DDS 582-1

CALCULATIONS FOR MOORING SYSTEMS

DEPARTMENT OF THE NAVY
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DESIGN DATA SHEET - CALCULATIONS FOR MOORING SYSTEMS

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DDS-582-1-a. INTRODUCTION

A fixed mooring system provided on Navy ships should permit the ship to remain safely moored to a pier under specified design loading conditions.

The purpose of this design data sheet is to provide guidance and uniform standards for design calculations for mooring of Navy ships.

The design procedure presented in the DDS applies to mooring lines of different materials, including manila, synthetic fiber, and wire.

The data sheet contains three main parts: Part I (DDS 582-1-d) presents a recommended procedure for calculating wind and current forces, Part II (DDS 582-1-e) describes a calculation procedure for determining mooring line tension forces based on a system that has two degrees of freedom, and Part III (DDS 582-1-f) provides information on mooring equipment such as ropes, mooring chocks, bitts, hawser reels, and capstans.

Calculation sheets and tables are prepared for use in both metric and inch-pound units. Only Calculation Sheet-1 is presented in two versions, one for inch-pound units and the other for metric units. The two other calculation sheets are presented in one version each.

To illustrate the design procedure, an example is included in DDS 582-1-i.

A bibliography of referenced documents cited in the text is provided in DDS 582-1-j. Additional references of related material are listed in DDS 582-1-k.

DDS-582-1-b. SYMBOLS FOR FORMULAS; ABBREVIATIONS

Symbol or abbreviation	Quantity or meaning	SI units	U.S. inch-pound units
a	$\sum_{i=1}^{n} k_i$	N/m	lb/ft
A_b	End projected area below the waterline	m^2	ft^2
A_e	Longitudinal projected wind area model	m^2	ft^2
a_i	Cross-sectional area of mooring line	mm^2	in^2
A_s	Lateral (side) projected wind area of vessel	m^2	ft^2
b	$\sum_{i=1}^{n} k_i \cdot X_i$	N	lb
B	Beam	m	ft
BS	Breaking strength of line	kN	lb
BS_r	Breaking strength of rope	kN	lb
c	$\sum_{i=1}^{n} k_i \cdot X_i^2$	kNm	ft-lb
C	Circumference of rope	mm	in
C_{xca}	Longitudinal current skin friction coefficient	(Dimensionless)	
C_{xcb}	Longitudinal current force drag coefficient	do.	
C_{xw}	Longitudinal wind force coefficient	do.	
C_{xyc}	Current yaw moment coefficient	do.	
C_{xyw}	Wind yaw moment coefficient	do.	
C_{yc}	Lateral current force coefficient	do.	
C_{yw}	Lateral wind force coefficient	do.	

Symbol or abbreviation	Quantity or meaning	SI units	U.S. inch-pound units
E_i	Young's modulus of rope material	kN/mm^2	lb/in^2
FS	Factor of safety of mooring line	(Dimensionless)	
F_x	Total external longitudinal force	N	lb
F_{xc}	Longitutional current force	N	lb
F_{xw}	Logitutional wind force	N	lb
F_y	Total external lateral force	N	lb
F_{yc}	Lateral current force	N	lb
F_{yi}	Mooring line force	N	lb
F_{yw}	Lateral wind force	N	lb
HP	Capstan power	kW	hp
i	Line number (often in subscript)		
k_{yi}	Line spring constant component in Y-direction	N/m	lb/ft
K_i	Line spring constant = $\frac{a_i \times E_i}{L_i}$	N/m	lb/ft
l_i	Line length from chock to bollard	m	ft
l_o	Line length from bitts to chock	m	ft
L	Length of rope	m	ft
L_i	Line length from bollards to bitts	m	ft
LWL	Waterline length of the ship	m	ft
M_c	Current yaw moment	Nm	ft-lb
M_r	Overall yaw moment	Nm	ft-lb
M_w	Wind yaw moment	Nm	ft-lb
P_{cp}	Capstan line pull	N	lb

Symbol or abbreviation	Quantity or meaning	SI units	U.S. inch-pound units
S	Wetted surface	m^2	ft^2
T	Draft	m	ft
T_i	Line tension	kN	lb
V	Volume	m^3	ft^3
V_b	Lateral berthing speed	kt	kt
V_c	Current speed	kt	kt
V_{cp}	Capstan line speed	m/min 1/	ft/min
V_w	Wind speed	kt	kt
WD	Water depth	m	ft
X_{bl}, Y_{bl}, Z_{bl}	Bollard coordinates	m	ft
X_{ch}, Y_{ch}, Z_{ch}	Mooring chock coordinates	m	ft
γ	Ship rotation about vertical axis	rad	rad
Δ	Displacement of ship	t	LT
δ_y	Ship translation in Y-direction	m	ft
η_g	Efficiency of gears and bearings	(Dimensionless)	
η_h	Efficiency of hydraulic pump and motor	do.	
η_c	Efficiency of capstan head	do.	
θ	Mooring line angle in horizontal plane	(°) 1/	(°)

Symbol or abbreviation	Quantity or meaning	SI units	U.S inch-pound units
θ_c	Relative bearing of approaching current (also called angle of current attack)	(°) 1/	(°)
θ_w	Relative bearing of approaching wind (also called angle of wind attack)	(°) 1/	(°)
ρ_c	Mass density of water	$\frac{kg}{m^3}$	$\frac{lb\text{-}s^2}{ft^4}$ 2/
ρ_w	Mass density of air	$\frac{kg}{m^3}$	$\frac{lb\text{-}s^2}{ft^4}$ 2/
ϕ_i	Mooring line angle in vertical plane	(°) 1/	(°)
CG	Center of gravity		
deg	Degree		
do.	Ditto		
FS	Factor of safety		
ft	Foot		
g	Gram		
hp	Horsepower		
in	Inch		
k	Kilo (prefix, as in kW)		
kt	Knot (1852 meters per hour)		
lb	Pound (force unless otherwise indicated)		
m	Meter		
m	Milli (prefix, as in mm)		
min	Minute (of time)		
N	Newton		

Symbol or abbreviation	Quantity or meaning	SI units	U.S inch-pound units
rad	Radian		
rev	Revolution		
s	Second (of time)		
SI	International System of Units		
SNAME	Society of Naval Architects and Marine Engineers		
t	Metric ton 3/		
LT	Long ton		
W	Watt		

1/ The minute (of time) and the degree (of arc) are not strictly part of SI, but are usable with it, and each has the same meaning in both systems of units.

2/ A unit of one $\frac{lb\text{-}s^2}{ft}$ is also known as the slug, which is equivalent to 32.174 pounds mass, approximately.

3/ The metric ton, common in commerce, is not an SI unit, but is identically equal to 1000 kg. When used as a unit of force the metric ton is taken as 9.806 65 kilonewtons.

DDS-582-1-c. MOORING DESIGN CONDITIONS

General

The design of a system for mooring to a pier shall be in accordance with the methods and criteria described herein.

The mooring equipment on Navy ships is intended to permit the ship to remain moored under the conditions of wind and current prevalent at its usual berthing sites, except for extreme conditions such as those caused by hurricanes or typhoons.

In this DDS the ship is assumed to be moored at conventional pier facilities where the environmental forces imposed on it are those of wind and current. In the calculations, the wind and current forces are considered to be steady state in nature and accordingly are treated as static loads. To allow for dynamic forces, conservative assumptions are made in establishing wind and current velocities for design purposes.

The equipment for mooring systems is designed for two weather conditions:

(1) Normal weather condition. Wind of 25 knots and current of 1 knot acting simultaneously and at right angles to the ship's centerline, both tending to push the ship away from the pier.

(2) Heavy weather condition. Wind of 50 knots and current of 3 knots acting simultaneously and at right angles to the ship's centerline, both tending to push the ship away from the pier.

To determine the worst-case stresses on the ship, wind and current forces should be calculated for the ship lightly loaded (shallow draft) and fully loaded (deepest draft), for each weather condition.

Factors of Safety of Mooring Lines

To provide factors of safety based on a doubled up line under the foregoing conditions, the calculated tension forces in mooring lines should be not less than the following:

- Normal weather condition, FS = 9.0 for design applied loads
- Heavy weather condition, FS = 3.0 for limit applied loads

DDS-582-1-d. MOORING LOADS

The mooring arrangement is designed to accommodate static steady state wind and current forces. Owing to their complexity, the dynamic forces caused by surge, wind gusts, waves, and passing ship effects are not considered in the calculations. Instead, conservatively established design loading conditions specified in DDS 582-1-c provide sufficient reserve strength in the mooring arrangement to allow for these transient dynamic stresses. Both wind and current are applied at the ship's center of gravity (CG). (1)

DDS-582-1-D(1) WIND FORCES

The magnitude of the wind force on the ship is influenced by the wind velocity (speed and relative direction) and by the projected wind area of the ship. Generally, the moored ship is exposed to the highest wind forces when the wind strikes the ship from abeam with the ship in its light condition.

The resultant wind forces and yaw moment acting through the ship's center are expressed by the following equations:

Longitudinal wind force

$$F_{xw} = 1/2 \cdot C_{xw} \cdot \rho_w \cdot V_w^2 \cdot A_e \qquad (1)$$

Lateral wind force

$$F_{yw} = 1/2 \cdot C_{yw} \cdot \rho_w \cdot V_w^2 \cdot A_s \qquad (2)$$

Wind yaw moment

$$M_w = 1/2 \cdot C_{xyw} \cdot \rho_w \cdot V_w^2 \cdot A_s \cdot LWL \qquad (3)$$

DDS-582-1-d(2) CURRENT FORCES

Longitudinal current force

$$F_{xc} = 1/2 \cdot \rho_c \cdot V_c^2 \, (C_{xca} \cdot S \cdot B/LWL + C_{xcb} \cdot A_b) \qquad (4)$$

where:

$$S = 15.5 \sqrt{LWL \cdot \Delta} \quad (ft^2)$$

or

$$S = 2.588 \sqrt{LWL \cdot \Delta} \quad (m^2)$$

Lateral current force

$$F_{yc} = 1/2 \cdot C_{yc} \cdot \rho_c \cdot V_c^2 \cdot LWL \cdot T \qquad (5)$$

Current yaw moment

$$M_c = 1/2 \cdot C_{xyc} \cdot \rho_c \cdot V_c^2 \cdot LWL^2 \cdot T \qquad (6)$$

where:

C_{xca}, C_{yc}, and C_{xyc} are longitudinal, lateral, and yaw current coefficients determined from the diagrams on figures 1, 2, and 3.

(1) Mooring Design Physical and Empirical Data, Design Manual 26.6, Department of the Navy, Naval Facilities Engineering Command, March 1982.

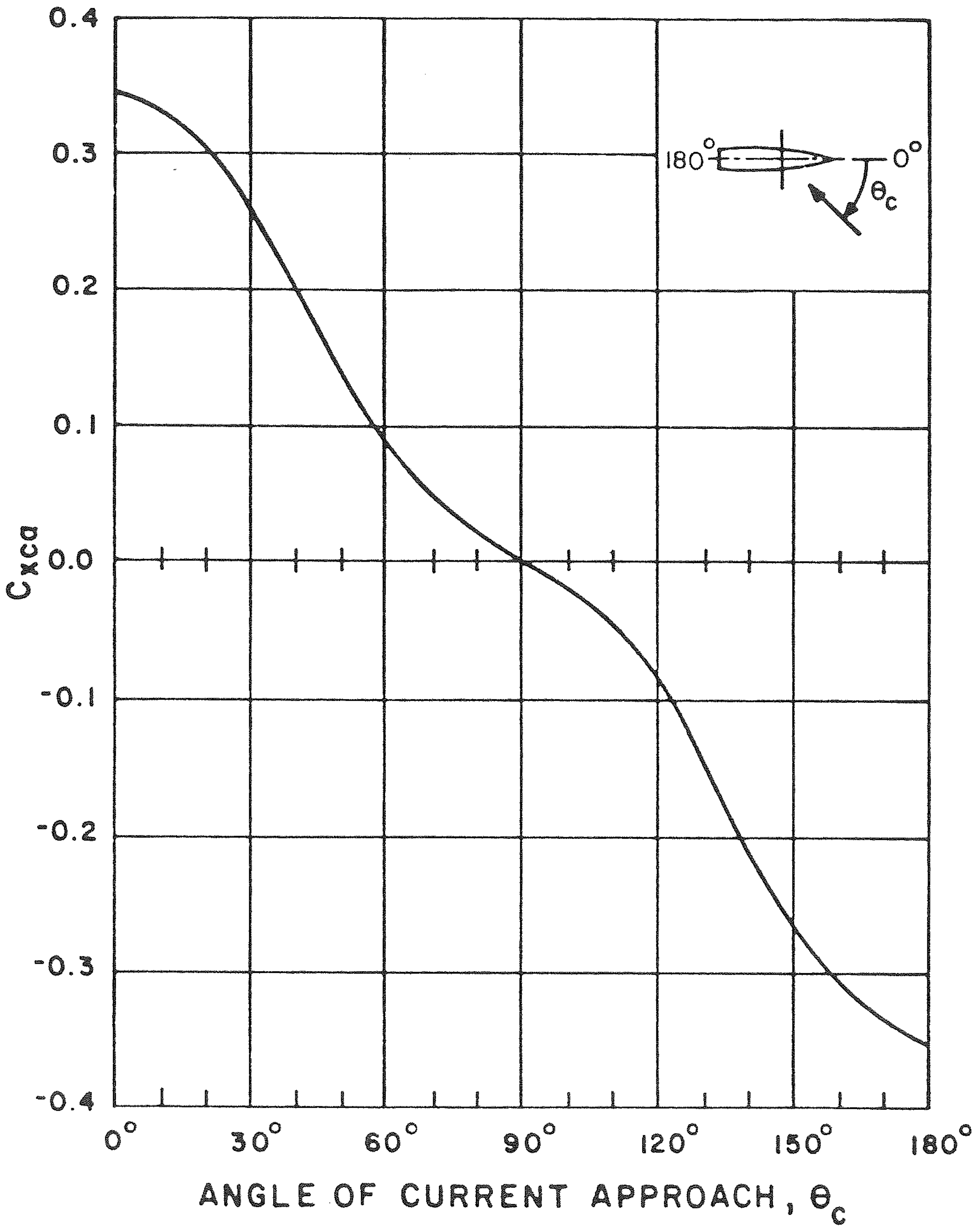


FIGURE 1. Longitudinal current skin friction coefficient (C_{xca}), based on reference (1).

