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CHESAPEAKE DIV NAVFACENGCOM

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Preliminary Mooring Plan for

The Egress II Barge

by

William N. Seelig

FPO-1-85(10)

Revised 29 June 1983

Ocean Engineering

CHESAPEAKE DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON NAVY YARD
WASHINGTON, DC 20374

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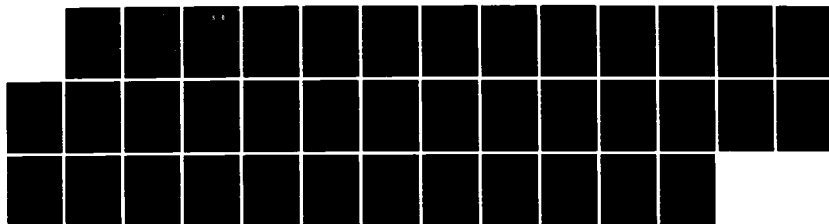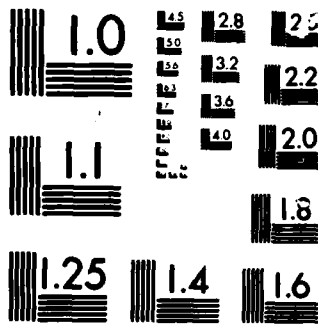
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The best method of mooring the Empress 11 and test vessel is by using a four-point mooring illustrated. Each point of the mooring will be a riser-type mooring with a buoy that can be used to moor the vessels because of their ease in handling. The mooring lines should: (1) stretch to act as shock   (Con't)

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absorbers; (2) have strength; (3) float or have floats attached; (4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet light. The type and dimensions of the lines will be determined in the final design stage.

Several sites have been examined. The sheltered waters in the Chesapeake Bay are recommended for testing small to medium class ships. The Bay area has the advantages that waves are fetch- and depth limited and that land areas will tend to reduce local wind speed slightly. The major disadvantages of the Bay area are the limited water depth and maneuvering room which poses a hazards to large vessels. Test sites in coastal ocean waters have the advantages of greater water depth and maneuvering room for the test ship. However, waves at the ocean sites will be generally larger than in the Bay. Testing in the summer will minimize wave effects. An ocean mooring should be in at least 70 feet of water to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in the mooring and to examine motions of the moored barge.

EXECUTIVE SUMMARY

The best method of mooring the Empress II and test vessel is
by using a four-point mooring illustrated in the attached figure.
Each point of the mooring will be a riser-type mooring with a buoy
that can be used to restrain the barge and/or test ship. Synthetic
lines should be used to moor the vessels because of their ease in
handling. The mooring lines should: (1) stretch to act as shock
absorbers; (2) have strength; (3) float or have floats attached;
(4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet
light. The type and dimensions of the lines will be determined in
the final design stage.

Several sites have been examined. The sheltered waters in the
Chesapeake Bay are recommended for testing small to medium class
ships. The Bay area has the advantages that waves are fetch- and
depth-limited and that land areas will tend to reduce local wind
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larger than in the Bay. Testing in the summer will minimize wave
effects. An ocean mooring should be in at least 70 feet of water
to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in
the mooring and to examine motions of the moored barge.

OPERATIONAL CONDITIONS

The following operational conditions are tentatively recommended:

a. Significant wave heights less than 5 feet (This height should
    be better defined as the highest waves when personnel can work
    and safely leave the barge. Further model studies and prototype
    experience will help define this limit).

b. Wind speeds less than 28 knots (below a "Moderate Gale")

EVACUATION

Personnel should seriously consider leaving the barge and have the barge towed into sheltered water from an operation-only mooring when the following are expected:

a. Significant wave heights of 5 feet or greater; or

b. Winds higher than 28 knots (a "Moderate Gale" or higher).

These limitations can be relaxed if the freeboard can be increased by the crew and if an ocean storm-hardened mooring is included.

SURVIVAL MOORING

The barge should be moved out of an operation-only mooring and put into the survival mooring if the wind speeds greater than 28 knots are expected.

DOWNTIME

Based on the above advice and available statistics, testing will not be possible for the following times:

Predicted Downtime When Testing Is Not Recommended Due To Adverse Wind and Wave Conditions
(HOURS PER MONTH)

Location	Due to Waves	Due to Wind	Total
Chesapeake Bay (all year)	14	52	52
Dam Neck (May-July)	12	9	12 to 21
Caribbean (all year)	80	34	80 to 114

MOORING DESIGN

Each corner of the four-point mooring will consist of a mooring buoy, a riser chain and an anchor. The buoy should be large and 4-inch Grade 3 riser chain is recommended. A deadweight anchor will require a weight of several hundred tons made of scrap metal and concrete. The details of the final anchor design will depend on sediment characteristics at the site and the design loads determined from the model studies.

WORKING COST ESTIMATE

The approximate cost of the installed four-point mooring is $950K in FY83 dollars. Exact cost will depend on detailed design and location, as well as year of installation. The mooring line costs will have to be determined during final design.

CHESAPEAKE	DIVISION	PROJECT: Empress II Mooring
Naval Facilities Engineering Command	NDW	Station: _____
DISCIPLINE		E S R: _____ Contract: _____
Calcs made by: SEELIG date: 4/8/83		Calculations for: Mooring Lay-out
Calcs ck'd by: _____ date: _____		

Mooring Buoys

Mooring Lines

Barge

Test Ship

Mooring Configuration for a Moored Test Ship

Note: Test ship leaves and the barge goes to a single-point
mooring during storm conditions.

Preliminary Mooring Plan for the Empress II Barge

by

William N. Seelig

Naval Engineering Facilities Command

Chesapeake Division

Ocean Engineering & Construction Project Office

1. Introduction

The Empress II will be a test barge 120 feet long, 105 feet wide, 12 feet high with an operational freeboard of≈3 feet. The barge holds a cone-shaped antenna 120 feet high with a maximum diameter of 220 feet. The barge will be used in sheltered water as well as in coastal ocean waters.

2. Problem

The problem is how to safely moor the barge during testing and for "survival" conditions. Factors that need to be considered are safety of the crew and equipment, operational requirements and cost.

3. Approach

This report presents preferred preliminary mooring designs and recommends methods of using these moorings. These designs were formulated after the following steps were taken:

a. reviewed previous work (Reference 1);

b. examined wind, wave and current statistics (References 2,3 and 4);

c. determined operational requirements of the system;

d. formulated preliminary designs and made cost estimates;

e. performed computer analyses and limited physical model studies; and

f. selected the most promising designs.

4. Operational Requirements (per meeting of PM-23, NAVSEA & CHESDIV)

During operation the barge will have a freeboard of≈3 feet and the amount of metal above this level should be minimized. During some tests the test ship will pass in the vicinity of the moored barge. During other tests the ship will be moored for as long as two weeks and moved into various positions. The barge should survive extreme storms in case it cannot be towed.

5. Conceptual Design

The design layout shown in Figure 1 (Reference 1) is ideal because it allows the barge (which has no internal propulsion) to position itself by letting out and pulling in on the various mooring lines. The test ship can also go into a bow-stern mooring between two of the four-point moorings (Figure 1).

Several of the possible designs for each point on the mooring are shown in Figure 2. The deadweight anchor type mooring with riser chain and buoy is recommended (Figure 2 D). Advantages of this last type of mooring are:

1) highly reliable
2) reasonable cost
3) design can easily be applied to a number of sites
4) simple design
5) easy to install (the deadweight anchor can be floated to the site)
6) low maintenance
7) no ground legs to tangle with ships anchors

The details of the anchor design will have to be worked out in final design to suit the selected site. Preliminary calculations show that it will have to be several hundred tons. However, costs can be kept reasonable if concrete and scrap metal are used to form a deadweight anchor.

Much of the design effort will have to be devoted to designing the lines used to moor the barge to the mooring, because this will be the weakest link in the system. These lines should resist the environmental forces, absorb dynamic loads, be easy to handle, resist wear and be non-ultraviolet sensitive. Working lines should float to allow easy usage.

6. Wave Statistics

Waves play an important role in the design of the moorings and in the operation of the barge for several reasons. First, at a 3-foot freeboard it will only take a relatively small wave to place the decks awash making operations hazardous and endangering the crew. During high waves the freeboard should be increased by deballasting and/or by moving the barge to sheltered waters. Second, waves can cause high mooring loads in a stiff mooring (Reference 5). Third, waves may damage the antenna through rapid accelerations and motions of the barge.

Model studies still need to be performed to determine under which wave conditions the crew can safely work and what is the maximum conditions under which evacuation can take place.

The Chesapeake Bay has the best wave climate of the sites proposed with significant wave heights 6 feet or higher less than 10 hours per month throughout the year (Figure 3). Dam Neck (off the mouth of the Chesapeake Bay) could also be used for testing during the months of May through July, when the chance of high waves is minimized (Figure 4). The best time to conduct tests in the Caribbean would be April through June or October through November (Figure 3).

The above statistics lead to the following conclusions: operate whenever possible in the Chesapeake Bay; operate off of the mouth of the Chesapeake Bay in the summer; and moor the barge in the Chesapeake Bay during major storms to reduce the possibility of problems caused by waves (see Figure 5 for wave height statistics in cumulative form and Table 1).

Mariners have long recognized that even small waves in shallow water are much more dangerous than larger waves in deep water. This is because as waves move into shallower water they shoal. These non-linear, shoaled waves produce a variety of problems, such as very high mooring loads (Reference 6). Mooring chain loads reach 1 million pounds (Reference 5) for the worst possible breaking wave conditions that can occur in 50 feet of water for the Empress II (wave period = 12 seconds,

see Figure 6). However, these monochromatic breaking two-dimensional wave conditions used in the laboratory tests are highly unlikely in nature. The natural wave trains have a three-dimensional nature and waves higher than the significant wave height occur only about 13% of the time.

