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UNIFIED FACILITIES CRITERIA (UFC)

MILITARY HARBORS AND COASTAL FACILITIES

U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

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HARBORS AND COASTAL FACILITIES

Record of Changes (changes indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes DESIGN MANUAL 26.1, 26.2 and 26.3.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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CHAPTER 1:

INTRODUCTION

1-1 **SCOPE**. The objective of this document is to cite and supplement existing government and commercial standards for design and construction of harbor and coastal facilities. It serves as planning, engineering and design guidance for professional facility planners, designers, constructors, and maintainers, including Navy personnel and Government contractors. Designers and planners will use this handbook for individual project planning, for preparing engineering documentation, and for preparing contract documents for construction and repair. This document extensively references the U.S. Army Corps of Engineers (USACE) *Coastal Engineering Manual* (CEM). The CEM is in the final stages of development and can be accessed at http://bigfoot.wes.army.mil/cem001.html. For sections not currently available contact NAVFACENGCOM EICO office.

1-2 **PURPOSE**. The purpose of UFC 4-150-06 is to provide adequate harbor and dredging project criteria, design and maintenance guidance, and relevant lessons learned with respect to shore infrastructure. This document also provides the complete criteria and guidance package needed by appropriate end users. To the extent practical, it addresses the range of harbor and dredging criteria needed at stateside and overseas military installations. **Note**: This document does not include overseas data.

1-3 **ORGANIZATION**. The majority of the information for subjects of this handbook is introduced as references to the applicable government and consensus standards in which the original information resides. Where other documents are not available or are inadequate, additional narrative information regarding Navy-specific issues has been developed and inserted, as appropriate.

1-4 **CANCELLATION**. UFC 4-150-06 cancels and supersedes NAVFAC Design Manual 26.1, *Harbors*, dated 1 December 1984, NAVFAC Design Manual 26.2, *Coastal Protection* and NAVFAC Design Manual 26.3, *Coastal Sedimentation and Dredging*, dated 1 September 1986.

CHAPTER 2:

HYDRODYNAMICS

2-1 **INTRODUCTION**. This chapter covers design considerations related to the physical effects on structures caused by various types of water movement, such as tides, currents, and wave action along the open shore line and those occurring within restricted bodies of water. This subject is thoroughly covered by the *Coastal Engineering Manual* (CEM) but is outlined below by subjects of interest to Navy coastal facilities designers and then cross-referenced to the appropriate section of the CEM and other applicable references. Note that references made to sections in the draft CEM may change once the final version is published. The most current version of the CEM at the time of this publication can be found on the web at http://bigfoot.wes.army.mil/cem001.html.

Port, harbor and facility issues, such as trends in port and harbor development, deep versus shallow draft projects and motivation, are discussed in CEM, Section V-5. These issues are discussed as explanations and justifications for harbor needs. For example, the motivation for developing new or existing port and harbor facilities is the importance of overseas trade to the U.S. economy and government.

Development of local design criteria is essential in many cases due to the variation in meteorological and geological conditions at different geographical sites. These criteria are based upon raw and hindcast environmental information and the forecasting of data with analytical descriptor models.

2-2 **WATER WAVE MECHANICS**. The very complex phenomenon of wave action on the sea surface, and how it affects structures, is a primary concern in design of coastal facilities. An extensive study to characterize regular and irregular waves is contained in Section II-1 of the CEM.

2-2.1 **Selection of Design Waves**. The selection of design waves should be related to the economics of construction, maintenance, and repairs. The selection of design conditions for larger structures requires more detailed consideration of the economics of the design. Wave analysis yields the recurrence interval of a given wave height. The economics of increasing the initial cost versus making occasional repairs must be evaluated. Furthermore, the cost and extent of damages to areas that the structure is designed to protect must also be considered. Physical and economic factors, such as design wave height versus annual costs, must be optimized. For small projects, a 20- to 25-year design wave, coupled with an annual extreme water level, is appropriate. In addition to the general design parameters for determining cost-benefit relationships, specific local design criteria must be determined and applied. For example, Norfolk, VA would not use a 50-year hurricane, although it may be an appropriate criterion for other locations. Refer to the CEM, Section II-8: Coastal Hydrodynamics, for further details.

2-3 **METEOROLOGY AND WAVE CLIMATE**. A basic understanding of marine and coastal meteorology and the relationship between meteorological processes and wave generation is important to coastal design and planning. Section II-2 of the CEM contains an analysis of this subject.

2-4 **ESTIMATION OF NEARSHORE WAVES**. The size and directions of nearshore waves that impact coastal design are strongly influenced by underlying seafloor geometry and currents. While overestimating wave height can inflate the price of a project, underestimating can result in catastrophic loss. Section II-3 of the CEM evaluates wave transformation analyses methods and provides guidance for selecting a reasonable approach for making wave transformation calculations.

2-5 **SURF ZONE HYDRODYNAMICS**. Breaking waves, and the resulting dissipation of energy, induce nearshore currents and other hydrodynamic processes that make the surf zone the most dynamic coastal region. Section II-4 of the CEM describes shallow-water wave breaking and associated hydrodynamic processes that affect shoreline and beach profile, which impact the design of coastal structures and beach fills.

2-5.1 **Coastal Bottom Boundary Layers**. The severe interaction between the slowly varying current boundary layer and the turbulent wave bottom boundary layer during severe storm events plays a significant role in sediment transport. This interaction, which occurs primarily in the area just outside the surf zone, in water depth ranging between 2 or 3 m (6.6 to 9.8 ft) up to 20 to 30 m (65.6 to 98.4 ft), affects sediment that is not usually suspended under normal wave conditions. The fate of the sediments in this zone is a complex question for coastal engineers. The factors and complexities that make analysis of this activity so difficult are discussed in Section III-6 of the CEM. An extensive analysis of this process is contained in *Coastal Bottom Boundary Layers and Sediment Transport* by Peter Nielsen.

2-6 **WATER LEVELS AND LONG WAVES**. A significant component of coastal design is protection of structures from some predefined water surface elevation. The following sections, the scope of which is summarized in Section II-5, of the CEM, classify the various types of surface elevation variation generated by long waves and guidance for developing a preliminary study approach and applicable design procedure. A discussion of the geological effects of wave action is contained in Section IV-2 of the CEM.

2-6.1 **Water Wave Classification**. Section II-5-2 of the CEM gives a brief review of wave classification criteria and a summary of long wave properties.

2-6.2 **Astronomical Tides**. Astronomical tides represent an important example of long waves. Section II-5-3 of the CEM describes tidal processes and effects.

2-6.3 **Water Surface Elevation Datums**. Section II-5-4 of the CEM describes the various means of defining water surface elevation datums and the relationship between tidal observation-based datums, which account for spatial variability of sea level and vary according to locale, and the National Geodetic Vertical Datum (NGVD), which does not. It also discusses several processes that result in long-term changes in relative mean sea level. An additional discussion of datums and relationship to coastal geology is contained in Section IV-2-4 of the CEM. The selected datum and a rationale for its choice should be stated specifically in the design documentation.

2-6.4 **Storm Surge**. High-wind systems and low barometric pressures over shoaling water will create a temporary water-level rise along shorelines. Especially susceptible are areas where large cyclonic storm systems (such as hurricanes and typhoons) track across relatively shallow offshore water. A relatively short-duration water-level rise (setup) will occur along coastlines during episodes of high-wave attacks. The rise in water level is caused by breaking waves trapping a water mass along the shoreline. This water rise can increase water heights in protected water areas hydraulically linked to the coast, shoreward of the breaker line. This phenomenon, and generated currents associated with it, can be significant in harbor sites located behind reefs or large shoals. Section II-5-5 of the CEM discusses the effect of tropical and extra-tropical storm activity on water surface elevation.

2-6.5 **Seiche**. Defined as a standing-wave oscillation of an enclosed body of water that continues, pendulum fashion, after the cessation of the originating force, seiche may be either seismic or atmospheric in origin. Seiche is a phenomenon associated with ocean waves having periods in excess of those of normal sea swell. Such waves, commonly known as "long waves," have periods ranging from 20 seconds to several hours. Long waves exhibit relatively low heights, on the order of 0.03 to 0.12 meters (0.1 to 0.4 foot.) They are highly reflective, even off flat-slope beaches, and will pass virtually unimpeded through porous breakwaters. Seiche occurs within a basin, harbor, or bay during certain critical wave periods when the period of incident long-wave energy matches the resonating period of the basin. The result is a standing wave system comprising reinforced wave heights greater than those of the incident wave. The water surface exhibits a series of nodes and antinodes with respect to the water column. Antinodes are regions where the vertical motion is a maximum and the horizontal velocities are minimum. Where wavelength is sufficiently greater than ship length, a ship berthed at the antinode will experience a gentle rise and fall with the standing-wave period. At the node, the ship will be subject to a periodic horizontal surging action due to currents. A ship in combination with its mooring lines behaves as a spring-mass system which, when excited, can resonate at certain critical frequency ranges. During seiching action, the horizontal surging motion of a vessel located near a node can interfere with loading operations and, in severe cases, cause the mooring lines to part. Section II-5-6 of the CEM discusses further details of this phenomenon.

2-6.6 **Tsunamis**. In certain ocean regions, waves generated by seismic disturbances or landslides occur. From event history, some shoreline locations are more susceptible to damage from tsunamis than others. Probability approximations of water-level height exist for some coastal locations. These are included in reports by the U.S. Army Corps of Engineers (USACE) and licensing studies by Public Utility Commissions. If warranted, a site-specific risk analysis can be performed which relies heavily upon probability parameters for specifics of the underwater seismic movement.

Contact the NAVFAC EICO Office regarding when to perform such site-specific risk analyses. This is coupled with a three-dimensional numerical analysis of ocean-basin propagation and near-shore site shoaling of the resulting long wave.

2-6.7 **River Discharge and Flood Control Channel Discharge**. Where a harbor site is hydraulically influenced by river discharge, present as well as future river flood discharge effects on water levels need to be considered. Effects of river discharge on harbor hydrodynamics are discussed briefly in Section II-7-6 of the CEM. Deltaic processes, river mouth flow, and sediment disposition, and inlet processes and dynamics are discussed in Section IV-3.

2-6.8 **Extreme Water Levels**. The estimation of extreme water levels is discussed in Section II-8-6-e of the CEM.

2-6.9 **Numerical Modeling of Long Wave Hydrodynamics**. Due to the complexity of most natural flow systems, engineering analyses for coastal engineering design projects often require numerical modeling of the hydrodynamic processes. Methods for applying this analytical tool are described in Section II-5-7 of the CEM. NAVFAC EICO Office should be contacted when contemplating using numerical modeling.

2-7 **HARBORS**. Because harbors are, by nature and design, protected from short wave effects, long wave processes primarily drive their hydrodynamic environment. Specific information on these processes is examined in the sections on tides, seiche, storm surge and other long wave phenomenon. Section II-7 of the CEM covers the hydrodynamics of harbors, including effects of wave action, flushing/circulation, and vessel interaction. The discussion of inlet hydrodynamics contained in Section II-6 of the CEM also adds insight into the processes that take place at the entrance of a harbor and impact its overall hydrodynamic environment. The impact of these processes on moored ships and criteria for acceptable ship motions in safe working conditions is contained in the Permanent International Association of Navigation Congresses (PIANC) report titled *Criteria for Movements of Moored Ships in Harbours - A Practical Guide*.

2-7.1 **General Function**. A harbor is described as a water area that is bounded by natural features or manmade structures or a combination of both. As such, it provides refuge and safe moorings and protection for vessels during storms or accommodations for such water to water or water to land activities as resupply, refueling, repairs, or transferring cargo and personnel. In such cases when a harbor is used to transfer commercial cargo or passengers, it is designated as a “port”. More specifically, when military services use a harbor or portions thereof, the facility is referred to as a “military harbor”. The landside areas adjacent to military harbors are also included under this designation because they support various waterborne naval activities. Additional terms such as naval base, naval station, naval depot, and naval shipyard are also used depending upon the appropriate support activity.

2-7.2 **Purpose of Harbor Construction**. The intended goals in designing and constructing a harbor are twofold: to obtain a relatively large area of water, with adequate depth during all tidal stages that will provide shelter for ships and to provide a means by which to transfer cargo and passengers between ships and shore locations and facilities.

2-7.3 **Harbor Features**. Though it may not be feasible to provide all of the desirable characteristics of an ideal harbor at any one location, the ideal waterside harbor would include the following features:

- shelter from open-sea waves,
- minimum tidal range and moderate currents,
- freedom from troublesome long-wave agitation (seiche),
- freedom from fog and ice,
- access through one or more safe navigational channels under all weather conditions,
- adequate room and depth to maneuver ships within the sheltered area,
- space for an adequate number of fixed moorings,
- shelter from strong winds from all directions,
- minimum maintenance dredging, and
- room for future expansion.

The following landside features provide accommodation for naval ship activities:

- layout of quays, piers, and wharves to accommodate ships of varying lengths and drafts,
- waterfront structures of dimensions and strength to accommodate weight-handling equipment and cargo-hauling vehicles, including both road and rail,
- utility services at berth
- covered and uncovered transit storage in the immediate area of the berth, with additional long-term and depot storage at a more remote location where required,
- space for adequate road and rail transportation linkage between the waterside area and inland distribution,

- provisions for the transfer and accommodation of passengers,
- provisions for small craft, shore boats, lighters, and tugs,
- safety from fire hazards,
- minimum general maintenance,
- proximity to labor and material sources,
- proximity to air-transport facilities,
- adaptability of shore installations for alternate uses, and
- room for expansion.

2-7.4 **Types of Harbors**. The locations for constructing harbors range from open coastlines requiring artificial impoundments to natural bays, estuaries, and navigable rivers that need a minimum of manmade structures for the necessary storm protection. Within limits, harbors may be built wherever suitable water depth exists or can be provided and maintained with dredging operations. The degree of artificial works necessary to construct a viable harbor varies with the site's natural features. Examples of various siting classifications are shown in Figure 2-1. The characteristics of harbor location types are given in Table 2-1.

Figure 2-1 Examples of Harbor Siting Classifications

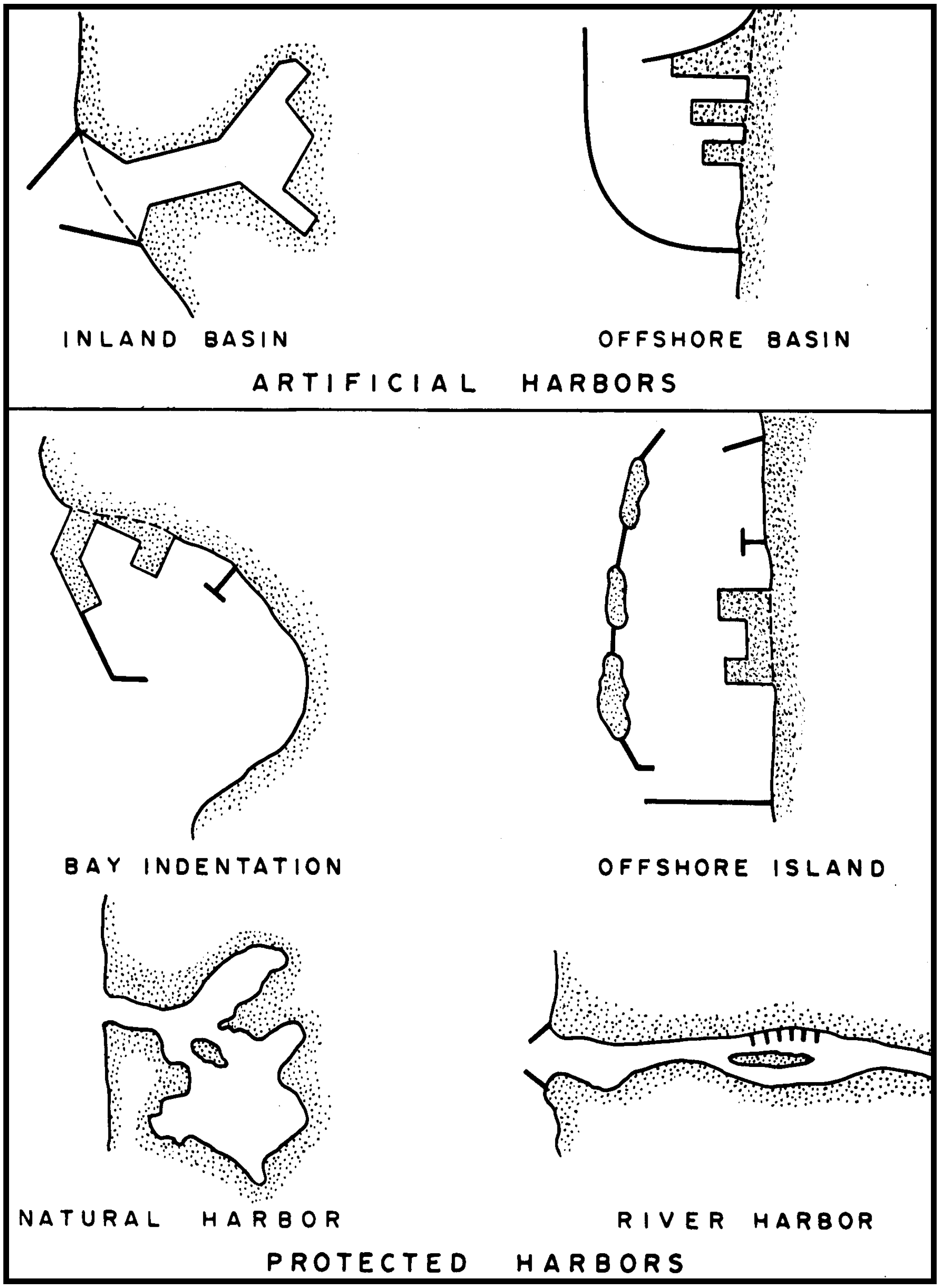


Table 2-1 Characteristics of Harbor Location Types

Type		Characteristics
Artificial – inland basin	Needs: Advantages: Concerns:	Low elevation; economical excavation. Less breakwater costs; feasibility of expansion. Low ground may contain poor soils; potential of flooding and sedimentation from upland sources; distance to offshore navigational water depth; littoral drift; silting.
Artificial – offshore basin	Needs: Advantages: Concerns:	Adequate sources for extensive breakwater construction material. Normally good foundation conditions can be developed with minimal dredging. Construction costs relatively high for harbor size; minimum expansion capability; littoral drift; shoaling.
Protected	Needs: Advantages: Concerns:	Shoreline relief features help to reduce storm-wave exposure. Less breakwater development cost. Can be same as other locations.
Natural	Needs: Advantages: Concerns:	Natural ocean access passage of adequate dimensions leading to embayment protected from storm waves. Minimal effort required for developing protected water area. If not historically used as ship refuge area, ascertain reason (example: Lituga Bay, Alaska, which is subject to landslides and massive waves); natural sediment regime should be thoroughly investigated if extensive deepening of natural depths is proposed.
River	Needs: Advantages: Concerns:	Historically stable river of adequate natural depths and widths to accommodate proposed vessel sizes. Minimal effort required for developing protected water area. Currents and water-level fluctuations due to variation in river stages; effects of new works on river's natural alluvial regime require thorough analysis, including effects of salinity changes; extensive basin dredging and channel deepening should be avoided where possible.

2-7.5 **Open Coastlines**. When harbors are situated on open coastlines, a high degree of artificial work is required to provide shelter. Consequently, as the coastline itself becomes more winding and offshore islands appear, the degree of natural shelter provided in turn reduces the harbor's exposure to wind and waves. Thus a corresponding decrease in the amount of artificial protection is required.

2-7.6 **Bays, Estuaries, and Navigable Rivers**. When the harbor is situated entirely within an enclosed bay or estuary having a narrow opening into the sea, an environment of total natural protection results. Depending on the orientation of the naturally occurring protective features, these harbor sites need little or no additional protection. Nonetheless, a degree of entrance improvement is usually required to ensure safety during storms and as the entrance widens, the degree of protection required increases as well.

2-7.7 **Hydraulic Impoundments**. Hydraulic impoundments are defined as harbor basins in which the vessel mooring depth is constantly maintained behind locks, versus the case in harbors where free-flowing water linkages to the sea or other large bodies of water exposed to storms exist. Since harbors are not located in bays, estuaries, and rivers, the hydraulic-impoundment harbors are not influenced by tidal fluctuations. Either admitting or releasing water through the locks maintains water levels. Though constructed worldwide economically efficient for commercial port facilities, the constricted access of hydraulic impoundments makes then generally undesirable for military purposes.

2-7.8 **Roadsteads**. In cases when protection is provided only as a moored-ship refuge, the protected harbor area is referred to as a "roadstead." Roadsteads need a bottom in the protected area in the protected area that is suitable for sufficient anchor holding power. Examples of roadstead anchorages in a natural bay and a protected harbor are shown in Figure 2-2.

2-8 **HYDRODYNAMIC INVESTIGATIONS**. Effective coastal engineering studies require appropriate understanding of the hydrodynamics of the project area and its impact on design parameters. A summary of the considerations and procedures for hydrodynamic investigations is contained in Section II-8 of the CEM.

2-9 **SHIP DYNAMICS IN CHANNELS**. Ships moving in shallow or restricted waterways experience dynamic behavior different from that exhibited in open water that can significantly affect control of the ship. The width and depth of the channel, if insufficient, can interfere with the normal passage of water around the hull of the ship and inhibit steering control. The sinkage and trim of a vessel in a navigation channel depend primarily on vessel speed, the ratio of the channel cross section area to the vessel wetted cross section area, and the ratio of the water depth to the vessel draft. The maximum vessel draft is determined through consideration of the effects on vessel draft by such factors as squat, variation in salinity, effects of wave motion, and loading. In addition, some judgment needs to be exercised in considering the conditions that could realistically be expected to occur. For example, it wouldn't be practical to design a ship channel for extremes of vessel draft during a hurricane, because the ships probably will not attempt to transit the channel during the storm. The effect of these and other factors on design parameters are discussed in the CEM, Section II-7-7-b(4). Additional analysis of this subject is contained in *Principles of Naval Architecture, Vol. 3* (Lewis, 1990).

2-10 **SOURCES OF HYDRODYNAMIC INFORMATION**. Because coastal engineering design requires considerable knowledge of many physical sciences and engineering disciplines, the CEM contains a summary of sources for available information in Section II-8.

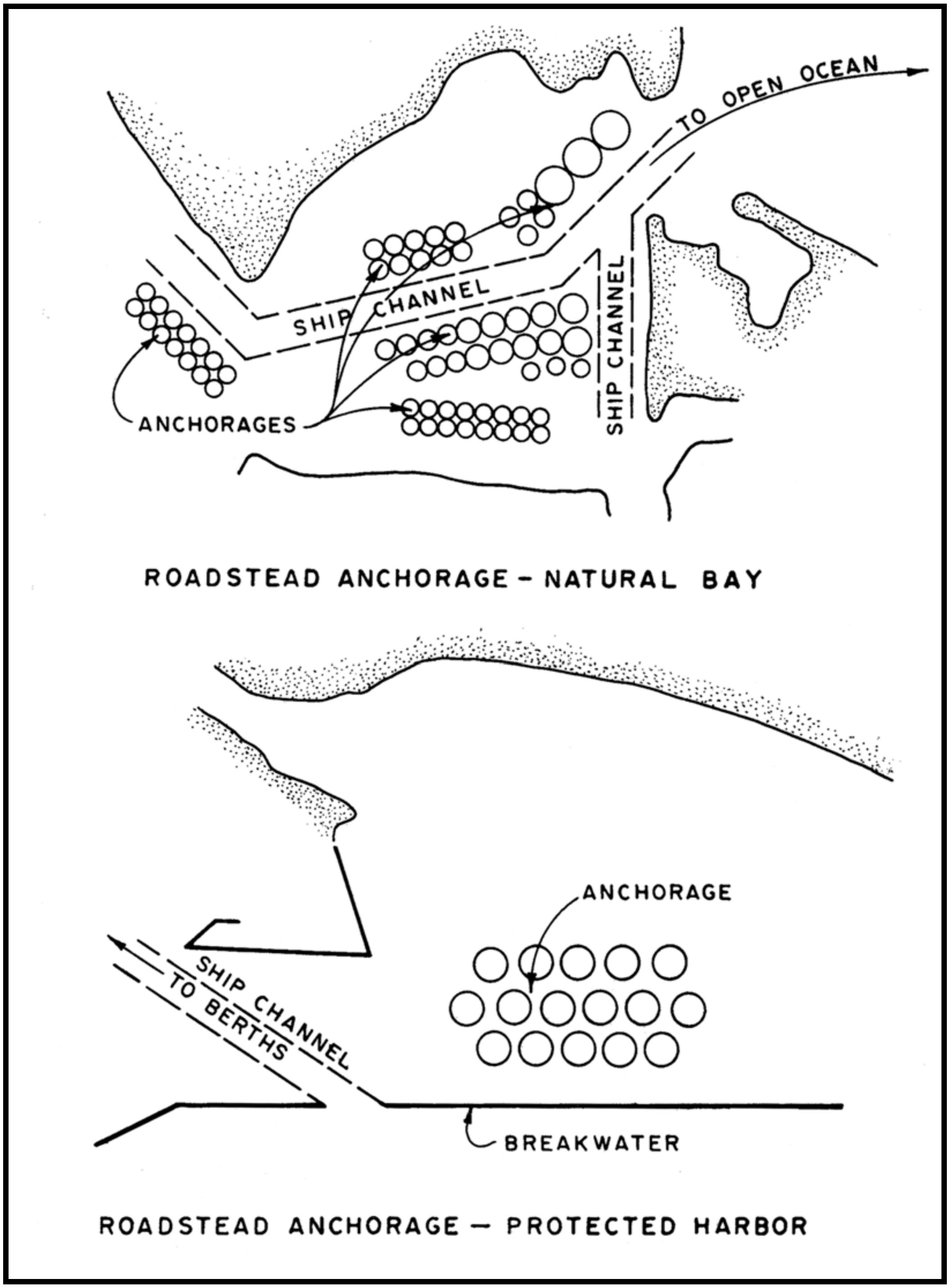
2-11 **COMBINING DESIGN EVENTS**. Consideration of specific event extremes is the first step toward determination of design requirements. However, there are situations where the probability of coincident events is significant enough to warrant a further analysis of the combined effects of those events. As stated in the CEM, Section II-5-5-a(3), the importance of the timing of a storm event with tide phase cannot be over-emphasized because the resulting combined effect can be catastrophic. Methods for determining the frequency of occurrence for a 25- or 50-year storm are discussed in Section II-5-5-b of the CEM.

2-11.1 **Earthquake and Low Tide**. Coastal projects in areas with a high probability of seismic activity need to consider potential impacts related to ground deformation and severe liquefaction. The decision to allow for seismic loading in a coastal project design may hinge on such factors as estimated repair costs versus replacement costs, if loss of life and interruption of vital services are not considerations. Flexibility of the structure is a consideration in areas where rubble mound structures tend to be less affected by seismic activity than monolithic structures. Although not discussed in available texts, there is the potential that the stability of bluffs and coastal structures can be catastrophically affected if that activity occurs at a time of extreme low tide.

2-11.2 **Storm Surge and High Tide**. Coastal areas are susceptible at certain times of the year to the effects of storm surge associated with high surf, which, if combined with an extreme high tide, can cause disastrous erosion of the shoreline. The importance of considering this interaction in coastal design is discussed in Section II-5-5-a(3) of the CEM.

The majority of coastal structures are designed to provide a level of protection to the beach and the surrounding population and supporting structures. This level of protection is generally based on a determination of the frequency-of-occurrence of a storm surge of a specified maximum elevation selected through an assessment of the risks of structural failure or consequences of overtopping versus project design costs. Consequently, it is important to determine stage frequency or frequency-of-occurrence relationships for the area in question. The designer must investigate and determine such factors as how to define high tide (2 min per day or 2 hours per day) and the probability of this happening with an extreme event such as a 25- or 50-year hurricane. Essentially, the phasing of the storm and tide both impact the design of the structure and the probability analysis of the design.

Figure 2-2 Examples of Roadstead Moorings



2-11.3 **Storm Water Runoff and High Tide or Storm Surge**. The orientation, magnitude, and thickness of storm water runoff plumes are functions of the amount of river discharge, wind speed, direction, and duration, local ocean currents due to tides and surge, and local bathymetry. The runoff plume generally spreads out in a thin-layer over a large area as it mixes with ambient seawater. As a river discharges along the coast, the storm water runoff plume tends to spread in a longshore direction, parallel to the coast.

It is unclear as to whether or not dissolved and suspended plume components spread similarly throughout the water column. Thus, sufficient turbulence caused by river eddies or strong winds can cause particles to remain in suspension. With time, as turbulence decreases, particles will come out of suspension and deposit on the seafloor.

Coastal engineers should be aware that a coupling action between storm water runoff dynamics coincident with high tide or storm surge would undoubtedly have an effect on coastal project designs.

A lack of information covering this topic in the literature indicates that a need exists to more closely study these phenomena by conducting *in situ* observation and combining this data with analytical models to simulate the coupled effects. We solicit any comments and information regarding this phenomenon.

CHAPTER 3:

SEDIMENT DYNAMICS

3-1 **INTRODUCTION**. This chapter describes the important physical processes related to the movement of sediment around and in harbors and coastal facilities. An understanding of sediment movement is required for the proper design and maintenance of coastal facilities, such as siltation in harbors, shoreline erosion near structures, scour and burial of cables and pipelines, or anchoring in the nearshore. Much of the information related to these topics is contained in the CEM and the draft American Society of Civil Engineers (ASCE) “Standard for Shore Protection Systems". These and other applicable references are cross-referenced below by subject. The development of local criteria is essential in many cases due to the variation in meteorological and geological conditions at different geographical sites. If there are specific additional criteria to be considered, recommendations should be provided to Naval Facilities Engineering Service Center, Code 51, Port Hueneme, CA 93043, telephone (805) 982-1170.

3-2 **SEDIMENT TRANSPORT PROCESSES**. Sediment transport in the nearshore zone is generally a result of the combination of breaking waves and various patterns of nearshore currents, characterized as a vector with both longshore and cross-shore components. Analysis of these two components has historically been performed separately because one or the other tends to dominate in a particular scenario. A discussion of the components of sediment transport and methods of analysis is found in Section III of the CEM, starting with a discussion of sediment classification by size and properties, followed by transport processes of cohesionless and cohesive sediments, and concluding with a discussion of sediment transport outside the surf zone.

3-2.1 **Sediment Transport Rates**. Estimates of sediment transport rates can be derived either from calculations or through analysis of historical data. Although analysis of historical shoreline changes may provide a higher level of confidence, underestimation of the transport rate has not been uncommon in past practice. Where accuracy is critical to project development, construction and monitoring of a test groin to verify the estimate should be considered. However, the test groin must extend seaward far enough to trap all the littoral material. Representative examples of historical data for various coastal locations are shown in Table 3-1.

Sediment transport and deposition occur on open coasts, in tidal inlets, estuaries, harbors, and rivers. Sedimentation problems occurring in locations such as these are a function of soil type, continuity of materials, and the potential for fluid motion to transport material.

3-2.2 **Harbor Siting**. Assess sedimentation processes when siting a harbor or an open-coastal littoral system, in an inlet system, or in a river-mouth estuary system. In each of these systems, transport capacity and sediment supply factors must be taken into account. A state of natural equilibrium may be due to unchanging channel depths or stable shoreline positions; alternatively, gradual and long-term sedimentation or erosion processes may be occurring. Refer to Sections III and V-6 of the CEM.

Table 3-1 Longshore-Transport Rates at Selected U.S. Coastal Locations

Location	Predominant Direction of Transport	Longshore Transport[a] m^3/yr (cu yd/yr)	Date of Record
Atlantic Coast			
Suffolk County NY	W	152,920 (200,000)	1946-55
Sandy Hook, NY	N	376,948 (493,000)	1885-1933
Sandy Hook, NY	N	333,366 (436,000)	1933-51
Asbury Park, NJ	N	152,920 (200,000)	1922-25
Shark River, NJ	N	229,380 (300,000)	1947-53
Manasquan, NJ	N	275,256 (360,000)	1930-31
Barneget Inlet, NJ	S	191,150 (250,000)	1939-41
Absecon, Inlet, NJ[b]	S	305,840 (400,000)	1935-46
Ocean City, NJ[b]	S	305,840 (400,000)	1935-46
Cold Spring Inlet, NJ	S	152,920 (200,000)	-
Ocean City, MD	S	114,690 (150,000)	1934-36
Atlantic Beach, NC	E	22,556 (29,500)	1850-1908
Hillsboro Inlet, FL	S	57,345 (75,000)	1850-1908
Palm Beach, FL	S	114,690 to 172,035 (150,000-225,000)	1925-30
Gulf of Mexico			
Pinellas County, FL	S	38,230 (50,000) 152,920	1922-50
Perdido Pass, AL	W	(200,000)	1934-53
Pacific Coast			
Santa Barbara, CA	E	214,088 (280,000)	1932-51
Oxnard Plain Shore, CA	S	746,600 (1,000,000)	1938-48
Port Hueneme, CA[c]	S	746,600 (1,000,000)	-
Santa Monica, CA	S	206,442 (270,000)	1936-40
El Segundo, CA	S	123,865 (162,000)	1936-40
Redondo Beach, CA	S	22,938 (30,000)	-
Anaheim Bay, CA[b]	E	114,690 (150,000)	1937-48
Camp Pendleton, CA	S	76,460 (100,000)	1950-52
Great Lakes			
Milwaukee County, WI	S	6117 (8,000)	1894-1912
Racine County, WI	S	30,584 (40,000)	1912-49
Kenosha, WI	S	11,469 (15,000)	1872-1909
IL State Line to Waukegan	S	68,814 (90,000)	-
Waukegan to Evanston, IL	S	43,582 (57,000)	-
South of Evanston, IL	S	30,584 (40,000)	-
Hawaii			
Waikiki Beach, HI[b]	-	7646 (10,000)	-

[a]Transport rates are estimated net transport rates. In some cases, these approximate the gross transport rates.
[b]Method of measurement is by accretion except for Absecon Inlet, NJ, Ocean City, NJ, and Anaheim Bay, CA (by erosion) and Waikiki Beach, HI (by suspended load samples).
[c]Reference for Port Hueneme, CA, is U.S. Army (1980).

3-3 **COASTAL GEOLOGIC MORPHOLOGY**. Classification of coastal geology and geologic character is of great importance to coastal engineers because of the complexity and diversity of the coastal environment. Section IV-3 of the CEM describes the historical emergence of coastal geologic classifications and summarizes the current preferred classifications and their influence on contemporary coastal design.

3-4 **COASTAL MORPHODYNAMICS**. The discussion of coastal morphodynamics in Section IV-4 of the CEM states that coastal landforms are the result of the interactions of many physical processes, man-made influences, global tectonics, local underlying geology, and biology. Significant to the coastal designer is the fact that the physical conditions along the coast are constantly changing in response to many processes and often, in a relatively limited area, influence the formation of a combination of the four types of coastal environments: deltas, inlets, sandy shores, and cohesive shores (CEM, Section IV-4).

3-5 **FOUNDATIONS AND ANCHORING**. Seafloor conditions and materials must be considered when placing structures and establishing an area for anchorage. Considerations for seafloor foundation design are discussed in Section VI-3-1 of the CEM. "Scour" occurs where sediment is eroded from beneath or around a structure's foundation making it susceptible to failure. A summary of this process and its effects is found in the *Handbook for Marine Geotechnical Engineering*, edited by K. Rocker (Naval Civil Engineering Laboratory (NCEL), 1985). Additional design considerations regarding sediment transport are discussed in Section III-1-1 of the CEM.

3-5.1 **Anchoring**. Selection of anchor type is based on bottom conditions. Information on this subject is also contained in the "Handbook for Marine Geotechnical Engineering" (Rocker, 1985). Where possible, locate the anchorage over a bottom of loose sand or gravel, clay, or soft coral. Avoid locations where the bottom consists of rock, hard gravel, deep mud, and deep silt.

3-6 **SEDIMENT BUDGET**. Sediment budget is based on the principle of continuity or conservation of mass as applied to coastal sediments. A discussion of the processes and methods of evaluation are found in Section III-2-3-g of the CEM. Related information concerning wind blown sediment transport is contained in Section III-4-5-c of the CEM.

3-7 **EFFECTS OF STRUCTURES ON SEDIMENT TRANSPORT**. Man-made structures have a significant influence of sediment transport mechanisms. Groins, seawalls, jetties, breakwaters and piers all affect sediment transport and deposition processes. Numerous examples given in Sections III-2 and III-3 of the CEM indicate that the effect of these man-made structures on sediment deposition is significant in coastal engineering design. These effects can often be a source of technical data when investigating sediment transport.

3-8 **MATERIAL PROPERTIES**. Sediment transport and deposition occur on open coasts, in tidal inlets, in estuaries, in harbors, and in rivers. The types of sedimentation problems that occur at each of these locations depend, in part, on the soil type. Properties and composition of coastal sediments are discussed in Section III-1 of the CEM. Additional information can be found in *Technical Notes, Technical Area 2: Material Properties Related to Navigation Dredging, published by the USACE Waterways Experiment Station (WES) for the Dredging Research Program (DRP)*. The Dredging Research Program Bibliography can be found on the web at http://bigfoot.wes.army.mil/c180.html.

3-9 **OPEN WATER DISPOSAL**. Disposal of project-removed sediment in open water can be an appropriate alternative where transportation costs for land disposal become prohibitive. In some cases, it is also useful for replenishment of shoreline where erosion is a problem. However, when foreign sediment is introduced into the marine environment, associated environmental issues arise. Whether from dredging operations or any other construction activity that affects the natural sediment environment, the coastal engineer needs to evaluate the impact on bottom dwelling and water column organisms due to such factors as blockage of light or toxicity of the sediment. Additional information is contained in Technical Notes published by the U.S. Army Engineer Waterways Experiment Station (WES) for the Dredging Research Program (DRP).

3-9.1 **Contaminated Sediment Risk Assessment**. The sediment property of most environmental consequence is grain size. Turbidity in the water column depends on the fall velocity of the sediment particles, which is largely a function of the grain size. Turbid waters can be carried away by currents from the immediate project site, blocking the light to organisms over a wide area. As the sediments settle out, they blanket the bottom at a rate faster than the organisms can accommodate. Fine sediments (silts and clays) get greater scrutiny under environmental regulation because they produce greater and longer-lasting turbidity, which will impact larger areas of the seafloor than will coarser, sand-sized material. The dredging of sand usually encounters less severe environmental objection, provided that there are few fine sediments mixed with it and that the site has no prior toxic chemical history. Environmental regulation is changing, and many regulatory questions are outside the usual experience of coastal engineers. However, a basic coastal engineering contribution to facilitating the progress of a project through regulatory review is the early collection of relevant sediment samples from the site and obtaining accurate data on their size, composition, and toxicity. These issues are discussed in Sections III-1-1-b(2) and V-6-1-d of the CEM. Environmental requirements are discussed further in paragraph 5.3, “Regulatory Requirements,” of this handbook.

3-10 **GEOLOGICAL INVESTIGATIONS**. Effective coastal engineering studies require appropriate understanding of the geology of the project area and its impact on design parameters. A presentation of the considerations and procedures for coastal geological investigations is contained in Section IV of the CEM.

3-11 **SOURCES OF SEDIMENT PROCESS INFORMATION**. A summary of sources of available coastal information and data can be found in Section IV of the CEM.

CHAPTER 4:

CONSTRUCTION MATERIALS

4-1 **INTRODUCTION**. The majority of materials utilized in coastal construction are quite similar to those used in dry-land construction. However, their introduction into the marine environment results in a need for the designer to expand his view of material degradation methods. In addition to the increased corrosive environment and possible freeze-thaw cycles, they must withstand relentless wave pounding and marine organisms that can attack most materials in a variety of ways. Primary material selection criteria are physical properties and strength, durability, adaptability, cost, availability, handling requirements, maintenance requirements, and environmental impact. Much of the information related to this topic is contained in Section VI-4 of the CEM.

4-2 **CONSTRUCTION MATERIALS CONSIDERED, ANALYZED, OR COMMONLY USED**. The primary materials used in construction of coastal projects are stone, concrete, beach sand, steel, timber, composites, and geotextiles. These materials are critically important to the success and longevity of the project. Knowledge of past material performance on similar coastal projects is an important consideration for the design engineer. Detailed information on the materials discussed below and their selection criteria can be found in Section VI-4 of the CEM.

4-2.1 **Availability**. In addition to the technical considerations for material selection, local availability of materials plays a big role in cost, both for initial construction and for future maintenance and repair planning. A summary of this and other material availability issues is contained in Section VI-3-7 and VI-4-1 of the CEM.

4-3 **EARTH AND SAND**. Coastal projects tend to be fairly large and require a significant volume of construction materials. When feasible, structures are designed to use earth or sand as an economic filler material, and in many cases the mechanical strength properties of the soil are an integral part of the design. Some varieties, properties, and common uses of earth and sand in coastal construction are described in Section VI-4-2 and VI-4-3 of the CEM.

4-4 **STONE**. Used extensively to construct coastal structures, stone is by far the most common material used in the United States for breakwaters, jetties, groins, revetments, and seawalls. A description of types of stone and their uses for coastal projects is contained in Section VI-4-1 and VI-4-3 of the CEM.

4-5 **CONCRETE**. Concrete is the predominant construction material for waterfront facilities due to its durability, strength, and economy as a bulk construction material, and the basic components to make concrete are readily available at most locations. To optimally design a breakwater, for example, it is important to budget for minimum capital cost without excessive maintenance costs over the lifetime of the structure. Common breakwater designs based on an inner mound of small rocks or rubble provide stability, while an outer armor of large boulders protects the structure from wave action. Outer armoring designs range from simple concrete cubics or rectangulars, dense natural rock, and four-legged tetrapods (with each leg projecting from the center at an angle of 109 1/2° from each of the other three), to solid breakwaters made of concrete or masonry. Section VI-4-4 of the CEM summarizes specific applications of concrete in coastal construction.

4-6 **STEEL**. Use of steel and considerations for appropriate applications are discussed in Section VI-4-5 of the CEM.

4-7 **WOOD AND TIMBER**. Wood and timber members are widely used for the construction and maintenance of waterfront facilities due to availability, economy, and ease of handling relative to other construction materials. Wood can be used in coastal projects such as seawalls, revetments, bulkheads, piers, wharves, sand fences, and floating platforms. It's also used for temporary constructions such as formwork, bracing, and blocking. Uses of wood and timber and applicable properties, benefits, and drawbacks are described in Section VI-4-6 of the CEM.

4-8 **COMPOSITES**. Though the subject of composite materials is applicable to the design of piers and wharves, this relatively new field is not addressed in the CEM. Nonetheless, many of the nation's leading academic institutions are investigating the use of fiber reinforced composite materials for concrete reinforcement.

The use of fiber reinforced plastics as an outside shell has been found to increase the load capacity and durability of piers, wharves, and bridges. These materials offer particular advantages over traditional reinforcements, though an understanding of their long term performance characteristics in aggressive environments is necessary before their use is widely accepted.

4-9 **GEOTEXTILES**. As strong fabrics consisting of strong woven plastic filaments, geotextiles are predominantly used as filter cloth and are sometimes called filter fabrics, construction fabrics, plastic filter cloth, or engineering fabrics. The most frequent use of geotextiles in coastal construction is as a filter between fine granular sands or soils and overlying gravel or small stones that forms the first under layer of a coastal structure such as a revetment. A discussion of their properties and design considerations for their application is contained in Section VI-4-7 of the CEM.

CHAPTER 5:

PROJECT PLANNING

5-1 **INTRODUCTION**. In order to properly plan a project, a basic sequence of tasks should be considered as a basis for project planning:

- Problem Definition
- Initial Site Characterization
- Criteria Development (Functional, Accepted Damage Level, Performance)
- Define Without Project Condition
- Formulate Alternatives
- Detailed Site Characterization
- Refine Alternatives
- Evaluate/compare Alternatives
- Select Plan
- Final Design
- Plans and Specifications
- Cost Assessment/bid and Award
- Construction
- Quality Assurance
- Post Construction Inspection and Monitoring
- Operation and Maintenance
- Modifications to Existing Elements.

This process is discussed in detail in Section V-1 of the CEM.

5-2 **DESIGN DATA**. Factors to be considered in general harbor site selection are listed in Table 5-1. Some sources of site data information are listed in Table 5-2.

Table 5-1 Principal Factors in Harbor Siting

Factor	Considerations
External Access	1. Vessel access to harbor site contains adequate depths and clearance for safe navigability. 2. Land access to harbor site is or can be reasonably developed to provide required land transportation linkage.
Size and Depth	1. Protected water depth and space adequate to accommodate intended vessel traffic in the following areas: (a) entrance and turning basins, (b) mooring areas, and (c) berthing areas. 2. Land areas of sufficient size and elevation to accommodate support needs free from flooding or inundation. 3. Potential for future enlargement or change in harbor use.
Physical and Topographic	1. Sheltering from winds and ocean waves; natural sheltering features such as headlands, offshore reefs, and islands will reduce both artificial sheltering requirements (breakwaters) and costs. 2. Limited fetch. The protected water area shall not contain segments of sufficient fetch to act as a generating area for waves that would cause difficulties within the harbor. 3. Bottom. Heavy, stiff, or overconsolidated clays furnish the best holding ground for anchors. Sands will provide acceptable holding ground. Sites should be avoided where the bottom consists of extremely hard clays, rocks, or very soft clays. If this is not possible, costly provisions (such as mooring islands) must be made to secure ships. Similarly, the costs of breakwaters, piers, and shore side structures will also depend upon the underlying soil conditions. Location of extensive structural systems in areas of deep, soft clays should be avoided. 4. Dredging. Avoid locations involving dredging of large quantities of rock or other hard bottoms. 5. Shoreline relief. Land adjacent to shoreline should gradually slope away from beach. Avoid locations with pronounced topographic relief (cliffs) adjacent to shoreline. 6. Upland drainage. Preferably, the upland area should be naturally well drained. Evaluate occurrence of health hazards due to local conditions.
Hydrographic and Hydrological	1. Variations in water level. The range between water level extremes due to cumulative effects of astronomical and storm tides as well as flood flows in river-affected harbors should be minimized as far as practicable. 2. Currents. Current velocity should be minimum and, except for localized areas and/or special considerations, should not exceed 4 knots. 3. Fouling rate. Desirable factor is a low fouling rate and relative freedom from marine borers, hydroids, and other biofouling organisms, which can be drawn into the cooling systems of ships. 4. Water circulation. Water basins should have sufficient natural circulation. 5. Sedimentation. The effect of the harbor site on natural regimes of coastal and riverine sediment transport and supply must be thoroughly evaluated. It is desirable not to interfere with the natural regime of sediment movements. The effects of harbor development on the sediment system may require maintenance dredging and/or shore-stabilization needs that must be considered as part of the overall development effort.
Meteorological	1. Storm. Avoid locations subject to the direct effects of pronounced, severe, and frequent storms. 2. Fog. Consider local variation in fog intensity and avoid the more severe sites where practicable. 3. Ice. Avoid locations that might be ice-locked for several months a year.
Other	1. Availability of construction material. In particular, rock for breakwater and jetty construction. 2. Fresh water availability. In particular, water for potable water supply.

