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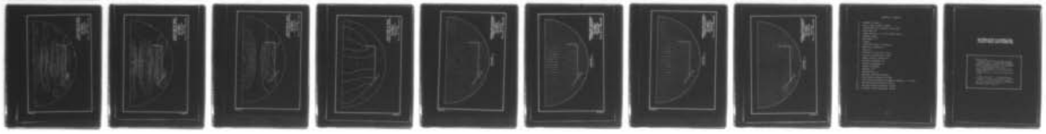

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LONG BEACH HARBOR NUMERICAL ANALYSIS OF HARBOR OSCILLATIONS

Report 4

ALTERNATE PLANS FOR PIER J COMPLETION AND TANKER TERMINAL PROJECT (NO LANDFILL)

by

John J. Wanstrath

Hydraulics Laboratory
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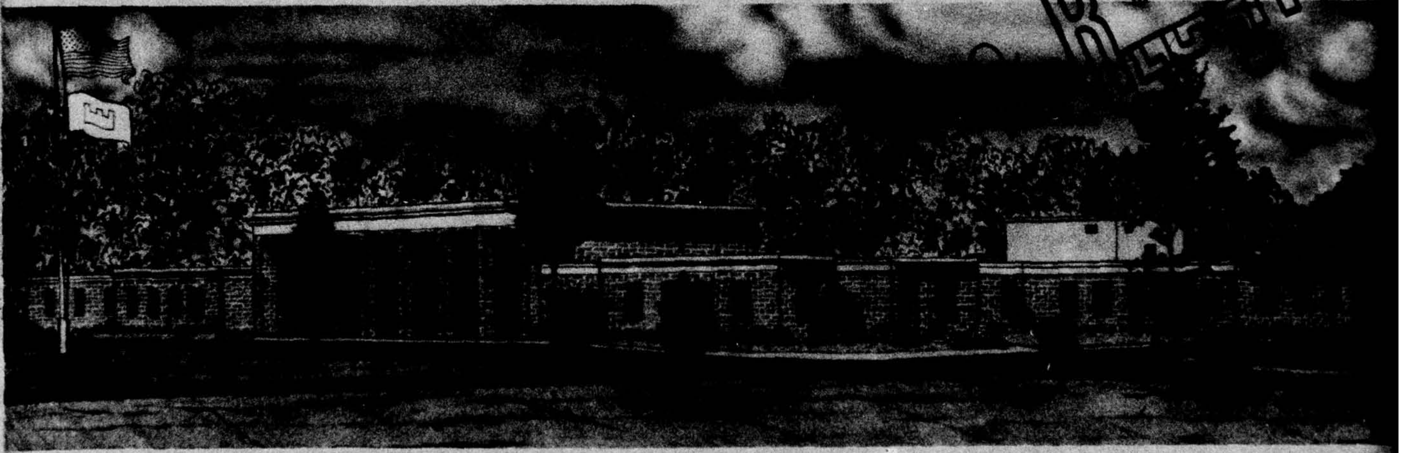
P. O. Box 631, Vicksburg, Miss. 39180

February 1977
Report 4 of a Series



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A hybrid finite element numerical model was used to calculate harbor resonance for the Pier J completion and tanker terminal project of Long Beach Harbor with no landfill. The numerical model calculates harbor oscillation for harbors of arbitrary shape and variable depth. A finite element grid which covered the immediate vicinity of the breakwater-protected tanker terminal area was used to calculate the response of this area to incident waves with periods from 30 sec to approximately 6 min.

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PREFACE

The investigation reported herein was authorized by the Long Beach Port Authority under a contract, Agreement No. WES 76-4, dated 12 September 1975.

The investigation was conducted from September 1975 to October 1976 by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, Dr. R. W. Whalin, Chief of the Wave Dynamics Division, and Mr. C. E. Chatham, Chief of the Harbor Wave Action Branch. Dr. J. J. Wanstrath, Research Oceanographer, conducted the investigation and prepared this report. Mr. R. R. Bottin, Jr., aided in the development of the finite element grids. Drs. H. S. Chen and C. C. Mei of the Massachusetts Institute of Technology provided documentation of the hybrid finite element computer program they developed and materials to aid in its utilization.

Directors of WES during the investigation and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
feet per second	0.3048	metres per second
square feet per second	0.09290304	square metres per second
feet per second per second	0.3048	metres per second per second

LONG BEACH HARBOR NUMERICAL ANALYSIS OF HARBOR OSCILLATIONS

ALTERNATE PLANS FOR PIER J COMPLETION AND TANKER TERMINAL PROJECT (NO LANDFILL)

PART I: INTRODUCTION

Objective

1. The objective of this study was to investigate by use of a numerical model* the response to long-period wave excitation of a proposed modification to Pier J in Long Beach Harbor for oil tanker berthing and general cargo facilities. Wave-height amplification factors ar normalized maximum current velocities were plotted versus wave period a the three proposed tanker terminals to ascertain whether or not significant harbor oscillations might occur that would pose problems to ship berthing.

Scope

2. The tanker terminal configuration under consideration in this study (plan 3) omits the landfill of approximately 111 acres** (11 million cu yd) on the end of Pier J (Figure 1). Three other plans have been tested† and are summarized on the following page (Figures 2 and 3).

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* H. S. Chen and C. C. Mei, "Oscillations and Wave Forces in an Offshore Harbor (Applications of the Hybrid Finite Element Method to Water-Wave Scattering)," Report No. 190, 1974, Massachusetts Institu of Technology, Cambridge, Mass.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

† J. R. Houston, "Long Beach Harbor Numerical Analysis of Harbor Oscillations; Alternate Plans for Pier J Completion and Tanker Terminal Project," Miscellaneous Paper H-76-20, Report 2, Sep 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Plan	Designation	Description
1A	Scheme STFP 2	300-ft opening (1000-ft-long east breakwater) at the east end of the 62-ft-deep basin requiring 111 acres of landfill on Pier J.
1B	Scheme STFP 2	600-ft opening (700-ft-long east breakwater) at east end of the 62-ft-deep basin requiring 111 acres of landfill on Pier J.
2	Scheme STFP 3	1100-ft opening (1300-ft-long east breakwater) at the east end of the 62-ft-deep basin requiring 50 acres of landfill on Pier J.
3		1700-ft opening (700-ft-long east breakwater) at the east end of the 62-ft-deep basin requiring no landfill on Pier J.

3. For all plans, including plan 3, the incident waves were directed normal to the main breakwater with periods from 30 sec to 300-360 sec. For this study, wave amplitudes and currents were calculated every 6 sec for the period range. Resonant peaks also were defined by considering incident wave periods in increments as low as 1 sec. Frequency response curves are given comparing plans 1B and 3 in detail, and a tabular summary of resonant peaks is presented for all plans.