The following method was used to select a maximum ocean design wave height for the various water depths of interest:

a. The maximum possible level of wave energy was determined at various ocean water depths using methods in Reference 7 with a deepwater design wave period of 12 seconds;

b. The wave energy was converted into a significant wave height and corrected for non-linear effects using techniques described in Reference 8; and

c. The maximum wave height was taken as 1.8 times the significant wave height (Reference 9).

The resulting ocean design wave heights for various water depths are given in Table 2, together with design wave forces in a riser-type chain mooring (see Figure 6). Note that the design force increases as the barge is moored in shallower ocean water, even though the design wave height decreases (Figure 6).

7. Winds

Winds are important because the force on the barge increases approximately as the square of the wind velocity and very high velocities are possible. Figure 7 shows wind speed statistics for extreme events in the Chesapeake Bay area. Some extreme winds and resulting forces are:

Wind (knots)	Return Period (years)	Force on Barge (Kips)
120	100	300*
105	40	225*
90	25	100

*includes wave forces in the Chesapeake Bay (33% of static force)

Winds are also important during operation because forces and moments are induced in the antenna, significant mooring line forces may occur and waves and wind will produce green water over the deck. The probabilities of various winds being exceeded, in terms of hours per month, is given in Table 3 and in cumulative form on Figure 8 and by month on Figure 8A.

8. Currents

Reference 1 shows that current forces are not very large, so an operational current of 1.5 knots and survival current of 2.0 knots are used in this study.

9. Working Cost Estimate

A four-point mooring placed in the Chesapeake Bay area will cost approximately $950K as outlined in Appendix A. Costs of the lines to moor the Empress II and test vessel to the four-point mooring will have to be worked out in final design. Physical model studies are recommended to provide information on mooring line forces due to waves.

10. Summary and Recommendations

The Empress II barge and test vessel can conviently be moored as shown in Figure 1. In this configuration the barge is moored in a four-point mooring. The barge is then moved around for testing by letting in and out on the barge mooring lines. The vessel to be tested is in the meantime put into a two-point bow and stern mooring. The Empress II is moored with heavy lines to one of more of the buoys during poor weather.

The best place to conduct tests would be in sheltered water, such as the Chesapeake Bay. However, wind and wave conditions are quite mild off the Dam Neck area in the summer (especially May through July), so larger vessels requiring deep water or extra maneuvering room could be tested in the coastal Atlantic. Other sites, such as the Caribbean, could also be used.

Test sites exposed to ocean waves should be selected to have water depths of at least 70 feet. This will minimize forces due to waves because waves in deeper water are more linear. Water depths much greater than 100 feet should also be avoided to allow easy diver inspection of the moorings.

The two critical items requiring careful design are: (a.) the mooring lines between the Empress II and the buoys and (b.) the anchor. Large 1/28 scale model tests are recommended to aid in the final design of this mooring system.

Embedment anchors are a lower cost method of mooring the Empress II for temporary operation of less than a year.

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    May 1983.

Table 1. Hours per Month Various Wave Heights are Exceeded

Location	Significant Wave Height				
	3'	4'	5'	6'	10'
Chespeake Bay (all year)	90	40	14	6	1
Dam Neck (May-Jul)	90	30	12	4	1
(all year)	260	140	80	44	10

Table 2. Design Conditions for a Storm-Hardened Ocean Mooring

Water Depth (ft)	H_s (ft) [4]	H_{max} (ft) [1]	Wave Force (kips) [5]	Wind Force (kips) [2]	Current Force (kips) [3]	Total Force (kips)
50	14.8	27	500	100	55	655
75	16.2	29	130	100	55	285
100	18.7	34	65	100	55	220

[1] H_{max} is used for design and here taken as 1.8 times H_s. Higher waves are possible, but unlikely.

[2] A 90 knot wind is used for design; this has a 25 year return period

[3] A 2.0 knot current is used for design.

[4] $\alpha = 0.0081$; R=1.0

[5] Tested with no hawser. A properly designed mooring hawser will reduce these wave forces.

Table 3. Hours per Month Various Wind Speeds are Exceeded

Location	Wind Velocity in Knots		
	28	30	35
Chesapeake Bay (all year)	42	25	11
Dam Neck (May-Jul)	9	6	3
Puerto Rico (all year)	30	25	14

Passing Test Ship

$1000' < L < 1400'$

Mooring Line

Barge

Mooring Buoy

Moored Ship
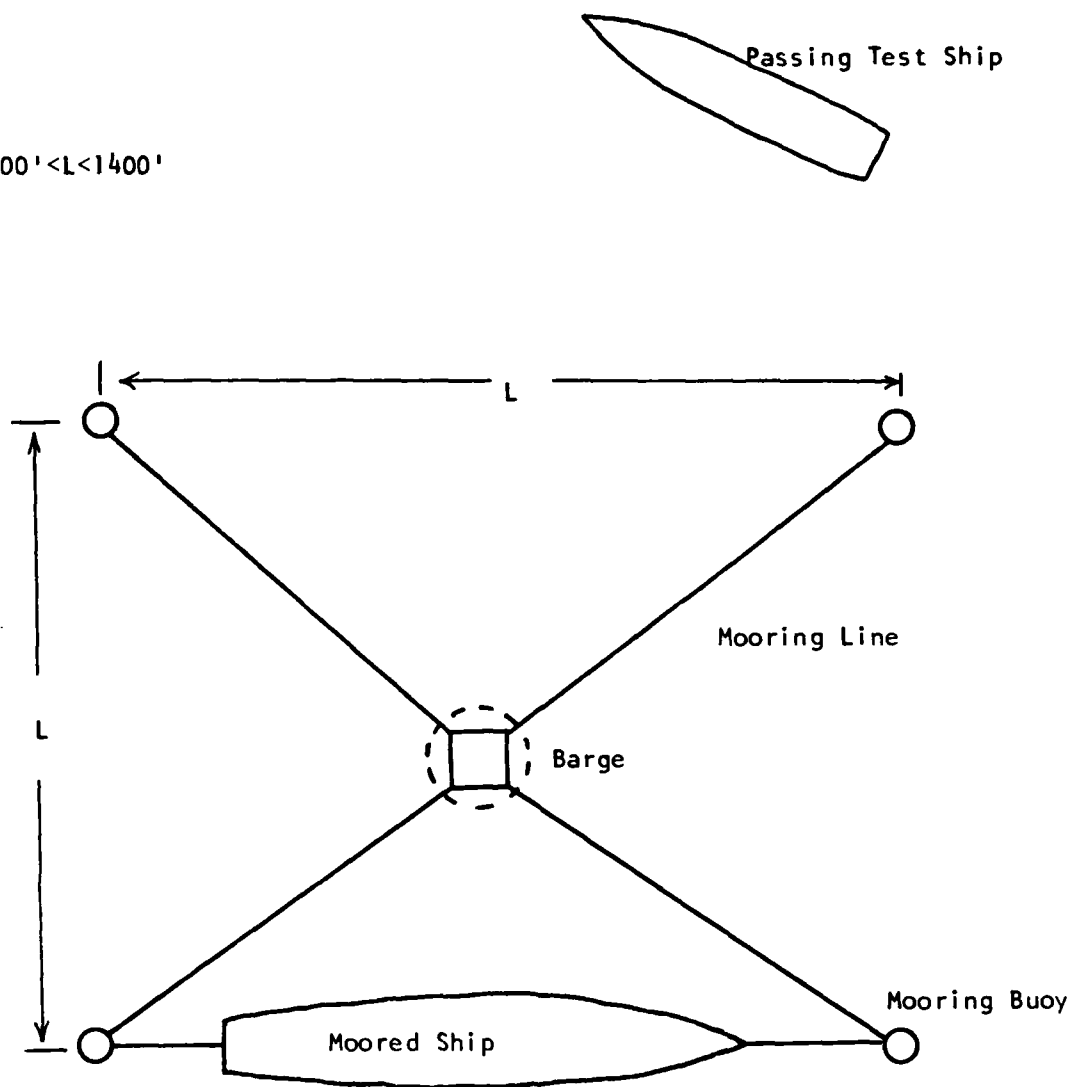
Figure 1.   The Mooring Plan

CHESAPEAKE	DIVISION	PROJECT: Empress II
Naval Facilities Engineering Command NDW		Station:
DISCIPLINE		E S R: _____ Contract: _____
Calcs made by: Seelig date: 7/11/83		Calculations for: Mooring Types
Calcs ck'd by: _____ date: _____		_____