Table 5-2 Informational Sources for Harbor Site Selections

Data Required	Sources
Underwater Bathymetry	National Imagery and Mapping Agency – NIMA (http://164.214.2.59/nimahome.html), National Ocean Survey - NOS (http://www.nos.noaa.gov), U.S. Naval Oceanographic Office - NAVO (http://www.navo.navy.mil), U.S. Army Corps of Engineers - USACE (http://www.usace.army.mil/), local Government Public Works and/or Hydrographic Survey Offices; where such is not available, survey is required.
Upland Topography	U.S. Geographical Survey – USGS (http://www.usgs.gov), National Imagery and Mapping Agency – NIMA (http://164.214.2.59/nimahome.html); local Government Public Works mapping offices.
Subsoil Characteristics	Borings, probings, or seismic survey; use diver for preliminary reconnaissance.
Astronomical Tides	National Ocean Survey – NOS (http://www.nos.noaa.gov), U.S. Naval Oceanographic Office - NAVO (http://www.navo.navy.mil; observation at site.
Storm Surge/Tsunamis	Site history. Probability forecasts for some areas have been prepared by U.S. Army Corps of Engineers – USACE (www.usace.army.mil) and Federal Emergency Management Agency, Storm Watch (http://www.fema.gov/fema/trop.htm); review available tide records (marigrams) to compare predicted astronomical tide to measured water levels during storm or tsunami occurrences.
Seiche	Historic experience in general area including marigram inspection can provide some indication of potential activity; long-term observations at site are desirable.
Currents	U.S. Naval Oceanographic Office - NAVO (http://www.navo.navy.mil), National Ocean Survey - NOS (http://www.nos.noaa.gov), Pilot Manuals, U.S. Geological Survey – USGS, for riverine currents (http://www.usgs.gov).
Meteorological Characteristics	Weather Bureau - National Oceanic and Atmospheric Administration (NOAA), (http://www.noaa.gov); Fleet Numerical Meteorology and Oceanography Center (http://www.fnoc.navy.mil).
Waves	National Oceanic and Atmospheric Administration, (http://www.noaa.gov); National Climatic Data Center, http://lwf.ncdc.hoaa.gov/oa/ncdc.html; Fleet Numerical Meteorology and Oceanography Center (http://www.fnoc.navy.mil), U.S. Army Corps of Engineers (http://usace.army.mil); WIS Reports – see references.
Sedimentation/Erosion	U.S. Army Corps of Engineers, (http://www.usace.army.mil), U.S. Geological Survey, (http://www.usgs.gov); analysis of shoreline and hydrographic changes in comparison of successive surveys from initial to present conditions.
Fouling Conditions	Observations at site; consultation with local residents and authorities.

5-3 **COASTAL PROJECT PLANNING AND DESIGN**. The type of structure required for a particular design situation depends upon the protection required, such as harbor protection, beach erosion control, and stabilization of an entrance channel. The primary types of coastal structures and methods of marine improvement and shore protection are breakwaters, jetties, revetments, bulkheads, seawalls, groins, headlands, and beach restoration and nourishment. Paragraph 5-7 of this document provides introductory descriptions and figures showing each of these. In many cases, more than one type of structure may provide a possible solution. Studies of alternative solutions, including consideration of first and annual costs, maintenance, construction methods, and environmental impacts, should be conducted to select the most appropriate one. Selection of the structure type requires that the foundation condition, availability of construction materials and equipment, and probable impacts on the adjacent shores be considered.

5-3.1 **Planning and Design Process**. The CEM, Section V-1, discusses this topic at length. It emphasizes function of components, concepts, non-structural, dynamic and static structures. It offers information regarding coastal zone management, coastal armoring, sediment issues, temporary solutions, and others.

5-4 **REGULATORY REQUIREMENTS**. Permitting, inspection, and enforcement activities are conducted by various organizations.

5-4.1 **USACE.** The responsibilities of USACE are outlined below:

5-4.1.1 **Jurisdiction**. All works located in the waters of the United States and its territories are under the jurisdiction of the USACE. This zone is generally located seaward from the mean high water line. A USACE permit is required for all dredging, filling, construction, or maintenance works. The permit must be approved prior to commencement of work. Therefore, processing of permits should be initiated well in advance of the date work is scheduled to begin because of the lead time required to obtain USACE permits. The USACE's jurisdiction also includes interior wetlands, rivers, and lakes. Questions regarding the extent of the jurisdiction for specific areas inland of the high-tide line should be addressed to the local USACE District Office.

5-4.1.2 **Review Procedure**. In reviewing permit applications for works in U.S. waters, the USACE circulates the application to other Federal and local agencies. In accordance with various executive actions, the USACE cannot, at a local level, override the permit objections of the following:

- Department of the Interior, U.S. Fish and Wildlife
- Environmental Protection Agency (EPA)
- Department of Commerce, Bureau of Commercial Fisheries

In addition to input by Federal agencies, input by State or regional agencies are considered. To date, most concerns address changes in water quality and loss of marine habitat. In specific cases critical to national defense, regulations and procedures can be modified through the Office of the Secretary of the Navy. However, most Navy facility projects are subject to the concerns and regulations of other authorities, which have jurisdiction. Specific contact should be made at project inception with the agencies affected. Liaison is particularly important where harbor works involve:

- dredging and disposal of dredged materials,
- work in or around existing marshes, and
- significant reduction of existing intertidal or shallow-water areas.

5-4.2 **U.S. Coast Guard**. All aids to navigation for U.S. waters are prescribed and installed under the jurisdiction of the U.S. Coast Guard (USCG). In addition, USCG jurisdiction extends to drawbridges and encompasses construction clearances for new drawbridges, modifications of existing drawbridges, and drawbridge operations.

Prior to construction of any coastal project that may impact navigation or interrupt any existing aids to navigation, complete project information should be provided to local authorities (USCG district commander). This information should include details about project authorization, proposed construction schedule, and detailed drawing showing the project location relative to existing feature. Local authorities may require a set of "as-built" plans after the project has been completed, and it may be necessary to include new aids to navigation as part of the project design (CEM, Section VI-3-8).

5-4.3 **Harbor Control Lines**. USACE, through the Secretary of the Army, establishes harbor control lines for all U.S. ports. Control lines include:

- bulkhead lines – seaward limit of solid-fill structures;
- pierhead lines – seaward limit of open waterfront structure; and
- channel lines – extent of channel limits usually maintained by the Federal Government.

5-4.4 **Jurisdiction**. USACE has jurisdiction over construction and dredging in the navigable waters of the United States and of its territories and possessions. EPA has jurisdiction over water quality relating to dredging, disposal of dredged material, and fill activities. Dredging activities and equipment must comply with USCG regulations. Consultation with the district office of the USCG is recommended before dredging projects are started.

5-4.4.1 **Federal Permits**. A USACE permit is required to locate a structure, excavate, or discharge dredged or fill material in waters of the United States. A USACE permit is also necessary for transport of dredged materials into ocean waters for the purpose of dumping. Application for Federal permits can be made through the local district office of the USACE. Applications must be accompanied by drawings of the dredge and disposal areas and a description of the proposed work. Although there are general guidelines established for the permit process, each district is somewhat autonomous and has the authority to amend the requirements for each particular project. These requirements include explanatory documentation of existing data, supplementary chemical and biological testing, and additional environmental surveys. The extent of each requirement is dependent upon the quantity and quality of the dredged material, the proposed form of disposal, and the environmental sensitivity of the area. To expedite permit application processing, appropriate regulatory agencies (e.g., USACE and EPA) should be contacted early in project planning. In extreme cases, early notification can expedite processing emergency dredging permits by the USACE.

5-4.4.2 **State Permits**. Federal law assures the right of any state or interstate agencies to control the discharge of dredged or fill material in any portion of the navigable waters of any state jurisdiction. Typically, a water-quality certificate, a hydraulic-fill permit, or both, are required at the state level.

5-4.4.3 **Local Permits**. In certain areas, a local permit may be required. Most states have federally endorsed coastal development and water quality plans. Many consider the operation and maintenance of existing Navy facilities as consistent with, and part of, their planning documentation. Direct authority over new Navy construction works does not presently extend to local State agencies; however, for consistency with local plans, notification of new works is desirable. Notification of concerned local agencies may be through circulation of an environmental impact statement for new works, public notice in the case of operation or maintenance projects, or directly through an exchange of memoranda.

5-4.5 **Disposal of Dredged Material**. Dredging may be required to gain access to the project site, for entrenching toe materials, for backfilling higher quality foundation material, or for other reasons. When dredging is to occur, dredging volume should be estimated, and the method of dredged material transport and disposal should be determined. Beneficial uses of the dredged material should be considered, particularly if the displaced material consists primarily of beach-quality sediment. Some dredged sediments may be disposed offshore in a designated and permitted Ocean Dredged Material Disposal Site (ODMDS); note that management of an ODMDS requires predicting the response of the sediment mound to wave and current forces with the aid of validated numerical models for the region in question. Guidance on dredging disposal and beneficial uses of dredging material can be found in Engineer Manuals (EM) 1110-2-5025 (USACE, 1983) and 1110-2-5026 (USACE, 1987). Also, papers from technical specialty conferences, e.g., Dredging '94 (American Society of Civil Engineers, 1994), provide useful information; for additional information, see Section VI-3-8 of the CEM.

5-4.6 **Environmental Considerations**. Understanding and mitigating environmental impacts of coastal projects are key considerations throughout the planning, design, construction, and maintenance phases of all projects. Refer to CEM Sections V and VI-3-6.

5-4.6.1 **Discussion**. The Coastal Zone Management (CZMA) Act of 1972, PL 92-583, establishes a national policy to preserve, protect, develop, and, where possible, restore and enhance the resources of the coastal zone of the United States. DoD Implementation of the Coastal Zone Management Act, DOD Instruction 4165.59 of 29 December 1975, authorized the Navy to implement programs to achieve the objectives of PL 92-583. The Navy will cooperate and provide information on Navy programs within the coastal zone to states responsible for developing state CZMA plans. Naval operations, activities, projects, or programs affecting coastal lands or waters shall insure that such undertakings, to the maximum extent practicable, comply with state-approved coastal-zone programs.

5-4.6.2 **Guidelines and Standards**. All natural resources management programs on naval installations in the coastal zone have potential effects on the coastal zone and should be reviewed for consistency with approved state Coastal Zone Management plans. The Navy shall develop, in cooperation with a designated state agency, a set of criteria and standards for judging the consistency of natural resource management programs with respect to approved state management programs. Consistency determinations shall be made in accordance with provisions of PL 92-583.

Agricultural out lease of real property affecting land or water uses in the coastal zone shall provide a certification that the proposed use complies with the coastal state's approved program and that such usage will be conducted in a manner consistent with the program.

Technical assistance requested by the states to assist their implementation of CZMA will be provided to the extent practicable. Data collected by the Navy on subjects such as beach erosion, hydrology, meteorology, and navigation may be useful for coastal-zone planning and shall be made available.

5-4.7 **Natural Resource Protection Criteria**. In recognition of the intrinsic value of natural resources, the National Environmental Policy Act (NEPA) of 1969, amended in 1970, 1975, and 1982, provides a vehicle for arresting any rapid degradation and destruction of critical natural resources. Appropriate permitting procedures shall be followed by the design team prior to beginning any activity that will be located in, on, or over any protected natural resource or is located adjacent to an activity that will cause material or soil to impact coastal wildlife habitats, among others. The importance of working to conserve and restore endangered and threatened species and the ecosystems upon which they depend on for survival is also recognized via the Endangered Species Act (ESA) of 1973 and the Marine Mammal Protection Act of 1972. The attendant dredging, displacement, and filling of soil during construction projects in the coastal zone underlines the necessity for the Navy to address natural resource protection issues early in the planning process.

5-5 **SITE CHARACTERIZATION AND DESIGN CRITERIA**. Many coastal failures can be traced back to inadequate site characterization analysis. Site characterization involves identifying distinguishing qualities and features of a region that have a direct and indirect impact on the conception, design, economics, aesthetics, construction and maintenance of a coastal project. The coastal environment varies spatially and temporally and therefore a design that is functionally, economically, and environmentally appropriate at one location may be inappropriate at another. Physical, biological, and cultural attributes need to be delineated so that an acceptable project is adopted and potential effects of the project are determined. Sections V-2 and VI-3 of the CEM cover this topic in detail.

5-5.1 **Hydrographic Surveys and Subbottom Profiling**. It is important to perform surveys to identify bottom conditions and to determine if any structures are present which need to removed or avoided. This knowledge pertains to both construction efforts and dredging. Table 5-2 provides information on some of the bathymetric, Differential Global Positioning System (DGPS), and sidescan sonar sources available to the design engineer.

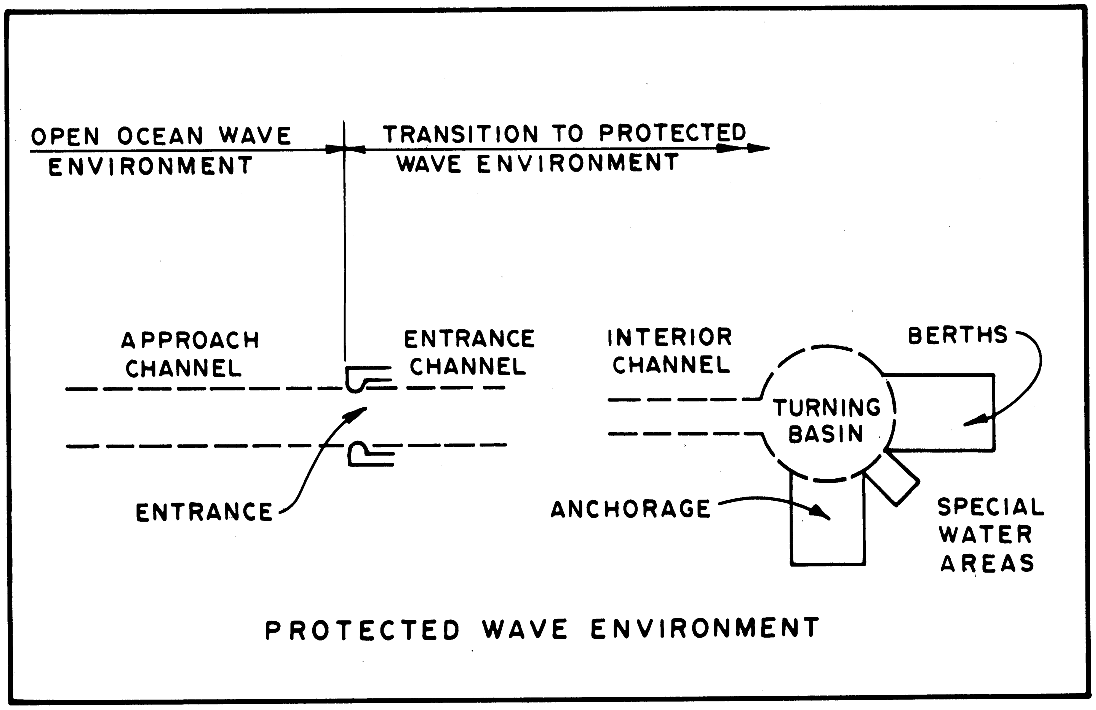
5-6 **PORT AND HARBOR PROJECT DESIGN - DREDGING AND NAVIGATION PROJECTS**. Planning efforts must consider environmental policies such as the National Environmental Policy Act (NEPA), the Environmental Assessment (EA), and the Environmental Impact Statement (EIS). Project Assessment and Alternative Selection, and Development of a Navigation Project, are addressed in the following sections.

5-6.1 **Project Assessment and Alternative Selection**. This information is readily available from the CEM, Section V-5, which acts as a complement to EM 1110-2-1613, *Hydraulic Design Guidance for Deep-Draft Navigation Projects* and EM 1110-2-1615, *Hydraulic Design of Small Boat Harbors*.

5-6.1.1 **General Harbor and Port Facility Issues**. Within limits, any site may be modified to accommodate the required vessel use. Ideally, the minimum and maximum area requirements must be estimated in order to properly evaluate a proposed location. For military purposes, it is desirable to allow for unrestricted operation of all vessels at all times. However, it is not always practical to design for statistically infrequent low-water conditions or an all-weather navigable entrance at locations exposed to extreme wave climates. Before proceeding with the design, trade-offs based upon the probabilities of occurrences should be discussed with the using agency.

5-6.1.1.1 **Major Water-Area Elements**. Figure 5-1 illustrates the arrangement of major water-area elements associated with a harbor facility. Depending upon siting, a harbor facility may include all of, or portions of, these elements. Functionally, approach- and entrance-channel elements provide the transition between open-sea and protected water environments. The protected interior channel serves as a navigational linkage; in riverine situations, this channel length can become of increasing importance. Turning basins provide area for a ship to maneuver while approaching its final terminus, either alongside berths or in open mooring areas. In some harbors, special water areas are required for vessel electronic and navigation calibration. Sizing of water-area dimensions is related to both capacity and operational requirements.

Figure 5-1 Water-Area Elements



5-6.1.1.2 **Capacity**. Ascertain the approximate anticipated capacity requirement from the using agency in terms of numbers, types, and sizes of vessels expected to simultaneously anchor within the harbor limits. Also estimate the number of these vessels that must be simultaneously accommodated at pier or wharf berths and determine the needs for special water areas for ship calibration.

5-6.1.1.3 **Operation**. Proposed vessel-handling methods and navigational minimums need to be defined. Included in this assessment is the use of pilots and tugs for ship handling and berthing. Tolerances for ship movement restrictions in cases of extreme tide or weather conditions need to be defined.

5-6.1.1.4 **Dimensioning**. Guidelines for dimensioning harbor water-area elements, and spatial and water-depth values are provided below. Alternative evaluations may be made through comparison using existing operating Navy facilities. However, caution should be exercised in making such operational comparisons in that, to do so, the wind, wave, and current environments must also be similar.

- Water Areas. The water-area elements of harbors schematized in Figure 5-1 are composed of channels for vessel transit and basins for vessel maneuvering, berthing, and anchorage.

- Channels. General channel classifications and elements are shown on Figure 5-2.

5-6.1.1.5 **Economics**. Economic considerations must be weighed against depth requirements. In harbors where tidal range is very large and, particularly, where an entrance channel is long, consider the possibility of restricting the entrance of the largest draft ships using the harbor to the higher tidal stages. Where hard bottoms prevail and excavation costs are high, consider the exclusion of certain classes of deep-draft vessels, with provision of lighter service between deep-water anchorage and docks.

5-6.1.2 **Depth Requirements**. In general, the depth of harbor areas varies. Certain areas are reserved for small craft usage while larger ships are set aside for larger ships. Additionally, channel depth requirements differ from those at anchorages and berths. Depending upon the specific area under consideration, it is imperative to provide for adequate depths at all anticipated water levels.

5-6.1.2.1 **Naval Vessel Characteristics.** Table 5-3 presents some of the characteristics of auxiliary and combatant vessels and service craft. In cases where the harbor design requires critical clearances for a particular vessel type or condition, specific verification by the Naval Sea Systems Command (NAVSEA) Ship Logistic Manager is required.

5-6.1.2.2 **Preliminary Design Depth**. Table 5-3 also provides suggested design depths for preliminary design purposes. These values were developed to incorporate certain generalized approximations of overdepth allowances for such parameters as static eccentricities, wave motion, and bottom-clearance allowances. Should unique siting or vessel conditions be critical in harbor-depth selection, a detailed analysis of all factors is required. Once the vessel type is known, the designer should obtain the maximum navigational draft to determine if the proposed depth is great enough to avoid interference with the vessel's hull and, in the case of destroyers, cruisers, and frigates, any special electronic gear that may be attached.

- *Anchorage and Berthing Areas*. For a specific vessel, the depth requirements at anchorage and berthing areas are the same. The required depth for an undamaged vessel is determined by adding 1.2 meters (4 feet) to the maximum navigational draft (Table 5-3). Berthing depths for floating drydocks are given in Table 5-4; note that these estimates are based upon the maximum submerged draft plus 0.6 meters (2 feet).

- *Channels*. In the case of a fully operational channel protected from direct storm-wave attack, the desirable ratio of channel depth to navigational draft of the largest vessel should be 1.3 for vessel speeds of less than 7 knots, and 1.5 for vessel speeds in excess of 7 to 8 knots. At these ratios, the bottom effects on vessel handling become negligible. In many cases, these desired criteria cannot be obtained. For general design minimums to be used in preliminary harbor planning, but still subject to detailed follow-up analysis, use the following approximations:

Vessel Type	Channel Depth
CV & AOE	13.7 m (45 ft)
CG	10.97 m (36 ft)
Destroyers, submarines, and auxiliary ships	Maximum navigational draft plus 1.5 m (5 ft)
Small craft	3.65 to 4.6 m (12 to 15 ft)

5-6.1.2.3 **Detail Depth Design**. The depth of the channel is determined by adding the estimated maximum vessel draft and bottom clearance relative to a design still water level (SWL). The maximum vessel draft is obtained by considering the various factors given in Figure 5-3: salinity effects, loading effects, wave effects, and ship motion and squat effects.

- *Static Draft.* The extreme draft of a vessel at rest in still water is equivalent to the distance from the water surface to its lowest underwater extremity. The value for the maximum loaded draft of an undamaged vessel must be adjusted to account for list, trim, and water density changes. Values using these adjustments for critical situations need to be verified through the using component. Preliminary estimates show the following: list is 3 degrees, trim 4 inches per 100 feet of vessel length stern down, and salt water-to-fresh water transition sinkage equals 2 ½ percent draft increase.

- *Wave Motion*. In cases where a vessel is in a water area that is subject to wave action, vertical motions will increase the extreme draft relative to the still water level. Rotational motions of pitch and roll, as well as vertical displacement through heaving motion, will take place. The motion of the ship subjected to steep waves requires that a dynamic analysis take into account the physical property of the ship modeled in the sea condition. Under certain critical ratios of vessel length to relative wavelength, the added vertical sinkage of the vessel can be appreciably greater than the water-level displacement at the wave trough. Generally, these critical ratios are generally believed to lie within the 0.3 to 0.6 range. This situation is normally critical where the unprotected harbor-entrance approach is situated in shoaling water. A recent harbor site selection at a particularly stormy site suggests that an overdepth in the approach and entrance channels on the order of 35% of the draft is required. In semi-protected water areas, such as when a ship is subjected to swell, but not to local seas, the increased displacement of the vessel due to pitch and heave can be determined by placing two points of the vessel on a trochoidal wave surface at two-thirds the vessel waterline-length normal to the wave crests, as is shown in Figure 5-4. Semi-protected water areas are shown in Figure 5-5.

Figure 5-2 Channel Types

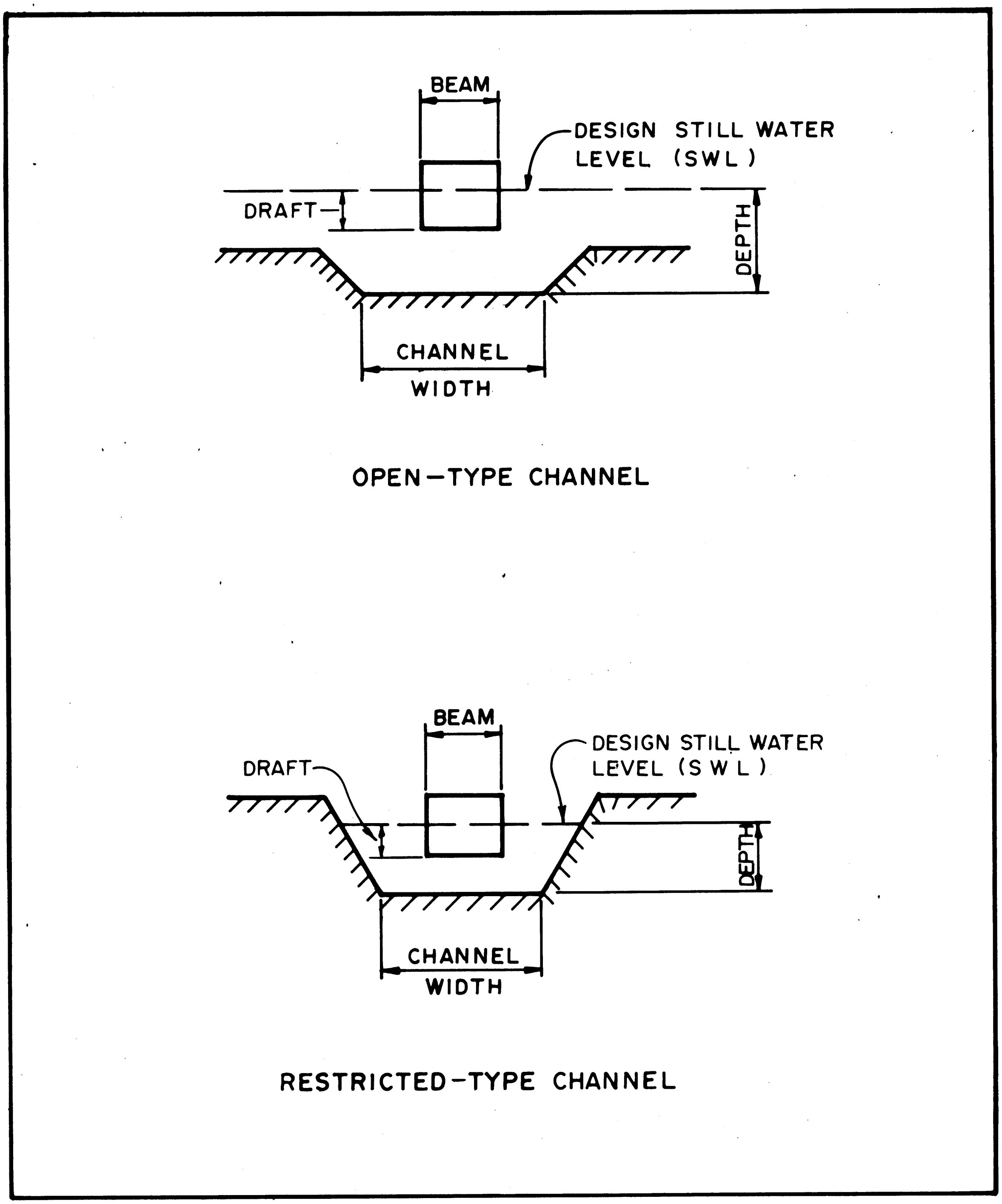


Table 5-3a Vessel Characteristics and Berthing Depths in <u>Meters</u>

Type	Designation	Characteristics (meters)				Undamaged Berthing Depth
		L.O.A. (l_v)	Breadth		Max. Nav. Draft	
			Extreme	@ Waterline		
Aircraft carrier Nimitz class	CVN 68	333.0	78.0	41.0	12.0	14.0
Fast combat support ship	AOE 1	243.0	33.0	33.0	12.0	14.0
Aircraft carrier	CV 66	319.0	77.0	40.0	12.0	13.0
Replenishment oiler	AOR 1	201.0	29.0	29.0	11.0	12.0
Tanker	AOT 182	205.0	27.0	27.0	11.0	12.0
Submarine Ohio class	SSBN 726	171.0	-----	-----	11.0	12.0
Guided missile cruiser	CGN 38	179.0	19.0	19.0	10.0	11.0
Submarine Lafayette class	SSBN 616	128.0	10.0	8.0	10.0	11.0
Guided missile destroyer (Aegis)	DDG 47	173.0	17.0	17.0	10.0	11.0
Guided missile cruiser	CGN 36	182.0	19.0	18.0	9.0	11.0
Submarine Los Angeles class	SSN 688	110.0	10.0	9.0	9.0	11.0
Guided missile cruiser	CG 26	167.0	17.0	16.0	9.0	11.0
Destroyer	DD 963	172.0	17.0	17.0	9.0	10.0
Amphibious command ship	LCC 19	190.0	33.0	25.0	9.0	10.0
Destroyer tender	AD 37	196.0	26.0	26.0	9.0	10.0
Submarine tender	AS 36	196.0	26.0	26.0	9.0	10.0
Submarine sturgeon class	SSN 637	88.0	10.0	8.0	9.0	10.0
Amphibious cargo ship	LKA 113	176.0	25.0	25.0	9.0	10.0
Amphibious transport	LPA 248	172.0	23.0	23.0	9.0	10.0
Combat store ship	AFS 1	177.0	24.0	24.0	9.0	10.0
Guarded missile destroyer	DDG 37	156.0	16.0	16.0	8.0	9.0
Frigate	FF1052	134.0	14.0	14.0	8.5	9.0
Amphibious assault ship	LHA 1	250.0	36.0	32.0	8.0	9.0
Repair ship	AR 5	162.0	22.0	22.0	8.0	9.0
Guided missile destroyer	DDG 2	133.0	14.0	14.0	7.0	9.0
Amphibious transport dock	LPD 4	174.0	32.0	26.0	7.0	8.0
Dock landing ship	LSD 36	169.0	26.0	26.0	6.0	7.0
Tank landing ship	LST 1179	172.0	21.0	21.0	6.0	7.0
Destroyer	DD 718	97.0	41.0	12.0	6.0	7.0
Submarine	SS 567	89.0	8.0	7.0	5.0	6.0
Salvage ship	ARS 38	65.0	13.0	13.0	5.0	6.0
Minesweeper	MSO 427	53.0	11.0	11.0	4.0	5.0

Table 5-3b Vessel Characteristics and Berthing Depths in Feet

Type	Designation	Characteristics (ft)				Undamaged Berthing Depth
		L.O.A. (l_v)	Breadth: Extreme	Breadth: @ Waterline	Max. Nav. Draft	
Aircraft carrier Nimitz class	CVN 68	1,092.0	257.0	134.0	41.0	45.0
Fast combat support ship	AOE 1	796.0	107.0	107.0	41.0	45.0
Aircraft carrier	CV 66	1,048.0	252.0	130.0	38.0	42.0
Replenishment oiler	AOR 1	659.0	96.0	96.0	36.5	40.5
Tanker	AOT 182	672.0	89.0	89.0	36.2	40.2
Submarine Ohio class	SSBN 726	560.0	-----	-----	35.9	39.9
Guided missile cruiser	CGN 38	586.0	63.0	61.0	32.6	36.6
Submarine Lafayette class	SSBN 616	421.0	33.0	25.0	32.0	36.0
Guided missile destroyer (Aegis)	DDG 47	568.0	55.0	55.0	31.6	35.6
Guided missile cruiser	CGN 36	596.0	61.0	60.0	31.0	35.0
Submarine Los Angeles class	SSN 688	361.0	33.0	29.0	30.5	34.5
Guided missile cruiser	CG 26	547.0	55.0	54.0	30.5	34.5
Destroyer	DD 963	564.0	55.0	55.0	30.0	34.0
Amphibious command ship	LCC 19	620.0	108.0	82.0	30.0	34.0
Destroyer tender	AD 37	645.0	85.0	85.0	30.0	34.0
Submarine tender	AS 36	644.0	85.0	85.0	30.0	34.0
Submarine sturgeon class	SSN 637	289.0	32.0	25.0	29.0	33.0
Amphibious cargo ship	LKA 113	576.0	82.0	82.0	28.0	32.0
Amphibious transport	LPA 248	564.0	76.0	76.0	28.0	32.0
Combat store ship	AFS 1	581.0	79.0	79.0	28.0	32.0
Guarded missile destroyer	DDG 37	513.0	53.0	52.0	27.0	31.0
Frigate	FF1052	438.0	47.0	47.0	26.5	30.5
Amphibious assault ship	LHA 1	820.0	118.0	106.0	26.0	30.0
Repair ship	AR 5	530.0	73.0	73.0	26.0	30.0
Guided missile destroyer	DDG 2	437.0	47.0	46.0	24.0	28.0
Amphibious transport dock	LPD 4	570.0	105.0	84.0	23.0	27.0
Dock landing ship	LSD 36	553.0	84.0	84.0	20.0	24.0
Tank landing ship	LST 1179	565.0	70.0	70.0	20.0	24.0
Destroyer	DD 718	319.0	41.0	40.0	19.0	23.0
Submarine	SS 567	293.0	27.0	24.0	17.3	21.3
Salvage ship	ARS 38	214.0	43.0	43.0	15.1	19.1
Minesweeper	MSO 427	173.0	35.0	35.0	14.0	18.0

Notes:

1. Berthing depths are usually measured from extreme low water (ELW).
2. Berthing depths for undamaged vessels are minimum values obtained by adding 1.2 m (4 ft) to the maximum navigational draft of the vessel. In case of excessive silting (0.3 m (1 ft) per year or over), more than 1.2 m (4 ft) should be added.
3. To obtain information concerning berthing depths for damaged vessels, consult the NAVSEA Ship Logistic Managers for the particular vessel.
4. For a more complete listing of naval vessel characteristics, see Ships Characteristics Database, http://criteria.navfac.navy.mil/criteria/tools.htm.
5. To obtain berthing depth for CVN, AOE, and CV vessels, refer to *Underkeel Clearance Study*, Hydro Research Science, Inc., Project Report No. 092-81, 31 March 1981.

Table 5-4 Berthing Depths Required for Active Floating Drydocks[1].

Class of Drydock	Number of Sections Per Dock	Length [2] (m (ft))	Beam (m (ft))	Required Berthing Depth[3] (m (ft))
AFDB-1	5	126 (412)	78 (256)	26 (84)
AFDB-2	10	252 (827)	78 (256)	26 (84)
AFDB-3	9	226 (743)	78 (256)	26 (84)
AFDB-4, 5	7	221 (725)	73 (240)	22 (72.5)
AFDB-7	4	126 (413)	73 (240)	22 (72.5)
AFDL-1, 2, 6, 8 to 12, 15, 16, 19 to 21, 23, 25, 29	1	61 (200)	20 (64)	9 (31)
AFDL-7, 22, 23, 33	1	88 (288)	20 (64)	10 (34)
AFDL-37, 38, 40, 41, 44, 45	1	119 (389)	26 (84)	12 (40)
AFDL-47	1	137 (448)	30 (97)	14 (45)
AFDL-48	1	122 (400)	29 (96)	16 (53)
AFDM-1, 2	3	166 (544)	35 (116)	16 (53)
AFDM-3, 5 to 10	3	168 (552)	38 (124)	17 (57)
ARD-5 to 8	1	126 (414)	22 (71)	12 (38)
ARD-12, 24, 30, 32	1	126 (414)	25 (81)	12 (38)
ARDM-1, 2	1	126 (414)	25 (81)	12 (38)
ARDM-3	1	136 (438)	25 (81)	15 (49)
ARDM-4	1	132 (432)	29 (96)	19 (61)
YFD-7	1	168 (552)	38 (124)	17 (55)
YFD-8	1	179 (587)	41 (133)	16 (54)
YFD-23	1	144 (472)	35 (114)	15 (50)
YFD-54	1	107 (352)	27 (90)	12 (41)
YFD-68 to 71	3	161 (528)	36 (118)	16 (52)
YFD-83	1	61 (200)	20 (64)	9 (31)

Notes: The displacement of floating drydocks and their maximum draft when submerged may be obtained from Ships Characteristics Database, http://criteria.navfac.navy.mil/criteria/tools.htm.

[1] Berthing depths are usually measured from extreme low water (ELW).
[2] Without outriggers.
[3] Berthing depth required is equal to maximum draft of floating drydocks in submerged condition plus 0.6 m (2 ft.) In case of excessive silting (0.3 m (1 ft) per year or over), more than 0.6 m (2 ft) should be added.

- *Squat*. When a vessel is underway in shallow water or situated in a restricted channel, the water surface near the quarter point of the vessel drops below the normal level and the vessel tends to settle itself or squat in the depression (Figure 5-6). The amount of squat depends upon the:

    - speed of the vessel through the water
    - distance between the keel and the bottom
    - trim of the vessel
    - cross-sectional area of the channel
    - presence of other vessels in the channel passing or overtaking the subject vessel, and
    - location of the vessel relative to the channel's centerline.

The following procedure is recommended for performing preliminary estimations of squat:

1. Compute S = $\frac{A}{\bar{w}h}$.
2. Using Figure 5-7 obtain F; compute V_L using F = $\frac{V_L}{\sqrt{gh}}$.
3. Compute $\frac{V}{V_L}$ and $\frac{h}{D}$; obtain $\frac{z}{h}$ using Figure 5-8.
4. Multiply by h to obtain z_{max}, valid for $\frac{\bar{w}}{B}$ = 6.
5. For other values of $\frac{\bar{w}}{B}$, find $\frac{\Delta z}{z_{max}}$ from Figure 5-9.
6. Compute z using $z = z_{max} + \Delta z$.

The amount of squat will increase when vessels travel near one side of the channel. This effect has been shown in a model test for a 9.8 m (32-ft) draft by 34.4 m (113-ft) beam vessel in a 152.4 m (500-ft) wide by 13.7 m (45-ft) deep channel with 1-on-1 side slopes. The results of this test, given in Figure 5-10, show that the additional squat due to a vessel traveling near the side of a channel is small for slower velocities. For higher velocities, additional squat due to a vessel traveling near the side of the channel may be 50 % greater than if the vessel were in the center of the channel.

Squat will also increase if there are two or more vessels passing one another, side by side. A vessel will normally travel near the side of a channel when it is passing alongside another vessel. In this case, the effective cross-sectional area of the channel will be reduced by the cross-sectional area of the vessel being passed. The total squat for a vessel can be approximated by first calculating the centerline squat with the reduced effective cross-sectional area of the channel. To this centerline squat is added the additional squat resulting from the vessel being off the centerline of the channel.

Figure 5-3 Factors Affecting Maximum Vessel Draft

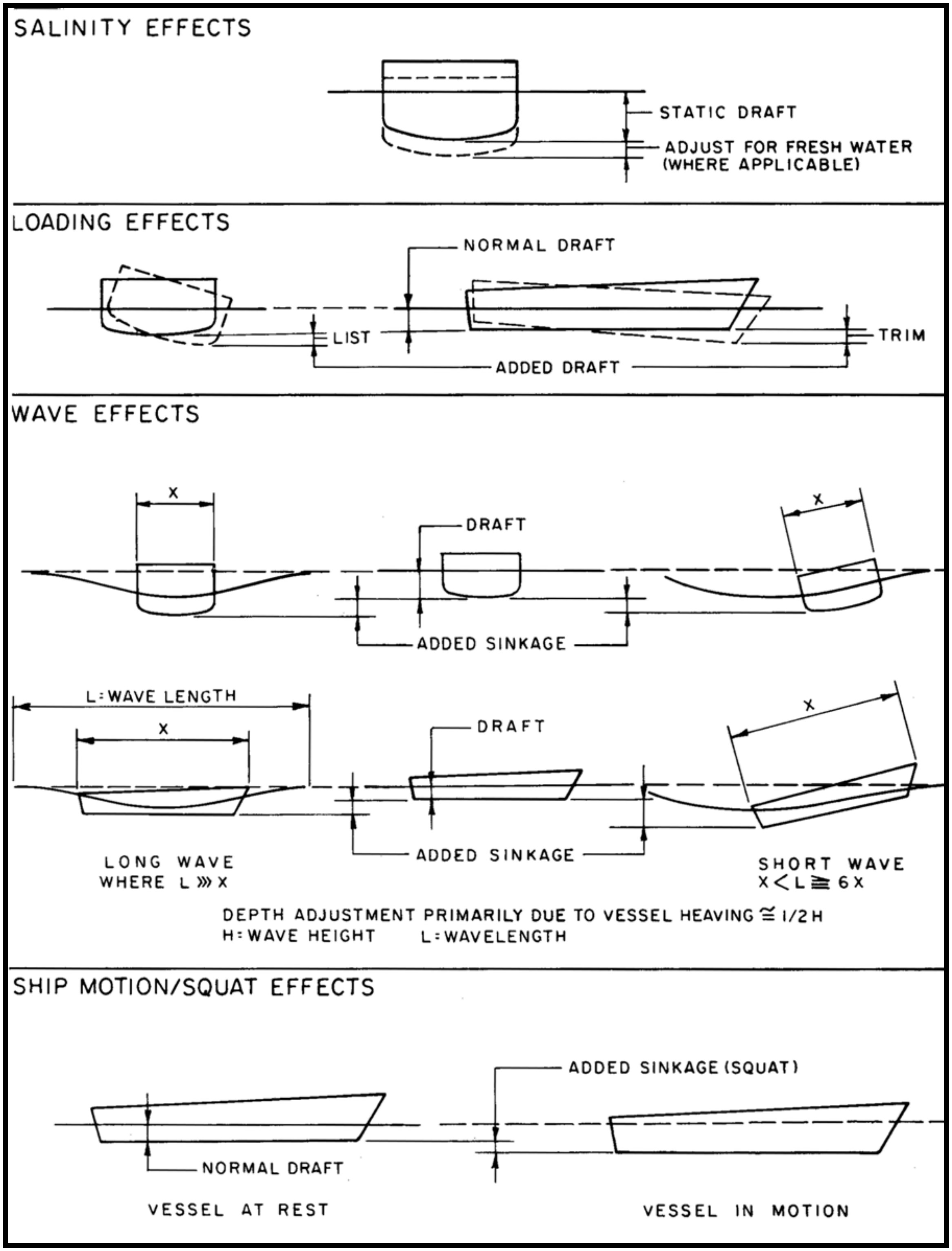


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Figure 5-4 Increase in Vertical Sinkage Due to Wave Action

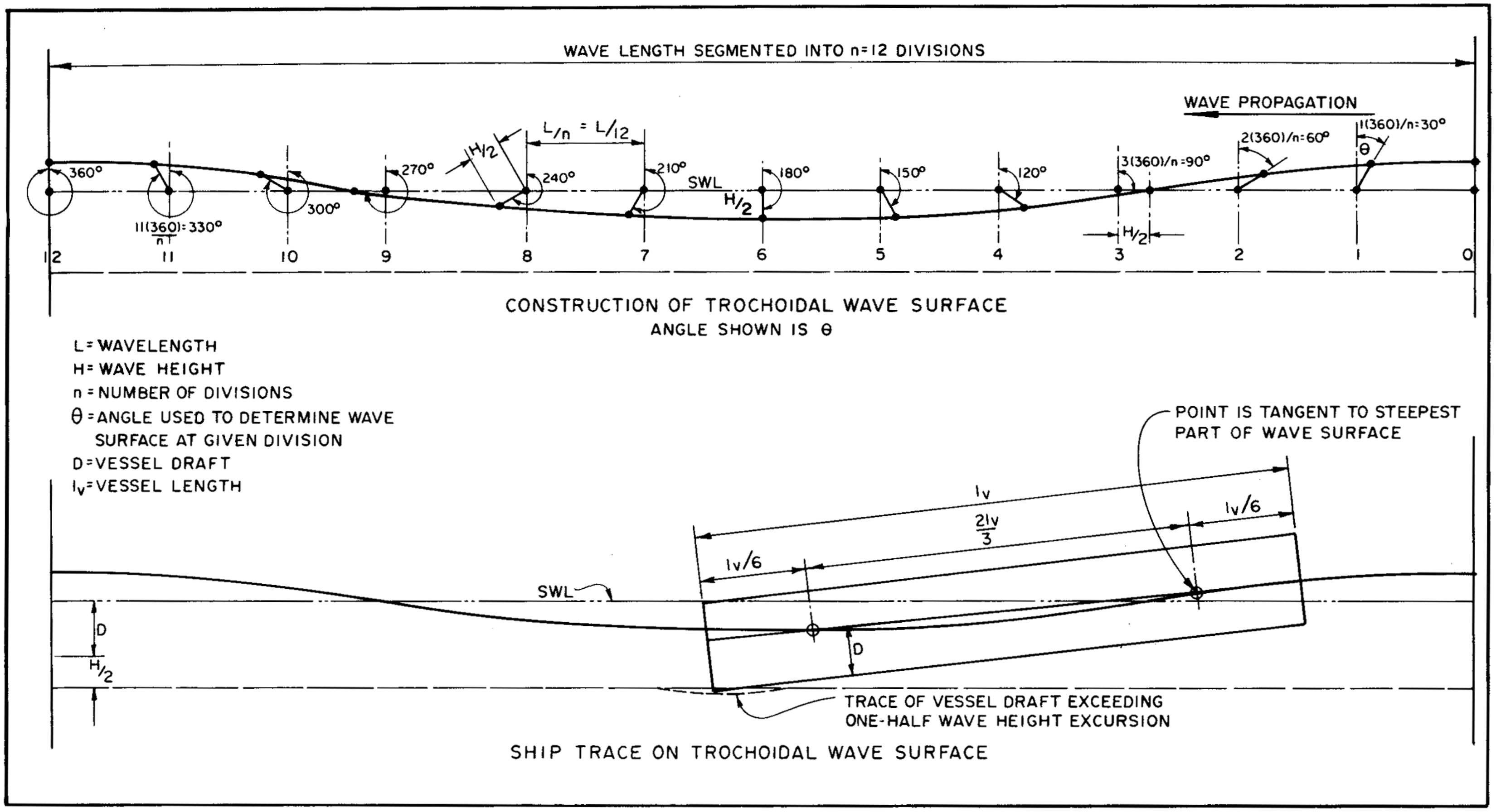


Figure 5-5 Example of Semi-Protected Water Area

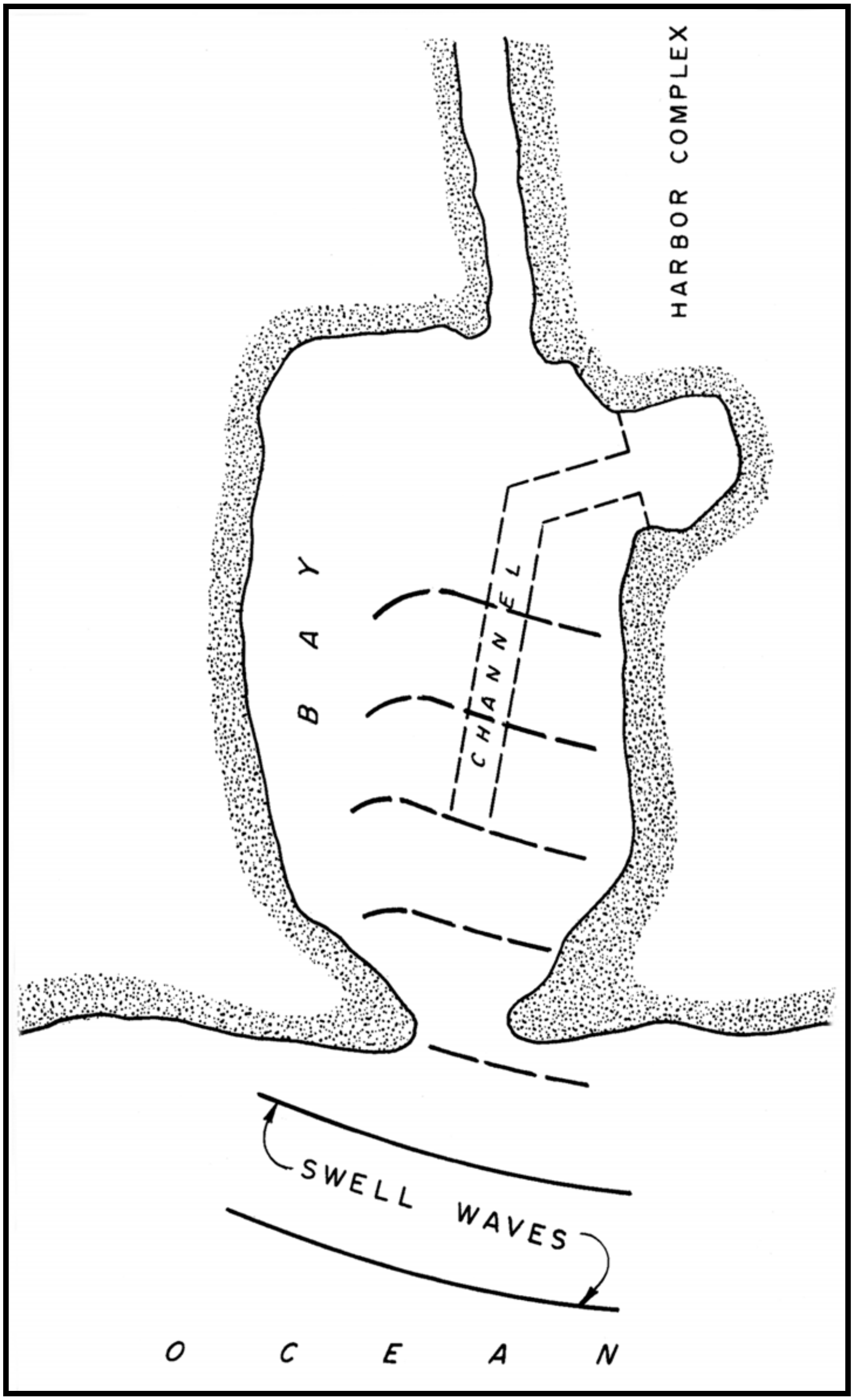
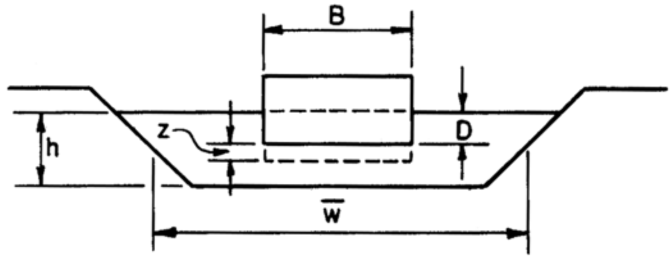


Figure 5-6 Factors Affecting Squat.



where: z = depth of squat [ft]

h = channel depth [ft]

$\overline{w}$ = average channel width [ft]

A = underwater midship cross section [ft^2] = DB

D = vessel draft [ft]

B = vessel beam [ft]

V = vessel speed through water [ft/sec]

V_L = theoretical limiting vessel speed [ft/sec]

g = gravitational acceleration [32.2 ft/sec^2]

S = ratio of underwater midship cross section to the channel cross section = $\frac{A}{\overline{w}h}$

F = Froude number = $\frac{V_L}{\sqrt{gh}}$

Figure 5-7 Sogreah Laboratory Squat Curve (Wicker, 1965).

