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MILITARY STANDARD

BENDING OF PIPE OR TUBE FOR SHIP PIPING SYSTEMS

FSC 4710

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND

WASHINGTON, DC 20362

Bending of Pipe or Tube for Ship Piping Systems,

MIL-STD-1627B(SH)

1. This Military Standard is approved for use by the Naval Sea Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

2. For Naval activities, this document may be invoked upon receipt.

3. For contracts or acquisition orders which invoke MIL-STD-1627A(SHIPS) or NAVSHIPS 250-582, the contractor or vendor shall not use this standard without prior contractual approval.

4. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 3112, Department of the Navy, Washington, DC 20362 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

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1. This standard covers fabrication requirements and acceptance criteria for pipe bending.

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APPENDIX

1. SCOPE

1.1 Scope. This standard covers pipe bending, heat treatment, and inspection requirements and acceptance criteria for piping used for ships of the United States Navy.

2. REFERENCED DOCUMENTS

2.1 Issues of documents. The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of this standard to the extent specified herein.

SPECIFICATIONS

FEDERAL

WW-T-700 - Tube, Aluminum and Aluminum Alloy, Drawn, Seamless, General Specification For.
WW-T-700/1 - Tube, Aluminum, Drawn, Seamless, 1100.
WW-T-700/2 - Tube, Aluminum Alloy, Drawn, Seamless, 3003.
WW-T-700/4 - Tube, Aluminum Alloy, Drawn, Seamless, 5052.
WW-T-700/5 - Tube, Aluminum Alloy, Drawn, Seamless, 5086.

MILITARY

MIL-P-1144 - Pipe, Corrosion-Resistant, Stainless Steel, Seamless or Welded.
MIL-T-1368 - Tube and Pipe, Nickel-Copper Alloy, Seamless and Welded.
MIL-T-15005 - Tubes, 70-30 and 90-10 Copper Nickel Alloy, Condenser and Heat Exchanger.
MIL-T-16286 - Tube, Steel, Seamless, Marine Boiler Application.
MIL-T-16420 - Tube, Copper-Nickel (70-30 and 90-10), Seamless and Welded.
MIL-T-17188 - Tube, Carbon Steel, Electric Resistance Welded, Marine Boiler.
MIL-T-18165 - Tube and Pipe, Chromium-Molybdenum Alloy Steel, Seamless.
MIL-T-20155 - Tubing, Steel, Alloy, Molybdenum, Seamless.
MIL-T-20157 - Tube and Pipe, Carbon Steel, Seamless.
MIL-T-20168 - Tubes, Brass (Red Brass), Seamless.
MIL-T-23226 - Tube and Pipe, Corrosion-Resistant Steel, Seamless.
MIL-T-23227 - Tube and Pipe, Nickel-Chromium-Iron Alloy.
MIL-T-23520 - Tube and Pipe, Nickel-Copper Alloy, Seamless Air Melted.
MIL-T-24107 - Tube, Copper (Seamless) (Copper Numbers 102, 103, 108, 120, 122, and 142).
MIL-P-24338 - Pipe, Carbon Steel, Seamless.

STANDARDS

MILITARY

MIL-STD-271 - Nondestructive Testing Requirements for Metals.
MIL-STD-278 - Fabrication Welding and Inspection; and Casting Inspection and Repair for Machinery, Piping and Pressure Vessels in Ships of the United States Navy.

PUBLICATIONS

NAVSEA 250-1500-1 - Welding Standard.
NAVSEA 0900-LP-001-7000 - Fabrication and Inspection of Brazed Piping Systems.
NAVSEA OD 45845 - Metrology Requirement List (METRL).

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

A 53 - Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless.
A 106 - Seamless Carbon Steel Pipe for High-Temperature Service.
A 213 - Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes.
B 167 - Nickel-Chromium-Iron Alloy (UNS N06600) Seamless Pipe and Tube.
B 444 - Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625) Seamless Pipe and Tube.

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. DEFINITIONS

3.1 Activity. The organization under the same quality assurance management performing work to which this standard is applicable.

3.2 Approved (approval). The item under consideration has been accepted by the authorized representative of the Commander, Naval Sea Systems Command (NAVSEA) (includes Naval Ship Systems Engineering Station (NAVSSES), Philadelphia, Supervisors of Shipbuilding, Conversion and Repair, and Naval Shipyard or Activity Commanders). Unless otherwise specified, approved as used herein shall be by the authorized representative.

3.3 Authorized representative. Any Government representative specifically authorized to approve equipment, material, or procedures within the scope of this document for NAVSEA. They are as follows:

(a) For Government shipyards: The delegated representative of the Shipyard Commander.

(b) For Commercial shipyards: The delegated representative of the Supervisor of Shipbuilding, Conversion and Repair (SUPSHIP), or the American Bureau of Shipping when specified in the Ship's Specifications for a particular ship. This includes all applicable areas in the shipyard and applicable items furnished to the shipyard by subcontractors.

(c) For Government purchase items: The delegated representative of the Commanding Officer, NAVSSES, Philadelphia or of the Officer in Charge, NAVSSES Detachment, Mechanicsburg, or of the Officer in Charge, NAVSSES Detachment, Norfolk.

(d) When delegated by (a), (b) or (c) above, the representative of the Defense Contract Administration Services Management Area (DCASMA).

(e) Technical representative specifically authorized by NAVSEA.

3.4 Backwall or pipe heel. The outer half or the half of the pipe undergoing tension during bending.

3.5 Bend radius. The radius from the center of curvature to the centerline (axis) of the pipe, expressed as a number multiplied by the pipe or tube size. For example, the bend radius of a 5D bend for a 2-inch nominal pipe size (nps) pipe or a 2-inch tube is 10 inches.

3.6 Bending procedure. A written pipe bending procedure containing all the essential elements and guidance information necessary to produce pipe bends which meet the requirements of this standard.

3.7 Buckles and bulges. A wavy condition which may form on the pipe throat surface during the bending operation.

3.8 Cold bending. The bending of pipe at any temperature at which strain hardening occurs (see table II).

3.9 Crack. A linear crevice, fissure, rupture, or fracture of the pipe surface.

3.10 Dent. A depression in the contour of the pipe surface.

3.11 Flatness. An area on the pipe surface having no curvature.

3.12 Gouge. A groove, cavity, or scooped out area on the pipe surface produced by a sharp object or abrasive.

3.13 Hot bending. The bending of pipe at a temperature at which strain hardening does not occur (see table II).

3.14 Hump. A rounded protrusion or bulge on the backwall or heel of the pipe bend caused by the improper placement of the bending mandrel.

3.15 Internal support. Rigid or flexible mandrels, silica sand, or low melting alloys used to support the inside of the pipe during bending.

3.16 Linear indication. An indication greater than 1/16-inch long, revealed by nondestructive inspection, whose length is equal to or greater than three times its width.

3.17 Local Government representative. The representative of the Government agency having cognizance of inspection at the place of bending or such other location where the workpiece requires inspection.

3.18 Minimum design wall thickness. The wall thickness specified on the fabrication drawing or computed in accordance with the applicable shipbuilding specification as the minimum acceptable for the temperature and pressure application, whichever is greater.

3.19 Pipe. The term "pipe" shall be assumed to mean "pipe or tube", in accordance with the nomenclature set forth by the material specification.

3.20 Pipe ratio. The ratio of the pipe outside diameter (D) to its wall thickness (t), i.e., D/t.

3.21 Procedure qualification. The term "procedure qualification" means a bending procedure which meets the requirements of and is evaluated in accordance with this standard.

3.22 Qualified. The term "qualified" means that the item under consideration has been approved as required by this standard.

3.23 Step. A round bottomed crease on the throat of a pipe bend caused by the lack of, or improper spacing of the wiper die during the bending operation.

3.24 Throat. The inner half or the half of the pipe undergoing compression during bending.

3.25 Wrinkles. Definite folds, creases, or crinkles formed on the surface of the pipe during bending operations.

4. GENERAL REQUIREMENTS

4.1 Responsibilities. Each organization performing work in accordance with this standard shall be responsible for conformance to the requirements contained herein.

4.2 Applicability. This standard shall be used when referenced in the applicable shipbuilding specification, fabrication document, fabrication drawing, contract, or equipment specification.

4.3 Maintenance of records. Unless otherwise specified by NAVSEA, required records shall be maintained by the organization performing the work and be available to the authorized representative throughout the life of the contract and for a period of 3 years after delivery. At the expiration of the record retention period, NAVSEA or its authorized representative shall be furnished written notification. Disposition of records shall be as agreed upon by NAVSEA and the contractor.

4.4 Material. Base material shall conform to the applicable contract, shipbuilding or equipment specifications. A list of generally used piping or tubing materials, arranged in groups in accordance with their composition, are specified in table I.

TABLE I. Grouping of base material.