Mooring Buoy

Equalizer

Wire
Rope

Chain

Embedment
Anchors
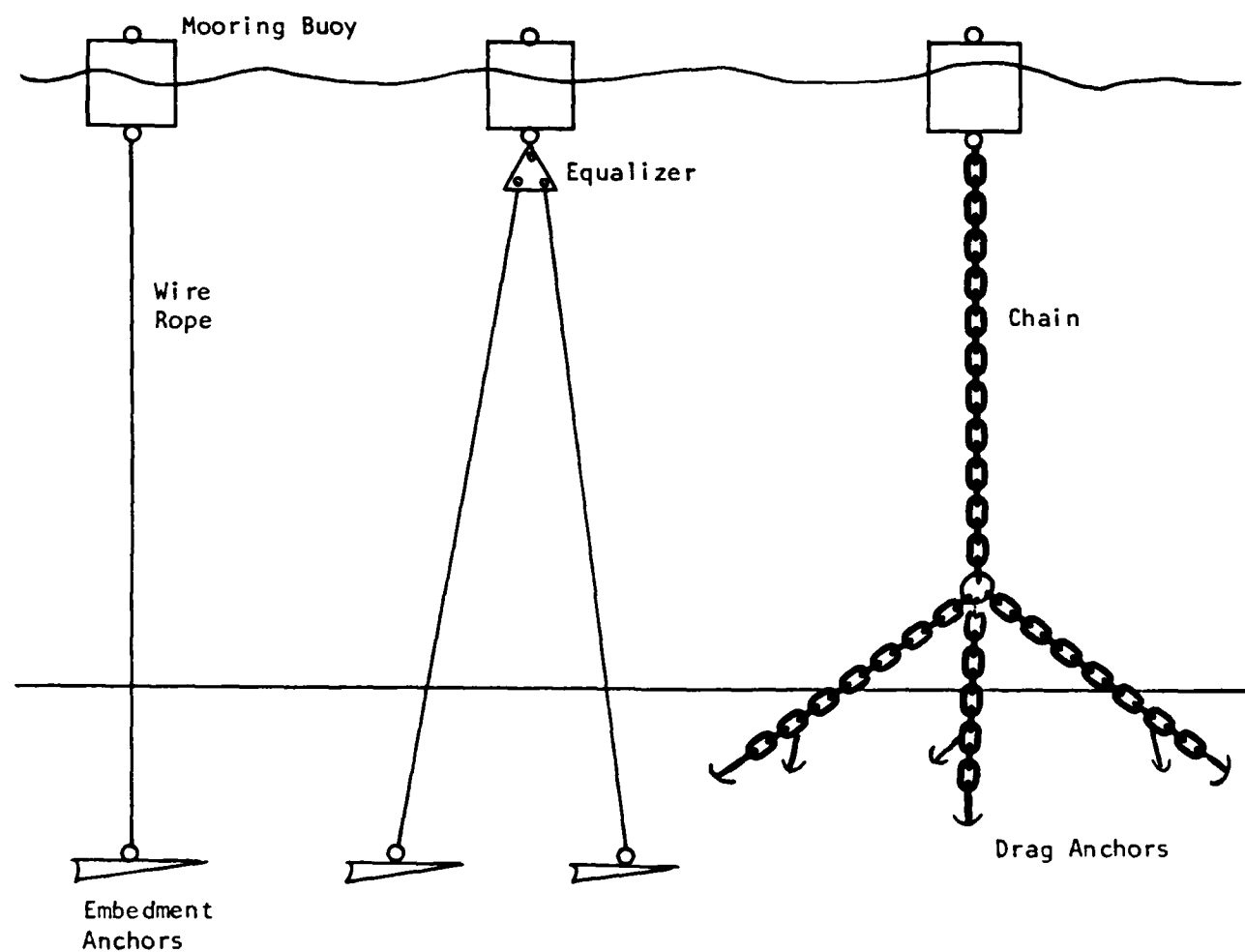
Drag Anchors

A) Single
   Embedment
   Anchors

B) Dual
   Embedment
   Anchors

C) Multiple Drag
   Anchors with Chain
   Riser

Figure 2. Mooring Types

CHESAPEAKE DIVISION	PROJECT: _Empress II_
Naval Facilities Engineering Command NDW	Station: _____
DISCIPLINE	E S R: _____ Contract: _____
Calcs made by: _Seelig_____ date: 6/27/83	Calculations for: _Mooring Types(cont)_
Calcs ck'd by: _____ date: _____	_____

Mooring Buoy

Riser Chain
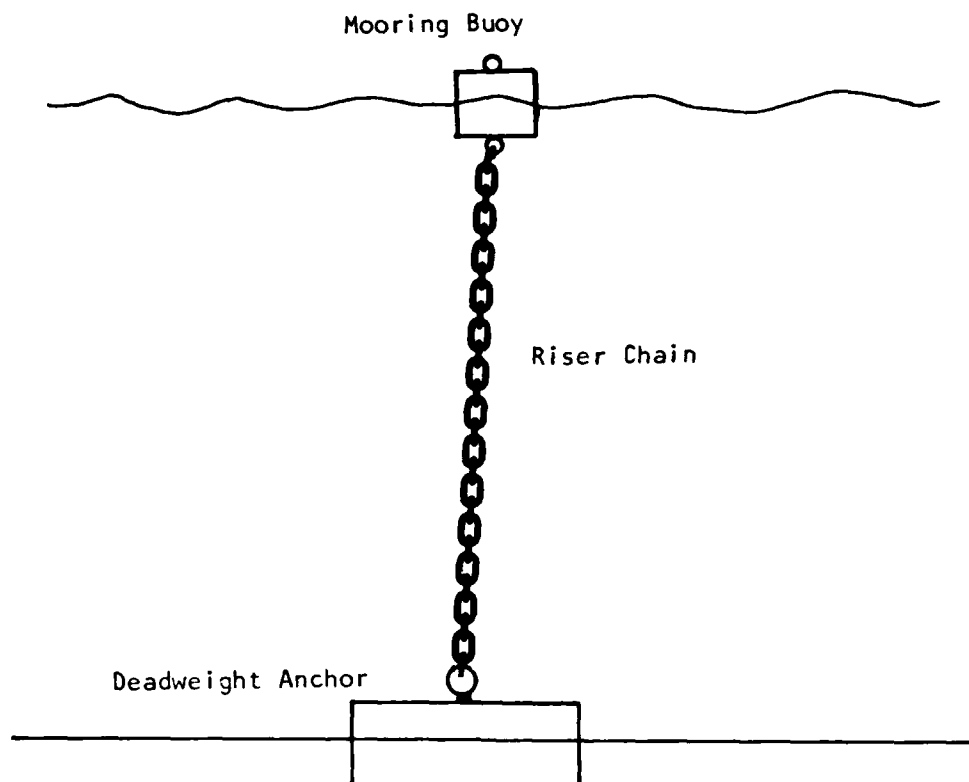
Deadweight Anchor

D) Deadweight Anchor & Riser Mooring

Figure 2. Mooring Types (cont.)

GEO HHR-E83

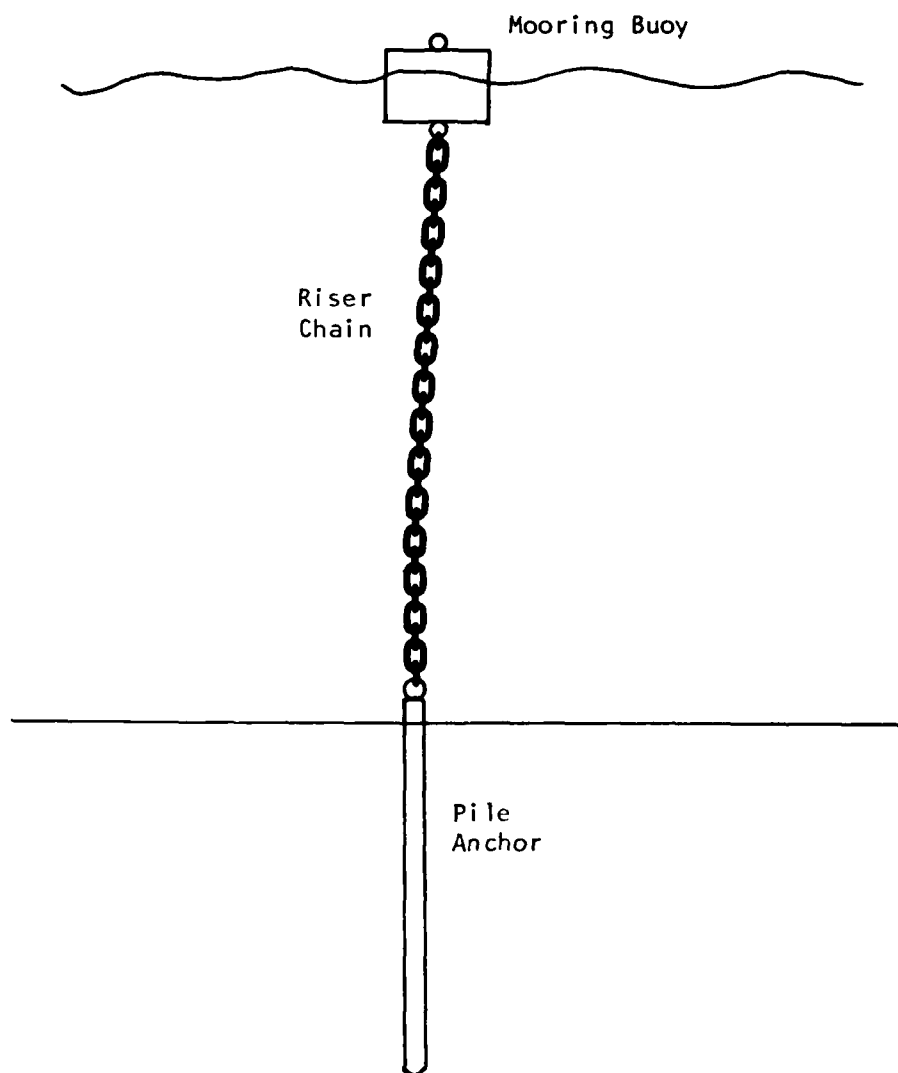| CHESAPEAKE	DIVISION	PROJECT: Empress II
Naval Facilities Engineering Command	NDW	Station:
DISCIPLINE		E S R: _____ Contract: _____
Calcs made by: Seelig	date: 7/11/83	Calculations for: Mooring Types (cont.)
Calcs ck'd by: _____	date: _____	