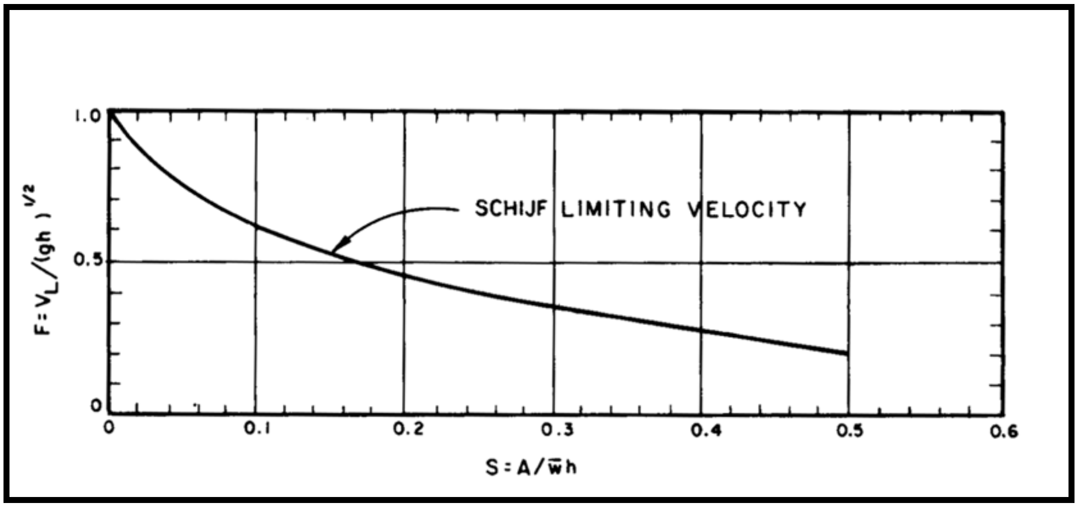


Figure 5-8 Sogreah Laboratory Squat Curves (Wicker, 1965).

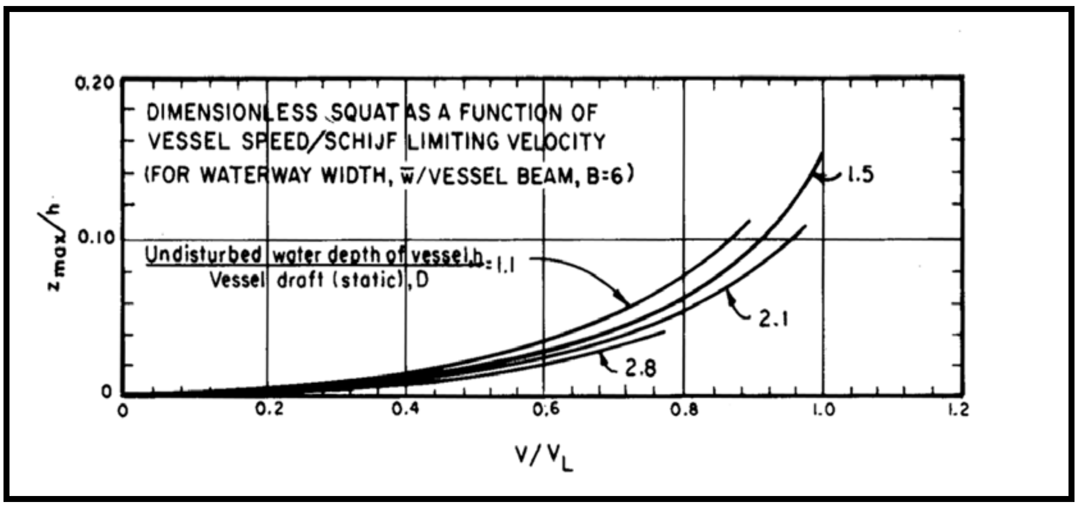


Figure 5-9 Sogreah Laboratory Squat Curves (Wicker, 1965).

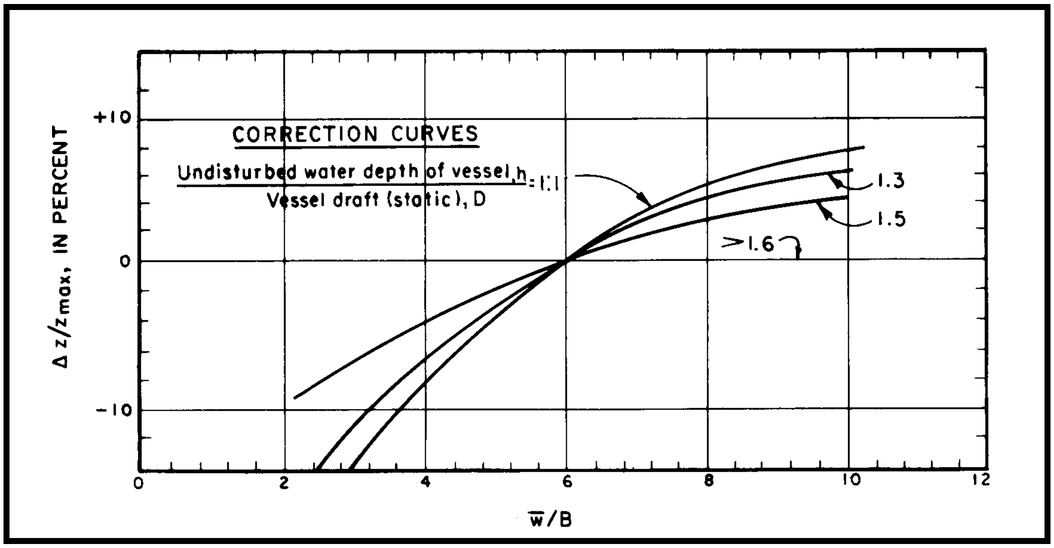
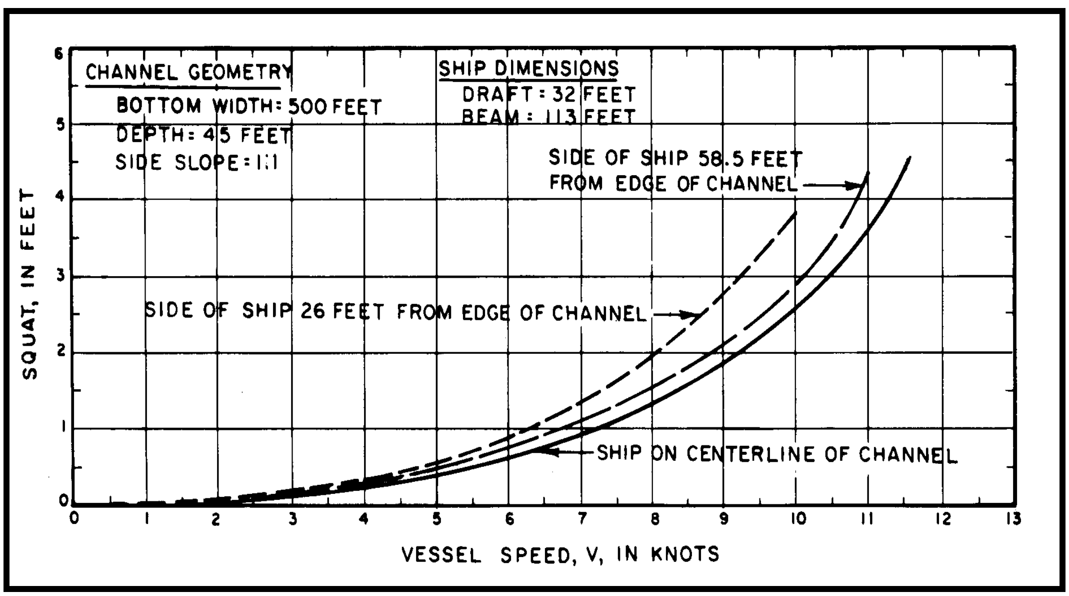


Figure 5-10 Effect of Ship's Location in Channel on Squat.



Where the results of this approximation appear to be critical to sustained operation or to project costs, additional investigations using the appropriate hydraulic model studies should be performed.

- *Bottom-Clearance Allowance*. Factors in addition to those presented above that must be considered in determining the clearance between the maximum vessel draft and the bottom are vessel operation, type of bottom material, and a factor of safety.

  - Vessel operation. Vessel handling and maneuverability become sluggish at low bottom clearances.

  - Bottom material. Soft bottom material can be displaced and shoaled by passing vessel propeller action. Hard bottoms with sharp outcroppings can cause severe damage to vessels upon grounding. In active sedimentation areas, bottom shoals can also occur during relatively short periods of storm activities.

  - Factor of safety. A clearance of 0.6 m (2 ft) between maximum vessel draft and the bottom must be provided for all vessels transiting a channel at any given time. Maximum vessel draft is that value which considers low water levels, vessel static conditions (i.e., salinity, trim, and list), wave motions, and squat. If a channel is not sufficiently deep to accommodate a deep-draft vessel at extreme low tides, then this factor must be evaluated depending on operational criteria.

5-6.1.3 **Currents**. The influence of entrance widths on the magnitude of the current also influence harbor site selection. Entrance widths should be adequate to reduce currents to acceptable values. The maximum allowable current in an entrance channel is a function of the type of ship or ships to be accommodated. It is only under special circumstances that the current exceed 4 knots.

5-6.1.3.1 If the entrance is not constrictive, as is shown in Figure 5-11 and the following conditions are met:

- the basin is relatively short and deep; that is

$$\frac{l_b}{\left(\sqrt{gd}\right)(T)} \leq 0.05 \qquad (5\text{-}1)$$

where l_b = basin length [ft]
d = average basin depth [ft]

- the bay water area is relatively constant

- freshwater inflow is minimal, and

- the ocean tide is approximately sinusoidal, then a good approximation for the current velocity is

$$\overline{V}_m = \frac{2\pi a_s A_b}{A_c T} \tag{5-2}$$

where $\overline{V}_m$ = average cross-section velocity at maximum tidal flow [ft/sec]
T = period of tide [sec]
A_b = surface area of basin [ft2]
A_c = cross section of opening at mean tide level [ft2]
a_s = ½ range of the ocean tide [ft]

The circumstance that the entrance is not constrictive, together with the condition in Equation 5-1, imply that the water surface in the bay fluctuates uniformly and equals the ocean tide.

5-6.1.3.2 If the entrance is constrictive, as shown in Figure 5-12, it reduces the tide range in the bay, so the above expression will overestimate the tidal currents. If conditions outlined in (1) are satisfied, the maximum current in the entrance can be determined from this equation:

$$\overline{V}_m = \frac{2\pi a_s A_b e}{A_c T} \tag{5-3}$$

where $\overline{V}_m$ = average cross-section velocity at maximum tidal flow [ft/sec]
A_c = cross section of opening at mean tide level [ft^2]
T = period of tide [sec]
a_s = ½ range of the ocean tide [ft]
e = dimensionless factor which depends on coefficients K_1 and K_2; see Figure 5-13.

The coefficients K_1 and K_2 are defined as follows:

$$K_1 = \frac{a_s A_b F_c}{2 l_b A_c} \tag{5-4}$$

$$K_2 = \frac{2\pi}{T}\sqrt{\frac{l_c A_b}{g A_c}} \tag{5-5}$$

where l_c = channel length [ft]

F_c = $k_{en} + k_{ex} + \left(\frac{f\, l_c}{4\, R}\right)$

k_{en} = entrance-loss coefficient (≈ 0.1)

k_{ex} = exit-loss coefficient (≈ 1.0)

f = Darcy-Weisbach friction factor (≈ 0.03)

R = hydraulic radius of inlet channel [ft]

K_l represents the ratio of the magnitude of the friction forces and inertia forces. K_2 is a measure of the magnitude of the inertia forces relative to the magnitude of the pressure (water-level) gradient.

Since the entrance is constrictive, the amplitude of the bay tide will differ from the amplitude of the tide range in the ocean. The bay-tide amplitude can be determined from the following relationship:

$$\frac{a_b}{a_s} = \varepsilon \qquad (5\text{-}6)$$

where ε = dimensionless factor which depends on the coefficients K_1 and K_2 (see Figure 5-14)

a_b = ½ range of bay tide [ft]

Note that for small values of K_1, which denotes large inertia forces, the value of ε is greater than one.

For irregular entrance channels, an effective channel length, l_c', can be used in place of l_c.

$$l_c' = \sum_i^n \left(\frac{\overline{R}}{R_n}\right)\left(\frac{\overline{A}_c}{A_n}\right)^2 \Delta X_n \qquad (5\text{-}7)$$

where:

$\overline{R}$ = average hydraulic radius of channel [ft]

$\overline{A}_c$ = average cross section of channel at mean tide level [ft^2]

R_n = hydraulic radius at each of n sections of equal length, ΔX_n , [ft]

A_n = cross section of channel at each of n sections of length, ΔX_n , [ft^2]

This analysis provides an estimate of the channel-inlet hydraulics applicable to design situations. However, if the assumptions in paragraph 5.5.1.3a are not satisfied, or if the current velocities are critical to the channel design, a more detailed analysis to include mathematical or physical-model simulation is necessary.

Figure 5-11 Basin With Nonconstricted Entrance.

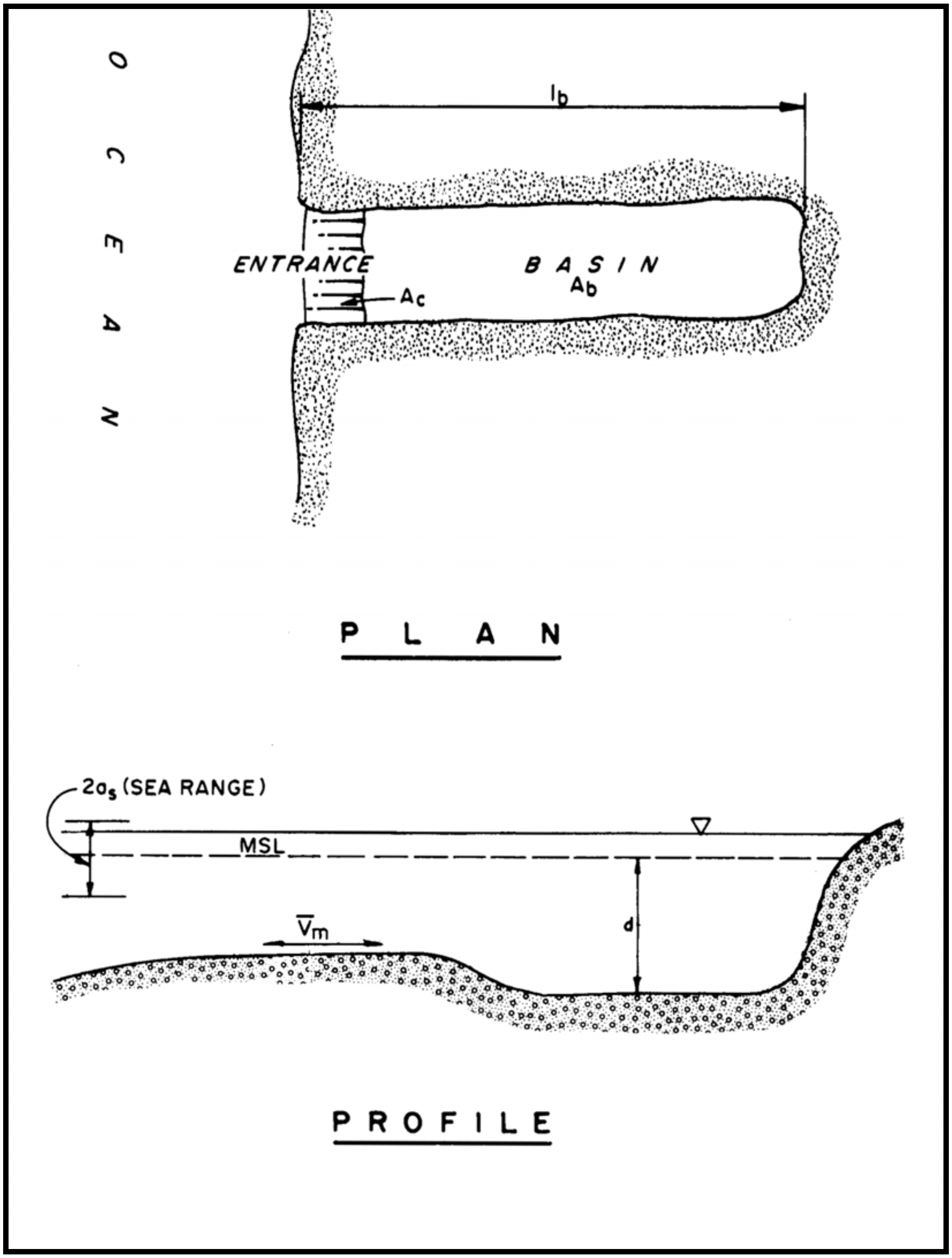


Figure 5-12 Sea-Inlet-Bay System (Sorenson, 1977).

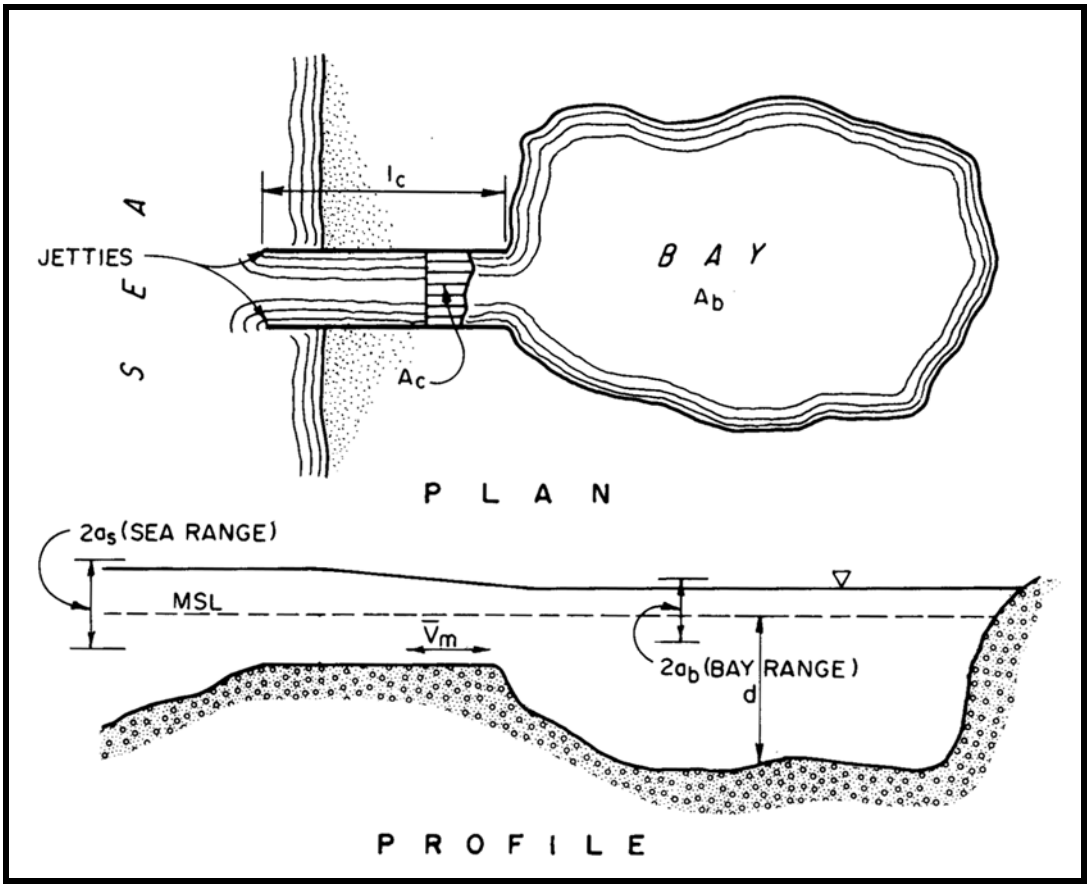


Figure 5-13 Dimensionless Maximum Velocity Versus K_1 and K_2 (Sorenson, 1977).

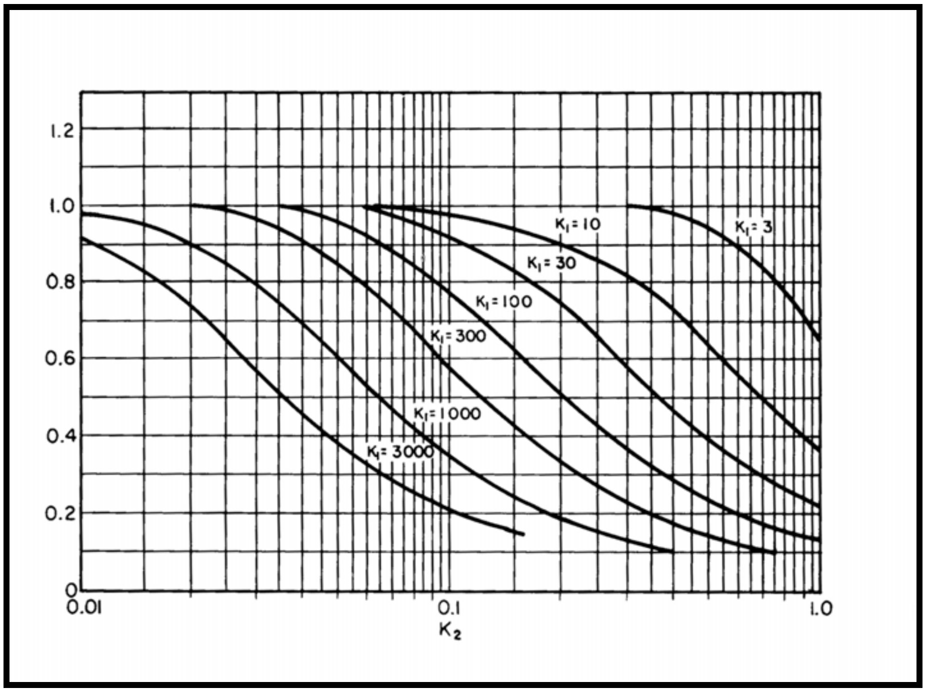
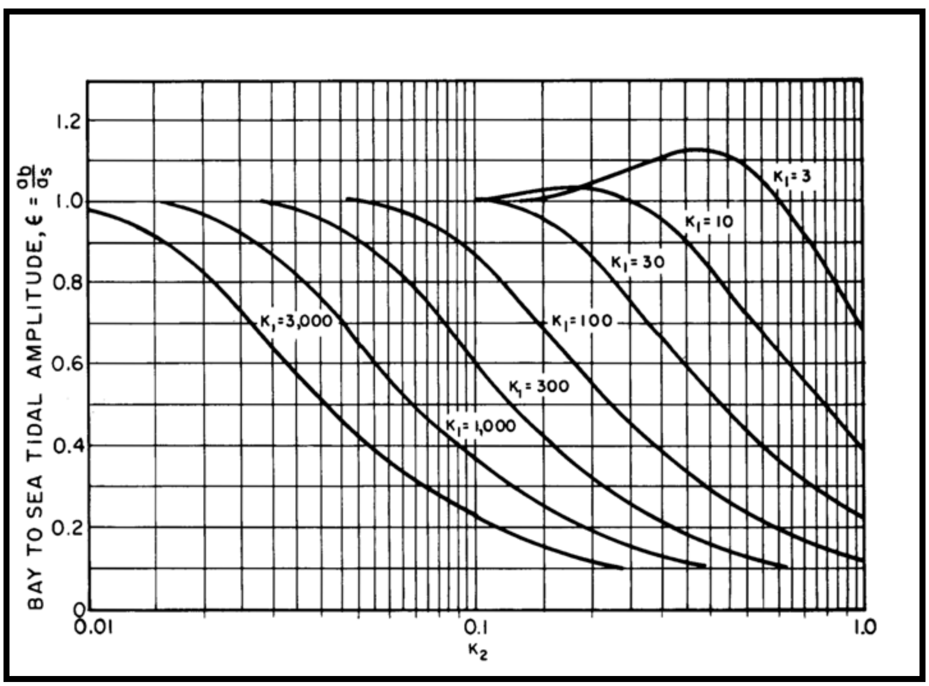


Figure 5-14 Ratio of Bay Sea Tidal Amplitude Versus K_1 and K_2 (Sorenson, 1977).



5-6.1.4 **New Facilities in Existing Harbors**. Where new facilities are to be developed in an existing port, these facilities are subject to the same criteria as the development of a new port. Although some information is contained in CEM, additional information is required. Further topics worthy of consideration are basin depth, Navy ship size and draft, ordnance issues, and new types of Electronic Counter Measures (ECM), such as deperming and degaussing.

5-6.1.5 **Submarine Facility Special Requirements**. The following submarine-specific requirements are provided:

5-6.1.5.1 **Special Considerations.** Harbors designed to accommodate naval submarines of the various classes require special attention during the planning stage. Since surfaced submarines are relatively unwieldy deep-draft vessels with low freeboards, channels and other water areas to be used by submarines must be wide and deep enough for safe maneuvering.

5-6.1.5.2 **Entrances and Channels.** Surfaced submarines are susceptible to wave action, surge and currents. Submarines require still water not only during docking and mooring operations, but also especially while negotiating the entrance and channels. Where moorings are located in estuaries and rivers subject to strong currents, or where entrances are subject to moderate to strong wave action, protection in the form of jetties or breakwaters should be provided.

5-6.1.5.3 **Moorings.** Because of its “barrel” cross-section, a submarine’s beam underwater exceeds the width of its above-water superstructure. Thus, to safely moor submarines, an underwater fendering system is mandatory. Such “deep-draft separators” function as camels, with the difference being that the apparatus extends deep enough to buffer the widest point of the vessel. The depth required depends upon the specific submarine. For example, if the draft of the submarine is 10.1 m (33 ft,) the separator must extend a minimum of 5.5 m (18 ft) below the surface. Separators are normally between 9.1 and 15.2 m (30 and 50 ft) in length. Facilities for docking submarines and the design of deep draft separators are described in MIL-HDBK-1025/1. However, it should be remembered when designing harbors to accommodate submarines that ample storage area is needed for deep-draft separators when not in use. Further, consideration should be given to water-area docking or mooring requirements for small craft servicing deep-draft separators and other support structures.

5-6.1.5.4 **Piers and Wharves.** Special requirements for the design of piers and wharves to accommodate submarines are contained in MIL-HDBK-1025/1. It is noted that in the absence of tug assist, the water approaches to submarine docking facilities should be designed to accommodate the largest vessel anticipated. Table 5-5 lists typical submarine dimensions for preliminary design purposes.

Table 5-5 Submarine Dimensions*

Class	Length Overall (m (ft))	Diameter of "Barrel" m (ft))	Breadth at Stern Planes (m (ft))
21	107.6 (353)	12.2 (40)	N/A
688	110 (361)	10 (33)	12.2 (40)
637	88 (289)	9.8 (32)	12.5 (41)

*Note: "Trident" class missile submarines, having much larger draft and requiring special service, are accommodated at special facilities.

5-6.1.6 **Aircraft Carrier Facility Special Requirements**. Dredge depth requirements for Nimitz Class Aircraft Carriers are summarized below.

5-6.1.6.1 Water depth requirements for Nimitz Class Aircraft Carriers transiting to and moored at homeports, ports of call, and shipyards are delineated in COMNAVSEASYSCOM ltr 11460 Ser 03D3/242 dtd 3 Jan 95, included as Appendix B. It specifies the minimum water depth required while the ship is in the waterway; however, it does not specify dredge depth requirements. The minimum water depth required to operate carriers in inner channels and turning basins on the way to and at piers at home ports is between 14.9 and 15.24 m (49 and 50 ft) depending on harbor salinity. These numbers are similar for ports of call. Due to the reduced draft when visiting shipyards, the minimum water depth required to operate carriers in inner channels and turning basins on the way to and at piers at shipyards is between 14 and 14.3 m (46 and 47 ft) depending on harbor salinity. Applying these requirements to determine dredge depths requires additional port specific information. Appendix B specifies the following:

- "The dredging project depth can be traded off with tides to obtain the necessary water depth in inner channels and turning basins with the corresponding operational conditions." Therefore, planners should consider channel accessibility and operational restrictions imposed when selecting a design water level above the extreme low water. To facilitate uniform application of the minimum water depth requirement in referenced letter, formal criteria guidance is required.

- "Shallower and/or narrow channels and/or higher speeds will require greater allowance for squat." Since narrow channel widths and greater speeds result in greater ship sinkage during transit (squat), and thus deeper water, planners should also include these effects.

- "Port specific fouling clearance studies can be performed if requested and funded" to possibly reduce the 6.0 ft fouling clearance criteria. The clearance criteria was derived from condenser fouling studies on stationary ships berthed at NAVSTA Norfolk, VA in 1980. Locations that exhibit more or less potential for fouling may require more or less clearance to prevent it.

- "Ship motions analyses of the remaining home ports and shipyards will be completed...after receipt of funding." The motion analyses that NAVFAC prepared for Mayport and San Diego predicted days of access and generated nomographs for other locations. For channels subjected to significant waves, engineers and planners must evaluate these wave effects on ship motions.

- Therefore, as provided for in Appendix B, facility engineers and planners should determine dredge depth requirements by including the additional considerations of design water level, channel width and ship speed impacts, dynamic effects of sea chest intake fouling, and wave effects. Additionally, they should include effects from sedimentation and dredging tolerances.

5-6.1.6.2 The requirements provide consistency and reliability in the determination of acceptable dredge depths for channels and berths used by active Nimitz class aircraft carriers. The NAVFAC Criteria Office will address reserve status condition of CVNs when required. Deviation from minimum criteria requires a waiver from the NAVFAC Criteria Office which will be coordinated with cognizant Major Claimants, Naval Sea Systems Command, and Chief of Naval Operations.

5-6.1.6.3 Ideally, engineers and planners should base ship channel designs on physical model testing, risk analysis, and ship simulator analysis. However, time and funding constraints may prevent this process. In any event, the requesting activity should determine the required dredge depths for Military Construction Projects. Dredge depth requirements for Nimitz class aircraft carriers depend on the type of waterway to be dredged. Four categories exist based on the magnitude of wave-induced and speed-induced ship movement:

- Outer channels – entrance channels or waterways subject to significant wave action, that is, wave energy resulting in vertical ship motions greater than 0.5 ft. under design conditions.

- Inner channels – interior protected channels or waterways subject to minimal wave action, that is, wave energy resulting in vertical ship motions less than 0.5 ft. under design conditions.

- Berths – water areas where ship velocity approaches zero, such as anchorages, slips, and pier and wharf berths that are subject to minimal wave action under design conditions; generally includes turning basins except as noted below.

- Special berths – defined as berths subject to significant wave action under design conditions.

5-6.1.6.4 The following definitions apply:

- Datum – the horizontal plane from which the dredge depth requirement is referred, normally the local tidal datum of Mean Lower Low Water (MLLW).

- Design depth – the distance below the datum that must be maintained for safe navigation and berthing, also called the advertised, nominal, or project depth. This depth usually appears on Navigational Charts.

- Contract depth – the distance below the datum that is initially dredged by the contract and includes advanced maintenance dredging requirements but not the dredging tolerance (allowable overdepth). Also called the required depth, it is the depth noted on the DD-1391 Project Documentation and indicates the minimum depth required under the dredging contract.

- Permitted depth – the distance below datum to the lowest depth authorized by the regulatory agencies and normally includes the dredging tolerance (allowable overdepth). Planners and engineers should use this depth to determine estimated dredging quantities.

5-6.1.6.5 Determine required dredge depths using sound engineering practice. The design depth is determined by summing the following parameters:

- Minimum water depth requirement – the minimum water depth that must be available for safe operation. For existing locations, use Appendices C through F implemented as follows for design water level, squat, ship motions, and underkeel clearances. For locations not addressed in the Appendices, contact the NAVFAC Criteria Office for assistance.

- Design water level – the distance above the datum from which the dredge depth is calculated. For outer channels – use 0 m (0 ft). The design water level should equal the datum to provide enough water depth and ensure that the ship can transit at all times. For inner channels and turning basins – use a water level that ensures safe passage to the berth or basin. This water level should be selected by the Activity based on optimizing cost and operation. Ship operators generally accept some minor operational restrictions and transit shallow channels at mid to high tide levels. Therefore, the design water level should be selected so that the carrier can transit from deep water to the berth, or vice versa, as frequently as expected without encroaching on the minimum water depth requirement noted in Appendix B. The user should identify for the planner the expected ship transit speed and desired days of accessibility, realizing that slow transits at low tide levels result in excessive dredge depths.

An example of this procedure is as follows:

- Determine level of accessibility; e.g. minimum of 339 days per year of access to homeports and 300 days per year of access to shipyards and ports of call. These accessibility levels equate to operational restrictions of approximately 2 consecutive days per month of encroachment on the underkeel clearance for homeports and 5 consecutive days per month for shipyards and ports of call, respectively.

- Based on local traffic and regulations, assume an average ship speed through channel; e.g. 5 knots.

- Using assumed transit speed and navigational charts, calculate the time required to accomplish the transit from the outer channel to the turning basin or berth.

- Using the calculated transit time, days of accessibility, and the charts in the Appendices, determine the channel depth requirement.

- Subtract the water depth requirement from the channel depth requirement to obtain the design water level. This number will usually be negative and thus result in a design water level above MLLW.

For all berths, except turning basins – use 0 m (0 ft). Since 1.83 m (6 ft) of clearance is provided, as noted later, the design water level may equal the datum (MLLW)

- Squat – the downward displacement of a vessel while underway. Assume no squat in berths. Appendices C - F incorporate squat for infinitely wide channels with ship speeds equal to or less than 10 knots. Ship squat greatly increases when CVNs transit channels less than 600 ft in width or move at speeds faster than 10 knots. To determine squat for conditions other than those addressed in Appendices C - F, use the method contained in paragraph 5-6.1.2.3) of this manual. All channels used by aircraft carriers in the United States, except the Southern Branch, Lower Reach, of the Elizabeth River, Norfolk, VA (137.2 m (450 ft) at narrowest point) and the Entrance Channel, Mayport, FL (152.4m (500 ft) at narrowest point), are wide enough to be considered infinitely wide. For these narrow channels, the squat increases by 0.6 m (2 ft) The water depth requirement determined above should be modified to incorporate any difference in calculated squat.

For outer channels, assume ship speed of 15 knots. For inner channels, base on local traffic and regulations, but as a minimum, assume an average ship speed through channel of 10 knots and include the effects of narrow channels as noted above. For berths and special cases, assume ship speed of zero.

- Ship motion -- vertical excursion of vessel from waves. Appendix E addresses ship motions only for San Diego and Mayport. For other locations, use nomographs in Appendix F. H_s is defined as the significant wave height. Each set of nomographs reflects the direction of the significant wave relative to the direction of the CVN in transit; i.e., Following Seas are collinear with and in the same direction of ship movement, Quartering Seas are those that approach the aft quarter of the ship at 45 degrees, Beam Seas impact broadside to the ship, Bow Seas are those that approach the forward quarter of the ship at 45 degrees, and Head Seas are collinear with but opposite to the ship movement. The wave height and period should be transformed to and through the channel entrance using local wave data or Army Corps of Engineers reports entitled, *Wave Information Studies of U.S. Coastlines*.

For outer channels, use H_s for periods greater than 10 seconds with a 6 days/month recurrence interval. Exclude hurricane waves. Here is an example: Determine the wave climatology using available data determine the significant wave height, direction, and period. Transform waves into harbor based on shoaling, refraction, and diffraction, etc. Then based on local traffic and regulations, assume an average ship speed through channel; e.g. 14 knots. Using the calculated wave climatology, assumed ship speed, and the charts in Appendix F, determine the predicted vertical ship motion for all applicable directions. For inner channels and berths, use $H_s = 0$. For special cases, use H_s for periods greater than 10 seconds with a 25 yr recurrence interval, unless directed differently by the Activity. Include hurricane waves if the berth is expected to be occupied during that extreme event.

- Clearance – distance from the lowest point on the vessel to the design depth. For berths, turning basins, and inner channels, Appendix B incorporates a 1.83 m (6 ft) clearance to prevent ingestion of benthic biota. This clearance when combined with installed discharge diffusers reduces the possibility of condenser fouling. Additional studies may reduce the requirement and can be performed if funded. The planner must collect all historical data available regarding fouling of condensers to ascertain the extent of the problem. The NAVFAC Criteria Office is available to assist in analyzing this data. Notwithstanding, at berths the planner must ensure that a minimum of 0.6 m (2 ft) of clearance is provided at Extreme Low Water. See Table 5-6 for other categories:

Table 5-6 Required Clearances

LOCATION CATEGORY	SOFT BOTTOM	HARD BOTTOM
1. Outer channel	0.9 m (3.0 ft) for 15.24m (50 ft) depth	1.22 m (4.0 ft) for < 15.85 m (52 ft) depth
	1.34 m (4.4 ft) for 16.46 m (54 ft) depth	1.68 m (5.5 ft) for > 17.68 m (58 ft) depth
	1.68 m (5.5 ft) for > 17.68 m (58 ft) depth	
2. Special berths	1.82 m (6 ft) (min.) coupled with discharge diffusers	6 ft. (min.) coupled with discharge diffusers

5-6.1.6.6 Determine the contract depth by adding the advanced maintenance dredging requirement to the design depth requirement. The advanced maintenance dredging is the additional depth to reduce life-cycle maintenance costs by decreasing the frequency of dredging. Base the quantity on the anticipated local channel sedimentation rates corresponding to the anticipated dredging cycle. Use a dredging frequency of not less than 3 yr., but based on local conditions. Include a minimum of 1 ft advanced maintenance dredging to prevent contractor change orders for differing site conditions on future maintenance dredging contracts. This minimum also provides the Contracting Officer field flexibility if the contractor does not achieve the contract depth in spot locations. The dredging tolerance, or overdredge, is the additional depth below the contract depth paid for by the dredging contract. The contract permits this additional depth because of inaccuracies in the dredging process. It is normally either +1 or +2 feet. Local conditions and anticipated dredging equipment may warrant a different value. NAVFAC Textbook DM 38.2, “Dredging Equipment” provides additional information.

5-6.1.6.7 Determine the permitted depth by adding the dredging tolerance, or overdredge, to the contract depth. Material samples for environmental testing should be accomplished at least to this depth.

5-6.1.6.8 OPNAVINST 11010.20E, Part 5 designates responsibilities of the Chief of Naval Operations, Lead Activities, Shore Activities having assigned water areas, Public Works Centers and Public Works Lead Activities, Naval Facilities Engineering Command and Engineering Field Divisions, and Major Claimants regarding dredging coordination.

- Lead Activities and Shore Activities having assigned water areas – determine dredge depth requirements for Nimitz class aircraft carriers following procedures contained herein.

- NAVFAC Headquarters, Engineering Field Divisions (EFDs) and Engineering Field Activities (EFAs) –
    - Provide technical advice and assistance to lead activities and shore activities having assigned water areas.
    - Plan, design, and construct channels in compliance with the guidance stated herein.
- NAVFAC Criteria Office will provide technical advice and assistance to lead activities, shore activities having assigned water areas, EFDs and EFAs.

5-6.1.7 **Dangerous Cargo Requirements**. Anchorages for tankers and similar vessels should be at least 152.4 m (500 ft) from adjacent berths, and located so that prevailing winds and currents carry spillage away from general anchorage and berthing areas.

Anchorages for vessels carrying explosives should be separated in accordance with quantity-distance relationships established in Ammunition and Explosives Safety Standards, DOD 5154.45 (DOD, 1978), which was superseded by DOD 6055.9 (DOD, 1997), and Ammunition and Explosives Ashore, NAVSEA OP 5 Vol 1, 6th edition (NAVSEA, 1999).

5-6.1.8 **Shipyard Special Requirements**. The following information is provided:

5-6.1.8.1 **Mission and Requirements.** Harbors or sections of harbors designed as shipyards require special facilities and designs. Shipyard facilities consist of navigation basins, piers, drydocks, and backland. Outfitting or repair piers are generally arranged as in Figure 5-15c or Figure 5-15f. Less commonly, where space permits, repair stations could be arranged along a marginal quay, as in Figure 5-15i. Drydocks may be either the floating or graving type.

5-6.1.8.2 **Waterways.** The shipyard portion of the harbor requires a channel sufficiently large to accommodate the largest vessel to be served by the shipyard. The water area fronting the shipyard should be a navigable basin in which the largest vessel is capable of maneuvering to and between repair facilities. It is essential that the shipyard has quiet water and be free of strong currents. Ships at repair are frequently in “hotel” status and short of the operating personnel needed to operate them in case currents should tear them loose from their moorings.

5-6.1.8.3 **Piers.** Special considerations for repair and outfitting piers include crane rails for portal cranes, railroad tracks between crane rails, and special service piping to shipside galleries or service boxes. For pier design, refer to MIL-HDBK-1025/1.

5-6.1.8.4 **Drydocks.** Drydocks are of two basic types: floating and graving. Floating drydocks may be moved from place to place and are suitable for servicing smaller ships and submarines. A floating drydock must be moored or anchored in a location where the water is considerably deeper than the draft of the ships it serves, and it must have access to the shore for supplies and utilities. A staging and laydown area alongside the drydock is required to provide operational support.

A graving drydock is a permanently placed facility dug into the embankment. Such drydocks are usually equipped with portal cranes that travel around the perimeter of the dock and are surrounded by service and laydown areas for large ship parts and equipment. Space along the quay near the drydock or other moorage and clear of vessels maneuvering into the dock is required for storage of the drydock's caisson gate. For all types of drydocks, keel blocks for the various vessels served must be stored nearby.

5-6.1.8.5 **Ancillary Facilities.** Additional facilities and water area should be allocated for anchorage or moorage of ships awaiting repair service and for tugboats and fireboats. These facilities and areas may not be required within the shipyard limits if they are available nearby in the harbor.

5-6.1.8.6 **Land Needs.** Land area should be allocated to shipyard use in sufficient quantity to provide for rail or highway access, including onsite storage of vehicles and goods required for shipyard operations. Shop and office buildings, storage areas, and laydown spaces should be arranged to provide the most efficient flow of work and personnel within the facility consistent with the available space and mission of the shipyard.