Material	Group No.	Applicable document	Class or type
Carbon steel	S-1	ASTM A 53	Pipe (seamless or welded)
		MIL-T-16286	Tube, seamless, class a
		MIL-T-17188	Tube, welded
		MIL-T-20157	Tube and pipe
		MIL-P-24338	Pipe, carbon steel, seamless
		ASTM A 106	Pipe, seamless, grade B
Alloy steel	S-3	MIL-T-16286	CMo class d (tube)
		MIL-T-20155	CMo (tube and pipe)
	S-4	ASTM A 213	CrMo grade T11
		MIL-T-16286	CrMo class f (tube)
		MIL-T-18165	CrMo class 1 (tube and pipe)
	S-5	MIL-T-16286	CrMo class e (tube)
		MIL-T-18165	CrMo class 2 (tube and pipe)
Corrosion-resistant steel	S-8	MIL-P-1144	304, 316, 321, 347, 304L, 316L
		MIL-T-16286	Class c (tube seamless)
		MIL-T-23226	304, 304L, 347, 348 (tube and pipe)

TABLE I. Grouping of base material. - Continued

Material	Group No.	Applicable document	Class or type
Aluminum alloy	S-21	WW-T-700	---
		WW-T-700/1	1100 (tube, drawn, seamless)
		WW-T-700/2	3003 (tube, drawn, seamless)
	S-22	WW-T-700/4	5052 (tube, drawn, seamless)
		WW-T-700/5	5086 (tube, drawn, seamless)
Copper	S-31	MIL-T-24107	Copper tube (seamless)
Brass	S-32	MIL-T-20168	Brass pipe
Copper-nickel	S-34	MIL-T-15005	70-30, 90-10 (tube)
		MIL-T-16420	70-30, 90-10 (tube)
Nickel-copper	S-42	MIL-T-1368	NiCu (tube)
		MIL-T-23520	NiCu (tube or pipe)
Ni-Cr-Fe	S-43	MIL-T-23227	Tube and pipe
		ASTM B 167	Tube and pipe
Ni-Cr-Mo-Cb		ASTM B 444	Tube and pipe

4.4.1 Material quality. Prior to bending, pipe materials shall have been given the required visual examination and nondestructive inspection in accordance with the applicable material specifications.

4.4.1.1 Base material condition. Prior to bending, the base material in the vicinity of the bend shall be in the following conditions:

Material (see table I)	Condition (see table IV)
S-1	Stress relieved, annealed, normalized, or normalized and tempered.
S-3, S-4, S-5	Annealed, normalized and tempered, or quenched and tempered.
S-8, S-21, S-22, S-31, S-32, S-34, S-42, S-43	Annealed.

4.4.1.2 Base material cleanliness. Prior to bending, the pipe surfaces, inside and outside, shall be clean and free of foreign matter which may result in nicks and gouge marks on the bent pipe surface.

4.4.2 Wall thickness. Pipes selected for bending shall have sufficient actual wall thickness to assure that the backwall meets the minimum design thickness (Tm) or the minimum required thickness in the applicable ship-building or component specification. In addition, backwall thinning shall not exceed 20 percent from the actual prebend pipe wall thickness. The 20 percent backwall thinning limit does not apply to copper and brass tubes.

4.4.3 Surface condition. The surfaces to be bent shall not have any dents, nicks, or gouges in excess of that permitted by this standard (see section 7).

4.5 Lubricants. Lubricants shall be used in bending operations to prevent galling of the pipe material during bending and to prevent rapid wear of the die. Lubricants shall be easy to remove after bending and shall not stain the pipe. A lubricant that works effectively on one pipe material may not be effective for another. Mineral oils and organic fats, such as lanolin, are commonly used lubricants. Examples of acceptable lubricants are lanolin, lard oil, viscous oils, and soap solutions. Lubricants shall have good surface adhesion and film strength at bending temperatures.

4.5.1 Unacceptable lubricant ingredients. Use of lubricants containing the following ingredients are not permitted:

(a) Lubricants containing sulfur or chlorine shall not be used on group S-8, S-31, S-32, S-34, S-42, and S-43 materials.
(b) Carbonaceous lubricants shall not be used on group S-8 materials.
(c) Lubricants containing halogens, arsenic, bismuth, copper, phosphorus, sulfur, tin, lead, cadmium or zinc in excess of 250 parts per million (p/m) total halides or 250 p/m of individual elements shall not be used on material intended for service at temperatures exceeding 400°F.

4.5.2 When mandrels are used, the pipe outer and inner surfaces shall be lubricated prior to bending. Tools in sliding contact with the pipe shall be lubricated prior to the start of the bending operation. Adequate lubrication shall be applied to aluminum alloys due to their tendency to gall with the mandrels. The wiper die, pressure die, and outer surface of the pipe should be coated with a light lubricant due to their close fit. Inadequate lubrication may result in bend failures.

4.6 Equipment.

4.6.1 Maintenance of equipment. Bending equipment shall be free of conditions which could result in tool marks, gouges, or scratches on pipe surfaces, exceeding the acceptable criteria of this standard.

4.6.2 Bending machines. Pipe bending may be performed on the following types of standard bending equipment:

(a) Ram type bending machine.
(b) Roll type bending machine.
(c) Compression type bending machine.
(d) Rotary type bending machine.
(e) Rotary type bending machine with a booster unit.
(f) Portable manual bending machine.

The selection of the type of bending machine that is to be employed is dependent on the bend radius and quality of the bend required. The ram and roll type bending machines may be employed where the bend radius required is large and high production rates are not required. When higher quality bends and smaller bend radii are required, the rotary or compression type bending machines should be employed. Rotary type bending machines with a booster unit should be employed when a bend radius equal to or less than 3D is required. Portable manual editions of some of the bending machines listed above may be employed when the energy required to make the bends is determined to be adequate.

4.6.2.1 Ram type bending machine. Ram type bending machines consist of a bending die mounted on a ram and two pivoted pressure dies. The pipe is bent by the bending die, pushing the pipe between the pressure dies, which wraps the pipe around the bending die as shown on figure 1. The force to push the bending die is usually supplied by a hydraulic ram or a press. The bend in a ram type bending machine is limited to 120 degrees and the bend radius should be at least 6D.

4.6.2.2 Roll type bending machine. Roll type bending machines consist of three properly spaced rolls. The method of bending pipe by this machine is shown on figure 1. Bend angles of 360 degrees can be obtained on this type of bending machine with a minimum bend radius of approximately 6D on unfilled pipes.

4.6.2.3 Compression type bending machine. The compression or stationary-die type bending machine consists of a stationary bending die, clamping block, and movable pressure die. The pipe is bent by clamping one end of the pipe to the bending die and the pressure die moves around the bending die, forcing the pipe into the bending die groove as shown on figure 1. The maximum angle of bend that can be produced is 180 degrees. This type of a bending machine is not recommended for pipe ratios greater than 30.

4.6.2.4 Rotary type bending machine. The rotary type or drawn bending machine is recommended for obtaining quality pipe bends up to 180 degrees. The machine consists of a rotating bending die, clamping block, wiper die and sliding or stationary pressure die. The method of bending is shown on figure 1 and described in 4.6.2.4.1 through 4.6.2.4.4. The maximum angle of bend is 180 degrees.

4.6.2.4.1 Clamping block. The clamping block holds the end of the pipe to the bending die with sufficient force to keep it from moving while it is being bent around the die. The groove surfaces of the clamping block need not be smooth and polished, unless it is detrimental to the finished product surface

finish requirements. When the groove surfaces of the clamping block are required to be smooth or polished, the clamping length of the pipe should be increased to distribute the higher clamping forces required. Resin or emery cloth may be employed in the clamping block to avoid slippage. When short clamping length must be employed, the end of the pipe should be plugged to avoid flattening by the clamping forces.

4.6.2.4.2 Bending die. The bending die rotates around a pivot and pulls or draws the pipe around it. The bending die also supports the inner half or throat of the pipe bend.

4.6.2.4.3 Pressure die. The pressure die presses the pipe into the groove of the bending die. The pressure die also supports the outer half or heel of the pipe bend. The pressure die may be stationary or slide with the pipe. The sliding type is preferred because it distributes the applied stresses more evenly.

4.6.2.4.4 Wiper dies. The wiper die is stationary and opposite the pressure dies. The wiper die supports the inner half of the pipe and keeps the pipe throat from wrinkling. When a wiper die is employed, the gap between the wiper die and bending die can be critical in avoiding steps in the throat of the pipe bend.

4.6.2.5 Rotary type bending machine with a booster unit. This machine is essentially the rotary type bending machine with the force being applied to the straight end of the pipe. This force reduces the pull on the pipe to bend it around the bending die as shown on figure 1. Booster unit enables smaller radius bends to be made on the pipe.

4.6.2.6 Internal support. A method for internally supporting pipe is usually required when bending to small radii or when bending pipes with a pipe ratio greater than 30. Internal supports are used to support the inside of the pipe during bending to prevent it from flattening and wrinkling. The minimum bend radius that a pipe can be bent without internal support is dependent on the pipe ratio. The greater the pipe ratio, the greater the minimum bend radii that will require internal support. The types of internal support normally employed in pipe bending are rigid mandrels, flexible mandrels, and loose fillers. The type of internal support that is to be employed is dependent on the pipe ratio, bending radius, and amount of out-of-roundness that is allowable. When employed, internal supports shall be inserted prior to the beginning of the bending operation. Internal supports do not correct flattening or wrinkling that has already occurred.

