Naval Facilities Engineering Command
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Fleet Moorings

Basic Criteria and Planning Guidelines

DESIGN MANUAL 26.5
JUNE 1985

ABSTRACT

Basic criteria and planning guidelines for the design of fleet moorings are presented for use by qualified engineers. The contents include types of fleet-mooring systems, basic design philosophy and selection factors for fleet moorings, discussion of fleet-mooring components, procedures for determining static forces on moored vessels, procedures for determining static forces on mooring elements, procedures outlining the detailed design of fleet moorings, and example calculations.

FOREWARD

This design manual is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command, other Government agencies, and the private sector. This manual uses, to the maximum extent feasible, national professional society, association, and institute standards in accordance with NAVFACENGCOM policy. Deviations from these criteria should not be made without prior approval of NAVFACENGCOM Headquarters (Code 04).

Design cannot remain static any more than can the naval functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged from within the Navy and from the private sector and should be furnished to NAVFACENGCOM Headquarters (Code 04). As the design manuals are revised, they are being restructured. A chapter or a combination of chapters will be issued as a separate design manual for ready reference to specific criteria.

This publication is certified as an official publication of the Naval Facilities Engineering Command and has been reviewed and approved in accordance with SECNAVINST 5600.16.

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HARBOR AND COASTAL FACILITIES DESIGN MANUALS

DM Number	Superseded Chapter in Basic DM-26	Title
26.1	1, 4	Harbors
26.2	2	Coastal Protection
26.3	1, 2, 3	Coastal Sedimentation and Dredging
26.4	5	Fixed Moorings
26.5	6	Fleet Moorings
26.6	7	Mooring Design Physical and Empirical Data

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FLEET MOORINGS

Section 1. INTRODUCTION

1. **SCOPE.** This manual presents basic information required for the selection and design of fleet-mooring systems in protected harbors.

2. **CANCELLATION.** This manual, NAVFAC DM-26.5, Fleet Moorings, cancels and supersedes Chapter 6 of the basic Design Manual 26, Harbor and Coastal Facilities, dated July 1968, and Change 1, dated December 1968.

3. **RELATED CRITERIA.** Certain criteria related to fleet moorings appear elsewhere in the design manual series. See the following sources:

Subject	Source
Characteristics of Vessels	DM-26.6
Fixed Moorings	DM-26.4
Foundations and Earth Structures	DM-7.2
General Criteria for Waterfront Construction	DM-25.6
Layout of Individual Moorings	DM-26.1
Sedimentation	DM-26.3
Soil Mechanics	DM-7.1
Strength and Dimensional Characteristics of Chain, Wire, and Fiber Rope	DM-26.6
Structural Engineering	DM-2
Water-Level Fluctuations	DM-26.1
Waves	DM-26.2

4. **DEFINITION.** Navy moorings are classified as either fleet moorings or fixed moorings. A fleet mooring consists of structural elements, temporarily fixed in position, to which a vessel is moored. These structural elements include anchors, ground legs, a riser chain, a buoy, and other mooring hardware. Lines and appurtenances provided by vessels are not a part of the fleet mooring.

A fixed mooring consists of a structural element, permanently fixed in position, to which a vessel is moored. Fixed moorings are discussed in DM-26.4, Fixed Moorings.

5. **STANDARD DRAWINGS.** A list of standard drawings for fleet moorings is presented in Table 1.

TABLE 1
Standard Drawings for Fleet Moorings

Description	NAVFAC Drawing Number
ANCHORS:	
Stato Anchor	--
Stockless anchor details	620603
Stockless anchors--stabilizer details	620656
BUOYS:	
Peg-top buoy--12′-0″ dia x 9′-6″ deep--sheets 1 and 2	1195707, 1195708
Aids to navigation buoys--lighted and unlighted--sheets 1 and 2	620609, 660800
Bar riser chain-type buoy details--sizes to 10′-6″ dia x 7′-6″ high	620659
Bar riser chain-type buoy--15′-0″ dia x 9′-6″ deep--sheets 1, 2, and 3	1404065-1404067
Marker or mooring buoy--3′-6" dia	620662
Hawsepipe, riser chain-type buoy--12′-0″ dia x 6′-0″ high	620605
CHAINS AND CHAIN FITTINGS:	
Release hook for offshore fuel-loading moorings	896091
MOORINGS:	
Degaussing and oil-barge mooring	660797
Free-swinging, riser-type--Classes AAA and BBB (PROPOSED)	
Free-swinging, riser-type--Classes AA, BB, CC, and DD	1404345
Free-swinging, riser-type moorings without sinkers--Classes A, B, C, D, E, F, and G	1404346
Free-swinging, riser-type moorings with sinkers--Classes A, B, C, D, and E	1404347
Fuel loading-type mooring--6,000-pound Stato anchor	1046688
Fuel loading-type mooring--l5,000-pound Stockless anchor	896129
SINKERS:	
12,600-pound cast-iron sinker	946172
STAKE PILES:	
300,000-pound stake pile--bearing pile design--14″ BP 73#	946171
200,000-pound stake pile--l2-3/4" O.D. pipe	660853
200,000-pound stake pile--bearing pile design--12″ BP 53#	660857
100,000-pound stake pile--bearing pile design--12″ BP 53#	896109

Section 2. FLEET-MOORING SYSTEMS

1. **FLEET MOORINGS.** The Navy uses several types of fleet moorings, including riser-type moorings, telephone-type moorings, anchor-and-chain moorings, and anchor, chain, and buoy moorings. Fleet-mooring configurations commonly used by the Navy include free-swinging moorings, multiple-point moorings, multiple-vessel moorings, trot-line moorings, and moorings for navigational buoys. Fleet-mooring types and configurations are discussed below.

2. **FLEET-MOORING TYPES.**

a. Riser-Type Moorings. Riser-type moorings are the most common type of fleet mooring currently used by the Navy. They consist of a buoy, riser chain, ground ring, ground legs, swivels, and anchors (Figure 1). The riser chain, equipped with a chain swivel, connects the ground ring to the buoy. Ground legs-connect the anchors to the ground ring, which is held about 10 to 20 feet above the bottom at mean high water (MHW) when there is no pull on the mooring.

The Navy has standardized riser-type fleet moorings and has classified them according to capacity (Table 2). The rated capacity of each standardized mooring is based upon the strength of the chain used in the mooring riser.

b. Telephone-Type Moorings. Telephone-type moorings differ from riser-type moorings in that the ground legs of the telephone-type are connected directly to the buoy (Figure 2). Telephone-type moorings are no longer used for their original purpose, which was to provide cables for telephone communication from vessel to shore. However telephone-type buoys have been used in recent designs for moorings requiring a limited watch circle. The use of telephone-type moorings should be restricted to multiple-point moorings; in a free-swinging mooring, the ground legs of a telephone-type mooring might cause damage to the hull of the vessel as the vessel swings around the mooring.

c. Anchor-and-Chain Moorings. Vessels are commonly moored by their own anchor when fleet moorings are not available. By definition, the anchor-and-chain mooring is not a fleet mooring. However, the design procedures presented in this manual can be used to analyze anchor-and-chain moorings.

d. Anchor, Chain, and Buoy Moorings. This mooring, which consists of a buoy, a single chain, and a drag-embedment or deadweight anchor, is normally a relatively lightweight system used to moor small boats and seaplanes. Although not fleet moorings by definition, anchor, chain, and buoy moorings may be analyzed using the design procedures presented in this manual.

3. **FLEET-MOORING CONFIGURATIONS. .**

a. Free-Swinging Moorings. A vessel moored to a free-swinging (single-point) mooring is restrained by a mooring line(s) attached to its bow. The vessel is free to swing or “weather-vane” around the mooring buoy (Figure 3). A free-swinging mooring is generally more economical than a multiple-point mooring but requires ample anchorage area to prevent the vessel from interfering with navigation, adjacent structures, or neighboring vessels.

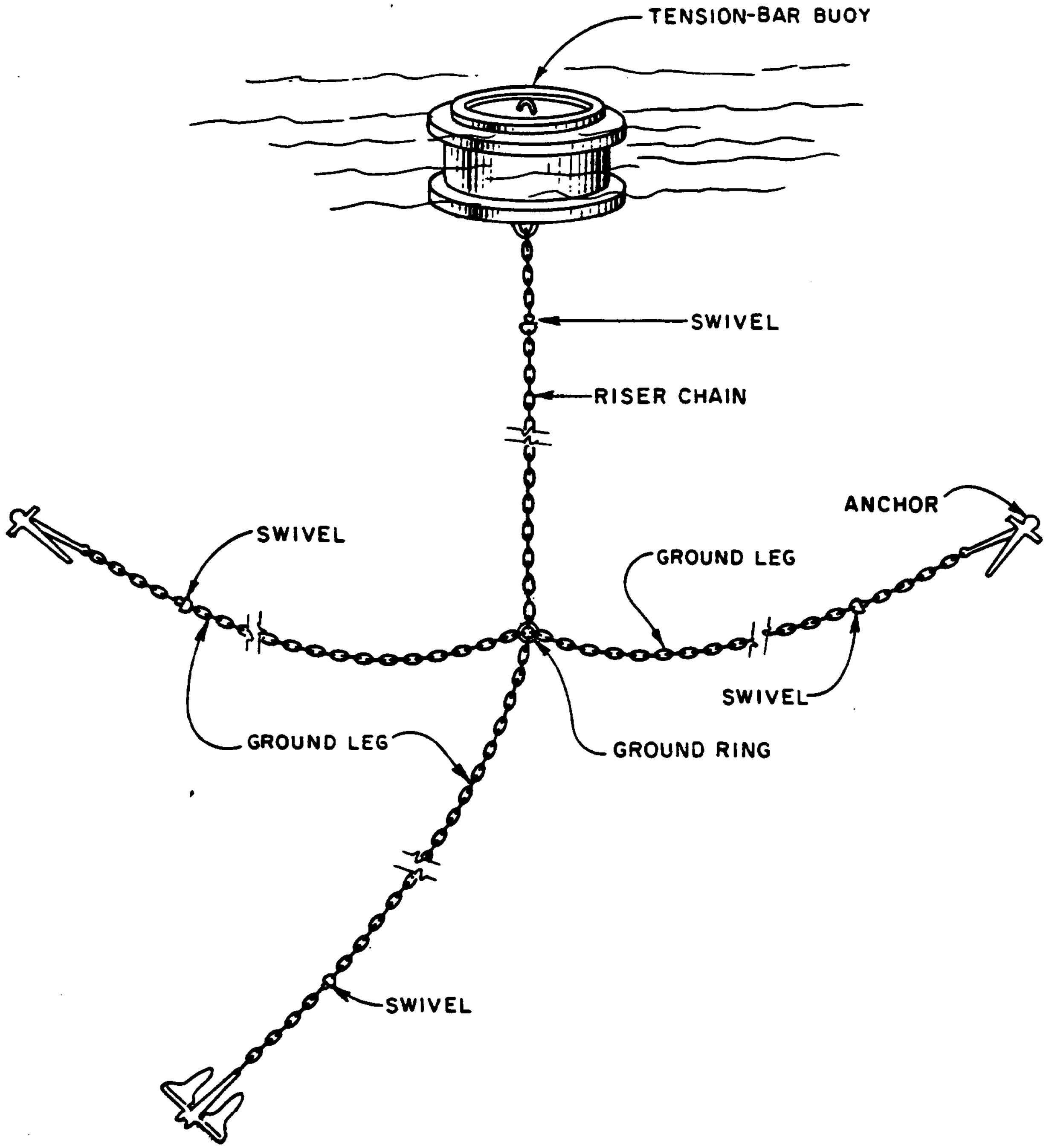


FIGURE 1
Typical Riser-Type Mooring

TABLE 2
Capacity of Standard Navy Fleet Moorings
(Riser-Type)

Class	Previous Class	Mooring Capacity (pounds)	Number of Ground Legs	Riser Chain Diameter (inches)	Type of Chain Throughout
AA	A-A	300,000	3 (Twin chain)	4	U.S. Navy Common A-Link
BB	B-B	250,000	3 (Twin chain)	3-1/2	U.S. Navy Common A-Link
CC	C-C	200,000	3 (Twin chain)	3-1/2	U.S. Navy Common A-Link
DD	D-D	175,000	3 (Single chain)	3	U.S. Navy Common A-Link
A	A	150,000	3 (Single chain)	2-3/4	U.S. Navy Common A-Link
B	B	125,000	3 (Single chain)	2-1/2	U.S. Navy Common A-Link
C	C	100,000	3 (Single chain)	2-1/4	U.S. Navy Common A-Link
D	D	75,000	3 (Single chain)	2	U.S. Navy Common A-Link
E	E	50,000	3 (Single chain)	1-3/4	U.S. Navy Common A-Link
F	F	25,000	3 (Single chain)	1-1/4	U.S. Navy Common A-Link
G	G	5,000	3 (Single chain)	3/4	U.S. Navy Common A-Link

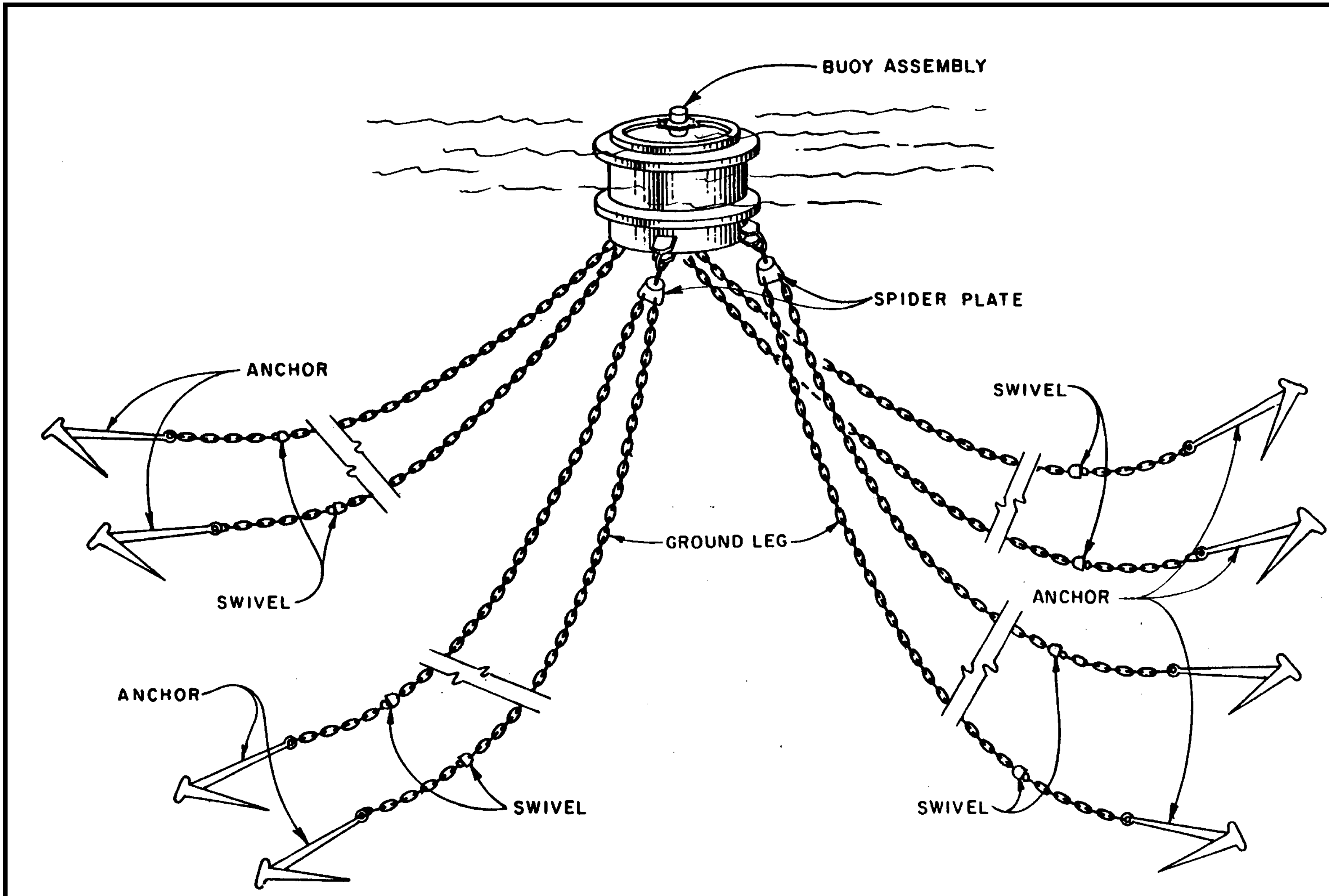


FIGURE 2
Typical Telephone-Type Mooring

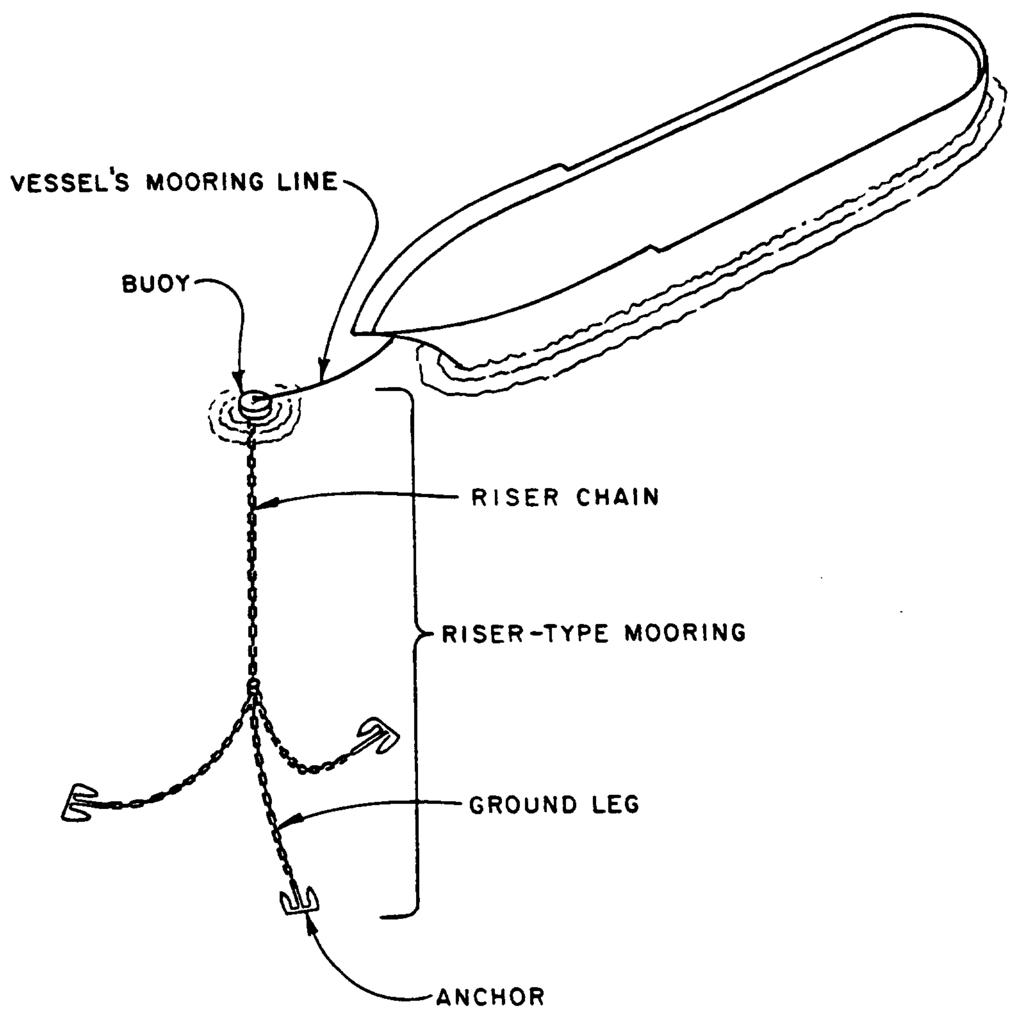


FIGURE 3
Typical Free-Swinging (Single-Point) Mooring

b. Multiple-Point Moorings. Several types of multiple-point moorings are used by the Navy. Selection of a specific type of multiple-point mooring depends upon site conditions, existing facilities, and mooring use. Some of the more common types of multiple-point moorings are presented below.

(1) Bow-and-Stern Moorings. A bow-and-stern mooring consists of a vessel secured at its bow and its stem to riser-type or telephone-type moorings. The system is generally used when there is insufficient area for free-swinging moorings, or when the vessel must be held more rigidly than at a free-swinging mooring. A typical bow-and-stern mooring arrangement is shown in Figure 4.

(2) Spread Moorings. A spread mooring consists of a vessel secured in position by several mooring lines radiating from the vessel. The number of mooring lines is variable and depends upon operational and design conditions. Spread moorings are used to secure a vessel when it must be held more rigidly than it would be in a free-swinging or bow-and-stern mooring. Figure 5 illustrates a typical spread mooring used to moor a floating drydock. (Figure 5 shows two mooring lines on each beam of the floating drydock, while some floating-drydock moorings require six or more mooring lines on each beam.) Several types of spread moorings are used by the Navy; these moorings are discussed below.

(a) Four-point moorings. A four-point mooring consists of a vessel secured at four points to riser-type or telephone-type moorings. A typical four-point mooring arrangement is shown in Figure 6. The four-point mooring concept can be extended to more than four points; that is, to six points, eight points, and so on.

(b) Meal-type moorings. In a reed-type (Mediterranean-type) mooring, the stern of the vessel is secured to a fixed structure, such as a pier, with mooring lines. The bow of the vessel is moored either by riser-type moorings, by mooring lines secured to pile anchors, or by its own anchors. A typical med-type mooring arrangement is shown in Figure 7. In Figure 7, the longitudinal axis of the vessel is oriented parallel to the predominant direction of the current in order to minimize current loads on the vessel. Meal-type moorings are used where there is insufficient harbor area for a free-swinging mooring or for another type of multiple-point mooring. Meal-type moorings are particularly well-suited for submarine tenders.

(c) Fuel oil-loading mooring. Fuel oil-loading facilities are often located offshore from a tank farm. Pipelines, laid on the seafloor, extend offshore to the mooring. Submarine hoses, marked by buoys, connect the pipelines to the vessel. The vessel is held in position by three riser-type moorings at its stern and by its own anchors at the bow. This mooring is shown in Figure 8. The mooring is normally designed for a maximum wind velocity of 30 miles per hour; the ship is removed from the berth at higher wind velocities. Navy fuel oil-loading moorings have been standardized (see Table 1).

(d) Moorings for degaussing and oil-barge facilities. Moorings for degaussing and oil-barge facilities have been standardized. Details of this mooring are given in the standard drawing listed in Table 1.

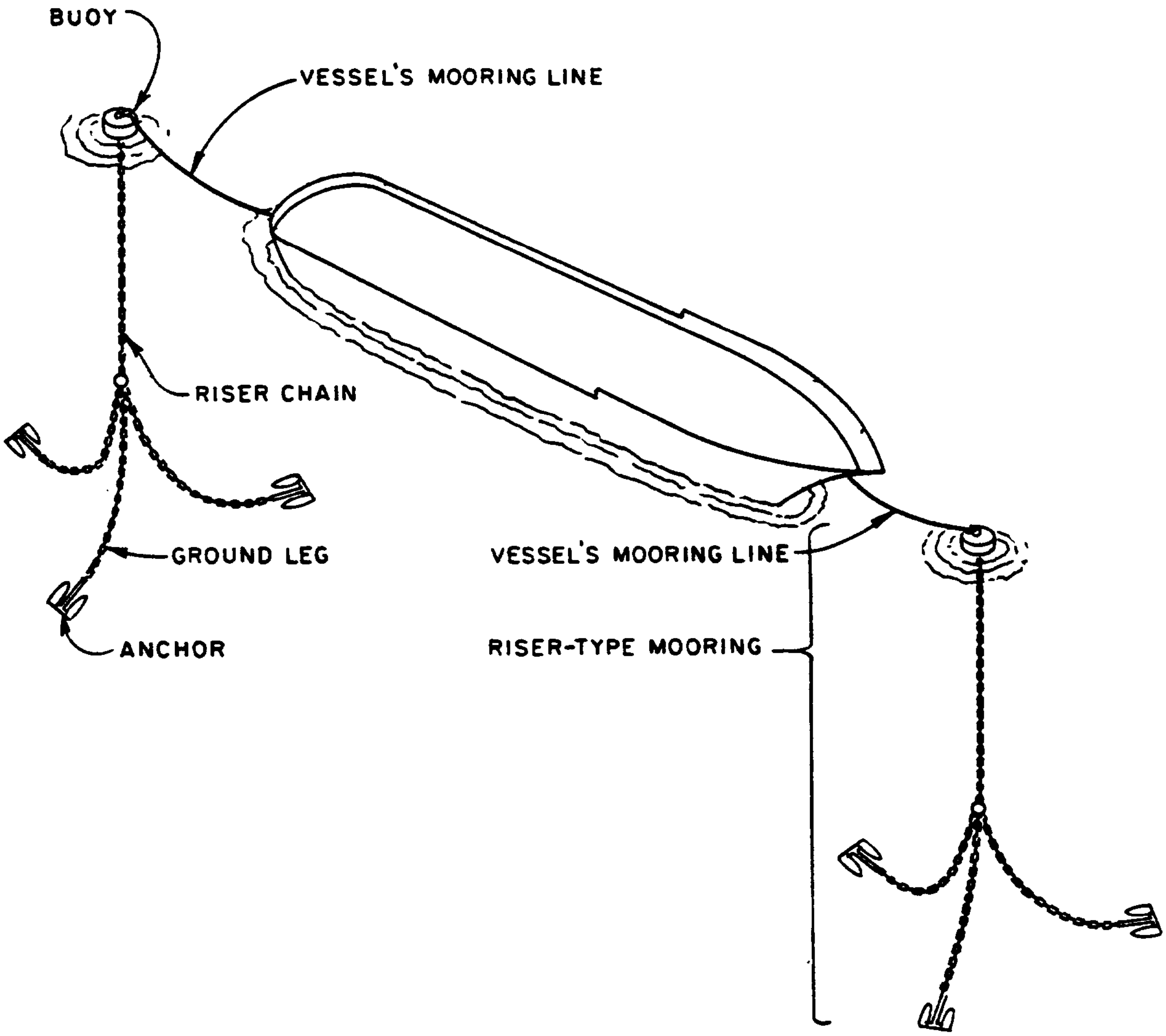


FIGURE 4
Typical Bow-and-Stern Mooring

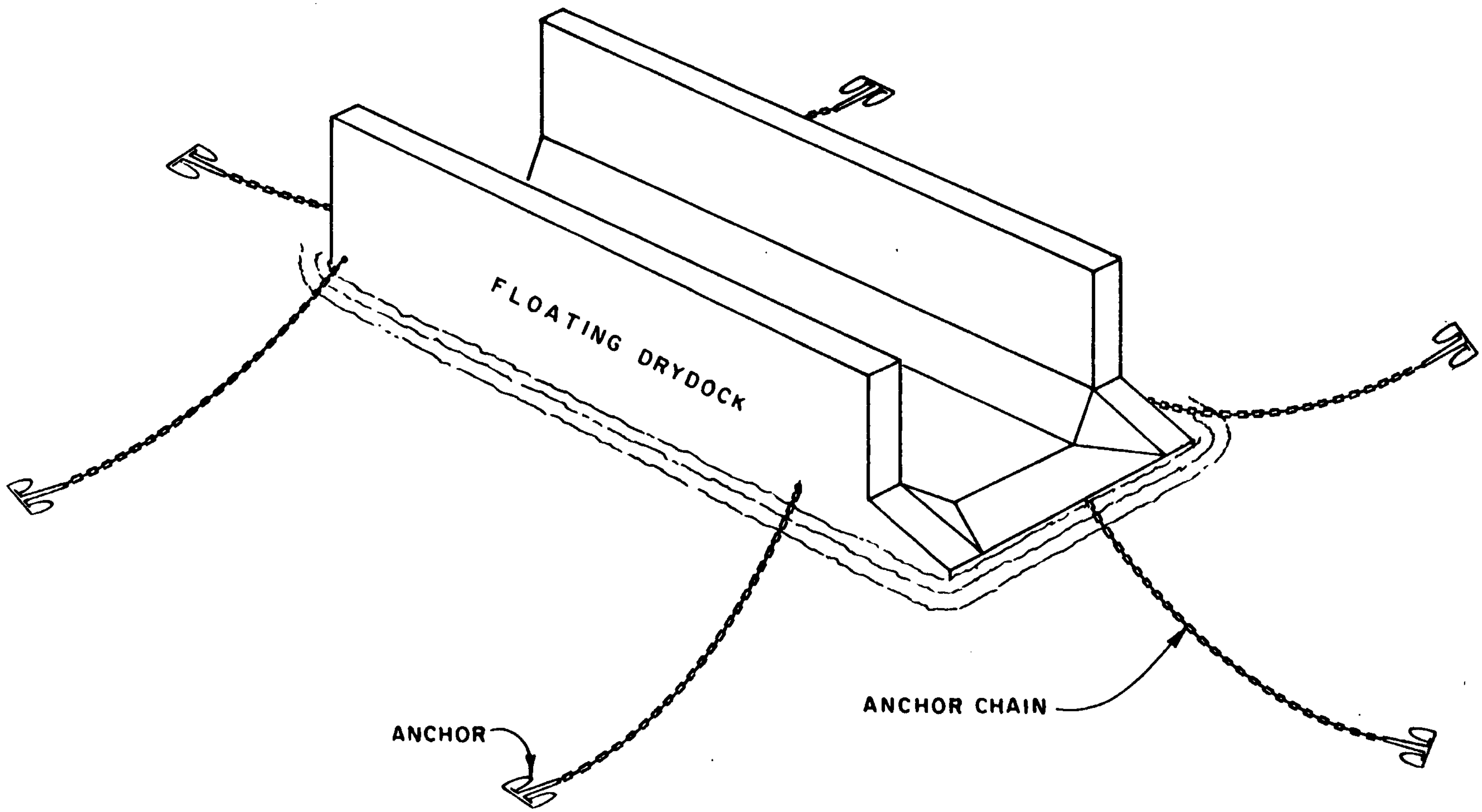


FIGURE 5
Typical Spread Mooring for Floating Drydock

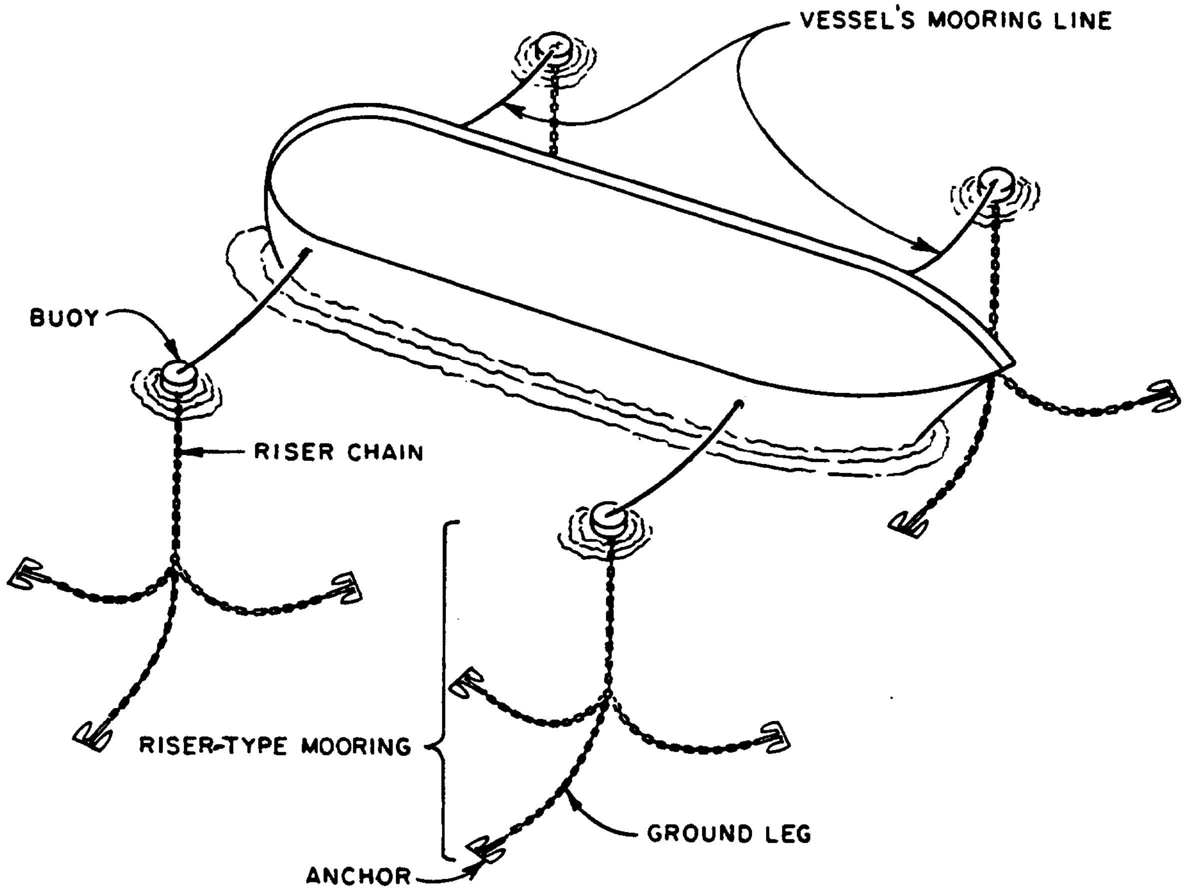


FIGURE 6
Typical Four-Point Mooring

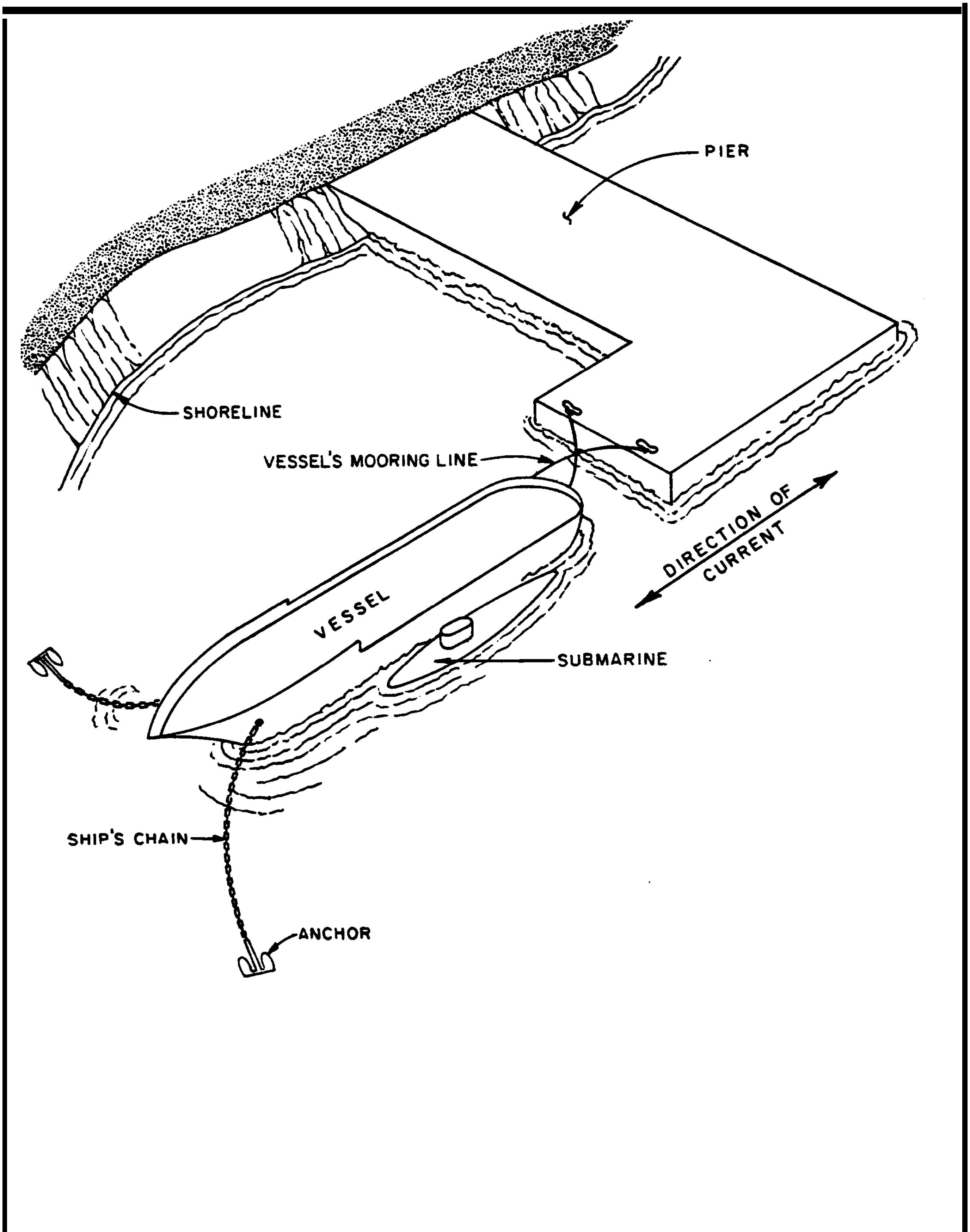


FIGURE 7
Typical Meal-Type Mooring

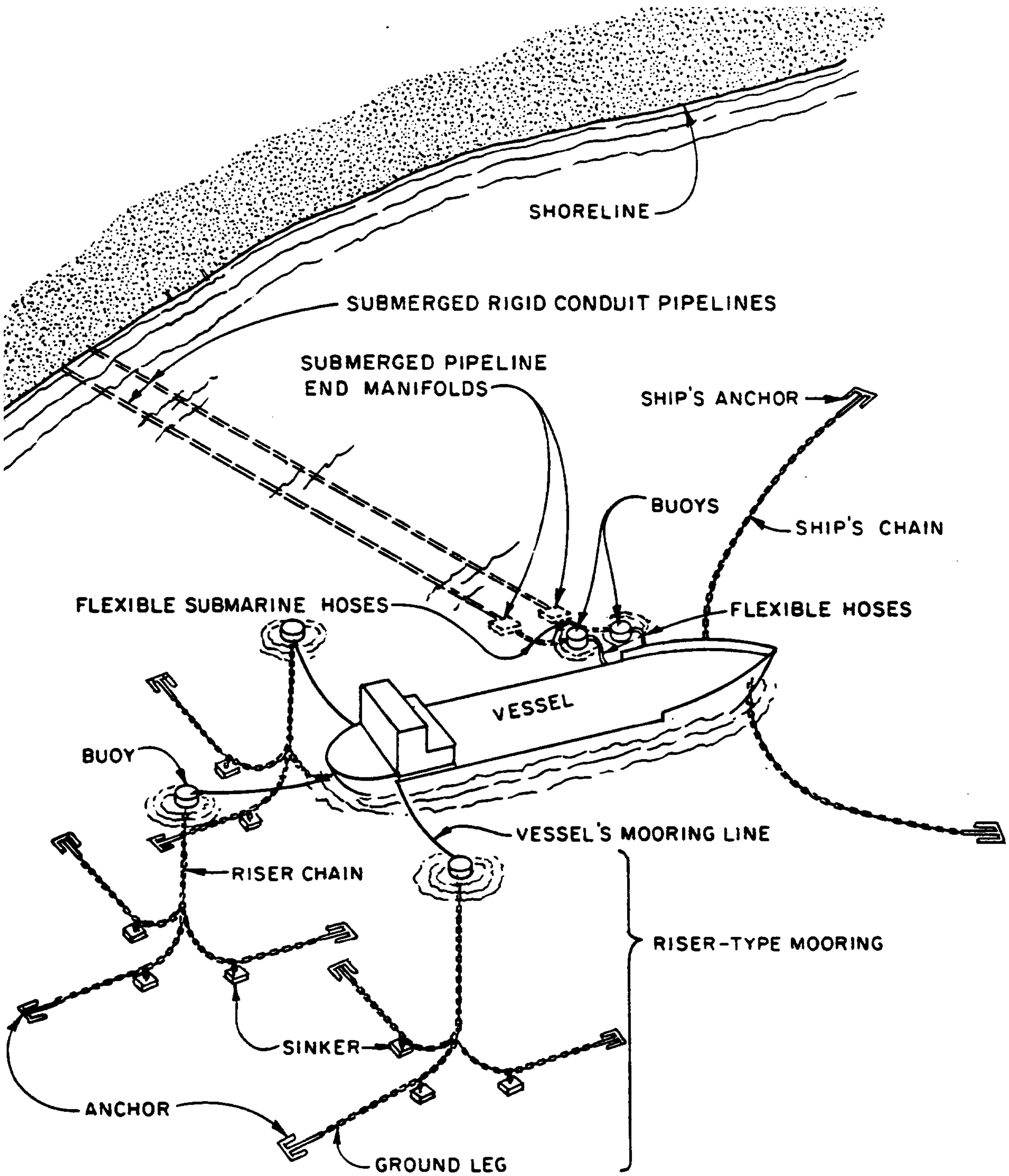


FIGURE 8
Typical Fuel Oil-Loading Mooring

c. Multiple-Vessel Moorings. A multiple-vessel (nested) mooring consists of vessels moored side by side, held together by interconnecting lines. These moorings are normally bow-and-stern or spread moorings. Multiple-vessel moorings are used to moor both active and inactive vessels. A typical active multiple-vessel mooring consists of a tender or similar vessel with submarine(s) secured to either one or both sides, as shown in Figure 7. Another typical active multiple-vessel mooring consists of several barges lashed together in a be-and-stern mooring, as shown in Figure 9. Multiple-vessel moorings for inactive vessels often consist of several identical vessels in a bow-and-stern or spread mooring.

d. Trot-Line Moorings. Trot-line moorings consist of a chain grid, anchored to the seafloor, to which a group of vessels is moored. Riser chains, connected at chain intersections, secure the vessels. This system has been used in the past to moor vessel groups; however, large amounts of chain and installation difficulties generally render this mooring system infeasible.

e. Moorings For Navigational Buoys. Navigational buoys are used to mark the limits of each side of a channel and to designate hazardous areas. The buoys are moored to concrete or cast-iron anchors by chains. The Navy has adopted Coast Guard-type buoys for use at its coastal facilities. A typical mooring arrangement for a navigational buoy is shown in Figure 10.

U.S. Coast Guard procedures for designing navigational buoys and associated components may be found in U.S. Coast Guard COMDTINST M16511.1 (December 1978). Physical and empirical data concerning navigational buoys are given in DM-26.6, Section 7.

4. METRIC EQUIVALENCE CHART. The following metric equivalents were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 2. Conversions are approximate.

10 feet = 3.0 meters
20 feet = 6.1 meters
30 miles per hour = 48 kilometers per hour

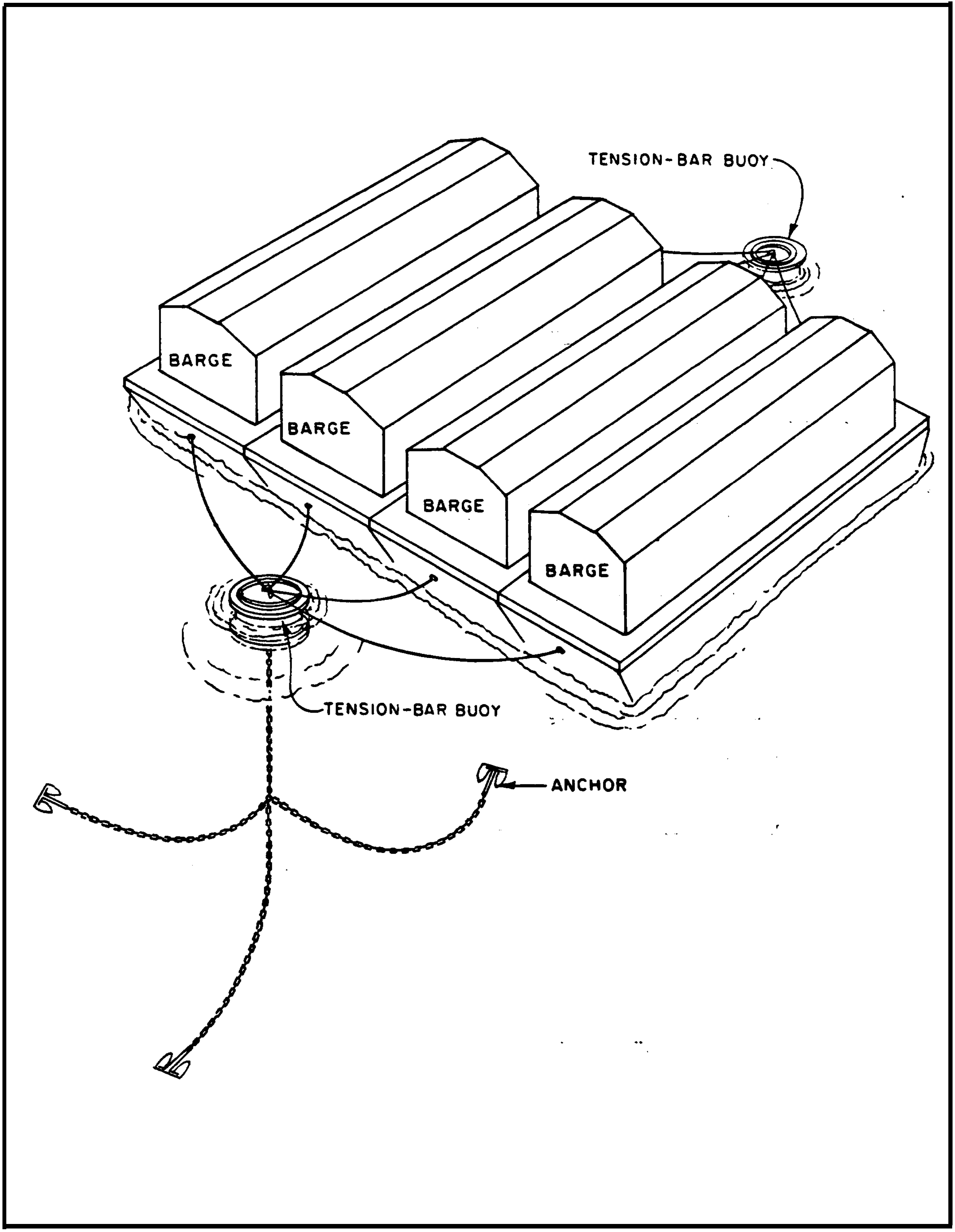


FIGURE 9
Typical Active Multiple-Vessel Mooring

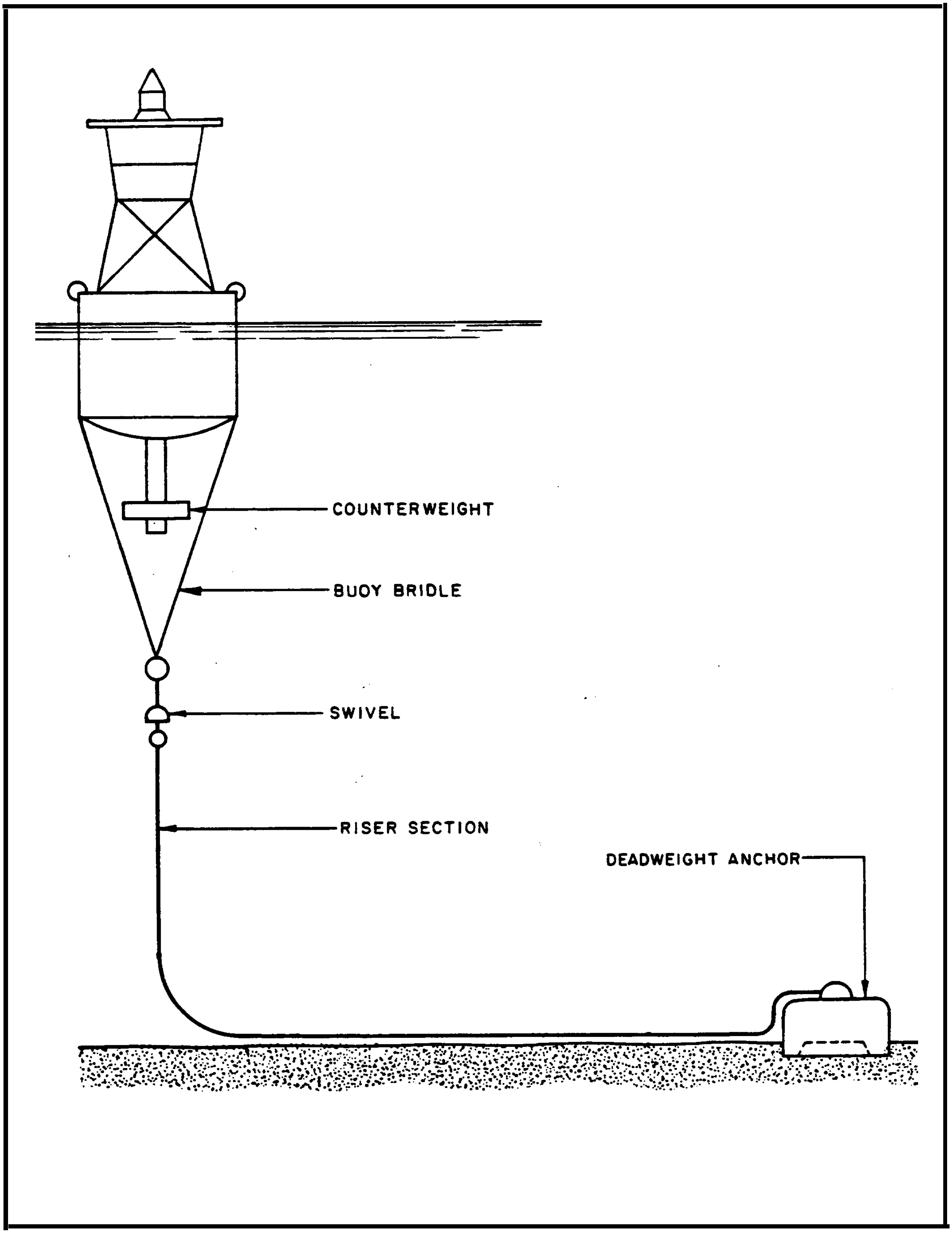


FIGURE 10
Typical Mooring Arrangement for Navigational Buoy

Section 3. FLEET-MOORING COMPONENTS

1. **FLEET-MOORING COMPONENTS.** Figure 11 presents the principal components of a free-swinging, riser-type fleet mooring. Components of a fleet mooring include anchors, sinkers, mooring chain, mooring-chain fittings, and buoys. The details of a fleet mooring vary with the type of mooring, but the principal components are illustrated by the riser-type mooring. The individual components shown in Figure 11 are discussed in detail below.

2. **ANCHORS.** Several types of anchors can be used in fleet moorings, including drag-embedment (conventional) anchors, pile anchors, deadweight anchors, and direct-embedment anchors. The advantages and disadvantages of each anchor are presented in Table 3. Detailed procedures for selecting drag-embedment anchoring systems are presented in Section 5.

a. Drag-Embedment (Conventional) Anchors. Drag-embedment anchors are the most commonly used anchors in Navy fleet moorings. The important elements of most drag-embedment anchors are summarized in Figure 12, which presents the Navy Stockless anchor. The anchor shank is used to transfer the mooring-line load to the anchor flukes, which have large surface areas to mobilize soil resistance. The leading edge of a fluke, called the fluke tip, is sharp so that the fluke will penetrate into the seafloor. Tripping palms, located at the trailing edge of the flukes, cause the flukes to open and penetrate the seafloor. The shank-fluke connection region is called the crown of the anchor. Some anchors have a stabilizer located at the anchor crown and oriented perpendicularly to the shank. Stabilizers resist rotational instability of the anchor under load. (See Figure 12B.)

Drag-embedment anchor performance is sensitive to seafloor soil type. Table 4 summarizes the general performance of drag-embedment anchors according to soil type. Information on soils-investigation requirements for anchor design may be found in the Handbook of Marine Geotechnology (NCEL, 1983a).

(1) Anchor Performance. Drag-embedment anchors are designed to resist horizontal loading. A near-zero angle between the anchor shank and the seafloor (shank angle) is required to assure horizontal loading at the anchor. Sufficient scope in the mooring line will result in a near-zero shank angle. (Scope is defined as the ratio of the length of the mooring line, from the mooring buoy to the anchor, to the water depth.) As the shank angle increases from zero, the vertical load on the anchor increases and the holding power of the anchor decreases.

Figure 13 shows how a drag-embedment anchor performs under loading. Drag-embedment anchors drag considerably before reaching peak holding capacity. The amount of drag depends upon anchor type and seafloor characteristics. When an anchor with movable flukes is loaded, the tripping palms will cause the anchor flukes to penetrate the seafloor as the anchor is dragged. (See Figure 13A.)

The ability of an anchor to penetrate the seafloor is primarily a function of the fluke angle (the fluke angle is the angle between the fluke and the shank). The optimum fluke angle depends primarily upon the,seafloor

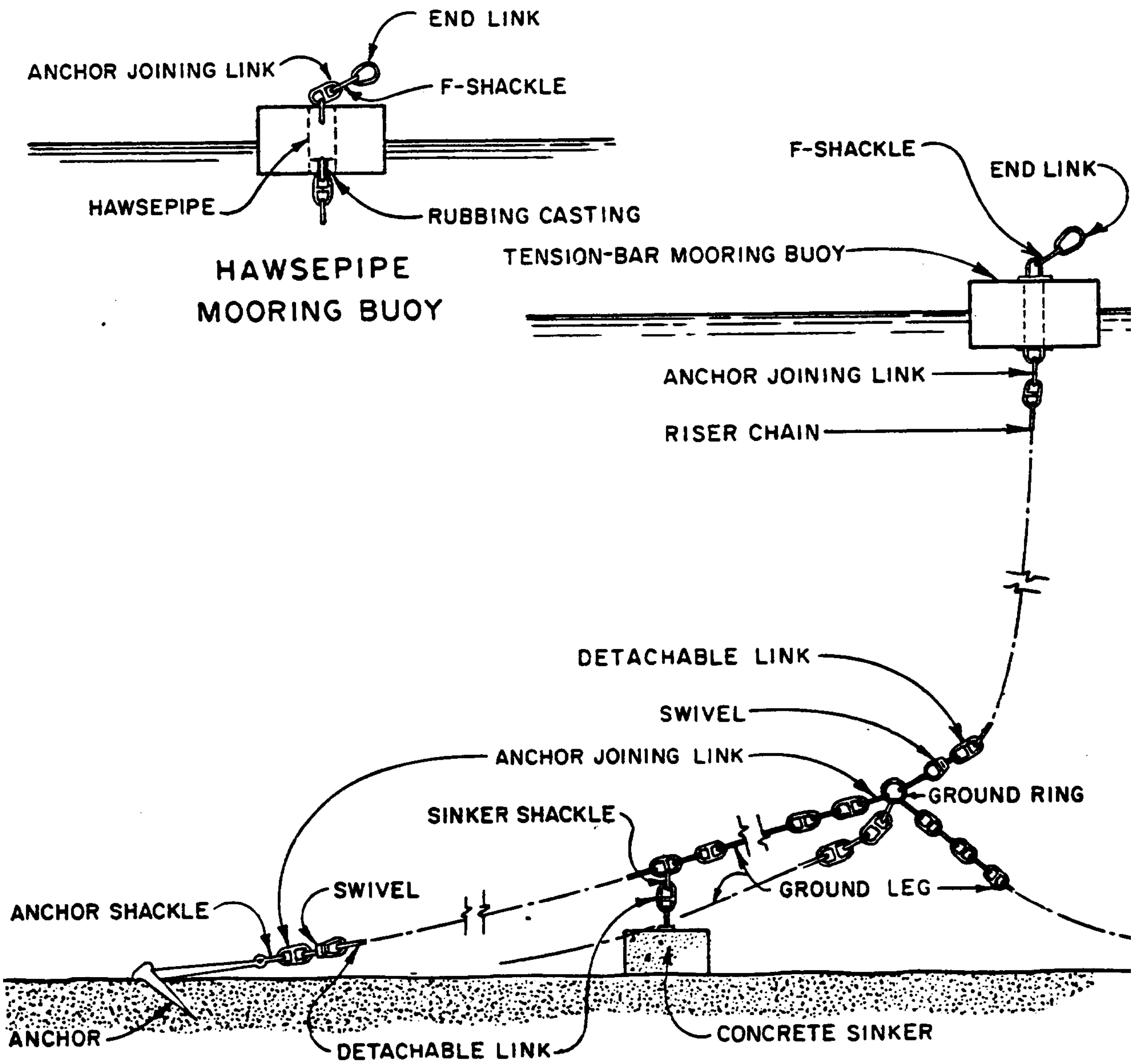


FIGURE 11
Components of a Free-Swinging, Riser-Type Mooring

TABLE 3
Advantages and Disadvantages of Various Anchors

Drag-Embedment Anchor	Deadweight Anchor
Advantages High capacity (> 100,000 pounds) is achievable. Broad range of anchor types and sizes are available. Standard, off-the-shelf equipment can be used. Broad use experience exists. Continuous resistance can be provided even though maximun capacity be exceeded. Anchor is recoverable. **Disadvantages** Anchor is incapable of sustaining uplift loading. Anchor is usable with wire or chain mooring lines. Anchor does not function in hard seafloors. Anchor behavior is erratic in layered seafloors. Resistance to uplift is low; therefore, large line scopes are required to cause near horizontal loading at seafloor. Penetrating/dragging anchor can damage pipelines, cables, and so forth.	**Advantages** Anchor has large vertical reaction component, permitting shorter mooring-line scope. No setting distance is required. Anchor has reliable holding force because most holding force is due to anchor mass. Simple, onsite constructions are feasible. Size is limited only to load-handling equipment. Anchor is economical If material is readily available. Anchor is reliable on thin sediment cover over rock. Mooring-line connection is easy to inspect and service. **Disadvantages** Lateral load resistance is low compared to that for other anchor types. Usable water depth is reduced; deadweight can be an undesirable obstruction. Anchor requires large-capacity load-handling equipment for placement.
Pile Anchor	**Direct-Embedment Anchor**
Advantages High capacity (> 100,000 pounds) is achievable. Anchor resists uplift as well as lateral loads. permitting use with short mooring-line scopes. Anchor setting is not required. Anchor dragging is eliminated. Short mooring-line scopes permit use in areas of limited area room or where minimum vessel excursions are required. Drilled and grouted piles are especially suitable for hard coral or rock seafloor. Anchor does not protrude above seafloor. driven piles are cost-competitive with other high-capacity anchors when driving equipment is available. Wide range of sizes and shapes is possible (such as pipe and structural shapes). Field modifications permit piles to be tailored to suit requirements of particular application. Accurate anchor placement is possible. Anchor can be driven into layered seafloors. **Disadvantages** Taut moorings may aggravate ship response to waves (low resilience). Taut lines and fittings must continuously withstand high stress levels. Drilled and grouted piles incur high installation coats and require special skills and equipment for installation. Costs increase rapidly in deep water or exposed locations where special installation vessels are required. Special equipment (pile extractor) is required to retrieve or refurbish the mooring. More extensive site data are required than for other anchor types. Pile-driving equipment must maintain Position during installation. [1]True for any taut mooring	**Advantages** High capacity (> 100,000 pounds) is achievable. Anchor resists uplift as well as lateral loads, permitting shorter mooring-line scope. Anchor dragging is a laminated. Anchor has higher holding capacity-to-weight ratio than any other type of anchor. Handling is simplified due to relatively light weight. Anchors can function on moderate slopes and in hard seafloors.[1] Instillation is simplified due to the possibility of instantaneous embedment on seafloor contact.[1] Accurate anchor placement is possible. Anchor does not protrude above seafloor. Anchor can accommodate layered seafloors or seafloors with variable resistance because of continuos power expenditure during penetration.[2,3,4] Penetration is controlled and can be monitored[2,3,4] **Disadvantages** Anchor is susceptible to cyclic load-strength reduction when used in taut moorings in loose-l and or coarse-silt seafloors. For critical moorings, knowledge of soil engineering properties is required. Anchor typically is not recoverable. Special consideration is needed for ordnance.[1] Anchor cable is susceptible to abrasion and fatigue.[1] Gun system is not generally retrievable in deep water (>1,000 feet).[1] Surface vessel must maintain position during installation.2,3,4 Operation is limited to sediment seafloors.[2,3] [1]Propellant-embedded l nchor [2]Screw-in anchor [3]Vibrated-in anchor [4]Driven anchor

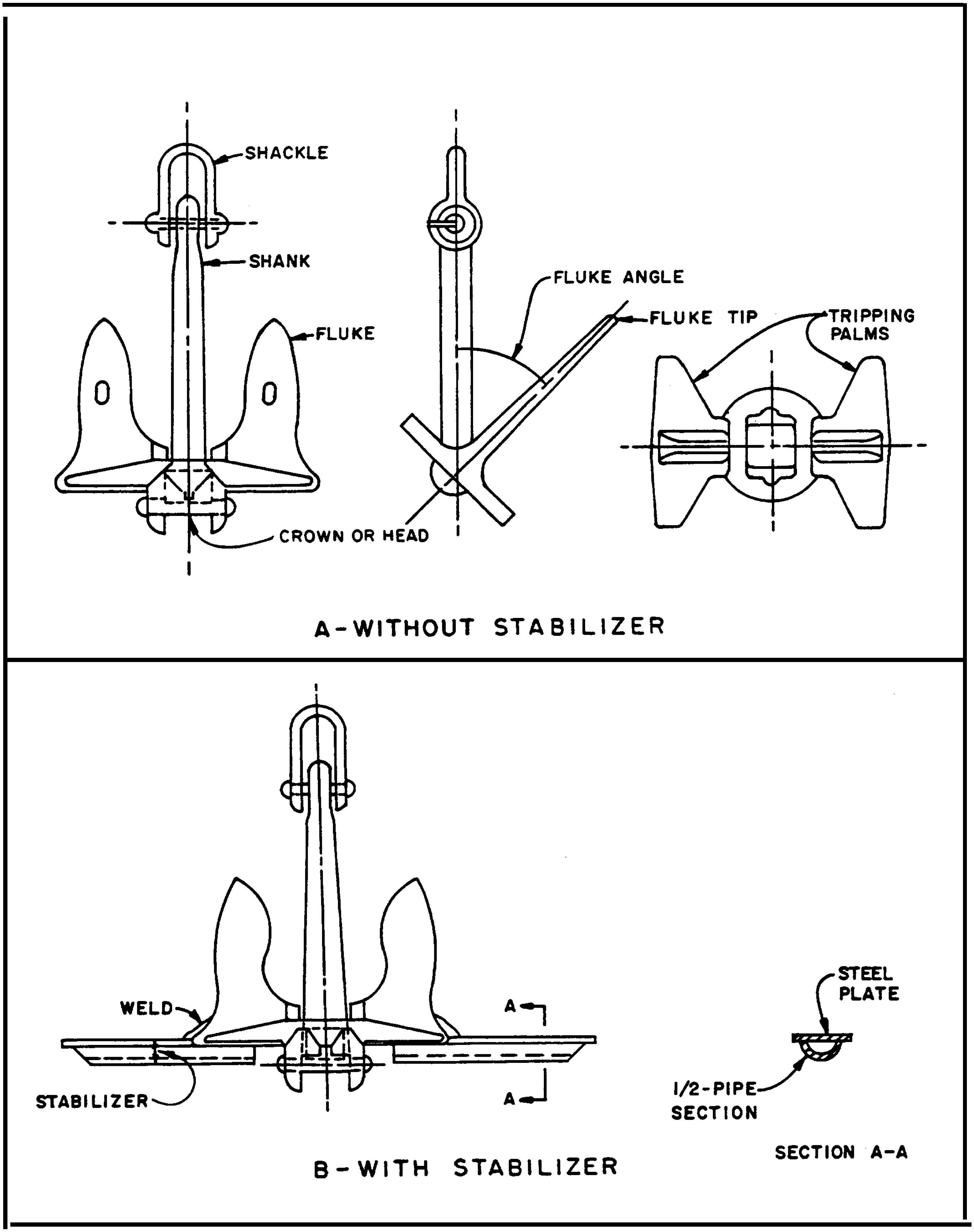


FIGURE 12
Elements of a Drag-Embedment Anchor
(Navy Stockless Anchor)

TABLE 4
Performance of Drag-Embedment Anchors According to Soil Type

Soil Type	Description	Anchor Capacity
Mud	Normally consolidated, very soft to soft, silt- to clay-size sediment typical of harbors and bays	Holding capacity is reasonably consistent provided anchor flukes trip open. Certain anchors require special care during installation to ensure fluke tripping.
Sand	Medium to dense sand typical of most nearshore deposits	Holding capacity is consistent provided appropriate sand fluke angle is used.
Clay l..l..l	Medium to stiff cohesive soil; soil shear strength considered constant with depth	Good holding capacity which will range between that provided for sand and mud. Use mud value conservatively or linearly interpolate between sand and mud anchor capacity. For stiff clay, use sand fluke angle.
Hard Soil . .	Very stiff and hard clay; seafloor type can occur in high-current, glaciated, dredged areas	Holding capacity is consistent provided anchor penetrates; may have to fix flukes open at sand fluke angle to enhance embedment; jetting may be required. Use holding capacity equal to 75 percent sand anchor capacity.
Layered Seafloor ..o	Seafloor consisting of sand, gravel, clay, and/or mud layers	Anchor performance can be erratic. Contact Naval Civil Engineering Laboratory (NCEL) for assistance if anchors cannot be proof-loaded to verify safe capacity.
Coral/ Rock	Can also include areas where coral or rock is overlain by a thin sediment layer that is insufficient to develop anchor capacity	Unsatisfactory seafloor for permanent moorings. Can be suitable for temporary anchoring if anchor snags on an outcrop or falls into a crevice. Consider propellant-embedded anchors; contact NCEL for assistance.

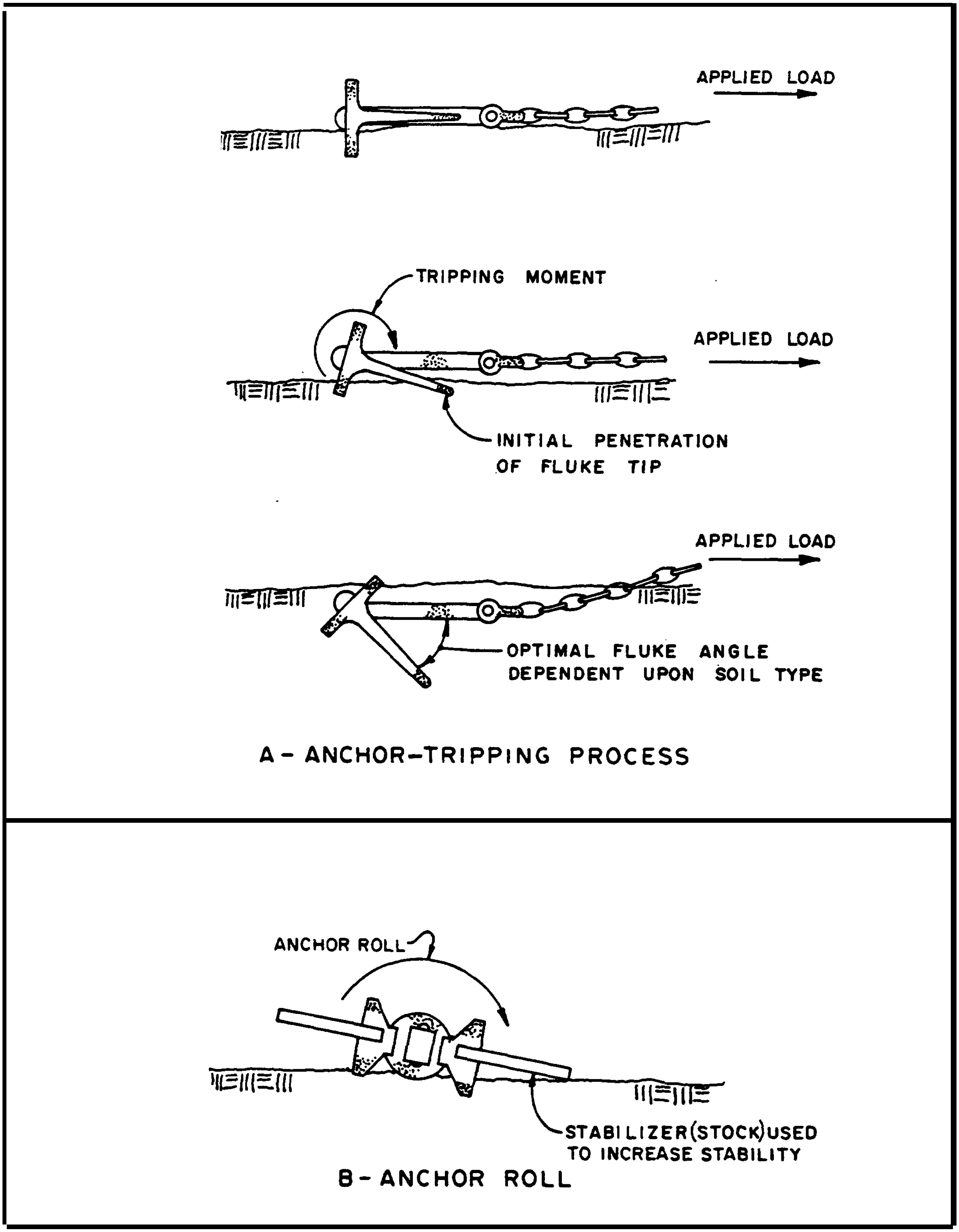


FIGURE 13
Performance of Drag-Embedment Anchor Under Loading

soil type. Values for mud range from 45 to 50 degrees and for sand from 29 to 35 degrees. In soft seafloors, the flukes of some anchors, such as the Stockless anchor, should be welded open to assure anchor tripping.

(2) Types of Drag-Embedment Anchors. Figure 14 presents several drag-embedment anchors which have been tested by the Naval Civil Engineering Laboratory (NCEL). Detailed drawings of these anchors are presented in DM-26.6, Section 4, along with tables which furnish dimensional and strength data for each of the anchors. Procedures for drag-embedment anchor selection are presented in Section 5 (DM-26.5).

The Navy Stockless anchor (Figure 12) was designed for use as a ship's anchor. Consequently, it is easily recoverable and less efficient than most anchors available for fleet-mooring use. Performance of the Stockless anchor is enhanced by using stabilizers and, when the anchor is used in mud, by welding the flukes open. Despite its limitations, the Stockless anchor has been tested extensively and is preferred for use in fleet moorings. Subsection 5.6 presents methods for using Stockless anchors to satisfy the majority of fleet-mooring holding-capacity requirements.

The NAVFAC Stato anchor was developed specifically for use in Navy fleet moorings. The Stato anchor is a more efficient anchor than the Stockless anchor, and it has been used for fleet moorings in the past. Subsection 5.6 presents procedures for sizing and selecting Stato anchors.

b. Pile Anchors. A pile anchor consists of a structural member, driven vertically into the seafloor, designed to withstand lateral (horizontal) and axial (vertical) loading. Pile anchors are generally simple structural steel shapes fitted with a mooring-line connection. Pile anchors are installed by driving, drilling, or jetting. High installation costs usually preclude their use when drag-embedment, deadweight, or direct-embedment anchors are available. Pile anchors are particularly well-suited when a short-scope mooring is desired, when rigid vessel positioning is required, when seafloor characteristics are unsuitable for other anchor types, or when material and installation equipment are readily available.

(1) Anchor Performance. Piles achieve their lateral and axial holding capacity by mobilizing the strength of the surrounding seafloor soil. The lateral strength of a pile anchor is derived from lateral earth pressure and its axial strength is derived from skin friction. (See Figure 15.) Pile anchors may fail in three ways: by pulling out of the seafloor, by excessive deflection, or by structural failure. In the first, the anchor pile may pull out of the seafloor when uplift loads exceed the axial capacity offered by skin friction. In the second, lateral loads applied at the upper end of the pile will generally cause the pile head and surrounding soil to deflect. Excessive and repeated deflections of the pile head and surrounding soil will cause a reduction in soil strength and may result in failure of the pile anchor. Finally, large lateral loads on a Pile may result in stresses in the pile which exceed its-structural strength. Pile-anchor design considers each of these failure modes.

(2) Types of Pile Anchors. Three examples of pile anchors are presented in Figure 16. Each of these pile anchors uses a different type of

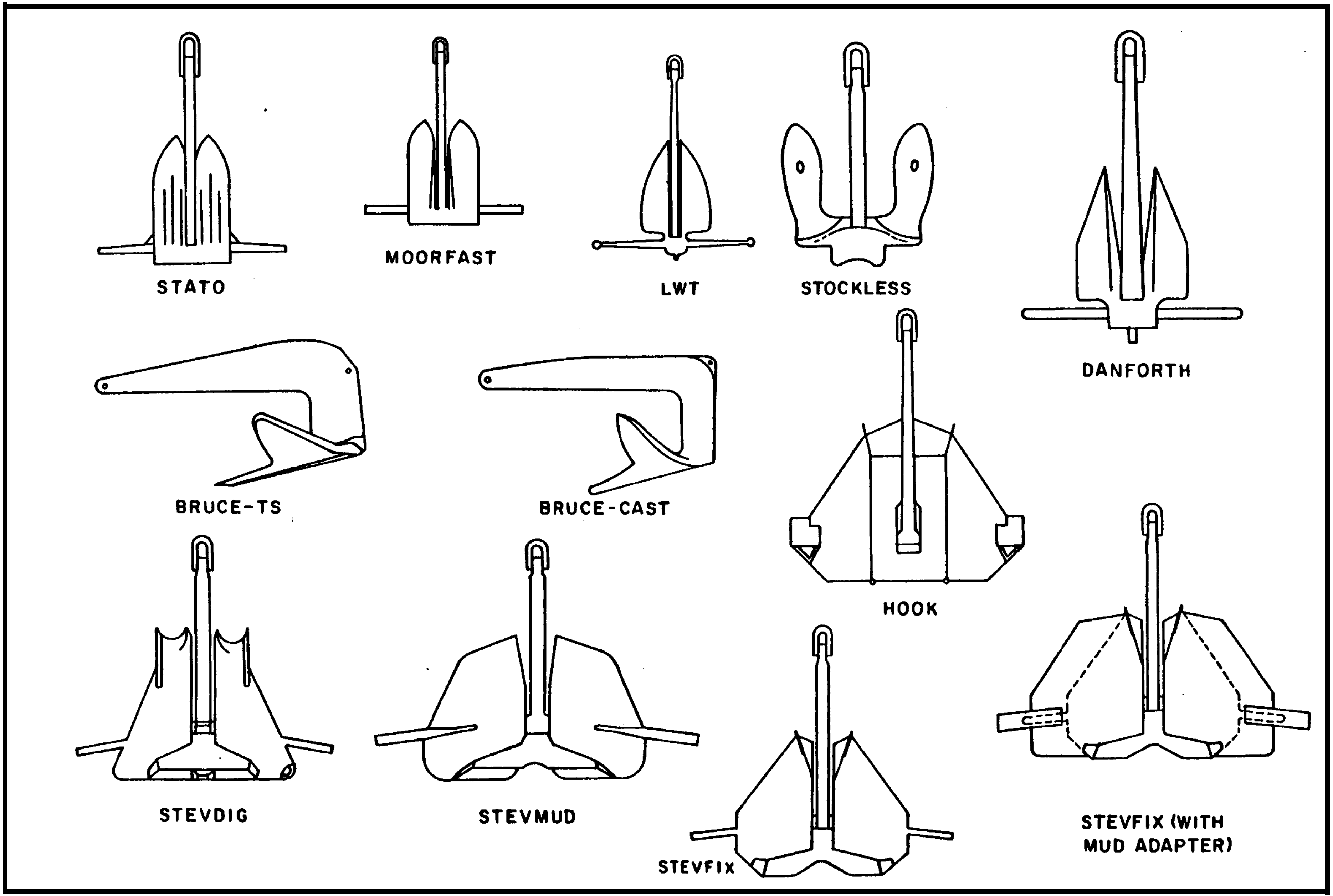


FIGURE 14
Types of Drag-Embedment Anchors

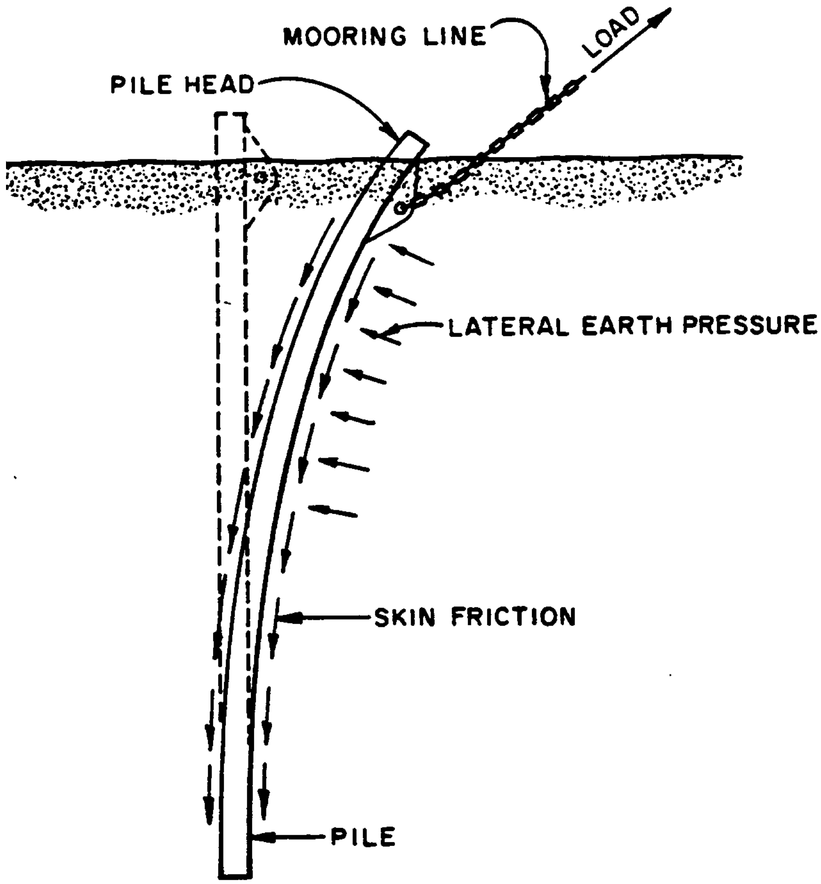


FIGURE 15
Lateral Earth Pressure and Skin Friction on a Pile Anchor

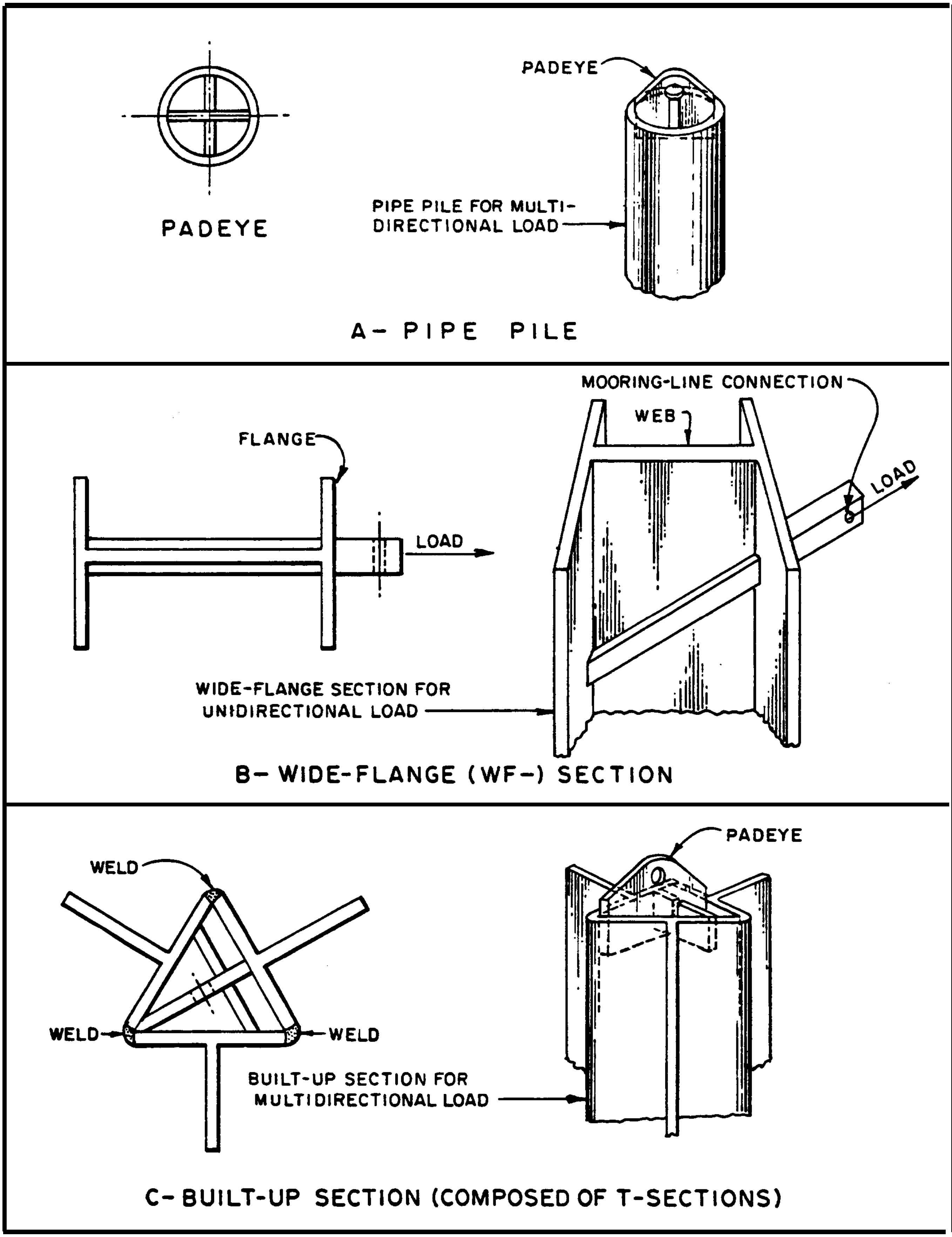


FIGURE 16
Types of Pile Anchors

structural steel shape: a pipe pile (Figure 16A), a wide-flange (WF-) section (Figure 16B), or a built-up section composed of T-sections (Figure 16C). Pipe piles are well-suited as anchors because they can sustain loading equally in any direction (although the mooring-line connection may not). In contrast, wide-flange sections possess both a weak and a strong axis against bending. Built-up sections may be fabricated with other strutural shapes to resist either multidirectional or unidirectional loading. A pile anchor must be fitted with a mooring-line connection. Typical mooring-line connections for pipe piles, WF-sections, and built-up sections are shown in Figures 16A, 16B, and 16C, respectively.

Several locations for mooring-line connections are shown in Figure 17. Soil strength generally increases with depth; therefore, locating the pile head below the seafloor (Figure 17A) places the pile in stronger soil. Furthermore, lateral pressure on the mooring chain contributes somewhat to the total capacity of the pile anchor. A chain bridle, located at or near the center of the pile (Figure 17B), can reduce the bending moment in a pile. Locating the mooring-line connection padeye at or near the center of the pile (Figure 17C) has the same effect as the above method of connection but at an increased cost in fabrication. Detailed design procedures for pile anchors may be found in Handbook of Marine Geotechnology, Chapter 5 (NCEL, 1983a).

c. Deadweight Anchors. A deadweight anchor is a large mass of concrete or steel which relies on its own weight to resist lateral and uplift loading. Lateral capacity of a deadweight anchor will not exceed the weight of the anchor and is more often some fraction of it. Deadweight-anchor construction may vary from simple concrete clumps to specially manufactured concrete and steel anchors with shear keys. Deadweight anchors are generally larger and heavier than other types of anchors. Installation of deadweight anchors may require large cranes, barges, and other heavy load-handling equipment.

(1) Anchor Performance. Deadweight anchors are designed to withstand uplift and lateral loads and overturning moments. Uplift loads are resisted by anchor weight and by breakout forces. Lateral capacity is attained by mobilizing soil strength through a number of mechanisms, depending upon anchor and soil type. In its most simple form, the lateral load is resisted by static friction between the anchor block and the seafloor. Static-friction coefficients are generally less for cohesive seafloors (clay or mud) than for cohesionless seafloors (sand or gravel). Friction-coefficient values are often very small immediately after anchor placement on cohesive seafloors. However, these values increase with time as the soil beneath the anchor consolidates and strengthens. Deadweight anchors should not be used on sloped seafloors.

A deadweight anchor will drag when the applied load exceeds the resistance offered by static friction. Once dragging occurs, the anchor tends to dig in somewhat as soil builds up in front of the anchor (Figure 18). Under these circumstances, the lateral capacity of the anchor *results* from shear forces along the anchor base and sides and from the forces required to cause failure of the wedge of soil in front of the anchor. Suction forces are induced at the *rear* of the anchor, but these are normally neglected for design purposes.

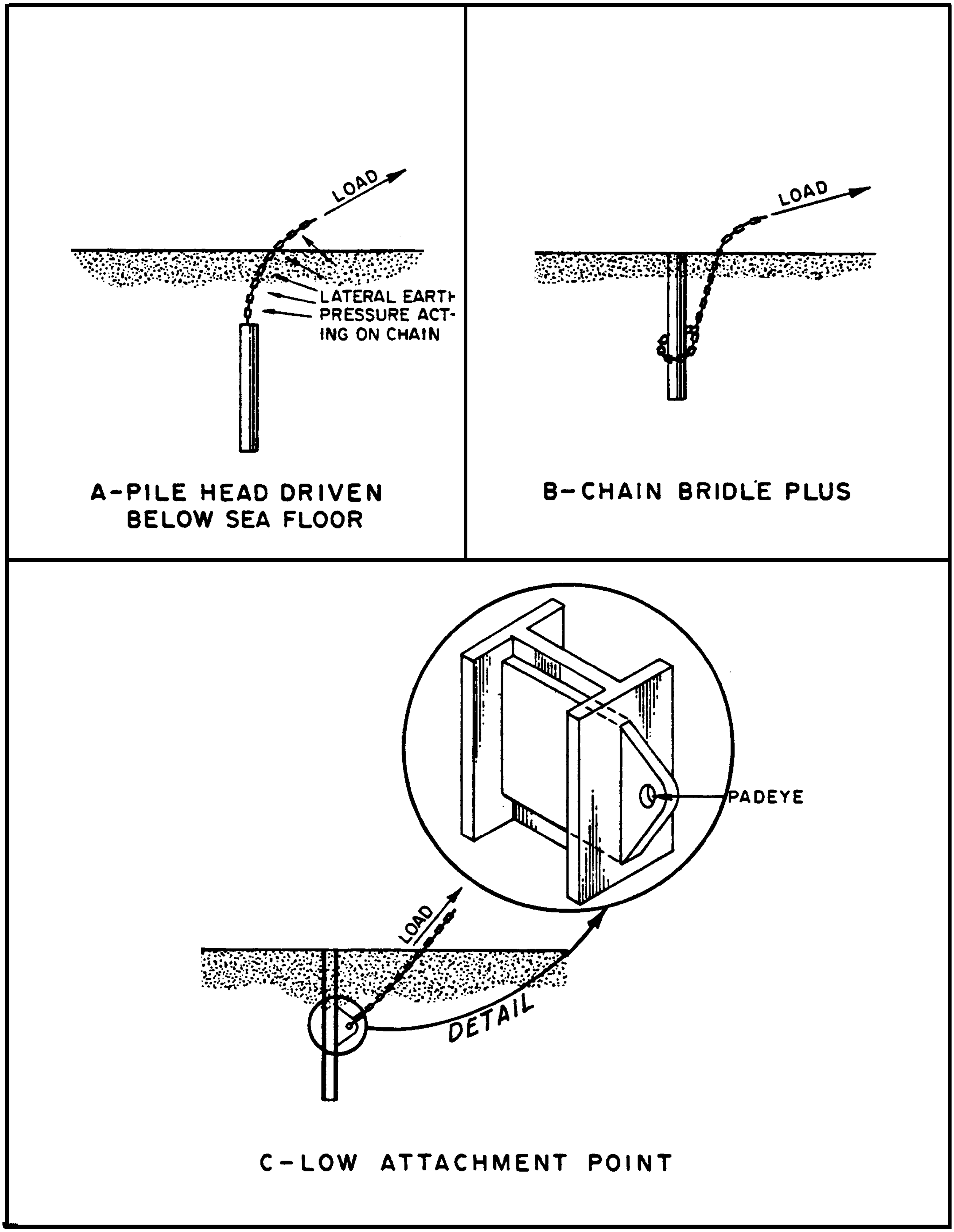


FIGURE 17
Alternative Mooring-Line Connections

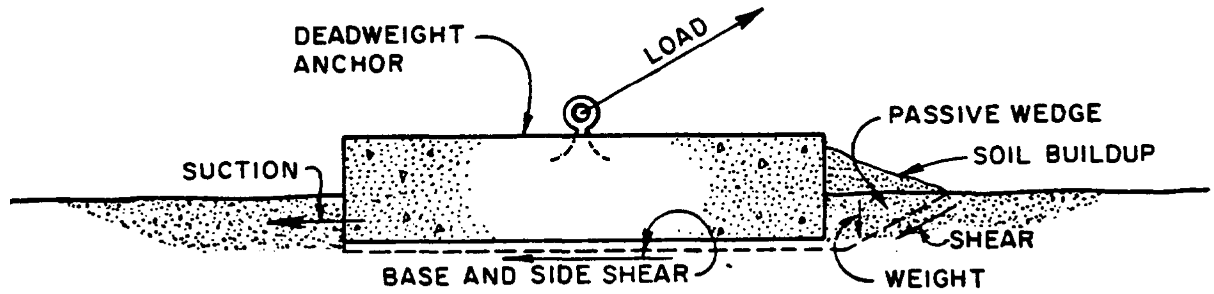


FIGURE 18
Loads Acting on a Deadweight Anchor

The lateral capacity of a deadweight anchor on cohesive seafloors may be increased with shear keys (cutting edges), as shown in Figure 19. Shear keys are designed to penetrate weaker surface soil to the deeper, stronger material. Shear keys may be located on the perimeter of the anchor to prevent undermining of the anchor. Shear keys are not used for cohesionless soils because they provide minimal additional lateral capacity.

(2) Types of Deadweight Anchors. Deadweight anchors may be fabricated in a variety of shapes and from a variety of materials. Figure 20 presents several types of deadweight anchors. One of the major advantages of deadweight anchors is their simplicity. Therefore, the additional capacity offered by special modifications should be balanced against increased fabrication costs. Detailed design procedures for deadweight anchors may be found in <u>Handbook of Marine Geotechnology</u>, Chapter 4 (NCEL, 1983a).

d. <u>Direct-Embedment Anchors</u>. A direct-embedment anchor is driven, vibrated, or propelled vertically into the seafloor, after which the anchor fluke is expanded or reoriented to increase pullout resistance.

(1) Anchor Performance. Direct-embedment anchors" are capable of withstanding both uplift and lateral loading. Direct-embedment anchors achieve their holding capacity by mobilizing soil bearing strength. Figure 21 presents two modes of failure for direct-embedment anchors. Shallow anchor failure is characterized by removal of the soil plug overlying the anchor fluke as the anchor is displaced under loading. A deep anchor failure occurs when soil flows from above to below the anchor as the anchor is displaced under load. The tendency toward the shallow or deep anchor-failure mode depends upon the size of the anchor fluke and the depth of embedment. Direct-embedment anchors are sensitive to dynamic loading. Therefore, design procedures must include analysis of anchor capacity under cyclic and impulse loadings.

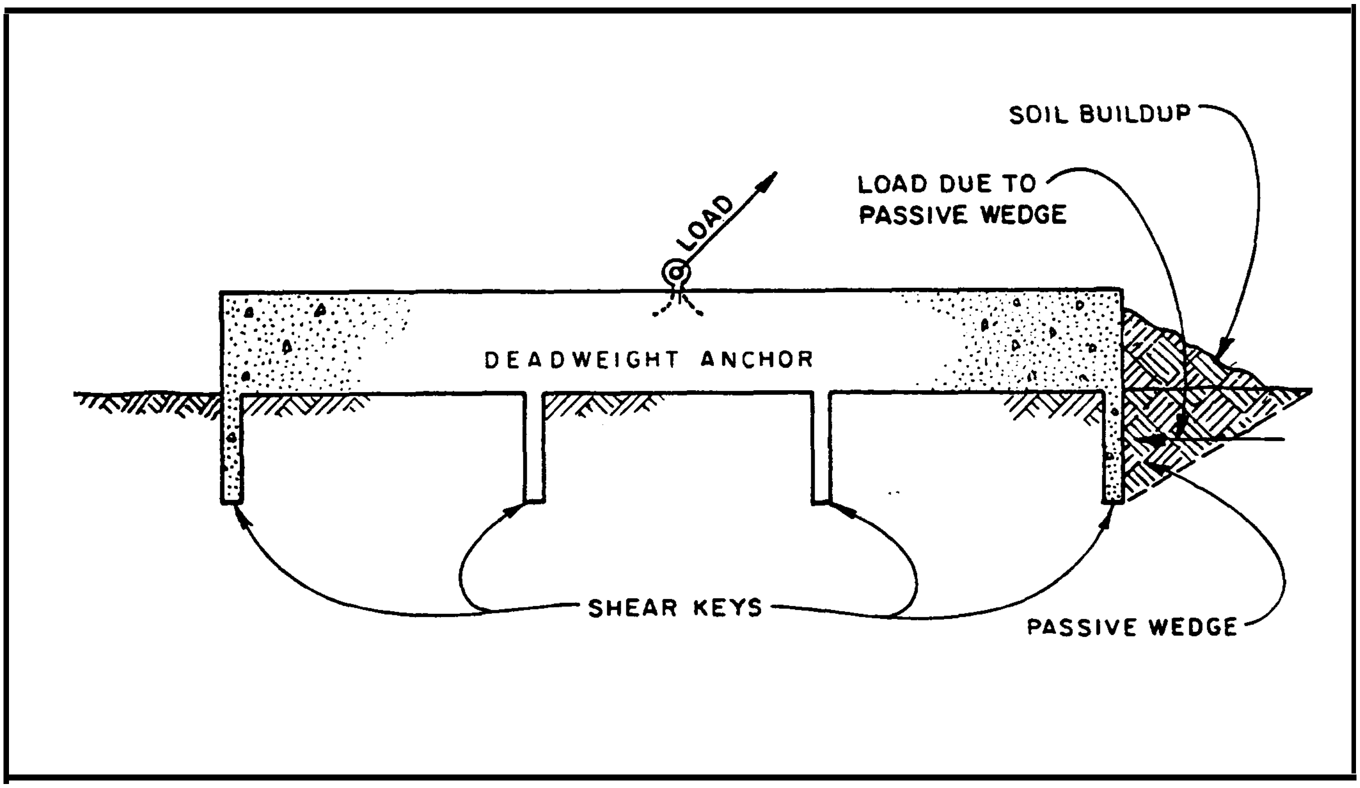


FIGURE 19
Deadweight Anchor With Shear Keys

(2) Types of Direct-Embedment Anchors. Several types of direct-embedment anchors have been developed. Propellant-embedded anchor (PEA) systems developed by NCEL are discussed below. A discussion of other types of direct-embedment anchors is presented in Handbook of Marine Geotechnology, Chapter 6 (NCEL, 1983a), along with detailed procedures for static and dynamic design of direct-embedment anchors.

A schematic of the CHESNAVFAC lOOK propellant-embedded anchor is shown in Figure 22. Flukes for the 100K propellant-embedded anchor are available for use in either sand or clay. The most significant advantage of the propellant-embedded anchor is that it can be embedded instantaneously into the seafloor. This process is illustrated in Figure 23. Propellant-embedded anchors are receiving increased use in fleet-mooring installations. However, use of a fleet mooring incorporating a propellant-embedded anchor will require consultation with the anchor developer (NCEL) and the operator (CHESNAVFAC FPO-1).

3. SINKERS . A sinker is a weight , usually made of concrete, used to assure horizontal loading at the anchor and to absorb energy. The sinker used in standard Navy moorings is shown in Figure 24. Dimensions of the sinker depend upon desired sinker weight. A steel rod (hairpin) is cast into the sinker to provide for connection to a mooring chain. Dimensional data and quantities of materials required to fabricate standard concrete sinkers are given in Tables 77 and 119 of DM-26.6, Section 6.

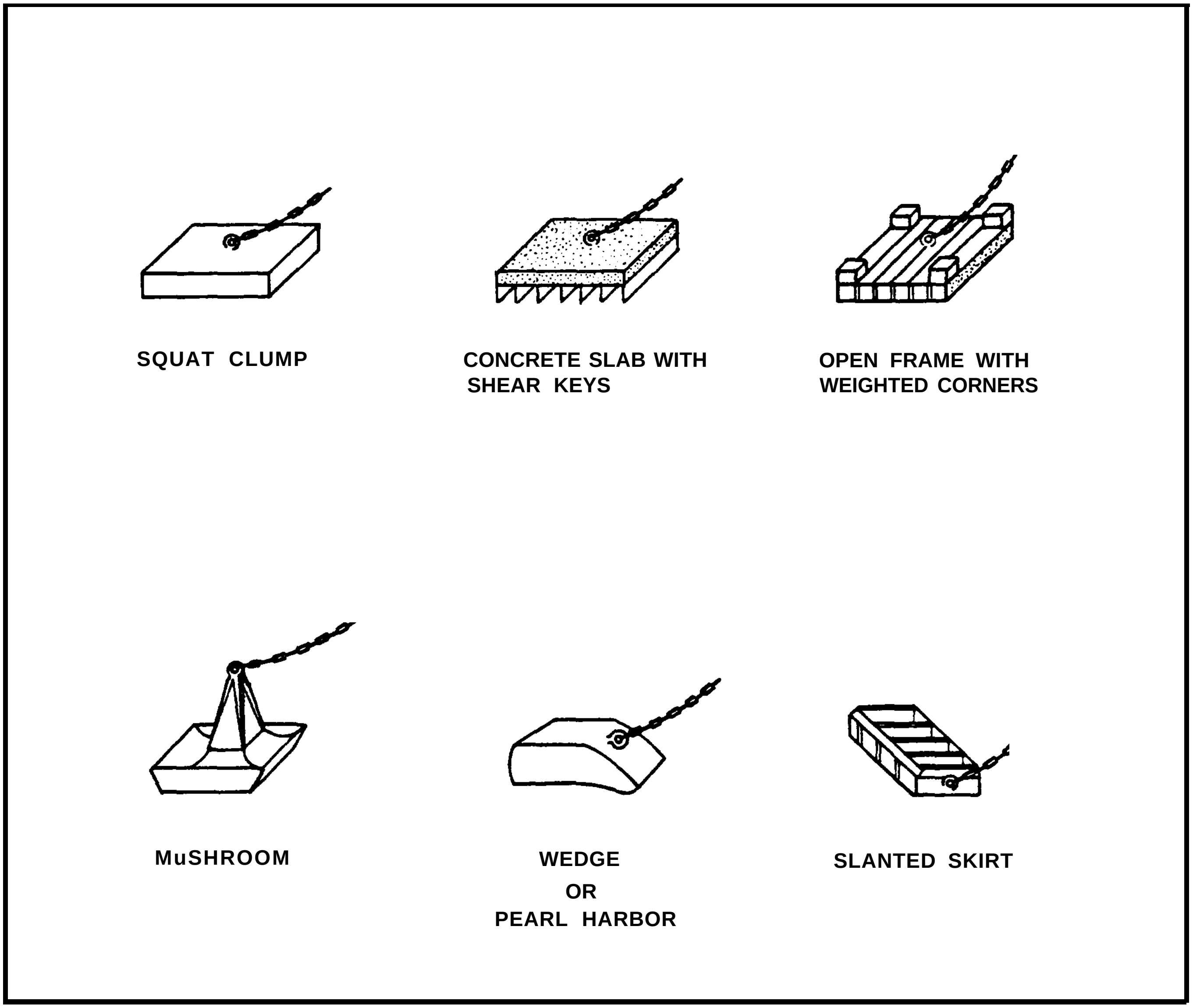


FIGURE 20
Types of Deadweight Anchors

Placing a sinker on a mooring leg will affect the energy-absorbing characteristics of *a* mooring system; a well-placed, adequately sized sinker can enhance the energy-absorbing characteristics of a mooring. However, improper sinker weight or placement may have the opposite effect. A discussion of sinkers and energy absorption is presented in Section 4.