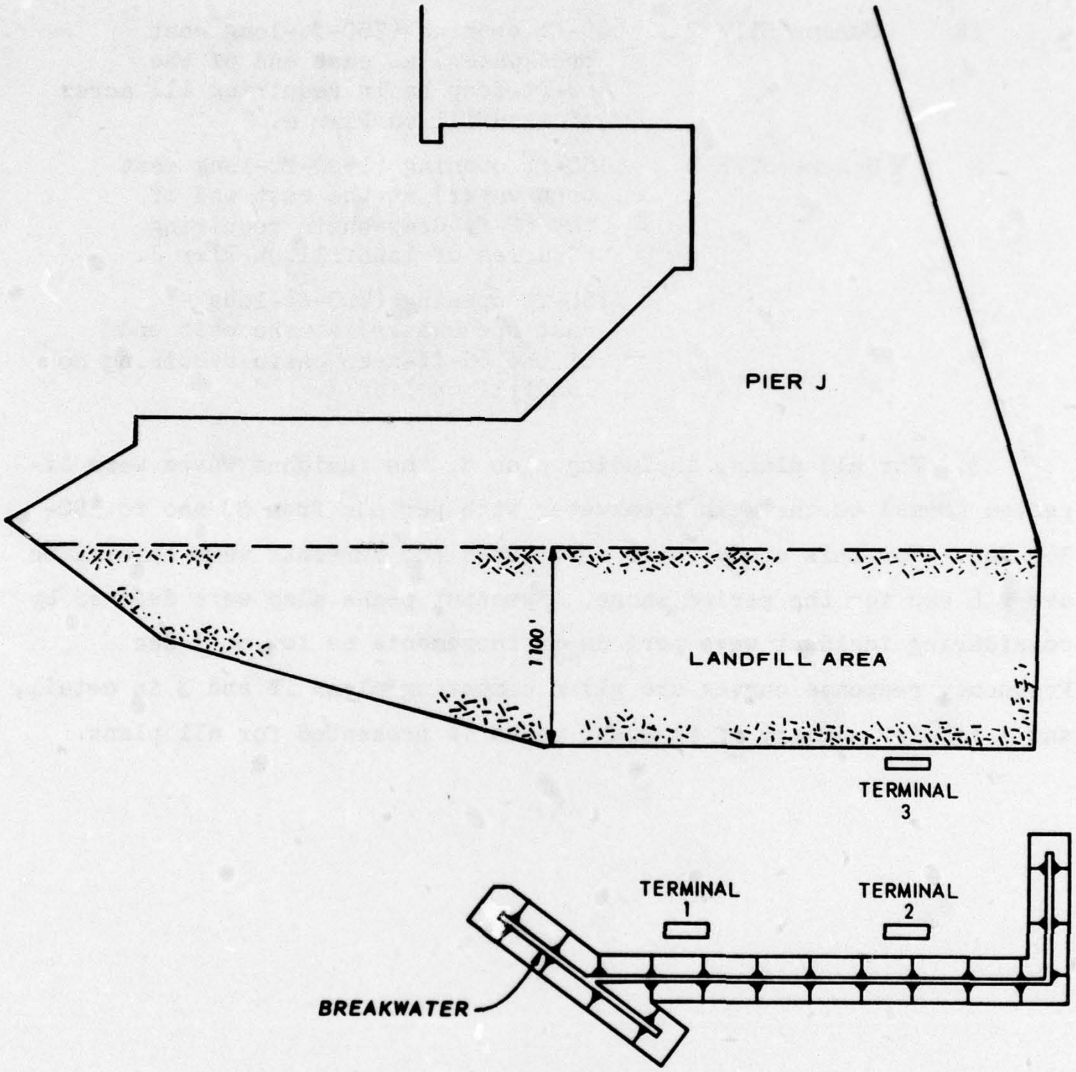

Figure 1. Location of tanker terminals

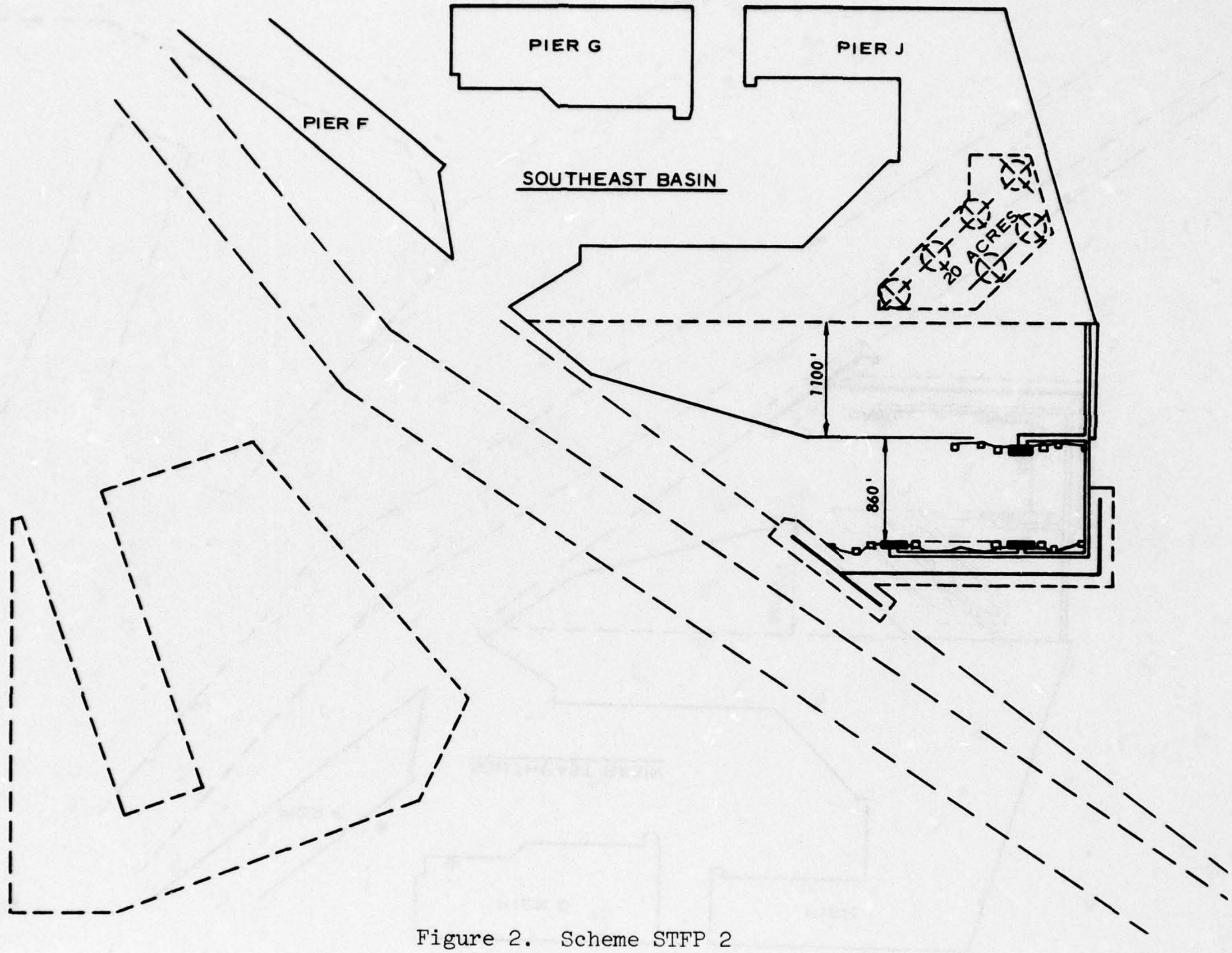

Figure 2. Scheme STFP 2

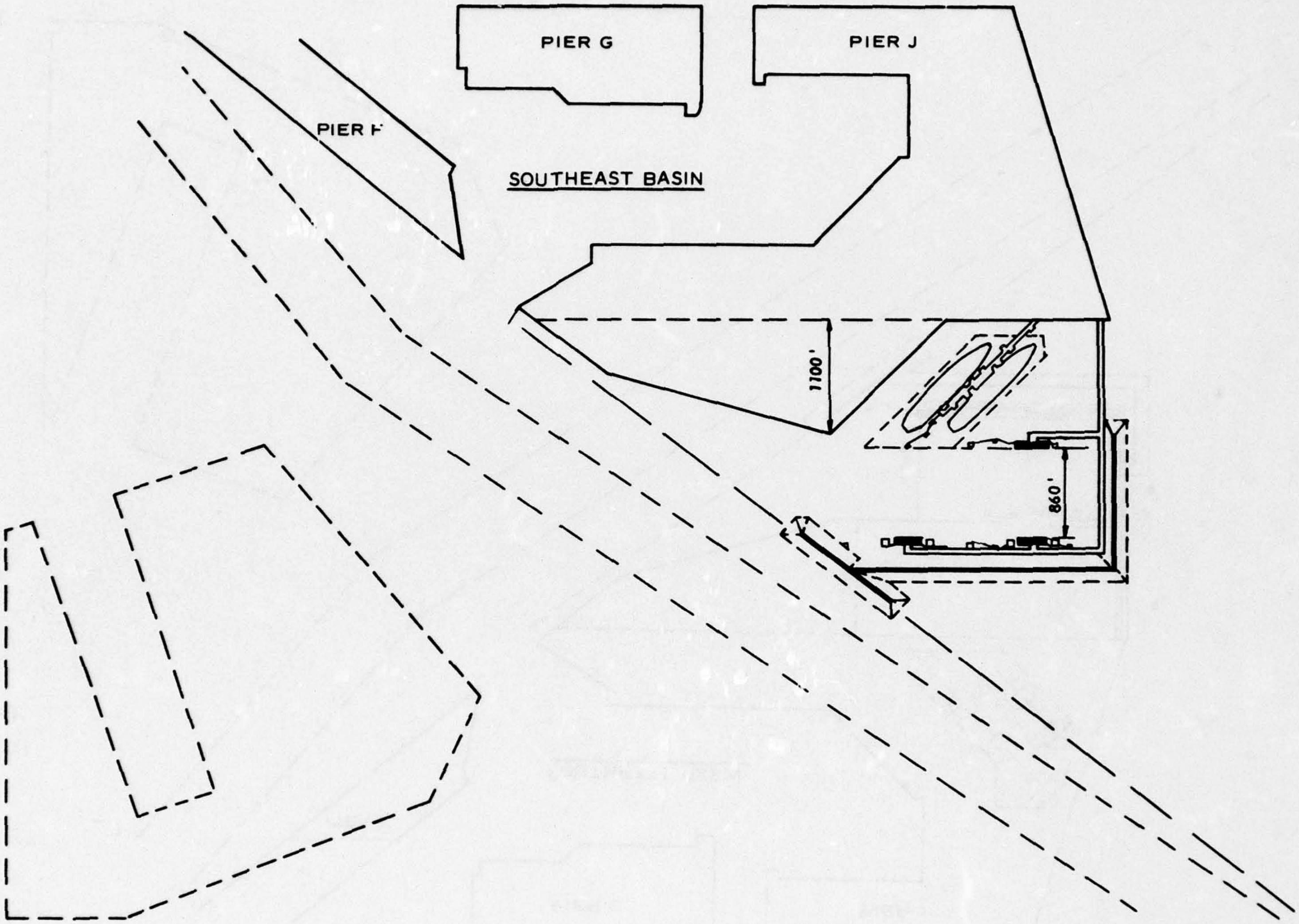

Figure 3. Scheme STFP 3

PART II: NUMERICAL MODEL

4. The response of the tanker terminal basin to long wave excitation was determined by using a hybrid finite element numerical model developed recently by Chen and Mei.* The model solves the following generalized Helmholtz equation:

$$\nabla \cdot \left[h(x,y)\nabla\phi(x,y)\right] + \frac{w^2}{g}\,\phi(x,y) = 0 \qquad (1)$$

where $\phi(x,y)$** is the velocity potential defined by $u(x,y) = -\nabla\phi(x,y)$, with $u(x,y)$ being a two-dimensional velocity vector and w an angular frequency. Equation 1 governs small amplitude undamped oscillations of water in a basin of arbitrary shape and variable depth forced by periodic long waves. It has been further assumed that the flow is irrotational.

5. The boundary condition along the shoreline and along the detached breakwater surrounding the three proposed berths is that the normal component of the velocity be equal to zero. Therefore, the breakwater is considered as a solid barrier. No special boundary conditions are made to account for any vessels utilizing the tanker terminal basin, since for long-period waves of small amplitude ship heave equals incident wave height. Therefore, the vessels do not significantly alter the oscillation characteristics of the basin.

6. The Helmholtz equation:

$$\nabla^2\phi(x,y) + \frac{w^2}{gh}\,\phi(x,y) = 0 \qquad (2)$$

is the governing equation for a constant-depth ocean region outside the basin.

7. For a harbor in a semi-infinite ocean with a straight coastline

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* Chen and Mei, op. cit.

** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

there is an incident, reflected, and scattered wave. The scattered wave has a velocity potential ϕ_s given by

$$\phi_s = \sum_{n=0}^{\infty} \alpha_n H_n(kr) \cos n\theta \tag{3}$$

where α_n are unknown coefficients and $H_n(kr)$ are Hankel functions of the first kind of order n . ϕ_s satisfies the radiation condition that the scattered wave must behave as an outgoing wave at infinity. This condition is known as the Sommerfeld radiation condition and may be expressed mathematically as follows:

$$\lim_{r \to \infty} \sqrt{r}\left(\frac{\partial}{\partial r} - ik\right) \phi_s = 0 \tag{4}$$

8. Chen and Mei used a calculus of variations approach and obtained a Euler-Lagrange formulation of the boundary value problem. The following functional with the property that it is stationary with respect to arbitrary first variations of $\phi(x,y)$ was constructed by Chen and Mei:

$$F(\phi) = \iint 1/2 \; \{h(\nabla\phi)^2 - \frac{w^2}{g}\phi^2\} \; dA$$

$$+ 1/2 \; \S\{h(\phi_R - \phi_I) \frac{\partial(\phi_R - \phi_I)\}}{\partial n_a} \; da - \S\{h\phi_a \frac{\partial(\phi_R - \phi_I))\}}{\partial n_a} \; da$$

$$- \S\{h\phi_a \frac{\partial\phi_I}{\partial n_a}\} \; da + \S\{h\phi_I \frac{\partial(\phi_R - \phi_I)\;\}}{\partial n_a} \; da \tag{5}$$

where

A = region inside the harbor

§ = line integral

ϕ_R = far field velocity potential

ϕ_I = velocity potential of the incident wave

n_a = unit normal vector outward from region A

a = boundary of region A

ϕ_a = total velocity potential evaluated on boundary a

Proof was given by Chen and Mei that the stationarity of this functional is equivalent to the original boundary value problem.

9. The integral equation obtained from extremizing the functional is solved by utilizing the finite element method. This method is a technique of numerical approximation which involves dividing a domain into a number of nonoverlapping subdomains which are called elements.

10. The solution of the problem is approximated within each element by suitable interpolation functions in terms of a finite number of unknown parameters. These unknown parameters are the values of the field variable $\phi(x,y)$ at a finite number of points which are called nodes. The relations for individual elements are combined into a system of equations for all unknown parameters.

11. In the region outside the basin, the velocity potentials are solved analytically in terms of unknown coefficients. The region is considered a single element with an "interpolation function" given by Equation 3. The infinite series is terminated at some finite value such that the addition of further terms does not significantly influence the calculated values of $\phi(x,y)$. The resulting equation is combined with the system of equations for unknown parameters at nodal points within the basin and this complete system is solved using Gaussian elimination matrix methods. $\eta(x,y)$ is related to $\phi(x,y)$ through the linearized dynamic free surface boundary condition

$$\eta(x,y) = -\frac{1}{g}\frac{\partial\phi(x,y)}{\partial t} \tag{6}$$

The horizontal velocity components have the following form:

$$u(x,y) = -\frac{g}{w}\frac{\partial\eta(x,y)}{\partial x};\quad v(x,y) = -\frac{g}{w}\frac{\partial\eta(x,y)}{\partial y} \tag{7}$$

12. The hybrid finite element method (so named by Chen and Mei because the method involves the combination of analytical and finite element numerical solutions) is a steady-state solution of the boundary value problem. The response of a harbor to an arbitrary forcing function can be easily determined within the framework of a linearized theory.

PART III: RESULTS

13. Locations of the three tanker terminals are shown in Figure 1. The finite element grid for plan 3 is presented in Plate 1. Plans 1B and 3 are similar regarding the dimensions of the breakwater, but relative to the east harbor opening and basin dimensions, plan 2 is more similar to plan 3 than is plan 1B to plan 3.

14. The frequency response curves of the normalized maximum current velocity (NMCV) versus incident wave period at each tanker terminal for plans 1B and 3 are shown in Plates 2-4. The current velocity multiplied by the incident wave amplitude in feet gives velocity in units of feet per second. The velocities have no vertical component or variation since only long waves are considered. Also, the maximum velocity over one wave period is plotted. Plates 5-7 are the frequency response curves of the wave-height amplification factor (WHAF) at each tanker terminal. WHAF is defined at a point inside the basin as the wave height at the point divided by twice the incident wave height. This definition of amplification factor is traditional and is a result of the fact that the standing wave height for a straight coast with no harbor would be twice the incident wave due to the superposition of the incident and reflected waves.

15. The following tabulation gives peak values of NMCV and WHAF and the resonant wave period for the various Pier J configurations. "Blanks" in the tabulation reflect either the absence of a resonant condition or that NMCV or WHAF did not exceed 1.0. Several observations regarding either the NMCV or WHAF are apparent. For the wave period range under consideration, plan 3 exhibits four resonant wave periods (44, 66, 124, and, nominally, 340 sec) at each tanker terminal. If a resonant condition is observed at a particular terminal in either plan 1A, 1B or 2, it is also observed in plan 3 at a slightly different resonant wave period. If the peak is absent in plan 3, it is also absent in the other plans. The peaks in plan 3 are generally greater than those in the other plans for the first three resonant periods. However, for the last resonant period (that covering a wave period range

from approximately 2 min to well over 6 min, and where a greater proportion of wave energy is concentrated per wave period interval) plan 3 always exhibits a lower peak value than those in the other plans.

STFP 2 (300)		STFP 2 (600)		STFP 3			
Plan 1A		Plan 1B		Plan 2		Plan 3	
NMCV	WHAF	NMCV	WHAF	NMCV	WHAF	NMCV	WHAF
				Terminal 1			
--	--	--	--	1.20 (36)	--	3.22 (44)	2.08 (44)
--	--	--	--	2.26 (56)	--	3.47 (66)	3.25 (66)
--	--	--	--	1.52 (106)	1.00 (102)	2.01 (124)	2.93 (124)
2.45 (280)	3.93 (285)	1.93 (260)	3.22 (268)	2.50 (350)	2.75 (349)	1.55 (330)	2.22 (348)
				Terminal 2			
--	--	--	--	--	--	2.72 (44)	1.78 (44)
--	--	1.65 (59)	--	4.36 (56)	1.61 (56)	3.43 (66)	2.39 (66)
--	--	--	--	2.55 (106)	2.55 (106)	1.94 (124)	3.40 (124)
--	3.49 (286)	--	3.66 (264)	--	3.24 (352)	--	2.33 (348)
				Terminal 3			
--	--	--	--	1.24 (46)	--	3.68 (44)	--
--	--	1.00 (58)	1.12 (58)	1.90 (57)	3.72 (54)	2.79 (66)	3.80 (66)
--	--	--	--	3.48 (108)	--	4.80 (125)	--
1.78 (280)	3.69 (284)	1.74 (260)	3.32 (270)	--	3.12 (360)	1.72 (330)	2.25 (348)

Note: Numbers in parentheses are the wave period in seconds at the peak.

16. Plan 3 evidently establishes a harbor of sufficient length, width, and depth that the first four principal harmonics can be nicely generated. These harmonics are portrayed in the contours of the WHAF shown in Plates 8-11. Three nodal areas oriented parallel to the long axis of the basin are generated for the first resonant wave period (44 sec). The binodal and uninodal conditions (each nodal area oriented east-west as in the trinodal oscillation) occur for the next two resonant periods (66 and 124 sec). Antinodes form along the inside of the detached breakwater (the corners of which do not particularly accentuate the oscillation) and along the face of Pier J. However, for the 6-min resonant period, a single antinode is formed in the middle of the basin, oriented north-south. This is the only harmonic which is similarly well developed and oriented in all the plans.

17. Plates 12-15 present the NMCV patterns for the resonant peaks of plan 3. Comparison of these plates with those from the previous study* for plans 1A, 1B, and 2 shows the currents are generally larger

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* Houston, op. cit.

in the basin interior (especially along nodal lines) for the first three resonant oscillations (44, 66, and 124 sec) of plan 3 than for the other plans. However, the current patterns for plan 3 exhibit no particular modification at the interior breakwater corners or high velocities at the ends of the breakwater as observed in the other plans. For the 6-min resonant condition of plan 3, the current pattern is similar to that of the other plans except that as observed from the preceding tabulation, the magnitudes of the current velocities at the tanker terminals are smaller than those in any other plan.

18. In summary, larger resonant oscillations occur in plan 3 than in the other plans for wave periods less than 2 min. The basin is of sufficient length, width, and depth that three resonant periods (44, 66, and 124 sec) can be excited. The other plans are of such basin dimensions that one or more of the principal harmonics are not excited or are excited to a lesser degree than that in plan 3. Plan 3, however, excites the first principal east-west oscillation (6 min) with lower wave amplifications and current velocities at the tanker terminals than those of any other plan.

PART IV: CONCLUSIONS

19. The resonant peaks of the normalized maximum current velocity and wave-height amplification factor do not appear to preclude safe berthing at the terminal areas, given proper mooring practice and adequate mooring equipment. The resonant response peaks for incident waves with periods less than 2 min are generally larger for plan 3 than for the other plans. Plan 3, however, exhibits smaller response peaks for the longer period (6 min) oscillation than in the other plans. Whether or not incident waves in this period range excite significant ship motion depends upon ship characteristics (length, width, and draft) and mooring conditions (type of lines, amount of slack, etc.).

20. The incident wave spectrum and ship response versus wave period curves must be known in addition to the harbor response curves of Plates 2-7 to definitively determine whether or not ship surge problems resulting from harbor resonance will occur in the tanker terminal basin.

21. Until detailed information on moored ship response as a function of incident wave amplitude and frequency is obtained, definitive conclusions on the precise amount of ship motion cannot be made. However, the oscillations of the tanker terminal basin are significantly smaller than the typical oscillation noted throughout the Los Angeles and Long Beach Harbors complex in the numerical study performed for the entire harbor complex.* Thus, it is reasonable to assume, prior to obtaining additional data on moored ship response, that satisfactory berthing conditions will obtain in the tanker terminal basin.