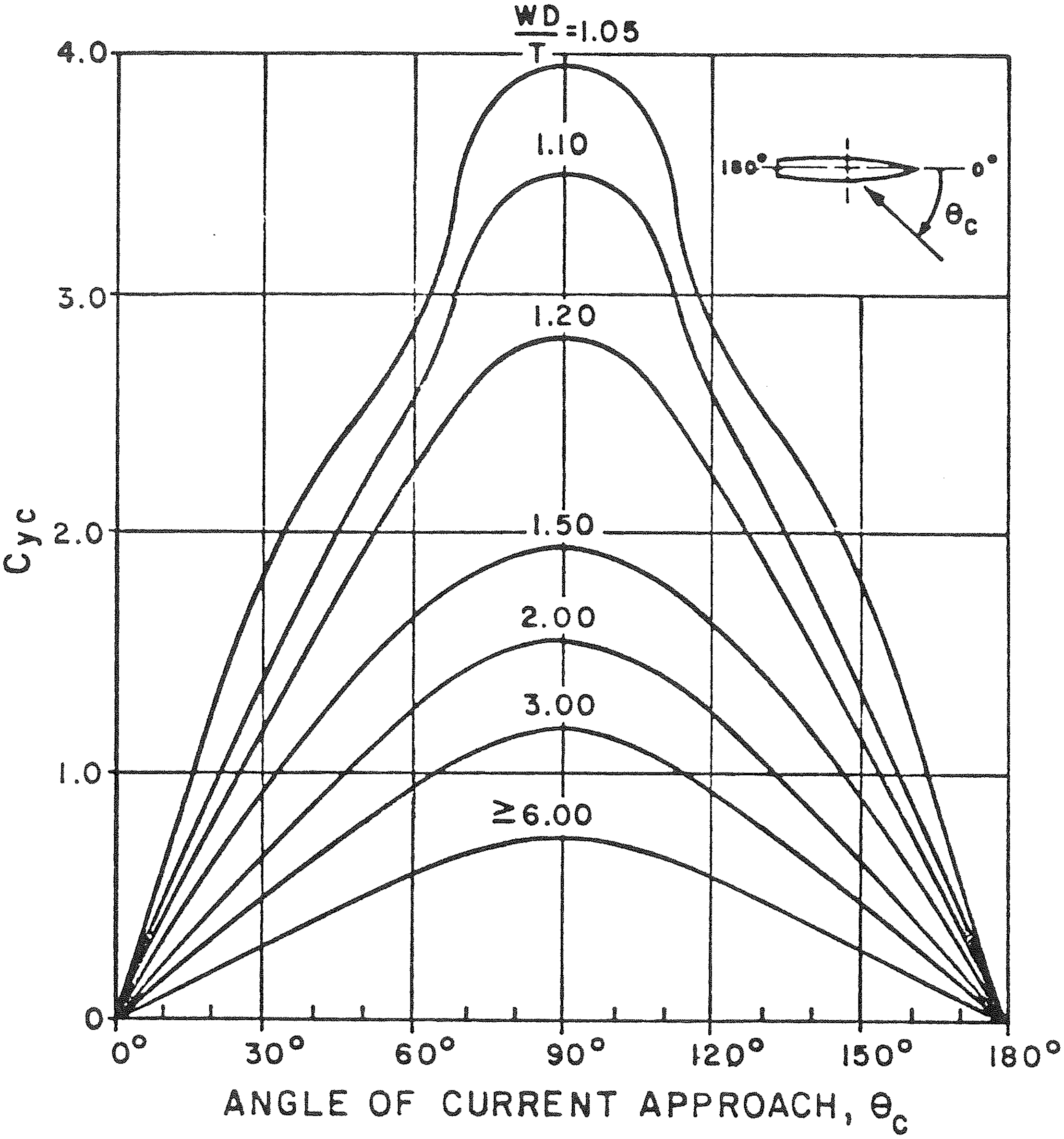


FIGURE 2. Lateral current force coefficient (C_{yc}), based on reference (1).

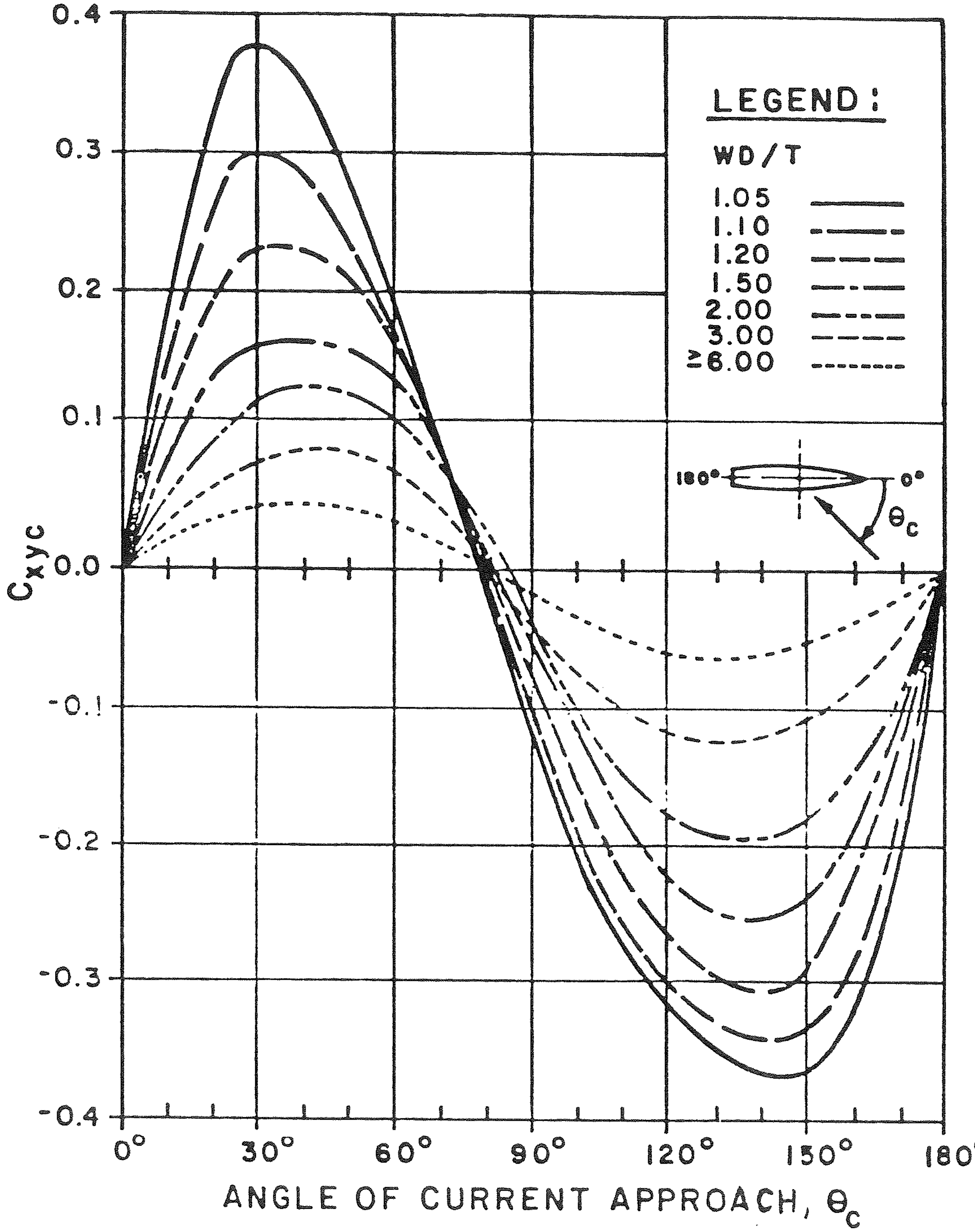


FIGURE 3. Current yaw moment coefficient (C_{xyc}), based on reference (1).

The coefficients C_{yc} and C_{xyc} are affected by the clearance between the ship's keel and the sea bottom. To facilitate computations, the underkeel clearance is expressed as the ratio of the water depth (WD) to the ship's draft (T).

DDS-582-1-d(3) CALCULATION PROCEDURE FOR WIND AND CURRENT FORCES

A step-by-step procedure is used in Calculation Sheet-1 (see appendix D) for determining wind and current loads. The procedure is general and may be used for wind and current velocities oriented at any angle to the ship's centerline.

To meet the mooring design requirements for Navy ships, the wind and current forces must be calculated for both normal weather and heavy weather conditions.

Based on the definitions in DDS 582-1-d (1) and DDS 582-1-d (2), the wind and current calculation procedure consists of the following steps as numbered on Calculation Sheet-1.

INPUT DATA

Steps 1 - 4

Specify ship particulars used for wind and current force calculations.

Steps 5 and 6

Determine end and side projected wind areas (A_e and A_s).

Steps 7 - 10

Specify wind and current speed (V_w, V_c) and their attack angles (HH_w, HH_c).

Step 11

Specify water depth (WD).

WIND FORCE

Step 12

Determine longitudinal wind force coefficient (C_{xw}) from figure 4.

Step 13

Determine lateral wind force coefficient (C_{yw}) from figure 5.

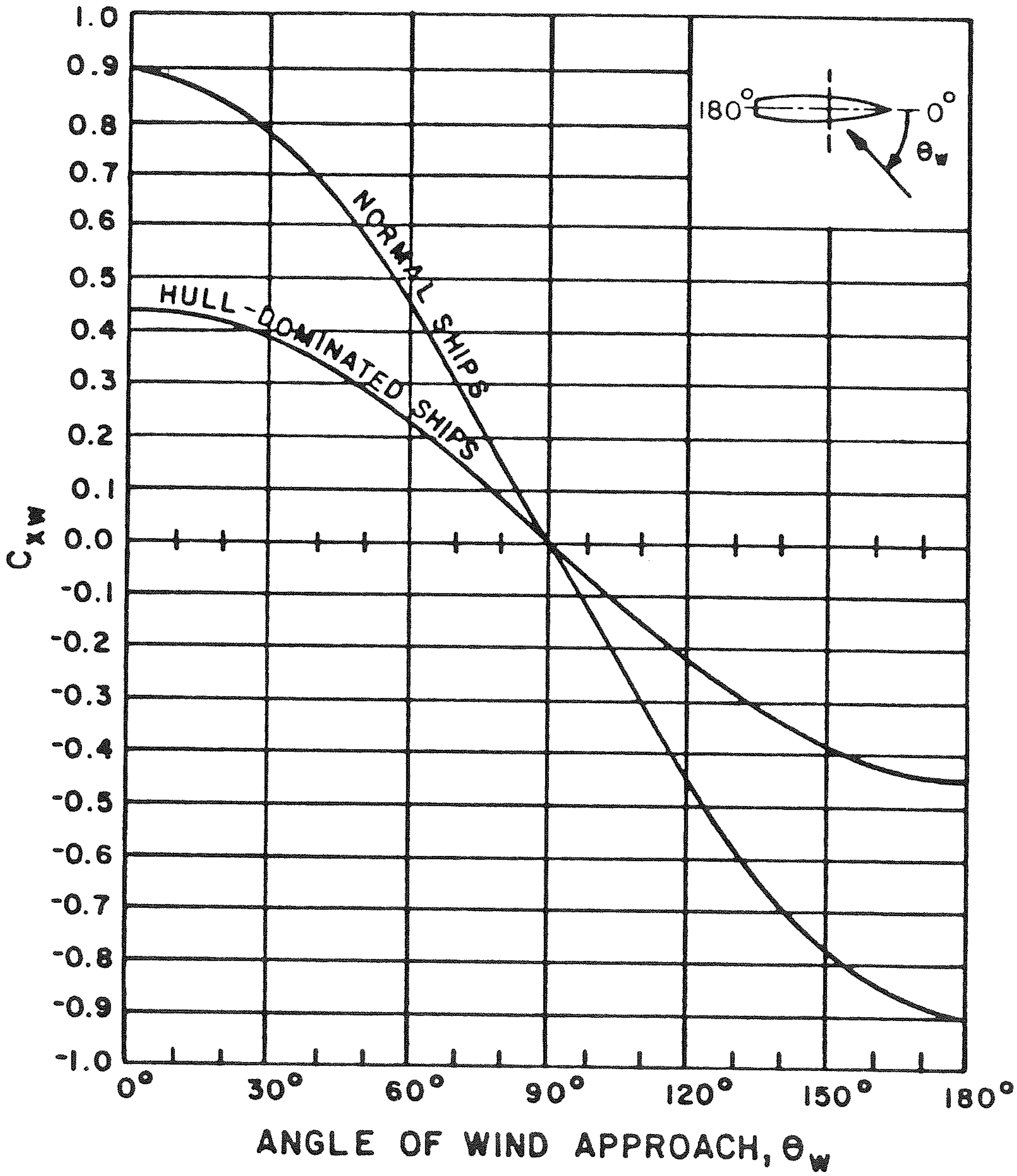


FIGURE 4. Longitudinal wind force coefficient (C_{xw}), based on reference (1).

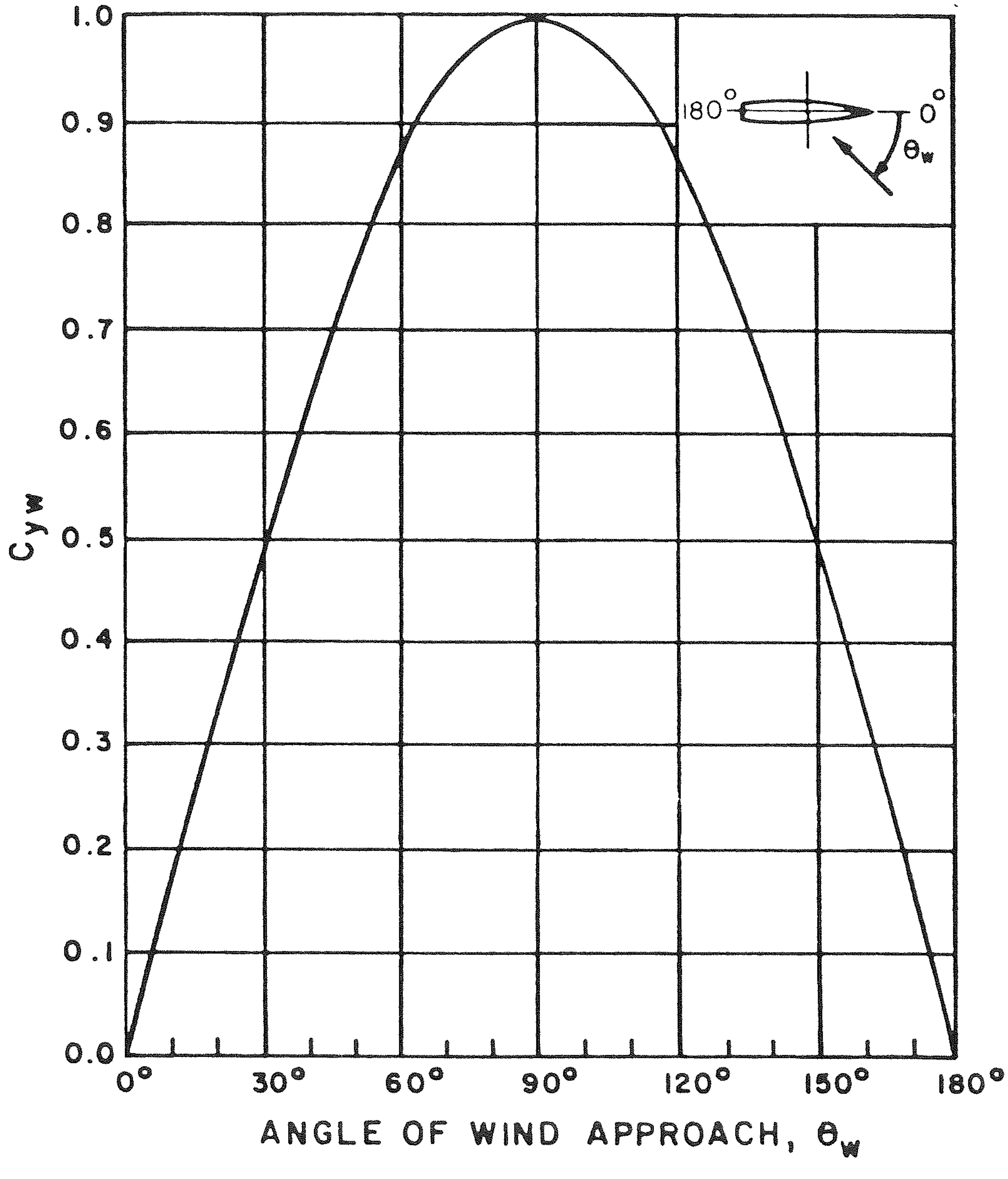


FIGURE 5. Lateral wind force coefficient(C_{yw}), based on reference (1).