The connection between the mooring chain and the sinker is critical to design. If this connection fails, the sinker will be lost and the entire mooring may fail. Therefore, certain precautions must be observed. First, the connection must allow free movement of the chain links to avoid distortion and failure of the links. Second, a sinker must not be cast around the chain itself.

4. **MOORING CHAIN.** Chain is used in all standard Navy moorings in lieu of other mooring-line types, such as synthetic fiber, natural fiber, or wire

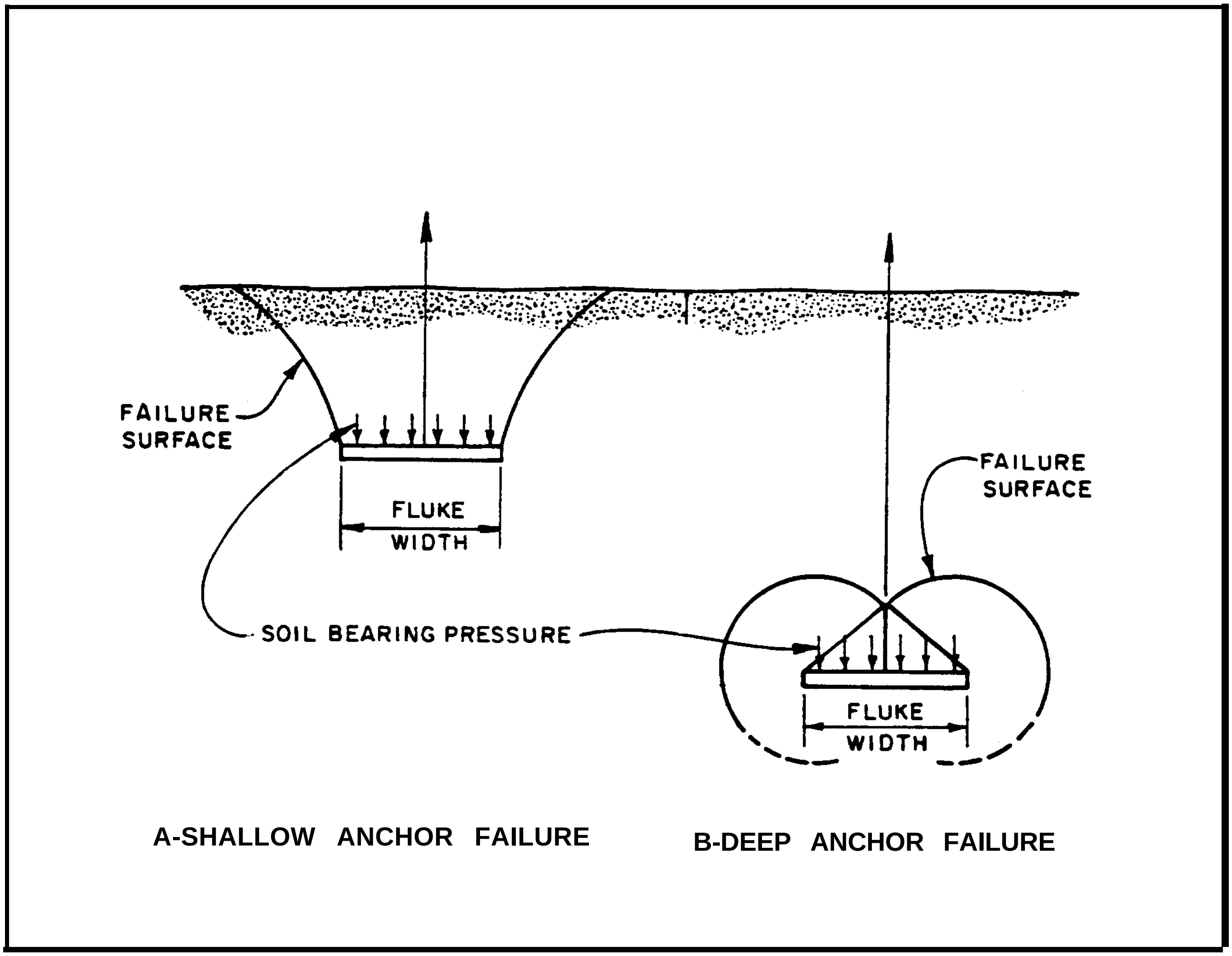


FIGURE 21
Failure Modes for Direct-Embedment Anchors

rope, because the Navy has a large amount of experience with chain. Also, chain has relatively good resistance to abrasion and has good shock-absorbing characteristics.

Mooring chain with links having center cross-bars is called stud link chain. The general features of stud link chain are presented in Figure 25. The center stud is designed to hold the link in its original shape under tension and to prevent the chain from kinking when it is piled. The different types of chain, the different types of chain links, chain size, chain strength, and chain protection are summarized in the following paragraphs.

a. Chain Types. There are three major types of mooring chain used by the Navy: cast, flash butt-welded, and dilok. These chain types differ from one another in their methods of manufacture and their strengths. Both cast and flash butt-welded stud link chain are used in Navy fleet moorings,. while dilok is used primarily as ship's chain.

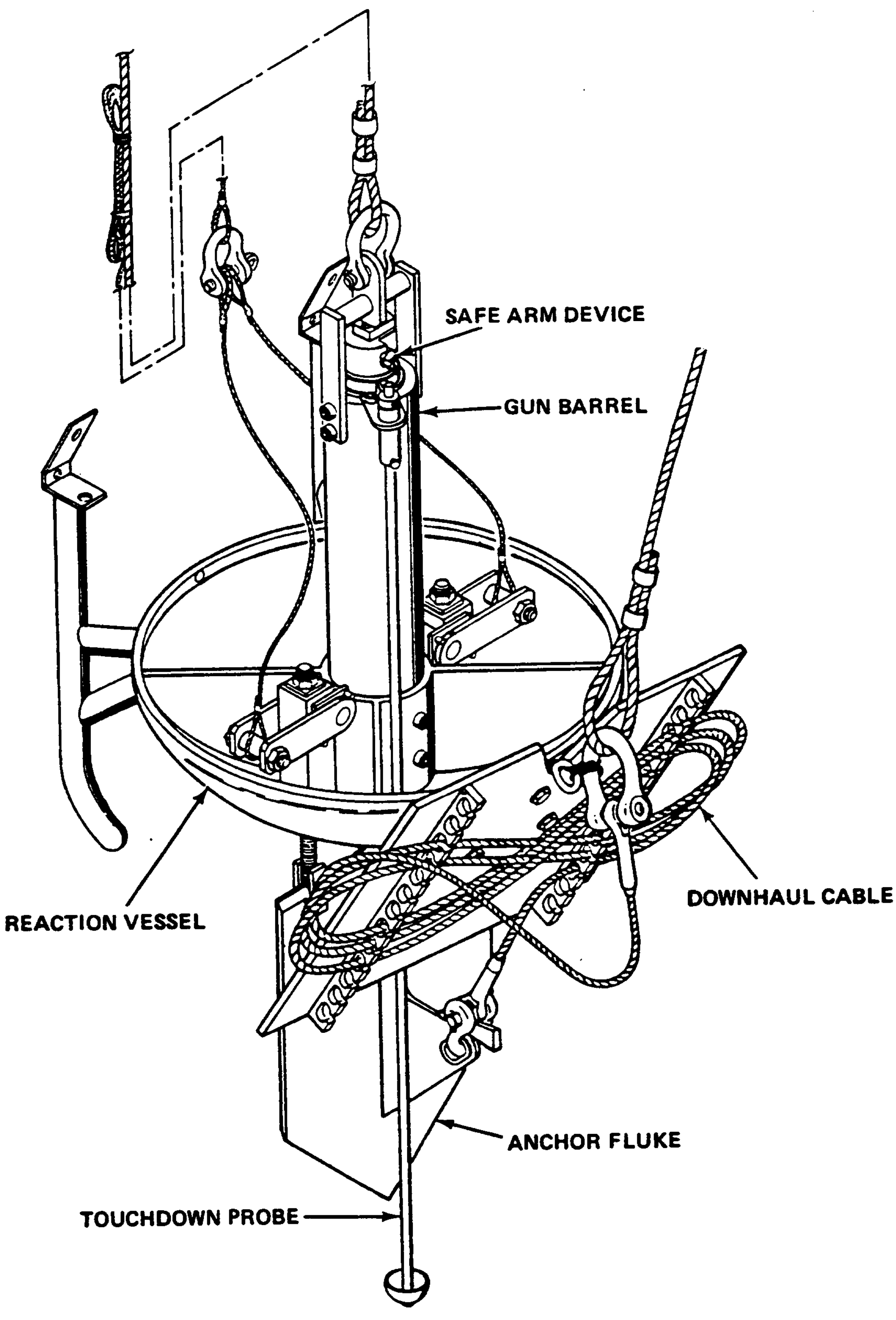


FIGURE 22
Schematic of CHESNAVFAC 100K Propellant-Embedded Anchor

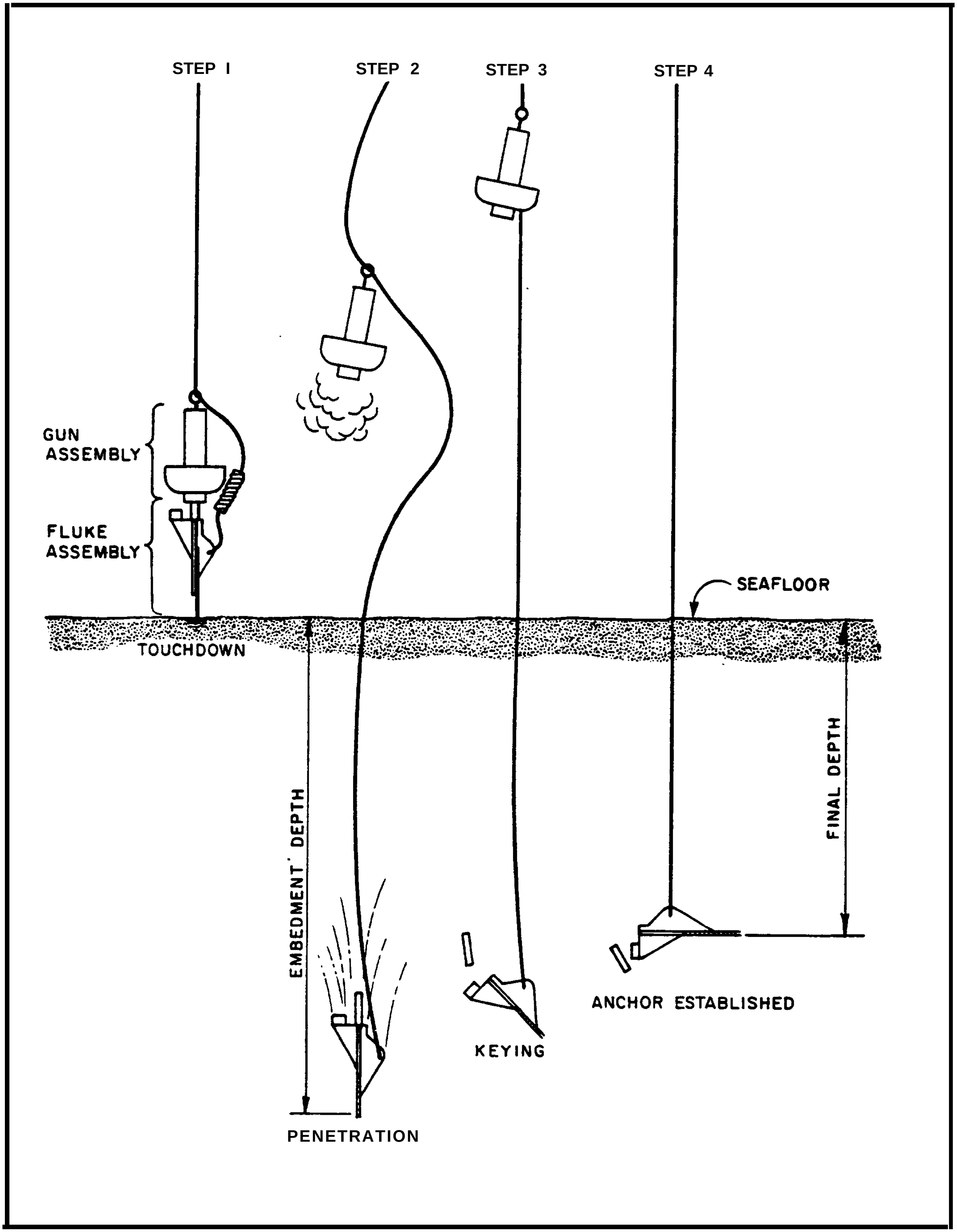


FIGURE 23
Penetration and Keying of a Propellant-Embedded Anchor

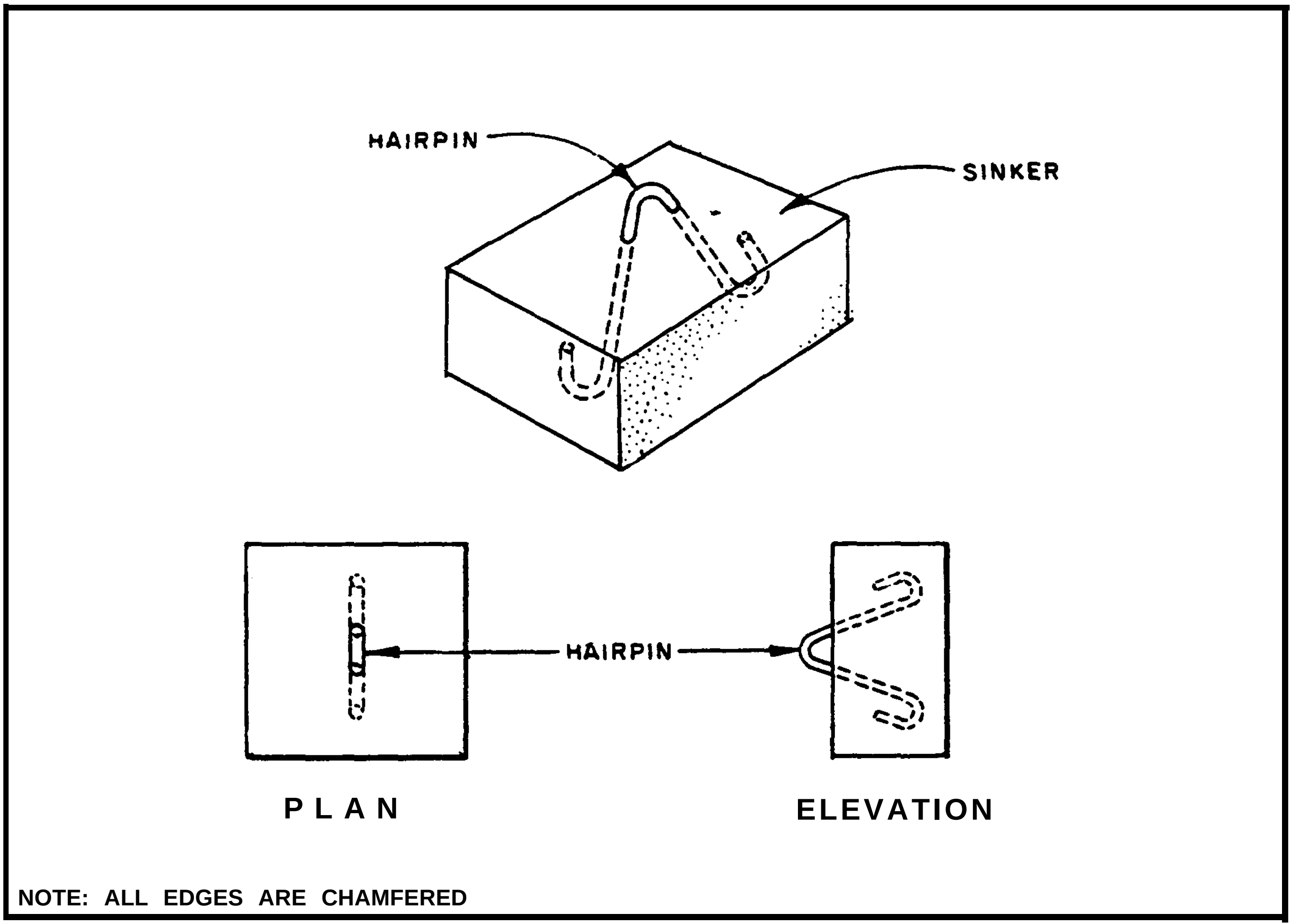


FIGURE 24
Concrete Sinker Used in Standard Navy Moorings

In standard fleet moorings, both cast and flash butt-welded chain are referred to as Navy common A-link chain. The commercially available equivalent is known as American Bureau of Shipping (ABS) stud link chain. ABS stud link chain is available in several grades, which are classified by ABS according to chain strength: Grade 1, Grade 2, Grade 3, oil-rig quality, and extra-strength. Navy common A-link chain is slightly stronger than ABS Grade 2 chain, but the latter is an acceptable substitute.

(1) Cast Chain. The stud is cast as an integral part of a cast chain link. A cast chain link is shown in Figure 26A. Due to internal imperfections (defects), poor grain structure, and poor surface integrity commonly associated with the casting process, cast chain is perceived as being less desirable than flash butt-welded chain. These internal defects are presumed to make the chain vulnerable to corrosion and similar strength-degradation mechanisms. This vulnerability can be minimized through adequate inspection and quality-control techniques. One advantage of cast chain is that the stud, being an integral part of the link, cannot be lost.

(2) Flash Butt-Welded Chain. Two types of flash butt-welded chain links are shown in Figure 26B, the standard double stud weld link and the FM3

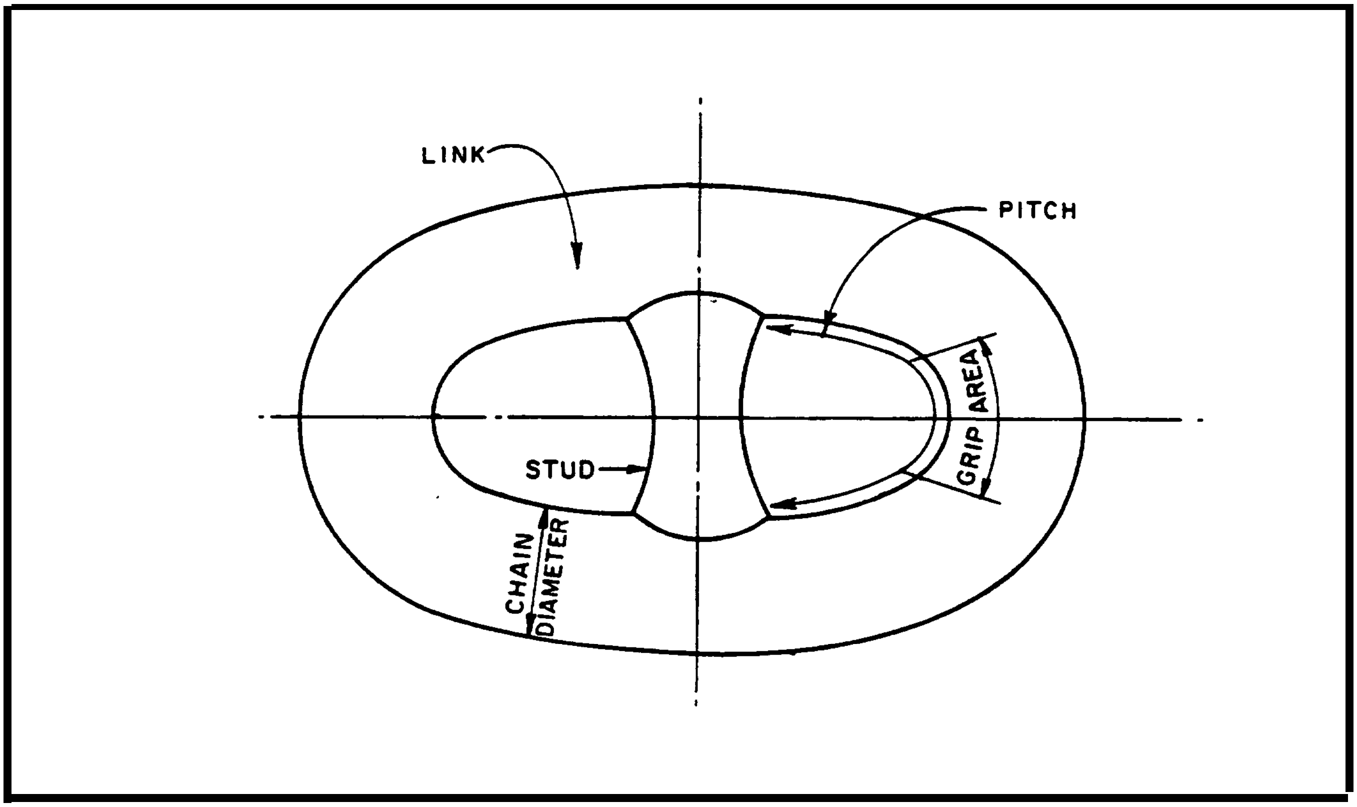


FIGURE 25
General Features of Stud Link Chain

link with pressed-in stud and threaded hole. Flash butt-welded chain may be fabricated by one of several methods. The general process involves forging a steel rod into a link shape and flash-butt welding the link closed at the joint. The stud is inserted before the metal cools and the link is pressed together on the stud. In some types, the stud is then welded in place. The type of fabrication used for flash butt-welded chain is believed to provide a better quality link, less prone to internal and surface imperfections, than a cast chain link.

(3) Dilok Chain. Dilok chain is a forged chain which requires no welding or adhesion of metal during fabrication. Figure 26C shows the general features of a dilok chain link. Each dilok link consists of a male and a female part. The link is fabricated by first punching out the female end and heating it. The male end is then threaded through the next link and inserted cold into the female end, which is then hammered down over the male end. This process results in a link, of relatively uniform strength, which is usually stronger than a cast or flash butt-welded link of the same size.

There is some evidence that dilok chain is more susceptible to failure than stud link chain. Due to the nature of construction of dilok chain, there is the possibility of water seeping in through the locking area and causing crevice corrosion which is not detectable during a visual inspection. The use of dilok chain in fleet moorings is not recommended due to the above

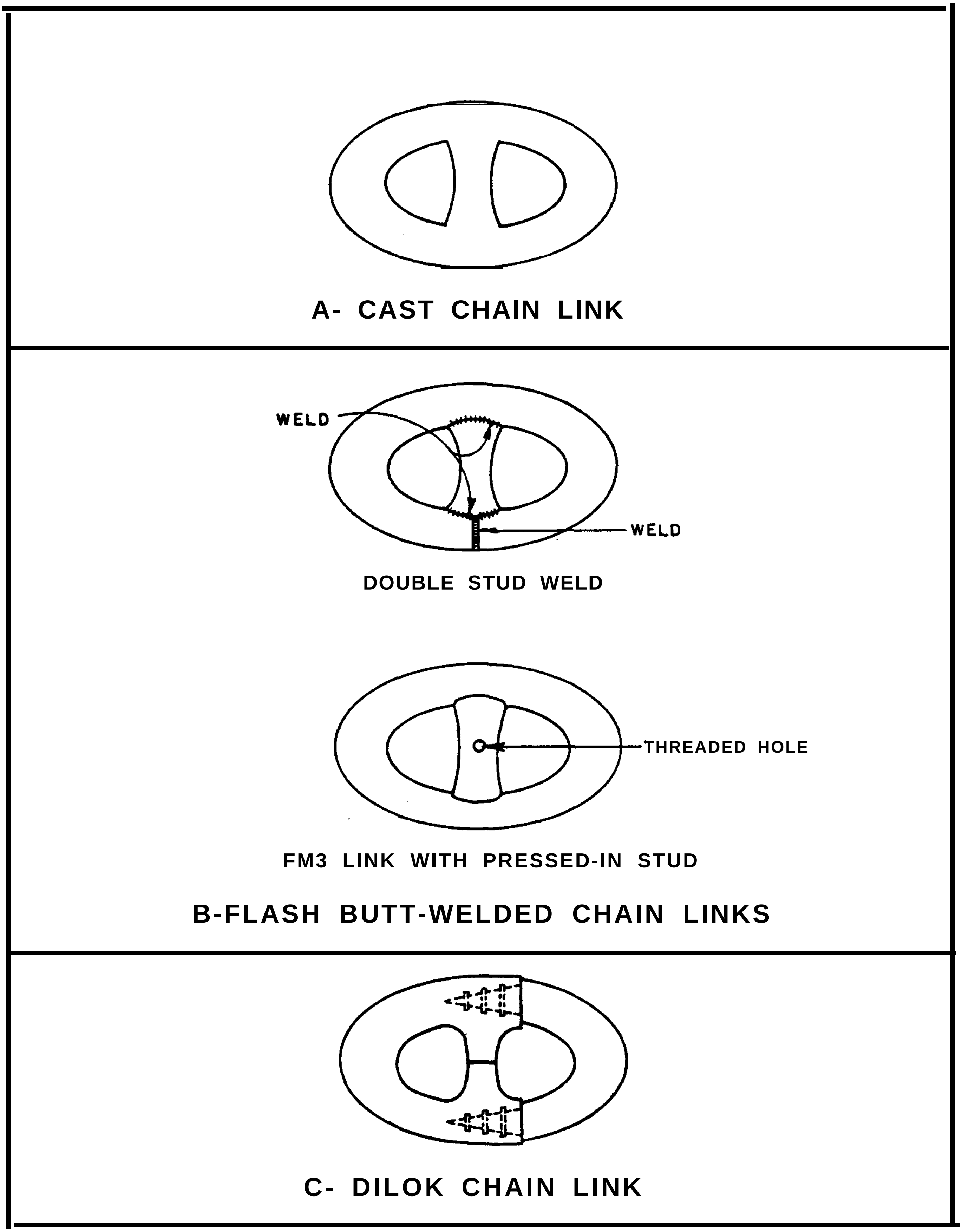


FIGURE 26
Links of Cast Chain, Flash Butt-Welded Chain, and Dilok Chain

concerns “about the long-term integrity of dilok chain in a corrosive marine environment.

b. Chain Links. Different sizes and shapes of links used to make up mooring chain are designated by letter (Figure 27):

(1) A-Link. This is the common type of link used.
(2) B-Link. The B-link is like an A-link but has a slightly larger chain diameter.
(3) C-Link. The C-link is a long stud link with a stud placed close to one end. A D- or F-shackle pin can pass through its larger opening.
(4) E-Link. The E-link is an enlarged open link, like the C-1ink but without a stud. (This is also called an open end link.) A D- or F-shackle eye can be threaded through an E-link.
(5) D-Link (D-shackle) and F-Link (F-shackle). Because D- and F-links are shackles, they are discussed in Subsection 3.5.a.(4).

B-, C-, and E-links, which always have proportionately larger chain diameters than those of A-links, are used extensively as intermediate links to go from a larger-diameter connector to a smaller-diameter A-link. (See Figure 27A.) Table 5 summarizes terminology and uses for chain links.

c. Chain Size. There are three measures of chain size important to the design of fleet moorings: chain diameter, chain pitch, and chain length. (See Figure 25.) The chain diameter is associated with chain strength. The inside length (pitch) of a chain link is important in determining the dimensions of sprockets used to handle chain. Chain length is generally reported in 15-fathom (90-foot) lengths known as shots. Mooring chain is normally ordered in either shots or half shots.

Size and weight data for each of the chain types discussed above are presented in DM-26.6: Table 94 gives these data for Navy common A-link chain, Tables 11 and 12 give these data for several grades of ABS stud link chain, and Tables 13, 14, and 15 give these data for several grades of dilok chain.

d. Chain Strength.

(1) Strength Tests. A break test and a proof test are required before chain is accepted from the manufacturer. A break test consists of loading three links of chain in tension to a designated breaking strength of that grade and size chain. The ultimate strength of the chain will be referred to subsequently as the breaking strength of the chain. A proof test consists of applying about 70 percent of the designated breaking strength to each shot of chain. The strength of chain measured in the proof test will be referred to subsequently as the proof strength of the chain.

ABS stud link chain is available in several grades; these grades differ in strength characteristics, chemical composition, and metallurgy. The breaking strengths and proof strengths of several grades of ABS stud link chain are given in Tables 11 and 12 of DM-26.6; these data are reported in

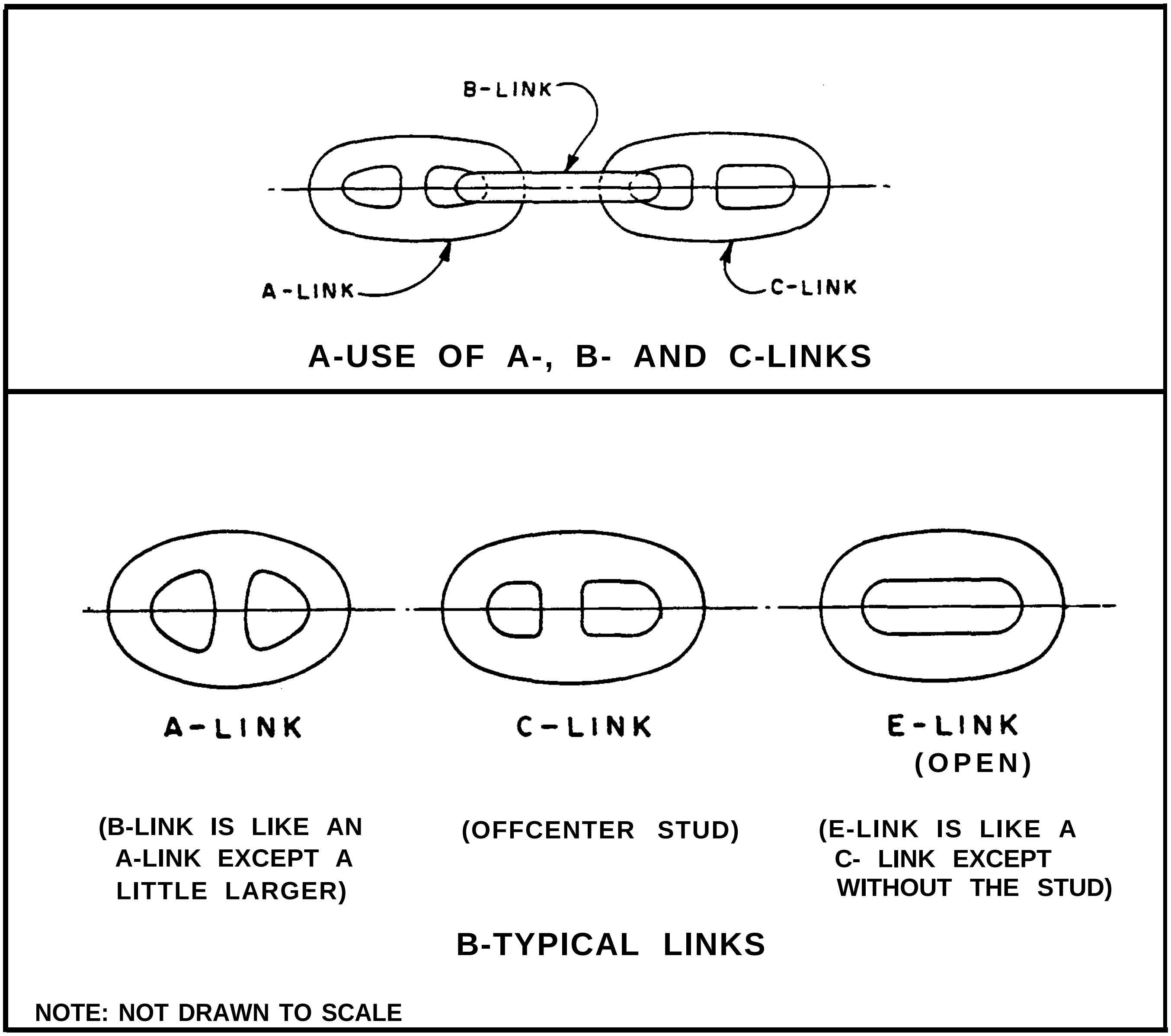


FIGURE 27
Chain Links

Tables 13, 14, and 15 of DM-26.6 for dilok chain and in Table 95 of DM-26.6 for Navy common A-link chain.

e. Chain Protection. Mooring chain is susceptible to two basic forms of corrosion: uniform and fretting. Uniform corrosion occurs over the entire chain link. The link initially corrodes at a relatively fast, uniform rate, which then decreases with time. Fretting corrosion, which is more damaging and more difficult to prevent, occurs at the grip area of the link. It results when movement of the chain links under load grinds away the outer, corroded layer of steel in the grip area. This process continuously exposes new, noncorroded surfaces of the steel, which are then corroded at the initial, faster, corrosion rate. Loss of chain diameter is accelerated in the grip area and the useful life of the chain is reduced.

TABLE 5
Chain Links: Terminology and Uses

Terminology		Uses
New	Other	
Common stud link chain	A-link Common link Stud link chain	The common type of link used
Enlarged link	B-link	An adaptor link used between the common stud link chain and the end link
--	C-link	Used as an end link, this link will allow the pin of a shackle to pass through it
Joining shackle	D-link D-shackle Joining shackle "D" type	Used to connect two end links together
End link	E-link Open end link	Commercially used as the "end link" on a shot of chain, allowing a joining shackle to connect the two shots of chain together
Anchor joining shackle	F-link F-shackle End shackle Bending shackle Anchor shackle "D" type	Used to connect the end link to an anchor shank and other structural supports

Plans are underway to incorporate cathodic protection in all standard fleet moorings. Cathodic protection should be considered for each standard fleet mooring in an attempt to deter corrosion and extend the useful life of mooring chain. The following guidelines apply to the use of cathodic protection:

> The use of cathodic protection on high-strength steel could cause hydrogen embrittlement of the steel. For this reason, cathodic protection should not be used on dilok chain or retrofits of existing moorings with chain that is not FM3. Only military-grade zinc (MIL-A-18001, 1983) should be used for anodes. Each chain link and fitting should be electrically grounded to the anode.

f. <u>Specifications</u>. Specifications governing fabrication and strength requirements of cast and flash butt-welded stud link chain are included in MIL-C-18295 (1976). Specifications concerning the fabrication and strength requirements of dilok chain are included in MIL-C-19944 (1961).

5. MOORING-CHAIN FITTINGS. Mooring-chain fittings include the hardware used to interconnect mooring elements, as well as the hardware used during mooring operations. The former, an integral part of the mooring, will be referred to in this manual as common chain fittings, while the latter will be referred to as miscellaneous chain fittings. Both types of fittings are discussed below.

a. <u>Common Chain Fittings</u>. Chain fittings used to connect chain shots to one another, chain to anchor, chain to buoy, chain to ground ring, and so forth, are discussed below. Terminology and uses of several of these fittings are summarized in Table 6.

(1) Detachable Links. Detachable links, also called joining links or chain-connecting links, are used to connect shots of chain. An example of a detachable link is shown in Figure 28A. A detachable link consists of two parts which can be separated in the field. As a rule, detachable links are designed to join together only one size of chain. Normally, the links have the same breaking strength as that of the connected chain. Experience has shown that most chain failures are due to detachable-link failures. Standard practice in industry is to use the next larger size or higher grade of detachable link for added strength. However, these detachable links must be checked to determine if they are compatible in size with other links or fittings.

Dimensional and strength data for commercially available detachable links are given in Tables 22 through 25 of DM-26.6, Section 4. These data are given for detachable links used in standard fleet moorings in Tables 96 through 100 of DM-26.6, Section 6.

(2) Anchor Joining Links. Anchor joining links are used to join common A-link chain to enlarged connections, such as ground rings, buoy lugs, padeyes, anchor shackles, and end links. Figure 28B shows an example of a pear-shaped anchor joining link.

Dimensional and strength data for commercially available anchor joining links are presented in Tables 25 and 26 of DM-26.6, Section 4. Dimensional

TABLE 6
Chain Fittings: Terminology and Uses

Terminology		
New	Other	Uses
Detachable joining link	Detachable link Lugless joining shackle Detachable connecting link Detachable chain-connecting link Kenter shackle	Connects common stud link chain together
Anchor joining link	Detachable anchor connecting link	Connects common stud link chain to ground rings, buoy shackles, pear links, swivels, spider plates, and tension bars
Pear link	Pear-shaped end link Pear-shaped link Pear-shaped ring	Used as an adaptor, for example, to connect the ground ring to an anchor joining link
Sinker shackle	Sinker shackle	Connects sinkers to common stud link chain; this shackle is not considered a structural member of the mooring
Buoy shackle	End joining shackle	Used to connect an end link or anchor joining shackle to the buoy tension bar
Swivel	Swivel	Allows the chain to rotate
Ground ring	Ground ring	Used to connect riser chain to several ground legs
Spider plate	Spider	Used to join several chains together

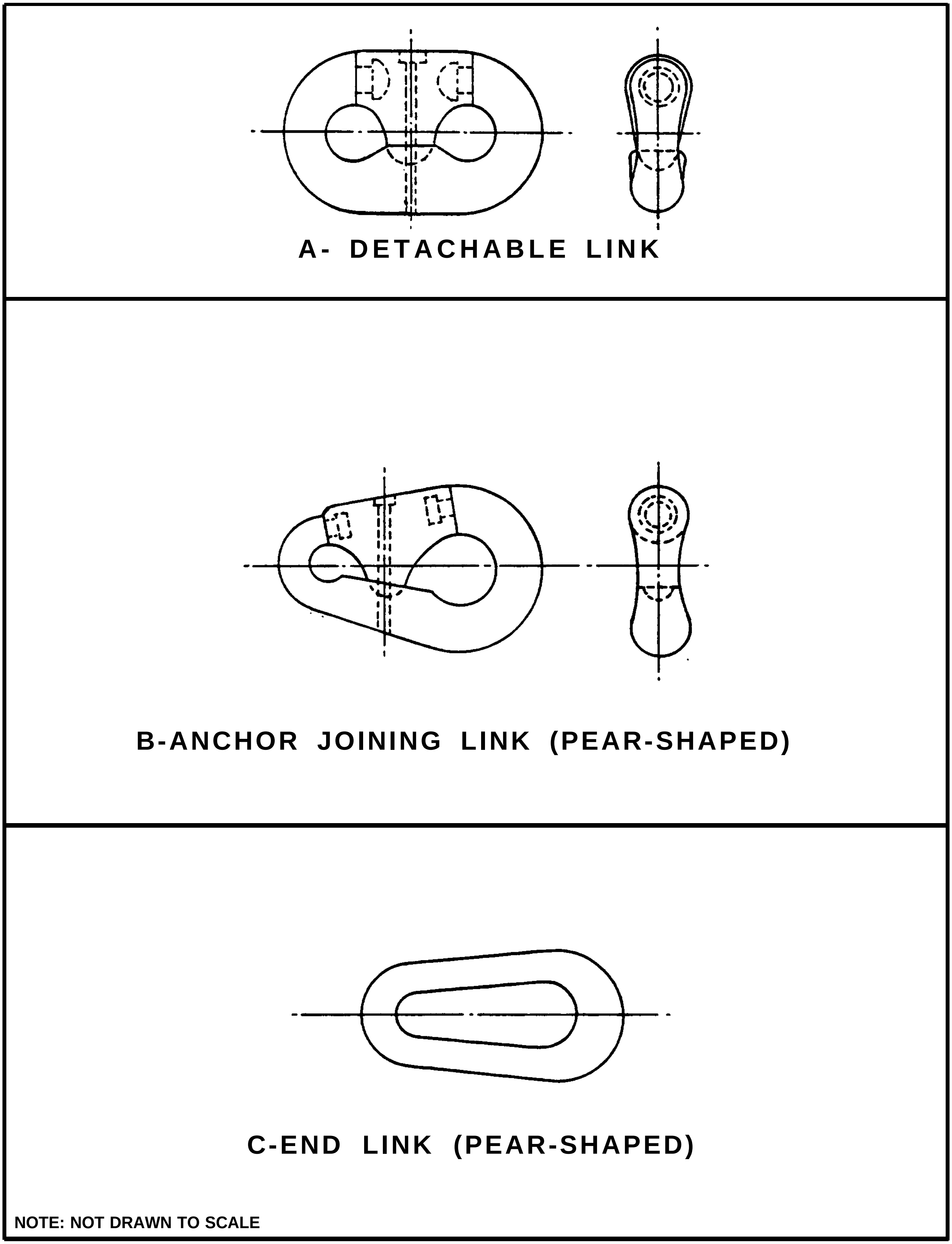


FIGURE 28
Detachable Link, Anchor Joining Link, and End Link

and strength data for anchor joining links used in standard Navy moorings are given in Tables 101 through 108 of DM-26.6, Section 6.

(3) End Links. Several types of links may be classified as end links. These are discussed below.

(a) Pear-shaped end links. A pear-shaped end link, shown in Figure 28C, is a chain link with an enlarged end having an increased chain diameter. In standard moorings, pear-shaped end links are used to connect the ship's chain to a buoy (see Figure 11).

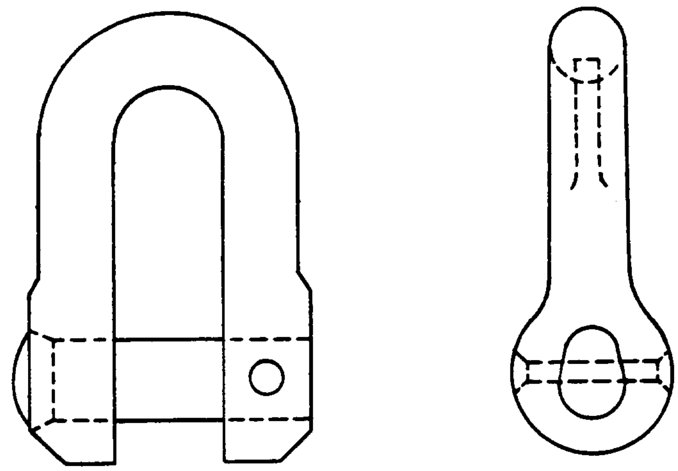
(b) Enlarged end links. Shots of chain sometimes have enlarged end links, such as the C-link and the E-link. (See Figure 26.) Enlarged end links are used to connect a larger-diameter link to a smaller-diameter link. The C-link is wide and elongated, with an offcenter stud. A D- or F-shackle pin can pass through its larger opening. The E-link (open end link) is like the C-link but without a stud. A D- or F-shackle lug can pass through an E-link.

Dimensional and strength data for commercially available end links are presented in Tables 18 through 21 of DM-26.6, Section 4. Dimensional and strength data for end links used in standard Navy moorings are given in Table 109 of DM-26.6, Section 6.

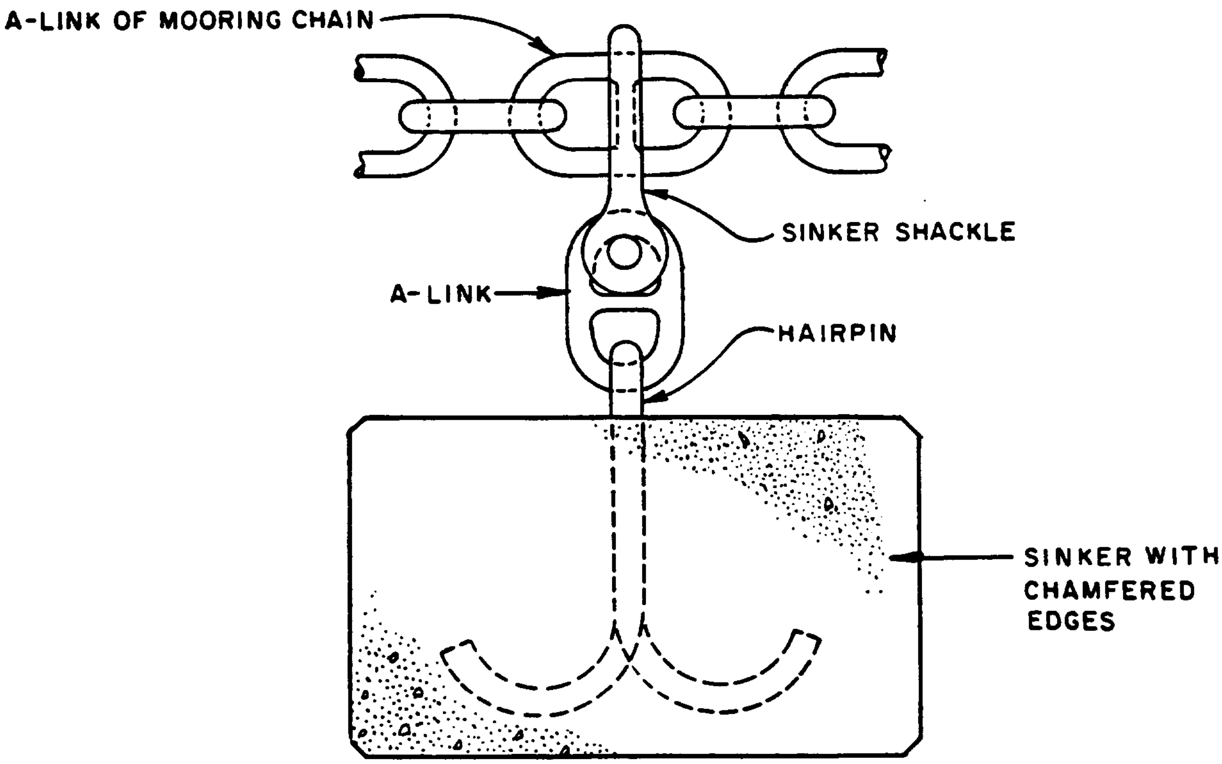
(4) Shackles. Four types of shackles are used in fleet moorings: joining shackles (D-shackles), bending shackles (F-shackles), sinker shackles, and buoy shackles. Joining, bending, and sinker shackles are used in fleet moorings to connect chain to anchors, ground rings, buoy lugs, padeyes, and so forth. A joining (or D-) shackle joins shots of chain having B-, C- , or E-enlarged end links. A D-shackle is similar to, but smaller than, an F-shackle. A bending (F-) shackle, shown in Figure 29A, is an enlarged end-connecting shackle. Enlarged end links (B-, C-, or E-links) are required at the end of the chain before the shackle can be attached. A sinker shackle is a special fitting for joining a sinker to a chain. It has an elongated shank made to fasten around the width of an A-link and provides a connection for a detachable or A-link fastened to the sinker. (See Figure 29B.) Buoy shackles are used to connect an end link or bending shackle (F-link) to the buoy tension bar.

Dimensional and strength data for various commercially available shackles are given in Tables 27 through 34 of DM-26.6, Section 4. Dimensional and strength data for shackles used in standard Navy moorings are presented in Tables 110 and 111 and Figure 6 of DM-26.6, Section 6.

(5) Swivels. Swivels are shown in Figure 30A. A swivel consists of two pieces. The male end fits inside the female end and is retained by a button which is an integral part of the male end. In regular swivels, both pieces have closed ends which are connected to chain links or detachable links. A swivel shackle is a variation of the swivel in which both parts have a shackle opening. Swivels prevent twist in the riser chain and ground legs of a mooring. A twisted ground leg without a swivel has enough torque to rotate an anchor and cause its failure.



A-BENDING SHACKLE (F-SHACKLE)
(D-SHACKLE IS LIKE F-SHACKLE EXCEPT SMALLER)



SINKER SHACKLE ATTACHED
TO MOORING CHAIN

B-SINKER SHACKLE

NOTE: NOT DRAWN TO SCALE

FIGURE 29
Shackles

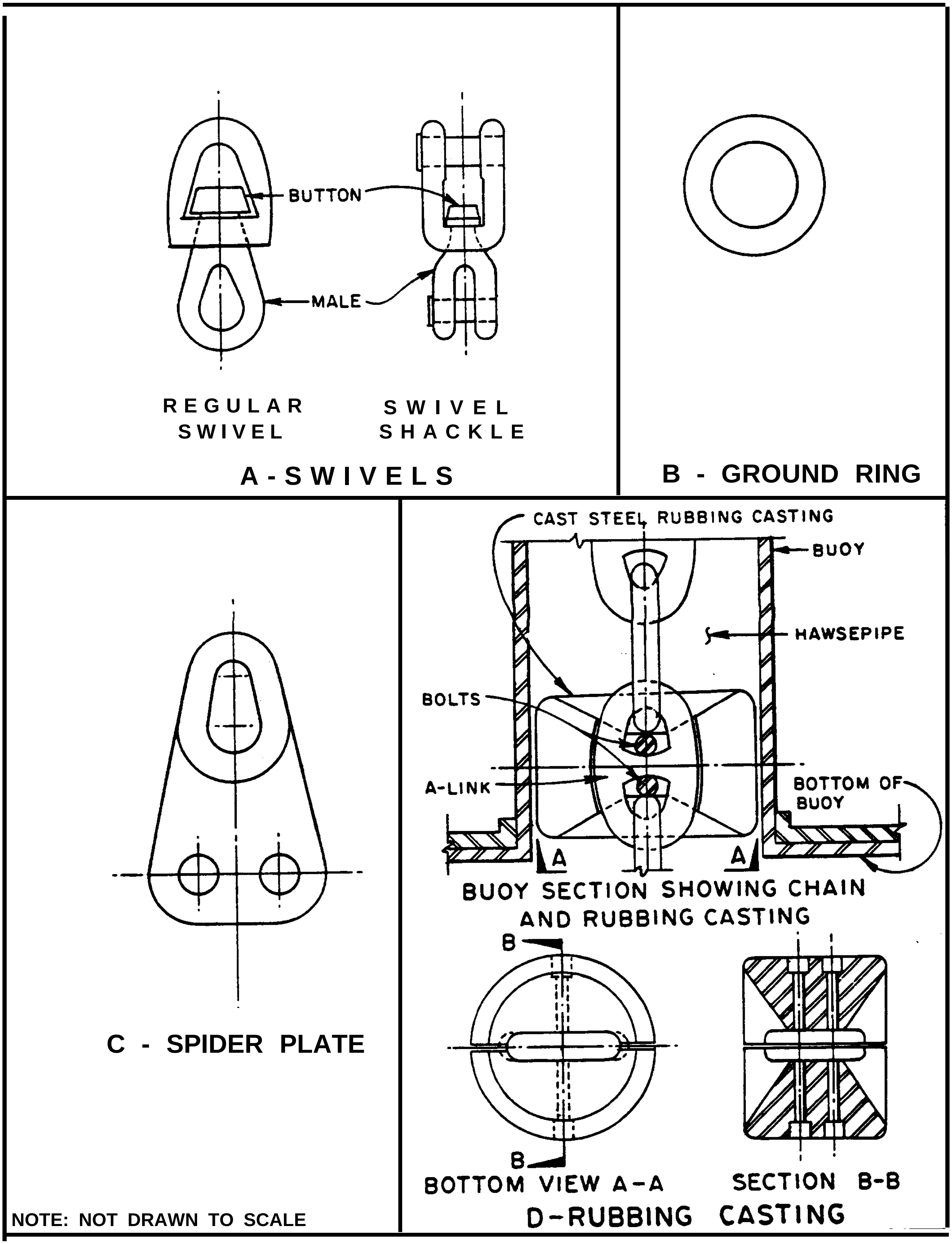


FIGURE 30
Swivels, Ground Ring, Spider Plate, and Rubbing Casting

Dimensional and strength data for commercially available swivels are given in Tables 35 through 39 of DM-26.6, Section 4. Dimensional and strength data for swivels used in standard Navy moorings are shown in Table 113 of DM-26.6, Section 6.

(6) Ground Rings. A ground ring joins the riser chain to the ground legs in a riser-type mooring. Figure 30B shows a ground ring.

Dimensional and strength data for commercially available ground rings are given in Tables 20 and 21 of DM-26.6, Section 4. Dimensional and strength data for ground rings used in standard Navy moorings are given in Table 112 of DM-26.6, Section 6.

(7) Spider Plates. A spider plate is a steel plate with three or more holes used to connect several chains. In riser moorings, three pairs of ground legs are sometimes used, extending out from the ground ring 120 degrees apart. (See DM-26.6, Section 5, Figures 1 and 2. In Figure 1, a spider plate is used to connect the two legs of a pair to the end-link assembly connected to the ground ring.) Figure 30C presents a spider plate used in standard moorings. Dimensional and strength data for spider plates used in standard Navy moorings are given in Figure 7 of DM-26.6, Section 6.

(8) Rubbing Casting. A rubbing casting is a cast-steel block (made in two parts) that can be bolted around a chain. The rubbing casting fits inside the hawsepipe of a hawsepipe-type buoy and prevents the riser chain from contacting or rubbing the hawsepipe as the chain leaves the buoy. A rubbing casting is shown in Figure 30D. Dimensional data for rubbing castings used in standard' Navy moorings are given in Table 114 of DM-26.6, Section 6.

(9) Quick-Release Hooks. A quick-release hook, shown in Figure 31, is placed at the top of a mooring buoy when a ship's line must be released quickly in an emergency. It is used for offshore fuel-loading type moorings, as' well as for other types of moorings. Fitting details for commercially available quick-release hooks are given in Table 43 of DM-26.6, Section 1. Fitting details for quick-release hooks used in standard Navy moorings are given in Figure 8 of D-26.6, Section 4.

(10) Equalizers.. Equalizers are used to equally distribute load among groups of propellant-embedded or pile anchors on the same ground leg. Groups of anchors are used on one ground leg when mooring-line loads calculated for the leg exceed the rated capacity of a single anchor. Equalizers prevent overloading of the individual anchors in the group. Propellant-embedded and pile anchors will not move unless overloaded; however, once overloaded, the anchor cannot recover its lost holding power. When a group of anchors on the same leg are loaded at the same time, overloading will occur unless the load is equally shared among the individual anchors. To equalize the load between two anchors in a pair, the chains from the anchors are connected together and passed through an equalizer, and the load is applied to the equalizer (Figure 32). Figure 33 shows a typical sliding-type equalizer. The interconnected chains are allowed to slide over a curved plate. Unequal tension on one of the chains forces the chain to slip over the plate to equalize the chain length/load.

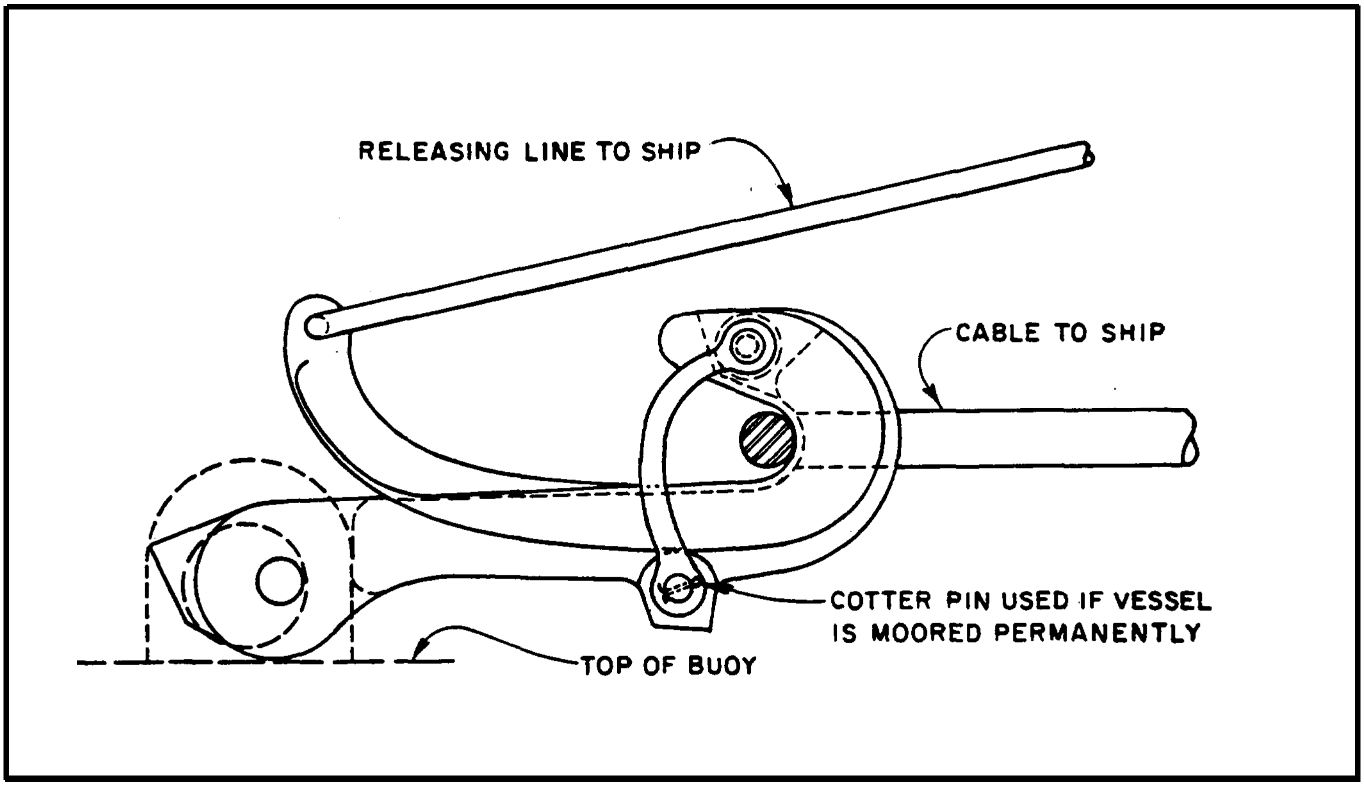


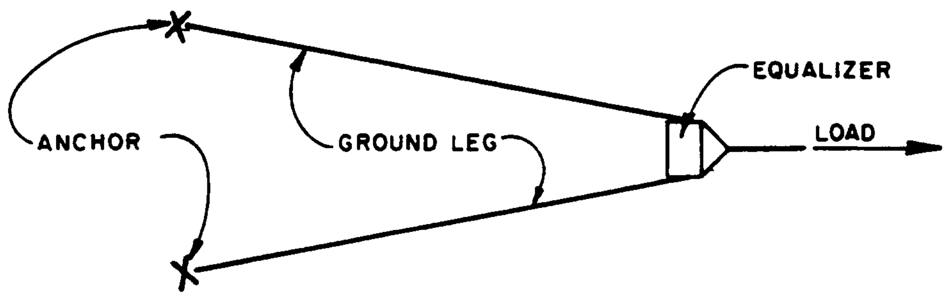
FIGURE 31
Quick-Release Hook

b. Miscellaneous Chain Fittings. Several devices are used to handle mooring chain during mooring installation and retrieval and during other mooring operations. These devices, shown in Figure 34, are discussed below.

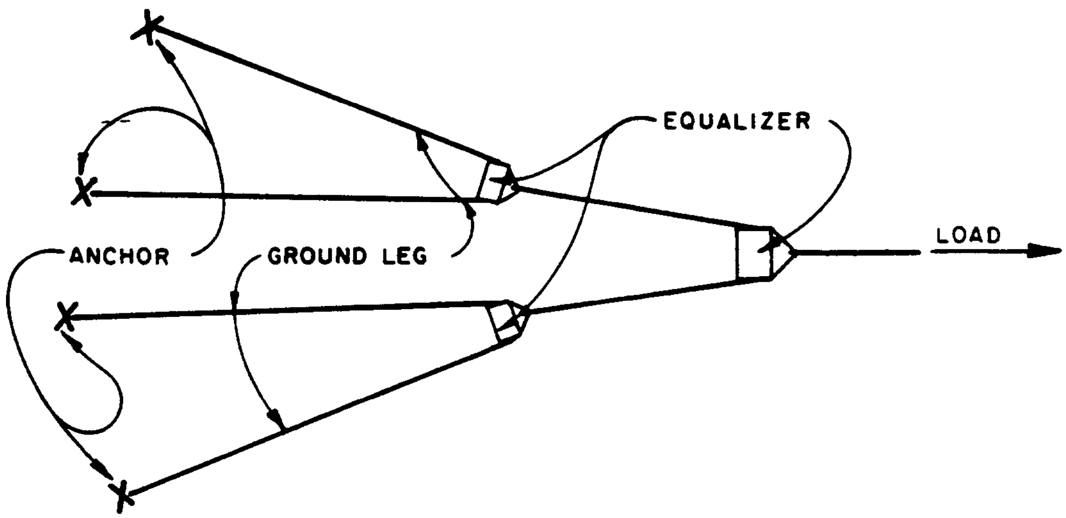
(1) Release Hooks. A release hook, shown in Figure 34A, is a device that can be quick-released by pulling a pin with a release line. Release hooks are used to place mooring anchors and weights into the water.

(2) Chain Clamps. Chain clamps are used to hook or engage the main hoisting tackle to the mooring chain when laying or recovering moorings. The clamp prevents damage that would result from sudden slippage of the load. A chain clamp consists of two steel plates tightly fastened with two bolts across one link of the mooring chain, as shown in Figure 34B. The clamp fits tightly against the two adjoined links because the two plates are grooved on each edge to fit the links.

(3) Chain Stoppers. Chain stoppers are used in groups of two or more to secure a mooring chain. They relieve the strain on a windlass due to towing loads or mooring-chain loads. In fleet-mooring installations, chain stoppers are used to temporarily secure parts of the mooring, allowing these parts to be connected while not under tension. There are two major kinds of chain stoppers: the pelican hook and the dog-type. The Navy prefers the pelican hook, while merchant ships generally use the dog-type. These two types are discussed below.



A-EQUALIZER USED FOR TWO ANCHORS



B- EQUALIZERS USED FOR FOUR ANCHORS

NOTE: NOT DRAWN TO SCALE

(AFTER CHESNAVFAC FPO-1-81-(14))

FIGURE 32
Equalized Pairs of Anchors

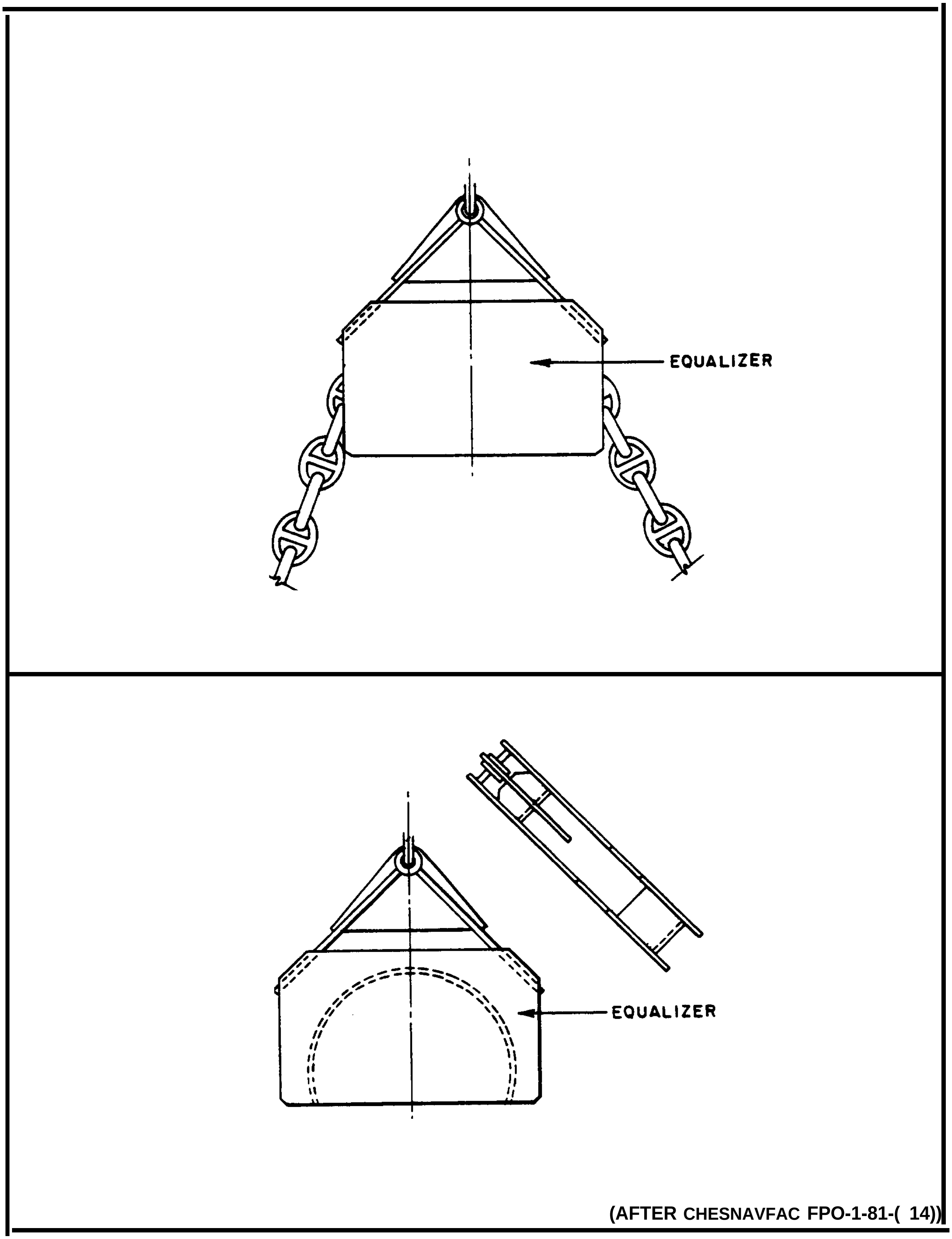


FIGURE 33
Typical Sliding-Type Equalizer

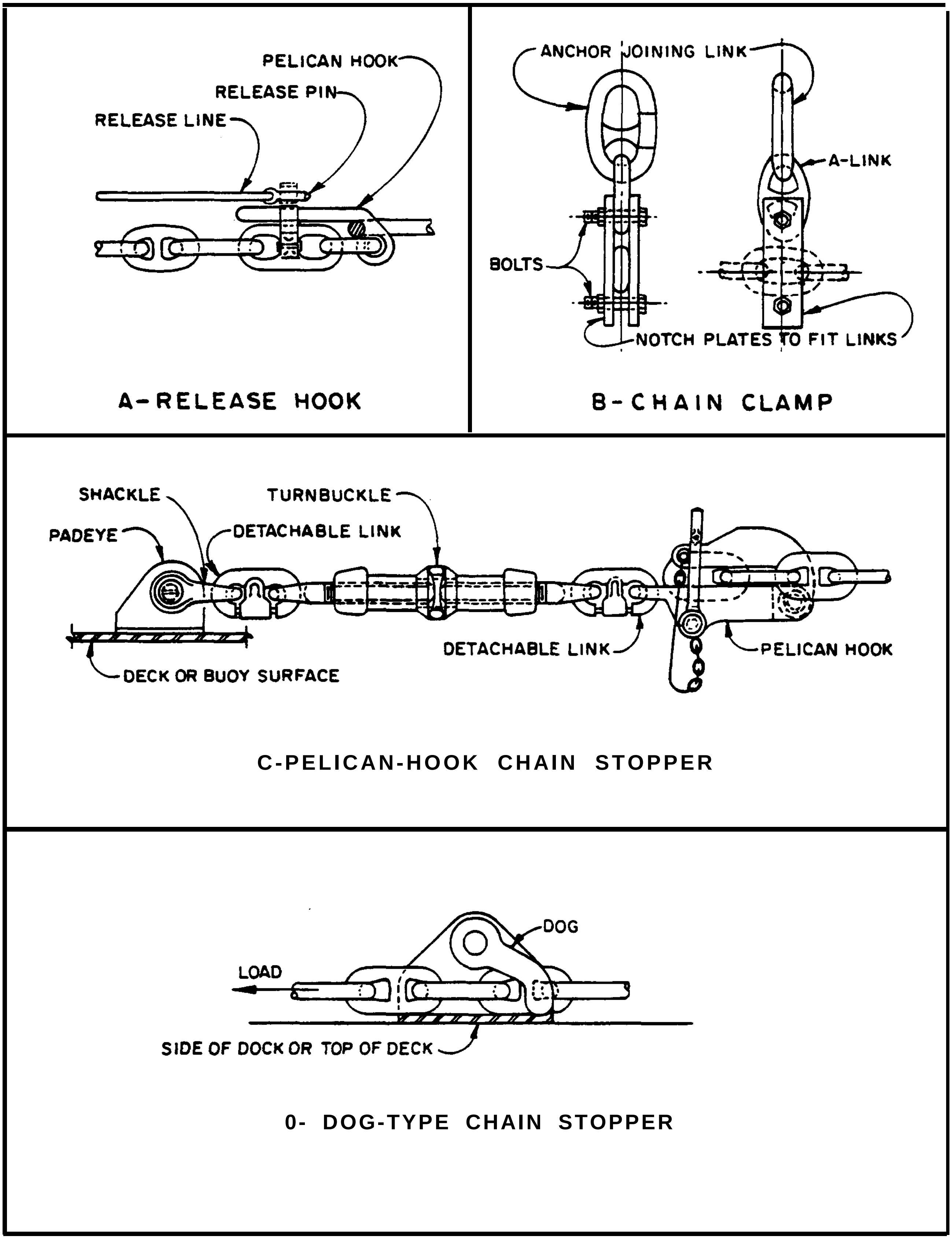


FIGURE 34
Release Hook, Chain Clamp, and Pelican-Wok and Dog-Type Chain Stoppers

The pelican hook has jaws which are fastened around a link of chain and held in place with a pin. Typically, the pelican hook is connected to a turnbuckle by a detachable link. Another detachable link connects the other end of the turnbuckle to a shackle, which is pinned through a padeye welded to the deck surface. A diagram of this arrangement is shown in Figure 34C. Figure 35A shows how pelican-hook chain stoppers are used to relieve load on a windlass while a floating drydock is being towed.

The dog-type chain stopper has a stationary plate, welded to the deck, and a movable lever (dog). The chain is passed between the plate and the dog. When the links move into proper alinement, the dog catches between links and the chain is secured. A diagram of the dog-type chain stopper is shown in Figure 34D. Figure 35B shows how dog-type chain stoppers are used to secure a floating drydock.

Dimensional and strength data for commercially available chain stoppers are given in Tables 40, 41, and 42 0f DM-26.6, Section 4.

c. Strength Tests. All new chain fittings are proof tested, and fittings having the greatest elongation are subjected to a break test and a flaw-detection test. Surface defects are filed or ground away until they are no longer visible by a flaw-detecting method. Fittings With major defects are rejected. Where ’identification marks or stampings are required on a fitting, they are located on the least-stressed parts.

6. BUOYS . Four types of buoys are discussed below: riser-type, telephone-type, marker-type, and navigational. The two most important types used in fleet moorings are the riser-type and the telephone-type. These differ from one another in the configuration of the ground tackle used to secure them to their anchorages. Both types have fendering systems on the top and around the outside to protect the buoy from abrasion and chafing. Mooring-buoy fendering systems are usually made of wood. While wooden fenders are easily fabricated, they are also very susceptible to damage by marine boring organisms when in contact with sea water, especially in warm waters, for an extended period of time. Therefore, priority consideration should be given to rubber as the fender material.

Buoy size depends upon the maximum pull it may be subjected to and upon the weight of the chain supported by the buoy. Large buoys have an air-connection plug for blowing out water that may have leaked into the buoy.

a. Riser-Type Buoys. Riser-type buoys are used in riser-type moorings. (See Figure 1.) Riser-type buoys may be of two types: tension-bar and hawsepipe.

1) Tension-Bar. Tension-bar, riser-type buoys have a vertical tension bar (rod) which passes through the cylindrical body of the buoy, with fittings at each end. The riser chain is connected to the submerged end of the tension bar, while a mooring line(s) is attached to the other end. A typical tension-bar, riser-type buoy is shown in Figure 36A. Typical details are presented in DM-26.6, sections 4 and 6.

2) Hawsepipe. Hawsepipe, riser-type buoys have a central hawsepipe through which the riser chain is run. The top link of the riser chain is

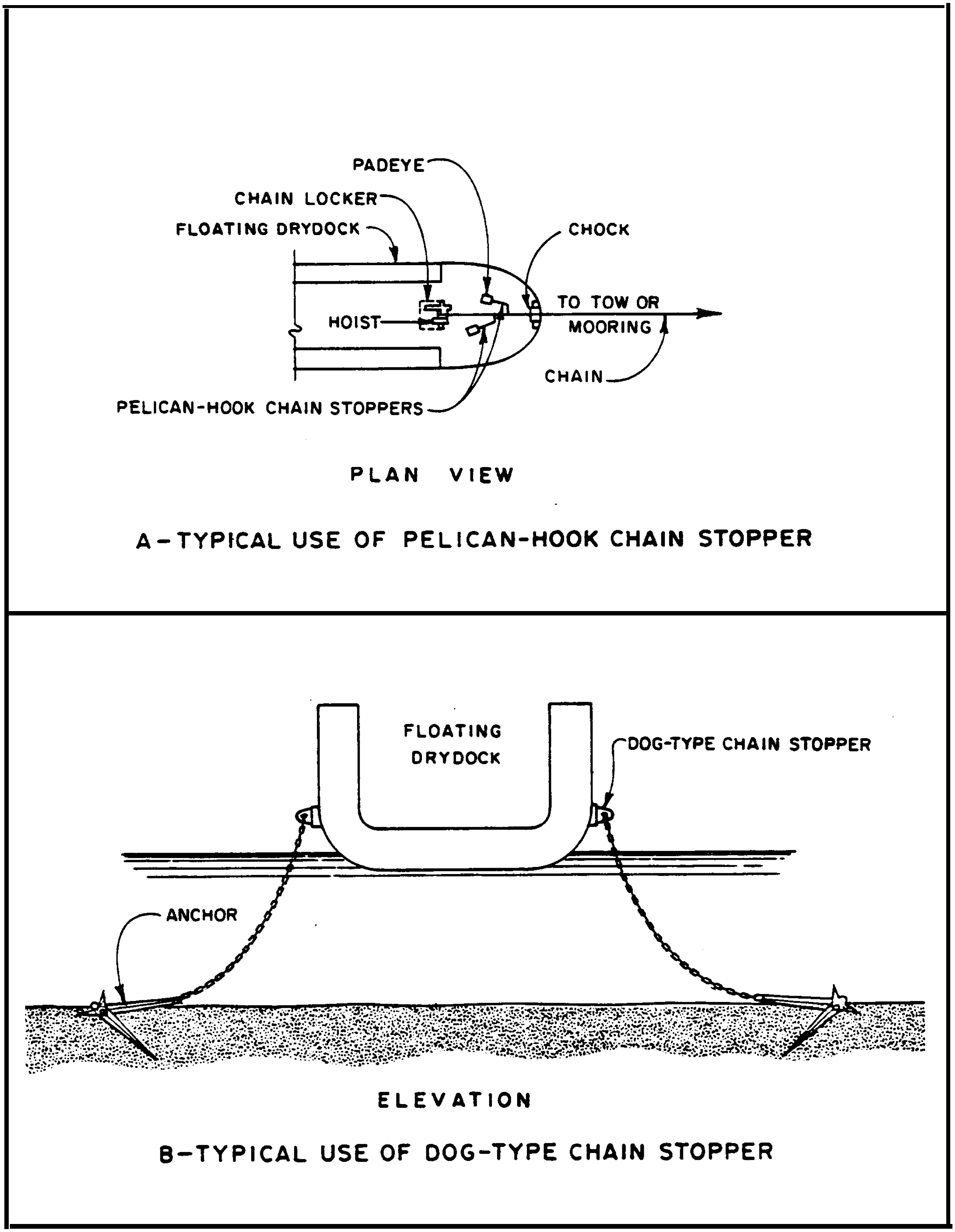


FIGURE 35
Typical Uses of Chain Stoppers

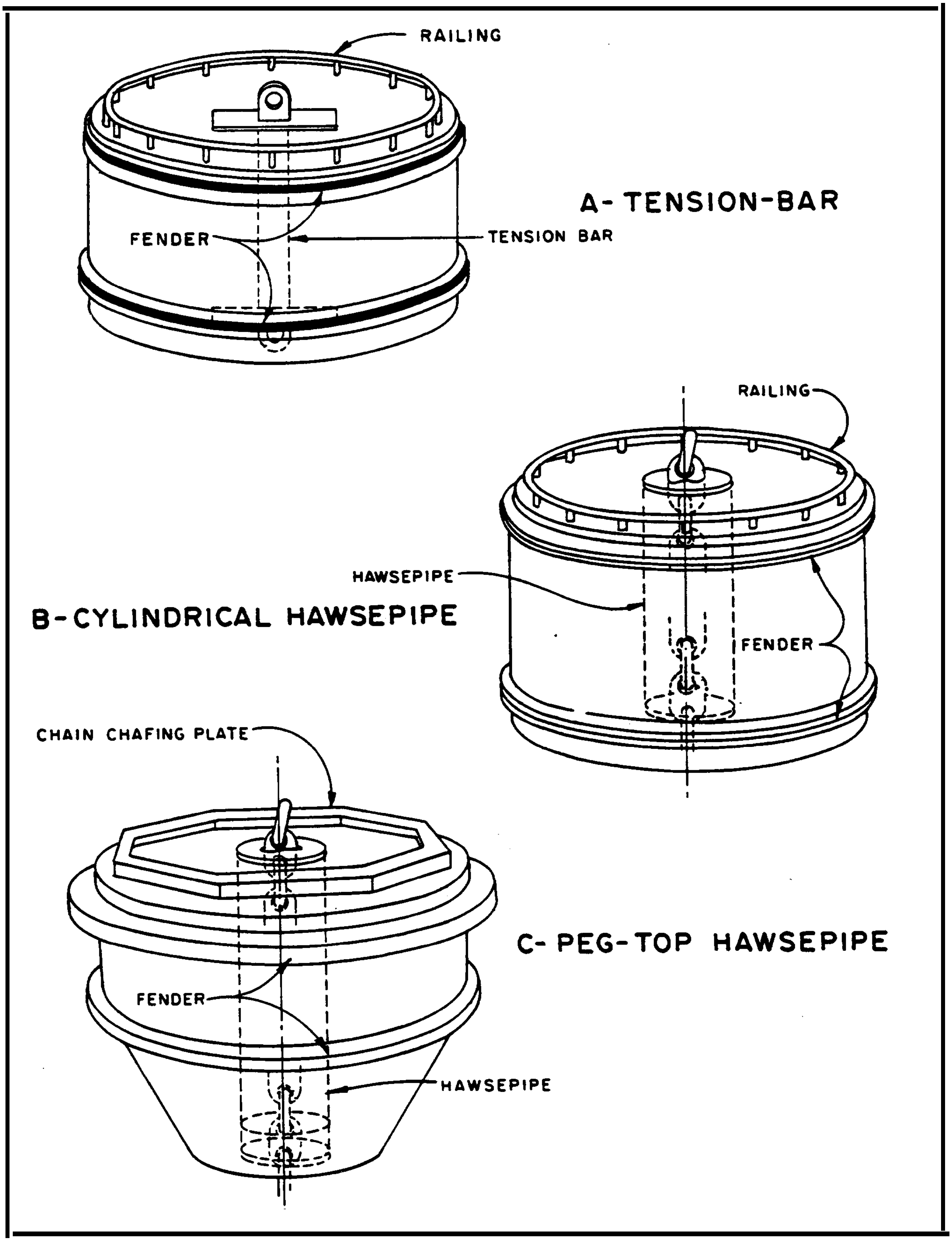


FIGURE 36
Riser-Type Buoys

held with a slotted chain plate on the top of the buoy. An anchor joining link and end link are attached to the top chain link, above the supporting plate. The ship's chain is attached to the end link on the buoy with a shackle. (See Figure 11.) A steel rubbing casting is attached to the chain where it leaves the bottom of the hawsepipe. (See Figure 281.) The rubbing casting minimizes wear on the riser chain and on the hawsepipe. Hawsepipe, "riser-type buoys have three compartments and plugs for blowing out water with compressed air. Two typical hawsepipe, riser-type buoys are shown in Figure 36: Figure 36B shows a cylindrical hawsepipe buoy and Figure 36C shows a peg-top hawsepipe buoy. Typical details are presented in DM-26.6, Sections 4 and 6.

The advantage of the hawsepipe-type of riser-type buoy is that any pull may be made through the buoy, provided that the riser chain can pass through the hawsepipe and that the chain has the proper strength for the pull. However, chain within a hawsepipe is difficult to inspect; consequently, tension-bar buoys are preferred to hawsepipe buoys. It is common practice to replace the hawsepipe assembly with a tension-bar assembly.

b. Telephone-Type Buoys. Telephone-type buoys are used in telephone-type moorings. (See Figure 2.) A telephone-type buoy is secured in place by ground-leg chains attached to three or four eyes projecting from the circular bottom edges of the buoy. The ground-leg chains extend to anchors on the bottom. At the top of the buoy is a swivel, where ship's chain may be connected. The eyes, which are equally spaced around the bottom of the buoy, are located at the ends of tension bars that pass diagonally up through the buoy to the center, in line with the swivel. There may be three or four tension bars. The three-bar type is the one normally used; a four-bar type is used for bow-and-stern moorings where broadside winds produce heavy loads in mooring lines. Telephone-type buoys have three compartments with compressed air connections for ejecting water. A typical telephone-type buoy is shown in Figure 37. Telephone-type buoys are larger than riser-type buoys because they have to support three or four ground-leg chains, as well as, in their original usage, a telephone cable, instead of the single riser chain of a riser-type buoy.

c. Marker-Type Buoys. Marker-type buoys are usually spherical or barrel-shaped. (See Figure 38.) These buoys are connected to the end of submerged chains that must be recovered for future use. They also mark a particular location. For example, in fuel-oil moorings, they locate the end of the oil hose. Typical details are presented in DM-26.6, Section 6.

d. Navigational Buoys. Navigational buoys and accessories are made in accordance with U.S. Coast Guard specifications. (See DM-26.1, Section 4.) A typical navigational buoy and mooring are shown in Figure 10. Navigational buoys are used to delimit a channel in a harbor or river, as well as to mark the location of an obstruction or a navigational hazard. Typical details are presented in DM-26.6, Section 7.

7* METRIC EQUIVALENCE CHART. The following metric equivalents were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 3. Conversions are approximate.

15 fathoms = 90 feet = 27.4 meters

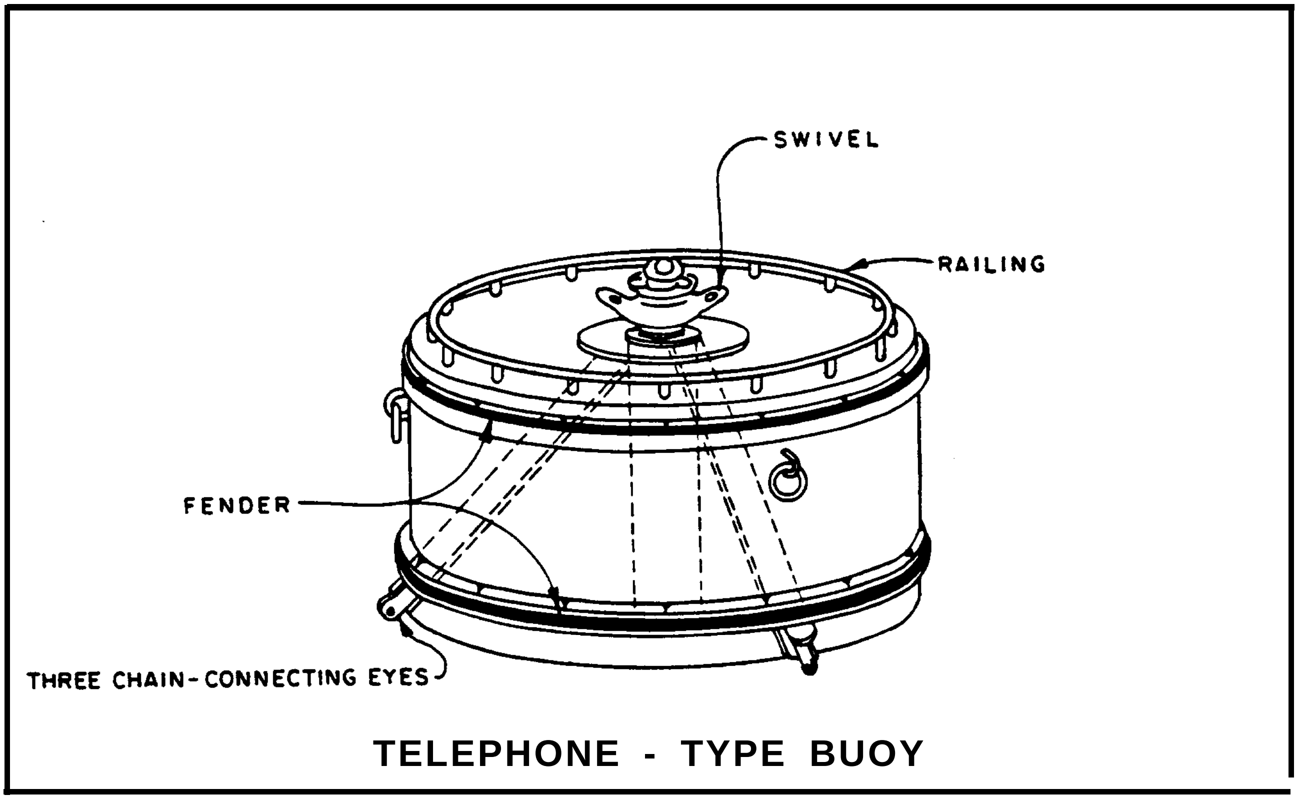


FIGURE 37
Telephone-Type Buoy

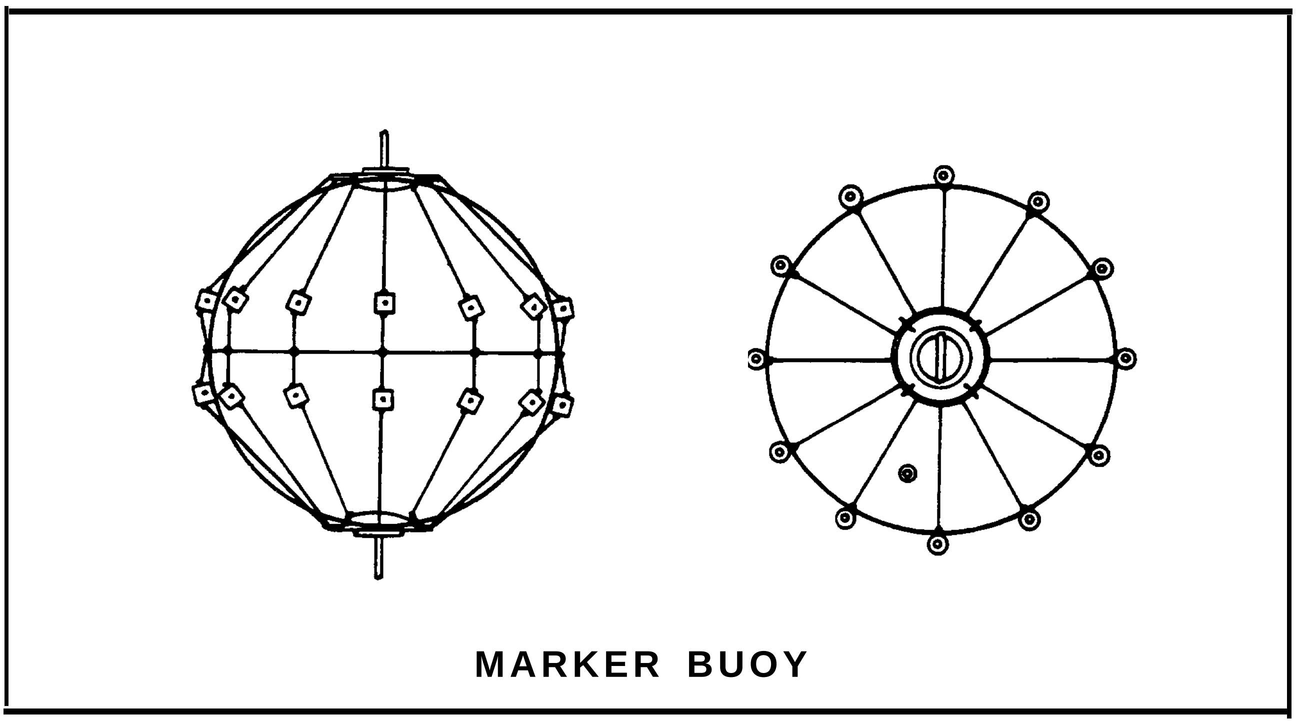


FIGURE 38
Marker Buoy

Section 4. BASIC DESIGN PROCEDURE

1. FLEET-MOORING DESIGN. Design of a fleet mooring consists of three major steps: determination of the mooring layout, evaluation of environmental conditions and associated loads, and design of mooring components. A flow chart outlining the design process is shown in Figure 39. This section discusses each element of the design process qualitatively. Specific design procedures are given in Section 5.

2. DETERMINATION OF MOORING LAYOUT.

a. Mooring Site. Fleet moorings should be located at well-protected sites in order to minimize environmental loads. Most fleet moorings are located within harbors. Wherever possible, the mooring should be oriented so that the longitudinal axis of the vessel is parallel to the direction of the prevailing winds, waves, and/or currents. Planning guidelines for determining the location, size, and depth of anchorage basins are provided in Table 16 of DM-26.1, Section 3. Tables 17, 18, and 19 of DM-26.1, Section 3, provide the berth sizes required for free-swinging and spread mooring arrangements.

b. Vessel Type. The vessel(s) expected to use the mooring must be determined. Vessel characteristics, including length, breadth, draft, displacement, broadside wind area, and frontal wind area, must be determined for each of the vessels. These characteristics are presented in Tables 2, 3, and 4 of DM-26.6, Section 3, for fully loaded and light-loaded conditions.

c. Mooring Configuration. Table 7 presents a summary of several commonly used mooring configurations. The mooring configuration used depends upon mooring usage; space available for mooring; mooring loads; strength, availability, and cost of mooring components; allowable vessel movement; and difficulties associated with maneuvering the vessel into the mooring. Free-swinging moorings are used when there is sufficient area in the harbor to accommodate vessel movement, when there are no operations requiring rigid positioning, and when environmental conditions are severe. A multiple-point mooring is required when a vessel must be held rigidly. Multiple-point moorings used by the Navy include moorings for the transfer of cargo and supplies, moorings for fueling facilities, moorings located in limited berthing areas, and moorings for floating drydocks.

Free-swinging moorings allow the vessel to assume the most advantageous position under the action of wind and current. Multiple-point moorings, on the other hand, hold the vessel in place under the action of wind and current. The loads on a vessel in a multiple-point mooring are higher than if the vessel were to be allowed to swing freely. Mooring lines in a multiple-point mooring should be arranged symmetrically about the longitudinal and transverse axes in order to obtain a balanced distribution of mooring loads.

3. EVALUATION OF ENVIRONMENTAL CONDITIONS AND ASSOCIATED LOADS.

a. Environmental Conditions. Environmental conditions important to mooring design include bottom soil conditions, water depth, winds, currents, and waves.

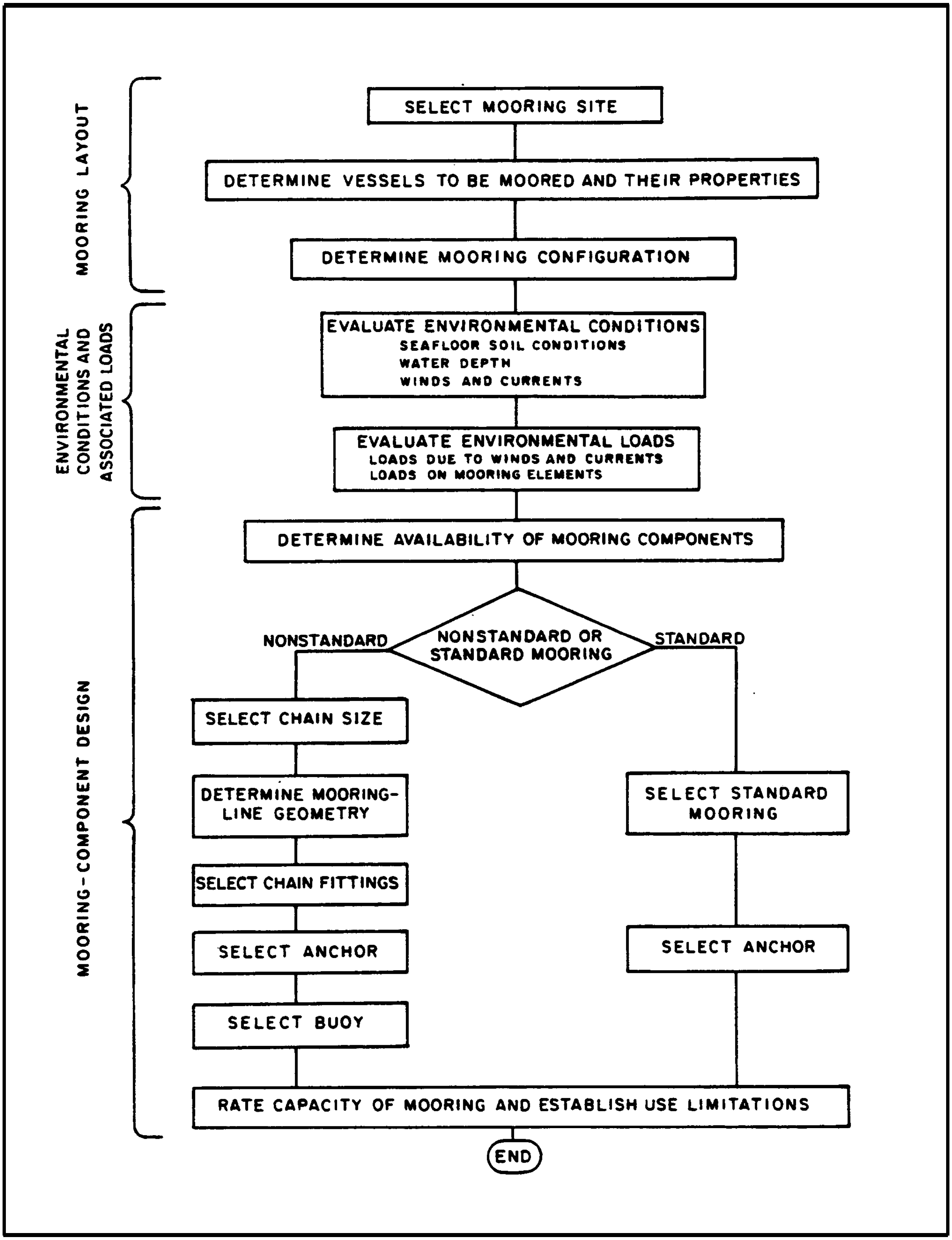


FIGURE 39
Basic Design Procedure for a Fleet Mooring

Table 7
Mooring-Configuration Summary

Configuration	Positioning Capability	Remarks
Free-Swinging (Single-Point) . . .	Minimal; large excursion as vessel swings to aline with wind or current	Vessel will assume the most advantageous position under combined action of wind and current; best for heavy weather or transient mooring
Bow-and-Stern (Two-Point) .. 00.0	Minimal; limits swing somewhat; large excursions for loads slightly off centerline	Not for precise positioning; suitable for transient mooring with limited sea room
Spread Mooring . . .	Good for load from any direction	Best for situations where direction of wind and/or current may shift and precise positioning must be maintained
Meal-Type . . ...00..	Relatively good; longitudinal axis of vessel should be oriented toward largest load	Good for situations where reasonably precise positioning is required in a limited area

(1) Seafloor Soil Conditions. Seafloor soil conditions must be evaluated in order to properly select and design fleet-mooring anchors. In fact, some anchors can be eliminated based on soil type as certain types of anchors are well-suited to certain soil types. Ropellant-embedded anchors, for instance, are well-suited for use in hard coral seafloors. Drag anchors, on the other hand, perform poorly in hard seafloors. Table 8 presents soil-investigation requirements for each anchor type; see DM-7.1 and DM-7.2 for details.

(2) Water Depth. Mooring-site bathymetry and water-level fluctuations must be investigated to assure that there is adequate depth for vessels using the mooring, to determine mooring-line geometry, and to determine current loads on the vessel. Current loads are sensitive to the ratio of vessel draft to water depth.

Factors contributing to water-level fluctuations include astronomical tides, storm surge, seiche, and tsunamis. These phenomena are discussed in DM-26.1, Subsection 2.7. The design water level at a mooring site is controlled primarily by the astronomical tide. However, the other factors mentioned above can be significant and must be investigated.

Harbor sedimentation produces variations in bottom elevation. The potential for long-term changes in bottom elevation must be investigated. Deposition of sediment at a fleet-mooring site can decrease water depth to

Table 8
Soil-Investigation Requirements for Various Anchor Types

Anchor Type	Required Soil Properties
Deadweight	Seafloor type, depth of sediment, variation in soil properties with area, estimate of soil cohesion, friction angle, scour potential
Drag-Embedment	Seafloor type and strength, depth to rock, stratification in upper 10 to 30 feet, variation in soil properties with area
Direct-Embedment	Engineering soil data to expected embedment depth (soil strength, sensitivity, density, depth to rock)
Pile	Engineering soil properties to full embedment depth (soil strength, sensitivity, density, soil modulus of subgrade reaction)

unacceptable values and bury sinkers and other mooring hardware, thereby reducing the resiliency of a shock-absorbing mooring. Harbor shoaling and current Navy dredging requirements are discussed in DM-26.3.

(3) Winds. Wind loads on moored vessels are important to fleet-mooring design. The duration of a wind event affects the magnitude of the wind-induced load on the moored vessel. A wind gust with a speed 50 percent higher than the average windspeed, but lasting only a couple of seconds, may cause little or no response of a moored vessel. On the other hand, repeated wind gusts with only slightly higher-than-the-average windspeed, with duration near the natural period of a vessel-mooring system, can excite the vessel dynamically and result in mooring-line loads in excess of the mean mooring-line loads. Hence, it is necessary to establish a standard wind duration which will provide reliable estimates of steady-state, wind-induced loads on moored vessels. Winds of longer or shorter duration should be corrected to this level. Based on analytical considerations and previous experience, a 30-second-duration windspeed has been chosen as the standard for determining wind-induced loads on moored vessels. This value is less than the l-minute duration recommended by Flory et al. (1977) for large tankers, but seems appropriate for naval vessels.

The most reliable method for determining design windspeed at a site is to analyze wind measurements taken at or near the site over an extended period of time. Windspeeds are reported according to a variety of definitions, including fastest-mile, peak-gust, l-minute-average, lo-minute-average, and hourly average. The fastest-mile windspeed is defined as the highest measured windspeed with duration sufficient to travel 1 mile. For example, a reported fastest-mile windspeed of 60 miles per hour is a 60-mile-per-hour wind that lasted for 1 minute. On the other hand, a fastest-mile windspeed of 30 miles per hour would have lasted 2 minutes. Peak-gust windspeed measures a wind of high velocity and very short duration.

