklist, Sinking.

Site Survey:

Exposed to:

swell: ______________________

seas: ______________________

wind: ______________________ (surface)

currents: ______________________ (subsurface)

Water temperature: ______________ (surface), ______________ (bottom)

Type and range of tide: ______________

Botom: ______________

material: ______________

slope: ______________

topography: ______________

Bottom survey/area soundings conducted? ______________________________

Access:

to the wreck site: ______________

to beach/shore: ______________

to beaching ground: ______________

to flat bottoms at intermediate depths for staged lifting: ______________

General Site Description:

(exposure): ______________________________

____

____

(weather): ______________________________

____

____

Weather forecasts available? ______________

Tide tables available? ______________ Tide gage set up? ______________

Current preditictions available? ______________ Current monitored? ______________

Current effects: Scouring? ______________________________

Silting/sand buildup? ______________________________

Accurate large scale chart, recent edition, covering salvage site available? ______________

Table K-2 (continued). Salvage Survey Checklist, Sinking.

Pollution noted:

Description: ______________________________

Magnitude: ______________________________

Source: ______________________________

Attach sketch showing position/orientation of casualty relative to shoreline, obstructions, hazards, deep water, beaching grounds; soundings; extent of any pollution and containment efforts, etc.

Table K-2 (continued). Salvage Survey Checklist, Sinking.

Casualty Survey:

Date/Time: ______________________

Dive Survey? ____________ Supervisor:

Photographs, video tapes, sonar traces, etc., available? ______________________

Settled into bottom? ____________

	Afloat	Sunk
Hog/sag (if any)		
Displacement:		
Trim:		
List:		
Heading:		
Loading summary***		
Solid cargo:		
Liquid cargo:		
Fuel:		
Lube oil:		
Permanent ballast:		
Ammunition/explosives:		
Flooding summary***		

***See attached sheet(s) for detailed loading/flooding accounting

Table K-2 (continued). Salvage Survey Checklist, Sinking.

External Damage:

General Position/Attitude Damage:

____

____

____

____

Cargo leaking/spilling from hull ruptures:

Hatches and W/T Closures: ____________________________

Attach sketches or copy of arrangement plans showing damage to shell plating, superstructure and decks, mudline.

Potential removal weights:

	Object	Location	Approximate Weight
Lifting points:			
Pulling points:			

Table K-2. Salvage Survey Checklist, Sinking.

Internal Survey:

Tank Soundings/Hold Inspections: record information on liquid load, cargo or flooding summary sheets. Verify that conditions are unchanged in undamaged spaces.

Structural Damage:

Framing: ____________________

____

____

Tank Tops: ____________________

____

____

Hatches/Doors: ____________________

____

____

Piping Systems: ____________________

____

____

Machinery Spaces: ____________________

____

____

Machinery:

Type:	________	No. Shafts:	________
Immersed?	________	Salvageable?	________

APPENDIX L
FORMATS FOR SALVAGE SURVEY FORMS – STRANDING

Table L-1. Salvage Survey Checklist, General.

Type of Casualty: ____________________

Date/time of Casualty: ____________________

Ship's Name: ____________________

Hull Type: ____________________

Builder: ____________________

Flag: __________ Year: __________

Hull or Pennant # (Naval)/Official # and Builder's # (merchant): ____________________

Homeport: ____________________

Planning Yard (USN): ____________________

Owner: ____________________

ISIC (Naval)/Agent (Merchant): ____________________

____

____

____

Local Contact: ____________________

Location (area name): ____________________

(coordinates): ____________________

Nearest Port: __________ Distance: __________

Nearest U.S. or Allied Naval facility: ____________________

Nearest major U.S. or Allied Naval station or repair facility: ____________________

Crew status: ____________________

____

____

Hazardous Cargo? __________ Spill? __________

Oil spill or other pollution occurred or likely? ____________________

Table L-1 (continued). Salvage Survey Checklist, General.

Principal Characteristics of Casualty:

LBP: ____________ LOA: ____________

Beam: ____________ Normal Service Draft: ____________

Displacement: ____________ Light ship/Full load

Number of Tanks/Holds: ____________

Deadweight: ____________

Propulsion: ____________

Framing system/significant structure details: ____________

Brief description of casualty, pre-casualty condition, cargo load, major damage, and ship's overall condition:

____

Damage (hull/structural) ____________

Machinery (condition/status): ____________

Flooding: ____________

Fire: ____________

Aim of Salvage Operation:

____

Table L-1 (continued). Salvage Survey Checklist, General.

Available Assets:

On-scene: ______________________________

____

____

____

In-area: ______________________________

____

____

Other assets (with estimated transit time): ______________________________

____

____

Drawings and documents available:

General Arrangement:	________	Lines:	________
Section Scantlings:	________	Shell Expansion:	________
Offsets:	________	Curves of Form:	________
DC Book:	________	DC Plates:	________
Liquid Load Diagram:	________	Flooding Effect Diagram:	________
Draft Diagram:	________	Ship's Information Book:	________
Bonjean's Curves:	________	Structural Plans:	________
Sounding/Ullage Tables:	________	Capacity Plan:	________
Deadweight Scale:	________	Trim and Stability Book:	________
Stowage/Load Plan:	________	Cargo Manifest:	________
Deck Log:	________	Engineer's Log:	________

Pre-casualty stability information known or available from plans/documents:

KG:	________	TPI:	________
KM:	________	MT1:	________

Comments: ______________________________

____

____

____

____

____

____

Table L-2. Salvage Survey Checklist, Strandings - General.

			After Stranding*	
Drafts:	Forward:	______	______ Port	______ Stbd
	Aft:	______	______ Port	______ Stbd
Hog/Sag (if any):		______	______	
Displacement:		______	______	
Trim:		______	______	
List:		______	______	
Heading:		______	______	
Engine order:		______	______ **	
Loading Summary***		______	______	
	Solid Cargo:	______	______	
	Liquid Cargo:	______	______	
	Fuel:	______	______	
	Lube Oil:	______	______	
	Feed Water:	______	______	
	Potable Water:	______	______	
	Water Ballast:	______	______	
	Permanent Ballast:	______	______	
	Ammunition/Explosives:	______	______	
Flooding Summary***		______	______	
Course/speed at time of stranding:		______		
Position of rudder at time of stranding:		______		
* Date, time, state of tide for after draft figures:		______		
** Maintained for what length of time?		______		
*** See attached sheet(s) for detailed loading/flooding accounting		______		

Table L-3. Salvage Survey Checklist, Strandings – Action Taken to Date.

ACTION TAKEN TO DATE

Action:	**Date**	**Accomplished by**
Anchors laid out		
Ship ballasted		
Ship lightened		
Weigh shifts/changes		
Other:		

Table L-4. Salvage Survey Checklist, Strandings – Site Survey.

SITE SURVEY

Casualty exposed to:

Swell:	____________________	(height/period)
Seas:	____________________	(height/period, breaking?)
Wind:	____________________	(speed/direction)
Currents:	____________________	(surface, speed/direction
Water temperature:	____________________	(Subsurface, speed/direction)
Type and range of tide:	____________________	
Bottom:		
Material:	____________________	
Slope:	____________________	
Topography:	____________________	
Beach survey conducted?	____________________	
Access:		
To the wreck site:	____________________	
To the wreck:	____________________	
To beach/shore:	____________________	
General site description:		
Exposure:	____________________	
	____________________	
	____________________	
Weather:	____________________	
	____________________	
	____________________	
Access to deep water:	____________________	
	____________________	
	____________________	
	____________________	

Table L-4 (continued). Salvage Survey Checklist, Strandings – Site Survey.

SITE SURVEY (continued) ____________________

Weather forecasts available? ____________________

Tide tables available? ____________________ Tide gage set up? ____________________

Current predictions available? ____________________ Current monitored? ____________________

Current effects:

Scouring? ____________________

Silting/sand buildup? ____________________

Accurate large-scale chart, recent edition, covering salvage site available? ____________________

Area around casualty and channel to deep water sounded? ____________________

Pollution noted:

Description: ____________________

Magnitude: ____________________

Source: ____________________

Attach sketch showing position/orientation of casualty relative to shoreline, obstructions, hazards, deep water; channel to deep water; soundings; any anchors laid out; extent of any pollution and containment efforts, etc.

Table L-5. Salvage Survey Checklist, Strandings – External Casualty Site Survey.

EXTERNAL CASUALTY SURVEY

Date/Time: ______________________________

Dive Survey? ______________ Supervisor: ______________

Photographs, video tapes, sonar traces, etc., available? ______________________________

Aground over what length(s): ______________________________

Settled into bottom? ______________ Machinery suctions clear? ______________

Soundings:

Distance from bow	Port	Startboard

External Damage:

General Position/Attitude/Damage: ______________________________

Cargo leaking/spilling from hull ruptures: ______________________________

Table L-5 (continued). Salvage Survey Checklist, Strandings – External Casualty Site Survey.

EXTERNAL CASUALTY SURVEY (continued)

Propeller(s) and Shaft(s): ______________________________

____

Rudder ______________________________

____

____

Hatches and W/T Closures
(hull and weather decks): ______________________________

____

____

____

Attach sketches or copy of arrangement plans showing damage to shell plating, superstructure and decks, mudline, portions of ship aground. Scaled underwater profiles for U.S. Navy hulls can be found in Chapter 2 of the *Underwater Ship Husbandry Manual (UWSHM)* (S0600-AA-PRO-020).

Potential removal weights:

	Object	Location	Approximate Weight
Lifting points:			
Pulling points:			

Table L-6. Salvage Survey Checklist, Strandings – Internal Casualty Site Survey.

INTERNAL CASUALTY SURVEY

Tank Soundings/Hold Inspections: record information on liquid load, cargo or flooding summary sheets. Verify that conditions are unchanged in undamaged spaces.

Structural Damage:

Framing: ______________________________
____
____

Tank Tops: ______________________________
____
____

Hatches/Doors: ______________________________
____
____

Piping Systems: ______________________________
____
____

Machinery Spaces: ______________________________
____
____

Significant material available from casualty Bos'n Locker/Riggers' Stores? ______________

Main Machinery:

Type:	______________	No. Shafts:	______________
SHP:	______________	Engines per shaft:	______________
Status:	______________	Repairable on-site?	______________
Fuel avail?	______________	Salvageable?	______________

Table L-7. Salvage Survey Checklist, Strandings – Auxiliary Machinery Summary.