Step 14

Determine wind yaw moment coefficient (C_{xyw}) from figure 6.

Step 15

Calculate longitudinal wind force:

$$F_{xw} = 0.00338 \cdot C_{xw} \cdot V_w^2 \cdot A_e \quad (lb) \qquad (1a)$$

or

$$F_{xw} = 0.1618 \cdot C_{xw} \cdot V_w^2 \cdot A_e \quad (N) \qquad (1b)$$

Step 16

Calculate lateral wind force:

$$F_{yw} = 0.00338 \cdot C_{yw} \cdot V_w^2 \cdot A_s \quad (lb) \qquad (2a)$$

or

$$F_{yw} = 0.1618 \cdot C_{yw} \cdot V_w^2 \cdot A_s \quad (N) \qquad (2b)$$

Step 17

Calculate wind yaw moment:

$$M_w = 0.00338 \cdot C_{xyw} \cdot V_w^2 \cdot A_s \cdot LWL \quad (ft\text{-}lb) \qquad (3a)$$

or

$$M_w = 0.1618 \cdot C_{xyw} \cdot V_w^2 \cdot A_s \cdot LWL \quad (Nm) \qquad (3b)$$

CURRENT FORCE

Step 18

Calculate the wetted surface:

$$S = 15.5 \sqrt{\Delta \cdot LWL} \quad (ft^2)$$

$$S = 2.588 \sqrt{\Delta \cdot LWL} \quad (m^2)$$

Step 19

Determine ratio of water depth to draft (WD/T).

Step 20

Determine longitudinal current skin friction coefficient (C_{xca}) from figure 1.

Step 21

Determine lateral current force coefficient (C_{yc}) from figure 2.

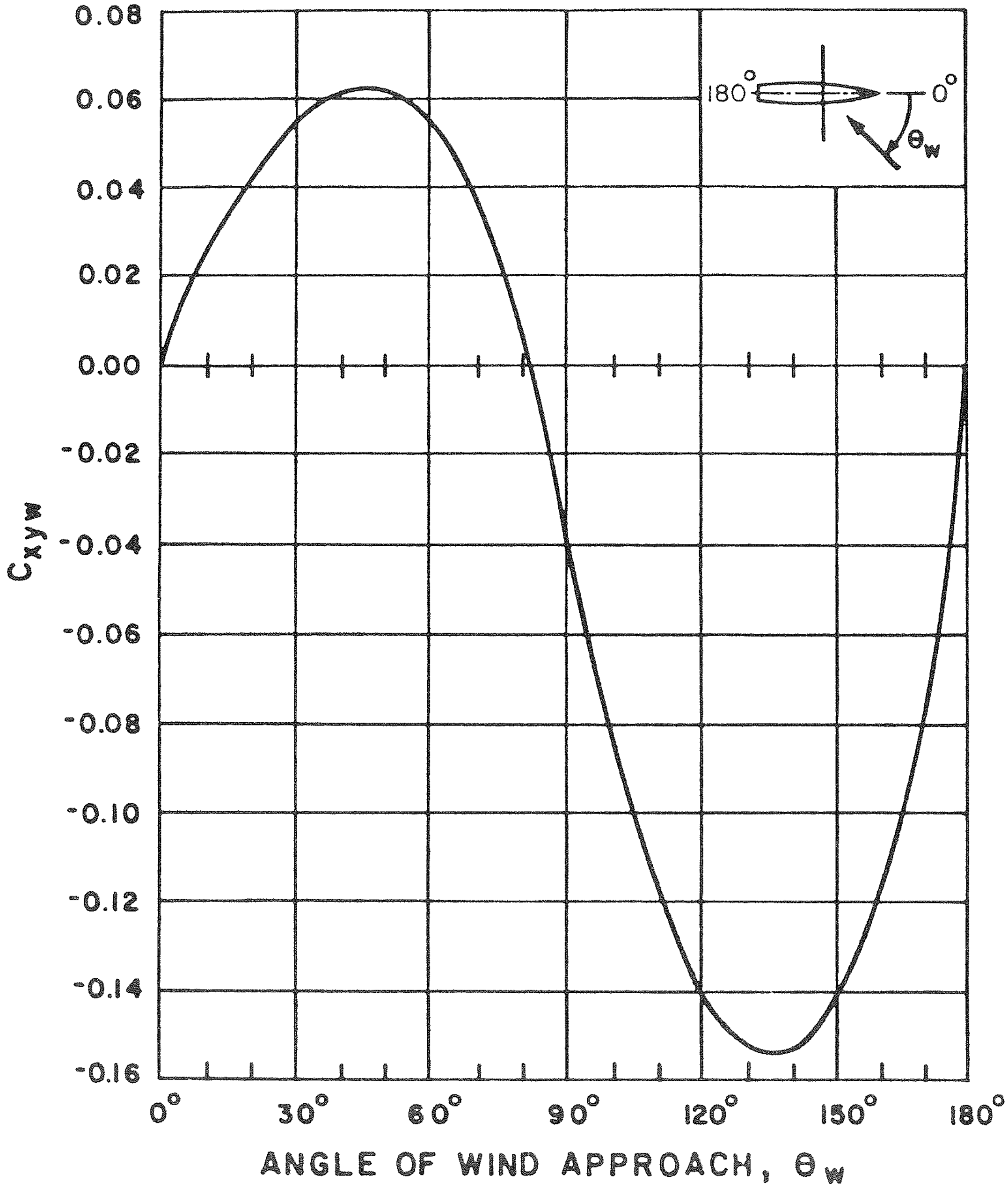


FIGURE 6. Wind yaw moment coefficient (C_{xyw}), based on reference (1).

Step 22

Calculate the longitudinal current force drag coefficient:

$$C_{xcb} = C_{yc} \cdot \cos^2 \theta_c$$

Step 23

Determine current yaw moment coefficient (C_{xyc}) from figure 3.

Step 24

Calculate the longitudinal current force:

$$F_{xc} = 2.835 \cdot V_c^2 \cdot B\,(C_{xca} \cdot S / LWL + C_{xcb} \cdot T) \quad \text{(lb)} \qquad (4a)$$

or

$$F_{xc} = 135.95 \cdot V_c^2 \cdot B\,(C_{xca} \cdot S / LWL + C_{xcb} \cdot T) \quad \text{(N)} \qquad (4b)$$

Step 25

Calculate lateral current force:

$$F_{yc} = 2.835 \cdot C_{yc} \cdot V_c^2 \cdot LWL \cdot T \quad \text{(lb)} \qquad (5a)$$

or

$$F_{yc} = 135.95 \cdot C_{yc} \cdot V_c^2 \cdot LWL \cdot T \quad \text{(N)} \qquad (5b)$$

Step 26

Calculate current yaw moment:

$$M_c = 2.835 \cdot C_{xyc} \cdot V_c^2 \cdot LWL^2 \cdot T \quad \text{(ft-lb)} \qquad (6a)$$

or

$$M_c = 135.95 \cdot C_{xyc} \cdot V_c^2 \cdot LWL^2 \cdot T \quad \text{(Nm)} \qquad (6b)$$

TOTAL RESISTANCE AND YAW MOMENT

Step 27

Determine total longitudinal force applied at intersection of ship's axes:

$$F_x = F_{xw} + F_{xc} \qquad (7)$$

Step 28

Determine total lateral force applied at intersection of ship's axes:

$$F_y = F_{yw} + F_{yc} \qquad (8)$$

Step 29

Determine total yaw moment:

$$M_r = M_w + M_c - 0.48 \cdot LWL \cdot F_x \qquad (9)$$

DDS-582-1-e. CALCULATION OF MOORING LINE FORCES

General

One solution to the mooring problem uses a simplified analysis that considers the moored ship as a system that has only two degrees of freedom. Figure 7 illustrates the general mooring layout and nomenclature used in the calculation procedure.

Calculation Sheet-2 (see appendix D) is used to calculate the line forces of a moored ship that is subjected to wind and current forces acting perpendicular to the ship's centerline at the CG. The calculations are based on the following assumptions:

- Young's modulus of mooring lines does not vary with line tension forces. (The line spring coefficients are constant.)
- Mooring line arrangement is symmetrical about the Y-axis.
- Yaw moment M_r and lateral force F_y are applied at the center of gravity of the ship at a fixed distance (X_{cg}) from the forward perpendicular.

DDS-582-1-e(1) STEP-BY-STEP CALCULATION PROCEDURE FOR MOORING LINE FORCES

The step-by-step procedure used in Calculation Sheet-2 is as follows:

Steps 1 - 6

Prepare a mooring arrangement showing locations of mooring lines, camels, bollards, and mooring chocks; specify the coordinates of the chock (X_{ch}, Y_{ch}, Z_{ch}) and bollard (X_{bl}, Y_{bl}, Z_{bl}) for each mooring line. (For preliminary analysis purposes the designer may consult appendix C to establish approximate number of lines, line sizes, and camel dimensions.)

Step 7

Determine horizontal projection (l_i) for each mooring line as shown in figure 7.

$$l_i = \sqrt{(X_{ch} - X_{bl})^2 + (Y_{ch} - Y_{bl})^2}$$

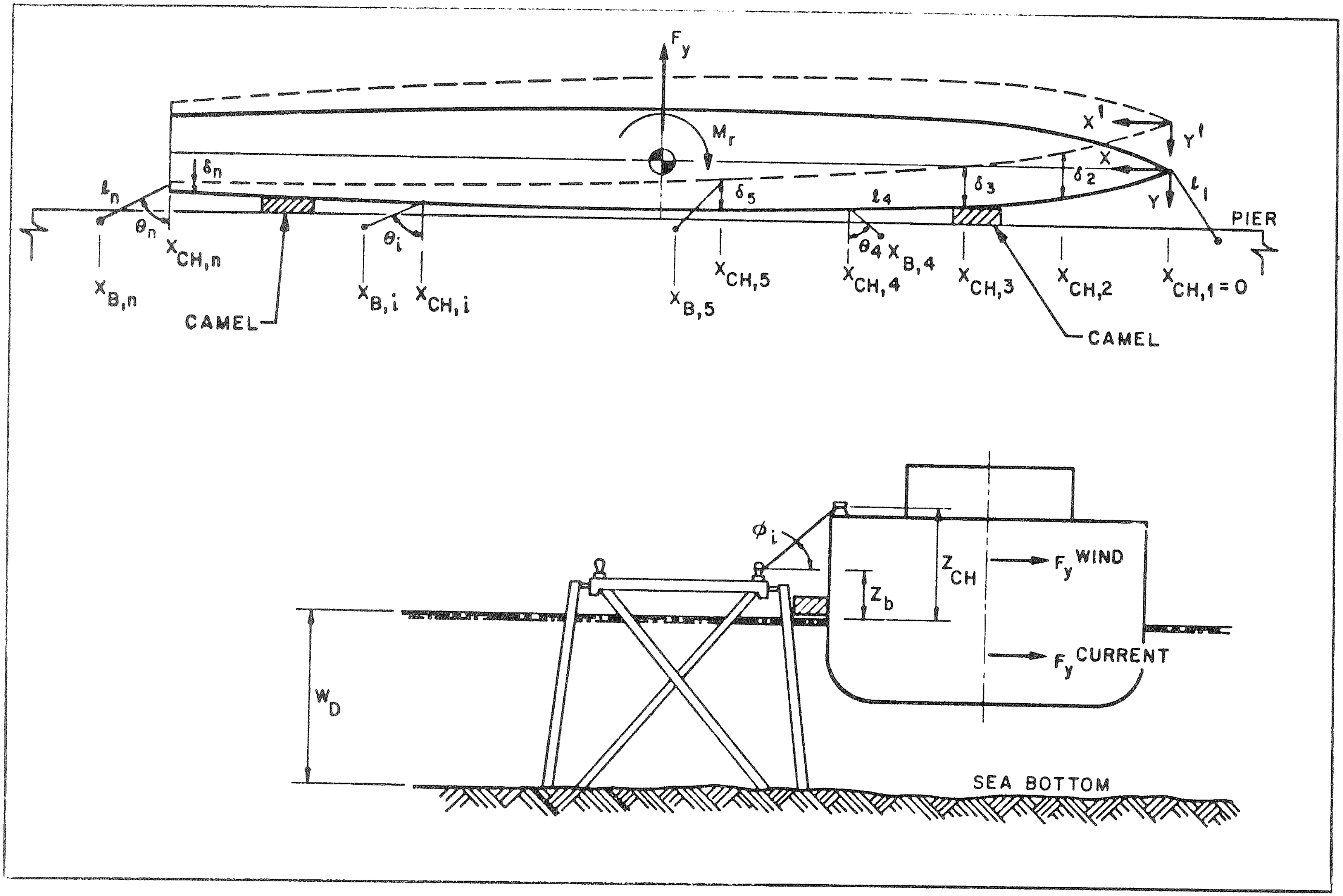


FIGURE 7. Diagram of mooring system with two degress of freedom.

Step 8

Determine vertical line projection along Z-axis.

$$\Delta Z_i = Z_{ch} - Z_{bl}$$

Step 9

Specify total cross-sectional area (a_i) of mooring line as a product of rope cross-section times number of parts per line (normally three parts per line).

Step 10

Using figure 8, specify Young's modulus (E_i) for each line.

Step 11

Determine $\cos \theta_i = (Y_{bl} - Y_{ch}) / l_i$ for each line (see figure 7).

Step 12

Determine angle ϕ_i in vertical plane.

$$\phi_i = \tan^{-1}(\Delta Z_i / l_i)$$

Step 13

Determine $\cos \phi_i$ of each line.

Step 14

Specify the length of the line between the chock and mooring bitts (l_o).