Fastest-mile and peak-gust windspeeds are generally the most useful measurements for determining design windspeeds at a mooring site for several reasons. First, they represent the highest wind recorded during a period of observation. Secondly, they can be converted to a 30-second duration windspeed. Finally, these measurements are available at most naval facilities. (This is particularly true for the peak-gust windspeed.)

(a) Data sources. Sources for windspeed data are summarized . in Table 10, Section 5.

(b) Windspeed adjustments. Windspeed data must be adjusted for elevation, duration, and overland-overwater effects in order to represent conditions at the mooring site. First, the windspeed must be adjusted to a standard elevation; this is particularly true when comparing data measured at several locations near the mooring site. The design windspeed must also be adjusted to an elevation suitable for determining wind loads on a moored vessel dependent upon the geometry of that vessel. However, for the purposes of determining the design windspeed, the wind measurements are corrected to a standard elevation of 10 meters (33.33 feet). Secondly, the windspeed must be corrected to a 30-second-duration windspeed. Finally, because most wind measurements are taken at inland sites over land, rather than at the mooring site over water, it is necessary to correct for overland-overwater effects. These adjustments must be made before the probabilistic analysis, discussed below, is done. Procedures for making the above adjustments are given in Section 5.

(c) Determining maximum windspeed. In order to achieve an economical and safe mooring design, the maximum windspeed is determined using probabilistic methods. Probabilistic analysis of wind measurements taken at or near a site will provide an estimate of how frequently a given windspeed will occur or be exceeded (probability of exceedence) during the design life of the mooring. The return period of a windspeed, estimated from the probability of exceedence, is defined as the average length of time between occurrences of that windspeed. The concept of statistical return period is useful for determining the design windspeed. For example, a 50-year design windspeed indicates that a windspeed equal to or greater than the 50-year design windspeed will occur, on the average, once every 50 years. The So-year windspeed (windspeed with a So-year return period) is used for design of fleet moorings, although estimates of more frequent (l-year, lo--year) and less frequent (75-year, 100-year) windspeeds are useful for planning purposes. Operational criteria may require that a vessel leave a mooring at a given windspeed. (For example, as stated in Subsection 2.4.(b)(3), a fuel oil-loading mooring is normally designed for a maximum wind velocity of 30 miles per hour.) In such a case, the fleet mooring would be designed for the operational criteria unless there is a possibility that, under some circumstances, a vessel would remain at the mooring during higher winds.

Procedures for determining the probability of exceedence and the return period for various windspeeds based on measured data are presented in Section 5. The results of a probabilistic analysis can be conveniently presented as shown in Figure 40, which is an example plot of probability of exceedence (left ordinate) and return period (right ordinate) versus 30-second windspeed (abscissa).

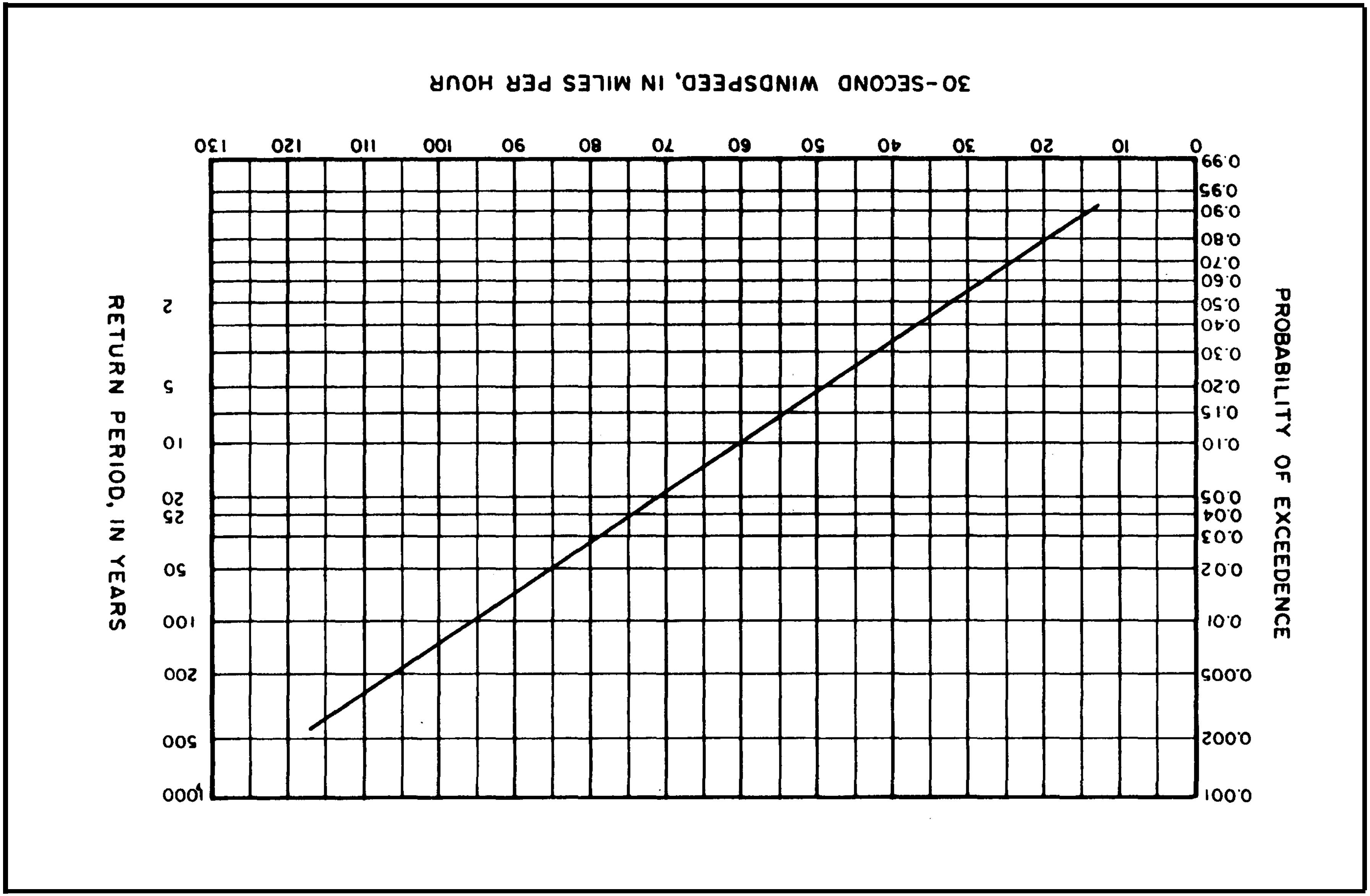


FIGURE 40
Example Plot of Probability of Exceedence and Return Period Versus 30-Second Windspeed

(4) Currents. Currents can play a major role in the layout and design of a fleet mooring. Current loads on a moored vessel can be very high. In order to reduce these loads, it is desirable to moor vessels headed into the current. Currents may also affect the ability of a vessel to maneuver into the mooring.

(a) Tidal currents. Tidal currents are the most common type of current in Navy harbors. They range in speed from less than 1 knot to about 6 knots. Ideally, the designer should obtain data on current velocity and direction, and on the variation of these parameters, both areally and with depth. Determination of tidal currents is best achieved by direct measurement. Where measurements are not available, current speeds may be estimated using physical or numerical models. If the harbor geometry is simple and other appropriate assumptions are valid, the procedures presented in DM-26.1, Subsection 2.9, may be used to determine tidal-current velocities.

Estimates of the peak flood and ebb tidal currents for numerous locations on the Atlantic coast of North America and the Pacific coasts of North America and Asia are published in tables by the U.S. Department of Commerce, National Ocean Survey (NOS). The published values are for specific locations, generally within harbors. Because tidal currents can vary significantly within a harbor, currents obtained from the NOS tidal-current tables must be used with caution unless they are values reported directly at the mooring site.

Tidal currents vary in speed and reverse their direction during the tidal cycle, but the forces induced by tidal currents are normally treated statically. Exceptions may occur, and these must be investigated on a site-by-site basis.

(b) River discharge. Currents resulting from river discharge can also be significant. Estimates of currents due to river discharge are best achieved by direct measurement or by analysis of existing flow records.

(c) Wind-driven currents. Wind-driven currents are surface currents which result from the stress exerted by the wind on the *sea* surface. Wind-driven currents generally attain a mean velocity of about 3 to 5 percent of the mean windspeed at 10 meters above the sea surface. The magnitude of the current decreases sharply with depth. The direction of the current is roughly that of the wind. Wind-driven currents are seldom a factor in protected harbors, but they must be investigated when they exceed 0.5 knot. Methods for estimating wind-driven currents are presented in Bretschneider (1967).

(d) Probability of currents. The probabilistic nature of current speed and direction at a given site should be taken into account. A probabilistic estimate of the speed and direction of tidal currents can be determined by extensive field measurements or through physical or numerical modeling; however, neither time nor budget is normally available to generate these data. Therefore, maximum flood and ebb currents should be used for fleet-mooring design unless more detailed information is available. This design criterion is reasonable for two reasons. First, these currents occur frequently; thus, there is a reasonable probability that these currents will occur during the design storm. Secondly, while a vessel could conceivably be subject to higher current speeds than the peak values, the higher currents would be of short duration. Hence, the impact of higher-than-average peak flood or ebb current speeds would not be too great. The statistical probability of river flows, which may be obtained from records of peak yearly flood flow, should be analyzed using the probabilistic methods described for wind in Section 5.

(5) Waves. Waves can exert significant dynamic loads on moored. vessels and mooring elements sited in unprotected waters. This manual assumes moorings are sited in a protected harbor; therefore, dynamic analysis of moored vessels is not considered herein. If there is doubt as to whether or not a mooring is located in a protected harbor, or if prior experience at the site indicates that wave action may affect mooring design, then wave conditions must be investigated.

Waves important to the design of fleet moorings fall into three categories: short waves, long waves, and waves generated by passing vessels. Short waves are wind-generated waves with periods of 20 seconds or less; those generated locally are referred to as seas and those generated great distances away are called swell. Moorings located in protected harbors are generally sheltered from short waves by structures, such as breakwaters or jetties. However, if the mooring is located near the harbor opening, it may be exposed to sea and swell, and the assumption of a protected harbor may not be valid. If the harbor is sufficiently large, local winds may generate seas within the harbor of sufficient size to affect the moored vessel.

Waves with periods ranging from greater than 20 seconds to several minutes are classified as long waves. Tang-wave energy is capable of causing oscillations in a harbor. This phenomenon, called seiche, is discussed in DM-26.1, Subsection 2.8.

Waves generated by passing vessels can be important to the design of a fleet mooring. This is particularly true when the mooring is sited in a narrow channel where other vessels pass close to the moored vessel.

In general, the most reliable methods for determining design-wave conditions use measurements taken at the site; however, this information is seldom available. Consequently, the methods described in DM=26.2, Sections 1 and 2, for obtaining wave data and estimating short-wave conditions must be used. Methods for estimating the possibility of mooring problems associated with long waves are lacking. It is best to rely on previous experience at the mooring site. In the same way, potential for problems associated with waves generated by passing ships must be determined based on previous experience.

(6) Unusual Conditions. The potential for the occurrence of unusual conditions must be investigated. Design may require significant deviations from the standard procedures presented in this manual. Table 9 presents a summary of unusual environmental conditions which require analysis not covered by this manual. If the occurrence of these conditions is probable, the designer should consult NCEL or CHESNAVFAC FPO-1 for specialized mooring designs.

TABLE 9
Unusual Environmental Conditions Requiring Special Analysis

Condition	Special Analysis Required
Waves [1]	> 1.5 feet for small craft > 4 feet for larger vessels
Wind	> 60 knots
Hurricanes and Typhoons [1] . . .	All cases where these are possible
Seiche [1]	Possibly a problem for taut multiple-point moorings
Short-Scope Moorings [1]	Those subjected to above wave conditions
Current	> 3 knots
Water Depth	> 150 feet
Anchors	Prpellant-embedded
Ice	Free-floating ice

[1]Requires dynamic analysis

b. Environmental Loads. Winds, currents, and waves produce loads on moored vessels. Static wind and current loads are discussed in detail below. A brief discussion of dynamic loads due to waves follows.

Static loads due to wind and current are separated into longitudinal load, lateral load, and yaw moment. Flow mechanisms which influence these loads include friction drag, form drag, circulation forces, and proximity effects. The predominant force-generating mechanisms are friction drag and form drag. Circulation forces play a secondary role. Proximity effects are important in multiple-vessel moorings and in moorings sited in very restricted channels.

(1) Load Due to Wind. Loads on moored vessels due to wind result primarily from form drag. The general equation used to determine wind load is:

$$F_w = \frac{1}{2} \rho_a V_w^2 A_w C_{DW} \qquad (4\text{-}1)$$

WHERE: F_w = load due to wind

ρ_a = mass density of air

V_W = wind velocity

A_W = projected area exposed to wind; may be either side area or end area

C_{DW} = wind-force drag coefficient which accounts for form drag and friction drag

The value of A_W differs for lateral load and longitudinal load: the side area is used for determining lateral load, and the end area is used for determining longitudinal load. The wind-force drag coefficient, C_{DW}, also differs for lateral load and longitudinal load: C_{DW} is a function of the angle at which the wind impinges upon the vessel. The value of C_{DW} is based upon model-test results. Section 5 presents methods for determining the lateral and longitudinal wind-force drag coefficients.

(2) Load Due to Current. Current loads developed on moored vessels result from form drag, friction drag, and propeller drag. Lateral forces are dominated by form drag. Form drag is dependent upon the ratio of vessel draft to water depth: as the water depth decreases, current flows around rather than underneath the vessel. Longitudinal forces due to current are caused by form drag, friction drag, and propeller drag. The general equation used to determine current load is:

$$F_c = \frac{1}{2} \rho_w V_c^2 A_c C_{DC} \tag{4-2}$$

WHERE: F_c = load due to current

ρ_w = mass density of water

V_c = current velocity

A_c = projected area exposed to current; may be either below-water side or end areas, hull surface area, or propeller area

C_{DC} = current-force drag coefficient

Methods for determining lateral and longitudinal current loads are presented in Section 5. Current-load estimates are not as reliable as those for wind loads. However, the procedures presented in this manual provide conservative results.

(3) Load Due to Waves. Wave-induced loads on moored vessels can dominate wind and current loads for moorings sited in unprotected, high-energy environments. As the mooring site is moved into protected areas, these forces diminish, and the previously discussed wind and current loads begin to dominate. Quantitative analysis of wave-induced forces is beyond the scope of this manual; however, a qualitative discussion is provided to give information on the magnitude, character, and relative importance of wave-induced loads.

The hydrodynamic response of a moored vessel in the presence of waves can be resolved into an oscillatory response and a static response (wave-drift force). The oscillatory response is characterized by vessel movements in six degrees of freedom (three translational: heave, sway, and surge, and three rotational: yaw, pitch, and roll) with associated mooring-line loads that occur with roughly the same period as that of the incoming waves. Theoretical analysis of the oscillatory response of a moored vessel is achieved through the coupled solution of six simultaneous equations of motion for the vessel mooring system. Solution of these equations is complicated. An outline of the solution is presented in DM-26.1, Subsection 2.8. The static wave drift force on a moored vessel in regular waves (that is, in waves with. the same height and period) is usually small compared to the oscillatory wave load. However, ocean waves are generally irregular (that is, waves which vary in height and period) and may be characterized by groups of high waves. The static drift force present in regular waves will slowly oscillate with the period of wave grouping in irregular waves. If the period of slow drift oscillation is close to the natural period of the moored-ship system, then large mooring loads may result.

Numerical models have been used to determine wave loading on moored vessels. Some of these numerical techniques are discussed in Van Oortmerssen (1976) and Webster (1982). Physical models , although expensive and time-consuming, are considered the most reliable means for determining wave loading (Flory et al., 1977).

(4) Multiple-Vessel Moorings. Wind and current loads on multiple-vessel moorings are greatly influenced by the sheltering effect of the first vessel on leeward vessels. The procedures and data necessary to determine the loads and moments induced on multiple-moored vessels by either wind or currents are extremely limited. The only data that are directly applicable for this purpose were collected at the David Taylor Model Basin (DTMB) shortly after World War 11; these were summarized graphically in the previous edition of Design Manual 26. Altmann (1971) noted that these data are not fully applicable to contemporary multiple-vessel mooring problems because only identical vessels were examined and no systematic variation of lateral separation distance was investigated. Altmann (1971) has also indicated a number of deficiencies in the data itself.

A contemporary multiple-vessel mooring arrangement consists of a tender with one or more identical vessels moored in parallel fashion alongside the tender. There are currently no model-test results for this type of mooring arrangement. Methods for determining loads on vessels in multiple-vessel moorings with both identical and nonidentical vessels are presented in Section 5.

c. Loads on Mooring Elements. Winds and currents produce a longitudinal load, a lateral load, and a yaw moment on a moored vessel. These loads displace and rotate the vessel relative to its position before the loads were applied. The vessel will move until it reaches an equilibrium position, at which the applied loading is equal to the restraint provided by the mooring lines. Procedures for determining the mooring-line loads differ depending upon whether the mooring is free-swinging (single-point) or multiple-point.

(1) Free-Swinging (Single-Point) Moorings. The-procedure for determining the horizontal mooring-line (hawser) load in a free-swinging mooring involves determining the equilibrium position of the vessel. Figure 41 schematizes a typical design situation, wherein wind and current act

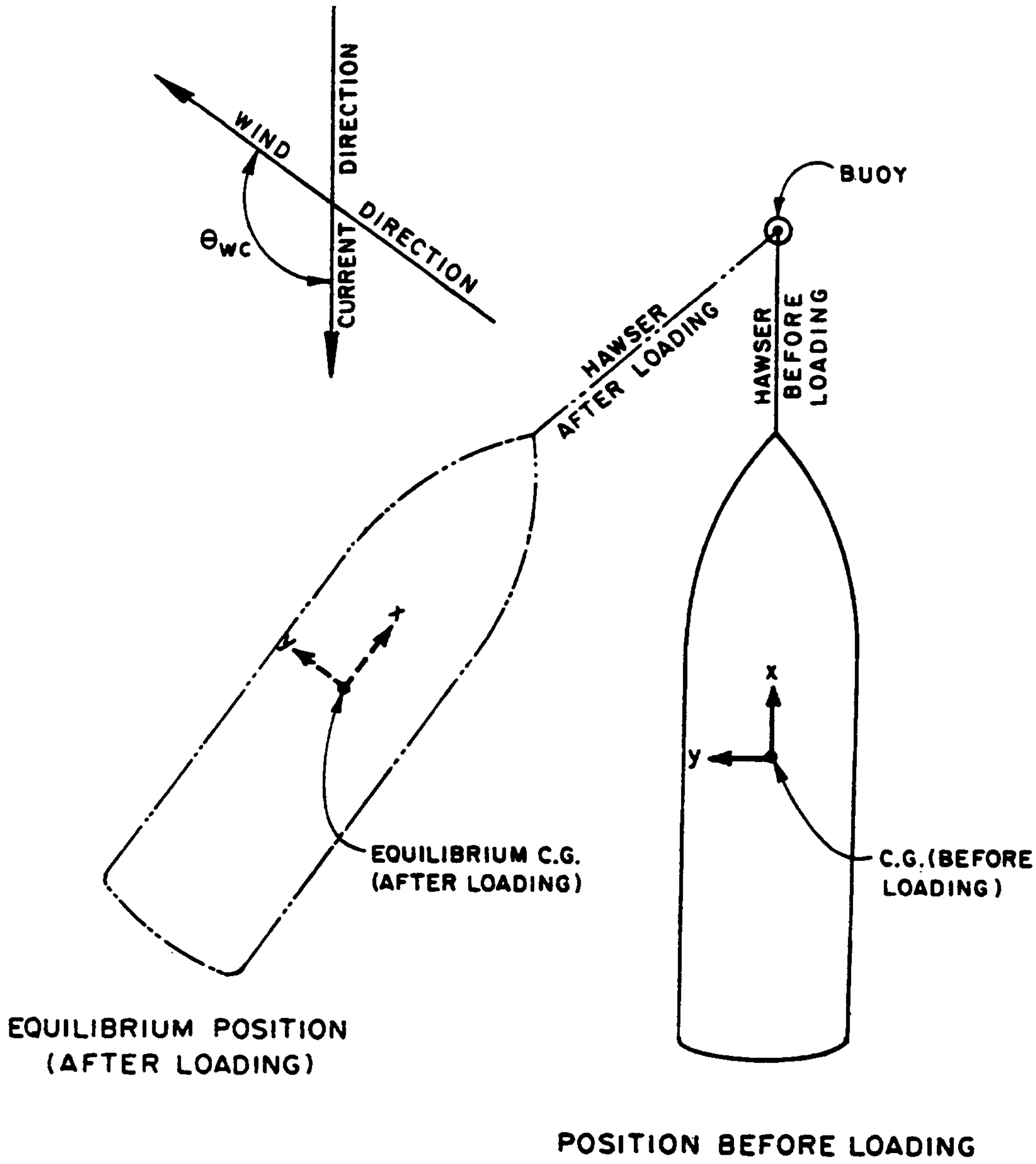


FIGURE 41
Free-Swinging Mooring Under Simultaneous Loading of Wind and Current

simultaneously on a moored vessel. The angle between the wind and the current is θ_{wc}. The longitudinal and lateral forces are assumed to act through the center of gravity (C.G.) of the vessel. The yaw moment is assumed to act about the center of gravity. Wind and current forces and moments displace and rotate the vessel relative to its initial position. For static equilibrium, the applied loads must equal the restoring loads of the mooring system, according to the following equations:

$$\Sigma F_x = 0 \qquad (4\text{-}3)$$

$$\Sigma F_y = 0 \qquad (4\text{-}4)$$

$$M_{C.G.} = 0 \qquad (4\text{-}5)$$

WHERE ΣF_x = sum of the applied and restoring loads along the longitudinal axis of the vessel

ΣF_y = sum of the applied and restoring loads along the lateral axis of the vessel

$\Sigma M_{C.G.}$ = sum of the applied and restoring yaw moments about the center of gravity of the vessel

The vessel willadjust its position around the single-point mooring until the above equations of equilibrium are satisfied.

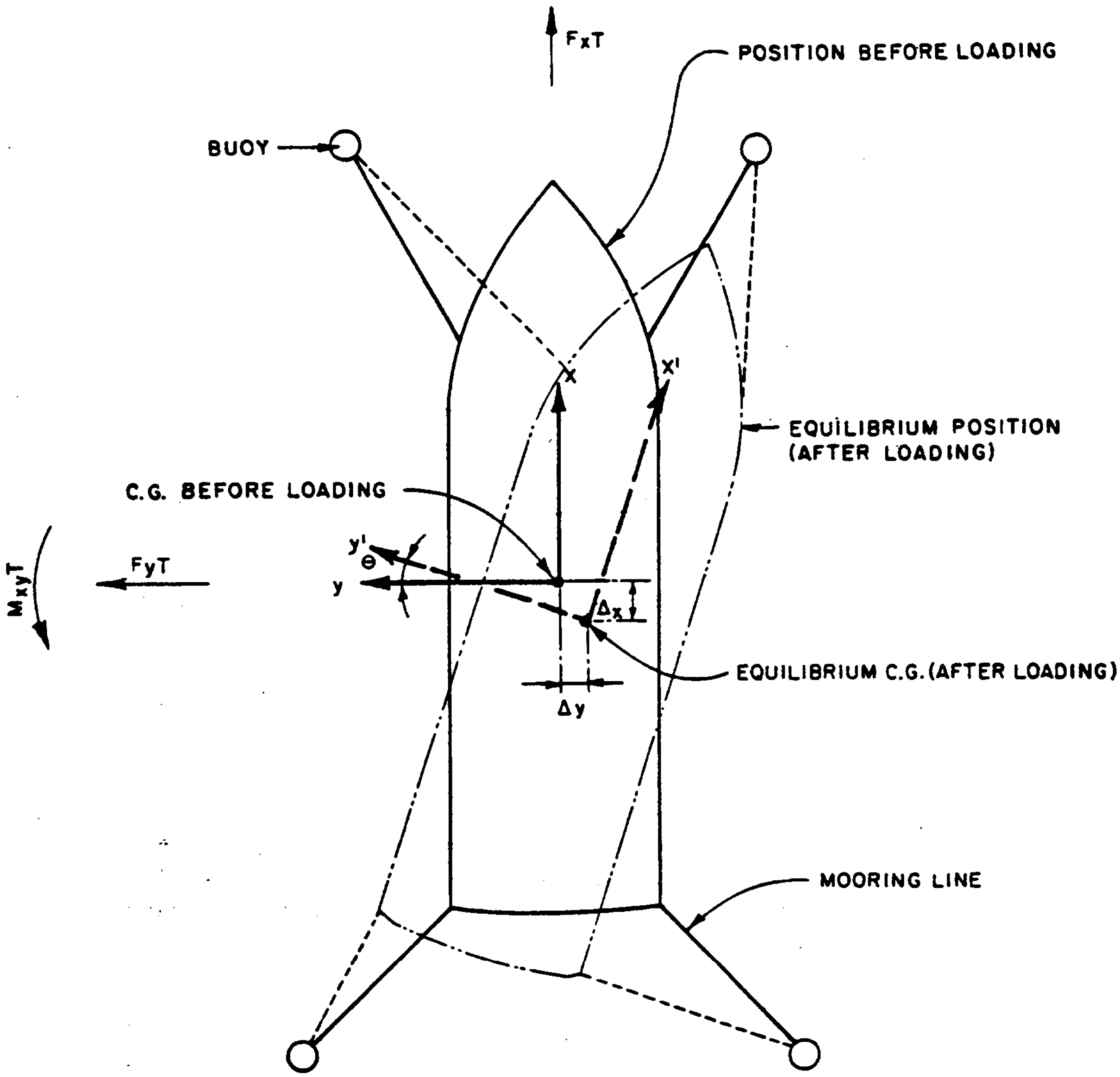
The longitudinal forces due to wind and current are designated F_{xw} and F_{xc}, respectively. The lateral forces due to wind and current are designated F_{yw} and F_{yc}, respectively. The yaw moments due to wind and current are designated M_{xyw} and M_{xyc}, respectively. The longitudinal forces, lateral forces, and yaw moments are a function of the angle between the vessel and the wind, θ_w, and the angle between the vessel and the current, θ_c. These angles vary as the vessel achieves its equilibrium position.

Computation of the maximum hawser load is a trial-and-error procedure in which the orientation of the vessel is continually adjusted until the point of zero moment is determined. The vessel response is dependent upon the relative angle, θ_{wc}, between the wind and the current. Details of the computation procedure are presented in Section 5.

(2) Multiple-Point Moorings. The procedure for determining the horizontal line loads in a multiple-point mooring differs from the free-swinging mooring procedure. Figure 42 depicts a typical spread mooring both before and after wind and current loads are applied. The vessel is reoriented as the applied load is distributed to the mooring lines. The mooring lines, which behave as catenaries, will deflect (that is, lengthen or shorten) until they are in equilibrium with the applied loads. Equations (4-3), (4-4), and (4-5) must be satisfied for static equilibrium to exist. Determining the equilibrium position of the vessel under load is outlined as follows:

(a) Determine the total longitudinal load, lateral load, and yaw moment on the vessel due to wind and current.

(b) Determine the mooring-line configuration and the properties of each of the mooring lines. Calculate a load-deflection



F_{xT} = TOTAL FORCE ALONG X-AXIS
F_{yT} = TOTAL FORCE ALONG Y- AXIS
M_{xyT} = TOTAL YAW MOMENT ABOUT CENTER OF GRAVITY (C.G.)
Δx = SURGE DISPLACEMENT
Δy = SWAY DISPLACEMENT
θ = YAW ROTATION

NOTE: VESSEL ROTATION AND LINE ELONGATIONS ARE EXAGGERATED

FIGURE 42
Multiple-Point Mooring Under Simultaneous Loading of Wind and Current

curve (see Subsection 4.4. d.(3)) for each of the mooring lines using catenary analysis.

(c) Assume an initial displacement and rotation of the vessel (new orientation) under the applied load.

(d) Determine the deflection in each of the mooring lines corresponding to the vessel orientation.

(e) Determine the forces in each of the mooring lines from the above mooring-line deflections.

(f) Sum the forces and moments according to the above equations, accounting for all the mooring-line loads and applied wind and current loads.

(g) Determine if the restraining forces and moments due to all the mooring-line loads balance out the applied forces and moments due to wind and current.

(h) If the above forces and moments do not balance, then the vessel is not in its equilibrium position under the applied load. A new vessel orientation must be assumed.

(i) Steps c through h are repeated until the equilibrium position of the vessel is determined.

The above procedure can be solved using the computer program in Appendix B. Simplified methods for analyzing multiple-point moorings are presented in Section 5.

4. DESIGN OF MOORING COMPONENTS.

a. Probabilistic Approach To Design. A probabilistic approach to mooring design is used to evaluate uncertainties in environmental conditions at the mooring site, uncertainties in accurately predicting mooring forces, and uncertainties concerning material strength of the mooring-system hardware.

(1) Uncertainties in Environmental Conditions.

(a) Windspeed. The uncertainty associated with determining a design windspeed is reduced by using the probabilistic approach described in Subsection 4.3.a.(3). Fleet moorings must be designed for a windspeed with a So-year return period, unless operational criteria dictate that the vessel leave the mooring at a windspeed less than the So-year windspeed. For a mooring with a 5-year life expectancy, there is about a 9.6-percent chance that the mooring will be subjected to the So-year windspeed. Similarly, there is about an 18-percent chance that a mooring with a 10-year life expectancy will be subjected to the So-year windspeed.

(b) Currents. There are generally insufficient data to perform a probabilistic analysis of tidal currents. Consequently, the design tidal current shall be the larger of the maximum flood or ebb current at the site. Wind-driven-current statistics can be derived from wind data. River-discharge data can be analyzed and probabilities determined using methods similar to those described for wind.

(2) Uncertainties in Predicting Forces. Uncertainties involved in determining wind- and current-induced loads on moored vessels should be recognized. Wind loads are relatively accurate (± 10 to 15 percent of the

predicted value), while current loads are more uncertain and may be as high as ± 30 percent of the predicted value for currents with speeds greater than 3 knots.

(3) Uncertainties immaterial Strength. The holding capacity of anchors under design loading and the material strength of mooring chain are uncertain. Hence, a factor of safety is used in anchor selection, and mooring chain is selected on the basis of a working load, which is considerably less than the breaking strength of the chain.

Uncertainties in anchor selection are associated with soil strength and behavior of the anchor under load. Uncertainties in chain strength are associated with variations in chain quality and with degradation of chain strength with time as the chain is exposed to the marine environment. Recommendations concerning factors of safety for anchors and mooring chain are given in Section 5.

b. Design Philosophy. Mooring components, such as mooring chain, fittings, anchors, sinkers, and buoys, must sustain anticipated loads without failure. Mooring failures can occur in various manners, including anchor dragging, breakage of ground leg or riser chain, and breakage of the ship's chain or mooring line. The impact of a mooring failure can range from minor, for anchor dragging, to catastrophic, for breakage of a riser chain or ship's chain. The factor of safety on anchors is generally less than that for mooring chain. This practice forces the anchor to fail before a mooring chain fails. For drag-embedment and deadweight anchors, there is some residual resisting force after failure due to the weight of the anchor. This is not true for direct-embedment anchors and pile anchors, which, like the mooring chain, can fail suddenly. The factors of safety for direct-embedment and pile anchors are generally higher than those for drag-embedment and deadweight anchors; however, they should be less than those for the mooring chain and fittings.

c. Availability of Mooring Components. Situations may arise where availability of materials and/or installation equipment may dictate design. For example, if steel piles and installation equipment are available, it may be cost-effective to use pile anchors in lieu of conventional drag anchors. The designer should be aware of available materials and existing designs before arbitrarily specifying mooring components. Standardized mooring components are often stored at or near the mooring site. Therefore, it is desirable from an economic standpoint to specify mooring components which are currently in stock. Deviations from standardized mooring components should be kept to a minimum as these deviations give rise to procurement and quality-control problems.

d. Design of Mooring Chain and Fittings.

(1) Mooring-Line Geometry. A loaded mooring chain, extending from the bottom of the buoy to the anchor, behaves as a catenary. Catenary equations, presented in detail in Section 5, give the horizontal and vertical tension at any point in the line, in addition to giving the mooring-line geometry.

Mooring designs may be classified into two categories: normal moorings and short-scope moorings. Normal moorings have a sufficient length of chain to maintain a near-zero bottom angle between the mooring line and the horizontal. This precludes any vertical load at the anchor and is desirable for drag anchors. Short-scope moorings use shorter lengths of chain, and the bottom angle between the mooring line and the horizontal is not near zero. This results in both horizontal and vertical loads at the anchor and requires an uplift-resisting anchor.

(2) Selection of Chain Size. Mooring chain is designed to withstand the maximum anticipated environmental loading. Mooring chain is selected on the basis of its maximum working load, defined as 35 percent of the chain breaking strength. For chain which passes through hawsepipes, chocks, chain stoppers, or other fittings which cause the chain to change its direction abruptly within its loaded length, the maximum working load is 25 percent of the chain breaking strength. The maximum working load may be taken as 35 percent of the chain breaking strength provided the minimum bending radius is nine times the chain diameter, according to NAVSEASYSCOM criteria.

(3) Load-Deflection Curve. Figure 43 shows a vessel, attached to a free-swinging mooring, prior to and after the environmental loads are applied to the vessel. Upon loading, the vessel deflects from its initial position, in the direction of the applied load. As the vessel moves, the restraining force in the mooring chain increases. A plot of the restraining force in the catenary mooring chain versus the deflection of the vessel is known as a load-deflection tune. An example of a load-deflection curve is shown in Figure 44. The load-deflection curve can be used to determine vessel movement for a given applied load. This information is useful for planning a mooring layout and estimating the amount of area required to moor a vessel under normal and design conditions.

The load-deflection tune also provides information on the energy-absorbing capability of a mooring. This information is obtained by applying the concepts of work and energy to the load-deflection curve. A vessel may be moored with some initial tension (pretensioning) in the mooring line. Pretensioning takes the initial slack out of a mooring line prior to application of wind and/or current loading and prevents excessive vessel movement under loading. When wind and/or current load is applied to the vessel, the vessel will deflect from its initial position under the pretension load. Assuming the load is applied slowly to the vessel and the anchor does not drag, the work required to move the vessel must be absorbed by an increase in the potential energy of the mooring-line system. An increase in potential energy results as the mooring lines and hardware are raised under loading. The principle of work-energy dictates that the work done on the vessel as it is moved from its initial position to its equilibrium position is equal to the area under the load-deflection curve. This concept is illustrated in Figure 44. Point A denotes the initial position of the vessel resulting from the initial pretension in the mooring line. Point B denotes the equilibrium position of the vessel after the static wind and current loads have been applied; the load associated with Point B is the sum of the static wind and current loads. The area under the load-deflection curve between Points A and B represents the work done on the vessel by the static wind and current loads. If dynamic loads due to wind, current, or wave loads are present,

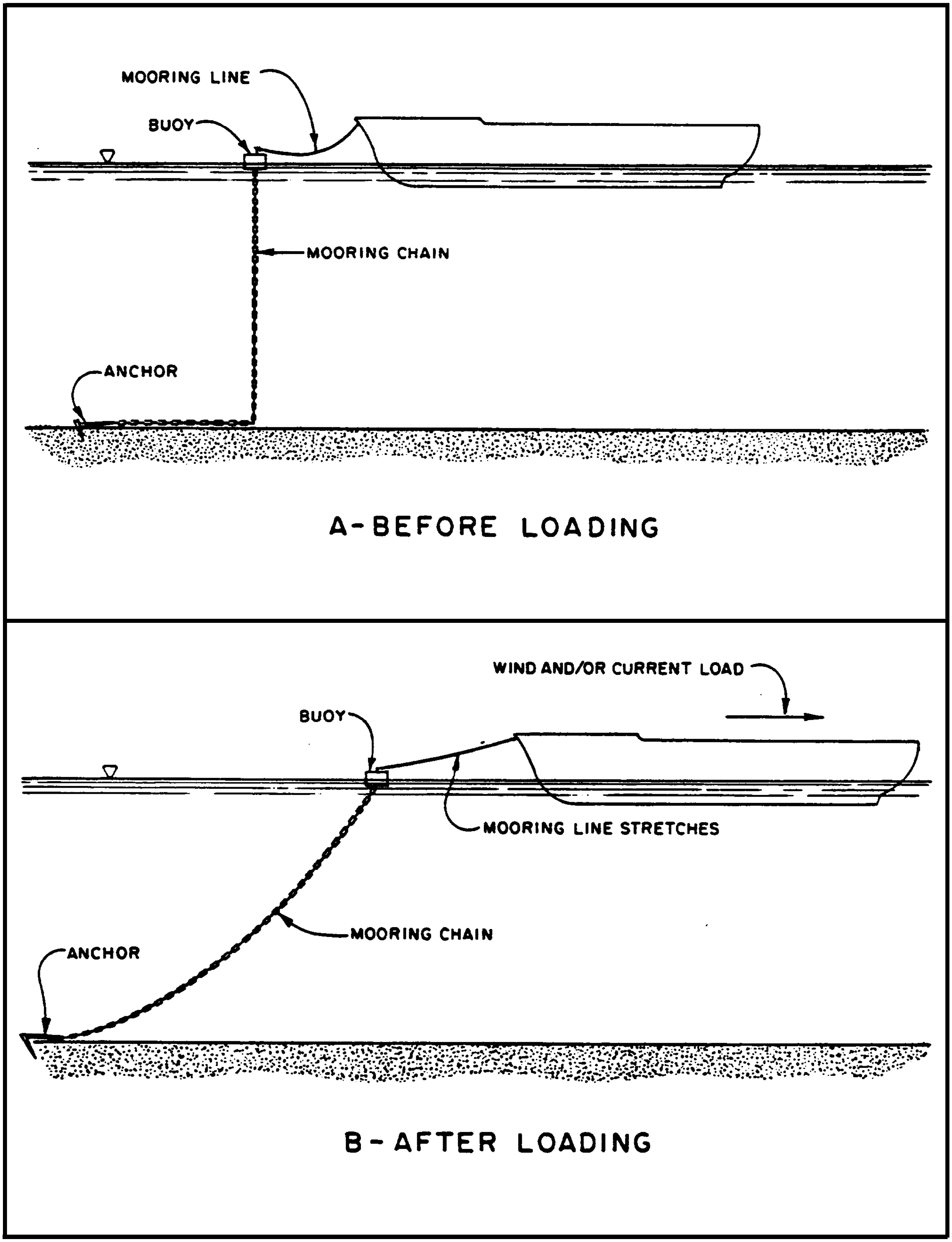


FIGURE 43
Behavior of Mooring Under Environmental Loading

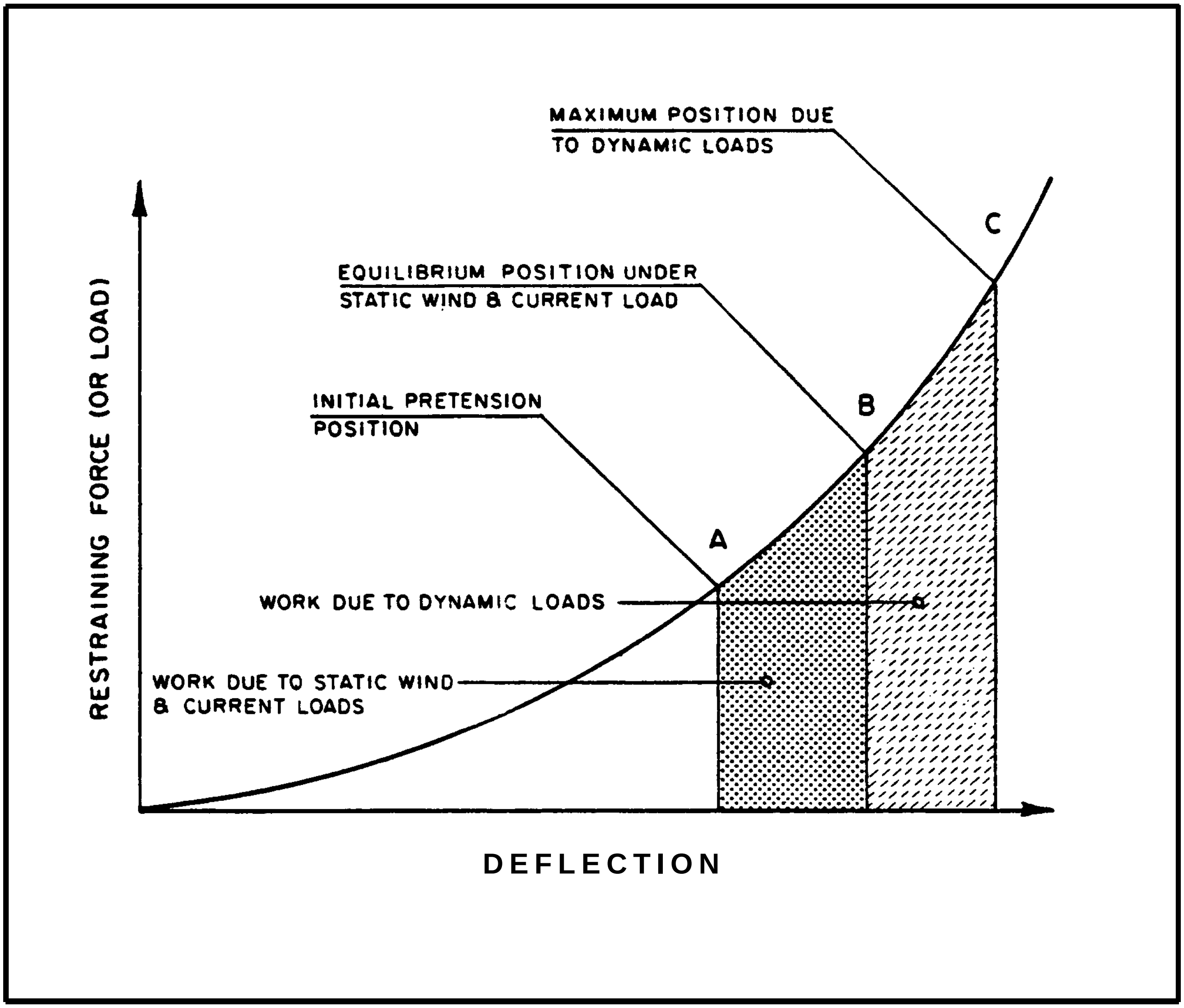


FIGURE 44
Load-Deflection Curve Illustrating Work-Energy Principle

then additional work will be done on the vessel. Point C denotes the maximum position due to dynamic wind, current, or wave loads. The area under the load-deflection curve from Point B to Point C represents the work done on the vessel by dynamic loads. This additional work must be absorbed by the mooring system without allowing the maximum load in the mooring line (Point C) to exceed the working load of the mooring line. The maximum dynamic mooring load (Point C) is generally difficult to determine. However, where moderate dynamic effects, such as those due to wind gusts, are anticipated, a resilient mooring capable of absorbing work (or energy) is required.

Sinkers can be used to make a mooring more resilient. Figure 45 illustrates the use of a sinker to increase the energy-absorbing capability of a mooring. Curve 1 is the load-deflection curve for a mooring system without a sinker. Curve 2 is the load-deflection curve for the same mooring system with a sinker added to it. The portion of the load-deflection tune which

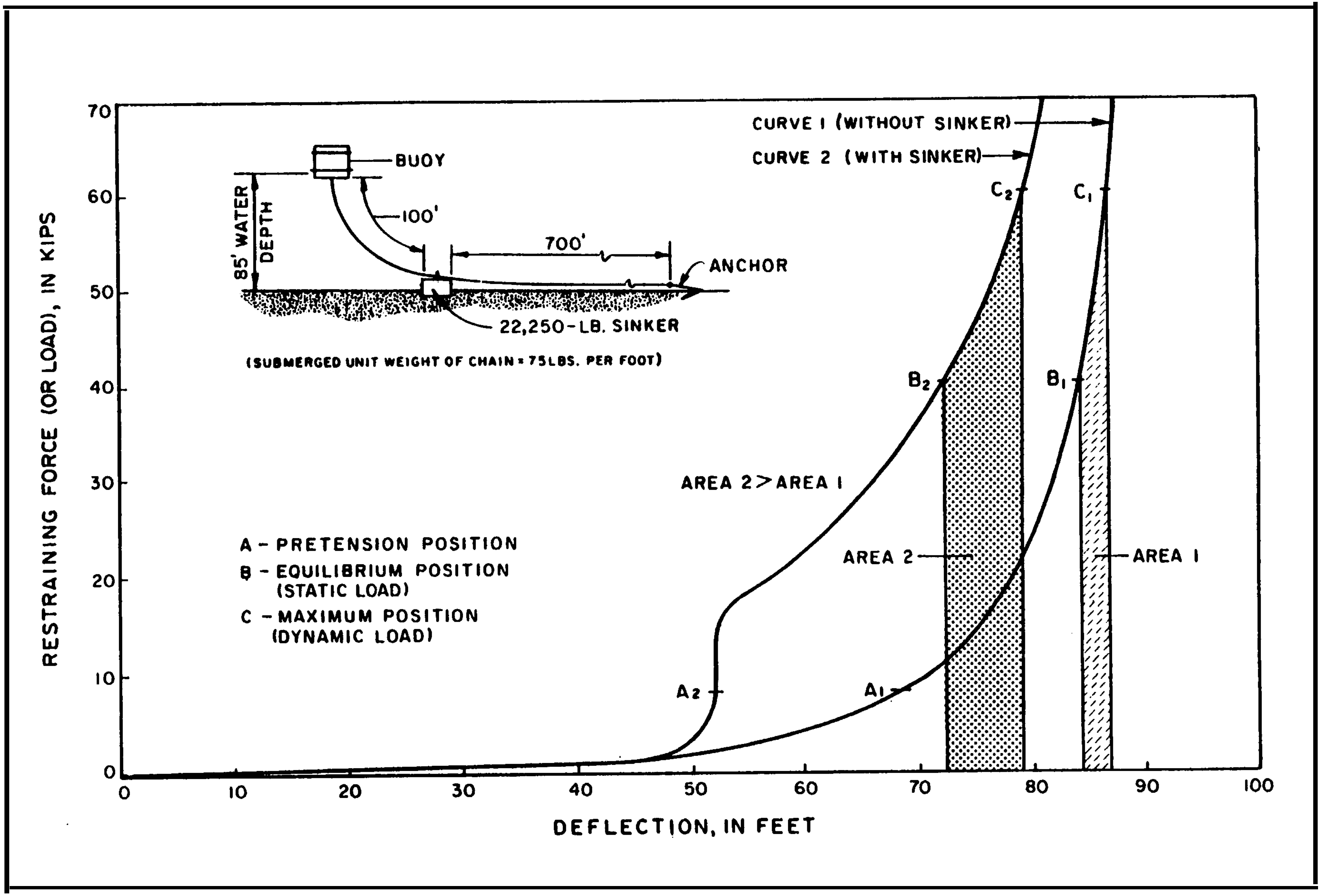


FIGURE 45
Load-Deflection Curves With and Without a Sinker

rises vertically on Curve 2 corresponds to the loads which lift the sinker off the bottom. Points A, B, and C represent the pretension position, equilibrium position under static loading, and the maximum position under dynamic loading, respectively. The sinker is added to the mooring line to increase the energy-absorbing capability of the mooring between Points B and C. The shaded Areas 1 and 2 under load-deflection Curves 1 and 2 represent the amount of energy absorbed by the mooring without the sinker and with the sinker, respectively. Clearly, the amount of energy absorbed between Points B and C by the mooring equipped with a sinker is considerably larger than that absorbed by the mooring without a sinker.

Figure 46 illustrates the situation where an equal amount of energy due to dynamic loads (above the static load) must be absorbed by both the mooring systems represented by Curve 1 (without sinker) and that represented by Curve 2 (with sinker). Points C_1 and C_2 depict the maximum mooring loads due to dynamic loads for Curves 1 and 2, respectively. This figure shows that the maximum mooring-line load for Curve 1 (without sinker) is considerably larger than the corresponding load for Curve 2 (with sinker) when both moorings must absorb the same amount of energy. This example illustrates the effect of a properly placed sinker on the energy-absorbing capacity of a mooring. A design example of an energy-absorbing mooring incorporating sinkers can be found in CHESNAVFAC FPO-1-81-(14).

e. Choice of Fittings. Selection of chain fittings is made using the same criteria as those stipulated for mooring chain. The working load on fittings should be less than or equal to 35 percent of the fitting breaking strength. It is essential that the fittings be checked for compatibility in size with selected mooring chain and other fittings. Failure to perform a "fit-check" can result in major delays during installation and, consequently, in higher installation costs.

f. Layout of Mooring Ground Legs. The ground legs of fleet moorings should be laid out in a symmetrical pattern in order to resist multidirectional loading. The three-legged or six-legged (three groups of two) standard moorings are laid out with 120 degrees between legs. For bow-and-stern or spread moorings, the ground legs may be oriented to one side of the mooring to resist unilateral loading.

g. Standard Designs. The Navy has standardized free-swinging moorings into 11 classes ranging in capacity from 5 to 300 kips (1 kip = 1,000 pounds). The mooring components have been selected using a working load of 35 percent of the component breaking strength. Standards for chain assemblies for various water depths have been prepared for each of these standard moorings and are presented in DM-26.6, Section 4, Part 2. Details of the standard moorings are presented in Figures 1 through 5 and Tables 79 through 92 of DM-26.6. Details of standard Navy mooring components are given in Figures 6 through 13 and Tables 93 through 119 of DM-26.6; these components have remained relatively unchanged for a number of years. Consequently, most of the current Navy inventory is made up of the components described in the above tables.

The Navy is currently pursuing a program for the maintenance and monitoring of fleet moorings in order to upgrade and extend their useful lives. The program also has the goal of extending the mooring maintenance cycle from

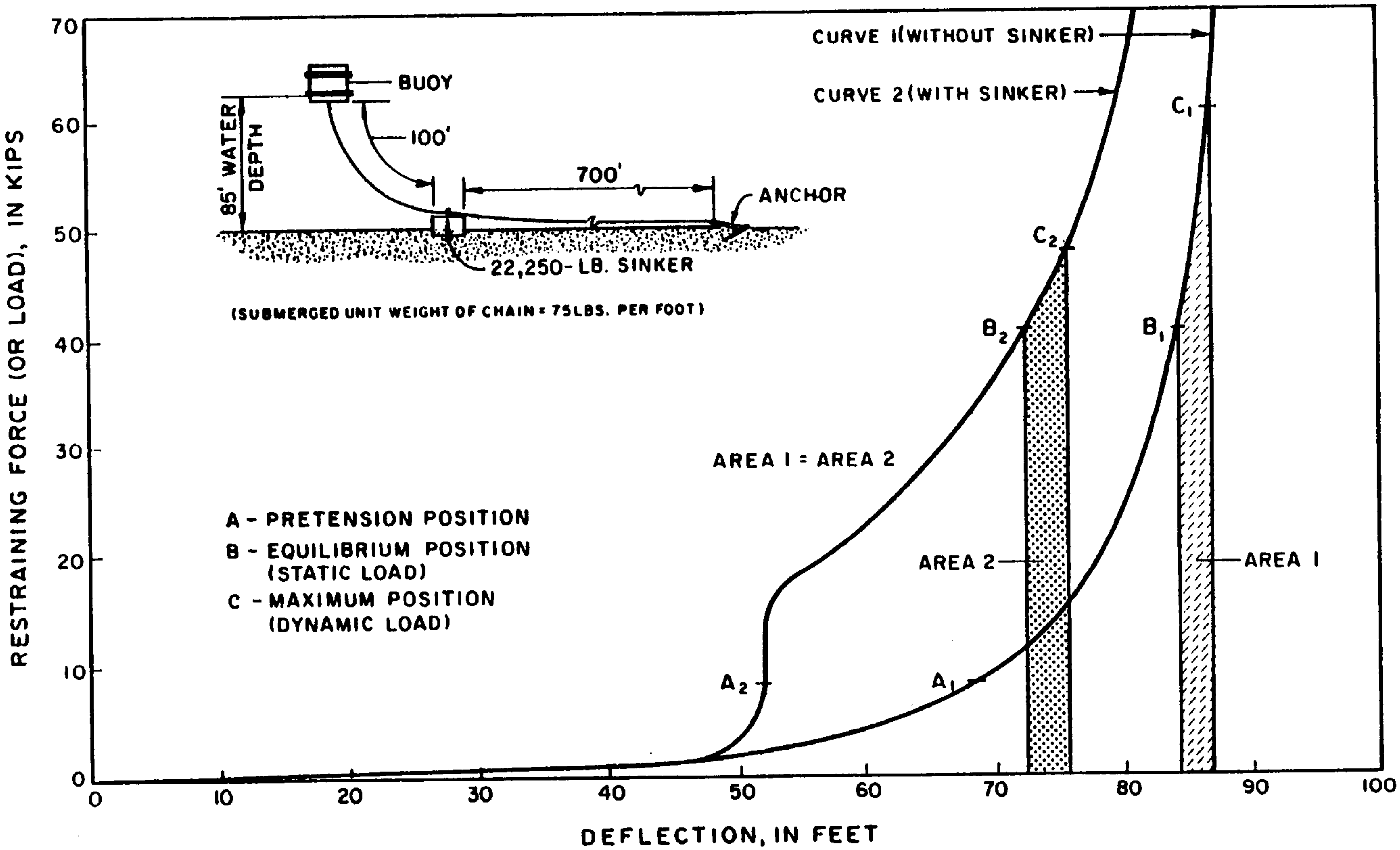


FIGURE 46

Load-Deflection Curves, Where Equal Amounts of Energy Are Absorbed, With and Without a Sinker every 5 years to every 10 to 15 years. The maintenance cycle will be lengthened by making some modifications to present standard designs. These modifications include the addition of cathodic protection and several structural modifications summarized in Figure 47. The resulting modified mooring will be designated as a Class X mooring, wherein the X stands for extra longevity (10 to 15 years). For instance, once a standard A mooring has been modified as shown in Figure 47, it will be known as a Class AX mooring.

h. Anchor Selection. Factors pertaining to anchor selection are presented in Sections 3 and 5.

i. Buoy Selection. Buoy selection is not covered in this manual. However, in the selection of a buoy for a fleet-mooring design, it is important to select a buoy with adequate capacity to support the mooring chain with a freeboard of 2 feet. The weight which the buoy must support is determined by computing the weight of the chain lifted off the bottom. The maximum tension bar vertical-load capacity of several fleet-mooring buoys is provided in Figures 10 and 11 of DM-26.6.

5. RATING CAPACITY OF MOORING. The final step of the design procedure consists of determining the size of vessels which can use the mooring. Furthermore, the environmental conditions under which the above vessels may use the mooring must be determined. Establishing the rated capacity of the mooring will deter inappropriate usage of the mooring.

6. INSPECTION AND MAINTENANCE OF MOORINGS. Over 225 fleet moorings of various sizes and classifications are in place at 25 different naval activities worldwide. Many of these moorings were initially designed and placed during World War 11 and have seen various forms of maintenance, overhaul, replacement , and relocation since that time. The Naval Facilities Engineering Command (NAVFAC) is the Navy’s central manager for fleet moorings. In that capacity, NAVFAC has responsibilities that include:

(a) management of a Navy-wide procurement and maintenance program;
(b) budgeting for current- and out-year Other Procurement Navy (OPN) and Operations and Maintenance Navy (OMN) funding requirements for the fleet-mooring program;
(c) execution of current-year OPN and OMN funds for the fleet-mooring program; and
(d) establishing and executing NAVFACENGCOM policies on all matters related to fleet moorings and governing:

  (1) design;
  (2) procurement;
  (3) installation;
  (4) inspection; and
  (5) maintenance and repair.

NAVFAC discharges these responsibilities through its network of geographical Engineering Field Divisions (EFD) and naval shore activities worldwide. In doing so, it utilizes various support programs, manuals, directives, and organizational entities that articulate, synthesize, and activate NAVFAC’S fleet-mooring program management. These elements of the

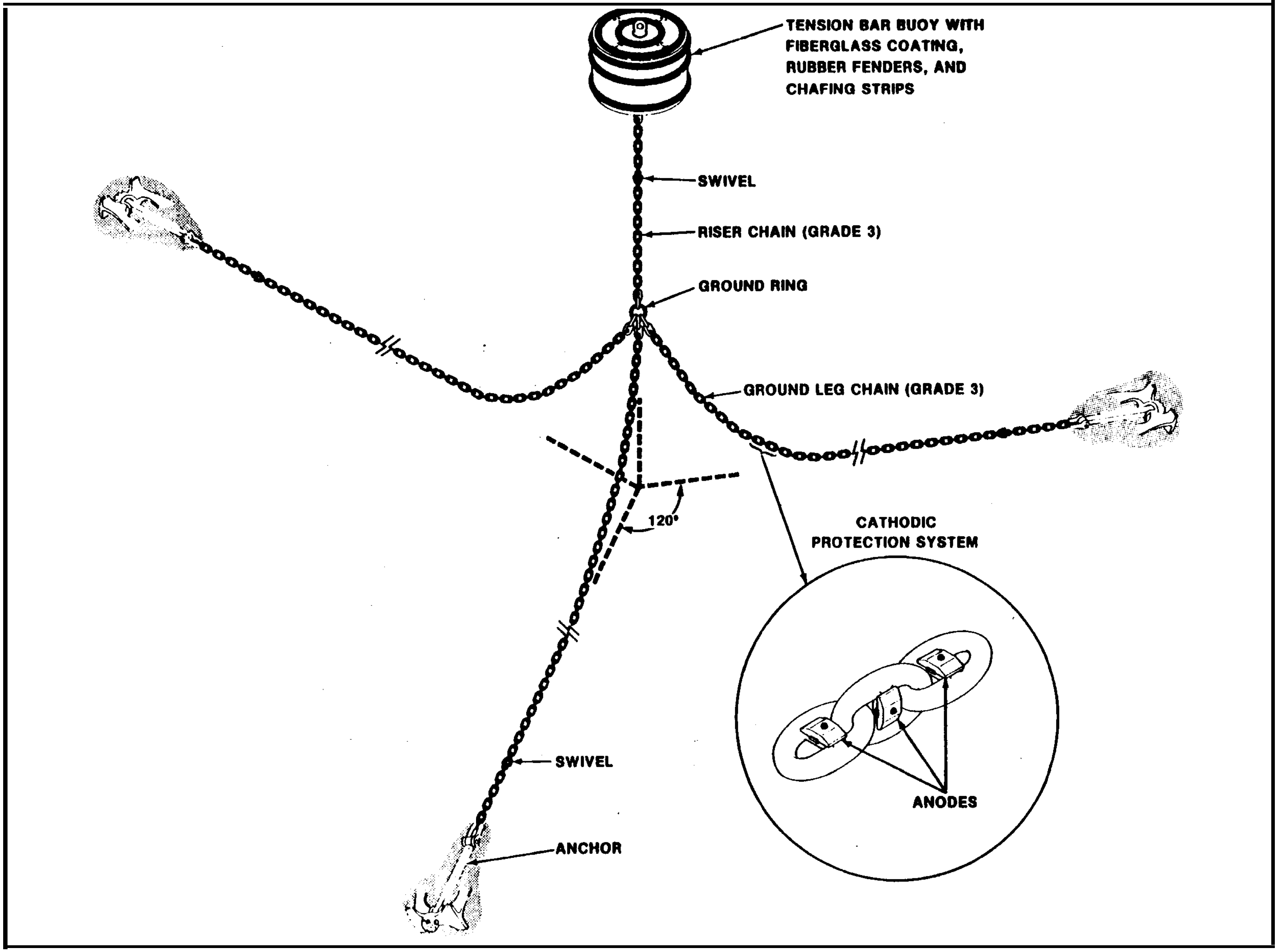


FIGURE 47
Upgraded Mooring

fleet-mooring management are highly interrelated and it is therefore difficult, if not impossible, to deal with one element without being influenced by one or more of the others.

DM-26.5 is the design manual which establishes guidelines and procedures for the design of Navy fleet moorings. The user of the manual should have some familiarity with two other highly interrelated items of the fleet-mooring program. The first and most comprehensive of these two items is the Fleet Mooring Maintenance (FMM) program, which gets it primary direction out of the Ocean Engineering and Construction Project Office of the Chesapeake Division, Naval Facilities Engineering Command. The second item is Mooring Maintenance (NAVFAC MO-124), the NAVFAC document that defines Navy policy and procedures for fleet-mooring maintenance in the same manner that DM-26.5 defines Navy policy and procedures for fleet-mooring design.

The user of DM-26.5 possessing an awareness and understanding of these other two items will unquestionably be in a better position to design a fleet mooring which embraces not only the stated policies and procedures for design, but also integrates all major Navy philosophies and objectives of the total fleet-mooring maintenance program.

a. Fleet Mooring Maintenance (FMM) Program. The FMM program is au ongoing and dynamic program for managing the fleet-mooring assets of the Navy to best meet the current and future needs of the fleet and the shore establishment. The program necessarily includes processes for inspection, overhaul, reinstallation, and replacement of mooring systems, as well as individual components of these systems. To optimize the effectiveness of such a program, viable and practical supporting subsystems and processes are also required. In the case of the Fleet Mooring Maintenance program, supporting subsystems and processes need to address and deal with such elements as procurement; financial management of OPN and OMN funds; life cycle costing; extended useful life; component inventory levels and stock point locations; performance and condition status; inspection and overhaul criteria; means, methods, and procedures for overhaul; and communication of philosophies and policies.

The Ocean Engineering and Construction Project Office of the Chesapeake Division, Naval Facilities Engineering Command, is the major organizational component that supports the Fleet Mooring Maintenance Program. This support ranges across the entire spectrum of objectives and activities of this program. Specifically, it embraces the development, execution, and monitoring of the required program-supporting subsystems and processes suggested above. In addressing these FMM program needs, the Ocean Engineering and Construction Project Office, during the early and mid-1980's, is focusing on the development and refinement of the following activities and processes:

(1) preparation of fleet-mooring purchase description;
(2) definition of an upgraded mooring;
(3) defining and monitoring OPN money for fleet-mooring procurement;
(4) conducting fleet-mooring site inspections;
(5) developing automated Fleet-Mooring Inventory (FMI) management system;
(6) preparation of FMM performance work statement;

(7) preparation of revised NAVFAC instructions and revised M0-124;
(8) conducting workshops on current fleet-mooring policies and procedures; and
(9) providing program management support for:

   (a) monitoring the overhaul/upgrade of fleet moorings;
   (b) monitoring the status of fleet-mooring inventory;
   (c) defining OPN funding requirements for FMI procurements; and
   (d) projecting OMN funding requirements for maintenance services; and

(10) performing fleet-mooring diver inspections:

   (a) providing post-installation inspection for overhauled/ upgraded moorings; and
   (b) providing periodic maintenance inspections to monitor performance of moorings.

The Fleet Mooring Maintenance program, therefore, provides for the use, maintenance, and operation of the entire Navy inventory of fleet moorings. This management system has many diverse elements which are interdependent and keenly interrelated. As such, any participant involved with a seemingly singular and independent element of the program will find the involvement and accompanying contributing effort to the program enhanced by having a comprehensive understanding of the total FMM program and its objectives.

b. M-124. DM-26.5 is, by NAVFAC intent, a document which standardizes Navy concepts and procedures for the design of fleet moorings. As such, this document communicates these concepts to the Navy user. In a like manner, MO-124 is the document that articulates the NAVFAC position on mooring maintenance. It defines, in detail, methods and procedures for placement and recovery, reconditioning, and inspection and maintenance of moorings, as well as for cathodic protection and fiberglass-polyester coating.

Knowing and understanding the contents of MO-124 allow the activity engineer to develop the short-term and long-term funding requirements that serve as input to establish total Navy OPN and OMN funding requirements. MO-124 in essence serves as a baseline document for determining fleet-mooring maintenance requirements for labor effort and material. DM-26.5 and MO-124 complement each other as they make similar, but distinctly different, contributions to the overall FMM Program.

In summary, the management by the Navy of its fleet-mooring inventory is realized through a many-faceted, diverse, and dynamic program. DM-26.5 and MO-124 are two distinct elements of that program. The user of either will enhance his effectiveness and his contribution to the program by maintaining a keen awareness of the contents of the other manual, as well as an awareness of the Fleet Mooring Maintenance program in general.

7. METRIC EQUIVALENCE CHART. The following metric equivalents were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 4. Conversions are approximate.

1 mile = 1.61 kilometers
60 miles per hour = 96.6 kilometers per hour
30 miles per hour = 48.3 kilometers per hour
33.33 feet = 10 meters
1 knot = 0.5 meter per second
6 knots = 3.1 meters per second
0.5 knot = 0.25 meter per second
3 knots = 1.5 meters per second
5 kips = 5,000 pounds = 2 268 kilograms
300 kips = 300,000 pounds = 136 080 kilograms
1 kip = 1,000 pounds = 453.6 kilograms
2 feet = 61 centimeters

Section 5. DESIGN OF FLEET MOORINGS

1. **INTRODUCTION.** This section provides equations, graphs, and tables necessary for fleet-mooring design. Detailed procedures are presented for each element of the design process. Section 4 provides a qualitative discussion of the design process.

2. **MOORING LAYOUT.** It is assumed that the mooring site, the vessel, and the mooring configuration are given prior to commencement of detailed design. In some cases, it may be necessary to review several mooring configurations in order to determine the one most appropriate. Often the designer will have to analyze several vessels for a given mooring configuration.

3. **ENVIRONMENTAL CONDITIONS.**

a. Seafloor Soil Conditions. Seafloor soil conditions must be investigated in order to design fleet-mooring anchors. Refer to DM-7 for soil-investigation requirements.

b. Design Water Depth. Determine the bottom elevation and the anticipated range of water elevation expected at the mooring site. Bathymetric charts are usually available from National Ocean Survey (NOS). The primary cause of water-level fluctuations is the astronomical tide. Estimates of the maximum high and low water levels due to tide for most naval harbors are given in DM-26.1, Table 6. A summary of tide levels for U.S. locations is given in Harris (1981).

c* Design Wind. Steps for wind-data analysis, discussed below, are summarized in Figure 48. This procedure involves some concepts of probability, which are discussed in Appendix A.

(1) Obtain Wind Data. Collect available windspeed data for the site. Data which give the annual maximum windspeed (extreme wind) and direction for each year of record are required. In most situations, the annual maximum windspeeds are either fastest-mile or peak-gust values. A minimum of 20 years of yearly extreme windspeed data is desired for a good estimate of the So-year design windspeed.

Several possible sources for obtaining windspeed data are presented in Table 10. These are discussed below:

(a) Naval Oceanography Command Detachment. The Naval Oceanography Command Detachment is a source of wind data for naval harbors worldwide. Wind data available through the Naval Oceanography Command Detachment are summarized in "Guide to Standard Weather Summaries and Climatic Services, NAVAIR 50-lC-534 (1980). The most useful of the standard wind summaries available at the Naval Oceanography Command Detachment for mooring design is the table of extreme winds. This table, available for a large number of naval sites, provides the extreme peak-gust windspeed (and its direction) for each month of each year of record. This standard summary provides sufficient information to determine extreme winds for all directions combined, but provides insufficient information to determine extreme winds for each direction individually. Extreme peak-gust windspeed for each direction for each

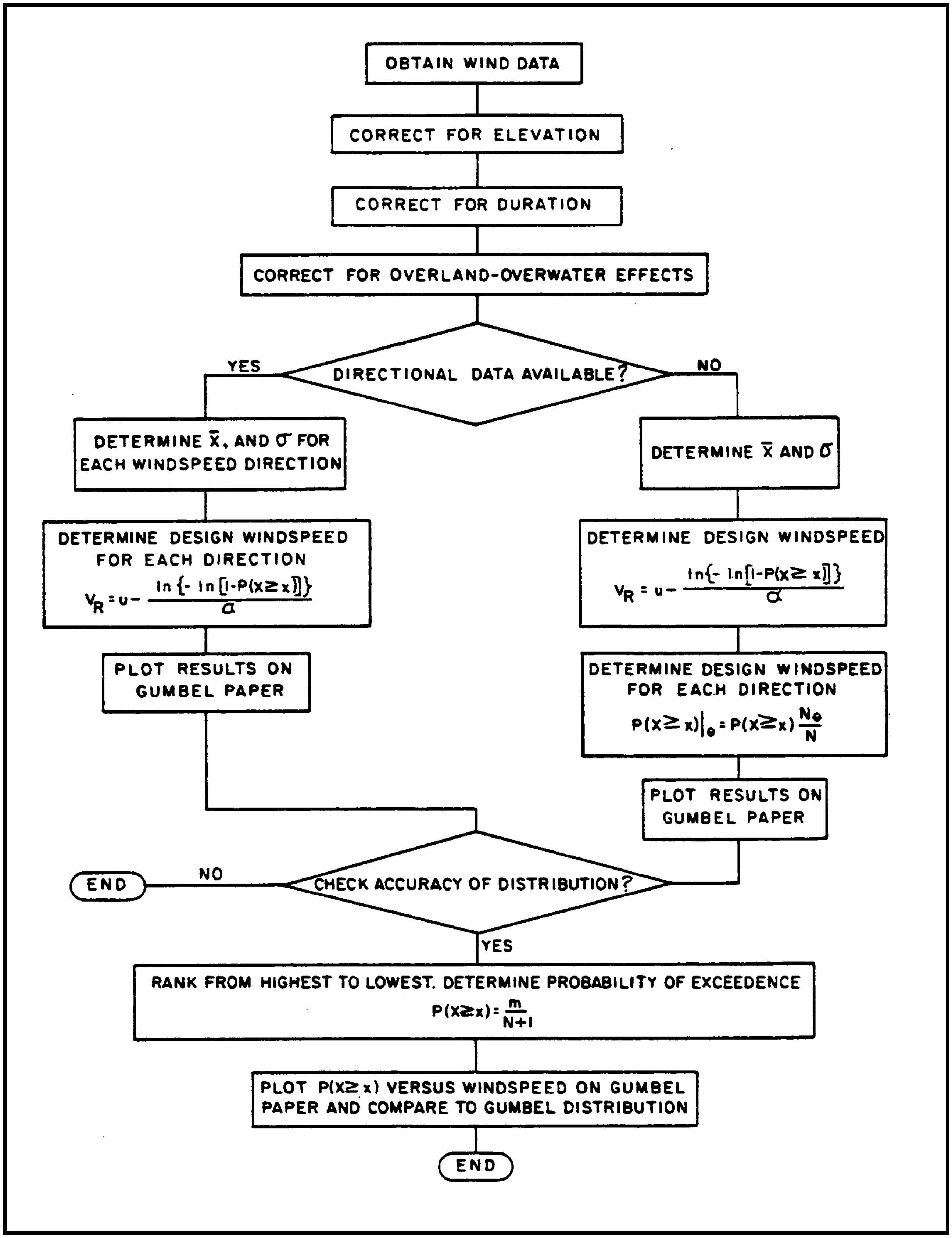


FIGURE 48
Procedure for Wind-Data Analysis

TABLE 10
Sources of Wind Data

- Naval Oceanography Command Detachment, Federal Building, Asheville, North Carolina 28801
- National Climatic Data Center (NCDC), Federal Building, Asheville, North Carolina 28801
- Naval Environmental Prediction Research Facility, Monterey, California 93940
- Wind records from local wind stations

year of record is required to determine extreme winds for each direction (for example, using eight-compass points). The Naval Oceanography Command Detachment is presently planning to provide directional extreme winds as a standard product, and summaries of directional extreme-wind statistics for naval harbors should be available in the future.

(b) National Climatic Data Center (NCDC) . The National Climatic Data Center has wind data for the continental United States and United States territories. Wind data available at NCDC for the continental United States are cataloged in the “National Wind Data Index” (Changerey, 1978) . Extreme-wind data available at NCDC are generally fastest-mile windspeeds. Changerey (1982a, 1982b) gives extreme windspeeds (that is, 2- to 1,000-year winds) for a number of east coast and Great Lakes. sites, some of which are near naval facilities. The results do not give directional extreme winds, but do give extreme winds for all directions. Wind data, sufficient for determining directional extreme winds, are available at NCDC; the cost for these data varies from site to site.

(c) Naval Environmental Prediction Research Facility. Climatological data for naval harbors throughout the world are presented in a series of publications from the Naval Environmental Prediction Research Facility. Turpin and Brand (1982) provide climatological summaries of Navy harbors along the east coast of the United States. Climatological data for United States Navy harbors in the western Pacific and Indian Oceans are summarized in Brand and Blelloch (1976). Climatological data for United States Navy harbors in the Mediterranean are summarized in Reiter (1975). The above publications provide information on the following: harbor geography and facilities; susceptibility of the harbor to storms, such as tropical cyclones, hurricanes, and typhoons; wind conditions at the harbor and the effects of local topography; wave action; storm surge; and tides. The publications have been prepared to provide guidance for determining when a vessel should leave a harbor; the publications may not be sufficiently detailed to provide design windspeeds. However, they will help the designer determine the threat of storms at the site and provide a good background on local climatology.

The designer must not use data from summarized hourly average wind statistics, such as those presented in the <u>Summary of Synoptic Meteorological</u>

Observations (SSMO). These average data are not annual maximum values and do not report the infrequent, high-velocity windspeeds necessary to predict extreme-wind events for design use. If average summaries are the only data available, it is best to obtain the original observations and analyze these data for extreme statistics.

(2) Correct for Elevation. The level at which windspeed data are recorded varies from site to site. Windspeed data should be transformed to a standard reference level of 33.33 feet or 10 meters. Adjustments are made using the following equation, which accounts for the wind gradient found in nature:

$$V_{33.33} = V_h \left(\frac{33.33}{h} \right)^{1/7} \qquad (5\text{-}1)$$

WHERE: $V_{33.33}$ = windspeed at elevation of 33.33 feet above water or ground level

V_h = windspeed at elevation h

h = elevation of recorded wind above water or ground level, in feet

(3) Correct for Duration. Figure-49 presents a graph which allows one to correct windspeeds ranging from 1 second to 10 hours in duration to a 30-second-duration windspeed. This figure gives a conversion factor, C_t, which is used to determine the 30-second windspeed as follows:

$$V_{t=30\ \text{seconds}} = \frac{V_t}{C_t} \qquad (5\text{-}2)$$

WHERE: $V_{t=30\ \text{seconds}}$ = windspeed with a 30-second duration

V_t = windspeed of given duration, t

C_t = conversion factor = $\frac{V_t}{V_{t=30\ \text{seconds}}}$

Peak-gust windspeed statistics give no information on the duration of the wind event; therefore, these data cannot be accurately corrected to a 30-second duration. Based on Figure 49, an 8-second peak gust is 1.1 times faster than a 30-second wind. As an approximation, peak-gust windspeeds should be reduced by 10 percent to obtain the 30-second windspeed. This will provide a reasonably conservative estimate of the 30-second windspeed for fleet-mooring design. Where detailed information on the duration of peak gusts can be obtained (that is, from an actual wind anemometer trace at the site), Figure 49 can be used to make more accurate estimates of 30-second sustained windspeeds.

Fastest-mile wind statistics give wind duration directly. The fastest-mile windspeed is a wind with duration sufficient to travel 1 mile.

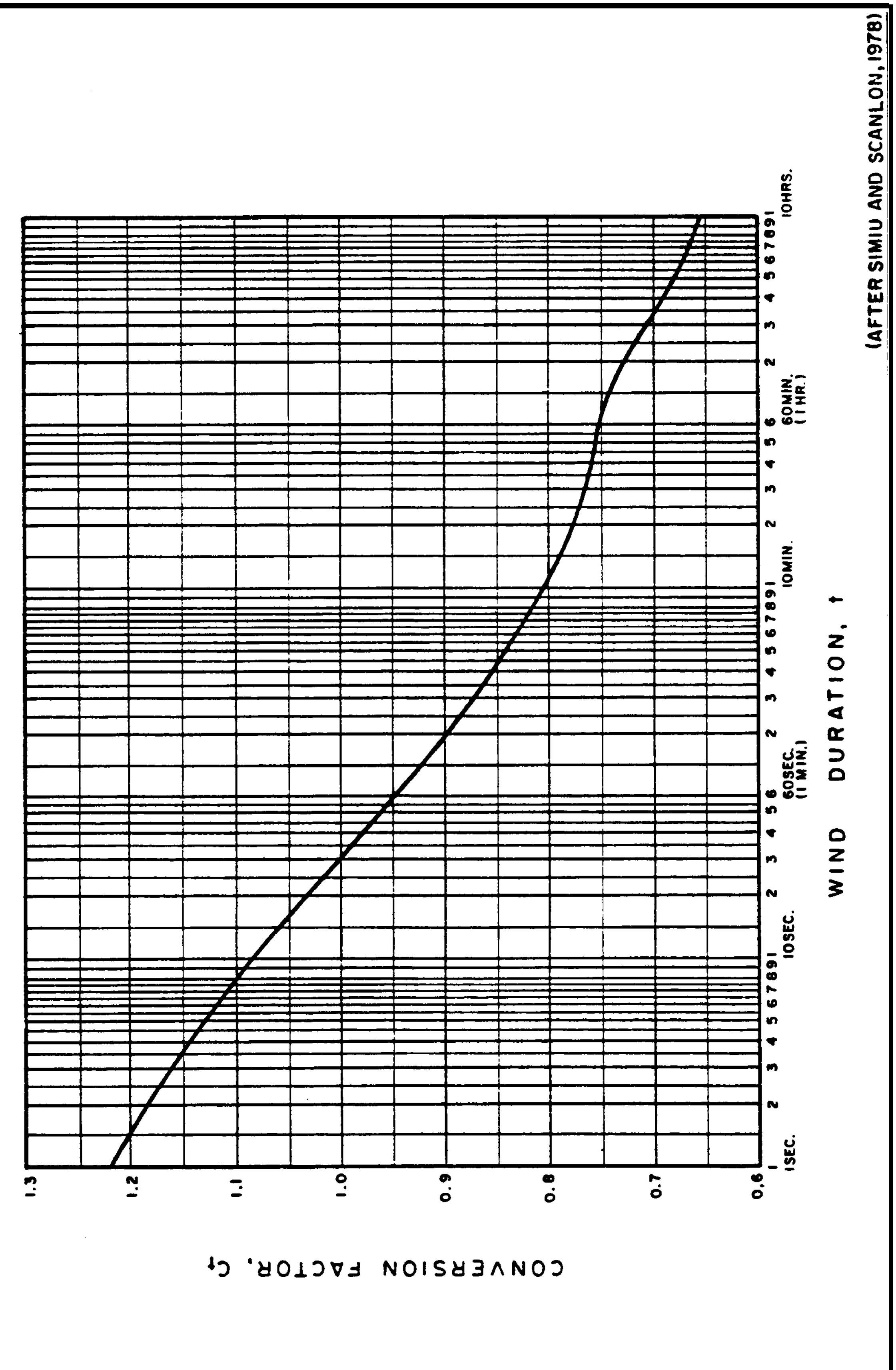

(AFTER SIMIU AND SCANLON, 1978)
WIND DURATION, t
CONVERSION FACTOR, Ct
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
1SEC.
10SEC.
60SEC. (1 MIN.)
10MIN.
60MIN. (1 HR.)
10HRS.

Figure 49 can be used to correct the windspeed to the 30-second-duration wind. For example, a conversion factor, C_t, of 0.945 is applied to a 60-mile-per-hour fastest-mile windspeed (60-second duration) to convert it to a 30-second-duration windspeed.

Figure 49 can be used to convert hourly average windspeeds to the 30-second windspeed. However, unless the hourly average windspeeds are annual extreme values, they cannot be used directly to estimate extreme conditions.

(4) Correct for Overland-Overwater Effects. Windspeed data recorded at inland stations, V_L, must be corrected for overland-overwater effects in order to obtain the overwater windspeed, V_W. This overland-overwater correction for protected harbors (fetch lengths less than or equal to 10 miles) is achieved using the following equation (U.S. Army Corps of Engineers, 1981):

$$V_W = 1.1\, V_L \tag{5-3}$$

WHERE: V_W = overwater windspeed

V_L = overland windspeed adjusted for elevation and duration

Subsection 2.3.b.(l)(c) of DM-26.2 provides an overland-overwater correction for fetch lengths greater than 10 miles.

(5) Determine Windspeed Probability.

(a) Determine mean value and standard deviation. Determine the mean value, $\bar{x}$, and standard deviation, σ, for each windspeed direction:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{5-4}$$

$$\sigma = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2 \tag{5-5}$$

WHERE: $\bar{x}$ = mean value of windspeeds

N = total number of observations

x_i = windspeed for i^{th} year

σ = standard deviation of windspeeds

(b) Determine design windspeed for each direction. Use the Gumbel distribution (see Appendix A for description) to determine design windspeeds for each direction:

$$V_R = u - \frac{\ln\{-\ln[1 - P(x > x)]\}}{\alpha} \tag{5-6}$$

WHERE : V_R = windspeed associated with return period (return period = l/[P(X > x)])

$$\alpha = \frac{1.282}{\sigma} \quad (5\text{-}7)$$

$$u = \bar{x} - \frac{0.577}{\alpha} \quad (5\text{-}8)$$

P(X > x) = probability of exceedence associated with desired return period (see Table 11)

The easiest way to use Equation (5-6) is to compute the windspeed, V_R, for each of the return periods given in Table 11. The results will plot as a straight line on Gumbel paper. (A blank sheet of Gumbel probability paper which can be photocopied for design use is provided in Appendix A, Figure A-2.)

TABLE 11
Return Period for Various P(X > X)

Return Period	P(X > X)
1,000	0.001
100	0.01
50	0.02
25	0.04
20	0.05
15	0.0667
10	0.1
5	0.2
2	0.5

Note: The return period is the reciprocal of the probability of exceedence.

(c) Determine directional probability. The directional probability can be determined if directional wind data are available. Usually, available data consist of one extreme windspeed and its direction for each year of record. Data which provide extreme windspeed for each year of record from each direction (say, eight compass points) are needed to accurately determine directional probability. Nondirectional windspeed data collected for 50 years would consist of 50 data points (that is, 50 values of windspeed and the direction of each), whereas 400 data points (50 extreme-windspeed values from each of the eight compass points) would be required to determine directional probability accurately. When a complete data set consisting of the yearly extreme windspeed from each of the eight compass-point directions is available, directional probability is determined using the above steps given in (a) and (b) for each direction. When the data set consists of the yearly extreme windspeed and direction of that windspeed, the directional probability is approximated. Steps (a) and (b) are used to develop a plot of probability of exceedence versus windspeed for all directions combined (Figure 50). Approximate the directional probability using the following:

$$P(x > x)\,|\theta = P(x > x)\,\frac{N_\theta}{N} \tag{5-9}$$

WHERE: $P(x > x)\,|\theta$ = probability of exceedence for a windspeed from direction θ

$P(x > x)$ = probability of exceedence for windspeeds from all directions combined

N_θ = number of times extreme windspeed came from direction θ

N = total number of extreme windspeeds

The above equation can be used to construct lines for the probability of exceedence versus windspeed for each direction (Figure 50). The design windspeeds are then determined from the constructed lines. Examples illustrating this procedure are provided in Section 6.

(d) Check accuracy of Gumbel distribution. The designer may want to determine how well the Gumbel distribution fits the data. This is done by first ranking windspeed data from highest to lowest. The number 1 is assigned to the highest windspeed on record, the number 2 to the second highest windspeed, and so on. The lowest windspeed will be assigned the number N, which is the number of extreme windspeeds on record.

Compute the probability of exceedence for each windspeed using the “following equation:

$$P(x > x) = \frac{m}{N + 1} \tag{5-10}$$

WHERE: $P(X > X)$ = probability that a variable, X (windspeed), is equal to or greater than a specified value, x, with rank m

m = rank of windspeed x

N = total number of windspeeds in the record

Plot the probability of exceedence, $P(X > x)$, versus windspeed on Gumbel probability paper. Compare the plotted data to the straight lines for the Gumbel distribution determined above. If the data do not fit the Gumbel distribution well, the designer should investigate other statistical distributions described in Simiu and Scanlon (1978).

d. <u>Design Current</u>. In the determination of probabilistic design current, a conservative procedure is recommended where tidal current governs the design. A peak flood- or ebb-current velocity should be used, in

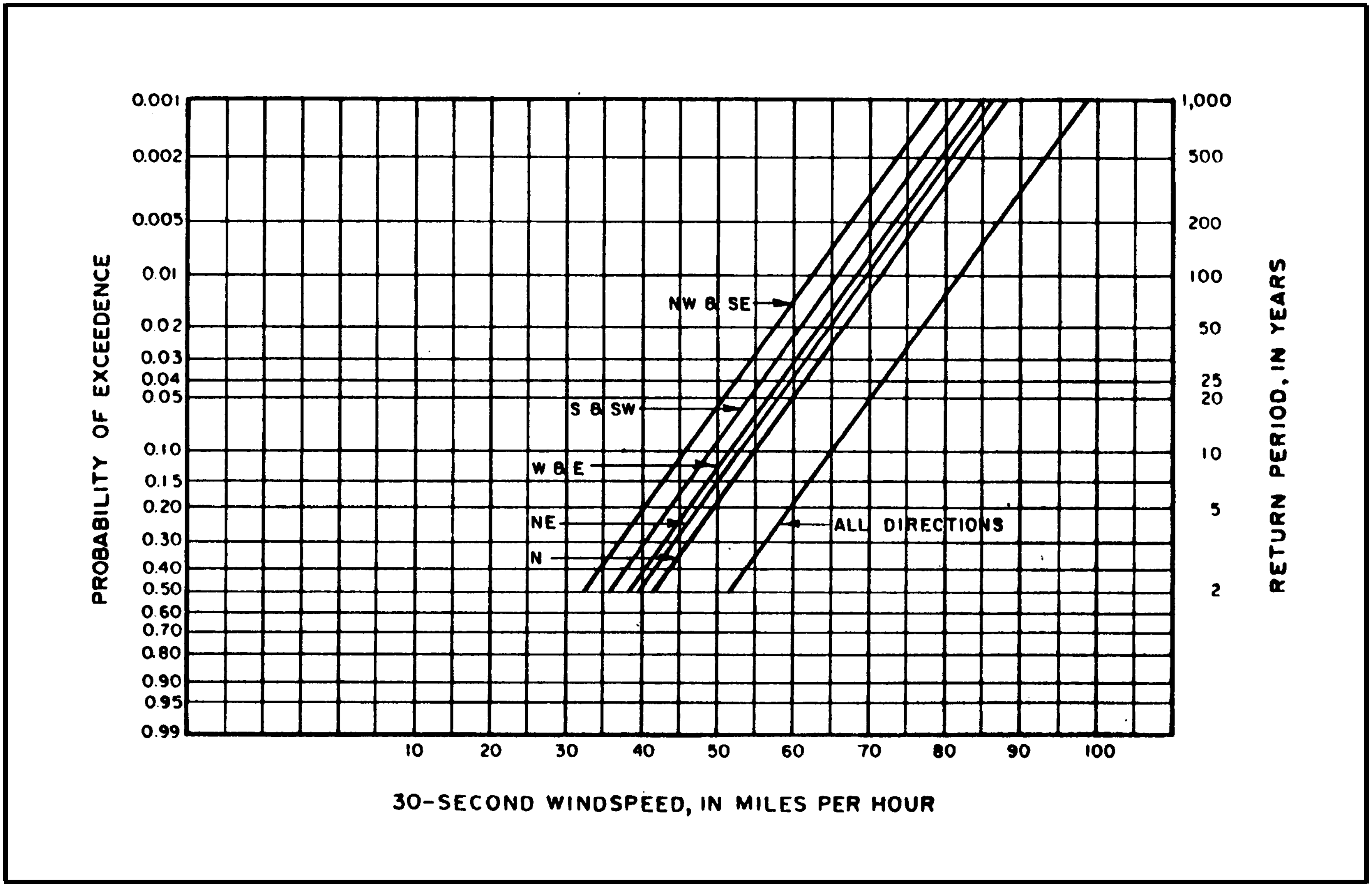


FIGURE 50
Probability of Exceedence and Return Period Versus Windspeed

conjunction with the So-year design wind. Values of peak ebb and flood currents for the Atlantic and Pacific coasts of North America and the Pacific coast of Asia may be obtained from tidal current tables published by National Ocean Survey (NOS), Rockville, MD 20852. These tables present the average speeds and directions of the maximum floods and maximum ebbs. Directions are given in degrees, reading clockwise from O to 359 degrees, and are in the directions toward which the currents flow. If there are no current data, then measurements of currents should be made. Tidal currents reverse; therefore, in the determination of maximum loads, both flood and ebb tidal currents should be investigated.

Moorings located in rivers may be subjected to high currents during floods . River-discharge statistics may be analyzed using the above methods for wind probability. A 50-year river velocity is recommended for design. A So-year wind-induced current should be used in designs where wind-induced currents are important.

4. ENVIRONMENTAL LOADS ON SINGLE MOORED VESSELS. This section describes methods for determining static wind and current loads on single moored vessels. The lateral force, longitudinal force, and yaw moment are evaluated. Figure 51 defines the coordinate system and nomenclature for describing these loads. The wind angle, θ_W , and current angle, θ_c , are defined as positive in clockwise direction. A discussion of the various physical phenomena involved in these procedures is provided in Section 4.

a. Wind Load. Determining wind load on single moored vessels differs for ship-shaped vessels and floating drydocks.

(1) Ship-Shaped Vessels. The procedure for determining static wind loads on ship-shaped, single moored vessels is taken from Owens and Palo (1982).

(a) Lateral wind load. Lateral wind load is determined using the following equation:

$$F_{yw} = \frac{1}{2} \rho_a V_w^2 A_y C_{yw} f_{yw}(\theta_w) \qquad (5\text{-}11)$$

wHERE: F_{yw} = lateral wind load, in pounds

ρ_a = mass density of air = 0.00237 slugs per cubic foot at 68°F

V_w = wind velocity, in feet per second

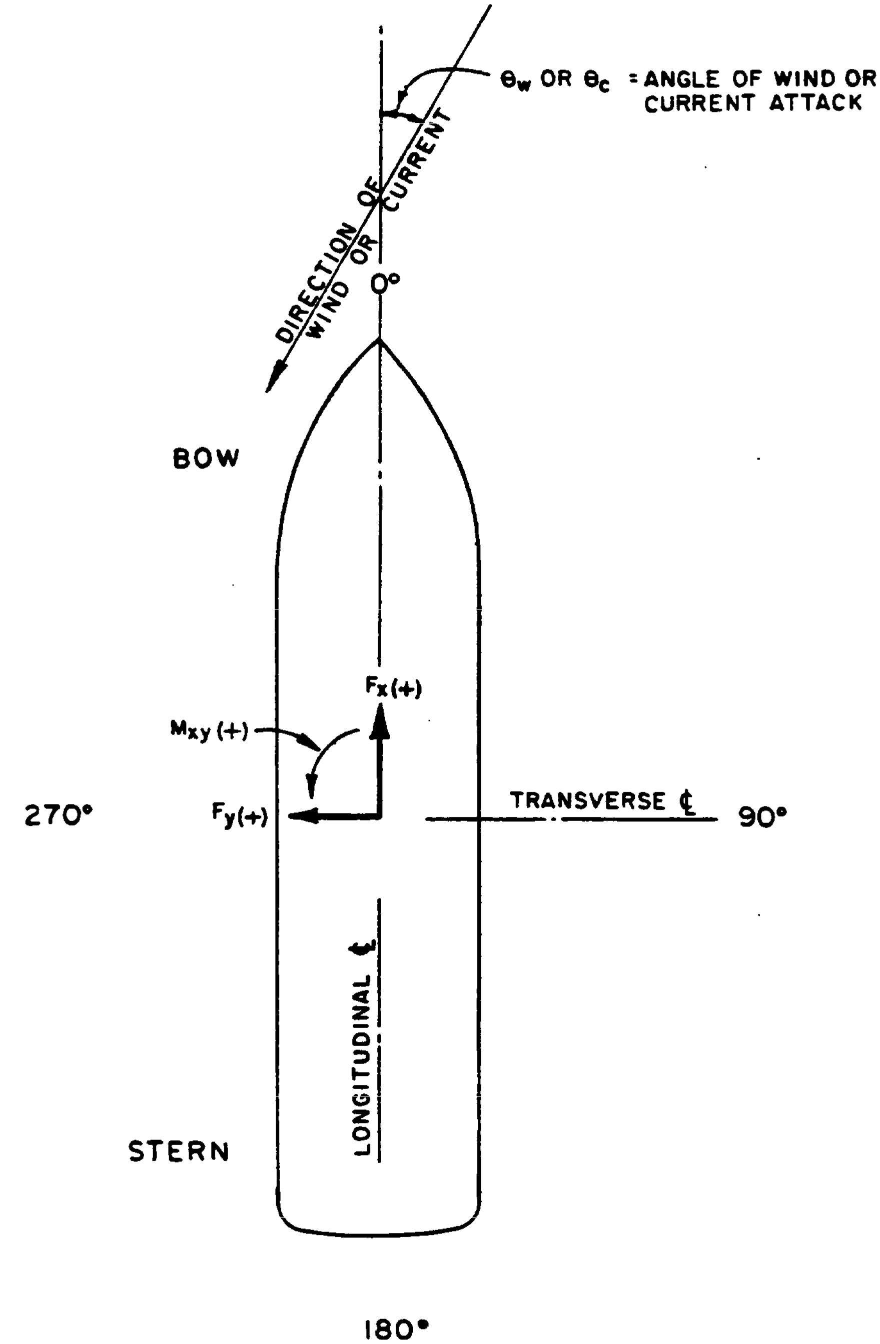
A_Y = lateral projected area of ship, in square feet

C_{yw} = lateral wind-force drag coefficient

$f_{yw}(\theta_W)$ = shape function for lateral load

θ_w = wind angle

The lateral wind-force drag coefficient depends upon the hull and superstructure of the vessel:



NOTE: DEGREES REFER To θ_w OR θ_c

FIGURE 51
Coordinate System and Nomenclature for Wind and Current Loads

[redacted] (5-12)

WHERE: c_{yw} = lateral wind-force drag coefficient

V_S/V_R = average normalized wind velocity over superstructure

V_R = reference wind velocity at 33.33 feet above sea level

A_S = lateral projected area of superstructure only, in square feet

V_H/V_R = average normalized wind velocity over hull

A_H = lateral projected area of hull only, in square feet

A_Y = lateral projected area of ship, in square feet

The values of V_S/V_R and V_H/V_R are determined using the following equations:

$$\frac{V_S}{V_R} = \left(\frac{h_S}{h_R}\right)^{1/7} \quad (5\text{-}13)$$

$$\frac{V_H}{V_R} = \left(\frac{h_H}{h_R}\right)^{1/7} \quad (5\text{-}14)$$

WHERE : V_S/V_R = average normalized wind velocity over superstructure

h_S = average height of superstructure, in feet

h_R = reference height of windspeed (33.33 feet)

V_H/V_R = average normalized wind velocity over hull

h_H = average height of hull, in feet

Details of the hull and superstructure areas of vessels can be determined from the book of general plans for the vessel or from Jane's Fighting Ships 1976).

The shape function for lateral load, $f_{YW}(\theta_W)$, is given as:

$$f_{yw}(\theta_w) = \frac{+\left(\sin\theta_w - \frac{\sin 5\theta_w}{20}\right)}{1 - \frac{1}{20}} \quad (5\text{-}15)$$

WHERE: $f_{yw}(\theta_W)$ = shape function for lateral load

θ_W = wind angle

(b) Longitudinal wind load. Longitudinal wind load is determined using the following equation:

$$F_{XW} = \frac{1}{2}\rho_a V_w^2 A_x C_{xw} f_{xw}(\theta_w) \qquad (5\text{-}16)$$

WHERE: F_{xw} = longitudinal wind load, in pounds

ρ_a = mass density of air = 0.00237 slugs per cubic foot at 68°F

V_W = wind velocity, in feet per second

A_x = longitudinal projected area of ship, in square feet

C_{XW} = longitudinal wind-force drag coefficient

$f_{XW}(\theta_w)$ = shape function for longitudinal load

The longitudinal wind-force drag coefficient varies according to vessel type and characteristics. Additionally, a separate wind-force drag coefficient is provided for headwind (over the bow: θ_W = 0 degrees) and tailwind (over the stern: θ_W = 180 degrees) conditions. The headwind (bow) wind-force drag coefficient is designated C_{xwB} and the tailwind (stern) wind-force drag coefficient is designated C_{xwS}. The following longitudinal wind-force drag coefficients are recommended for hull-dominated vessels, such as aircraft carriers, submarines, and passenger liners:

$$C_{xwB} = 0.40 \qquad (5\text{-}17)$$

$$C_{xwS} = 0.40 \qquad (5\text{-}18)$$

For all remaining types of vessels, except for specific deviations, the following are recommended:

$$C_{xwB} = 0.70 \qquad (5\text{-}19)$$

$$C_{xwS} = 0.60 \qquad (5\text{-}20)$$

An increased headwind wind-force drag coefficient is recommended for center-island tankers:

$$C_{XWB} = 0.80 \qquad (5\text{-}21)$$

For ships with an excessive amount of superstructure, such as destroyers and cruisers, the recommended tailwind wind-force drag coefficient is:

$$C_{xwS} = 0.80 \qquad (5\text{-}22)$$

An adjustment consisting of adding 0.08 to C_{xwB} and C_{xwS} is recommended for all cargo ships and tankers with cluttered decks.

Longitudinal shape function, $f_{xw}(\theta_w)$, differs over the headwind and tailwind regions. The incident wind angle that produces no net longitudinal force, designated θ_{wz} for zero crossing, separates these two regions. Selection of θ_{wz} is determined by the mean location of the superstructure relative to midships. (See Table 12.)

TABLE 12
Selection of θ_{wz}

Location of Superstructure	θ_{wz}
Just forward of midships	80°
On midships	900
Aft of midships	100°
Hull-dominated	120°

For many ships, including center-island tankers, θ_{wz} ~ l00 degrees is typical; θ_{wz} ~ 110 degrees is recommended for warships.

The shape function for longitudinal load for ships with single, distinct superstructures and hull-dominated ships is given below. (Examples of ships in this category are aircraft carriers, EC-2, and cargo vessels.)

$$f_{xw}(\theta_w) = -\cos\phi \tag{5-23}$$

WHERE:

$$\phi_{(-)} = \left(\frac{90^\circ}{\theta_{wz}}\right)\theta_w \quad \text{for } \theta_w < \theta_{wz} \tag{5-24}$$

$$\phi_{(+)} = \left(\frac{90^\circ}{180^\circ - \theta_{wz}}\right)(\theta_w - \theta_{wz}) + 90^\circ \quad \text{for } \theta_w > \theta_{wz} \tag{5-25}$$

θ_{wz} = incident wind angle that produces no net longitudinal force

θ_w = wind angle

The value of $f_{xw}(\theta_w)$ is symmetrical about the longitudinal axis of the vessel. Therefore, when $\theta_w > 180°$, use $360° - \theta_w$ as θ_w in determining the shape function. For example, if $\theta_w = 330°$, use $360° - \theta_w = 360° - 330° = 30°$ for θ_w.

Ships with distributed superstructures are characterized by a "humped" cosine wave. The shape function for longitudinal load is:

$$f_{xw}(\theta_w) = \frac{-\left(\sin\gamma - \frac{\sin 5\gamma}{10}\right)}{1 - \frac{1}{10}} \quad (5\text{-}26)$$

WHERE: $$\gamma_{(-)} = \left(\frac{90°}{\theta_{wz}}\right)\theta_w + 90° \text{ for } \theta_w < \theta_{wz} \quad (5\text{-}27)$$

$$\gamma_{(+)} = \left(\frac{90°}{180° - \theta_{wz}}\right)\theta_w + \left(180° - \frac{90°\ \theta_{wz}}{180° - \theta_{wz}}\right) \text{ for } \theta_w > \theta_{wz} \quad (5\text{-}28)$$

As explained above, use 360° - θ_w for θ_w when $\theta_w > 180°$.