Mooring Buoy

Riser
Chain

Pile
Anchor

E) Pile Anchor & Riser Mooring

Figure 2. Mooring Types (cont)

page ____ of ____

CHESAPEAKE   DIVISION
Naval Facilities Engineering Command   NDW
DISCIPLINE

Calcs made by: ___SEELIG___   **date:** _4/1/83_

Calcs ck'd by: _____   **date:** _____

PROJECT: __Empress II__
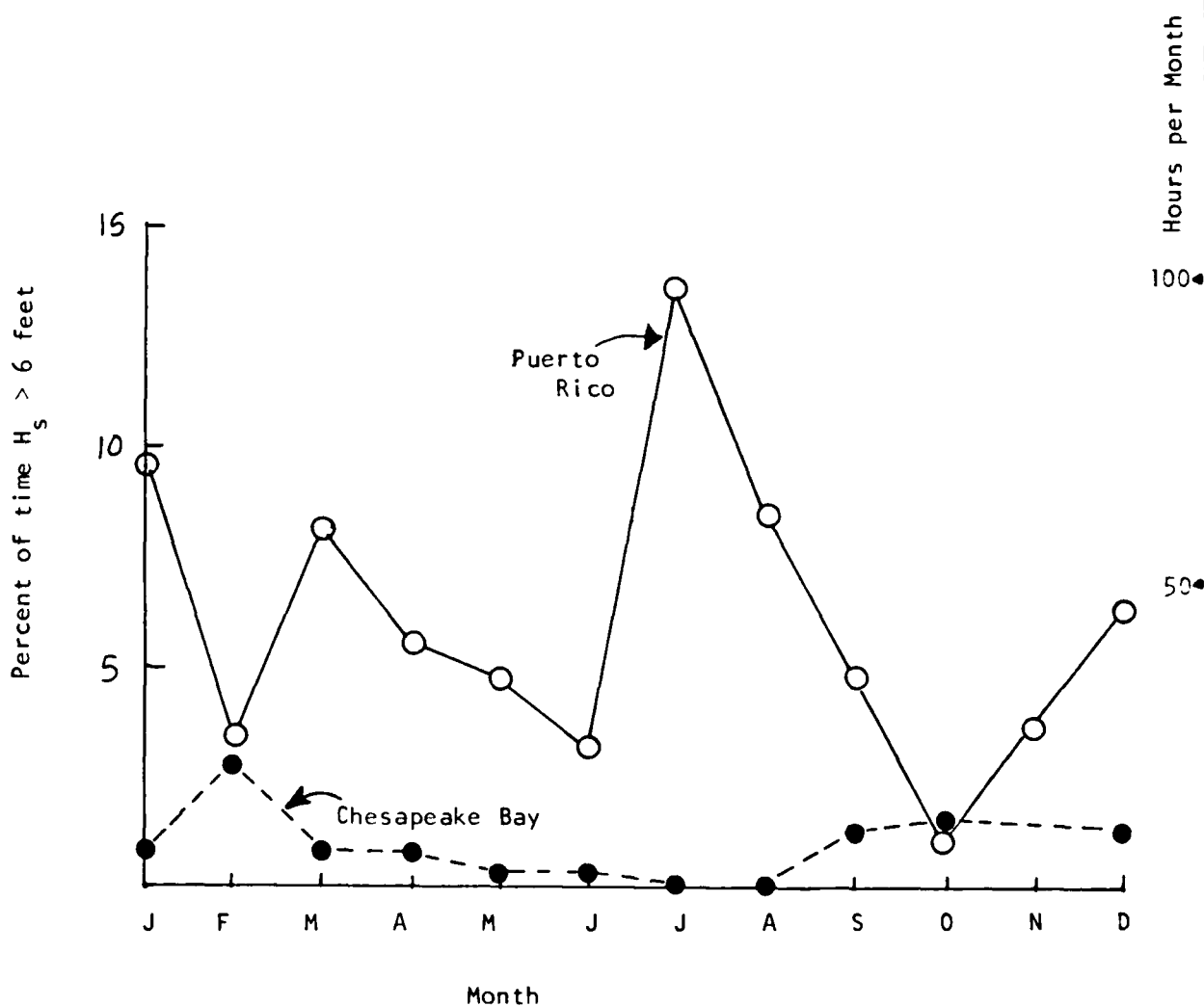
Station: _____

E S R: _____ **Contract:** _____

Calculations for: _Seasonal Wave Statistics_

Figure 3.   Percent of time the significant wave height is greater than 6'

page ___ of ___

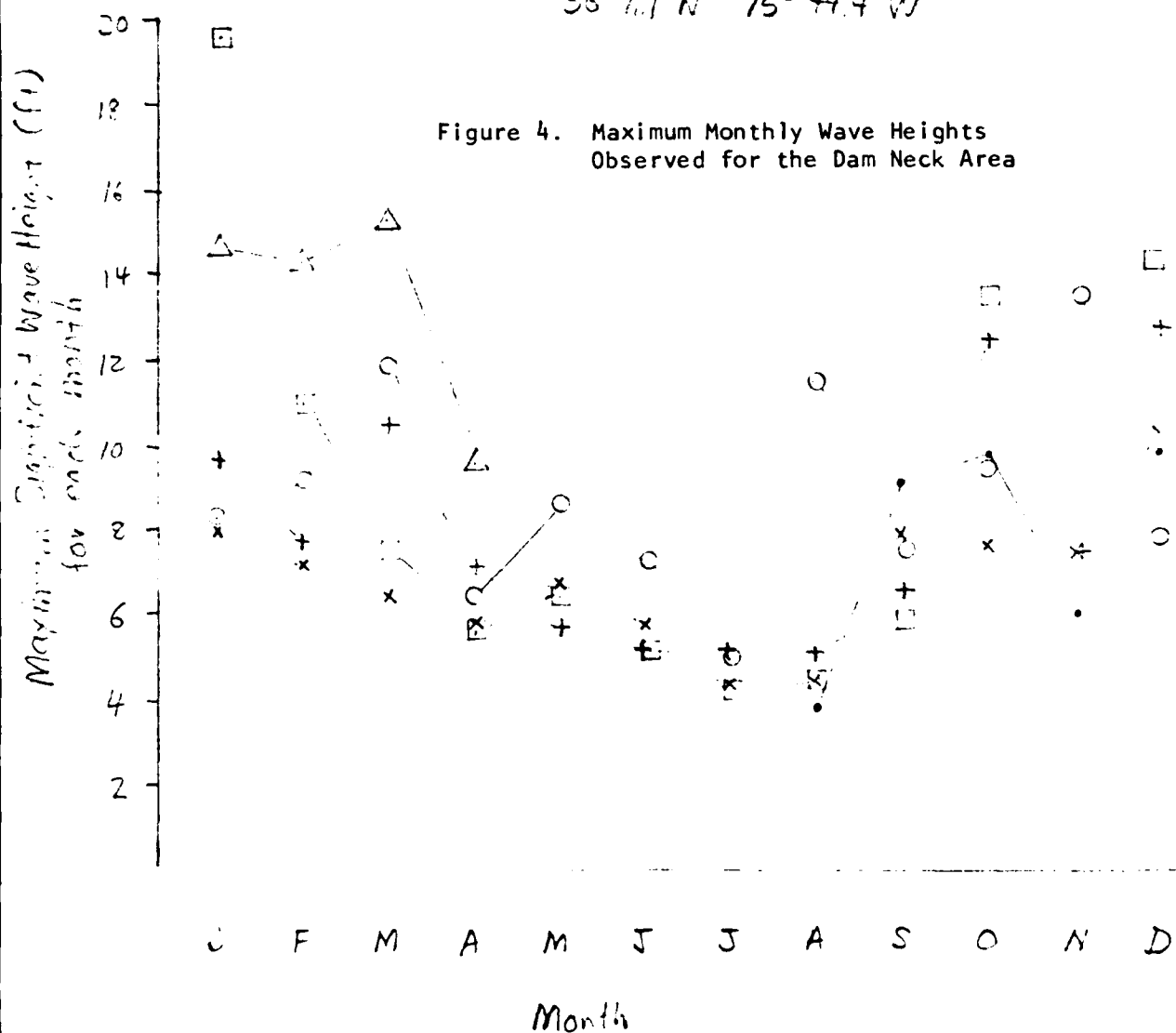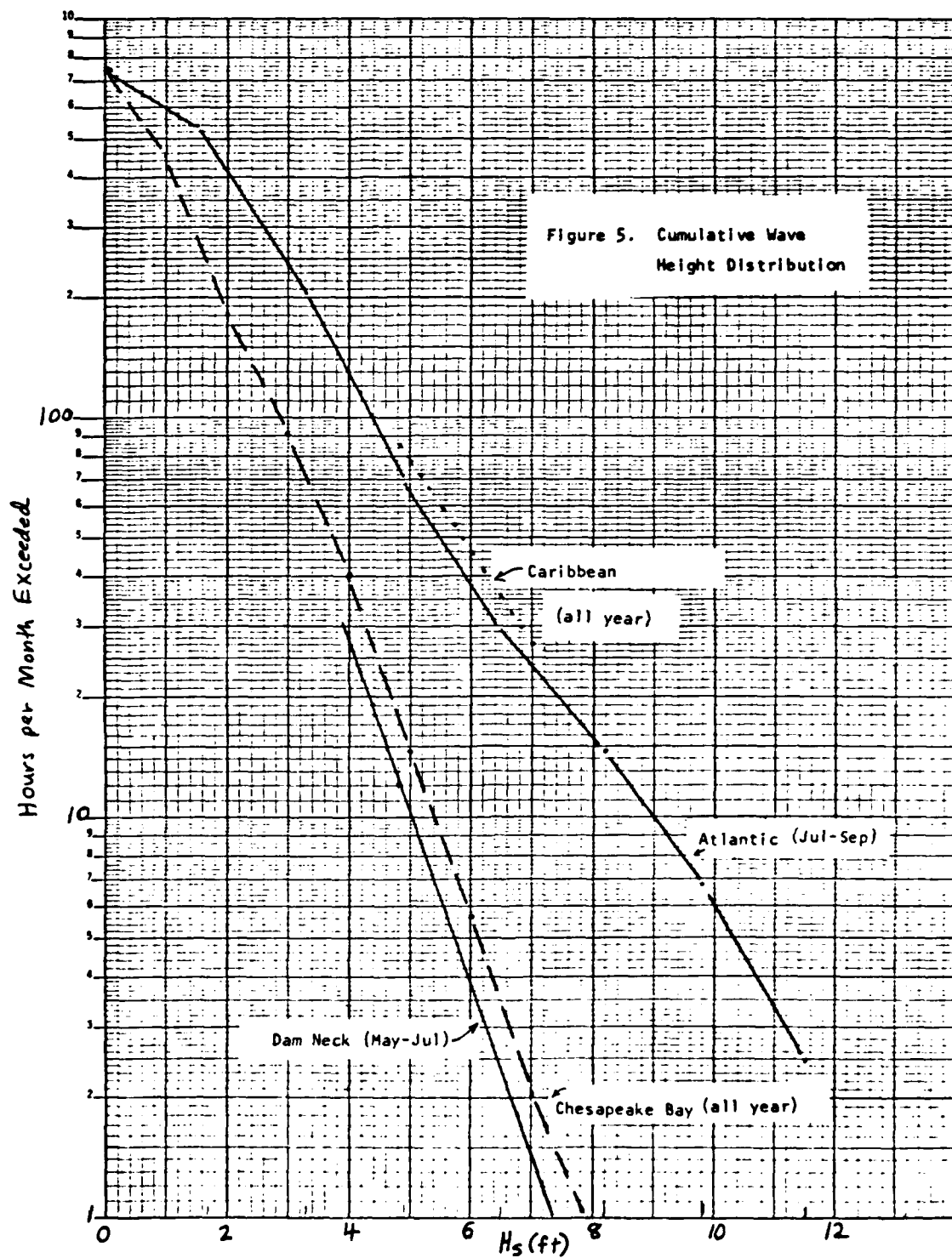| CHESAPEAKE	DIVISION	PROJECT: _Empress II_
Naval Facilities Engineering Command	NDW	Station: _____
DISCIPLINE		E S R: _____ Contract: _____
Calcs made by: _Seelig_ date: _6/3/83_		Calculations for: _Wave Heights_
Calcs ck'd by: _____ date: _____		