Step 15

Determine total length of each mooring line (bitts to bollard).

$$L_i = l_o + l_i / \cos \phi_i$$

Step 16

Specify total breaking strength $(BS)_i$ of each line (see appendix A)

$$(BS) = (BS)_r \cdot (\text{number of parts})$$

where:

$$(BS)_r = \text{breaking strength of rope.}$$

Step 17

Determine spring constant of each line in its principal direction.

$$K_i = a_i \cdot E_i / L_i$$

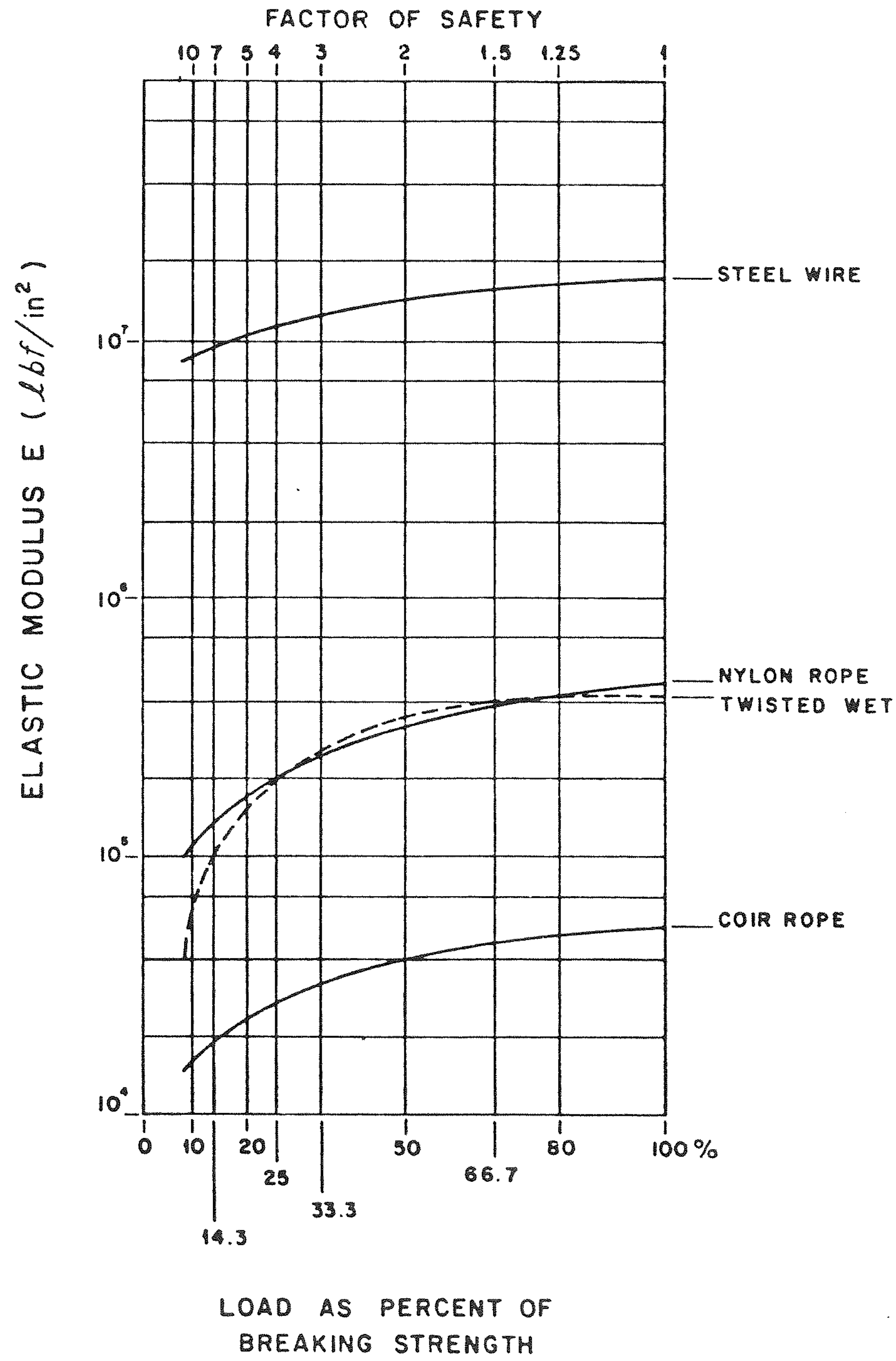


FIGURE 8. Elastic moduli of mooring ropes.

Step 18

Determine spring component (k_{yi}) of a line in Y-direction.

$$k_{yi} = K_i \cos\theta_i \cos\phi_i$$

Step 19

Determine term ($k_{yi} \cdot X_i$) where $X_i = X_{ch}$.

Step 20

Determine term ($k_{yi} \cdot X_i^2$).

Step 21

Perform the following summations:

$$a = \sum_{i=1}^{n} k_{yi}$$

$$b = \sum_{i=1}^{n} k_{yi} \cdot X_{ch}$$

$$c = \sum_{i=1}^{n} k_{yi} \cdot X_{ch}^2$$

As a check, notice that the restoring force $f = \sum_{i=1}^{n} F_{yi}$ must be equal in magnitude to the total external lateral force (F_y).

Step 22

Apply total external lateral force (F_y) and total yaw moment (M_r) to intersection of the ship's axes at X_{cg} (see DDS-582-1-d).

Step 23

Calculate translation of ship's CG in Y-direction.

$$\delta_y = [F_y \cdot c - (M_r + F_y \cdot X_{cg}) \cdot b] / (ac - b^2) \quad (10)$$

Step 24

Calculate rotation of ship about vertical axis.

$$\gamma = [F_y \cdot b - (M_r + F_y \cdot X_{cg}) \cdot a] / (b^2 - ac) \quad (11)$$

where X_{cg} is the abscissa of the ship's CG.

Step 25

For each line calculate its force component in Y-direction.

$$F_{yi} = K_{yi} \, (\delta_y + X_{ch} \cdot \gamma)$$

Step 26

Obtain line tension forces.

$$T_i = F_{yi} / (\cos \theta_i \cdot \cos \phi_i)$$

Step 27

Determine factor of safety for each mooring line.

$$FS = (BS) \, / \, T_i$$

If the factor of safety of one or more lines is less than 9.0 (for normal weather condition) or 3.0 (for heavy weather condition) one or more of the following actions must be taken to obtain adequate mooring arrangement:

(a) Slacking of the overstressed line(s) (reducing spring constants).

(b) Shifting of mooring lines to different bollards or mooring chocks.

(c) Increasing the number of lines.

(d) Increasing the rope sizes.

DDS-582-1-f. MOORING EQUIPMENT

General

The size of mooring equipment selected is primarily a function of the size, breaking strength, and length of the mooring lines.

Figures 9 and 10 illustrate a typical layout of mooring equipment used on Navy surface ships.

DDS-582-1-f(1) LAYOUT OF MOORING LINES

Figure 11 presents two basic mooring arrangements, one for normal weather conditions and the other for heavy weather conditions. Mooring lines that tend forward (or aft) are called forward (or after) spring lines; those that tend abeam are called breast lines. Mooring lines are also referred to as bow, stern, or quarter lines depending on their location on the ship. A breast line amidships is called a waist breast.

The overall mooring line pattern affects the load distribution to individual lines. The effectiveness of a mooring line is influenced by its slope (that is, the vertical angle (ϕ_i) formed by the line with the pier deck), and by

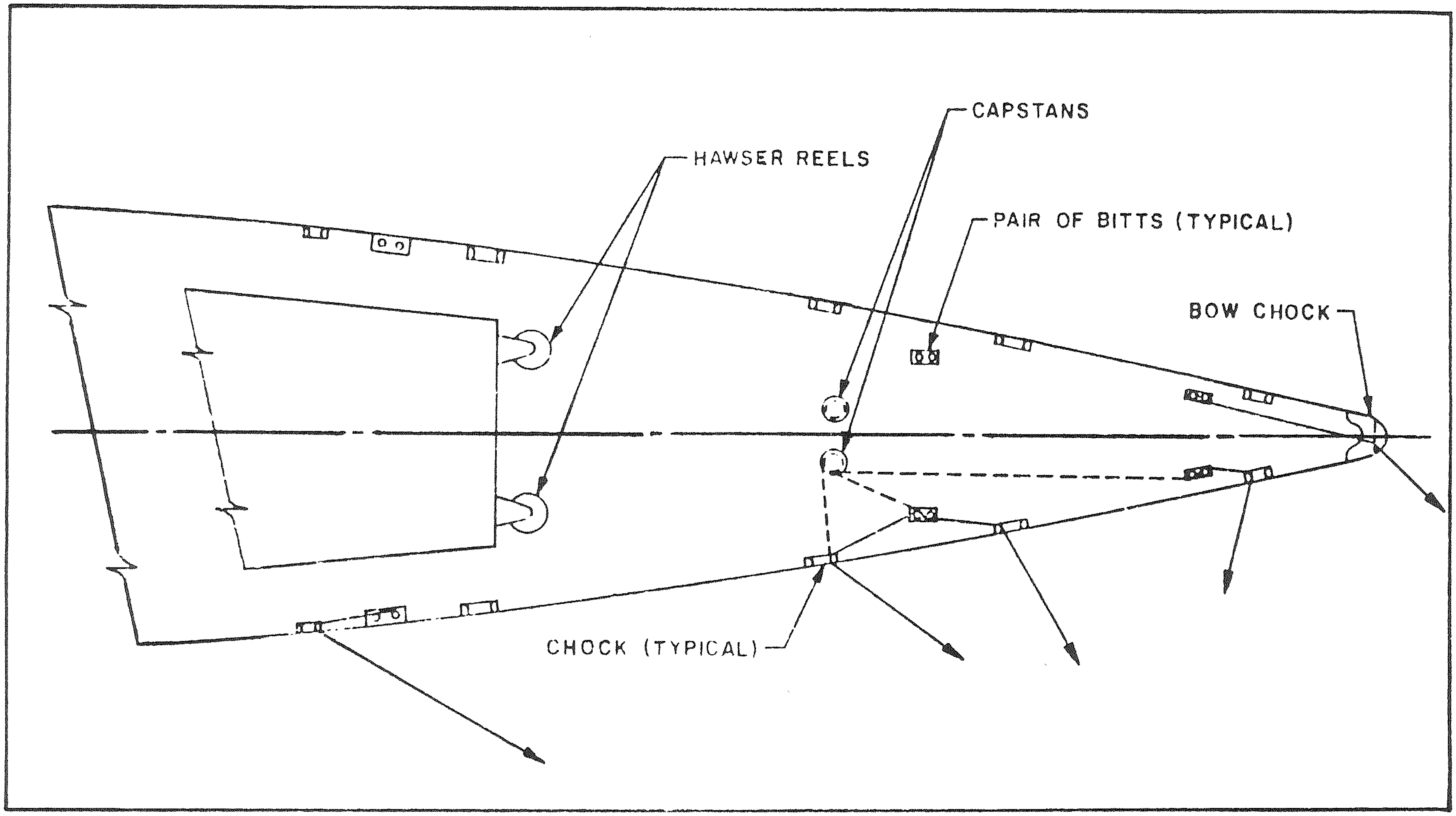


FIGURE 9. Typical mooring arrangement on ship's forecastle.

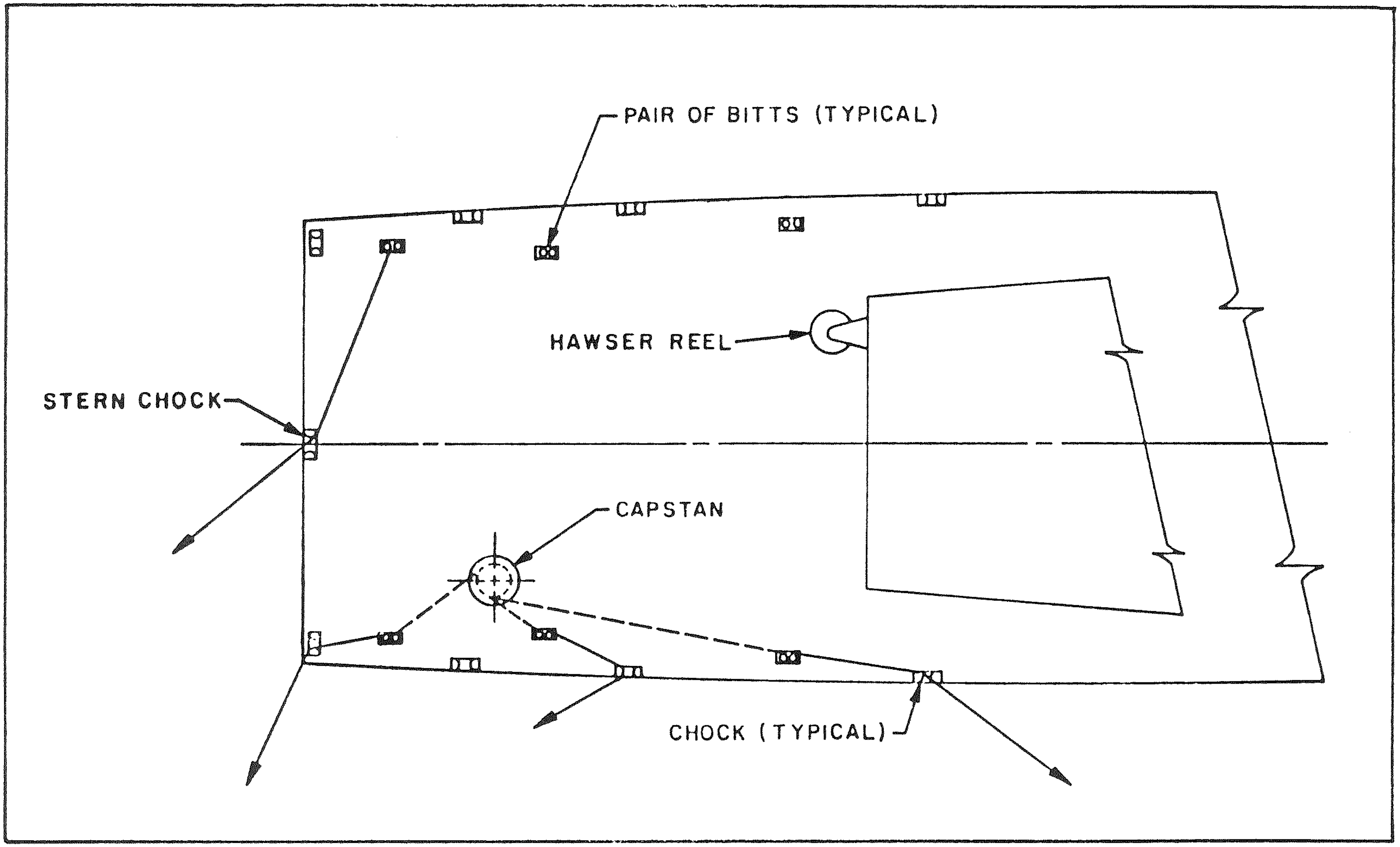


FIGURE 10. Typical mooring arrangement on ship's quarter.