AUXILIARY MACHINERY SUMMARY

	No. Units	Power Required	Capacity	Status*
Air Compressors:		(cfm/psi)		
	______	______	______	______
	______	______	______	______
Generator Sets:		(kW/volt)		
	______	______	______	______
	______	______	______	______
Boilers:		(lbs/hr, psi)		
	______	______	______	______
	______	______	______	______
Evaporators:		(gal/hr)		
	______	______	______	______
	______	______	______	______
Hydraulic Units:		(gpm/psi)		
	______	______	______	______
	______	______	______	______
Pumps:		(gpm/psi)		
	______	______	______	______
	______	______	______	______
	______	______	______	______
Other (note):				
	______	______	______	______
	______	______	______	______
	______	______	______	______

* STATUS

OOC	Out-of-commission, not operable
CW	Operable, if cooling water can be supplied
PWR	Operable, but requires power source
F	Operable, prime mover requires fuel — note fuel type (DFM, No 2, gas, etc.)
A1	Fully operable
A2	Operable at reduced capability

Table L-8. Salvage Survey Checklist, Strandings – Deck Machinery Summary.

DECK MACHINERY SUMMARY

	Location	Power Required	Capacity	Status*
Winches:		(wire/tons)		
	______	______	______	______
	______	______	______	______
	______	______	______	______
Booms/cranes:		(tons)		
	______	______	______	______
	______	______	______	______
	______	______	______	______
Capstans/Gypsy Heads:		(tons)		
	______	______	______	______
	______	______	______	______
Evaporators:		(gal/hr)		
	______	______	______	______
	______	______	______	______
	______	______	______	______
Davits:				
	______	______	______	______
	______	______	______	______
	______	______	______	______
Anchor Windlass:		(anchor)		
	______	______	______	______
	______	______	______	______

Port and stbd units? ______________ Cross connect? ______________

* STATUS

OOC	Out-of-commission, not operable
CW	Operable, if cooling water can be supplied
PWR	Operable, but requires power source
F	Operable, prime mover requires fuel — note fuel type (DFM, No 2, gas, etc.)
A1	Fully operable
A2	Operable at reduced capability

Table L-9. Salvage Survey Checklist, Strandings – Boat Summary.

BOAT SUMMARY

Location[1]	Type[2]	Weight[3]	Capacity[4]	Status[5]

1 Note whether in skids, davits or welldeck, fore/aft and p/s position
2 LCM, motor whaleboat, etc., note propulsion
3 Weight in tons
4 Pounds cargo/number of personnel
5 Use following codes for boat status and availability

A1 fully operable	L1 launchable
A2 operable at reduced capability	L2 launchable, risk of damage
A3 inoperable propulsion/hull sound	L3 crane/boom required
A4 hull damage, repairable	L4 inaccessible
A5 OOC, beyond repair on site	

Table L-10. Salvage Survey Checklist, Strandings – Cargo Summary .

CARGO SUMMARY

Hold	Type	Contents	Weight	LCG	KG

TOTAL CARGO WEIGHT: ______

LCG measured from: ______

Hold: Give number/letter designation; list 'tween-decks separately if loaded w/cargo different from hold

Type: Bulk (BLK), break-bulk (BK BLK), palletized (PLT), containerized (CTR-40 or CTR-20), roll-on/roll-off (RO/RO), vehicles (VEH)

Contents: Give actual commodities carried, i.e., grain, coal, machine parts, etc.

If arrangement plans not available, include sketch showing hold locations

Items of cargo useful for salvage operations? ______________________

____

Table L-11. Salvage Survey Checklist, Strandings – Liquid Load Summary .

LIQUID LOAD SUMMARY

Liquid Load as of ____________ / ____________ casualty

(before/after)

Tank	Content	Weight	LCG	KG	TCG

TOTAL LIQUID WEIGHT: ____________

List all liquids carried. Segregate cargo, ships, fuel, lube oil, feed and potable water, ballast, etc. Casualty's pre-printed sounding record sheets may be used if available (obtain from fuel, oil, water king, liquid cargo officer, DCA). Include sketches if arrangement plans or liquid load diagram are not available. Mark ruptured/leaking tanks.

Compare before and after stranding quantities. Can differences be accounted for? ____________

Table L-12. Salvage Survey Checklist, Strandings – Flooding Summary .

FLOODING SUMMARY

Flooding as of ______ / ______ casualty
(before/after)

Compartment	Depth	Weight	LCG	KG	TCG	FS?	FC?

TOTAL FLOODING WEIGHT: ______

Comments: ______

GLOSSARY

ACRONYMS

ABS	American Bureau of Shipping
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BHP	Brake Horsepower
BL	Baseline
CB	Center of Buoyancy
CG	Center of Gravity
CL	Centerline
DLA	Defense Logistics Agency
EIPS	Extra Improved Plow Steel
EOD	Explosive Ordnance Disposal
FOSC	Federal On-Scene Coordinator
FSW	Feet of Seawater
GM	Transverse Metacentric Height
HASP	Health and Safety Plan
HGPS	High Grade Plow Steel
HMIS	Hazardous Materials Information System
HMTC	Hazardous Materials Technical Center
IHP	Indicated Horsepower
IMCO	Intergovernmental Maritime Consultative Organization
IMO	International Maritime Organization
IPS	Improved Plowed Steel
IWRC	Independent Wire Rope Core
MEDEVAC	Medical Evacuation
MT1	Moment to Trim One Inch
NAVSEA	Naval Sea Systems Command
NOSC	Naval On-Scene Coordinator
NOSCDR	Naval On-Scene Commander
NSTM	Naval Ships Technical Manual
OPLAN	Operations Plan (in complete format)
OPORD	Operations Order
OSHA	Occupational Safety and Health Administration
PMS	Preventive Maintenance System
POL	Petroleum, Oil, and Lubricants
PPM	Parts Per Million
PQS	Personnel Qualification Standards
RPM	Revolutions Per Minute
SHML	Ship's Hazardous Materials List
SHP	Shaft Horsepower
SITREP	Situation Report
SWL	Safe Working Load
TPI	Tons Per Inch Immersion
WL	Waterline
WSC	Wire Strand Core
XIPS	Extra-Improved-Plow Steel

DEFINITIONS

Acid. Any corrosive having a pH less than 7.

Aft. Near the stern; toward the stern.

Afterbody. That portion of a ship's body aft of the midships section.

After frames. Frames aft of amidships, or frames near the stern of the ship.

After peak. The aftermost tank or compartment forward of the stern post.

After perpendicular (AP). A vertical line at or near the stern of the ship. In naval practice, the after perpendicular is through the after extremity of the design waterline; in merchant 7-practice, the after perpendicular usually passes through the rudder post.

Aloft. In the upper rigging; above the decks.

Alongside "Chinese". Denotes that two ships are alongside one another in such a manner that the stern of one is facing in the same direction as the bow of the other.

Amidships. In the vicinity of the middle portion of a vessel as distinguished from her ends. The term is used to convey the idea of general locality but not a definite point.

Anchor. A heavy iron or steel implement attached to a vessel by means of a rope or chain cable for holding the vessel at rest in the water. When an anchor is lowered to the bottom, the drag on the cable causes one or more of the prongs, — called flukes — to sink into the ground and provide holding power.

Anchor, bower. The large anchors carried in the bow of a vessel. One or two are usually carried in hawse pipes or on billboards. The weight varies with the size and service of the ship.

Anchor, kedge. A small anchor used for warping or kedging. It is usually planted from a small boat — the vessel being hauled up toward it. The weight varies — usually from 900 to 1,200 pounds.

Anchor, sea. This is not a true anchor as it does not sink to the bottom. It is a conical-shaped canvas bag required by the Bureau of Marine Inspection to be carried in each lifeboat. When placed overboard it serves a double purpose in keeping the boat head-on into the sea and in spreading a vegetable or animal oil from a container placed inside the bag. It is sometimes called an oil spreader.

Anchor hawk. Grappling device used to recover lost anchors, chains, wire rope, etc.

Anchor windlass. The machine used to hoist and lower anchors.

Ancillary equipment. Equipment that supports the operation of a system's principal components or assemblies.

Angle. Same as **angle bar**.

Angle bar. A bar of angle-shaped section used as a stiffener and for attachment of one plate or shape to another.

Angle collar. A collar or band made of one or more pieces of angle bar fitted tightly around a pipe, trunk, frame, longitudinal, or stiffener, intersecting or projecting through a bulkhead or deck for the purpose of making a watertight or oiltight joint.

Appendages. Relatively small portions of a vessel extending beyond its main outline as shown by transverse and waterplane sections, including: shafting, struts, bossings, docking and bilge keels, propellers, rudder, and any other feature extraneous to the hull and generally immersed.

Appendage drag. The hydrodynamic force created by the resistance of underwater appendages such as rudders, skegs, struts, propellers, etc.

Area of sections. The area of any cross-section of the immersed portion of a vessel, the cross-section being taken at right angles to the fore-and-aft centerline of the vessel.

Assembly. The parts to be fitted together to make a whole system or system component.

Astern. Signifying position, in the rear of or abaft the stern; as regards motion, the opposite of going ahead; backwards.

Athwart. Lying at right angles to the fore-and-aft centerline of a ship, sometimes pronounced "thwartships."

Athwartship. Reaching across a vessel, from side to side.

Automatic-tension towing machine. Winch-like machine which relieves tension on the towline by automatically paying out and then reclaiming wire when the tension is reduced.

Auxiliaries. Various winches, pumps, motors, engines, etc., required on a ship, as distinguished from main propulsive machinery (e.g., boilers and engines on a steam installation).

Auxiliary. A vessel that maintains, supplies, or supports combatants.

Back stay. Stays which extend from all mast levels, except the lower, to the ship's side at some distance abaft the mast. They serve as additional supports to prevent the masts from going forward, and also contribute to lateral support, thereby assisting the shrouds.

Bail. The part of a pelican hook or chain stopper that holds the hook closed.