(c) Wind yaw moment. Wind yaw moment is calculated using the following equation:

$$M_{xyw} = \frac{1}{2}\rho_a V_w^2 A_y L C_{xyw}(\theta_w) \quad (5\text{-}29)$$

WHERE: M_{xyw} = wind yaw moment, in foot-pounds

ρ_a = mass density of air = 0.00237 slugs per cubic foot at 68°1?

V_W = wind velocity, in feet per second

A_Y = lateral projected area of ship, in square feet

L = length of ship

$C_{xyw}(\theta)$ = normalized yaw-moment coefficient

Figures 52 through 55 provide yaw-moment coefficients for various vessel types.

(2) Wind Load on Floating Drydocks.

(a) Lateral wind load. Lateral wind load on floating drydocks (without the maximum vessel on the blocks) is determined using the following:

$$F_{yw} = \frac{1}{w}\rho_a V_w^2 A_y C_{DW} \sin\theta_w \quad (5\text{-}30)$$

WHERE: F_{yw} = lateral wind load, in pounds

ρ_a = mass density of air = 0.00237 slugs per cubic foot at 68°F

VW = wind velocity, in feet per second

A_Y = lateral projected area of drydock, in square feet

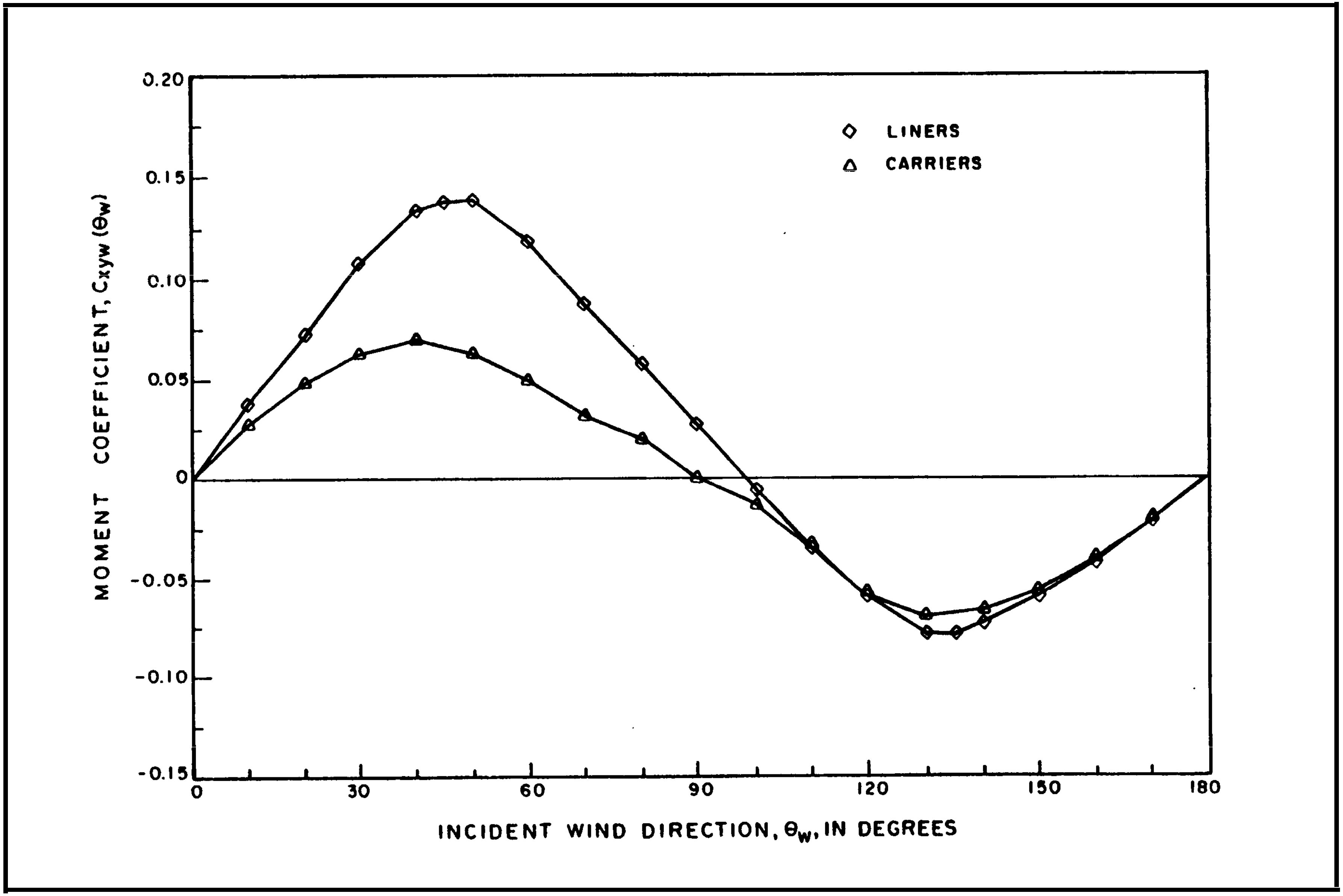


FIGURE 52
Recommended YawMoment Coefficient for Hull-Dominated Vessels

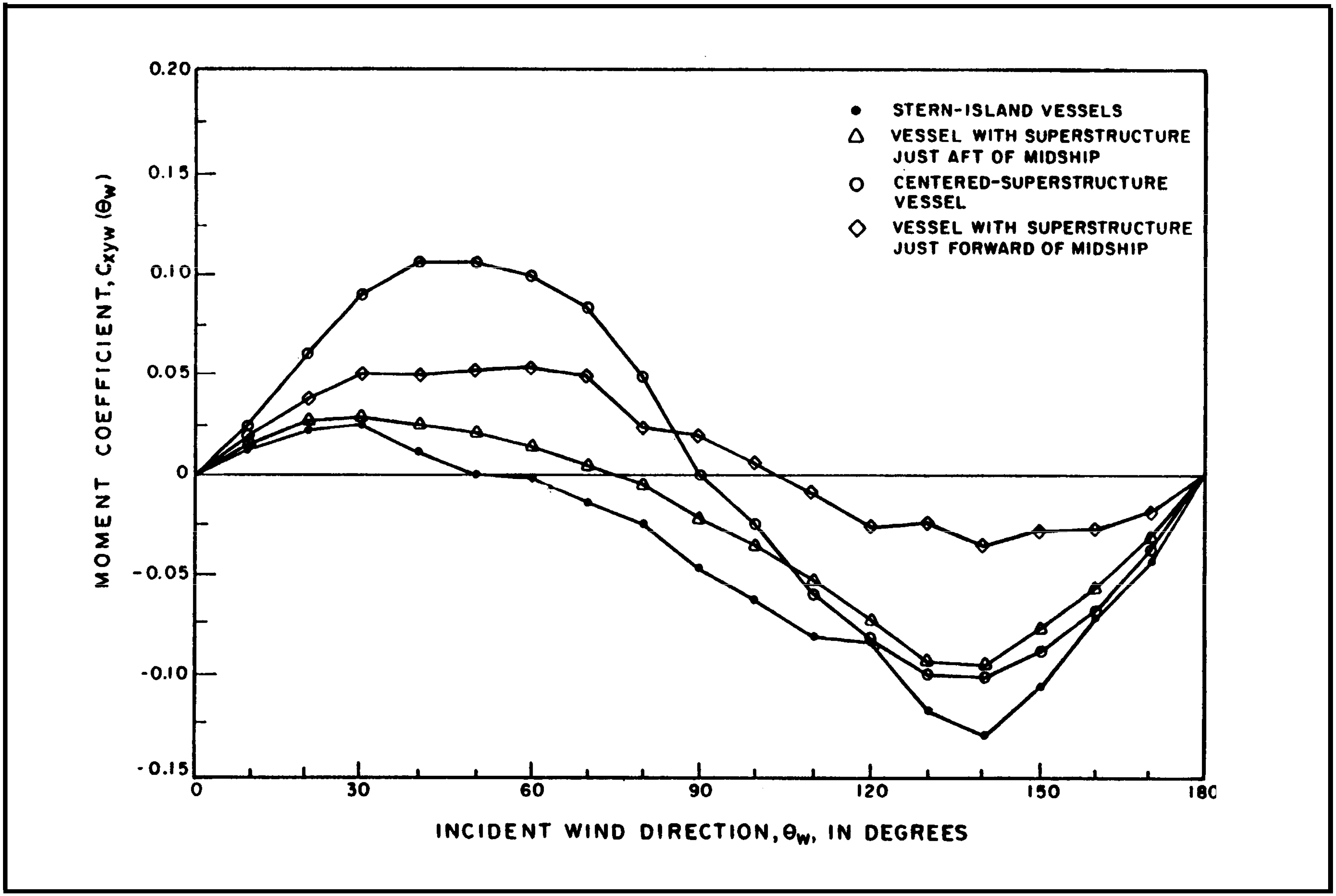


FIGURE 53

Recommended Yaw-Moment Coefficient for Various Vessels According to Superstructure Location

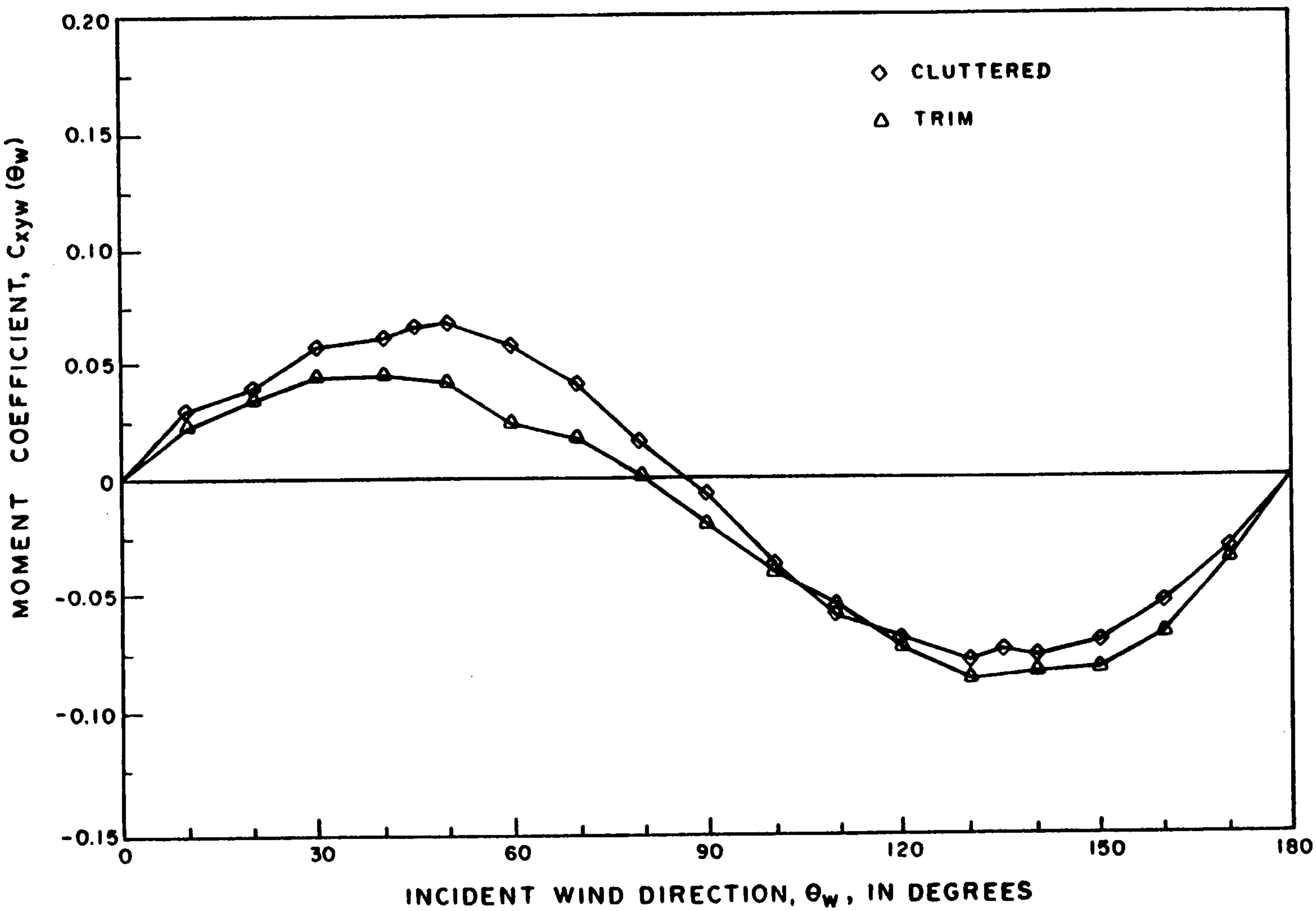


FIGURE 54
Recommended Yaw-Moment Coefficient for Center-Island Tankers

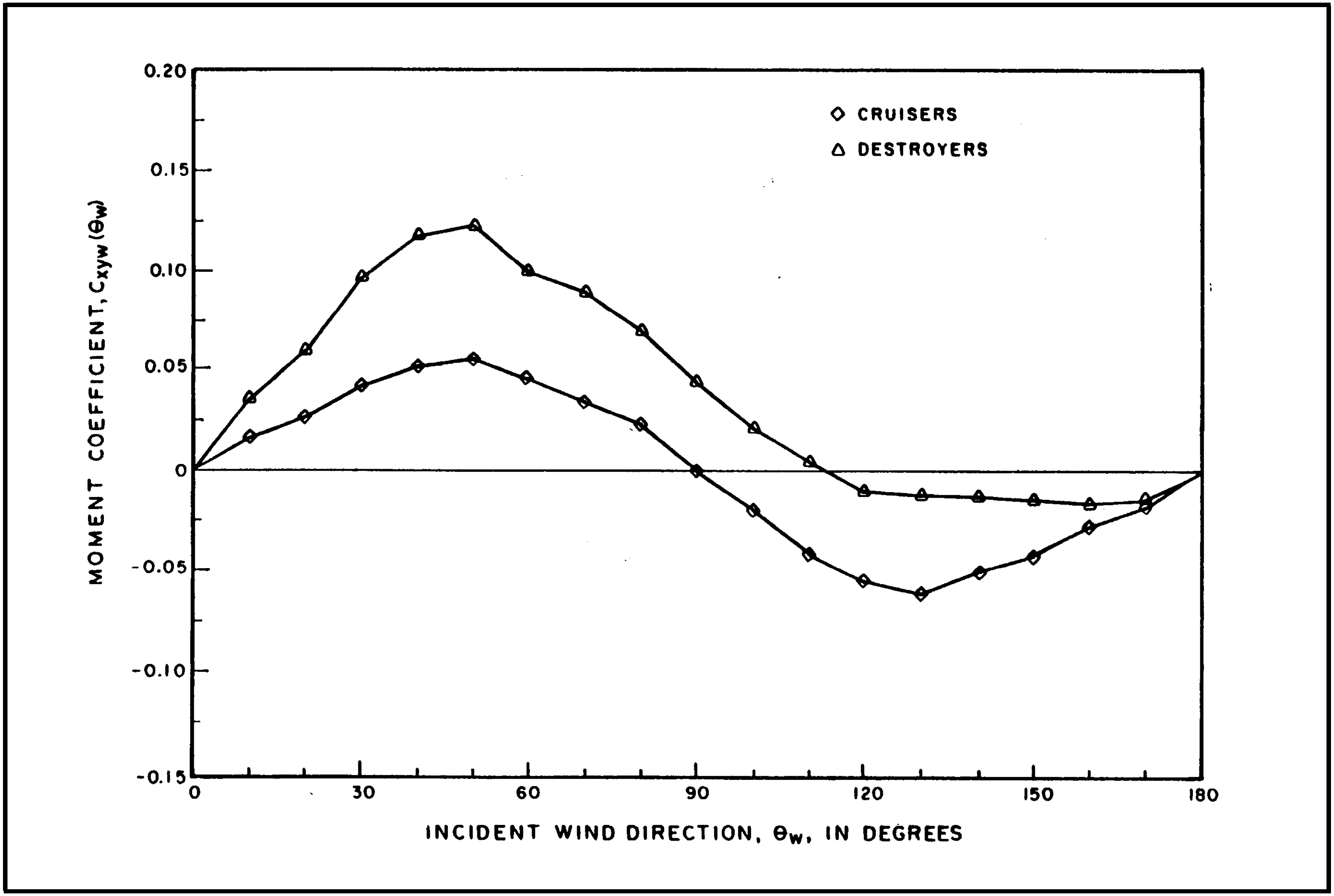


FIGURE 55
Recommended Yaw-Moment Coefficient for Typical Naval Warships

C_{DW} = wind-force drag coefficient

θ_W = wind angle

When a vessel within the dock protrudes above the profile of the dock, the dock should be treated as a normal, “ship-shaped” vessel. (See Subsection 5.4.a.(1).) Table 3 of DM-26.6 provides characteristics of floating drydocks and gives broadside wind areas for the drydocks with the maximum vessel on the blocks.

The wind-force drag coefficient, C_{DW}, for various drydocks in various loading conditions is presented in Table 13. The values of C_{DW} in Table 13 are given for floating drydocks without a vessel on the blocks.

TABLE 13
Wind-Force Drag Coefficient, C_{DW}, for Floating Drycbcks

Vessel	C_{DW}	Condition
ARD- 12	0.909	Loaded draft but no ship
ARD-12	0.914	Minimum draft
AFDL- 1	0.788	Minimum draft
AFDL- 1	0.815	Loaded draft but no ship
AFDB-4	0.936	Minimum draft
AFDB-4	0.893	Loaded draft but no ship
AFDB-4	0.859	Drydock folded wing walls

(b) Longitudinal wind load. Longitudinal wind load on floating drydocks (without a vessel within the dock) is determined using the following:

$$F_{xw} = -\frac{1}{2} \rho_a V_w^2 A_x C_{DW} \cos\theta_w \qquad (5\text{-}31)$$

WHERE: F_{xw} = longitudinal wind load, in pounds

ρ_a = mass density of air = 0.00237 slugs per cubic foot at 68°F

V_w = wind velocity, in feet per second

Ax = longitudinal projected area of dock, in square feet

C_{DW} = wind-force drag coefficient

The frontal wind areas for floating drydocks are provided in Table 3 of DM-26.6. As in the case of lateral load, when the maximum vessel on the blocks protrudes above the dock profile, then the dock should be treated as a "ship-shaped" vessel. (See Subsection 5.4.a.(1).)

The longitudinal wind load on a floating drydock is computed in the same manner as is the lateral wind load. Therefore, the wind-force drag coefficients, C_{DW}, for the lateral and longitudinal wind loads are the same and are those given in Table 13.

(c) Wind yaw moment. Wind yaw moment is computed using the following equation for the ARD-12 taken from Altmann (1971):

$$M_{xyw} = F_{yw} \, e_w \tag{5-32}$$

WHERE: M_{xyw} = wind yaw moment, in foot-pounds

F_{yw} = lateral wind load, in pounds

e_w = eccentricity of F_{yw}, in feet

$$e_w = L \left[\frac{3.125}{100} - 0.0014 \left(\theta_w - 90°\right)\right] \text{ for } 0 \leq \theta_w \leq 180° \tag{5-33}$$

$$e_w = L \left[\frac{3.125}{100} + 0.0014 \left(\theta_w - 270°\right)\right] \text{ for } 180° < \theta_w \leq 360° \tag{5-34}$$

L = length of drydock

Unlike the ARD-12, which is asymmetrically shaped, the AFDL-1 and AFDB-4 are symmetrically shaped drydocks. Therefore, from an analytical standpoint, the wind yaw moment on the AFDL-1 and AFDB-4 drydocks is zero when there is no vessel within the dock. When the vessel within the dock protrudes above the drydock profile, the wind yaw moment is computed using the procedures for "ship-shaped" vessels. (See Subsection 5.4.a.(1).)

b. Current Load.

(1) Lateral Current Load. Lateral current load is determined from the following equation:

$$F_{yc} = \frac{1}{2} \rho_w V_c^2 L_{wL} T \; C_{yc} \sin \theta_c \tag{5-35}$$

WHERE: F_{yc} = lateral current load, in pounds

ρ_w = mass density of water = 2 slugs per cubic foot for sea water

V_c = current velocity, in feet per second

L_{wL} = vessel waterline length, in feet

T = vessel draft, in feet

C_{yc} = lateral current-force drag coefficient

θ_c = current angle

The lateral current-force drag coefficient is given by:

$$C_{yc} = C_{yc}\big|_{\infty} + \left(C_{yc}\big|_{1} - C_{yc}\big|_{\infty}\right) e^{-k\left(\frac{wd}{T} - 1\right)} \qquad (5\text{-}36)$$

WHERE:

C_{yc} = lateral current-force drag coefficient

$C_{yc}\big|_{\infty}$ = limiting value of lateral current-force drag coefficient for large values of $\frac{wd}{T}$

$C_{yc}\big|_{1}$ = limiting value of lateral current-force drag coefficient for $\frac{wd}{T} = 1$

e = 2.718

k = coefficient

wd = water depth, in feet

T = vessel draft, in feet

Values of $C_{yc}\big|_{\infty}$ are given in Figure 56 as a function of L_{wL}/B (the ratio of vessel waterline length to vessel beam) (ordinate) and vessel block coefficient, ϕ, (abscissa). The block coefficient is defined as:

$$\phi = \frac{35\ D}{L_{wL}\ B\ T} \qquad (5\text{-}37)$$

WHERE:

ϕ = vessel block coefficient

D = vessel displacement, in long tons

L_{WL} = vessel waterline length, in feet

B = vessel beam, in feet

T = vessel draft, in feet

Values of $C_{yc}\big|_{1}$ are given in Figure 57 as a function of $C_p L_{wL}/\sqrt{T}$. C_p, the prismatic coefficient of the vessel, is defined as:

$$C_P = \frac{\phi}{C_m} \qquad (5\text{-}39)$$

WHERE:

C_P = prismatic coefficient of vessel

ϕ = vessel block coefficient

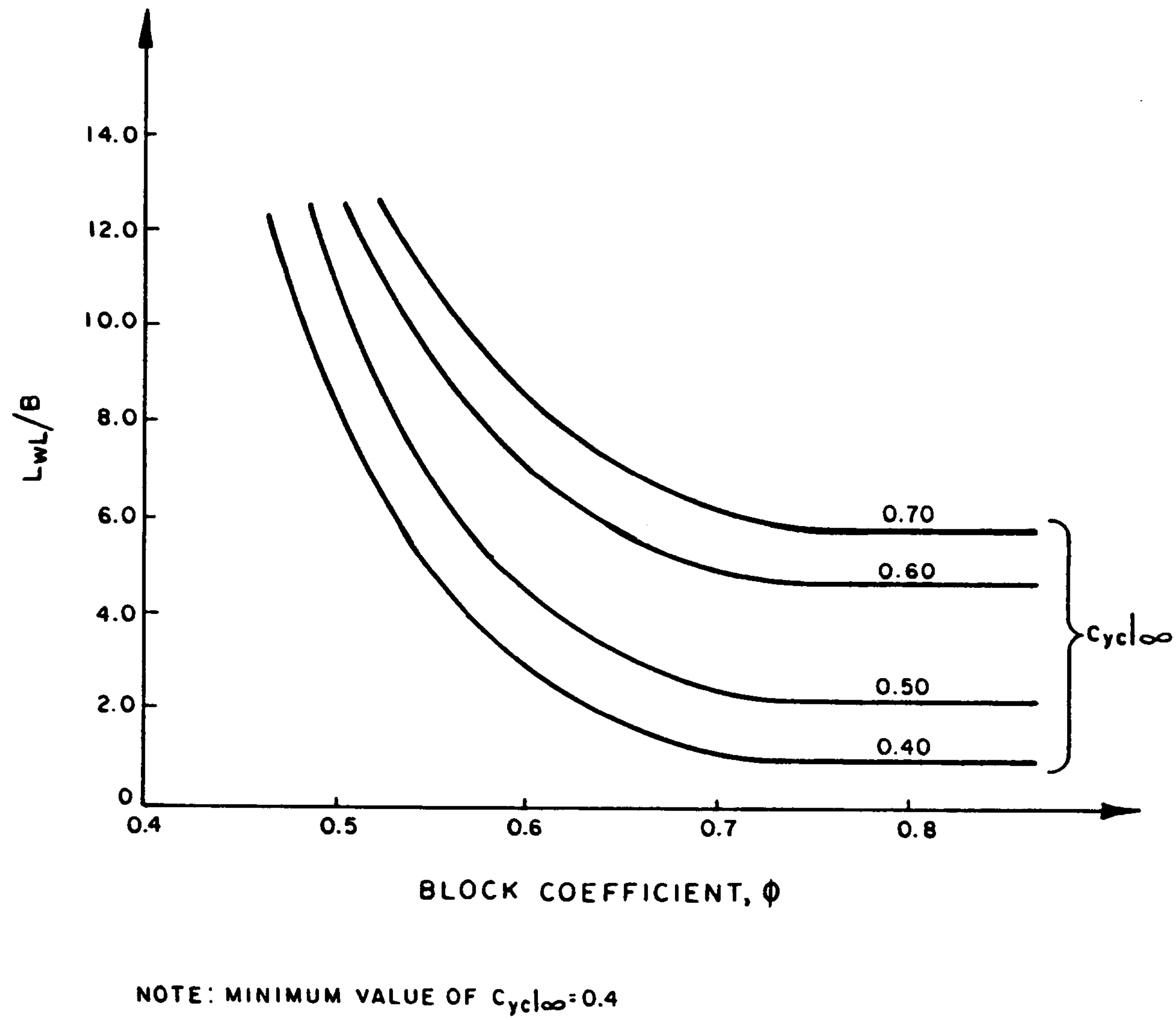


FIGURE 56

$C_{yc}|_{\infty}$ as a Function of L_{wL}/B and ϕ

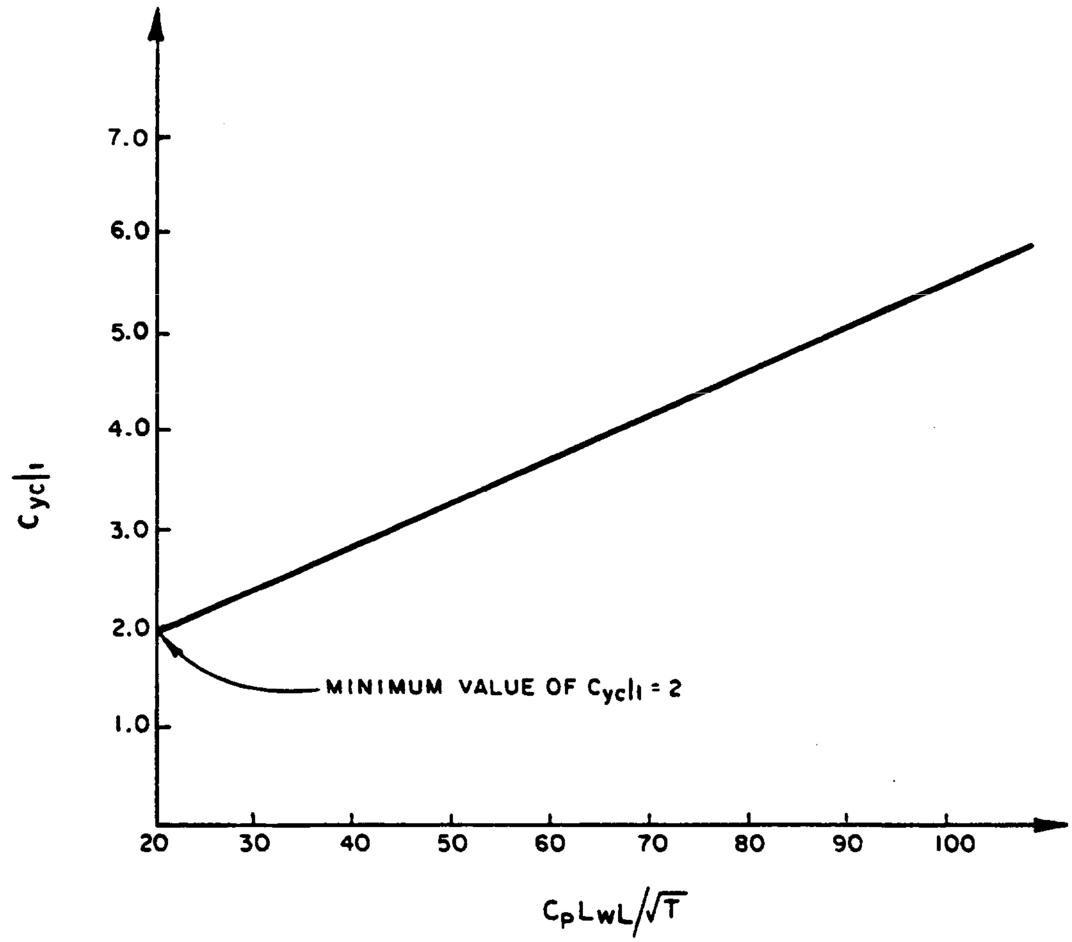


FIGURE 57

$C_{yc}\,|\,1$ as a Function of $C_p L_{wL}/\sqrt{T}$

C_m = midship section coefficient

$$= \frac{\text{immersed area of midship section}}{B\ T} \qquad (5\text{-}39)$$

B = vessel beam, in feet

T = vessel draft, in feet

The value of the coefficient, k, is given in Figure 58 as a function of the vessel block coefficient, ϕ, and vessel hull shape (block-shaped or normal ship-shaped).

The values of the coefficients $C_{yc}|_{\infty}$, $C_{yc}|_{1}$, and k are presented in Table 14 for each vessel originally tested by the David Taylor Model Basin. Dimensional properties of each vessel are also given in this table.

(2) Longitudinal Current Load. Longitudinal current load procedures are taken from Cox (1982). Longitudinal current load is determined using the following equation:

$$F_{xc} = F_{x\ form} + F_{x\ friction} + F_{x\ prop} \qquad (5\text{-}40)$$

WHERE: F_{xc} = total longitudinal current load

$F_{x\ form}$ = longitudinal current load due to form drag

$F_{x\ friction}$ = longitudinal current load due to skin friction drag

$F_{x\ prop}$ = longitudinal current load due to propeller drag

Form drag is given by the following equation:

$$F_{x\ form} = -\frac{1}{2}\rho_w V_c^2\ B\ T\ C_{xcb} \cos\theta_c \qquad (5\text{-}41)$$

WHERE: $F_{x\ form}$ = longitudinal current load due to form drag

ρ_w = mass density of water = 2 slugs per cubic foot for sea water

V_c = average current speed, in feet per second

B = vessel beam, in feet

T = vessel draft, in feet

C_{xcb} = longitudinal current fomn-drag coefficient = 0.1

θ_c = current angle

Friction drag is given by the following equation:

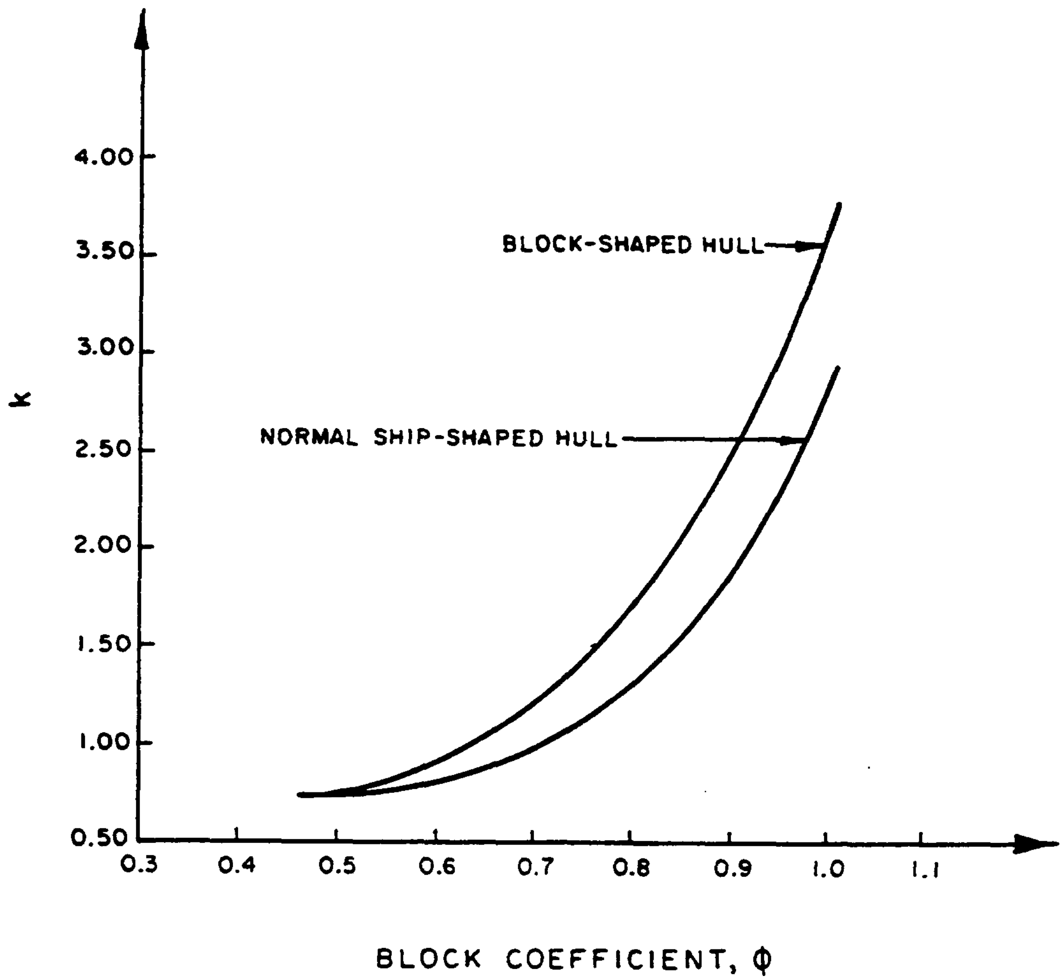


FIGURE 58
k as a Function of ϕ and Vessel Hull Shape

TABLE 14

ϕ, $C_{yc}|_{\infty}$, $C_{yc}|_{1}$, C_p, $C_pL_{wL}/\sqrt{T}$, k, and Dimensional Properties for DTMB Models

Ship Type	L_{wL} (feet)	B (feet)	T (feet)	Block Coefficient, ϕ	$C_{yc}\|_{\infty}$ (deep water)	$C_{yc}\|_{1}$ (shallow water)	C_p (estimated)	$\frac{C_pL_{wL}}{\sqrt{T}}$	k
AFDB-4	725	240	10.0	0.721	0.50	5.00	*		5.00
			20.0	0.785-0.820			*		
			67.0	0.855			1	88	
AFDL- 1	200	64	4.5	0.675	0.55	2.55	*		3.00
			8.0	0.728			*		
			28.5	0.776			1	37	
ARD- 12	489	81	6.0	0.805	0.70	4.25	*		1.80
			10.5	0.828			*		
			32.0	0.864			1	86	
AO-143(T-5)	655	86	16.6	0.636	0.75	4.00	0.684	82	0.75
			35.1	0.672					
EC- 2	410	57	10.0	0.626	0.60	4.60	0.758	98	0.80
CVE-55	490	65	16.64	0.547	0.60	4.60	0.567	68	0.80
SS-212	307	27	14.25	0.479	0.40	2.80	0.479	39	0.75
DD-692	369	41	10.62	0.472	0.40	3.30	0.539	61	0.75

*Not computed for smaller draft; assume that drydock is moored to accommodate maximum draft

$$F_{x\ friction} = -\frac{1}{2}\rho_w V_c^2 S\, C_{xca} \cos\phi_C \qquad (5\text{-}42)$$

WHERE: $F_{x\ friction}$ = longitudinal current load due to skin friction

ρ_W = mass density of water = 2 slugs per cubic foot for sea water

V_c = average current speed, in feet per second

S = wetted surface area, in square feet

$$= (1.7\ TL_{WL}) + \frac{(35\ D)}{T} \qquad (5\text{-}43)$$

T = vessel draft, in feet

L_{WL} = waterline length of vessel, in feet

D = displacement of ship, in long tons

C_{xca} = longitudinal skin-friction coefficient

$$= 0.075/(\log R_n - 2)^2 \qquad (5\text{-}44)$$

R_n Reynolds number $= V_c\, L_{WL} \cos\theta_c/\nu$ (5-45)

ν kinematic viscosity of water (1.4×10^{-5} square feet per second)

θ_c = current angle

Repeller drag is the form drag of the vessel's propeller with a locked shaft. Repeller drag is given by the following equation:

$$F_{x\ prop} = -\frac{1}{2}\rho_w V_c^2 A_P\, C_{prop} \cos\theta_C \qquad (5\text{-}46)$$

WHERE: $F_{x\ prop}$ = longitudinal current load due to propeller drag

ρ_W = mass density of water = 2 slugs per cubic foot for sea water

V_c = average current speed," in feet per second

A_P = propeller expanded (or developed) blade area, in square feet

C_{prop} = propeller-drag coefficient (assumed to be 1)

θ_c = current angle

A_p is given by:

$$A_p = \frac{A_{Tpp}}{1.067 - 0.229\ p/d} = \frac{A_{Tpp}}{0.838} \qquad (5\text{-}47)$$

WHERE: A_p = propeller expanded (or developed) blade area, in square feet

A_{TPP} = total projected propeller area, in square feet

p/d = propeller pitch to diameter ratio (assumed to be 1)

Table 15 shows the area ratio, A_R, for six major vessel groups. (The area ratio is defined as the ratio of the waterline length times the beam to the total projected propeller area.) Then, the total projected propeller area, A_{Tpp} can be given in terms of the area ratio as follows:

$$A_{Tpp} = \frac{L_{wL}\ B}{A_R} \qquad (5\text{-}48)$$

WHERE: A_{Tpp} = total projected propeller area, in square feet

L_{wL} = waterline length of vessel, in feet

B = vessel beam, in feet

A_R = area ratio, found in Table 15

TABLE 15
A_R for Propeller Drag

Vessel Type	Area Ratio, A_R
Destroyer	100
Cruiser	160
Carrier	125
Cargo	240
Tanker	270
Submarine	125

(3) Current Yaw Moment. Procedures for determining current yaw moment are taken from Altmann (1971). Current yaw moment is determined using the following equation:

$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{wL}}\right) L_{wL} \qquad (5\text{-}49)$$

WHERE: M_{Xyc} = current yaw moment, in foot-pounds

F_{yc} = lateral current load, in pounds

$\left(\frac{e_c}{L_{wL}}\right)$ = ratio of eccentricity of lateral current load measured along the longitudinal axis of the vessel from amidships to vessel waterline length

e_c = eccentricity of F_{yc}

L_{WL} = vessel waterline length, in feet

The value of (e_c/L_{wL}) is given in Figure 59 as a function of current angle, θ_c, and vessel type.

5. ENVIRONMENTAL LOADS ON MULTIPLE MOORED VESSELS. This section describes methods for determining static wind and current loads on multiple moored vessels. The longitudinal force, lateral force, and yaw moment are evaluated. Figure 51 defines the coordinate system and nomenclature for describing these loads. A discussion of the various physical phenomena involved in these procedures is provided in Section 4. Procedures vary depending upon whether the multiple-vessel mooring consists of identical or nonidentical vessels.

a. Identical Vessels. Altmann (1971) has formulated a procedure for estimating wind and current loads induced on nests of identical moored vessels. The procedures provide conservative estimates of lateral loads, longitudinal loads, and yaw moment.

(1) Wind Load.

(a) Lateral wind load. The lateral wind load on a single vessel within a group of identical vessels depends upon the position of that vessel within the group. For example, the wind load is larger on the first (most windward) vessel in a group than on the interior vessels. The following empirical equation gives lateral wind load on a group of identical vessels:

$$F_{ywg} = F_{yws}\,[K_1 \sin\theta_w + K_2 \sin 3\theta_w + K_3 \sin 3\theta_w + K_4 (1 - \cos 4\theta_w) + \ldots K_5 (1 - \cos 4\theta_w)] \qquad (5\text{-}50)$$

WHERE: F_{ywg} = total lateral wind load on a group of identical vessels (g refers to “group”)

F_{yws} = lateral wind load on a single vessel (Equation (5-11)) at $\theta_w = 90°$ (s refers to “single”)

$K_1 \ldots K_5$ = dimensionless wind-force coefficients

θ_w = wind angle (assumes values between 0 and 180 degrees; beyond 180 degrees, the relative positions of the vessels become reversed)

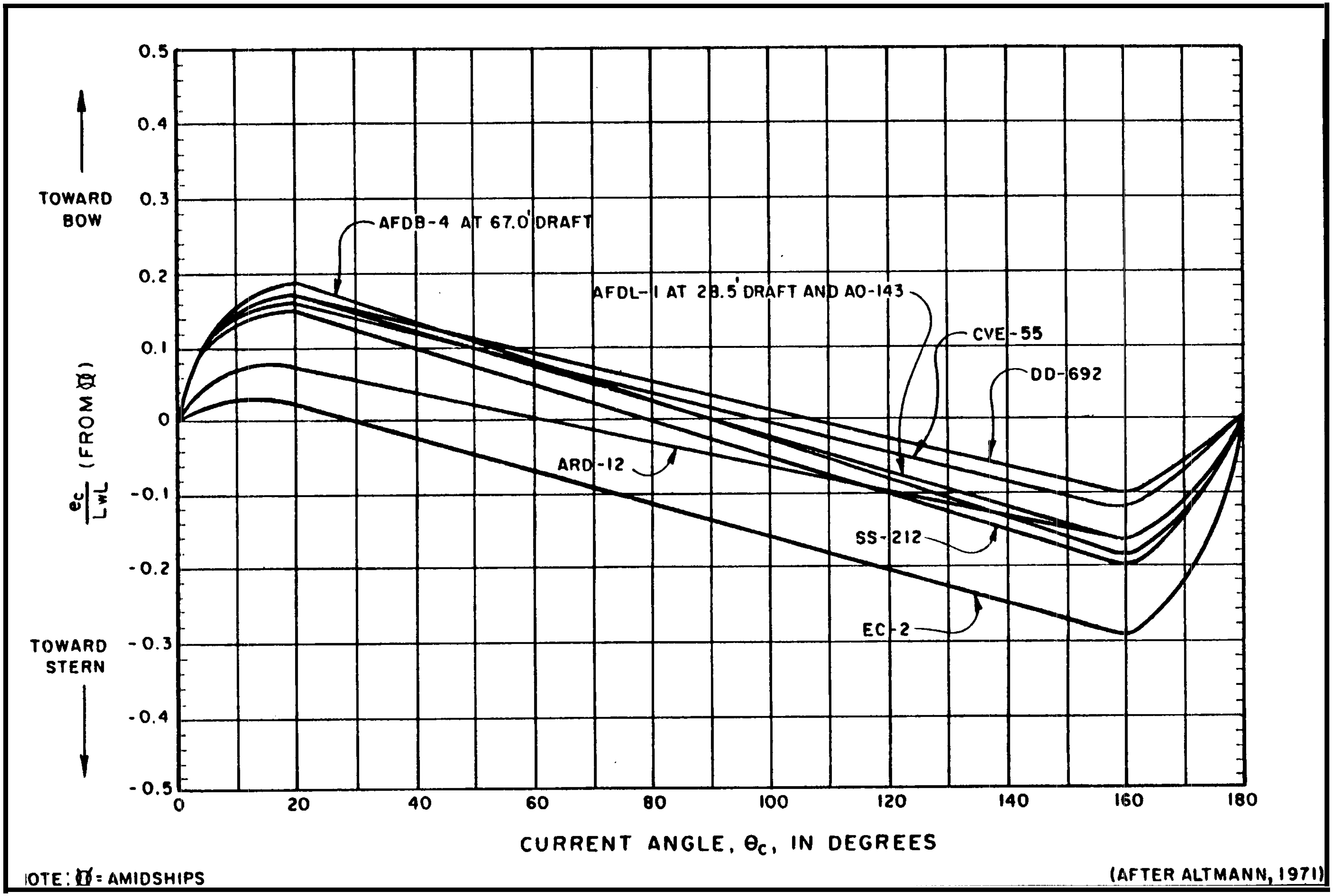


FIGURE 59
(e_c/L_{wL}) as a Function of Vessel Type and Current Angle

The dimensionless wind-force coefficients, K_1, K_2...K_5, are presented in Table 16 as a function of ship type (normal or hull-dominated) and position of the vessel in the mooring. The number of K terms used in Equation (5-50) is a function of the number of ships in the mooring. If the load on only one of the vessels in the mooring is desired, then only the term of interest is needed. For example, if the load on the second vessel in a group of three is needed, then only K_2 is used in Equation (5-50). The load on the entire mooring is the summation indicated by Equation (5-50). The terms K_1 and K_5, which represent the most windward and leeward vessels in a mooring, respectively, are always used. K is used for the second vessel in a group of three or more. K_4 is used for the second-from-last vessel in a group of four or more vessels. The K_3 coefficient is used for the third vessel in moorings of five or more vessels. The K_4 coefficient is used for each additional vessel in moorings of six or more vessels. Figure 60 shows how to assign the various K coefficients for vessel groups consisting of two to six vessels.

TABLE 16
Lateral Wind-Force Coefficients for Multiple-Vessel Moorings

Ship Model	Ship Type	‘1	‘2	‘3	‘4	‘5
CVE-55 SS-212	Hull-dominant; little superstructure	1.00	0.20	0.16[1]	0.35	0.44
EC-2 DD-692	Standard profile; considerable superstructure	1.00	0.14	0.11	0.13	0.30

[1]No data; suggested value

(b) Longitudinal wind load. The total longitudinal wind load on a group of identical vessels is determined as follows:

$$F_{xwg} = F_{xws}\ n \qquad (5\text{-}51)$$

WHERE: F_{xwg} = total longitudinal wind load on a group of identical vessels

F_{xws} = longitudinal wind load on a single vessel (Equation (5-16))

n = number of vessels in the group

(c) Wind yaw moment. The wind yaw moment on a single vessel within a group of identical vessels is a function of the position of that vessel and the number of vessels in the mooring. First, the yaw moment on a single vessel, M_{xyws}, at a specified wind angle, θ_w, is calculated. Then, the appropriate coefficients from Figure 61 are used to determine the moment

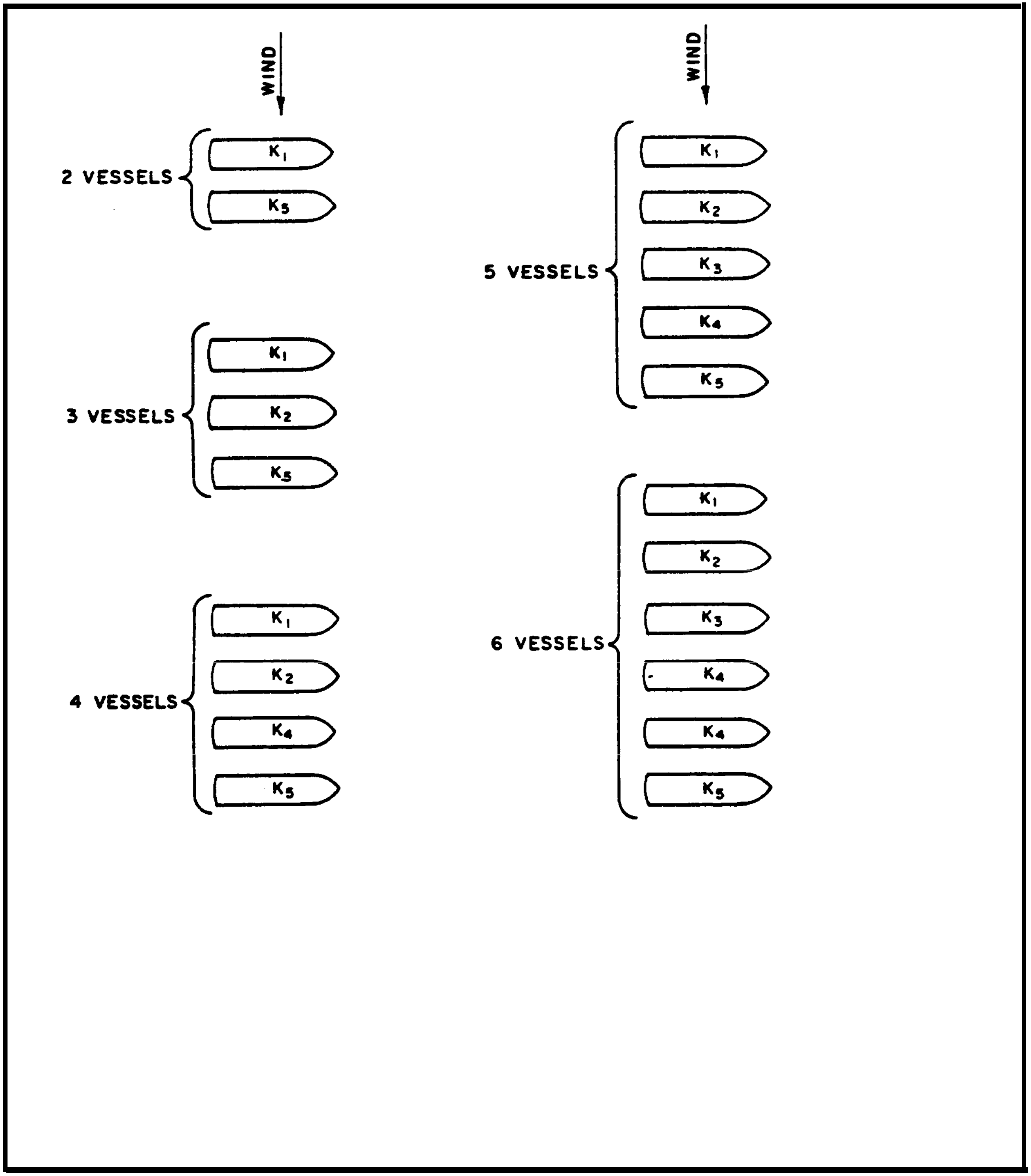


FIGURE 60
Assignment of K Coefficients For Vessel Groups of Two to Six Vessels

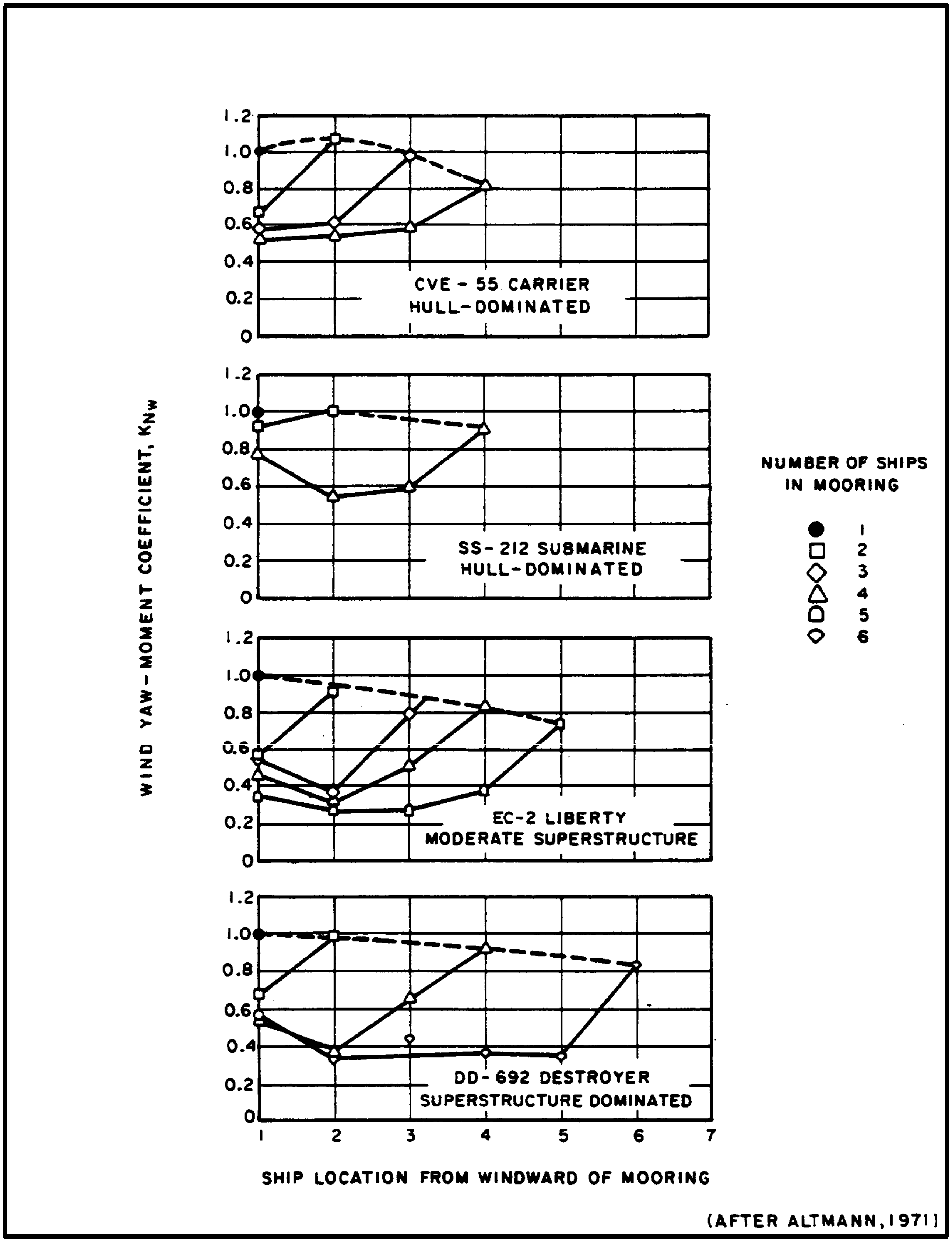


FIGURE 61
Wind Yaw-Moment Coefficient, K_{Nw}, for Multiple-Vessel Moorings

on individual vessels in the mooring. The coefficients, K_{Nw}, from Figure 61 are summed and multiplied by M_{xyws} to determine the total moment on the vessel group:

$$M_{xywg} = M_{xyws}(K_{Nw1} + K_{Nw2} + K_{Nw3} + ...) \qquad (5\text{-}52)$$

WHERE : M_{xywg} = total wind yaw moment on a group of identical vessels

M_{xyws} wind yaw moment on a single vessel (Equation (5-29))

K_{Nw1}, K_{Nw2} ... wind yaw-moment coefficient which accounts for the number and location of vessels in the mooring; given in Figure 61

(2) Current Load.

(a) Lateral current load. The lateral current load on a single vessel within a group of identical vessels depends upon the spacing of the vessels and the position of the vessel within the group. The effect of vessel spacing is shown in Figure 62, which provides the ratio (K_6) of the load on the first vessel in the mooring to that on a single vessel for several values of dimensionless spacing and for vessel types. (The first vessel is the one which is subjected to the full current load, analogous to the most windward vessel discussed previously.) Dimensionless spacing is defined as the ratio of distance between vessel centerlines, d_{cL}, to vessel beam, B. The effect of vessel position in a multiple-vessel mooring is shown in Figure 63, which presents the ratio, K_7, of lateral current load on a vessel within a mooring to that on the first vessel as a function of the position and total number of vessels in the mooring.

The following equations can be used to determine lateral current loads on a group of identical vessels. The lateral current load on the first vessel in the mooring is given by:

$$F_{ycl} = \frac{1}{2} F_{ycs} K_6 (1 - \cos 2 \theta_c) \qquad (5\text{-}53)$$

The lateral current load on the second vessel of a mooring with three or more vessels is given by:

$$F_{yc2} = (F_{ycl} @ 90°) [\sin \theta_c - K_7 (1 - \cos 2 \theta_c)] \qquad (5\text{-}54)$$

The lateral current load on each remaining vessel in a mooring, or on the second vessel if there are only two vessels in the mooring, is given by:

$$F_{ycz} = (F_{ycl} @ 90°) [\sin \theta_c - K_7 (1 - 0.5 \cos 2 \theta_c - 0.5 \cos 6 \theta_c)] \qquad (5\text{-}55)$$

WHERE: F_{ycl} = lateral current load on the first vessel in a group

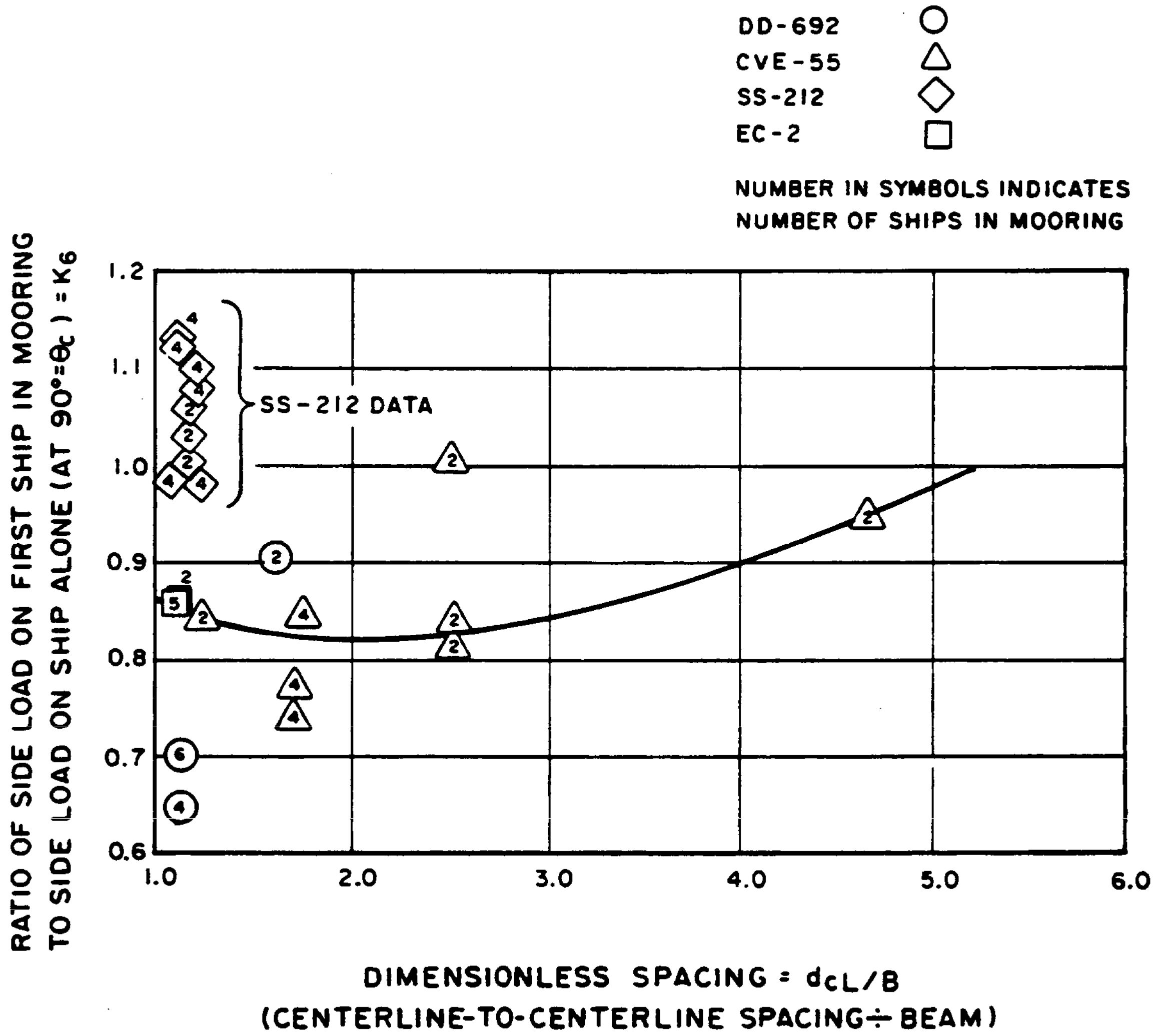


FIGURE 62
K_6 as a Function of Dimensionless Spacing

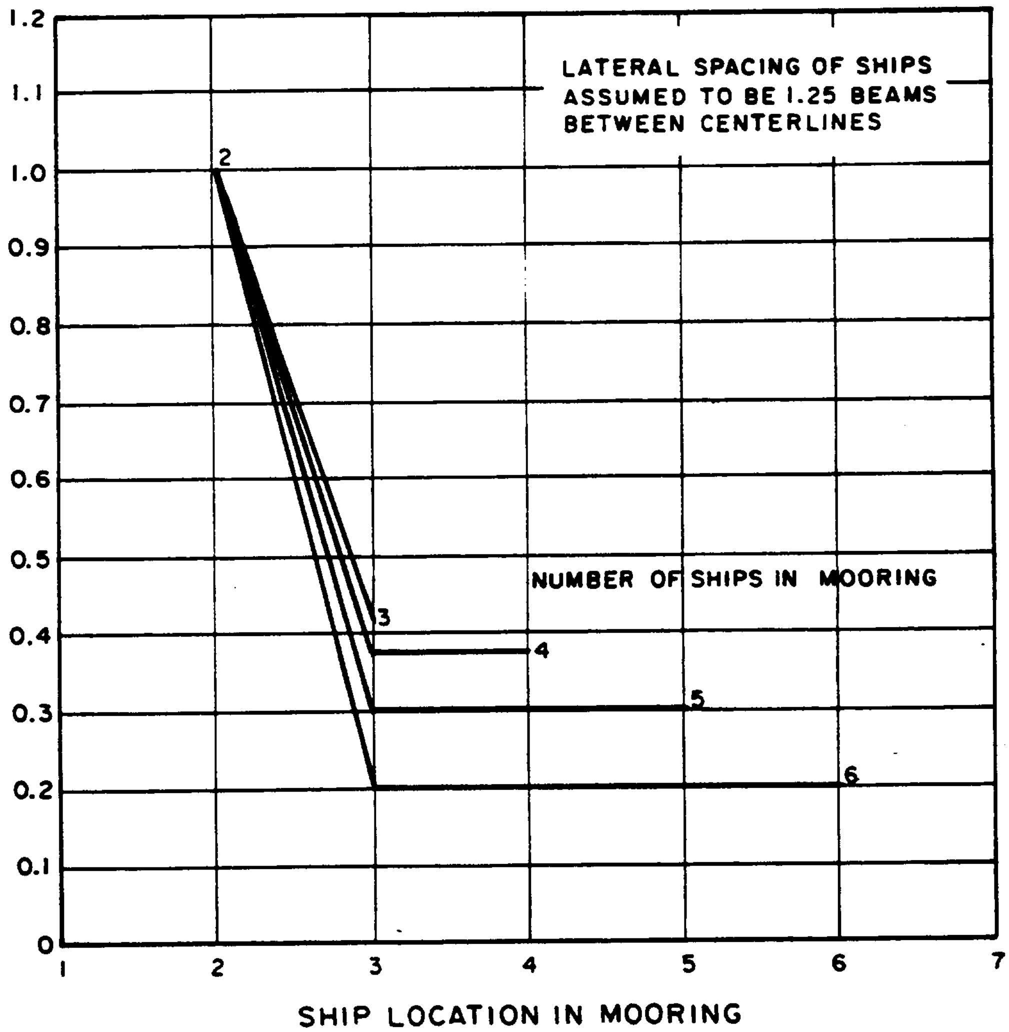


FIGURE 63
K, as a Function of Vessel Position and Number of Vessels in Mooring

F_{ycs} = lateral current load on a single vessel at $\theta_c = 90°$ (Equation (5-35))

K_6 = spacing factor, given in Figure 62

θ_c = current angle

F_{yc2} = lateral current load on the second vessel in a group of, three or more

F_{yc1} @ 90° = lateral current load on the first vessel in a group at $\theta_c = 90°$

K_7 = factor for position and number of vessels in a mooring, given by Figure 63

F_{ycz} = lateral current load on the z^{th} vessel in a mooring, or on the second vessel if there are only two vessels in the mooring

z = position of vessel

The above equations can be used to determine the loads on each individual vessel or, when summed, to determine the total load on the group of identical vessels.

(b) Longitudinal current load. The total longitudinal current load on a group of identical vessels is determined by the following equation:

$$F_{xcg} = F_{xcs}\, n \tag{5-56}$$

WHERE: F_{xcg} = total longitudinal current load on a group of identical vessels

F_{xcs} = longitudinal current load on a single vessel (Equation (5-40))

n = number of vessels in the group

(c) Current yaw moment. The current yaw moment on a single vessel within a group of identical vessels is a function of the position of that vessel and the number of vessels in the mooring. First, the yaw moment on a single vessel, M_{xycs} at a specified current angle, θ_c, is calculated. Then, the appropriate coefficients from Figure 64 are used to determine the moment on individual vessels in the mooring.
Figure 64 are summed and multiplied by M_{xycs} to determine the total moment on the vessel group:

$$M_{xycg} = M_{xycs}\, K_{Nc1} + K_{Nc2} + K_{Nc3} + \ldots) \tag{5-57}$$

WHERE: M_{xycg} = total current yaw moment on a group of identical vessels

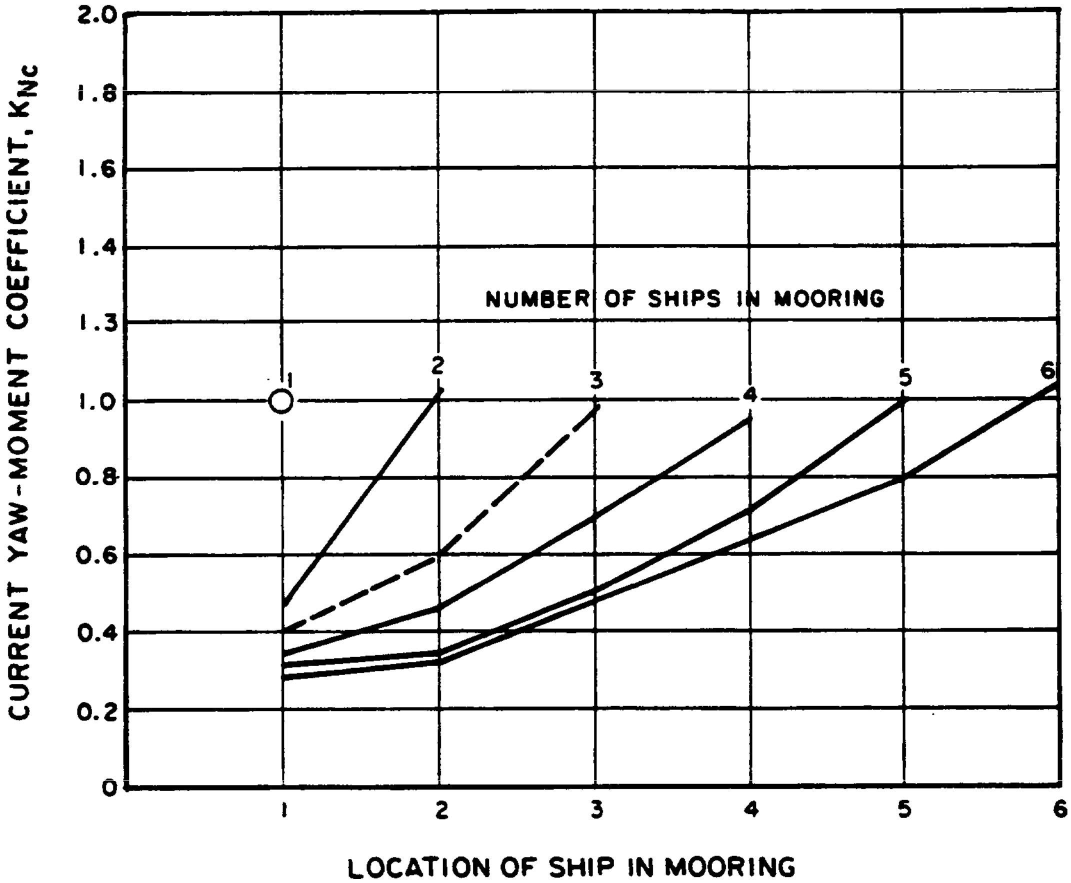


FIGURE 64
Current Yaw-Moment Coefficient, K_{Nc} for Multiple-Vessel Moorings

M_{xycs} = current yaw moment on a single vessel (Equation (5-49))

K_{Nc1}, K_{Nc2} = current yaw-moment coefficient which accounts for the number and location of vessels in the mooring, given in Figure 64

b. Nonidentical Vessels. Typical present-day multiple-vessel mooring arrangements consist of a tender with a number of identical vessels moored alongside in parallel fashion. In these moorings, the separation distance between the nested vessels and the tender is small. Frequently, the nested vessels are moored to each other and then to the tender. In this case, the mooring must be able to sustain the entire loading pattern induced on all vessels. This situation requires special treatment and additional model testing. In the absence of proper data, or until such data become available, the following approximate procedure for estimating wind loads on multiple moored vessels is suggested:

(1) Estimate the wind loads on the nest of identical vessels moored alongside the tender following the approach outlined above.
(2) Estimate the wind loads induced on the tender as a single vessel.
(3) Add the longitudinal loads linearly, since there is minimum interference between projected areas for streamlined objects in head-on winds. These additive loads constitute the longitudinal loads for the vessel group in wind.
(4) Compare the beam of the tender with the composite beam of the nested group. Compare the projected broadside areas exposed to wind for the nested group and the tender and compare the respective lateral forces, as determined from (1) and (2), above. The following cases are possible:

  (a) The beam of the tender is greater than half the composite beam of the nested group.
  (b) The beam of the tender is less than half the composite beam of the nested group.
  (c) The projected broadside area of the tender exposed to wind is greater than twice the projected broadside area of the nested group (or single vessel).
  (d) The projected broadside area of the tender exposed to wind is less than twice the projected broadside area of the nested group (or single vessel).

  If (a) and (c) occur, then there is essentially complete sheltering, and the lateral load for the group should be taken as the greater of the loads computed under (1) or (2) above. If (a) and (d) or (b) and (c) occur, then there is some sheltering, but it is not complete. Therefore, increase the maximum lateral load determined under (1) or (2) above by 10 percent for standard-profile vessels and by 15 percent for hull-dominated vessels. If (b) and

(d) occur, then the sheltering that occurs is minimal and is not very effective. Under this circumstance, the maximum lateral load as determined under (1) or (2) above should be increased by 20 percent for standard-profile vessels and by 30 percent for hull-dominated vessels. The percentage increments indicated above are compatible with, but not the same as, the K factors defined for identical vessels.

(5) With the maximum lateral and longitudinal loads as determined in steps (1) through (4) above, the following equation is used to determine loads acting at angles other than head-on and beam-on:

$$F_{xwg} = (F_{xwg} \text{ @ } 0°) \cos \theta_W \tag{5-58}$$

$$F_{ywg} = (F_{ywg} \text{ @ } 90°) \sin \theta_W \tag{5-59}$$

WHERE: F_{xwg} = longitudinal wind load acting on vessel group from wind with angle θ_w

F_{xwg} @ 0° = longitudinal wind load on vessel group at $\theta_w = 0°$

θ_W = wind angle

F_{ywg} = lateral wind load acting on vessel group from wind with angle θ_w

F_{ywg} @ 90° = lateral wind load on vessel group at $\theta_w = 90°$

(6) The yaw moments should be taken as the maximum of either the individual values determined in (1) or (2) above or the algebraic sum if the signs are the same.

In order to estimate current loads on multiple moored vessels, a similar procedure to that outlined in steps (1) through (6) above is used. There are differences in the procedure. First, instead of broadside projected area, the product of the waterline length (L_{wL}) and the draft (T) (that is, L_{wL} times T) is used. Secondly, the effect of sheltering seems to be more effective over longer beam distances in the case of current than in the case of wind. The following change in procedure as outlined in Steps (4) and (5) above is recommended:

(4) (Changed) Compare the product $L_{WL}T$ for the tender and for the nested group, and compare the respective lateral loads as determined from (1) and (2) above. Compare the beam of the tender with the composite beam of the nested group (including separation distances). The following cases are possible:

(a) The beam of the tender is greater than one-fourth of the beam of the composite group.
(b) The beam of the tender is less than one-fourth of the beam of the composite group.
(c) The L_{WL} T area of the tender exposed to current is greater than the L_{WL} T of the nested group.
(d) The L_{WL} T area of the tender exposed to current is less than the L_{WL} T of the nested group.

If (a) and (c) occur, then there is essentially complete sheltering and the lateral load for the group should be taken as the greater of the loads computed under (1) and (2) above. If (a) and (d) or (b) and (c) occur, then there is some sheltering, but it is not complete. Therefore, increase the maximum lateral load determined under (1) or (2) above by 10 percent for all vessels. If (b) and (d) occur, then the sheltering that occurs is minimal and equivalent to that of an additional vessel in the group. Increase the maximum lateral load as determined under (1) and (2) above by 20 percent. These percentage increments are compatible with the analysis for identical vessels. These increments are not the same as, but represent, both the effect of ship spacing (K_6) and the cumulative effect of the number of ships (K,).

(5) (Changed) With the maximum lateral and longitudinal loads as determined above, the following equations are used to determine loads acting at angles other, than head-on and beam-on:

$$F_{xcg} = (F_{xcg} @ 0°) \cos \theta_C \qquad (5\text{-}60)$$

$$F_{ycg} = (F_{ycg} @ 90°) \sin \theta_C \qquad (5\text{-}61)$$

WHERE: F_{xcg} = longitudinal current load acting on vessel group from current with angle θ_c

F_{xcg} @ 0° = longitudinal current load on vessel group at $\theta_c = 0°$

θ_c = current angle

F_{ycg} „ lateral current load acting on vessel group from current with angle θ_c

F_{ycg}@ 9 0° = lateral current load on vessel group at $\theta_c = 90°$

As the dimensions of the tender vessel approach those of the vessel moored alongside, then the analysis should be the same as that obtained by considering a group of identical vessels (including the tender). On the other hand, as the dimensions of the tender vessel increase relative to those of the vessels moored alongside, the forces on the tender vessel dominate the loading pattern, and the forces induced on the nested group of vessels are inconsequential.

Often, in fleet moorings, the separation between the nested vessels and the teader is such that the vessels and tender act independently of each other. In fact, it is often desirable that the moorings be independent. This is an important consideration in exposed locations. Because the tender may not always be present, a conservative approach is one that emphasizes analysis and design of the mooring for the nested vessels separately from that of the tender mooring. In this case, the procedures for predicting loads (and moments) on the group of identical vessels should be used.

6. LOADS ON MOORING ELEMENTS. Procedures for determining the horizontal load in mooring lines for several mooring arrangements are summarized below.

a. Total loads. The first step in analyzing loads on mooring elements is to determine the total longitudinal load, total lateral load, and total yaw moment on the moored vessel using the following equations:

$$F_{xT} = F_{xw} + F_{xc} \tag{5-62}$$

$$F_{yT} = F_{yw} + F_{yc} \tag{5-63}$$

$$M_{xyT} = M_{xyw} + M_{xyc} \tag{5-64}$$

WHERE: F_{xT} = total longitudinal load

F_{xw} = longitudinal wind load

F_{xc} = longitudinal current load

F_{yT} = total lateral load

F_{yw} = lateral wind load

F_{yc} = lateral current load

M_{xyT} = total yaw moment

M_{xyw} = wind yaw moment

M_{xyc} = current yaw moment

b. Free-Swinging Mooring. The general procedure for determining the maximum load on a free-swinging (single-point) mooring involves assuming a ship position (θ_c and θ_w) and calculating the sum of moments on the vessel. This process is repeated until the sum of moments is equal to zero. The procedure is tedious and involves a number of iterations for each wind-current angle, θ_{wc} (angle between wind and current). Due to the large values of moment (which can be on the order of 10^5 to 10^7 foot-pounds) it is difficult to determine the precise location at which the sum of moments is zero. As a result, the point of equilibrium (zero moment) is determined graphically. The procedure involves halving the interval (between values of θ_c) for which the moment changes signs. A step-by-step procedure is given in Figure 65. An accompanying example plot of sum of moments, ΣM, versus current angle, θ_c, is shown in Figure 66. (An example problem which shows each of these steps is given in Section 6.)

ΣM is determined using the following equation:

$$\Sigma M = M_{xyw} + M_{xyc} - F_{yT} \, ARM \tag{5-65}$$

WHERE: ΣM = sum of moments

M_{xyw} = wind yaw moment

M_{xyc} = current yaw moment

F_{yT} = total lateral load

ARM = distance from bow hawser attachment point to center of gravity of vessel (ARM = 0.48 LOA)

LOA = length overall

Once the point of zero moment has been found, the horizontal hawser load, H, is determined using the following equation:

$$H = \sqrt{F_{xT}^{2} + F_{yT}^{2}} \tag{5-66}$$

WHERE: H = horizontal hawser load

F_{xT} = total longitudinal load

F_{yT} = total lateral load

The use of computer programs is an alternate method of determining free-swinging mooring loads (Naval Facilities Engineering Command, 1982, and Cox, 1982).

c. Simplified Multiple-Point Mooring Analysis. Simplified methods for determining mooring-line loads in multiple-point moorings are presented below. These procedures, and the assumptions inherent to them, differ depending upon the geometry of the mooring. Although crude, these simplified solutions have been used successfully in the past and are satisfactory for preliminary design. The computer program presented in Appendix B is recommended for final design or for preliminary designs involving mooring geometries other than those discussed below.

(1) Bow-and-Stern Mooring. A force diagram for a typical bow-and-stern mooring is shown in Figure 67. In order to facilitate hand computations, a vessel in a bow-and-stern mooring is assumed to move under applied

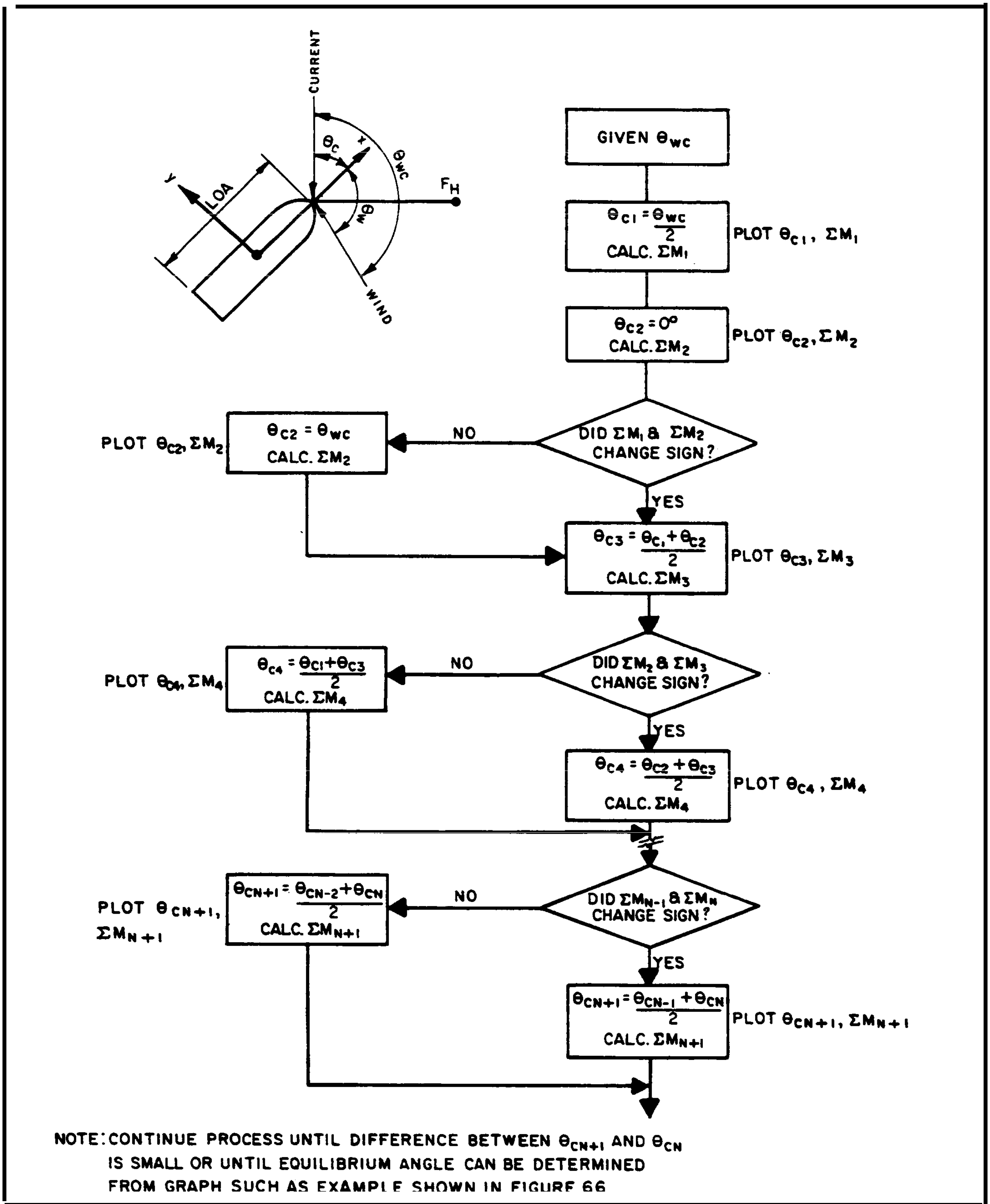


FIGURE 65
Procedure for Determining Equilibrium Point of Zero Moment

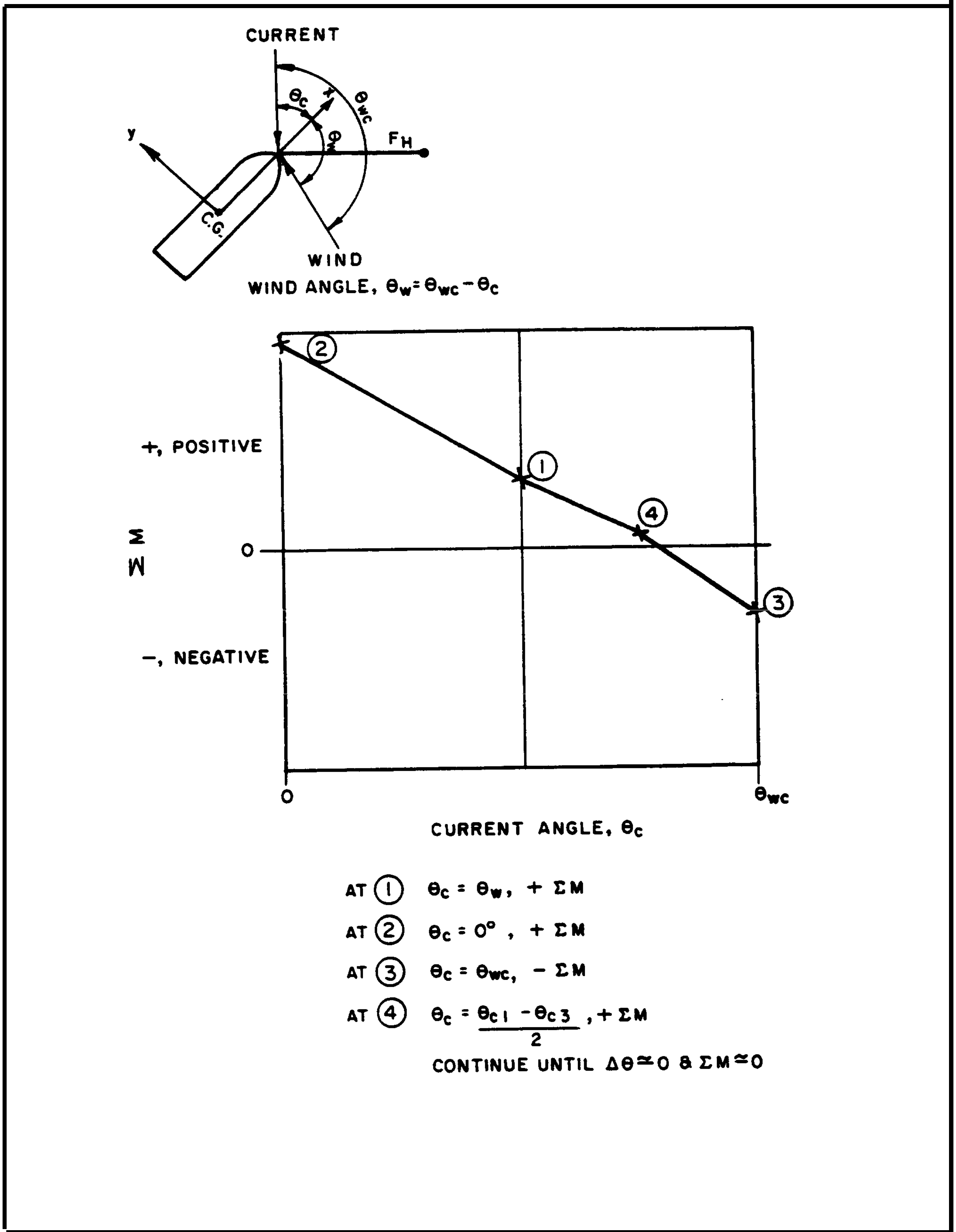
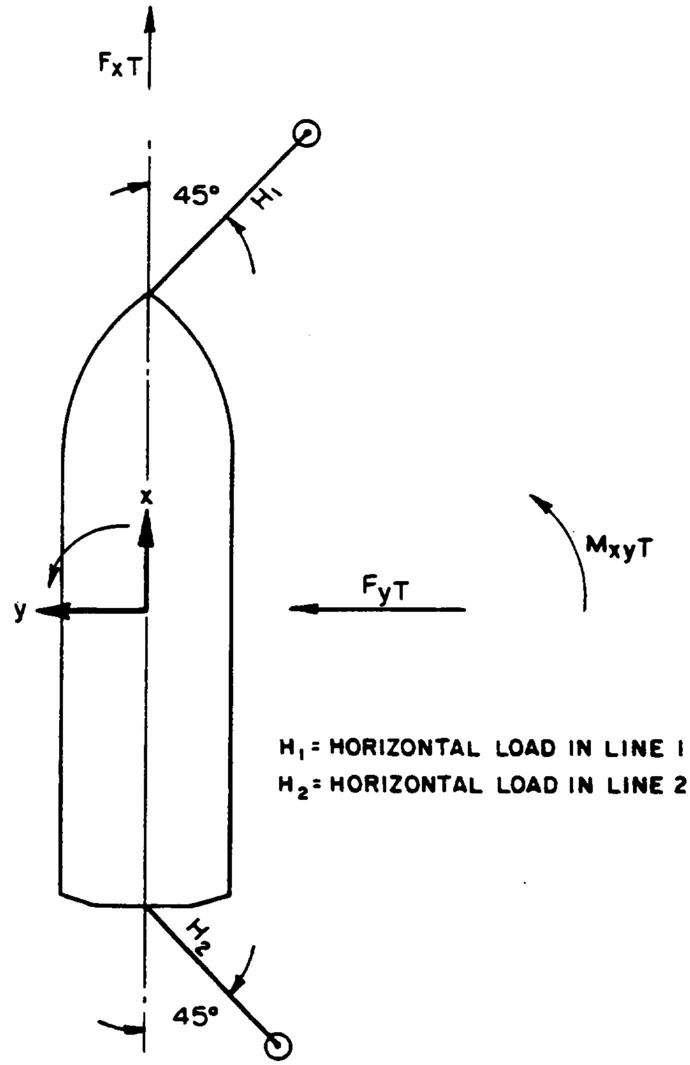


FIGURE 66
Example Plot of Σ M Versus θ c



$$\Sigma F_x = 0 = F_xT + \cos 45° H_1 - \cos 45° H_2 \qquad \text{EQ.(5-67)}$$

$$\Sigma F_y = 0 = F_yT - \sin 45° H_1 - \sin 45° H_2 \qquad \text{EQ.(5-68)}$$

OR

$$H_2 = \frac{F_yT}{2 \sin 45°} + \frac{F_xT}{2 \cos 45°} \qquad \text{EQ.(5-69)}$$

$$H_1 = H_2 - \frac{F_xT}{\cos 45°} \qquad \text{EQ.(5-70)}$$

NOTE: DESIGNER MUST BE SURE THAT ALL SIGNS ARE CONSISTENT WITH APPLIED LOADS AND LINE ORIENTATIONS

FIGURE 67
Force Diagram for a Typical Bow-and-Stern Mooring

loading until the mooring lines make an angle of 45 degrees with the longitudinal axis of the vessel. (See Figure 67.) Horizontal line loads in the bow line (H_1) and in the stern line (H_2) are determined by summing the forces in the x- and y-directions. Equations for line loads are given on Figure 67. Note that this procedure is an approximation which does not provide a moment balance.

(2) Spread Mooring. A force diagram for a typical spread mooring for a floating drydock is shown in Figure 68. The mooring consists of bow and stern mooring lines, which resist longitudinal load, and four mooring lines, placed perpendicularly to the longitudinal axis of the vessel, which resist lateral load. The bow or stern mooring line is assumed to take the longitudinal mooring load. Mooring-line loads may be determined from the equations shown on Figure 68.

(3) Four-Point Mooring. A force diagram for a typical four-point mooring is shown in Figure 69. The hand solution used to analyze this mooring arrangement is presented in CHESNAVFAC FPO-1-81-(14). Each of the lines in this mooring resists both longitudinal and lateral load. Mooring-line loads may be determined from the equations shown on Figure 69.

d. <u>Computer Solution</u>. Appendix B provides a description of and documentation for a computer program which analyzes multiple-point moorings.

7. DESIGN OF MOORING COMPONENTS.

a. Selection of Chain and Fittings.

(1) Approximate Chain Tension. The maximum mooring-chain tension is higher than the horizontal load on the chain. However, normally only the horizontal load is known. The maximum tension is approximated as follows:

$$T = 1.12\ H \qquad (5\text{-}78)$$

WHERE: T = maximum tension in the mooring chain

H = horizontal load on the mooring chain determined in previous subsection (for example, H, H_1, H_2. . .)

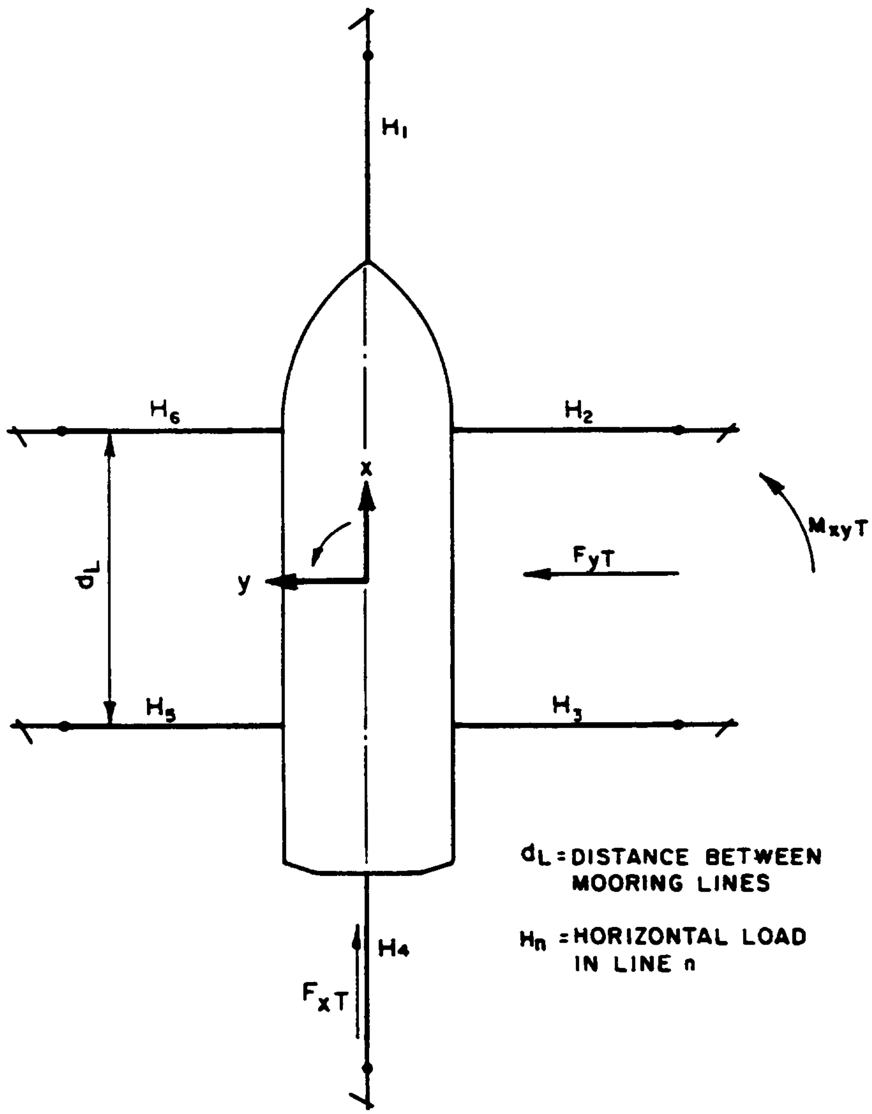
This equation provides conservative estimates of mooring-chain tension for water depths of 100 feet or less.

(2) Maximum Allowable Working Load. The maximum allowable working load for mooring chain loaded in direct tension is:

$$T_{design} = 0.35\ T_{break} \qquad (5\text{-}79)$$

WHERE: T_{design} = maximum allowable working load on the mooring chain

T_{break} = breaking strength of the chain



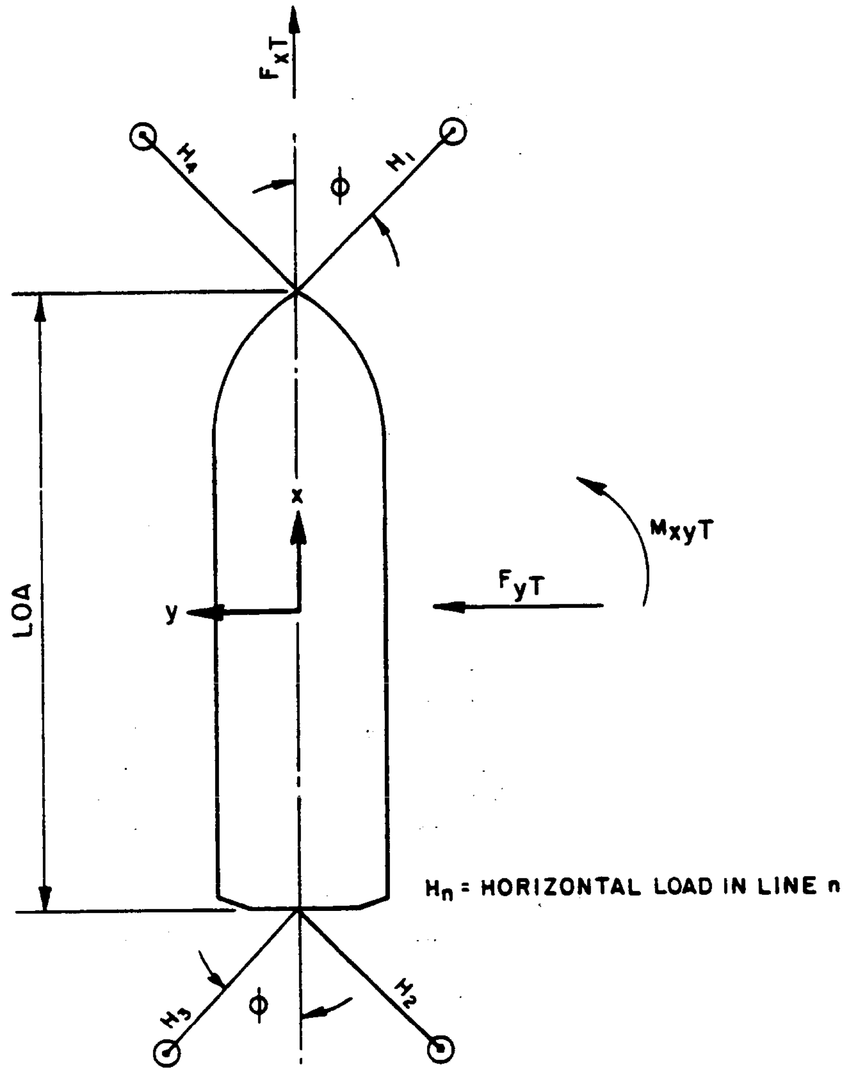
$$H_4 = F_{xT} \quad \text{EQ.(5-71)}$$

$$H_2 = \frac{F_{yT}}{2} + \frac{M_{xyT}}{d_L} \quad \text{EQ.(5-72)}$$

$$H_3 = \frac{F_{yT}}{2} + \frac{M_{xyT}}{d_L} \quad \text{EQ.(5-73)}$$

NOTE: DESIGNER MUST BE SURE THAT ALL SIGNS ARE CONSISTENT WITH APPLIED LOADS AND LINE ORIENTATIONS

FIGURE 68
Force Diagram for a Typical Spread Mooring



$$H_1 = \frac{-F_{xT}}{2\cos\phi} + \left(\frac{F_{yT}}{2} + \frac{M_{xyT}}{LOA}\right)\frac{1}{\sin\phi} \qquad \text{EQ.(5-74)}$$

$$H_2 = \frac{+F_{xT}}{2\cos\phi} + \left(\frac{F_{yT}}{2} - \frac{M_{xyT}}{LOA}\right)\frac{1}{\sin\phi} \qquad \text{EQ.(5-75)}$$

$$H_3 = \frac{+F_{xT}}{2\cos\phi} + \left(\frac{-F_{yT}}{2} + \frac{M_{xyT}}{LOA}\right)\frac{1}{\sin\phi} \qquad \text{EQ.(5-76)}$$

$$H_4 = \frac{-F_{xT}}{2\cos\phi} + \left(\frac{-F_{yT}}{2} - \frac{M_{xyT}}{LOA}\right)\frac{1}{\sin\phi} \qquad \text{EQ.(5-77)}$$

NOTE: DESIGNER MUST BE SURE THAT ALL SIGNS ARE CONSISTENT WITH APPLIED LOADS ANO LINE ORIENTATIONS

FIGURE 69
Force Diagram for a Typical Four-Point Mooring

For mooring chain which passes through hawsepipes, chocks, chain stoppers, or other fittings which cause the chain to change direction abruptly within its loaded length:

$$T_{design} = 0.25 \ T_{break} \tag{5-80}$$

(The maximum working load may be taken as 35 percent of the chain breaking strength provided the minimum bending radius is nine times the chain diameter, according to NAVSEASYSCOM criteria.)

(3) Chain Selection. Chains and fittings are to be selected with a breaking strength equal to or exceeding T_{break}. This criterion is consistent with practice in the offshore oil industry (Flory et al., 1977).

The breaking strength of Navy common A-link chain is presented in Table 95 of DM-26.6. The breaking strengths of the various types of fittings used in standard fleet moorings are presented in Tables 96 through 113 and Figures 6 through 8 of DM-26.6. Breaking strengths for various types of commercially available chains and fittings are presented in Tables 10 through 43 of DM-26.6.

It is common practice to round up to the nearest l/4-inch size when selecting chain or fittings. It may be desirable to specify the next largest size of chain or fitting if excessive wear is expected. Since excessive wear generally occurs in the fittings, it is customary to use the next largest size for these parts only. Care should be taken to assure that larger fittings are compatible in size to standard chain and fittings.