Figure 5-16 is an example of the space allocation and arrangement of a sample shipyard.

5-6.1.9 **Degaussing and Deperming Requirements**. NAVORD OP 2706, Introduction to Degaussing (NAVORD, 1960) and NAVSEASYSCOM SS475-AD-MMD-010/MAG FAC, Magnetic Silencing Facilities Description and Installation of Permanent and Portable Equipment (NAVSEASYSCOM, 1980) cover the two methods used in magnetic silencing: magnetic compensation (degaussing coils) and magnetic treatment (deperming). Deperming which reduces the permanent magnetization accumulated by a ship during construction and operation complements the use of opposing magnetic fields in degaussing.

Figure 5-15 Types of Berthing Layouts

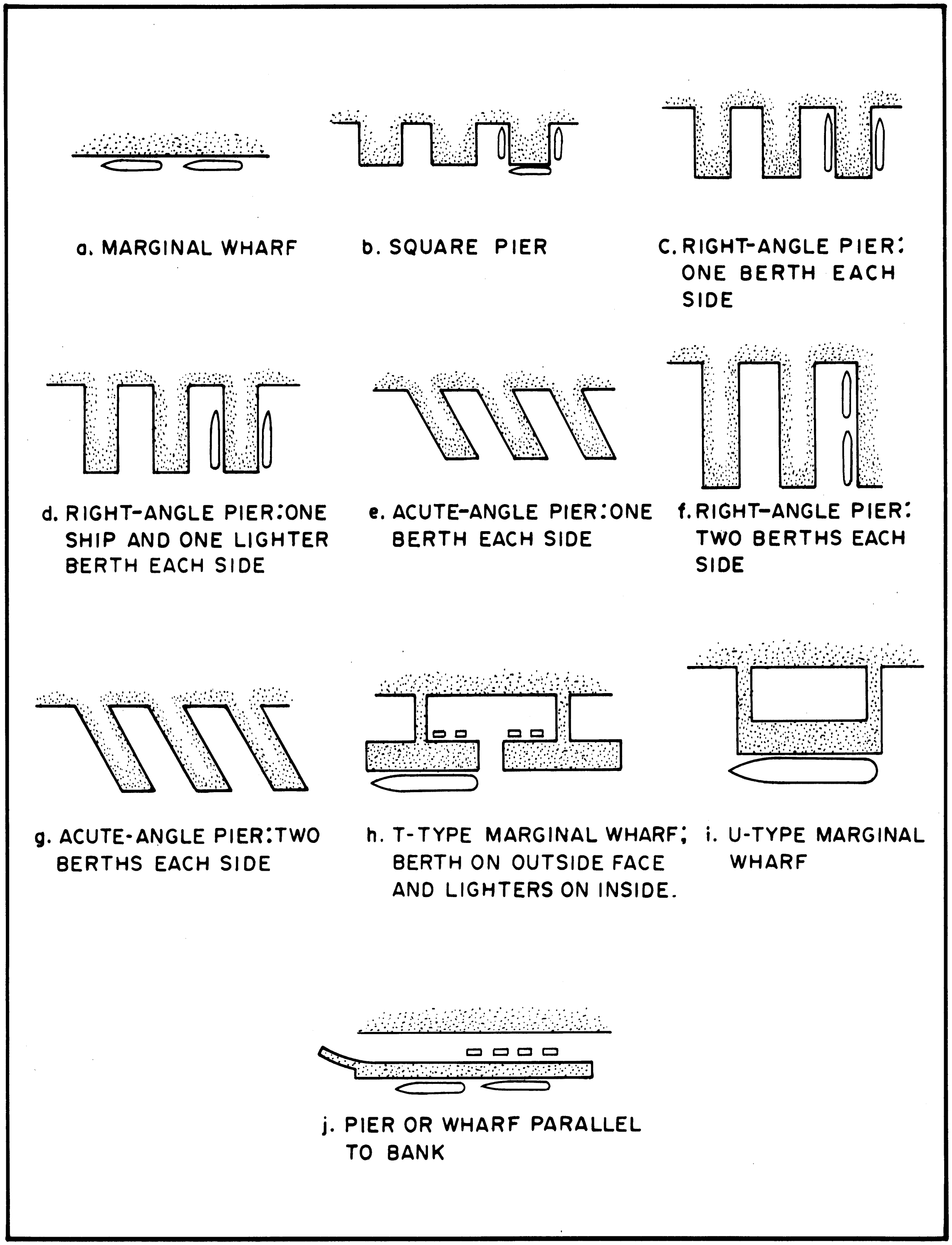
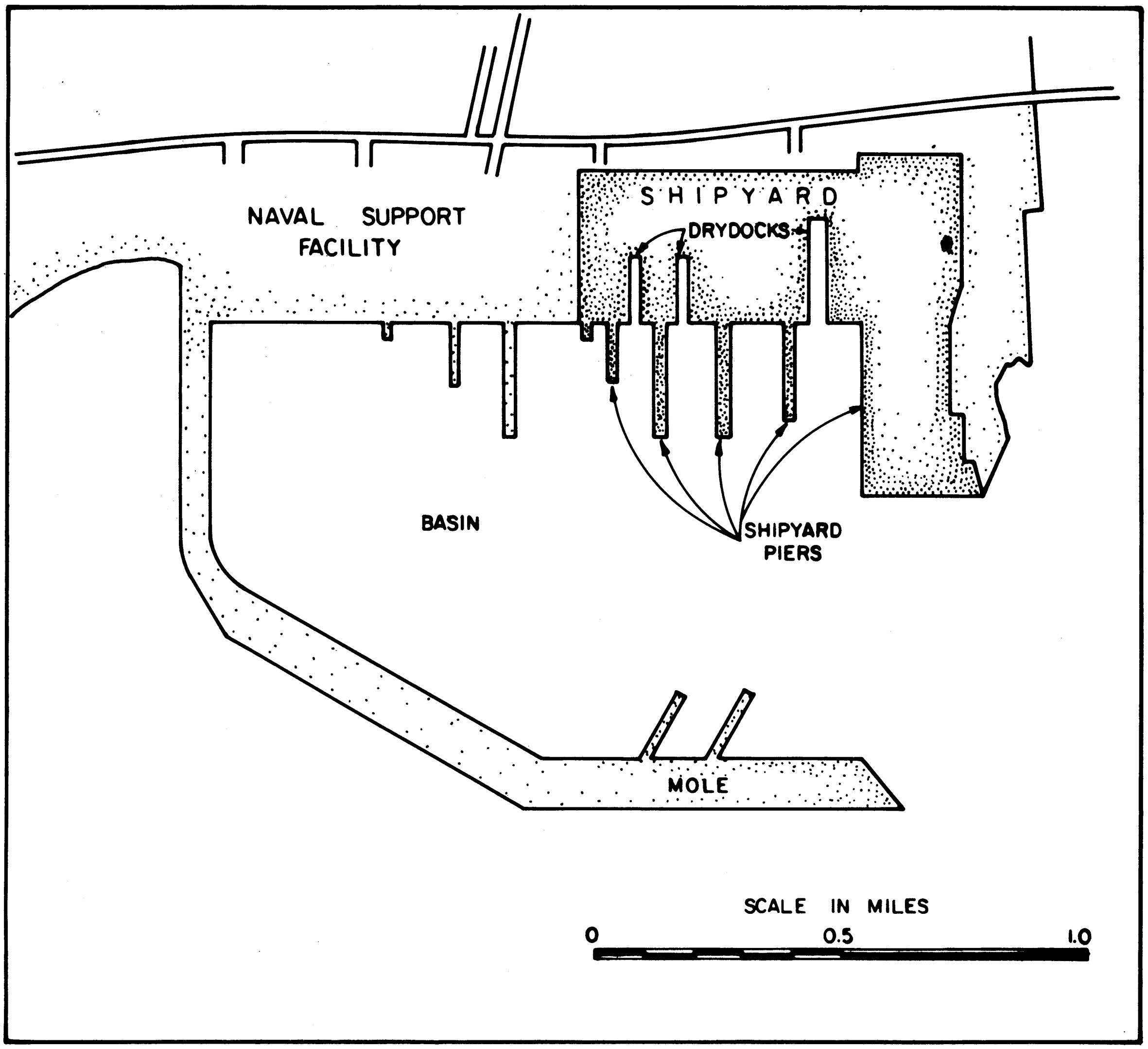


Figure 5-16 Sample Shipyard Layout



5-6.1.9.1 A steel object under the magnetic forces of the earth will itself become polarized and set up a magnetic field of its own. A steel-hulled ship will become a huge floating magnet itself. In addition, there are induced magnetic signatures caused by inside electronics and motors. This magnetic field makes the ship vulnerable to magnetically sensitive mines or other magnetic influence detecting devices.

5-6.1.9.2 The science of degaussing deals with reducing the ship's magnetic field, or signature. Normal deperming techniques based on alternate reversals of ship polarity are used to reduce the ship's permanent structural hull signature whereas equipment induced signatures are controlled by interior degaussing cables. In order to determine the characteristics of a ship's magnetic field it is necessary to make periodic measurements of the field, referred to as "ranging". The primary type of degaussing/magnetic silencer range consists of a linear pattern of instrumentation tubes containing magnetometers embedded in the channel bottom.

5-6.1.9.3 There are three depth classifications of check ranges based on class of ship:

- Minesweeper – shallow (9.1 m (30 ft))
- Medium depth (16.8 m (55 ft)); and
- Deep (25.9 m (85 ft))

There are now 6 Forward Area Combined Degaussing and Acoustic Ranges (FACDAR) for forward deployed areas where no permanent ranges are available.

5-6.1.9.4 In order to deal with magnetic silencing facilities for degaussing and deperming purposes, it is necessary to design with dredging in mind. If the facilities are already in place, a dredging method, which will not impact the facilities, must be chosen.

5-6.1.10 **Seismic Loading**. Coastal projects constructed in regions known to experience seismic activity may need to consider potential impacts related to ground deformation and severe liquefaction. Seismic loading may also be a concern in design of confined dredge material berms (subaerial) and caps (subaqueous) where liquefaction could release contaminated sediments. CEM Section VI-3-4 provides further guidance.

5-6.1.11 **Ice Loading**. At some latitudes, fresh water lakes and coastal regions experience annual ice formation during portions of the year. Thus, in project planning stages, it is important to determine if the presence of ice adversely impacts the project functionality; furthermore, during design, it is important to consider the effect that ice loads and impacts might have on individual coastal project elements. CEM Sections VI-3-5, and EM 1110-2-1612, Ice Engineering**,** provide further guidance. Chapter 10 of the Report on Ship Channel Design provides a cursory view of design of channels with ice cover, locks, erosion and sediment movement, and vibration and mitigation of ice problems in channels (ASCE, 1993).

5-6.1.12 **Debris Entering Harbors**. Marine debris entering harbors is composed of a broad range of materials, which include litter (e.g., aluminum cans, plastic pieces, glass pieces, and cigarette butts), waste (e.g., medical, galley, operational, and sewage), and wood from branches from trees and other inland vegetation. As such, it can interfere with harbor operations. Assessment and strategies to reduce marine debris in the coastal and ocean environment can be accomplished by managing uses and activities that contribute to the entry of such debris. Existing regulations include, but are not limited to, prohibiting littering and dumping of debris and discharging pollutants in near shore waters. Harbor activities are also subject to the same rules and statutes relating to debris control.

5-6.1.13 **Drydocks**. This subject is covered in detail in MIL-HDBK-1029.

5-6.2 **Development of a Navigation Project**. Often a navigation project requires one or more engineered structures to accomplish its objectives. Structures can serve a variety of purposes. However, their presence also establishes a major hazard for vessels. Hence, a navigation structure must be designed with regard to several functional concerns. Basic types of structures and functions involved in navigation projects are briefly discussed in CEM Section V-5. Sediment processes and management at inlets and harbors are discussed in CEM Section V-6. Detailed guidance on structure design is given in CEM Section VI.

5-6.2.1 **Defining Fleet Requirements**.

- All dredging activities must be coordinated with the NAVFAC Criteria Office.
- The activity should coordinate the following issues with the major claimant: classes of ships used at the facility, access frequency, days of harbor access required, and function performed in the harbor,
- Most harbors cannot design for 100% accessibility, so the amount of risk the claimancy wants to take on should be addressed.
- Seakeeping issues in the channel shall also be addressed.
- Check for criteria of thickness of ice; refer to paragraph 5-5.1.11, Ice Loading, for references.

5-6.2.2 **Entrance Channel Configuration**. Designing approach-channel and entrance-channel widths for harbors located in exposed ocean-wave environments is largely accomplished by comparing presently operating harbors. The forces of waves and currents acting on a vessel in exposed locations induce excursions of the vessel from its intended path of travel. For example, to pass in the lee of an entrance structure, a vessel needs maneuvering room in order to adjust to the rapid changes in sea conditions.

Where naval activities share common entrance approaches with commercial port activities, entrance-channel widths greater than 304.8 m (1,000 ft) are common. Table 5-7 gives entrance-channel dimensions for several typical harbors. Table 5-8 provides typical harbor entrances serving naval facilities.

For new entrance designs, preliminary width approximations can be made as given in paragraph 5-6.2.2c, Entrance Channels, by adjusting ship beam with yaw angle increase and then proceeding as for an interior-channel design. In the case where the hydraulic environment at the entrance is unique and without precedent, navigational studies involving suitable-scale physical model methods are recommended.

5-6.2.2.1 **Interior Channels**. The dimensioning of interior channels protected from open sea waves and strong cross currents is shown in Figure 5-17, where B = beam of vessel.

- Ship-Lane Widths. Where good operating conditions (that is, a maximum ship speed of 10 knots, currents less than 3 knots, good visibility, and wind less than 15 knots) exist, the following ship-lane widths should be used:

Vessel Maneuvering Characteristics	Lane Width as a Multiple of Beam
Excellent – CG and DD	1.6
Good – FFG, CV, AOE, and LSD 36	1.8
Poor – Submarines, Tenders, AE, and AS	2.0

- Ship Clearance. Ship clearance is normally assumed to be equal to the beam at waterline of the largest vessel. Where a channel is to be frequently used by aircraft carriers having large overhanging decks, increase the clearance between ship lanes to maximum vessel breadth.

- Bank Clearance. Vessels traveling in restricted waterways experience hydrodynamic suction from the banks. This is offset by rudder-angle adjustment. Results of limited model studies are shown in Figure 5-18.

For sustained travel by a naval vessel in a restricted channel, a 5-degree rudder angle is a desired maximum.

Figure 5-17 Dimensioning Protected Interior Channels

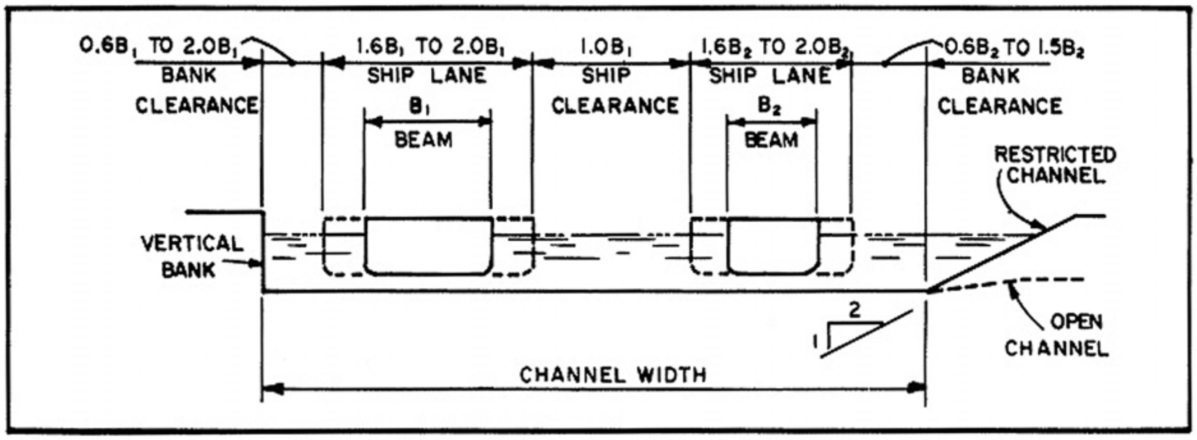


Figure 5-18 Bank Clearance Versus Rudder Angle

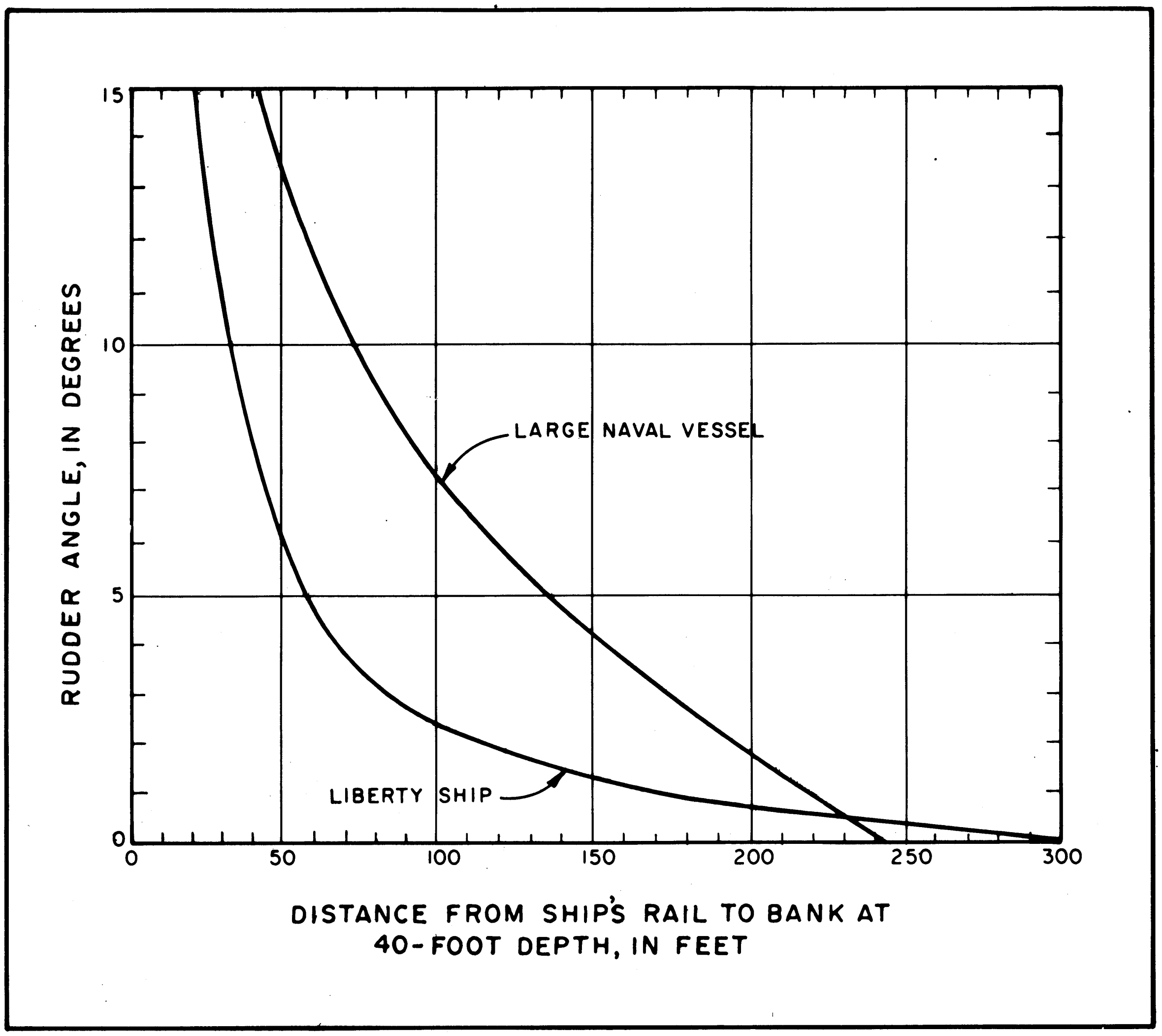


Table 5-7 Typical Entrance-Channel Dimensions

Harbor	Width (m (ft))	Depth (m (ft))	Remarks
Boston, MA	335.3 (1,100)	12.2 (40)	Access to port entrance
New York, NY	548.6 (1,800)	13.4 (44)	Access to port entrance
Charleston, SC	457.2 (1,500)	10.7 (35)	Non-restricted outlet for three rivers
Columbia River, OR	804.7 (2,640)	14.6 (48)	River bar crossing in severe wave environment – closed during certain storms
Long Beach, CA	548.6 (1,800)	18.3 (60)	Breakwater gap
San Diego, CA	243.8 (800)	12.5 (41)	Entrance channel through parallel jetties
Apra Harbor – Guam	411.5 (1,350)	36.6 (120)	Entrance between breakwater head and shore

Table 5-8 Typical Harbor Entrances Serving Naval Facilities

Harbor	Width (m (ft))	Depth (m (ft))	Largest Naval Vessel – Normal Use	Remarks
Mayport, FL	274.3 (900)	12.8 (42)	Unrestricted	Entrance through parallel jetties
Port Hueneme, CA	182.9 (600)	11.9 (39)	Destroyer	Entrance through non-parallel jetties
Pearl Harbor, HI	481.6 (1,580)	18.3 (60)	Unrestricted	Broad, ill-defined entrance
Seal Beach, CA	182.9 (600)	11.6 (38)	Destroyer	Entrance through non-parallel jetties

In addition to rudder-angle and vessel-handling criteria, overall vessel safety must be considered in determining bank-clearance distance. In an open channel, the markings of the channel limits may not be as fully defined as in a restricted channel. This can be compounded in times of poor visibility. Similarly, where there exists a high damage probability for grounding, as in the case of an underwater rock ledge, additional bank-clearance margins should be considered. Extra allowance should also be made where the channel is subject to siltation from the side slopes. Under conditions such as those mentioned above, the minimum desired bank clearance for design purposes should be equal to the beam of the largest vessel frequenting the harbor. For open channels with steeper than 1-on-3 side slopes, this minimum clearance should be 1.2 times the beam. Examples of existing interior channels are given in Table 5-9.

5-6.2.2.2 **Channel Bends**. Bends in channels should be avoided if possible. If channel bends are unavoidable, the channel should be widened to account for the fact that the path of a ship in a bend is wider than in straight sections. The criteria for designing channel bends depend upon:

- The angle of deflection, defined as the angle between the two straight sections of the channel,

- The speed of travel of and the properties of the vessel,

- The characteristics of the channel,

- The visibility, obstructions, and aids to navigation in the vicinity of the bend, and

- Human elements.

Table 5-9 Examples of Existing Interior Channels

Harbor	Width (ft)		Depth (ft)		Remarks
	m	ft	m	ft	
Baltimore-Fort McHenry Channel	121.9	400	10.7	35	Open-type channel
Norfolk- Thimble Shoal	469.4	1540	13.7	45	Open-type channel
Charleston-Naval Weapons Annex, Kingston	152.4	500	10.7	35	Riverine, open-type channel
Columbia River-Astoria Range	182.9	600	12.2	40	Riverine, open-type channel
Oakland-Bar Channel	91.4	300	10.7	35	Open-type channel
San Pablo Bay-Pinhole Shoal	182.9	600	10.7	35	Open-type channel
Long Beach	304.8	1000	10.4	34	Restricted-type channel
San Diego	213.4	700	12.5	41	Open-type channel

- Open-Type Channels. A change from one direction of the channel into another can be accomplished for an open-type channel without the introduction of a curved bend, provided the vessels encountering the bend are highly maneuverable and the change in direction is not too large. Such a bend is called a straight-line bend and is shown with alternative methods of widening the channel in Figure 5-19.

- Restricted-Type Channels. If the bend occurs in a restricted-type channel, the change of direction is large, or the maneuvering characteristics of the vessels frequently using the channel are poor, introduction of a curve in the channel becomes necessary. In designing a channel curve, the critical factor is determination of the radius of the curve. The criteria upon which the radius, R, is based are the length, l_v, of the ship entering the channel and the angle of deflection, α, of the channel bend. The general rules governing determination of the radius are as follows:

  - Minimum R = 914.4 m (3,000 ft) for a ship under its own power.
  - R = 365.8 to 609.6 m (1,200 to 2,000 ft) for tug assistance.
  - If the angle of deflection is greater than 10 degrees, the curve should be widened at the inside curve.
  - The tangent length between consecutive curves where there are no obstructions should be 304.8 m (1,000 ft) or 2 l_v (where l_v = length of the largest ship using the channel), whichever is larger.
  - Reverse curves should not be used except in special situations.

Rules governing the radius, based on angle of deflection, are:

R = 3 l_v minimum for α < 25 deg.

R = 5 l_v minimum for 25 deg. < α < 35 deg.

R = 10 l_v minimum for α > 35 deg.

Rules governing the radius, based on vessel length, are:

R = 1219.2 m (4,000-ft) minimum for l_v < 152.4 m (500 ft)

R = 2133.6 m (7,000-ft) minimum for l_v = 152.4 m (500 ft)

R = 2133.6 to 3048 m (7,000 to 10,000 ft) for (152.4 m (500 ft) < l_v < 213.4 m (700 ft)

The radius of the curve must fulfill the above criteria. Once R has been determined, the channel-bend geometry must be determined. This consists of widening the channel at the bend and providing a smooth transition from the straight portions of the channel through the curve. This can be done in several ways, as shown in Figure 5-20 to Figure 5-24. The entire amount of widening in the channel could be added to the inside of the channel, as shown with curved transitions in Figure 5-21 and straight transitions in Figure 5-22. The widening could also be split on the inside and outside of the curves equally, as shown in Figure 5-23, or unequally, as shown in Figure 5-24. For final design, an investigation considering local conditions and dredging costs is required to optimize bend geometry. If widening the channel cannot be achieved due to existing soil conditions or structures, tugs must be used to assist ships.

5-6.2.2.3 **Entrance Channels**.

- Entrance Channel Widths

  Breakwater gaps. In practice, vessels transit gaps between breakwaters one at a time. Observations reveal that in practice a second vessel will normally stand off and allow the first vessel to complete its passage through the gap to and from protected water. A minimum entrance gap width of 0.8 to 1.0 times the length of the vessel appears to be adequate for most sea conditions.

  Channel entrances. Vessels require more room to maneuver in and out of channels leading to protected harbor waters. Therefore, prescribed widths for interior channels must be increased to allow for additional channel width at the entrance. By utilizing vessel beam and its length, the increase in vessel beam can be approximated by the following equation:

$$B' = B + l_v \tan \theta \qquad (5\text{-}8)$$

where: B' = adjusted vessel beam

B = vessel beam

l_v = vessel length

θ = yaw angle

Yaw angle should be assumed to range from 5 to 15 degrees, depending upon entrance exposure. The adjusted vessel width, B', is used in ship lane width determinations with ratio factors similar to those used in interior-channel design (see Figure 5-17).

- Entrance Channel Length. In order to safely negotiate the entrance channel, vessels normally must maintain a higher rate of speed than is required or permitted within a harbor. Thus, the entrance channel should be of a length sufficient to allow vessels to reduce velocity before entering the harbor proper. For vessels entering with speeds in the range of 5 to 10 knots, allow one vessel length of slowing distance per knot of entering speed between the entrance and the turning basin. For medium-sized vessels with no tug-assisted speed arrestment, a minimum of 1066.8 m (3,500 ft) should be provided. CEM Section V-5 deals with the crucial elements of channel design: width, depth and alignment. In addition, the special requirements of entrance channels are discussed.

Figure 5-19 Straight-Line Bend – Alternative Methods of Widening Open-Type Channel.

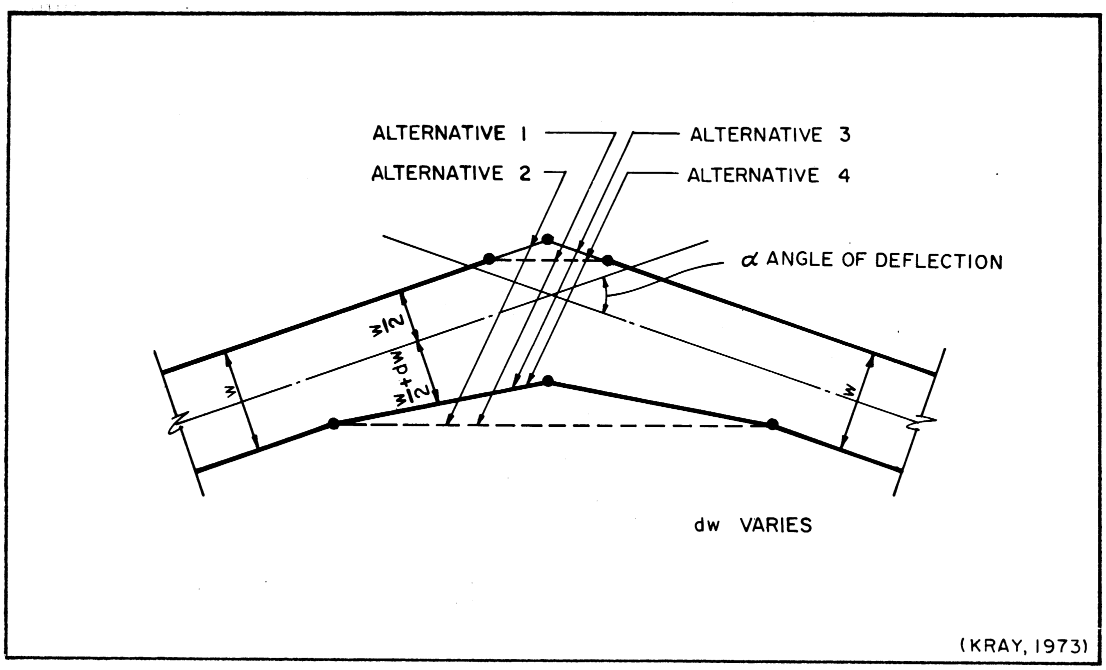


Figure 5-20 Parallel Constant – Width Turn in Channel.

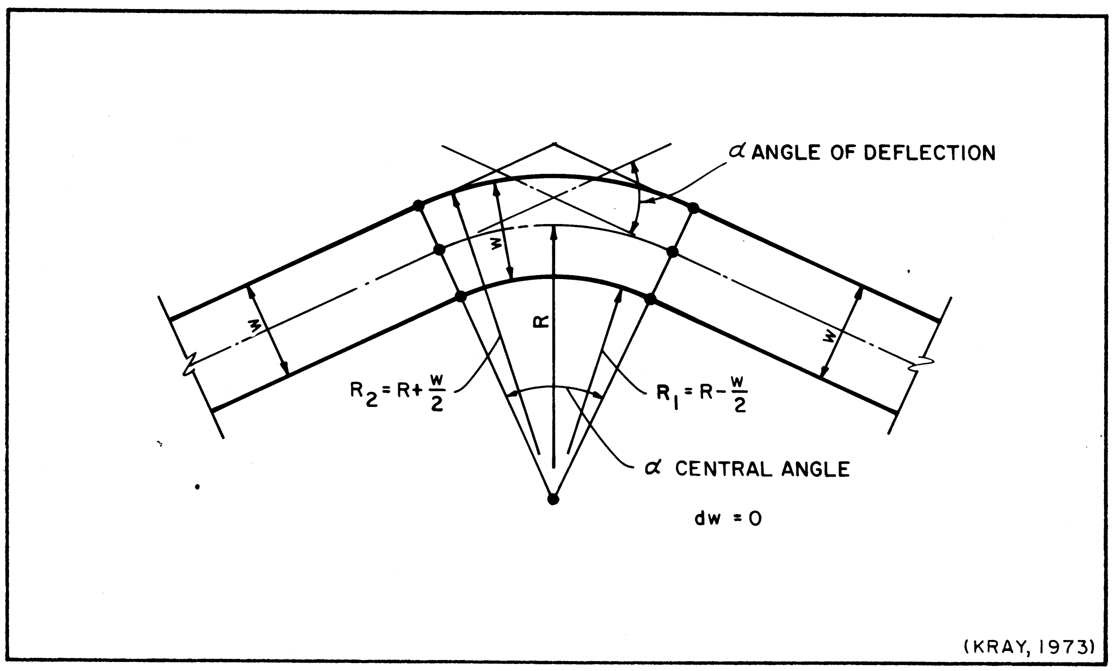


Figure 5-21 Unsymmetrically Widened Turn With Curved Transitions

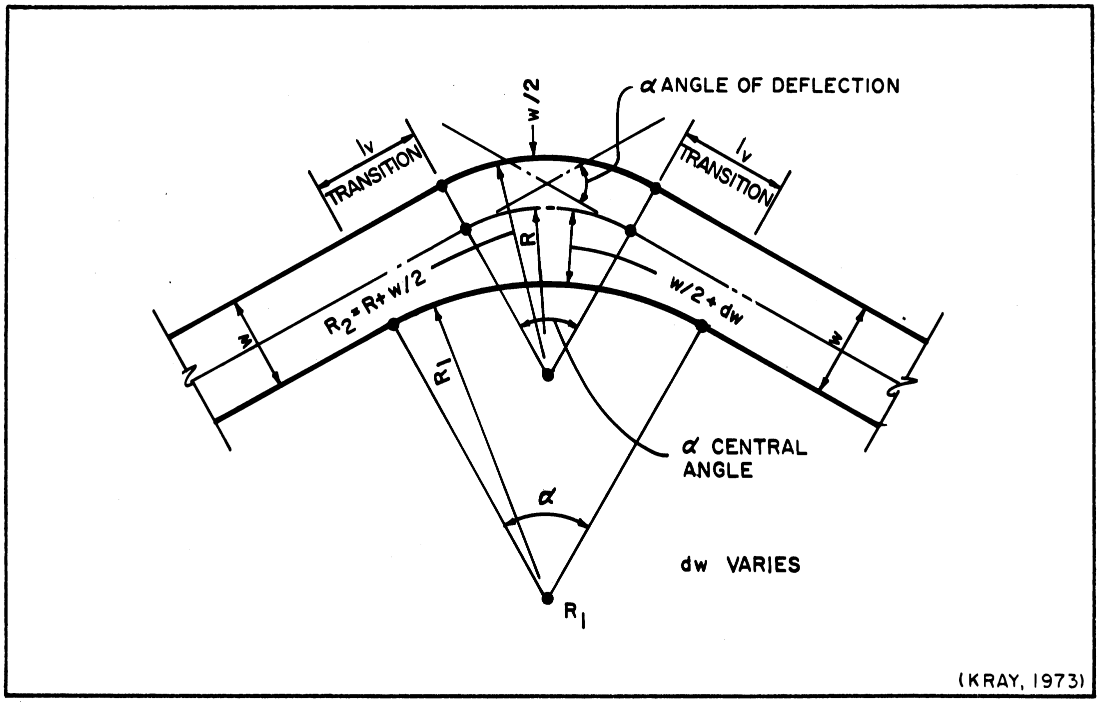


Figure 5-22 Unsymmetrically Widened Turn With Straight Transitions

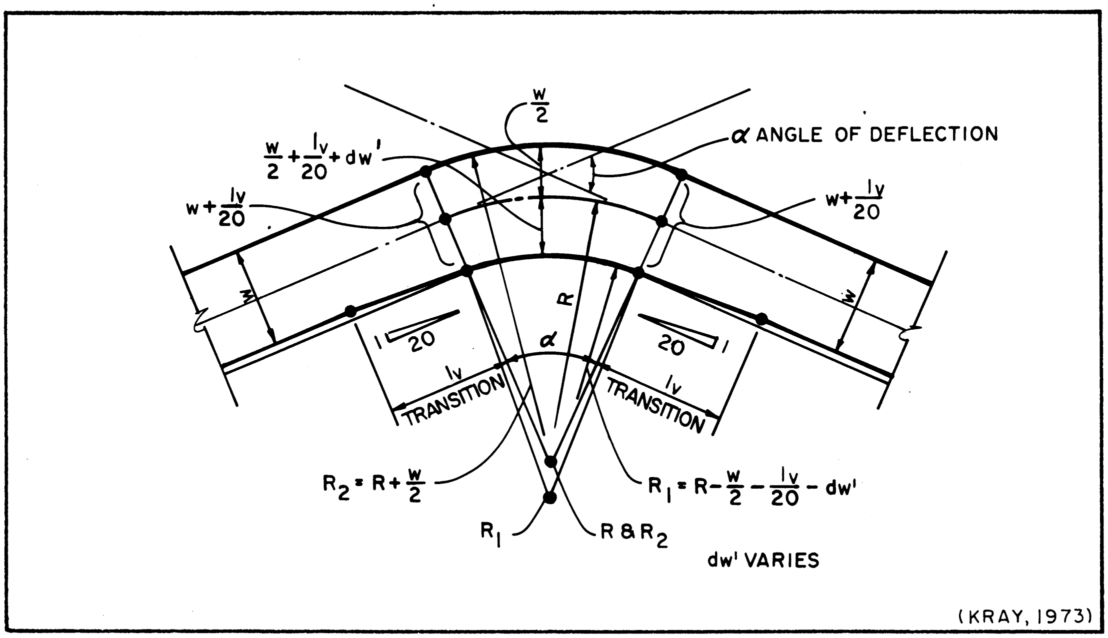


Figure 5-23 Parallel Widened Turn in Channel

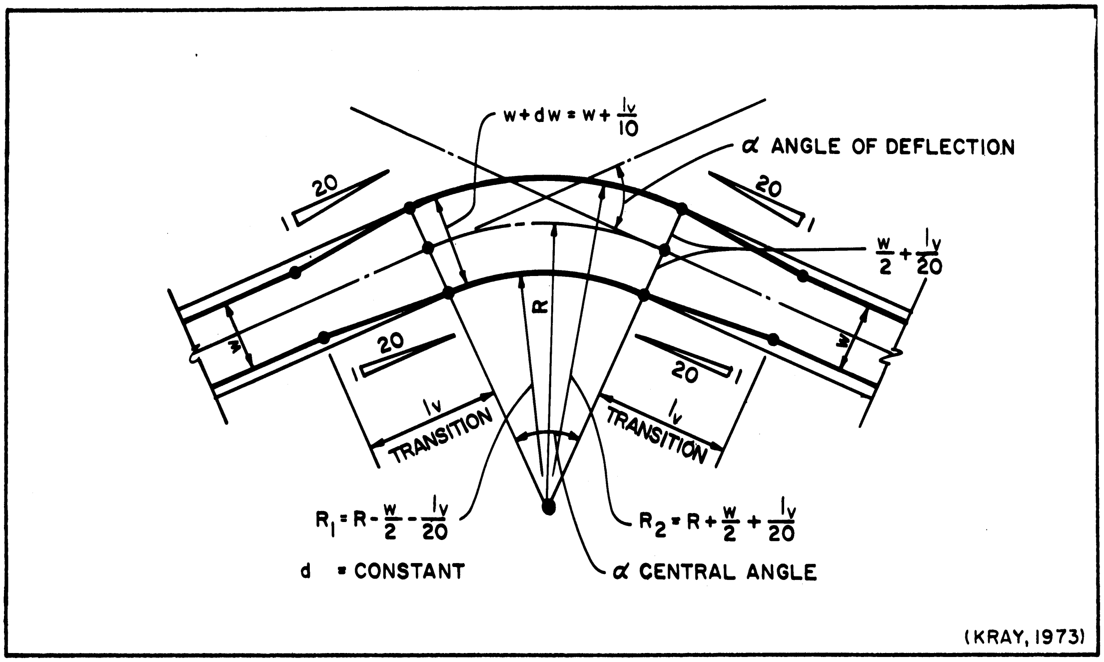
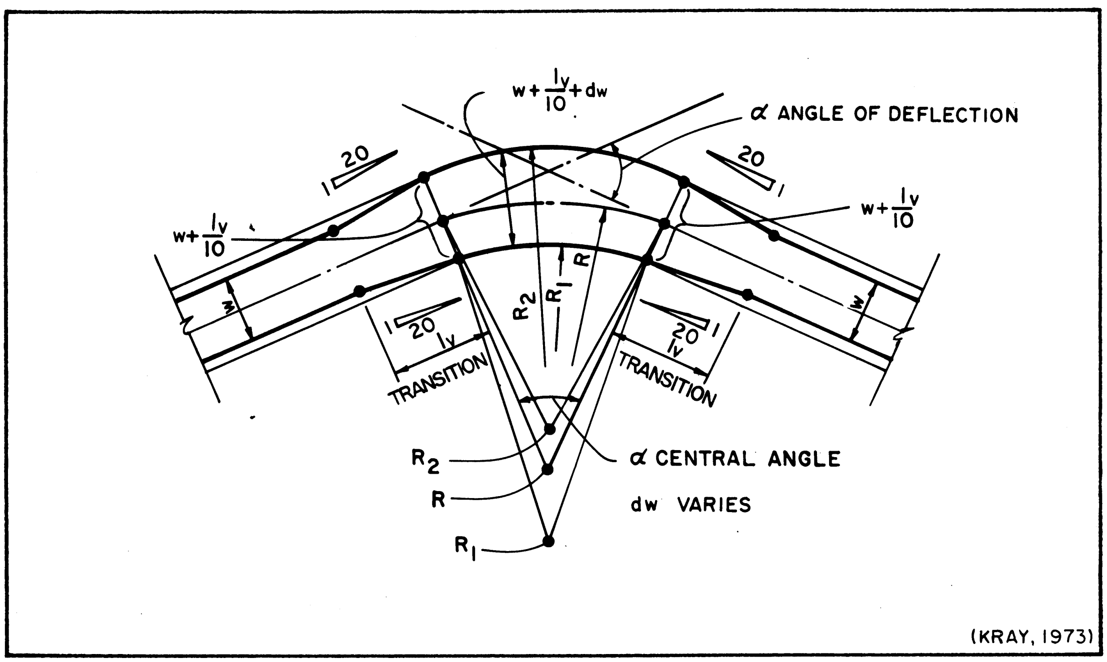


Figure 5-24 Symmetrically Widened Turn With Straight Transitions



5-6.2.3 **Berths and Berthing Basins**. Figure 5-15 showed types of berth arrangements. Table 5-10 lists factors affecting the selection of the location of berthing basins. A rule of thumb is that the wave height in the berthing basin should not exceed 0.6 m (2 ft) for comfortable berthing, but in no case shall the wave height exceed 1.2 m (4 ft).

5-6.2.3.1 **Quayage Required**. Quayage requirements of piers and wharves for the various classes of vessel may be estimated from tabulated data in MIL-HDB-1025/1. Consult with the using agency for data on the maximum number of ships of various classes (including lighters) to be simultaneously accommodated.

5-6.2.3.2 **Arrangement of Berths**.

- Selection. The arrangement of berths must fit the proposed site without encroaching on pierhead or bulkhead lines. For steeply sloping subgrades, the berths must fit within the depth contour below which the driving of piles is impractical. In selecting the berthing arrangement, consider the factors relating to economics and utility (see Table 5-11).

- Relative Berthing Capacities. Table 5-12 shows linear feet of berthing space per 304.8 m (1,000 ft) of shorefront.

5-6.2.3.3 **Size and Depth of Basin and Berths**. For the general depth requirements for the basin, see paragraph 5-6.1.2.

- Berthing Area. For berthing-area requirements for piers, see Table 5-13. For ships berthed at marginal wharves or quay walls, provide twice the total area requirement shown in Table 5-13 for pier berthing. Allow additional area within the harbor limits for channels, special berths, turning basins, and other facilities.

- Depth. Except where heavy silting conditions require greater depth at individual berths at low water, the depth should equal the maximum navigational draft of the largest vessel to be accommodated plus 10 percent. On mud or silt bottoms, consider increasing depth requirements if investigation indicates probable fouling of condensers on the vessel due to the proximity of the mudline to intake pipes of the condenser system. Where vessels to be accommodated are not specifically known, the values in Table 5-14 may be used.

- Clear Width of Slips Between Piers; see MIL-HDB-1025/1.

- Length of Berth; see MIL-HDB-1025/1.

- Width of Piers.

  - Square pier systems. Width should be capable of berthing the longest expected ship. The net area of the pier should be three times that required for a single berth terminal.

  - Finger pier system. Pier width varies. Width requirements may be estimated from data in MIL-HDB-1025/1.

- Special Berths.

  - Fueling vessels. Berths should be at least 152.4 m (500 ft) from adjacent berths.

  - Explosives. Berths should be separated in accordance with the quantity-distance relationships established in DOD 5154.45 and NAVSEA OP 5.

5-6.2.4 **Turning Basins**. Where space is available, providing turning basins will minimize tug usage. However, where space is restricted, tugs may be used to turn vessels, thereby eliminating the need for turning basins.

5-6.2.4.1 **Location**. The following location requirements must be met:

- locate one turning basin at the head of navigation

- locate a second turning basin just inside the breakwater

- in areas where especially heavy traffic is anticipated, provide intermediate basins to reduce congestion and save time

- where feasible, use an area of the harbor, which in its natural state has the required size and depth.

- it is frequently advantageous for a turning basin to be located at the entrance to drydocks or at the interior or landward end of long piers or wharves that provide multiple-length berthing.

5-6.2.4.2 **Size and Form**. As a rule of thumb, a vessel can be turned comfortably in a radius of twice the vessel length, or, where ease of maneuver is not an issue, in a radius equal to the vessel length. For shorter turning radii, tug assistance for the vessel is necessary. Also in this case, where wind and current effects are not critical, naval vessels can be turned in a circle with a diameter of 1.5 times the vessel length. Table 5-15 provides dimensions of typical turning basins in existence.

5-6.2.5 **Anchorage Basins**

5-6.2.5.1 **Siting Factors**. Table 5-16 lists factors affecting location, size, and depth of anchorage basins.

- Free-Swinging Moorings and Standard Fleet Moorings. For the diameter of the swing circle and the area requirements per vessel, see Table 5-17 and Table 5-18. For size of berth for floating drydocks, spread-moored, Table 5-19. Additional area allowance should be made for maneuvering vessels into and out of berths and for waste space between adjacent berths.

a) Demarcation. Anchorage areas should be marked.

b) Dangerous Cargo.

- Tankers. Anchorages for tankers and similar vessels should be at least 152.4 m (500 ft) from adjacent berths, and located so that prevailing winds and currents carry spillage away from general anchorage and berthing areas.

- Explosives. Anchorages for vessels carrying explosives should be separated in accordance with quantity-distance relationships established in DOD 5154.45 (DOD, 1978), which has since been superceded by DOD 6055.9 (DOD, 1997), and NAVSEA OP 5 (NAVSEA, 1999).