Ballast. Any weight carried solely for the purpose of making the vessel more seaworthy. Ballast may be either portable or fixed, depending upon the condition of the ship. Fixed or permanent ballast in the form of sand, concrete, lead, scrap, or pig iron is usually fitted to overcome an inherent defect in stability or trim due to faulty design or changed character of service. Portable ballast, usually in the form of water pumped into or out of the bottom, peak, or wing ballast tanks, is utilized to overcome a temporary defect in stability or trim due to faulty loading, damage, etc., and to submerge submarines.

Ballast tanks. Tanks provided in various parts of a ship for introduction of water ballast; when necessary, to add weight to produce a change in trim or stability of the ship, and for submerging submarines.

Ballast water. Seawater confined to double-bottom tanks, peak tanks, and other designated compartments for use in obtaining satisfactory draft, trim, or stability.

Ballasted condition. A condition of loading in which it becomes necessary to fill all or part of the ballast tanks in order to maintain proper immersion, stability, and steering qualities brought about by consumption of fuel, stores, and water, or lack of part or all of the designed cargo.

Barge. A craft of full body, heavy construction, designed for the carriage of cargo but having no machinery for self-propulsion.

Baseline (BL). A fore-and-aft line passing through the lowest point of the hull.

Barrel. The rotating drum of a capstan or winch.

Beach gear. A generic term for all equipment meant to be used during the extraction of a grounded ship.

Beam (B). The breadth of the ship at the broadest point. Beam is measured in feet.

Beam. Any of the heavy, horizontal crosspieces of a ship; the side of a ship; or, the direction extending outward on either side at right angles to the fore-and-aft of a ship or other craft.

Beam ends. A vessel hove over or listed until her deck beams approach vertical is said to be "on her beam ends."

Beam line. A line showing the points of intersection between the top edge of the beam and the molded frame line, also called "molded deck line."

Bearer. A term applied to foundations, particularly those having vertical web plates as principal members. The vertical web plates of foundations are also called bearers.

Beaufort Scale. A numerical scale (from 0 to 12) used for rating velocity of wind in ascending velocity.

Between decks. The space between any two decks. Decks need not be adjacent. Frequently expressed as "tween decks."

Bight. A loop or bend in a rope; strictly, any part between the two ends may be termed a bight.

Bilge. The rounded portion of a vessel's shell which connects the bottom with the side. To open a vessel's lower body to the sea.

Bilge plates. The curved shell plates that fit the bilge.

Bilges. The lowest portion of a ship inside the hull, considering the inner bottom, where fitted, as the bottom hull limit.

Billboard. An inclined platform, fitted at the intersection of the forward weather deck and the shell, for stowing an anchor. It may be fitted with a tripping device for dropping the anchor overboard.

Bird-caging. The phenomenon of wires flaring out around the full diameter of wire rope, with resulting kinks in the wires. This can occur when there is a sudden release of a heavy load on a wire rope.

Bitter end. The inboard end of a vessel's anchor chain which is made fast in the chain locker; the free end of a fiber or wire rope.

Bitts. A term applied to short metal or wood columns extending up from a base plate secured to a deck or bulwark rail or placed on a pier for the purpose of securing and belaying ropes, hawsers, cables, etc.

Block, snatch. A single-sheave block having one side of the frame hinged so that it can be opened to allow the bight of a rope to be placed on the sheave, thus avoiding the necessity of threading the end of the rope through the swallow of the block. Usually employed as a fairlead around obstructions.

Body plan. A plan consisting of two half-transverse elevations, or end views, of a ship having a common vertical centerline, so that the right-hand side represents the ship as seen from ahead, and the left-hand side from astern. On the body plan appear the forms of the various cross sections, the curvature of the deck lines at the side, and the straight-line projections of the water, bow, buttock, and diagonal lines.

Bollard. A single cast-steel post secured to a wharf or pier and used for mooring vessels by means of lines extending from the vessel.

Bollard pull. The maximum pulling power of a ship at a given power rating with no way on.

Bonjean curves. Curves of areas of transverse sections of a ship. The curves of the moments of these areas above the baseline are sometimes included.

Boom. A term applied to a spar used in handling cargo, or to which the lower edge of a fore-and-aft sail is attached.

Boom lines. The wire ropes supporting the boom or jib on cranes and vangs.

Boot topping. An outside area on a vessel's hull from bow to stern between certain waterlines to which special air-, water-, and grease-resisting paint is applied; also, the paint applied to such areas.

Bottom. That portion of a vessel's shell between the keel and the lower turn of the bilge.

Bottom, outer. A term applied to the bottom shell plating in a double-bottom ship.

Bottom plating. That part of the shell plating which is below the waterline. More specifically, the immersed shell plating from bilge to bilge.

Bow. The forward end of the ship. The sides of the vessel at and for some distance abaft the stem, designated as the right-hand or starboard bow, and the left-hand, or port bow.

Bow thruster. A transversely-mounted propeller or other thrusting device located near the bow and used to control lateral movement.

Breadth, extreme. The maximum breadth measured over plating or planking, including beading or fenders.

Breaking strength. The actual or ultimate rated load required to pull a wire, strand, or rope to destruction. As an aggregate value, the sum of individual breaking loads of all wires in a strand or rope.

Breakwater. A term applied to plates or timbers fitted on a forward weather deck to form a V-shaped shield against water shipping over the bow.

Breast line. A mooring line from ship to pier, or ship to ship, perpendicular to the fore-and-aft axis, or at right angles to the ship.

Bridle. A two-legged towing rig of wire or chain attached to towing pads or a set of bitts on the tow. At the apex is a flounder plate or ring, dependent upon whether a chain bridle is being used. The two legs and the imaginary line between the points of attachment should form an equilateral triangle.

Bridle rig. The rigging of a tow with two legs from the tow's bow to a flounder plate.

Buckle. A distortion, such as a bulge; to become distorted; to bend out of its own plane.

Bulkhead. A term applied to any one of the partition walls which subdivide the interior of a ship into compartments or rooms.

Bulkhead, collision. The foremost transverse watertight bulkhead in a ship, which extends from the bottom of the hold to the freeboard deck. It is designed to limit flooding in case of collision damage. Usually, this is the forepeak bulkhead at the after end of the forepeak tank.

Bulkhead, swash. A strongly built, non-tight bulkhead placed in oil or water tanks to slow down the motion of the fluid induced by the motion of the ship.

"Bull rope". Colloquial term referring to a towline, or to the largest, strongest rope carried on board.

Bullnose. A closed chock at the bow of a vessel.

Bulwark. The section of a ship's side continued above the main deck that serves as a protection against heavy weather.

Buoyancy. Ability to float; the supporting effort exerted by a liquid (usually water) upon the surface of body, wholly or partially immersed in it. Any ship partially or wholly immersed in water will experience an upward push called buoyancy. The force of buoyancy is equal to the weight of the volume of water the ship displaces.

Buoyancy, reserve. The floating or buoyant power of the unsubmerged portion of the hull of a vessel. Usually refers to a specific condition of loading.

BUSHIPS. Bureau of Ships, now Naval Sea Systems Command

Buttock lines. The curves shown by taking vertical longitudinal sections of the after part of a ship's hull parallel to the ship's keel. Similar curves in forward part of hull are "bow lines."

Cable grip. A termination which is wrapped about the end of a wire rope using interlocking helical strands, designed so that tensile loads are resisted by induced radial pressures.

Cable-laid. Three ropes laid up like strands from right-to-left. The ropes which serve as strands are laid up from left to right, (e.g., non-rotating wire).

Calculated risk. Accepting an operation or decision based on less than satisfactory conditions, information or assets.

Cant. A term signifying an inclination of an object away from the perpendicular; to turn anything so that it does not stand perpendicularly or square in relation to a given object.

Caprail. Rail on the stern of a towing vessel over which the sweep of the tow wire rides.

Capstan. A revolving device with a vertical axis used for heaving in mooring lines.

Cargo. Merchandise or goods accepted for transportation by ship.

Cargo boom. A heavy boom used in loading cargo. See **boom**.

Carpenter stopper. A mechanical device consisting of a cover that encloses a sliding wedge within the body that can be opened by knocking away a latch that holds them closed. Used for stopping off wire rope.

Catenary. The downward curve or sag of a rope suspended between two points.

Center of Buoyancy. The geometric center of gravity of the immersed volume of the displacement or of the displaced water, determined solely by the shape of the underwater body of the ship. It is calculated for both the longitudinal location, forward or aft of the middle perpendicular, and the vertical location above the baseline or below the designed waterline.

Center of Flotation. The geometric center of gravity of the water plane at which the vessel floats, forward or aft of the middle perpendicular. It is that point about which a vessel rotates longitudinally when actuated by an external force without change in displacement.

Center of Gravity. The point in a ship where the sum of all moments of weight is zero; the point at which the combined weight of all the individual components of the vessel's total weight may be considered as concentrated; generally located longitudinally forward or aft of the middle perpendicular and vertically above bottom of keel or below a stated waterline.

Centerline. A vertical plane passing fore and aft down the center of a ship; the middle line of the ship from stem to stern as shown in any waterline view.

Chafing pendant. A length of chain used to reduce chafing or wearing.

Chain. A connected, flexible series of links, usually of metal, used for binding, connecting, or other purposes.

Chain bridle. A chain used in a bridle rig or a single pendant rig.

Chain connecting link. See **detachable link**.

Chain locker. Compartment in forward lower portion of ship in which anchor chain is stowed.

Chain pendant. A piece of chain used as a strap; chain rigged between the tow and tow hawser; chain used to create a catenary.

Chain stopper. A device used to secure chain, thereby relieving the strain on the windlass; also used to secure the anchor in the housed position in the hawse pipe.

Check. To keep a strain on a line without parting it.

Chock. A heavy, smooth-surfaced fitting usually located near the edge of the weather deck through which wire ropes or fiber hawsers may be led.

Chute. An inclined or vertical trough or passage, down which something may be slid or passed.

Clamp. A metal fitting used to grip and hold wire ropes. Two or more may be used to connect two ropes in lieu of a short splice or in turning in an eye.

Cleats. Pieces of wood or metal, of various shapes according to their uses, usually having two projecting arms or horns upon which to belay ropes.

