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PHYSICAL MODEL STUDY OF WAVE FORCES ON A MOORED BARGE
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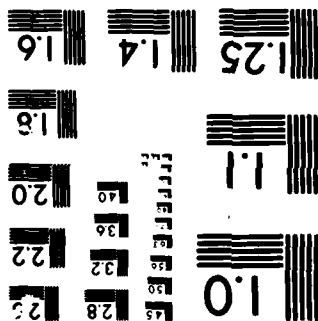
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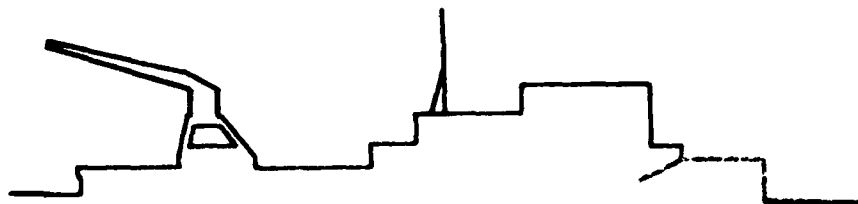
by

William N. Seelig

Anne Capodice

FP0-1-83(9)

April 1983



Ocean Engineering

CHESAPEAKE DIVISION
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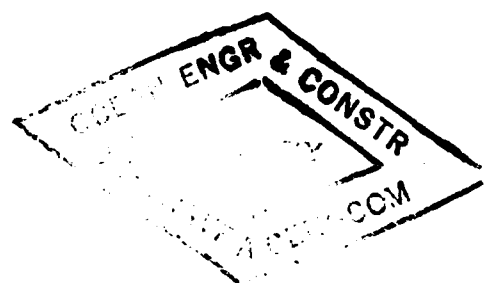


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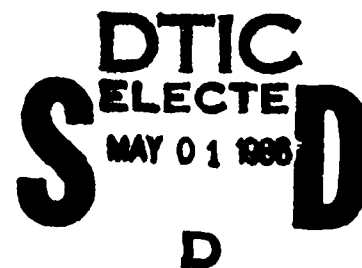
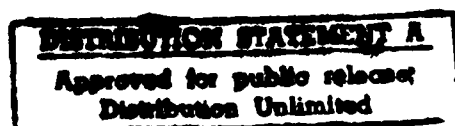


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Measured forces were as high as 1 million pounds for a wave breaking on the barge moored in 50 feet of water. The magnitude of this force decreased as the barge was moored in deeper water and decreased rapidly at a given water depth when the wave height was reduced.

EXECUTIVE SUMMARY

Very high mooring forces occur when a wave breaks on a barge moored with chain. These high forces are produced by a combination of lifting the barge, along with high water velocities and accelerations at the breaking wave crest. The interaction of the barge with this type of non-linear waves is best studied with a physical model. This report describes a brief set of 1 to 100 scale Froude model studies conducted to model a barge moored in from 50 to 100 feet of water. The wave period tested was 12 seconds and wave heights ranged from one-half the breaker height to the breaker height.

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NOTATION

Symbol	Description
d	water depth
F	force at an angle of 23° to the horizontal
g	acceleration due to gravity
H	wave height
H_b	breaking wave height
l	barge length
L	wave length from Airy wave theory
η_c	elevation of the wave crest above still water level
T	wave period

PHYSICAL MODEL STUDY OF WAVE FORCES ON A MOORED BARGE

by

William N. Seelig
Anne Capodice

1. Introduction

Forces on a moored barge are due to the combined action of wind, wave, current and possibly wave forces. Wave induced forces in the mooring lines are due to a number of factors and the forces are the greatest when the waves are highly non-linear. Physical model studies are one of the best tools for determining these forces. This report describes a series of nine tests conducted to determine the maximum mooring line force for selected conditions.

2. The Problem

Little is known about the wave induced forces in a mooring line restraining a barge during "survival" condition when the maximum wave breaker height is reached. However sailors have long recognized that it is best to head to deep water during a storm¹, even though the heights of waves may increase in deeper water. The reason for increased mooring problems in transitional or shallow water is clear; waves very rapidly become non-linear as the ratio of the water depth to wave length becomes small and the ratio of wave height to water depth increases. Non-linear wave theories, such as Stream Function Wave Theory², clearly show that as a given wave moves from deep to shallow water:

- a. the wave crest height becomes a large fraction of the wave height
- b. the wave crest becomes steeper
- c. water particle velocities at the crest increase.