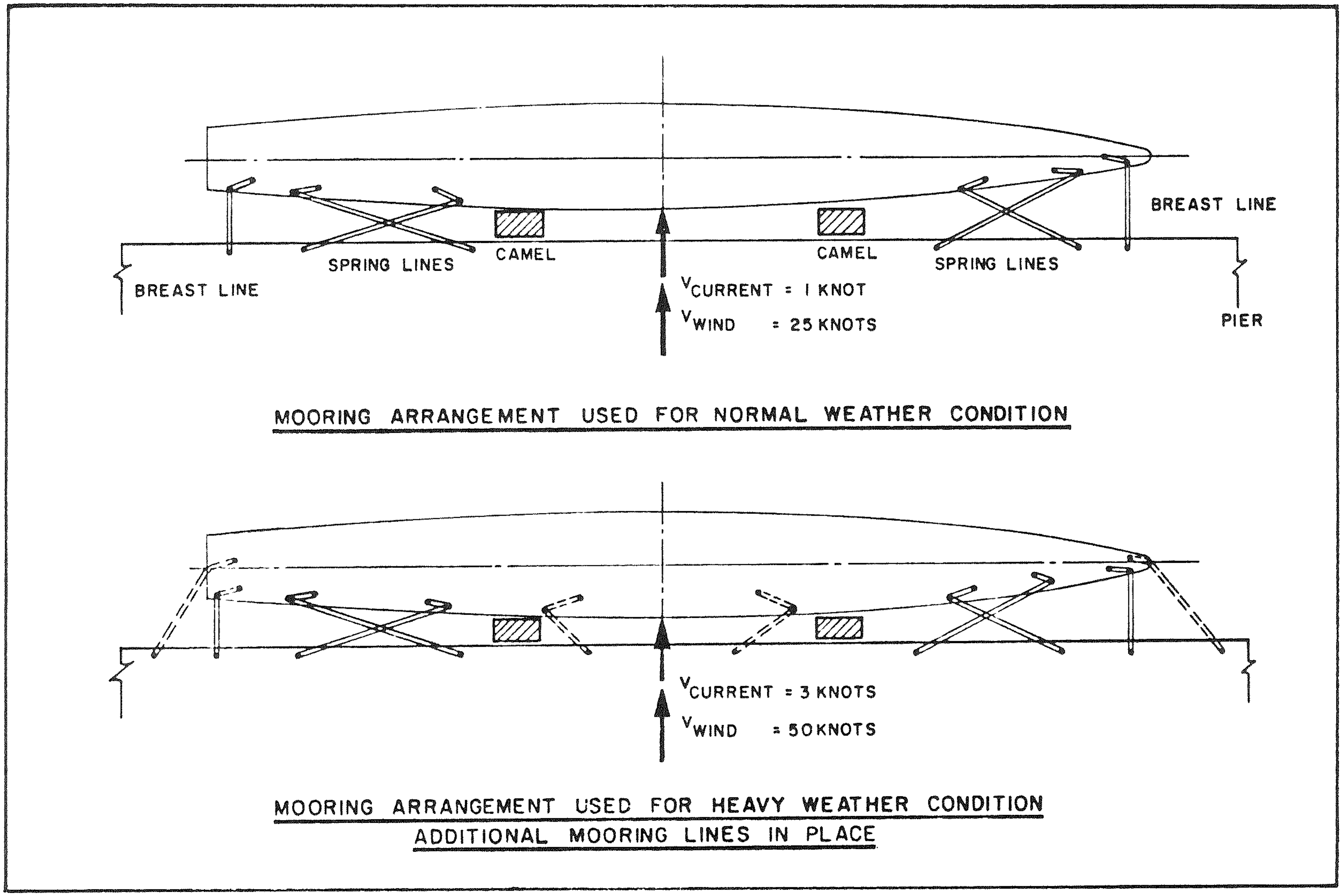


FIGURE 11. Mooring line layouts for normal and heavy weather conditions.

the horizontal angle (θ_i) formed by the line with the centerline of the ship. The steeper the orientation of a line, the less effective it is in resisting horizontal loads.

The principal guidelines for design of mooring arrangements are as follows:

- Mooring lines should be arranged as symmetrically as possible about the transverse centerline of the ship (Y-axis) to ensure a balanced load distribution among them.
- Breast lines should be oriented perpendicular to the ship's centerline and as far aft and forward as possible.
- Spring lines should be oriented as nearly parallel as possible to the longitudinal centerline of the ship.
- Slope of mooring lines should be kept as slight as possible.
- Since the elasticity of a line is proportional to its length, the shorter lines will assume greater loads.
- Synthetic mooring lines should not be used together with lines of wire rope.
- Individual mooring chocks, bitts, or bollards should not accommodate more than one mooring line at a time, either for the same ship or for different ships.

DDS-582-1-f(2) MOORING LINES

In selecting mooring equipment, rope must be selected that is of size suitable for mooring and easy handling and that has sufficient length to allow doubling up of lines. All fiber rope that has 8-inch or greater circumference is handled by means of capstans or warping winches. Synthetic ropes, especially those made of nylon, are used for mooring and warping operations chiefly because of their ease of handling and low maintenance requirments. Nylon rope is manufactured in three principal constructions (see appendix A). (2)

(a) Three-strand or twisted rope - consists of three strands, twisted together. The rope is suitable for mooring and warping applications.

(b) Plaited rope - is made up of eight rope strands. Plaited rope is torque free and is widely used in mooring and towing applications. It does not require special handling procedures.

(c) Double-braided rope - has one hollow braided rope within another. This rope construction is also torque free. Double-braided rope is stronger than either three-strand or plaited construction.

(2) Fiber Ropes; Natural and Synthetic, Naval Ships' Technical Manual, Chapter 9280, NAVSHIPS, 0901-280-0001, 1967.

The modulus of elasticity (known as Young's modulus) for synthetic rope is a tension dependent function and is highly nonlinear, as shown on figure 8. Nevertheless, in calculation of mooring line forces, a single, typical value of Young's modulus is selected for each set of calculations.

In securing a Navy ship, the mooring lines are normally doubled up, that is, an extra bight of line is passed to the pier, giving three parts of line between ship and pier instead of only one part, for each mooring line.

DDS-582-1-f(3) MOORING CHOCKS

The selection of mooring chocks for synthetic and natural fiber ropes is based on the rope breaking strength. The chock size is determined from table I. Open or closed chocks are generally welded to the edge of the deck. On ships that have bulwarks, the chocks consist of heavy rings welded into the bulwark. Mooring chocks used for Panama Canal operation are designed in accordance with Canal specifications. (3)

DDS-582-1-f(4) MOORING BITTS

Mooring bitts are used for securing the inboard ends of mooring lines, warping lines, and tow lines. Bitts must be not less than 8 feet from chocks to allow proper drift for line handling.

The mooring bitt size is based on the design moment, which is equal to the product of the breaking strength of the rope times half the height of the bitt barrel above the base plate, as shown in table II.

DDS-582-1-f(5) HAWSER REELS

Vertical and horizontal hawser reels for storing mooring lines and towing hawsers are selected by type according to rope size and rope length as shown in tables III and IV. Hawser reels are designated as vertical or horizontal according to the orientation of their reel shafts.

DDS-582-1-f(6) ROPE STORAGE BINS

Rope storage bins are used for storing fiber rope. The bin capacity (V) needed to contain rope that has not been carefully placed in the bin to conserve storage space is estimated from the following formula:

$$V = C^2 \times L / 840 \quad (ft^3)$$

where

C = circumference of rope in inches

L = length of rope in feet

(3) Panama Canal Commission, 9. Marine Director's Notice to Shipping No. 9-81, March 6, 1981.

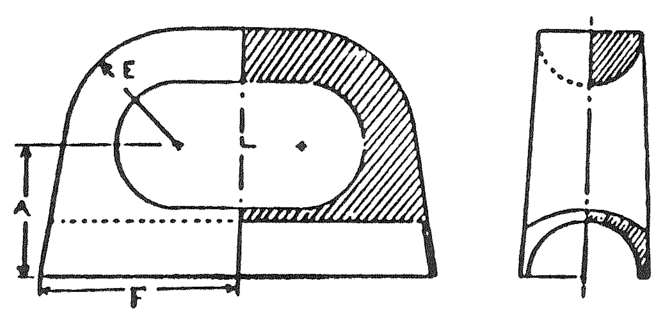
TABLE I. Chocks for nylon rope. (4)

Chock size		Breaking strength of rope		A		E		F		Chock weight	
in.	mm	lb	kN	in.	mm	in.	mm	in.	mm	lb	kg
6	152	22,000	98	4 1/2	114	3 5/8	92	6 1/2	165	50	23
8	203	37,500	167	5 1/2	140	4 1/2	114	8	203	80	36
10	254	54,400	242	6	152	5 1/4	133	9 1/2	241	120	54
12	305	74,000	329	7	178	6	152	11	279	180	82
14	356	110,000	489	8	203	6 3/4	171	12	305	230	104
16	406	137,000	609	9	229	7 3/4	197	14	356	360	163
18	475	170,000	756	10	254	8 1/2	216	15	381	470	213
20	508	200,000	890	10 1/2	267	9 1/4	235	16	406	550	249

Notes to table 1.

1. Chock shall be set parallel to baseline athwartships and shall follow sheer in force and aft direction.

2. Chock is designed for use with nylon rope as shown in table. Chock shall withstand a horizontal endwise pull equal to double the minimum breaking strength of 2 parts of the specified size of nylon rope applied one inch above the centerline of the chock. The chock shall also withstand an upward load of 50,000 pounds applied at its midpoint.



(4) NAVSHIPS Drawing 805-1843363, Chocks for nylon rope.

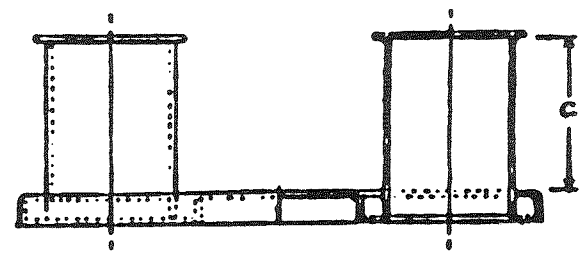
TABLE II. Bitts for nylon rope. (5)

Nominal bit size		Maximum size of nylon rope		Maximum allowable moment		C		E		F		Approximate weight	
in.	mm	in.	mm	in.-lb (000)	kNm	in.	mm	in.	mm	in.	mm	lb	kg
4	102	3 1/2	89	142.5	16.10	10	254	16 1/2	419	7 1/2	191	80	36
6	152	6	152	481.0	54.35	13	330	24 1/8	613	11 1/8	283	210	95
8	203	7	178	770.0	87.0	14	355	30 5/8	778	13 5/8	346	320	145
10	254	9	228	1490.0	168.35	17	432	39 1/4	997	17 1/4	438	580	263
12	305	10	254	2110.0	238.4	21	533	45 1/4	1150	20 1/4	514	870	395

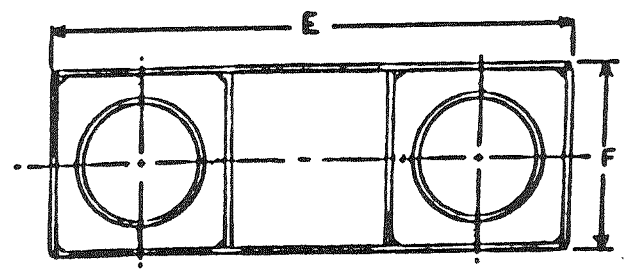
Notes to table 2.

1. The maximum moment is the product of the breaking strength of the rope times half the height of the barrel above the base plate.

2. Bitts are designed for a yield stress of 24,000 lb/in^2 based on the maximum moment.



Front elevation and section.

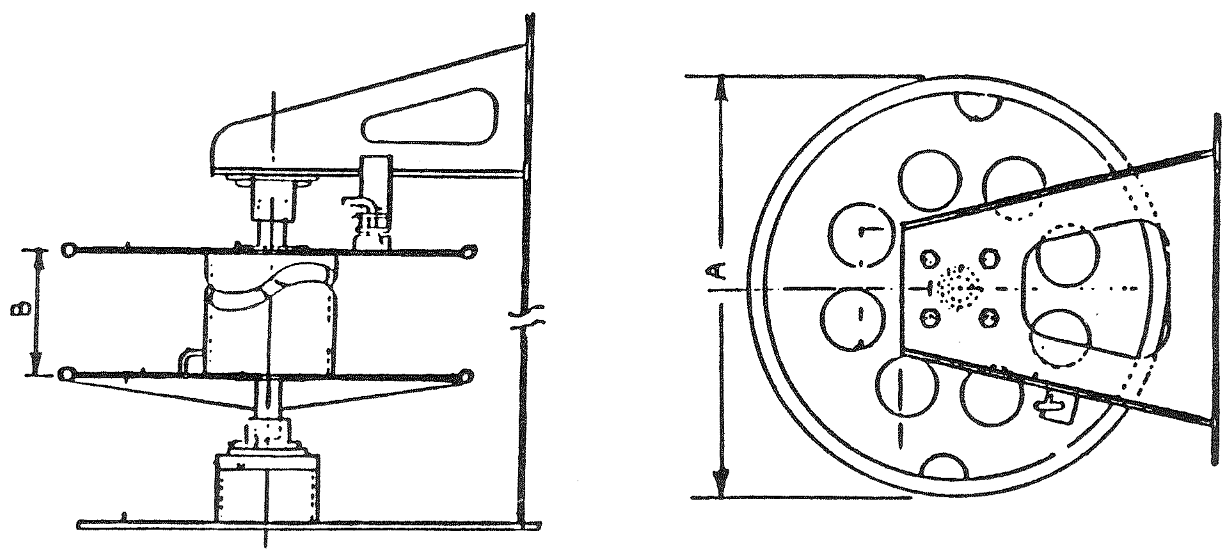


Bottom view.

(5) NAVSHIPS Drawing 804-1843362, Bitts for nylon rope

TABLE III. Vertical howser reels. (6)

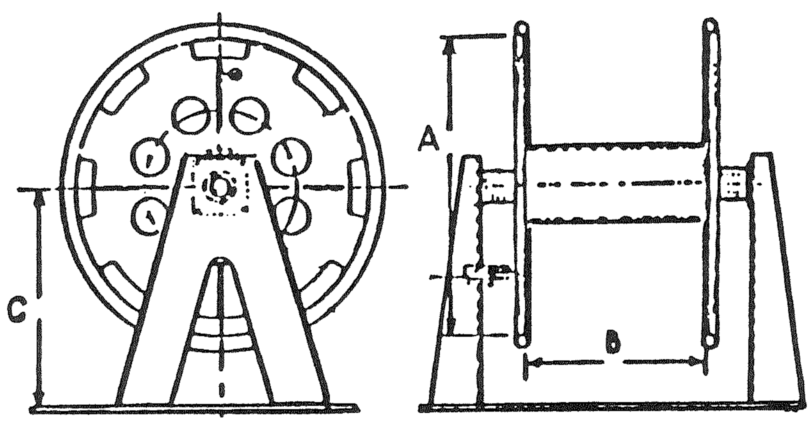
Reel type	Rope size		Capacity	A		B		Approx assy weight		Approx rope weight	
	in.	mm	fathoms	in.	mm	in.	mm	lb	kg	lb	kg
I	6	152	100	30	762	72	1829	285	129	648	294
	6	152	120	30	762	72	1829	285	129	778	353
	7	178	100	30	762	72	1829	285	129	876	397
II	7	178	120	34	864	66	1676	325	147	1050	476
	8	203	80	34	864	66	1676	325	147	935	424
III	8	203	100	38	965	66	1676	400	181	1128	512
	8	203	120	38	965	66	1676	400	181	1352	613
	10	254	80	38	965	66	1676	400	181	1440	653
IV	10	254	100	45	1143	66	1676	460	209	1798	816
V	10	254	120	50	1270	66	1676	510	231	2154	977



(6) NAVSHIPS Drawing S2604-921842, Vertical hawser reels for manila rope.

TABLE IV. Horizontal hawser reels. (7)

Reel type	rope size		Capacity	A		B		C		Approx assy weight		Approx rope weight	
	in.	mm	fathoms	in.	mm	in.	mm	in.	mm	lb	kg	lb	kg
A	3	76	300	32	813	38	965	21	533	330	150	485	220
	4	102	167	32	813	38	965	21	533	330	150	485	220
	5	127	100	32	813	38	965	21	533	330	150	485	220
B	6	152	100	38	965	39	991	24	610	380	172	875	397
C	7	178	100	38	965	39	991	24	610	380	172	875	397
	8	203	100	38	965	52	1321	24	610	440	200	1150	522



(7) NAVSHIPS Drawing S2604-921841, Horizontal hawser reels for manila rope.

DDS-582-1-f(7) CAPSTAN HEADS

The barrel diameter and barrel height of capstan heads for nylon ropes are determined from table V.

DDS-582-1-f(8) FAIRLEADERS

Fairleaders are used to lead mooring lines around obstructions and provide proper alignment with winches or capstans. Fairleaders are located to accommodate lines from both sides of the ship.

DDS-582-1-g. CAPSTAN POWER REQUIREMENT

The two commonly used powering systems for capstans are (a) direct-connected electric motor drives (also called electromechanical drives) and (b) electrohydraulic drives. The advantage of electrohydraulic systems is that they permit finer control of warping speed.