Clinometer. An instrument used for indicating the angle of roll or pitch of a vessel.

Closed socket. A wire rope termination similar to a padeye or ring.

Coaming, hatch. A frame bounding a hatch for the purpose of stiffening the edges of the opening and forming the support for the covers. In a steel ship, it generally consists of a strake of strong vertical plating completely bounding the edges of a deck opening.

Cofferdams. Empty spaces separating two or more compartments for the purpose of insulation, or to prevent the liquid contents of one compartment from entering another in the event of the failure of the walls of one to retain their tightness.

COLREGS. U.S. Coast Guard rules of the road.

Control, lateral. The power to direct or regulate sideways movement.

Cordage. A comprehensive term for all ropes, of whatever size or kind, on board a ship.

Core (line). The axial member of a wire rope about which the strands are laid. It may consist of wire strand, wire rope, synthetic or natural fiber, or solid plastic.

Counter. That part of a ship's stern which overhangs the stern post, usually that part above the waterline.

Crabbing. Moving sideways through the water.

Crane. A machine used for hoisting and moving pieces of material and portions of structures or machines that are too heavy to be handled by hand or cannot be handled economically by hand.

Cutwater. The stem of a ship; the forward-most portion of the bow which cuts the water as the ship moves.

Dead rise. The amount which the straight portion of the bottom of the floor of the midships section rises above the baseline in the half-beam of the vessel. Usually expressed in inches.

Deadweight. The difference between the light displacement and the full load displacement of a vessel; the total weight of cargo, fuel, water, stores, and passengers and crew, and their effects, that a ship can carry when at her maximum allowable draft.

Deck. The floor of a compartment. The deck space exposed to weather where towing and beach gear operations take place.

Deckhouse. A term applied to a partial superstructure that does not extend from side to side of a vessel, as do the bridge, poop, and forecastle.

Deck machinery. A term applied to capstans, windlasses, winches, and miscellaneous machinery located on the deck of the ship.

Deck plating. A term applied to the steel plating of a deck.

Deck stringer. The strip of deck plating that runs along the outer edge of a deck.

Deep floors. A term applied to the floors at the ends of a ship which are deeper than the standard depth of floor at amidships.

Deep tanks. Tanks extending from the bottom or inner-bottom of a vessel up to or higher than the lowest deck. They are fitted with hatches so that they also may be used for cargo.

Depth (D). The distance between the baseline and the uppermost watertight deck. Depth is measured in feet.

Depth, molded. The vertical distance from the molded baseline to the top of the uppermost strength deck beam at side, measured at midlength of the vessel.

Deshackling kit (Detachable-Link Tool Kit). A tool set used to assemble and disassemble detachable links. Tools included in these sets are hammers, punches, lead pellets, spare taper pins, and hair pins.

Detachable link. A joining link or chain link used to connect chain to anchors, chain, or other pieces of mooring, towing, or beach gear equipment.

Di-lok chain. Integral stud-link chain formed by forging.

"Dipped" shackle, padeye. The placement of a shackle through a padeye or connection, as opposed to passing the mortise over the padeye. The padeye is shaped to accept a shackle as described.

Displacement (W). The displacement is the weight of the ship and all cargo on board and is measured in weight units, usually in long tons of 2,240 pounds. Displacement is directly related to displacement volume and is normally obtained by dividing the displacement volume by 35, the number of cubic feet of salt water in a long ton.

Displacement curves. Curves drawn to give the displacement of the vessel at varying drafts. Usually, these curves are drawn to show the displacement in either salt or fresh water, or in both.

Displacement volume (V). The displacement volume is the total volume of the underwater hull. Displacement volume is measured in cubic feet.

Displacement, designed. The displacement of a vessel when floating at her designed draft.

Displacement, full load. The displacement of a vessel when floating at her greatest allowable draft as established by the classification societies.

Displacement, light. The displacement of the vessel complete with all items of outfit, equipment, and machinery on board but excluding all cargo, fuel, water, stores, dunnage, and passengers and the crew and their effects.

Dog. A pawl; a device applied to a winch drum to prevent rotation. See **"On the dog."**

Dolphin. A term applied to several piles that are bound together, situated either at the corner of a pier or out in the stream and used for docking and warping vessels. Also applied to single piles and bollards on piers that are used in docking and warping.

Door, watertight. A door so constructed that when closed it will prevent water under pressure from passing through.

Double-bottom. A term applied to the space between the inner and outer skins of a vessel called respectively the "inner-bottom" and "shell," usually extending from bilge to bilge for nearly the whole length of the vessel, subdivided into watertight or oiltight compartments.

Doubling plate. An extra plate secured to the original plating to provide additional strength or to compensate for an opening in the structure.

Draft (T). The vertical distance between the waterline and the deepest part of the ship at any point along the length. Draft is measured in feet. Drafts are usually measured at the forward (draft forward, T_f) and the after perpendiculars (draft aft, T_a). The mean draft (T_m), frequently used in salvage calculations, is the average of the forward and after drafts. The draft is assumed to be the mean draft if the point at which the draft is taken is not specified. The navigational draft of a ship accounts for sonar domes, pit swords, and other underwater appendages. The navigational draft is never used for salvage calculations.

Draft marks. The numbers which are placed on each side of a vessel near the bow and stern, and often also amidships, to indicate the distance from the number to the bottom of the keel or a fixed reference point. These numbers are six inches high, are spaced twelve inches bottom to bottom vertically, and are located as close to the bow and stern as possible.

Drag. Forces opposing direction of motion due to friction, profile, and other components; the designed excess of draft aft measured from the designer's waterline. The drag is constant and should not be confused with trim.

Drogue. A device used to slow the rate of movement.

Dunnage. Any material, such as blocks, boards, paper, burlap, etc., necessary for the safe stowage of stores and cargo.

Dynamic load. Relating to energy or physical force in motion; as opposed to static load, a force producing motion or change.

Elongation. Stretching of chain or other tension member caused by an excessive load.

Equilibrium, neutral. The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to maintain the inclined position assumed after that force has ceased to act.

Equilibrium, stable. The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to return to its original position after that force has ceased to act.

Equilibrium, unstable. The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to depart farther from the inclined position assumed after that force has ceased to act.

Even keel. When a ship rides on an even keel, its plane of flotation is either coincident with or parallel to the designed waterline.

Eye splice. A loop formed in the end of a rope by tucking the strand ends under or around the strands of the line part of the rope. A thimble is often used in the loop.

Fairlead. Fittings which lead lines in the direction desired.

Fairlead chock. A chock with a roller(s) installed to lead a line to a bitt or cleat.

Fairleader. A fitting or device used to preserve or to change the direction of a rope, chain, or wire so that it will be delivered fairly, or on a straight lead, to a sheave or drum without the introduction of extensive friction. Fairleaders, or fairleads, are fixtures, as distinguished from temporary block rigs.

Fake (Faked down). To lay out a line in long, flat bights in such form that when needed, it will pay out freely.

Fall. The entire length of rope used in a tackle. The end secured to the block is called the standing part; the opposite end, the hauling part.

Falling off. Drifting away from a desired position or direction.

Fathom. A nautical unit of length used in measuring cordage, chains, depths, etc. The length varies in different countries, being six feet in the United States and Great Britain.

Fatigue. The tendency for materials or devices to break under repeated (cyclic) loading.

Fender. The term applied to various devices fastened to or hung over the sides of a vessel to prevent rubbing or chafing against other vessels or piers.

Fish Hooks. Outer wires of wire rope that break and cause short ends to project from the rope; a sign of wire rope deterioration.

Flare. The spreading out from the central vertical plane of the body of a ship with increasing rapidity as the section rises from the waterline to the rail. Also a night distress signal.

Floor. A plate used vertically in the bottom of a ship running athwartship from bilge to bilge, usually on every frame to deepen it. In wood ships, the lowest frame timber or the one crossing the keel is called the floor.

Flounder plate. A triangular steel plate to which chain bridle legs are connected, sometimes called "fish plate."

Flukes. The palms, or broad holding portions, at the arm extremities of an anchor, which penetrate the ground.

Fore. A term used in indicating portions or that part of a ship at or adjacent to the bow. Also applied to that portion and parts of the ship lying between the midship section and stem; as, forebody, forehold, and foremast.

Fore and Aft. Lengthwise of a ship.

Forefoot. The lower end of a vessel's stem which is stepped on the keel.

Forward. In the direction of the stem.

Forward perpendicular (FP). A vertical line through the forward extremity of the design waterline — the waterline at which the ship is designed to float; a line perpendicular to the baseline and intersecting the forward side of the stem at the designed waterline.

Founder. To sink as the result of entrance of water.

Frame. A term generally used to designate one of the transverse ribs that make up the skeleton of a ship. The frames act as stiffeners, holding the outside plating in shape and maintaining the transverse form of the ship.

Frame spacing. The fore-and-aft distances between frames, heel to heel.

Freeboard (F). The distance between the waterline and the uppermost watertight deck at any location along the ship is freeboard. Freeboard is measured in feet.

Freeing ports. Holes in the lower portion of a bulwark, which allow deck wash to drain off into the sea. Some freeing ports have swinging gates which allow water to drain off but are automatically closed by seawater pressure.

Free-spooling. To lengthen scope by releasing the clutch-brake and allowing the towing drum to rotate as a result of the drag of the tow. The tow motor is stationary.

"Freshening the nip". Paying out or hauling in the line to move the contact point so as to distribute wear.

Frictional resistance. The force created by an object as it moves through a fluid such as water or air.

Fuse pendant. A pendant of wire rope or chain specifically designed to fail at a known tension. May be used to protect the rest of the rigging arrangement.

GM. See **metacentric height**.

Gooseneck. A swiveling fitting on the heel or mast end of a boom for connecting the boom to the mast.

Grapnel. A small, 4-armed anchor used mainly to recover objects in the water; an implement having from four to six hooks or prongs, usually four, arranged in a circular manner around one end of a shank having a ring at its other end. Used as an anchor for small boats, for recovering small articles dropped overboard, to hook on to lines, and for similar purposes. Also known as a grappling hook.

Ground tackle. A general term for all anchors, cables, ropes, etc., used in the operations of mooring and unmooring a ship.