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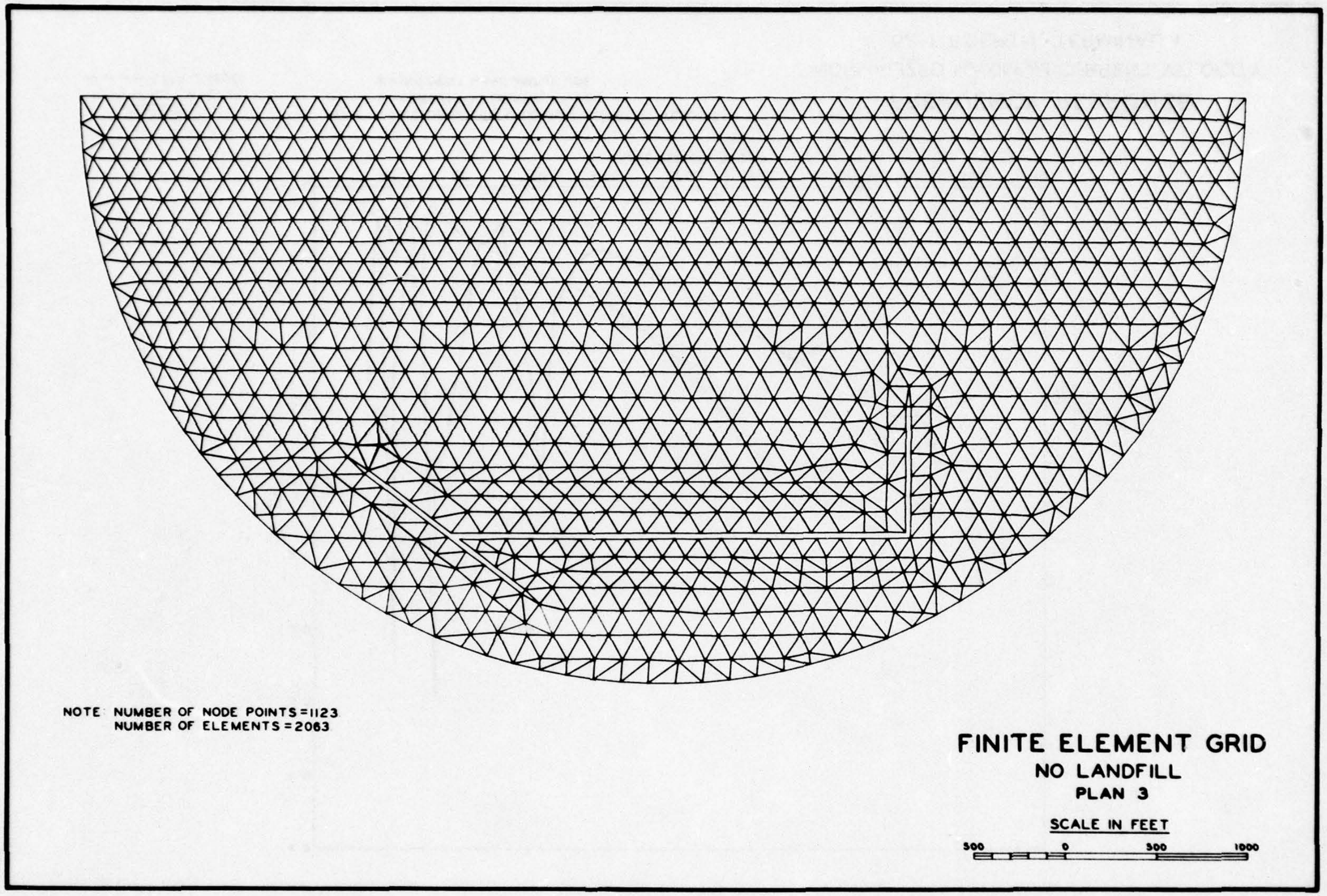
* J. R. Houston, "Long Beach Harbor Numerical Analysis of Harbor Oscillations; Existing Conditions and Proposed Improvements," Miscellaneous Paper H-76-20, Report 1, Sep 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.



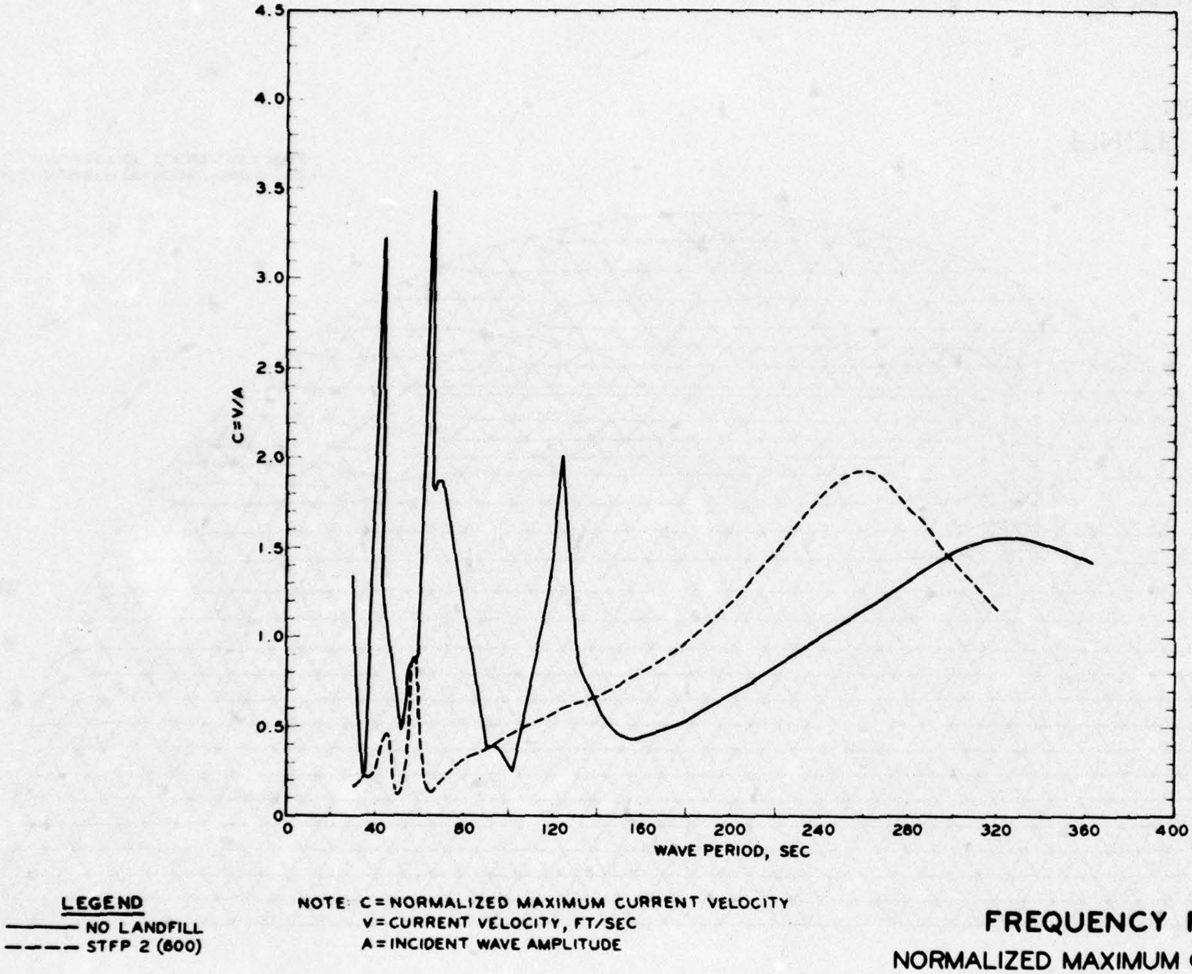
NOTE NUMBER OF NODE POINTS = 1123
NUMBER OF ELEMENTS = 2063