4.6.2.6.1 Loose fillers. Loose fillers, such as silica sand and approved low-melting material (such as rosin) may be employed for internal support when mandrels are not available or practicable. Low-melting rosin, melting at temperatures not to exceed 400°F, shall be used for bending at ambient temperature. Removal of rosin by direct torch heating shall be limited to 400°F. Silica sand used for high temperature bending shall be dry. The sand should be 91 percent minimum silica, containing no nonferrous contaminants and have a fineness sufficient to yield a surface which meets specification requirements. Sand previously used in nonferrous pipes shall not be used in ferrous pipes and vice versa. A guide as to when internal support may be needed is shown on figures 2 and 3.

4.6.2.6.1.1 Filling the pipe prior to heating. One pipe end shall be closed off and the pipe filled with sand. Care shall be taken to insure that the sand is dry, otherwise internal pressure will build-up during heating and may be detrimental to the bending operation. The sand shall be tamped or the pipe vibrated to ensure that the sand is packed tightly. Then the second end shall be closed off.

4.6.2.6.2 Rigid mandrels. Rigid mandrels consist of the plug or formed type and are shown on figure 4. The mandrel is held in a fixed position and the pipe is pulled over it. This work hardens the backwall of the pipe which increases its resistance to flattening. The pulling force of the pipe acting on the mandrel tip holds the mandrel and the pipe in the groove of the bending die and prevents the inner wall from wrinkling. The placement of the rigid mandrel in the pipe is important to achieve a satisfactory pipe bend. The largest diameter portion of the mandrel should extend a short distance into the bend as shown on figure 4. If the mandrel extends too far into the bend it can cause a bulge or hump in the backwall of the pipe. If the mandrel does not extend in far enough, flattening of the pipe and wrinkling and bulging of the throat of the pipe bend can occur. The clearance between the rigid mandrel and the pipe should not exceed 20 percent of the wall thickness. If the mandrel is too tight, the pipe may rupture in the bend. Mandrels shall be lubricated.

4.6.2.6.3 Flexible mandrels. Flexible mandrels consist of one or more balls attached to a rigid mandrel. Flexible mandrels extend further into the bend and should be employed in small radii bending operations that require more support. Flexible mandrels are held in a fixed position similar to that for the rigid mandrels. The flexible mandrels and their positions are shown on figure 5. Flexible mandrels shall be lubricated and require an apparatus to remove them from the bent pipe. Clearance between the mandrel and the pipe wall should range from 0.001 inch to 0.095 inch. The maximum clearance for pipe ratios greater than 30 should be 10 percent of the wall thickness. The higher quality bends will have the closest fit. Flexible mandrels shall be made of heat-treated tool steel, ground and polished to prevent marring the inside surface of the pipe. Chromium-plated carbon steel mandrels may also be used; however, areas that display loose or flaked plating shall be immediately replated. For corrosion-resistant steel, Cu-Ni, Ni-Cu, or Ni-Cr-Fe pipes, mandrels made of aluminum bronze may also be used.

5. BENDING REQUIREMENTS

5.1 Bending procedures. Prior to performing production bending, each organization shall prepare detailed written bending procedures based on the requirements and acceptance criteria of this standard (see appendix). The procedures shall include the following information:

(a) Base material type, pipe size and wall thickness.
(b) Pre-bending preparations (see 4.4.1 and 4.4.1.1).
(c) Bend radius.
(d) Bending temperature range.
(e) Type of bending machine.
(f) Type of lubricant.

(g) Bend angle adjustment procedure, where applicable.
(h) Out-of-round and buckling repair procedures.
(i) Post bending heat treatment, as applicable.
(j) Post bending cleaning requirements.
(k) Inspection requirements and acceptance standards.

5.2 Bending criteria. Unless otherwise approved by NAVSEA, piping shall not be bent to a radius less than 2D, except that S-31 and S-32 (copper and brass) materials may be bent to 1.5D.

5.3 Bending procedure qualification. When pipe is bent to a radius of less than 5D, each organization shall qualify its procedure by performing test bends for each of the following groups of material:

(a) S-1, S-3, S-4, and S-5 (carbon and alloy steel).
(b) S-8 (CRES).
(c) S-21, S-22 (aluminum alloy).
(d) S-31, S-32 (copper, brass).
(e) S-34, S-42, S-43, (Cu-Ni, Ni-Cu, Inconel).

Qualification of any material in a group qualifies for all materials within that group. Qualification of a bend to a radius of less than 5D qualifies for all bends intermediate to that radius and 5D.

5.3.1 Test specimens. Test specimens for bending procedure qualification shall be as follows:

(a) Qualification up to 6 inches nps: Two 90 degree bends each consisting of one thickest and one thinnest wall thickness pipe used in production, on 1 inch nps and 6 inches nps pipes (or the largest production pipe less than 6 inches nps).

(b) Qualification over 6 inches nps: Two 90 degree bends for each nps size, consisting of one thickest and one thinnest wall thickness pipe used in production.

5.3.2 Production bends as qualification test. At the option of the activity, two production bends which represent the smallest radius bend for the system may be used as qualification test. In this case, qualification applies to that particular size and wall thickness only; however, the qualification applies to all material within that group.

5.3.3 The test bends shall meet the requirements of sections 4 and 7.1 through 7.9.

5.4 Qualification test approval. The qualification test report (see appendix) shall be submitted to the authorized representative for approval and the bending procedure submitted for information. A copy of the qualification test report and the bending procedure shall be submitted to NAVSEA for information.

5.4.1 The qualification test report shall include the following test data:

(a) Magnetic particle or liquid penetrant inspection, as applicable.
(b) Wall thickness survey.
(c) Out-of-round measurements.
(d) Bending quality (such as buckles and waviness in bending).
(e) Description of repairs, if performed.
(f) Description of post bending heat treatment, if performed.

5.4.2 Special requirements. Depending on the application of the proposed procedure or the bend radius used, NAVSEA or its authorized representative may request that additional tests be performed to supplement the qualification tests.

5.4.3 Vendor qualification. It shall be the responsibility of each activity to assure that all sub-contractors have procedures based on this standard or have procedures qualified and approved in accordance with 5.3.

5.4.4 Waiver of qualification test. Qualification tests for bending pipe, where the possible failure of the pipe is remote and would not endanger the ship or equipment, may be omitted provided this omission is permitted by the applicable fabrication document or is approved in writing by the authorized representative.

5.4.5 Transferral of qualification. Qualification shall not be transferred from one activity to another activity.

5.4.6 Alternative procedures. Procedures contained in NAVSEA technical manuals may be used when authorized by the applicable contract, equipment, or shipbuilding specification without requalification.

5.4.7 Previously qualified procedures. Procedures previously qualified shall not require requalification.

5.5 Bending temperature. Pipe bending may be accomplished "cold" or "hot", except as prohibited in table II or by fabrication drawings or specifications. The "cold" or "hot" bending temperatures shall be as specified in table II.

TABLE II. Cold and hot bending temperatures.

Material	Group No.	Cold bending (°F maximum)	Hot bending (°F)
Carbon steel	S-1	1150	1650 - 1850
Alloy steel	S-3 S-4, S-5	900 900	1650 - 1900 1700 - 1950
Corrosion-resistant steel	S-8	1/ 800	
Aluminum alloy	S-21 S-22	400 500	500 - 800 600 - 800
Copper	S-31	400	800 - 1600
Brass	S-32	500	800 - 1650
Copper-nickel	S-34	1/ 400	
Nickel-copper	S-42	1/ 900	
Ni-Cr-Fe and Ni-Cr-Mo-Cb	S-43	1/ 1000	

1/ These materials shall be cold bent only.

5.6 Material control. The following material controls shall be required:

(a) For corrosion-resistant steel pipes: The silica sand used shall be clean and dry, and shall not be used for purposes other than filling corrosion-resistant steel pipes. Hand tools that come in contact with the corrosion-resistant steel pipe shall be either corrosion-resistant steel or rust free ferrous tool steel and shall not be used on material other than corrosion-resistant steel. Resin shall not be used for pipe filling.

(b) For carbon and alloy steel pipes: The silica sand shall be clean and dry and shall not be used for purposes other than filling ferrous pipes. Resin shall not be used for pipe filling. Galvanized parts, bronze or lead tools shall not be used or come in contact with the pipe.

(c) Nonferrous pipes: The silica sand shall be clean and dry and shall not be used for purposes other than filling nonferrous pipes. Galvanized parts or lead tools shall not come in contact with the pipe.

5.7 Bending of longitudinally welded pipes. When bending longitudinally welded pipes, the weld shall not be located in any of the principal axes as shown on figure 6. Preferably, the weld should be located 60 ± 15 degrees from the back arc of the bend.

5.8 Heating of pipes. The pipe shall be heated by furnace, induction heating, or by gas torch only long enough to obtain the desired bending temperature throughout the section to be bent. The fuel used in heating shall not contain more than 30 grains of total sulfur per 100 cubic feet of gas. The atmosphere or type of flame during heating shall be slightly reducing for all materials except corrosion-resistant steels. Corrosion-resistant steels require a slightly oxidizing atmosphere or flame.