Gun tackle. A tackle using two single-sheave blocks.

Gunwale. The upper edge of a boat's side. Pronounced "gun-el." A term applied to the line where a weather deck stringer intersects the shell.

Gypsy head. A drum attached to a winch around which a rope is turned for heaving in.

H-bitt. A larger structure mounted on the deck or in a bulkhead that is used to lead or stop off a tow hawser. A head point used for towing.

Half-Breadth Plan. A plan or top view of one-half of a ship divided by the middle vertical plane. It shows the waterlines, cross-section lines, bow and buttock lines, and diagonal lines of the ship's form projected on the horizontal base plane of the ship.

Hawk anchor. See **Anchor Hawk**.

Hawse pipe. Heavy castings through which the anchor chain runs from the deck down and forward through the ship's bow plating.

Hawser. A heavy line or wire rope used in warping, towing, and mooring; any line over 5 inches in circumference.

Hazardous material (HM). A naturally occurring or synthesized material that can cause the deterioration of other materials or be injurious to living things.

Heave-around. To haul in.

Heave-in. To haul in.

Heave-taut. To haul in until the line has a strain on it.

Heave-to. To stop; to bring the ship to a halt, dead in the water.

Heavy lift. A system used to supply part or all of the external lifting force required to salvage a sunken vessel.

Heel. The convex intersecting point or corner of the web and flange of a bar; the inclination of a ship to one side, caused by wind or wave action or by shifting weights on board.

Heeling. Listing over.

Helix. The twist or curvature of the individual strands of a wire rope.

Hockle. Kinking of one or more strands of twisted fiber line or wires on a wire rope.

Hog (Hogging). Distortion of a ship's hull which results in the bow and stern being lower than the midships section; opposite of sagging.

Hogging strap. A restraining line executing force on the towline to hold it close against the caprail and/or closer to the fantail.

Hook. A curved or bent piece of metal, wood, etc., used to catch, hold, or pull something.

Horsepower, indicated (IHP). Engine power calculated from cylinder pressure, not accounting for the mechanical efficiency of the engine.

Horsepower, shaft (SHP). The power transmitted through the shaft to the propeller. It is usually measured aboard the ship as close to the propeller as possible by means of a torsionmeter. The power actually delivered to the propeller is somewhat less than that measured by the torsionmeter. Shaft horsepower is usually 90 to 98 percent of BHP.

Horsepower, brake (BHP). Engine power measured at the engine output coupling. Brake horsepower is usually 65 to 75 percent of IHP.

Hull. The framework of a vessel, together with all decks, deckhouses, and the inside and outside plating or planking, but exclusive of masts, yards, rigging, and all outfit or equipment.

"In Irons". An expression used by shiphandlers to indicate limited control in maneuvering the ship.

"In Step". An expression used to indicate that the towing ship and its tow are riding the crests and troughs of waves simultaneously.

Inboard. Toward the center.

Inboard profile. A plan representing a longitudinal section through the center of the ship, showing deck heights, transverse bulkheads, assignment of space, machinery, etc., located on the center plane or between the center and the shell on the far side.

Independent Wire Rope Core (IWRC). The internal strand of a multiple strand wire rope, made up of wire strands twisted together.

Initial stability. The stability of a vessel in the upright position or at small angles of inclination. It is measured by the metacentric height.

Inner bottom. A term applied to the inner skin or tank top plating. The plating over the double-bottom.

Intercostal. Occurring between ribs, frames, etc. The term is broadly applied, where two members of a ship intersect, to the member that is cut.

Keckling. Chafing gear on a cable, consisting of old rope.

Keel. A centerline strength member running fore and aft along the bottom of a ship and often referred to as the backbone. It is composed either of long bars or timbers scarfed at their ends or by flat plates connected together by riveting or welding.

Keel, bilge. A fin fitted on the bottom of a ship at the turn of the bilge to reduce rolling. It commonly consists of a plate running fore and aft and attached to the shell plating by angle bars.

Kenter detachable link. A type of connection normally used to join two pieces of stud-link or cast chain. See **detachable link**.

King post. A strong vertical post used to support a derrick boom. See **Sampson post**.

Kjellam grips. A lightweight stopper useful for passing a wire rope where there is only low tension likely to be exerted on the rope.

Knot. A unit of speed equaling one nautical mile (6,080.20 feet) an hour.

Knuckle. An abrupt change in direction of the plating, frames, keel, deck, or other structure of a vessel.

Kort nozzle. A nozzle used to enclose the propeller of a ship.

Lagging. A term applied to the insulating material that is fitted on the outside of boilers, piping, etc.

Lateral control wire. An auxiliary wire used to move the tow hawser athwartships.

Lay. The direction of the twist of strands of a rope.

Lay length. The distance measured parallel to the axis of the rope (or strand) in which a strand (or wire) makes one complete helical convolution about the core (or center).

Layer. A single thickness, coat, fold, wrap, or stratum.

"Lazy Jacks". Small lines used to tend and recover the towline when rigging a recovery for a Liverpool bridle.

Length between perpendiculars (LBP or L). The horizontal distance between the forward and after perpendiculars. Length between perpendiculars is measured in feet.

Length on design load waterline (LWL). The length along the centerline at the waterline in the ship's design loaded condition. Length on design load waterline is measured in feet.

Length overall (LOA). The extreme length of the ship along the centerline. Length overall is measured in feet; the length of a ship measured from the foremost point of the stem to the aftermost part of the stern.

Levelwind. A device used to wind the wire on a drum evenly.

Lightening hole. A hole cut out of any structural member, as in the web, where very little loss of strength will occur. These holes reduce the weight and in many cases serve as access holes. This is particularly true in floor plates and longitudinals in double bottoms.

Lighter. A boat used in harbors for transporting merchandise; a full-bodied, heavily built craft, usually not self-propelled, used in bringing merchandise or cargo alongside or in transferring it from a vessel.

Limber hole. A hole or slot in a frame or plate for the purpose of preventing water from collecting. Most frequently found in floor plates just above the frames and near the centerline of the ship.

Limiting draft marks. Asterisk-shaped marks near the forward, after, and midships draft marks of warships and certain auxiliaries showing the deepest drafts to which the ship can be loaded and still retain sufficient reserve buoyancy.

Line. A term frequently applied to a fiber or synthetic rope, especially if it moves or is used to transmit a force.

Lines. The plans of a ship that show its form. From the lines drawn full-size on the mold loft floor are made templates for the various parts of the hull.

List. The deviation of a vessel from the upright position due to bilging, shifting of cargo, or other cause.

Liverpool bridle. A method of rigging a tow used to maintain ship control when the large yawing of the tow can overcome directional stability of the towing vessel; most commonly used in debeaching a ship.

Load cell. An instrument for measuring tension or torque.

Load line. The line 18 inches long and 1 inch wide on each side of the ship at the midships section which indicates the maximum draft to which the ship may be loaded.

Locking pin. Keeper or device used to hold or maintain a chain stopper, shackle, or other similar devices in a designated position.

Longitudinals. A term applied to the fore-and-aft frames in the bottom of a ship. These frames are usually made up from plates and shapes and are sometimes intercostal and sometimes continuous.

Magazine. Spaces or compartments devoted to the stowage of ammunition.

Main body. The hull proper, without the deckhouses, etc.

Main deck. The principal deck of the hull, usually the highest, extending from stem to stern and providing strength to the main hull.

Manhole. A round or oval hole cut in decks, tanks, boilers, etc., for the purpose of providing access.

Messenger. A light line used for hauling over a heavier rope or hawser.

Metacentric height (GM). Distance between the metacenter and the center of gravity of a ship; a measure of stability.

Metacentric Radius (BM). Distance between center of buoyancy and metacenter (I_{WP}/V)

Midships. Same as **Amidships**.

Midships section (MS). The vertical transverse section located at the midpoint between the forward and after perpendiculars, usually the largest section of the ship in area. Also, applied to a drawing showing the contour of the midship frame, upon which are depicted all the structural members at that point, with information as to their size and longitudinal extent.

Moment of Inertia. A measurement of a plane surface's resistance to rotation about an axis in the same plane. The magnitude of moment of inertia depends upon the shape of the surface and varies with the axis used for rotation. The moment of inertia is measured in the fourth power of a linear unit such as $feet^4$ or $inches^4$ or a combination of both.

Mortise. The opening of a shackle or detachable link. The inside dimension, measured across the opening, of a shackle or detachable link.

Nip. A sharp bend in a line or wire.

Norman pin. A steel rod or post that can be raised or lowered, usually mounted toward the stern of a vessel, to limit the sweep of a hawser across the rear deck to provide safe areas for the crew.

Offset. A term used for the coordinates of a ship's form, deck heights, etc.

Offset shackle. A device used to connect the towline to the towing pendant. One end of the shackle is the size of the towline thimble, whereas the other end is especially made to accommodate different sizes of chain pendants or anchor bending shackles.

"On the brake". Towing with the tow hawser restrained by the brake system of the towing machine or winch.

"On the dog". Occurs when a pawl is engaged in the ratchet teeth of the drum of the towing machine.

Open socket. A wire rope termination that is shaped similarly to a shackle; mates with a closed socket.

Outboard. Away from the centerline toward the outside; outside the hull.

Outboard profile. A plan showing the longitudinal exterior of the starboard side of a vessel, together with all deck erections, stacks, masts, yards, rigging, rails, etc.

Padeye. A fitting having one or more eyes integral with a plate or base to provide ample means of securing and distributing the strain over a wide area. The eyes may be either "worked" or "shackled." Also known as lug pads, hoisting pads, etc.

Padeye (horizontal, vertical). A metal structure with a hole for a shackle or pin to pass a ring. On a vertical padeye, the axis of the hole is parallel to the deck. On a horizontal padeye, the axis is perpendicular to the deck. Vertical padeyes are often referred to as free-standing padeyes.

Palm. The flat, inner surface of the fluke of an anchor.

Parcelling. Wrapping a line or wire with strips of canvas.

Pay out. To slack off a line, or let it run out.

Pear-shaped link. A shackle or detachable link used to connect a small fitting or chain to a larger fitting or chain.