For preliminary design purposes, a step-by-step procedure presented in Calculation Sheet-3 is used to determine berthing line force and required capstan power. The procedure consists of the first 12 of the following steps for all capstans, plus steps 13 and 14 for electromechanical capstans or steps 13, 15, and 16 for electrohydraulic capstans.

Step 1

Specify the ship's waterline length (LWL).

Step 2

Specify draft (T).

Step 3

Calculate lateral projected wind area (A_s).

Step 4

Specify lateral wind speed (V_w) in knots perpendicular to ship's centerline (for wind not specified assume 15 knots).

Step 5

Specify capstan low line-warping speed (V_{cp}) in m/min or ft/min.

Step 6

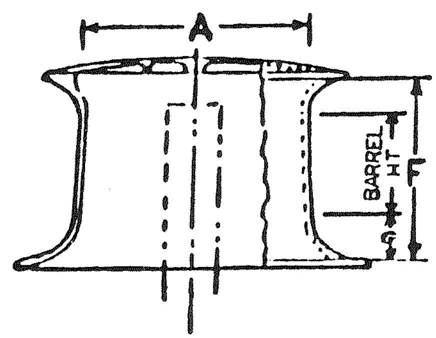
Calculate lateral berthing speed (V_b) in knots.

Step 7

Specify number of capstans used during the berthing operation.

TABLE V. Capstan head sizes for nylon ropes. (8)

Nylon rope circumference		A (Barrel diameter)		F		G		Barrel height		Nylon rope wrap height	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
3	76	12	305	9.6	244	2.5	64	5.4	137	5.0	127
3 1/2 - 4	89 - 102	15	381	12.0	305	3.1	79	6.7	170	6.5	165
4 1/2	114	18	457	14.4	366	3.7	94	8.1	206	7.5	190
5 - 5 1/2	127 - 140	21	533	16.8	427	4.4	112	9.4	239	8.1	206
6 - 6 1/2	152 - 164	24	610	19.2	488	5.0	127	10.8	274	10.0	254
7	178	27	686	21.6	549	5.6	142	12.2	310	11.2	284
8	203	30	762	24.0	610	6.2	157	13.5	343	13.1	333
9	229	36	914	28.8	732	7.5	190	16.2	411	15.0	381



(8) NAVSHIPS Drawing S2601-860303, Capstan & gypsy heads.

Step 8

Calculate wind force perpendicular to ship's centerline.

Step 9

Based on θ_c = 90 degrees, determine lateral current force coefficient.

Step 10

Calculate lateral current force (F_{yc}) from the following expression:

$$F_{yc} = C \cdot V_b^2 \cdot LWL \cdot T$$

where

$C = 14.8$ for destroyers; $C = 15.6$ for auxiliaries.

Step 11

Determine operating line pull per capstan, and round to the nearest 500-pound multiple.

$$P_{cp} = (F_{yw} + F_{yc}) \;/\; (\text{number of capstans})$$

Step 12

Specify capstan head efficiency (η_c) (if not available, assume 0.95).

ELECTROMECHANICAL DRIVE CAPSTAN (Steps 1 through 14)

Step 13

Specify overall bearing and gear efficiency (η_g). If not available use 0.85 for spur or helical gear drive and 0.75 for worm gear drive.

Step 14

Calculate the required power.

ELECTROHYDRAULIC CAPSTAN (Steps 1 through 13 plus steps 15 and 16)

Step 15

Specify combined hydraulic pump and motor efficiency (η_h). If not available use 0.80.

Step 16

Calculate the required power of electrohydraulic capstan.

DDS-582-1-h. BERTHING PIER BOLLARD SPACINGS

The mooring arrangement must be optimized to fit the expected berthing facility. Bollard spacings for three different berthing piers are as follows:

(a) Berthing pier for destroyer (9)

Low bitts alternate with bollards at 22-meter (72-foot) intervals, and intermediate cleats are at 7.3-meter (24-foot) distances so that two cleats are between each bitt and its neighboring bollard.

(b) Berthing pier for cruiser and auxiliary (10)

Standard bollards alternate with intermediate cleats at 15.2-meter (50-foot) intervals.

(c) Berthing pier for carrier (11)

Intermediate bollards alternate with cleats at 18.3-meter (60-foot) intervals.

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(9) Berthing Pier for Destroyer, NAVFAC Drawing 80091-1293318
(10) Berthing Pier for Cruiser and Auxiliary, NAVFAC Drawing 80091-1293320
(11) Berthing Pier for Carrier, NAVFAC Drawing 80091-1293319

DDS-582-1-i. EXAMPLE. MOORING ANALYSIS USING THE CALCULATION PROCEDURE

Required: To check the mooring equipment for a destroyer class ship that is subjected to normal and heavy weather loading conditions. The ship is restrained in 45-foot water depth to a destroyer berthing pier with 9 or 6 doubled-up mooring lines, as shown in figure 11. Each doubled-up line consists of three parts of 5-inch double braided nylon rope. Determine the required power for electrohydraulic capstans, and establish the sizes of mooring chocks and bitts and hawser reels. Ship particulars for the destroyer in the fully loaded condition are as listed. (See also figures 8 through 11, and 12 through 20 at the end of this example.)

Displacement, Δ	= 3,350 long tons
LWL	= 383 ft
Beam	= 41.1 ft
Draft	= 14 ft
Calculated projected lateral wind area, A_s	= 9,100 ft^2
Ship CG abscissa, X_{cg}	= 190 ft

To establish mooring arrangement, additional data are used (see figure 7)

Pier level (above MWD)	= 8 ft
Mean water depth (MWD)	= 45 ft
Camel width	= 4 ft

Solution: Using the calculation procedure (system with 2 degrees of freedom) two mooring arrangements are investigated:

(a) Nine doubled-up mooring lines used for heavy weather condition
(b) Six doubled-up mooring lines used for normal weather condition

The mooring analysis is based on the following assumptions:

- Both mooring arrangements are elastically symmetrical about the Y-axis.
- The average Young's modulus of the given nylon rope is 200,000 lb/in^2 and does not vary with line tension. The breaking strength of the rope is 73,000 pounds (appendix A) or 219,000 pounds per line.

(continued)

(A) Wind and current forces

(a) Heavy weather condition (50-kt wind and 3-kt current)
By Calculation Sheet-1 (see figures 12 and 13) the wind and current forces and moments for the heavy weather condition are found to be as follows:

F_{yw} = 76,895 lb F_{xw} = 0

F_{yc} = 153,230 lb F_{xc} = 0

M_w = -971,880 ft-lb

M_c = -1,048,000 ft-lb

Total external forces are:

F_y = 230,120 ft-lb

F_x = 0

M_r = -2,019,900 ft-lb

(b) Normal weather condition (25-kt wind and 1-kt current)
The wind and current forces and moments for the normal weather condition are deduced from the calculated values for the heavy weather condition by proportionation of squares:

$F_{yw} = 76{,}895 \times (25/50)^2 = 19{,}224$ lb

$F_{yc} = 153{,}230\ (1/3)^2 = 17{,}026$ lb

$M_w = -971{,}880\ (25/50)^2 = -242{,}970$ ft-lb

$M_c = -1{,}048{,}000\ (1/3)^2 = -116{,}440$ ft-lb

Total external forces are:

$F_y = 19{,}224 + 17{,}026 = 36{,}250$ lb

$M_r = -242{,}970 - 116{,}440 = -359{,}410$ ft-lb

(B) Line forces

By Calculation Sheet-2 (see figures 14 through 19) the line forces for both normal and heavy weather conditions are calculated. Results indicate that the factors of safety for mooring lines for the heavy and normal weather conditions exceed 3 and 9 respectively, thus satisfying the requirements in DDS 582-1-c.

(continued)

(C) Mooring Equipment

(a) Mooring Chocks

The 12-inch mooring chocks based on 5-inch nylon rope (BS = 73,000 lb) were selected from table I.

(b) Mooring bitts

The 6-inch mooring bitts were determined (see table II) from the maximum bending moment, which is calculated as follows:

$$M = 73{,}000 \text{ lb} \times \frac{13 \text{ inches}}{2} = 474{,}500 \text{ in-lb}$$

(Moment allowed = 481,000 in-lb.)

(c) Hawser Reels

Type A horizontal hawser reels (table III) were selected to store 5-inch nylon rope in lengths of 100 fathoms.

(d) Capstan

By Calculation Sheet-3, (figure 20) the line pull and required power of the electrohydraulic capstan are found to be as follows:

- Line pull = 10,000 lb/capstan
- Capstan power = 20 horsepower at 40 ft/min line speed.

The capstan barrel diameter for 5-inch nylon rope was determined to be 21 inches (see table V).

CALCULATION SHEET–1
WIND AND CURRENT FORCES
(inch–pound units)

Ship: EXAMPLE (heavy weather condition)

	Ship particulars		Value
1	Displacement, Δ	LT	3350
2	LWL	ft	383
3	Draft, T	ft	14
4	Beam, B	ft	41.1
5	End projected wind area, A_e	ft^2	———
6	Side projected wind area, A_s	ft^2	9100
7	Wind speed, V_w	kt	50
8	Current speed, V_c	kt	3
9	Wind angle, θ_w	degrees	90
10	Current angle, θ_c	degrees	90
11	Water depth, WD	ft	45
	Wind force		
12	C_{xw} (see figure 4)		0
13	C_{yw} (see figure 5)		1.0
14	C_{xyw} (see figure 6)		(–)0.033
15	$F_{xw} = 0.00338 \times (12) \times ((7))^2 \times (5)$	lb	0
16	$F_{yw} = 0.00338 \times (13) \times ((7))^2 \times (6)$	lb	76,895
17	$M_w = 0.00338 \times (14) \times ((7))^2 \times (6) \times (2)$	ft–lb	(–)971,880

From DDS 582–1

FIGURE 12. Example of wind and current force calculations for heavy weather condition.

CALCULATION SHEET–1 (continued)
WIND AND CURRENT FORCES
(inch–pound units)

Ship: EXAMPLE (heavy weather condition)

	Current force		Value
18	Wetted surface, $S = 15.5\sqrt{(1) \times (2)}$	ft^2	17,557
19	Water depth/draft, $WD/T = (11)/(3)$		3.21
20	C_{xca} (see figure 1)		0
21	C_{yc} (see figure 2)		1.12
22	$C_{xcb} = (21) \times \cos^2 \theta_c$		0
23	C_{xyc} (see figure 3)		(–)0.02
24	$F_{xc} = 2.835 \times ((8))^2 \times (4)[(20) \times (18)/(2) + (22) \times (3)]$	lb	0
25	$F_{yc} = 2.835 \times (21) \times ((8))^2 \times (2) \times (3)$	lb	153,230
26	$M_c = 2.835 \times (23) \times ((8))^2 \times (2)^2 \times (3)$	ft–lb	(–)1,048,000
	Total forces		
27	Total longitudinal force, $F_x = (15) + (24)$	lb	0
28	Total lateral force, $F_y = (16) + (25)$	lb	230,120
29	Total yaw moment, $M_r = (17) + (26) - 0.48 \times (2) \times (27)$	ft–lb	(–)2,019,900

From DDS 582–1

FIGURE 13. Example of wind and current force calculations for heavy weather condition (continued).

CALCULATION SHEET-2

MOORING LINE FORCES

Units: Inch-lb ✓ Metric ______

Ship: EXAMPLE (normal weather condition)

Line No.	Chock Coordinates			Bollard Coordinates			⑦	⑧	⑨	⑩
	① X_{ch} m (ft)	② Y_{ch} m (ft)	③ Z_{ch} m (ft)	④ X_{bl} m (ft)	⑤ Y_{bl} m (ft)	⑥ Z_{bl} m (ft)	$l_i = \sqrt{(X_{ch} - X_{bl})^2 + (Y_{ch} - Y_{bl})^2}$ m (ft)	$\Delta Z_i = Z_{ch} - Z_{bl}$ m (ft)	a_i mm^2 $(in)^2$	E_i GPa (1000 lb/in^2)
1										
2	16	5	19	0	27	9	27.203	10	6	200
3	38	9	18	72	27	9	38.471	9	6	200
4	70	16	15.5	24	27	9	47.297	6.5	6	200
5	318	20	9.5	336	27	9	19.313	0.5	6	200
6	350	17.5	10	312	27	9	39.170	1	6	200
7	364	16	10.5	384	27	9	22.825	1.5	6	200
8										
9										
10										

From DDS 582-1

FIGURE 14. Example of mooring line force calculations for normal weather condition.

CALCULATION SHEET–2 (continued)

MOORING LINE FORCES

Units: Inch–lb ✓ Metric ______ Ship: EXAMPLE (normal weather condition)

Line No.	(11) $\cos \theta_i =$ ((5)–(2))/(7)	(12) $\phi_i = \tan^{-1}\frac{(8)}{(7)}$ (degrees)	(13) $\cos \phi_i$	(14) l_o m (ft)	(15) $L_i =$ (14) $+ \frac{(7)}{(13)}$ m (ft)	(16) (BS)* kN (1000 lb)	(17) $k_i = \frac{a_i E_i}{L_i}$ kN/m (1000 lb/ft)
1							
2	0.80873	20.184	0.93859	8	36.983	219	32.447
3	.46788	13.167	.97371	8	47.510	219	25.258
4	.23257	7.8251	.99069	8	55.741	219	21.528
5	.36245	1.4830	.99966	10	29.320	219	40.928
6	.24253	1.4624	.99967	8	47.183	219	25.433
7	.48193	3.7599	.99785	8	30.874	219	38.868
8							
9							
10							

* (BS) is total line breaking strength=(BS)rope x (number of rope parts per line) From DDS 582–1

FIGURE 15. Example of mooring line force calculations for normal weather condition (continued).

CALCULATION SHEET-2 (continued)

Units: Inch-lb ✓ Metric ___

MOORING LINE FORCES

Ship: EXAMPLE (normal weather condition)

Line No.	(18) $k_{yi} = k_i \cos\theta_i \cos\phi_i$ kN/m (1000 lb/ft)	(19) $k_{yi} \cdot X_{ch}$ kN (1000 lb)	(20) $k_{yi} \cdot X_{ch}^2$ kN•m (1000 ft-lb)	(25) $F_{yi} = k_{yi}(\delta_y + X_{ch} \cdot \gamma)$ kN (1000 lb)	(26) $T_i = \frac{F_{yi}}{\cos\theta_i \cos\phi_i}$ kN (1000 lb)	(27) $FS = \frac{(BS)}{T_i}$
1						
2	24.630	394.08	6305.3	11.331	14.928	14.670
3	11.507	437.27	16,616.	5.2768	11.583	18.907
4	4.9602	347.21	24,305	2.2639	9.8258	22.288
5	14.829	4715.6	1,499,600	6.5196	17.994	12.171
6	6.1662	2158.2	755,360	2.6977	11.127	19.682
7	18.691	6803.5	2,476,500	8.1594	16.967	12.907
8						
9						
10						
(21)	a= 80.7834	b= 14,855.9	c= 4,778,637	f= 36.249		

(22) F_y = 36.249 kN (1000 lb)
X_{cg} = 190 m (ft)
M_r = (−)359.41 kN•m (1000 ft-lb)
From DDS 582-1

(23) $\delta_y = \frac{F_y \cdot c - (M_r + F_y \cdot X_{cg}) \cdot b}{ac - b^2}$ = 0.46114 m (ft)

(24) $\gamma = \frac{F_y \cdot b - (M_r + F_y \cdot X_{cg}) \cdot a}{b^2 - ac}$ = (−)6.7573x10^{-6} radian

FIGURE 16. Example of mooring line force calculations for normal weather condition (continued).