5.8.1 Torch heating. Every precaution shall be taken to ensure gradual heating of the section and that it is within the temperature range specified. Sweeping motions of the torch shall be employed to avoid local overheating in any location. In general, heating of pipes by torch should not be attempted for pipes greater than 3.50 inches nps. However, local heating of larger pipe sizes to keep the pipe at a desired temperature during bending is permitted.

5.8.2 Temperature measurements during heating and bending. Optical or contact pyrometers shall be employed to check temperatures during heating, to prevent overheating, and during bending to ensure bending in the specified temperature range. Temperature indicating crayons that contain no halogens, arsenic, bismuth, copper, phosphorous, sulfur, tin, lead, cadmium, or zinc, in excess of 250 p/m total halides or 250 p/m of individual elements may also be employed.

5.8.3 Adjustments and corrections. Bend angles, out-of-round, and correctable buckling or other surface irregularities may be adjusted or corrected at the original bending temperature or at any temperature within the range of "cold" or "hot" bending as applicable (see table II). When post bending heat treatment is required, it shall conform to the requirement specified (see table III) for bends less than 3D.

5.8.3.1 Bend adjustment in the closing direction. Bend angle may be adjusted in the closing direction to any degree. Post bending heat treatment is not required unless the bend requires post bending heat treatment. Adjustment made after post bending heat treatment need not be re-heat treated if the adjustment did not exceed 10 degrees.

5.8.3.2 Bend adjustment in the opening direction. Bend angle may be adjusted once in the opening direction. The adjustment shall not exceed 10 degrees. Post bending heat treatment is not required unless the bend requires post bending heat treatment. For adjustments greater than 10 degrees, the pipe shall be restored to the pre-bending condition in accordance with 4.4.1.1 before the adjustment.

5.8.3.3 Reverse bending. Reverse bending, after the pipe has been adjusted in the opening direction, is not permitted unless the pipe is removed from the bending machine and restored to its pre-bending condition in accordance with 4.4.1.1.

5.8.3.4 Corrections for out-of-round, buckles, bulges, and dents. Excessive out-of-round may be corrected. Post bending heat treatment is not required unless the bend itself requires it. Correction of buckles, bulges and dents may be accomplished cold by the use of curved face or broad face hammers or by hammer and flatter provided that the corrections do not produce dents or peen marks which are not in accordance with 7.3, 7.6 and 7.7.

5.9 Marking. Marking of pipe for identification purposes shall not be applied on any area within the pipe bend.

6. POST BENDING HEAT TREATMENT REQUIREMENTS

6.1 General. Unless otherwise approved by NAVSEA or its authorized representative, post bending heat treatment shall be performed as specified in 6.2 through 6.6.5. Post bending heat treatment is performed to restore ductility, improve corrosion-resistance, or reduce peak stresses.

6.2 Cleaning prior to heat treatment. The bent pipe shall be cleaned to remove all of the lubricants and filler material prior to heat treating in accordance with section 8.

6.3 Post bending heat treatment. The post bending heat treatment required and the heat treating temperatures shall be as specified in tables III and IV. If a post bending heat treatment other than that required in this section is specified in an applicable system or component specification, it shall apply.

TABLE III. Post bending heat treatment. 1/

Material group	Bend radii	Bending temperature	Post bending heat treatment
S-1, S-3, S-4, S-5	5D and over	Cold	None 2/ and 3/
	3D to less than 5D	Cold	Stress relieve
	2D to less than 3D	Cold	Anneal or normalize and temper
	2D and over	Hot	None
S-8, S-34	2D and over	Cold	None
S-21, S-22, S-42, S-43	3D and over	Cold	None
	2D to less than 3D	Cold	Anneal
	2D and over	Hot 4/	None
S-31, S-32	1-1/2D and over	Cold	None
		Hot	None

Footnotes at top of next page.

1/ Material condition prior to bending shall be in accordance with 4.4.1.1.

2/ Carbon steel with wall thickness 3/4 inch and over shall be stress relieved.

3/ Alloy steel with wall thickness 1/2 inch and over or pipe sizes 4 inches and over shall be stress relieved.

4/ Aluminum alloys (S-21, S-22) only may be hot bent. Alloys S-42 and S-43 shall be cold bent.

TABLE IV. Prebending and postbending heat treatment temperatures and mode of cooling. 1/

Material group	Stress relieve °F	Anneal °F	Normalize °F	Temper °F
S-1	1100 - AC	1600 - FC	2/1675 - AC	1200 - AC
S-3	1100 - AC	1600 - FC	1700 - AC	1200 - AC
S-4	1300 - AC	1600 - FC	1675 - AC	1325 - AC
S-5	1350 - AC	1600 - FC	1650 - AC	1350 - AC
S-β		1900 - WQ		
S-21, S-22		3/650 - AC		
S-31, S-32		800 - AC		
S-34		1300 - WQ or AC		
S-42		1450 - AC		
S-43		1850 - AC		

Note: AC = Air cool; FC = Furnace cool; WQ = Water quench.

1/ Temperature tolerance shall be plus or minus 25°F. The holding time at temperature shall be 1 hour per inch of material thickness but shall be not less than 1/2 hour.

2/ Tempering is required if carbon content exceeds 0.30 percent.

3/ 750°F for 3003 aluminum alloy.

6.4 Post bending heat treatment procedures (furnace).

6.4.1 Loading temperature. The furnace temperature shall not exceed 600°F at time the bent component is placed in it.

6.4.2 Rate of heating. The rate of heating above 600°F shall be not greater than 400°F per hour.

6.4.3 Holding temperature and time. The bent pipe shall be heated to the specified temperature. The holding times shall be 1 hour per inch of maximum thickness with a minimum of 1 hour for pipe sizes 4.500 inches and above and 30 minutes for pipe sized below 4.500 inches. During the holding period the temperature differential between the highest and lowest reading of the bent component shall not exceed 75°F.

6.4.4 Preventing oxidation, distortion, and embrittlement. During the heating and holding periods, the furnace atmosphere shall be controlled to minimize surface oxidation and embrittlement. The furnace atmosphere shall be sulfur-free. A slightly reducing furnace atmosphere is recommended for all materials except corrosion-resistant steels. A slightly oxidizing furnace atmosphere shall be employed for corrosion-resistant steel. The flame shall not impinge directly on the bent component surface. Support shall be provided for the bent component, to minimize distortion.

6.4.5 Rate of cooling. The mode of cooling from the holding temperature shall be as specified in table IV. When furnace cooling is specified, the rate of cooling above 600°F shall be not greater than 200°F per hour.

6.4.6 Quenching. Where water quenching is specified, the quenching shall be accomplished immediately (less than 10 seconds) after the pipe is removed from the furnace.

6.5 Post bending heat treatment procedures (localized area).

6.5.1 Applicability. Unless otherwise approved by the authorized representative, local post bending heat treatment shall not be performed on group 3-3, S-4, S-5, S-8, or S-43 base materials.

6.5.2 Heating method. Post bending heating shall be accomplished by the use of electric inductance or electrical resistance devices, or other approved local heating methods.

6.5.3 Rate of heating. The rate of localized heating shall not exceed 0°F per 5 minute period.

6.5.4 Holding temperature and time. Holding temperature and time shall e as specified in 6.4.3.

6.5.5 Rate of cooling. The rate of cooling shall be as specified in 6.4.5.

6.6 Temperature measuring methods.

6.6.1 Pyrometric equipment. Except as specified in 6.6.4, recording rometric equipment shall be provided to indicate the temperature of the pipe id not the furnace. The average of the observed temperatures of the pipe is nsidered to be the temperature of the pipe, provided all observed temperatures e within the temperature range specified in table IV.

6.6.2 Locating thermocouples. Thermocouples shall be located to measure e temperature at the anticipated hottest point on the pipe and at the anticited coolest point. The number of thermocouples provided shall assure complete verage of the pipe and adequate temperature history. If more than one pipe to be stress relieved at the same time, thermocouples shall be attached to ch pipe. In no case, however, shall more than six thermocouples be required r a furnace charge. For local heating operations, not less than two thermouples shall be attached to the pipe.

6.6.3 Installing thermocouples. Thermocouple wires shall be electrically insulated except at their hot junctions. In order to avoid erroneous readings, thermocouples shall be so arranged that flames do not impinge on the junctions or the wires themselves. When the electrical resistance heating method is used, the thermocouple provided to control the operation shall be covered by a protective wrapping, to prevent direct radiation of the heating elements on its hot junction. Thermocouples shall be attached to the pipe by a method which insures that the thermal junction is held firmly.

6.6.4 Pyrometrically controlled furnaces. When a recording pyrometric control furnace can be verified that the temperature variation within the furnace does not exceed 75°F, the furnace control thermocouples may be used as the indication of the temperature of the part being heat treated in lieu of thermocouples attached to the component.

6.6.5 Maintaining calibration. Temperature recording instrument and accessories shall be periodically calibrated at intervals in accordance with NAVSEA OD 45845 or when any changes or repair to furnaces or heating devices would mitigate the accuracy of previous calibrations.