Pelican hook. A hook which can be opened while under a strain by knocking away a locking ring which holds it closed; used to provide an instantaneous release.

Pendant (pendant rig). A length of wire rope, chain, or fiber line used to facilitate connecting longer lengths of the same; a single wire or chain that leads from the apex of a towing bridle to the towline; a length of wire used as an underrider wire in a "Christmas Tree" rig.

Period of roll. The time occupied in performing one double oscillation or roll of a vessel, as from port to starboard and back to port.

Permeability . The characteristics of a material which allow a liquid or gas to pass through.

Plate shackle. A connecting device made up of two metal plates and bolts, used to connect the towing pendant and the towline, or to serve as a connecting unit in beach gear.

Platform. A partial deck.

Plating, shell. The plating forming the outer skin of a vessel. In addition to constituting a watertight envelope to the hull, it contributes largely to the strength of the vessel.

Port. The left-hand side of a ship when looking forward; the opposite of starboard.

Poured socket. A wire rope termination installed by pouring molten zinc over splayed wire, often referred to as spelter socket.

Power block (transport block). A portable, hydraulic motor-driven line sheave; provides back tension to the traction winch.

Preventer. Any line, wire, or chain whose general purpose is to act as a safeguard in case something else carries away.

Preventer hawser. A hawser secured to the chain as a preventer.

Proof strain. The test load applied to anchors, chains, or other parts, fittings, or structures to demonstrate proper design, construction, and material.

Proof strength. The strength of a material, part, or structure, at which it has been proved by test to possess.

Prow. The part of the bow above the waterline.

"Pudding". Chafing gear used to protect such items as a towline or spar.

Purchase. A general term for any mechanical arrangement of blocks and tackle for multiplying force; any mechanical advantage which increases the power applied.

Quarter rollers. Rollers mounted in the forward and stern waists of a tug for mooring, beach gear, and other similar evolutions.

Reeving. The threading of a line or wire through a block, sheave, or other parts of a wire rope system.

Resistance. A force that retards, hinders, or opposes motion.

Riding chocks. The chock on deck through which the anchor chain or towing gear passes inboard.

Rise of bottom. See **deadrise**.

Risk assessment . The identification of the potential hazard; the parameters that determine the degree of hazard.

Roller chock. A chock fitted with a roller.

Rope. A flexible, heavy cord of twisted hemp or other fiber.

Roundings. Condemned rope under 4 inches in diameter used to wrap around a rope to prevent chafing.

Run out. To send out, as to run out a towing hawser.

Safe working load (SWL). The proper load that a rope or working gear may carry economically and safely.

Safety factor. A multiple representing extra strength over maximum intended stress.

Safety shackle. A connecting device similar to the common shackle, except that a hole is drilled in the bolt to accommodate a cotter key for the purpose of locking the nut on the bolt.

Sag (Sagging). Distortion of a ship's hull in which the keel droops downward in the middle; the deformation or yielding caused when the middle portion of a structure or ship settles or sinks below its designed or accustomed position. The reverse of hogging.

Salvage towing. Special towing where a discarded, wrecked, sunk, or damaged ship is rescued or saved.

Sampson post. A strong vertical post that supports cargo booms. See **king posts**.

Scantlings. A term applied to the dimensions of the frames, girders, plating, etc., of a ship's structure.

Scope. The amount of towline anchor cable out.

Scow. A large, open, usually flat-bottomed boat for transporting sand, gravel, or mud.

Screw-pin shackle. A type of shackle in which the pin passes through one side of the shackle and threads into the other side of it to form a closure.

Screw stopper. A chain stopper fitted with a turnbuckle.

Sea anchor. A device, usually of wood and/or canvas, streamed by a vessel or boat in heavy weather to hold the bow, side or stern up to the sea.

Seaway. The motion of the sea when clear of shoal water.

Seize. To bind with small stuff, as one rope to another or a rope to a spar.

Serving. To wrap any small stuff tightly around a rope that may have been previously wound and parcelled.

Shackle (anchor, chain). U-shaped metal fittings closed at the open end with a pin; used to connect wire, chain, padeyes, etc. The anchor type has an exaggerated bow; the chain type has parallel sides.

Shackle bolt. A pin or bolt that passes through both eyes of a shackle and completes the link. The bolt may be secured by a pin through each end, or a pin through one end and through the eye, or by having one end and one eye threaded, or one end headed and a pin through the other.

Sheer legs. A rig for handling heavy weights, consisting of an A-frame of timber or steel with the top overhanging the base, having the lower ends fixed or pivoted and the top ends held either by fixed stays or by topping lifts which permit change of slope of the legs. Tackles are secured at the top of the frame through which the hoisting rope or cable is run. Sometimes called "sheers."

Sheave. A pulley with a rim used to support or guide a rope in operation.

Shot. A standard length of chain; 15 fathoms (90 feet).

Side-slipping. Moving sideways through the water.

Side plating. A term applied to the plating above the bilge in the main body of a vessel; also to the sides of deckhouses, or to the vertical sides of enclosed plated structures.

Situation Report (SITREP). A special report generally informal in nature, required to keep higher authority advised. Prescribed under certain predictable circumstances, but may also be required at any time.

Skeg. The extreme after part of the keel of a vessel; the portion that supports the rudder post and stern post.

Skin. The term usually applied to a vessel's outside planking or plating forming the watertight envelope over the framework. It is also applied to the inner-bottom plating when it is called an inner skin.

Slack. Not fully extended as applied to a rope; the opposite of taut; to "slack away" means to pay out a rope or cable by carefully releasing the tension, while still retaining control; to "slack off" means to ease up, or lessen the degree of tautness.

Sling. A length of chain or rope employed in handling weights with a crane or davit. The rods, chains, or ropes attached near the bow and stern of a small boat into which the davit or crane tackle is hooked. The chain or rope supporting the yard at the masthead.

Slip stopper. A chain stopper hooked or shackled to the deck and fitted with a slip-hook for holding the towline.

Small stuff. Any small-circumference line used to seize or serve larger lines.

Snapback. The force generated when a line carries away.

"Snorter". Four lines with a common eye.

Socket. A wire rope termination attached by zinc or resin. Sockets poured with resin are not approved for towing. See **poured socket**.

Span. The distance between any two similar members, as the span of the frames. The length of a member between its supports, as the span of a girder. A rope whose ends are both made fast some distance apart, the bight having attached to it a topping lift, tackle, etc. A line connecting two davit heads so that when one davit is turned the other follows.

Spanish windlass. A device to exert force in bringing together two parts of a rope for any purpose. Shortening a pair of parallel lines by twisting them with a lever inserted between them at a right angle to their axis.

Spelter socket. See **poured socket**.

Splay. To unlay and broom the bitter end of a wire rope, usually done preparatory to attaching a socket.

Spliced eye. A wire rope termination formed by unlaying the rope and intertwining the strands to form an eye.

Spooling. Winding a rope on a reel or drum.

Spring. A mooring or docking line leading at an angle less than 45 degrees with the fore-and-aft lines of the vessel. Used to turn a vessel or prevent it from moving ahead or astern.

Spring lay rope. A rope combined of rope fiber and wire, used to spring a ship.

Spring line. See **spring**.

Spring, stretcher. A pendant or grommet used to dampen towline surges.

Stability. The tendency which a vessel has to return to the upright position after the removal of an external force which inclined her away from that position. To have stability, a vessel must be in a state of equilibrium.

Stability, range of. The number of degrees through which a vessel rolls or lists before losing stability.

Starboard. The right-hand side of a ship when looking forward. Opposite of "port."

Static load. The force applied by deadweight, often referred to as the average or mean load.

Stem. The bow of a ship.

Stern. The aftermost section of a ship.

Stern line. A mooring line leading from the stern of a vessel.

Stern rollers. The horizontal and vertical rollers at the stern of a tug used to lead, capture, and control the tow hawser.

Stiff (stiffness). The tendency of a vessel to remain in the upright position, or a measure of the rapidity with which she returns to that position after having been inclined from it by an external force.

Stiffener. An angle bar, T-bar, channel, etc., used to stiffen plating of a bulkhead, etc.

Stopper. A short length of rope secured at one end and used in order to stop it from running.

Stopper hitch. Two rolling hitches backed up with half-hitches to secure lines or wire.

Strain. To draw or stretch tight; to injure or weaken by force, pressure, etc.; to stretch or force beyond the normal, customary limits; to change the form or size of, by applying external force; the measure of the alteration of form which a solid body undergoes when under the influence of a given stress.

Strake. A term applied to a continuous row of plates. The strakes of shell plating are usually lettered, starting with "A", at the bottom row or garboard strake.

Strake, bilge. A term applied to a strake of outside plating running in the way of the bilge.

Strand. An element of a rope consisting of a number of rope yarns twisted together; and, in a wire rope, of a primary assemblage of wires.

Stranded. To drive or run aground; to beach.

Strap. A ring of wire or line, made by splicing the ends together, used for handling weight, etc.

Stream. To extend, or increase, the scope of the tow hawser.

Strength member. Any plate or shape which contributes to the strength of the vessel. Some members may be strength members when considering longitudinal strength but not when considering transverse strength, and vice versa.

Stress. The intensity of the force which tends to alter the form of a solid body; also, the equal and opposite resistance offered by the body to a change of form.

Stringer. A term applied to a fore-and-aft girder running along the side of a ship and also to the outboard strake of plating on any deck. The side pieces of a ladder or staircase into which the treads and risers are fastened.

Stud-link. A chain link with a bar fitted across the middle to prevent the chain from kinking.

Surge. To hold a line taut on a winch drum without hauling in; to slack off a line or let it slip around a fitting. A sudden transient increase in electrical current. A violent or sudden increase in load on a wire, line, winch, etc.

Surge load. Sudden strain on a towline caused by the pitching, shearing, or yawing of the tow and/or the towing ship.

Swage. To connect, splice, or terminate wire rope by use of steel fittings installed under extremely high pressure.

Swash bulkheads. Longitudinal or transverse nontight bulkheads fitted in a tank to decrease the swashing action of the liquid contents. A plate serving this purpose is called a swash plate.

Swivel. A removable anchor chain link fitted to revolve freely to keep turns out of a chain.