(4) Chain Weight. "Weights per shot of chain given in the above tables from DM-26.6 are-weights in air; the weight of chain in water is obtained by multiplying the weight in air by 0.87. When tables of actual chain weights are unavailable, the submerged weight of stud link chain may be approximated as follows:

$$w_{air} = 9.5 \ d^2 \tag{5-81}$$

$$w_{submerged} = 8.26 \ d^2 \tag{5-82}$$

WHERE: w_{air} = weight of chain (in air), in pounds per foot of length

$w_{submerged}$ = weight of chain (in water), in pounds per foot of length (submerged unit weight of chain)

d = diameter of chain, in inches

b. Computation of Chain Length and Tension.

(1) Catenary Equations. A chain mooring line supported at the surface by a buoy and extending through the water column to the seafloor behaves as a catenary. Figure 70 presents a definition sketch for use in catenary analysis. At any point (x, y) the following hold:

$$V = w \ S = T \sin \theta \tag{5-83}$$

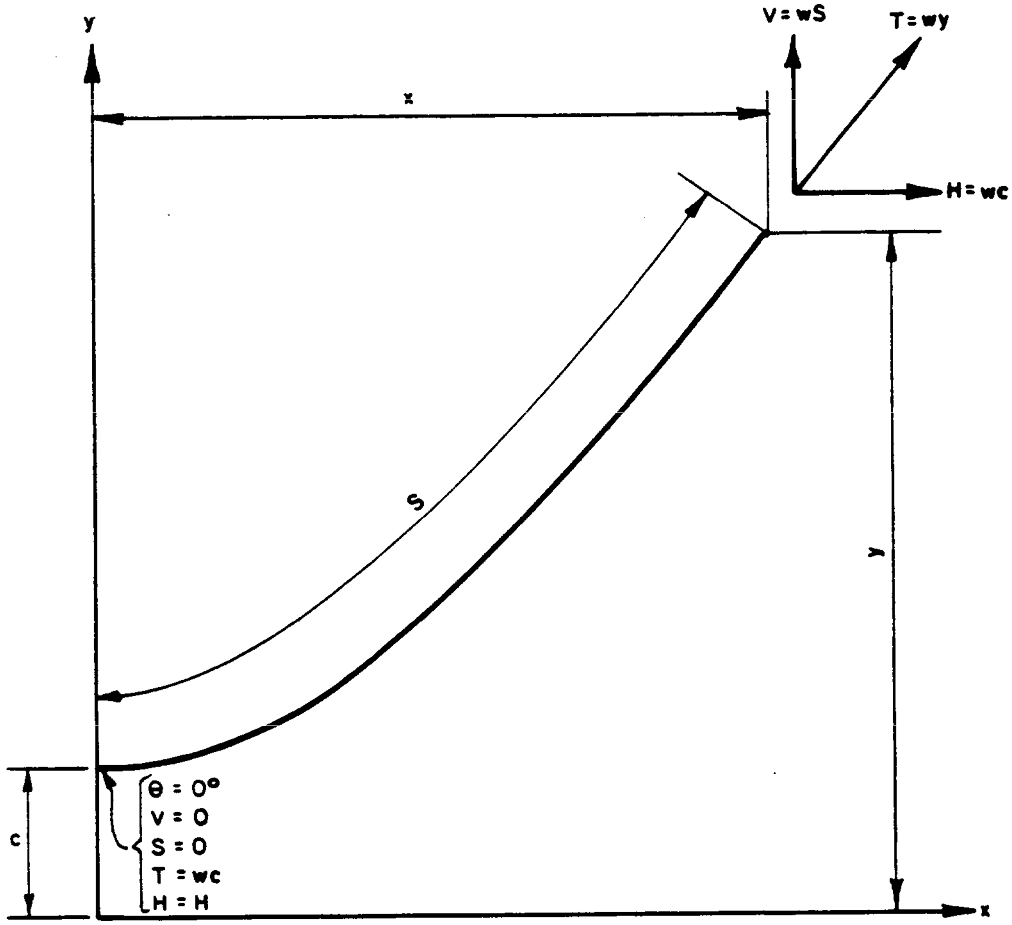


FIGURE 70
Definition Sketch for Use in Catenary Analysis

$$H = w\,c = T\cos\theta \tag{5-84}$$

$$T = w\,y \tag{5-85}$$

WHERE: V = vertical force at point (x, y)

w = submerged unit weight of chain

S = length of curve (chain length) from point (O, c) to point (x, y)

T = line tension at point (x, y)

θ = angle of mooring line with horizontal

H = horizontal force at point (x,y)

C = distance from origin to y-intercept = H/w

The shape of the catenary is governed by the following:

$$y^2 = S^2 + C^2 \tag{5-86}$$

$$y = C\cosh\frac{x}{c} \tag{5-87}$$

$$s = c\sinh\frac{x}{c} \tag{5-88}$$

WHERE: S = length of curve (chain length) from point (O, c) to point (x, y)

c = distance from origin to y-intercept

Equation (5-88) may be more conveniently expressed as:

$$x = c\ \ln\left[\frac{S}{c} + \sqrt{\left(\frac{S}{c}\right)^2 + 1}\right] \tag{5-89}$$

Note that, in the above equations, the horizontal load in the chain is the same at every point and that all measurements of x, y, and S are referenced to the catenary origin.

When catenary properties are desired at point (x_m, y_m), as shown in Figure 71, the following equations are used:

$$\sqrt{S_{ab}^{\,2} - (wd)^2} = 2c\sinh\frac{x_{ab}}{2c} \tag{5-90}$$

$$\frac{wd}{S_{ab}} = \tanh\frac{x_m}{c} \tag{5-91}$$

$$x_m = x_a + \frac{x_{ab}}{2} \tag{5-92}$$

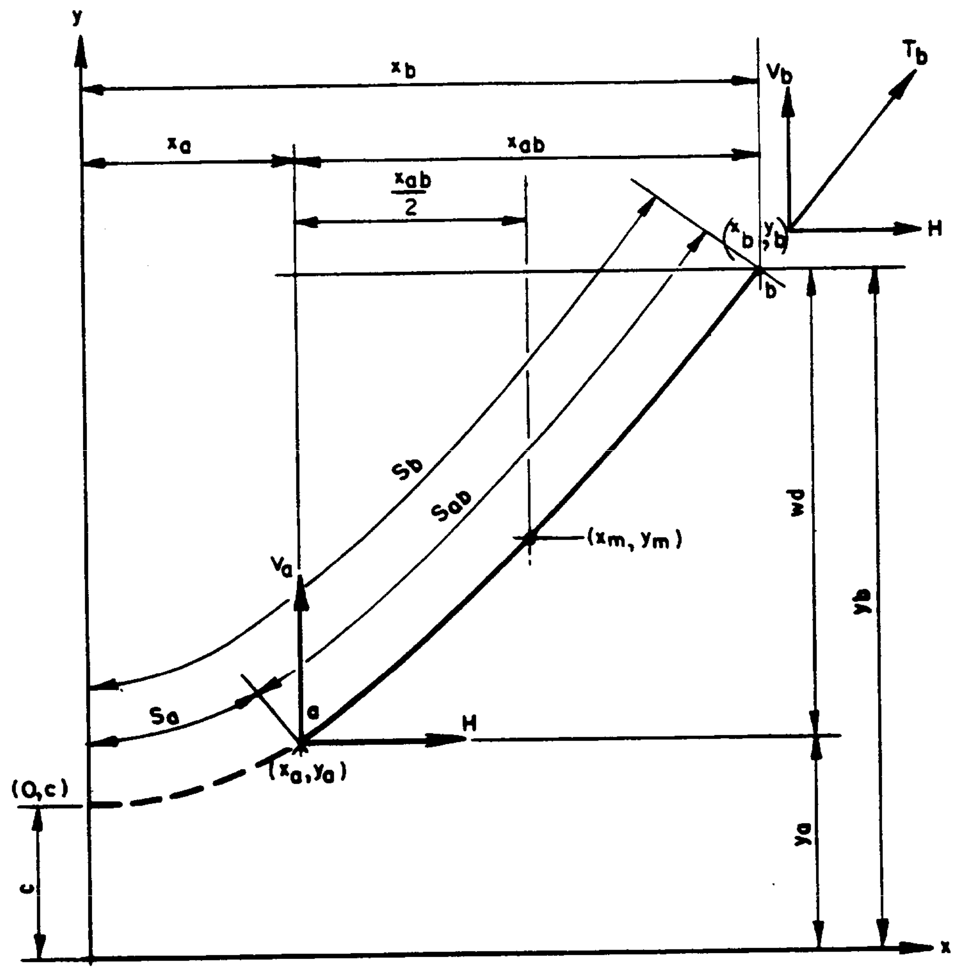


FIGURE 71
Definition Sketch for Catenary Analysis at point (X_m, Y_m)

$$x_b = x_m + \frac{x_{ab}}{2} \qquad (5\text{-}93)$$

WHERE : terms are defined in Figure 71

Equation (5-91) is more conveniently written as:

$$x_m = \frac{c}{2}\left[\ln\left(1 + \frac{wd}{S_{ab}}\right) - \ln\left(1 - \frac{wd}{S_{ab}}\right)\right] \qquad (5\text{-}94)$$

Due to the nature of the hyperbolic functions in the above equations, it sometimes may be convenient to express the catenary equations in trigonometric form:

$$S = c\,(\tan\theta_b - \tan\theta_a) \qquad (5\text{-}95)$$

$$y = c\,(\sec\theta_b - \sec\theta a) \qquad (5\text{-}96)$$

$$x = c\ \ln\left(\frac{\tan\theta_b + \sec\theta_b}{\tan\theta_a + \sec\theta_a}\right) \qquad (5\text{-}97)$$

$$\sec\ \theta = \frac{1}{\cos\theta} \qquad (5\text{-}98)$$

$$C = \frac{H}{w} \qquad (5\text{-}99)$$

WHERE: S = length of curve from point (O, c) to point (x, y)

c = distance from origin to y-intercept

θ_b = angle of the mooring line with the horizontal at point b

θ_a = angle of the mooring line with the horizontal at point a

θ = angle of the mooring line with the horizontal

H = horizontal force at point (x, y)

w = submerged unit weight of chain

(2) Some Applications of the Catenary Equations.

(a) Case 1. The known variables are the mooring-line angle at the anchor, θ_a (which is zero: $\theta_a = 0°$), the water depth, wd, the horizontal load, H, and the submerged unit weight of the chain, w. A zero anchor angle is often specified because drag-anchor capacity is drastically reduced as the angle of the chain at the seafloor is increased. The length of mooring line, S_{ab} the horizontal distance from the anchor to the buoy, x_{ab}, and the tension in the mooring line at the buoy, T_b, are desired. procedures for determining these values are outlined in Figure 72. Check to determine if the entire chain has been lifted off the bottom by comparing the computed

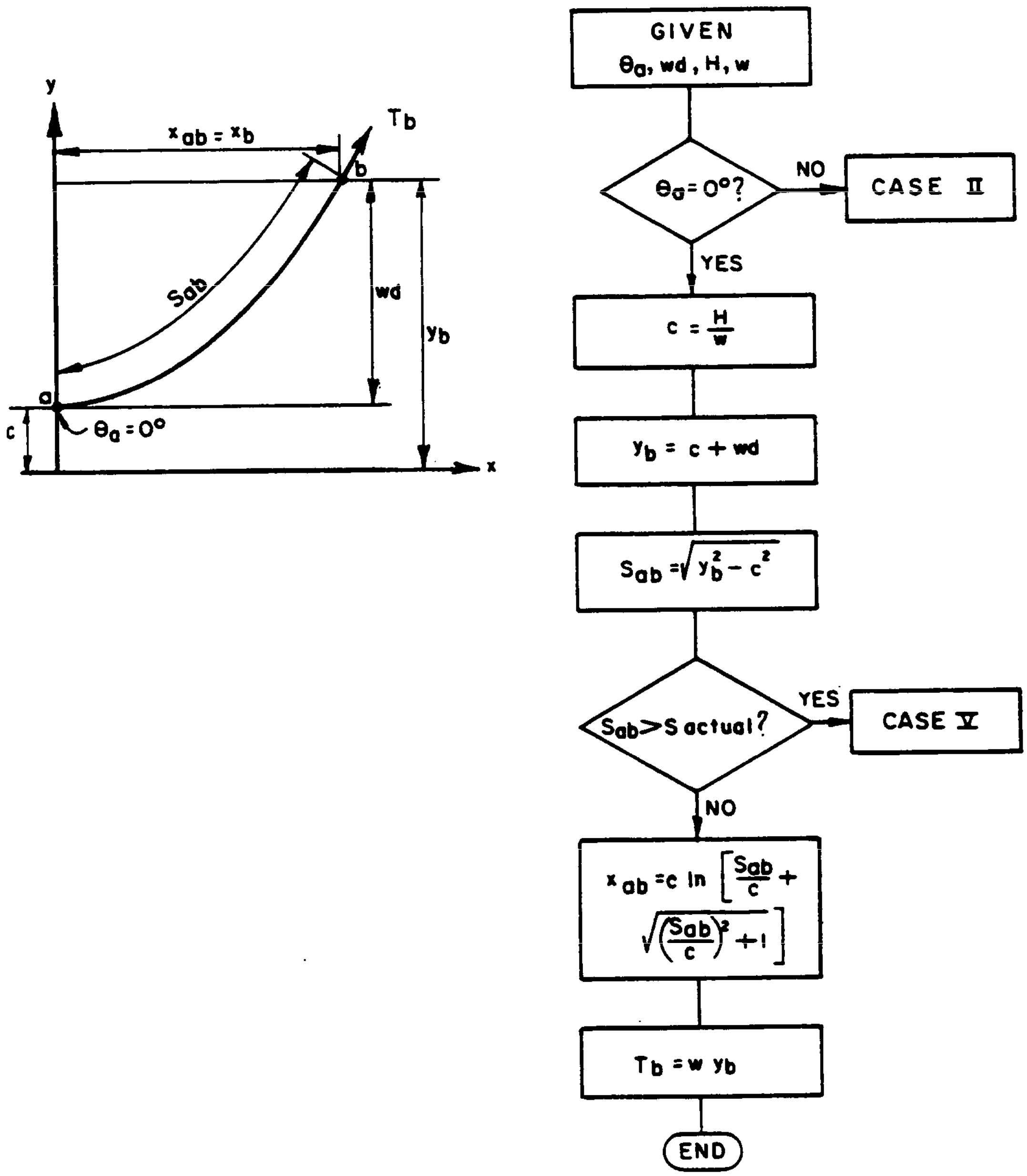


FIGURE 72
Case I

chain length from anchor to buoy, S_{ab}, to the actual chain length, S_{actual} If the actual chain length is less than the computed, then Case I cannot used and Case V must be used.

(b) Case 11. The known variables are the mooring-line angle at the anchor, θ_a (or, equivalently, a specified vertical load at the anchor, V_a), the water depth, wd, the horizontal load at the surface, H, and the submerged unit weight of the chain, w. This situation arises when a drag anchor is capable of sustaining a small prescribed angle at the anchor, or an uplift-resisting anchor of given vertical capacity, $V_a = H \tan \theta_a$, is specified. The origin of the catenary is not at the anchor, but is some distance below the bottom. The length of the chain from anchor to buoy, S_{ab}, the tension in the mooring line at the buoy, T_b, and the horizontal distance from the anchor to the surface, X_{ab} are desired. Procedures for determining these values are presented in Figure 73.

(c) Case III. The known variables are the horizontal distance from the anchor to the buoy, x_{ab}, the water depth, wd, the horizontal load, H, and the submerged unit weight of the chain, w. This situation arises when it is necessary to limit the horizontal distance from buoy to anchor due to space limitations. The length of chain from anchor to buoy, S_{ab}, the tension in the mooring line at the buoy, T_b, and the vertical load at the anchor, V_a, are required. Procedures for determining these values are outlined in Figure 74.

(d) Case IV. The known variables are the water depth, wd, the horizontal load, H, the submerged unit weight of the chain, w, the angle at the anchor, θ_a, the sinker weight, W_s, the unit weight of the sinker, γ_s, the unit weight of water, γ_w, and the length of chain from anchor to sinker, S_{ab} The mooring consists of a chain of constant unit weight with a sinker attached to it. The total length of chain, S_{ac} the distance of the top of the sinker off the bottom, y, and the tension the mooring line at the buoy, T_{c2}, are desired. solution to this problem is outlined in Figure 75.

(e) Case V. The known variables are the water depth, wd, the horizontal load on the chain, H, the submerged unit weight of the chain, w, and the length of chain from anchor to buoy, S_{ab}. The horizontal load, H, is sufficiently large to lift the entire chain off the bottom, resulting in an unknown vertical load at the anchor, V_a. This situation arises when one is computing points on a load-deflection curve for higher values of load.

Solution involves determining the vertical load at the anchor, V, using the trial-and-error procedure presented in Figure 76. The problem is solved efficiently using a Newton-Raphson iteration method (Gerald, 1980); this method gives accurate solutions in two or three iterations, provided the initial estimate is close to the final answer.

c. Selection of Anchor.

(1) Selection Procedure. Ibis section provides procedures for selecting and sizing drag anchors for fleet moorings. Procedures for selecting pile, deadweight, and direct-embedment anchors are not included, but may be found in the Handbook of Marine Geotechnology (NCEL, 1983a).

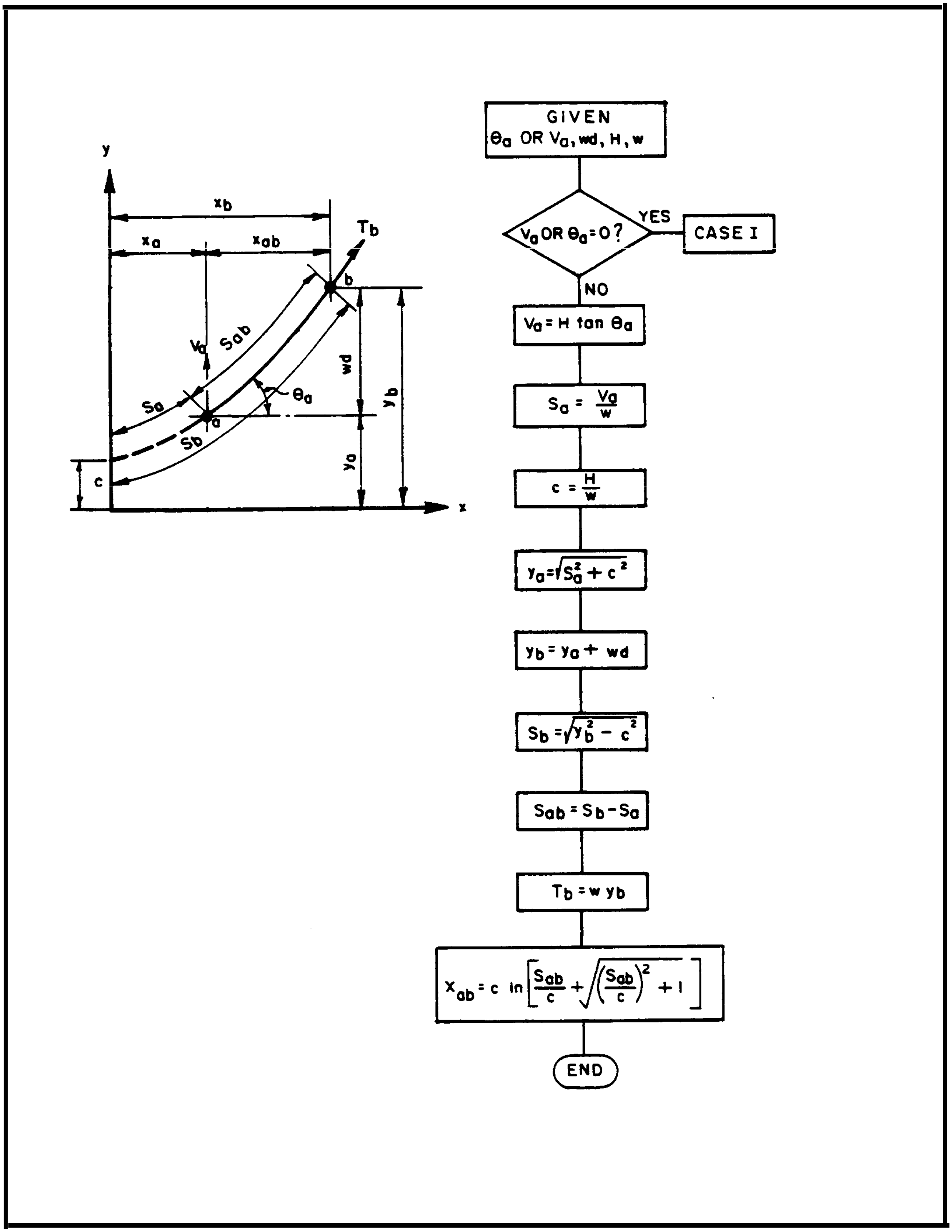


FIGURE 73
Case II

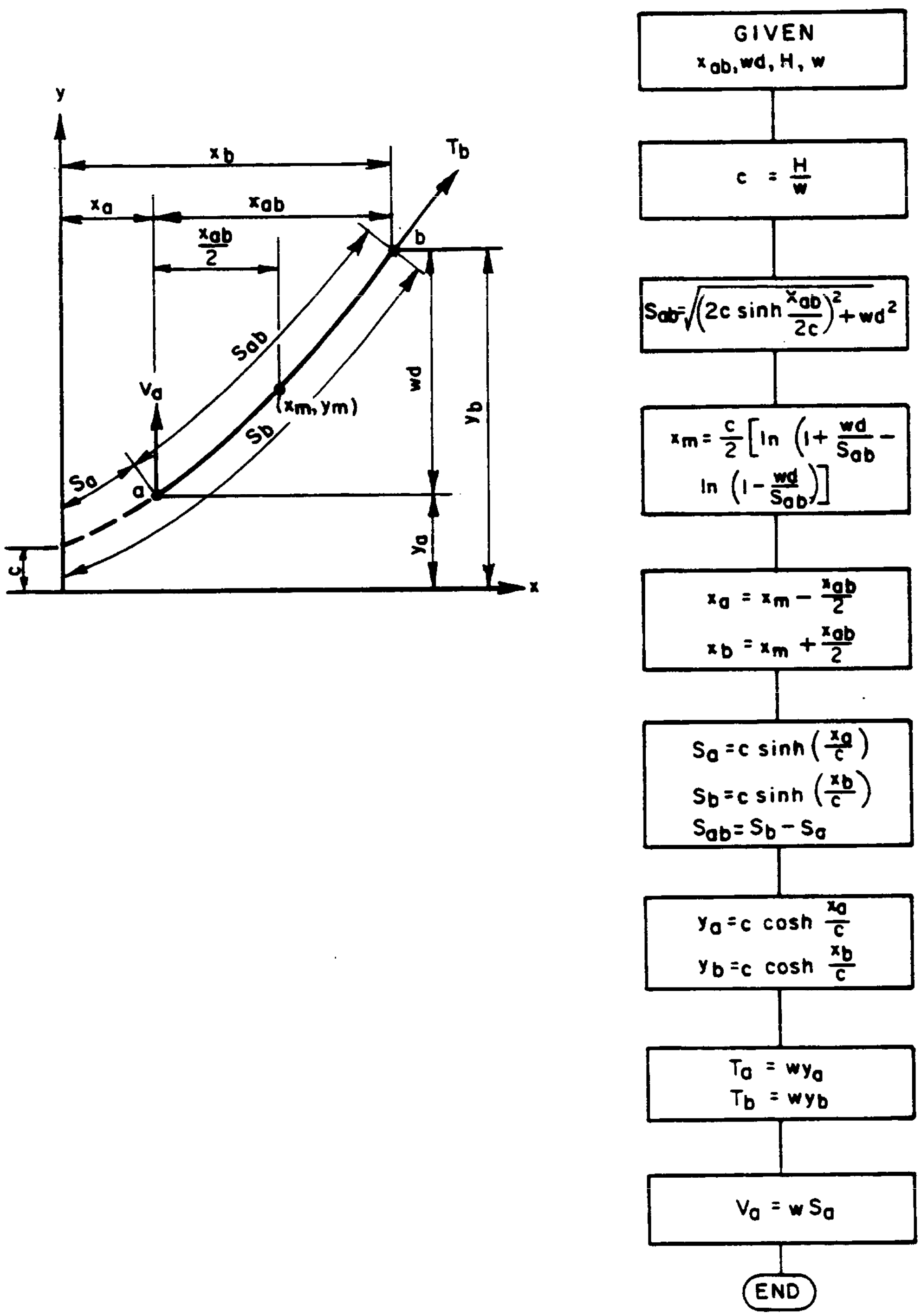
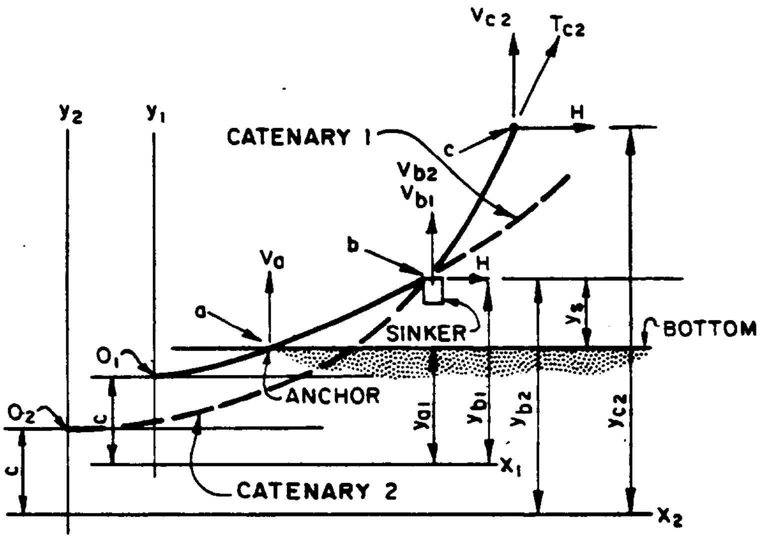


FIGURE 74
Case 111



S_{eq} = EQUIVALENT LENGTH OF CHAIN FOR SINKER

GIVEN wd, H, w, θ_a, W_s, γ_s, γ_w, LENGTH OF CHAIN FROM SINKER TO ANCHOR, S_{ab}

$V_a = H \tan \theta_a$

$S_{a1} = \frac{V_a}{w}$

$c = \frac{H}{w}$

$y_{a1} = \sqrt{S_{a1}^2 + c^2}$

$S_{b1} = S_{ab} + S_{a1}$

$y_{b1} = \sqrt{S_{b1}^2 + c^2}$

$y_s = y_{b1} - y_{a1}$ *

$S_{eq} = \left(\frac{\gamma_s - \gamma_w}{\gamma_s}\right) \frac{W_s}{c}$

$S_{b2} = S_{b1} + S_{eq}$

$y_{b2} = \sqrt{S_{b2}^2 + c^2}$

$y_{c2} = y_{b2} + (wd - y_s)$

$S_c = \sqrt{y_{c2}^2 - c^2}$

$S_{bc} = S_c - S_b$

$S_{ac} = S_{ab} + S_{bc}$

$X_{ac} = c \ln \left[\frac{S_{ac}}{c} + \sqrt{\left(\frac{S_{ac}}{c}\right)^2 + 1} \right]$

$T_c = w\, y_c$

END

NOTE: IF $y_s \leq 0$, GO TO CASE V

FIGURE 75
Case IV

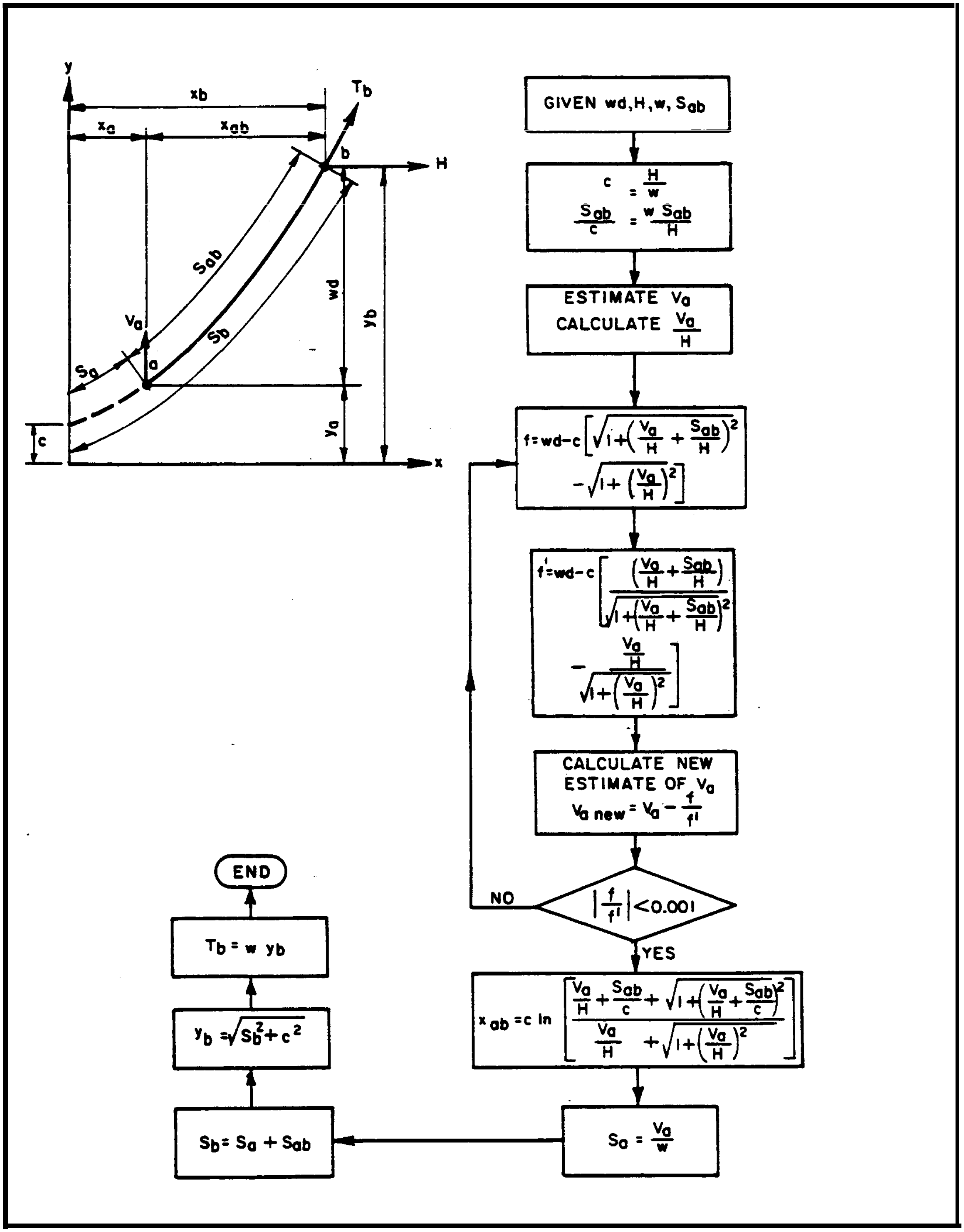


FIGURE 76
Case V

The procedure for selecting and sizing drag anchors is outlined in Figure 77. The anchor holding capacity, burial depth, and drag distance must be determined. The procedure allows the designer to size and select drag anchors in both sand and mud. Methods for sizing and selecting multiple-anchor arrangements for Stockless anchors are also provided. The following procedures have been adapted from NCEL Techdata Sheets 83-05, 83-08, and 83-09 (NCEL, 1983b, 1983c, 1983d).

(a) Determine required holding capacity. The required holding capacity is determined from Subsection 5.6. The required holding capacity used in anchor selection should be the maximum horizontal mooring-line load determined in Subsection 5.6.

(b) Determine seafloor type and sediment depth. In general, the soil type, soil depth, and variation of soil type over the mooring area are required for selecting and sizing drag anchors. Information on soils-investigation requirements for anchor design may be found in the Handbook of Marine Geotechnology (NCEL, 1983a) . The soil types encountered in most mooring designs *may* be classified as either mud or sand; these soil classifications are described in Table 4 of Section 3. Soil depth is an important consideration because there must be sufficient soil depth for anchor embedment. Extreme variation in soil type within the anchor drag distance may result in poor anchor performance.

(c) Select anchor type and size. A suitable anchor must be chosen. Most fleet moorings use either a Stockless or a Stato anchor because there is considerable Navy experience with these anchor types, they are currently in large supply, and they have been tested extensively by NCEL. Furthermore, Stockless and Stato anchors can be used to satisfy the required capacity of the standard fleet moorings for most conditions.

Several modifications to the Stockless and Stato anchors are recommended based on the results of extensive testing. Stabilizer bars should be added to the Stockless anchors for use in all soil types. The flukes of Stockless and Stato anchors should be fixed fully open in mud seafloors to assure fluke tripping. For sand, stiff clay, or hard seafloors, the flukes should be restricted to 35 + 2 degrees. The flukes of a Stato anchor should be 50 + 2 degrees for a mud seafloor and 29 + 1 degrees for a sand, stiff clay, or hard seafloor. Stabilizers should also be added to the Stato anchor and the length should be adjusted according to the recommendations presented in Table 17.

There is a large variety of commercially available drag anchors. Some of these anchors are presented in Figure 14 of Section 3. These anchors have not been tested as extensively as the Stockless or Stato anchors; they should be considered only if Stockless or Stato anchors are not available.

Once the anchor type has been selected, the anchor size (weight) is chosen to satisfy the required holding capacity. The maximum and recommended safe anchor holding capacities of Stockless and Stato anchors are determined by multiplying the efficiencies found in Table 18 by the weight of the anchor. Table 19 presents the minimum Stato and Stockless anchor sizes in mud, sand, or hard soil for each of the standard fleet-mooring classifications. The recommended safe anchor efficiencies were determined using a factor of safety of 1.5 for the Stockless and 2 for the State.

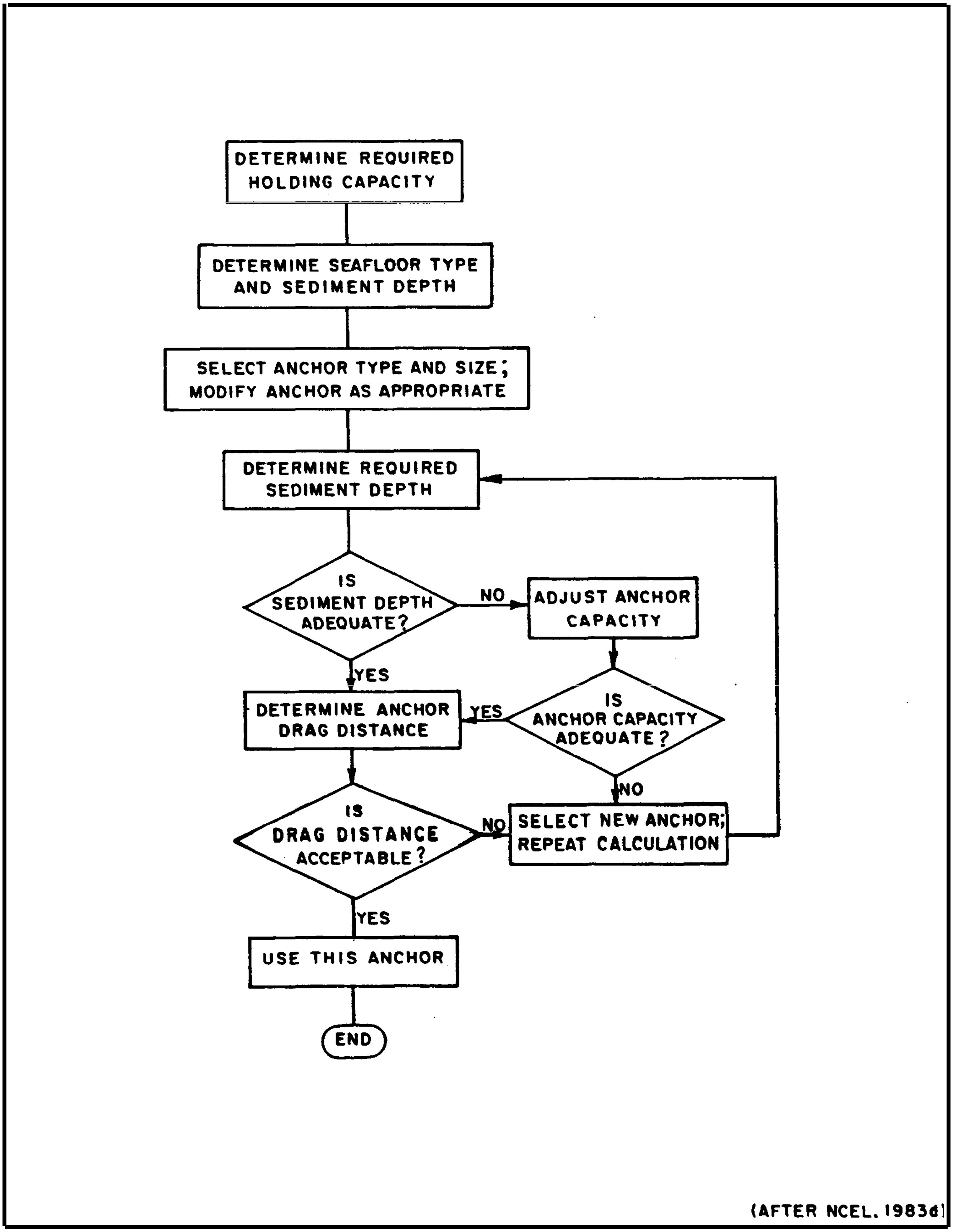


FIGURE 77
Procedure for Selecting and Sizing Drag Anchors

TABLE 17
Recommended Stabilizer Characteristics for Stato Anchor

Anchor Size (pounds)	Overall Anchor Width (inches)		Stabilizer Length (inches)	
	Old	New	Old	New
3,000	109	139	34	49
6,000	143	175	44	60
9,000	170	200	54	69
12,000	197	221	64	76
15,000	224	236	74	80

(AFTER NCEL, 1983d)

TABLE 18[1,2,3]
Maximum and Safe Efficiencies for Navy Stockless and Stato Anchors with Chain Mooring Line

Seafloor	Stockless (stabilized)	Stato
Sand		
Maximum	6	23
Safe	4	11-1/2
Mud[4]		
Maximum	4	20
Safe	2-3/4	10
Hard Soil		
Maximum	4-1/2	18
Safe	3	9

[1] Anchor holding capacity = anchor weight times efficiency
[2] Efficiencies include the effect of the buried part of the chain mooring line.
[3] Efficiencies based on capacity of 15,000-pound Stato and Stockless anchors.
[4] Can conservatively include clay-seafloor performance in this category.

(AFTER NCEL, 1983d)

TABLE 19
Minimum Single-Anchor Size for Fleet Moorings[1]

Mooring		Anchor Size (kips)					
		Stato			Stockless		
Class	Capacity (kips)	Mud	Sand	Hard soil	Mud	Sand	Hard soil
A	150	15	12	--	--	--	--
B	125	12	12	15	--	30	--
c	100	12	9	12	--	25	--
D	75	9	6	9	30	20	25
E	50	6	6	6	18	13	16
F	25	3	3	3	9	7	8
G	5	--	--	--	1.8	1.2	1.8

[1]Anchor holding capacity = anchor weight times efficiency

(AFTER NCEL, 1983d)

Figures 78 and 79 provide maximum holding capacity versus anchor weight for several anchor types for sand and clay/silt bottoms, respectively. The required maximum holding capacity, H_M, is determined by applying a factor of safety to the horizontal load, H:

$$H_M = FS \quad H \tag{5-100}$$

WHERE: H_M = maximum holding capacity

FS = factor of safety (FS = 1.5 for Stockless anchors and FS = 2 for Stato and other high-efficiency anchors)

H = horizontal load on mooring chain (determined in Subsection 5.6)

When H_M and the anchor type are known, Figures 78 and 79 provide the required anchor weight (in air) for sand and clay/silt bottoms, respectively.

(d) Determine required sediment depth. Anchor holding capacities determined from the above procedures assume there is a sufficient depth of soil to allow for anchor penetration. However, at some sites there may be a limited layer of soil overlying a hard strata such as coral or rock.

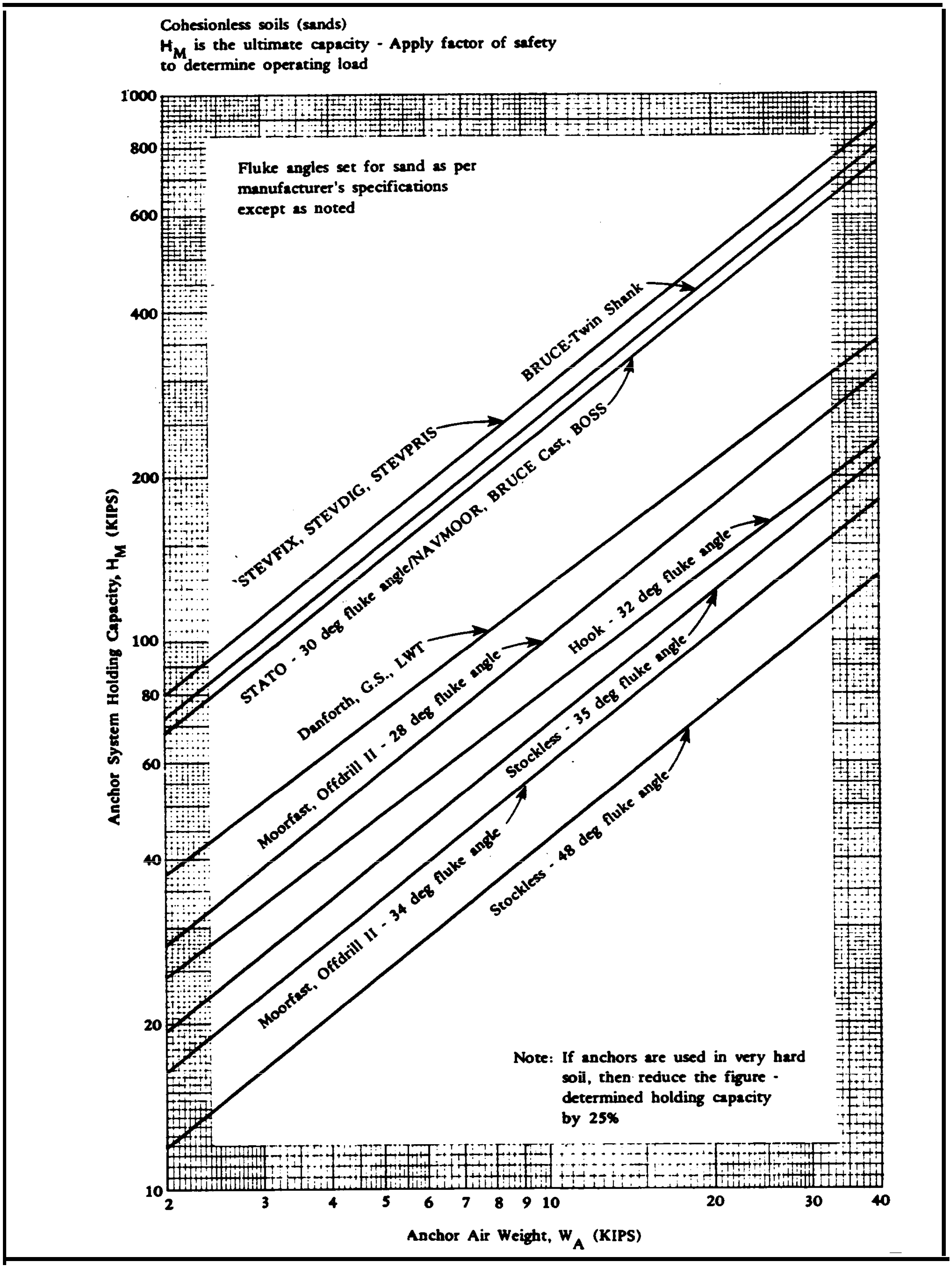


FIGURE 78
Maximum Holding Capacity for Sand Bottoms

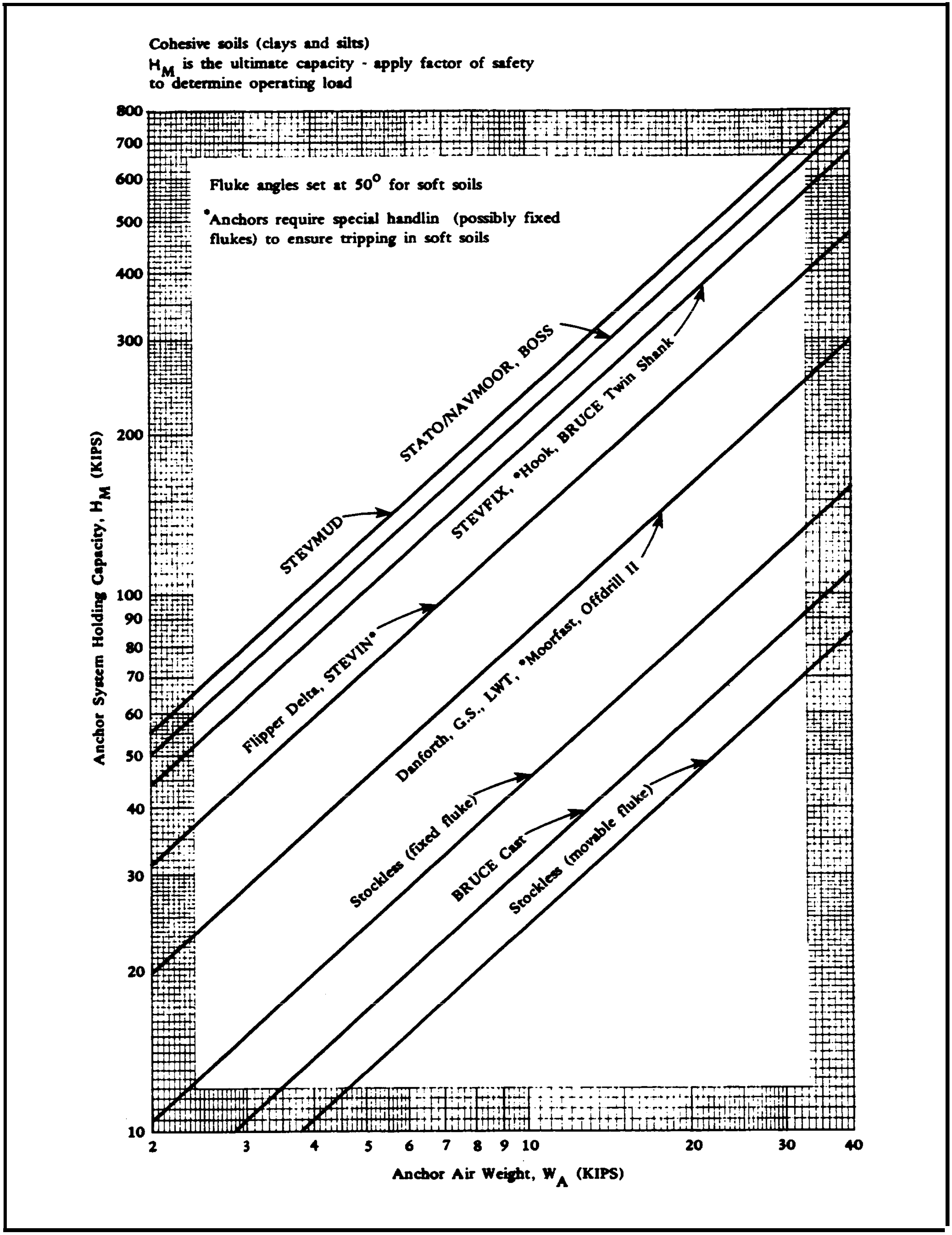


FIGURE 79
Maximum Holding Capacity for Clay/Silt Bottoms

The soil-depth requirements for the Stockless and Stato anchors are presented in Figure 80. This figure provides soil-depth requirements for mud, sand, and hard soil. The maximum fluke-tip penetration for various types of anchors in sand and mud is summarized in Table 20.

TABLE 20
Estimated Maximum Fluke-Tip Penetration of Some Drag-Anchor Types in Sands and Soft Clayey Silts (Mud)

Anchor Type	Normalized Fluke-Tip Penetration (fluke lengths)	
	Sands/Stiff Clays	Mud [1]
Stockless	1	3[2]
Moorfast Offdrill II	1	4
Stato Stevfix Flipper Delta Boss Danforth LWT GS (type 2)	1	4-1/2
Bruce Twin Shank Stevmud	1	5-1/2
Hook	1	6

[1]For example, soft silts and clays
Fixed-fluke Stockless

(AFTER NCEL, 1983c)

If the depth of sediment is less than that determined from the above procedures, then the anchor capacity must be reduced. The procedure below is recommended for mud and sand. (For hard seafloors, consult NCEL.) Determine the reduced anchor capacity due to insufficient sediment depth using the following equation:

$$H_A' = f\ H_A \qquad (5\text{-}101)$$

WHERE : H_A' = reduced anchor capacity due to insufficient sediment

f = a factor to correct anchor capacity

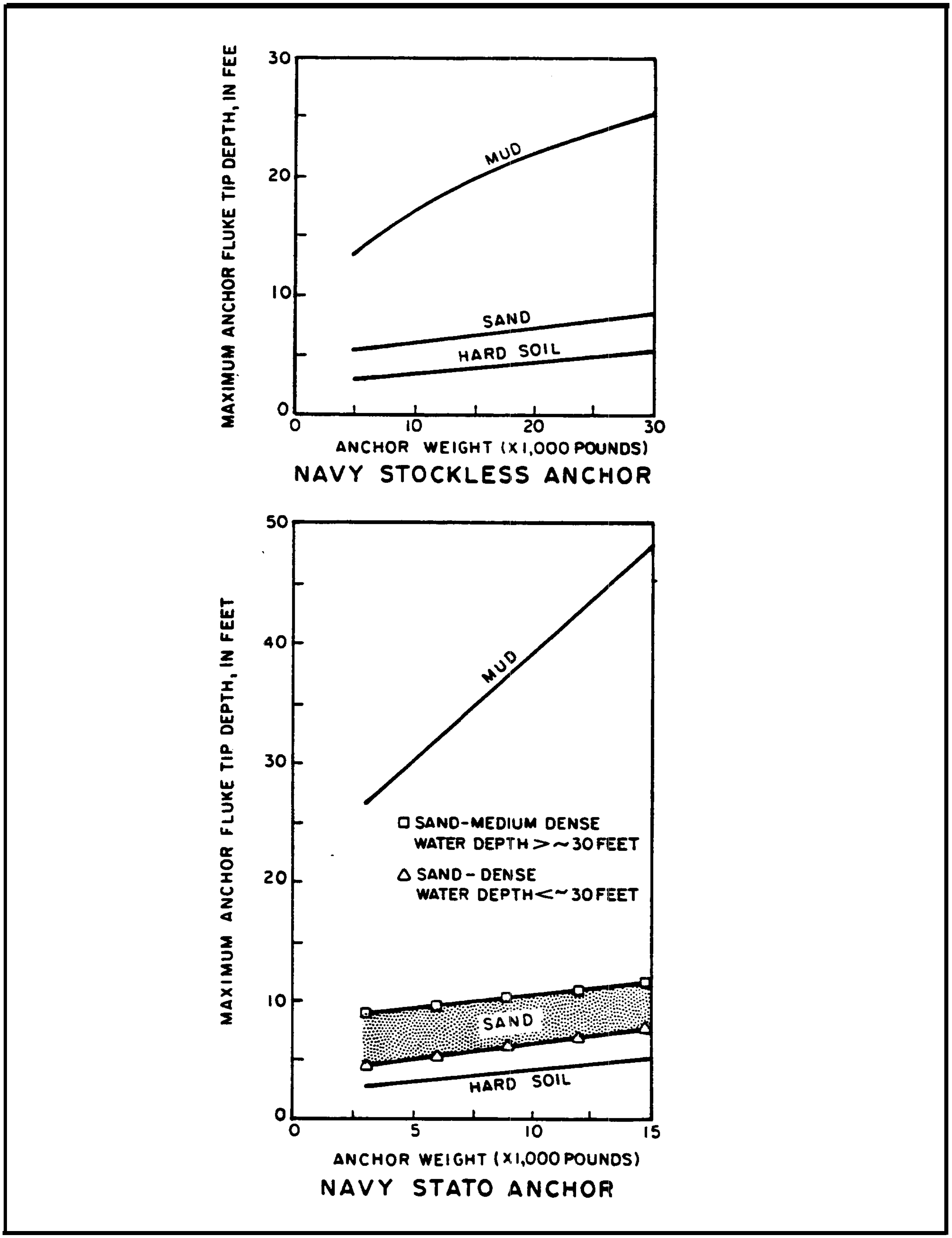


FIGURE 80
Soil-Depth Requirements for Navy Stockless and Stato Anchors

H_A = anchor capacity

The correction factor, f, is determined using the following equations for mud and sand, respectively:

$$f(mud) = \frac{\text{actual mud depth}}{\text{required mud depth (Figure 80 or Table 20)}} \qquad (5\text{-}102)$$

$$f(sand) = \frac{\text{actual sand depth}}{\text{required sand depth (Figure 80 or Table 20)}} \qquad (5\text{-}103)$$

WHERE: f(mud) = a factor to correct anchor capacity in mud

f(sand) = a factor to correct anchor capacity in sand

(e) Determine anchor drag distance. In general, anchor holding capacity increases with drag distance. However, for many fleet-mooring applications, anchor drag distance must be limited (50 feet of drag is recommended as a maximum). Anchor drag distances in sand for the Stockless and Stato anchors are determined from Figure 81, which presents a plot of the percent of maximum capacity (ordinate) versus the normalized drag distance (abscissa) .

Drag distances for factors of safety of 1.5 (for the Stockless) and 2 (for the State) are indicated in Figure 81. The anchor drag distances for the various commercially available anchors is estimated to be about 3-1/2 to 4 fluke lengths, corresponding to a factor of safety of 2.

Anchor drag distances in mud can be determined from Figure 82. The drag distances for the Stockless (factor of safety of 1.5) and Stato (factor of safety of 2) anchors are indicated in the figure. Figure 83 provides anchor drag distance for various commercially available anchors.

(2) Multiple-Anchor Arrangements. Increased holding capacity can be achieved by using combinations of anchors in fleet-mooring ground legs. The methods for using multiple anchors described below are limited to arrangements of Stockless anchors.

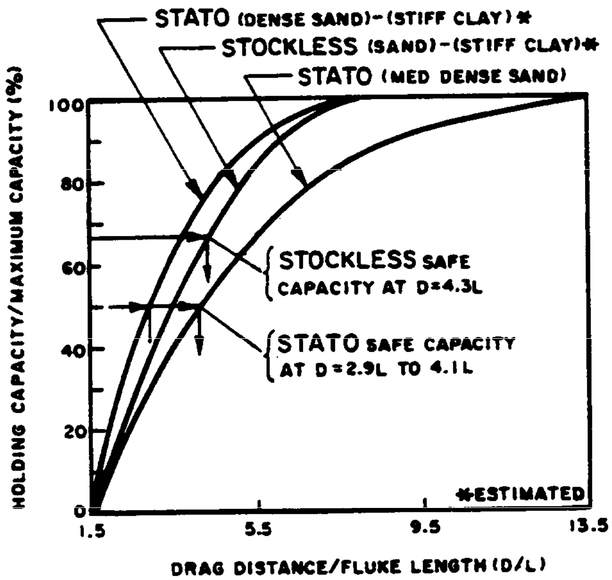
Table 21 summarizes five options for arranging anchors on fleet-mooring ground legs. This table also provides the holding capacities, operational characteristics, and operational guidelines for each of the methods. The holding capacities are given for mud, sand, and hard soil. The factor of safety used to determine the safe holding capacity was 1.5 for mud and sand and 2 for hard soils. The higher factor of safety for hard soils results from uncertainty associated with the performance of the rear anchor should it pass through soil disturbed by the front anchor.

Table 22 summarizes the minimum Stockless anchor, for each of the standard fleet-mooring classifications, for the five multiple-anchor options presented in Table 21. Table 22 gives recommendations for mud, sand, and hard soil.

Options 3 and 5 from Table 22 consist of two anchors secured to the same mooring chain. This requires a special connection, which is summarized in Figure 84. The padeye shown on the top of the anchor crown must be designed to resist nine times the anchor weight.

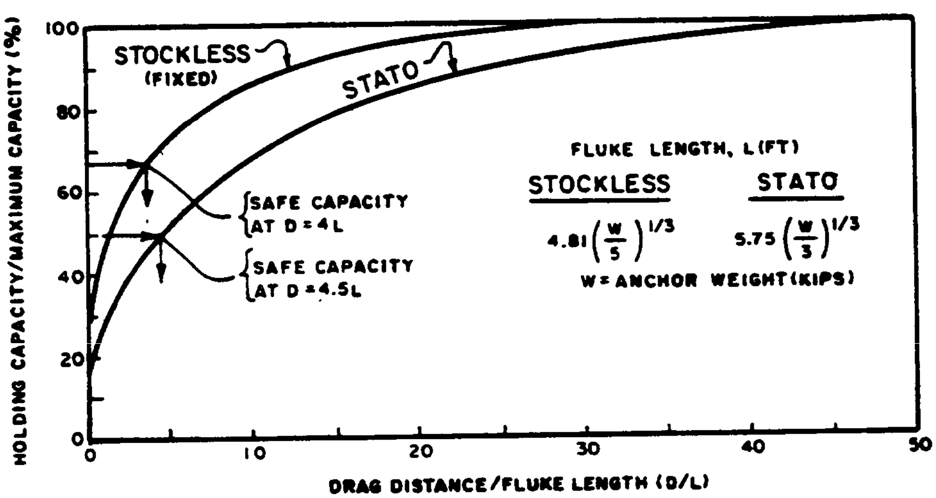
8. **METRIC EQUIVALENCE CHART.** The following metric equivalents were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Section 5. Conversions are approximate.

33.33 feet = 10 meters
1 mile = 1.61 kilometers
60 miles per hour = 96.6 kilometers per hour
10 miles = 16.1 kilometers
0.00237 slugs per cubic foot = 0.00122 gram per cubic centimeter
2 slugs per cubic foot = 1.031 grams per cubic centimeter
1.4×10^{-5} square feet per second = 1.3×10^{-6} square meters per second
10^{5} foot-pounds = $1,4 \times 10^{4}$ kilogram-meters
10^{7} foot-pounds = 1.4×10^{6} kilogram-meters
100 feet = 30.5 meters
1/4 inch = 0.64 centimeter
50 feet = 15.2 meters



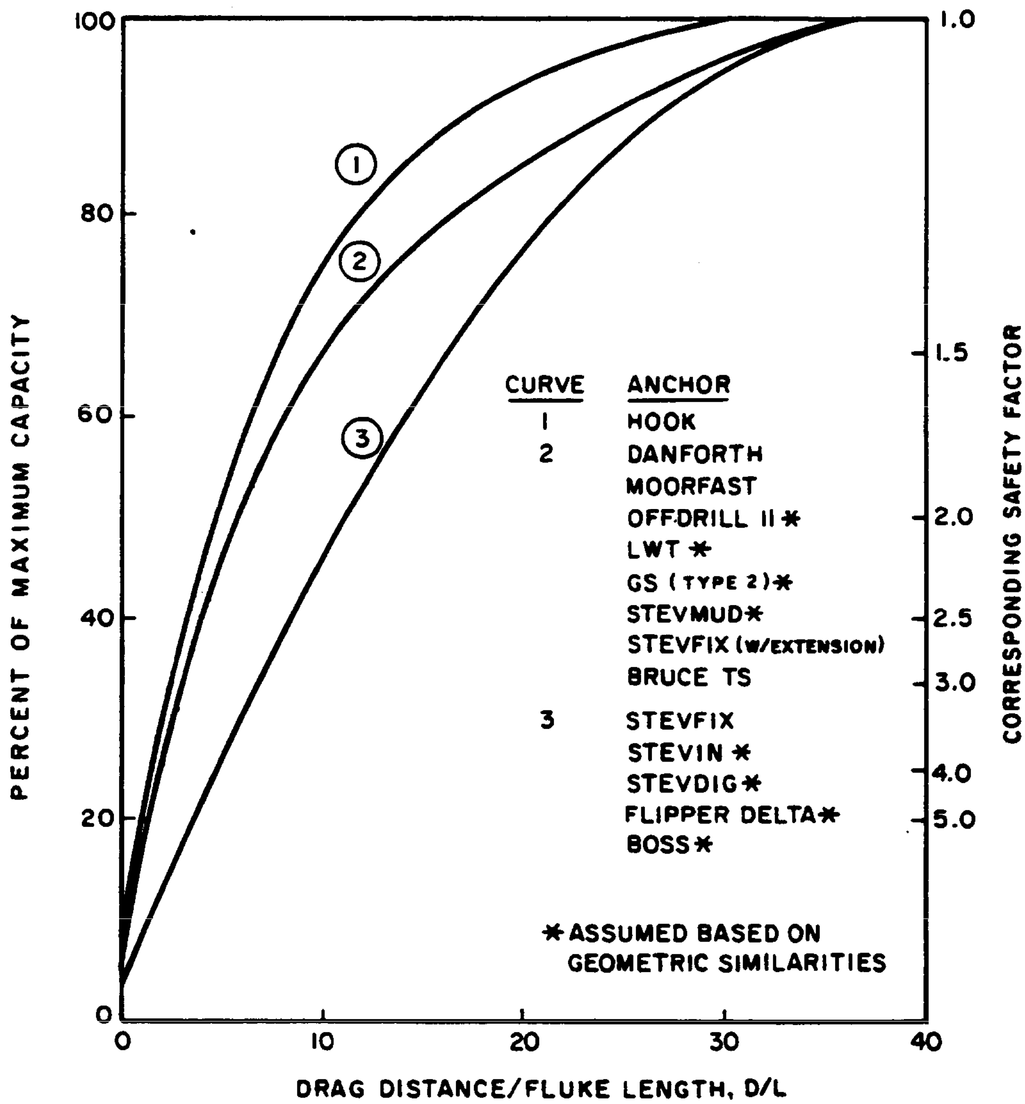
(NCEL, 1983d)

FIGURE 81
Normalized Holding Capacity Versus Normalized Drag Distance in Sand



(NCEL 1983d)

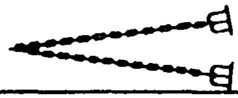
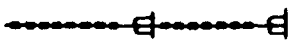
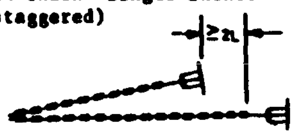
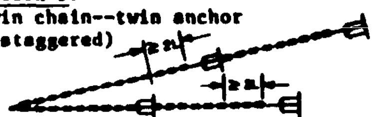
FIGURE 82
Normalized Holding Capacity Versus Normalized Drag Distance in Mud



(AFTER NCEL, 1983c)

FIGURE 83
Percent Holding Capacity Versus Drag Distance in Mud

TABLE 21
Navy Fleet-Mooring Ground-Leg Options

	Ground-Leg Option	Anchor-Leg Holding Capacity: Mud Max.	Mud Safe	Sand Max.	Sand Safe	Hard Soil Max.	Hard Soil Safe	Operational Characteristics	Operational Guidelines
STANDARD NAVY METHODS	Option 1: Single chain--single anchor 	4W	$2\frac{3}{4}$W	6W	4W	$4\frac{1}{2}$W	3W	Simplest installation. Recovery can be a problem for large, deeply buried anchors in mud.	Add stabilizers. Fix flukes fully open (48° fluke angle) for mud. Restrict fluke angle to 35° ±2° maximum for sand or hard soil. May be necessary to fix flukes at specified angle to ensure fluke tripping in hard soil.
	Option 2: Twin chain--single anchor 	4W	$2\frac{3}{4}$W	$5\frac{1}{4}$W	$3\frac{1}{2}$W	4W	2W	Simple installation. Care needed to ensure proper anchor location during installation. Potential for anchor interference and reduced capacity in sand/hard soils during drag.	Same guidelines as those for Option 1. Fixing flukes at specified angle for all seafloors would minimize drag distance and maximize probability of proper anchor embedment before the anchors come together.
OPTIONAL METHODS	Option 3: Single chain--twin anchor (crown to shackle connection) 	4W	$2\frac{1}{2}$W	6W	4W	$4\frac{1}{2}$W	$2\frac{1}{4}$W	More complex installation, but demonstrated as feasible. Variety of rigging methods possible; attachment of rear anchor chain to crown of forward anchor is recommended for the Stockless anchor. Reduces number of mooring legs and overall installation time. Potential for using additional anchors in tandem. Rear-anchor capacity in sand may be substantially greater than single-anchor capacity.	Use fluke angle per Option 1 guidelines. Fluke must be fixed at proper fluke angle for crown-shackle connection. Chain length between anchors should be greater than the water depth to enable individual anchor placement. Rear anchor should be equal to or smaller than the inboard anchor to ensure peak rear-anchor performance, except in hard soil (see text for hard-soil guidelines).
	Option 4: Twin chain--single anchor (staggered) 	4W	$2\frac{3}{4}$W	6W	4W	$4\frac{1}{2}$W	$2\frac{1}{4}$W	Simple installation. Anchor spacing prevents anchor interference. Performance in mud considered superior to that for Option 2. Rear-anchor capacity same as that for Option 3.	Same guidelines as those for Option 1. Minimum anchor separation is two fluke lengths for optimum performance.
	Option 5: Twin chain--twin anchor (staggered) 	4W	$2\frac{3}{4}$W	6W	4W	$4\frac{1}{2}$W	$2\frac{1}{4}$W	More complex installation, but feasibility demonstrated. Potential for satisfying very large fleet-mooring requirements.	Same guidelines as those for Option 3.

NOTES: 1. W = total weight of anchors; does not include weight of chain between anchors; L = fluke length
2. Capacity includes effects of buried chain.
3. If anchors are used with wire in sand, decrease capacity by 25 percent.
4. Can conservatively include clay in mud category.
5. Safe capacities include factors of safety and appropriate reduction factors defined in text.

(NCEL, 1983b)

TABLE 22
Required Minimum Stockless Anchor Size for Navy Fleet Moorings

Ground-Leg Option		Anchor Size (x 1000 pounds)											
		1. Single Chain—Single Anchor			2. Twin Chain—Single Anchor			3. Single Chain—Twin Anchor or 4. Twin Chain-Single Anchor (Staggered)			5. Twin Chain-Twin Anchor (Staggered)		
Mooring Class	Flooring capacity	Mud	Sand	Bard soil	Mud	Sand	Hard soil	Mud	Sand	Hard soil	Mud	Sand	Hard soil
AAA (PROPOSED)	500K											30	
BBB (PROPOSED)	350K											22.5	
AA	300K										30	20	
BB	250K								30		22.5		30
CC	200K					30			25		18		22.5
DD	175K					25			22.5		18		20
A	150K				30	22.5	30	30	20				18
B	125K		30		22.5		25	22.5		30			
C	100K		25		18		20	18		22.5			
D	75K	30	20	25									
E	50K	18	13	16									
F	25K	9	7	8									
G	5K	1.8	1.2	1.8									

Assumptions for l above anchor weights:
1 Stockless l anchor is stabilized.
2. Fluke angle is 35 degrees in sand/hard soil and 48 degrees in mud.
3. Flukes fixed open for Options 1 through 5 for mud; 3 l nd 5 for sand/hard soil.

(After NCEL, 1983b)

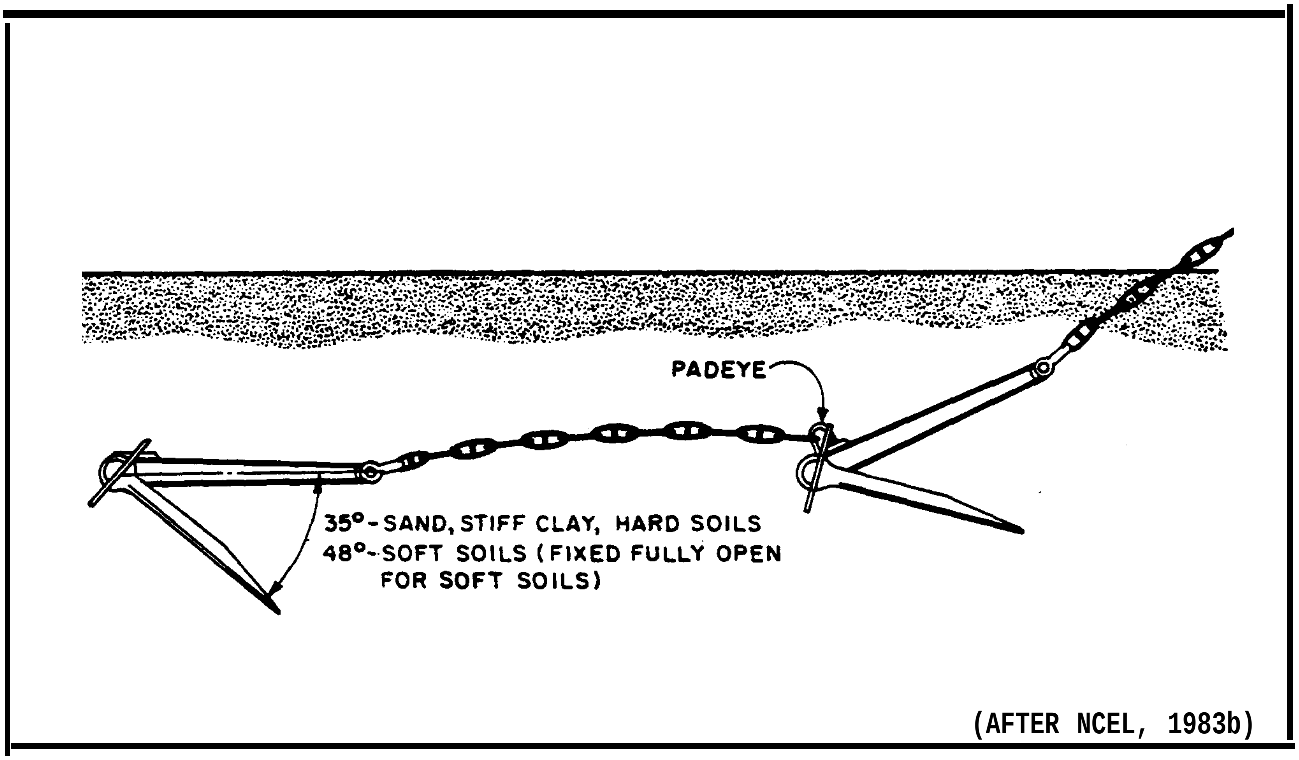


FIGURE 84
Recommended Twin-Anchor Rigging Method
(For Options 3 and 5 of Tables 21 and 22)

Section 6. EXAMPLE PROBLEMS

EXAMPLE PROBLEM 1: FREE-SWINGING MOORING

Given:
a. Single-point mooring for a DD-940.
b. The bottom material is sand. The depth of the sand layer is 60 feet. Stockless anchors will be used.
c. The water depth at the site is 35 feet mean lower low water (MLLW).
d. The tide range from MLLW to mean higher high water (MHHW) is 6 feet.
e. Wind data for the site are given in Table 23.
f. Currents are due to tides. The maximum flood-current speed, V_c, is 2 knots (θ_c = 15°) and the maximum ebb-current speed, V_c, is 2 knots (θ_c = 195°).

Find: Design the mooring for wind and current loads.

Solution: 1. Determine Vessel Characteristics for DD-940 from DM-26.6, Table 2:

Overall length, L = 418 feet
Waterline length, L_{WL} = 407 feet
Beam (breadth at the loaded waterline), B = 45 feet
Fully loaded draft, T = 16 feet
Light-loaded draft T = 12.5 feet
Fully loaded displacement, D = 4,140 long tons
Light-loaded displacement, D = 2,800 long tons
Fully loaded broadside wind area, A_y = 13,050 square feet
Light-loaded broadside wind area, A_y = 14,450 square feet
Fully loaded frontal wind area, A_x = 2,100 square feet
Light-loaded frontal wind area, A_x = 2,250 square feet

2. Mooring Configuration: single-point mooring

3. Evaluate Environmental Conditions:

a. Seafloor Soil Conditions:

(1) Bottom material is sand.

(2) Soil depth is 60 feet.

(3) Soil material is uniform over mooring area.

b. Design Water Depth:

(1) Water depth at low tide, $wd_{low\ tide}$ = 35 feet

(2) Water depth at high tide $wd_{high\ tide}$ = 35 + 6
= 41 feet

EXAMPLE PROBLEM 1 (Continued)

TABLE 23
Wind Data for Site

Year	Windspeed[1] (miles per hour)							
	N	NE	E	SE	S	SW	W	NW
1950	38.4	41.6	57.6	30.4	48	39.2	28.8	22.4
1951	25.6	33.6	22.4	27.2	32.8	31.2	30.4	24
1952	44.8	32	26.4	36.8	31.2	31.2	32.8	33.6
1953	36	35.2	33.6	25.6	36.8	41.6	25.6	24
1954	28	28	29.6	21.6	36.8	28	35.2	25.6
1955	25.6	36.8	28.8	24.8	24.8	28.8	33.6	25.6
1956	29.6	29.6	30.4	35.2	39.2	28	26.4	28.8
1957	24.8	28	28.8	32	36.8	21.6	27.2	22.4
1958	22.4	31.2	24.8	25.6	23.2	26.4	33.6	25.6
1959	27.2	28.8	21.6	25.6	30.4	29.6	27.2	23.2
1960	28	36.8	32.8	24	26.4	32.8	31.2	27.2
1961	32.8	28	27.2	31.2	26.4	38.4	35.2	25.6
1962	28	33.6	43.2	31.2	22.4	33.6	32	28.8
1963	49.6	41.6	36	32	22.4	24.8	40	41.6
1964	65.6	38.4	62.4	36	38.4	32.8	34.4	30.4
1965	28.8	36	45.6	28.8	31.2	33.6	38.4	36
1966	24	32	38.4	28.8	29.6	31.2	29.6	28
1967	22.4	60.8	28	23.2	24	31.2	27.2	37.6
1968	41.6	32.8	25.6	31.2	26.4	36.8	27.2	25.6
1969	46.4	41.6	24.8	22.4	28	29.6	28	32
1970	28	28	31.2	35.2	31.2	27.2	29.6	28.8
1971	21.6	29.7	19.8	31.5	25.2	39.6	30.6	42.3
1972	22.5	27	35.1	28.8	27.9	34.2	27.9	39.6
1973	24.3	38.7	36.9	24.3	23.4	31.5	43.2	30.6
1974	22.5	31.5	21.6	39.6	30.6	30.6	30.6	30.6
1975	55.8	24.3	21.6	24.3	24.3	48.6	31.5	30.6
1976	23.4	26.1	18	24.3	26.1	36	37.8	37.8
1977	23.4	23.4	19.8	23.4	18.9	27.9	29.7	25.2
1978	22.5	22.5	17.1	21.6	26.1	35.1	30.6	34.2
1979	28.8	31.5	22.5	26.1	24.3	27.9	28.8	28.8

[1] Windspeeds were collected over water at an elevation of 43 feet. Windspeeds are peak-gust values.

EXAMPLE PROBLEM 1 (Continued)

c. Design Wind:

(1) Obtain Wind Data: Wind data obtained for the site are presented in Table 23. Note that directional data are available and directional probability may be determined accurately.

(2) Correct for Elevation:

EQ. (5-1)

$$V_{33.33} = V_h \left(\frac{33.33}{h}\right)^{1/7}$$

$$V_{33.33} = V_{43} \left(\frac{33.33}{43}\right)^{1/7} = 0.964\ V_{43};\ \text{use } 0.96\ V_{43}$$

Therefore, elevation correction factor = 0.96

(3) Correct for Duration: The recorded windspeeds are peak-gust values; reduce the windspeeds by 10 percent to obtain the 30-second windspeeds. Therefore, duration correction factor = 0.90.

(4) Correct for Overland-Overwater Effects: Data were collected over water; therefore, no correction is necessary.

THEREFORE: Total correction factor = (0.9)(0.96) = 0.864

Multiply each value in Table 23 by 0.864 to obtain the 30-second windspeed at 33.33 feet above the water surface. The results are shown in Table 24.

(5) Determine Windspeed Probability:

(a) Determine mean value, $\bar{x}$, and standard deviation, σ, for each windspeed direction:

EQ. (5-4)

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i$$

EQ. (5-5)

$$\sigma = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2$$

These-values are tabulated in Table 24. Note that x and σ can be calculated with most hand-held calculators.

(b) Use Gumbel distribution to determine design windspeed for each direction:

TABLE 24
Adjusted Wind Data for Site

Year	Windspeed (miles per hour)							
	N	NE	E	SE	S	SW	W	NW
1950	33.2	35.9	49.8	26.3	41.5	33.9	24.9	19.4
1951	22.1	29	19.4	23.5	28.3	27	26.3	20.7
1952	38.7	27.7	22.8	31.8	27	27	28.3	29
1953	31.1	30.4	29	22.1	31.8	35.9	22.1	20.7
1954	24.2	24.2	25.6	18.7	31.8	24.2	30.4	22.1
1955	22.1	31.8	24.9	21.4	21.4	24.9	29	22.1
1956	25.6	25.6	26.3	30.4	33.9	24.2	22.8	24.9
1957	21.4	24.2	24.9	27.7	31.8	18.7	23.5	19.4
1958	19.4	27	21.4	22.1	20	22.8	29	22.1
1959	23.5	24.9	18.7	22.1	26.3	25.6	23.5	20
1960	24.2	31.8	28.3	20.7	22.8	28.3	27	23.5
1961	28.3	24.2	23.5	27	22.8	33.2	30.4	22.1
1962	24.2	29	37.3	27	19.4	29	27.7	24.9
1963	42.9	35.9	31.1	27.7	19.4	21.4	34.6	35.9
1964	56.7	33.2	53.9	31.1	33.2	28.3	29.7	26.3
1965	24.9	31.1	39.4	24.9	27	29	33.2	31.1
1966	20.7	27.7	33.2	24.9	25.6	27	25.6	24.2
1967	19.4	52.5	24.2	20	20.7	27	23.5	32.5
1968	35.9	28.3	22.1	27	22.8	31.8	23.5	22.1
1969	40.1	35.9	21.4	19.4	24.2	25.6	24.2	27.6
1970	24.2	24.2	27	30.4	27	23.5	25.6	24.9
1971	18.7	25.7	17.1	27.2	21.8	34.2	26.4	36.5
1972	19.4	23.3	30.3	24.9	24.1	29.6	24.1	34.2
1973	21	33.4	31.9	21	20.2	27.2	37.3	26.4
1974	19.4	27.2	18.7	34.2	26.4	26.4	26.4	26.4
1975	48.2	21	18.7	21	21	42	27.2	26.4
1976	20.2	22.6	15.6	21	22.6	31.1	32.7	32.7
1977	20.2	20.2	17.1	20.2	16.3	24.1	25.7	21.8
1978	19.4	19.4	14.8	18.7	22.6	30.3	26.4	29.5
1979	24.9	27.2	19.4	22.6	21	24.1	24.9	24.9
x	27.14	28.48	26.26	24.57	25.16	27.91	27.2	25.81
σ	9.63	6.32	9.31	4.26	5.48	4.76	3.7	4.91
α	0.133	0.2028	0.138	0.301	0.234	0.2693	0.347	0.261
u	22.8	25.63	22.08	22.65	22.69	25.77	25.5	23.6

(i) Compute Gumbel parameters α and u for each direction:

EQ. (5-7)
$$\alpha = \frac{1.282}{\alpha}$$

EQ. (5-8)
$$u = \bar{x} - \frac{0.577}{\alpha}$$

For example, for north:

$$\alpha = \frac{1.282}{9.63} = 0.133$$

$$u = 27.14 - \frac{0.577}{0.133} = 22.8$$

These values are presented in Table 24 for each direction.

(ii) Compute V_R for 25- and 50-year return periods for each direction. Plot results on Gumbel paper. (Note: So-year return period is used for design.) Use Equation (5-6):

EQ. (5-6)
$$V_R = u - \frac{\text{in}\{-\ \text{in}\ [1 - P(X > X)]\}}{\alpha}$$

For example, for north:

From Table 11, for a return period of 25 years, P(X > X) = 0.04, and, for a return period of 50 years, P(X > X) = 0.02.

THEN :

$$V_{25} = 22.8 - \frac{\text{in}\ [-\ \text{in}\ (1 - 0.04)]}{0.133}$$

$$V_{25} = 22.8 + \frac{3.2}{0.133}$$

$$V_{25} = 46.9 \text{ miles per hour}$$

AND :

$$V_{50} = 22.8 - \frac{\ln\ [-\ \text{in}\ (1 - 0.02)]}{0.133}$$

$$V_{50} = 22.8 + \frac{3.9}{0.133}$$

$$V_{50} = 52.1 \text{ miles per hour}$$

These values, plotted in Figure 85, are presented in Table 25.

d. Design Current: The design currents are due to tides.

(1) Flood current = 2 knots toward 1950 true north (θ_c = 15°)

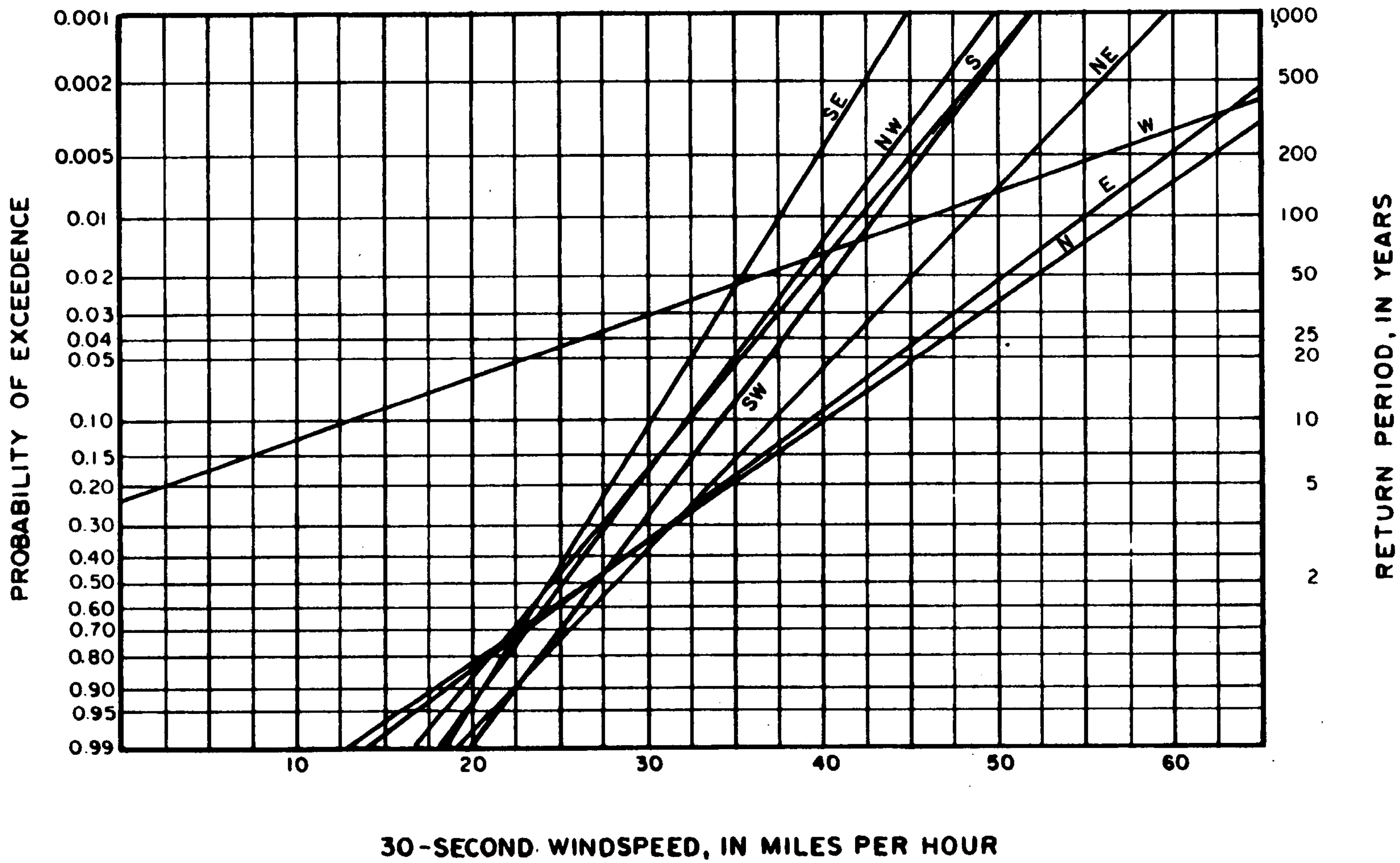


FIGURE 85
Plot of V_R for Each Direction (Example Problem 1)

TABLE 25

V_{25} and V_{50}

Direction	V_{25} (miles per hour)	V_{50} (miles per hour)	V_{50} (feet per second)
N	46.9	52.1	76.4
NE	41.4	44.9	65.8
E	45.3	50.3	73.7
SE	33.3	35.6	52.2
S	36.4	39.4	57.8
SW	37.7	40.2	58.9
W	26.6	36.7	53.8
NW	35.9	38.5	56.4

Note: 1.467 feet per second = 1 mile per hour

(2) Ebb current = 2 knots toward 15° true north (θ_c = 195°)

4. Evaluate Environmental Loads: For the purposes of this example, only the fully loaded case will be analyzed.

a. Wind Load:

(1) Lateral Wind Load: Find F_{yw}:

EQ. (5-11) $$F_{yw} = \frac{1}{2}\rho_a V_w^2 A_y C_{yw} f_{yw}(\theta_w)$$

ρ_a = 0.00237 slugs per cubic foot

A_y = 13,050 square feet

EQ. (5-12) $$C_{yw} = 0.92\left[\left(\frac{V_S}{V_R}\right)^2 A_S + \left(\frac{V_H}{V_R}\right)^2 A_H\right]/A_y$$

EQ. (5-13) $$\frac{V_S}{V_R} = \left(\frac{h_S}{h_R}\right)^{1/7}$$

EQ. (5-14) $$\frac{V_H}{V_R} = \left(\frac{h_H}{h_R}\right)^{1/7}$$

h_R = 33.33 feet

Assume h_S = 35 feet and h_H = 10 feet:

EXAMPLE PROBLEM 1 (Continued)

THEN :
$$\frac{V_S}{V_R} = \left(\frac{35}{33.33}\right)^{1/7} = 1.01$$

AND :
$$\frac{V_H}{V_R} = \left(\frac{10}{33.33}\right)^{1/7} = 0.84$$

Assume:

$A_S = 0.45\ A_y = (0.45)(13,050) = 5,873$ square feet

$A_H = 0.55\ A_y = (0.55)(13,050) = 7,177$ square feet

THEN :
$$C_{yw} = \frac{0.92\ [(1.01)^2(5,873) + (0.84)^2(7,177)]}{13,050}$$

$$C_{yw} = 0.78$$

AND :
$$F_{yw} = \frac{1}{2}\ (0.00237)\ V_w^2\ (13,050)\ (0.78)\ f_{yw}(\theta_w)$$

EQ. (5-15)
$$f_{yw}(\theta_w) = \frac{+\left(\sin\theta_w - \frac{\sin 5\theta_w}{20}\right)}{1 - \frac{1}{20}}$$

THEREFORE :
$$F_{yw} = 12.06\ V_w^2\ f_{yw}(\theta_w) \qquad (6\text{-}1)$$

This equation is used to determine F_{Yw} for V_w and θ_w in evaluating loads on mooring elements

(2) Longitudinal Wind Load. Find F_{xw}:

EQ. (5-16)
$$F_{xw} = \frac{1}{2}\rho_a\ V_w^2\ A_x\ C_{xw}\ f_{xw}(\theta_w)$$

$\rho_a = 0.00237$ slugs per cubic foot

Ax = 2,100 feet

EQ. (5-19) For destroyers, $C_{xwB} = 0.70$

EQ. (5-22) $C_{XWS} = 0.80$

For vessels with distributed superstructures:

EQ. (5-26)
$$f_{xw}(\theta_w) = \frac{-\left(\sin\gamma - \frac{\sin 5\gamma}{10}\right)}{1 - \frac{1}{10}}$$

EQ. (5-27) $\gamma_{(-)} = \left(\frac{90°}{\theta}\right)\theta + 90°$ for $\theta < \theta$

[redacted]

EQ. (5-28) $$\gamma_{(+)} = \left(\frac{90°}{180° - \theta_{wz}}\right)\theta_w + \left(180° - \frac{90°\ \theta_{wz}}{180° - \theta_{wz}}\right)$$
for $\theta_w > \theta_{wz}$

For warships, $\theta_{wz} \sim 110$ degrees:

THEN : $$\gamma_{(-)} = \left(\frac{90°}{110°}\right)\theta_w + 90° = 0.82\ \theta_w + 90°$$

AND : $$\gamma_{(+)} = \left(\frac{90°}{180° - 110°}\right)\theta_w + 180° - \frac{(90°)(110°)}{180° - 110°}$$
$$= 1.29\ \theta_w + 38.6$$

THEN : $$F_{xw} = \frac{1}{2}\ (0.00237)\ V_w^2\ (2{,}100)\ C_{xw}\ f_{xw}(\theta_w)$$

THEREFORE: $$F_{xw} = 2.49\ V_w^2\ C_{xw}\ f_{xw}(\theta_w) \qquad (6\text{-}2)$$

This equation is used to determine F_{xw} for V_w, C_{xw} (C_{xwB} or C_{xwS}), and θ_w in evaluating loads on mooring elements.

(3) Wind Yaw Moment. Find M_{xyw}:

EQ. (5-29) $$M_{xyw} = \frac{1}{2}\rho_a\ V_w^2\ A_y\ L\ C_{xyw}(\theta_w)$$

ρ_a = 0.00237 slugs per (

A_y = 13,050 square feet

L = 418 feet

$C_{xyw}(\theta_w)$ is found in Figure 55.

THEN : $$M_{xyw} = \frac{1}{2}(0.00237)\ V_w^2\ (13{,}050)\ (418)\ C_{xyw}(\theta_w)$$

THEREFORE : $$M_{xyw} = 6{,}464\ V_w^2\ C_{xyw}(\theta_w) \qquad (6\text{-}3)$$

This equation is used to determine M_{xyw} for V_w and θ_w in evaluating loads on mooring elements.

b. Current Load:

(1) Lateral Current Load. Find F_{yc}:

EQ. (5-35)

$$F_{yc} = \frac{1}{2} \rho_w V_c^2 L_{wL} T C_{yc} \sin\theta_c$$

ρ_w = 2 slugs per cubic foot

$V_c = (2 \text{ knots})\left(\frac{1.69 \text{ feet per second}}{\text{knot}}\right)$

= 3.38 feet per second

L_{wL} = 407 feet

T = 16 feet (fully loaded)

EQ. (5-36)

$$C_{yc} = C_{yc}\Big|_{\infty} + \left(C_{yc}\Big|_1 - C_{yc}\Big|_{\infty}\right) e^{-k\left(\frac{wd}{T} - 1\right)}$$

Find $C_{yc}\big|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

EQ. (5-37)

$$\phi = \frac{35 \quad D}{L_{wL} \quad B \quad T}$$

D = 4,140 long tons

B = 45 feet

$$\phi = \frac{(35)(4,140)}{(407)(45)(16)} = 0.49$$

$L_{wL}/B = 407/45 = 9.04$

THEN :

$C_{yc}\big|_{\infty} = 0.4$

Find $C_{yc|1}$ from Figure 57 for $C_p \; L_{wL}/\sqrt{T}$:

From Table 14, use $C_p = 0.539$ for DP-692:

$C_p \; L_{wL}/\sqrt{T} = (0.539)(407)/\sqrt{16} = 54.8$

THEN :

$C_{yc}\big|_1 = 3.3$

Find k from Figure 58 for ϕ = 0.49 for a ship-shaped hull:

k = 0.75

wd = 35 feet

For fully loaded condition:

EXAMPLE PROBLEM 1 (Continued)

$$\frac{wd}{T} = \frac{35}{16} = 2.19$$

THEN :

$$C_c = 0.4 + (3.3 - 0.4)\, e^{-(0.75)(2.19 - 1)}$$

$$C_{yc} = 1.59$$

TEEN :

$$F_{yc} = \frac{1}{2}(2)(3.38)^2(407)(16)(1.59) \sin \theta_c$$

THEREFORE :

$$F_{yc} = 118{,}289 \sin \theta_c \qquad (6\text{-}4)$$

This equation is used to determine F_{yc} for θ_c in evaluating loads on mooring elements.

(2) Longitudinal Current Load. Find F_{xc}:

EQ. (5-40)

$$F_{xc} = F_{x\ form} + F_{x\ friction} + F_{x\ prop}$$

EQ. (5-41)

$$F_{x\ form} = -\frac{1}{2}\rho_w V_c^2\, B\, T\, C_{xcb} \cos\theta_c$$

ρ_w = 2 slugs per cubic foot

V_c = 3.38 feet per second

B = 45 feet

T = 16 feet

$C_{xcb} = 0.1$

THEN:

$$F_{x\ form} = -\frac{1}{2}(2)(3.38)^2(45)(16)(0.1) \cos \theta_c$$

$$F_{x\ form} = -822.6 \cos \theta_c$$

EQ. (5-42)

$$F_{x\ friction} = -\frac{1}{2}\rho_w V_c^2\, C_{xca}\, S \cos\theta_c$$

ρ_w = 2 slugs per cubic foot

V_c = 3.38 feet per second

EQ. (5-44)

$$C_{xca} = 0.075/(\log R_n - 2)^2$$

EQ. (5-45)

$$R_n = V_c L_{wL} \cos\theta_c / \nu$$

L_{WL} = 407 feet

$\nu = 1.4 \times 10^{-5}$ square feet per second

THEN :

$$R_n = (3.38)(407) \cos \theta_c / (1.4 \times 10^{-5})$$

EXAMPLE PROBLEM 1 (Continued)

$$R_n = 9.8261 \times 10^7 \cos\theta_c$$

THEN :

$$C_{xca} = \frac{0.075}{[\log(9.826 \times 10^7 \cos\theta_c) - 2]^2}$$

EQ. (5-43) $S = (107\ TL_{WL}) + (35\ D/T)$

$D = 4{,}140$ long tons

THEN : $S = [(1.7)(16)(407)] + [\frac{(35)(4{,}140)}{16}]$

$= 20{,}127$ square feet

THEN :

$$F_{x\ friction} = -\frac{1}{2}(2)(3.38)^2 \left\{\frac{0.075}{[\log(9.8261 \times 10^7 \cos\theta_c) - 2]^2}\right\}(20{,}127)\cos\theta_c$$

$$F_{x\ friction} = -\frac{17{,}246\cos\theta_c}{[\log(9.8261 \times 10^7 \cos\theta_c) - 2]^2}$$

EQ. (5-46) $F_{x\ prop} = -\frac{1}{2}\rho_w V_c^2 A_p C_{prop} \cos\theta_c$

$\rho_w = 2$ slugs per cubic foot

$V_c = 3.38$ feet per second

EQ. (5-47) $A_p = \frac{A_{Tpp}}{0.838}$

EQ. (5-48) $A_{TPP} = \frac{L_{WL}\ B}{A_R}$

From Table 15 for destroyers, $A_R = 100$:

TEEN : $A_{TPP} = \frac{(407)(45)}{100} = 183$ square feet

THEN : $A_p = \frac{183}{0.838}\ 218$ square feet

$C_{prop} = 1$

THEN : $F_{x\ prop} = -\frac{1}{2}(2)(3.38)^2(218)(1)\cos\theta_c$

$F_{x\ prop} = -2{,}490.5\cos\theta_c$

EXAMPLE PROBLEM 1 (Continued)

THEN :

$$F_{xc} = - 822.6 \cos \theta_c - \frac{17{,}246 \cos \theta_c}{[\log (9.8261 \times 10^7 \cos \theta_c) - 2]^2} - 2{,}490.5 \cos \theta_c)$$

THEREFORE :

$$F_{xc} = - \cos \theta_c \{822.6 + \frac{17{,}246}{[\log (9.8261 \times 10^7 \cos \theta_c) - 2]^2} + 2{,}490.5\} \quad (6\text{-}5)$$

This equation is used to determine F_{xc} for θ_c in evalu-sting loads on mooring elements.

(3) Current Yaw Moment. Find M_{xyc}:

EQ. (5-49)

$$M_{xyc} = F_{yc} \left(\frac{e_c}{L_{wL}}\right) L_{wL}$$

$\left(\frac{e_c}{L_{wL}}\right)$ is found in Figure 59 as a function of θ_c and vessel type:

THEREFORE :

$$M_{xyc} = F_{yc} \left(\frac{e_c}{L_{wL}}\right) (405) \quad (6\text{-}6)$$

This equation is used to determine M_{xyc} for θ_c in evaluat-ing loads on mooring elements.

5. Evaluate Loads on Mooring Elements: Directions and velocities for wind and currents are summarized in Table 26.

The maximum single-point mooring loads were determined for the eight loading conditions designated in Table 27, using the pro-cedures outlined in Figure 65. An example of the maximum load for θ_{wc} = 165 degrees is given below.

For example, for θ_{wc} = 165° and ebb current: V_w = 76.4 feet per second and V_c = 3.38 feet per second

a. First Try:

Note: the procedure for determining the maximum horizontal load does nut require computation of F_{xT} until the equilibrium θ_c has been determined.