CEM Section V-5 discusses the details of inner harbor elements.

Table 5-10 Factors Affecting Location of Berthing Basins

Factor	Requirement and Comment	
Protection	Locate berthing basins in harbor areas that are best protected from wind and wave disturbances and/or in areas remote from the disturbances incident upon the harbor entrance.	
Orientation	Orient berths for ease of navigation to and from entrance and channel.	
Offshore Area	Provide sufficient area offshore of berths for turning ships, preferably without use of tugs.	
Quayage adequacy	Adequate quayage shall be provided for expected traffic.	
Expansion	Provide area for future expansion.	
Fouling and Borers	Where possible, locate berthing basin in area of harbor with minimum fouling conditions and minimum incidence of marine borers. Elliott, Tressler, and Meyers (1952) indicate some advantages for locations in the ebb side of an estuary harbor. The ebb side of an estuary in the Northern Hemisphere is the right side looking seaward.	
Foundations	Where feasible, locate in area of favorable subsoil conditions, in order to minimize cost of berthing structures.	
Supporting shore facilities	Locate supporting shore facilities in proximity to their respective berths. Adequate space and access for upland road and railroad facilities are essential. In general, it is desirable to have a wide marginal street at the inshore ends of the piers or wharves and a wide street on the pier axis. Annual capacity per terminal is based on commercial throughput values obtained from Hockney (1979).	
	Single Berth Terminal by Cargo Class	Cargo Throughput (tons per year)
	Break-bulk general	66,000
	Neo-bulk general cargo	130,000
	Containerized general cargo	360,000
	Dry bulk – silo storage	1,000,000
	Dry bulk – open storage – low density	500,000
	Dry bulk – open storage – high density	1,000,000
	Liquid bulk – other than petroleum	80,000
	Petroleum bulk – up to 50,000 dwt ships	1,500,000
	Petroleum bulk – 30,000 to 200,000 dwt ships	6,000,000

Table 5-11 Selection Factors for Berthing Arrangements

Berthing System	Advantages	Disadvantages
Marginal Wharf (Figure 5-15a)	Solid fill supports deck loads without expensive framing. Accessibility of entire upshore area for working space, storage space, laydown operations, and traffic circulation adds to the utility of the wharf as compared to pier or offshore wharf systems. Permits utilization of surplus fill material. Suitable for sites where pier cannot be projected out from shore and where dredging of a recessed basin for piers would be expensive. Also suitable where the navigation channel is too narrow to permit maneuvering into finger piers.	Costs per berth greater than for pier systems. Ratio of berthing space to length of waterfront is low. Berthing length is limited to length of face of wharf, unless mooring dolphins are used to extend usable length.
Square Pier (Figure 5-15b)	Solid fill supports deck loads without expensive framing. Upshore area is accessible for storage and traffic circulation. Side-berth accommodations add to linear feet of berthing accommodations. Permits utilization of surplus fill material.	Economy depends on availability of inexpensive fill. The requirements for fill or piling are great compared to the usable space provided on the deck.
Rectangular Pier and Slip (Figures 5-15c, 15d, and 15f)	Length of accommodation for a given length of shoreline is great. In general, this system has the lowest relative cost per berth.	In some bottom formations, any considerable later dredging of slips may be hazardous. Space between slips is limited, and adds to the density of navigation traffic. Reduces width of navigation channel. Cargo handling is restricted unless pier has at least 6 acres per berth.
Angle Pier and Slip (Figures 5-15e and 5-15g)	Layout is advantageous compared to rectangular pier-and-slip system where navigation channel is too narrow for perpendicular pier layout. Currents or prevailing winds may also dictate the use of angle piers.	Construction is more difficult and expensive than that for rectangular pier-and-slip system. Corners of the pier are waste space where cargo-handling equipment cannot work.
Offshore Marginal Wharves (Figures 5-15h, 5-15i, and 5-15j)	Layout adaptable to many types of construction methods, including floating wharfage. Moorings for shallow-draft craft may be provided along the sides of the causeway. When multiple causeways are used, a movable section can be provided to give access to space between causeways. Suitable along rocky shores. Suitable where water of adequate depth is located at large distance offshore.	When a single causeway is used, craft along the causeway create loading and unloading and traffic problems. Usually requires separate moorings, supported by the wharf structure, because a relatively large area of the wharf structure is not tied to shore anchorages.
Floating Wharves	Floating wharves can be moored in water too deep for pile driving. Pontoon or prefabricated sections can be used. Equipment can be quickly assembled, moved, and replaced.	Maintenance is high. (Maintenance of steel floating wharves is higher than that of concrete floating wharves.) Not suitable for heavy craft nor in exposed locations without heavy anchorage requirements. Difficult to maintain alignment in heavy tide range. Restricted cargo-handling capability.

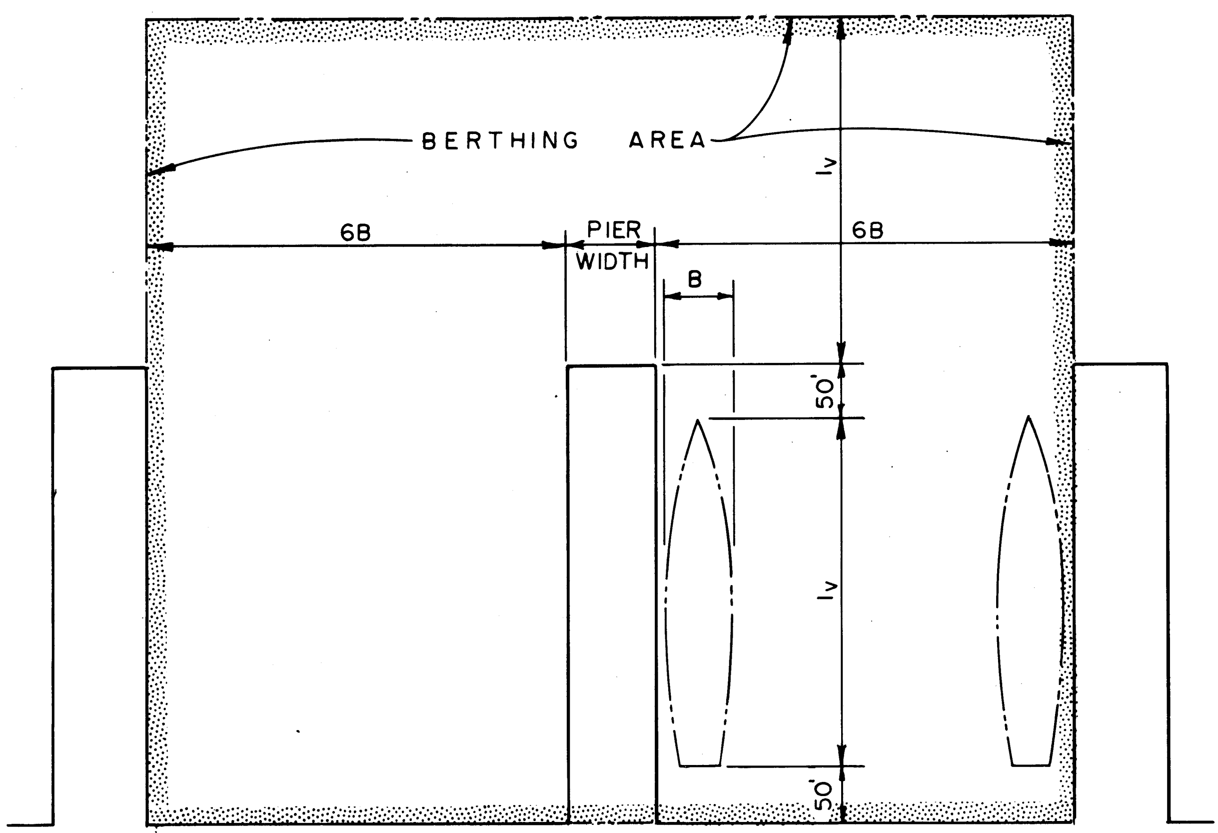
Table 5-12 Linear Feet of Berthing Space Per 305 m (1,000 ft) of Shore Front

Type of Layout	Freighter[a]	Lighter[a]	Total[a]
Marginal wharf	305 (1,000)	-	305 (1,000)
Square pier	653 (2,143)	-	653 (2,143)
Right-angle pier for one freighter on each side	951 (3,120)	95 (313)	1046 (3,433)
Right-angle pier for one freighter plus one lighter on each side	951 (3,120)	381 (1,250)	1332 (4,370)
Acute-angle pier for one freighter on each side	820 (2,690)	82 (270)	902 (2,960)
Right-angle pier for two freighters on each side	1268 (4,160)	63 (208)	1331 (4,368)
Acute-angle pier for two freighters on each side	1097 (3,600)	55 (180)	1152 (3,780)
T-type marginal wharf for freighter on outside face and lighters on inside face	235 (770)	421 (1,380)[b]	655 (2,150)[b]
U-type marginal wharf	305 (1,000) or less	-	305 (1,000) or less
Pier or wharf parallel to bank	610 (2,000)	-	610 (2,000)

[a]These figures are for purposes of comparison only.
[b] 513 m (1,682 ft) and 747 m (2,452 ft), respectively, if traffic conditions are such that lighters can be worked along the faces of the causeway.

Table 5-13 Approximate Berthing Area Requirements for Single-Berth Piers[a]

Class of Ship	Sizes of Piers (m (ft))	Spacing of Piers (m (ft))	Total Area Required in Harbor (hectares (acres))
Submarines	18 x 159(60 x 520)	101 (330)[b]	6.48 (16)[b]
Destroyers	24 x 204 (80 x 670)	101 (330)	8.50 (21)
Auxiliaries	24 x 274 (80 x 900)	195 (640)	21.45 (53)
Aircraft Carrier	30 x 381 (100 x 1,250)	238 (780)	35.61 (88)



[a]Area = [2 1_v + (2) (50*)] [^{2}12B + pier width]. (See diagram.) Values for 1_v, B, and pier width are from MIL-HDBK-1025/1 for purposes of this table.
[b]At submarine slips, pier spacing should be increased by at least four vessel beams.
*30 m (100 ft) for aircraft carrier.

Table 5-14 Berthing Depths for Typical Naval Vessels

Vessel	Depth[a] (m (ft)
Small boats	2.4 to 4.6 (8 to 15)
Minesweepers	5.5 (18)
Landing ships	7.3 (24)
Frigates	9.1 (30)
Tenders, cargo, and transport ships	10.3 (34)
Guided missile cruisers, destroyers, and medium submarines	11 (36)
Carriers and fast combat support ships[b]	13.7 (45)

[a]These depths are referenced to mean low water (MLW) or mean lower low water (MLLW) statistics for the area under study.
[b]To obtain optimum berthing depth for CVN, AOE, and CV vessels, refer to *Underkeel Clearance Study,* Hydro Research Science, Inc., Project Report No. 092-81, 21 Mar 1981.

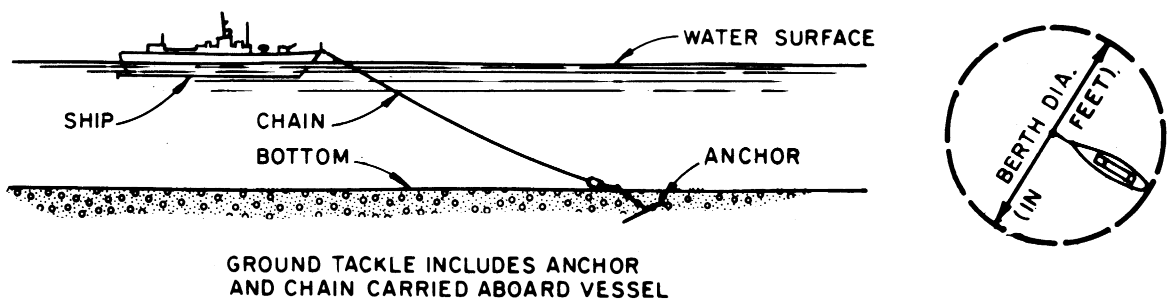
Table 5-15 Dimensions of Typical Existing Turning Basins

Location	Depth Below MLW (m (ft))	Dimensions (m (ft))	Area (hectares (acres))
Port Arthur, East Turning Basin	11 (36)	128 x 549 (420 x 1,800)	7.02 (17.35)
Port Arthur, West Turning Basin	11 (36)	183 x 519 (600 x 1,700)	7.33 (18.12)
Brazosport Turning Basin	9.8 (32)	213 x 213 (700 x 700)	4.55 (11.25)
Norfolk Harbor, Virginia South Branch Project	10.7 (35)	183 x 183 (600 x 600)	3.34 (8.25)
Wilmington Harbor	9.8 (32)	305 x 244 (1,000 x 800)	7.43 (18.36)
Miami Harbor	9.1 (30)	411 x 427 (1,350 x 1,400)	8.27 (20.43)
Tampa Harbor	9.1 (30)	213 x 266 (700 x 1,200)	7.84 (19.38)
Alameda Naval Air Station	12.8 (42)	1219 x 762 (4,000 x 2,500)	93.08 (230.00)
San Diego Harbor	12.2 (40)	732 x 914 (2,400 x 3,000)	66.89 (165.29)

Table 5-16 Factors Affecting Location, Size, and Depth of Anchorage Basins

Consideration	Factor	Requirement and Comment
Location	Isolation	Locate near entrance, away from channels, out of traffic, and in shelter. The area should be isolated, insofar as possible, from attack by surface or subsurface craft.
	Depth	Locate in area of sufficient natural depth to avoid dredging.
	Currents	Area should be free from strong currents.
	Accessibility of shore facilities	The area should be accessible to fresh water, fuel, and fleet recreation facilities. Shore facilities shall be provided to accommodate liberty parties, mail, light freight, and baggage.
	Foundation conditions	Where possible, locate over a bottom of loose sand or gravel, clay, or soft coral. Avoid locations where the bottom consists of rock, hard gravel, deep mud, and deep silt.
	Subaqueous structures	Anchorage areas should be free of cables and pipelines and cleared of wrecks and obstructions.
	Expansion	Leave provision for future expansion.
Size and Depth		Sizes of individual free-swinging moorings and of spread moorings for floating drydocks are contained in Tables 5-17, 5-18, and 5-19. Use free-swinging moorings where available area will permit. Where available area is limited, use fixed moorings or moorings in which the swing of the vessel is restricted. Various types of restricted moorings are described in DM 26.5.

Table 5-17a Diameter of Berth, in Meters, Using Ship's Anchor and Chain[a]



Overall Vessel Length, In Meters	31	61	91	122	152	183
Depth of Water at MLLW (m						
3.1	151	215	274	334	-	-
6.1	187	247	311	370	430	494
9.1	224	283	347	407	466	530
12.2	261	320	384	443	503	567
15.2	297	357	416	480	540	599
18.3	334	389	453	517	576	636
21.3	357	402	489	553	613	678
24.4	375	421	521	585	649	704
27.4	389	434	540	613	668	722
30.5	407	448	553	626	686	736
33.5	421	462	567	640	700	750
36.6	434	471	581	654	713	764
39.6	448	485	594	672	727	777
42.7	462	498	608	681	741	791
45.7	471	507	622	695	754	800
48.8	485	521	636	709	764	814
51.8	494	531	649	722	777	823
54.9	507	542	658	732	791	837
57.9	517	549	672	745	800	846
61	531	562	681	759	814	860

Table 5-17a Diameter of Berth, in Meters, Using Ship's Anchor and Chain[a] - Continued

Overall Vessel Length, m (ft)	213	244	274	305	335	366
Depth of Water at MLLW (ft)						
3.1	-	-	-	-	-	-
6.1	-	-	-	-	-	-
9.1	590	649	713	-	-	-
12.2	596	686	750	809	869	933
15.2	663	722	809	846	905	965
18.3	700	759	818	882	933	1001
21.3	736	796	855	919	978	1038
24.4	764	823	892	951	992	1079
27.4	777	837	905	965	1006	1093
30.5	796	850	919	978	1033	1106
33.5	809	864	933	992	1047	1120
36.6	823	878	946	1001	1061	1134
39.6	832	887	956	1015	1074	3348
42.7	846	901	969	1029	1084	1157
45.7	860	914	983	1038	1097	1170
48.8	869	924	992	1055	1106	1180
51.8	882	937	1006	1061	1116	1193
54.9	892	946	1015	1070	1129	1202
57.9	901	956	1024	1079	1138	1212
61	914	965	1038	1093	1148	1221

[a]For shallower water depths, the swing radii implied by this table are based on the following
assumptions:

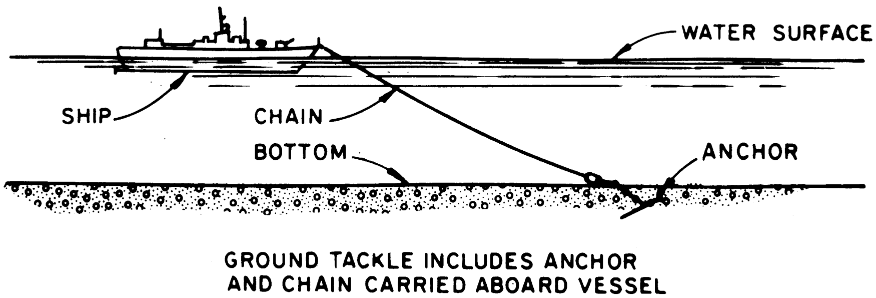
a) Scope = 6 x depth
b) Anchor rode has no sag
c) Allowance for anchor drag = 27.4 m

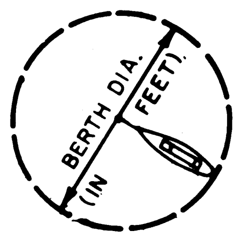
For depths greater than about 21.3 m, the 6:1 scope is excessive, and swing radii are based on the computed horizontal length of the anchor chain under heavy load. Typical ship characteristics and chain sizes have been selected for each ship length category.

Assumed load conditions are as follows:

a) Wind speed = 50 knots
b) Current = 4 knots, aligned with wind direction
c) Vertical projection of anchor chain = depth + height of hawse hole
d) Vertical angle of chain at anchor = 0 degrees

Table 5-17b Diameter of Berth, in Feet, Using Ship's Anchor and Chain[a]





Overall Vessel Length, In Feet	100	200	300	400	500	600
Depth of Water at MLLW (ft)						
10	495	705	900	1,095	-	-
20	615	810	1,020	1,215	1,410	1,620
30	735	930	1,140	1,335	1,530	1,740
40	855	1,050	1,260	1,455	1,650	1,860
50	975	1,170	1,365	1,575	1,770	1,965
60	1,095	1,275	1,485	1,695	1,890	2,085
70	1,170	1,320	1,605	1,815	2,010	2,205
80	1,230	1,380	1,710	1,920	2,130	2,310
90	1,275	1,425	1,770	2,010	2,190	2,370
100	1,335	1,470	1,815	2,055	2,250	2,415
110	1,380	1,515	1,860	2,100	2,295	2,460
120	1,425	1,545	1,905	2,145	2,340	2,505
130	1,470	1,590	1,950	2,205	2,385	2,550
140	1,515	1,635	1,995	2,235	2,430	2,595
150	1,545	1,665	2,040	2,280	2,475	2,625
160	1,590	1,710	2,085	2,325	2,505	2,670
170	1,620	1,740	2,130	2,370	2,550	2,700
180	1,665	1,779	2,160	2,400	2,595	2,745
190	1,695	1,800	2,205	2,445	2,625	2,775
200	1,740	1,845	2,235	2,490	2,670	2,820

Table 5-17b Diameter of Berth, in Feet, Using Ship's Anchor and Chain[a] - Continued

Overall Vessel Length, m (ft)	700	800	900	1,000	1,100	1,200
Depth of Water at MLLW (ft)						
10	-	-	-	-	-	-
20	-	-	-	-	-	-
30	1,935	2,130	2,340	-	-	-
40	1,955	2,250	2,460	2,655	2,850	3,060
50	2,175	2,370	2,655	2,775	2,970	3,165
60	2,295	2,490	2,685	2,895	3,060	3,285
70	2,415	2,610	2,805	3,015	3,210	3,405
80	2,505	2,700	2,925	3,120	3,255	3,540
90	2,550	2,745	2,970	3,165	3,300	3,585
100	2,610	2,790	3,015	3,210	3,390	3,630
110	2,655	2,835	3,060	3,255	3,435	3,675
120	2,700	2,880	3,105	3,285	3,480	3,720
130	2,730	2,910	3,135	3,330	3,525	3,765
140	2,775	2,955	3,180	3,375	3,555	3,795
150	2,820	3,000	3,225	3,405	3,600	3,840
160	2,850	3,030	3,255	3,450	3,630	3,870
170	2,895	3,075	3,300	3,480	3,660	3,915
180	2,925	3,105	3,330	3,510	3,705	3,945
190	2,955	3,135	3,360	3,540	3,735	3,975
200	3,000	3,165	3,405	3,585	3,765	4,005

[a]For shallower water depths, the swing radii implied by this table are based on the following
assumptions:

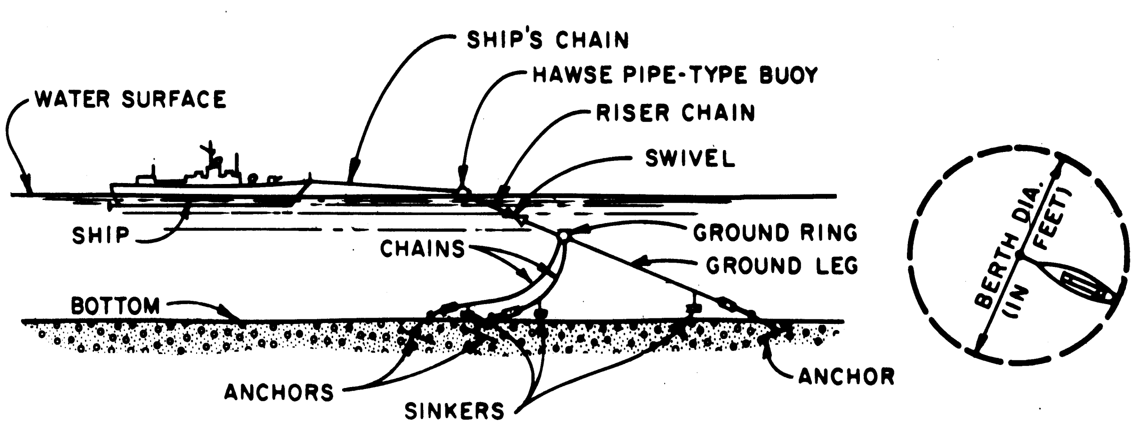
d) Scope = 6 x depth
e) Anchor rode has no sag
f) Allowance for anchor drag = 90 ft

For depths greater than about 70 ft, the 6:1 scope is excessive, and swing radii are based on the computed horizontal length of the anchor chain under heavy load. Typical ship characteristics and chain sizes have been selected for each ship length category.

Assumed load conditions are as follows:

e) Wind speed = 50 knots
f) Current = 4 knots, aligned with wind direction
g) Vertical projection of anchor chain = depth + height of hawse hole
h) Vertical angle of chain at anchor = 0 degrees

Table 5-18 Diameter of Berth, in Feet, Using Standard Fleet Moorings, Rise Chain[a]



Overall Vessel Length, M (ft)	31 (100)	61 (200)	91 (300)	122 (400)	152 (500)
Depth of Water at MLLW (m (ft))					
3.1 (10)	251 (825)	311 (1,020)	370 (1,215)	434 (1,425)	-
6.1 (20)	256 (840)	315 (1,035)	379 (1,245)	438 (1,440)	498 (1,635)
9.1 (30)	261 (855)	325 (1,065)	384 (1,260)	443 (1,455)	504 (1,655)
12.2 (40)	270 (885)	329 (1,080)	389 (1,275)	453 (1,485)	512 (1,680)
15.2 (50)	274 (900)	334 (1,095)	398 (1,305)	457 (1,500)	517 (1,695)
18.3 (60)	279 (915)	343 (1,125)	402 (1,320)	462 (1,515)	526 (1,725)
21.3 (70)	288 (945)	347 (1,140)	407 (1,335)	471 (1,545)	530 (1,740)
24.4 (80)	293 (960)	352 (1,155)	416 (1,365)	475 (1,560)	535 (1,755)
27.4 (90)	297 (975)	361 (1,185)	421 (1,380)	480 (1,575)	544 (1,785)
30.5 (100)	306 (1,005)	366 (1,200)	425 (1,395)	489 (1,605)	549 (1,800)
33.5 (110)	311 (1,020)	370 (1,215)	434 (1,425)	494 (1,620)	553 (1,815)
36.6 (120)	315 (1,035)	379 (1,245)	439 (1,440)	498 (1,635)	562 (1,845)
39.6 (130)	325 (1,065)	384 (1,260)	443 (1,455)	507 (1,665)	567 (1,860)
42.7 (140)	329 (1,080)	389 (1,275)	453 (1,485)	512 (1,680)	572 (1,875)
45.7 (150)	334 (1,095)	398 (1,305)	457 (1,500)	517 (1,695)	581 (1,905)
48.8 (160)	343 (1,125)	402 (1,320)	462 (1,515)	526 (1,725)	585 (1,920)
51.8 (170)	347 (1,140)	407 (1,335)	471 (1,545)	530 (1,740)	590 (1,935)
54.9 (180)	352 (1,155)	416 (1,365)	475 (1,560)	535 (1,755)	599 (1,965)
57.9 (190)	361 (1,185)	421 (1,380)	480 (1,575)	544 (1,785)	604 (1,980)
61 (200)	366 (1,200)	425 (1,395)	489 (1,605)	1,000	608 (1,995)

Table 5-18 Diameter of Berth, in Feet, Using Standard Fleet Moorings, Rise Chain[a] - Continued

Overall Vessel Length, m (ft)	183 (600)	213 (700)	244 (800)	274 (900)	305 (1,000)
Depth of Water at MLLW (m (ft))					
3.1 (10)	-	-	-	-	-
6.1 (20)	562 (1,845)	-	-	-	-
9.1 (30)	567 (1,860)	626 (2,055)	-	-	-
12.2 (40)	572 (1,875)	636 (2,085)	695 (2,280)	754 (2,475)	818 (2,685)
15.2 (50)	581 (1,905)	640 (2,100)	700 (2,295)	764 (2,505)	823 (2,700)
18.3 (60)	585 (1,920)	645 (2,115)	709 (2,325)	764 (2,505)	828 (2,715)
21.3 (70)	590 (1,935)	654 (2,145)	713 (2,340)	788 (2,585)	837 (2,745)
24.4 (80)	599 (1,965)	658 (2,160)	718 (2,355)	782 (2,565)	841 (2,760)
27.4 (90)	604 (1,980)	663 (2,175)	727 (2,385)	786 (2,580)	846 (2,775)
30.5 (100)	608 (1,995)	678 (2,205)	732 (2,400)	791 (2,595)	855 (2,805)
33.5 (110)	617 (2,025)	677 (2,220)	736 (2,415)	800 (2,625)	860 (2,820)
36.6 (120)	622 (2,040)	681 (2,235)	748 (2,455)	805 (2,640)	864 (2,835)
39.6 (130)	626 (2,055)	690 (2,265)	750 (2,460)	809 (2,655)	873 (2,865)
42.7 (140)	636 (2,085)	695 (2,280)	754 (2,475)	818 (2,685)	878 (2,880)
45.7 (150)	640 (2,100)	700 (2,295)	764 (2,505)	823 (2,700)	882 (2,895)
48.8 (160)	645 (2,115)	709 (2,325)	768 (2,520)	828 (2,715)	892 (2,925)
51.8 (170)	654 (2,145)	713 (2,340)	773 (2,535)	837 (2,745)	896 (2,940)
54.9 (180)	658 (2,160)	718 (2,355)	782 (2,565)	841 (2,760)	901 (2,955)
57.9 (190)	663 (2,175)	727 (2,385)	786 (2,580)	846 (2,775)	910 (2,985)
61 (200)	678 (2,205)	732 (2,400)	791 (2,595)	855 (2,805)	914 (3,000)

[a]This table is based on the following assumptions:

(a) Length of riser chain is equal to depth of water at mean high water.

(b) Ground chains are of length called for by drawings and are pulled taut when installed.

(c) Anchor drags 27 m (90 ft) from initial position.

(d) 55 m (180 ft) of ship's chain used between vessel and buoy.

(e) Basic formula b = (2/3) (d + 1_v + C_1)

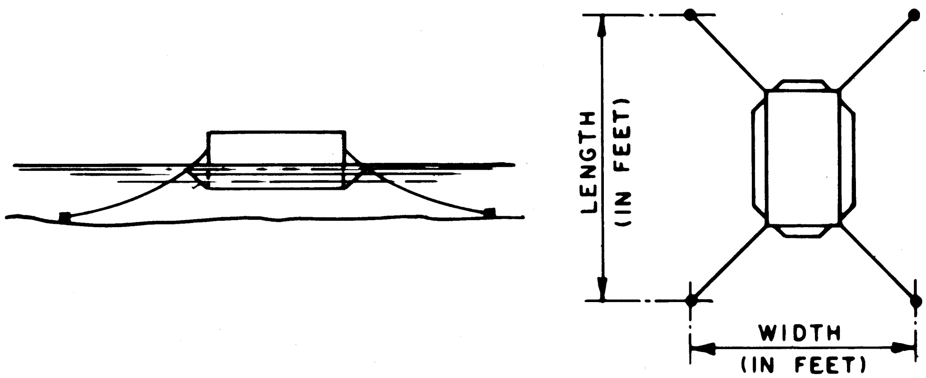
Where: b = diameter of berth, in feet

d = depth of water, in feet at MHW

l_v = length overall of vessel, in feet

C_1 = 91 m (300 ft) (includes 9 m (30-ft) allowance for increase in radius of berth for drop in waterline due to fall of tide, 55 m (180 ft) from buoy to ship, and 27 m (90-ft) allowance for drag of anchor

Table 5-19a Size of Berth, in Meters, for Floating Drydocks and Spread Moorings[a]



Depth of Water at MLLW (m)	ARD		AFDL 2,800 T Concrete		AFDB 10 Sections		AFDB 9 Sections	
	Width	Length	Width	Length	Width	Length	Width	Length
10	-	-	-	-	-	-	-	-
11.6	183	288	-	-	-	-	-	-
12.5	183	288	187	274	-	-	-	-
15.2	210	306	210	297	-	-	-	-
17.4	233	320	238	315	-	-	-	-
19.8	233	325	238	329	-	-	-	-
22.6	256	343	261	347	-	-	-	-
25.6	283	361	288	366	347	521	347	494
27.4	306	375	311	379	357	530	357	507
30.5	306	384	311	402	375	553	375	526
33.5	306	398	334	416	393	567	393	540
36.6	347	407	361	430	407	581	407	558
39.6	370	425	384	443	421	594	421	572
42.7	393	434	384	462	434	608	434	581
45.7	416	453	402	475	448	622	448	594
48.8	416	453	425	489	457	631	457	604
51.8	430	462	425	503	466	640	466	613
54.9	448	475	448	512	471	645	471	617
57.9	471	489	471	526	475	649	475	622
61	471	494	471	530	475	649	475	622

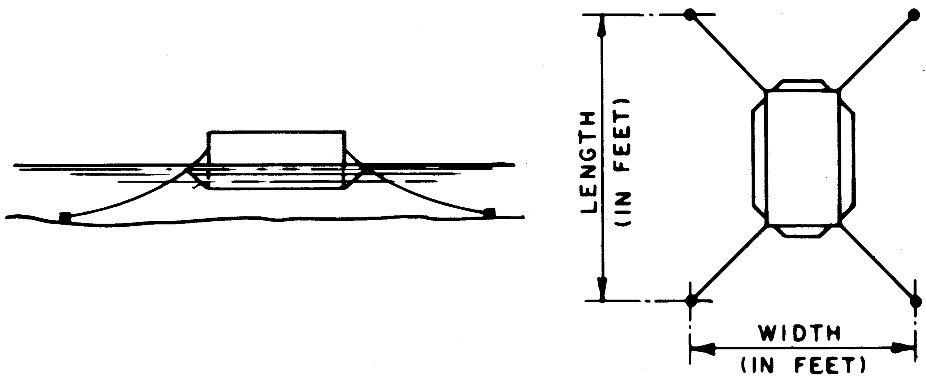
Table 5-19a Size of Berth, in Meters, for Floating Drydocks and Spread Moorings[a] - Continued

Depth of Water at MLLW (ft)	AFDB 7 Sections		YFD 18,000 T		AFDL 1,000 T Steel		AFDL 1,900 T Steel	
	Width	Length	Width	Length	Width	Length	Width	Length
10	-	-	-	-	183	229	-	-
11.6	-	-	-	-	183	229	183	261
12.5	-	-	-	-	183	229	183	215
15.2	-	-	-	-	206	251	206	283
17.4	-	-	251	384	233	274	233	302
19.8	-	-	251	393	233	283	233	320
22.6	306	453	270	410	256	306	256	343
25.6	306	453	293	443	283	329	279	366
27.4	325	475	320	462	311	352	306	375
30.5	352	498	320	471	311	361	306	398
33.5	352	498	339	494	334	379	329	411
36.6	306	512	357	517	361	402	352	430
39.6	389	535	379	535	384	485	379	448
42.7	407	558	379	544	384	430	684	462
45.7	416	558	398	567	407	448	398	475
48.8	416	567	413	585	430	471	421	494
51.8	434	585	413	590	430	475	421	507
54.9	434	585	421	608	457	494	439	521
57.9	439	585	439	626	480	521	462	535
61	439	585	439	631	480	521	471	549

[a]The width and length of berths for floating drydocks include out to out of anchors, assuming that anchors are placed in accordance with the diagram. Berth diameter for free-swinging floating drydocks may be obtained from Tables 5-17 and 5-18; in addition to that for drydock length, allowance must be made for vessel entering dock. Berth types are as follows:

ARD = Auxiliary Repair Drydock
AFDL = Small Auxiliary Floating Drydock
AFDB = Large Auxiliary Floating Drydock
YFD = Floating Drydock

Table 5-19b Size of Berth, in Feet, for Floating Drydocks and Spread Moorings[a]



Depth of Water at MLLW (ft)	ARD		AFDL 2,800 T Concrete		AFDB 10 Sections		AFDB 9 Sections	
	Width	Length	Width	Length	Width	Length	Width	Length
33	-	-	-	-	-	-	-	-
38	600	945	-	-	-	-	-	-
41	600	945	615	900	-	-	-	-
50	690	1,005	690	975	-	-	-	-
57	765	1,050	780	1,035	-	-	-	-
65	765	1,065	780	1,080	-	-	-	-
74	840	1,125	855	1,140	-	-	-	-
84	930	1,185	945	1,200	1,140	1,710	1,140	1,620
90	1,005	1,230	1,020	1,245	1,170	1,740	1,170	1,665
100	1,005	1,260	1,020	1,320	1,230	1,815	1,230	1,725
110	1,005	1,305	1,095	1,365	1,290	1,860	1,290	1,770
120	1,140	1,335	1,185	1,410	1,335	1,905	1,335	1,830
130	1,215	1,395	1,260	1,455	1,380	1,950	1,380	1,875
140	1,290	1,425	1,260	1,515	1,425	1,995	1,425	1,905
150	1,365	1,485	1,320	1,560	1,470	2,040	1,470	1,950
160	1,365	1,485	1,395	1,605	1,500	2,070	1,500	1,980
170	1,410	1,515	1,395	1,650	1,530	2,100	1,530	2,010
180	1,470	1,560	1,470	1,680	1,545	2,115	1,545	2,025
190	1,545	1,605	1,545	1,725	1,560	2,130	1,560	2,040
200	1,545	1,620	1,545	1,740	1,560	2,130	1,560	2,040

Table 5-19b Size of Berth, in Feet, for Floating Drydocks and Spread Moorings[a] - Continued

Depth of Water at MLLW (ft)	AFDB 7 Sections		YFD 18,000 T		AFDL 1,000 T Steel		AFDL 1,900 T Steel	
	Width	Length	Width	Length	Width	Length	Width	Length
33	-	-	-	-	600	750	-	-
38	-	-	-	-	600	750	600	855
41	-	-	-	-	600	750	600	705
50	-	-	-	-	675	825	675	930
57	-	-	825	1,260	765	900	765	990
65	-	-	825	1,290	765	930	765	1,050
74	1,005	1,485	885	1,365	840	1,005	840	1,125
84	1,005	1,485	960	1,455	930	1,080	915	1,200
90	1,065	1,560	1,050	1,515	1,020	1,155	1,005	1,230
100	1,155	1,635	1,050	1,545	1,020	1,185	1,005	1,305
110	1,155	1,635	1,110	1,620	1,095	1,245	1,080	1,350
120	1,200	1,680	1,170	1,695	1,185	1,320	1,155	1,410
130	1,275	1,755	1,245	1,755	1,260	1,395	1,245	1,470
140	1,335	1,830	1,245	1,785	1,260	1,410	2,245	1,515
150	1,365	1,830	1,305	1,860	1,335	1,470	1,305	1,560
160	1,365	1,860	1,355	1,920	1,410	1,545	1,380	1,620
170	1,425	1,920	1,355	1,935	1,410	1,560	1,380	1,665
180	1,425	1,920	1,380	1,995	1,500	1,620	1,440	1,710
190	1,440	1,920	1,440	2,055	1,575	1,710	1,515	1,755
200	1,440	1,920	1,440	2,070	1,575	1,710	1,545	1,800

[a]The width and length of berths for floating drydocks include out to out of anchors, assuming that anchors are placed in accordance with the diagram. Berth diameter for free-swinging floating drydocks may be obtained from Tables 5-17 and 5-18; in addition to that for drydock length, allowance must be made for vessel entering dock. Berth types are as follows:

ARD = Auxiliary Repair Drydock
AFDL = Small Auxiliary Floating Drydock
AFDB = Large Auxiliary Floating Drydock
YFD = Floating Drydock

5-7 **NAVIGATION AIDS**. Aids to navigation are the markers and signals vessels require to safely use a navigation project. The navigation safety of a project is directly related to the clarity and visibility of aids to navigation. Channel design must be planned so that the layout, dimensions, and alignment facilitate clear marking. A reduced width may be possible in a well-marked channel as compared to a poorly marked channel, so a tradeoff between channel widening cost and aids to navigation costs should be considered in design; additional information is available in CEM Section VI-3.

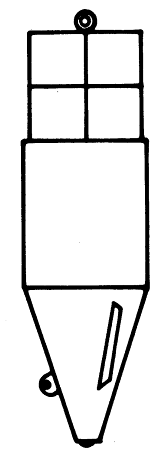
5-7.1 **Jurisdiction**. Where aids to navigation, such as lights, daybeacons, or buoys, are required, consult the District Office of the USCG or, in the case of areas where no district office has jurisdiction, the Commandant, USCG. This organization will advise as to requirements for aids to navigation. The aids, which conform to USCG specifications, may be purchased from the USCG. Structures for supporting the aids (towers for lights or daybeacons and moorings for buoys) shall be provided by or under the cognizance of the NAVFAC. The USCG has specific jurisdiction over all aids to navigation in the continental United States and in all outlying territories and possessions. Refer to Code of Federal Regulations, Title 33, for information relating to establishing aids to navigation. In foreign countries, the regulations of local agencies, where such agencies exist, govern in lieu of the USCG, but the USCG will assist, when requested, in establishing aids to navigation, even in foreign countries.

5-7.2 **Types of Aids**. The following general data on aids to navigation are given to assist in preliminary layouts and as a basis to discuss requirements with the regulating agency. Aids to navigation include, but are not limited to, lighthouses (light stations), range lights, directional lights, minor lights, lighted and unlighted buoys, daybeacons, and sound signals. Other types of aids to navigation that are not under the primary cognizance of the NAVFAC include lightships, radio beacons, radar beacons, and loran stations. Several types of navigational aids are illustrated in Figure 5-25 through Figure 5-29.

5-7.2.1 **Lighted Aids**. The placing of lights is a function of local navigation requirements and topography. General rules are not applicable. Height of the lantern and type and candlepower of illuminant shall be specified. For daytime use, light structures shall be distinctively marked or painted in order to provide easy identification.

- Primary Seacoast Lights. These lights, which may be attended or automatic, are established on seacoasts, bays, sounds, and lakes for the purpose of marking landfalls and coastwise passages from headland to headland, and in harbors where powerful candlepower is necessary. The light source is designed to obtain the maximum geographic range.

Figure 5-25 The 2 CR Buoy



1952 TYPE STANDARD

FUNCTION

THE 2 CR BUOY IS DESIGNED AND CONSTRUCTED FOR EXPOSED OR SEMIEXPOSED LOCATIONS WHERE AN UNLIGHTED BUOY IS REQUIRED.

PHYSICAL CHARACTERISTICS

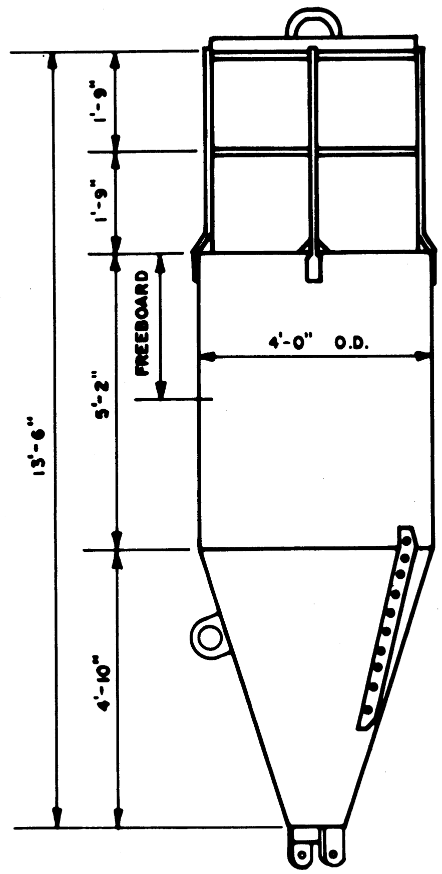
BUOY WEIGHT	2,700 LB
BUOY DRAFT (NO MOORING)	6 FT - 1 IN
FREEBOARD (NO MOORING)	3 FT - 11 IN
MINIMUM FREEBOARD	1 FT - 0 IN
POUNDS PER INCH OF IMMERSION	67

RELATED EQUIPMENT

MOORING CHAIN SIZE	7/8 IN
SINKER SIZE	4,000 LB

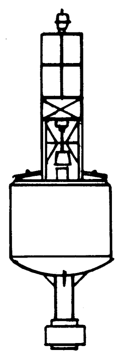
OPERATIONAL CHARACTERISTICS

NOMINAL VISUAL RANGE OF DAYMARK	2.8 NMI
RADAR RANGE	2.5 NMI
MAXIMUM CURRENT	6 K
MINIMUM MOORING DEPTH	15 FT
MAXIMUM MOORING DEPTH	200 FT



DIMENSIONS OF THE 2 CR

Figure 5-26 The 8 x 26 LBR Buoy



1962 TYPE STANDARD

FUNCTION

THE 8x26 LBR BUOY IS DESIGNED AND CONSTRUCTED FOR EXPOSED OR SEMIEXPOSED LOCATIONS. THIS BUOY CONFIGURATION IS USED WITH A 225-LB BELL, WAVE-ACTUATED SOUND SIGNAL. THE BASIC BUOY IS THE SAME AS THE 8x26LR.

PHYSICAL CHARACTERISTICS

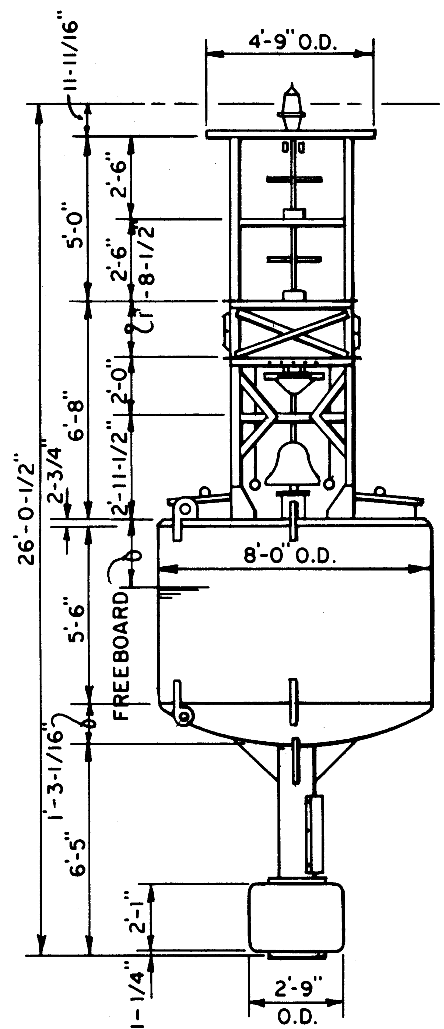
BUOY WEIGHT	11,917 LB
BUOY DRAFT (NO MOORING)	10 FT-3 IN
FOCAL HEIGHT OF LIGHT (NO MOORING)	15 FT.-8 IN
FREEBOARD (NO MOORING)	3 FT-1 IN
MINIMUM FREEBOARD	1 FT-3 IN
POUNDS PER INCH OF IMMERSION	270

RELATED EQUIPMENT

POWER UNITS (MAXIMUM NUMBER AND SIZE)	2-B30
SOUND EQUIPMENT	225-LB BELL
BRIDLE SIZE (CHAIN DIAMETER AND LENGTH)	1-1/4 IN x 15 FT
MOORING CHAIN SIZE	1-1/4 IN
SINKER SIZE	8,500 LB

OPERATIONAL CHARACTERISTICS

NOMINAL VISUAL RANGE OF DAYMARK	3.2 NMI
RADAR RANGE	3.7 NMI
MAXIMUM CURRENT	4 K
MAXIMUM MOORING DEPTH	25 FT
MAXIMUM MOORING DEPTH (B10)	220 FT
(B30)	190 FT



DIMENSIONS OF 8x26 LBR.