water depth = 59'
36° ll.l' N   75° 44.4' W

Figure 4.   Maximum Monthly Wave Heights
Observed for the Dam Neck Area

Month

- 1978   ○ 1981
× 1979   □ 1982
+ 1980   △ 1983

Figure 5. Cumulative Wave Height Distribution

Caribbean (all year)

Atlantic (Jul-Sep)

Dam Neck (May-Jul)

Chesapeake Bay (all year)

Hours per Month Exceeded

H_s (ft)

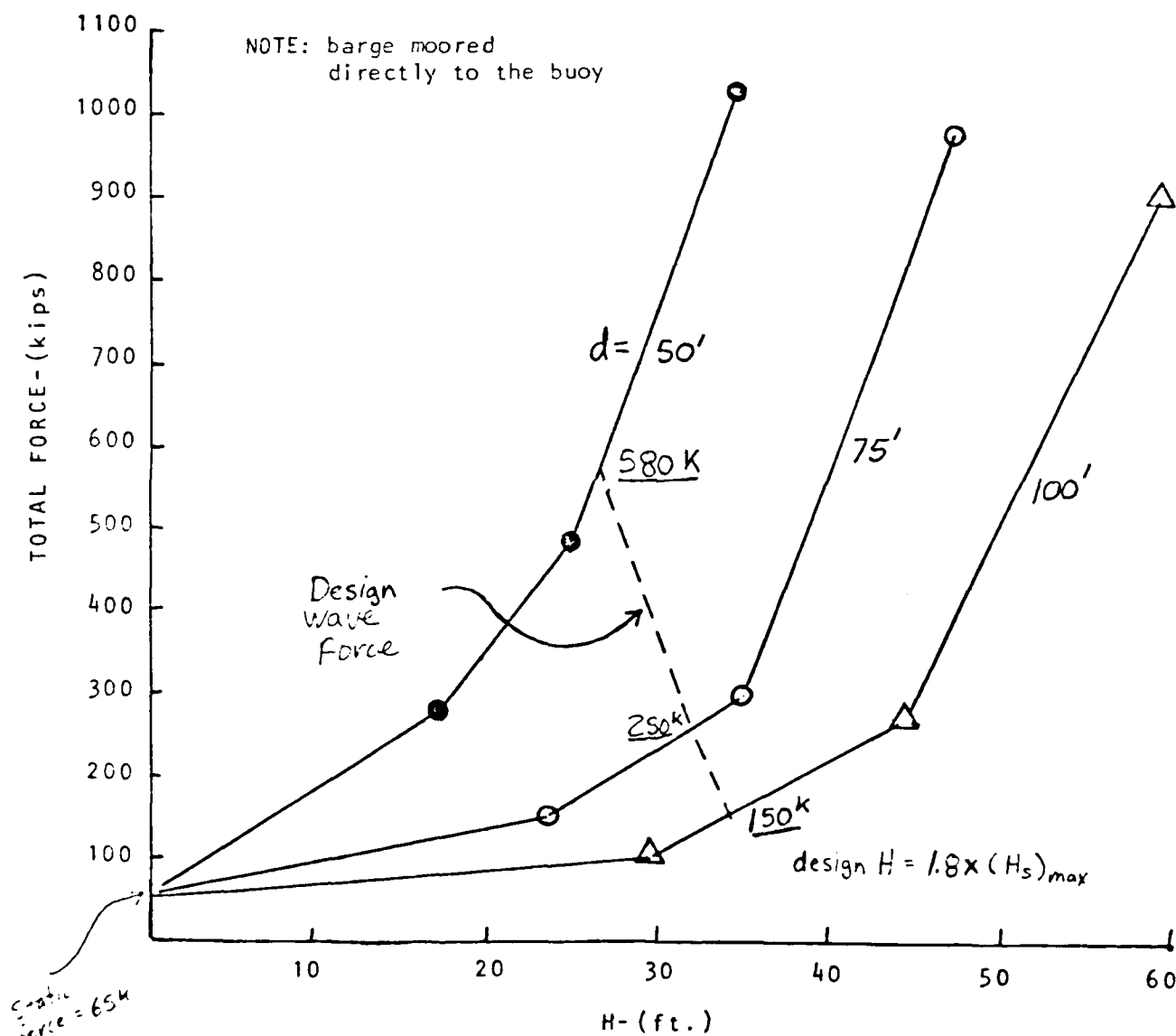| CHESAPEAKE DIVISION	PROJECT: _Empress II_
Naval Facilities Engineering Command NDW	Station: _____
DISCIPLINE	E S R: _____ Contract: _____
Calcs made by: _Seelig_ date: _3/24/83_	Calculations for: _Wave Forces on Mooring_
Calcs ck'd by: _____ date: _____	_'/100 Scale Froude Model_

$T = 12$ sec

NOTE: barge moored
directly to the buoy

TOTAL FORCE-(kips)

$d = 50'$

580 K

Design
Wave
Force

75'

100'

250^k

150^k

design $H = 1.8 \times (H_s)_{max}$

static force = 65^k

H-(ft.)

Barge $105' \times 120' \times 12'$

page ____ of ____

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Figure 6.   Design Waves and Wave Forces for a Storm Hardened
Mooring in the Ocean

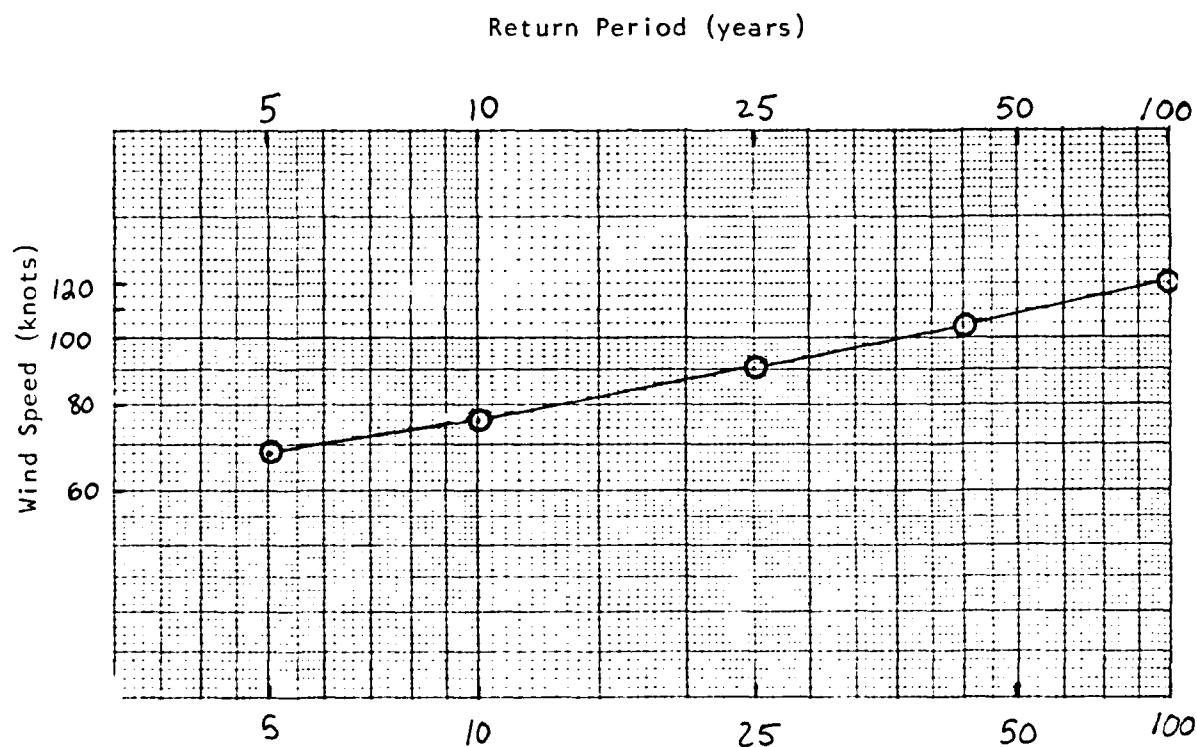| CHESAPEAKE DIVISION	PROJECT: Empress II
Naval Facilities Engineering Command NDW	Station:
DISCIPLINE	E S R: _____ Contract: _____
Calcs made by: Seelig date: 4/4/83	Calculations for: Wind Return Periods
Calcs ck'd by: _____ date: _____	

Return Period (years)