Tackle. An arrangement of ropes and blocks to give a mechanical advantage; a purchase; any combination of ropes and blocks that multiplies power. Also applied to a single whip which does not multiply power but simply changes direction.

Tee bar. A rolled or extruded structural shape having a cross section shaped like the letter "T."

Thimble. A grooved metal buffer fitted snugly into an eye splice.

Tiller (Tiller arm). Casting or forging attached to the rudder stock.

Tonnage. Tonnage is a description of the cargo capacity of a merchant ship. Tonnage is a volume measurement and does not indicate displacement.

Topside. That portion of the side of the hull which is above the designed waterline; on or above the weather deck.

Tow pad. A padeye designated or dedicated as the connection to the tow hawser or bridle. See **padeye**.

Traction winch. A capstan-like device that generates line tension in synthetic or fiber lines. Tension is generated by friction between the line and traction heads.

Transverse. At right angles to the fore-and-aft centerline.

Transverse frames. Vertical athwartship members forming the ribs.

Trim. Fore-and-aft inclination measured as the difference between the drafts at the forward and after perpendiculars. Ships designed to have drag — a deeper draft aft than forward — have zero trim when floating at or parallel to the design drafts. Excessive trim, usually considered to be more than one percent of the length of the ship, can be dangerous because it increases the danger of plunging (sinking by the bow or stern).

Tumble home. The decreasing of a vessel's beam above the waterline as it approaches the rail. Opposite of "flare."

Turnbuckle. A metal appliance consisting of a threaded link bolt and a pair of opposite-threaded screws, capable of being set up or slacked off, and used for setting up standing rigging or stoppers.

Two-blocked. When the two blocks of a tackle have been drawn together or tightened.

Ullage. The void above a liquid surface in a tank, and the measurement of this void.

Vapor. Any substance in the gaseous state that is usually a liquid or solid.

Veer. To pay out chain.

Veer away. To pay out chain under control by reversing winch or windlass rather than by surging.

Waterline. A term used to describe a line drawn parallel to the molded baseline and at a certain height above it, as the 10-foot waterline. It represents a plane parallel to the surface of the water when the vessel is floating on an even keel, i.e., without trim. In the body plan and the sheer plan it is a straight line, but in the plan view of the lines it shows the contour of the hull line at the given distance above the baseline. Used also to describe the line of intersection of the surface of the water with the hull of the ship at any draft and any condition of trim.

Watertight compartment. A space or compartment within a ship having its top, bottom, and sides constructed in such a manner as to prevent the leakage of water into or from the space unless the compartment is ruptured.

Web. The vertical portion of a beam; the athwartship portion of a frame; the portion of a girder between the flanges.

Web frame. A built-up frame to provide extra strength consisting of a web plate with flanges on its edges, placed several frame spaces apart, with the smaller, regular frames in between.

Whip. A term loosely applied to any tackle used for hoisting light weights and serves to designate the use to which a tackle is put, rather than to the method of reeving the tackle.

Wildcat. A special type of drum whose faces are formed to fit the links of a chain of given size.

Winch. An electric, hydraulic, or steam machine aboard ship used for hauling in lines, wire, or chain; a hoisting or pulling machine fitted with a horizontal single or double drum. A small drum is generally fitted on one or both ends of the shaft supporting the hoisting drum. These small drums are called gypsies or winch heads.

Windlass. An apparatus in which horizontal or vertical drums or gypsies and wildcats are operated by means of a steam engine or motor for the purpose of handling heavy anchor chains, hawsers, etc.

Wire rope. Rope made of wire strands twisted together, as distinguished from the more common and weaker fiber rope. Sometimes called a cable, or wire cable.

Wire rope pendant. A long wire strap.

Worming. Filling the lays of line or wire before parcelling.

Yard tug. A term used to describe harbor tugs used in berthing operations; e.g., YTL, YTM, and YTB Class of tugs.

Yaw. Failure of a vessel to hold a steady course because of forces of wind, sea, damage to vessel, etc.

Yellow gear. Salvage machinery.

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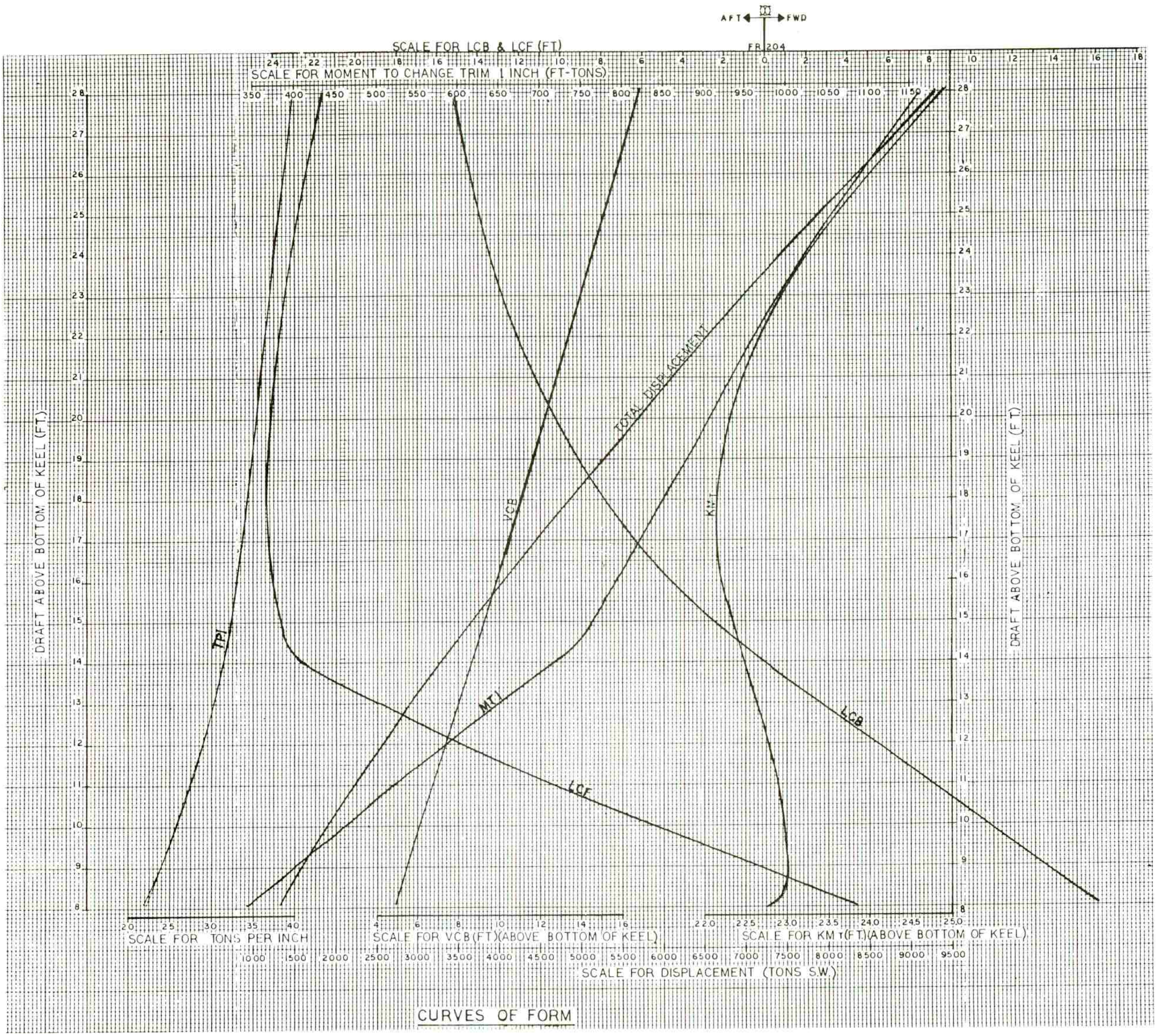

Figure FO-1. FFG-7 Class Curves of Form.

WATERLINE HALF BREADTHS

STA.	0'-0"	2'-0"	4'-0"	8'-0"	12'-0"	14.35	16'-0"	20'-0"	24'-0"	28'-0"	32'-0"	STA.
0							0 4 5+	1 1 6	2 0 5	3 3 4	4 9 4	0
1		0 9 5	1 2 7	2 0 3	2 8 7	3 3 2	3 7 6	4 8 7	6 1 5-	7 10 0	9 8 4	1
2	0 7 0	2 7 3	3 7 4	4 9 6	5 9 3	6 4 6	6 10 5	8 3 3	9 11 1	11 9 4	13 9 1	2
3	0 7 0	4 1 6	5 9 1	7 7 2	8 9 5	9 5 7	10 0 2	11 6 1	13 3 0	15 1 7	17 1 7	3
4	0 7 0	5 3 6	7 7 2	10 2 3	11 6 7	12 4 0	12 11 0	14 5 0	16 1 0	17 10 5	19 9 2	4
5	0 7 0	6 3 3	9 3 2	12 4 5	14 0 2+	14 10 7	15 6 1+	16 11 4	18 4 7+	19 11 3+	21 6 3	5
6	0 7 0	7 1 5	10 9 4	14 4 5	16 3 6+	17 2 3+	17 9 2	19 0 2	20 2 4	21 4 6	22 6 6	6
7	0 7 0	7 11 0	12 2 4	16 4 0	18 3 4	19 1 1	19 6 7	20 7 3	21 6 1	22 3 6	23 0 5	7
8	0 7 0	8 6 3+	13 4 6	18 0 5	19 11 0	20 7 0	20 11 5	21 9 1	22 4 5	22 10 3	23 3 0	8
9	0 7 0	8 11 6+	14 2 0	19 3 0	21 1 6	21 8 2	21 11 5	22 6 1	22 10 7	23 2 1	23 4 3	9
10	0 7 0	9 0 5	14 5 6	19 10 7+	21 10 4	22 4 4+	22 7 1	22 11 4	23 2 2	23 4 0+	23 5 2+	10
11	0 7 0	8 6 7+	13 11 6	19 10 2+	22 0 3+	22 7 0	22 9 4+	23 1 4+	23 4 1	23 5 3+		11
12	0 7 0	7 8 4	12 10 1+	19 2 5	21 9 3	22 5 2+	22 8 3	23 0 7+	23 3 7+	23 5 4		12
13	0 7 0	6 5 3+	11 1 7+	18 0 0+	21 2 0+	22 0 0+	22 3 7+	22 9 6+	23 2 0+	23 5 0		13
14		3 8 5+	8 8 3+	16 3 1	20 3 0	21 3 4	21 8 4	22 4 6+	22 11 1	23 4 1		14
15			4 7 6	14 0 5+	19 0 5	20 3 2	20 9 5+	21 9 1+	22 6 5+	23 3 1+		15
16				11 1 4+	17 6 4+	18 11 1	19 7 1	20 10 5	22 0 1+	23 0 7+		16
17				5 1 2	15 7 6	17 4 2+	18 2 1+	19 9 1+	21 1 7	22 5 3+		17
18					13 1 7	15 8 1+	16 8 6	18 5 0	19 9 7+	21 2 0+		18
19					6 11 1+	13 9 3+	15 1 0	16 9 6	18 1 1	19 3 7		19
20							12 7 0	14 10 7+	16 0 6+	17 0 4		20