FINITE ELEMENT GRID
NO LANDFILL
PLAN 3

SCALE IN FEET

PLATE 1

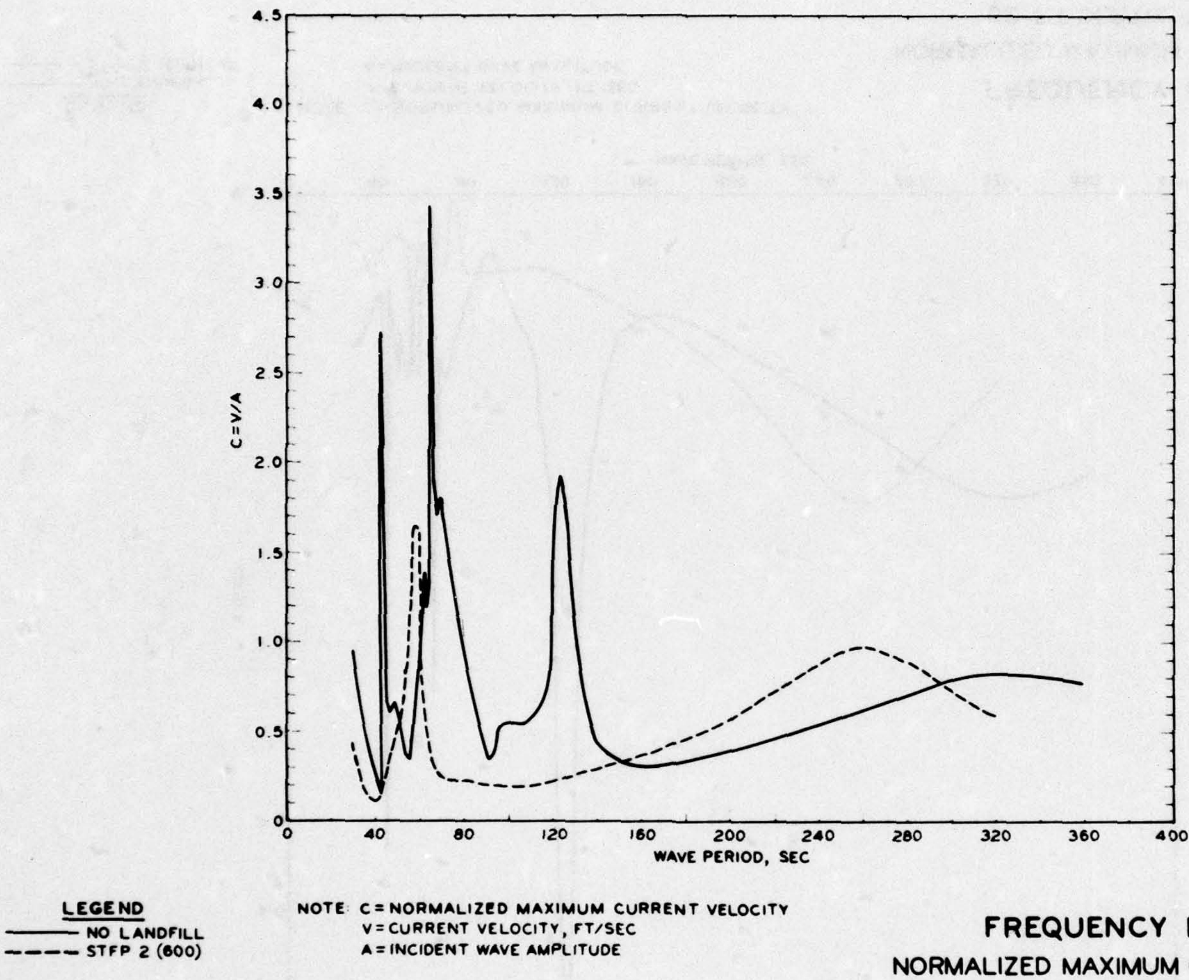
PLATE 2



NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

FREQUENCY RESPONSE

NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 1

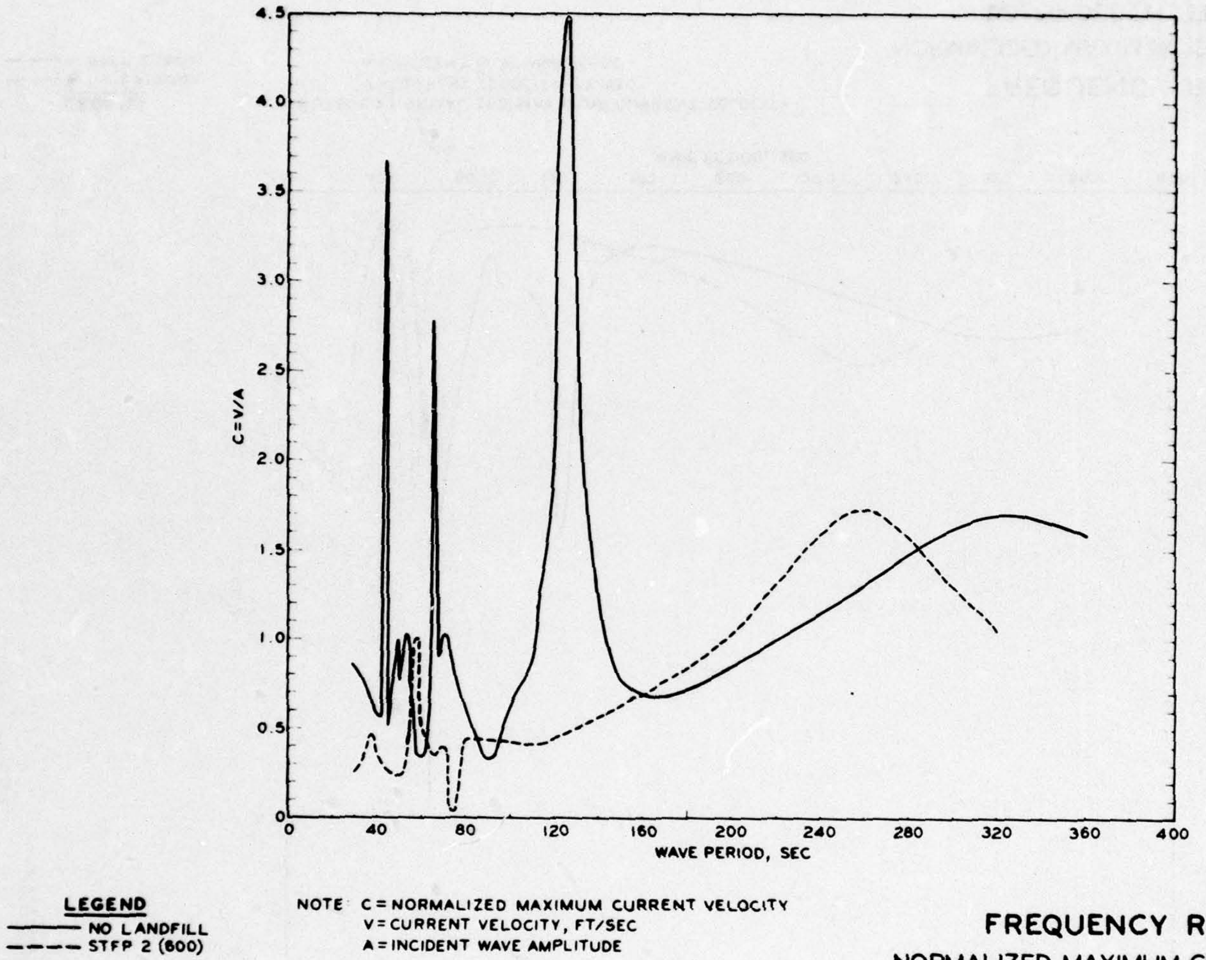


NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

FREQUENCY RESPONSE
NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 2

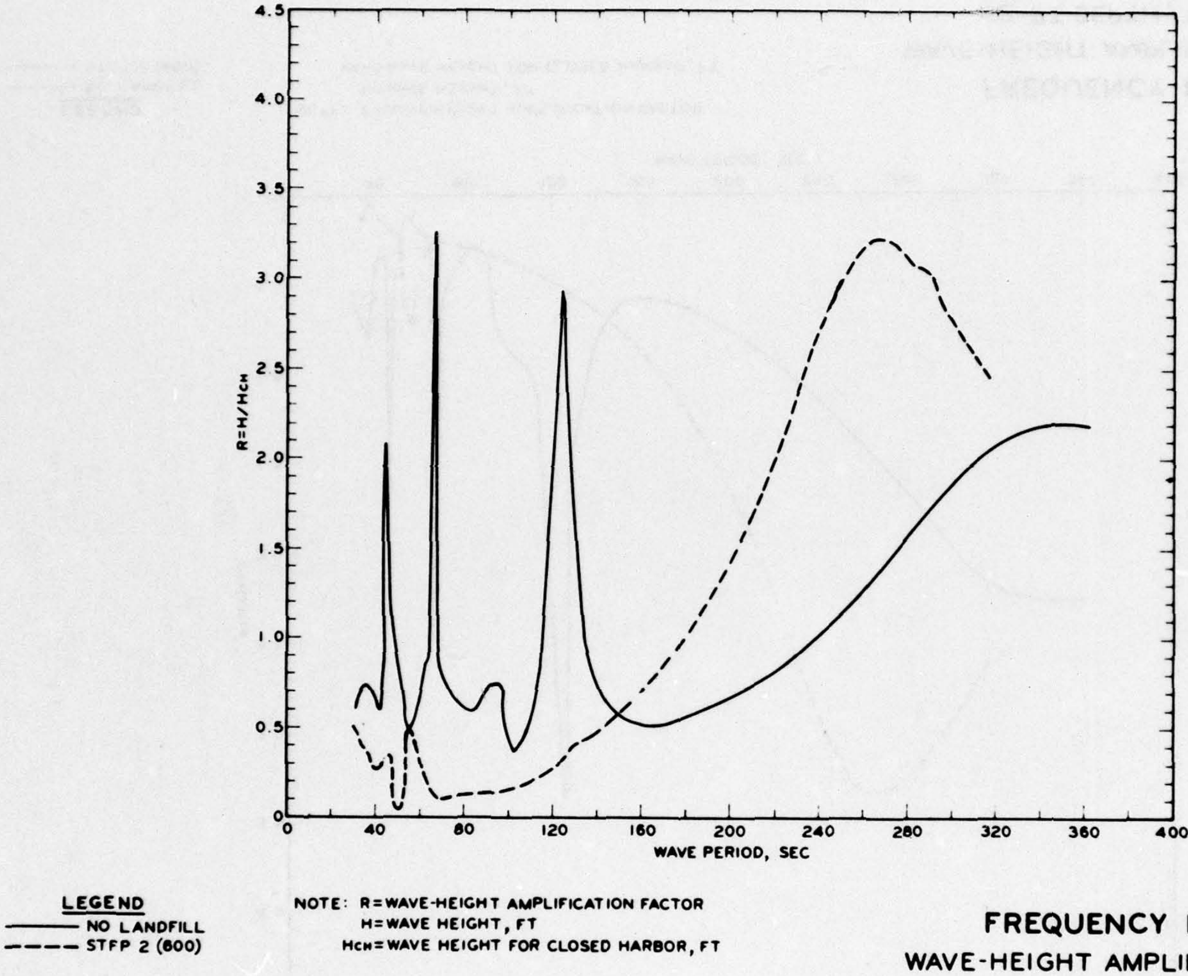
PLATE 3

PLATE 4



NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

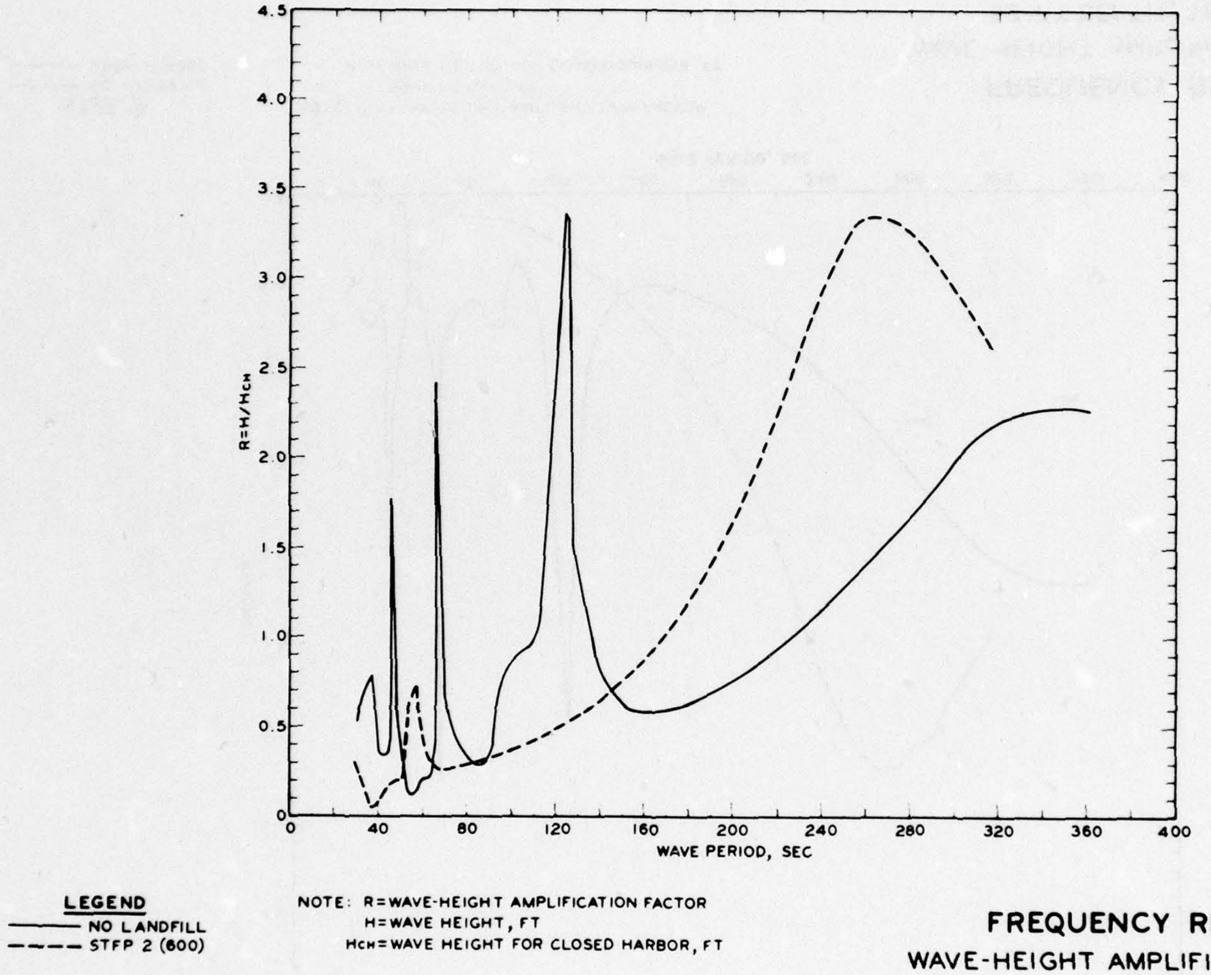
FREQUENCY RESPONSE
NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 3



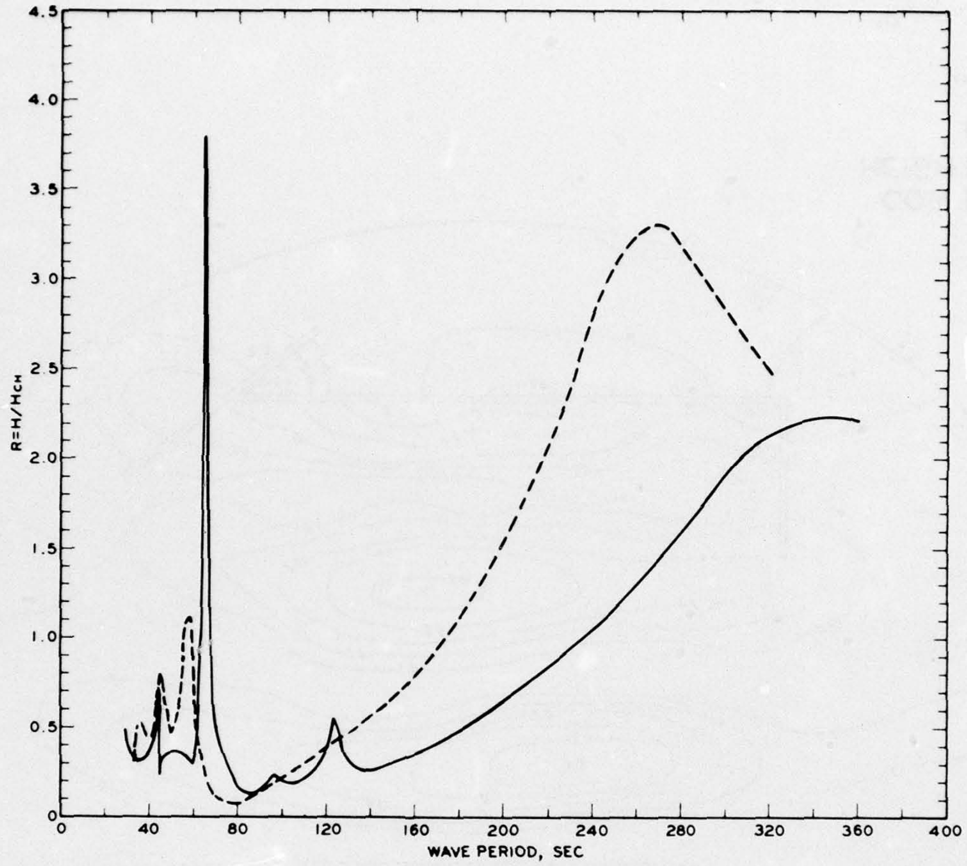
NOTE: R=WAVE-HEIGHT AMPLIFICATION FACTOR
H=WAVE HEIGHT, FT
HCH=WAVE HEIGHT FOR CLOSED HARBOR, FT

FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION FACTOR
62-FT DEPTH, TERMINAL 1

PLATE 6



FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION FACTOR
62-FT DEPTH, TERMINAL 2

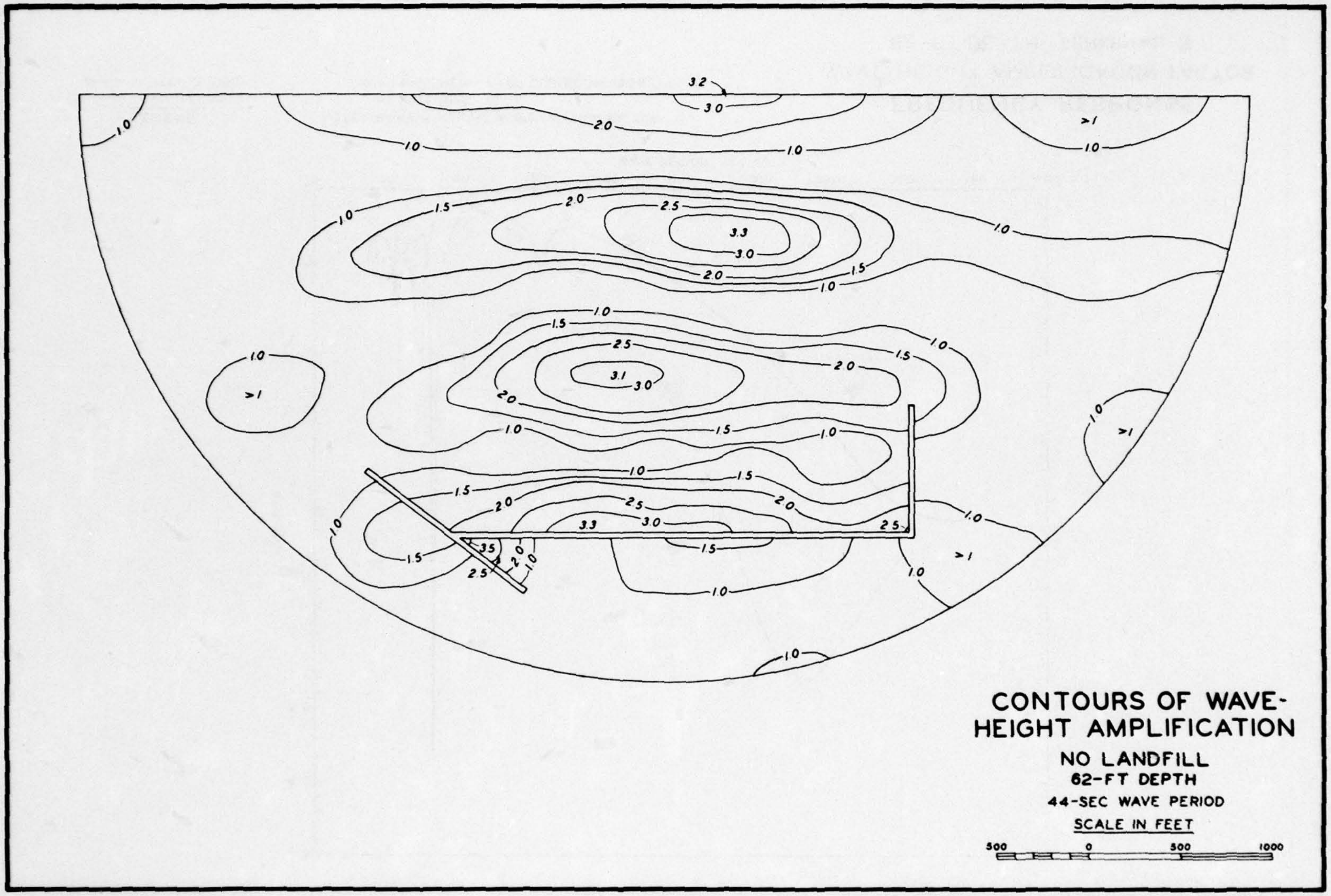


LEGEND

NOTE: R=WAVE-HEIGHT AMPLIFICATION FACTOR
H=WAVE HEIGHT, FT
H_{CH}=WAVE HEIGHT FOR CLOSED HARBOR, FT

FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION FACTOR
62-FT DEPTH, TERMINAL 3