CALCULATION SHEET–2

MOORING LINE FORCES

Units: Inch–lb ✓ Metric ______

Ship: EXAMPLE (heavy weather condition)

Line No.	Chock Coordinates ① X_{ch} m (ft)	② Y_{ch} m (ft)	③ Z_{ch} m (ft)	Bollard Coordinates ④ X_{bl} m (ft)	⑤ Y_{bl} m (ft)	⑥ Z_{bl} m (ft)	⑦ $l_i=\sqrt{(X_{ch}-X_{bl})^2+(Y_{ch}-Y_{bl})^2}$ m (ft)	⑧ $\Delta Z_i = Z_{ch}-Z_{bl}$ m (ft)	⑨ a_i mm² (in)²	⑩ E_i GPa (1000 lb/in²)
1	0	0	21	−24	27	9	36.125	12	6	200
2	16	5	19	0	27	9	27.203	10	6	200
3	38	9	18	72	27	9	38.471	9	6	200
4	70	16	15.5	24	27	9	47.297	6.5	6	200
5	318	20	9.5	336	27	9	19.313	0.5	6	200
6	350	17.5	10	312	27	9	39.170	1	6	200
7	364	16	10.5	384	27	9	22.825	1.5	6	200
8	390	10	10.5	408	27	9	24.759	1.5	6	200
9	264	20	9.5	288	27	9	25.000	0.5	6	200
10										

From DDS 582–1

FIGURE 17. Example of mooring line force calculations for heavy weather condition.

CALCULATION SHEET–2 (continued)

MOORING LINE FORCES

Units: Inch–lb ✓ Metric ______ Ship: EXAMPLE (heavy weather condition)

Line No.	(11) $\cos \theta_i = ((5)-(2))/(7)$	(12) $\phi_i = \tan^{-1}\frac{(8)}{(7)}$ (degrees)	(13) $\cos \phi_i$	(14) l_o m (ft)	(15) $L_i = (14) + \frac{(7)}{(13)}$ m (ft)	(16) (BS)* kN (1000 lb)	(17) $k_i = \frac{a_i E_i}{L_i}$ kN/m (1000 lb/ft)
1	0.74740	18.375	0.94901	12	50.066	219	23.968
2	.80873	20.184	.93859	8	36.983	219	32.447
3	.46788	13.167	.97371	8	47.510	219	25.258
4	.23257	7.8251	.99069	8	55.741	219	21.528
5	.36245	1.4830	.99966	10	29.320	219	40.928
6	.24253	1.4624	.99967	8	47.183	219	25.433
7	.48193	3.7599	.99785	8	30.874	219	38.868
8	.68662	3.4670	.99817	11	35.804	219	33.516
9	.28000	1.1458	.99980	8	33.005	219	36.358
10							

* (BS) is total line breaking strength=(BS)rope x (number of rope parts per line) From DDS 582–1

FIGURE 18. Example of mooring line force calculations for heavy weather condition (continued).

CALCULATION SHEET-2 (continued)

Units: Inch-lb ✓ Metric ___

MOORING LINE FORCES

Ship: EXAMPLE (heavy weather condition)

Line No.	(18) $k_{yi} = k_i \cos\theta_i \cos\phi_i$ kN/m (1000 lb/ft)	(19) $k_{yi} \cdot X_{ch}$ kN (1000 lb)	(20) $k_{yi} \cdot X_{ch}^2$ kN•m (1000 ft-lb)	(25) $F_{yi} = k_{yi}(\delta_y + X_{ch} \cdot \gamma)$ kN (1000 lb)	(26) $T_i = \frac{F_{yi}}{\cos\theta_i \cos\phi_i}$ kN (1000 lb)	(27) $FS = \frac{(BS)}{T_i}$
1	17.001	0	0	34.519	48.667	4.5000
2	24.630	394.08	6305.3	49.478	65.183	3.3598
3	11.507	437.27	16,616.	22.774	49.989	4.3810
4	4.9602	347.21	24,305	9.6031	41.679	5.2544
5	14.829	4715.6	1,499,600	23.752	65.554	3.3408
6	6.1662	2158.2	755,360	9.6106	39.640	5.5247
7	18.691	6803.5	2,476,500	28.779	59.845	3.6595
8	22.971	8958.7	3,493,900	34.564	50.432	4.3425
9	10.178	2687.0	709,370	17.043	60.880	3.5972
10						
(21)	a= 130.93	b= 26,502.	c= 8,982,000	f= 230.12		

(22) F_y = 230.12 kN (1000 lb)
X_{cg} = 190 m (ft)
M_r = (−)2,019.9 kN•m (1000 ft-lb)

From DDS 582-1

(23) $\delta_y = \frac{F_y \cdot c - (M_r + F_y \cdot X_{cg}) \cdot b}{ac - b^2}$ = 2.0304 m (ft)

(24) $\gamma = \frac{F_y \cdot b - (M_r + F_y \cdot X_{cg}) \cdot a}{b^2 - ac}$ = (−)0.0013480 radian

FIGURE 19. Example of mooring line force calculations for heavy weather condition (continued).

CALCULATION SHEET-3

CAPSTAN DESIGN

Units: Inch-lb ✓ Metric ________ Ship: EXAMPLE

	PROCEDURE		Value
1	LWL	m (ft)	383
2	Draft, T	m (ft)	14
3	Side projected wind area, A_s	m^2 (ft^2)	9100
4	Wind speed at 90 degrees to ship's keel, V_w	knots	15
5	Capstan warping line speed, V_{cp}	m/min (ft/min)	40
6	Ship's lateral berthing speed, V_b = (5) {(m/min)/30; (ft/min)/100}	knots	0.4
7	Number of capstans		2
8	Lateral wind force, F_{yw} = 0.1618 × $(4)^2$ × (3) Lateral wind force, F_{yw} = 0.00338 × $(4)^2$ × (3)	N (lb)	6920.6
9	Drag Coefficient — $N \cdot kt^{-2} m^{-2}$ ($lb-kt^{-2}-ft^{-2}$) Destroyers — 709 (14.8) Auxiliaries — 747 (15.6)		14.8
10	Lateral current resistance, F_{xc} = (9) × $(6)^2$ × (1) × (2)	N (lb)	12,697
11	Capstan line pull, P_{cp} = [(8) + (10)] / (7)	N (lb)	9808.8
12	Capstan head efficiency, η_c		0.95
	Electromechanical capstan		
13	Overall bearing and gear efficiency, η_g		0.85
14	Power $= \frac{(11) \times (5)}{60 \times (12) \times (13)}$ watts $= \left(\frac{(11) \times (5)}{33{,}000 \times (12) \times (13)}\right)$(hp)		14.7
	Electrohydraulic capstan		
15	Efficiency of hydraulic pump & motor, η_{hy}		0.75
16	Power $= \frac{(11) \times (5)}{60 \times (12) \times (13) \times (15)}$ W $= \left(\frac{(11) \times (5)}{33{,}000 \times (12) \times (13) \times (15)}\right)$(hp)		19.6

From DDS 582-1

FIGURE 20. Example of calculation of required capstan power.

DDS-582-1-j. BIBLIOGRAPHY

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APPENDIX A

LISTS OF SYNTHETIC ROPES AND THEIR BREAKING STRENGTH

Rope | Page

Three-strand nylon rope 54
Plaited nylon 55
Double braided nylon rope 56
Plaited continuous polyester filament with staple wrap 57
Three-strand polyester 57
Three-strand polypropylene 58
Double braided polyester filament with staple wrap 58
Three-strand dual fiber 59
Plaited dual fiber 59

THREE-STRAND NYLON ROPE

MIL-R-17343

Circumference inches	mm	Breaking strength lb	kN	Standard length feet	m	NSN (4020-00-)
5/8	16	950	4.20	700	213	541-7075*
5/8	16	950	4.20	1200	365	263-3483*
5/8	16	950	4.20	2250	685	701-3044
5/8	16	950	4.20	2250	685	242-4083*
5/8	16	950	4.20	100	30	270-8245*
3/4	19	1,500	6.65	2250	685	618-0261
3/4	19	1,500	6.65	900	274	523-9461
3/4	19	1,500	6.65	600	182	542-2523*
3/4	19	1,500	6.65	200	61	929-0058*
1	25	2,600	11.55	2250	685	641-8898
1	25	2,600	11.55	42	12	593-9584
1 1/8	29	3,300	14.65	1620	493	842-2431*
1 1/8	29	3,300	14.65	1620	493	641-8899
1 1/4	32	4,800	21.35	1200	365	753-2886
1 1/4	32	4,800	21.35	50	15	530-2701
1 1/2	38	5,800	25.80	1200	365	641-8900
1 1/2	38	5,800	25.80	300	91	741-3154
1 3/4	44	7,600	33.80	1200	365	560-7732
2	51	9,800	43.60	1200	365	753-2887
2 1/4	57	13,200	58.70	125	38	585-2530
2 1/2	64	15,300	68.05	1200	365	753-2888
2 3/4	70	19,000	84.50	1200	365	174-1231
3	76	23,200	103.20	1200	365	752-8878
3 1/2	89	32,000	142.30	1200	365	174-1232
4	102	41,300	183.70	600	182	752-8879
4 1/2	114	50,000	222.40	600	182	542-3306
5	127	60,000	266.90	600	182	752-8880
5 1/2	140	72,000	320.25	600	182	542-3307
6	152	90,000	400.35	600	182	542-3308
6 1/2	165	100,000	444.82	600	182	843-6306
7	178	127,000	564.90	600	182	752-8881
8	203	164,000	729.50	720	219	752-8892
8	203	164,000	729.50	600	182	892-4028
9	229	209,000	929.65	600	182	842-7468
10	254	265,000	1178.75	600	182	843-6307

* An asterisk indicates an NSN for which an alternative (nonasterisked) NSN pertaining to the same rope size may be substituted when the order is filled.

PLAITED NYLON

MIL-R-24337

Circumference inches	Circumference mm	Breaking strength lb	Breaking strength kN	Standard length feet	Standard length m	NSN (4020-00-)
3/4	19	1,500	6.70	2250	685	106-9384
1	25	2,400	10.70	2250	685	106-9388
1 1/8	29	3,300	14.70	1620	494	106-9389
1 1/4	32	4,800	21.40	1200	365	106-9390
1 1/2	38	6,200	27.60	1200	365	106-9391
1 3/4	44	7,700	34.30	1200	365	106-9392
2	51	10,000	44.50	1200	365	106-9393
2 1/4	57	13,800	61.40	1200	365	106-9394
2 1/2	64	16,000	71.20	1200	365	106-9395
2 3/4	70	19,000	84.50	1200	365	106-9396
3	76	25,000	111.20	1200	365	106-9397
3 1/2	89	33,000	146.80	1200	365	106-9398
3 3/4	92	38,000	169.00	600	182	106-9399
4	102	43,000	191.30	600	182	106-9164
4 1/2	114	50,000	222.40	600	182	106-9400
5	127	60,000	266.90	600	182	106-9401
5 1/2	140	75,000	333.60	600	182	106-9261
6	152	86,000	382.50	600	182	106-9298
6 1/2	165	98,000	435.90	600	182	106-9333
7	178	117,000	520.40	600	182	106-9334
7 1/2	191	134,000	596.10	600	182	106-9335
8	203	153,000	680.60	600	182	106-9336
9	229	192,000	854.10	600	182	106-9337
10	254	237,000	1054.20	600	182	106-9338
11	279	280,000	1245.50	500	152	106-9339
12	305	345,000	1534.60	400	122	106-9340

DOUBLE BRAIDED NYLON ROPE

MIL-R-24050

Circumference		Breaking strength		Standard length		NSN
inches	mm	lb	kN	feet	m	(4020-)
3/4	19	1,700	7.55	600	182	00-106-9342
1	25	2,700	12.00	600	182	00-106-9341
1 1/8	29	3,900	17.30	600	182	00-946-0436
1 1/4	32	5,100	22.70	600	182	00-926-4529
1 1/2	38	6,900	30.70	600	182	00-106-9361
1 3/4	44	9,000	40.00	600	182	00-106-9364
2	51	12,000	53.40	600	182	00-106-9402
2	51	12,000	53.40	480	146	01-025-5175
2	51	12,000	53.40	300	91	01-025-5176
2	51	12,000	53.40	180	54	01-025-5177
2 1/4	57	15,000	66.70	600	182	00-106-9403
2 1/2	64	18,400	81.80	600	182	00-106-9404
2 3/4	70	22,500	100.10	600	182	00-106-9405
2 3/4	70	22,500	100.10	900	274	01-025-5172
2 3/4	70	22,500	100.10	300	91	01-025-5173
2 3/4	70	22,500	100.10	200	61	01-025-5174
3	76	26,500	117.90	600	182	00-471-9336
3 1/2	89	36,000	160.10	600	182	00-519-7916
3 3/4	92	42,000	186.80	600	182	00-106-9406
4	102	48,000	213.50	600	182	00-106-9407
4	102	48,000	213.50	900	274	01-025-5170
4	102	48,000	213.50	300	91	01-025-5171
4 1/2	114	60,000	266.90	600	182	00-106-9408
5	127	73,000	324.70	600	182	00-106-9409
5 1/2	140	90,000	400.30	600	182	00-106-9410
5 1/2	140	90,000	400.30	900	274	01-025-5178
5 1/2	140	90,000	400.30	300	91	01-025-5180
6	152	102,500	455.90	600	182	00-106-9411
6 1/2	165	123,000	547.10	600	182	00-106-9412
7	178	140,000	622.80	600	182	00-519-7946
7 1/2	191	160,000	711.80	600	182	00-486-6009
8	203	180,000	800.70	600	182	00-003-6293
8	203	180,000	800.70	1200	365	01-025-5179
9	229	225,000	1000.80	600	182	00-519-7951
10	254	273,000	1214.40	600	182	00-519-7960
11	279	325,000	1445.70	600	182	00-519-7980
12	305	385,000	1712.60	600	182	00-519-7992

PLAITED CONTINUOUS POLYESTER FILAMENT WITH STAPLE WRAP MIL-R-24537

Circumference		Breaking strength		Standard length		NSN
inches	mm	lb	kN	feet	m	(4020-01-)
3/4	19	2,080	9.30	2250	685	029-2778
1	25	2,980	13.30	2250	685	028-3842
1 1/8	29	3,970	17.70	1620	493	028-3825
1 1/4	32	5,050	22.50	1200	365	028-3828
1 1/2	38	6,400	28.50	400	122	028-3826
1 1/2	38	6,400	28.50	800	244	028-3829
1 1/2	38	6,400	28.50	1200	365	028-3830
1 1/2	38	6,400	28.50	200	61	028-3843
1 3/4	44	8,100	36.00	1200	365	028-3839
2	51	9,900	44.00	1200	365	028-3831
2 1/4	57	12,200	54.30	1200	365	029-8664
2 1/2	64	14,500	64.60	1200	365	028-3832
2 3/4	70	16,700	74.30	1200	365	028-3833
3	76	19,000	84.50	400	122	028-3834
3	76	19,000	84.50	600	182	028-3835
3	76	19,000	84.50	1200	365	028-3841
3 1/4	83	22,000	97.90	200	61	028-3836
3 1/2	89	25,000	111.20	1200	365	028-3837
3 3/4	92	27,500	122.30	600	182	028-3840
4	102	30,700	136.60	600	182	028-3838
4 1/2	114	37,000	164.60	600	182	028-3827

THREE-STRAND POLYESTER MIL-R-30500

Circumference		Breaking strength		Standard length		NSN
inches	mm	lb	kN	feet	m	(4020-)
5/8	16	800	3.60	2700	823	00-202-1345*
5/8	16	800	3.60	50	15	00-659-8923
3/4	19	1,200	5.30	2250	685	00-536-3476*
1	25	2,500	11.10	24	7	00-180-6548
1	25	2,500	11.10	2250	685	01-041-0789
1 1/4	32	3,800	16.90	1200	365	00-085-4424
1 1/2	38	5,000	22.20	1200	365	00-630-4873
3	76	18,500	82.30	1200	365	00-142-6115
4	102	31,000	137.90	600	182	00-630-4875

* An asterisk indicates an NSN for which an alternative (nonasterisked) NSN pertaining to the same rope size may be substituted when the order is filled.