Figure 5-27 Single Pile Steel Beacon Structure

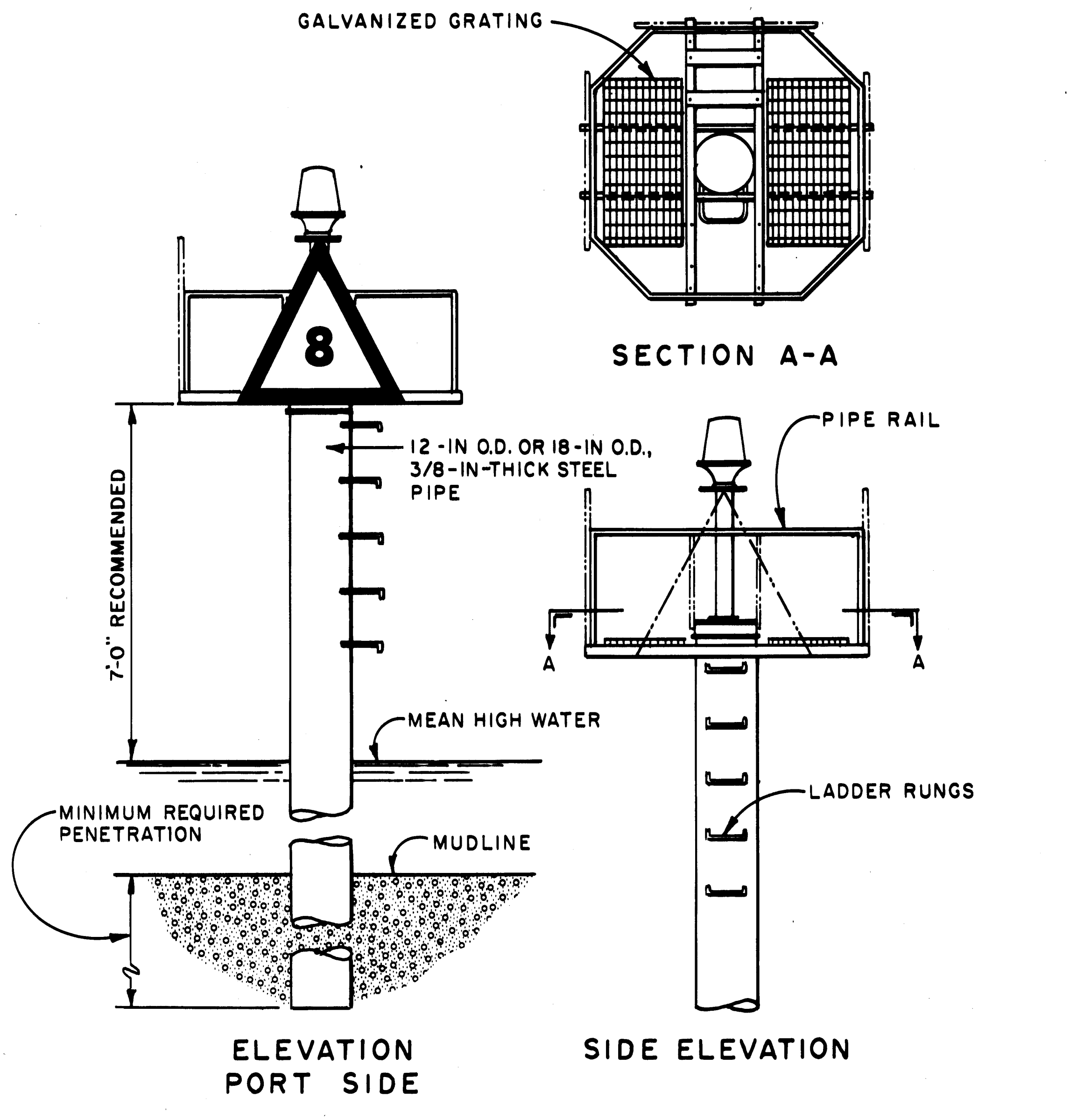
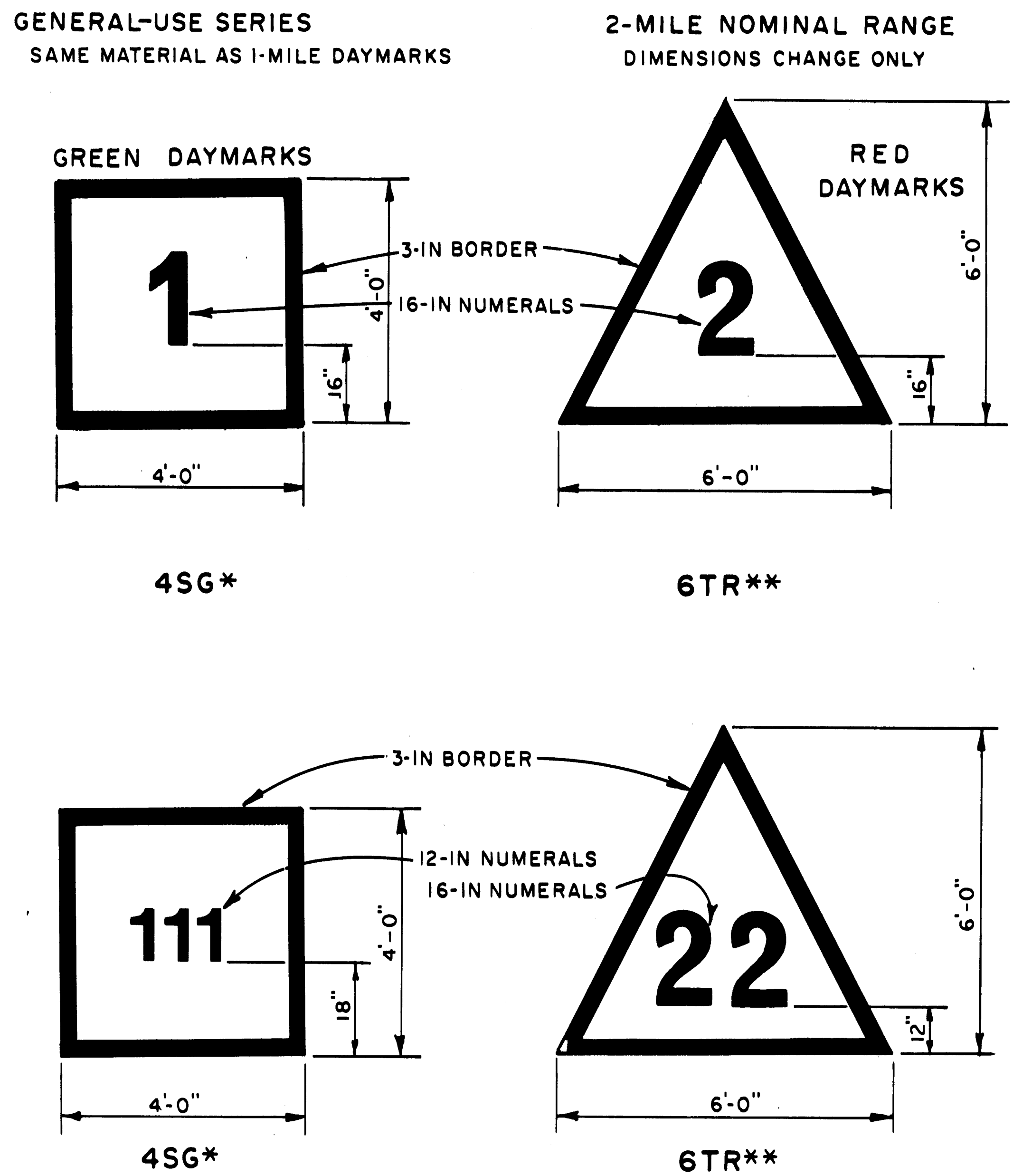
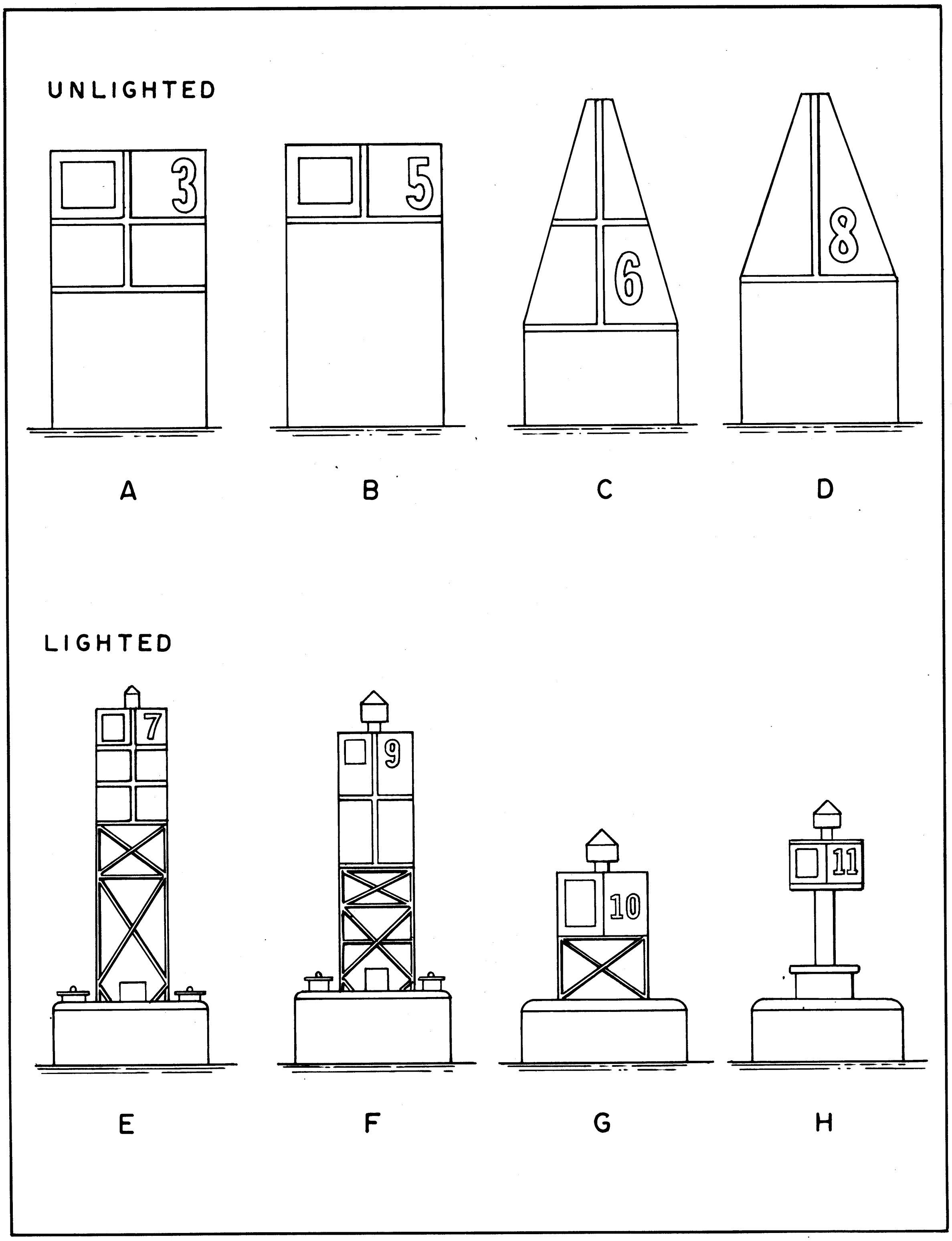


Figure 5-28 Lateral Daymarks



* FOR 2 NUMERALS USE 16-IN NUMERALS AT HEIGHT OF 16 IN OFF BASE
** FOR 3 NUMERALS USE 12-IN NUMERALS AT HEIGHT OF 12 IN OFF BASE
NOTE: DAYMARKS CONSIST OF RETROREFLECTIVE BORDERS AND NUMERALS ON A FLUORESCENT BACKGROUND.

Figure 5-29 General Use Series Buoys, Radar Reflector Type



- Secondary Lights. These lights, which also may be attended or automatic, are established at harbor entrances and other locations where the needs for high candlepower and long range are less necessary, and on large inland waterways as intermediate aids in harbor channels and in other inshore channels where the requirements of navigation indicate that the range and candlepower of this class are necessary.

- Range Lights. These are pairs of lights located to form a range in line with the center of a channel or entrance to a harbor. The rear light is higher than the front light and a considerable distance in back of it. The length of the range and width of the channel govern the height and distance of separation necessary between the lights. Range-light structures shall be equipped with daymarks for ordinary daytime use. Ranges may be used either ahead or over the stern.

- Directional Lights. A directional light is a single light which will project a beam of high intensity, separate color, or other special characteristic, in a given direction. It has limited use in those cases where a two-light range may not be practicable or necessary, and for other special applications. The directional light is essentially a narrow-sector light with or without adjacent sectors which give information as to the direction of and relative displacement from the narrow sector.

- Minor Lights. These are lights of relatively low candlepower usually established in harbors, along channels, along rivers, and in isolated locations. They are generally unattended and unwatched and should operate automatically. Depending upon circumstances, these lights may be displayed from towers, skeleton structures, or from a group of piles. They shall be colored to distinguish them from the surrounding background and from adjacent structures.

- Lighted Buoys. These are floating aids showing from the upper of their structures an automatically operated, low-candlepower light. Colors and characteristics vary. Lighted buoys are established for the purpose of definitely identifying spots. These include the entrance and side limits of natural and dredged channels, centers of fairways, obstructions and wrecks, isolated natural dangers in offshore or restricted waters, and for special purposes such as quarantine or general anchorages. These lights are powered by batteries.

5-7.2.2 **Unlighted Aids**.

- Unlighted Buoys. These are floating aids of varying size, shape, and color. They serve the same general purposes as lighted buoys. They are used in areas of lesser importance or as intermediate aids to supplement lighted buoys in the more important areas.

- Daybeacons. Although all aids, whether lighted or unlighted, serve as a daymark to the mariner, daybeacons are specifically designed as unlighted structures used to mark isolated dangers, channels, edges, or alignment.

5-7.2.3 **Sound Signals**. Sound signals are sound-producing devices operated mechanically or by the action of the sea, consisting of horns, sirens, diaphones, bells, gongs, and whistles. They are installed on shore structures and on buoys.

- Operation. Most sound signals on structures are attended. Sound signals on a few minor shore structures or on buoys shall be automatically operated. Other signals on buoys shall be operated by action of the sea.

- Purpose. Sound signals are intended to warn of danger and provide the mariner with the best practicable means of determining his position. This is in relation to the sound signal station at such times as the station, or any light that it might display, is obscured from view by fog, haze, smoke, or generally poor visibility.

- Range. To be effective, sound signals must be capable of a useful range, and they must be of such characteristic duration as to permit their direction to be judged with reasonable accuracy by ear. It must be remembered that due to the uncertainty of passage of sound through the atmosphere, the range of sound signals cannot be depended upon or specifically fixed. Major fog signals shall have a minimum range of 2.4 km (1-1/2 miles).

5-7.3 **Lights**. Due to the increase in shore illumination along navigable waters, the usefulness of fixed white lights is limited to areas where the usable range is short or where the natural background includes few other lights.

5-7.3.1 **Length of Period**. The period of a flashing or occulting light is the time required to go through a full set of changes. The limiting basis for the period of light characteristics is 60 seconds, since it is considered that the mariner cannot always safely watch the light to the exclusion of everything else for a longer period. Light characteristics that are so similar as to require careful timing in order to differentiate between them should not be established in close proximity to one another.

5-7.3.2 **Colors**. White, red, yellow, and green are used for navigational lights. Other colors are not used.

- Means of Obtaining Color. The light source in all illuminating apparatus is white. Color is produced by the addition of colored-glass shades or screens.

- Alternating Colors. In certain instances, light characteristics consist of alternations of colors, with either two or three colors being used in combination. Where an alternating white and red or white and green light is desired, the candlepower of the colors shall be equalized by selection of the lens panels.

5-7.3.3 **Visibility**. The distances at which lights may be seen in clear weather are computed for a height of the observer's eye of 4.6 m (15 feet) above sea level. Table 5-20 gives the approximate geographical range of visibility for objects of varying elevations that may be seen by an observer whose eye is at sea level. To determine the distance of visibility for an observer whose eye is at an elevation other than sea level, add to the distance of visibility (determined from Table 5-20) the distance of visibility from Table 5-20 which corresponds to the elevation of the observer's eye above sea level.

5-7.3.4 **Suppliers**. Lights built to USCG specifications may be purchased from the USCG or from a manufacturer.

Table 5-20 Distances of Visibility for Objects of Various Elevations above Sea Level

Elevation (m (ft))	Distance (nmi)	Elevation (m (ft))	Distance (nmi)	Elevation (m (ft))	Distance (nmi)
1.5 (5)	2.5	21.3 (70)	9.6	76.2 (250)	18.2
3.0 (10)	3.6	22.9 (75)	9.9	91.4 (300)	19.9
4.6 (15)	4.4	24.4 (80)	10.3	106.7 (350)	21.5
6.1 (20)	5.1	25.9 (85)	10.6	121.9 (400)	22.9
7.6 (25)	5.7	27.4 (90)	10.9	137.2 (450)	24.3
9.1 (30)	6.3	29 (95)	11.2	152.4 (500)	25.6
10.7 (35)	6.8	30.5 (100)	11.5	167.6 (550)	26.8
12.2 (40)	7.2	33.5 (110)	12.0	182.69 (600)	28.0
13.7 (45)	7.7	36.6 (120)	12.6	198.1 (650)	29.1
15.2 (50)	8.1	39.6 (130)	13.1	213.4 (700)	30.3
16.8 (55)	8.5	42.7 (140)	13.6	243.8 (800)	32.4
18.3 (60)	8.9	45.7 (150)	14.1	274.3 (900)	34.4
19.8 (65)	9.2	61 (200)	16.2	304.8 (1,000)	36.2

5-7.4 **Buoys**. Buoys are used for lateral identification for channels in navigable waters. Demarcation of the channel is accomplished by arranging the colors, shapes, numbers, and light characteristics of the buoys. The standard coding system of the USCG should be followed, where possible, and shall be obtained from that organization. Special buoys, having no lateral significance, should be used for marking anchorages, nets, and dredging and other special-purpose areas. For characteristics of buoys, consult the USCG.

5-7.5 **Daybeacons**. Daybeacons shall be constructed and painted in order to be distinct and conspicuous. Only white, green, or red color shall be used, either separately or in combination. Where a number of daybeacons are to be used within a limited area, use different types of construction to assist in distinguishing among them. Daybeacons should be reflectorized for night use.

5-7.6 **Fog Signals**. Design fog signals at stations, where a continuous watch is maintained, to be sounded both when the visibility decreases to 8.1 km (5 miles) and when the fog whistle of a passing vessel is heard. Design fog signals at locations where no watch is maintained to operate continuously or automatically. Fog signals on buoys generally should be operated by the motion of the sea and should operate continuously.

5-7.6.1 **Sound Intervals**. Time blasts for a minimum 2 seconds in length, occurring at intervals not exceeding 60 seconds; preferable interval length is 15 seconds.

5-7.6.2 **Suppliers**. Fog signals built to USCG specifications may be purchased from the USCG or from a manufacturer.

5-7.7 **Ranges**. Height, distance apart, size of daymark, and color marking are dependent on local conditions, and general rules are not applicable. There are no rules as to shape of the daymark, except that it be the most distinctive possible shape in the range system.

5-7.8 **Design of Support Structures**. Design dolphins, towers, and similar supports for lights, daybeacons, and similar aids in accordance with requirements for the same or similar structures established elsewhere in this manual.

5-7.9 **Moorings**. Design moorings for buoys according to the requirements of MIL-HDBK-1026/4

5-7.10 **Buoy Systems**. The U.S. and most Western-Hemisphere countries use a buoy system based on green daymarks/black buoys for port hand and red daymarks/red buoys for starboard hand when returning from sea. Many Eastern-Hemisphere countries use green for starboard and red for port hand. The system that is used in the local area is an important consideration when designing a new aid system.

5-7.11 **Environmental Monitoring and Operator Guidance System**. As an operational underkeel clearance (UKC) forecasting system, the Environmental Monitoring and Operator Guidance System (EMOGS) was developed to provide safe transit of deep draft vessels through shallow entrance channels. A risk-based system used to avoid vessel grounding and to minimize channel depth requirements, EMOGS can predict the estimated UKC during a specified transit through a shallow water channel for the vessel in question. Silver et al.'s David Taylor Research Center (DTRC) publication, Environmental Monitoring and Operator Guidance System (EMOGS) Overall Technical Description, DTRC Report SHD-1283-16, provides for further details.

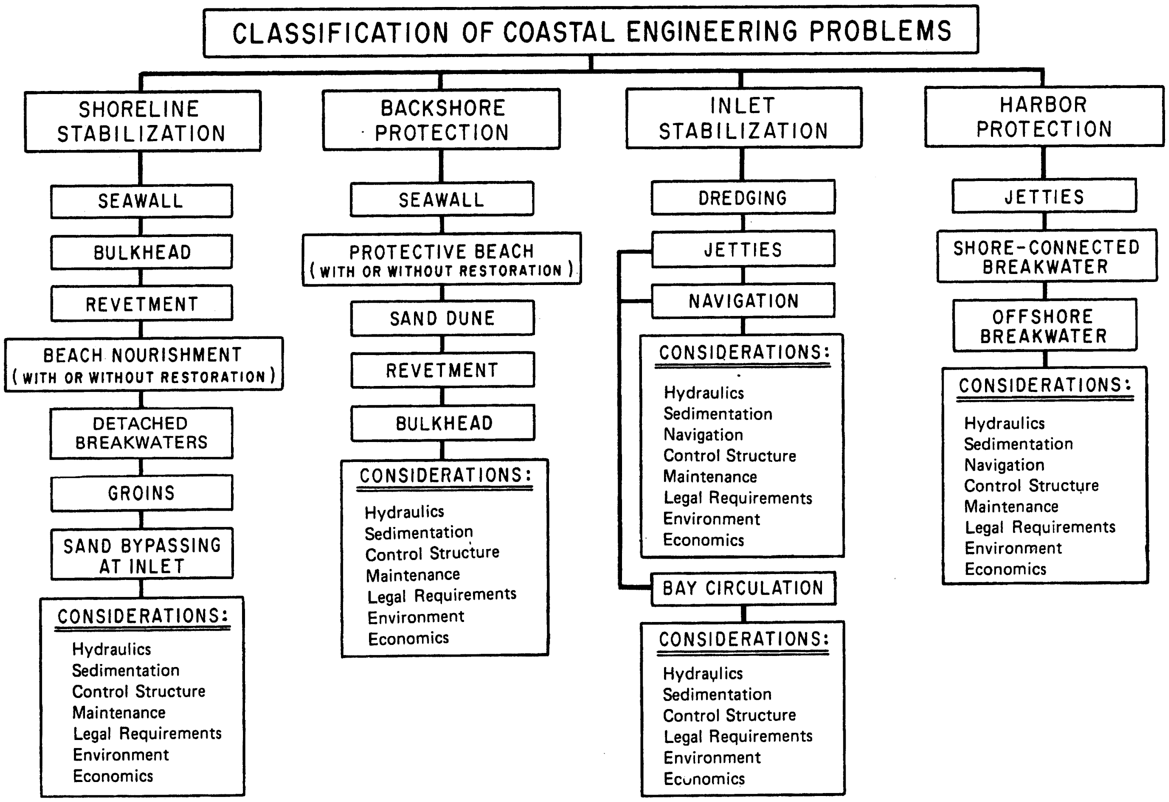
- The EMOGS, as installed at Kings Bay to protect OHIO class submarines, is used because it is not economically feasible to dredge the channel to provide safe transits of the vessels in all weather conditions. EMOGS provides the clearance between the vessel hull and the bottom in near real time. EMOGS software uses bottom survey data, statistical and measured wave and tidal data, and calculated ship motions to assess the risk of the submarine touching the channel bottom. Where the MicroVAX computer is not available, there is a manual procedure for carrying out the calculations; refer to the EMOGS User Handbook by Silver et al. (DTRC Report SHD-1283-02).

- The level of risk is sensitive to sedimentation rates and dredging activities, and any change in environmental conditions must be represented in the predictions.

5-7.12 **Carrier Channel Guidance System**. A guidance system was developed to reduce the risk of aircraft carriers touching the channel bottom while transiting entrance channels at Norfolk, Mayport, Pensacola, San Diego, and Pearl Harbor. This system is used by the navigation officer to determine the advisability of transiting the channel at a scheduled date and time. The system is PC based and is set up in the Meteorological Office aboard ship. The system provides the predicted clearance between the vessel hull and the bottom in near real time using bottom survey data, statistical and measured meteorological data, water depth measurements and calculated ship motions.

5-8 **MARINE IMPROVEMENT AND SHORE PROTECTION**. Coastal engineering problems may be classified into four general categories: shoreline stabilization, backshore protection (from waves and surge), and inlet stabilization and harbor protection (Figure 5-30). A coastal problem may fall into more than one category. Once classified, various solutions are available to the coastal engineer. Some of the solutions are structural; however, other techniques may be employed such as zoning and land-use management. The primary types of coastal structures and methods of marine improvement and shore protection are discussed in Chapter 7.

Figure 5-30 General Classification of Coastal Engineering Problems (USACE, 1984b).



5-9 **SEDIMENT MANAGEMENT PROJECTS**. The development of sediment management projects is available in CEM Section V-5. Discussions are presented on the use of weir jetties, sediment traps, and training dikes to interrupt longshore sand movement, to accumulate sand on the shore, or to retard sand losses. Maintenance in existing channels, berthing areas, and the expansion of coastal facilities requires dredging in areas that may contain elevated levels of heavy metals, pesticides, and other contaminants. Though concentrations of these contaminants may not always approach hazardous levels, contaminated sediments are not suitable for unconfined ocean disposal. Remediation of these sites may require dredging and disposal of contaminated dredged materials, which requires special management. Material may be placed in a confined, aquatic disposal site, capped, disposed in an upland site, or possibly treated and then undergo beneficial re-use. Management alternatives, cumulative impacts, and long-term solutions to prevent re-contamination of sediment are issues that need to be addressed with respect to the ecological and health implications of contaminated dredged material disposal. All project areas are to be evaluated for environmental risks early in the planning stages of a project. Subsequently, if a hazardous substance is suspected at a project site, the sediment should be left undisturbed and the appropriate Environmental Department or Regional Environmental Coordinator of the appropriate activity be notified.

5-10 **PHYSICAL SECURITY**. The physical security of harbor and coastal facilities must be addressed in the early stages of project planning. The NAVFAC Engineering Innovation and Criteria Office (EICO) is presently developing Anti-Terrorism, Force Protection (AT/FP) design and construction criteria for the programming, planning, design, and construction of AT/FP systems for waterfront facilities. Interim Technical Guidance on Anti-Terrorism, Force Protection and Physical Security of Waterfront Facilities and Installation can be found on the NAVFAC Intranet at http://navfacilitator.navfac.navy.mil/cheng/enet/tdls/security/security.cfm or by contacting the NAVFAC Engineering Innovation and Criteria Office at 757-322-4200.

CHAPTER 6.

DESIGN OF DREDGING PROJECTS

6-1 **INTRODUCTION**. Dredging is generally carried out either to increase the depth of a body of water, or to replace, re-configure or mine for *in situ* sediments. It may involve new construction (Capital dredging), such as excavation for harbors or canals, the construction of stable bases for tunnels or reclamation of submerged land. Maintenance dredging on the other hand is used for such purposes as maintaining waterway utility and restoring the hydraulic efficiency of reservoirs. Section V-5-3 of the CEM contains information on dredging. Additional extensive detailed information on dredging project design can be found in the Handbook of Dredging Engineering by J.B. Herbich; Dredging: A Handbook for Engineers by Bray, Bates and Land and the ASCE Engineering Practice #80, “Report on Ship Channel Design (Herbich, 1992; Bray et al., 1997; ASCE, 1993).

6-2 **ACCOMPLISHMENT OF WORK**. Government-owned dredges should be used to the maximum extent consistent with economy. When the only suitable dredging equipment is in private ownership, or when the workload exceeds the capability of available government dredging facilities, private contractors may accomplish dredging. Some of the factors to be considered in planning a dredging project are:

- Marine environment, including water depths, waves, tides, currents;
- Nature and character of the sediments;
- Dredged quantities and disposal areas;
- Social, biological, regulatory and institutional factors;
- Long term dredging and disposal problems.

More detailed information on dredging project implementation is found in Chapter 2 of Dredging: A Handbook for Engineers (Bray, 1997).

6-3 **TERMINOLOGY**. Some common terminology is provided in the section below. For additional information on this subject, refer to the Dredging Desk Reference (Verna and Maciejewski, 1994).

Centrifugal Pump. A pump operated by centrifugal force, the force outward exerted by a body moving in a curved path.

Clamshell. A dredging bucket made of two similar pieces hinged together at one end.

Drag Head. A device placed on the end of a suction pipe (connected to a dredge) used for loosening or cutting away the bottom material that is to be dredged.

Dredge. (1) To excavate or move soil or rock underwater. (2) A vessel, or item of floating plant, equipped with means to move or excavate soil or rock underwater.

Hopper. A funnel-shaped chamber in which materials are stored temporarily and later discharged through the bottom.

6-4 **CURRENT DREDGING DESIGN PRACTICE**. Dredging practice and plant equipment is determined based on whether one is dealing with river dredging, estuary or coastal dredging, ocean dredging, beach replenishment, etc. Preliminary investigations must first be conducted to provide data to confirm that dredging will be necessary and that environmental regulations can be satisfied. A preliminary study will provide estimates of the sedimentation regimes, disposal areas, and the type of dredging plant that will be employed.

6-4.1 **Navy Harbors**. The dredging of Navy harbors may involve the dredging of clay and silt from estuarine harbors or the dredging of sand from harbors on open coasts. By 1980, 87 percent of the Navy's total annual maintenance-dredging volume consisted of cohesive sediments, while 13 percent consisted of sand. A large part of the total dredging in naval harbors consists of removing shoaled material from under berthing piers. Other dredging activities include dredging of navigation channels and turning basins, as well as channel-entrance bypassing.

6-4.2 **Dredging Research Program**. The USACE Dredging Research Program (DRP) conducts studies to develop up-to-date information on dredging technology. The results of these studies are compiled in technical reports that may be obtained from WES. Additional information can be found on the USACE web site.

6-4.3 **Methods**. Extensive discussion of current practices, including agitation dredging, barrier curtains, water injection dredging, sediment bypassing, and jet scour arrays, can be found in Chapter 7 of Dredging: A Handbook for Engineers (Bray et al., 1997) and the Handbook of Dredging Engineering (Herbich, 1992).

6-5 **PROJECT DEPTH**. According to the Permanent International Association of Navigational Congresses (PIANC), the required dredge depth for ship channels is determined by summing up the following components:

- Reference Water level minus lowest low water level
- Admissible ship draft, including trim and density change allowances
- Vertical ship motions, including squat, pitch and roll
- Net required under-keel clearance
- Depth sounding precision
- Sediment deposition thickness between scheduled dredgings

- Dredging accuracy tolerances

Discussions of this subject are contained in various sources including the joint PIANC and IAPH Final Report entitled, "Approach Channels - A Guide for Design," PTC II-30, dated June 1997; the Report of Ship Channel Design (ASCE, 1993); Chapters 3.2.1 and 8.3.1 in Dredging: A Handbook for Engineers (Bray et al., 1997).

6-5.1 **Overdepth Dredging**. Previous studies have shown up to 20 percent of over excavation on typical dredging projects. In addition to the additional dredging costs encountered, this can also result in premature filling of scarce disposal areas. Two factors that control overdepth dredging are dredge control and dredge survey. Modern dredge control is achieved by instrumentation, which provides real time knowledge of cutterhead depth and velocity and density of the slurry being pumped (Herbich, 1992). However, in some situations, it is less expensive to overdredge an area by 0.3 or 0.6 m (1 or 2 feet) than to pay for the careful manipulation of dredging equipment and for the extra time involved in dredging to the exact depth required. Overdepth dredging also allows for some additional shoaling before dredging is required again. Overdepth dredging should be investigated for each specific site as it cannot be used in every situation. For example, it may jeopardize stability of nearby structures.

6-5.2 **Advanced Maintenance Dredging**. It is advantageous to minimize maintenance costs by performing advanced maintenance dredging to increase the interval between dredgings. The channel is dredged deeper and/or wider than its original design or authorized depth, thereby allowing for shoaling to occur while the channel can still be navigable. Advance maintenance dredging can also greatly increase the time intervals between maintenance dredging operations, which can reduce the number of mobilization and demobilization tasks and the costs associated with them. This method is economically feasible if the money saved through a reduced dredging frequency schedule is greater than the cost of removing any additional sediment that may have been deposited as a result of the deeper and wider channel.

To determine whether or not advanced maintenance dredging is economically feasible, the design engineer must analyze and extrapolate shoaling data for "prior to dredging" depths of the channel and use numerical models to simulate site-specific estuarine hydrodynamics and sediment transport mechanisms. If appropriate data are unavailable for performing analytical studies, and numerical modeling studies are cost prohibitive, a minimal advance maintenance effort can be put into effect and the results evaluated. Thus, if money is saved, advanced maintenance dredging efforts can be stepped up and, conversely, if money is lost, the efforts can be abandoned (Sedimentation Control To Reduce Maintenance Dredging of Navigational Facilities in Estuaries, 1987).

6-5.3 **Disposal Areas**. The selection of an appropriate disposal area depends upon the physical characteristics of the dredged material, potential environmental impacts, size of the project and social, political, economic and regulatory considerations. Dredged material disposal sites may be offshore or onshore sites, confined by levees or containment dikes, or unconfined. Because of environmental considerations, confined upland sites are generally preferred unless the dredge spoil is being used to create wetlands. Selection of an upland site requires consideration of return of effluent water to the waterway. Unnecessary entrapment of water that may cause flooding must be avoided. It must be assured that effluent water does not pick up additional turbidity or toxic chemicals as it returns to the waterway. A more thorough discussion of these options is contained in the Handbook of Dredging Engineering (Herbich, 1992), Chapter 8, and in Chapter 5 of Dredging: A Handbook for Engineers (Bray et al., 1997). Bray also discusses the various types of sites for disposal as well as various processes of disposal and cleaning of dredged material and the decision making process for disposal (Bray et al., 1997). The PIANC bulletin, Management of Dredged Material From Inland Waterways (PIANC, 1990) and USACE EMs 1110-2-5026 and 1110-2-5027 are also useful and recommended sources of information.

6-5.3.1 **Upland Open Site**. This disposal location is generally used for placement of coarse, cohesionless sediments. Material placement is controlled with small berms constructed by a bulldozer or similar land-construction equipment.

6-5.3.2 **Upland Diked Site**. This type of disposal location is generally used for the confined placement of fine-grained sediments. Dikes constructed prior to sediment placement typically have overflow weirs to minimize turbidity in receiving waters. Dikes may be constructed of existing soil or may be built up with hydraulically placed fill. Soil embankments should have a maximum slope of 1 vertical to 2 horizontal on the exterior face and 1 vertical to 3 horizontal on the interior face. Hydraulic fill must be placed at the natural angle of repose. Care should be taken to provide a cross-sectional area sufficient to withstand the water depths in the fill. A minimum freeboard of 2 feet is typical. Placement of dredged material at an upland diked site may cause ground-water contamination; investigations should be made to determine if this possibility exists. Certain situations require that the diked site be lined with filter cloth or a layer of clay to prevent penetration of pollutants into the ground-water system.

6-5.3.3 **Open-Water Site**. With this type of disposal location, materials are generally limited to coarse sediments due to environmental considerations. EPA regulations and designated disposal areas should be investigated.

6-5.3.4 **Contained-Water Site**. For this type of disposal location, earthen dikes are usually constructed prior to dredging. The use of silt curtains instead of earthen dikes is possible under certain combinations of sediment, tides, currents, and environmental considerations.

6-5.4 **Downtime Criteria for Projects and Water Level Extremes**. An acceptable method for determining the design basis for water level extremes, such as the frequency and duration of low and high water levels should be determined from the historical record and used to define the maximum level of planned and unplanned downtime with respect to project scheduling.

6-6 **ECONOMIC FACTORS**. The economic factors affecting the dredging of Navy harbors are the following.

6-6.1 **Amount of Material to be Dredged**. The mobilization and demobilization costs will constitute a significant portion of the total project cost for small-volume dredging projects. For large-volume dredging projects, the mobilization and demobilization costs will only increase the cost per cubic yard by a relatively small amount.

6-6.2 **Distance From the Dredging Site to the Disposal Site**. This distance depends on the availability of disposal sites, the volume, and the environmental mental quality of the dredged material. If the sediment is contaminated, regulatory agencies may require dumping at a "contained" land disposal site. In many areas these sites are limited. Ocean disposal sites are attractive alternatives because of their unlimited capacity and general proximity to Navy harbors. In either case additional costs and time delays may be incurred because the dredged material must be proven environmentally clean prior to issuance of a dredging permit. Regardless of where the material is dumped, cost is a function of distance to the disposal site and mode of transport.

6-6.3 **Environmental Considerations**. Some form of environmental documentation is required for every dredging project, which can add substantially to project costs. The minimum requirement is a Preliminary Environmental Assessment. Additional chemical or biological testing may be required to supplement this documentation. If ocean disposal is proposed, it is likely that bioassays will be required at an additional cost. Most costly of all are environmental surveys of the dredge site and the disposal site which may be required in environmentally sensitive areas or cases of critical contamination. It is recommended to involve the local environmental office in the planning discussions from the inception of the project.

6-6.4 **New Work Versus Maintenance Dredging**. Where an area has not been dredged before, the bottom sediments may be consolidated and difficult to dredge. The added time required to dredge new material may incur additional costs.

6-6.5 **Other Factors**. Other factors include the cost of fuel, competition between private and public dredgers, and the configuration and use of the naval harbor to be dredged. Refer to either Chapter 8 of The Handbook of Dredging Engineering (Herbich, 1992) for an Economic Analysis for Disposal or Chapter 10 in Dredging: A Handbook for Engineers (Bray et al., 1997) for a discussion of Dredging Costs and Prices.

6-7 **GEOTECHNICAL FACTORS**. Soil investigations and testing techniques are generally similar to terrestrial procedures except that trial dredging may be resorted to where conditions for a particular type of dredge are marginal. Soil classifications generally refer to the PIANC adopted system.

6-7.1 **Sediment Analysis**. Sediment samples from the dredge area should be obtained and analyzed.

- *Grab samples*. Samples for maintenance dredging are often not necessary as review of historical records reveals sediment characteristics. If samples are necessary for maintenance projects they are usually grab sampled taken from the bed surface.

- *Subsurface investigation*. New-work dredging requires subsurface investigation. Recoverable cores are recommended where consolidated sediments may be encountered.

- *Probing or sonar profiling*. If rock pinnacles or debris are detected by grab or core samples, extensive probing or sonar profiling of the dredging area should be accomplished to locate and quantify rock and debris.

- *Sediment testing*. To evaluate dredging-plant requirements and disposal procedure, cohesionless samples should undergo mechanical sieve analysis. A chemical analysis is necessary for cohesive sediments. Bioassays may be necessary for cohesive sediments, depending on results of chemical analysis and proposed disposal action. If the project involves dredging of new sediments, a principal element of interest may be the density (or consistency) of material and, for cohesive sediments, the shear strength.

6-8 **UNEXPLODED ORDNANCE**. Currently the Navy has embarked on a number of efforts to locate and dispose of unexploded ordnance (UXO). Where there is a past history indicating potential existence of such ordnance, it must first be located so that care can be exercised to avoid injury to individuals or property damage.

6-9 **MAGNETIC SILENCING FACILITIES**. In order to deal with magnetic silencing facilities (for degaussing and deperming), the facility should be designed with future dredging requirements in mind. If the facilities are already in place, a dredging method that will not impact the facilities must be chosen.

6-10 **DREDGING EQUIPMENT**. A comprehensive summary of descriptions and optimum uses for various types of dredging equipment is found in Chapter 7 of The Handbook of Dredging (Herbich, 1992) and in Chapter 7 of Dredging: A Handbook for Engineers (Bray et al., 1997).

6-10.1 **Mechanical Dredges**. Mechanical dredges dislodge and raise sediment by mechanical means. Mechanical-dredging methods are generally used in protected waters, but because the equipment is relatively mobile, some mechanical dredging may be accomplished in open water during short-term, calm-water conditions. Mechanically dredged sediments may be disposed alongside the dredge at a dumpsite or may be transferred to scows which transport the sediments to a dump site. The production rate by means of mechanical dredging is relatively low. Mechanical dredges produce a more irregular bottom than hydraulic dredges.

6-10.1.1 **Types of Mechanical Dredges**.

- *Clamshell, grab, or bucket dredge*. This system consists of a crane, or derrick, mounted on a floating barge, with a clamshell, orange peel, or dragline bucket used to pick up sediment and transfer it to an adjacent scow or barge. This dredge may be a specially built machine or may consist of land equipment on a suitable floating platform. This form of dredging can remove loose, unconsolidated sediments ranging in size from silts and clays to blasted rock. The dredge can be used in moderate-swell conditions. The system is not exceedingly efficient but has the advantage of high mobility. This mobility enables dredging at the base of bulkheads, piers, and fender piles without damaging these structures or the dredge equipment.

- *Ladder, or bucket-ladder, dredge*. This dredge consists of a floating dredge that has a continuous chain of buckets on a frame which is called a ladder. Each of the buckets possesses a cutting edge for digging into the sediment. The ladder is lowered to the bed so that the buckets can reach and cut sediments to be dredged. The buckets dump the dredged sediment by gravity at the opposite end of the ladder onto a conveyor system or an adjacent open barge. The barge may then transport the material to the disposal site. This dredging system is effective in hardpan and cemented sediments, but is ineffective in firm rock. The system cannot be used in swell conditions. This system is not often used in the United States.

- *Dipper-barge dredge*. This dredge consists of a backhoe mounted on a barge equipped with a trapdoor shovel. Sediment is removed from the bed and deposited alongside the dredge, in another barge, in the water, or onshore. Where the sediment is deposited depends on the length of backhoe reach. Spuds, which penetrate the bottom, are usually used to keep the barge from moving during a dredging activity. This dredging method is effective for hardpan and cemented sediments, as well as for firm rock that has been blasted. The effectiveness of this type of dredging system is limited in moderate-swell conditions.

6-10.2 **Hydraulic Dredges**. Hydraulic dredges lift sediment from the bottom and transport it by means of a centrifugal pump. Hydraulic dredges can be used in either open or protected waters, depending on the type of dredge. The dredged material is transported in a slurry and is generally discharged by a pipeline in the hull of the dredge; the slurry is discharged alongside the dredge, or it may be pumped ashore. The rate of production depends on sediment type, depth of cut, and dredge size and power; it generally exceeds that of mechanical dredges.

6-10.2.1 **Types of Hydraulic Dredges**.

6-10.2.1.1 **Pipeline, or suction, dredge**. This dredge consists of a barge-mounted centrifugal pump. A suction line, or pipe, extends from the pump beyond the bow and is lowered to the bed by means of an "A" frame and ladder. At the end of this ladder, the pipe moves along the bottom dislodging the material. The material is then pumped in a slurry to a discharge line extending beyond the stern of the dredge. The material may then be pumped to the disposal site through a discharge line. Using booster pumps can extend the distance through which the material may be pumped. Sweeping the suction pipe over an area at constant depth will result in the excavation of the channel bottom. Pipeline dredges are not self-propelled, but move by forward-mounted swing wires and aft-mounted walking spuds or wires. This type of dredge can be operated safely only in the absence of moderate to high swell; it can excavate material ranging from clays and silts to blasted rocks. The dredge is generally capable of dredging large volumes of material. Pipeline dredges are usually limited to excavation depths of approximately 60 feet. The rate of production will decrease with increased length of discharge line, increased lift, and increased bed-sediment compaction.

6-10.2.1.2 **Cutterhead dredge**. This dredge consists of a pipeline dredge equipped with a rotary cutter at the end of the ladder. The cutter is used to dislodge bed sediments.

6-10.2.1.3 **Dustpan dredge**. This dredge consists of a pipeline dredge with a dustpan-shaped head at the end of the ladder. The head is equipped with water jets that are used to dislodge bed sediments.

6-10.2.1.4 **Bucket-wheel excavator**. This dredge consists of a pipeline dredge with a bucket wheel rotating (on a horizontal axis) at end of the ladder.

6-10.2.1.5 **Trailing suction dredge**. This dredge consists of a self-propelled or tug-assisted vessel. The hull of the vessel contains a hopper and the dredge is equipped with one or two suction pipes (normally fitted with drag heads) extending below the hull to the bed. This dredge usually operates while underway, drawing slurry by centrifugal pumps to the hopper, where excess water is overflowed back to the waterway. Sediment is discharged at the disposal site by opening doors located on the hopper bottom or by pumping out the hopper. This dredge is a self-contained unit and is capable of operating in higher swell conditions. Because the dredge is self-propelled, it is capable of dredging material from sites which are large distances from the point of disposal.

6-10.2.1.6 **Hopper dredge**. This dredge consists of a trailing suction dredge with a ship shaped hull, a bridge, an engine room, and crew quarters. This dredge is typically used for the dredging of estuary and river-mouth bars that are prone to ocean-swell conditions.

6-10.3 **Special Equipment**.

6-10.3.1 **High Solids-Content Dredge**. This dredge consists of a floating system capable of pumping high concentrations of solids through the use of compressed air. It is primarily used for removal of industrial wastes from rivers and harbors. The production rates are generally low and the distance over which the material may be pumped is limited. This type of dredge is not generally available.

6-10.3.2 **Elevated-Platform Dredge**. This system consists of a pipeline dredge that incorporates a "jack-up" barge to elevate the equipment above the surface swells. The system incorporates a submerged discharge pipeline. Availability of this type of dredge is very limited.

6-10.4 **Selection of Dredging Equipment**. Principal considerations upon which equipment selection is made include:

- exposure of dredging site
- volume and distribution of materials to be dredged
- type of material to be dredged
- location of disposal area
- distance to disposal area
- time available for work
- vessel traffic
- availability of equipment.

The US ACE DRP Technical Areas 3 and 4 contain numerous reports on the types of mechanical dredges listed in this chapter.

6-11 **DISPOSAL OPTIONS**. Disposal of dredged material generally presents problems, particularly when there is a lack of candidate disposal sites. The beneficial use of dredged materials should be investigated.

6-11.1 **Landfill**. Dredged sediments may be used as a landfill for commercial, industrial, and recreational purposes.

6-11.2 **Construction Materials**. Coarse sediments are often suitable for use as construction aggregate. These sediments may be stockpiled for present and future use.

6-11.3 **Marshland Wetland Habitat**. After intertidal- and submerged-fill operations are completed, shellfish larvae, wetland vegetation, or other organisms indigenous to the locale may be placed in the area to create a productive marshland.