PLATE 7

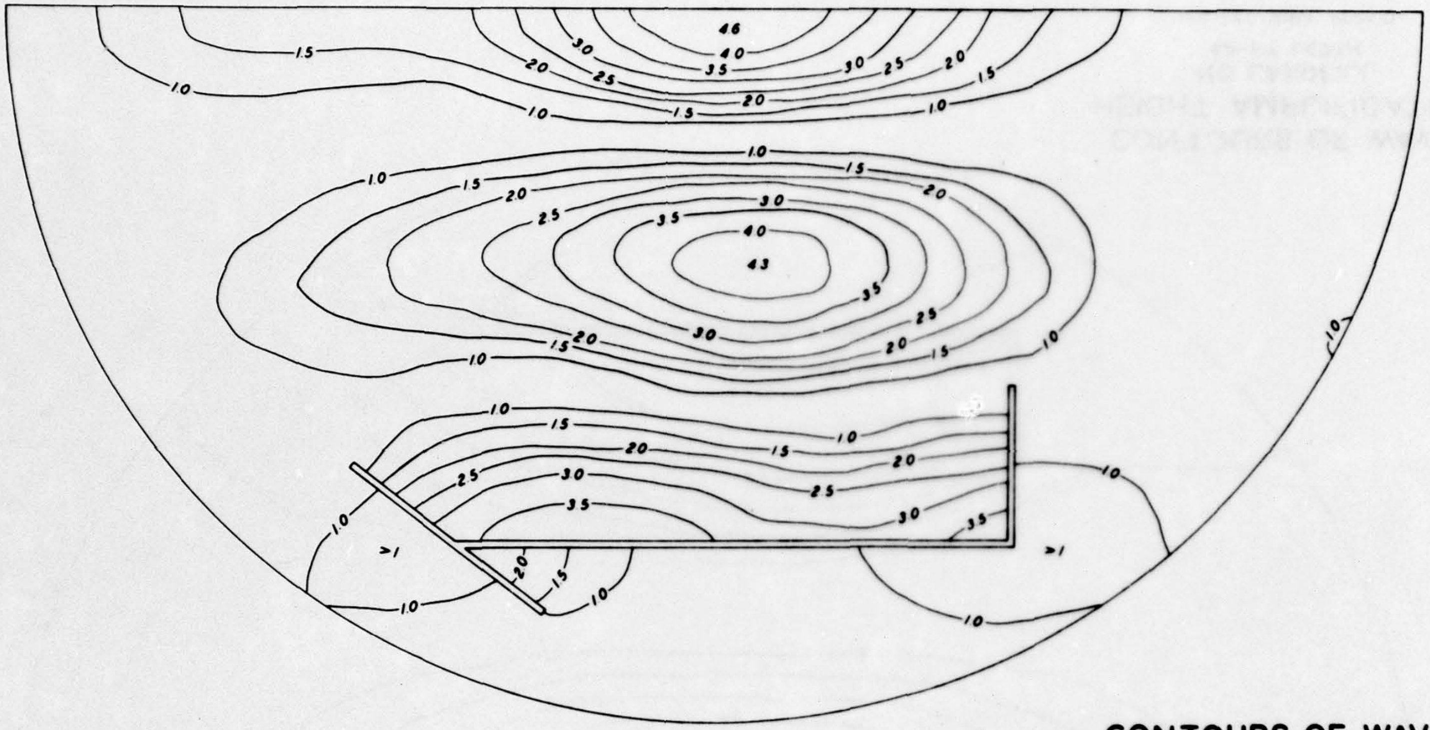


CONTOURS OF WAVE-HEIGHT AMPLIFICATION

NO LANDFILL
62-FT DEPTH
44-SEC WAVE PERIOD

SCALE IN FEET

PLATE 8



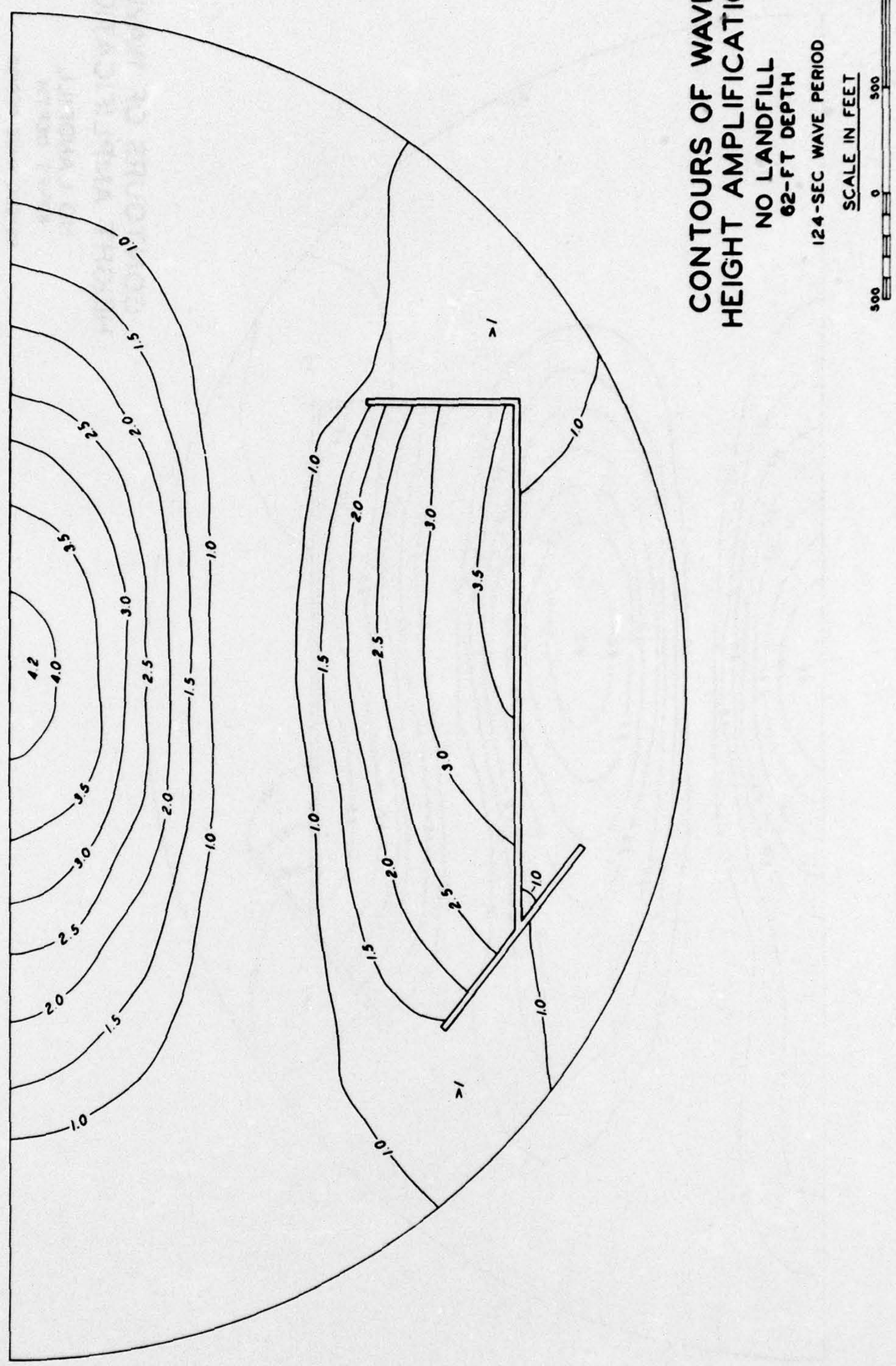
CONTOURS OF WAVE-HEIGHT AMPLIFICATION

NO LANDFILL
62-FT DEPTH

66-SEC WAVE PERIOD

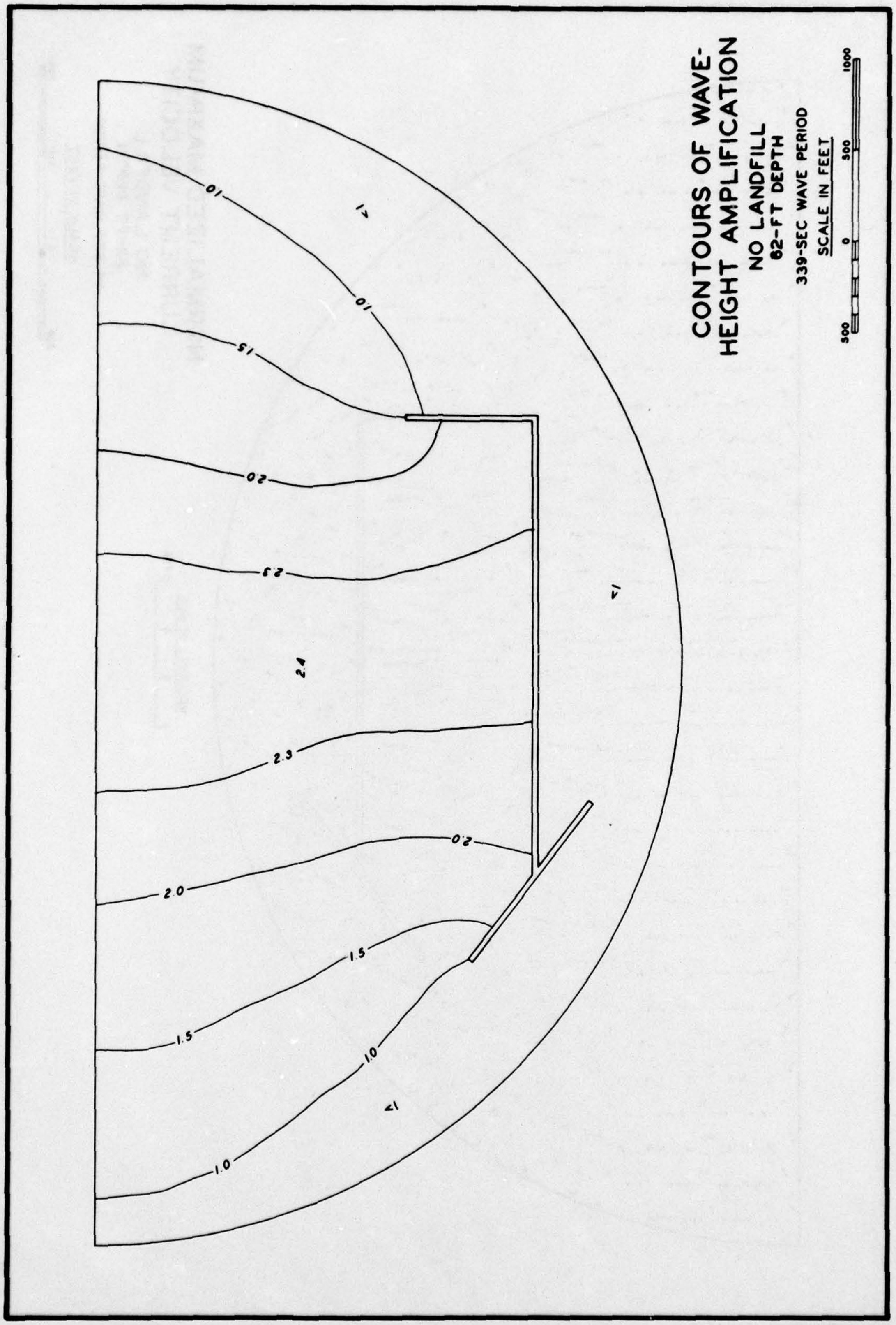
SCALE IN FEET

PLATE 9