3. Wave - Structure Interaction

The interaction between a moored barge and non-linear wave is highly complicated. When a wave breaks on such a system some of the water may go over the barge, there is some wave reflection, some wave energy dissipation and often a significant amount of wave transmission past the moored barge. As the wave hits the barge a large force is transmitted into the mooring line because:

- a. the barge is lifted by the wave crest
- b. the barge is pushed in the direction of the wave
- c. the barge will rotate as the crest passes
- d. there is some net force due to "radiation stress"
- e. long group-induced waves act on the system
- f. other forces, such as wind and current, act on the barge.

4. The Model Study

A 1 to 100 scale Froude model was selected for this study because the scale was convenient, breaking waves were sufficiently turbulent to minimize Reynold's effects and the model wave period was sufficiently long enough to prevent significant surface tension effects. The scales are:

horizontal and vertical lengths	1 to 100
time scale	1 to 10
weight and force scale	1 to 1,000,000

The tests were conducted in the One and One-Half Foot wave tank of the U.S. Army Corps of Engineers Coastal Engineering Research Center. Only monochromatic waves were tested and a prototype wave period of 12 seconds was used in all tests^{*}.

^{*}Note: all results are presented in prototype units for a barge width of 105 feet.

The model barge was represented by a rectangular shape and a 120 foot high antenna placed on the barge. Figure 1 shows the experimental set-up and gives dimensional units for the tests in prototype measurements. A water depth of 126 feet was used in the flat portion of the tank and waves produced with a piston-type wavemaker. The barge was then placed at various points along a 1 on 30 slope to simulate moored water depths of 50, 75 and 100 feet.

5. Test Procedure

The following procedure was used in these tests:

- a. the barge removed
- b. waves were generated and the stroke of the generator blade gradually increased until the wave broke at the depth of interest
- c. wave height measured with a point gage
- d. the wave generator stroke that produced waves one-half and three-quarters of the breaking height also determined
- e. the barge moored at the point of interest
- f. a line was extended shoreward at a 23° angle to the horizontal (see Figure 1)
- g. various static forces, F , were applied to this line and the length of chain pulled off the bottom by each static force was determined
- h. a force $F = 65$ kips was put on the line to simulate steady wind and current forces
- i. the test was run and the maximum amount of chain pulled off the bottom measured ; this chain length was used with the information in g. (above) to determine the force, F , in each experiment (force calibration curves are shown on Figure 2)

6. Test Results

Test results are given in Table 2 for the nine experiments conducted. Examination of the maximum forces, F , on the chain shows that at a given depth the force rapidly increases with wave height (Figure 3) for a wave period of 12 seconds. As the water depth increases from 50 to 100 feet the wave height also increases, but maximum force decreases (Figure 3). The same data is presented in a different form in Figure 4 where force is plotted vs. H/H_b . This again shows that force increases as water depth decreases.

Wave non-linearity is the primary reason forces increase as the water depth decreases for a given wave period. One good measure of non-linearity is the ratio of the wave crest elevation to the wave height, η_c/H . At a value of this parameter equal to 0.5 the wave is linear, while as $\eta_c/H \rightarrow 1.0$ the wave becomes increasingly non-linear. Figure 5 shows predicted relative crest elevations from stream function theory² and indicates the conditions tested in this study. Conditions in 50 feet of water can be seen to be more non-linear than in 100 feet.

7. Observations

The following observations were made during the tests, although measurements were not taken:

- a. Large volumes of water may flow across the deck. Figure 6 shows conditions observed by a breaking wave in 50 feet of water. The model probably underestimates this process because of the high surface tension in the model. Larger volumes will also occur in the prototype because of wind.
- b. The moored barge is highly stable.
- c. As the wave crest passes the barge undergoes large translation and rotation motion. This means that riding the barge would be very uncomfortable and that an 120' high antenna would experience high acceleration forces.