6-11.4 **Upland Wildlife Habitat**. During and after completion of above-water fills, seeding and contouring of sediments can provide a habitat indigenous to wildlife; this procedure may also prevent erosion.

6-11.5 **Beach Nourishment**. Placement of suitable fill in water or on beaches can help to replenish losses of material caused by seasonal storms, washouts, currents, and other natural phenomena.

CHAPTER 7

DESIGN OF MARINE IMPROVEMENT PROJECTS

7-1 **INTRODUCTION TO COASTAL PROJECT ELEMENT DESIGN**. The CEM Section VI-2 contains sections on the introduction to coastal project element design, types and functions of coastal structures, site specific design conditions, materials and construction aspects, fundamentals of design, reliability based design of coastal structures, design of specific project elements, and designing for repair, rehabilitation, and modification.

7-2 **TYPES AND FUNCTIONS OF COASTAL STRUCTURES**. Coastal structures are used in coastal defense schemes with the objective of preventing shoreline erosion and flooding of the hinterland. Other objectives include sheltering of harbor basins and harbor entrances against waves, stabilization of navigation channels at inlets, and protection of water intakes and outfalls. An overview of the various types of coastal structures and their application is given in CEM Section VI-2. Overall planning and development of coastal projects is covered in CEM Section V.

7-2.1 **Breakwaters**. Primary applications of breakwaters are to provide protection against waves for shore areas, harbors, anchorages, and basins, and to enable maintenance-dredging operations. A secondary purpose is beach erosion control.

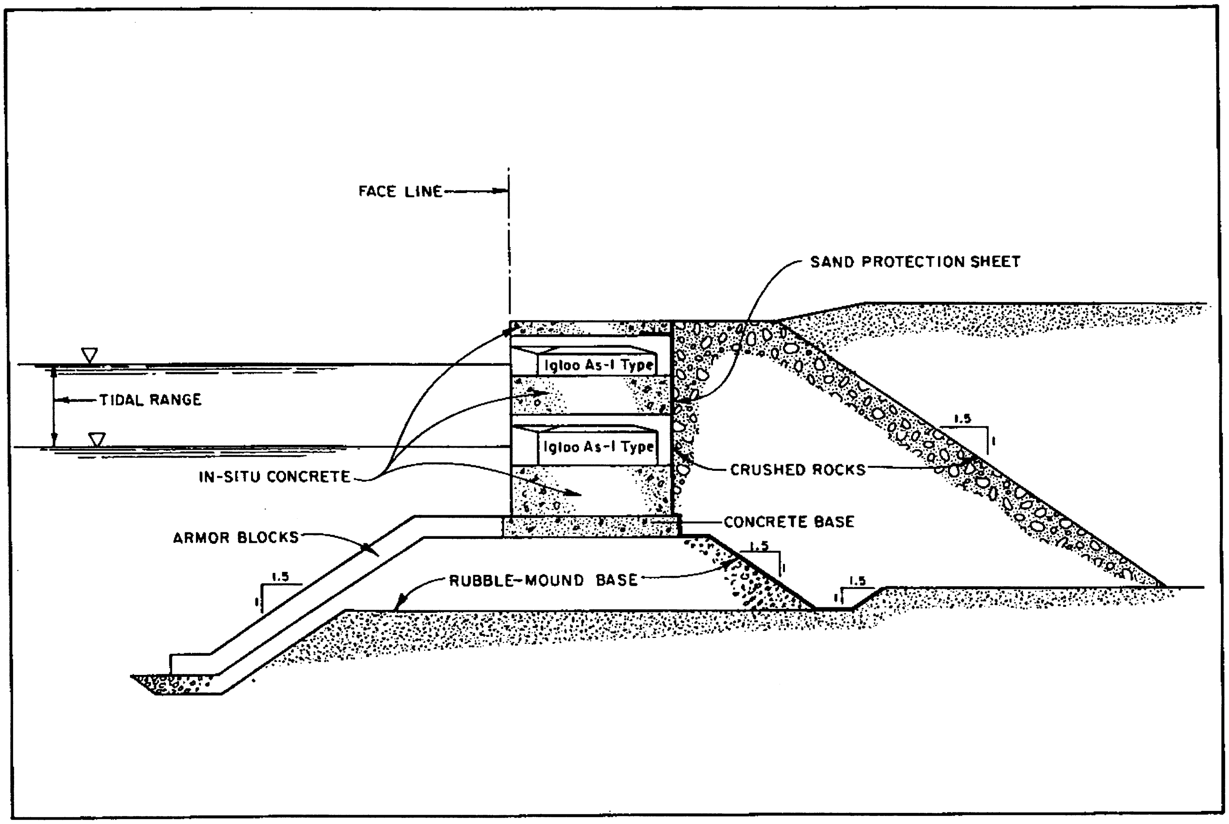
7-2.2 **Jetties**. Jetties are devices parallel to a navigation channel used to protect the channel from shoaling with littoral drift and to stabilize the entrance to a tidal inlet. They may also provide wave and wind protection and direct or confine the flow of river or tidal currents. Sand bypassing of jettied inlets is often necessary to preclude erosion of the downdrift coast.

7-2.3 **Revetments, Bulkheads, and Seawalls**. These structures are used to protect embankments or shore structures from eroding or from damage due to wave attack or currents and to retain or prevent sliding of land. Revetments are generally rubble construction. Seawalls and bulkheads are generally more rigid structures constructed of steel, concrete, or timber. Another design for seawalls is to use Igloos, patented by Nippon Tetrapod (Figure 7-1). Igloos can be used as space-saving wave absorbers or breakwaters. Prefabricated concrete units have been used successfully as wave-dissipating walls in harbors.

7-2.4 **Groins**. Groins are used to protect the coast from erosion and to retard or control littoral transport to stabilize a beach. Groin fields should generally be filled with imported material to preclude erosion of the downdrift coast.

7-2.5 **Headlands**. Headlands are high, steep-faced border points of land extending into the ocean or other body of water. Large segments of shorelines can be stabilized by construction of artificial headlands.

Figure 7-1 Typical Igloo Seawall



7-2.6 **Beach Restoration and Nourishment**. Beaches that are eroding due to an interrupted or inadequate sand source can be stabilized by deposition of sand brought from a source on land or of dredged materials.

7-3 **SITE SPECIFIC DESIGN CONDITIONS**. When developing a harbor or other coastal project, much of the information that is required is site specific. This requires the engineer to pursue various methods of field testing or existing data regarding a site. The various types of information that are typically required are foundation/geotechnical requirements, seasonal profile variation, flanking possibility, seismic activity, ice, environmental considerations, construction considerations and other design considerations (including regulatory, maintenance, etc.). CEM Section VI-3 presents an overview of these subjects.

7-4 **RELIABILITY OF DESIGN**. CEM Section VI-6 discusses reliability in design in depth. First, the engineer must decide on what design life is desired and/or permitted by the budget. The level of protection must then be considered.

The CEM also provides information on the factors to be considered in a complete design, necessary baseline data (field surveys, etc.) and concept of risk/reliability in project design. Finally, the CEM discusses overall performance criteria.

7-5 **FUNDAMENTALS OF DESIGN**. Planning and design procedures for coastal projects are described in CEM Section V-1. The engineering design steps related to a specific type of coastal structure can be schematized as follows:

- Specification of functional requirements and structure service life time.
- Establishment of the statistics of local short-term and long-term sea states as well as estimation of possible geomorphological changes.
- Selection of design levels for the hydraulic response: wave runup, overtopping, wave transmission, and wave reflection.
- Consideration of construction equipment and procedures, and of availability and durability of materials (e.g., only land based equipment operational and available at reasonable costs, rock of sufficient size easily available).
- Selection of alternative structure geometries to be further investigated (e.g., composite caisson structures, rubble structures with and without crown walls).
- Identification of all possible failure modes for the selected structure (e.g., armor layer displacement).
- Selection of design damage levels for the identified failure modes (e.g., 50% probability of displacement of 5% of the armor units within 50 years).
- Conceptual design of the structural parts based on the chosen design levels for failure mode damage and hydraulic responses (e.g., determination of armor layer block size and crest height for a breakwater).
- Evaluation of costs of the alternative structures and selection of preferred design(s) for more detailed analysis and optimization.
- Detailed design including economical optimization and evaluation of the overall safety of the structure. This stage will involve scale model tests and/or advanced computational analyses for non-standard and major structures.

7-6 **DESIGN OF SPECIFIC PROJECT ELEMENTS**. The design of specific coastal project elements is outlined below. For additional information and case studies, see CEM Section VI-7-1.

7-6.1 **Sloping-Front Structures**. The types of structures discussed here are armor units, one-sided shoreline sloping and two-sided sloped structures. Refer to CEM Part VI-7-2 for further information regarding this subject.

Rubble-mound structures generally have a core covered with one to several quarry stone underlayers that are protected with armor units of stone or specially shaped concrete units. Breakwaters have a core material of randomly dumped, well-graded quarry run, sand or coral. This material is generally impermeable. Successive underlayers cover the core; the material in each successive layer is carefully increased in size to prevent loss of the smaller-sized core material. Armor units are placed on the outer surface to hold to core and the underlayers in place against wave attack. Rubblemound revetments, groins, and jetties are similarly built in that armor units hold the underlying material in place. Rubble-mound structures are well suited to the coastal zone because they can absorb the forces of waves with relatively minor damage even when design conditions are exceeded to a moderate degree.

7-6.2 **Vertical Front Structures**. The types of structures of concern in this chapter are gravity structures and sheet-pile structures. CEM Section VI-7-3 is the nominal source.

7-6.3 **Beach Fill Systems**. Adding fill to a beach is an economical and effective method to replace lost beach materials or to increase the size of an existing beach. The added fill increases the backshore width and moves the high water line farther offshore. The choice of fill type should resemble the original beach material and the slope of the beach should also match the original slope as closely as possible. Note that the cost and ease of beach fill as an erosion control method depends on the rate of material loss from the beach. If fill is readily available from a nearby location, the initial cost of refilling the beach would be low. However, regular refilling translates into recurrent maintenance costs. See CEM Section VI-7-4 for information on beach fill systems.

7-6.4 **Floating Structures**. Floating breakwaters are a special classification of breakwater. A floating breakwater comprises a float, of sufficient size relative to the wavelength, held in place by mooring lines fixed to anchors or to guide piles. Floating breakwaters can be constructed of barges, pontoons, floating docs, or rubber tires, or one can be specifically designed. The recommended source for more information on this subject is CEM Section VI-7-5.

7-6.5 **Pile Structures**. As the most common type of deep foundation, piles are used to transmit loads through upper weak and/or compressible soil strata to underlying competent zones. These include driven piles, drilled piles, drilled piers/caissons, sheet piles (for containing fills), and fender piles for docking. Piles also provide support in areas where shallow foundations are impractical, such as underwater, in close proximity to existing structures, and other conditions, and to provide uplift resistance and/or lateral load capacity. The performance of a deep foundation is highly dependent on the installation procedures and quality of workmanship. Forces on piles and piers and pile design are addressed in the recommended source for information on this subject, CEM Section VI-7-6.

7-6.6 **Pipelines and Outfalls and Submarine Cables**. Pipelines, outfalls and submarine cable systems that cross a shoreline, harbor, river or other bodies of water are exposed to many hazards. Fishing activity, anchors, wave action, currents, ice scour, and vandalism are just a few of the causes of damage to these systems. A variety of methods are used for protection and stabilization including, armor, split pipe, rock riprap, concrete encasement, mechanical anchoring, trenching and horizontal direction drilling. The recommended source for information on this subject is CEM Section VI-7-7.

7-6.7 **Miscellaneous Structure Examples**. Examples of low-cost shore protection, sand-filled beach structures, low-energy shore protection, and beach draining are provided in CEM Section VI-7-8.

7-7 **DESIGNING FOR REPAIR, REHABILITATION, AND MODIFICATION**. CEM Section VI-8 provides information on this topic with emphasis on the reliability of existing structures, sloping-front structures, vertical-front structures and monitoring of structures.

CHAPTER 8

HARBOR AND COASTAL MAINTENANCE

8-1 **INTRODUCTION**. After a navigation project has been designed and constructed, operation and maintenance are required to sustain safe and efficient use of the project. Operation and maintenance requirements and costs can be substantial. They are typically estimated with care and optimized against initial construction costs in planning and designing a navigation project. Anticipated maintenance costs are based on predictions of physical changes after the project is constructed.

A completed navigation project must be monitored to insure safe operation and to plan for maintenance activities as needed; see CEM Section V-2-1-q. Monitoring typically includes hydrographic surveys, beach profile surveys, tide and wave data collection, and navigation structure condition surveys. Surveys are typically done on a planned schedule, such as annually, and before and after periods of maintenance and repair. Surveys should be analyzed comparatively to determine rates of erosion, shoaling, and structure deterioration. The recommended source for information on this subject is CEM Section V-4-3.

8-2 **HARBOR AND CHANNEL SEDIMENTATION AND MAINTENANCE**. Often periodic dredging to maintain project depths is the major maintenance need (CEM, Appendix VII-4). Maintenance dredging intervals are dependent on factors such as shoaling rate, dredge availability, and dredge mobilization costs. Typical maintenance intervals are on the order of 1-3 years at some projects. However, environmental forces impacting a navigation project are highly variable. The number and intensity of storms affecting a project each year can only be predicted in terms of probabilities. Maintenance needs are often strongly influenced by storm events. A single severe storm can cause major shoaling and structure damage. Consequently, monitoring and maintenance activities may occasionally need to respond quickly to maintain project integrity. See CEM Section V-4-3 for further information.

8-2.1 **Navigation Aids**. Information on Navigation Aids can be found in the Code of Federal Regulations: 33 CFR Part 62 and 33 CFR Part 209.325.

8-3 **INSPECTION AND REPAIR OF MARINE IMPROVEMENTS**. The recommended source for information on this topic is the "ASCE Standard for Shore Protection Systems - Draft," August 20, 1997.

8-3.1 **Revetments**. The recommended source for information on this topic is the "ASCE Standard for Shore Protection Systems - Draft" (ASCE, 1997).

8-3.2 **Beach Nourishment**. The recommended sources for information on this topic are the CEM Chapter V-3-3-a(1) and "ASCE Standard for Shore Protection Systems – Draft," August 20, 1997.

8-3.3 **Sedimentation Around Piers and Basins**. Deepening harbors to provide for deeper draft ships and the installation of piers can increase the rate of sedimentation, in those cases where the entire sediment supply isn't already depositing itself. The ramifications of siltation around piers, for example, can induce localized changes; silt or microorganisms can be picked up through a ship's saltwater intakes, thereby causing significant damage to vessels and high repair costs.

Since sedimentation control is a site-specific phenomenon, each location must be accessed and the best method chosen for the area. Modeling sites can provide valuable information, but all sites cannot be modeled at full scale due to cost limitations; additionally, scaling can be problematic. Research and development into sediment limitation by way of stopping the sediment from reaching the site, keeping the material in suspension through the site, or diverting the sediment flow from critical areas has produced ideas for several different systems and methods: the venting canal, the scour jet array, the vortex foil array, the barrier curtain, and the maintenance trench (Sedimentation Control to Reduce Maintenance Dredging of Navigational Facilities in Estuaries, 1987).

APPENDIX A REFERENCES

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APPENDIX B

IN REPLY REFER TO
11460
Ser 03D3/242
3 Jan 95

From: Commander, Naval Sea Systems Command
To: Chief of Naval Operations (W44) Chief of Naval Operations (WB8)

Subj: CVN 68 CLASS WATER DEPTH REQUIREMENTS

Ref: (a) NAVSEA ltr 11460 Ser PMS312/792 of 30 Apr 91
(b) NAVSEA ltr 11460 Ser 03D3/144 of 9 Aug 94
(c) COMNAVAIRLANT ltr 4700 Ser N431F/01400 of 19 May 94

Encl: (1) CNV 68 C1ass Home Port Water Depth Requirements
(2) CVN 68 Class Shipyard Water Depth Requirements
(3) CVN 68 Class Shallow Water Navigation Improvements

1. NAVSEA has determined the water depth requirements for CVN 68 Class aircraft carriers in home ports, ports of call, and shipyards. The pier and channel depths requirements previously provided in reference (a) are superseded. These water depth requirements augment those previously provided for San Diego in reference (b), and respond to the reference (c) request for Norfolk Naval Shipyard.

2. Enclosure (1) provides water depth requirements for home ports. Attachment (1) of enclosure (1) also applies to ports of call. The ship’s mean draft used for home ports corresponds to the limiting displacement and is considered the proper basis for dredging since it will permit operations of a fully loaded ship. Enclosure (2) provides water depth requirements for shipyards. The ship’s mean draft used for shipyards was reduced based on the assumption that only 55% of the sbip's loads (aircraft, fuel, personnel, stores, etc) would be onboard. Each enclosure describes and quantifies the components that contribute to the CVN 68 Class draft and clearance; the governing depth requirements for the pier, turning basin, inner channel, and outer channel for each home port and shipyard; general tide information for each home port and shipyard; and a graphical representation of the relationship between the number of days of access to the turning basin and inner channel, the length of the tide window, and the dredging project depth for the governing depth requirement of each home port and shipyard.

3. While at the pier, in the turning basin, or in the inner channel of a home port or a port of call, it is recommended that there be a minimum of 50 feet of water depth. While at the pier, in the turning basin, or in the inner channel of a shipyard, it is recommended that there be a minimum of 47 feet of water depth, assuming the ship has been offloaded. Entering a shipyard without offloading should be treated as a port of call. These water depth requirements are governed by the sea chest fouling

clearance criterion established as a result of sea chest fouling problems at Norfolk. Port specific fouling clearance studies can be performed it requested and funded. Note that this criterion also provides clearance for divers (5 feet) while at the pier. The dredging project depth can be traded off with tides to obtain the necessary water depth in inner channels and turning basins with the corresponding operational restrictions; however, tide tradeoffs cannot be used at piers. Localized pier dredging in way of sea chests can save 2 feet of dredging costs outside of the sea cheat area; however, operational restrictions may result (e.g. less transit time in tide window and limited diver access). In ports with large amounts of debris on the bottom, locally dredged areas will tend to collect debris requiring more frequent maintenance dredging.

4. In the outer channel, wave action usually dominates the depth requirements and can have a large variance. A ship motions analysis was performed for the outer channels of San Diego and Mayport to account for the statistical nature of the tides and wave action. The ship motions analyses of the remaining home ports and shipyards will be completed within 6 months after receipt of funding. Dredging to support unrestricted access is clearly unaffordable. Consequent1y, the selection of a project depth is a tradeoff between cost, operational requirements, and the risk of grounding.

5. Many of the factors that affect channel transit are operational issues such as operating schedule and contingencies; port operations; ship displacement, trim, list, and speed; as well as weather and tides. Actual transit situations will vary and will involve different combinations of these factors. Consequently, a given transit could require more or less water depth. Enclosure (3) describes efforts underway or proposed to improve onboard shallow water navigation aids that predict ship’s motion, provide real time channel condition measurement, improve ship's draft and attitude indication, and provide a load management system.

6, The NAVSEA point of contact is W. Page Glennie, NAVSEA 03D37, (703) 4I8-8876.

M. S. FIREBAUGH
Deputy Commander for Engineering

Copy to: (w/encls)
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CINCPACFLT (Code N4, N43)
NSWC-CD (Code 1561)
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Subj   CVN 68 CLASS WATER DEPTH REQUIREMENTS

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PMS312X

Writer: W. Page Glennie, SEA 03D37, 418-8876
Typist: W. Page Glennie, SEA 03D37, 418-8876

CVN 68 CLASS HOME PORT WATER DEPTH REQUIREMENTS

Attachments:

(1) CVN 68 Class Home Port and Ports of Call Draft and Clearance Requirements
(2) CVN 68 Class Water Depth Requirements for Norfolk Operating Base
(3) Sewell's Point Tide Access, 50 foot Depth Requirement
(4) CVN 68 Class Water Depth Requirements for San Diego
(5) San Diego Inner Channel Tide Access, 50 foot Depth Requirement
(6) CVN 68 Class Water Depth Requirements for Everett
(7) Everett Tide Access, 50 foot Depth Requirement
(8) CVN 68 Class Water Depth Requirements for Bremerton
(9) Rich Passage Tide Access, 50 foot Depth Requirement
(10) CVN 68 Class Water Depth Requirements for Mayport
(11) Mayport Tide Inner Channel Access, 50 foot Depth Requirement

Enclosure (1)

APPENDIX C

CVN 68 Class Home Port and Ports of Call Draft and Clearance Requirements

STATIC DRAFT					
Mean	40.8 ft 103,800 tons (CVN 68-75) 104,200 tons (CVN 76)				– Accounts for: Actual operating condition (+2000 tons) Service life weight growth (+70 tons/year) Unreported weight Assumes weight is added in best location. Assumes good ship weight control.
Trim	0.25 degrees	Bow Sea Chest Rudder	2.3 ft 0.8 ft 2.1 ft		– Based on operational experience. Instances of greater trim do occur, but rarely when the ship is at or near the limiting displacement.
List	Pier	2 degrees	Bilge Keel Sea Chest	2.3 ft 1.4 ft	– Based on operational experience. Instances of greater list do occur, but rarely when the ship is at the limiting displacement.
	Channel	0 degrees			– Assumed ship is leveled prior to transit. TYCOM confirmation needed
Appendages	9 inches				– All of the CVN 68 Class except CVN 70 have discharge sea chest diffusers. – Assumed to be overshadowed by trim.
Salinity & Temperature	0.5 feet (50% salinity reduction & 10° temperature rise)				– This calculation is port, season, and tide specific. – Assumed constant.
Dynamic Draft					
Wind & Waves	Outer Channel		See Note		– This calculation is port specific. – See indiv. port summary sheet for details.
	Inner Channel		0 ft		– Protected harbor.
	Pier & Turning Basin				
Squat	10 kts	Forward	0.9 ft		– Based on wide channel that is 50 ft deep.
		Aft	1.3 ft		– Shallower and/or narrower channels a/o higher
		Sea Chest	1.0 ft		speeds will require a greater allowance for squat
Heel	1.4 degrees	Bilge Keel	1.6 ft		– Based on operational experience, 10 kts and
		Sea Chest	0.8 ft		10 degrees rudder.
Clearance					
Fouling	6 ft				– Based on operational experience at NOB and NAVFAC study and applies to soft bottoms and bottoms with loose sea growth. – Assumes diffusers are installed.
Grounding	Soft Bottom		2 ft		– NAVFAC deterministic standard.
	Hard Bottom		3 ft		
					– Proposed probabilistic standard.

Enclosure (1)   Attachment (1)

CVN 68 Class Water Depth Requirements for Norfolk Operating Base

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	40.8	40.8	40.8	40.8
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	0.5	0.5	0.5	0.5
Motions (b)	-	-	-	(f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	49.5	49.5	49.9	(f)

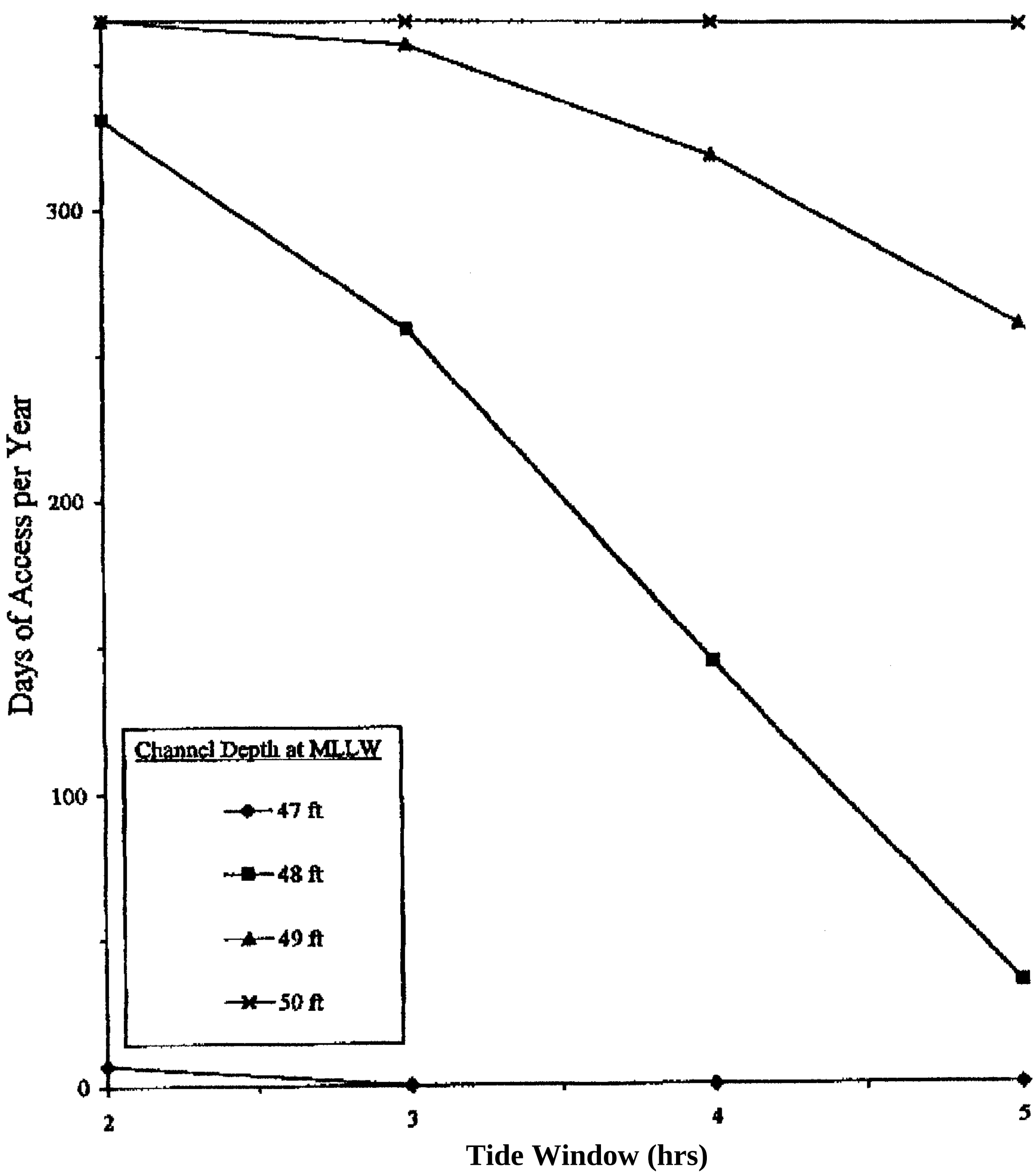
Notes:
(a) Harbor contains fresh water inlet.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; good estimate.
(d) Operational experience.
(e) Standard clearances.
(f) Analysis not complete.

NOB Tide Data

Mean Higher High Water	2.8 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-3.5 feet

Enclosure (1)
Attachment (2)

Sewell's Point Tide Access
50 Foot Depth Requirement



Enclosure (1)
Attachment (3)

CVN 68 Class Water Depth Requirements for San Diego

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	40.8	40.8	40.8	40.8
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	-	-	-	-
Motions (b)	-	-	-	4.2/27.7 (f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	49.0	49.0	49.4	50.4/73.9 (g)

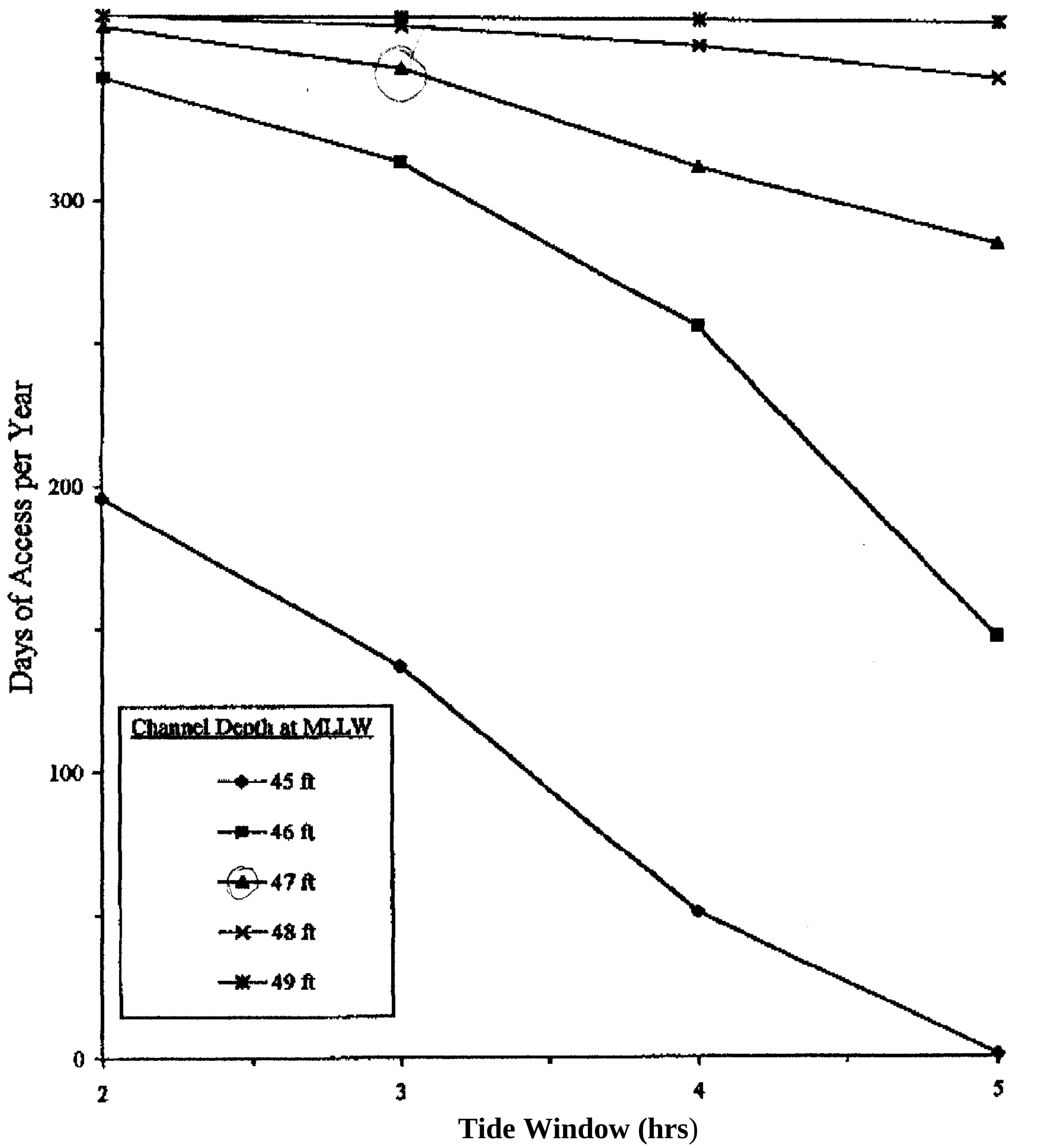
Notes:
(a) Sa1t water port; no correction required.
(b) Unprotected harbor; significant wave action.
(e) Based on wide, 50 ft deep channel; good estimate.
(d) Operational experience.
(c) Standard clearances.
(f) Weighted average and extreme values.
(g) A water depth of 74 feet provides unrestricted access.

San Diego Tide Data

Mean Higher High Water	5.8 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-2.0 feet

Enclosure (1)
Attachment (4)

San Diego Inner Channel Tide Access
50 Foot Depth Requirement



Enclosure (1)
Attachment (5)

CVN 68 Class Water Depth Requirements for Everett

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	40.8	40.8	40.8	(f)
Trim	0.8	0.8	0.8	
List	1.4	1.4		
Appendages				
Salinity & Temp (a)	0.5	0.5	0.5	
Motions (b)				
Squat (c)			1.0	
Heel (d)			0.8	
Clearance (e)	6.0	6.0	6.0	
TOTAL	49.5	49.5	49.9	

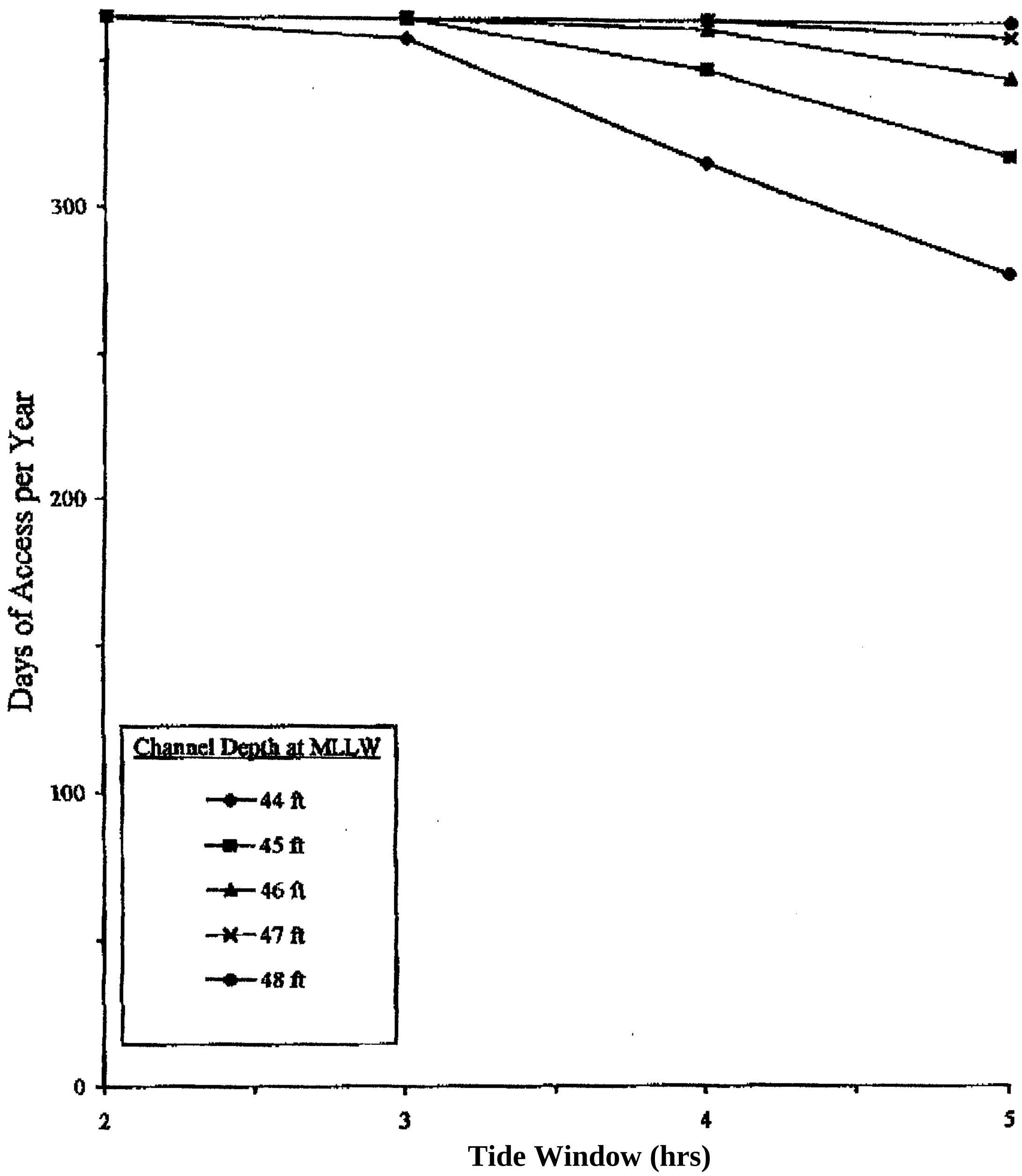
Notes:
(a) Harbor contains fresh water inlet.
(b) Protected harbor; no significant wave action,
(C) Based on wide, 50 ft deep channel; need more information.
(d) Operational experience.
(e) Standard clearances,
(f) Unrestricted outer channel due to deep depth.

Everett Tide Data

Mean Higher High Water	11.1 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-4.5 feet

Enclosure (1)
Attachment (6)

Everett Tide Access
50 Foot Depth Requirement



Enclosure (1)
Attachment (7)

CVN 68 Class Water Depth Requirements for Bremerton

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	40.8	40.8	40.8	(f)
Trim	0.8	0.8	0.8	
List	1.4	1.4	-	
Appendages	-	-	-	
Salinity & Temp (a)	0.5	0.5	0.5	
Motions (b)	-	-	-	
Squat (c)	-	-	1.0	
Heel (d)	-	-	0.8	
Clearance (e)	6.0	6.0	6.0	
TOTAL	49.5	49.5	49.9	

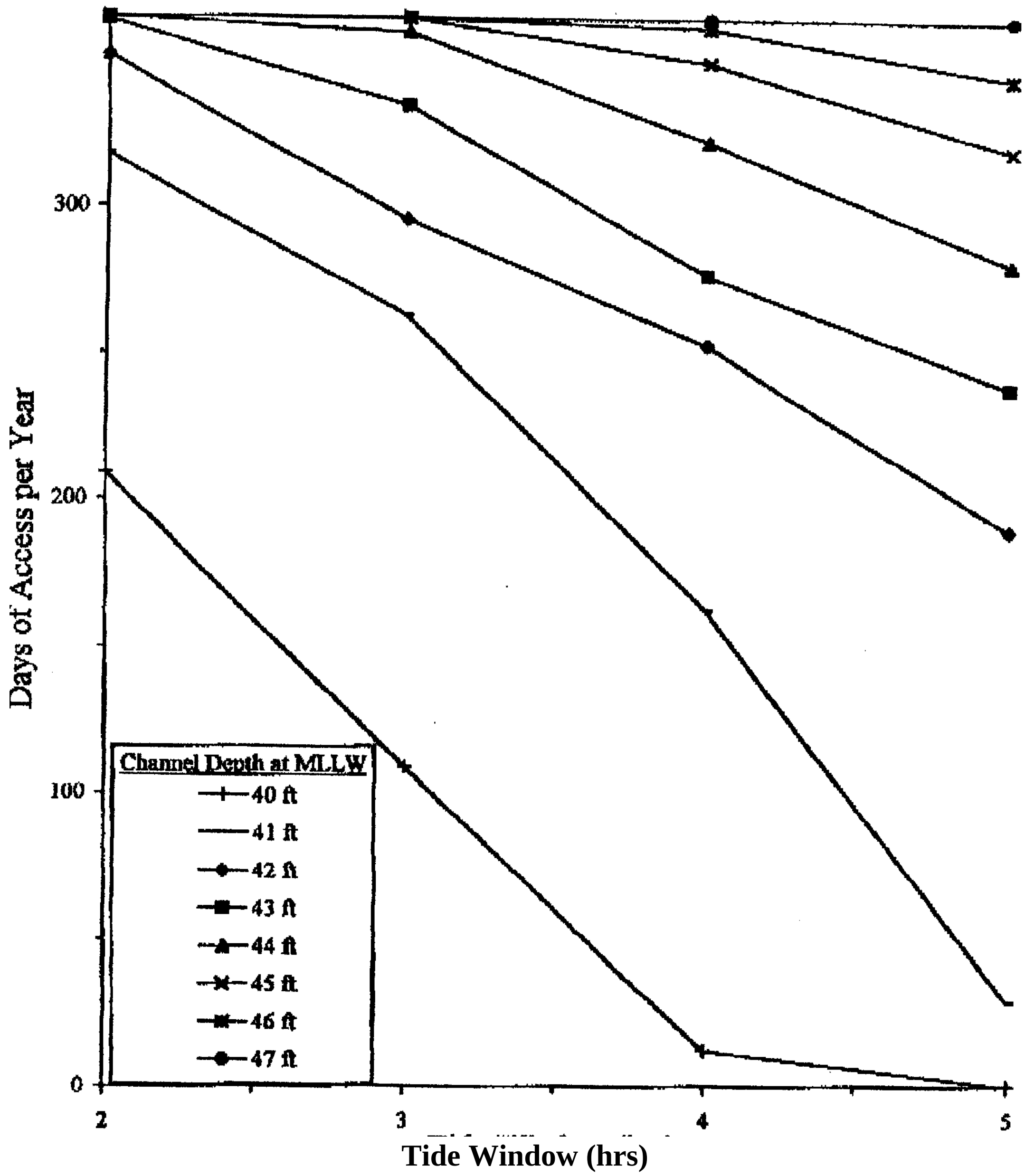
Notes: (a) Harbor contains fresh water inlet.
(b) Protected harbor; no significant wave action.
(c) Based on wide, 50 ft deep channel; need more information.
(d) Operational experience.
(e) Standard clearances.
(f) Unrestricted outer channel due to deep depth.

Bremerton Tide Data

Mean Higher High Water	11.7 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-4.7 feet

Enclosure (1)
Attachment (8)

Rich Passage Tide Access
50 Foot Depth Requirement



Enclosure (1)
Attachment (9)

CVN 68 Class Water Depth Requirements for Mayport

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	40.8	40.8	40.8	40.8
Trim	0.8	0.8	0.8	0.8/2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	0.5	0.5	0.5	0.5
Motions (b)	-	-	-	0.5/14.3 (f)
Squat (c)	-	-	1.0	1.0/1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	6.0/2.0
TOTAL	49.5	49.5	49.9	49.6/61.0 (g)

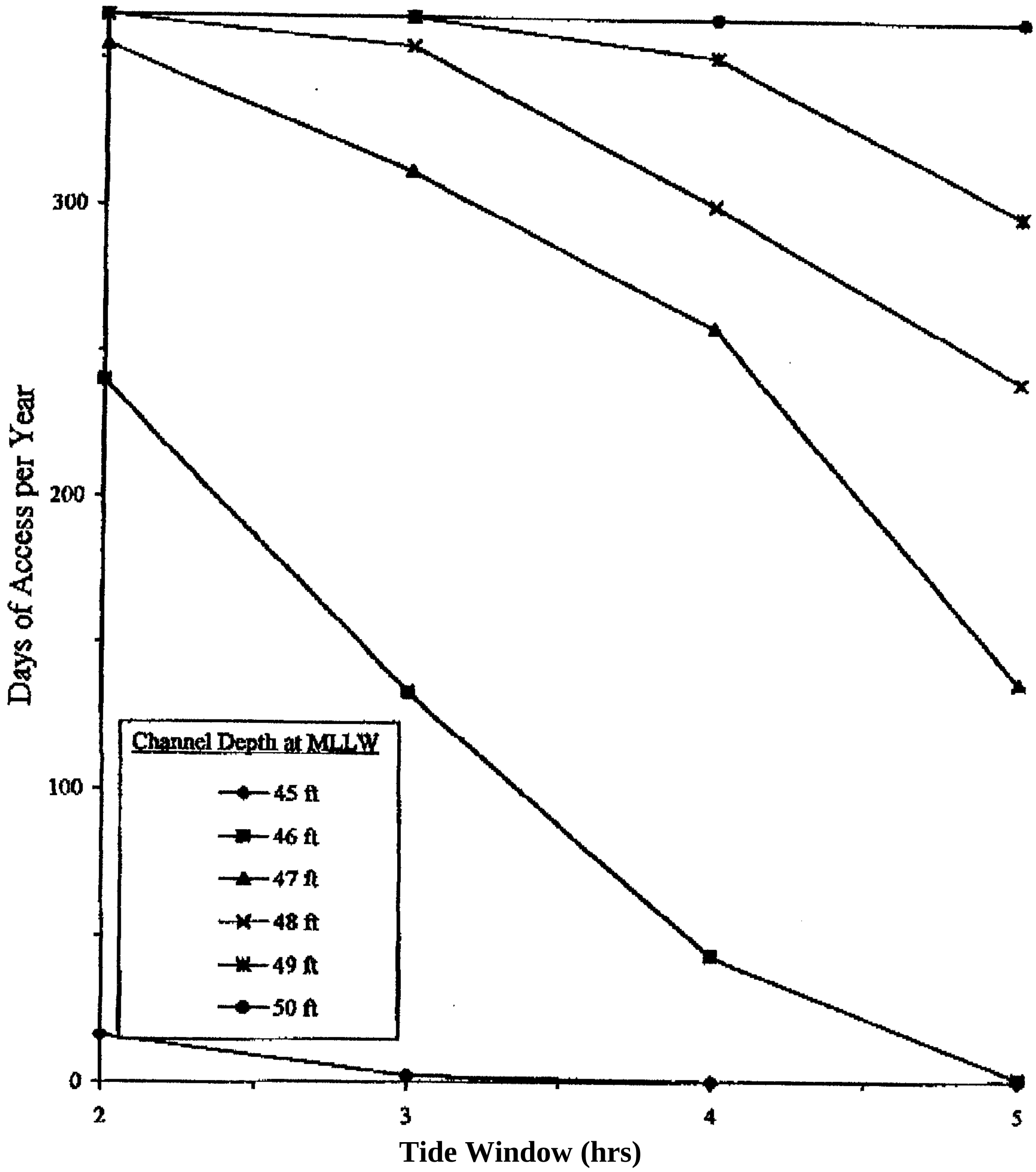
Notes. (a) Harbor contains fresh water inlet.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; need more information.
(d) Operational experience.
(e) Standard clearances.
f) Weighted average value at sea chest and extreme value at rudder.
(g) A water depth of 61 feet provides unrestricted access.
The minimum water depth (50 feet) is governed by fouling.