BUTTOCK HEIGHTS

STA.	℄	2'-0"	4'-0"	8'-0"	12'-0"	16'-0"	STA.
0	14 4 1+	23 8 7+	29 11 4	39 9 7+			0
1	0 8 4+	7 10 6	17 5 0	28 4 3+	37 0 0+	45 8 0	1
2	0 0 0	1 2 5	5 0 7+	19 3 2	28 5 1+	36 7 .	2
3	0 0 0	0 6 2+	1 10 3	9 2 7	21 2 1	29 8 3+	3
4	0 0 0	0 4 3+	1 2 4	4 5 4	13 4 0+	23 9 7+	4
5	0 0 0	0 3 7	0 11 5	3 0 2+	7 3 6	17 3 7	5
6	0 0 0	0 3 5+	0 10 2	2 4 5	5 0 2	11 2 5+	6
7	0 0 0	0 3 3+	0 9 2	2 0 3	3 10 3+	7 6 2	7
8	0 0 0	0 3 2	0 8 5	1 9 7+	3 3 5+	5 9 2	8
9	0 0 0	0 3 0+	0 8 0+	1 8 4	3 0 4	5 0 3	9
10	0 0 0	0 3 1	0 8 1	1 8 2+	2 11 5+	4 9 2+	10
11	0 0 0	0 3 4	0 8 7	1 9 7	3 2 1	5 0 2+	11
12	0 0 0	0 4 0	0 10 2	2 1 1+	3 7 4+	5 6 7+	12
13	0 0 0	0 5 2+	1 1 1+	2 7 3+	4 4 6	6 6 5+	13
14	0 11 2	1 4 6+	2 1 1+	3 8 2	5 7 2	7 10 0	14
15	2 8 4+	3 1 6+	3 9 3+	5 2 5	6 11 6	9 1 0	15
16	4 10 2+	5 2 5+	5 9 1+	6 11 2+	8 4 0	10 5 7	16
17	7 0 7+	7 4 2	7 9 1+	8 7 5+	9 9 5	12 4 3+	17
18	9 3 4	9 5 5+	9 8 7	10 4 2	11 5 1+	14 9 4	18
19	11 6 0+	11 7 1+	11 8 7	12 1 3+	13 1 5	17 9 7	19
20	14 4 1+	14 4 5+	14 6 0+	15 0 1+	15 10 4	25 9 0	20

	BULWARK		MAIN DECK		SECOND DECK		
STA.	HEIGHT	HALF BREADTH	HEIGHT	HALF BREADTH	HEIGHT	HALF BREADTH	STA.
0	43 6 4	9 7 4	39 6 6	7 10 5+	27 4 4+	3 0 7	0
1	42 1 1	14 4 1	38 1 0	12 6 0	26 8 5	7 3 2	1
2			36 9 2	16 1 0	26 0 5	10 10 2	2
3			35 6 5	18 11 1	25 4 5	13 10 5+	3
4			34 5 3	20 11 0	24 8 5	16 4 4	4
5			33 5 2	22 1 1	24 0 5+	18 5 1+	5
6			32 6 2	22 8 4	23 4 5	20 0 2	6
7			31 8 7	22 11 0+	22 8 5	21 2 6+	7
8			31 0 6	23 2 0	22 0 6	22 1 2	8
9			30 5 7	23 3 5	21 5 7	22 8 1	9
10			30 0 0	23 4 6+	21 0 0	23 0 3	10
11			29 7 1	23 5 5	20 7 1	23 2 0	11
12			29 3 6	23 5 5+	20 3 6	23 1 1+	12
13			29 2 0	23 5 5	20 2 0	22 10 0	13
14			29 1 5+	23 5 3	20 1 5+	22 5 0	14
15			29 2 0+	23 5 3+	20 2 0+	21 9 5+	15
16			29 3 4	23 4 7	20 3 4	20 11 5+	16
17			29 6 5	22 11 1	20 6 5	19 11 4+	17
18			29 10 7	21 9 4	20 10 7	18 8 7	18
19			30 4 1	20 0 2	21 4 1	17 3 0	19
20			30 10 2	17 7 7+	21 10 2+	15 5 6	20

HULL FORM CHARACTERISTICS

(BARE HULL, MOLDED, WITHOUT SKEG OR DOME)

- LENGTH BETWEEN PERPS ______ 408.0 FT
- LENGTH OVERALL ______ 453.0 FT
- T, (DRAFT, TO DWL AT SECT OF MAX. AREA) ______ 14.35 FT
- BEAM, MAX. AT STA 11 (DWL) ______ 45.17 FT
- PRISMATIC COEFFICIENT (BASED ON SECT. OF MAX. AREA) ______ 0.594
- MAX. SECT. COEFFICIENT (TO DWL AT SECT OF MAX AREA) ______ 0.745
- LCB AS % OF LPP AFT OF FP ______ 50.1
- LCF AS % OF LPP AFT OF FP ______ 55.7
- DISPLACEMENT (BARE HULL TO DWL) ______ 3345 LTSW
- SECTION OF MAXIMUM AREA ______ 10.22

ALL OFFSETS GIVEN ARE IN FEET, INCHES & EIGHTHS

Figure FO-2. FFG-7 Class Lines Plans.

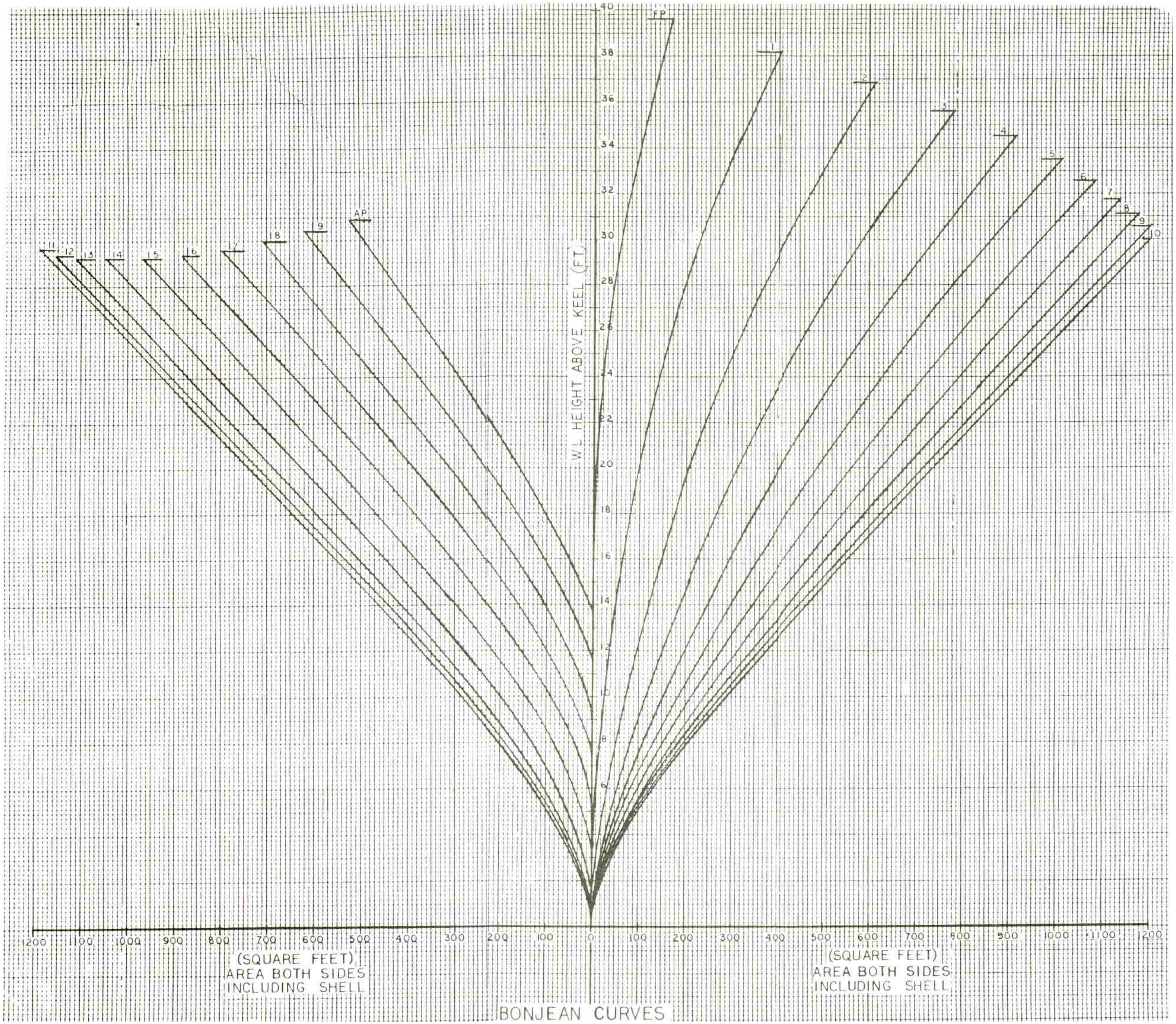

Figure FO-3. FFG-7 Class Bonjean Curves.

Ref: NAVSEAINST 4160.3A NAVSEA S0005-AA-GYD-030/TMMP

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