3. Summary and Conclusions

A 1 to 100 Froude model scale moored barge was tested for mooring forces. Forces were found to increase as wave non-linearity increased and for waves breaking over 1,000,000 pounds of force was measured. The moored barge is quite stable, but riding it in rough seas will be extremely uncomfortable and superstructures will experience high acceleration forces.

References Cited

¹Maloney, E. S., Chapmans Piloting, Seamanship and Small Boat Handling, 53rd Edition, American Book-Stratford Press, Inc., N.Y., 1977.

²Dean, R. G., "Evaluation and Development of Water Wave Theories for Engineering Application," SR-1, U.S. Army Coastal Engineering Research Center, Ft. Belvoir, Va., 1974.

CHESAPEAKE**DIVISION****PROJECT:** Barge Mooring**Naval Facilities Engineering Command****NDW****Station:** _____**DISCIPLINE****E S R:** _____**Contract:** _____**Calcs made by:** EEELIG**date:** 3/26/83**Calculations for:** Test Results**Calcs ck'd by:** _____**date:** _____

Table 1.

Prototype Wave Heights Tested

(wave period = 12 sec)

H_b (ft)	Water Depth (ft)	Wave Length (ft)	d/gT^2	Wave Height (ft)			$\frac{\lambda}{L}$
				$H/H_b=0.5$ "B"	$H/H_b=0.75$ "C"	$H/H_b=1.0$ "D"	
34.3	50	447	0.01078	17	25	34.4	0.27
47.7	75	526	0.0162	24	36	47.7	0.23
59.2	100	584	0.02156	29	44	59.2	0.21

Table 2.

TEST RESULTS

<u>Test Number</u>	<u>Depth(ft)</u>	<u>H/H_b</u>	<u>Calibration Curve</u>	<u>Links Off Bottom</u>	<u>Force for 105 Foot Wide Barge (Kips)</u>
1	50	0.5	a	50-56	280
2	50	0.75	a	78	480
3	50	1.0	b	98	1020
4	100	1.0	c	115	900
5	100	0.75	c	78	270
6	100	0.50	c	447	100
7	75	0.50	d	40-42	150
8	75	0.75	d	63	300
9	75	1.0	d	110	970

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Calculations for: Test Set-up

Calcs ck'd by: date:

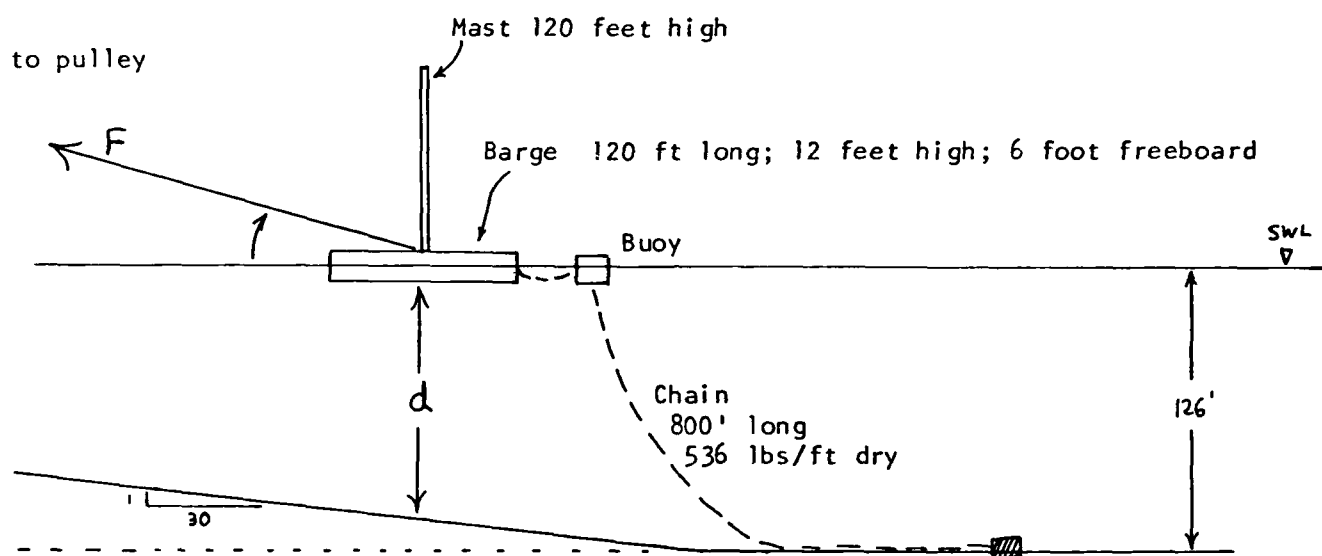


Figure 1. Test Set-up

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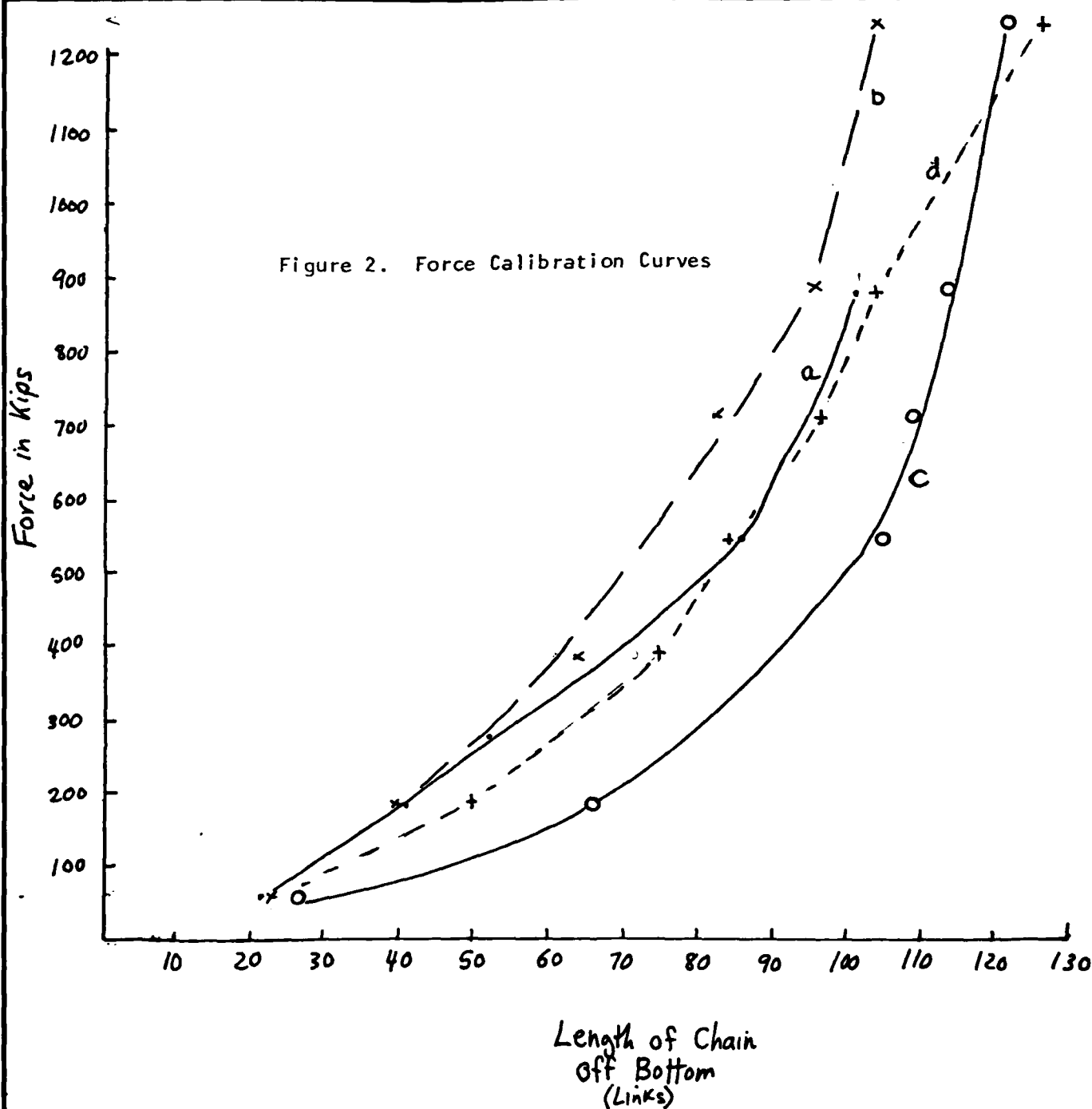
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Calculations for: Force Calibration