7. INSPECTION REQUIREMENTS AND ACCEPTANCE STANDARDS

7.1 Inspection personnel. Visual examination and nondestructive inspection personnel shall be required to pass a vision test in accordance with MIL-STD-271. Nondestructive inspection personnel for ultrasonic measurement, magnetic particle or liquid penetrant inspections shall also be qualified in accordance with MIL-STD-271.

7.2 Acceptance standards. Unless otherwise specified by NAVSEA, acceptance criteria shall be in accordance with 7.3 through 7.10.

7.3 Surface condition. The bent pipe shall be free of cracks. The pipe surface shall be examined for pits, gouges, scratches, or tool marks. Randomly distributed round bottomed discontinuities are acceptable provided they do not exceed a depth of 0.010 inch or 5 percent of the nominal thickness, whichever is greater, and provided this depth does not reduce the wall thickness below its minimum requirement. Discontinuities exceeding this limit shall be removed by fairing in either by grinding or buffing to a radius of 3 times the depth. The final wall thickness after defect removal shall meet the minimum thickness requirement.

7.4 Wrinkles. Pipe surface shall be free of wrinkles.

7.5 Out-of-roundness. Bent pipe shall be measured for out-of-roundness and shall meet the following requirements:

(a) For pipe with working pressure of 600 pounds per square inch (lb/in^2) and greater: 5 percent (maximum).
(b) For pipe working pressure less than 600 lb/in^2: 8 percent (maximum).

7.5.1 Out-of-roundness calculation. Out-of-roundness shall be calculated as follows:

$$\text{Out-of-round (percent)} = \frac{\text{o.d. max.} - \text{o.d. min.}}{\text{o.d. nom.}} \times 100$$

Where: o.d. max. = Maximum measured outside diameter (o.d.) at the bend.
o.d. min. = Minimum measured o.d. at the bend.
o.d. nom. = $\frac{\text{o.d. max.} + \text{o.d. min.}}{2}$

7.6 Buckles, bulges, humps, steps, and dents. The bent pipe shall be examined for excessive buckles, bulges, humps, steps, and dents. Buckles, bulges, humps, steps, and dents will be acceptable provided the following conditions (see figure 7) are met:

(a) Buckles, bulges, humps, steps, and dents shall blend smoothly in a gradual manner.
(b) The maximum vertical height of any buckle, bulge, hump, step, or dent shall not exceed 3 percent of the nominal pipe o.d.
(c) The diameter to height ratio (D/h) as shown on figure 7, shall equal or exceed 12/1.

7.7 Flatness. Flatness on the pipe surface will be acceptable if it meets the requirements shown on figure 8.

7.8 Wall thickness measurement. The wall thickness at the bend of the bent pipe shall meet the minimum design wall thickness requirement specified in the applicable shipbuilding specification and 4.4.2. Measurements shall be made with a micrometer or calibrated ultrasonic instrument in accordance with MIL-STD-271. Particular attention shall be given to the backwall and on those locations where defects have been removed by grinding or hammering.

7.9 Nondestructive inspection. Pipe bends of 3D and less shall be magnetic particle or liquid penetrant inspected, in accordance with MIL-STD-271 as applicable, on the area that was bent plus at least 1 inch beyond both ends of the bend. When magnetic particle inspection is required, the yoke method shall be used. Cracks are not acceptable. Linear indications exceeding 1/16-inch in length shall be examined and explored to assure that cracking is not present.

7.10 Measurements and inspections. Production P-1 piping in accordance with MIL-STD-278, P-3a piping in accordance with NAVSEA 0900-LP-001-7000, and piping for class 1 welds as defined in Supplement 2 of NAVSEA 250-1500-1, 0.080 inch in pre-bending wall thickness and over, which have a bend radius of 3D and less and which is bent to an angle greater than 60 degrees, shall have the wall thickness and out-of-roundness measured at each bend and the bent surfaces shall be inspected for conformance to the acceptance criteria of this section. Other pipe bends may be inspected on a sampling basis, in lieu of 100 percent, subject to the approval of the authorized representative.

8. CLEANING

8.1 General.

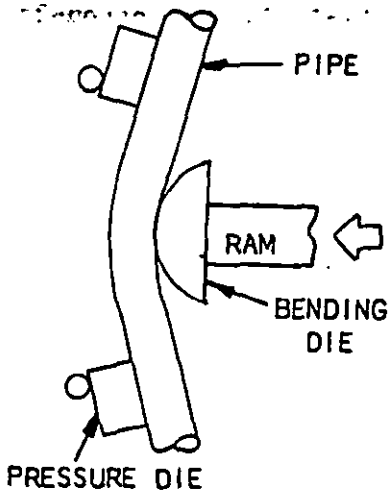
8.1.1 Safety. Some materials used for cleaning are hazardous. The area where cleaning operations are performed shall be adequately ventilated. Safety precautions shall be in accordance with the information provided in the applicable Material Safety Data Sheet (Form OSHA-20), or the precautionary label on the container of the material.

8.1.2 Cleaning. Piping components and assemblies of components shall be thoroughly cleaned after fabrication and before installation in the ship to remove loose particles, grease, dirt, oil, rust, and scale. Superficial soft rusting such as that caused by short time exposure to the atmosphere is acceptable. Open ends of piping and components shall be sealed for storage until final assembly. Cleaning, capping, and degreasing shall be in accordance with a written production procedure.

9. NOTES

9.1 Changes from previous issue. Asterisks (*) are not used in this revision to identify changes with respect to the previous issue, due to the extensiveness of the changes.

Preparing activity:
Navy - SH
(Project 4710-N576)



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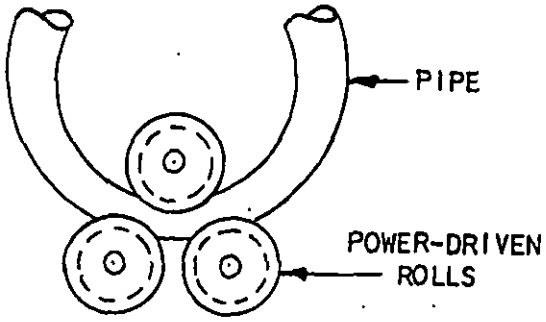

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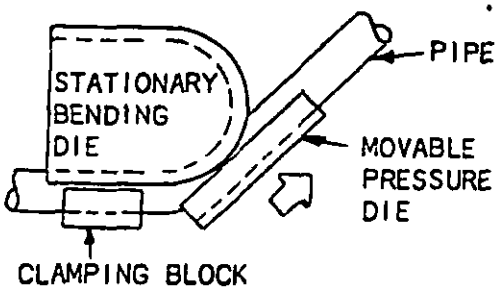

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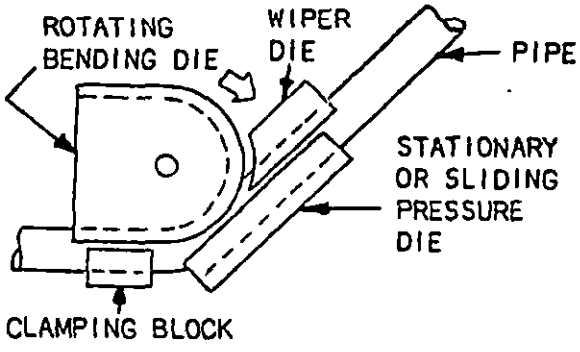
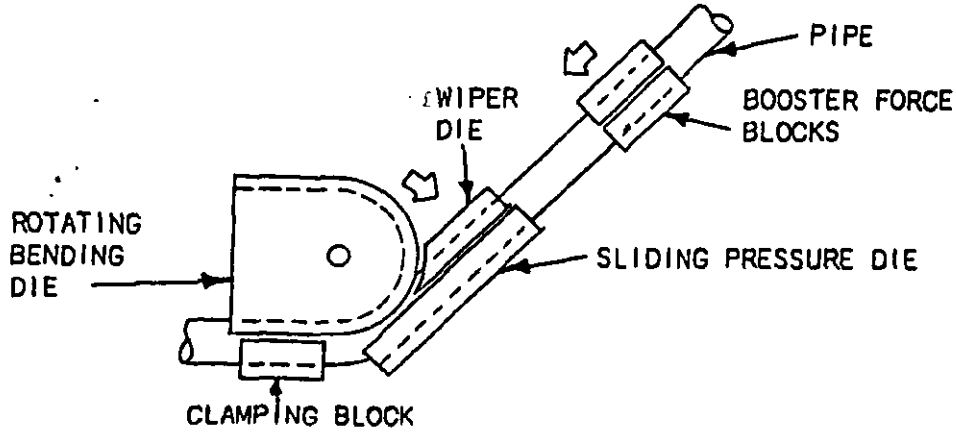


ROTARY OR DRAW TYPE



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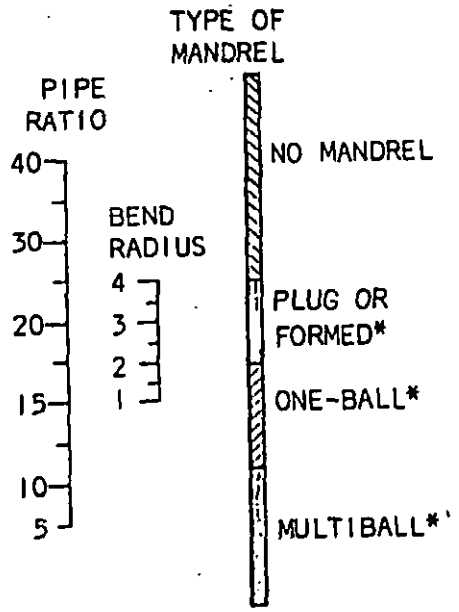
ROTARY TYPE WITH BOOSTER UNIT