(1) From Figure 65, $\theta_{cl} = \theta_{cw}/2 = 165°/2 = 82.5°$

EXAMPLE PROBLEM 1 (Continued)

TABLE 26
Wind and Current Values
Used to Determine Mooring Loads

Direction	Flood Current		Ebb Current	
	θ_{wc} (degrees)	V_w (feet per second)	θ_{wc} (degrees)	Vc (feet per second)
N	15*	76.4	165*	3.38
NE	30*	65.8	150*	3.38
E	75*	73.7	105*	3.38
SE	120	52.2	60	3.38
S	165	57.8	15	3.38
SW	150	58.9	30	3.38
W	105	53.8	75	3.38
NW	60*	56.4	120*	3.38

Note: All θ angles are defined between O and 180 degrees. This eases computations and avoids repeating unnecessary calculations. In the above table, there are only eight unique θ_{wc} angles among 16 loading conditions; therefore, those with the highest V are chosen for analysis. These are marked with an asterisk:

TABLE 27
Maximum Single-Point Mooring Load

θ_{wc} (degrees)	θ_c, relative to vessel bow (degrees)	H, horizontal load (pounds)
15	3.75	14,747
30	8.75	11,732
60	12.5	10,824
75	22	18,582
105	37.5	11,298
120	23	8,819
150	37.5	20,359
165	50	21,396

EXAMPLE PROBLEM 1 (Continued)

THEN : $\theta_{wl} = \theta_{cl} - (\theta_{wc} = 82.5° - 165° = -82.5°$

(a) Using Equation (6-l), calculate F_{yw} (use $\theta_w = \theta_{W1} = -82.50$):

$$F_{yw} = 12.06\ V_w^2\ f_{yw}(\theta_w)$$

$$f_{yw}(\theta_w) = \frac{\sin(-82.5) - \frac{\sin(5)(-82.5)}{20}}{1 - \frac{1}{20}}$$

$$f_{yw}(\theta_w) = -1.00$$

$$F_{Yw} = (12.06)(76.4)2(-1.00) = -70{,}525.4 \text{ pounds}$$

(b) Using Equation (6-4), calculate F_{yc} (use $\theta_c = \theta_{cl} = 82.5°$):

$$F_{yc} = 118{,}289 \sin\theta_c$$

$$F_{yc} = 118{,}289 \sin(82.5) = 117{,}277.0 \text{ pounds}$$

(c) Calculate F_{yT}:

EQ. (5-63) $$F_{yT} = F_{yw} + F_{yc}$$

$$F_{yT} = -70{,}525.4 + 117{,}277.0 = 46{,}751.6 \text{ pounds}$$

(d) Using Equation (6-3), calculate M_{xyw} (use $\theta_w = \theta_{W1} = -82.50$):

$$M_{xyw} = 6{,}464\ V_W^2\ C_{xyw}(\theta_w)$$

From Figure 55 for $\theta_w = -82.5°$, $C_{xyw}(\theta_w)$-0.075

$$M_{xyw} = (6{,}464)(76.4)^2(-0.075) = -2.8298 \times 10^6 \text{ foot-pounds}$$

(e) Using Equation (6-6), calculate M_{xyc}:

$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{wL}}\right)(405)$$

From Figure 59 for $\theta_c = \theta_{cl} = 82.5°$:

$$\left(\frac{e_c}{L_{wL}}\right) = 0.055$$

M_{xyc} = (117,277)(0.005) (405)
= 2.6123×10^6 foot-pounds

(f) Calculate M_{xyT}:

EQ. (5-64) $M_{xyT} - M_{xyw} + M_{xyc}$

$M_{xyT} = (-2.8298 \times 10^6) + (2.6123 \times 10^6)$

$M_{xyT} = -2.175 \times 10^5$ foot-pounds

EQ. (5-65) (2) $\Sigma M = M_{xyw} + M_{xyc} - F_{yT}$ ARM

EQ. (5-64) $M_{xyw} + M_{xyc} = M_{xyT} = -2.175 \times 10^5$ foot-pounds

ARM= 0.48 LOA -

ARM= (0.48)(418)

SUBSTITUTING: $\Sigma M_1 = (-2.175 \times 10^5) - (46{,}751.6)(0.48)(418)$
$= -9.5977 \times 10^6$ foot-pounds

Plot ΣM_1 versus θ_{c1} on Figure 86 for $\theta_{c1} = 82.5°$

b. Second Try:

(1) From Figure 65, $\theta_{c2} = 0°$

THEN : $\theta_{W2} = \theta_{c2}\ \theta_{wc} = 0° - 165° = -165°$

(a) $$f_{yw}(\theta w) = \frac{\sin(-165) - \dfrac{\sin(5)(-165)}{20}}{1 = \dfrac{1}{20}} = -0.2216$$

$F_{yw} = (12.06)(76.4)2(-0.2216) = -15{,}599$ pounds

(b) $F_{yc} = 0$

(c) $F_{YT} = -15{,}599$ pounds

(d) From Figure 55 for $\theta_w = -165°$, $C_{xyw}(\theta w) = 0.015$

$M_{xyw} = (6{,}464)(76.4)^2(0.015)$
$= 5.6595 \times 10^5$ foot-pounds

(e) $M_{xyc} = 0$

(f) $M_{xyT} = 5.6595 \times 10^5$ foot-pounds

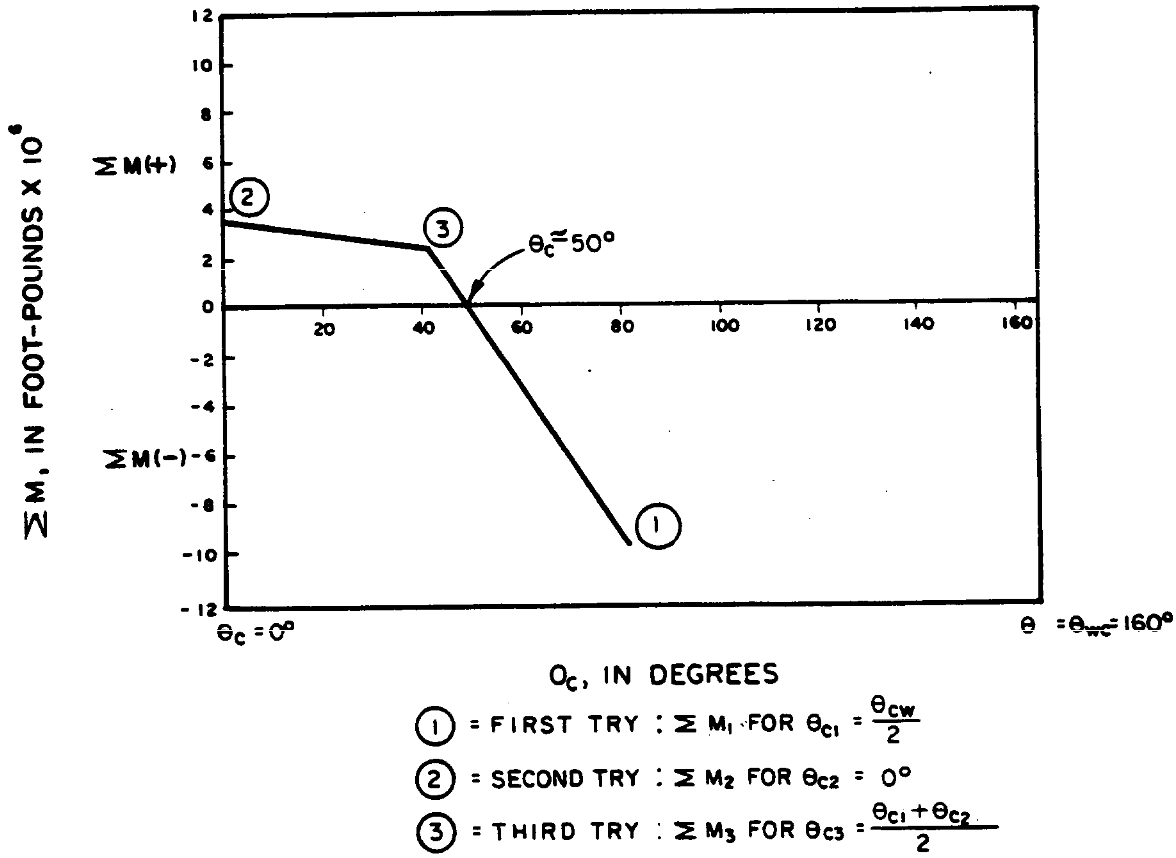


FIGURE 86
ΣM Versus θ_c (Example Problem 1)

(2) $\Sigma M_2 = (5.6595 \times 10^5) - (-15{,}599)(0.48)(418)$
$= 3.6957 \times 10^6$ foot-pounds

Plot ΣM_2 versus θ_{c2} on Figure 86 for $\theta_{c2} = 0°$

c. Third Try:

(1) ΣM_1 and ΣM_2 did change sign; therefore, from Figure 65:

$$\theta_{C3} = \frac{\theta_{cl} + \theta_{c2}}{2} = \frac{82.5° + 0°}{2} = 41.25°$$

THEN : $\theta_w = \theta_c - \theta)_{wc} = 41.25° - 165° = -123.75°$

EXAMPLE PROBLEM 1 (Continued)

$$(a)\quad f_{yw}(\theta_w) = \frac{\sin(-123.75) - \dfrac{\sin(5)(-123.75)}{20}}{1 - \dfrac{1}{20}}$$

$$= 0.9269$$

$$F_{yw} = (12.06)(76.4)^2(-0.9269) = -65{,}244 \text{ pounds}$$

(b) $F_{yc} = 118{,}289 \sin(41.25) = 77{,}993$ pounds

(c) $F_{YT} = -65{,}244 + 77{,}993 = 12{,}749$ pounds

(d) From Figure 55 for $\theta_w = -123.75°$,
$C_{xyw}(\theta_w) = 0.0145$

$$M_{xyw} = (6{,}464)(76.4)^2(0.0145)$$
$$= 5.4709 \times 10^5 \text{ foot-pounds}$$

(e) From Figure 59 for $\theta_c = 41.25°$, $\left(\dfrac{e_c}{L_{wL}}\right) = 0.14$

$$M_{xyc} = (77{,}993)(0.14)(405) = 4.4222 \times 10^6 \text{ foot-pounds}$$

(f) $M_{xyT} = (5.4709 \times 10^5) + (4.4222 \times 10^6)$
$= 4.9693 \times 10^6$ foot-pounds

(2) $\Sigma M_3 = (4.9693 \times 10^6) - (12{,}749)(0.48)(418)$
$= 2.4113 \times 10^6$ foot-pounds

Plot ΣM_3 versus θ_{c3} on Figure 86 for $\theta_{c3} = 41.25°$

For this example, further iteration does not significantly improve the estimate of θ. The equilibrium θ_c is approximated, as shown on Figure 86, as $\theta_c \sim 500$

TEEN : $\theta_w = \theta_C - \theta_{WC} = 50° - 165° = -115°$

d. Calculate loads for $\theta_c = 50°$ and $\theta_w = -115°$

$$(1)\quad f_{yw}(\theta_w) = \frac{\sin(-115) - \dfrac{\sin(5)(-115)}{20}}{1 - \dfrac{1}{20}} = -0.984196$$

$$F_{yw} = (12.06)(76.4)^2(-0.984196) = -69{,}281.2 \text{ pounds}$$

(2) $F_{yc} = 118{,}289 \sin(50) = 90{,}614.8$ pounds

EXAMPLE PROBLEM 1 (Continued)

(3) $F_{yT} = -69{,}281.2 + 90{,}614.8 = 21{,}333.6$ pounds

(4) Using Equation (6-2), calculate F_{xw}:

(Calculate F_{xw} for $\theta_w = +115°$ because F_{xw} is symmetrical about vessel bow.)

$$F_{XW} = 2.49\, V_W^2\, C_{xwB} \text{ or } {}_{xwS}\, f_{xw}(\theta_w)$$

$$f_{xw}(\theta_w) = \frac{-\left(\sin\gamma - \frac{\sin 5\gamma}{10}\right)}{1 - \frac{1}{10}}$$

$$\gamma = (1.29)(115) + 38.6 = 186.95$$

$$f_{xw}(\theta_w) = \frac{-\left[\sin(186.95) - \frac{\sin(5)(186.95)}{10}\right]}{1 - \frac{1}{2}} = 0.071115$$

$$F_{xw} = (2.49)(76.4)^2(0.8)(0.071115) = 826.9 \text{ pounds}$$

(5) Using Equation (6-5), calculate F_{xc}:

$$F_{XC} = -\cos\theta_c \left\{ 822.6 + \frac{17{,}246}{[\log(9.8261 \times 10^7 \cos\theta_c) - 2]^2} + 2{,}490.5 \right\}$$

$$F_{XC} = -\cos(50) \left\{ 822.6 + \frac{17{,}246}{\{\log\ [9.8261 \times 10^7 \cos(50)] - 2\}^2} + 2{,}490.5 \right\}$$

$$F_{XC} = -2{,}459.1 \text{ pounds}$$

(6) Calculate F_{xT}:

EQ. (5-62) $$F_{XT} = F_{XW} + F_{XC}$$

$$F_{XT} = 826.9 + (-2{,}459.1) = -1{,}632.2 \text{ pounds}$$

(7) Calculate H:

$$H = \sqrt{F_{xT}^2 + F_{yT}^2}$$

EQ. (5-66) $$H = \sqrt{(-1{,}632.2)^2 + (21{,}333.6)^2}$$

H = 21,396 pounds

H = 21,396 pounds

EXAMPLE PROBLEM 1 (Continued)

6. Design of Mooring Components.

a. Select Chain and Fittings:

(1) Approximate Chain Tension: Find T, using the maximum value of H from Table 27:

EQ. (5-78) $T = 1.12\ H$

$T = (1.12)(21{,}396) = 23{,}963.5$ pounds

(2) Maximum Allowable Working Load: Find T_{design}:

EQ. (5-79) $T_{design} = 0.35\ T_{break}$

$23{,}963.5 = 0.35\ T_{break}$

$T_{break} = 23{,}963.5/0.35 = 68{,}467.2$ pounds

(3) Select Chain: From Table 95 of DM-26.6, use l-inch chain with a breaking strength of 84,500 pounds.

(4) Chain Weight: Find $w_{submerged}$:

EQ. (5-82) $w_{submerged} = 8.26\ d^2 = 8.26$ pounds per foot of length

b. Compute Chain Length and Tension:

(1) Given:

(a) wd = 41 feet at high tide

(b) $\theta_a = 2°$

(c) H = 21,396 pounds

(d) $w_{submerged} = 8.26$ pounds per foot

This is Case II (Figure 73).

(2) Following the flow chart on Figure 73:

(a) $\theta_a \neq 0$

(b) $V_a = H \tan \theta_a$

$V_a = 21{,}396 \tan(2°) = 747.2$

(c) $S_a = V_a/w$

$S_a = 747.2/8.26 = 90.46$ feet

(d) $c = H/w = 21{,}396/8.26 = 2{,}590.3$ feet

(e) $y_a = \sqrt{S_a^2 + c^2}$

$y_a = \sqrt{(90.46)^2 + (2{,}590.3)^2} = 2{,}591.9$ feet

(f) $y_b = y_a + w\,d$

$Y_b = 2{,}591.9 + 41 = 2{,}632.9$ feet

(g) $S_b = \sqrt{y_b^2 - c^2}$

$S_b = \sqrt{(2{,}632.9)^2 - (2{,}590.3)^2} = 471.7$ feet

(h) $S_{ab} = S_b - S_a$

$S_{ab} = 471.7 - 90.46 = 381.25$ feet

Determine number of shots:

381.25 feet/90 feet = 4.24; use 4.5shots

(i) $T_b = W\,y_b$

$T_b = (8.26)(2{,}632.9) = 21{,}747.8$

(j) $x_{ab} = c \ln \left[\frac{S_{ab}}{c} + \sqrt{\left(\frac{S_{ab}}{c}\right)^2 + 1} \right]$

$x_{ab} = (2{,}590.3) \ln \left[\frac{381.25}{2{,}590.3} + \sqrt{\left(\frac{381.25}{2{,}590.3}\right)^2 + 1} \right]$

c. Anchor Selection: Following the flow chart on Figure 77:

(1) Required holding capacity = 21,396 pounds

(2) Seafloor type is sand (given)

Depth of sand = 60 feet (given)

EXAMPLE PROBLEM 1 (Continued)

(3) Anchor type is Stockless (given); flukes limited . (set) to 35°. From Table 18, safe efficiency = 4

Holding capacity = efficiency x weight

21,396 = (4)(weight)

Weight = 21,396/4 = 5,349 pounds = 5.3 kips

THEREFORE : Use 6,000-pound (6-kip) Stockless anchor

(4) Required sediment depth: From Figure 80, the maximum fluke-tip depth is 5.5 feet. Therefore, the sediment depth (60 feet) is adequate.

(5) Drag distance: From Figure 81, the normalized anchor drag distance is:

$$D = 4.3 L$$

Calculate fluke length, L, using the equation from Figure 82 for determining L for Stockless anchors:

$$L = 4.81 \left(\frac{W}{5}\right)^{1/3}$$

Use calculated anchor weight, W, in kips:

W= 5.3 kips

SUBSTITUTING: $L = (4.81)\left(\frac{5.3}{5}\right)^{1/3} = 4.9$ feet

TEEN : D = (4.3)(4.9) = 21.1 feet<50 feet; ok

Therefore, the drag distance is acceptable (maximum is 50 feet).

EXAMPLE PROBLEM 2: BOW-AND-STERN MOORING

Given:
a. Bow-and-stem mooring for a DD-940.
b. The bottom material is mud. The depth of the mud layer is 40 feet. Stato anchors will be used (θ_a = 2 degrees).
c. The water depth at the site is 35 feet mean lower low water (MLLW) .
d. The tide range from MLLW to mean higher high water (MHHW) is 6 feet.
e. Wind data are the same as those given in Example Problem 1. (See Table 23.)
f. Currents are due to tides. The maximum flood-current speed, V_c, is 2 knots (θ_c = 15°) and the maximum ebb-current speed, V_c is 2 knots (θ_c = 195°).

Find: Design the mooring for wind and current loads.

Solution: 1. Determine Vessel Characteristics for DD-940 from DM-26.6, Table 2:

Overall length, L = 418 feet
Waterline length, L_{WL} = 407 feet
Beam (breadth at the loaded waterline), B = 45 feet
Fully loaded draft, T = 16 feet
Light-loaded draft, T = 12.5 feet
Fully loaded displacement, D = 4,140 long tons
Light-loaded displacement, D = 2,800 long tons
Fully loaded broadside wind area, A_y = 13,050 square feet
Light-loaded broadside wind area, A_y = 14,450 square feet
Fully loaded frontal wind area, A_x = 2,100 square feet
Light-loaded frontal wind area, A_x = 2,250 square feet

2. Mooring Configuration: bow-and-stern mooring

3* Evaluate Environmental Conditions:

a. Seafloor Soil Conditions:

(1) Bottom material is mud.

(2) Soil depth is 60 feet.

(3) Soil material is uniform over mooring area.

b. Design Water Depth:

(1) Water depth at low tide, $wd_{low\ tide}$ = 35 feet

(2) Water depth at high tide $wd_{high\ tide}$ = 41 feet

c. Design Wind: Design wind, taken from Example Problem 1, is given in Table 28:

EXAMPLE PROBLEM 2 (Continued)

TABLE 28
Design Wind

Direction	V_{50} (miles per hour)	V_{50} (feet per second)
N	52.1	76.4
NE	44.9	65.8
E	50.3	73.7
SE	35.6	52.2
S	39.4	57.8
SW	40.2	58.9
W	36.7	53.8
NW	38.5	56.4

d. Design Current: The design currents are due to tides.

(1) Flood current: 2 knots toward 105° true north (θ_c = 15°)

(2) Ebb current: 2 knots toward 285° true north (θ_c = 195°)

e. A summary of design wind and current conditions is shown in Figure 87.

4. Evaluate Environmental Loads:

a. Wind Load:

(1) Lateral Wind Load: Find F_{yw}:

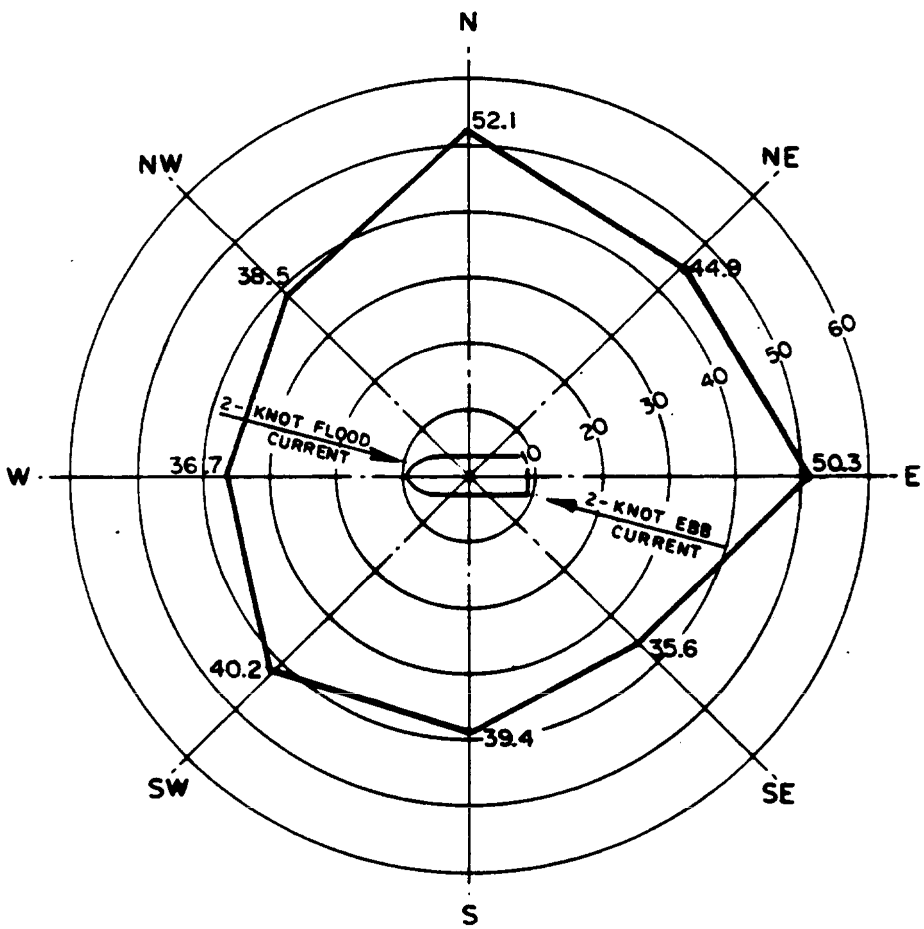
EQ. (5-11)
$$F_{yw} = \frac{1}{2} \rho_a V_w^2 A_y C_{yw} f_{yw}(\theta_w)$$

$$\rho_a = 0.00237 \text{ slugs per cubic foot}$$

EQ. (5-12)
$$C_{yw} = 0.92 \left[\left(\frac{V_S}{V_R} \right)^2 A_S + \left(\frac{V_H}{V_R} \right)^2 A_H \right] / A_y$$

EQ. (5-13)
$$\frac{V_S}{V_R} = \left(\frac{h_S}{h_R} \right)^{1/7}$$

EQ. (5-14)
$$\frac{V_H}{V_R} = \left(\frac{h_H}{h_R} \right)^{1/7}$$



NOTE: WIND VELOCITIES ARE IN MILES PER HOUR

FIGURE 87
Summary of Design Wind and Current Conditions (Example Problem 2)

EXAMPLE PROBLEM 2 (Continued)

$h_R = 33.33$ feet

EQ. (5-15)

$$f_{yw}(\theta_w) = \frac{+\left(\sin\theta_w - \frac{\sin 5\theta_w}{20}\right)}{1 - \frac{1}{20}}$$

(a) Light-Loaded Condition: Find F_{yw} for the light-loaded condition:

Assume $h_S = 40$ feet and $h_H = 15$ feet:

THEN :

$$\frac{V_S}{V_R} = \left(\frac{40}{33.33}\right)^{1/7} = 1.03$$

AND :

$$\frac{V_H}{V_R} = \left(\frac{15}{33.33}\right)^{1/7} = 0.89$$

$A_Y = 14{,}450$ square feet

Assume:

$A_S = 0.40\ A_y = (0.4)(14{,}450) = 5{,}780$ square feet

$A_H = 0.60\ A_y = (0.6)(14{,}450) = 8{,}670$ square feet

THEN :

$$C_{yw} = \frac{0.92\ [(1.03)^2(5{,}780) + (0.89)^2(8{,}670)]}{14{,}450}$$

$C_{yw} = 0.83$

AND :

$$F_{yw} = \frac{1}{2}\ (0.00237)\ V_w^2\ (14{,}450)(0.83)\ f_{yw}(\theta_w)$$

$F_{yw} = 14.21\ V_w^2 f_{yw}(\theta_w)$

This equation is used to determine F_{yw} for V_w and θ_w for the light-loaded condition. Results are given in Table 29.

(b) Fully Loaded Condition: Find F_{yw} for the fully loaded condition:

Assume $h_S = 35$ feet and $h_H = 10$ feet:

$$\frac{V_S}{V_R} = \left(\frac{35}{33.33}\right)^{1/7} = 1.01$$

EXAMPLE PROBLEM 2 (Continued)

TABLE 29
Lateral Wind Load: Light-Loaded Condition

Direction	(degrees)	(feet per second)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
W	0	53.8	0	0
NW	45	56.4	0.782	35,348
N	90	76.4	1	82,943
NE	135	65.8	0.782	48,112
E	180	73.7	0	0
SE	225	52.2	-0.782	-30,279
S	270	57.8	-1	-47,473
SW	315	58.9	-0.782	-38,551

$$\frac{V_H}{V_R} = \left(\frac{10}{33.33}\right)^{1/7} = 0.84$$

$A_y = 13,050$ square feet

From step (a), $A_s = 5,780$ square feet

$A_H = A_y - A_s = 13,050 - 5,780 = 7,270$ square feet

THEN :

$$c_{yw} = \frac{0.92\ [(1.01)^2(5,780) + (0.84)^2(7,270)]}{13,050}$$

$$c_{yw} = 0.78$$

AND :

$$F_{yw} = \frac{1}{2}\ (0.00237)\ V_w^2\ (13,050)(0.78)\ f_{yw}(\theta_w)$$

$$F_{yw} = 12.06\ V_w^2\ f_{yw}(\theta w)$$

This equation is used to determine F_{yw} for V_w and θ_w for the fully loaded condition. Results are given in Table 30.

(2) Longitudinal Wind Load: Find F_{xw}:

EQ. (5-16) $$F_{xw} = \frac{1}{2} \rho_a V_w^2 A_x C_{xw} f_{xw}(\theta_w)$$

ρ_a = 0.00237 slugs per cubic foot

EQ. (5-19) For destroyers, $C_{xwB} = 0.70$

EQ. (5-22) $c_{xwS} = 0.80$

EXAMPLE PROBLEM 2 (Continued)

TABLE 30
Lateral Wind Load: Fully Loaded Condition

Direction	θ_w (degrees)	V_w (feet per second)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
W	0	53.8	0	0
NW	45	56.4	0.782	29,999
N	90	76.4	1	70,394
NE	135	65.8	0.782	40,832
E	180	73*7	0	0
SE	225	52.2	-0.782	-25,698
S	270	57.8	-1	-40,291
SW	315	58.9	-0.782	-32,718

For vessels with distributed superstructures:

EQ. (5-26)

$$f_{xw}(\theta_w) = \frac{-\left(\sin\gamma - \frac{\sin 5\gamma}{10}\right)}{1 - \frac{1}{10}}$$

EQ. (5-27)

$$\gamma_{(-)} = \left(\frac{90°}{\theta_{wz}}\right)\theta_w + 90° \text{ for } \theta_w < \theta_{wz}$$

EQ. (5-28)

$$\gamma_{(+)} = \left(\frac{90°}{180° - \theta_{wz}}\right)\theta_w + \left(180° - \frac{90°\ \theta_{wz}}{180° - \theta_{wz}}\right)$$

for $\theta_w > \theta_{wz}$

For warships, $\theta_{wz} \sim 110$ degrees:

THEN :

$$\gamma_{(+)} = \left(\frac{90°}{110°}\right)\theta_w + 90° = 0.82\ \theta_w + 90°$$

AND :

$$\gamma_{(-)} = \left(\frac{90°}{180° - 110°}\right)\theta_w + 180° - \frac{(90°)(110°)}{180° - 110°}$$

$$= 1.29\ \theta_w + 38.6$$

(a) Light-Loaded Condition: Find F_{xw} for the light-loaded condition:

$A_x = 2,250$ square feet

THEN :

$$F_{xw} = \frac{1}{2}(0.00237)\ V_w^2\ (2,250)\ C_{xw}\ f_{xw}(\theta w)$$

$$F_{xw} = 2.67\ V_w^2 C_{xw} f_{xw}(\theta_w)$$

This equation is used to determine F_{xw} for V_w, C_{xw}(C_{xwB} or C_{xwS}), and θ_w for the light loaded condition. Results are given in Table 31.

TABLE 31
Longitudinal Wind Load: Light-Loaded Condition

Direction	θ_w (degrees)	V_w (feet per second)	C_x	$f_{xw}(\theta_w)$	F_{xw} (pounds)
W	0	53.8	0.7	-1	-5,410
NW	45	56.4	0.7	-0.999	-5,939
N	90	76.4	0.7	-0.2	-2,182
NE	135	65.8	0.8	0.57	5,271
E	180	73.7	0.8	1	11,602
SE	225	52.2	0.8	0.57*	3,318
S	270	57.8	0.7	-0.2*	-1,249
SW	315	58.9	0.7	-0.999*	-6,478

*$f_{xw}(\theta w)$ is symmetrical about the longitudinal axis of the vessel

(b) Fully Loaded Condition: Find F_{XW} for the fully loaded condition:

Ax = 2,100 square feet

THEN:.

$$F_{XW} = \frac{1}{2}(0.00237)\ V_w^2\ (2,100)\ C_{xw} f_{xw}(\theta_w)$$

$$F_{xw} = 2.49\ V_w^2 C_{xw} f_{xw}(\theta_w)$$

This equation is used to determine F_{xw} for V_w, C (C or C), and for the fully loaded condition. Results are given in Table 32.

(3) Wind Yaw Moment: Find M_{xyw}:

EQ. (5-29)

$$M_{xyw} = \frac{1}{2} \rho_a V_w^2 A_y L C_{xyw}(\theta_w)$$

ρ_a = 0.00237 slugs per cubic foot

L = 418 feet

EXAMPLE PROBLEM 2 (Continued)

TABLE 32
Longitudinal Wind Load: Fully Loaded Condition

Direction	θ_w (degrees)	V_w (feet per second)	C_x	$f_{xw}(\theta w)$	F_{xw} (pounds)
W	0	53.8	0.7	-1	-5,045
NW	45	56.4	0.7	-0.999	-5,539
N	90	76.4	0.7	-0.2	-2,035
NE	135	65.8	0.8	0.57	4,916
E	180	73.7	0.8	1	10,820
SE	225	52.2	0.8	0.57*	3,094
S	270	57.8	0.7	-0.2*	-1,165
SW	315	58.9	0.7	-0. 999*	-6,041

*f_{xw}(q w) is symmetrical about the longitudinal axis of the vessel

$C_{xyw}(\theta w)$ is found in Figure 55.

(a) Light-Loaded Condition: Find M_{xyw} for the light-loaded condition:

A_y = 14,450 square feet

THEN:

$$M_{xyw} = \frac{1}{2}(0.00237)\ V^2 (14,450)\ (418)\ C_{xyw}(\theta_w)$$

$$M_{xyw} = 7,157.5\ \ V_w^2 C_{xwy}(\theta_w)$$

This equation is used to determine M_{xyw} for V_w and θ_w for the light-loaded condition. Results are given in Table 33.

TABLE 33
Wind Yaw Moment: Light-Loaded Condition

Direction	θ_w (degrees)	V_w (feet per second)	$C_{xyw}(\theta w)$	M_{xyw} (foot-pounds)
W	0	53.8	0	0
NW	45	56.4	0.12	2.7321×10^6
N	90	76.4	0.0425	1.7756×10^6
NE	135	65.8	-0.0125	-3.8737×10^5
E	180	73.7	0	0
SE	225	52.2	0.0125	2.4379×10^5
S	270	57.8	-0.0425	-1.0163×10^6
SW	315	58.9	-0.12	-2.9797×10^6

(b) Fully Loaded Condition: Find M_{xyw} for the fully loaded condition.

$$A_Y = 13{,}050 \text{ square feet}$$

THEN :

$$M_{xyw} = \frac{1}{2}(0.00237)\ V_w^2\ (13{,}050)(418)\ C_{xyw}(\theta_w)$$

$$M_{xyw} = 6{,}464\ V_w^2\ C_{xyw}(\theta_w)$$

This equation is used to determine M_{xyw} for V_w and θ_w for the fully loaded condition. Results are given in Table 34.

TABLE 34
Wind Yaw Moment: Fully Loaded Condition

Direction	θ_w (degrees)	V_w (feet per second)	$C_{xyw}(\theta_w)$	(foot-pounds)
W	0	53.8	0	0
Nw	45	56.4	0.12	2.4674×10^6
N	90	76.4	0.0425	1.6035×10^6
NE	135	65.8	-0.0125	-3.4983×10^5
E	180	73.7	0	0
SE	225	52.2	0.0125	2.2017×10^5
S	270	57.8	-0.0425	-9.178×10^5
SW	315	58.9	-0.12	-2.691×10^6

b. Current Load: Note that lateral and longitudinal flood-current loads (θ_c = 15°) are computed below; lateral and longitudinal ebb-current loads are equal to the flood-current loads, but opposite in sign.

(1) Lateral Current Load: Find F_{yc}:

EQ. (5-35)

$$F_{yc} = \frac{1}{2}\rho_w V_c^2 L_{wL} T C_{yc} \sin\theta_c$$

ρ_w = 2 slugs per cubic foot

V_c = 2 knots $\left(1.69\ \frac{\text{feet per second}}{\text{knot}}\right)$

= 3.38 feet per second

EQ. (5-36)

$$C_{yc} = C_{yc}\big|_{\infty} + \left(C_{yc}\big|_1 - C_{yc}\big|_{\infty}\right) e^{-k\left(\frac{wd}{T} - 1\right)}$$

EQ. (5-37)

$$\phi = \frac{35\ D}{L_{wL}\ B\ T}$$

L_{WL} = 407 feet

B = 45 feet

(a) Light-Loaded Condition at Low Tide: Find F_{yc} for the light-loaded condition at low tide:

T = 12.5 feet

wd = 35 feet

D = 2,800 long tons

Find $C_{yc}\big|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

$$\phi = \frac{(35)(2,800)}{(407)(45)(12.5)} = 0.428$$

$L_{wL}/B = 407/45 = 9.04$

$C_{yc}\big|_{\infty} = 0.4$

Find $C_{yc}\big|_{1}$ from Figure 57 for $C_p\ L_{wL}/\sqrt{T}$:

From Table 14, use C_p = 0.539 for DD-692

$C_p\ L_{wL}/\sqrt{T} = (0.539)(407)/\sqrt{12.5} = 62$

$C_{yc}\big|_{1} = 3.6$

Find k from Figure 58 for ϕ = 0.428 for a ship-shaped hull:

k= 0.75

$$\frac{wd}{T} = \frac{35}{12.5} = 2.8$$

THEN :

$$C_{yc} = 0.4 + (3.6 - 0.4)\ e^{-(0.75)(2.8 - 1)} = 1.23$$

THEREFORE:

$$F_{yc} = \frac{1}{2}\ (2)(3\ .38)2(407)(12.5)(1.23)\ \sin(15)$$
$$= 18,503 \text{ pounds}$$

(b) Fully Loaded Condition at Low Tide: Find F_{yc} for the fully loaded condition at low tide:

$T = 16$ feet

$wd = 35$ feet

$D = 4{,}140$ long tons

Find $C_{yc}\big|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

$$\phi = \frac{(35)(4{,}140)}{(407)(45)(16)} = 0.49$$

$L_{wL}/B = 407/45 = 9.04$

$$C_{yc}\big|_{\infty} = 0.4$$

Find $C_{yc}\big|_1$ from Figure 57 for $C_p L_{wL}/\sqrt{T}$

From Table 14, use $C_p = 0.539$ for DD-692

$$C_p L_{wL}/\sqrt{T} = (0.539)(407)/\sqrt{16} = 54.8$$

$$C_{yc}\big|_1 = 3.3$$

Find k from Figure 58 for $\phi = 0.49$ for ship-shape hull:

$k = 0.75$

$$\frac{wd}{T} = \frac{35}{16} = 2.19$$

THEN :

$$C_{yc} = 0.4 + (3.3 - 0.4)\, e^{-(0.75)(2.19 - 1)} = 1.59$$

THEREFORE:

$$F_{yc} = \frac{1}{2} \quad 2)(3.38)2(407)(16)(1.59) \sin(15)$$
$$= 30{,}615 \text{ pounds}$$

(2) Longitudinal Current Load: Find F_{xc} :

EQ. (5-40) $\quad F_{xc} - F_{x\ form} + F_{x\ friction} + F_{x\ prop}$

EQ. (5-41) $\quad F_{x\ form} = -\frac{1}{2} \rho_w V_c^2 B T C_{xcb} \cos\theta_c$

ρ_w = 2 slugs per cubic foot

v_c = 3.38 feet per second

B = 45 feet

c_{xcb} = 0.1

EQ. (5-42) $$F_{x\ friction} = -\frac{1}{2}\rho_w V_c^2 S C_{xca} \cos\theta_c$$

EQ. (5-43) $$s = (1.7\ T L_{wL}) + \frac{35D}{T}$$

EQ. (5-44) $$c_{xca} = 0.075/(\log R_n - 2)^2$$

EQ. (5-45) $$R_n = V_c L_{wL} \cos\theta_c/\nu$$

L = 407 feet

ν = 1.4 x 10^{-5} square feet per second

EQ. (5-46) $$F_{x\ prop} = -\frac{1}{2}\rho_w V_c^2 A_p C_{prop} \cos\theta_c$$

EQ. (5-47) $$A_p = \frac{A_{Tpp}}{0.838}$$

EQ. (5-48) $$A_{Tpp} = \frac{L_{wL} B}{A_R}$$

From Table 15 for destroyers, A_R = 100

THEN : A_{Tpp} = (407)(4s)/100 = 183 square feet

THEN: $A_p = \frac{183}{0.838}$ 218 square feet

c_{prop} = 1

(a) <u>Light-Loaded Condition at Low Tide</u>: Find F_{xc} for the light-loaded condition at low tide:

T = 12.5 feet

D = 2,800 long tons

THEN : $$F_{x\ form} = -\frac{1}{2} (2)\ (3.38)^2(45)\ (12.5)(0.1)\ \cos(15°)$$
$$= -620 \text{ pounds}$$

R_n = (3.38)(407) cos(15°)/1.4 x 10^{-5} = 9.49 x 10^7

$$C_{xca} = 0.075/[\log(9.49 \times 10^7) - 2]^2 = 0.0021$$

$$s = (1.7)(12.5)(407)\ \frac{(35)(2,800)}{12.5}$$
$$= 16,489 \text{ square feet}$$

THEN :

$$F_{x\ friction} = -\frac{1}{2}\ (2)(3.38)^2(16,489)(0.0021)\ \cos(15°) = -\ 382 \text{ pounds}$$

THEN :

$$F_{x\ prop} = -\frac{1}{2}\ (2)(3.38)^2(218)(1)\ \cos(15°)$$
$$= -\ 2,406 \text{ pounds}$$

THEREFORE :

$$F_{xc} = -\ 620 - 382 - 2,406 = -\ 3,408 \text{ pounds}$$

(b) Fully Loaded Condition at Low Tide: Find F_{xc} for the fully loaded condition at low tide:

$T = 16$ feet

$D = 4,140$ long tons

THEN :

$$F_{x\ form} = -\frac{1}{2}\ (2)(3.38)^2(45)(16)(0.1)\ \cos(15°)$$
$$= -\ 795 \text{ pounds}$$

$$s = (1.7)(16)(407) + \frac{(35)(4,140)}{16}$$
$$= 20,127 \text{ square feet}$$

THEN :

$$F_{x\ friction} = -\frac{1}{2}\ (2)(3.38)^2(20,127)(0.0021)\ \cos(15°) = -\ 466 \text{ pounds}$$

THEN:

$$F_{x\ prop} = -\ 2,406 \text{ pounds}$$

THEREFORE :

$$F_{Xc} = -795 - 466 - 2,406 = -\ 3,667 \text{ pounds}$$

(3) Current Yaw Moment: Find M_{Xyc}:

EQ. (5-49)

$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{wL}}\right)L_{wL}$$

$\left(\frac{e_c}{L_{wL}}\right)$ is found in Figure 59 as a function of θ_c and vessel type. For a DD-696:

$\left(\frac{e_c}{L_{wL}}\right) = 0.16$ for (

Note that the moment is symmetrical about the vessel stern; therefore, (e_c/L_{wL}) for $\theta_c = 195°$ is equal to (e_c/L_{wL}) for $\theta_c = 360° - 195° = 165°$:

$$\left(\frac{e_c}{L_{wL}}\right) = -0.08 \text{ for } \theta_c = 195°$$

(a) Light-Loaded Condition at Low Tide: Find M_{xyc} for the light-loaded condition at low tide:

Flood current ($\theta_c = 15°$):

$$M_{xyc} = (18,503)(().16)(407) = 1.2049 \times 10^6 \text{ foot-pounds}$$

Ebb current ($\theta_c = 195°$):

$$M_{xyc} = (-18,503)(-0.08)(407)$$
$$= 6.0246 \times 10 \text{ foot-pounds}$$

(b) Fully Loaded Condition at Low Tide: Find M_{xyc} for the fully loaded condition at low tide:

Flood current ($\theta_c = 15°$):

$$M_{xyc} = (30,615)(0.16)(407) = 1.99 \times 10^6 \text{ foot-pounds}$$

Ebb current ($\theta_c = 195°$):

$$M_{xyc} = (-30,615)(-0.08)(407)$$
$$= 9.97 \times 10^5 \text{ foot-pounds}$$

5. Evaluate Loads on Mooring Elements:

a. Load Combinations: There are four cases of load combinations which must be analyzed in order to determine the maximum mooring loads on the vessel:

Load Case 1: Light-loaded condition and flood current
Load Case 2: Light-loaded condition and ebb current
Load Case 3: Fully loaded condition and flood current
Load Case 4: Fully loaded condition and ebb current

Note that, for each case, the maximum loads on the vessel occur when the directions of the wind and current forces coincide. Therefore, loads due to a flood current are combined with loads due to winds from the W, NW, N, and NE. Similarly, loads due to an ebb current are combined with loads due to winds from the E, SE, S and SW.

EXAMPLE PROBLEM 2 (Continued)

The load-combination calculations are summarized in Table 35. The following equations are used:

EQ. (5-62) $F_{xT} = F + F_{XC}$

EQ. (5-63) $F_{YT} = F_{yw} + F_{yc}$

EQ. (5-64) $M_{xyT} = M_{xyw} + M_{xyc}$

TABLE 35
Load Combinations

Load Case	Direction	θ_w (degrees)	θ_c (degrees)	F_{xT} (pounds)	F_{yT} (pounds)	X_{xyT} (foot-pounds)
Case 1	W	0	15	-8,818	18,503	1.20×10^6
	NW	45	15	-9,347	53,851	3.94×10^6
	N	90	15	-5,590	101,446	2.98×10^6
	NE	135	15	1,863	66,615	8.18×10^5
Case 2	E	180	195	15,010	-18,503	6.02×10^6
	SE	225	195	6,726	-48,782	8.46×10^5
	S	270	195	2,159	-65,976	-4.14×10^5
	SW	315	195	-3,070	-57,054	-2.38×10^6
Case 3	W	0	15	-8,712	30,615	1.99×10^6
	NW	45	15	-9,206	60,614	4.46×10^6
	N	90	15	-5,702	101,009	3.59×10^6
	NE	135	15	1,249	71,447	1.64×10^6
Case 4	E	180	195	14,487	-30,615	9.97×10^5
	SE	225	195	6,761	-56,313	1.22×10^6
	S	270	195	2,502	-70,906	7.92×10^4
	Sw	315	195	-2,374	-63,333	-1.69×10^6

b. Mooring-Line Load. Mooring-line loads are analyzed using the procedure outlined in Figure 67.

EQ. (5-69) $$H_2 = \frac{F_{yT}}{2 \sin (45°)} + \frac{F_{XT}}{2 \cos (45°)}$$

EQ. (5-70) $$H_1 = H_2 - \frac{= F_{XT}}{\cos (45°)}$$

Line loads for each of the cases in Table 35 are summarized in Table 36.

For example, for a N wind; Case 1:

EXAMPLE PROBLEM 2 (Continued)

F_{XT} = - 5,590 pounds

F_{yT} = 101,446 pounds

THEREFORE:

$$H_2 = \frac{101,446}{2 \sin (45°)} + \frac{(-5,590)}{2 \cos (45°)} = 67,780 \text{ pounds}$$

$$H_1 = 67,780 - \frac{(-5,590)}{\cos (45°)} = 75,686 \text{ pounds}$$

Equations (5-69) and (5-70) are used to determine H_2 and H_1 for Cases 1 through 4. Results are given in Table 36.

TABLE 36
Mooring-Line Loads

Load Case	Direction	H_1 (pounds)	H_2 (pounds)
Case 1	W	19,319	6,848
	NW	44,688	31,469
	N	75,686	67,780
	NE	45,786	48,421
Case 2	E	2,470	23,697
	SE	29,783	39,250
	S	45,126	48,179
	SW	42,515	38,173
Case 3	W	27,809	15,488
	NW	49,370	36,351
	N	75,456	67,392
	NE	49,638	51,404
Case 4	E	11,404	31,892
	SE	35,039	44,600
	S	48,369	51,907
	SW	46,462	43,105

6. Design of Mooring Components:

a. Select Chain and Fittings:

(1) Approximate Chain Tension: Find T: the maximum horizontal line load from Table 36 is H = 75,686 pounds

EQ. (5-78) $T = 1.12\ H$

EXAMPLE PROBLEM 2 (Continued)

THEN: $T = (1.12)(75,686) = 84,768$ pounds

(2) Maximum Allowable Working Load: Find T_{design}:

EQ. (5-79) $T_{design} = 0.35\ T_{break}$

THEREFORE : $T_{break} = T_{design}/0.35$

$T_{design} = 84,768$ pounds

$T_{break} = 84,768/0.35 = 242,194$ pounds

(3) Select Chain:

From Table 95 of DM-26.6, use l-3/4-inch chain with a breaking strength of 249,210 pounds.

(4) Chain Weight:

EQ. (5-82) $W_{submerged} = 8.26\ d^2 = (8.26)(1.75) = 25.3$ pounds per foot

b. Compute Chain Length and Tension:

(1) Given:

(a) wd = 41 feet at high tide

(b) $\theta a = 2$ degrees

(c) H= 75,686 pounds

(d) w = 25.3 pounds per foot

This is Case 11 (Figure 73).

(2) Following the flow chart on Figure 73:

(a) $\theta_a \neq 0$

(b) $V_a = H \tan \theta_a$

$V_a = 75,686 \tan(2°) = 2,643$ pounds

(c) $S_a = V_a / w$

$S_a = 2,643/25.3 = 104.47$ feet

(d) $c = H/w = 75,686/25.3 = 2,991.5$ feet

(e) $y_a = \sqrt{S_a^2 + c^2}$

$y_a = \sqrt{(104.47)^2 + (2,991.5)^2} = 2,993.3$ feet

(f) $Y_b\ y_a + w\ d$

$y_b = 2,993.3 + 41 = 3,034.3$ feet

(g) $S_b = \sqrt{y_b^2 - c^2}$

$S_b = \sqrt{(3,034.3)^2 - (2,991.5)^2} = 507.8$ feet

(h) $S_{ab} = S_b - S_a$

$S_{ab} = 507.8 - 104.47 = 403.4$ feet

Determine number of shots:

403.4 feet/90 feet = 4.48; use 4.5 shots

(i) $T_b = w\ y_b$

$T_b = (25.3)(3,034.3) = 76,768$ pounds

Check the breaking strength of the chain:

$T_b/0.35 = 76,768/0.35 = 219,337 < 249,210$ pounds; ok

(j) $x_{ab} = c\ \ln\left[\frac{S_{ab}}{c} + \sqrt{\left(\frac{S_{ab}}{c}\right)^2 + 1}\right]$

$x_{ab} = 2,991.5\ \ln\left[\frac{403.4}{2,991.5} + \sqrt{\left(\frac{403.4}{2,991.5}\right)^2 + 1}\right]$

$x_{ab} = 402.2$ feet

c. Anchor Selection: Following the flow chart on Figure 77:

(1) Required holding capacity = 75,686 pounds

(2) Seafloor type is mud (given)

Depth of mud is 40 feet (given)

(3) Anchor type is Stato (given). From Table 18, safe efficiency = 10

Weight = 75,686/10 = 7,569 pounds = 7.6 kips

THEREFORE: Use 9,000-pound (9-kip) Stato anchor

(4) Required sediment depth: From Figure 80, the maximum fluke-tip depth is 35 feet. Therefore, the sediment depth (40 feet) is adequate.

(5) Drag distance: From Figure 82, the normalized anchor drag distance is:

D= 4.5 L

Calculate fluke length, L, using the equation from Figure 82 for determining L for Stato anchors:

$$L = 5.75 \left(\frac{W}{3}\right)^{1/3}$$

Use calculated anchor weight, W, in kips:

W= 7.6 kips

SUBSTITUTING:

$$L = (5.75)\left(\frac{7.6}{3}\right)^{1/3} = 7.8 \text{ feet}$$

THEN : D= (4.5)(7.8) = 35.1 feet <50 feet; ok

Therefore, the drag distance is acceptable (maximum is 50 feet).

EXAMPLE PROBLEM 2 (Continued)

The following pages illustrate the use of the computer program described in Appendix B to solve Example Problem 2. The first type of output from the computer provides a load-deflection curve for the mooring, which consists of 5.5 shots of 1 ¾ inch chain. A wire mooring line was used in the analysis. The second type of computer output consists of a summary of the mooring geometry and applied and distributed mooring loads.

Chain legth = 495 Weight/length = 25.3
Water depth = 41

Steel hawser, area x modulus = 7.777E+07
Chock to buoy = 150 On-deck length = 0

Horiz Force	Vert Force	Total Force	Upper Chn Up	Sinker Ht	Lower Chn Up	Anchor Angle	Chock-Buoy	Chock-Anchor
0	1037	1037	41.0	0.0	0.0	0.0	150.0	604.0
4984	3379	6022	133.5	0.0	0.0	0.0	150.0	636.5
9968	4664	11006	184.4	0.0	0.0	0.0	150.0	638.9
14953	3665	15990	223.9	0.0	0.0	0.0	150.0	440.0
19937	6514	20974	257.5	0.0	0.0	0.0	150.0	640.7
24921	7265	25958	287.1	0.0	0.0	0.0	150.0	641.1
29905	7945	30942	314.0	0.0	0.0	0.0	150.1	641.5
34889	8571	35927	330.8	0.0	0.0	0.0	150.1	641.7
39874	9154	40911	361.0	0.0	0.0	0.0	150.1	642.0
44858	9702	45895	383.8	0.0	0.0	0.0	150.1	442.2
49042	10221	50879	404.0	0.0	0.0	0.0	150.1	642.3
54826	10715	55863	423.S	0.0	0.0	0.0	150.1	642.5
S9810	11187	60848	442.2	0.0	0.0	0.0	150.1	642.6
64795	11640	65832	460.1	0.0	0.0	0.0	150.1	642.7
69779	12076	70816	477.3	0.0	0.0	0.0	150.1	442.0
74763	12497	75800	494.0	0.0	0.0	0.0	150.1	642.9
79747	12910	80785	495.0	0.0	0.0	0.3	150.2	643.0
84731	13323	85772	495.0	0.0	0.0	0.5	150.2	443.0
897 1&	13736	90761	495.o	0.0	0.0	0.8	150.2	643.1
94700	14150	95751	495.0	0.0	0.0	1.0	150.2	643.1
99684	14s63	100742	495.0	0.0	0.0	1.2	150.2	643.2
104668	14977	105734	495.0	0.0	0.0	1.3	150.2	643.2
109652	15390	110727	495.0	0.0	0.0	1.5	150.2	643.2
114637	15804	115721	495.0	0.0	0.0	l.6	150.2	643.3
119621	16217	120715	495.o	0.0	0.0	1.8	150.2	643.3
124605	16631	125710	495.0	0.0	0.0	1.9	150.2	643.3
129589	17045	130705	495.o	0.0	0.0	2.0	150.2	643.4
134s73	174s9	133701	495.0	0.0	0.0	2.1	150.3	643.4
139s5e	17873	140697	495.0	0.0	0.0	2.2	150.3	643.4
144S42	10206	145694	495.0	0.0	0.0	2.3	150.3	643.4
149526	16700	*150691*	495.0	0.0	0.0	2.4	150.3	643.4
154510	19114	155688	495.0	0.0	0.0	2.4	150.3	643.5
159494	19528	160686	495.0	0.0	0.0	2.5	150.3	643.S
164479	19942	165683	495.0	0.0	0.0	2.6	150.3	643.5
169463	20356	*170601*	495.0	0.0	0.0	2.6	150.3	643.5
174447	20770	175679	495.0	0.0	0.0	2.7	150.3	643.5
179431	21184	180677	495.0	0.0	0.0	2.8	150.3	643.5
184415	21598	185676	495.0	0.0	0.0	2.8	150.4	643.6
109400	22012	190675	495.0	0.0	0.0	2.9	150.4	64?.. 6
194384	22426	195673	495.0	0.0	0.0	2.9	150.4	643.6
19938	22840	200672	495.0	0.0	0.0	3.0	150.4	643.4
204352	23254	20S671	495.0	0.0	0.0	3.0	150.4	643.6
209334	*23668*	210670	495.0	0.0	0.0	3.0	150.4	643.6
214321	24082	215669	495.0	0.0	0.0	3.1	150.4	643.6
219305	24496	220669	495.0	0.0	0.0	3.1	150.4	643.7
224289	24911	225668	495.0	0.0	0.0	3.2	150.4	643.7
229273	23325	230668	495.0	0.0	0.0	3.2	150.4	643.7

Horiz Force	Vert Force	Total Force	Upper Chn Up	Sinker Ht	Lower Chn Up	Anchor Angle	Chock-Buoy	chock-Anchor
234258	25739	235667	495.90	0.0	0.0	3.2	150.0	643.7
239242	26153	240667	495.0	0.0	0.0	3.3	150.0	643.7
244226	26567	245667	495.0	0.0	0.0	3.3	150.0	643.7
249210	26901	250664	495.0	0.0	0.0	3.3	150.0	643.7

MULTIPLE POINT MOORING ANALYSIS

EXAMPLE 2

ANCHOR LEG INPUT DATA:

Leg NO.	Chock Coords x	Chock Coords Y	Leq Angle	Preload	Anchor Coords X	Anchor Coords Y
1	209.0	0.0	-45. 0	2000	645. 3	436.3
2	-209.0	0.0	-135.0	2000	-645. 3	-436.3

RESULTS FOR LOAD CASE O INITIAL POSITION

	Applied Load	Load Error	Displacement
Surge	0. 000E+00	1. 259E-04	0.0
Sway	0. 000E+00	-B. 580E+01	-18.0
Yaw	O. 000E+00	2. 624E-02	0.0

Anchor Legs

Line No.	Horizontal Load	Anchor-Chock	Line Angle
1	62	604.4	-43.8
2	62	604.4	223. e

RESULTS FOR LOAD CASE 1 N WIND FLOOD CURRENT F.L.

	Applied Load	Load Error	Displacmnent
Surge	-5.702E+03	7.906E+00	13.0
Sway	1.010E+05	9.056E+00	33.0
Yaw	3.590E+06	-1.582E+03	3.3

Anchor Legs

Line No.	Horizontal Load	Anchor-Chock	Line Angle
1	74967	442.9	-48. 8
2	42440	642.6	225.6

EXAMPLE PROBLEM 3: MULTIPLE-VESSEL SPREAD MOORING

Given: a. Spread mooring for an AS-15 submarine tender. The tender will service two SSN 597 submarines on one side of the vessel.

b. The bottom material is mud. The depth of the mud layer is 50 feet. Stato anchors will be used.

c. The water depth at the site is 40 feet mean lower low water (MLLW) .

d. The tide range from MLLW to mean higher high water (MHHW) is 5 feet.

e. Wind data for the site are given in Table 37. Note that the SSN-597 submarines will be moored alongside the AS-15 for windspeeds up to 35 knots.

f. Currents are due to tides. The maximum flood-current speed, V_c is 1.5 knots (θ_c = 15°) and the maximum ebb-current speed, V_c, is 1.5 knots (θ_c= 195°).

Find: Design the mooring for wind and current loads.

Solution: 1. Determine Vessel Characteristics from DM-26.6, Table 2:

For AS-15:

Overall length, L = 531 feet
Waterline length, L_{WL} = 520 feet
Beam (breadth at the loaded waterline), B = 73 feet
Fully-loaded draft, T = 26 feet
Light-loaded draft, T = 16.8 feet
Fully loaded displacement, D = 17,150 long tons
Light-loaded displacement, D = 9,960 long tons
Fully loaded broadside wind area, A_y = 27,250 square feet
Light-loaded broadside wind area, A_y = 32,050 square feet
Fully loaded frontal wind area, A_x 5,500 square feet
Light-loaded frontal wind area, A_x = 6,200 square feet

For SSN-597:

Overall length, L = 273 feet
Waterline length, L_{WL} = 262 feet
Beam, B = 23 feet
Fully loaded draft, T = 19.4 feet
Light-loaded draft, T = 13.9 feet
Fully loaded displacement, D = 2,610 long tons
Light-loaded displacement, D = 2,150 long tons
Fully loaded broadside wind area, A_y = 2,050 square feet
Light-loaded broadside wind area, A_y = 3,490 square feet
Fully loaded frontal wind area, A_x =110 square feet
Light-loaded frontal wind area, A_x = 220 square feet

2. Mooring Configuration: spread mooring

3. Evaluate Environmental Conditions:

EXAMPLE PROBLEM 3 (Continued)

TABLE 37
Wind Data for Site

Year	Peak-Gust Windspeed [1] (miles per hour)	Direction
1950	62	E
1951	38	NE
1952	53	N
1953	46	SW
1954	41	SE
1955	41	NE
1956	43	N
1957	41	S
1958	38	W
1959	34	S
1960	41	NE
1961	42	NW
1962	47	E
1963	54	N
1964	70	N
1965	50	E
1966	42	E
1967	65	NE
1968	46	N
1969	50	N
1970	39	SE
1971	46	NW
1972	44	NW
1973	47	W
1974	44	SE
1975	60	N
1976	42	W
1977	34	W
1978	39	SW
1979	35	NE

[1] Data were collected over water at an elevation of 43 feet.

EXAMPLE PROBLEM 3 (Continued)

a. Seafloor Soil Conditions:

(1) Bottom material is mud.

(2) Soil depth is 50 feet.

(3) Soil material is uniform over mooring area.

b. Design Water Depth:

(1) Water depth at low tide, $wd_{low\ tide} = 40$ feet

(2) Water depth at high tide, $wd_{high\ tide} = 40 + 5$
$= 45$ feet

c. Design Wind:

(1) Obtain Wind Data: Wind data obtained for the site are presented in Table 37. These data provide yearly maximum windspeeds for all directions combined (that is, directional data are not available). Therefore, the approximate method for determining directional probability must be used.

(2) Correct for Elevation:

EQ. (5-1)

$$V_{33.33} = V_h\left(\frac{33.33}{h}\right)^{1/7} = V_{43}\left(\frac{33.33}{43}\right)^{1/7}$$

$$= 0.964\ V_{43};\ \text{use}\ 0.96\ V_{43}$$

Therefore, elevation correction factor = 0.96

(3) Correct for Duration: The recorded windspeeds are peak-gust values; reduce the windspeeds by 10 percent to obtain the 30-second windspeeds. Therefore, duration correction factor = 0.90.

(4) Correct for Overland-Overwater Effects: Data were collected over water; therefore, no correction is necessary.

THEREFORE: Total correction factor = (0.9)(0.96) = 0.864.

Multiply each value in Table 37 by 0.864 to obtain the 30-second windspeed at 33.33 feet above the water surface. The results are shown in Table 38.

(5) Determine Windspeed Probability:

(a) Determine mean value, $\bar{x}$, and standard deviation, σ, for windspeed data:

EXAMPLE PROBLEM 3 (Continued)

TABLE 38
Adjusted Wind Data for Site

Year	Peak-Gust Windspeed (miles per hour)	Direction
1950	53.6	E
1951	32.8	NE
1952	45.8	N
1953	39.7	SW
1954	35.4	SE
1955	35.4	NE
1956	37.2	N
1957	35.4	S
1958	32.8	W
1959	29.4	S
1960	35.4	NE
1961	36.3	NW
1962	40.6	E
1963	46.7	N
1964	60.5	N
1965	43.2	E
1966	36.3	E
1967	56.2	NE
1968	39.7	N
1969	43.2	N
1970	33.7	SE
1971	39.7	NW
1972	38.0	NW
1973	40.6	W
1974	38.0	SE
1975	51.8	N
1976	36.3	W
1977	29.4	W
1978	33.7	SW
1979	30.2	NE

EQ. (5-4) $$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i = 39.57$$

EQ. (5-5) $$\sigma = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2 = 7.76$$

Note that $\overline{X}$ and σ can be computed with most hand-held calculators.

(b) Use Gumbel distribution to determine design windspeeds for all directions combined:

(i) Compute Gumbel parameters α and u:

EQ. (5-7) $$\alpha = \frac{1.282}{\sigma} = \frac{1.282}{7.76} = 0.1652$$

EQ. (5-8) $$u = \overline{x} - \frac{0.577}{\alpha} = 39.57 - \frac{0.577}{0.1652} = 36.08$$

(ii) Compute V_R for 25- and 50-year return periods:

EQ. (5-6) $$V_R = u - \frac{\ln \{- \text{in} [1 - P(X > x)]\}}{\alpha}$$

From Table 11, for a return period of 25 years, P(X > x) = 0.04, and for a return period of SO years, P(X > x) = 0.02.

THEN :

$$'_{25} = 36.08 - \frac{\text{in} [- \text{in} (1 - 0.04)1}{0.1652}$$
$$= 55.4 \text{ miles per hour}$$

$$'_{50} = 36.08 - \frac{\text{in} [- \text{in} (1 - 0.02)]}{0.1652}$$
$$= 59.7 \text{ miles per hour}$$

These two points are plotted on Gumbel paper in Figure 88 and designated “all directions” on the figure.

(c) Determine directional probabilities: Find $P(X > X) \mid \theta$, the probability of exceedence for a windspeed from direction θ, where θ is one of the eight compass points (N, NE, E, SE, S, SW, W, and NW):

EQ. (5-9) $$P(X > x) \mid \theta = P(x > x) \frac{N_\theta}{N}$$

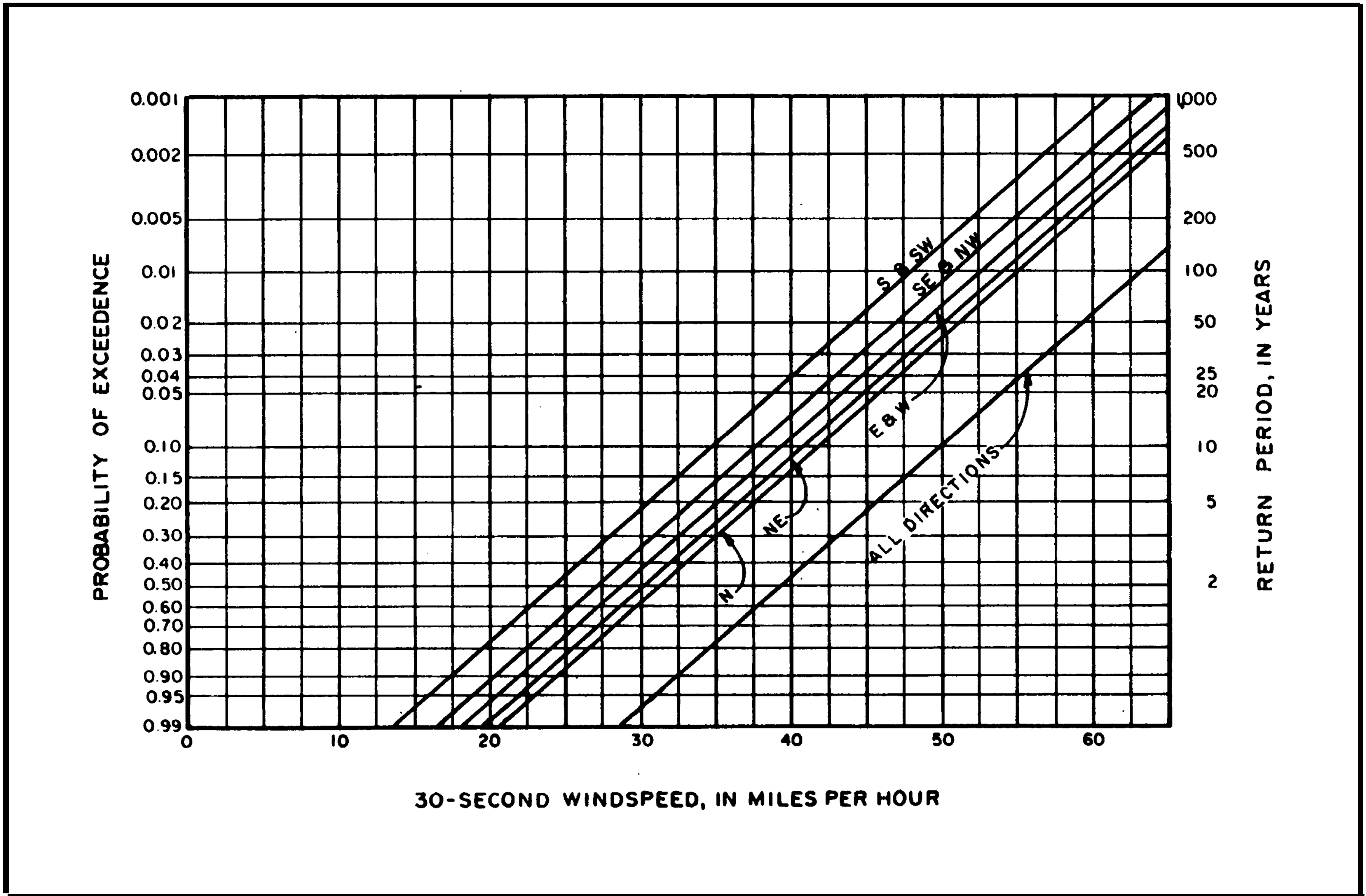


FIGURE 88
Design Windspeeds (Example Problem 3)

EXAMPLE PROBLEM 3 (Continued)

$P(x > x) = 0.02$ for a return period of 50 years

N is determined by counting the number of times that the extreme wind came from a particular direction (in Table 38).

N is the total number of extreme windspeeds in the data (in Table 38): N = 30

Values for N_θ and N_θ/N are given in Table 39.

TABLE 39
N_θ and N_θ/N

Direction (θ)	N_θ	N_θ/N
N	7	7/30
NE	5	5/30
E	4	4/30
SE	3	3/30
S	2	2/30
SW	2	2/30
W	4	4/30
NW	3	3/30

For example, for north:

SUBSTITUTING:

$$P(x > x)|_\theta = (0.02)\left(\frac{7}{30}\right) = 0.0047$$

Values of $P(X > x)|_\theta$ for the eight compass points are given in Table 40.

The probability of exceedence $[P(X > x)|_\theta]$ for each compass point is plotted on Gumbel paper versus the 50-year design windspeed (V_{50}) determined in Step (b), above (59.7 miles per hour). Using this plotted point, a straight line is drawn parallel to the line plotted in Step (b) for "all directions." Results are shown in Figure 88.

From the lines for each direction plotted in Figure 88, V_{50} is found for each direction by determining the value of the 30-second windspeed (abscissa) at a return period of 50 years (right ordinate). Results are given in Table 41.

TABLE 40
(P(X > x)| θ

Direction (θ)	Probability of Exceedence [P(X > x)| $_{\theta}$]
N	0.0047
NE	0.0033
E	0.0027
SE	0.0020
S	0.0013
SW	0.0013
W	0.0027
NW	0.0020

TABLE 41
Design Windspeed, V_{50}, for Each Direction

Direction	’50 (miles per hour)	’50 (feet per second)
N	51.2	75.1
NE	50.2	73.6
E	48.8	71.6
SE	46.7	68.5
s	44	64.5
Sw	44	64.5
w	48.8	71.6
NW	46.7	68.5

Note: 1.467 feet per second = 1 mile per hour

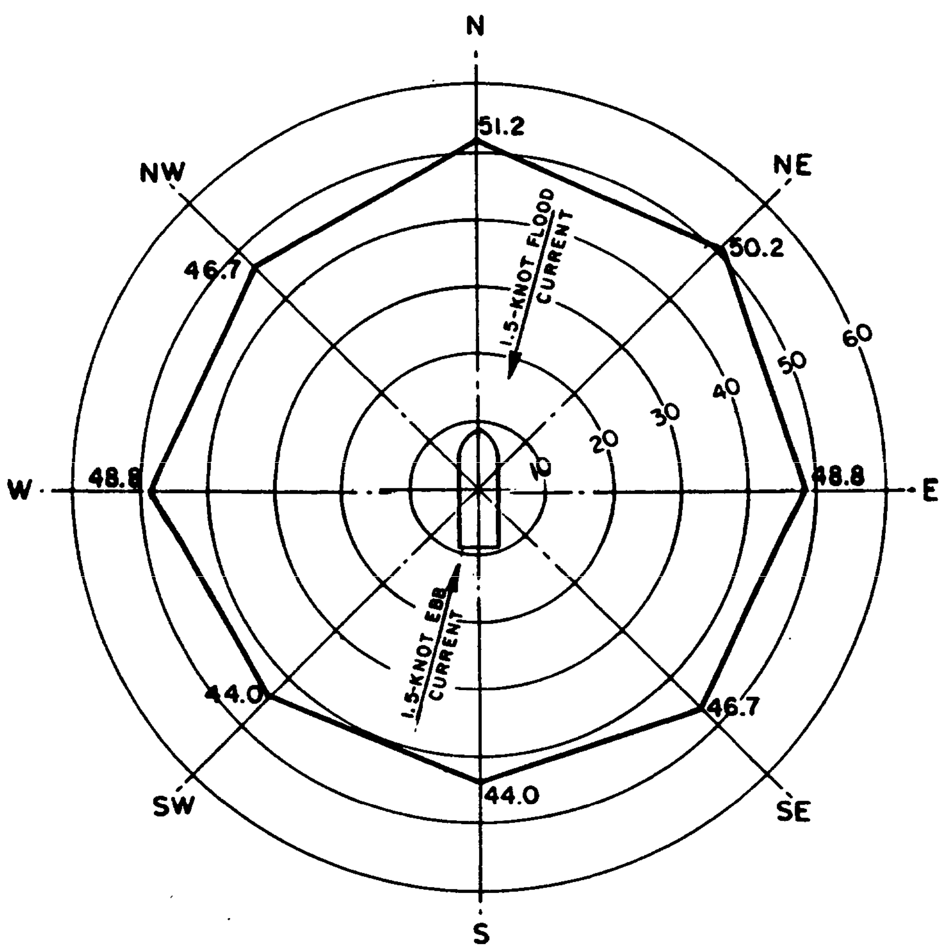
d. Design Current: The design currents are due to tides.

(1) Flood current: 1.5 knots toward 195° true north (θ_c = 15°)

(2) Ebb current: 1.5 knots toward 15° true north (θ_c = 195°)

e. A summary of design wind and current conditions is shown in Figure 89.

4. Evaluate Environmental Loads: Design criteria for the mooring state that the mooring must be capable of withstanding So-year design conditions with the AS-15 secured to the mooring alone.



NOTE: WIND VELOCITIES ARE IN MILES PER HOUR

FIGURE 89

summary of Design Wind and Current Conditions (Example Problem 3)

EXAMPLE PROBLEM 3 (Continued)

Operational criteria state that the mooring must be capable of withstanding 35-mile-per-hour winds with the AS-15 and two SSN-597 submarines secured to the mooring.

a. Single Vessel: AS-15 to satisfy design criteria:

(1) Wind Load:

(a) Lateral Wind Load: Find F_{YW}:

EQ. (5-11)
$$F_{yw} = \frac{1}{2} \rho_a V_w^2 A_y C_{yw} f_{yw}(\theta)$$

EQ. (5-12)
$$C_{yw} = 0.92 \left[\left(\frac{V_S}{V_R} \right)^2 A_S + \left(\frac{V_H}{V_R} \right)^2 A_H \right] / A_y$$

EQ. (5-13)
$$\frac{V_S}{V_R} = \left(\frac{h_S}{h_R} \right)^{1/7}$$

EQ. (5-14)
$$\frac{V_H}{V_R} = \left(\frac{h_H}{h_R} \right)^{1/7}$$

$h_R = 33.33$ feet

EQ. (5-15)
$$f_{yw}(\theta_w) = \frac{+\left(\sin\theta_w - \dfrac{\sin 5\theta_w}{20} \right)}{1 - \dfrac{1}{20}}$$

(i) Light-Loaded Condition: Find F_{yw} for the light-loaded condition:

Assume $h_S = 45$ feet and $h_H = 15$ feet:

$$\frac{V_S}{V_R} = \left(\frac{45}{33.33} \right)^{1/7} = 1.04$$

$$\frac{V_H}{V_R} = \left(\frac{15}{33.33} \right)^{1/7} \doteq 0.89$$

$A_Y = 32,050$ square feet

Assume:

EXAMPLE PROBLEM 3 (Continued)

$$A_S = 0.40\ A_y = (0.4)(32,050)$$
$$= 12,820 \text{ square feet}$$

$$A_H = 0.60\ A_y = (0.6)(32,050)$$
$$= 19,230 \text{ square feet}$$

THEN :

$$C_{yw} = 0.92\ \frac{[(1.04)^2(12,820) + (0.89)^2(19,230)]}{32,050}$$

$$C_{yw} = 0.84$$

AND :

$$F_{yw} = \frac{1}{2}\ (0.00237)\ V_w^2\ (0.84)(32,050)\ f_{yw}(\theta_w)$$

$$F_{yw} = 31.9\ V_W^2\ f_{yw}(\theta_w)$$

This equation is used to determine F_{yw} for V_w and θ_w for the light-loaded condition Results are given in Table 42.

TABLE 42
Lateral Wind Load: Light-Loaded Condition for AS-15

Direction	θ_w (degrees)	V_w (feet per second)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
N	0	75.1	0	0
NE	45	73.6	0.782	135,130
E	90	71.5	1	163,081
SE	135	68.5	0.782	117,052
S	180	64.5	0	0
SW	225	64.5	-0.782	-103,781
W	270	71.5	-1	-163,081
NW	315	68.5	-0.782	-117,052

(ii) Fully Loaded Condition: Find F_{yw} for the fully loaded condition:

Assume h_s = 40 feet and h_H = 10 feet:

$$\frac{V_S}{V_R} = \left(\frac{40}{33.33}\right)^{1/7} = 1.03$$

$$\frac{V_H}{V_R} = \left(\frac{10}{33.33}\right)^{1/7} = 0.84$$

EXAMPLE PROBLEM 3 (Continued)

$A_y = 27,250$ square feet

$A_H = A_y - A_S$

From Step (i) above, $A_S = 12,820$ square feet

$A_H = 27,250 - 12,820 = 14,430$ square feet

TEEN :

$$c_{yw} = \frac{0.92\ [(1.03)^2(12,820) + (0.84)^2(14,4301}{27,250}$$

$c_{yw} = 0.80$

AND :

$$F_{yw} = \frac{1}{2}(0.00237)\ V_w^2\ (0.80)\ (27,250)\ f_{yw}(\theta_w)$$

$$F_{yw} = 25.8\ V_w^2\ f_{yw}(\theta_w)$$

This equation is used to determine F_{yw} for V_w and θ_w for the fully loaded condition. The results are given in Table 43.

TABLE 43
Lateral Wind Load: Fully Loaded Condition for AS-15

Direction	θ_w (degrees)	V_w (feet per second)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
N	0	75.1	0	0
NE	45	73.6	0.782	109,290
E	90	71.5	1	131,896
SE	135	68.5	0.782	94,669
S	180	64.5	0	0
SW	225	64.5	-0.782	-83,936
W	270	71.5	-1	-131,896
NW	315	68.5	-0.782	-94,669

(b) Longitudinal Wind Load: Find F_{xw}:

EQ. (5-16)

$$F_{xw} = \frac{1}{2}\rho_a V_w^2 A_x C_{xw} f_{xw}(\theta_w)$$

$\rho_a = 0.00237$

EQ. (5-19) For submarine tender: CxwB = 0.70

EQ. (5-22) $C_{xwS} = 0.80$

EXAMPLE PROBLEM 3 (Continued)

For vessels with distributed superstructures:

EQ. (5-26)

$$f_{xw}(\theta_w) = \frac{-\left(\sin\gamma - \frac{\sin 5\gamma}{10}\right)}{1 - \frac{1}{10}}$$

EQ. (5-27)

$$\gamma_{(-)} = \left(\frac{90°}{\theta_{wz}}\right)\theta_w + 90° \text{ for } \theta_w < \theta_{wz}$$

EQ. (5-28)

$$\gamma_{(+)} = \left(\frac{90°}{180° - \theta_{wz}}\right)\theta_w + \left(180° - \frac{90°\ \theta_{wz}}{180° - \theta_{wz}}\right)$$

$$\text{for } \theta_w > \theta_{wz}$$

For warships, $\theta_{wz} \sim 110$ degrees:

THEN :

$$\gamma_{(-)} = \left(\frac{90°}{110°}\right)\theta_w + 90° = 0.82\ \theta_w + 90°$$

$$\gamma_{(+)} = \left(\frac{90°}{180° - 110}\right)(\theta_w + 180° - \frac{(90°)(110°)}{180° - 110°}$$

$$= 1.29\ \theta_w + 38.6$$

(i) Light-Loaded Condition: Find F_{xw} for the light-loaded condition:

$A_X = 6{,}200$ square feet

THEN :

$$F_{xw} = \frac{1}{2}(0.00237)\ V_w^2 (6{,}200)\ C_{xw}\ \phi_{\xi\omega}(\theta_w)$$

$$F_{XW} = 7.35\ V_w^2 C_{xw}\ \phi_{\xi\omega}(\theta_w)$$

This equation is used to determine F_{xw} for V , C_{xw}(C_{xwB} or C_{xwS}) , and , for the light-loaded condition. Results are given in Table 44.

(ii) Fully Loaded Condition: Find F_{xw} for the fully loaded condition:

$A_X = 5{,}500$ square feet

TEEN :

$$F_{XW} = \frac{1}{2}(0.00237)\ V_w^2\ (5{,}500)\ C_{xw}\ f_{xw}(\theta w)$$

$$F_{XW} = 6.52\ V_W^2\ C_{xw}\ f_{xw}(\theta_w)$$

This equation is used to find F_{XW} for V_W , C_{XW} (C_{xwB} or C_{xwS}) , and θ_w for the fully loaded condition Results are given in Table 45.

EXAMPLE PROBLEM 3 (Continued)

TABLE 44
Longitudinal Wind Load: Light-Loaded Condition for AS-15

Direction	C_{xw}	θ_w (degrees)	V_w (feet per second)	$f_{xw}(\theta_w)$	F_{xw} (pounds)
N	0.7	0	75.1	-1	-29,018
NE	0.7	45	73.6	-0.999	-27,842
E	0.7	90	71.5	-0.2	-5,261
SE	0.8	135	68.5	0.57	15,727
S	0.8	180	64.5	1	24,462
SW	0.8	225	64.5	0.57*	13,943
W	0.7	270	71.5	-0.2*	-5,261
NW	0.7	315	68.5	-0.999*	-24,118

*$f_{xw}(\theta_w)$ is symmetrical about the longitudinal axis of the vessel

TABLE 45
Longitudinal Wind Load: Fully Loaded Condition for AS-15

Direction	C_{xw}	θ_w (degrees)	V_w (feet per second)	$f_{xw}(\theta_w)$	F_{xw} (pounds)
N	0.7	0	75.1	-1	-25,741
NE	0.7	45	73.6	-0.999	-24,698
E	0.7	90	71.5	-0.2	-4,667
SE	0.8	135	68.5	0.57	13,951
S	0.8	180	64.5	1	21,700
SW	0.8	225	64.5	0.57*	12,369
W	0.7	220	71.5	-0.2*	-4,667
NW	0.7	315	68.5	-0.999*	-21,394

*$f_{xw}(\theta_w)$ is symmetrical about the longitudinal axis of the vessel

(c) Wind Yaw Moment: Find M_{xyw}:

EQ. (5-29)

$$M_{xyw} = \frac{1}{2} \rho_a V_w^2 A_y L C_{xyw}(\theta_w)$$

ρ_a = 0.00237 slugs per cubic foot

L = 531 feet

$C_{xyw}(\theta_w)$ Is found in Figure 55.

(i) Light-Loaded Condition: Find M_{xyw} for the light-loaded condition:

EXAMPLE PROBLEM 3 (Continued)

$A_y =$ 32,050 square feet

THEN :

$$M_{xyw} = \frac{1}{2}(0.00237)\ V_w^2\ (32,050)(531)\ C_{xyw}\ (\theta_w)$$

$$M_{xyw} = 20,167\ V_w^2\ C_{xyw}(\theta w)$$

This equation is used to find M_{xyw} for V and θ_w. for the light-loaded condition Results are given in Table 46.

TABLE 46
Wind Yaw Moment: Light-Loaded Condition for AS-15

Direction	θ_w (degrees)	V_w (feet per second)	$C_{xyw}(\theta_w)$	M_{xyw} (foot-pounds)
N	0	75.1	0	0
NE	45	73.6	0.12	1.3109×10^7
E	90	71.5	0.0425	4.3817×10^6
SE	135	68.5	-0.0125	-1.1829×10^6
s	180	64.5	0	0
Sw	225	64.5	0.0125	1.0487×10^6
w	270	71.5	-0.0425	-4.3817×10^6
NW	315	68.5	-0.12	-1.1355×10^7

(ii) Fully Loaded Condition:

$A_y =$ 27,250 square feet

TEEN :

$$M_{xyw} = \frac{1}{2}(0.00237)\ V_w^2\ (27,250)\ (531)\ C_{xyw}(\theta W)$$

$$M_{xyw} = 17,147\ V_w^2\ C_{xyw}(\theta_w)$$

This equation is used to find M for V and θ_w for the fully loaded condition Results are given in Table 47.

(2) Current Load: Note that lateral and longitudinal flood-current loads (θ_c = 150,) only are computed below; lateral and longitudinal ebb-current loads are equal to the flood-current loads, but opposite in sign.

(a) Lateral Current Load: Find F_{yc}:

EQ. (5-35)

$$F_{yc} = \frac{1}{2} \rho_w V_c^2 L_{wL} T C_{yc} \sin\theta_c$$

ρ_w = 2 slugs per cubic foot

EXAMPLE PROBLEM 3 (Continued)

TABLE 47
Wind Yaw Moment: Fully Loaded Condition for AS-15

Direction	θ_w (degrees)	V_w (feet per second)	$C_{xyw}(\theta_w)$	x_{Xyw} (foot-pounds)
N	0	75.1	0	0
NE	45	73.6	0.12	1.1146×10^7
E	90	71.5	0.0425	3.7255×10^6
SE	135	68.5	-0.0125	-1.0057×10^6
S	180	64.5	0	0
SW	225	64.5	0.0125	8.917×10^5
W	270	71.5	-0.0425	-3.7255×10^6
NW	315	68.5	-0.12	-9.655×10^6

$$V_c = 1.5 \text{ knots } \left(1.69 \frac{\text{feet per second}}{\text{knot}}\right)$$
$$= 2.54 \text{ feet per second}$$

$L_{wL} = 520$ feet

EQ. (5-36) $$C_{yc} = C_{yc}\big|_{\infty} + \left(C_{yc}\big|_{1} - C_{yc}\big|_{\infty}\right) e^{-k\left(\frac{wd}{T} - 1\right)}$$

EQ. (5-37) $$\phi = \frac{35\ D}{L_{wL} B\ T}$$

B = 73 feet

(i) Light-Loaded Condition at Low Tide: Find F_{yc} for the light-loaded condition at low tide:

T = 16.8 feet

Wd = 40 feet

D = 9,960 long tons

Find $C_{yc}\big|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

$$\phi = \frac{(35)(9,960)}{(520)(73)(16.8)} = 0.547$$

$$\frac{L_{wL}}{B} = \frac{520}{73} = 7.12$$

$$C_{yc}\big|_{\infty} = 0.52$$

Find $C_{yc|1}$ from Figure 57 for C_p $L_{wL}/\sqrt{T}$:

EXAMPLE PROBLEM 3 (Continued)

From Table 14, use $C_p = 0.539$ for DD-692:

$C_p L_{wL}/\sqrt{T} = (0.539)(520)/\sqrt{16.8} = 4$

$C_{yc}|_1 = 4.0$

Find k from Figure 58 for $\phi = 0.547$ for a ship-shaped hull:

$k = 0.75$

$\frac{wd}{T} = \frac{40}{16.8} = 2.38$

THEN:

$C_{yc} = 0.52 + (4 - 0.52)\ e^{-(0.75)(2.38-1)}$
$= 1.76$

THEREFORE:

$F_{yc} = \frac{1}{2}\ (2)\ (2.54)2(520)(16.8)(1.76)\ \mathrm{Sin}(15°)$
$= 25{,}674$ pounds

(ii) Fully Loaded Condition at Low Tide: Find F_{yc} for the fully loaded condition at low tide:

T = 26 feet

wd = 40 feet

D = 17,150 long tons

Find $C_{yc}|_\infty$ from Figure 56 for ϕ and L_{wL}/B:

$\phi = \frac{(35)(17,150)}{(520)\ (73)\ (26)} = 0.608$

$L_{WL}/B = \frac{520}{73} = 7.12$

$C_{yc}|_\infty = 0.60$

Find $C_{yc}|_1$ from Figure 57 for $C_p L_{wL}/\sqrt{T}$:

From Table 14, use $C_p = 0.539$ for DD-692:

$C_p L_{wL}/\sqrt{T} = (0.539)(520)/\sqrt{26} = 55$

$C_{yc}|_1 = 3.4$

Find k from Figure 58 for ϕ = 0.608 for a ship-shaped hull:

k= 0.8

$$\frac{wd}{T} = \frac{40}{26} = 1.54$$

THEN :

$$C_{yc} = 0.60 + (3.4 - 0.60)\, e^{-(0.8)(1.54-1)}$$
$$= 2.42$$

THEREFORE :

$$F_{yc} = \frac{1}{2}\ (2)(2.54)^2(520)(26)(2.42)\ \sin(15°)$$
$$= 54{,}633 \text{ pounds}$$

(b) Longitudinal Current Load: Find F_{xc}:

EQ. (5-40) $$F_{xc} = F_{x\ form} + F_{x\ friction} + F_{x\ prop}$$

EQ. (5-41) $$F_{x\ form} = -\frac{1}{2}\rho_w V_c^2\ B\ T\ C_{xcb}\cos\theta_c$$

ρ_w = 2 slugs per cubic foot

V_c = 2.54 feet per second

B = 73 feet

C_{xcb} = 0.1

EQ. (5-42) $$F_{x\ friction} = -\frac{1}{2}\rho_w V_c^2\ C_{xca}\ S\cos\theta_c$$

EQ. (5-44) $$C_{xca} = 0.075/(\log R_n - 2)^2$$

EQ. (5-45) $$R_n = V_c L_{wL}\cos\theta_c/\nu$$

L = 520 feet

$\nu = 1.4 \times 10^{-5}$ square feet per second

EQ. (5-43) $$S = (1.7\ T\ L_{wL}) + (35D/T)$$

EQ. (5-46) $$F_{x\ prop} = -\frac{1}{2}\rho_w V_c^2\ A_p\ C_{prop}\cos\theta_c$$

EQ. (5-47) $$A_p = \frac{A_{Tpp}}{0.838}$$

Eq. (5-48) $$A_{TPP} = \frac{L_{wL}\ B}{A_R}$$

EXAMPLE PROBLEM 3 (Continued)

From Table 15, use the value of A_R given for destroyers: $A_R = 100$:

TEEN : $A_{TPP} = \frac{(520)(73)}{100} = 379.6$ square feet

THEN : $A_P = \frac{379.6}{0.838} = 453$ square feet

$C_{prop} = 1$

(i) Light-Loaded Condition at Low Tide: Find F_{xc} for the light-loaded condition at low tide:

T = 16.8 feet

wd = 40 feet

D = 9,960 long tons

THEN : $F_{x\ form} = -\frac{1}{2}(2)(2.54)^2(73)(16.8)(0.1)\ COS(15°)$
$= -764$ pounds

$R_n = (2.54)(520)\cos(15°)/(1.4 \times 10^{-5})$
$= 9.1 \times 10^7$

$C_{xca} = 0.075/[\log(9.1 \times 10^7) - 2]^2 = 0.0021$

$S = (1.7)(16.8)(520) + [(35)(9,960)/16+8]$
$= 35,601$ square feet

THEN : $F_{x\ friction} = -\frac{1}{2}(2)(2.54)^2(0.0021)(35,601)$
$COS(15°) = -466$ pounds

THEN: $F_{x\ prop} = -\frac{1}{2}(2)(2.54)^2(453)\ COS(15°)$
$= -2,823$ pounds

THEREFORE: $F_{xc} = -764 - 466 - 2,823 = -4,053$ pounds

(ii) Fully Loaded Condition at Low Tide: Find F_{xc} for the fully loaded condition at low tide:

T = 26 feet

wd = 40 feet

D = 17,150 long tons

THEN: $F_{x\ form} = -\frac{1}{2}(2)(2.54)^2(73)(26)(0.1)\ COS(15°)$
$= -1,183$ pounds

EXAMPLE PROBLEM 3 (Continued)

$$S = (1.7)(26)(520) + [(35)(17{,}150)/26] = 46{,}071 \text{ square feet}$$

THEN :

$$F_{x\ friction} = -\frac{1}{2}(2)(2.54)^2(0.0021)(46{,}071)\cos(15°) = -603 \text{ pounds}$$

$$F_{x\ prop} = -2{,}823 \text{ pounds}$$

THEREFORE :

$$F_{xc} = -1{,}183 - 603 - 2{,}823 = -4{,}609 \text{ pounds}$$

(c) Current Yaw Moment: Find M_{xyc}:

EQ. (5-49)

$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{wL}}\right) L_{WL}$$

$\left(\frac{e_c}{L_{wL}}\right)$ is found in Figure 59 as a function of θ_c and vessel type. For a DD-696:

$$\left(\frac{e_c}{L_{wL}}\right) = 0.16 \text{ for } \theta_c = 15°$$

Note that the moment is symmetrical about the vessel stern; therefore, (e_c/L_{wL}) for $\theta_c = 195°$ is equal to (e_c/L_{wL}) for $\theta_c = 360° - 195° = 165°$:

$$\left(\frac{e_c}{L_{wL}}\right) \quad -0.08 \text{ for } (\theta_c = 195°$$

(i) Light-Loaded Condition at Low Tide: Find M_{xyc} for the light-loaded condition at low tide:

Flood current ($\theta_c = 15°$):

$$M_{xyc} = (25{,}674)(0.16)(520) = 2.14 \times 10^6 \text{ foot-pounds}$$

Ebb current ($\theta_c = 195°$):

$$M_{xyc} = (-25{,}674)(-0.08)(520) = 1.068 \times 10^6 \text{ foot-pounds}$$

(ii) Fully Loaded Condition at Low Tide: Find M_{xyc} for the fully loaded condition at low tide:

Flood current ($\theta_c = 150$):

$$M_{xyc} = (54,849)(0.16)(520)$$
$$= 4.56 \times 10^6 \text{ foot-pounds}$$

Ebb current (θ_c = 1950):

$$M_{xyc} = (-\ 54,859)(-\ 0.08)\ (520)$$
$$= 2.28 \times 10^6 \text{ foot-pounds}$$

(3) Load Combinations: There are four cases of load combinations which must be analyzed in order to determine the maximum mooring loads on the vessel:

Load Case 1: Light-loaded condition and flood current
Load Case 2: Light-loaded condition and ebb current
Load Case 3: Fully loaded condition and flood current
Load Case 4: Fully loaded condition and ebb current

Note that, for each case, the maximum loads on the vessel occur when the directions of the wind and current forces coincide. Therefore, loads due to a flood current are combined with loads due to winds from the N, NE, E, and SE. Similarly, loads due to an ebb current are combined with loads due to winds from the S, SW, W, and NW.

The load-combination calculations are summarized in Table 48. The following equations are used:

EQ. (5-62) $$F_{xT} = F_{xw} + F_{xc}$$

EQ. (5-63) $$F_{yT} = F_{yw} + F_{yc}$$

EQ. (5-64) $$M_{xyT} = M_{xyw} + M_{xyc}$$

b. Multiple Vessels: AS-15 and two SSN-597'S to satisfy operational criteria (35-mile-per-hour wind from any direction and design flood and ebb currents):

(1) Wind Load: The procedure for nonidentical vessels is used.

$$V_w = (35 \text{ miles per hour})\left(1.467\ \frac{\text{feet per second}}{\text{mile per hour}}\right)$$
$$= 51.34 \text{ feet per second}$$

(a) Wind Load on Two SSN-597'S: Step (1) of the procedure for nonidentical vessels is to estimate the wind loads on the nest of identical vessels (the two SSN-597'S) moored alongside the tender following the approach for identical vessels:

EXAMPLE PROBLEM 3 (Continued)

TABLE 48
Load Combinations for AS-15 Under Design Wind and Current

Load Case	Direction	θ_w (degrees)	θ_c (degrees)	F_{xT} (pounds)	F_{yT} (pounds)	M_{xyT} (foot-pounds)
Case 1	N	0	15	-33,071	25,674	2.14×10^6
	NE	45	15	-31,895	160,804	1.525×10^7
	E	90	15	-9,314	188,755	6.522×10^6
	SE	135	15	11,674	142,726	9.571×10^5
Case 2	S	180	195	28,515	-25,674	1.068×10^6
	SW	225	195	17,996	-129,455	2.117×10^6
	W	270	195	-1,208	-188,755	-3.314×10^6
	NW	315	195	-20,065	-142,726	-1.029×10^7
Case 3	N	0	15	-30,350	54,633	4.56×10^6
	NE	45	15	-29,307	163,923	1.57×10^6
	E	90	15	-9,276	186,529	8.29×10^6
	SE	135	15	9,342	149,302	3.55×10^6
Case 4	S	180	195	26,309	-54,633	2.28×10^6
	SW	225	195	16,978	-138,569	3.17×10^6
	W	270	195	-58	-186,529	-1.45×10^6
	NW	315	195	-16,785	-149,302	-7.38×10^6

(i) Lateral Wind Load: Find F_{ywg}:

Equation (5-50) for two vessels is as follows:

EQ. (5-50)

$$F_{ywg} = F_{yws} \left[K_1 \sin \theta_w + K_5 (1 - \cos 4\theta_w)\right]$$

EQ. (5-11)

$$F_{yws} = F_{yw} = \frac{1}{2} \rho_a V_w^2 A_y C_{yw} f_{yw}(\theta_w) \text{ @ } \theta_w = 90°$$

$$f_{yw}(\theta_w) = 1 \text{ @ } \theta_w = 90°$$

EQ. (5-12)

$$C_{yw} = 0.92 \left[\left(\frac{V_S}{V_R}\right)^2 A_S + \left(\frac{V_H}{V_R}\right)^2 A_H\right] / A_y$$

EQ. (5-13)

$$\frac{V_S}{V_R} = \left(\frac{h_S}{h_R}\right)^{1/7}$$

EQ. (5-14)

$$\frac{V_H}{V_R} = \left(\frac{h_H}{h_R}\right)^{1/7}$$

EXAMPLE PROBLEM 3 (Continued)

EQ. (5-15)

$$f_{yw}(\theta_w) = \frac{+\left(\sin\theta_w - \frac{\sin 5\theta_w}{20}\right)}{1 - \frac{1}{20}}$$

Light-Loaded Condition:

Assume $h_S = 25$ feet and $h_H = 5$ feet:

$$\frac{V_S}{V_R} = \left(\frac{25}{33.33}\right)^{1/7} = 0.96$$

$$\frac{V_H}{V_R} = \left(\frac{5}{33.33}\right)^{1/7} = 0.76$$

$A_Y = 3,490$ square feet

Assume :

$A_S = 0.25\ A_y = (0.25)(3,490)$
$= 872$ square feet

$A_H = 0.75\ A_y = (0.75)(3,490)$
$= 2,618$ square feet

THEN :

$$c_{yw} = \frac{0.92[(0.96)^2(872) + (0.76)2(2,618)]}{3,490}$$

$c_{yw} = 0.61$

THEREFORE :

$$F_{yws} = \frac{1}{2}(0.00237)(51.34)2(3,490)(0.61)(1)$$
$$= 6,642 \text{ pounds}$$

Determine K_1 and K_5 from Table 16 for SS-212:

$K_1 = 1$; $K_5 = 0.44$

THEN :

$$F_{ywg} = 6,642\ [1 \sin\theta_w + 0.44\ (1 - \cos 4\theta_w)]$$

This equation is used to determine F_{ywg_y} for θ_w for the light-loaded condition. The wind velocity, V_w, is the same for all directions; therefore, only loads from $\theta_w = 0°$ to $\theta = 180°$ are calculated. Results are given in Table 49.

EXAMPLE PROBLEM 3 (Continued)

TABLE 49
Lateral Wind Load: Light-Loaded Condition for Two SSN-597's

Direction	θ_w (degrees)	F_{ywg} (pounds)
N	0	0
NE	45	10,542
E	90	6,642
SE	135	10,542
S	180	0

Fully Loaded Condition:

Assume $h_S = 20$ feet and $h_H = 3$ feet:

$$\frac{V_S}{V_R} = \left(\frac{20}{33.33}\right)^{1/7} = 0.93$$

$$\frac{V_H}{V_R} = \left(\frac{3}{33.33}\right)^{1/7} = 0.71$$

$A_Y = 2,050$ square feet

$A_H = 2,050 - 872 = 1,178$ square feet

THEN :

$$C_{yw} = \frac{0.92\ [(0.93)^2(872) + (0.71)2(1,178)]}{2,050}$$

$C_{yw} = 0.60$

THEREFORE:

$$F_{yws} = \frac{1}{2}\ (0.00237)\ (51.34)^2(2,050)\ (0.60)\ (1)$$
$$= 3,837 \text{ pounds}$$

$$F_{ywg} = 3,837\ [1 \text{ Sin } \theta_w + 0.44\ (1 - \text{COS}4\ \theta_w)]$$

This equation is used to determine F_{ywg} for θ_w for the fully loaded condition. Results are given in Table 50.

(ii) Longitudinal Wind Load: Find F_{xwg}:

EQ. (5-51)

$$F_{xwg} = F_{xws}n$$

EXAMPLE PROBLEM 3 (Continued)

TABLE 50
Lateral Wind Load: Fully Loaded Condition for Two SSN-597'S

Direction	θ_w (degrees)	F_{ywg} (pounds)
N	0	0
NE	45	6,090
E	90	3,837
SE	135	6,090
S	180	0

EQ. (5-16)

$$F_{xws} = F_{xw} = \frac{1}{2} \rho_a V_w^2 A_x C_{xw} f_{xw}(\theta_w)$$

ρ_a = 0.00237 slugs per cubic foot

For hull-dominated vessels:

EQ. (5-17), (5-18)

$C_{XWB} = C_{xws} = 0.40$

We are interested in determining if the maximum longitudinal load on the vessel group is larger than the maximum longitudinal load on the AS-15 alone (under design and and current conditions). Therefore, we only need to check F_{xwg} at $\theta_w = 0°$ with $f_{xw}(\theta_w) = -1$.

Light-Loaded Condition:

A_x = 220 square feet

THEN :

$$F_{xws} = \frac{1}{2}(0.00237)(51.34)^2(220)(0.4)(-1)$$
$$= -275 \text{ pounds}$$

THEREFORE :

$F_{xwg} = (-275)(2) = -550$ pounds

Fully Loaded Condition:

A_x = 110 square feet

THEN :

$$F_{xws} = -\frac{1}{2}(0.00237)(51.34)^2(110)(0.4)(-1)$$
$$= -137 \text{ pounds}$$

THEREFORE :

$F_{xwg} = (-137)(2) = -274$ pounds

(iii) Wind Yaw Moment: Find M_{xywg}

EQ. (5-52)

$$M_{xywg} = M_{xyws}(K_{Nw1} + k_{Nw2})$$

EXAMPLE PROBLEM 3 (Continued)

EQ. (5-29)

$$M_{xyws} = M_{xyw} = \frac{1}{2} \rho_a V_w^2 A_y L C_{xyw}(\theta_w)$$

L = 273 feet

Light-Loaded Condition:

A_y = 3,490 square feet

K_{Nw1} and K_{Nw2} are given in Figure 61 as a function of ship location and type:

$K_{Nw1} = 0.93$

$K_{Nw2} = 1.0$

TEEN :

$$M_{xyws} = \frac{1}{2} (0.00237)(51.34)2(3,490)(273)\ C_{xyw}(\theta_w)$$

$$M_{xyws} = (2.97 \times 10^6)\ C_{xyw}(\theta_w)$$

$$M_{xywg} = (2.97 \times 10^6)\ C_{xyw}(\theta w)\ (0.93 + 1)$$

$$M_{xywg} = (5.73 \times 10^6)\ C_{xyw}(\theta_w)$$

This equation is used to determine M_{xywg} for $C_{xyw}(\theta_w)$ for the light-loaded condition. $C_{xyw}(\theta_w)$ is given in Figure 52 (for carriers). Results are given in Table 51.