Curves



page ____ of ____

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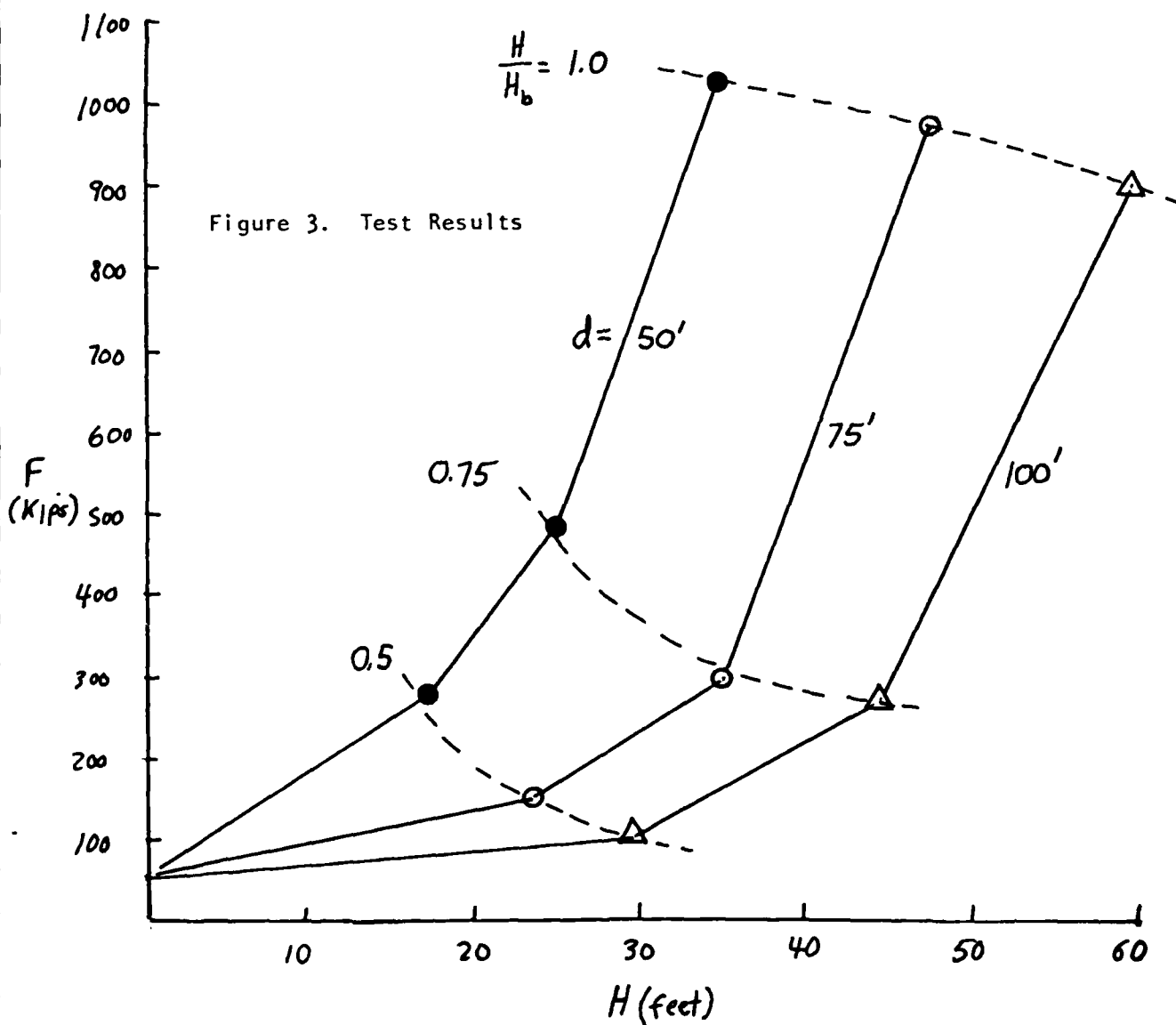
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1/100 Scale Froude Model $T = 12 \text{ sec}$ Barge $105' \times 120' \times 12'$

page ____ of ____

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Naval Facilities Engineering Command