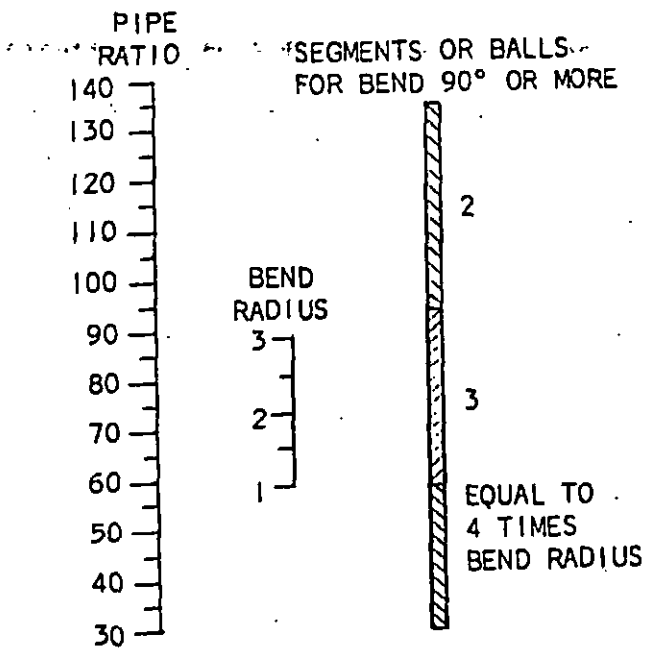
FIGURE 1. Types of bending machines.



Find the pipe ratio (D/t) and the bend radius (R/D) in the left-hand and center scales, and lay a straightedge across them. The zone on the right-hand scale where the straightedge falls shows whether or not an internal support is required, and what type. Bends for which the pipe ratio is more than 40 always require a multiball mandrel or filler material.

* Filler material is optional.

NOMOGRAPH A



IF A MULTIBALL MANDREL IS INDICATED IN NOMOGRAPH A, FIND THE PIPE RATIO AND THE BEND RADIUS IN THE LEFT-HAND AND THE CENTER SCALES AND LAY A STRAIGHTEDGE ACROSS THEM. THE NUMBER OF BALLS NEEDED IN THE MULTI BALL MANDREL WILL BE INDICATED ON THE RIGHT-HAND SCALE.

SH10878

NOMOGRAPH B

FIGURE 2. Nomographs to determine when internal support is required.

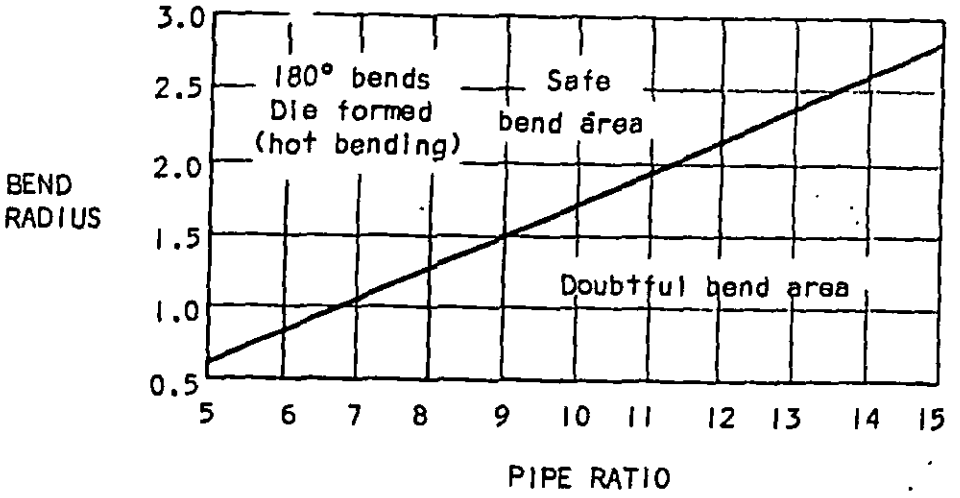


CHART A - For determining conditions for successful hot bending of pipes 1.5 to 3 inch in diameter without the use of a mandrel.

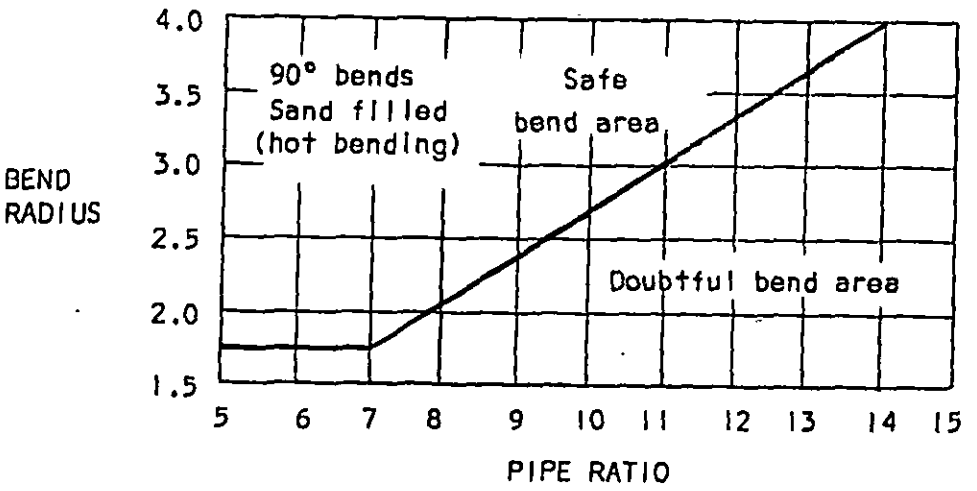


CHART B - For determining conditions for successful hot bending of pipes of all diameters with the use of a mandrel or filler.

SH10879

FIGURE 3. Guide for determining the need of internal support in hot bending.