Mayport Tide Data

Mean Higher High Water	5.4 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-3.0 feet

Enclosure (1)
Attachment (10)

Mayport Inner Channel Tide Access
50 Foot Depth Requirement



Attachment (11)

APPENDIX D

CVN 68 CLASS SHIPYARD WATER DEPTH REQUIREMENTS

Attachments:

(1) CVN 68 Class Shipyard Draft and Clearance Requirements
(2) CVN 68 Class Water Depth Requirements for Norfolk Naval Shipyard
(3) Elizabeth River Tide Access, 47 foot Depth Requirement
(4) CVN 68 Class Water Depth Requirements for Newport News Shipbuilding
(5) Sewell's Point Tide Access, 47 foot Depth Requirement
(6) CVN 68 Class Water Depth Requirements for Puget Sound Naval Shipyard
(7) Rich Passage Tide Access, 47 foot Depth Requirement
(8) CVN 68 Class Water Depth Requirements for Pearl Harbor Naval Shipyard
(9) Pearl Harbor Inner Channel Tide Access, 47 foot Depth Requirement
(10) CVN 68 Class Water Depth Requirements for Long Beach Naval Shipyard
(11) Terminal Island Tide Access, 47 foot Depth Requirement

CVN 68 Class Shipyard Draft and Clearance Requirements

STATIC DRAFT					
Mean	37.9 ft 94,800 tons (CVN 68-75) 95,200 tons (CVN 76)				– Accounts for: Actual operating condition (+2000 tons) Service life weight growth (+70 tons/year) Unreported weight Variable loads at 55% full load capacity. Assumes weight is added in best location. Assumes good ship weight control.
Trim	0.25 degrees	Bow Sea Chest Rudder	2.3 ft 0.8 ft 2.1 ft		– Based on operational experience. Instances of greater trim do occur, but rarely when the ship is at or near the limiting displacement.
List	Pier	2 degrees	Bilge Keel Sea Chest	2.3 ft 1.4 ft	– Based on operational experience. Instances of greater list do occur, but rarely when the ship is at the limiting displacement.
	Channel	0 degrees			– Assumed ship is leveled prior to transit. TYCOM confirmation needed
Appendages	9 inches				– All of the CVN 68 Class except CVN 70 have discharge sea chest diffusers. – Assumed to be overshadowed by trim.
Salinity & Temperature	0.5 feet (50% salinity reduction & 10^{o} temperature rise)				– This calculation is port, season, and tide specific. – Assumed constant.
Dynamic Draft					
Wind & Waves	Outer Channel		See Note		– This calculation is port specific. – See indiv. port summary sheet for details.
	Inner Channel Pier & Turning Basin		0 ft		– Protected harbor.
Squat	10 kts	Forward	0.9 ft		– Based on wide channel that is 50 ft deep. – Shallower and/or narrower channels a/o higher speeds will require a greater allowance for squat
		Aft	1.3 ft		
		Sea Chest	1.0 ft		
Heel	1.4 degrees	Bilge Keel	1.6 ft		– Based on operational experience, 10 kts and 10 degrees rudder.
		Sea Chest	0.8 ft		
Clearance					
Fouling	6 ft				– Based on operational experience at NOB and NAVFAC study and applies to soft bottoms and bottoms with loose sea growth. – Assumes diffusers are installed.
Grounding	Soft Bottom		2 ft		– NAVFAC deterministic standard.
	Hard Bottom		3 ft		
	1/100				– Proposed probabilistic standard.

Attachment (1)

CVN 68 Class Water Depth Requirements for Norfolk Naval Shipyard

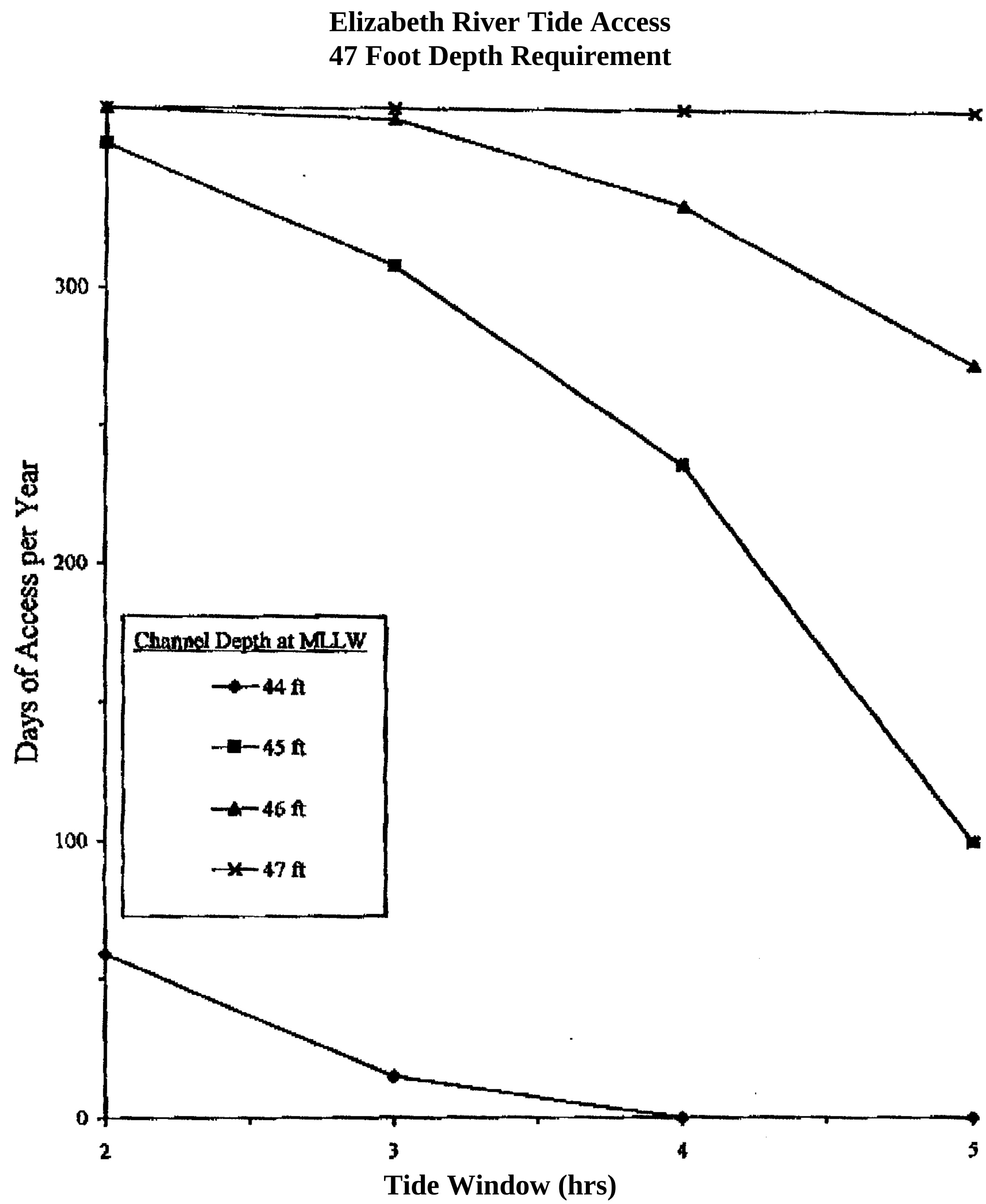
	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	37.9	37.9	37.9	37.9
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	0.5	0.5	0.5	0.5
Motions (b)	-	-	-	(f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	46.6	46.6	47.0	(f)

Notes:
(a) Harbor contains fresh water inlet.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; good estimate.
(d) Operational experience.
(e) Standard clearances.
(f) Analysis not complete.

NNSY Tide Data

Mean Higher High Water	3.2 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-3.5 feet

Attachment (2)



Attachment (3)

CVN 68 Class Water Depth Requirements for Newport News Shipbuilding

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	37.9	37.9	37.9	37.9
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	0.5	0.5	0.5	0.5
Motions (b)	-	-	-	(f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	46.6	46.6	47.0	(f)

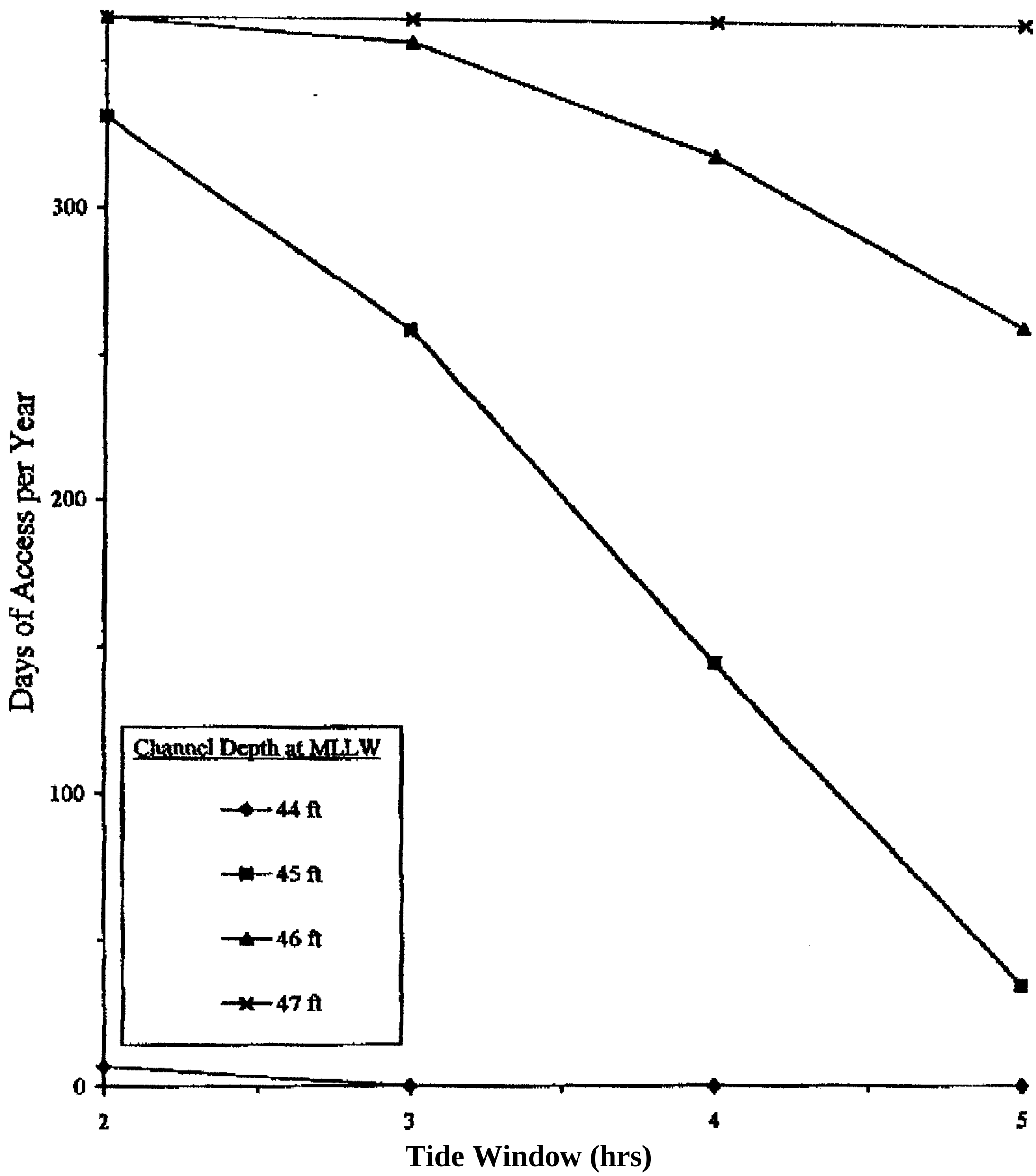
Notes:
(a) Harbor contains fresh water inlet.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; good estimate.
(d) Operational experience.
(e) Standard clearances.
(f) Analysis not complete.

Newport News Tide Data

Mean Higher High Water	2.9 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-3.5 feet

Attachment (4)

Sewell's Point Tide Access
47 Foot Depth Requirement



Attachment (5)

CVN 68 Class Water Depth Requirements for Puget Sound Naval Shipyard

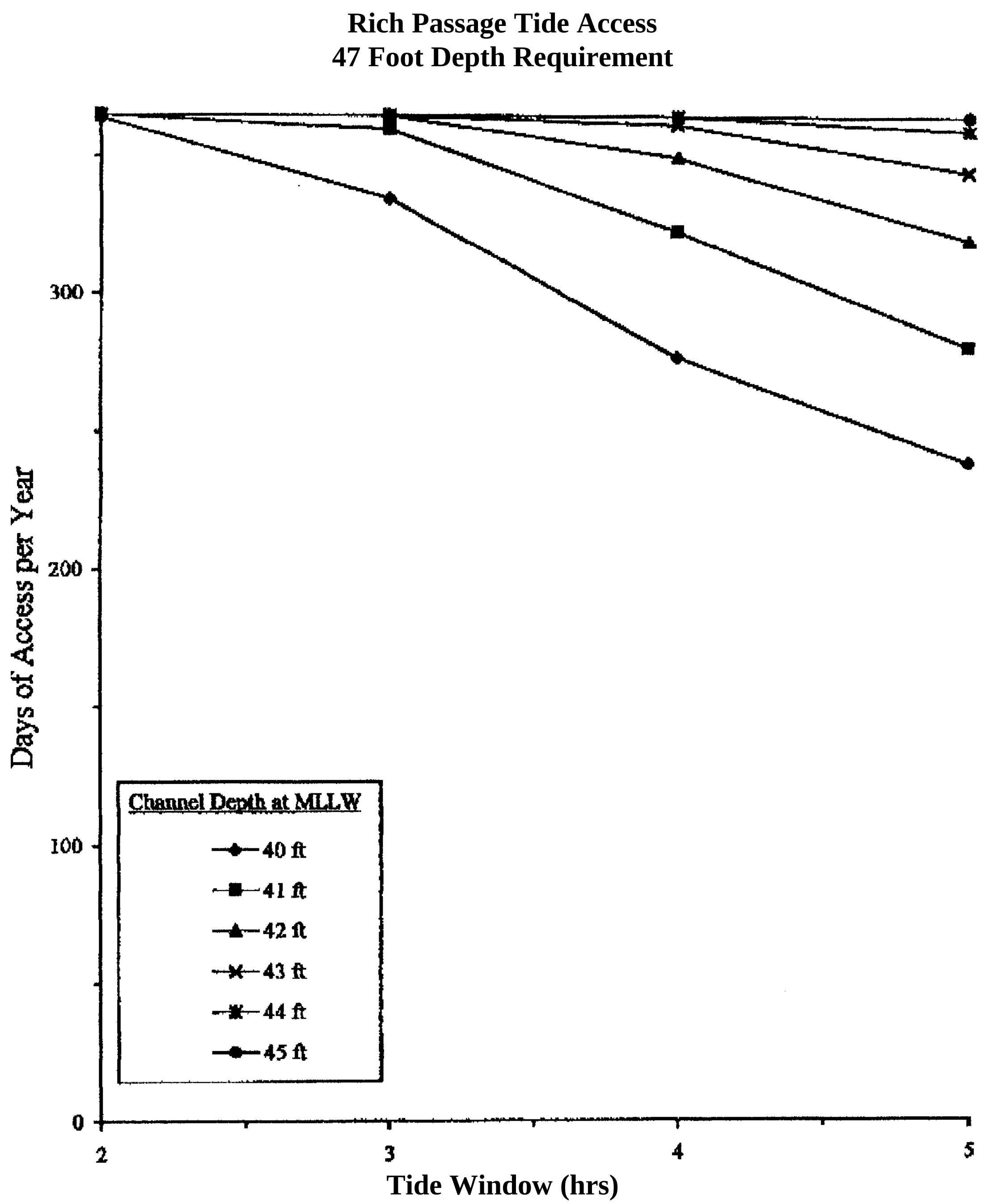
	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	37.9	37.9	37.9	(f)
Trim	0.8	0.8	0.8	
List	1.4	1.4	-	
Appendages	-	-	-	
Salinity & Temp (a)	0.5	0.5	0.5	
Motions (b)	-	-	-	
Squat (c)	-	-	1.0	
Heel (d)	-	-	0.8	
Clearance (e)	6.0	6.0	6.0	
TOTAL	46.6	46.6	47.0	

Notes:
(a) Harbor contains fresh water inlet.
(b) Protected harbor; no significant wave action.
(c) Based on wide, 50 ft deep channel; need more information.
(d) Operational experience.
(e) Standard clearances.
(f) Unrestricted outer channel due to deep depth.

Bremerton Tide Data

Mean Higher High Water	11.7 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-4.7 feet

Attachment (6)



Attachment (7)

CVN 68 Class Water Depth Requirements for Pearl Harbor Naval Shipyard

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	37.9	37.9	37.9	37.9
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	-	-	-	-
Motions (b)	-	-	-	(f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	46.1	46.1	46.5	(f)

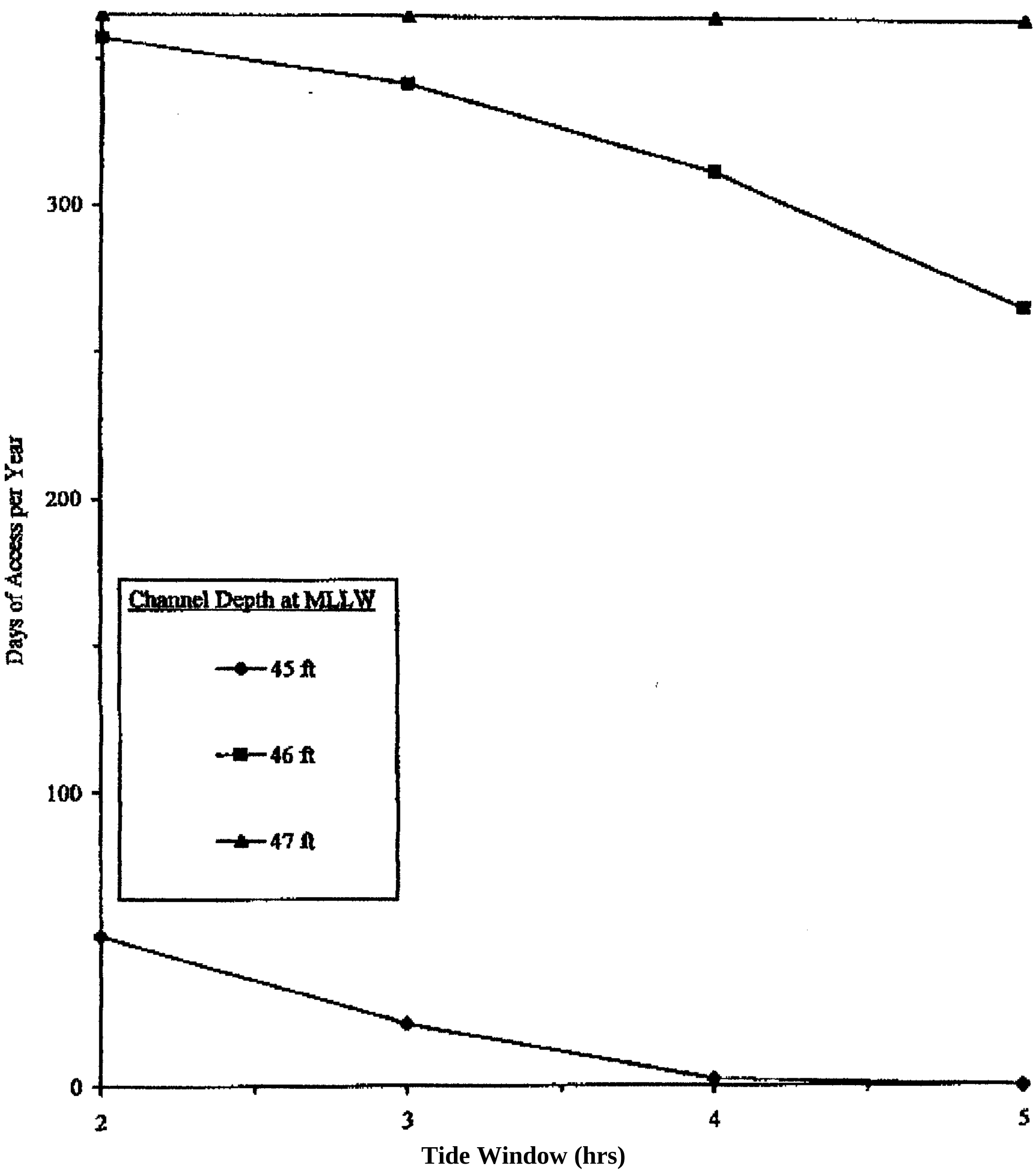
Notes:
(a) Salt water port; no correction required.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; need more information.
(d) Operational experience.
(e) Standard clearances.
(f) Analysis not complete.

Pearl Harbor Tide Data

Mean Higher High Water	2.0 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-1.6 feet

Attachment (8)

Pearl Harbor Inner Channel Tide Access
47 Foot Depth Requirement



Attachment (9)

CVN 68 Class Water Depth Requirements for Long Beach Naval Shipyard

	Pier	Turning Basin	Inner Channel	Outer Channel
Draft	37.9	37.9	37.9	37.9
Trim	0.8	0.8	0.8	2.1
List	1.4	1.4	-	-
Appendages	-	-	-	-
Salinity & Temp (a)	-	-	-	-
Motions (b)	-	-	-	(f)
Squat (c)	-	-	1.0	1.3
Heel (d)	-	-	0.8	-
Clearance (e)	6.0	6.0	6.0	2.0
TOTAL	46.1	46.1	46.5	(f)

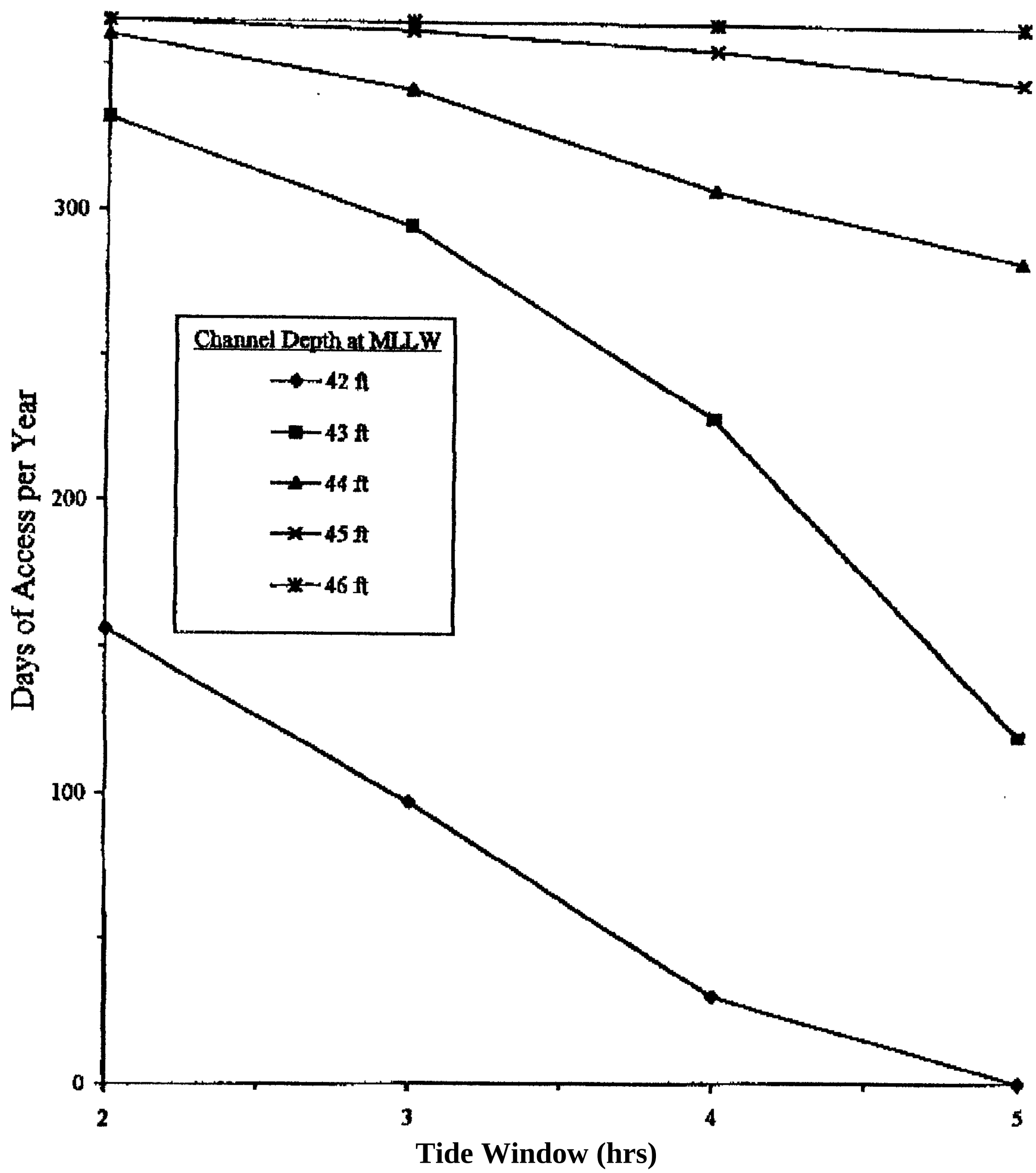
Notes:
(a) Salt water port; no correction required.
(b) Unprotected harbor; significant wave action.
(c) Based on wide, 50 ft deep channel; good estimate.
(d) Operational experience.
(e) Standard clearances.
(f) Analysis not complete.

Long Beach Tide Data

Mean Higher High Water	5.3 feet
Mean Lower Low Water	0.0 feet
Extreme Low Water	-2.5 feet

Attachment (10)

Terminal Island Tide Access
47 Foot Depth Requirement



Attachment (11)

APPENDIX E

CVN 68 CLASS SHALLOW WATER NAVIGATION IMPROVEMENTS

Due to the deep draft of the CVN 68 Class aircraft carriers, port and shipyard access can be restricted, in order to minimize the cost and environmental impacts of deep dredging, actual ship loading, tides, and favorable weather conditions can be used. Utilizing these factors affects operational issues such as operating schedule and contingencies as well as ship loading and speed. Actual transit situations will vary and will involve different combinations of these factors. Current dredging plans will not provide unrestricted access to CVN 68 Class home ports and shipyards. To reduce the risk of grounding, it is recommended that shallow water navigation aids be improved.

The wave and motion determination process in shallow water is complex. Wave conditions are port dependent; each port must be individually studied for an accurate assessment. The most extreme CVN motions are generated from seal swells originating from storms hundreds of miles away; consequently, they are difficult to detect. Waves and swells are predicted from the Fleet Numerical Oceanographic Center or observed by the crew. Waves seen in or predicted for the open ocean may not be that which are experienced at any given port. Local land and bottom effects and changes due to wind, tides, and currents are not included.

This plan improves onboard shallow water navigation aids by:

(a) Providing a channel guidance system.
(b) Providing real time channel condition measurement.
(c) Improving ship's draft and attitude indication.
(d) Providing a load management system.

These systems and other supporting systems would be integrated as appropriate to facilitate overall functionality and minimize cost.

Channel Guidance System

NAVSEA has developed and tested an onboard CV Channel Guidance System (CVCGS). This system aids in the determination of under keel clearances and the probability of grounding while operating in ports. It is a PC computer program which calculates depth requirements based on data from the ship's force concerning load and trim conditions. Environmental conditions are down loaded from Fleet Numerical or input from the ship's navigator. Ship motions, under keel clearance, and probability of grounding predictions are then calculated for channel transits. The CVCGS has been validated by ship model tests and full scale wave measurements. This system will be sent to all CVs by the and of FY95.

Channel Condition Measurement

The Environmental Monitoring and Operator Guidance System {EMOGS) incorporates analysis capabilities of the CVCGS. However, instead of using predicted information from Fleet Numerical and the navigator, EMOGS uses real time wave and tide data from sensors installed in the channel. Because this is a far more accurate prediction of waves and variable water levels, substantial risk reductions are realized. The following table shows the accessibility levels of CVCGS and EMOGS associated with different dredge depths for San Diego and Mayport. An EMOGS type system is successfully being used by SUBLANT at Kings Bay, Georgia for SSBN 726 Class transits. EMOGS is recommended for channels not dredged for unrestricted operations and are subject to wave action, particularly swells. EMOGS is a facilities improvement cost tradeoff with dredging.

OUTER CHANNEL ACCESSIBILITY
FOR A RISK OF EXCEEDING DREDGE DEPTH 1 IN 100 TIMES

CHANNEL DEPTH (feet)	DAYS PER YEAR	
	CVCGS	EMOGS
SAN DIEGO:		
55	227	333
59	295	355
MAYPORT:		
47	254	262
50	362	363

Without guidance of any sort in avoiding extreme wave conditions, risk may increase to 1 in 2.

Draft and Attitude Indication

Currently, the CVN 68 Class only has one Remote Draft Indicator and list and trim inclinometers. The Profile Draft Indicator has been removed because it contained about a pint of mercury. Consequently, the ship does not have the ability to accurately determine the ship's draft, list, and trim. Installation of two more Remote Draft Indicators would provide the ability to triangulate accurate draft, list, and trim values. Based on simple geometry, the ship could then accurately determine the extreme draft point. A JCF and ECPs are being prepared to add two Remote Draft Indicators.

Load Management System

The CVN 68 Class carries roughly 20,000 tons of loads (aircraft, fuel, personnel, stores, etc.). There are some 415 tanks and voids and some 245 storerooms and magazines. The amount of material continuously being brought onboard, moved, and being consumed is large. Aircraft carrier operations require the flight deck to be as level as possible. There is a list control system to account for aircraft movement. A system similar to those used on tankers (commercial and AOEs) would provide the ship with a tool to better track and manage loads. This would enable the crew to minimize displacement list, and trim; thereby, minimize operational restrictions. A load Management system is being investigated by the CVN 76 IC effort.

APPENDIX F NOMOGRAPHS OF CVN 68 MOTION IN SHALLOW WATER

Background

Shallow water motion transfer functions where developed for the CVN 68 class ship to aid in predicting the ship's underkeel clearance for a variety of different entrance channels. The motion transfer functions were validated by model tests conducted at the US Army Corps of Engineers Waterways Experiment Station.

Description

The nomographs of CVN 68 motion in shallow water were developed by combining the shallow water motion transfer functions with a variety of wave and ship operating conditions. The waves used in calculating ship motions were developed to simulate the shallow water environments. The modal wave periods ranged from 6 to 14 seconds and the significant wave height ranged from 1 to 10 feet. The wave energy was spread using the idealized JONSWAP spectrum which is consistent with fetch limited conditions generally found in shallow water, and the energy was spread +/- 90^{o} to simulate shortcrested seas.

The ship operating conditions used for these nomographs were the following. The ship speeds were 6, 10, and 14 knots which covers most transit conditions for CVN 68 class ships. The ship-to-wave heading on the nomographs are head, bow, beam, quartering and following seas. Defining these headings, head seas are directly at the bow of the ship, bow seas are 45^{o} off the bow, beam seas are directly at the beam or side of the ship, quartering seas are 45^{o} off the stern, and following seas are directly off the stem.

The vertical motion and velocity at the bow and stern of the ship is calculated for each of these conditions. The extreme motion expected in 100 transits is then calculated from the vertical motion and velocity using a statistical formula generated by Ochi (1973). The largest resulting vertical motion is then used in the nomographs.

Reference

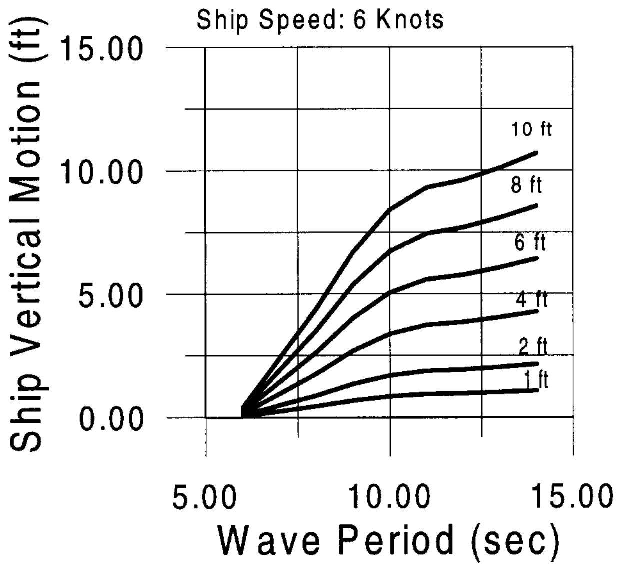
Ochi, M.K., "On Prediction of Extreme Values," Journal of Ship Research, Vol. 17 (1973).

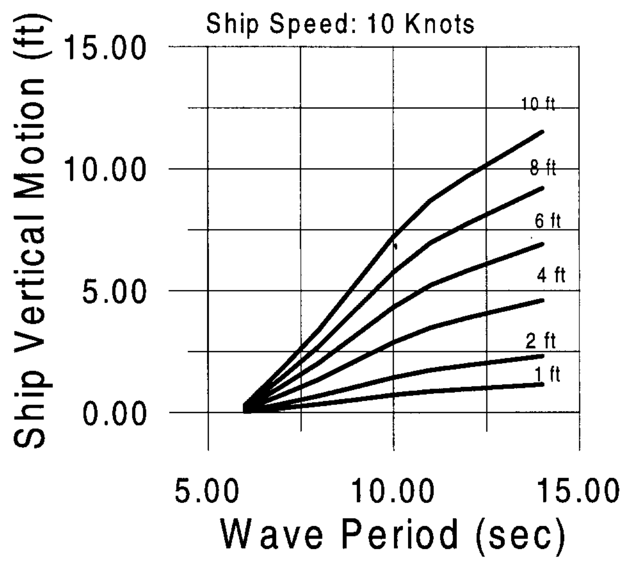
CVN 68 VERTICAL MOTION BY WAVE HEIGHT AND PERIOD

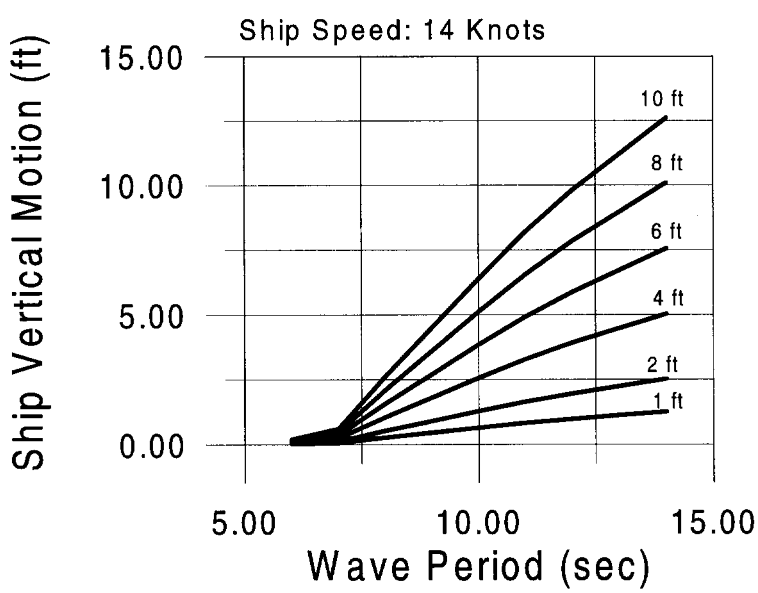
Vertical Motion Represents Extreme in 100 Transits

Curves represent significant wave height in feet

HEAD SEAS



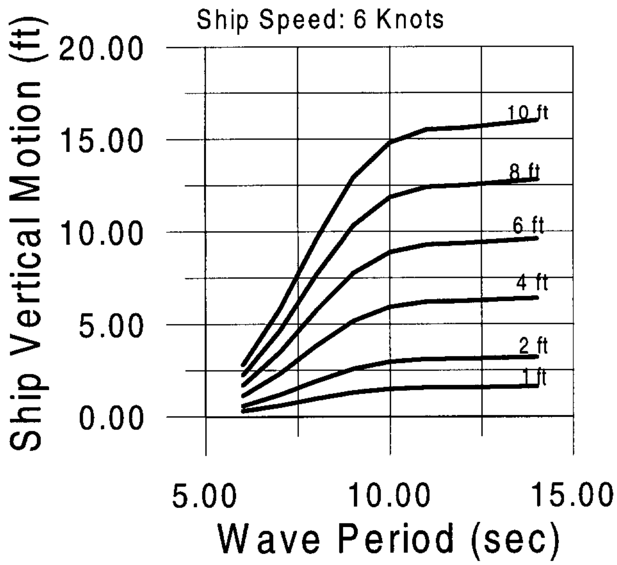


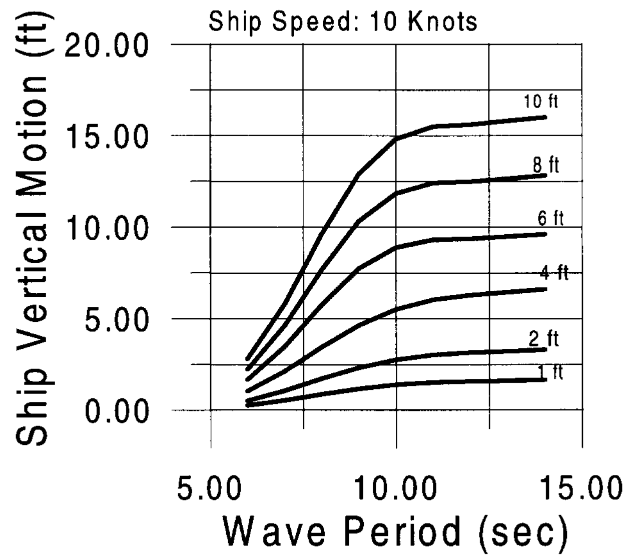


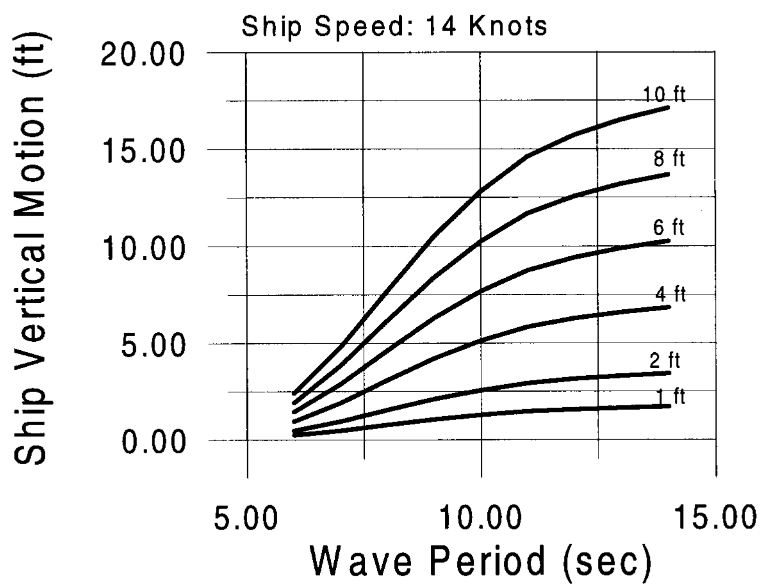
CVN 68 VERTICAL MOTION BY WAVE HEIGHT AND PERIOD

Vertical Motion Represents Extreme in 100 Transits
Curves represent significant wave height in feet

BOW SEAS





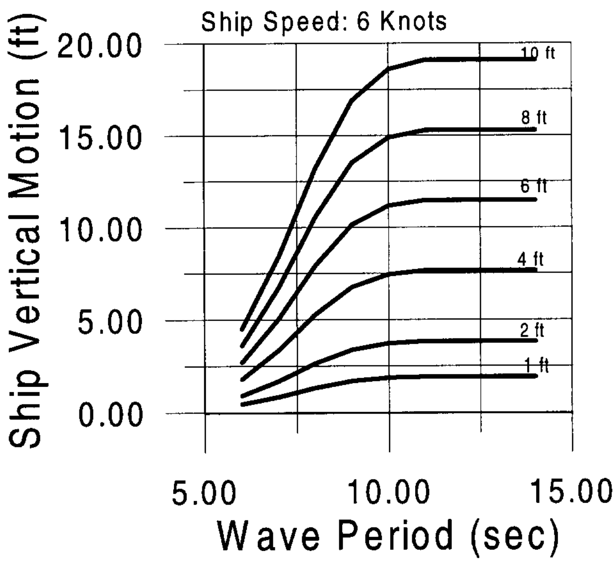


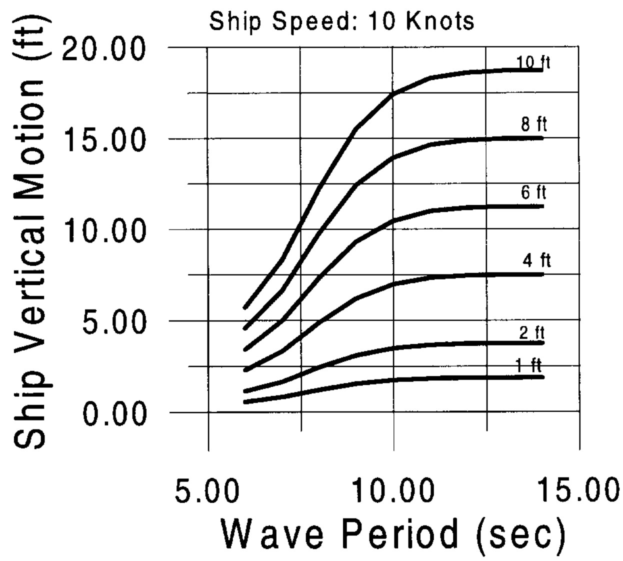
CVN 68 VERTICAL MOTION BY WAVE HEIGHT AND PERIOD

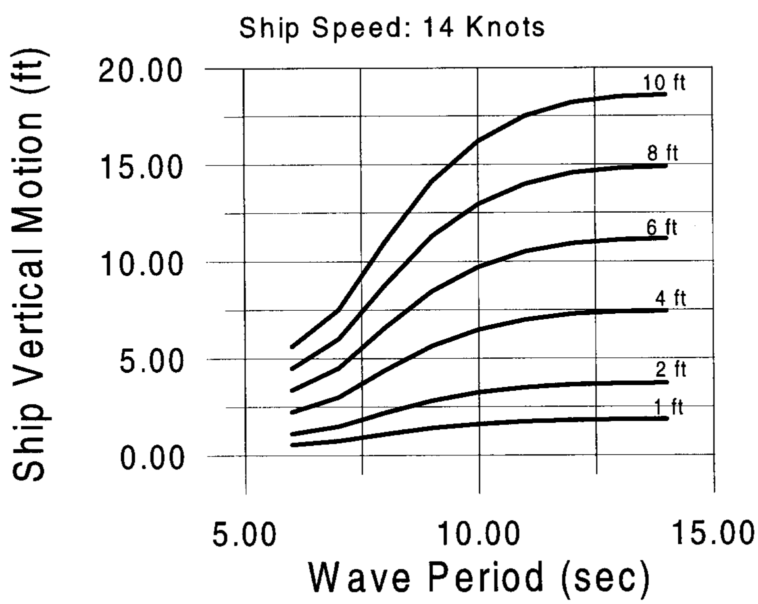
Vertical Motion Represents Extreme in 100 Transits

Curves represent significant wave height in feet

BEAM SEAS





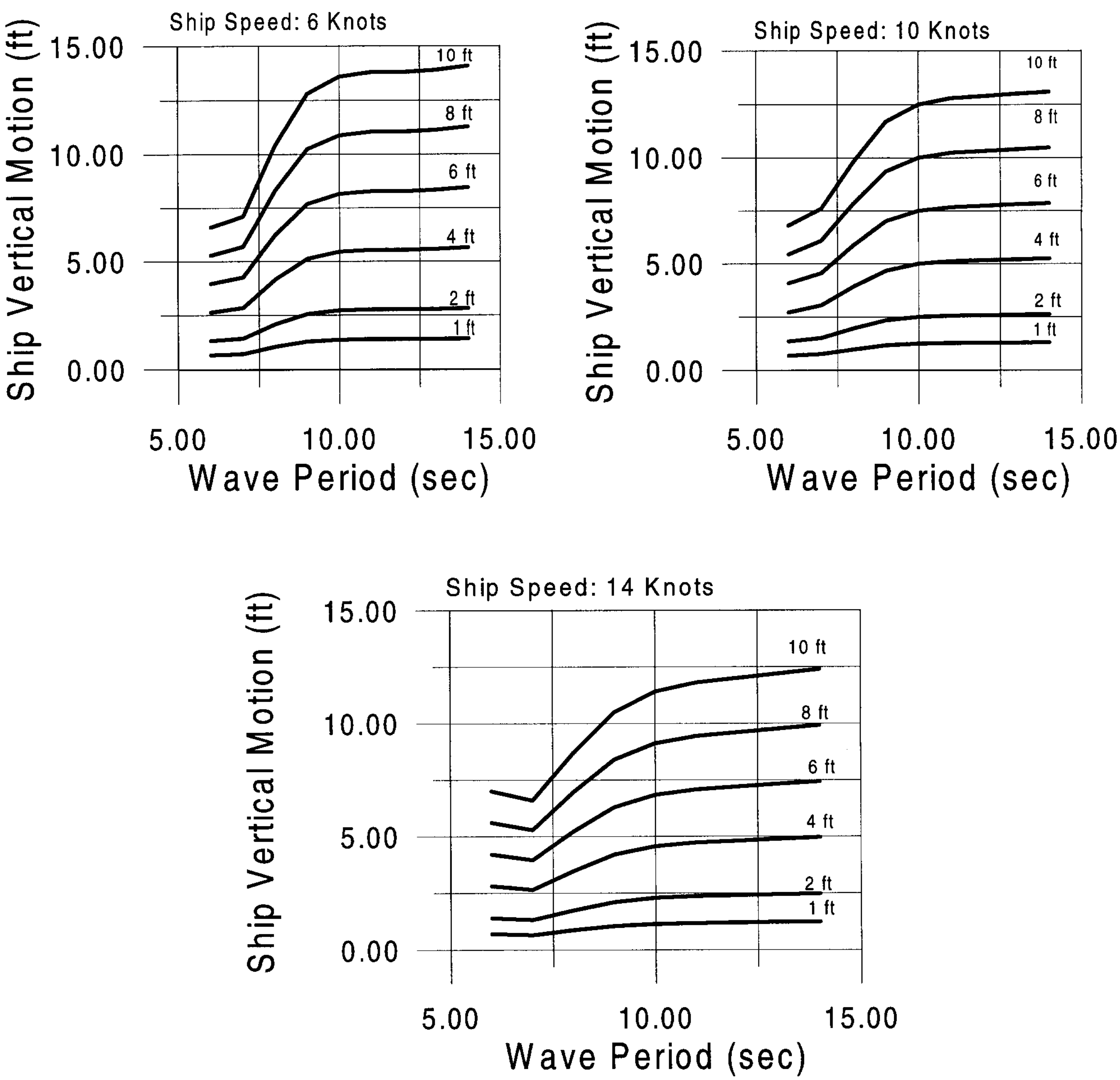


CVN 68 VERTICAL MOTION BY WAVE HEIGHT AND PERIOD

Vertical Motion Represents Extreme in 100 Transits

Curves represent significant wave height in feet

QUARTERING SEAS



CVN 68 VERTICAL MOTION BY WAVE HEIGHT AND PERIOD

Vertical Motion Represents Extreme in 100 Transits

Curves represent significant wave height in feet

FOLLOWING SEAS