NDW

Station: _____

DISCIPLINE

E S R: _____ Contract: _____

Calcs made by: Seelig date: 3/24/83Calculations for: Prototype Forces
From 1/100 Scale Fringe Model

Calcs ck'd by: _____ date: _____

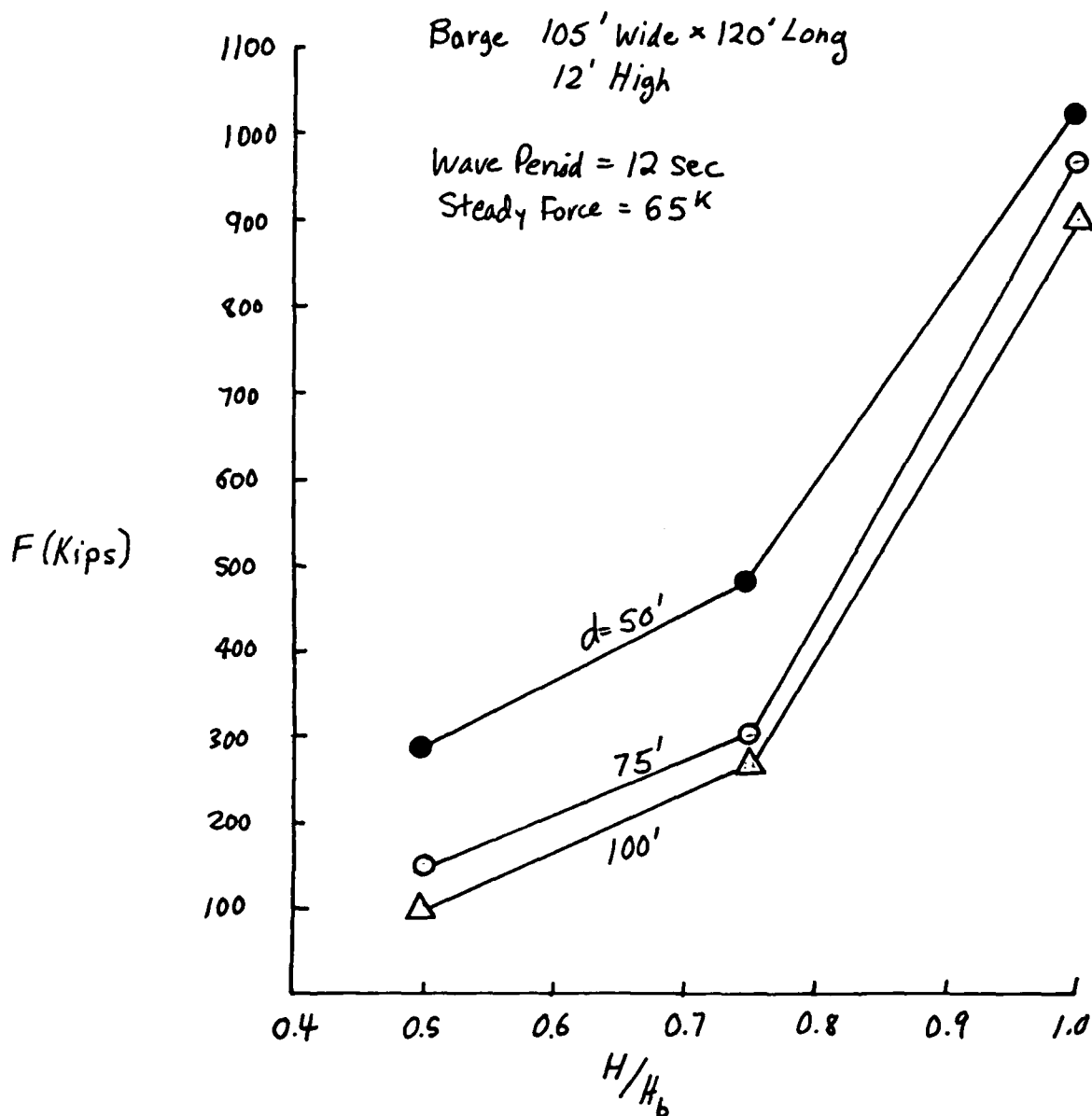


Figure 4. Test Results in terms of relative wave height

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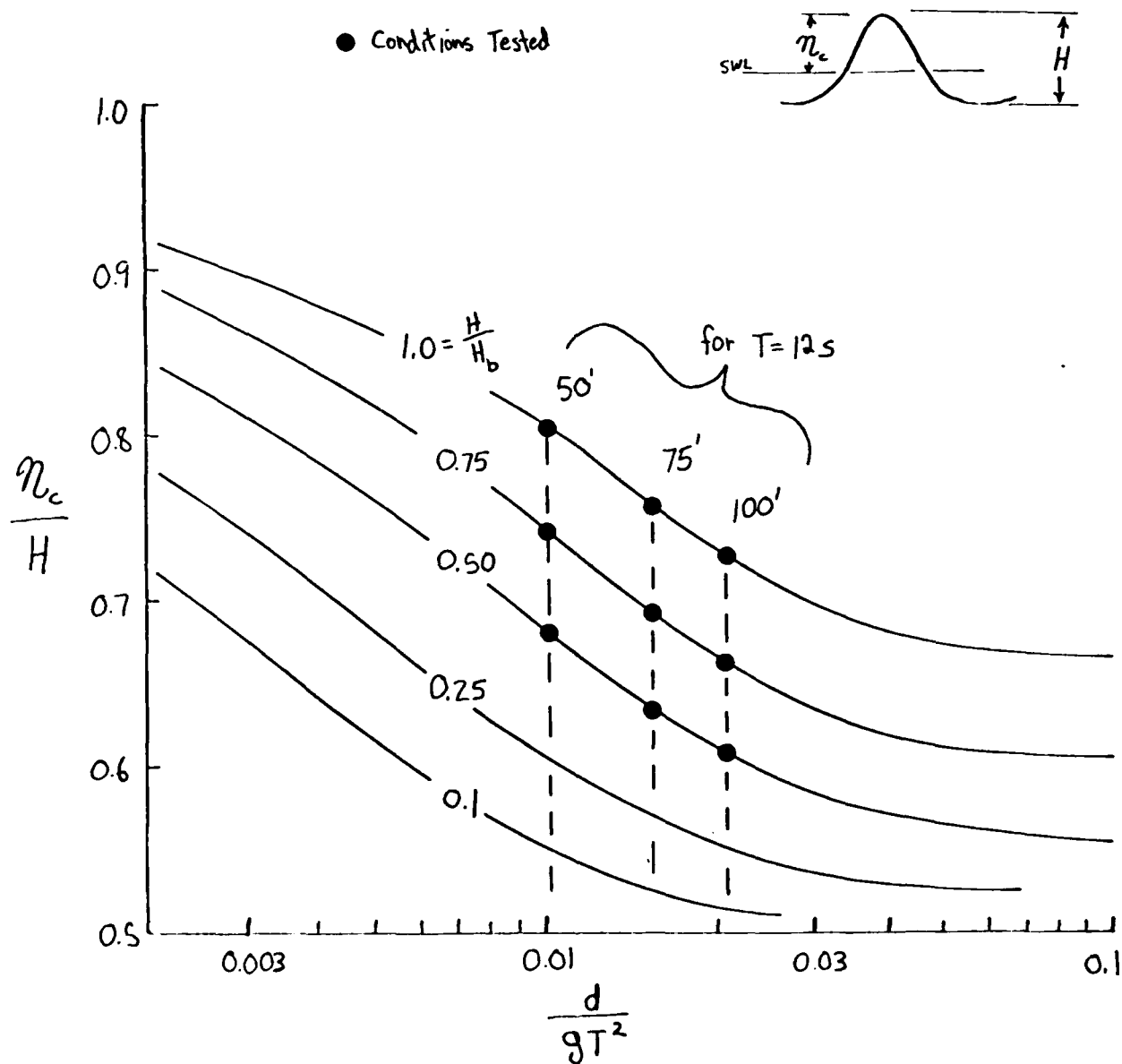