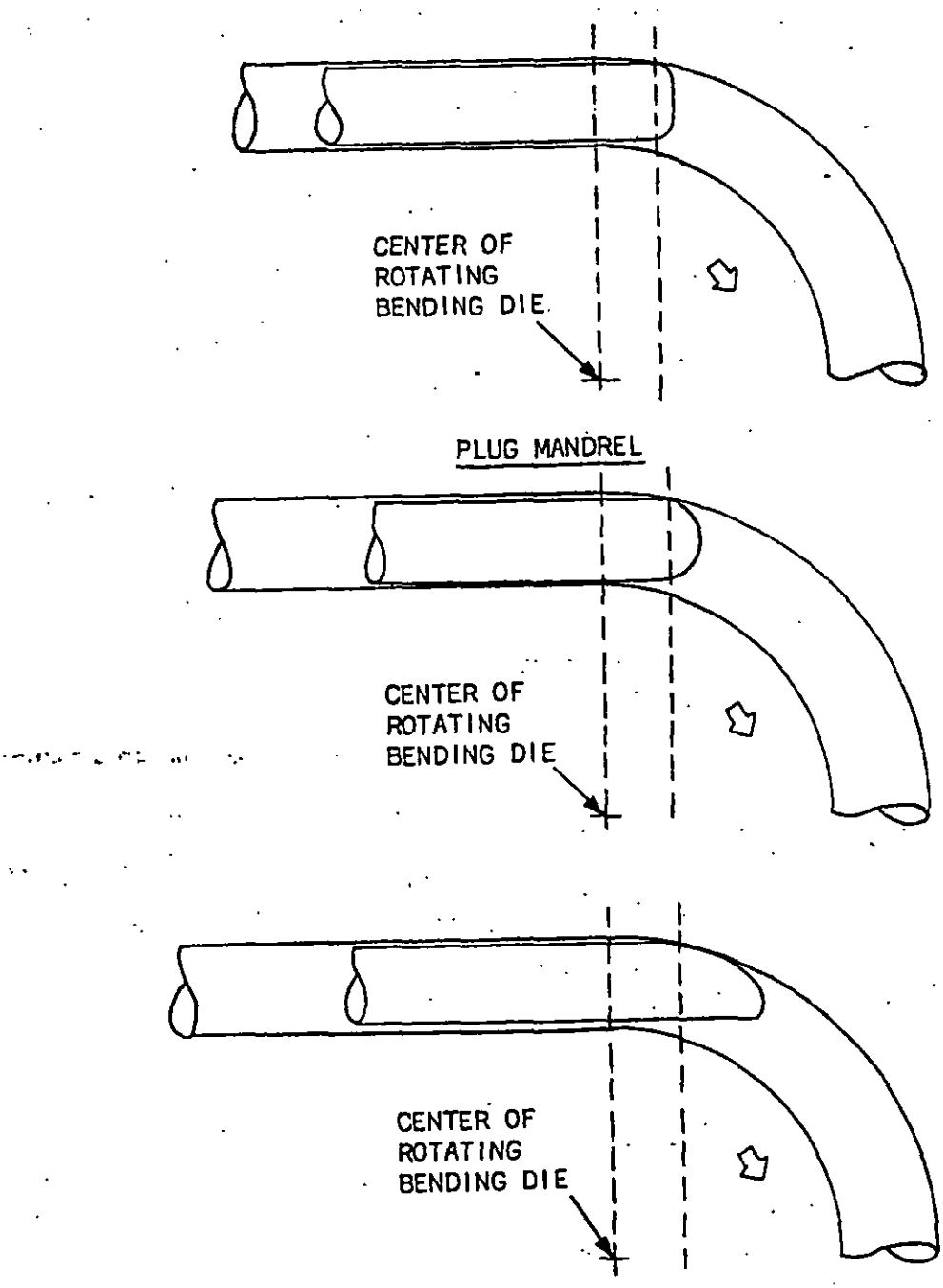
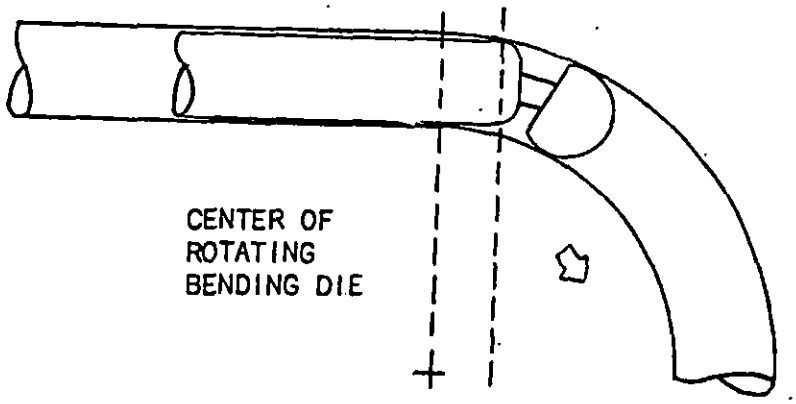
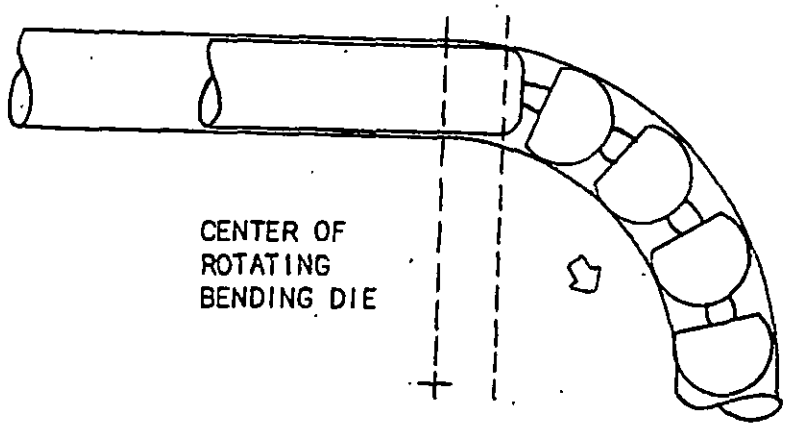


FIGURE 4. Rigid mandrels and their relative position in the pipe.



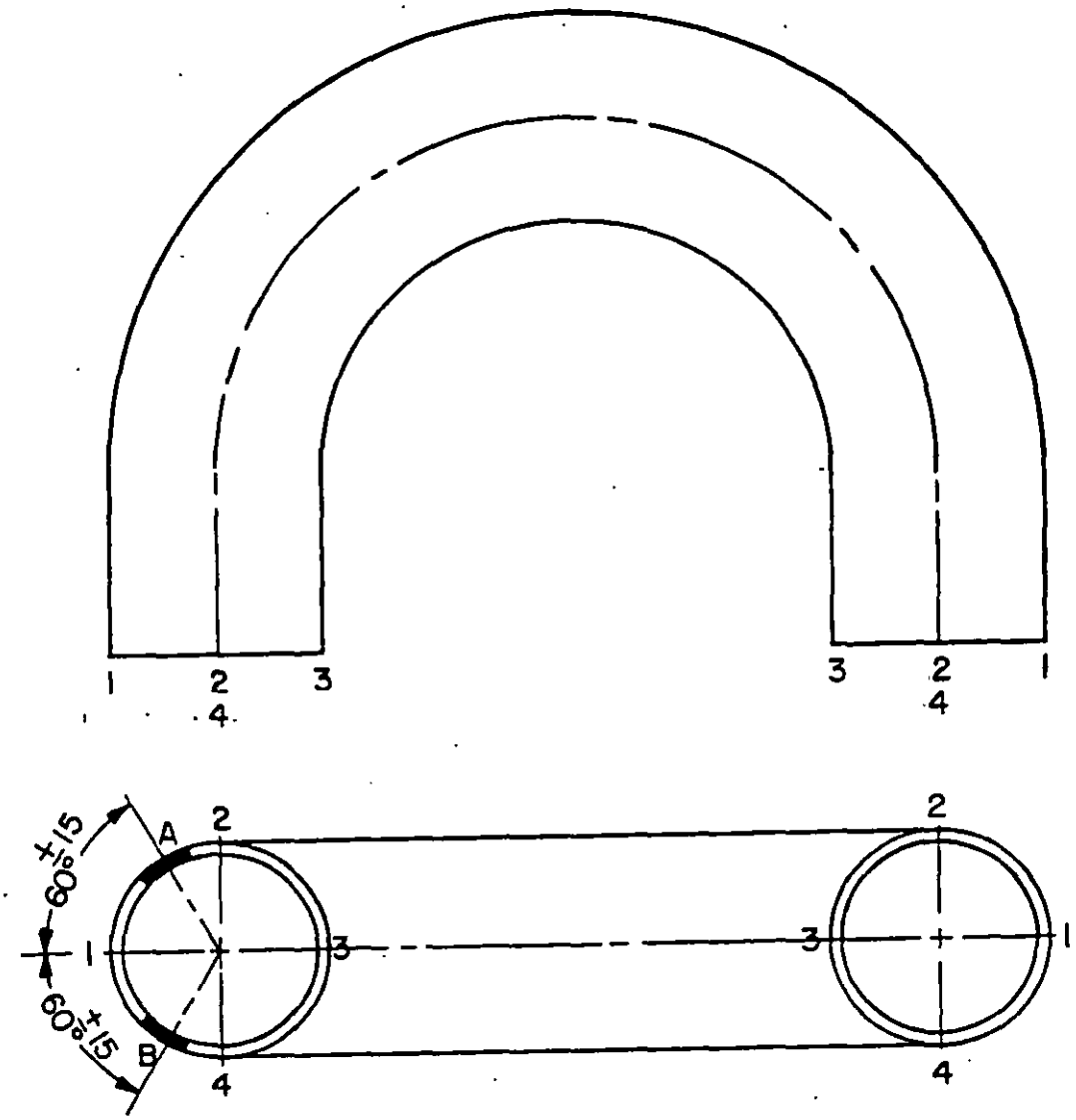
SINGLE BALL MANDREL



MULTI-BALL MANDREL

SH10881

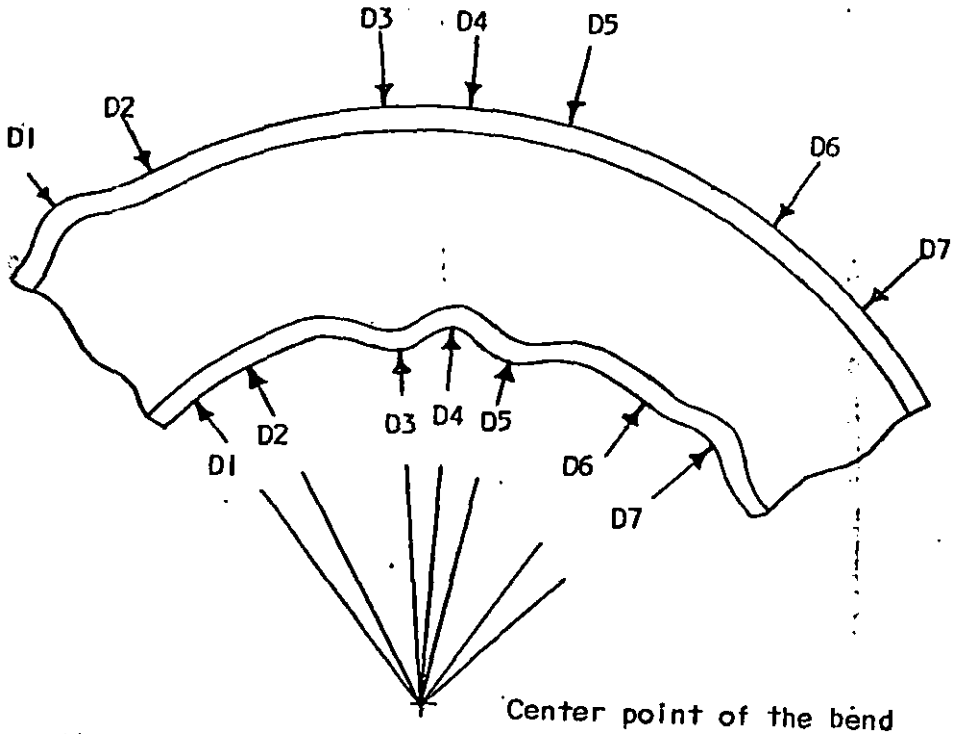
FIGURE 5. Flexible mandrels and their relative position in the pipe.