TABLE 51
Wind Yaw Moment: Light-Loaded Condition for Two SSN-597's

Direction	e (degrees)	$C_{xyw}(\theta_w)$	M_{xywg} (foot-pounds)
N	O	0	0
NE	45	0.066	3.78×10^5
E	90	0	0
SE	135	-0.068	-3.90×10^6
S	180	0	0

Fully Loaded Condition:

$A_Y = 2{,}050$ square feet

THEN:

$$M_{xyws} = \frac{1}{2}(0.00237)\ (51.34)2(2{,}050)(273)\ C_{xyw}(\theta_w)$$

$$M_{xyws} = (1.75 \times 10^6)\ C_{xyw}(\theta_w)$$

$$M_{xywg} = (1.75 \times 10^6)\ c_{xyw}(\theta_w)\ (0.93 + 1)$$

THEN :

$$M_{xywg} = (3.38 \times 10^6)\ C_{xyw}(\theta_w)$$

This equation is used to determine M_{xywg} for $C_{xyw}(\theta_w)$ for the fully loaded condition $C_{xyw}(\theta_w)$ is given in Figure 52 (for carriers). Results are given in Table 52.

TABLE 52
Wind Yaw Moment: Fully Loaded Condition for Two SSN-597's

Direction	θ_w (degrees)	$C_{xyw}(\theta_w)$	M_{xywg} (foot-pounds)
N	o	0	0
NE	45	0.066	2.23×10^5
E	90	0	0
SE	135	0.068	-2.30×10^5
s	180	0	0

(b) Wind Load on AS-15: Step (2) of the procedure for nonidentical vessels is to estimate the wind loads induced on the tender as a single vessel:

(i) Lateral Wind Load: Find F_{ywg}:

Light-Loaded Condition:

From previous calculations for AS-15:

$$F_{yw} = 31.9\ V_w^2 f_{yw}(\theta_w)$$

$$F_{yw} = (31.9)(51.34)^2 f_{yw}(\theta w)$$

EXAMPLE PROBLEM 3 (Continued

THEN : $F_{yw} = 83{,}984\ f_{yw}(\theta_w)$

This equation is used to determine F_{yw} for θ_w θ_w for the light-loaded condition. Results are given in Table 53.

TABLE 53
Lateral Wind Load: Light-Loaded Condition for AS-15
(Operational Criteria)

Direction	θ_w (degrees)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
N	O	0	0
NE	45	0.782	65,675
E	90	1	83,984
SE	135	0.782	65,675
S	180	0	0

Fully Loaded Condition:

From previous calculations for AS-15:

$F_{yw} = 25.8\ V_W^2 f_{yw}(\theta w)$

THEN : $F_{yw} = (25.8)\ (51.34)^2 f_{yw}(\theta_w)$

$F_{yw} = 67{,}924\ f_{wy}(\theta w)$

This equation is used to determine F_{yw} for θ_w for the fully loaded condition. Results are given in Table 54.

TABLE 54
Lateral Wind Load: Fully Loaded Condition for AS-15
(Operational Criteria)

Direction	θ_w (degrees)	$f_{yw}(\theta_w)$	F_{yw} (pounds)
N	O	0	0
NE	45	0.782	53,117
E	90	1	67,924
SE	135	0.782	53,117
S	180	0	0

(ii) Longitudinal Wind Load: Find F_{xw}:

We are interested in determining if the maximum longitudinal load on the vessel group is larger than the maximum longitudinal load on the AS-15 alone (under design wind and current conditions). Therefore, we only need to check 35-mile-per-hour F_{xw} on AS-15 at $\theta_w = 0°$ with $f_{xw}(\theta_w) = -1$:

Light-Loaded Condition:

From previous calculations for AS-15:

$$F_{xw} = 7.35\ V_w^2 C_{xw}\ f_{xw}(\theta_w)$$

THEN:

$$F_{xw} = (7.35)(51.34)2(0.7)(-1)$$
$$= -13{,}545 \text{ pounds}$$

Fully Loaded Condition:

From previous calculations for AS-15:

$$F_{xw} = 6.52\ V_w^2 C_{xw}\ f_{xw}(\theta_w)$$

THEN :

$$F_{xw} = (6.52)(51.34)^2(0.7)(-1)$$
$$= -12{,}016 \text{ pounds}$$

(iii) Wind Yaw Moment:

Light-Loaded Condition:

From previous calculations for AS-15:

$$M_{xyw} = 20{,}167\ V_w^2 C_{xyw}(\theta_w)$$

THEN :

$$M_{xyw} = (20{,}167)(51.34)2\ C_{xyw}(\theta_w)$$

$$M_{xyw} = 5.309 \times 10^7 \text{ foot-pounds}$$

This equation is used to determine M_{xyw} for $C_{xyw}(\theta_w)$ for the light-loaded condition. Results are given in Table 55.

Fully Loaded Condition:

From previous calculations for AS-15:

$$M_{xyw} = 17{,}147\ V_w2\ C_{xyw}(\theta_w)$$

EXAMPLE PROBLEM 3 (Continued)

TABLE 55
Wind Yaw Moment: Light-Loaded Condition for AS-15
(Operational Criteria)

Direction	θ_w (degrees)	$C_{xyw}(\theta_w)$	M_{xyw} (foot-pounds)
N	0	0	0
NE	45	0.12	6.38×10^6
E	90	0.0425	2.26×10^6
SE	135	-0.0125	-6.64×10^5
S	180	0	0

THEN :

$$M_{xyw} = (17,147)(51.34)^2 C_{xyw}(\theta w)$$

$$M_{xyw} = 4.52 \times 10^7 \text{ foot-pounds}$$

This equation is used to determine M_{xyw} for $C_{xyw}(\theta_w)$ for the fully loaded condition. Results are given in Table 56.

TABLE 56
Wind Yaw Moment: Fully Loaded Condition for AS-15
(Operational Criteria)

Direction	θ_w (degrees)	$C_{xyw}(\theta_w)$	M_{xyz} (foot-pounds)
N	O	0	0
NE	45	0.12	5.42×10^6
E	90	0.0425	1.92×10^6
SE	135	-0.0125	-5.64×10^5
S	180	0	0

(c) Total Longitudinal Load: Step (3) of the procedure for nonidentical vessels is to add the longitudinal loads linearly:

$$F_{xw} = F_{XW}\ (\text{SS-597's}) + F_{xw}\ (\text{AS-15})$$

Light-Loaded Condition:

$$F_{XW} = -550 + (-13,545) = -14,095 \text{ pounds}$$

Fully Loaded Condition:

F_{xw} = - 274 + (- 12,016) = - 12,290 pounds

(d) Compare Broadside Areas (A) and Beams (B):

Step (4) of the procedure for nonidentical vessels is to (a) compare the beam of the tender with the composite beam of the nested group and (b) compare the projected broadside areas exposed to wind for the nested group and the tender and compare the respective lateral forces as determined in Steps (1) and (2) .

For the purposes of this example, compare only light-loaded broadside areas, A_y:

For AS-15: A_y = 32,050 square feet

For SSN-597: A_y = 3,490 square feet

For AS-15: B = 73 feet

Assume SSN-597 submarines are separated by 15 feet:

For SSN-597: “Composite B = (2)(23) + 15 = 61 feet

The beam of the tender (73 feet) is greater than half the composite beam of the nested group [(½)(61) = 30.5 feet]. This is Case (a) in Step (4).

The projected broadside area of the tender exposed to wind (32,050 square feet) is greater than twice the projected broadside area of the nested group [(2)(3,490) = 6,980 square feet]. This is Case (b) in Step (4).

Therefore, there is complete sheltering, and the lateral wind load on the vessel group should be taken as the larger of the loads on the SSN-597’s or the AS-15 separately. [These *were* computed in Steps (1) and (2).] Comparing Tables 49 and 50, which give F_{yw} for the two SSN-597’s, and Tables 53 and 54, which give F_{yw} for the AS-15, the greater of the loads computed in Steps (1) and (2) is that for the AS-15. Therefore, the lateral wind load on the vessel group is taken as that on the AS-15 alone.

Note that the lateral wind load on the AS-15 alone (under design conditions) is greater than the lateral wind load on the vessel group. Therefore, the maximum wind moment on the vessel group will not be calculated.

(2) Current Load:

V_c = 2.54 feet per second

θ_c = 15°

(a) Current Load on Two SSN-597's (Step (1) of the procedure for nonidentical vessels) is to estimate current loads on the nest of identical vessels (the two SSN-597'S) moored alongside the fender following the approach for identical vessels:

(i) Lateral Current Load: Find F_{ycg}:

EQ. (5-53)
$$F_{ycl} = \tfrac{1}{2} \; F_{ycs} \; K_6 (1 - 2\cos\theta_c)$$

EQ. (5-35)
$$F_{ycs} = F_{yc} = \frac{1}{2} \rho_w V_c^2 L_{WL} T \; C_{yc} \sin\theta_c$$

ρ_w = 2 slugs per cubic foot

EQ. (5-36)
$$C_{yc} = C_{yc}\big|_{\infty} + (C_{yc}\big|_1 - C_{yc}\big|_{\infty}) e^{-k\left(\frac{wd}{T} - 1\right)}$$

EQ. (5-37)
$$\phi = \frac{35D}{L_{WL} \; B \; T}$$

L_{WL} = 262 feet

B = 23 feet

EQ. (5-55)
$$F_{ycz} = (F_{ycl} @ 90°)[\sin\theta_c - K_7(1 - 0.5\cos 2\theta_c - 0.5\cos 6\theta_c)]$$

Determine d_{cL}/B:

Assume SSN-597's separated by 15 feet:

d_{cL} = 15 + (2)(½)(B) = 15 + (2)(½)(23) = 38 feet

d_{cL}/B = 38/23 = 1.65

Determine K_6 from Figure 62:

$K_6 \sim 1.05$

EXAMPLE PROBLEM 3 (Continued)

Determine $(1 - 2 K_7)$ from Figure 63:

$(1 - 2 K_7 = 1$

THEN : $K_7 = 0$

Light-Loaded Condition:

T = 13.9 feet

D = 2,150 long tons

Find $C_{yc}|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

$$\phi = \frac{(35)\ (2,150)}{(262)\ (23)\ (13.9)} = 0.898$$

$$\frac{L_{WL}}{B} = \frac{262}{23} = 11.4$$

$C_{yc}|_{\infty} = 0.75$

Find $C_{yc}|_1$ from Figure 57 for $C_p\ L_{wL}/\sqrt{T}$

From Table 14, use $C_p = 0.479$

$C_p\ L_{wL}/\sqrt{T} = (0.479)(262)/\sqrt{13.9} = 33.7$

$C_{yc|\ 1} = 2.5$

Find k from Figure 58 for $\phi = 0.898$ for a ship-shaped hull:

k= 1.75

THEN: $C_{yc} = 0.75 + (2.5 - 0.75)\ e^{-\ (1.75)(\frac{40}{13.9}-1)}$
$= 0.82$

$F_{ycs} = ½\ (2)\ (2.54)^2(262)(13.90(0=82)$
$= 19,266$ pounds

$F_{ycl}\ @90° = ½\ (19,266)(1.05)\ \{1 - COS[(2)\ (90]\}$
$= 20,229$ pounds

THEN : $FY_{cl} = ½\ (19,266)(1.05)\ \{1 - \cos[(2)(15°)]\}$
$= 1,355$ pounds .

EXAMPLE PROBLEM 3 (Continued)

F_{yc2} = 20,229 {sin(15°) - (0){1 -0.5 COS[(2)(15°)]} - 0.5 COS[(6)(15°)I

F_{yc2} = 5,236 pounds

THEREFORE: F_{yc} = 1,355 + 5,236 = 6,591 pounds

Fully Loaded Condition:

T = 19.4 feet

D = 2,610 long tons

Find $C_{yc}|_{\infty}$ from Figure 56 for ϕ and L_{wL}/B:

$$\phi = \frac{(35)(2,610)}{(262)\ (23)(19.4)} = 0.78$$

$$\frac{L_{wL}}{B} = \frac{262}{23} = 11.4$$

Use $C_{yc}|_{\infty}$ = 0.75

Find $C_{yc}|_1$ from Figure 57 for $C_p\ L_{wL}/\sqrt{T}$

From Table 14, use C_p = 0.479

$C_p\ L_{wL}/\sqrt{T}$ = (0.479)(262)/$\sqrt{19.4}$ = 28.5

$C_{yc|1} \sim$ 2.5

Find k from Figure 58 for ϕ = 0.78 for a ship-shape hull:

k = 1.25

THEN : $C_{yc} = 0.75 + (2.5 - 0.75)\ e^{-(1.25)\left(\frac{40}{19.4}-1\right)}$
= 1.21

F_{ycs} = ½ (2) (2.54)2(262)(19.4)(1.21)
= 39,679 pounds

F_{ycl} @ 90° = ½ (39,679)(1.05) {1 - cos(2)(90°)]}
= 41,66 pounds

EXAMPLE PROBLEM 3 (Continued)

TEEN : $A_P = \frac{48.2}{0.838} = 57.5$ square feet

$C_{prop} = 1$

Light-Loaded Condition at Low Tide:

T = 13.9 feet

wd = 40 feet

D = 2,150 long tons

TEEN: $F_{x\ form} = -\frac{1}{2}(2)(2.54)^2(23)(13.9)(0.1)\cos(15°)$
$= -199$ pounds

$R_n = (2.54)(262)\cos(15°)/(1.4 \times 10^{-5})$
$= 4.59 \times 10^7$

$C_{xca} = 0.075/[\log(4.59 \times 10^7) - 2]^2 = 0.0023$

$S = (1.7)(13.9)(262) + (35)(2{,}150)/13.9$
$= 11{,}605$ square feet

THEN : $F_{x\ friction} = -\frac{1}{2}(2)(2.54)^2(0.0023)(11{,}605)$
$\cos(15°) = -172$ pounds

THEN: $F_{x\ prop} = -\frac{1}{2}(2)(2.54)^2(57.5)\cos(15°)$
$= -358$ pounds

THEN : $F_{xc} = -199 - 172 - 358 = -729$ pounds

THEREFORE : $F_{xc\ g} = -(729)(2) = -1{,}458$ pounds

Fully Loaded Condition at Low Tide:

T = 19.4 feet

wd = 40 feet

D = 2,610 long tons

THEN : $F_{x\ form} = -\frac{1}{2}(2)(2.54)^2(23)(19.4)(0.1)\cos(15°)$
$= -278$ pounds

$S = (1.7)(19.4)(262) + (35)(2{,}610)/19.4$
$= 13{,}350$ square feet

EXAMPLE PROBLEM 3 (Continued)

THEN : $F_{x\ friction} = -\frac{1}{2}\ (2)(2.54)^2(0.0023)(13{,}350)\cos(15°) = -\ 191$ pounds

THEN : $F_{x\ prop} = -\ 358$ pounds

TEEN : $F_{xc} = -278 - 191 - 358 = -\ 827$ pounds

THEREFORE : $F_{xcg} = -\ (827)(2) = -\ 1{,}654$ pounds

(iii) Current Yaw Moment: Find M_{xyc}:

EQ. (5-49)

$$M_{xyc} = F_{yc}\left(\frac{e_c}{L_{wL}}\right)L_{wL}$$

$\left(\frac{e_c}{L_{wL}}\right)$ is found from Figure 59 for $\theta_c = 15°$ and θ_c 195° and SS-212:

$$\left(\frac{e_c}{L_{wL}}\right) = 0.145 \text{ for } \theta_c = 15°$$

Note that the moment is symmetrical about the vessel stem; therefore, (e_c/L_{wL}) for $\theta_c = 195°$ is equal to (e_c/L_{wL}) for $\theta_c = 360° - 193° = 165°$

$$\left(\frac{e_c}{L_{wL}}\right) = -\ 0.175 \text{ for } \theta_c = 195°$$

Light-Loaded Condition at Low Tide:

Flood current ($\theta_c = 15°$)

$M_{xyc} = (6{,}591)(0.145)(262)$
$= 2.5 \times 10^5$ foot-pounds

Ebb current ($\theta_c = 195°$)

$M_{xyc} = (-\ 6{,}591)(-\ 0.175)\ (262)$
$= 3.02 \times 10^5$ foot-pounds

Fully Loaded Condition at Low Tide:

Flood current ($\theta_c = 15°$)

$M_{xyc} = (13{,}572)(0.145)(262)$
$= 5.16 \times 10^5$ foot-pounds

Ebb current (θ_c = 195°)

M_{xyc} =- (13,572)(0.175)(262)
= 6.22 x 10^5 foot-pounds

(b) Current Load on AS-15: Step (2) of the procedure for nonidentical vessels is to estimate the current loads induced on the tender as a single vessel:

Current loads on the AS-15 were determined in previous calculations.

(i) Light-Loaded Condition at Low Tide:

F_{xc} = - 4,053 pounds

F_{yc} = 25,674 pounds

Flood current: M_{xyc} = 2.14 x 10^6 foot-pounds

Ebb current: M_{xyc} = 1.068 x 10^6 foot-pounds

(ii) Fully Loaded Condition at Low Tide:

F_{xc} = - 4,609 pounds

F_{yc} = 54,859 pounds

Flood current: M_{xyc} = 4.56 x 10^6 foot-pounds

Ebb current: M_{xyc} = 2.28 x 10^6 foot-pounds

(c) Total Longitudinal Load: Step (3) of the procedure for nonidentical vessels is to add the longitudinal loads linearly:

F_{xc} = F_{xc} (SS-597's) + F_{xc} (AS-15)

(i) Light-Loaded Condition:

F_{xc} = - 1,458 + (- 4,053) = - 5,511 pounds

(ii) Fully Loaded Condition:

F_{xc} = - 1,654 + (- 4,609) = - 6,263 pounds

(d) Compare products (L_{WL} T) and beams (B):

For the purpose of this example, compare only fully loaded L_{WL} T:

For AS-15: $L_{WL}T$ = (520)(26) = 13,520 square feet

For SSN-597's: $L_{WL}T$ = (262)(19.4)
= 5,083 square feet

For AS-15: B = 73

For SSN-597's: Composite beam, B = 61 feet

Compare:

(i) B (AS-15) = 73 feet > ¼ B (SSN-S97 's)
= ¼ (61) = 15.25 feet

(ii) L_{WL} T (AS-15) = 13,520 square feet>
L_{WL} T (SSN-597) = 5,083
square feet

Therefore, there is complete sheltering, and the lateral current load on the vessel group should be taken as the larger of the loads on the SSN 597's or AS-15 separately. Previous calculations indicate that the lateral current loads on the AS-15 are considerably larger than those on the SSN-597's alone. Because the lateral loads on the AS-15 govern, the maximum current moment on the vessel group will not be calculated.

(3) Load Combinations:

(a) Lateral Load and Yaw Moment: Previous calculations indicate that lateral wind and current loads on the AS-15 alone will govern the lateral loads on the vessel group for operational conditions (35-mile-per-hour wind and 1.5-knot current). Therefore, the lateral loads (and moments) on the AS-15 alone under So-year design winds will govern the design of the mooring components.

(b) Longitudinal Load:

(i) Light-Loaded Condition:

Vessel group $F_{xT} = F_{xw} + F_{xc}$

F_{XT} = - 14,095 + (- 5,511) = - 19,606 pounds

EXAMPLE PROBLEM 3 (Continued)

(ii) Fully Loaded Condition:

Vessel group F_{XT} = - 12,290 + (- 6,263)
= - 18,553 pounds

The maximum value of F_{XT} on the AS-15 alone under design conditions is given from Table 57:

F_{XT} = - 33,071 pounds

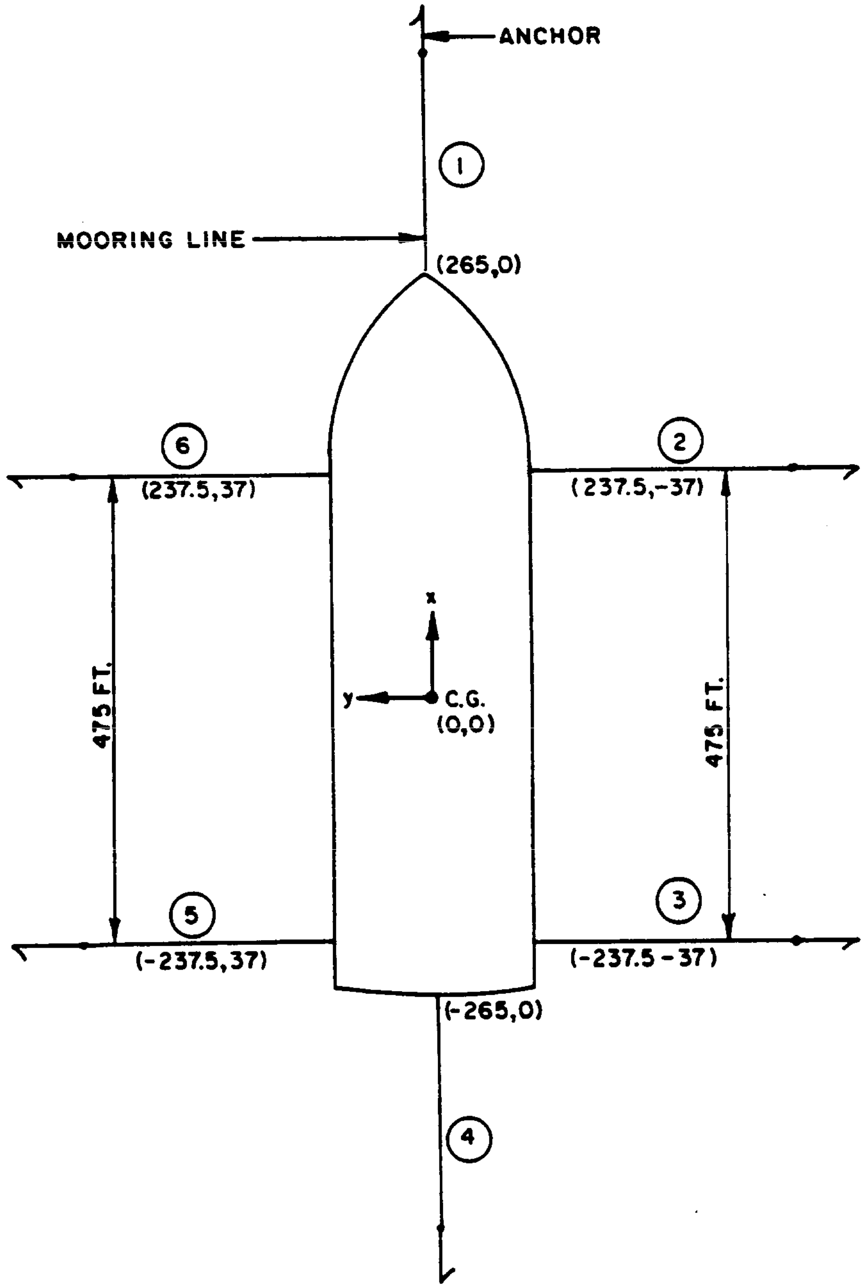
This value is larger than the maximum F_{XT} on the vessel group. Therefore, the longitudinal loads on the AS-15 under design conditions govern.

TABLE 57
Mooring-Line Loads

Load Case	Direction	H_1 (pounds)	H_2 (pounds)	H_3 (pounds)	H_4 (pounds)	H_5 (pounds)	H_6 (pounds)
Case 1	N	33,071	17,342	8,332	-		
	NE	31,895	112,494	48,283	-		
	E	9,314	108,095	80,634	-		
	SE	-	73,364	69,335	11,674	-	
Case 2	S				28,515	15,085	10,589
	SW				17,996	69,171	60,257
	W	1,208	-			87,387	101,341
	NW	20,065	-			49,686	93,013
Case 3	N	30,350	37,030	17,830	-		
	NE	29,307	115,127	49,022	-		
	E	9,276	110,830	75,925	-		
	SE		82,238	67,290	9,342	-	
Case 4	S				26,309	32,230	22,630
	SW				16,978	76,085	62,737
	W	58	-			86,704	100,051
	NW	16,785	-			59,227	90,301
Maximum	-	33,071	115,127	80,634	28,515	87,387	101,341

5. Loads on Mooring Elements: The mooring-line geometry is shown in Figure 90. Mooring-line loads are analyzed using the procedure outlined in Figure 68. For this example, d_L = 475 feet.

EQ. (5-71) $H_4 = F_{XT}$



NOTE: CHOCK COORDINATES FROM VESSEL CENTER OF GRAVITY (C. G.) ARE GIVEN IN PARENTHESES

FIGURE 90
Mooring Geometry

EXAMPLE PROBLEM 3 (Continued)

EQ. (5-72) $H_2 = \frac{F_{yT}}{2} + \frac{M_{xyT}}{d_L}$

EQ. (5-73) $H_3 = \frac{F_{yT}}{2} - \frac{M_{xyT}}{d_L}$

Line loads for each of the cases in Table 48 are summarized in Table 57.

For exmple, SE wind; Case 1:

H_4 = 11,674 pounds

$H_2 = \frac{142,699}{2} + \frac{9.571 \times 10^5}{475}$ = 73,364 pounds

$H_3 = \frac{142,699}{2} - \frac{9.571 \times 10^5}{475}$ = 69,335 pounds

6. Design of Mooring Components: For this example, the bow and stern lines (1 and 4) and lines 2, 3 and 5, 6 will be designed separately. Lines 1 and 4 will be designated longitudinal; lines 2, 3 and 5, 6 will be designated lateral.

a. Select Chain and Fittings:

(1) Approximate Chain Tension: Find T. The maximum horizontal line loads are given in Table 57.

EQ. (5-78) T = 1.12 H

(a) Longitudinal:

$H_{1,4}$ = 33,071 pounds

THEN : T = (1.12)(33,071) = 37,040 pounds

(b) Lateral:

$H_{2,3,5,6}$ = 115,127 pounds

THEN: T = (1.12)(115,127) = 128,942 pounds

(2) Maximum Allowable Working load: Find T_{design}:

EQ. (5-79) T_{break} = T/O.35

(a) Longitudinal:

T_{break} = 37,040/0 .35 -105,829 pounds

EXAMPLE PROBLEM 3 (Continued)

(b) Lateral:

T_{break} 128,9420/0.35 - 368,406 pounds

(3) Select Chain:

Select chain from Table 95 of DM-26.6:

(a) Longitudinal: Use 1¼-inch chain with a breaking strength of 130,070 pounds.

(b) Lateral: Use 2¼- inch chain with a breaking strength of 403,100 pounds.

(4) Chain Weight:

EQ. (5-82 $W_{submerged} = 8.26\ d^2$

Longitudinal:

$W_{submerged} = (8.26)(1.25)^2 = 12.9$ pounds per foot

Lateral:

$W_{submerged} = (8.26)(2.25)^2 = 41.8$ pounds per foot

b. Compute Chain Length and Tension:

(1) Longitudinal:

(a) Given:

(i) wd = 45 feet at high tide

(ii) $\theta_a = 0°$

(iii) H = 33,071 pounds

(iv) w= 12.9 pounds per foot

This is Case I (Figure 72)

(b) Following the flowchart on Figure 72:

(i) $\theta_a = 0°$

(ii) c = H/w= 33,071/12.9 = 2,563.6 feet

(iii) y_b = c + wd = 2,563.6 + 45 = 2,608.6 feet

(iv) $S_{ab} = \sqrt{y_b^2 - c^2} = \sqrt{(2,608.6)^2 - (2,563.6)^2}$
$= 482$ feet

Determine number of shots:

482 feet/90 feet = 5.35; use 5.5 shots = 495 feet .

(v) $$x_{ab} = c \ln \left[\frac{S_{ab}}{c} + \sqrt{\left(\frac{S_{ab}}{c}\right)^2 + 1} \right]$$

$$x_{ab} = 2,563.6 \ln \left[\frac{495}{2,563.6} + \sqrt{\left(\frac{495}{2,563.6}\right)^2 + 1} \right]$$

$x_{ab} = 492$ feet

(vi) $T_b = (12.9)(2,608.6) = 33,651$ pounds

33,651/0.35 = 96,146 pounds< 130,070 pounds; ok

(2) Lateral:

(a) Given:

(i) wd = 45 feet at high tide

(ii) $\theta_a = 0°$

(iii) H = 128,942 pounds

(iv) w = 41.8 pounds per foot

This is Case I (Figure 72)

(b) Following the flow chart on Figure 72:

(i) $\theta_a = 0°$

(ii) c = H/w = 128,942/41.8 = 3,084.7 feet

(iii) $y_b = c + wd = 3,084.7 + 45 = 3,129.7$ feet

(iv) $S_{ab} = \sqrt{y_b^2 - c^2} = \sqrt{(3,129.7)^2 - (3,084.7)^2}$
$= 528.8$ feet

Determine number of shots:

528.8 feet/90 feet = 5.9; use 6 shots = 540 feet

(v) $$x_{ab} = c \ln\left[\frac{S_{ab}}{c} + \sqrt{\left(\frac{S_{ab}}{c}\right)^2 + 1}\right]$$

$$x_{ab} = 3{,}084.7 \ln\left[\frac{540}{3{,}084.7} + \sqrt{\left(\frac{540}{3{,}084.7}\right)^2 + 1}\right]$$

x_{ab} = 537 feet

(vi) $T_b = W\ y_b =$ (41.8)(3,129.7)
= 130,821 pounds

130,821/0.35 = 373,776 pounds
<403,100 pounds; ok

c. Anchor Selection: Following the flow chart on Figure 77:

(1) Longitudinal:

(a) Required holding capacity = 33,071 pounds

(b) Seafloor type is mud (given)

Depth of mud is 50 feet (given)

(c) Anchor type is Stato (given). From Table 18, safe efficiency = 10

Weight = 33,071/10 = 3,307 pounds = 3.3 kips

THEREFORE : Use 3,000-pound (3-kip) Stato anchor (although slightly undersized, this anchor will be adequate and its use is more practical than using a 6,000-pound Stato anchor).

(d) Required sediment depth: From Figure 80, the maximum fluke-tip depth is 26.5 feet. Therefore, the sediment depth (50 feet) is adequate.

(e) Drag distance: From Figure 82, the normalized anchor drag distance is:

D = 4.5 L

Calculate fluke length, L, using the equation from Figure 82 for determining L for Stato anchors:

$$L = 5.75 \left(\frac{W}{3}\right)^{1/3}$$

EXAMPLE PROBLEM 3 (Continued)

Use calculated anchor weight, W, in kips:

W = 3.3 kips

SUBSTITUTING: $L = (5.75)\left(\frac{3.3}{3}\right)^{1/3} = 5.9$ feet

TEEN: D = (4.5)(5.9) = 26.6 feet<50 feet; ok

Therefore, the drag distance is acceptable (maximum is 50 feet).

(2) Lateral:

(a) Required holding capacity = 128,942 pounds

(b) Seafloor type is mud (given)

Depth of mud is 50 feet (given)

(c) Anchor type is Stato (given). From Table 18, safe efficiency = 10

Weight = 128,942/10 = 12,894 pounds = 12.9 kips

THEREFORE : Use 12,000-pound (12-kip) Stato anchor (although slightly undersized, this anchor will be adequate and its use is more practical than using a 15,000-pound Stato anchor).

(d) Required sediment depth: From Figure 80, the maximum fluke-tip depth is 42 feet. Therefore, the sediment depth (50 feet) is adequate.

(e) Drag distance: From Figure 82, the normalized anchor drag distance is:

D = 4.5 L

Calculate fluke length, L, using the equation from Figure 82 for determining L for Stato anchors:

$$L = 5.75\left(\frac{W}{3}\right)^{1/3}$$

Use calculated anchor weight, W, in kips:

W= 12.9 kips

SUBSTITUTING: $L = (5.75)\left(\frac{12.9}{3}\right)^{1/3} = 9.4$ feet

EXAMPLE PROBLEM 3 (Continued)

THEN: $D = (4.5)(9.4) = 42.3$ feet <50 feet; ok

Therefore, the drag distance is acceptable (maximum is 50 feet).

EXAMPLE PROBLEM 3 (Continued)

The following pages illustrate the use of the computer program described in Appendix B to solve Example Problem 3. The first type of output from the computer provides load-deflection curves for the bow (and stem) lines and the lateral lines. The second type of computer output consists of a summary of the mooring geometry and applied and distributed mooring loads.

Chain length = 585 Weight/length = 18.6
Water depth = 52

Horiz Force	Vert Force	Total Force	Upper Chn Up	Sinker Ht	Lower Chn Up	Anchor Angle	Chock-Buoy	Chock-Anchor
0	967	967	52.0	0.0	0.0	0.0	0.0	533.0
3701	2845	4668	153.0	0.0	0.0	0.0	0.0	572.9
7402	3906	8370	210.0	0.0	0.0	0.0	0.0	576.3
11104	4734	12071	254.5	0.0	0.0	0.0	0.0	577.9
14805	5438	15772	292.4	0.0	0.0	0.0	0.0	570.8
18506	6061	19473	325.9	0.0	0.0	0.0	0.0	579.4
22207	6625	23174	356.2	0.0	0.0	0.0	0.0	579.9
25908	7145	26876	384.1	0.0	0.0	0.0	0.0	580.3
29610	7630	30577	410.2	0.0	0.0	0.0	0.0	580.6
33311	8085	34278	434.7	0.0	0.0	0.0	0.0	580.8
37012	8517	37979	457.9	0.0	0.0	0.0	0.0	581.1
40713	8927	41680	479.9	0.0	0.0	0.0	0.0	581.2
44414	9319	45382	501.0	0.0	0.0	0.0	0.0	581.4
48116	9696	49083	521.3	0.0	0.0	0.0	0.0	581.5
51817	10058	52784	540.8	0.0	0.0	0.0	0.0	581.7
55518	10408	56485	559.6	0.0	0.0	0.0	0.0	581.8
59219	10747	60186	577.8	0.0	0.0	0.0	0.0	581.9
62920	11076	63888	585.0	0.0	0.0	0.2	0.0	582.0
66622	11406	67591	585.0	0.0	0.0	0.5	0.0	582.0
70323	11735	71295	585.0	0.0	0.0	0.7	0.0	582.1
74024	12064	75001	585.0	0.0	0.0	0.9	0.0	582.2
77725	12394	78707	585.0	0.0	0.0	1.1	0.0	582.2
81426	12723	82414	585.0	0.0	0.0	1.3	0.0	582.3
85128	13053	86122	585.0	0.0	0.0	1.5	0.0	582.3
88829	13383	89831	585.0	0.0	0.0	1.6	0.0	582.3
92530	13712	93541	585.0	0.0	0.0	1.8	0.0	582.4
96231	14042	97250	585.0	0.0	0.0	1.9	0.0	582.4
99932	14372	100961	585.0	0.0	0.0	2.0	0.0	582.4
103634	14702	104671	585.0	0.0	0.0	2.1	0.0	582.4
107333	15031	108382	585.0	0.0	0.0	2.2	0.0	582.4
111036	15361	112094	585.0	0.0	0.0	2.3	0.0	582.5
114737	15691	115805	585.0	0.0	0.0	2.4	0.0	582.5
118438	16021	119517	585.0	0.0	0.0	2.5	0.0	582.5
122140	16351	123229	585.0	0.0	0.0	2.6	0.0	582.5
125841	16681	126942	585.0	0.0	0.0	2.6	0.0	582.5
129542	17011	130654	585.0	0.0	0.0	2.7	0.0	582.5
133243	17341	134367	585.0	0.0	0.0	2.8	0.0	582.5
136944	17671	138080	585.0	0.0	0.0	2.8	0.0	582.5
140646	18001	141793	585.0	0.0	0.0	2.9	0.0	582.5
144347	18331	145506	585.0	0.0	0.0	3.0	0.0	582.5
148048	18661	149220	585.0	0.0	0.0	3.0	0.0	582.6
151749	18992	152933	585.0	0.0	0.0	3.1	0.0	582.6
155450	19322	156647	585.0	0.0	0.0	3.1	0.0	582.6
159152	19652	160360	585.0	0.0	0.0	3.2	0.0	582.6
162853	19982	164074	585.0	0.0	0.0	3.2	0.0	582.6
166554	20312	167788	585.0	0.0	0.0	3.2	0.0	582.6
170255	20642	171502	585.0	0.0	0.0	3.3	0.0	582.6
173956	20972	175216	585.0	0.0	0.0	3.3	0.0	582.6
177658	21302	178930	585.0	0.0	0.0	3.4	0.0	582.6
181359	21633	182645	585.0	0.0	0.0	3.4	0.0	582.6
185060	21963	186359	585.0	0.0	0. o	3.4	0.0	582.6

Chain length = 540 Weight/length = 41.8
Water depth = 52

Horiz Force	Vert Force	Tot al Force	Upper Chn Up	Sinker Ht	Lower Chn Up	Anchor Angle	Chock-Buoy	Chock-Ahchor
0	2174	2174	52.0	0.0	0.0	0.0	0.0	488.0
8062	6306	10236	150.9	0.0	0.0	0.0	0.0	527.8
16124	8650	18298	206.9	0.0	0.0	0.0	0.0	531.2
24186	10482	26360	250.8	0.0	0.0	0.0	0.0	532.7
32248	12038	34422	288.0	0.0	0.0	0.0	0.0	533.7
40310	13415	42484	320.9	0.0	0.0	0.0	0.0	534.4
48372	14663	50546	350.8	0.0	0.0	0.0	0.0	534.8
56434	15813	58608	378.3	0.0	0.0	0.0	0.0	535.2
64496	16885	66670	403.9	0.0	0.0	0.0	0.0	535.5
72558	17893	74732	428.1	0.0	0.0	0.0	0.0	535.8
80620	18847	82794	450.9	0.0	0.0	0.0	0.0	536.0
88682	19755	90856	472.6	0.0	0.0	0.0	0.0	536.2
94744	20623	98918	493.4	0.0	0.0	0.0	0.0	536.3
104806	21455	106980	513.3	0.0	0.0	0.0	0.0	536.5
112868	22257	115042	532.5	0.0	0.0	0.0	0.0	536.6
120930	23036	123104	540.0	0.0	0.0	0.2	0.0	536.7
128992	23813	131172	540.0	0.0	0.0	0.6	0.0	536.8
137054	24590	139243	540.0	0.0	0.0	0.8	0.0	536.9
145116	25367	147317	540.0	0.0	0.0	1.1	0.0	537.0
153178	26145	155393	540.0	0.0	0.0	1.3	0.0	537.0
161240	26923	163472	540.0	0.0	0.0	1.5	0.0	537.1
169302	27701	171553	540.0	0.0	0.0	1.7	0.0	537.1
177364	28480	179636	540.0	0.0	0.0	1.9	0.0	537.1
105426	29258	187720	540.0	0.0	0.0	2.1	0.0	537.2
193488	30037	195805	540.0	0.0	0.0	2.2	0.0	537.2
201550	30815	203892	540.0	0.0	0.0	2.3	0.0	537.2
209612	31594	211980	540.0	0.0	0.0	2.5	0.0	537.2
217674	32373	220068	540.0	0.0	0.0	2.6	0.0	537.3
223736	33152	228157	540.0	0.0	0.0	2.7	0.0	537.3
233798	33931	236247	540.0	0.0	0.0	2.8	0.0	537. 3
241860	34710	244338	540.0	0.0	0.0	2.9	0.0	537.3
249922	35489	252429	540. 0	0.0	0.0	3.0	0.0	537.3
257984	36269	260521	540.0	0.0	0.0	3.0	0.0	537.3
266046	37048	268613	540.0	0.0	0.0	3.1	0.0	537.3
274108	37827	276706	540.0	0.0	0.0	3.2	0.0	537.3
282170	30606	284799	540.0	0.0	0.0	3.3	0.0	537.3
290232	39386	292892	540.0	0.0	0.0	3.3	0.0	537.4
298294	40165	300986	540.0	0.0	0.0	3.4	0.0	537.4
306356	40945	309080	540.0	0.0	0.0	3.4	0.0	537.4
314418	41724	317174	540.0	0.0	0.0	3.5	0.0	537.4
322480	42504	325269	540.0	0.0	0.0	3.5	0.0	537.4
330542	43283	333364	540.0	0.0	0.0	3.6	0.0	537.4
338604	44063	341459	540.0	0.0	0.0	3.6	0.0	537.4
346666	44842	349554	540.0	0.0	0.0	3.7	0.0	537.4
354728	45622	357650	540.0	0.0	0.0	3.7	0.0	537.4
362790	46401	365745	540.0	0.0	0.0	3.8	0.0	537.4
370852	47181	37384	540.0	0.0	0.0	3.8	0.0	537.4
378914	47960	381937	540.0	0.0	0.0	3.8	0.0	537.4
306976	48740	390033	540.0	0.0	0.0	3.9	0.0	537.4
395038	49520	398130	540.0	0.0	0.0	3.9	0.0	537.4
403100	50299	406226	540.0	0.0	0.0	3.9	0.0	537.4

MULTIPLE POINT M00RING ANALYSIS

EXAMPLE S

ANCHOR LEG INPUT DATA:

Leg No.	Chock Coords x	Y	Leg Angle	Preload	Anchor Coords X	Y
1	265.0	0.0	0.0	2000	819.6	0.0
2	273.5	-37.0	-90.0	2000	273. 5	-534.9
3	-273.5	-37.0	-90.0	2000	-273.5	-534.9
4	-265.0	0.0	180.0	2000	-819.6	0.0
s	-273.5	37.0	90.0	2000	-273.5	534.9
6	273.5	37.0	90.0	2000	273.5	534.9

RESULTS FOR LOAD CASE 0 INITIAL POSITION

	Applied Load	Load Error	Displacement
Surge	0.000E+00	1.006E-02	0.0
Sway	0.000E+00	5.615E-03	0.0
Yaw	0.000E+00	-1.533E+O0	-0.0

Anchor Legs

Line No.	Horizontal Load	Anchor-Chock	Line Angle
1	2000	554.6	-0.0
2	2000	497.9	-90.0
3	2000	497.9	-90.0
4	2000	554. 6	100.0
5	2000	497.9	90.0
6	2000	497.9	90.0

RESULTS FOR LOAD CASE 1 MAX Y-LOAD

	Appliod Load	Load Error	Displacement
Surge	-9.314E+03	1.238E+01	-17.2
sway	1.888E+O5	-1.607E+O1	36.1
Yaw	6.522E+06	-1.159E+03	0.1

Anchor Legs

Line No.	Horizontal Load	Anchor-Chock	Line Angle
1	3832	573.0	-3.8
2	106507	536.5	-88.2
3	82067	536.0	-88.2
4	531	538 .7	184.0
5	0	460. 3	87.9
6	0	459 .8	87.9

RESULTS FOR LOAD CASE 2 MAX X-LOAD

	Applied Load	Load Error	Displacement
Surge	-3.307E+04	5.815E+00	-25.3
sway	2. 567E+04	-3.322E+01	31.0
Yaw	2.140E+06	2.383E+03	0.3

Anchor Legs

Line No.	Horizontal Load	Anchor-chock	Line Angle
1	31991	580.8	-3.2
2	15027	530. 7	-87.3
3	8933	528. 1	-87.3
4	0	530. 1	183. 2
5	0	468.9	86.9
6	0	466.3	86.9

Appendix A. BASIC CONCEPTS OF PROBABILITY

Most environmental conditions are randomly variable in nature; hence, they are best treated in probabilistic terms. The probability of an event is defined as the ratio of the number of times, n, that event occurred in N trials. This is written as follows:

$$P(E) = \frac{n}{N} \tag{A-1}$$

WHERE : $P(E)$ = probability that event E will occur

n = number of times event E occurred

N = total number of trials

The probability that event E will not occur is the complement of E and is written:

$$P(\overline{E}) = 1 - P(E) \tag{A-2}$$

WHERE : $P(\overline{E})$ = probability that event E till not occur

$P(E)$ = probability that event E will occur

The probability of an event always takes on a number between O and 1, unless it is written in percent. In this case, it takes on a value between 0 and 100 percent. The sum of the probabilities of all events is equal to 1 or, if written in percent, 100 percent. It is often desirable to know the probability that two (independent) events, E and E_2, will occur simultaneously. This is known as the joint probability of E_1 and E_2. This is written as follows:

$$P(E_1 \cap E_2) = [P(E_1)]\ [P(E_2)] \tag{A-3}$$

WHERE : $P(E_1 \cap E_2)$ = joint probability of events E_1 and E_2 occurring simultaneously

$P(E_1)$ = probability that event E_1 will occur

$P(E_2)$ = probability that event E_2 will occur

The probability that a given random variable, X, takes on a specified value, x, is designated as $P(X = x)$. An example of a plot of probability $P(X = x)$ for several values of x is shown in Figure A-1A. The probability that a given random variable, X, is less than or equal to a specified value, x, is known as the cumulative probability; cumulative probability is designated as $P(X < x)$. The cumulative probability may be evaluated as follows:

$$P(X \leq x) = \sum_{i=1}^{k} P(X = x_i) \tag{A-4}$$

WHERE: $P(X < X)$ = cumulative probability that variable X is less than or equal to value x

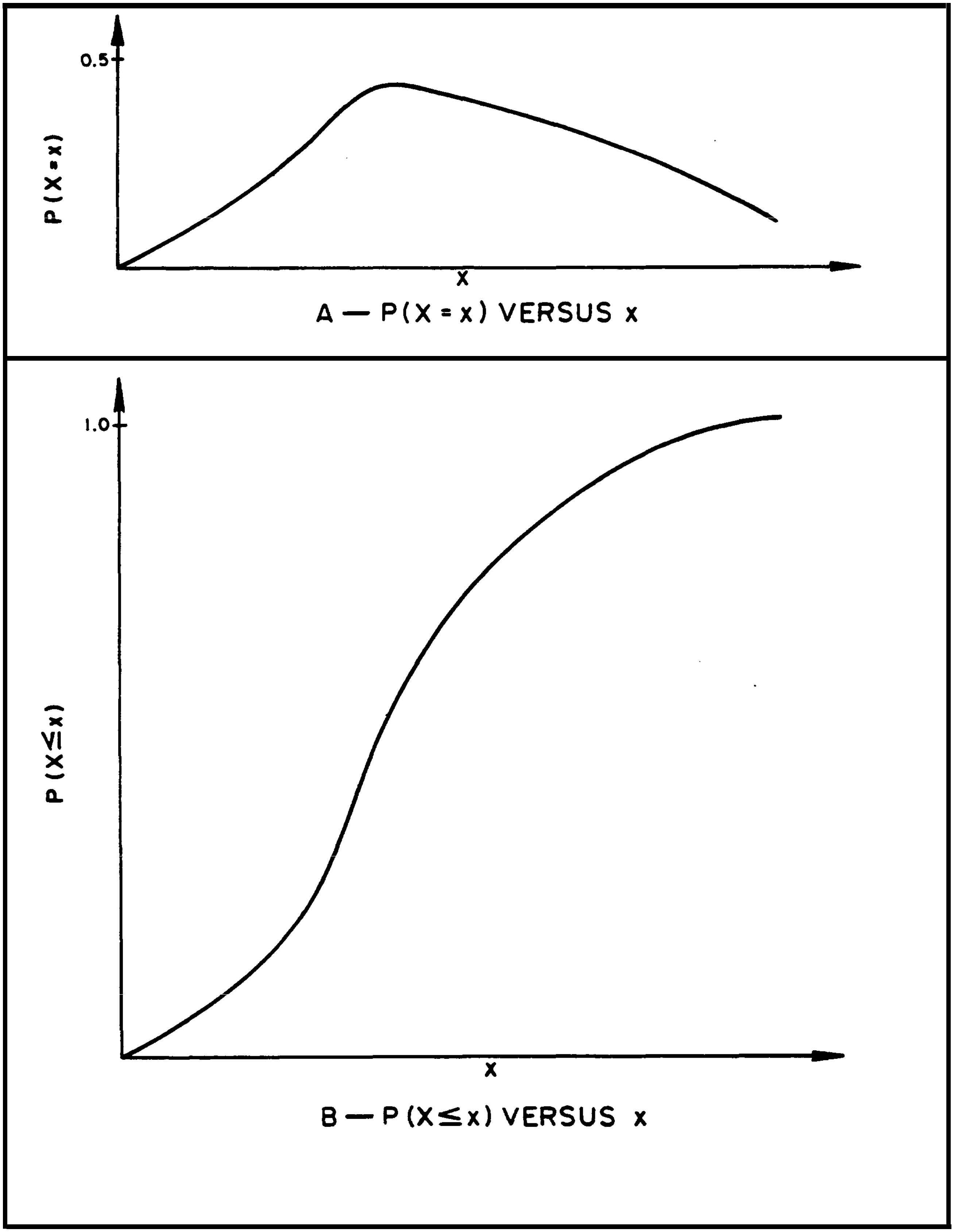


FIGURE A-1
Example Plots of Probability for P(X = x) and P(X < X)

$P(x = x_i)$ = probability that variable X will take on value x_i

An example plot of a cumulative distribution function is shown in Figure A-lB.

The probability of exceedence is the probability that a variable, X, is greater than or equal to x_k The probability of exceedence is given as:

$$P(X \geq x_k) = 1 - \sum_{i=1}^{k} P(X = x_i) \qquad \text{(A-5)}$$

WHERE: $P(x > x_k)$ = probability of exceedence (probability that variable X is greater than or equal to value x_k)

When the probability of exceedence of a given event is specified, the reciprocal of that probability is the average return period, T, also referred to as the recurrence interval:

$$T = \frac{1}{P(X > x)} = \frac{1}{1 - P(x < x)} \qquad \text{(A-6)}$$

WHERE : T = return period = recurrence interval

For example, if the probability that a windspeed, V, equals or exceeds 50 knots is 0.05, then, on the average, a windspeed greater than or equal to 50 knots will occur once every 20 years:

$$P(V > 50 \text{ knots}) = 0.05$$

THEN: $T = \frac{1}{0.05} = 20$ years

The probability that a variable, X, will not equal or exceed x in any year is defined as:

$$P(x < x) = 1 - \frac{1}{T} \qquad \text{(A-7)}$$

The probability that a variable, X, will not equal or exceed x in L successive years is defined as:

$$P(X<X)^L = (1 - \frac{1}{T})^L \qquad \text{(A-8)}$$

WHERE : $P(X<X)^L$ = probability that variable X will not equal or exceed value x in L sucessive *years*

L = number of successive years

The probability that a variable, X, will equal or exceed x at least once in L successive years is referred to as risk, R, and is defined as:

$$R(X > x) = 1 - (1 - \frac{1}{T})^L \qquad \text{(A-9)}$$

WHERE : R . risk (probability that variable X will equal or exceed value x at least once in L successive years)

For example, suppose that, for a given location, an 80-knot wind has a return period of 50 years. From Equation (A-6):

$$T = \frac{1}{P(x > x)}$$

SUBSTITUTING: $$50 = \frac{1}{P(V > 80\ \text{knots})}$$

THEN : $$P(V > 80\ \text{knots}) = 0.02$$

It is desired that a mooring located in the area have a design life of 5 years. Then the risk that the mooring will be subjected to a So-knot wind at least once in 5 years, using Equation (A-9) is:

$$R(V > 80\ \text{knots}) = 1 - (1 - \frac{1}{50})^5 = 0.096 = 9.6\ \text{percent}$$

Determining the probability of exceedence for wind events is useful for the purposes of estimating the probability and the return period of annual extreme events. Estimating extreme wind conditions for the purpose of mooring design is most easily done through analysis of annual maximum values. In the analysis of annual maximum values, an efficient means of determining the probability of exceedence and return period of those values is to use a "plotting formula." This technique involves ranking the annual maximum data in either increasing or decreasing order. The following equation is then used to determine the probability of each value:

$$P(x > x) = \frac{m}{N + l} \qquad \text{(A-10)}$$

WHERE : $P(x > x)$ = probability that the variable X will equal or exceed the specified value x with rank m, when the data are ranked from highest to lowest

m = rank of the value x

N = total number of maximum values in the record

The return period, T, associated with $P(X > x)$ is then given by:

$$T = \frac{1}{P(X > x)} \qquad \text{(A-11)}$$

WHERE : T = return period

Once the probabilities of each event have been determined, they are plotted on probability paper. Figure A-2 presents an example of probability paper based on the Gumbel extremal distribution, a commonly used distribution for the analysis of extreme values. The equation for this distribution is:

$$P(X > x) = 1 - e\ [-e^{-\alpha(X - u)}] \qquad \text{(A-12)}$$

WHERE : $P(X > X)$ = probability that variable X will equal or exceed a specified value x

e = base of natural logarithm = 2.7182818

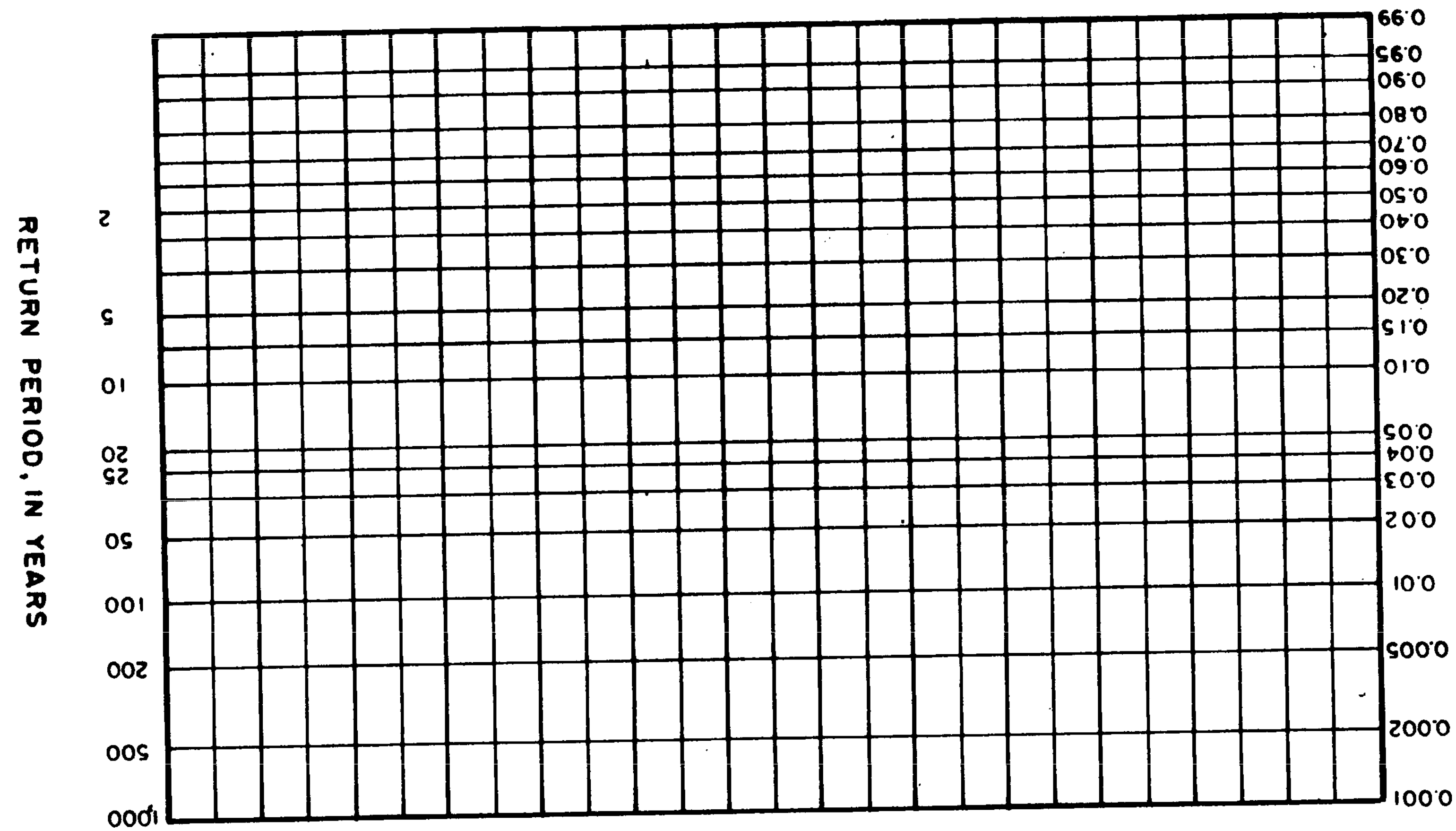


FIGURE **A-2**
Gumbel Paper

$$\alpha = \frac{1.282}{\sigma} \qquad \text{(A-13)}$$

$$\sigma = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2 = \text{standard deviation of the data} \qquad \text{(A-14)}$$

N = total number of occurrences

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i = \text{mean value of data} \qquad \text{(A-14)}$$

$$u = \bar{x} - \frac{0.577}{\alpha} \qquad \text{(A-15)}$$

Equation (A-12) can be used to plot a straight line on Figure A-2. The data plotted from the "plotting formula" procedure can be compared to the straight-line Gumbel distribution plot to determine how well the data fit the Gumbel distribution.

METRIC EQUIVALENCE CHART. The following metric equivalents were developed in accordance with ASTM E-621. These units are listed in the sequence in which they appear in the text of Appendix A. Conversions are approximate.

50 knots = 25.5 meters per second
80 knots = 40.8 meters per second

Appendix B. COMPUTER PROGRAM DOCUMENTATION

1. **MODEL DESCRIPTION.** The mooring program package is a menu-controlled group of microprocessor programs written in Microsoft GBASIC for solution to fixed- and fleet-mooring problems. Figure B-1 presents an outline of the mooring program. It can be used to determine forces and displacements in the mooring systems of ships subjected to horizontal static applied loads. The moorings may be composed of mooring lines (hawsers) , anchor chains, and fenders. The load-deflection characteristics of fenders and hawser materials are entered as input. Anchor chains are computed as catenaries.

Solutions are obtained iteratively, starting with the ship in an assumed position relative to its mooring points. Reactive loads in the lines and fenders are added successively to the applied forces to obtain the resultant surge and sway forces and yaw moment on the ship. Derivatives of these force components with respect to displacement in surge, sway, and yaw are also computed, and the Newton-Raphson method (Gerald, 1980) is used to get an approximation of the ship displacement which will bring the forces to equilibrium. The process is repeated with the ship in its new position, and continued until the resultant forces are within tolerance.

Two solving programs are provided. FLEET is used for mooring systems whose elements are all hawsers and anchor chains. The legs may consist of two different chain sizes with a sinker at the junction and may have a buoy and a hawser. Fixed moorings made up of fenders and lines, as well as chains, are solved using the program FIXEM. This program accounts for the vertical positions of mooring points when computing line stretch, and will compute line forces due to changing tide level.

Other features of this mooring program package are: (a) screen display of instructions for using programs, (b) separate entry and storage of load-deflection curves for anchor chains, (c) entry of dimensionless load-deflection tables for hawser materials, and (d) editing and storage of problem input data sets (separate programs for fleet and fixed moorings).

Figure B-2 is a definition sketch showing the main dimensional variables used in the programs. The coordinate system (referred to as the “global coordinate system”) is defined relative to the ship’s initial assumed position, with the origin, O, at the ship’s center of gravity. The x-axis coincides with the ship’s longitudinal axis; location of the y-axis is arbitrary, but it is convenient to locate the y-axis along the transverse axis of the ship. When the ship moves as the result of unbalanced forces, the center of gravity moves to a new location, designated S and referred to as the ship origin (or origin of ship local coordinate system). Three variables are needed to describe the new position: the surge displacement, x, the sway displacement, y, and the yaw angle, 9. Positive yaw is measured from the positive x-axis toward the positive y-axis. The horizontal component of tension in a mooring line, such as that shown as AC in Figure B-2, can be determined as a function of the horizontal distance between the attachment point (chock) on the ship and the fixed anchor or mooring point. The procedure for computing load-deflection curves is described later. The load-deflection curves are stored as series of load-distance pairs: Using

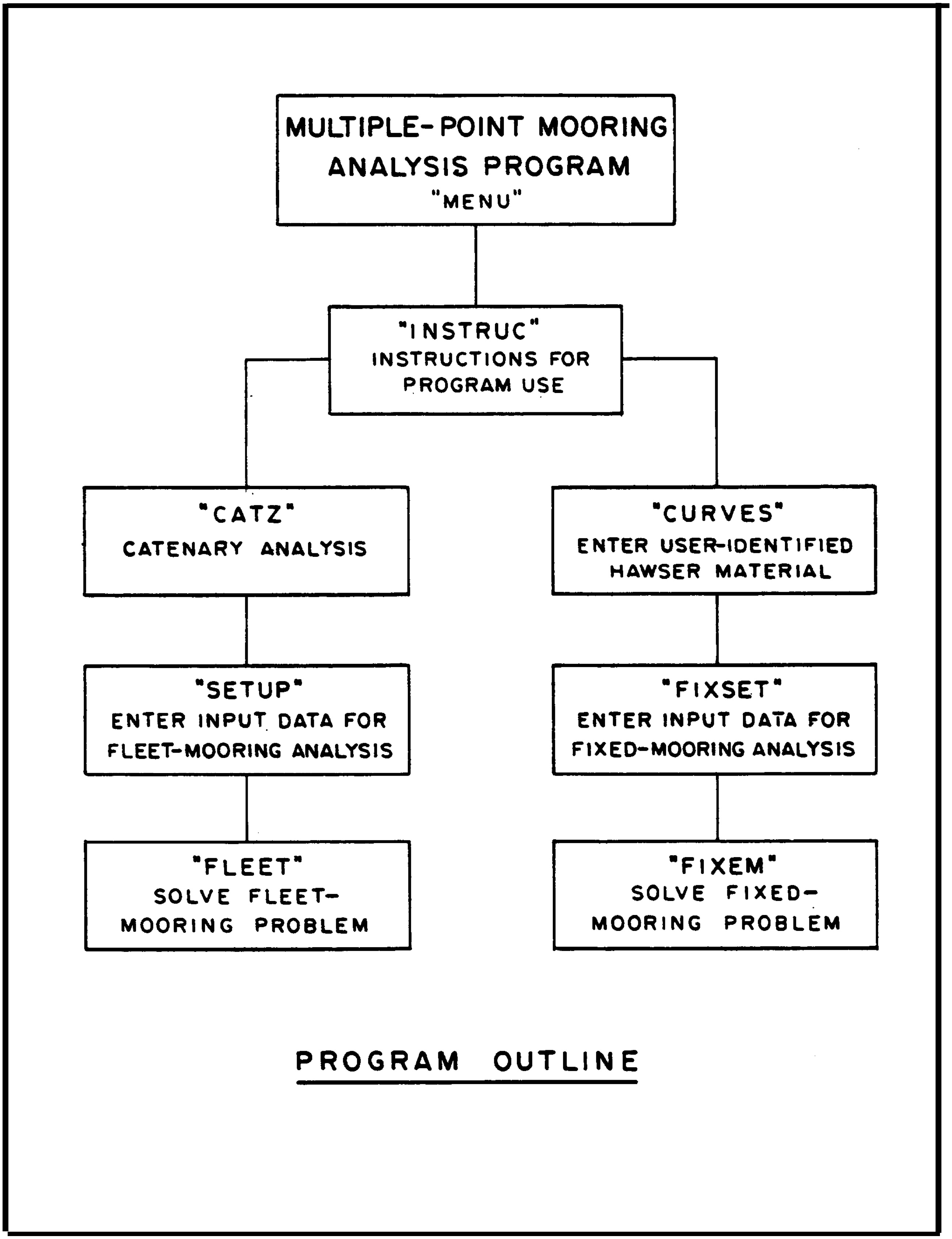


FIGURE B-1
Outline of the Mooring Program

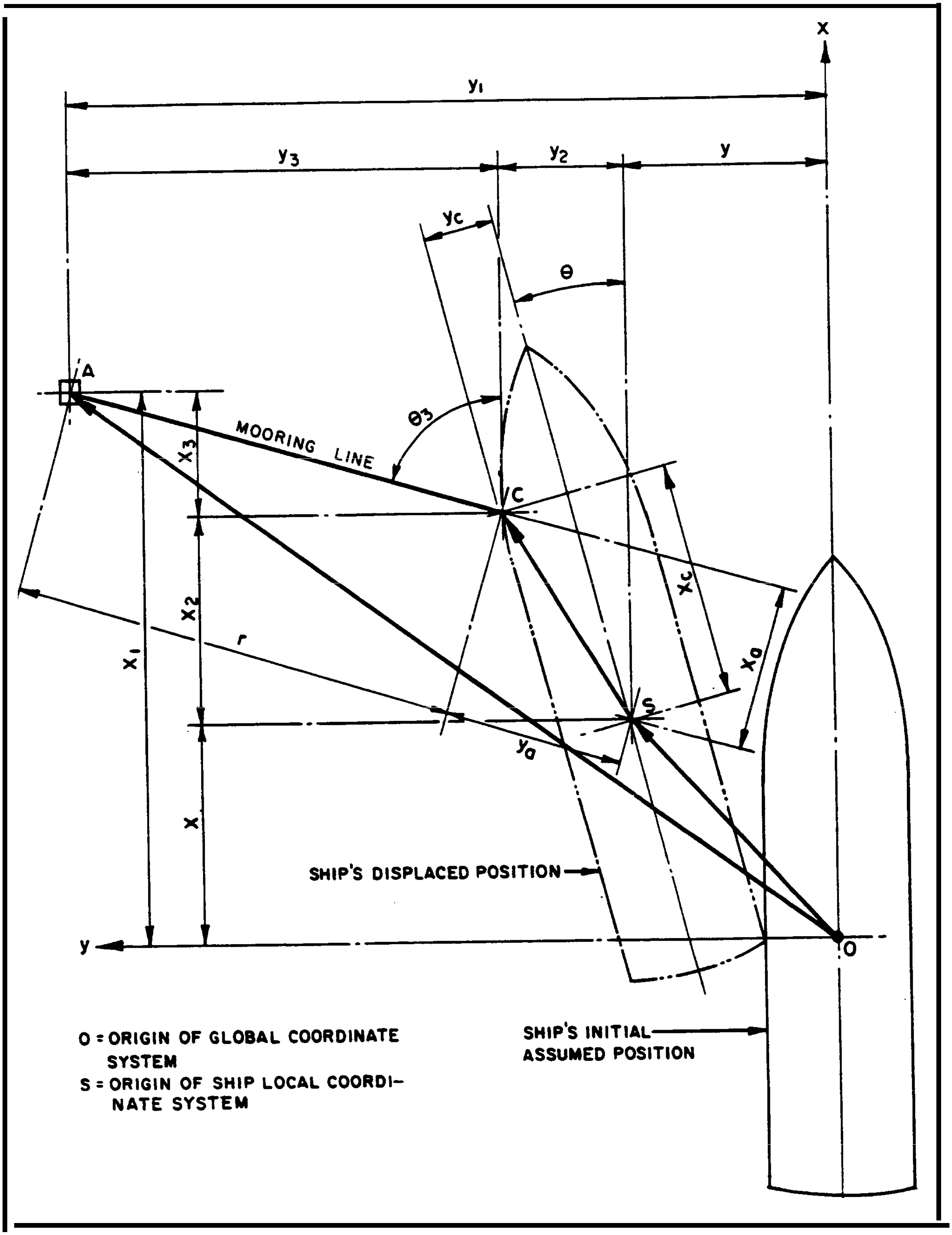


FIGURE B-2
Mooring-Line Definition Sketch

simple geometry, the following steps lead to expressions for the mooring-line length and its direction:

$$x_2 = x_c \cos\theta - y_c \sin\theta \tag{B-1}$$

$$y_2 = x_c \text{ Sin } \theta + y_c \cos\theta \tag{B-2}$$

$$x_3 = X_1 - X - X_2 \tag{B-3}$$

$$y_3 = y_1 - y - y_2 \tag{B-4}$$

$$r = \sqrt{x_3^{\,2} + y_3^{\,2}} \tag{B-5}$$

$$\cos\theta_3 = x_3/r \tag{B-6}$$

$$\text{six } \theta_3 = y_3/r \tag{B-7}$$

NOTE : A list of symbols is provided at the end of this subsection.

The x- and y-components of the force exerted by the mooring line on the ship, and the moment (due to the mooring line) about the ship origin, S, are then given by:

$$H = f(r) \tag{B-8}$$

$$F_x = H \text{ COS } \theta_3 \tag{B-9}$$

$$F_y = H \sin\theta_3 \tag{B-10}$$

$$M_{xy} = F_y x_2 - F_x y_2 \tag{B-11}$$

The derivatives of these force components with respect to x, y, and θ are also required. They are readily obtained by differentiating the above expressions, as follows:

$$dr/dx = -\cos\theta_3 \tag{B-12}$$

$$dr/dy = -\sin\theta_3 \tag{B-13}$$

$$d\theta_3/dx = (\sin\theta_3)/r \tag{B-14}$$

$$d\theta_3/dy = -(\cos\theta_3)/r \tag{B-15}$$

$$dr/d\theta = -X_2 \sin\theta_3 + y_2 \cos\theta_3 = -x_a \tag{B-16}$$

$$d\theta_3/d\theta = -(x_2 \cos\theta_3 + y_2 \sin\theta_3)/r = -y_a/r \tag{B-17}$$

$$H' = f'(r) \tag{B-18}$$

$$dF_x/dx = -H' \cos^2\theta_3 - (H/r)\sin^2\theta_3 \tag{B-19}$$

$$dF_x/dy = [-H' + (H/r)]\sin\theta_3 \cos\theta_3 \tag{B-20}$$

$$dF_x/d\theta = -H' x_a \cos\theta_3 + (H/r) y_a \sin\theta_3 \quad \text{(B-21)}$$

$$dF_y/dy = -H' \sin^2\theta_3 - (H/r)\cos^2\theta_3 \quad \text{(B-22)}$$

$$dF_y/d\theta = -H' x_a \sin\theta_3 - (H/r) y_a \cos\theta_3 \quad \text{(B-23)}$$

$$dM_{xy}/d\theta = x_2 (dF_y/d\theta - F_x) - y_2 (dF_x/d\theta + F_y) \quad \text{(B-24)}$$

$$dF_y/dx = dF_x/dy \quad \text{(B-25)}$$

$$dM_{yx}/dx = dF_x/d\theta \quad \text{(B-26)}$$

$$dM_{xy}/dy = dF_y/d\theta \quad \text{(B-27)}$$

The total surge force on the ship is obtained by summing expressions like Equations (B-9) through (B-n) over all of the mooring lines and adding the applied x-force (due to wind and current). Total sway force and yaw moment are computed in the same way, and the derivative expressions are also summed over all lines. It is assumed in the computation that the applied loads remain constant during changes in ship position and orientation.

The Newton-Raphson method is used to arrive at values of x, y, and θ for which the total force and moment on the ship are zero. In the expressions for the total differential of force components,

$$dF_i = (dF_i/dx)\, dx + (dF_i/dy)\, dy + (dF_i/d\theta)\, d\theta \quad \text{(B-28)}$$

the differential motions, dx, dy, and $d\theta$, are approximated by finite increments, Δx, Δy, and $\Delta\theta$, while the force differentials, dF_x, dF_y, and dM_{xy}, are replaced by the force increments needed to bring the total force to zero:

$$(\Sigma dF_x/dx)\,\Delta x + (\Sigma dF_x/dy)\,\Delta y + (\Sigma dF_x/d\theta)\,\Delta\theta = -F_{xa} - \Sigma F_x \quad \text{(B-29)}$$

$$(\Sigma dF_y/dx)\,\Delta x + (\Sigma dF_y/dy)\,\Delta y + (\Sigma dF_y/d\theta)\,\Delta\theta = -F_{ya} - \Sigma F_y \quad \text{(B-30)}$$

$$(\Sigma dM_{xy}/dx)\,\Delta x + (\Sigma dM_{xy}/dy)\,\Delta y + (\Sigma dM_{xy}/d\theta)\,\Delta\theta = -M_{xya} - \Sigma M_{xy} \quad \text{(B-31)}$$

This set of equations is solved for Δx, Δy, and $\Delta\theta$; the ship is moved to $x + \Delta x$, $y + \Delta y$, and $\theta + \Delta\theta$, and the process is repeated until the computed total force components are all within the desired tolerance.

The expressions given above for mooring-line forces and their derivatives are applicable to hawsers and to anchor chains, both of which run between a mooring point and a fixed chock on the ship. Compressible fenders work somewhat differently from hawsers and anchor chains in that the point of contact of a compressible fender with the ship's hull is variable. Figure B-3 defines the geometry used in handling fenders. The fender is assumed to occupy a relatively small volume and to be fixed in position against a wharf, quay, or dolphin. The ship's topsides are assumed *to* be parallel to the ship's axis wherever they come in contact with a fender. Deflection of a fender is the perpendicular distance from the fender location to the ship's side. The fender reaction is a known function of deflection, and acts in the opposite direction.

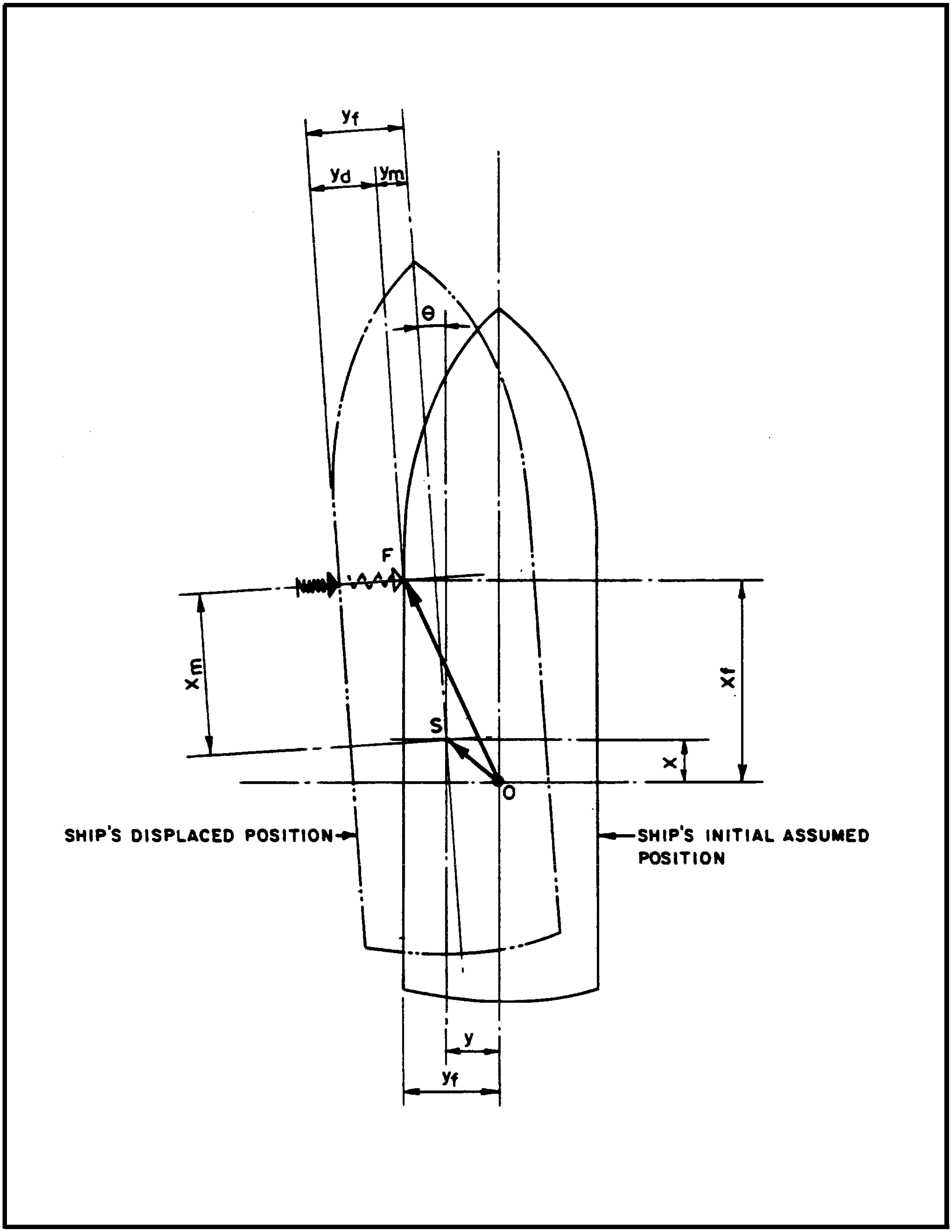


FIGURE **B-3**
Fender Definition Sketch

Relationships among various dimensions follow directly from the geometry of Figure B-3. Note that the dimensions X_f and y_f serve to define both the fender position and the ship's beam in the vicinity of the fender. For this reason, it is necessary, for purposes of the computation, that the ship be initially in contact with all active fenders. Expressions for the fender deflection are given below:

$$x_m = (X_f - x) \cos\theta + (y_f - y) \sin\theta \tag{B-32}$$

$$Y_m = -(X_f - x) \sin\theta + (y_f - y) \cos\theta \tag{B-33}$$

$$y_d = Y_f - Y_m \tag{B-34}$$

Fender force components and their derivatives become:

$$H = f(y_d) \tag{B-35}$$

$$F_x = H \sin\theta \tag{B-36}$$

$$F_y = -H \cos\theta \tag{B-37}$$

$$M_{xy} = -H x_m \tag{B-38}$$

$$H' = f'(y_d) \tag{B-39}$$

$$dF_x/dx = -H' \sin^2\theta \tag{B-40}$$

$$dF_x/dy = H' \sin\theta \cos\theta \tag{B-4 1}$$

$$dF_x/d\theta = H \cos\theta + H' X_m \sin\theta \tag{B-42}$$

$$dF_y/dy = -H' \cos^2\theta \tag{B-43}$$

$$dF_y/d\theta = -H \sin\theta - H' X_m \cos\theta \tag{B-44}$$

$$dM_{xy}/d\theta = Hy_m - H' X_m^2 \tag{B-45}$$

$$dF_y/dx = dF_x/dy \tag{B-46}$$

$$dM_{xy}/dx = dF_x/d\theta \tag{B-47}$$

$$dM_{xy}/dy = dF_y/d\theta \tag{B-48}$$

These expressions are used for fenders in the sums which appear in Equations (B-29) through (B-31).

bad-deflection curves for each line, chain, and fender in the mooring system must be available in order to proceed with the iterative computation described above. Curies for the three types of mooring units (fenders, lines, and chains) are introduced in different ways. The fender curves are entered manually as part of the input data set for fixed-mooring problems. Hawser curves are created within the program FIXEM. Curves for anchor chains are created by a separate program (CATZ) and saved on a disk file for subsequent use by the solving program (FLEET and FIXEM).

The characteristics of a hawser as accepted by the programs are illustrated in Figure B-4A. The line is assumed to be weightless. It runs from the mooring point to a chock on the ship, and there may be additional on-deck length between the chock and the point of attachment. The hawser may be made of elastic steel wire, or of other material for which a dimensionless load-deflection table has been furnished. If the hawser is steel, it may have a cordage tail. Chocks are frictionless. The dimensionless load-deflection tables used by the programs contain 21 fractional elongation values which correspond to 5-percent increments of breaking strength. In order to *compute* a hawser load-deflection curve, the breaking strength of the cordage portion (if any) must be given, and the unstretched lengths of cordage and steel sections are calculated from given preload and initial line geometry. For a steel hawser with a tail of unstretched length, L_t, the unstretched wire length, La, is:

$$La = \frac{L_o + L_d - L_t[1 + g(P_o/B)]}{1 + P_o/A\ E} \tag{B-49}$$

The unstretched length, L_t, of a cordage hawser is:

$$L_t = (L_o + L_d)/[l + g(P_o/B)l \tag{B-50}$$

In either case, the load-deflection curve is then constructed by computing the horizontal distance between chock and mooring point and the horizontal component of line load for 21 total line loads between zero and breaking strength. The total (stretched) line length outboard of the chock, L, is:

$$L=L_a[1 + (P/AE)] + L_t[1 + g(P/B)] - L_d \tag{B-5 1}$$

and the horizontal projections of line, r, and load, H, are:

$$r = \sqrt{L^2 - (z_1 - z_c - z_t)^2} \tag{B-52}$$

$$H = P r / L \tag{B-53}$$

Anchor chain load-deflection curves are computed with the aid of catenary equations. The most general system that can be handled by the program is shown in Figure B-4B. It consists of lower and upper sections of chain which can be of different weights, a sinker at the connection point, and a hawser between the ship and the mooring buoy. Hawser characteristics are as described above, except that the total line load and outboard line length are used in place of their horizontal projections (that is, the hawser is assumed to run horizontally between buoy and ship). The buoy, if present, is assumed always to remain at the water surface.

The horizontal length of chain systems subjected to given horizontal load can be calculated from simple equations once the length of chain raised off the bottom and the vertical force on the anchor are known. Four cases must be distinguished: Case l--upper chain partly raised, Case 2--upper chain completely raised but sinker on the bottom, Case 3--lower chain partly raised, and Case 4--lower chain completely raised. In computing a load-deflection curve, the four cases are examined in sequence to determine which one prevails. As the load increases, fewer cases need to be considered. A Newton-Raphson method algorithm is used to solve for raised chain length and

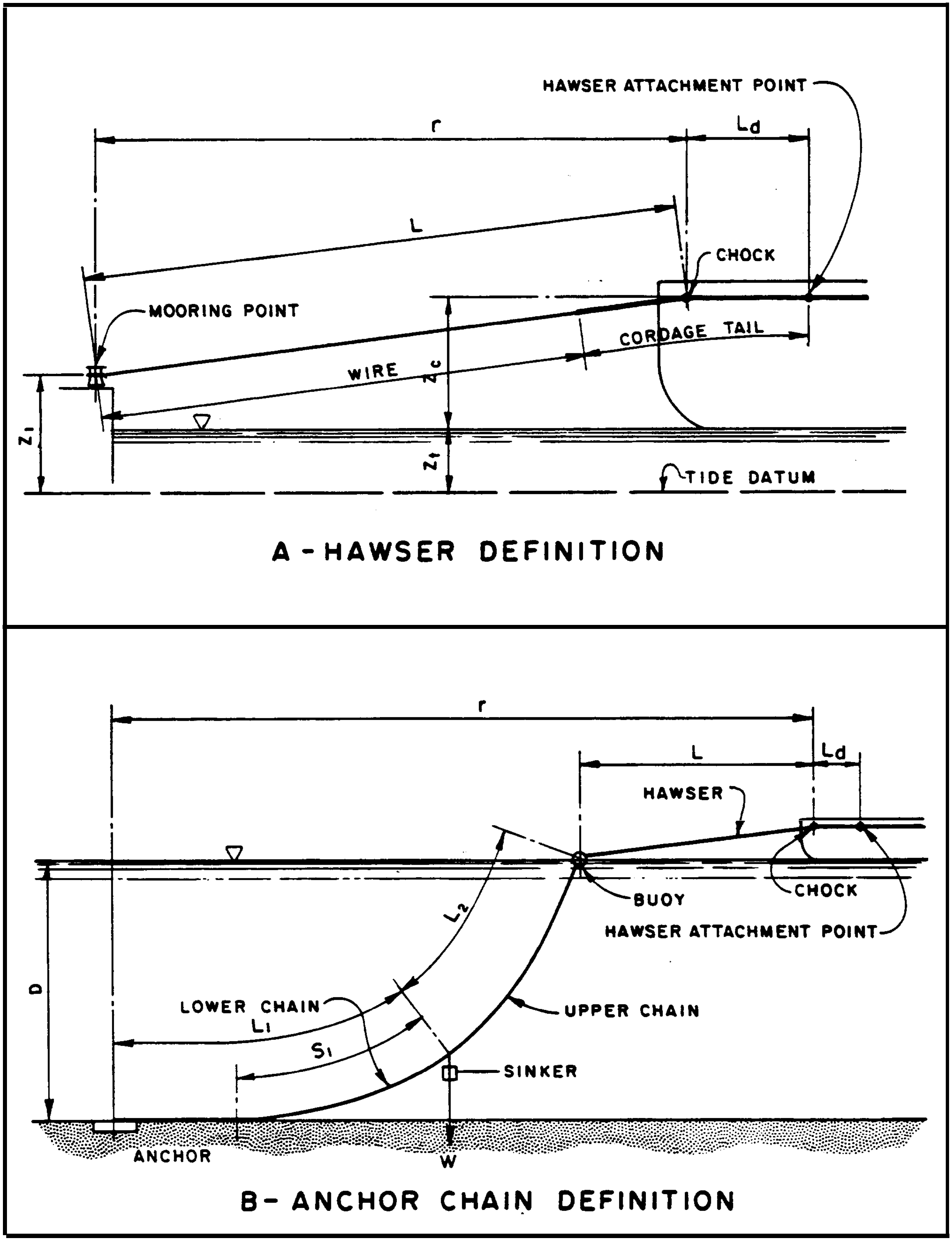


FIGURE B-4
Hawser and Anchor Chain Definition Sketches

vertical anchor load in Case 3 and Case 4, respectively. The equations used are the following:

Case 1: $S_2 = \sqrt{D(D + 2C_2)}$ (B-54)

$$r = L + L1 + L2 - S_2 + C_2 \log [s_2/c_2 + \sqrt{(s_2/c_2)^2 + 1}] \quad \text{(B-55)}$$

Case 2: $V = [(D/c_2) \sqrt{4/[(S_2/c_2)^2 - (D/c_2)^2] + 1} + (S_2/c_2)]\ 1/2$ (B-56)

$$a_1 = v + L_2/c_2 \quad \text{(B-57)}$$

$$r = L + L_1 + c_2 \log \frac{a_1 + \sqrt{a_1^2 + 1}}{v + \sqrt{v^2 + 1}} \quad \text{(B-58)}$$

Case 3: $a_1 = S_1/c_1 + W/H$ (B-59)

$$a_2 = a_1 + L_2/c_2 \quad \text{(B-60)}$$

$$c_1 [\sqrt{(S_1/c_1)^2 + 1} - 1] + c_2 [\sqrt{a_2^2 + 1} - \sqrt{a_1^2 + 1}] = D \quad \text{(B-6 1)}$$

(Solve for S_1 by the Newton-Raphson method.)

$$r = L + L_1 - S_1 + c_1 \log [S_1/c_1 + \sqrt{(S_1/c_1)^2 + 1}] + c_2 \log \frac{a_2 + \sqrt{a_2^2 + 1}}{a_1 + \sqrt{a_1^2 + 1}} \quad \text{(B-62)}$$

Case 4: $a_1 = v + L_1/c_1$ (B-63)

$$a_2 = a_1 + W/H \quad \text{(B-64)}$$

$$a_3 = a_2 + L_2/c_2 \quad \text{(B-65)}$$

$$c_1 (\sqrt{a_1^2 + 1} - \sqrt{v^2 + 1}) + c_2 (\sqrt{a_3^2 + 1} - \sqrt{a_2^2 + 1}) = D \quad \text{(B-66)}$$

(Solve for v by the Newton-Raphson method.)

$$r = L + c_1 \log \frac{a_1 + \sqrt{a_1^2 + 1}}{v + \sqrt{v^2 + 1}} + c_2 \log \frac{a_3 + \sqrt{a_3^2 + 1}}{a_2 + \sqrt{a_2^2 + 1}} \quad \text{(B-67)}$$

LIST OF SYMBOLS

A	cross-sectional area of steel hawser
a_1, a_2, a_3	intermediate variables in catenary equations
B	breaking strength of cordage portion of hawser
c_1, c_2	catenary constants, equal to H/w_1, H/w_2

D	water depth
E	elastic modulus of steel hawser
F_i	i^{th} force component
F_x, F_y	x- and y-components of force exerted on ship by mooring line
F_{xa}, F_{ya}	x- and y-components of total applied load on ship (due to wind. and current)
$f(r)$	horizontal force in mooring line as function of chock-anchor distance
$f'(r)$	first derivative of function f(r)
$f(y_d)$	horizontal fender reaction as function of fender deflection
$g(P/B)$	fractional extension of cordage material as function of fractional load
H	horizontal component of mooring-line load
H'	derivative of horizontal mooring-line load with respect *to* chock-anchor distance (r) *or* fender deflection (y_d)
L	true distance between chock on ship and mooring point
L_a	unstretched length of steel-wire hawser section
L_d	distance between mooring chock and hawser attachment point on ship
L_t	unstretched length of cordage hawser or cordage hawser tail
L_o	distance between chock and mooring point with ship at initial position
L_1, L_2	length of anchor chain sections
M_{xy}	yaw moment on ship due to load in mooring line
M_{xya}	yaw moment due to applied loads
O	origin of coordinate system relative to ship’s initial position (global coordinate system)
P	tension in mooring line
P_o	mooring-line tension with ship at initial position (preload)
r	horizontal distance between chock and anchor

S — origin of coordinate system relative to ship's displaced position (ship local coordinate system)

S_1, S_2 — length of chain sections raised off bottom

v — ratio of vertical force on anchor to horizontal load

W — submerged sinker weight

W_1, W_2 — submerged weight of anchor chain per unit length

x, y — ship displacement from initial position in x- and y-directions

x_c, y_c, z_c — coordinates of a mooring-line chock, relative to ship local origin

x_f, y_f — fender-position coordinates (in global system)

x_m, y_m — fender-position coordinates (in ship local system)

x_1, y_1, z_1 — coordinates of a mooring point or anchor (in global system)

x_2, y_2 — x- and y-distances between ship origin and mooring chock

x_3, y_3 — x- and y-distances between chock and anchor

y_d — fender deflection, defined as perpendicular distance from fender location to ship's side

z_t — tide height

θ — *yaw* angle of ship, relative to initial position

θ_3 — horizontal angle between mooring line and global x-axis

2. **DETAILED PROCEDURE**. The program disk provided can be used directly with a system consisting of an Apple IIe computer, Microsoft Premium Z80 card, one disk drive, and a printer. With other systems, the programs may require adaptation and editing. To use the programs, insert the program disk in Drive A. Set the printer to print near the top edge,of a fresh sheet. (If the printer is an Epson, the shiny metal shield on the printing head should have its upper edge lined up with a perforation.) Turn on power to the computer and printer. If the power is already on, insert the disk and press the Control, Hollow Apple, and Reset keys simultaneously. The disk drive will operate, first booting the CP/M system from the disk, then loading in GBASIC, and finally running the MENU program. On the menu screen are nine numbered options. Solution of problems is accomplished by executing a sequence of appropriate options from the menu. The menu screen returns on completion of each selection. To stop operation while a program is running, press Control-C; if the computer is waiting for input, press Control-C, Return. The options are numbered from O to 8. Their functions are as follows:

0. Quit. Clears screen and returns computer to GBASIC. MENU program remains loaded and can be started again by entering RUN. Other BASIC commands that may find use are FILES (displays catalog of files on disk), KILL “filename” (deletes file from disk), NEW (wipes out currently loaded program), NAME “oldfile” AS "newfile” (renames file on disk), and LOAD “filename” (loads new program from disk). Refer to GBASIC reference manual for complete information, including how to edit BASIC programs.
1. Display Instructions (Program INSTRUC). Text of instructions is read from file INFO and first page is displayed on screen. User can flip pages forward or backward, or return to menu, by pressing keys indicated at bottom of screen.
2. Compute Anchor Chain Load-Extension Curves (Program CATZ). This is a necessary preliminary step for solving moorings which include catenary chains. Characteristics of the chain system are entered by user in response *to* prompts on the screen. Data items to be entered are an ID number for the chain system, lengths and unit weights of upper and lower chain sections, sinker weight, hawser material code, length of hawser outboard of chock, ondeck hawser length, and breaking strength. If the hawser material is steel, the cross-sectional area and elastic modulus are entered. Finally, the maximum horizontal load and number of increments to be used in defining the load-extension curve are requested. The maximum number of points allowed by the program is 200; normally 50 are more than enough. The curve is computed, displayed, printed, if desired, and saved on disk under the file name CAT n, where “n” is the ID number designated by user. Items in the printout table are horizontal, vertical, and total load at the top of the chain, lengths of lower and upper chain raised off the bottom, height of sinker off bottom, vertical angle of chain at anchor, distance from chock to buoy, and horizontal distance from chock to anchor. The program recycles for additional curves if requested. If the ID number entered is the same as that of the previous curve, all other data items will appear on the screen during input; they may be left unchanged by pressing the Return key.

   In systems which have no mooring buoy, the water depth entered should be the actual depth plus the chock height. (A small error is introduced by accepting the submerged chain weight for the exposed section.) When chains are used in fixed systems, such as in a Mediterranean (Meal-type) mooring, it should be remembered that the solving program has no way of correcting these precomputed load-extension curves for changes in water depth due to tide. Therefore, tide height should be included in the depth when generating the curves. If necessary, several curves can be created for the same system at different tide levels.
3. Enter Hawser Material Load-Extension Curves (Program CURVES). Dimensionless load-extension curves are required for

nonelastic hawsers used in mooring systems. A material identification (ID) number, which must be in the range 4-20, is entered. If it corresponds with a curve already on file, the file is read and displayed on the screen. There are 21 values of percent elongation which correspond to 5-percent increments in the ratio of line load to breaking strength. Values may be entered or edited with the aid of editing commands shown at the top of the screen. They are “Space Bar” (move down one line), “/” (move up one line), “C” (clear whole file), “E” (terminate editing and save edited file), and “X” (cease editing and do not save). The series of points is saved on a disk file named LINE n. Files LINE 2 and LINE 3, for nylon and polypropylene, respectively, are already on the disk. Number 1 is reserved for steel, whose elongation is computed within programs CATZ and FIXEM by dividing the line tension by a cross section and elastic modulus. (This procedure can be applied to any material which has a linear load-extension tune, merely by calling it “steel.”)

4. Enter Input Data for Fleet-Mooring Problem (Program SETUP). User provides input data in response to screen prompts: file name (if editing an existing file), job title, choice of computing line loads at given ship position or computing equilibrium position for given loads, and error tolerances for total force components and yaw moment on ship. If an existing file is being edited, the former values will appear on the screen following their respective data-entry prompts. If the old value is to remain, press the Return key; otherwise, enter the new value (followed by the Return key). When entering a short new value on top of a long old value, it is not necessary to blank out the tail end of the old figures. Note that the right arrow key cannot be used to copy portions of an old data item from the screen.

   When the above data have been entered, a new screen appears, listing the old values (if any) for each anchor leg: load-extension curve ID; x- and y-coordinates of chock; and two numbers, which may be either: (1) the x-and y-coordinates of the anchor or (2) the anchor-leg pretension and its horizontal-direction angle. The final column contains a “l” or a “2,” in accordance with which of these alternatives applies. Editing commands are shown at the top of the screen: “Space Bar” (move down one line), “/” (move up one line), “E” (edit a line or enter new data), “I” (insert a line), “D” (delete a line), and “Q” (leave the screen). Up to 29 legs may be entered.

   The next screen displays the existing applied displacement or applied load sets (if any), in accordance with the choice made on the first screen. For each case (up to a maximum of four), the data lines contain the name of the case, the applied displacement (or force) in the x-direction, the y-displacement (or force), and the applied yaw angle (or yawing moment) . The same editing commands as provided with the previous display remain in force. The final screen provides a chance to repeat the editing sequence from the beginning, and, if not, to save the edited file. A new name may be given to the edited file; otherwise, it will replace the previous file of the same name on the disk. To save (or load) an input-data file from the second disk drive, prefix the file name with “B:”. Note that the input data for a mooring problem must be saved under some file name in order to be accessible to the solving program.

5. Enter Input Data Set for Fixed-Mooring Problem (Program FIXSET). Usage and screen formats for this option are similar to those of Option 4. The first screen asks for the name of the existing file to be edited (if any) , then the job name, tide height, and error tolerances for total force and moment. Following this, the characteristics of each mooring element are entered, with a fresh screen for each fender, line, and chain. Command options available when editing an element are displayed at the bottom of the screen. They are “E” [edit (or enter) data], “S” (leave existing data for this element intact and skip to next element), “X” (delete this element), and “Q” (cease editing this type of element, leaving any unedited elements intact, and proceed to next type).

   Fender-input data are the x- and y-coordinates of the fender and its load-deflection curve. The curve consists of up to 11 pairs of load-deflection points: (load, deflection). The loads must be given in ascending order; the program will not accept a load smaller than the preceding one. If the fender has not been previously defined, its load-deflection curve may be declared identical to that of the previous fender without entry of the individual points. Up to 15 fenders may be entered.

   Hawser data requested are: material type; ondeck length and tail length, if any; breaking strength; cross section and elastic modulus of steel section, if any; preload; and x-, y-, and z-coordinates of chock and of mooring point. The program will accept up to 25 hawsers. Data for chains are: ID number of catenary load-deflection curve; chock coordinates (x and y); and <u>either</u> (x, y) anchor coordinates or preload and horizontal angle of leg with x-axis. The maximum number of chains is 15. In the next screen, the applied-load sets (up to four) are entered or edited: load case label, x-force, y-force, and yawing moment. At this point, the edit can be repeated or saved on disk.

6. Solution of Fleet-Mooring Problem (Program FLEET). The only keyboard input required is the name of the input data file (which should have been created by Option 4). If a fixed-mooring input file (Option 5) is named, it will be rejected. After reading the input file, the program attempts to read the catenary load-extension curves named; if any are missing from the disk, a message is printed and MENU is run. Otherwise, a list of the chock coordinates, anchor coordinates, preload, and leg angle for each chain are printed. Printed results

consist of two tables: (1) applied loads, total loads on ship, and displacements in surge, sway, and yaw; and (2) horizontal load, chock-anchor distance, and line angle for each anchor leg. If the ship's equilibrium position and line loads were chosen, the total loads would actually be residual errors which should all be within the allowed tolerance. In this case, also, the progress of the iterative computation can be followed on the screen by the values of the current displacements which are displayed after each step. If the specified tolerances are zero, the program will use 0.5 percent of the applied load and/or moment.

Computation will stop if the total force components have not come within tolerance after 50 iterations. This can happen if the mooring system is exceptionally slack or if the tolerances are very tight. The calculations are all carried out using 4-byte, single-precision numbers, so that precision is limited to about six significant figures. Solution also fails if all lines become slack at any time during the approach to equilibrium. In either of these cases, a message is printed on the screen, and the system then returns to the MENU.

7. Solve Fixed-Mooring Problem (Program FIXEM). Characteristics of this program are closely parallel to those of Option 6. The only manual input is the name of the input data file. Three tables of input data are printed before calculations begin: (1) fender characteristics, consisting of the x- and y-coordinates and the first and last points on the load-deflection tunes; (2) for each mooring line, the x-, y-and z-coordinates of chock and mooring point, and for each chain, the x- and y-coordinates of chock and anchor; and (3) physical characteristics of each line and chain. For lines the physical characteristics consist of material-type number, ondeck length, tail length, breaking strength, preload, and the cross section and modulus of steel sections. For chains, the catenary load-extension ID number, followed by a "C," is given in place of material-type number, and only breaking strength and preload are given additionally.

   The load-extension curves of all chains are read from their disk files before the solution proceeds. Curves for all lines are computed, making use of the dimensionless material curves for nonelastic materials, which are also saved as disk files. If any such disk file is missing, a message is displayed, and control returns to the MENU. Given preloads are considered to be for zero tide, and the unstretched lengths of mooring lines are computed on that basis. However, the load-extension curves are computed with chock elevations raised by the given tide height. Since the load-extension curves of chains are precalculated, they cannot be corrected for tide by the solving program; therefore, the tide should be included in the water depth used to compute the chain curves in the first place.