Figure 5. Predicted wave crest height (after Dean, 2)

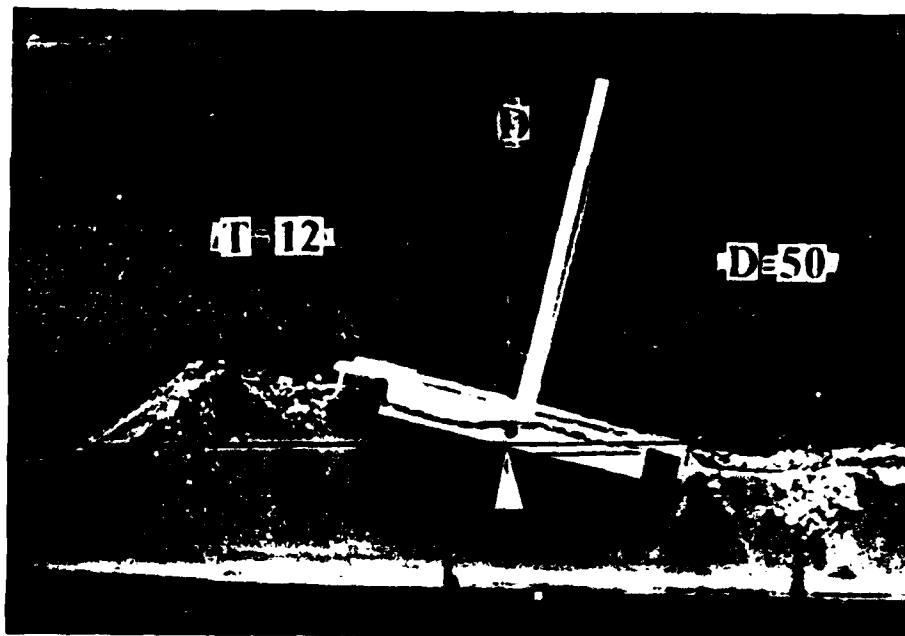
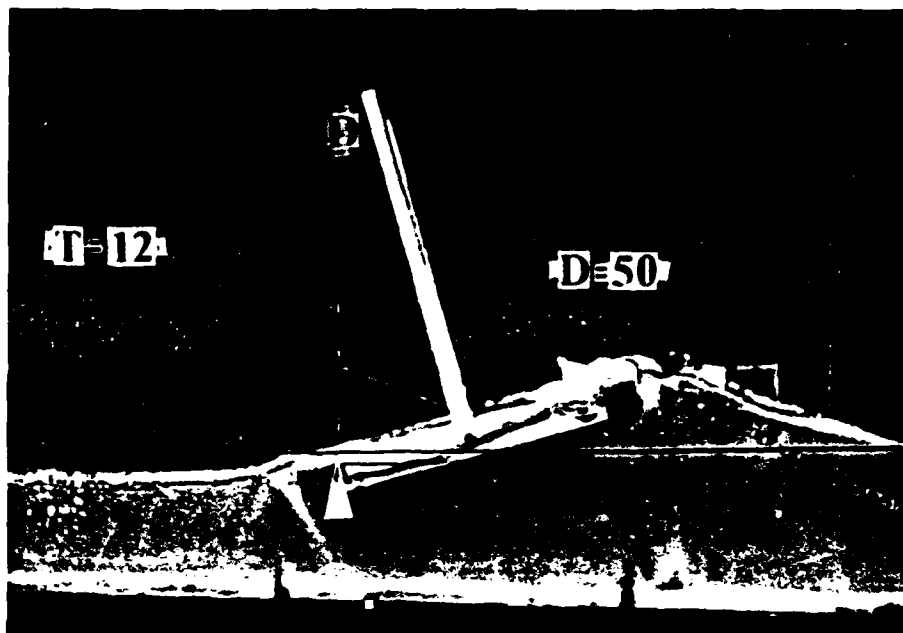


Figure 6. Test photos taken for the case of
wave breaking in 50' of water
(wave period = 12 sec)

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