Figure 7.   Extreme Wind Return Periods for the
Chesapeake Bay Area

Figure 8.   Cumulative Wind Speed Statistics
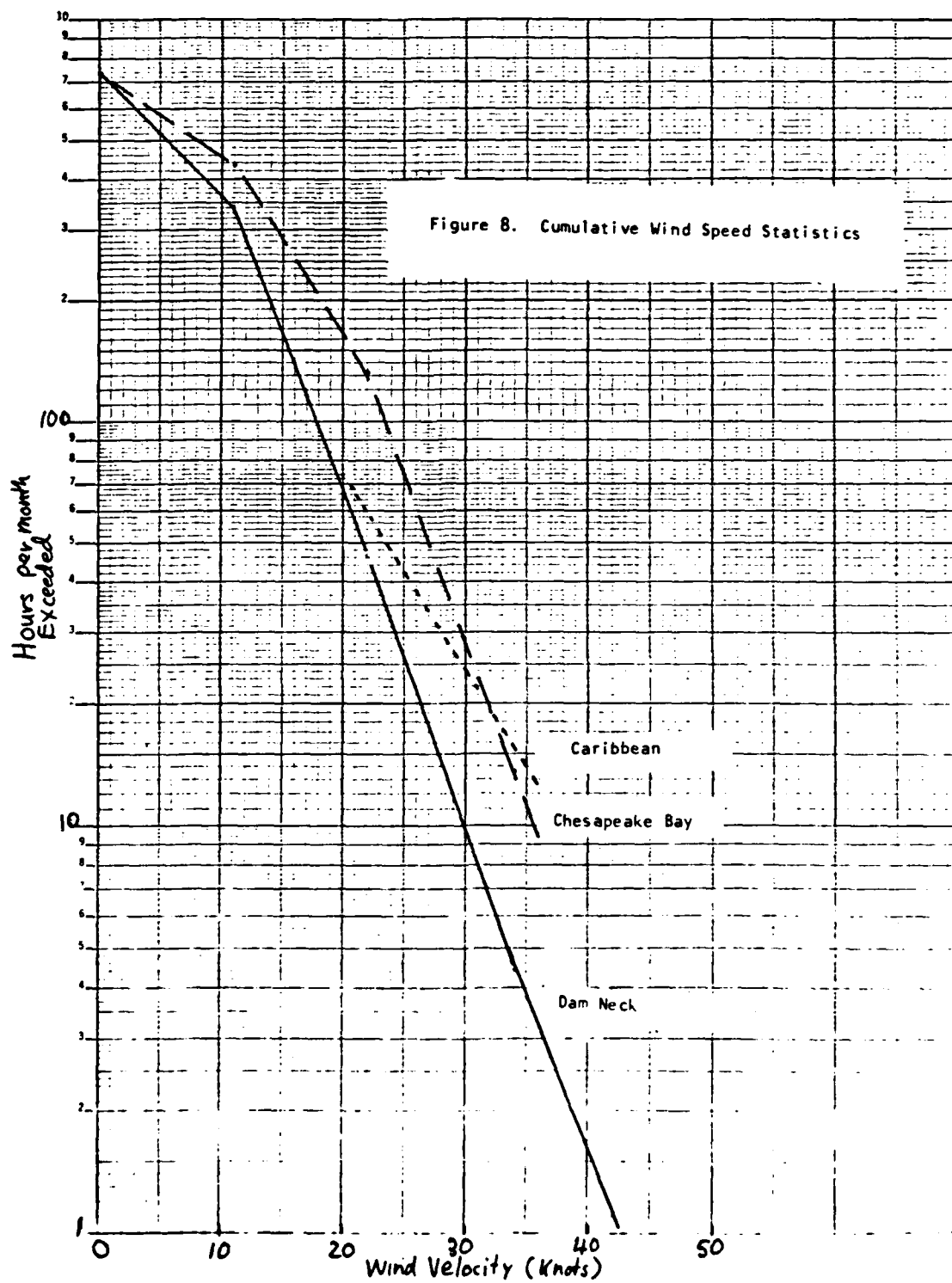
Figure 8A. Wind statistics by month for Norfolk

Percent of Time which Wind Speed is exceeded (%) — vertical axis (left)

Hours per month which Wind Speed is exceeded — vertical axis (right)

22 Knots

28 Knots

34 Knots

48 Knots

Months
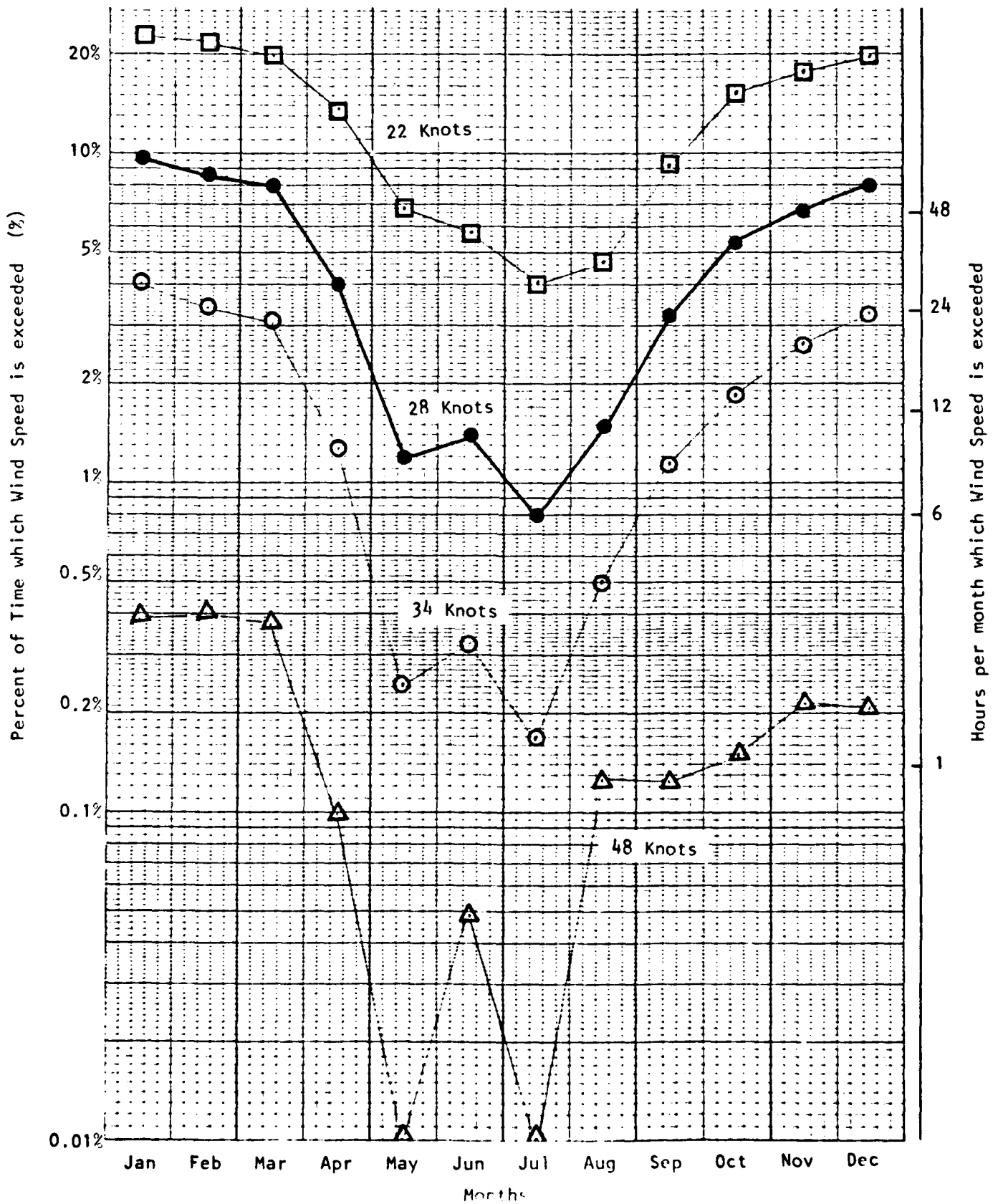
Appendix A. Working Cost Estimate
(Fy83 dollars)

<u>Each Corner of the Mooring</u>

Buoy	$50 K
Riser (4" Grade 3 chain)	$47 K

Anchor

Concrete 110 yd^3 x $85/yd^3 = $10 K	
Forming	$ 8 K
Steel $950/ton x 18 tons = $17 K	
Welding	$ 2 K
Misc	$13 K
TOTAL	$50 K

Sub-Total	$147 K

<u>Total Cost of Mooring Buoy System</u>

Four-Point Mooring Materials 4 x $147 K	$588 K
Installation & Contingency	$342 K
Total	$930 K

Appendix B. Ship Forces on Moorings

If a ship is to be moored while testing, then wind and
currents on the ship will transmit forces into the moorings. These
are preliminary calculations to indicate the amount of force that
must be with held for a LHA-1 ship.

GIVEN   Ship Designation   :   LHA-1

Water Depth   WD =   65   feet

(_ @ High Tide or _ @ Low Tide)

*Current Speed   V$_c$ = (__1.5__) knots x 1.689 = __2.53__ ft/sec

(Use average value of current profile between waterline and ship's keel)

*Wind Speed   V$_w$ = (__32__) mph x 1.467 = __47.3__ ft/sec

(@ 33 feet above water level)   **28 knots**

* If current speed and wind speed are unknown, refer to Table 1.

In calculations below, use ft/sec quantities.

ASSUMPTIONS

a)   Water density is constant and equals 1.9876 lb-sec^2/ft^4 @ 68°F.

b)   Air density is constant and equals 0.00237 lb-sec^2/ft^4 @ 68°F.