Printed results begin with a table of applied loads, total loads, and displacements for the three horizontal degrees of freedom. Then follows a table of reaction, deflection, and direction for fenders; horizontal load, total load, chock-mooring point distance, and horizontal angle for lines; and horizontal load, chock-anchor distance, and horizontal angle for chains. Separate output tables are provided for each load case, starting with Case O, which is always for zero applied load (but includes the effects of tide rise). Provision is made for nonconvergence in the same manner as with Option 6, described above, but the problem rarely occurs with fixed-mooring systems because they are stiff compared to fleet-mooring systems.

8. Display Directory of Files on Disk. Lists names of all programs and data files on disk in Drive A.

3. PROGRAM SYNOPSES.

a. Program CATZ: Anchor-Chain Load-Extension Curves:

Line	Operation
10-60	Dimension arrays and set values of constants.
70-80	Print screen title and initialize variables.
90-300	Enter input data.
310	Determine load increment and also interval between values to be displayed.
320-330	Print table headings on screen.
340-440	If printout flag is set, print title and mooring-leg characteristics on printer.
450-460	Compute lengths of raised chain, sinker height, and hawser length for no load.
470-690	Compute horizontal spread of anchor leg for number of increments requested. In particular:
470	On first iteration (zero load), go directly to hawser routine at Line 640.
480	Increment horizontal load and compute catenary constants. If upper chain is missing, go to Case 3 at Line 560.
490	If upper chain is completely raised, skip Case 1 and go to Line 510.
500	Case 1. Compute raised chain length. If not completely raised, compute chain extension, then skip to Line 630.

510 Compute dimensionless weight of raised chain. If sinker is raised off bottom, skip Case 2 and go to Line 550.

520 Case 2. Compute vertical force on sinker. If lower chain is missing, set vertical force on anchor to sinker force and go to 540.

530 If sinker lifting force is greater than sinker weight, go to 550.

540 Compute chain extension and go to 630.

550 If lower chain is completely raised, go to Case 4 at 590.

560-570 Case 3. Go through the Newton-Raphson method, computing length of raised lower chain, until error is within tolerance.

580 If lower chain is not completely raised, compute chain extension and go to 630.

590-610 Case 4. Do the Newton-Raphson method to get vertical force on anchor.

620 Compute chain extension.

630 Compute vertical angle of chain at anchor and vertical force at top of chain.

640-660 Compute extension of hawser and add to chain extension; compute total load in upper end of chain.

670 Pint load, extension, and other data on printer if print flag is set.

680-690 If print interval for screen display has been reached, print data on screen.

700 Eject page from printer.

710 Save load-extension curve on disk file.

720-730 Return to Line 70 if additional curves are requested; otherwise, run MENU.

(1) Subroutines:

740-750 Compute extension of textile hawser.

760-770 Print continuation page heading.

780-800 Enter or edit a data item.

810-820 Error-processing routine.

(2) Program Variables:

(a) Constants:

RD = 180/pi TL = 0.01	F$, G$ print format images

(b) Variables:

A, Al, A2, A3, A4, AA, Bl, B2, B3, B4, BA, DF, F, Q	intermediate variables used in the Newton-Raphson method algorithm
AG	vertical angle of chain at anchor
AS	steel hawser cross section
AS, H$, Y$	other intermediate variables
B	sinker weight
BB	ratio of sinker weight to horizontal load = B/H
BI	sinker height
BS	hawser breaking strength
Cl, C2	catenary constants, H/Wl and H/W2, respectively
DH	load increment
DK	total length of hawser ÷ 100
DL	ondeck length of hawser
DP	water depth
EM	stiffness of steel hawser = 100/(ES x AS)
ES	elastic modulus of steel hawser
FM	maximum horizontal force to be used in computing curve
H	horizontal load in leg
I, J, JL	counters
IG	edit flag; if set to “l,” edit data set just entered
IP	number of points computed between screen displays
IR	flag set when sinker raised off bottom

JI , JO	screen tab positions
JP	print flag; if set to "l," print output on printer
KC	ID number of computed load-extension curve
L1, L2	lengths of lower and upper chain, respectively
MT	hawser material code
NP	page number
NT	number of increments in curve
R	horizontal distance from anchor to buoy
RF	total load at top of chain
RH	distance from chock to buoy
RL	unstretched hawser length, chock to buoy
S1, S2	lengths of raised lower and upper chain, respectively
V	slope of chain at anchor
VP	slope of chain (or vertical force) at top of chain
V2	slope of chain right above sinker
WR	ratio W1/W2
Wl, W2	unit weights of lower and upper chain, respectively

(c) Arrays:

EL(I)	Ith dimensionless elongation value on curve for hawser material
M$ (I)	name of Hawser Material I
SC(I), RC(I)	Ith computed horizontal load and chock-anchor distance, respectively

b. Program FLEET: Fleet-Mooring Analysis

Line	Operation
10-50	Set values of constants.
60-80	Display title screen and enter input-data file name.
90-110	Read input file and dimension array variables in accordance with number of mooring legs. Count number of different load-extension curves.

120-130	Dimension and read in load-extension curves.
140	Print title.
150-220	Compute either anchor coordinates or preload for each chain. , Also, determine maximum and minimum x- and y-anchor coordinates. Set maximum allowable x- and y-displacement correction to 0.125 times diagonal of anchor spread.
220-250	Print mooring-leg input data.
260-600	Carry out solution for each load case. In particular, if computation of line forces for given displacements has been selected, then set displacements to their input values and go directly to Line 500. Otherwise, do iterations to get equilibrium displacements, starting at Line 270.
270-280	Initialize displacements and loads; compute load error tolerances if they are not specified; print load case header on screen.
290-380	Iterate up to 50 times to find equilibrium ship position. First, call force subroutine at 420, which returns total loads and derivatives. Then:
300	Compute determinant of three simultaneous equations giving displacement corrections. If determinant is zero, print error message and run MENU.
310	If errors are all within tolerances, stop iterating and go to Line 500.
320	If past the tenth iteration, apply a factor to the determinant so that computed displacement corrections are reduced by 25 percent (to stifle oscillations).
330-380	Solve for corrections and apply them to previous displacements to get new values. Display displacements on screen. Recycle to Line 290 (unless the 50th iteration has been reached; if it has, print message and run MENU program).
500-590	Call force subroutine once and print out results.
600	Recycle to Line 260 for next load case, or run MENU program when finished.

(1) Force Subroutine:

420-490	This routine computes and accumulates mooring-line forces and their six derivatives. In particular:
420	Initialize force and derivative sums.

430-440 For each mooring leg, compute horizontal chock-anchor distance and bearing. Call subroutine at 390 to get horizontal force.

450 Compute and accumulate force components and moment. If completion flag is set, compute anchor bearing angle; save chock-anchor distance and bearing along with chain load, and skip derivatives.

460-480 Otherwise compute and accumulate derivatives.

490 Return when all legs have been processed.

(2) Other Subroutines:

390-410 Compute horizontal force and its gradient from chock-anchor distance, using load-extension curve.

610-620 Compute angle from x- and y-offsets.

630-640 Print continuation page heading.

650-670 Error-processing routine.

680 Reject bad input data file.

(3) Program Variables:

(a) Constants:

PI = pi
DR = pi/180
RT = 0.75
PC = 0.005

P2 = pi/2
RD = 180/pi
F1$-F3$ print format images

(b) Undimensioned Variables:

AA, BB	applied surge and sway forces on ship, respectively
AB, A$, C2, G, R, S2, XA, XB, YA, YB	intermediate variables
CC	applied yaw moment
DE	determinant of equations for displacement corrections
DX, DY, DZ	displacement corrections in surge, sway, and yaw, respectively
E	yaw angle
F$	input file name

H	horizontal mooring-line force on ship
HP	slope of load-extension curve
HX, HY	x- and y-components of mooring-line force on ship, respectively
I, J, K, L, JJ	counters and indices
IC	completion flag; set to "l" when load errors are within tolerance
IE	convergence flag; set to "l" when iteration count reaches 50
JB	tab setting for printing job title
JE	flag: if "O," compute forces for given displacements; if "l," compute displacements for given forces
JL	printed line counter
JN$	job title
N	highest mooring-leg number
NL	highest load-case number
NP	page number
NZ	number of different mooring-leg curves, minus 1
R	horizontal chock-anchor distance of mooring leg
RG	diagonal of smallest rectangle that circumscribes all anchors, divided by 8
SM	total yaw moment on ship
SN, CS	sine and cosine of chock-anchor bearing, respectively
SX, CX	sine and cosine of yaw angle, respectively
TM	specified error tolerance for yaw moment
TX	specified error tolerance for total surge and sway (x- and y-) forces
T1	error tolerance used for surge and sway forces
T2	error tolerance used for yaw moment
X, Y	surge and sway displacements of ship, respectively

XH , YH	total surge and sway forces on ship, respectively
XX, XY, XZ	derivatives of total surge force with respect to surge, sway, and yaw, respectively
X2, Y2	x- and y-components of vector from ship origin to a mooring chock
X3, Y3	x- and y-components of vector from a mooring-line chock to corresponding anchor
YY	sway derivative of total sway force
YZ , ZZ	derivatives of total sway force and yaw moment with respect to yaw angle, respectively

(c) Arrays:

AL(I)	bearing angle of Leg I
C$ (I)	label for Load Case I
FM(I)	given yaw angle or yawing moment for Case I
FX(I), FY(I)	given surge and sway (x- and y-) applied displacements or loads for Case I, respectively
HL(I)	horizontal load in Leg I
KC(I)	ID number of load-extension curve for Leg I
KP(I)	flag: (1) has value "l" if PL and AN are anchor coordinates, "2" if they are preload and bearing; (2) has value "l" if leg load exceeds breaking strength, "O" otherwise
KR(I)	index number of load-extension curve for Leg I
L$(O or 1)	column headings "Total Load" and "Load Error"
NT(I)	number of points on I^{th} load-extension curve, minus 1
PL(X)	(1) preload in Leg I; (2) chock-anchor distance of Leg I
SC(J, I), RC(J, I)	J^{th} load and extension values of Curve I, respectively
XC(I), YC(I)	chock coordinates of Leg I
Xl(I), Y1(I)	anchor coordinates of Leg I
2$(0 or 1)	blank or star printed after mooring-leg load

c. Program FIXEM: Fixed-Mooring Analysis:

Line	Operation
10-90	Set values of constants.
100-120	Print title screen and enter data file name.
130-180	Read input file and dimension array variables in accordance with number of fenders, lines, and chains.
190-210	Count number of different hawser materials and dimension elongation table.
220	Read material elongation table.
230-250	Decode chain material codes to get curve ID and coordinate/ preload flag; count number of different chain load-extension curves; dimension and read curves.
260-280	Compute either anchor coordinates or preload for each chain.
290-400	Print title and input data for fenders, lines, and chains.
410-450	Compute unstretched lengths of hawsers and their load-extension curves.
460-900	Carry out solution for each load case. In particular:
460	Print title on screen.
470-480	Initialize displacements and loads; print load case header on screen.
490-570	Iterate up to 50 times to find equilibrium ship position. First call subroutine at 590, which returns total loads and their derivatives. Then:
490	Check whether total loads are within tolerance. they are, go to 580.
500	Compute determinant of three simultaneous equations giving displacement corrections. If determinant is zero, print error message and run MENU; otherwise:
510	If beyond the seventh iteration, reduce displacement corrections by 25 percent to suppress oscillations.
520-540	Solve equations.
550-570	Compute new displacements and display them; recycle to 460 unless the 50 iteration has been reached.

580 Set completion flag and call force subroutine one more time, loading printout arrays. Go to 790.

790-900 Print results.

(1) Force Subroutine:

590-780 This subroutine computes and accumulates the line forces and their six derivatives. In particular:

590 Initialize sums of loads and derivatives.

600-610 Compute horizontal length of hawsers and chains.

620-680 Compute and accumulate hawser and chain loads and derivatives.

690-700 If completion flag is set, compute line bearing and total load; save these plus horizontal line length and load.

710-760 Compute and accumulate fender loads and derivatives.

770 If completion flag is set, save fender load, deflection, and direction.

780 Return to Line 490.

(2) Other Subroutines:

910-920 Compute an angle from x, y offsets.

930-940 Print new page heading.

950-980 Error-handling procedure.

990 Reject bad input file.

1000-1010 Compute dimensionless load in hawser material from fractional elongation.

1020 Reject slack hawser encountered during computation of unstretched length.

1030-1050 Compute preload in chain.

1060-1080 Compute chain load from length (during execution of force subroutine) .

(3) Program Variables:

(a) Constants:

PI = pi P2 = pi/2
DR= pi/180 RD = 180/pi

HU = 0.01
RT = 0.75
PC = 0.005

Ru = 0.00001
F1$-F10$ print format images

(b) Undimensioned Variables:

AA, BB	applied surge and sway forces on ship, respectively
AB, A$, CQ, G, Q, R, S, T, X4, XB, YA , YB	intermediate variables
CC	applied yaw moment
CH	chock height
DE	determinant of equations for displacement corrections
DX, DY, DZ	displacement corrections in surge, sway, and yaw, respectively
E	yaw angle
F$	input file name
H	horizontal force exerted by line, chain, or fender on ship
HP	slope of load-extension curve or of fender load-deflection curve
HR	H/R
HX, HY	x- and y-components of line or fender force on ship, respectively
I, J, K, L, JJ	counters and indices
IC	completion flag; set to “l” when load errors are within tolerance
IE	convergence flag; set to “l” when iteration count reaches 50
JB	tab position to print job title
JL	printed line counter
JN$	job title
N	highest mooring-line number
NC	number of chains, minus 1
NF	highest fender number

NL	highest load-case number
NM	number of hawser-material elongation curves
NP	page number
NZ	number of catenary load-extension curves, minus 1
N1, N2	numbers of first and last chains, respectively
R	horizontal chock-mooring point distance, or fender deflection
SM	total yaw moment on ship
SN, CS	sine and cosine of chock-mooring point bearing, respectively
Sx, Cx	sine and cosine of yaw angle, respectively
TM	specified error tolerance for yaw moment
TX	specified error tolerance for total surge and sway (x- and y-) forces
T1, T2	error tolerances used for force components and yaw moment, respectively
X, Y	surge and sway displacements of ship, respectively
XH, YH	total surge and sway forces on ship, respectively
XX, XY, X2	derivatives of total surge force with respect to surge, sway, and yaw, respectively
X2, Y2	x- and y-components of vector from ship origin to chock
X3, Y3	x- and y-components of vector from chock to mooring point
YY	sway derivative of total sway force
YZ , ZZ	derivatives of sway force and yaw moment with respect to yaw angle, respectively
ZT	tide height

(c) Arrays:

AF(I)	direction of I^{th} fender reaction
AL(I)	bearing angle of I^{th} line or chain
AS(I)	(1) cross section of I^{th} line (if steel); (2) total load in I^{th} line
BS(I)	breaking strength of I^{th} line or chain

C$ (I)	label for Load Case I
DL(I)	ondeck length of Mooring Line I
EL(J, I)	J^{th} percent elongation value on curve of Hawser Material I .
ES(I)	elastic modulus of I^{th} line (if steel)
FM(I)	applied yawing moment in Load Case I
FX(I), FY(I)	applied surge and sway (x- and y-) loads in Load Case I, respectively
HF(I)	reaction of I^{th} fender
HL(I)	horizontal load in I^{th} line or chain
KC(I)	material code of I^{th} line or chain
KP(I)	overload flag; set equal to “l” if breaking strength of I^{th} line or chain is exceeded
KR(I)	number of I^{th} chain load-extension curve encountered
KT(I)	number of I^{th} dimensionless hawser-material elongation curve encountered
NE(I)	number of points on load-deflection curve for Fender I, minus 1
NT(I)	number of points on load-extension curve of I^{th} chain, minus 1
PL(I)	preload in I^{th} line or chain
SC(J, I), RC(J, 1)	J^{th} load and extension values on I^{th} chain tune, respectively
SF(J, I), RF(J, I)	J^{th} load and deflection values on curve of I^{th} fender, respectively
SL(J, I), RL(J, I)	J^{th} load and extension values on curve of I^{th} line, respectively
TL(I)	tail length of Mooring Line I
XC(I), YC(I) ZC(I)	chock coordinates of I^{th} mooring line or chain
XF(I), YF(I)	x- and y-coordinates of Fender I
Xl(I), Y1(I), Z1(I)	mooring-point coordinates of I^{th} line or chain [X1(I) and Y1(I) may also be preload and horizontal angle of mooring line I]
YD(I)	deflection of I^{th} fender

Z$(0 or 1)   blank and star printed after loads

4. PROGRAM LISTING.

```
10 REM MASTER MENU FOR MOORING PROGRAM PACKAGE
20 N=8: DIM B$(N): FOR I=0 TO N: READ B$(I):NEXT
30 HOME: VTAB 3: HTAB 29: INVERSE: PRINT "*** MOORING ANALYSIS ***": NORMAL
40 VTAB 24: HTAB 59: PRINT "M & N Engrs. 12/84":
50 VTAB 7: FOR I=0 TO N: HTAB 16: PRINT USING "##!  &":I,".",B$(I): NEXT
60 PRINT: PRINT: PRINT TAB(21):"Selection:     ":
70 GET A$: PRINT A$:: IF A$="0" THEN HOME: END
80 A=VAL(A$): ON A GOTO 100,110,120,130,140,150,160,170
90 HTAB 36: GOTO 70
100   RUN "INSTRUC"
110   RUN "CATZ"
120 RUN "CURVES"
130 RUN "SETUP"
140 RUN "FIXSET"
150 RUN "FLEET"
160 RUN "FIXER"
170 HOME: FILES: PRINT: PRINT: HTAB 23: PRINT "Press any key":: GET AS: GOTO 30
180 DATA "Quit","Display instructions","Compute load-extension curve of anchor leg","Enter load-extension curve for hawser material"
 "Enter or edit fleet mooring input data"
190 DATA 'Enter or edit fired mooring input data", Solve fleet mooring problem, Solve fixedmooring problems", Display list of files
 on disk"
```

```
10 REM   MOORING PROGRAM INSTRUCTIONS
20 K2=19: NP=1: GOSUB 130: OPEN "I",#1,"INFO": INPUT #1,N: DIM A$(N): FOR I=0 TO N: LINE INPUT #1,A$(I): NEXT: CLOSE #1
30 FOR I=K1 TO K2: PRINT A$(I): NEXT
40 VTAB 24: HTAB 1: INVERSE: PRINT "      (F)orward                      (B)ackward                      (Q)uit      ";: NORMAL: GET B$
50 IF B$="F" OR B$="f" THEN 80
60 IF B$="B" OR B$="b" THEN 110
70 IF B$<>"Q" AND B$<>"q" THEN 40 ELSE RUN "MENU"
80 K1=K1+20: NP=NP+1: IF K1>N THEN K1=0: NP=1
90 K2=K1+19: IF K2>N THEN K2=N
100 GOSUB 130: GOTO 30
110 K1=K1-20: NP=NP-1: IF K1<0 THEN K1=0: NP=1
120 K2=K1+19: GOSUB 130: GOTO 30
130 HOME: HTAB 27: INVERSE: PRINT "MOORING PROGRAM INSTRUCTIONS";: NORMAL: HTAB 72: PRINT "Page";NP: PRINT: RETURN
```

```
10 REM  CATENARY ANCHOR LEGS
20 DEFINT I-K,M-N: ON ERROR GOTO 810
30 DIM RC(200),SC(200),EL(20),M$(3): RD=180/3.14159: TL=.01: JI=60: JD=JI-1
40 DEF FNS(R)=SQR(R*R+1): DEF FNA(R)=SQR(R*R+1)+R
50 F$="########  #########  ##########  ########.#  ######.#  ########.#  ########.#"
60 B$="      ######## ####### ######## #####.# #####.# #####.# ####.# #####.# ######.#"
70 HOME: VTAB 2: HTAB 21: INVERSE: PRINT "*** CATENARY LOAD-EXTENSION CURVE ***": NORMAL: NP=1: H=0: V=0: V2=0: VF=0: AG=0: JP=0
80 PRINT: PRINT "      This module computes load-extension curves for anchor legs consisting": PRINT "of a lower chain, a sinker, an
 upper chain, and a hawser.": PRINT
90 PRINT "     Input data:": HTAB 16: PRINT "Catenary leg number";: A=KC: GOSUB 780: IF A<>KC THEN IB=0
100 KC=A: IF KC<0 OR KC>20 THEN 90 ELSE PRINT
110 HTAB 16: PRINT "Water depth";: A=DP: GOSUB 780: DP=A: IF DP<=0 THEN 110 ELSE PRINT
120 HTAB 16: PRINT "Upper chain length";: A=L2: GOSUB 780: L2=A: IF L2>0 THEN PRINT: HTAB 16: PRINT "Upper chain weight/length";: A=
W2: GOSUB 780: W2=A: ELSE L2=0
130 PRINT: HTAB 16: PRINT "Sinker weight";: A=B: GOSUB 780: B=A: PRINT
140 HTAB 16: PRINT "Lower chain length";: A=L1: GOSUB 780: L1=A: IF L1>0 THEN PRINT: HTAB 16: PRINT "Lower chain weight/length";: A=
W1: GOSUB 780: W1=A: ELSE L1=0
150 PRINT: IF L1+L2<DP THEN PRINT: HTAB 16: INPUT;"Chain won't reach bottom.  Press RETURN to start over.    ",A$: GOTO 70
160 PRINT: HTAB 16: PRINT "Hawser material:  (0) None": HTAB 34: PRINT "(1) Steel": HTAB 34: PRINT "(2) Nylon": HTAB 34: PRINT "(3)
Polypropylene": HTAB 33: PRINT "(4-20) User defined": VTAB VPOS(0)-2
170 VTAB VPOS(0)-1: A=MT: GOSUB 780: MT=A: PRINT: IF MT<0 OR MT>20 THEN 170
180 IF MT>1 THEN OPEN "I",#1,"LINE"+STR$(MT): FOR I=0 TO 20: INPUT #1,EL(I): NEXT: CLOSE #1
190 VTAB VPOS(0)+3: HTAB 16: PRINT SPC(60);: ON MT+1 GOTO 260,230
200 HTAB 16: PRINT "Hawser breaking strength";: A=BS: GOSUB 780: BS=A: IF BS<=0 THEN 200 ELSE PRINT
210 HTAB 16: PRINT "Hawser length, chock to buoy";: A=RL: GOSUB 780: RL=A: IF RL<0 THEN 210 ELSE PRINT
220 HTAB 16: PRINT "Hawser length, on deck";: A=DL: GOSUB 780: DL=A: IF DL<0 THEN 220 ELSE PRINT: PRINT: GOTO 270
230 HTAB 16: PRINT "Cross-sectional area";: A=AS: GOSUB 780: AS=A: IF AS<=0 THEN 230
240 PRINT: HTAB 16: PRINT "Elastic modulus";: A=ES: GOSUB 780: ES=A: IF ES<=0 THEN 240
250 PRINT: EM=100/(ES*AS): GOTO 200
260 RL=0: DL=0
270 HTAB 16: PRINT "Max. horizontal load";: A=FM: GOSUB 780: FM=A: IF FM<=0 THEN 270 ELSE PRINT
280 IF BS<FM AND MT>0 THEN FM=BS
290 HTAB 16: PRINT "Number of increments";: A=NT: GOSUB 780: NT=A: IF NT<1 OR NT>200 THEN 290 ELSE PRINT
300 HTAB 16: PRINT "Print out load-extension curve (Y/N) ?";: HTAB JI: PRINT Y$;: HTAB JI: INPUT"",A$: IF A$<>"" THEN Y$=A$
310 DH=FM/NT: IP=(NT+1)\19+1: HOME: IG=1: JP=(Y$="Y" OR Y$="y"): IF W1=0 THEN W1=TL
320 PRINT "   Horiz        Vert        Total       Lifted     Anchor       Chock-     Chock-"
330 PRINT "   Force       Force       Force        Chain     Angle         Buoy       Anchor": IF W2=0 THEN W2=TL
340 IF JP=0 THEN 450
350 M$(1)="Steel": M$(2)="Nylon": M$(3)="Polypropylene": LPRINT: LPRINT: LPRINT TAB(10);"LOAD-EXTENSION CURVE";TAB(62);"ANCHOR LEG T
YPE";KC: LPRINT: JL=4
360 IF L1+L2=0 THEN 390 ELSE IF L2=0 THEN LPRINT TAB(18);"Chain length =";L1;TAB(51);"Weight/length =";W1: JL=JL+1: GOTO 390
370 IF L1=0 THEN LPRINT TAB(18);"Chain length =";L2;TAB(51);"Weight/length =";W2: JL=JL+1: GOTO 390
380 LPRINT TAB(18);"Upper chain length =";L2;TAB(51);"Weight/length =";W2: LPRINT TAB(18);"Lower chain length =";L1;TAB(51);"Weight/
length =";W1: JL=JL+2
390 JL=JL+1: LPRINT TAB(18);"Water depth =";DP;: IF B>0 THEN LPRINT TAB(51);"Sinker weight =";B ELSE LPRINT
400 IF MT=0 THEN 440
410 IF MT<4 THEN H$=M$(MT) ELSE H$="Line"+STR$(MT)
420 LPRINT: LPRINT TAB(18);H$;" hawser, ";: IF MT=1 THEN LPRINT "area x modulus =";AS*ES ELSE LPRINT "breaking strength =";BS
430 LPRINT TAB(18);"Chock to buoy =";RL;TAB(51);"On-deck length =";DL: JL=JL+3
440 GOSUB 770: JL=JL+4
450 PRINT: A1=L1: BI=0: A2=L2-DP: IF A2<0 THEN BI=-A2: A1=A1+A2: A2=0: VF=B
460 R=A1+A2: S2=L2-A2: S1=L1-A1: VF=VF+S1*W1+S2*W2: RH=RL: WR=W1/W2: BK=.01*(RL+DL): IR=SGN(S1)
470 FOR J=0 TO NT: IF J=0 THEN 640
480 H=H+DH: C1=H/W1: C2=H/W2: BB=B/H: IF L2=0 THEN 560
490 IF S2=L2 THEN 510
500 S2=SQR(DP*(DP+C2+C2)): IF S2<=L2 THEN VF=S2/C2: R=L1+L2-S2+C2*LOG(FNA(VF)): GOTO 630 ELSE S2=L2
510 A2=S2/C2: IF IR THEN 550
```

```
520 AA=DP/C2: V2=.5*(AA*SQR(4/(A2*A2-AA*AA)+1)-A2): IF L1=0 THEN V=V2: GOTO 540
530 IF V2>BB THEN IR=1: GOTO 550
540 VF=V2+A2: R=L1+C2*LOG(FNA(VF)/FNA(V2)): GOTO 630
550 IF S1=L1 THEN 590
560 A1=S1/C1: B1=FNS(A1): AA=A1+BB: BA=FNS(AA): A3=AA+A2: B3=FNS(A3): BI=C1*(B1-1)
570 F=DP-BI-C2*(B3-BA): IF ABS(F)>TL THEN DF=A1/B1+WR*(A3/B3-AA/BA): S1=S1+F/DF: GOTO 560
580 IF S1<=L1 THEN VF=A3: R=L1-S1+C1*LOG(FNA(A1))+C2*LOG(FNA(VF)/FNA(AA)): GOTO 630 ELSE S1=L1
590 A1=S1/C1
600 B1=FNS(V): A3=V+A1: B3=FNS(A3): AA=A3+BB: BA=FNS(AA): A4=AA+A2: B4=FNS(A4): BI=C1*(B3-B1)
610 F=DP-BI-C2*(B4-BA): IF ABS(F)>TL THEN DF=C1*(A3/B3-V/B1)+C2*(A4/B4-AA/BA): V=V+F/DF: GOTO 600
620 VF=A4: R=C1*LOG(FNA(A3)/FNA(V))+C2*LOG(FNA(VF)/FNA(AA))
630 AG=RD*ATN(V): VF=VF*H
640 IF NT=0 THEN 660
650 IF NT=1 THEN RH=RL+H*EN*DK ELSE GOSUB 740
660 R=R+RH: RF=SQR(VF*VF+H*H): SC(J)=H: RC(J)=R
670 IF JP THEN LPRINT USING B$;H,VF,RF,S2,BI,S1,AG,RH,R: JL=JL+1: IF JL>59 AND NT-J>2 THEN GOSUB 760
680 I=J MOD IP: IF I=0 THEN PRINT USING F$;H,VF,RF,S1+S2,AG,RH,R
690  NEXT: IF I THEN PRINT USING F$;H,VF,RF,S1+S2,AG,RH,R
700 IF JP THEN LPRINT CHR$(12);
710 OPEN "O",#1,"CAT"+STR$(KC): PRINT#1,NT: FOR I=0 TO NT: WRITE#1,SC(I),RC(I): NEXT I: CLOSE #1
720 PRINT: PRINT TAB(16);"Continue with anchor leg definition (Y/N) ?      ";: GET A$: IF A$="N" OR A$="n" THEN RUN "MENU"
730 IF A$="Y" OR A$="y" THEN 70 ELSE 720
740 Q=H/DS*20: I=INT(Q)-19: I=20+.5*(I-ABS(I))
750 RH=EL(I)+(EL(I)-EL(I-1))*(Q-I): RH=RL+RH*DK: RETURN
760 NP=NP+1: JL=7: LPRINT CHR$(12): LPRINT: LPRINT TAB(10);"Anchor Leg Type";KC;TAB(74);"Page";NP
770 LPRINT: LPRINT TAB(10);"Horiz    Vert    Total   Upper   Sinker  Lower  Anchor  Chock-   Chock-": LPRINT TAB(10);"Force   Force
   Force  Chn Up     Ht    Chn Up  Angle    Buoy    Anchor": LPRINT: RETURN
780 IF IG THEN HTAB J0: PRINT A;
790 HTAB JI: INPUT;"",A$: IF A$<>"" OR IG=0 THEN A=VAL(A$): HTAB J0: PRINT SPC(10);: HTAB J0: PRINT A;
800 RETURN
810 IF ERR=53 AND ERL=180 THEN VTAB VPOS(0)+3: HTAB 16: PRINT "Load-extension curve for Line";NT;"not found. Try another?";: VTAB VP
OS(0)-3: RESUME 170
820 ON ERROR GOTO 0
```

```
10 REM  LOAD-DEFLECTION CURVE INPUT
20 ON ERROR GOTO 290: DIM X(20): B$=STRING$(20," "): HOME: VTAB 2: HTAB 22: INVERSE: PRINT "*** LOAD-DEFLECTION CURVE EDITOR ***": N
ORMAL
30 VTAB 5: PRINT "        Use this module to enter or edit load-deflection curves.  Provide ": PRINT "  percent elongation for load
 intervals of 5% of breaking strength."
40 VTAB 8: PRINT "        Commands:        (Space)  Move down": HTAB 29: PRINT"/     Move up": HTAB 29: PRINT "C     Clear file": H
TAB 29: PRINT "X     Cancel edit": HTAB 29: PRINT "E     Enter edit": PRINT
50 HTAB 9: PRINT "Continue with curve editing (Y/N) ?   ";: GET A$: PRINT A$;: IF A$="Y" OR A$="y" THEN 80
60 IF A$<>"N" AND A$<>"n" THEN 50 ELSE RUN "MENU"
70 JF=0: HOME: VTAB 3: GOTO 50
80 PRINT: PRINT
90 HTAB 1: INPUT;"        Curve number (4-20) ?    ",NF: PRINT B$;: IF NF<4 OR NF>20 THEN 90
100 HTAB 34: PRINT NF;B$: F$="LINE"+STR$(NF): OPEN "I",#1,F$: FOR I=0 TO 20: INPUT#1,X(I): NEXT: CLOSE #1: JF=1
110 HOME: INVERSE: PRINT "  ( ) Down     (/) Up     (C)lear file     (X) Cancel edit     (E)nter edit   ": NORMAL
120 PRINT: PRINT TAB(20);"Load, % Break Str";TAB(45);"% Elongation"
130 N=4: FOR I=0 TO 20: VTAB N: HTAB 25: PRINT 5*I;: IF JF THEN PRINT TAB(49);X(I);
140 N=N+1:  NEXT: N=4: VTAB N: HTAB 50
150 GET A$: IF A$=" " THEN 190 ELSE IF A$="/" THEN 210 ELSE IF A$="C" OR A$="c" THEN 230 ELSE IF A$="E" OR A$="e" THEN 250 ELSE IF A
$="X" OR A$="x" THEN FOR I=0 TO 20: X(I)=0: NEXT: GOTO 70
160 A=ASC(A$): IF A<46 OR A>57 THEN 150
170 PRINT A$;: INPUT;"",B$: A=VAL(A$+B$)
180 HTAB 49: PRINT A;B$;: X(N-4)=A: HTAB 50
190 N=N+1: IF N=25 THEN N=4
200 VTAB N: GOTO 150
210 N=N-1: IF N=3 THEN N=24
220 VTAB N: GOTO 150
230 N=4: FOR I=0 TO 20: X(I)=0: VTAB N: HTAB 49: PRINT B$;: N=N+1: NEXT
240 N=4: VTAB N: HTAB 50: GOTO 150
250 JF=1: KILL F$
260 FOR I=0 TO 20: IF X(I)=0 THEN NEXT: GOTO 70
270 FOR I=1 TO 20: IF X(I)>X(I-1) THEN NEXT ELSE 320
280 OPEN "O",#1,F$: FOR I=0 TO 20: PRINT#1,X(I): NEXT: CLOSE #1: GOTO 70
290 IF ERR<>53 THEN 310
300 IF ERL=100 THEN RESUME 110 ELSE RESUME 260
310 ON ERROR GOTO 0
320 HOME: VTAB 8: PRINT TAB(11);"Curve must increase monotonically.  Revise or cancel.": PRINT: PRINT TAB(11);"Press any key to cont
inue.    ";: GET A$: GOTO 110
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10 REM   FLEET MOORING DATA INPUT
20 ON ERROR GOTO 690: GOSUB 680: VTAB 6: PRINT TAB(11);"This section creates and edits input data sets.": DEF FNN(X)=.5*(X-ABS(X))
30 DIM W(5,30),X(2,4),NB(5),NC(2),C$(4),T$(1): JE=1: T$(0)="DISPLACEMENT": T$(1)="APPLIED LOAD": FOR I=0 TO 5: READ NB(I): NEXT: REA
D NC(0),NC(1),NC(2): DATA 15,25,36,47,59,72,41,54,67: JJ=10
40 VTAB 8: HTAB 11: PRINT "Edit existing input data (Y/N) ?      ";: GET A$: IF A$="N" OR A$="n" THEN 80
50 HTAB 50: PRINT A$;: IF A$<>"Y" AND A$<>"y" THEN 40
60 VTAB 10: HTAB 33: INPUT;"File name:       ",F$: OPEN "I",#1,F$: INPUT #1,A$: IF A$<>"BSS" THEN 720 ELSE INPUT #1,JN$,JE,TX,TM,N,N
L: N=N+1: FOR I=1 TO N: FOR J=0 TO 5: INPUT #1,W(J,I): NEXT: NEXT
70 FOR I=1 TO NL: INPUT #1,C$(I): FOR J=0 TO 2: INPUT #1,X(J,I): NEXT: NEXT: CLOSE #1
80 GOSUB 680: VTAB 5: PRINT TAB(16);"General Data.": PRINT: PRINT: PRINT TAB(16);"Job name:";TAB(50);JN$
90 PRINT: PRINT TAB(16);"Compute forces with vessel at:": PRINT TAB(26);"(1) Given displacements": PRINT TAB(26);"(2) Equilibrium po
sition";TAB(59);JE
100 IF JE=2 THEN GOSUB 600
110 VTAB 5: HTAB 36: PRINT "Edit this part (Y/N) ?     ";: GET A$: IF A$="N" OR A$="n" THEN 160
120 IF A$<>"Y" AND A$<>"y" THEN 110
130 HTAB 31: PRINT B$: VTAB 8: HTAB 50: LINE INPUT;A$: IF A$<>"" THEN JN$=A$
140 L=59: VTAB 12: V=JE: GOSUB 610: JE=V: IF JE<1 OR JE>2 THEN 140
150 IF JE=2 THEN GOSUB 600: VTAB 15: V=TX: GOSUB 610: TX=V: VTAB 16: V=TM: GOSUB 610: TM=V
160 ID=0: GOSUB 650: I=1: JJ=8
170 VTAB I-ID+4: HTAB 5: PRINT I;: HTAB 6: GET A$
180 IF A$=" " THEN 220 ELSE IF A$="/" THEN 240 ELSE IF A$="I" OR A$="i" THEN 260 ELSE IF A$="D" OR A$="d" THEN 300 ELSE IF A$="Q" OR
 A$="q" THEN 340 ELSE IF A$<>"E" AND A$<>"e" THEN 170
190 FOR J=0 TO 5: L=NB(J): V=W(J,I): GOSUB 610: W(J,I)=V: NEXT
200 IF V<1 OR V>2 THEN L=NB(5): GOSUB 610: W(5,I)=V: GOTO 200
210 IF I>N THEN N=I
220 IF I<N+1 THEN I=I+1: IF I>29 THEN I=ID+1 ELSE IF I>ID+19 THEN ID=10: GOSUB 650
230 GOTO 170
240 I=I-1: IF I<1 THEN I=K2 ELSE IF I<ID+1 THEN ID=0: GOSUB 650
250 GOTO 170
260 IF N=29 THEN 170
270 N=N+1: K2=K2-ID-18: K2=FNN(K2)+ID+19: FOR K=N TO I+1 STEP-1: FOR J=0 TO 5: W(J,K)=W(J,K-1): NEXT
280 IF K<=K2 AND K>ID THEN VTAB K-ID+4: HTAB 5: PRINT K;SPC(68);: HTAB 10: FOR J=0 TO 5: PRINT TAB(NB(J));W(J,K);: NEXT
290 NEXT: VTAB I-ID+4: HTAB 10: PRINT SPC(68);: FOR J=0 TO 5: W(J,I)=0: NEXT: GOTO 190
300 N=N-1: FOR K=I TO N: FOR J=0 TO 5: W(J,K)=W(J,K+1): NEXT
310 IF K<=K2 THEN HTAB 15: PRINT SPC(64);: FOR J=0 TO 5: HTAB NB(J): PRINT W(J,K);: NEXT: PRINT
320 NEXT: FOR J=0 TO 5: W(J,K)=0: NEXT: IF N<=K2 THEN HTAB 15: PRINT SPC(64);
330 GOTO 170
340 HOME: PRINT T$(JE-1);" DATA   ";: GOSUB 640: JJ=13
350 VTAB 5: PRINT "  Case #                   Label";: IF JE=1 THEN PRINT TAB(41);"X Displ       Y Displ       Rotation" ELSE PRINT TAB(41)
;"X Force       Y Force       Moment"
360 PRINT: FOR I=1 TO NL: PRINT TAB(5);I;TAB(15);C$(I);: FOR J=0 TO 2: PRINT TAB(NC(J));X(J,I);: NEXT: PRINT: NEXT: I=1
370 VTAB I+6: HTAB 5: PRINT I;: HTAB 6: GET A$
380 IF A$=" " THEN 410 ELSE IF A$="/" THEN 440 ELSE IF A$="I" OR A$="i" THEN 460 ELSE IF A$="D" OR A$="d" THEN 490 ELSE IF A$="Q" OR
 A$="q" THEN 510 ELSE IF A$<>"E" AND A$<>"e" THEN 370
390 HTAB 15: LINE INPUT;A$: IF A$<>"" THEN C$(I)=A$: HTAB 15: PRINT SPC(27);: HTAB 15: PRINT A$;
400 FOR J=0 TO 2: L=NC(J): V=X(J,I): GOSUB 610: X(J,I)=V: NEXT
410 IF I>NL THEN NL=I
420 IF I<NL+1 THEN I=I+1: IF I>4 THEN I=1
430 GOTO 370
440 I=I-1: IF I<1 THEN I=NL+1: IF I>4 THEN I=4
450 GOTO 370
460 IF NL=4 THEN 370
470 NL=NL+1: FOR K=NL TO I+1 STEP-1: VTAB K+6: HTAB 5: PRINT K;SPC(64);: HTAB 15: C$(K)=C$(K-1): PRINT C$(K);: FOR J=0 TO 2: X(J,K)=
X(J,K-1): PRINT TAB(NC(J));X(J,K);: NEXT: NEXT
480 VTAB I+6: HTAB 15: PRINT SPC(64);: C$(I)="": FOR J=0 TO 2: X(J,I)=0: NEXT: GOTO 390
490 NL=NL-1: FOR K=I TO NL: HTAB 15: PRINT SPC(64);: C$(K)=C$(K+1): HTAB 15: PRINT C$(K);: FOR J=0 TO 2: X(J,K)=X(J,K+1): HTAB NC(J)
: PRINT X(J,K);B$;: NEXT J: PRINT: NEXT
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500 HTAB 15: PRINT SPC(64);: GOTO 370
510 HOME: VTAB 6: HTAB 21: PRINT "Shall we go around again (Y/N) ?       ";: GET A$: HTAB 60: PRINT A$;: IF A$="N" OR A$="n" THEN 54
0
520 IF A$<>"Y" AND A$<>"y" THEN 510
530 GOTO 80
540 VTAB 8: HTAB 21: PRINT "Save edited data (Y/N) ?              ";: GET A$: HTAB 60: PRINT A$;: IF A$="N" OR A$="n" THEN HOME: RU
N "MENU"
550 IF A$<>"Y" AND A$<>"y" THEN 540
560 VTAB 10: PRINT TAB(21);"File name:                    ";F$;: HTAB 50: INPUT "",A$: IF A$<>"" THEN F$=A$
570 OPEN "O",#1,F$: WRITE #1,"SSS",JN$,JE,TX,TM,N-1,NL: FOR I=1 TO N: FOR J=0 TO 5: PRINT #1,M(J,I): NEXT: NEXT:
580 FOR I=1 TO NL: WRITE #1,C$(I): FOR J=0 TO 2: PRINT #1,X(J,I): NEXT: NEXT: CLOSE #1
590 RUN "MENU"
600 VTAB 14: HTAB 16: PRINT "Error tolerance:": PRINT TAB(26);"X and Y Forces";TAB(59);TX: PRINT TAB(26);"Moment";TAB(59);TM: RETURN
610 M=L: IF V>=0 THEN M=M+1
620 HTAB M: INPUT;"",A$: IF A$<>"" THEN V=VAL(A$)
630 HTAB L: PRINT V;TAB(L+JJ);: RETURN
640 INVERSE: PRINT " ( )Down   (/)Up   (E)dit   (I)nsert   (D)elete   (Q)uit  ": NORMAL: PRINT: RETURN
650 HOME: PRINT "MOORING LINE DATA   ";: GOSUB 640: PRINT "   Line       L-D         Chock Coords";TAB(47);"Anchor Coord (X,Y)";TAB
(69);"A,C (1) or"
660 PRINT TAB(6);"#       Curve        X          Y      or Preload, Line Angle  PL,LA (2)"
670 K2=N-ID-19: K2=FNN(K2)+ID+19: FOR K=ID+1 TO K2: PRINT TAB(5);K;: FOR J=0 TO 5: PRINT TAB(NB(J));M(J,K);: NEXT: PRINT: NEXT: RETU
RN
680 HOME: VTAB 2: HTAB 25: INVERSE: PRINT "*** FLEET MOORING DATA INPUT ***": NORMAL: RETURN
690 IF ERR<>53 THEN 710
700 IF ERL=60 THEN PRINT: PRINT: PRINT TAB(11);"File not found.  Try another?": RESUME 40
710 ON ERROR GOTO 0
720 CLOSE #1: PRINT: PRINT: PRINT TAB(11);F$;" is not a fleet mooring input data file.": PRINT TAB (11);"Care to try another one?":
GOTO 40
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10 REM   FIXED MOORING DATA INPUT
20 ON ERROR GOTO 1110: GOSUB 1100: VTAB 6: PRINT TAB(16):"This section creates and edits input data sets": PRINT TAB(11);"for analys
is of shoreside berths."
30 DIM XF(14),YF(14),NE(14),SF(11,14),RF(11,14),A(2,24),B(2,24),KR(24),DL(24),TL(24),BS(24),ES(24),AS(24),PL(24),HC(2),C$(4),X(2,4),
HD(1),KT(14),Z(3,14)
40 READ HC(0),HC(1),HC(2),NF,N,NC,HD(0),HD(1): DATA 41,54,67,-1,-1,-1,48,68
50 VTAB 9: HTAB 16: PRINT "Edit existing input data (Y/N) ?        ";: GET A$: HTAB 55: PRINT A$;: IF A$="N" OR A$="n" THEN 100
60 IF A$<>"Y" AND A$<>"y" THEN 50
70 VTAB 11: HTAB 33: INPUT;"File name:        ",F$: OPEN "I",#1,F$: INPUT #1,A$: IF A$<>"FFF" THEN 1140 ELSE INPUT #1,JN$,ZT,TX,TM,NF
,N,NC,NL: FOR J=0 TO NF: INPUT #1,NE(J),XF(J),YF(J): FOR I=0 TO NE(J): INPUT #1,SF(I,J),RF(I,J): NEXT: NEXT
80 FOR J=0 TO N: INPUT #1,KR(J),DL(J),TL(J),BS(J),PL(J),ES(J),AS(J): FOR I=0 TO 2: INPUT #1,A(I,J),B(I,J): NEXT: NEXT
90 FOR J=0 TO NC: INPUT #1,KT(J),Z(0,J),Z(1,J),Z(2,J),Z(3,J): NEXT: FOR J=1 TO NL: INPUT #1,C$(J),X(0,J),X(1,J),X(2,J): NEXT: CLOSE
#1
100 J=-1: L1=44: L2=62: L3=15: GOSUB 1100: VTAB 5: PRINT TAB(16);"General Data.": PRINT: PRINT: PRINT TAB(16);"Job name:";TAB(50);JN
$
110 VTAB 10: HTAB 16: PRINT "Tide Height:";TAB(59);ZT
120 VTAB 12: HTAB 16: PRINT "Error tolerance:": PRINT TAB(26);"X and Y Forces";TAB(59);TX: PRINT TAB(26);"Moment";TAB(59);TM
130 VTAB 5: HTAB 36: PRINT "Edit this part (Y/N) ?      ";: GET A$: IF A$="N" OR A$="n" THEN 180
140 IF A$<>"Y" AND A$<>"y" THEN 130
150 HTAB 31: PRINT SPC(40): VTAB 8: HTAB 50: LINE INPUT;A$: IF A$<>"" THEN JN$=A$
160 L=59: VTAB 10: V=ZT: GOSUB 1060: ZT=V
170 VTAB 13: V=TX: GOSUB 1060: TX=V: VTAB 14: V=TM: GOSUB 1060: TM=V
180 J=J+1: IF J>14 THEN 340 ELSE HOME: VTAB 2: HTAB 11: PRINT "FENDER DEFINITION";TAB(45);"Fender No.";J+1: VTAB 4: HTAB 46: PRINT "
X";TAB(64);"Y"
190 PRINT TAB(11);"Coordinates:";TAB(44);XF(J);TAB(62);YF(J): PRINT: PRINT TAB(11);"Load-Deflection Curve:";TAB(45);"Load";TAB(60);"
Deflection": PRINT TAB(15);"(2-11 points)";
200 FOR I=0 TO NE(J): PRINT TAB(44);SF(I,J);TAB(62);RF(I,J): NEXT
210 I=0: GOSUB 1180
220 IF A$="S" OR A$="s" THEN IF J>NF THEN 340 ELSE 180
230 IF A$="X" OR A$="x" THEN NE(J)=-1: IF J>NF THEN 340 ELSE 180
240 IF A$="Q" OR A$="q" THEN 340
250 IF A$<>"E" AND A$<>"e" THEN 210
260 VTAB 5: L=L1: V=XF(J): GOSUB 1060: XF(J)=V: L=L2: V=YF(J): GOSUB 1060: YF(J)=V
270 IF J>0 AND NE(J)<=0 THEN FOR K=J-1 TO 0 STEP -1: IF NE(K)>0 THEN 1160 ELSE NEXT
280 VTAB I+8: L=L1: V=SF(I,J): GOSUB 1060: SF(I,J)=V: IF V>0 OR I=0 THEN 310
290 NE(J)=I-1: IF J>NF THEN NF=J
300 GOTO 180
310 L=L2: V=RF(I,J): GOSUB 1060: RF(I,J)=V: IF I=0 THEN I=I+1: GOTO 280
320 IF V>RF(I-1,J) AND SF(I,J)>SF(I-1,J) THEN I=I+1
330 GOTO 280
340 K=-1: FOR J=0 TO NF: IF NE(J)<=0 THEN 360
350 K=K+1: XF(K)=XF(J): YF(K)=YF(J): FOR I=0 TO NE(J): SF(I,K)=GF(I,J): RF(I,K)=RF(I,J): NEXT: NE(K)=NE(J)
360 NEXT J: L=NF: NF=K: FOR K=K+1 TO L: XF(K)=0: YF(K)=0: NE(K)=-1: NEXT: J=-1
370 J=J+1: IF J>24 THEN 590 ELSE L=54: L3=11: HOME: VTAB 2: PRINT TAB(11);"MOORING LINE DEFINITION";TAB(46);"Line No.";J+1
380 VTAB 4: PRINT TAB(11);"Material:  (1) Steel, no tail";TAB(L);KR(J): PRINT TAB(22);"(2) Nylon": PRINT TAB(22);"(3) Polypropylene"
: PRINT TAB(21);"(4-20) User defined"
390 VTAB 9: PRINT TAB(11);"On-deck Length";TAB(L);DL(J): IF KR(J)>1 THEN PRINT TAB(11);"Tail Length";TAB(L);TL(J) ELSE PRINT
400 PRINT TAB(11);"Breaking Strength";TAB(L);BS(J): IF KR(J)=1 OR TL(J)>0 THEN VTAB 12: PRINT TAB(11);"Steel elastic modulus";TAB(L)
;ES(J): PRINT TAB(11);"Steel cross-section";TAB(L);AS(J)
410 VTAB 14: PRINT TAB(11);"Preload";TAB(L);PL(J): VTAB 16: PRINT TAB(43);"X";TAB(56);"Y";TAB(69);"Z": PRINT TAB(11);"Chock Coordina
tes";: FOR I=0 TO 2: HTAB HC(I): PRINT A(I,J);: NEXT
420 PRINT TAB(11);"Anchor Coordinates";: FOR I=0 TO 2: HTAB HC(I): PRINT B(I,J);: NEXT
430 GOSUB 1180
440 IF A$="S" OR A$="s" THEN IF J>N THEN 590 ELSE 370
450 IF A$="X" OR A$="x" THEN KR(J)=0: IF J>N THEN 590 ELSE 370
460 IF A$="Q" OR A$="q" THEN 590
470 IF A$<>"E" AND A$<>"e" THEN 430
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480 VTAB 4: V=KR(J): GOSUB 1060: KR(J)=V: IF V<1 OR V>20 THEN 480
490 VTAB 9: V=DL(J): GOSUB 1060: IF V<0 THEN DL(J)=0 ELSE DL(J)=V
500 IF KR(J)>1 THEN VTAB 10: HTAB 11: PRINT "Tail Length";: V=TL(J): GOSUB 1060: IF V<0 THEN TL(J)=0 ELSE TL(J)=V
510 VTAB 11: HTAB 11: PRINT "Breaking Strength";: V=BS(J): GOSUB 1060: BS(J)=V: IF V<0 THEN 510
520 VTAB 12: HTAB 11: IF KR(J)<>1 AND TL(J)=0 THEN PRINT SPC(60): PRINT SPC(70): GOTO 540
530 PRINT "Steel elastic modulus";: V=ES(J): GOSUB 1060: ES(J)=V: IF V<=0 THEN 530 ELSE PRINT: PRINT TAB(11);"Steel cross-section";:
 V=AS(J): GOSUB 1060: AS(J)=V: IF V<=0 THEN 530
540 VTAB 14: HTAB L: V=PL(J): GOSUB 1060: PL(J)=V
550 VTAB 17: FOR I=0 TO 2: L=MC(I): V=A(I,J): GOSUB 1060: A(I,J)=V: NEXT
560 VTAB 18: FOR I=0 TO 2: L=MC(I): V=B(I,J): GOSUB 1060: B(I,J)=V: NEXT
570 IF J>N THEN N=J
580 GOTO 370
590 K=-1: FOR J=0 TO N: IF KR(J)<=0 THEN 610
600 K=K+1: KR(K)=KR(J): DL(K)=DL(J): TL(K)=TL(J): BS(K)=BS(J): ES(K)=ES(J): AS(K)=AS(J): PL(K)=PL(J): FOR I=0 TO 2: A(I,K)=A(I,J): B
(I,K)=B(I,J): NEXT
610 NEXT: L=N: N=K: FOR K=K+1 TO L: KR(K)=0: DL(K)=0: TL(K)=0: BS(K)=0: ES(K)=0: AS(K)=0: PL(K)=0: FOR I=0 TO 2: A(I,K)=0: B(I,K)=0:
 NEXT: NEXT: J=-1
620 J=J+1: IF J>14 THEN 790 ELSE HOME: L=59: VTAB 2: PRINT TAB(11);"CATENARY ANCHOR LEGS";TAB(50);"Chain No.";J+1
630 K2=1: K1=KT(J): IF K1>31 THEN K2=2: K1=K1-32
640 VTAB 5: PRINT TAB(11);"Catenary load-extension curve number:";TAB(L);K1
650 VTAB 8: PRINT TAB(11);"Specify anchor coordinates (1) or": PRINT TAB(11);"preload & horizontal angle (2) ?";TAB(L);K2
660 VTAB 12: PRINT TAB(11);"Chock coordinates:            X    ";Z(0,J);TAB(63);"Y    ";Z(1,J)
670 VTAB 15: IF K2=1 THEN PRINT TAB(11);"Anchor coordinates:            X    ";Z(2,J);TAB(63);"Y    ";Z(3,J) ELSE PRINT TAB(37);"Pr
eload    ";Z(2,J);TAB(59);"Angle    ";Z(3,J)
680 GOSUB 1180
690 IF A$="S" OR A$="s" THEN IF J>NC THEN 790 ELSE 620
700 IF A$="X" OR A$="x" THEN KT(J)=0: IF J>NC THEN 790 ELSE 620
710 IF A$="Q" OR A$="q" THEN 790
720 IF A$<>"E" AND A$<>"e" THEN 680
730 VTAB 5: V=K1: GOSUB 1060: K1=V: IF K1<0 OR K1>20 THEN 730
740 VTAB 9: V=K2: GOSUB 1060: K2=V: IF K2<1 OR K2>2 THEN 740
750 VTAB 15: HTAB 11: IF K2=1 THEN PRINT "Anchor Coordinates:            X";: HTAB 59: PRINT "    Y";: ELSE PRINT TAB(37);"Preload"
;: HTAB 59: PRINT "Angle";
760 HTAB 11: VTAB 12: JJ=0: GOSUB 1150
770 VTAB 15: JJ=2: GOSUB 1150: KT(J)=K1+32*(K2-1): IF J>NC THEN NC=J
780 GOTO 620
790 K=-1: FOR J=0 TO NC: IF KT(J)>0 THEN K=K+1: KT(K)=KT(J): FOR I=0 TO 3: Z(I,K)=Z(I,J): NEXT
800 NEXT J: L=NC: NC=K: FOR K=K+1 TO L: KT(K)=0: FOR I=0 TO 3: Z(I,K)=0: NEXT: NEXT
810 HOME: L3=13: PRINT "APPLIED LOAD DATA   ";: GOSUB 1090
820 VTAB 5: PRINT "  Case #              Label";: PRINT TAB(41);"X Force       Y Force        Moment"
830 PRINT: FOR I=1 TO NL: PRINT TAB(5);I;TAB(15);C$(I);: FOR J=0 TO 2: PRINT TAB(MC(J));X(J,I);: NEXT: PRINT: NEXT: I=1
840 VTAB I+6: HTAB 5: PRINT I;: HTAB 6: GET A$
850 IF A$=" " THEN 890 ELSE IF A$="/" THEN 910 ELSE IF A$="I" OR A$="i" THEN 930 ELSE IF A$="D" OR A$="d" THEN 950 ELSE IF A$="Q" OR
 A$="q" THEN 960 ELSE IF A$<>"E" AND A$<>"e" THEN 840
860 HTAB 15: LINE INPUT;A$: IF A$<>"" THEN C$(I)=A$: HTAB 15: PRINT SPC(27);: HTAB 15: PRINT A$;
870 FOR J=0 TO 2: L=MC(J): V=X(J,I): GOSUB 1060: X(J,I)=V: NEXT
880 IF I>NL THEN NL=I
890 IF I<NL+1 THEN I=I+1: IF I>4 THEN I=1
900 GOTO 840
910 I=I-1: IF I<1 THEN I=NL+1: IF I>4 THEN I=4
920 GOTO 840
930 IF NL=4 THEN 840
940 NL=NL+1: FOR K=NL TO I+1 STEP-1: VTAB K+6: HTAB 5: PRINT K;SPC(71);: HTAB 15: C$(K)=C$(K-1): PRINT C$(K);: FOR J=0 TO 2: X(J,K)=
X(J,K-1): PRINT TAB(MC(J));X(J,K);: NEXT: NEXT: VTAB I+6: HTAB 15: PRINT SPC(64);: FOR J=0 TO 2: X(J,I)=0: NEXT: GOTO 860
950 NL=NL-1: FOR K=I TO NL: HTAB 15: PRINT SPC(64);: C$(K)=C$(K+1): HTAB 15: PRINT C$(K);: FOR J=0 TO 2: X(J,K)=X(J,K+1): HTAB MC(J)
: PRINT X(J,K);: NEXT J: PRINT: NEXT: HTAB 15: PRINT SPC(64);: GOTO 840
960 HOME: VTAB 6: HTAB 21: PRINT "Shall we go around again (Y/N) ?       ";: GET A$: HTAB 60: PRINT A$;: IF A$="N" OR A$="n" THEN 98
0
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970 IF A$<>"Y" AND A$<>"y" THEN 960 ELSE 100
980 VTAB 8: HTAB 21: PRINT "Save edited data (Y/N) ?                    ";: GET A$: HTAB 60: PRINT A$;: IF A$="N" OR A$="n" THEN HOME: RU
N "MENU"
990 IF A$<>"Y" AND A$<>"y" THEN 980
1000 VTAB 10: PRINT TAB(21);"File name:                    ";F$;: HTAB 50: INPUT "",A$: IF A$<>"" THEN F$=A$
1010 OPEN "O",#1,F$: WRITE #1,"FFF",JN$,ZT,TX,TM,NF,N,NC,NL: FOR J=0 TO NF: WRITE #1,NE(J),XF(J),YF(J): FOR I=0 TO NE(J): WRITE #1,S
F(I,J),RF(I,J): NEXT: NEXT
1020 FOR J=0 TO N: WRITE #1,KR(J),DL(J),TL(J),DS(J),PL(J),ES(J),AS(J): FOR I=0 TO 2: WRITE #1,A(I,J),B(I,J): NEXT: NEXT
1030 FOR J=0 TO NC: WRITE #1,KT(J),Z(0,J),Z(1,J),Z(2,J),Z(3,J): NEXT: FOR J=1 TO NL: WRITE #1,C$(J),X(0,J),X(1,J).X(2,J): NEXT: CLOS
E #1
1040 RUN "MENU"
1050 VTAB 14: HTAB 16: PRINT "Error tolerance:": PRINT TAB(26);"X and Y Forces";TAB(59);TX: PRINT TAB(26);"Moment";TAB(59);TM: RETUR
N
1060 Q=L: IF V>=0 THEN Q=Q+1
1070 HTAB Q: INPUT;"",A$: IF A$<>"" THEN V=VAL(A$)
1080 HTAB L:PRINT V;TAB(L+L3);: RETURN
1090 INVERSE: PRINT " ( )Down   (/)Up   (E)dit   (I)nsert   (D)elete   (Q)uit  ": NORMAL: PRINT: RETURN
1100 HOME: VTAB 2: HTAB 25: INVERSE: PRINT "+++ FIXED MOORING DATA INPUT +++": NORMAL: RETURN
1110 IF ERR<>53 THEN 1130
1120 IF ERL=70 THEN PRINT: PRINT: PRINT TAB(16);"File not found.  Try another?": RESUME 50
1130 ON ERROR GOTO 0
1140 CLOSE #1: PRINT: PRINT: PRINT TAB(11);F$;" is not a fixed mooring input data file.": PRINT TAB(11);"Care to try another one?":
GOTO 50
1150 FOR K=0 TO 1: L=KD(K): V=Z(K+JJ,J): GOSUB 1060: Z(K+JJ,J)=V: NEXT: RETURN
1160 VTAB 7: HTAB 45: PRINT SPC(34);: HTAB 40: PRINT "Same as last fender (Y/N)?   ";: GET A$: IF A$<>"Y" AND A$<>"y" THEN HTAB 40:
PRINT "     Load            Deflection ": GOTO 280
1170 FOR I=0 TO NE(K): SF(I,J)=SF(I,K): RF(I,J)=RF(I,K): NEXT: GOTO 290
1180 VTAB 23: HTAB 11: PRINT "Edit (E), skip (S), cancel (X), or move on (Q)?";: HTAB 65: GET A$: RETURN
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500 IC=1: GOSUB 420
510 LPRINT: LPRINT: JL=JL+2: IF JL>53 THEN GOSUB 630
520 LPRINT TAB(11);"RESULTS FOR LOAD CASE";L;TAB(40);C$(L)
530 IF IE THEN LPRINT TAB(31);"CAUTION!  DID NOT CONVERGE.": JL=JL+1
540 LPRINT: LPRINT TAB(29);"Applied Load";TAB(50);L$(JE);TAB(68);"Displacement"
550 LPRINT: LPRINT USING F2$;"Surge",AA,XH,X: LPRINT USING F2$;"Sway",BB,YH,Y: LPRINT USING F2$;"Yaw",CC,SM,E*RD
560 LPRINT: JL=JL+8: IF JL>52 THEN GOSUB 630
570 LPRINT TAB(40);"Anchor Legs": LPRINT: LPRINT TAB(12);"Line";TAB(30);"Horizontal";TAB(51);"Anchor-";TAB(72);"Line": LPRINT TAB(13
);"No.";TAB(33);"Load";TAB(52);"Chock";TAB(71);"Angle": LPRINT: JL=JL+5
580 FOR I=0 TO N: IF JL>60 AND N-I>1 THEN GOSUB 630
590 LPRINT TAB(13): LPRINT USING F3$;I+1,HL(I),Z$(KP(I)),PL(I),AL(I)*RD: JL=JL+1: NEXT
600 NEXT L: LPRINT CHR$(12);: RUN "MENU"
610 IF CS=0 THEN G=P2*SGN(SN) ELSE G=ATN(SN/CS)+P2*(1-SGN(CS))
620 RETURN
630 NP=NP+1: LPRINT CHR$(12): LPRINT: LPRINT TAB(11);"MOORING ANALYSIS";TAB(JB);JN$;TAB(72);"Page";NP: LPRINT
640 JL=4: RETURN
650 IF ERR<>53 THEN ON ERROR GOTO 0
660 IF ERL=90 THEN PRINT: PRINT TAB(11);"Input file not found.  Try another?      ";: GET A$: IF A$="Y" OR A$="y" THEN PRINT A$: VTA
B 8: RESUME 80 ELSE RUN "MENU"
670 IF ERL=130 THEN PRINT: PRINT: PRINT TAB(11);"Load-extension curve for Anchor Leg Type";KC(I);"not found.": PRINT TAB(11);"Run Op
tion 2.  Press any key to return to menu.     ";: GET A$: RUN "MENU"
680 CLOSE #1: PRINT: PRINT TAB(11);F$;" is not an input file for fleet mooring analysis.": PRINT TAB(11);"Care to try another?";: HT
AB 52: GET A$: IF A$="Y" OR A$="y" THEN PRINT A$: VTAB 8: GOTO 80 ELSE RUN "MENU"
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10 REM   FIXED MOORING ANALYSIS
20 DEFINT I-N: ON ERROR GOTO 950: DIM Z$(1),KT(18),KC(20)
30 PC=.005: PI=3.14159: P2=PI/2: DR=PI/180: RD=1/DR: NU=.01: NP=1: KT(0)=1: NZ=-1: RU=.00001: Z$(1)="*": RT=.75: DEF FNB(X)=.5*(X+AB
S(X))
40 F1$="        ##       ####.#    ####.#    #######    ###.#    #######    ###.#": F2$="       ##    ######.#   ######.#
 ####.#  ######.#  ######.#     ####.#"
50 F3$="        ##    #  ####.#  ####.#    #######    #######": F4$="   ##.##^^^^   ##.###"
60 F5$="          \  \          ##.###^^^^       ###########             ####.##": F6$="       ##         #######         ######
#!       #####.#          #####.#"
70 FT$="          ##  ######.#  ######.#  ######.#  #######  ######.#  #####.#": F7$="       ##         #######
          #####.#         #####.#"
80 F8$="        ##    ######.#  ######.#              ######.#  ######.#": F9$="       ##   ##!                  #######
#######"
90 F10$="        ##         #######!                       #####.#        #####.#"
100 HOME: VTAB 2: HTAB 25: INVERSE: PRINT "*** FIXED MOORING ANALYSIS ***": NORMAL
110 PRINT: PRINT: PRINT TAB(16);"Analysis will be carried out using data previously": PRINT TAB(11);"set up in an input file.": PRIN
T
120 HTAB 16: INPUT "Input file name:                    ",F$
130 IF F$="" THEN RUN "MENU" ELSE OPEN "I",#1,F$: INPUT #1,A$: IF A$<>"FFF" THEN 990 ELSE INPUT #1,JN$,ZT,TX,TM,NF,N,NC,NL: IF NF>=0
 THEN DIM NE(NF),XF(NF),YF(NF),HF(NF),YD(NF),AF(NF),SF(10,NF),RF(10,NF)
140 N1=N+1: N2=N1+NC: DIM XC(N2),YC(N2),ZC(N),X1(N2),Y1(N2),Z1(N),KR(N2),DL(N),TL(N),BS(N2),PL(N2),ES(N),AS(N2),HL(N2),AL(N2),KP(N2)
,SL(20,N),RL(20,N),FX(NL),FY(NL),FM(NL),C$(NL): C$(0)="INITIAL POSITION"
150 FOR I=0 TO NF: INPUT #1,NE(I),XF(I),YF(I): FOR J=0 TO NE(I): INPUT #1,SF(J,I),RF(J,I): NEXT: NEXT
160 FOR I=0 TO N: INPUT #1,KR(I),DL(I),TL(I),BS(I),PL(I),ES(I),AS(I),XC(I),X1(I),YC(I),Y1(I),ZC(I),Z1(I): NEXT
170 FOR I=N1 TO N2: INPUT #1,KR(I),XC(I),YC(I),X1(I),Y1(I): NEXT
180 FOR I=1 TO NL: INPUT #1,C$(I),FX(I),FY(I),FM(I): NEXT: CLOSE #1: JB=43-INT(.5*LEN(JN$))
190 FOR J=0 TO N: FOR K=0 TO NM: IF KR(J)=KT(K) THEN 210
200 NEXT: NM=K: KT(K)=KR(J)
210 KR(J)=K: NEXT J: DIM EL(20,NM)
220 FOR J=1 TO NM: OPEN "I",#1,"LINE"+STR$(KT(J)): FOR I=0 TO 20: INPUT #1,EL(I,J): NEXT: CLOSE #1: NEXT
230 FOR I=N1 TO N2: JJ=KR(I): KP(I)=JJ\32: JJ=JJ AND 31
240 FOR J=0 TO NZ: IF JJ<>KC(J) THEN NEXT: NZ=J: KC(J)=JJ
250 KR(I)=J: NEXT I: IF NZ<0 THEN 290 ELSE DIM NT(NZ),SC(200,NZ),RC(200,NZ): FOR I=0 TO NZ: OPEN "I",#1,"CAT"+STR$(KC(I)): INPUT #1,
NT(I): FOR J=0 TO NT(I): INPUT #1,SC(J,I),RC(J,I): NEXT: CLOSE #1: NEXT
260 FOR I=N1 TO N2: JJ=KR(I): IF KP(I)=1 THEN R=X1(I): GOSUB 1030: Q=DR*Y1(I): X1(I)=XC(I)+R*COS(Q): Y1(I)=YC(I)+R*SIN(Q): GOTO 280
270 R=FNR(XC(I)-X1(I),YC(I)-Y1(I)): IF R<=RC(0,JJ) THEN R=0 ELSE FOR J=1 TO NT(JJ)-1: IF R>RC(J,JJ) THEN NEXT ELSE R=(SC(J,JJ)-SC(J-
1,JJ))/(RC(J,JJ)-RC(J-1,JJ))*(R-RC(JJ))+SC(J,JJ)
280 HL(I)=R: NEXT I
290 LPRINT: LPRINT: LPRINT TAB(32);"FIXED MOORING ANALYSIS": LPRINT: LPRINT TAB(JB);JN$: JL=5: IF NF<0 THEN 320
300 LPRINT: LPRINT: LPRINT TAB(9);"FENDER INPUT DATA:": LPRINT: LPRINT TAB(7);"Fender          Location";SPC(15);"Minimum";SPC(15);
"Maximum": LPRINT TAB(9);"No.          X          Y          Load       Defl        Load       Defl": LPRINT
310 FOR I=0 TO NF: LPRINT USING F1$;I+1,XF(I),YF(I),SF(0,I),RF(0,I),SF(NE(I),I),RF(NE(I),I): NEXT: LPRINT: LPRINT: JL=JL+NF+10
320 LPRINT TAB(9);"MOORING LINE INPUT DATA:": LPRINT: LPRINT TAB(8);"Line            Chock Coordinates";SPC(15);"Anchor Coordinates
":  LPRINT TAB(9);"No.          X          Y          Z          X          Y          Z": LPRINT
330 FOR I=0 TO N: LPRINT USING F2$;I+1,XC(I),YC(I),ZC(I),X1(I),Y1(I),Z1(I): NEXT
340 FOR I=N1 TO N2: LPRINT USING F8$;I+1;XC(I),YC(I),X1(I),Y1(I): NEXT: JL=JL+N2+6
350 LPRINT: LPRINT: LPRINT TAB(8);"Line  Type       Length        Breaking    Preload       Steel Hawser": LPRINT TAB(9);"No.  Code
 On-deck     Tail     Strength";SPC(16);"Modulus     Area": LPRINT: JL=JL+5
360 FOR I=0 TO N: LPRINT USING F3$;I+1,KT(KR(I)),DL(I),TL(I),BS(I),PL(I);: IF TL(I)>0 OR KR(I)=0 THEN LPRINT USING F4$;ES(I),AS(I) E
LSE LPRINT
370 JL=JL+1: IF JL>59 THEN GOSUB 930
380 NEXT: IF JL>54+SGN(NC) THEN GOSUB 930
390 IF NC<0 THEN 410 ELSE LPRINT: LPRINT TAB(9);"Catenaries": JL=JL+2: FOR I=N1 TO N2: JJ=KR(I): LPRINT USING F9$;I+1,KC(JJ),"C",SC(
NT(JJ),JJ),HL(I): JL=JL+1: IF JL>59 THEN GOSUB 930
400 NEXT
410 FOR J=0 TO N: CS=X1(J)-XC(J): SN=Y1(J)-YC(J): CH=Z1(J)-ZC(J): AB=SQR(CS*CS+SN*SN+CH*CH)+DL(J): X=0: Y=0: JJ=KR(J): IF JJ=0 THEN
Y=AB: GOTO 440
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420 R=PL(J)/BS(J)*20: GOSUB 1000: IF TL(J)=0 THEN X=AB/(1+R): GOTO 450
430 X=TL(J): Y=AB-X*(1+R): IF Y<0 THEN 1020
440 ES(J)=1/(ES(J)*AS(J)): Y=Y/(1+PL(J)*ES(J))
450 Q=.05*BS(J): T=X+Y-DL(J): CH=CH-ZT: CH=CH*CH: ZC(J)=CH: FOR K=0 TO 20: G=K*Q: R=X*EL(K,JJ)*MU+Y*ES(J)*G+T: S=SQR(R*R-CH): RL(K,J
)=S: SL(K,J)=G/R*S: NEXT: NEXT J
460 HOME: PRINT TAB(28);"ITERATIVE COMPUTATION"
470 FOR L=0 TO NL: AA=FX(L): BB=FY(L): CC=FM(L): IC=0: IE=0: X=0: Y=0: E=0: IF TX THEN T1=TX ELSE T1=FNB(ABS(AA)-ABS(BB))+ABS(BB): T
1=FNB(PC*T1-1)+1
480 PRINT: PRINT TAB(5);"Case";L;TAB(33);"#";TAB(43);"Surge";TAB(57);"Sway";TAB(71);"Yaw": PRINT TAB(5);C$(L);TAB(32);0;TAB(44);"0.0
0";TAB(57);"0.00";TAB(70);"0.00": IF TM THEN T2=TM ELSE T2=FNB(PC*ABS(CC)-10)+10
490 FOR K=1 TO 50: GOSUB 590: IF ABS(XH)<T1 AND ABS(YH)<T1 AND ABS(SM)<T2 THEN 580
500 DE=XX*(YY*ZZ-YZ*YZ)-XY*(XY*ZZ-XZ*YZ)+XZ*(XY*YZ-XZ*YY): IF DE=0 THEN  PRINT: PRINT TAB(11);"Error:  Too many slack lines.  Press
any key.     ";: GET A$: RUN "MENU"
510 DE=1/DE: IF K>7 THEN DE=RT*DE
520 DX=(XH*(YY*ZZ-YZ*YZ)-YH*(XY*ZZ-YZ*XZ)+SM*(XY*YZ-YY*XZ))*DE
530 DY=(XX*(YH*ZZ-SM*YZ)-XY*(XH*ZZ-SM*XZ)+XZ*(XH*YZ-YH*XZ))*DE
540 DZ=(XX*(YY*SM-YZ*YH)-XY*(XY*SM-YZ*XH)+XZ*(XY*YH-YY*XH))*DE
550 X=X-DX: Y=Y-DY: E=E-DZ
560 HTAB 32: PRINT USING "## ";K;: PRINT USING "  ########.##";X,Y,E*RD
570 NEXT K:  PRINT: PRINT "    No convergence in 50 iterations.": IE=1
580 IC=1: GOSUB 590: GOTO 790
590 XH=AA: YH=BB: SM=CC: XX=0: XY=0: XZ=0: YY=0: YZ=0: ZZ=0
600 CX=COS(E): SX=SIN(E): FOR I=0 TO N2: X2=XC(I)*CX-YC(I)*SX: Y2=XC(I)*SX+YC(I)*CX
610 X3=X1(I)-X-X2: Y3=Y1(I)-Y-Y2: R=SQR(X3*X3+Y3*Y3): CS=X3/R: SN=Y3/R: KP(I)=0: IF I>N THEN 1060
620 IF R<=RL(0,I) THEN H=0: PL(I)=0: GOTO 690
630 FOR J=1 TO 20: IF R>RL(J,I) THEN NEXT: KP(I)=1: J=20
640 HP=(SL(J,I)-SL(J-1,I))/(RL(J,I)-RL(J-1,I)): H=HP*(R-RL(J,I))+SL(J,I)
650 HR=H/R: HX=H*CS: HY=H*SN: SM=SM+HY*X2-HX*Y2: XH=XH+HX: YH=YH+HY
660 C2=CS*CS: S2=SN*SN
670 XA=-HR*S2-HP*C2: XX=XX+XA: YA=-HR*C2-HP*S2: YY=YY+YA: AB=(HR-HP)*CS*SN: XY=XY+AB
680 XB=AB*X2-XA*Y2: XZ=XZ+XB: YB=YA*X2-AB*Y2: YZ=YZ+YB: ZZ=ZZ+(YB-HX)*X2-(XB+HY)*Y2
690 IF IC THEN HL(I)=H: GOSUB 910: AL(I)=G: AS(I)=R: IF H>0 AND I<N1 THEN PL(I)=H/R*SQR(R*R+ZC(I))
700 NEXT I
710 CQ=1-CX: G=Y*CX-X*SX: FOR I=0 TO NF: Q=SGN(YF(I)): R=CQ*YF(I)+SX*XF(I)+G+Q*RU: IF R*Q<0 THEN H=0: GOTO 770
720 R=ABS(R): FOR J=1 TO NE(I)-1: IF R>RF(J,I) THEN NEXT
730 HP=(SF(J,I)-SF(J-1,I))/(RF(J,I)-RF(J-1,I)): H=HP*(R-RF(J,I))+SF(J,I)
740 H=Q*H: HX=H*SX: HY=H*CX: XA=(XF(I)-X)*CX+(YF(I)-Y)*SX: XH=XH+HX: YH=YH-HY: SM=SM-XA*H
750 YA=HP*SX: XX=XX-YA*SX: XY=XY+YA*CX: YY=YY-HP*CX*CX: HR=XA*HP
760 XZ=XZ+HY+HR*SX: YZ=YZ+HX-HR*CX: ZZ=ZZ+H*(R-YF(I))-HR*XA
770 IF IC THEN YD(I)=R: HF(I)=ABS(H): AF(I)=E+Q*P2
780 NEXT I: RETURN
790 LPRINT: LPRINT: JL=JL+2: IF JL>53 THEN GOSUB 930
800 LPRINT TAB(9);"RESULTS FOR LOAD CASE";L;TAB(39);C$(L);TAB(68);"Tide =";ZT
810 IF IE THEN LPRINT TAB(41);"CAUTION!  DID NOT CONVERGE.": JL=JL+1
820 LPRINT: LPRINT TAB(27);"Applied Load";TAB(48);"Load Error";TAB(66);"Displacement"
830 LPRINT: LPRINT USING F5$;"Surge",AA,XH,X: LPRINT USING F5$;"Sway",BB,YH,Y: LPRINT USING F5$;"Yaw",CC,SM,E*RD
840 LPRINT: JL=JL+8: IF JL>53 THEN GOSUB 930
850 LPRINT TAB(37);"Mooring Legs": LPRINT: LPRINT TAB(9);"No.        Horiz Load       Total Load       Chock-Anchor       Horiz Angle"
: JL=JL+3
860 IF NF<0 THEN 880 ELSE LPRINT: LPRINT TAB(9);"Fenders": JL=JL+2: FOR I=0 TO NF: LPRINT USING F7$;I+1,HF(I),YD(I),AF(I)*RD: JL=JL+
1: IF JL>59 THEN GOSUB 930
870 NEXT I
880 LPRINT: LPRINT TAB(9);"Lines": JL=JL+2: FOR I=0 TO N: LPRINT USING F6$;I+1,HL(I),PL(I),Z$(KP(I)),AS(I),AL(I)*RD: JL=JL+1: IF JL>
59 THEN GOSUB 930
890 NEXT: FOR I=N1 TO N2: LPRINT USING F10$;I+1,HL(I),Z$(KP(I)),AS(I),AL(I)*RD: JL=JL+1: IF JL>59 THEN GOSUB 930
900 NEXT: NEXT L: LPRINT CHR$(12);: RUN "MENU"
910 IF CS=0 THEN G=P2*SGN(SN) ELSE G=ATN(SN/CS)+P2*(1-SGN(CS))
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920 RETURN
930 NP=NP+1: LPRINT CHR$(12): LPRINT: LPRINT TAB(9);"MOORING ANALYSIS";TAB(JB);JN$;TAB(73);"Page";NP: LPRINT
940 JL=4: RETURN
950 IF ERR<>53 THEN 980 ELSE IF ERL=130 THEN PRINT: PRINT TAB(11);"Input file not found.  Try another?      ";: GET A$: IF A$="Y" OR
 A$="y" THEN PRINT A$: VTAB 8: HTAB 1: RESUME 120 ELSE RUN "MENU"
960 IF ERL=220 THEN PRINT: PRINT TAB(11);"Load-extension curve for line type";KT(J);"not found.": PRINT TAB(11);"Fix input data or p
rovide curve (Option 3).";: INPUT;"  Press RETURN.     ",A$: RUN "MENU"
970 IF ERL=250 THEN PRINT: PRINT TAB(11);"Load-extension curve for catenary type";KC(I);"not found.": PRINT TAB(11);"Provide it usin
g Option 2.";: INPUT "Press RETURN.      ",A$: RUN "MENU"
980 ON ERROR GOTO 0
990 CLOSE #1: PRINT: PRINT TAB(11);F$;" is not an input file for fixed mooring analysis.": PRINT TAB(11);"Care to try another?";: HT
AB 52: GET A$: IF A$="Y" OR A$="y" THEN PRINT A$: VTAB 8: GOTO 120 ELSE RUN "MENU"
1000 IF R=0 THEN RETURN ELSE FOR K=1 TO 19: IF R>K THEN NEXT
1010 R=(EL(K,JJ)-EL(K-1,JJ))*(R-K)+EL(K,JJ): R=NU*R: RETURN
1020 PRINT: PRINT TAB(11);"Line No.";J;"has";INT(-X+.5);"length units of slack.": PRINT TAB(11);"Fix by shortening tail. ";: INPUT "
Press RETURN.     ",A$: RUN "MENU"
1030 IF R<=0 THEN R=RC(0,JJ): RETURN
1040 K=NT(JJ): R=R/SC(K,JJ)*K: J=INT(R)-K+1: J=K+.5*(J-ABS(J))
1050 R=(RC(J,JJ)-RC(J-1,JJ))*(R-J)+RC(J,JJ): RETURN
1060 JJ=KR(I): IF R<=RC(0,JJ) THEN H=0: GOTO 690
1070 FOR J=1 TO NT(JJ): IF R>RC(J,JJ) THEN NEXT: KP(I)=1: J=NT(JJ)
1080 HP=(SC(J,JJ)-SC(J-1,JJ))/(RC(J,JJ)-RC(J-1,JJ)): H=HP*(R-RC(J,JJ))+SC(J,JJ): GOTO 650
```

```
10 REM   FLEET MOORING ANALYSIS
20 DEFINT I-N: ON ERROR GOTO 650: DIM KC(20),Z$(1),L$(1): READ Z$(1),L$(0),L$(1),PC,PI,RT,NZ,NP: DATA "#","Total Load","Load Error",
.005,3.14159,.75,-1,1
30 P2=PI/2: DR=PI/180: RD=1/DR: DEF FNR(CS,SN)=SQR(CS*CS+SN*SN): DEF FNA(X)=.5*(X-ABS(X)): DEF FNB(X)=.5*(X+ABS(X))
40 F2$="          \  \            ##.###^^^^            ##.###^^^^           #####.#": F3$="##                ##########!              #####
#.#          #####.#"
50 F1$="          ## ########.# ########.# ########.# ######### ########.# #######.#"
60 HOME: VTAB 2: HTAB 25: INVERSE: PRINT "*** FLEET MOORING ANALYSIS ***": NORMAL
70 PRINT: PRINT: PRINT TAB(16);"Analysis will be carried out using data previously": PRINT TAB(11);"set up in an input file.": PRINT
80 HTAB 16: INPUT "Input file name:                  ",F$
90 OPEN "I",#1,F$: INPUT #1,A$: IF A$<>"SSS" THEN 680 ELSE INPUT #1,JN$,JE,TX,TM,N,NL: JE=JE-1: DIM KR(N),XC(N),YC(N),X1(N),Y1(N),AL
(N),PL(N),HL(N),KP(N): FOR I=0 TO N: INPUT #1,K,XC(I),YC(I),PL(I),AL(I),KP(I)
100 FOR J=0 TO NZ: IF K<>KC(J) THEN NEXT: NZ=J: KC(J)=K
110 KR(I)=J: NEXT I: DIM FX(NL),FY(NL),FM(NL),C$(NL): FOR I=1 TO NL: INPUT #1,C$(I),FX(I),FY(I),FM(I): NEXT: CLOSE #1: C$(0)="INITIA
L POSITION"
120 DIM SC(200,NZ),RC(200,NZ),NT(NZ): FOR I=0 TO NZ
130 OPEN "I",#1,"CAT"+STR$(KC(I)): INPUT #1,NT(I): FOR J=0 TO NT(I): INPUT #1,SC(J,I),RC(J,I): NEXT: CLOSE #1: NEXT: JB=43-INT(.5*LE
N(JN$))
140 LPRINT: LPRINT: LPRINT TAB(28);"MULTIPLE POINT MOORING ANALYSIS": LPRINT: LPRINT TAB(JB);JN$: LPRINT: LPRINT: LPRINT TAB(11);"AN
CHOR LEG INPUT DATA:": LPRINT
150  FOR I=0 TO N: IF KP(I)=1 THEN 190
160 JJ=KR(I): K=NT(JJ): R=PL(I)/SC(K,JJ)*K: J=INT(R)-K+1: J=K+FNA(J)
170 R=(RC(J,JJ)-RC(J-1,JJ))*(R-J)+RC(J,JJ)
180 G=AL(I)*DR: X1(I)=XC(I)+R*COS(G): Y1(I)=YC(I)+R*SIN(G): GOTO 210
190 X1(I)=PL(I): Y1(I)=AL(I): CS=X1(I)-XC(I): SN=Y1(I)-YC(I): R=FNR(CS,SN)
200 GOSUB 610: AL(I)=G*RD: GOSUB 390: PL(I)=H
210 X=X1(I)-X3: X3=X3+FNA(X): X=X1(I)-X2: X2=X2+FNB(X): X=Y1(I)-Y3: Y3=Y3+FNA(X): X=Y1(I)-Y2: Y2=Y2+FNB(X)
220 NEXT I: RG=.125*FNR(X2-X3,Y2-Y3): LPRINT TAB(9);"Leg No.     Chock Coords          Leg      Preload      Anchor Coords"
230 LPRINT TAB(21);"X            Y         Angle                   X          Y": LPRINT
240 FOR I=0 TO N: LPRINT USING F1$;I+1,XC(I),YC(I),AL(I),PL(I),X1(I),Y1(I)
250 NEXT: JL=N+13: HOME: IF JE THEN PRINT TAB(28);"ITERATIVE COMPUTATION"
260 FOR L=0 TO NL: AA=0: BB=0: CC=0: IF JE=0 THEN X=FX(L): Y=FY(L): E=FM(L)*DR: GOTO 500
270 AA=FX(L): BB=FY(L): CC=FM(L): IC=0: X=0: Y=0: E=0: IF TX THEN T1=TX ELSE T1=FNB(ABS(AA)-ABS(BB))+ABS(BB): T1=FNB(PC*T1-1)+1
280 PRINT: PRINT TAB(5);"Case";L;":";TAB(33);"#";TAB(44);"Surge";TAB(57);"Sway";TAB(71);"Yaw": PRINT TAB(5);C$(L);TAB(32);0;TAB(45);
"0.0";TAB(58);"0.0";TAB(71);"0.0": IF TM THEN T2=TM ELSE T2=FNB(PC*ABS(CC)-10)+10
290 IE=0: FOR K=1 TO 50: GOSUB 420
300 DE=XX*(YY*ZZ-YZ*YZ)-XY*(XY*ZZ-XZ*YZ)+XZ*(XY*YZ-XZ*YY): IF DE=0 THEN PRINT TAB(11);"Error:  Too many slack lines.  Press any key.
";: GET A$: RUN "MENU"
310 IF ABS(XH)<T1 AND ABS(YH)<T1 AND ABS(SM)<T2 THEN 500
320 DE=1/DE: IF K>10 THEN DE=RT*DE
330 DX=(XH*(YY*ZZ-YZ*YZ)-YH*(XY*ZZ-YZ*XZ)+SM*(XY*YZ-YY*XZ))*DE: IF ABS(DX)>RG THEN DX=RG*SGN(DX)
340 DY=(XX*(YH*ZZ-SM*YZ)-XY*(XH*ZZ-SM*XZ)+XZ*(XH*YZ-YH*XZ))*DE: IF ABS(DY)>RG THEN DY=RG*SGN(DY)
350 DZ=(XX*(YY*SM-YZ*YH)-XY*(XY*SM-YZ*XH)+XZ*(XY*YH-YY*XH))*DE: IF ABS(DZ)>.03 THEN DZ=.03*SGN(DZ)
360 X=X-DX: Y=Y-DY: E=E-DZ
370 HTAB 32: PRINT USING "## ";K;: PRINT USING "  ########.#";X,Y,E*RD
380 NEXT K: PRINT: PRINT "    No convergence in 50 iterations.": PRINT: IE=1: GOTO 500
390 KP(I)=0: IF R<=RC(0,JJ) THEN H=0: HP=0: RETURN
400 FOR J=1 TO NT(JJ): IF R>RC(J,JJ) THEN NEXT: KP(I)=1: J=NT(JJ)
410 HP=(SC(J,JJ)-SC(J-1,JJ))/(RC(J,JJ)-RC(J-1,JJ)): H=HP*(R-RC(J,JJ))+SC(J,JJ): HR=H/R: RETURN
420 XH=AA: YH=BB: SM=CC: XX=0: XY=0: XZ=0: YY=0: YZ=0: ZZ=0
430 CX=COS(E): SX=SIN(E): FOR I=0 TO N: X2=XC(I)*CX-YC(I)*SX: Y2=YC(I)*CX+XC(I)*SX
440 X3=X1(I)-X2-X: Y3=Y1(I)-Y2-Y: R=FNR(X3,Y3): CS=X3/R: SN=Y3/R: JJ=KR(I): GOSUB 390
450 HX=H*CS: HY=H*SN: SM=SM+HY*X2-HX*Y2: XH=XH+HX: YH=YH+HY: IF IC THEN PL(I)=R: GOSUB 610: AL(I)=G: HL(I)=H: GOTO 490
460 C2=CS*CS: S2=SN*SN
470 XA=-HR*S2-HP*C2: XX=XX+XA: YA=-HR*C2-HP*S2: YY=YY+YA: AB=(HR-HP)*CS*SN: XY=XY+AB
480 XB=AB*X2-XA*Y2: XZ=XZ+XB: YB=YA*X2-AB*Y2: YZ=YZ+YB: ZZ=ZZ+(YB-HX)*X2-(XB+HY)*Y2
490 NEXT I: RETURN
```

REFERENCES

U.S. Coast Guard, Department of Transportation:" Buoy Mooring Selection Guide for Chain Moorings, " COMDTINST M16511.1, December 1978.

ASTM E-621: "Standard Practice for the Use of Metrics (SI) Units in Building Design and Construction," Annual Book of ASTM Standards, Part 18, American Society for Testing and Materials (ASTM), Philadelphia, PA, 1979.

Naval Civil Engineering Laboratory (NCEL): Handbook of Marine Geotechnology, 1983a.

MIL-A-18001J: "Anode, Corrosion Preventative zinc, Slab Disc and Rod Shaped," 25 November 1983.

MIL-C-18295: "Military Specification for Chain and Fittings for Fleet Moorings ," December 1976.

MIL-C-19944: "Chain, Stud Link, Anchor, Steel, Dielock Standard, Heavy Duty and High Strength Types," 18 January 1961.

CHESNAVFAC FPO-l-81-(14); "Diego Garcia Fleet Mooring Design Report," Ocean Engineering and Construction Project Office, Chesapeake Division, Naval Facilities Engineering Command, Washington, DC, April 1981.

Flory, John F., Benham, Frank A., Marcello, James T ., Poranski, Peter F., and Woehleke, Steven P.; "Guidelines for Deepwater Port Single Point Mooring Design," Report No. EE-17E-T77, Exxon Research and Engineering Company, September 1977.

Bretschneider, Charles L; "Estimating Wind-Driven Currents Over the Continental Shelf," Ocean Industry, June 1967, pp. 45-48.

Van Oortmerssen, G.; "The Motions of a Moored Ship in Waves," Netherlands Ship Model Basin (NSMB), Publication No. 510, Wageningen, The Netherlands, 1976.

Webster, R. L.; "SEADYN Mathematical Manual," Contract Report CR-82.019, Naval Civil Engineering Laboratory (NCEL), April 1982.

Altmann, Ronald; "Forces on Ships Moored in Protected Waters," Technical Report 7096-1, Hydronautics Incorporated, July 1971.

Harris, D. L.; "Tides and Tidal Datums in the United States," Special Report No. 7, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, February 1981.

National Oceanography Command Detachment; "Guide to Standard Weather Summaries and Climatic Services," NAVAIR 50-lC-534, NOCD, Asheville, NC, January 1980.

Changery, M. J.; “National Wind Data Index, Final Report,” HCO/T1041-01, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, December 1978.

Changery, M. J.; *’Historical Extreme Winds for the United States--Atlantic and Gulf of Mexico Coastlines,” NUREG/CR-2639, National Oceanic and Atmospheric Ministration, National Climatic Data Center, Asheville, NC, May 1982a.

Changery, M. J.; “Historical Extreme Winds for the United States--Great Lakes and Adjacent Regions,” NUREG/CR-2890, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, August 1982b.

Turpin, Roger J. B., and Brand, Samson; “Hurricane Havens Handbook for the North Atlantic Ocean,” Technical Report TR82-03, Naval Environmental Prediction Research Facility, Monterey, CA, June 1982.

Brand, Samson, and Blelloch, Jack W.; “Typhoon Havens Handbook for the Western Pacific and Indian Oceans,” Technical Paper 5-76, Naval Environmental Prediction Research Facility, Monterey, CA, June 1976.

Reiter, Elmar R.; “Handbook for Forecasters in the Mediterranean,” Technical Paper 5-75, Naval Environmental Prediction Research Facility, Monterey, CA, November 1975.

summary of Synoptic Meteorological Observations, prepared under the direction of the U.S. Naval Weather Service Command by the National Climatic Center, Asheville, NC. (Copies are obtainable from the National Technical Information Service, Springfield, VA 22161.)

U.S. Army Corps of Engineers; "Method of Determining Adjusted Windspeed, U_A, for Wave Forecasting,” Coastal Engineering Technical Note, CETN-I-5, Coastal Engineering Research Center, Fort Belvoir, VA, 1981.

Simiu, Emil, and Scanlon, Robert H.; Wind Effects on Structures: An Introduction To Wind Engineering, A Wiley-Interscience Publication, New York, 1978.

Owens, R., and Palo, P. A.; “Wind Induced Steady Loads on Moored Ships,” TN: N-1628, Naval Civil Engineering Laboratory (NCEL), 1982.

Jane’s Fighting Ships, edited by Captain John E. Moore, Macdonald and Jane’s Publishers Limited, London, England, 1976.

Cox, J. V.; “STATMOOR--A Single-Point Mooring Static Analysis Program,” TN: N-1634, Naval Civil Engineering Laboratory (NCEL), June 1982.

Naval Facilities Engineering Command; “FSMOOR (Free-Swinging MOORing) Computer Manual,” January 1982.

Gerald, Curtis F.; Applied Numerical Analysis, Addison-Wesley Publishing Company, Reading, MA, May 1980.

Changery, M. J.; "National Wind Data Index, Final Report," HCO/T1041-01, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, December 1978.

Changery, M. J.; "Historical Extreme Winds for the United States--Atlantic and Gulf of Mexico Coastlines," NUREG/CR-2639, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, May 1982a.

Changery, M. J.; "Historical Extreme Winds for the United States--Great Lakes and Adjacent Regions," NUREG/CR-2890, National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, August 1982b.

Turpin, Roger J. B., and Brand, Samson; "Hurricane Havens Handbook for the North Atlantic Ocean," Technical Report TR82-03, Naval Environmental Prediction Research Facility, Monterey, CA, June 1982.

Brand, Samson, and Blelloch, Jack W.; "Typhoon Havens Handbook for the Western Pacific and Indian Oceans," Technical Paper 5-76, Naval Environmental Prediction Research Facility, Monterey, CA, June 1976.

Reiter, Elmar R.; "Handbook for Forecasters in the Mediterranean," Technical Paper 5-75, Naval Environmental Prediction Research Facility, Monterey, CA, November 1975.

summary of Synoptic Meteorological Observations, prepared under the direction of the U.S. Naval Weather Service Command by the National Climatic Center, Asheville, NC. (Copies are obtainable from-the National Technical Information Service, Springfield, VA 22161.)

U.S. Army Corps of Engineers; "Method of Determining Adjusted Windspeed, U_A, for Wave Forecasting," Coastal Engineering Technical Note, CETN-I-5, Coastal Engineering Research Center, Fort Belvoir, VA, 1981.

Simiu, Emil, and Scanlon, Robert H.; Wind Effects on Structures: An Introduction To Wind Engineering, A Wiley-Interscience Publication, New York, 1978.

Owens, R., and Palo, P. A.; "Wind Induced Steady Loads on Moored Ships," TN: N-1628, Naval Civil Engineering Laboratory (NCEL), 1982.

Jane's Fighting Ships, edited by Captain John E. Moore, Macdonald and Jane's Publishers Limited, London, England, 1976.

Cox, J. V.; "STATMOOR--A Single-Point Mooring Static Analysis Program," TN: N-1634, Naval Civil Engineering Laboratory (NCEL), June 1982.

Naval Facilities Engineering Command; "FSMOOR (Free-Swinging MOORing) Computer Manual," January 1982.

Gerald, Curtis F.; Applied Numerical Analysis, Addison-Wesley Publishing Company, Reading, MA, May 1980.

Naval Civil Engineering Laboratory (NCEL); “Multiple Stockless Anchors for Navy Fleet Moorings, ” Techdata Sheet 83-05, February 1983b.

Naval Civil Engineering Laboratory (NCEL); “Drag Embedment Anchors for Navy Moorings,” Techdata Sheet 83-08, March 1983c.

Naval Civil Engineering Laboratory (NCEL); “Stockless and Stato Anchors for Navy Fleet Moorings,” Techdata Sheet 83-09, March 1983d.

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GLOSSARY

Breaking Strength. The ultimate strength of a mooring chain or fitting as determined by a break test.

Break Test. A test which involves measuring the breaking strength of a mooring chain or fitting.

Chock. A metal casting with two horn-shaped,arms used for passage, guiding, or steadying of mooring or towing lines.

Degaussing. The process by which the magnetic field of a ship is neutralized.

Factor of Safety. The ratio of the breaking or ultimate strength of a mooring component to the working load of that component.

Fastest-Mile Windspeed. The highest measured windspeed with a duration sufficient to travel 1 mile.

Fluke Angle. The angle between the anchor shank and the anchor fluke.

Ground Tackle. The anchors, chain, and other supporting equipment used to secure a buoy in a specific location.

Hawsepipe. A cast-iron or steel pipe placed on the bow or stern of a ship or in the center of a buoy for the anchor chains or tension bar to pass through.

Hawser. The mooring rope or line between a fleet-mooring buoy and the moored vessel. For a fixed mooring, the hawser is the mooring rope or line between the deck of a fixed-mooring structure and the moored-vessel.

Holding Capacity. The load which an embedment anchor is capable of withstanding.

Mean High Water (MEW). The average height of the high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and to reduce the results to the equivalent of a 19-year value.

Mean Higher High Water (MHHW). The average height of the higher high waters over a 19-year period. For shorter periods of observation, corrections are applied to eliminate known variations and reduce the result to the equivalent of a mean 19-year value.

Mean Lower Low Water (MLLW). The average height of the lower low waters over a 19-year period. For shorter periods of observations, corrections are applied to-eliminate known variations and reduce the results to the equivalent of a mean 19-year value. Frequently abbreviated to lower low water.

Midships (Amidships). Midway between the bow and the stern of a ship or vessel.

Peak-Gust Windspeed. A measure of the maximum windspeed for a given period of record; normally a high-velocity, short-duration wind.

Proof Test. A test which involves loading a mooring chain or fitting with a load equal to 70 percent of the breaking strength, as determined by the break test.

Return Period. The average length of time between occurrences of a specified event. For example, a 50-year windspeed will occur, on the average, once every 50 years.

Watch Circle. The water surface area delineated by the maximum excursions of a fleet-mooring buoy.

Working Load. The maximum allowable load on the mooring component. Usually, the working load is some fraction of the breaking strength of the component. For example, the working load of mooring chain is 35 percent of its breaking strength.

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