THREE-STRAND POLYPROPYLENE

MIL-R-24049

Circumference inches	mm	Breaking strength lb	kN	Standard length feet	m	NSN (4020-00-)
3/4	19	1,000	4.45	2250	685	999-3894
1	25	1,700	7.55	900	274	530-0698
1	25	1,700	7.55	210	64	499-7529
1 1/2	38	3,700	16.45	50	15	874-7920
1 1/2	38	3,700	16.45	600	182	968-1352
2 1/4	57	7,000	31.15	200	61	874-7921
2 1/4	57	7,000	31.15	600	182	968-1354
3	76	13,000	57.80	600	182	968-1355

DOUBLE BRAIDED POLYESTER FILAMENT WITH STAPLE WRAP

MIL-R-24536

Circumference inches	mm	Breaking strength lb	kN	Standard length feet	m	NSN (4020-01-)
3/4	19	1,700	7.55	600	182	028-3823
1	25	2,600	11.55	600	182	028-3824
1 1/8	29	3,600	16.00	600	182	029-2775
1 1/4	32	4,700	20.90	600	182	028-3844
1 1/2	38	6,000	26.70	600	182	028-4526
1 3/4	44	7,900	35.15	600	182	028-4527
2	51	10,000	44.50	600	182	028-4525
2 1/4	57	12,200	54.25	600	182	028-6770
2 1/2	64	14,700	65.40	600	182	029-2776
2 3/4	70	17,400	77.40	600	182	028-4531
3	76	20,000	89.00	350	106	029-8665
3	76	20,000	89.00	700	213	028-3845
3 1/4	83	23,400	104.00	600	182	029-2777
3 1/2	89	26,700	118.75	600	182	028-3846
3 3/4	92	30,000	133.45	600	182	028-3822
4	102	33,700	150.00	350	106	029-8663
4	102	33,700	150.00	1200	365	028-4528
4 1/2	114	45,000	200.15	600	182	028-4529
5	127	50,000	222.40	600	182	028-4530

THREE-STRAND DUAL FIBER

MIL-R-43942

Circumference		Breaking strength		Standard length		NSN
inches	mm	lb	kN	feet	m	(4020-01-)
3/4	19	1,130	5.00	2250	685	036-6819
1	25	1,710	7.60	2250	685	036-6820
1 1/8	29	2,430	10.80	1600	487	037-6290
1 1/2	38	3,960	17.60	1200	365	036-6291
2	51	5,760	25.60	1200	365	037-6292
2 1/4	57	7,560	33.60	1200	365	037-6293

PLAITED DUAL FIBER

MIL-R-43952

Circumference		Breaking strength		Standard length		NSN
inches	mm	lb	kN	feet	m	(4020-01-)
1 1/8	29	2,430	10.80	1600	487	038-4897
1 1/2	38	3,960	17.60	1200	365	038-4898
2 1/2	64	9,180	40.85	1200	365	038-4899

DDS-582-1-m

APPENDIX B

CONVERSION TABLE FOR METRIC UNITS

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CONVERSION TABLE FOR METRIC UNITS

To convert a quantity given in the units of the first column to the same quantity stated in the units of the third column, multiply by the factor listed in the middle column.

To convert from	Multiply by	To obtain
Degrees (of arc)	0.017 453 3	radians
Do.	1	degrees
Radians	1	radians
Fathoms	1.8288 *	meters
Feet	0.3048 *	meters
Inches	0.0254 *	meters
Square feet	0.092 903 *	square meters
Cubic feet	0.028 317	cubic meters
Pounds mass	0.453 592 37 *	kilograms
Long tons mass	1.016 047	metric tons
Slugs mass	14.594	kilograms
Pounds force	4.448 222	newtons
Long tons force	9.9640	kilonewtons
Pounds force per square inch	6.894 757	kilopascals
Do.	6.894 757 x 10^{-6}	kilonewtons per square millimeter
Do.	6.894 757 x 10^{-6}	gigapascals
Foot-pounds force (energy)	1.355 818	joules
Foot-pounds force (torque or moment)	1.355 818	newton-meters
Foot-long tons force (torque or moment)	3.037 032	kilonewton-meters
Horsepower	0.745 700	kilowatts
Feet per minute	0.3048 *	meters per minute
Knots	1	knots
Do.	1852 *	meters per hour

* Conversion factors equal to unity or marked by an asterisk are exact; others are approximate.

DDS 582-1-n

APPENDIX C

MINIMUM NUMBER OF LINES USED IN PRELIMINARY MOORING ANALYSIS

APPENDIX C

MINIMUM NUMBER OF LINES USED IN PRELIMINARY MOORING ANALYSIS

In the preliminary design stage the following table may be used to prepare a mooring line arrangement for analysis purposes. All lines are presumed to be doubled up, with three parts per line.

Ship type	Displacement (long tons)	Number and size of mooring lines (heavy weather condition)	Camel width (feet)
Destroyers	2000 - 4000	Eight 5-inch	4
	4000 - 6000	Eight 6-inch	4
	6000 - 8000	Nine 6-inch	4
Cruisers	8000 - 12000	Two 8-inch, eight 6-1/2-inch	6
	12000 - 16000	Four 8-inch, eight 6-1/2-inch	6
Auxiliaries	15000 - 20000	Four 8-inch, eight 6-1/2-inch	6
	20000 - 25000	Four 9-inch, eight 6-1/2-inch	6
	25000 - 30000	Four 9-inch, eight 7-inch	6
Minesweepers		Six 5-inch	--
Tugs		Six 5-inch	--

DDS 582-1-o

APPENDIX D

BLANK CALCULATION SHEETS

- 1 Wind and current forces, foot-pound units

- 1 Wind and current forces, metric units

- 2 Mooring line forces

- 3 Capstan design

CALCULATION SHEET–1
WIND AND CURRENT FORCES
(inch–pound units)

Ship: ____________

	Ship particulars		Value
1	Displacement, Δ	LT	
2	LWL	ft	
3	Draft, T	ft	
4	Beam, B	ft	
5	End projected wind area, A_e	ft^2	
6	Side projected wind area, A_s	ft^2	
7	Wind speed, V_w	kt	
8	Current speed, V_c	kt	
9	Wind angle, θ_w	degrees	
10	Current angle, θ_c	degrees	
11	Water depth, WD	ft	
	Wind force		
12	C_{xw} (see figure 4)		
13	C_{yw} (see figure 5)		
14	C_{xyw} (see figure 6)		
15	$F_{xw} = 0.00338 \times ⑫ \times (⑦)^2 \times ⑤$	lb	
16	$F_{yw} = 0.00338 \times ⑬ \times (⑦)^2 \times ⑥$	lb	
17	$M_w = 0.00338 \times ⑭ \times (⑦)^2 \times ⑥ \times ②$	ft–lb	

From DDS 582–1

CALCULATION SHEET-1 (continued)
WIND AND CURRENT FORCES
(inch-pound units)

Ship: ______________________

Current force			Value
18	Wetted surface, $S = 15.5\sqrt{(1) \times (2)}$	ft^2	
19	Water depth/draft, $WD/T = (11)/(3)$		
20	C_{xca} (see figure 1)		
21	C_{yc} (see figure 2)		
22	$C_{xcb} = (21) \times \cos^2 \theta_c$		
23	C_{xyc} (see figure 3)		
24	$F_{xc} = 2.835 \times ((8))^2 \times (4)[(20) \times (18)/(2) + (22) \times (3)]$	lb	
25	$F_{yc} = 2.835 \times (21) \times ((8))^2 \times (2) \times (3)$	lb	
26	$M_c = 2.835 \times (23) \times ((8))^2 \times (2)^2 \times (3)$	ft-lb	
Total forces			
27	Total longitudinal force, $F_x = (15) + (24)$	lb	
28	Total lateral force, $F_y = (16) + (25)$	lb	
29	Total yaw moment, $M_r = (17) + (26) - 0.48 \times (2) \times (27)$	ft-lb	

From DDS 582-1

CALCULATION SHEET–1
WIND AND CURRENT FORCES
(metric units)

Ship: ____________

	Ship particulars		Value
1	Displacement, Δ	metric tons, t	
2	LWL	m	
3	Draft, T	m	
4	Beam, B	m	
5	End projected wind area, A_e	m^2	
6	Side projected wind area, A_s	m^2	
7	Wind speed, V_w	kt	
8	Current speed, V_c	kt	
9	Wind angle, θ_w	degrees	
10	Current angle, θ_c	degrees	
11	Water depth, WD	m	
	Wind force		
12	C_{xw} (see figure 4)		
13	C_{yw} (see figure 5)		
14	C_{xyw} (see figure 6)		
15	$F_{xw} = 0.1618 \times ⑫ \times (⑦)^2 \times ⑤$	N	
16	$F_{yw} = 0.1618 \times ⑬ \times (⑦)^2 \times ⑥$	N	
17	$M_w = 0.1618 \times ⑭ \times (⑦)^2 \times ⑥ \times ②$	N•m	

From DDS 582–1

CALCULATION SHEET-1 (continued)
WIND AND CURRENT FORCES
(metric units)

Ship: ____________

	Current force		Value
18	Wetted surface, $S = 2.588\sqrt{(1) \times (2)}$	m^2	
19	Water depth/draft, WD/T = (11)/(3)		
20	C_{xca} (see figure 1)		
21	C_{yc} (see figure 2)		
22	C_{xcb} = (21) x $\cos^2 \theta_c$		
23	C_{xyc} (see figure 3)		
24	F_{xc} = 135.95 x((8))^2 x (4)[(20) x (18)/(2) + (22) x (3)]	N	
25	F_{yc} = 135.95 x (21) x((8))^2 x (2) x (3)	N	
26	M_c = 135.95 x (23) x((8))^2 x (2)^2 x (3)	N•m	
	Total forces		
27	Total longitudinal force, F_x = (15) + (24)	N	
28	Total lateral force, F_y = (16) + (25)	N	
29	Total yaw moment, M_r = (17) + (26) − 0.48 x (2) x (27)	N•m	

From DDS 582-1

CALCULATION SHEET-2

MOORING LINE FORCES

Units: Inch-lb ________ Metric ________ Ship: ____________________

Line No.	Chock Coordinates			Bollard Coordinates			⑦	⑧	⑨	⑩
	① X_{ch} m (ft)	② Y_{ch} m (ft)	③ Z_{ch} m (ft)	④ X_{bl} m (ft)	⑤ Y_{bl} m (ft)	⑥ Z_{bl} m (ft)	$l_i = \sqrt{(X_{ch} - X_{bl})^2 + (Y_{ch} - Y_{bl})^2}$ m (ft)	$\Delta Zi = Z_{ch} - Z_{bl}$ m (ft)	a_i mm^2 $(in)^2$	E_i GPa (1000 lb/in^2)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

From DDS 582-1

CALCULATION SHEET-2 (continued)

MOORING LINE FORCES

Units: Inch-lb __________ Metric __________ Ship: ____________________

Line No.	(11) $\cos \theta_i =$ ((5)-(2))/(7)	(12) $\phi_i = \tan^{-1} \frac{(8)}{(7)}$ (degrees)	(13) $\cos \phi_i$	(14) l_o m (ft)	(15) $L_i = (14) + \frac{(7)}{(13)}$ m (ft)	(16) (BS)* kN (1000 lb)	(17) $k_i = \frac{a_i E_i}{L_i}$ kN/m (1000 lb/ft)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

* (BS) is total line breaking strength=(BS)rope x (number of rope parts per line) From DDS 582-1

CALCULATION SHEET-2 (continued)

Units: Inch-lb ___ Metric ___

MOORING LINE FORCES

Ship: ____________________

Line No.	(18) $k_{yi} = k_i \cos\theta_i \cos\phi_i$ kN/m (1000 lb/ft)	(19) $k_{yi} \cdot X_{ch}$ kN (1000 lb)	(20) $k_{yi} \cdot X_{ch}^2$ kN•m (1000 ft-lb)	(25) $F_{yi} = k_{yi} (\delta_y + X_{ch} \cdot \gamma)$ kN (1000 lb)	(26) $T_i = \frac{F_{yi}}{\cos\theta_i \cos\phi_i}$ kN (1000 lb)	(27) $FS = \frac{(BS)}{T_i}$
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
(21)	a=	b=	c=	f=		

(22) F_y = ____________ kN (1000 lb)
X_{cg} = ____________ m (ft)
M_r = ____________ kN•m (1000 ft-lb)

(23) $\delta_y = \frac{F_y \cdot c - (M_r + F_y \cdot X_{cg}) \cdot b}{ac - b^2}$ = ____________ m (ft)

(24) $\gamma = \frac{F_y \cdot b - (M_r + F_y \cdot X_{cg}) \cdot a}{b^2 - ac}$ = ____________ radian

From DDS 582-1

CALCULATION SHEET–3
CAPSTAN DESIGN

Units: Inch–lb ________ Metric ________ Ship: ________________

	PROCEDURE		Value
1	LWL	m (ft)	
2	Draft, T	m (ft)	
3	Side projected wind area, A_s	m^2 (ft^2)	
4	Wind speed at 90 degrees to ship's keel, V_w	knots	
5	Capstan warping line speed, V_{cp}	m/min (ft/min)	
6	Ship's lateral berthing speed, $V_b = ⑤ \begin{cases}(m/min)/30 \\ (ft/min)/100\end{cases}$	knots	
7	Number of capstans		
8	Lateral wind force, $F_{yw} = 0.1618 \times ④^2 \times ③$ Lateral wind force, $F_{yw} = 0.00338 \times ④^2 \times ③$	N (lb)	
9	Drag Coefficient — $N \cdot kt^{-2} m^{-2}$ ($lb-kt^{-2}-ft^{-2}$) Destroyers — 709 (14.8) Auxiliaries — 747 (15.6)		
10	Lateral current resistance, $F_{xc} = ⑨ \times ⑥^2 \times ① \times ②$	N (lb)	
11	Capstan line pull, $P_{cp} = [⑧ + ⑩] / ⑦$	N (lb)	
12	Capstan head efficiency, η_c		
	Electromechanical capstan		
13	Overall bearing and gear efficiency, η_g		
14	Power $= \frac{⑪ \times ⑤}{60 \times ⑫ \times ⑬}$ watts $= \left(\frac{⑪ \times ⑤}{33{,}000 \times ⑫ \times ⑬}\right)$(hp)		
	Electrohydraulic capstan		
15	Efficiency of hydraulic pump & motor, η_{hy}		
16	Power $= \frac{⑪ \times ⑤}{60 \times ⑫ \times ⑬ \times ⑮}$ W $= \left(\frac{⑪ \times ⑤}{33{,}000 \times ⑫ \times ⑬ \times ⑮}\right)$(hp)		

From DDS 582–1