PROCEDURE

A.   From Table 2:

Length Overall   LOA = __820__ feet   _ Normal

Length at waterline LWL = __765__ feet   X Hull-Dominated

Beam   B = __106__ feet

Load condition:		Fully Loaded	1/3 Stores/Cargo /Ballasted	Light
Draft	T =	_____ feet	21.3 feet	_____ feet
Below water end area	A$_b$=BT =	_____ sq.ft.	21000 sq.ft.	_____ sq.ft.
End-projected wind area	A$_e$ =	_____ sq.ft.	11250 sq.ft.	_____ sq.ft.
Side-projected wind area	A$_s$ =	_____ sq.ft.	74950 sq.ft.	_____ sq.ft
Displacement	D =	_____ long tons	36020 long tons	_____ long tons

B.   Basic constants:

ARM = 0.48 LOA   = _____ = __394__ feet

**S   = (1.7 T LWL) + ($\frac{35D}{T}$) = _____ = __27,700__ sq.ft.

** For a normal vessel S should be multiplied by a factor of 0.95.

F_{yc} = C_{yc} 1/2 ρ_c V_c^2 LWL T = C_{yc} 1/2 (1.9876) $(2.53)^2$ 765 (21.3) = C_{yc} $1.04 + 10^5$

M_c = C_{xyc} 1/2 ρ_c V_c^2 LWL^2 T = C_{xyc} 1/2 (1.9876) $(2.53)^2 (765)^2 (21.3)$ = C_{xyc} 7.9×10^7

F_{xw} = C_{xw} 1/2 ρ_w V_w^2 A_e = C_{xw} 1/2 (0.00237) $(47.3)^2$ 11250 = C_{xw} $2.98 + 10^4$

F_{yw} = C_{yw} 1/2 ρ_w V_w^2 A_s = C_{yw} 1/2 (0.00237) $(47.3)^2$ 74950 = C_{yw} $1.99 + 10^5$

M_w = C_{xyw} 1/2 ρ_w V_w^2 A_s LWL = C_{xyw} 1/2 (0.00237) $(47.3)^2$ 74950 (765) C_{xyw} 1.52×10^8

FIGURE 8a

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

26.6-16

C. TRIAL # __LHA-1__ $^{WD}/_T$ = __2.6__

WIND ← | current

∫M 83.7+10³ K-ft
9ᵏ ↓   ← 199ᵏ
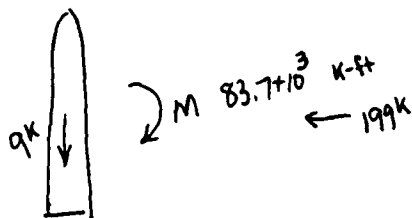
WIND/CURRENT ANGLE θ_T = _____ °
*CURRENT ANGLE θ_c = __0__ °
*WIND ANGLE θ_w = __90'__ °

*θ_c and θ_w are measured clockwise
from ship's bow.

Note: Use sketch to indicate directions
      (+ or -) of Forces and Moments.

Coefficients for this θ_c, θ_w and $^{WD}/_T$:
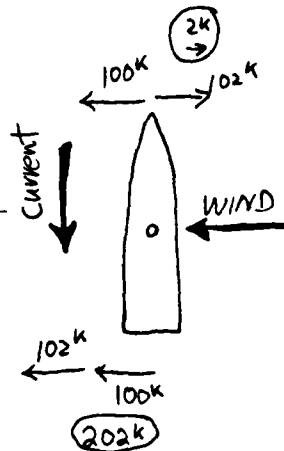
C_{xca} = __0.35__ (Figure 2)

C_{yc} = __0__ (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = ___0___ ____ - _____

C_{xyc} = __0.__ (Figure 4)

C_{xw} = __0.__ (Figure 5) __Normal, or __Hull-Dominated

C_{yw} = __1.0__ (Figure 6)

C_{xyw} = __-0.035__ (Figure 7)

Forces and Moments:

F_{xc} = $1/2 \, \rho_c \, v_c^2 \, [(C_{xca} \, S \frac{B}{LWL}) + (C_{xcb} \, A_b)]$

F_{xc} = 1/2 (1.9876) (2.53)² [(_0.35_ * 27700 $\frac{106}{765}$)+(_____)] = __8580__ lbs

F_{yc} = C_{yc} _____ = _____ = __0__ lbs

M_c = C_{xyc} _____ = _____ = __0__ ft-lbs

F_{xw} = C_{xw} _____ = _____ = __0__ lbs

F_{yw} = C_{yw} __1.99*10⁵__ = _____ = __199,000__ lbs

M_w = C_{xyw} __1.52+10⁸__ = _____ = __-5.3*10⁶__ ft-lbs

F_f = $F_{xc} + F_{xw}$ = __8580__ + _____ = __8580__ lbs

F_t = $F_{yc} + F_{yw}$ = _____ + _____ = __199,000__ lbs

M = $M_c + M_w - (F_t \, ARM)$ = __0 + -5.3×10⁶ - (199,000 × 394)__ = __-83.7×10⁶__ ft-lbs

a) If M equals zero, the equilibrium position has been found.

   F_H = $\sqrt{F_\ell^2 + F_t^2}$ = _____ = _____ lbs
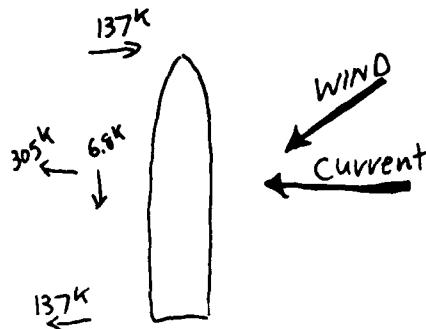
b) If M is a large positive or negative number, the vessel is not in equilibrium and a
   different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship
   is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)
Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

C.   TRIAL # LHA-1

137^K →

WIND

Current

305^K ← 6.5^K ↓

137^K ←

WD/T = 2.6

WIND/CURRENT ANGLE θ_T = _____ °

*CURRENT ANGLE θ_c = 90 °

*WIND ANGLE θ_w = 60 °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or −) of Forces and Moments.

Coefficients for this θ_c, θ_w and WD/T:

15.2^K ←

290^K ←

C_{xca} = 0.   (Figure 2)

C_{yc} = 1.3   (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = _____ = 0.

C_{xyc} = 0.   (Figure 4)

C_{xw} = 0.23   (Figure 5)   __Normal, or X Hull-Dominated

C_{yw} = 0.86   (Figure 6)

C_{xyw} = 0.055   (Figure 7)

Forces and Moments:

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

$F_{xc} = 1/2 \, (1.9375) \, (2.53)^2 \, [(0.\qquad)+(0.\qquad)] = 0.$ lbs

$F_{yc} = C_{yc} \quad 1.3 \times 1.04 \times 10^5 = \qquad = 135,000$ lbs

$M_c = C_{xyc} \quad 7.9 \times 10^7 \times 0 = \qquad = 0$ ft-lb

$F_{xw} = C_{xw} \quad 2.98 \times 10^4 = 2.98 \times 10^4 \, (0.23) \qquad = 6850$ lb

$F_{yw} = C_{yw} \quad 1.99 \times 10^5 = 0.86 \, (1.99 \times 10^5) \qquad = 171,000$ lbs

$M_w = C_{xyw} \quad 1.52 \times 10^8 = 0.055 \, (1.52 \times 10^8) \qquad = 8,350,000$ ft-lb

$F_{\ell} = F_{xc} + F_{xw} = \qquad 0 \quad + \quad 6850 \qquad = 6850$ lbs

$F_t = F_{yc} + F_{yw} = \qquad 135,000 \quad + \quad 171,000 \qquad = 305,000$ lbs

$M = M_c + M_w - (F_t \, ARM) = \qquad 0 + 8,350,000 - 305,000 \,(394) \qquad = -112 \times 10^6$ ft-lb

a)   If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_{\ell}^2 + F_t^2} = \qquad = \qquad$ lbs

b)   If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).
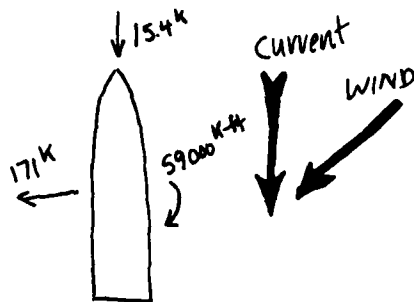
FIGURE 8a (Continued)
Sample Calculation Procedure for Single Hulled Vessels - Blunt Form

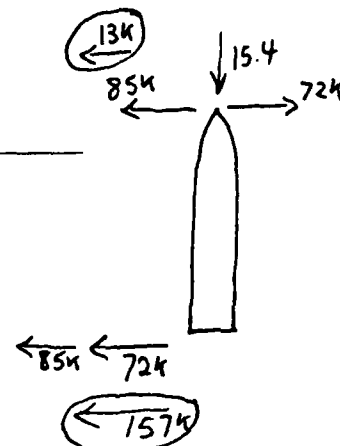C. TRIAL # __LHA-1__   WD/T = __2.6__

WIND/CURRENT ANGLE θ_T = _____ °
*CURRENT ANGLE θ_c = __O__ °
*WIND ANGLE θ_w = __60__ °

*θ_c and θ_w are measured clockwise
from ship's bow.

Note: Use sketch to indicate directions
(+ or -) of Forces and Moments.