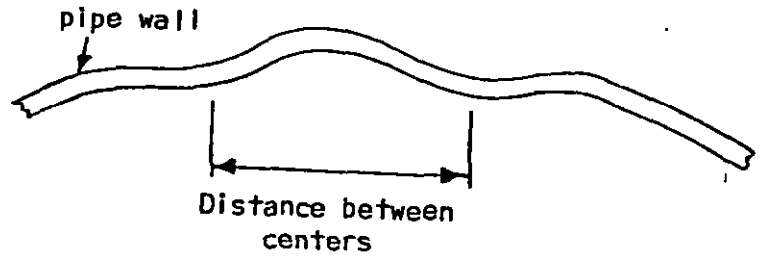


NOTES:
1. The weld shall not be located at the axes 1-3 or 2-4.
2. It is preferred that the weld be located at locations A or B.

SH10882

FIGURE 6. Location of weld for welded pipe.





MINIMUM ALLOWABLE DISTANCE BETWEEN CENTERS OF BULGES, BUCKLES, OR HUMPS

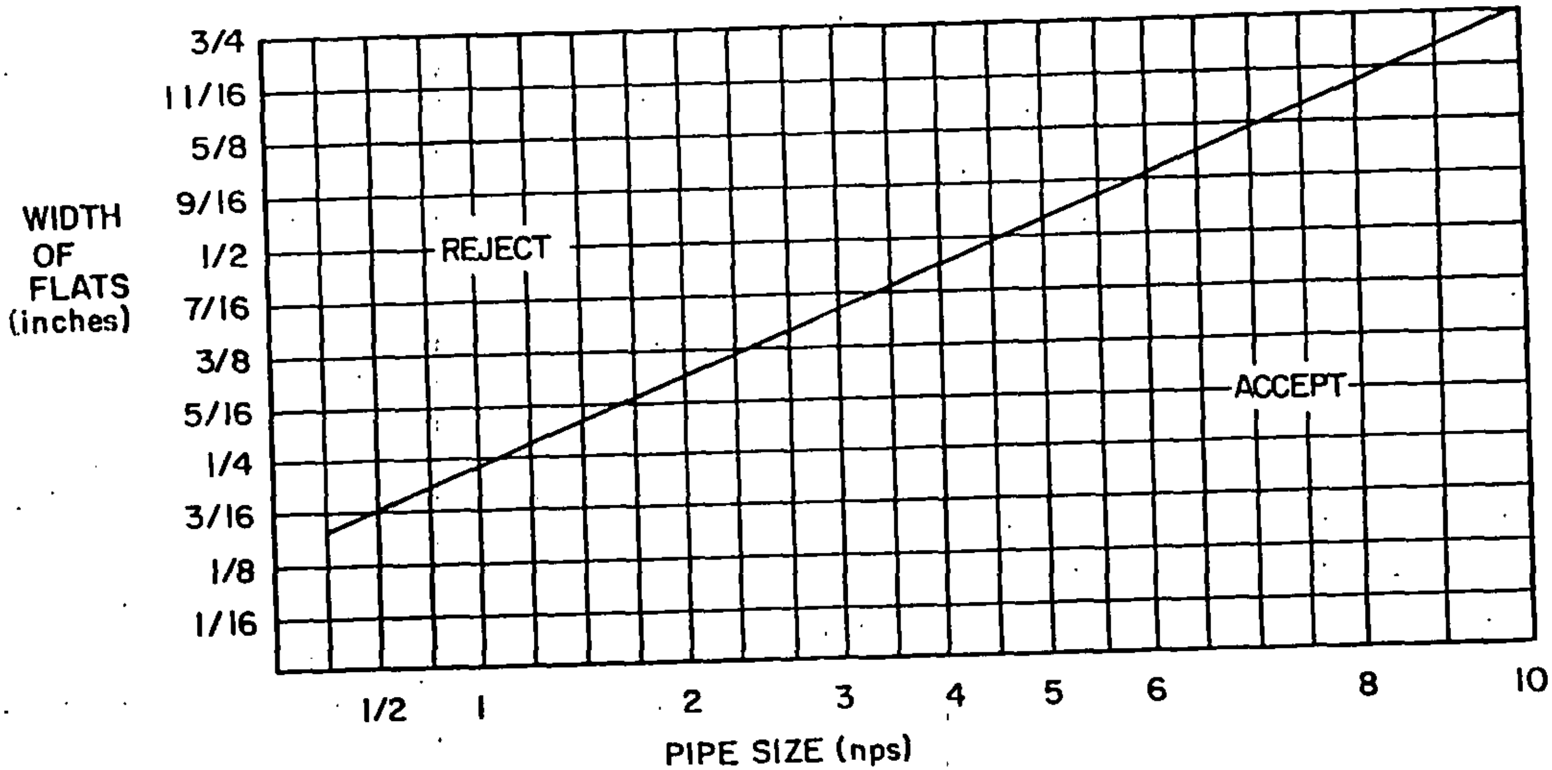
$$\frac{\text{Distance between centers}}{\text{Vertical height of largest bulge, buckle or hump}} \geq 12$$

CALCULATION OF VERTICAL HEIGHT (3% of o.d. maximum)

1. Vertical height of the largest hump = D1 - D2
2. Vertical height of the largest bulge or buckle = $\frac{D3 + D5}{2} - D4$
3. Vertical height of the largest step = D6 - D7

SH10883

FIGURE 7. Calculations for buckles, bulges, humps, steps, and dents in pipe bends.



PIPE SIZE EQUIVALENTS (nps = outside diameter)

1/4 = 0.540	1 = 1.125	2 = 2.375	4 = 4.500
3/8 = 0.675	1-1/8 = 1.315	2-1/2 = 2.875	5 = 5.563
1/2 = 0.840	1-1/4 = 1.660	3 = 3.500	6 = 6.625
3/4 = 1.050	1-1/2 = 1.900	3-1/2 = 4.000	8 = 8.625

10 = 10.750

SH10884

FIGURE 9. Flatness limits.

APPENDIX
DATA REQUIREMENTS

10. DATA

10.1 Data requirements. When this standard is used in a contract which incorporates a DD Form 1423 and invokes the provisions of 7-104.9(n) of the Defense Acquisition Regulation (DAR), the data requirements identified below will be developed as specified by an approved Data Item Description (DD Form 1664) and delivered in accordance with the approved Contract Data Requirements List (DD Form 1423) incorporated into the contract. When the provisions of DAR-7-104.9(n) are not invoked, the data specified below will be delivered by the contractor in accordance with the contract requirements. Deliverable data required by this standard is cited in the following paragraphs:

Paragraph	Data requirement	Applicable DID	Option
5.1	Procedures, test	UDI-T-23732	---
5.4	Reports, test	DI-T-2072	10.1.b

(Copies of data item descriptions required by the contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

10.1.1 The data requirements of 10.1 and any task in the standard required to be performed to meet a data requirement may be waived by the contracting/acquisition activity upon certification by the offeror that identical data were submitted by the offeror and accepted by the Government under a previous contract or identical item acquired to this standard. This does not apply to specific data which may be required for each contract, regardless of whether an identical item has been supplied previously (for example, test reports).

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STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

OMB Approval
No. 22-R255

INSTRUCTIONS: The purpose of this form is to solicit beneficial comments which will help achieve procurement of suitable products at reasonable cost and minimum delay, or will otherwise enhance use of the document. DoD contractors, government activities, or manufacturers/vendors who are prospective suppliers of the product are invited to submit comments to the government. Fold on lines on reverse side, staple in corner, and send to preparing activity. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements. Attach any pertinent data which may be of use in improving this document. If there are additional papers, attach to form and place both in an envelope addressed to preparing activity.

DOCUMENT IDENTIFIER AND TITLE

MIL-STD-1627B(SH)

NAME OF ORGANIZATION AND ADDRESS

CONTRACT NUMBER

MATERIAL PROCURED UNDER A

☐ DIRECT GOVERNMENT CONTRACT ☐ SUBCONTRACT

1. HAS ANY PART OF THE DOCUMENT CREATED PROBLEMS OR REQUIRED INTERPRETATION IN PROCUREMENT USE?

A. GIVE PARAGRAPH NUMBER AND WORDING.

B. RECOMMENDATIONS FOR CORRECTING THE DEFICIENCIES

2. COMMENTS ON ANY DOCUMENT REQUIREMENT CONSIDERED TOO RIGID

3. IS THE DOCUMENT RESTRICTIVE?

☐ YES ☐ NO *(If "Yes", in what way?)*

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DD FORM 1 JAN 72 1426

REPLACES EDITION OF 1 JAN 66 WHICH MAY BE USED

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