Coefficients for this θ_c, θ_w and WD/T:

C_{xca} = __0.35__ (Figure 2)

C_{yc} = __O.__ (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = _____ = __O.__

C_{xyc} = __O__ (Figure 4)

C_{xw} = __0.24__ (Figure 5)   __Normal, or _X_Hull-Dominated

C_{yw} = __0.86__ (Figure 6)

C_{xyw} = __0.055__ (Figure 7)

Forces and Moments:

$F_{xc} = 1/2 \, \rho_c \, v_c^2 \, [(C_{xca} \, S \, \frac{B}{LWL}) + (C_{xcb} \, A_b)]$

F_{xc} = 1/2 (1.9875) __(2.53)__² [(__0.35 × 27,700__ $\frac{106}{765}$__)+(__O__)] = __8,600__ lbs

F_{yc} = C_{yc} _____ = _____ = __O__ lbs

M_c = C_{xyc} _____ = _____ = __O__ ft-lbs

F_{xw} = C_{xw} _____ = _____ = __6850__ lbs

F_{yw} = C_{yw} _____ = _____ = __171,000__ lbs

M_w = C_{xyw} _____ = _____ = __8,350,000__ ft-lbs

$F_\ell = F_{xc} + F_{xw}$ = __8600__ + __6850__ = __15,400__ lbs

$F_t = F_{yc} + F_{yw}$ = __O__ + __171,000__ = __171,000__ lbs

$M = M_c + M_w - (F_t \, ARM)$ = __O + 8,350,000 - (171,000 × 394)__ = __-59 × 10⁶__ ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_\ell^2 + F_t^2}$ = _____ = _____ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a
different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship
is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)
Simple Calculation Procedure for Single-Hulled Vessels - Blank Form

GIVEN   Ship Designation   : **LHA-1**

Water Depth   WD = ___**55**___ feet

(_ @ High Tide or _ @ Low Tide)

*Current Speed V_c = (___**2**___) knots x 1.689 = **3.3**___ ft/sec

(Use average value of current profile between waterline and ship's keel)

*Wind Speed V_w = (___**40.3**___) mph x 1.467 = ___**59**___ ft/sec

(@ 33 feet above water level)   **(35 knots)**

* If current speed and wind speed are unknown, refer to Table 1.

  In calculations below, use ft/sec quantities.

ASSUMPTIONS

a)   Water density is constant and equals 1.9876 lb-sec^2/ft^4 @ 68°F.

b)   Air density is constant and equals 0.00237 lb-sec^2/ft^4 @ 68°F.

PROCEDURE

A.   From Table 2:

Length Overall   LOA = ___**820**___ feet   _ Normal

Length at waterline LWL = ___**765**___ feet   **X** Hull-Dominated

Beam   B = _**106**_ feet

Load condition:		Fully Loaded	1/3 Stores/Cargo /Ballasted	Light
Draft	T =	_____ feet	**21.3** feet	_____ feet
Below water end area	A_b=BT =	_____ sq.ft.	**21000** sq.ft.	_____ sq.ft.
End-projected wind area	A_e =	_____ sq.ft.	**11250** sq.ft.	_____ sq.ft.
Side-projected wind area	A_s =	_____ sq.ft.	**74950** sq.ft.	_____ sq.ft
Displacement	D =	_____ long tons	**30020** long tons	_____ long tons

B.   Basic constants:

ARM = 0.48 LOA   = _____ = **394** feet

**S = (1.7 T LWL) + $(\frac{35D}{T})$ = _____ = 27,700 sq.ft.

** For a normal vessel S should be multiplied by a factor of 0.95.

$F_{yc} = C_{yc} \ 1/2 \ \rho_c \ V_c^2 \ LWL \ T = C_{yc} \ 1/2 \ (1.9876) \ $ **$(3.3)^2$ 765 (21.3)** $= C_{yc}$ **1.77×10^5**

$M_c = C_{xyc} \ 1/2 \ \rho_c \ V_c^2 \ LWL^2 \ T = C_{xyc} \ 1/2 \ (1.9876) \ $ **$(3.3)^2 (765)^2 \ 21.3$** $= C_{xyc}$ **1.36×10^8**

$F_{xw} = C_{xw} \ 1/2 \ \rho_w \ V_w^2 \ A_e \ = C_{xw} \ 1/2 \ (0.00237) \ $ **$(59)^2$ 11250** $= C_{xw}$ **4.64×10^4**

$F_{yw} = C_{yw} \ 1/2 \ \rho_w \ V_w^2 \ A_s \ = C_{yw} \ 1/2 \ (0.00237) \ $ **$(59)^2$ 74950** $= C_{yw}$ **3.09×10^5**

$M_w = C_{xyw} \ 1/2 \ \rho_w \ V_w^2 \ A_s \ LWL = C_{xyw} \ 1/2 \ (0.00237) \ $ **$(59)^2$ 74950 (765)** $= C_{xyw}$ **2.37×10^8**

FIGURE 8a

Sample Calculation Procedure for Single-Hulled Vessels – Blank Form

26.6-16

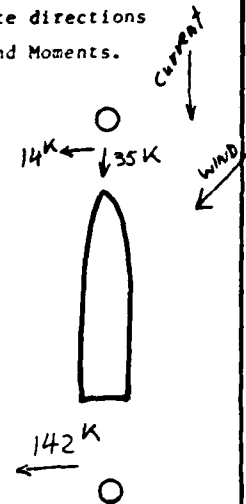C. TRIAL # _____

$^{WD}/_T$ = **2.6**

WIND/CURRENT ANGLE θ_T = _____ °

*CURRENT ANGLE θ_c = **0** °

*WIND ANGLE θ_w = **30** °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or −) of Forces and Moments.

155^K $M = 4.9 \times 10^4$ ft-k

33^K

14^K ← ↓35 K   Current   WIND

142^K

Coefficients for this θ_c, θ_w and $^{WD}/_T$:

C_{xca} = **0.35** (Figure 2)

C_{yc} = **0.0** (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = **0.** = _____

C_{xyc} = **0.0** (Figure 4)

C_{xw} = **0.39** (Figure 5) ___Normal, or **X** Hull-Dominated

C_{yw} = **0.5** (Figure 6)

C_{xyw} = **0.05** (Figure 7)

Forces and Moments:

$F_{xc} = 1/2 \, \rho_c \, v_c^2 \, [(C_{xca} \, S \frac{B}{L_wL}) + (C_{xcb} \, A_b)]$

F_{xc} = 1/2 (1.9876) (**3.3**)^2 [(**0.35** × 27700 × $\frac{106}{765}$) + (**0.**)] = **14,600** lbs

$F_{yc} = C_{yc}$ **1.77×10^5** = _____ = **0** lbs

$M_c = C_{xyc}$ **1.36×10^8** = _____ = **0** ft-lbs

$F_{xw} = C_{xw}$ **4.64 ×10^4** = _____ = **18,100** lbs

$F_{yw} = C_{yw}$ **3.09×10^5** = _____ = **155,000** lbs

$M_w = C_{xyw}$ **0.05 × 2.37×10^8** = _____ = **1.19×10^7** ft-lbs

$F_{\ell} = F_{xc} + F_{xw}$ = **14,600** + **18,100** = **33,000** lbs

$F_t = F_{yc} + F_{yw}$ = **0** + **155,000** = **155,000** lbs

$M = M_c + M_w - (F_t \, ARM)$ = **1.19×10^7** − (**1.55×10^5** × **394**) = **−4.9×10^7** ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_{\ell}^2 + F_t^2}$ = _____ = _____ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).
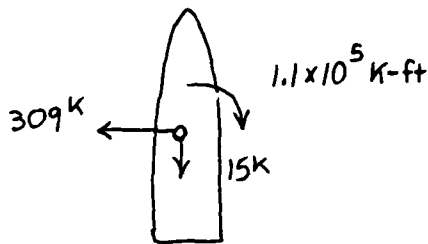
FIGURE 8a (Continued)

Sample Calculation Procedure for Single-Hulled Vessels — Blank Form

2 knot current, 35 knot WIND

C. TRIAL # _____

$^{WD}/_T$ = __2.6__

WIND/CURRENT ANGLE θ_T = _____°

*CURRENT ANGLE θ_c = __O__ °

*WIND ANGLE θ_w = __90__ °

*θ_c and θ_w are measured clockwise from ship's bow.

1.1×10^5 K-ft

309^K

$15K$

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Current

15^K ↓ →$11K$

Wind

299^K

Coefficients for this θ_c, θ_w and $^{WD}/_T$:

C_{xca} = __0.35__ (Figure 2)

C_{yc} = __O.__ (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = __O.__ = _____

C_{xyc} = __0.0__ (Figure 4)

C_{xw} = __0.0__ (Figure 5) __Normal, or __Hull-Dominated

C_{yw} = __1.0__ (Figure 6)

C_{xyw} = __−0.035__ (Figure 7)
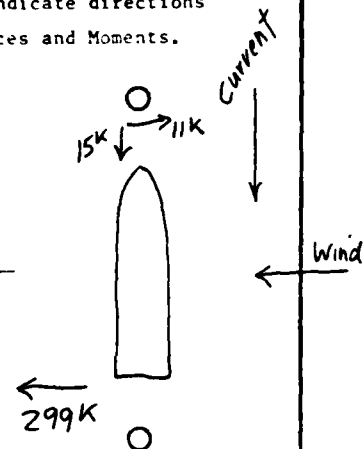
Forces and Moments:

F_{xc} = $1/2\ \rho_c\ v_c^2\ [(C_{xca}\ S\ \frac{B}{LWL}) + (C_{xcb}\ A_b)]$

F_{xc} = $1/2$ (1.9876) $(3.3)^2$ [($0.35 \times 27700\ \frac{106}{765}$)+(_____)] = __14,600__ lbs

F_{yc} = C_{yc} _____ = _____ = __O__ lbs

M_c = C_{xyc} _____ = _____ = __O__ ft-lbs

F_{xw} = C_{xw} 4.64×10^4 = _____ = __O__ lbs

F_{yw} = C_{yw} 3.09×10^5 = _____ = __309,000__ lbs

M_w = C_{xyw} 2.37×10^8 = $-0.035 \times 2.37 \times 10^8$ = __8.3×10^6__ ft-lbs

F_ℓ = F_{xc} + F_{xw} = __14,600__ + __O__ = __14,600__ lbs

F_t = F_{yc} + F_{yw} = __O__ + __309,000__ = __309,000__ lbs

M = M_c + M_w - (F_t ARM) = __$O + 8.3 \times 10^6 - (3.1 \times 10^5 \times 394)$__ = __$-114 \times 10^6$__ ft-lbs

a) If M equals zero, the equilibrium position has been found.

F_H = $\sqrt{F_\ell^2 + F_t^2}$ = _____ = _____ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)
Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

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