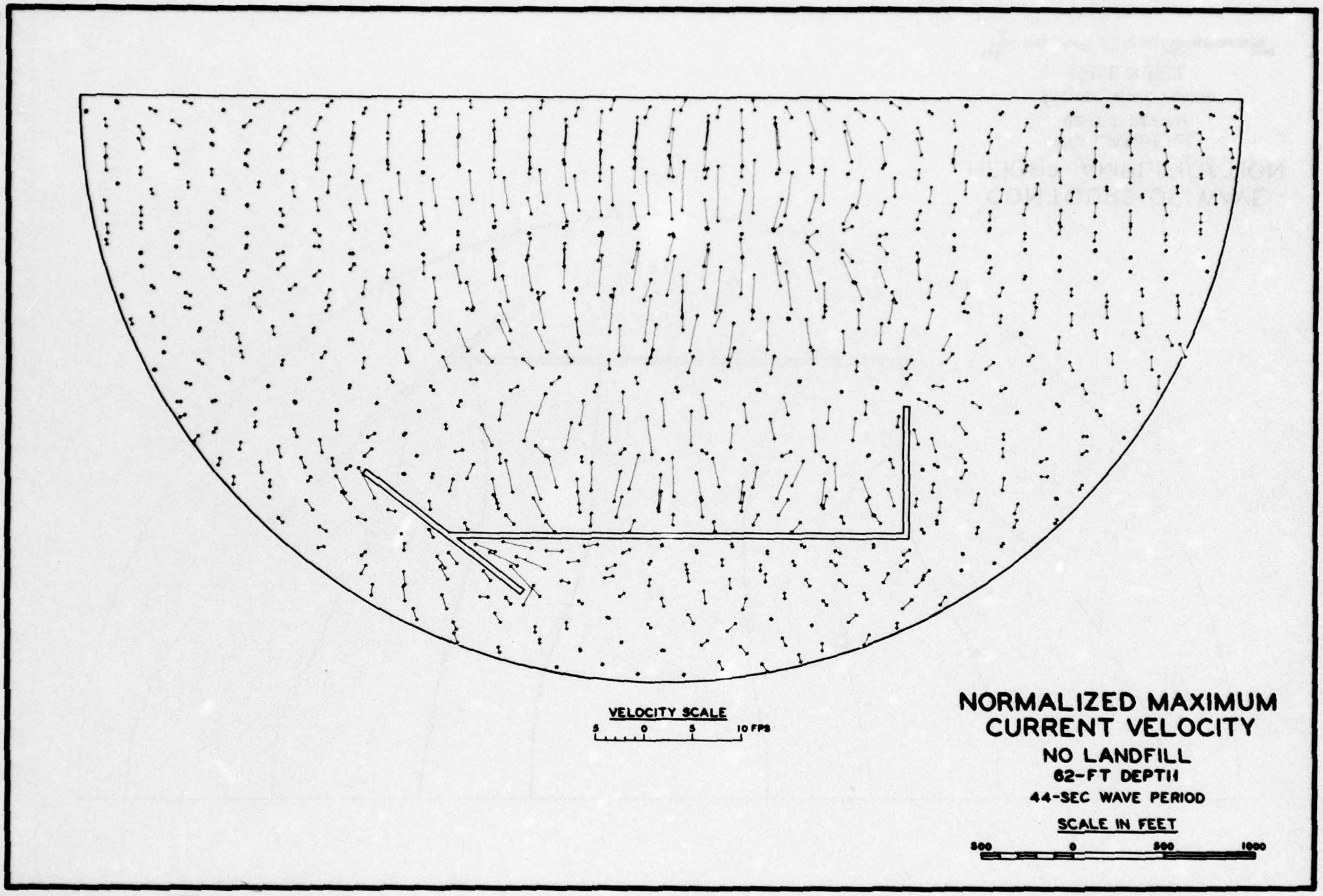
CONTOURS OF WAVE-HEIGHT AMPLIFICATION
NO LANDFILL
62-FT DEPTH
124-SEC WAVE PERIOD

PLATE 10



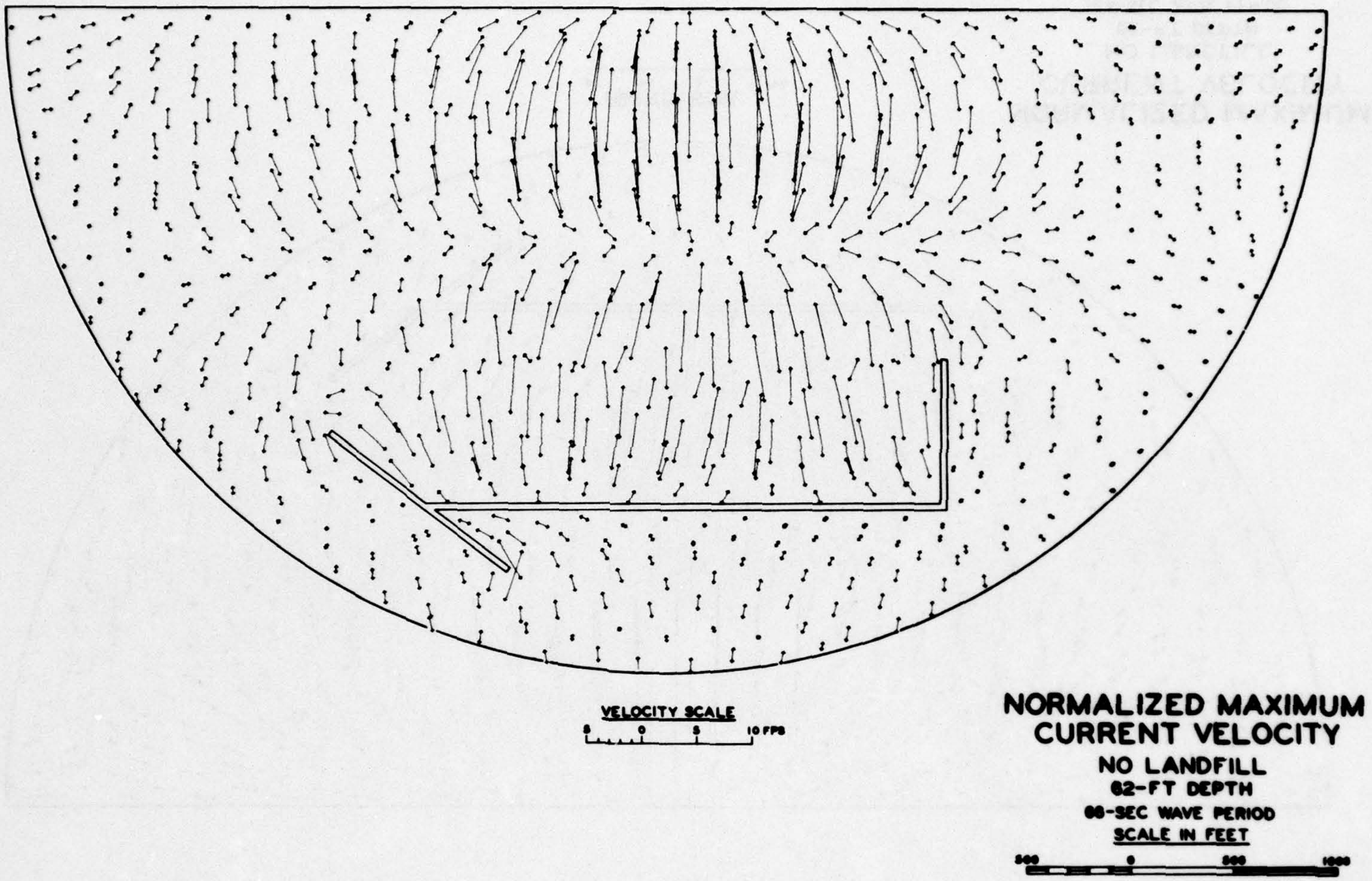
CONTOURS OF WAVE-HEIGHT AMPLIFICATION
NO LANDFILL
62-FT DEPTH
339-SEC WAVE PERIOD

PLATE 11



NORMALIZED MAXIMUM CURRENT VELOCITY
NO LANDFILL
62-FT DEPTH
44-SEC WAVE PERIOD

PLATE 12

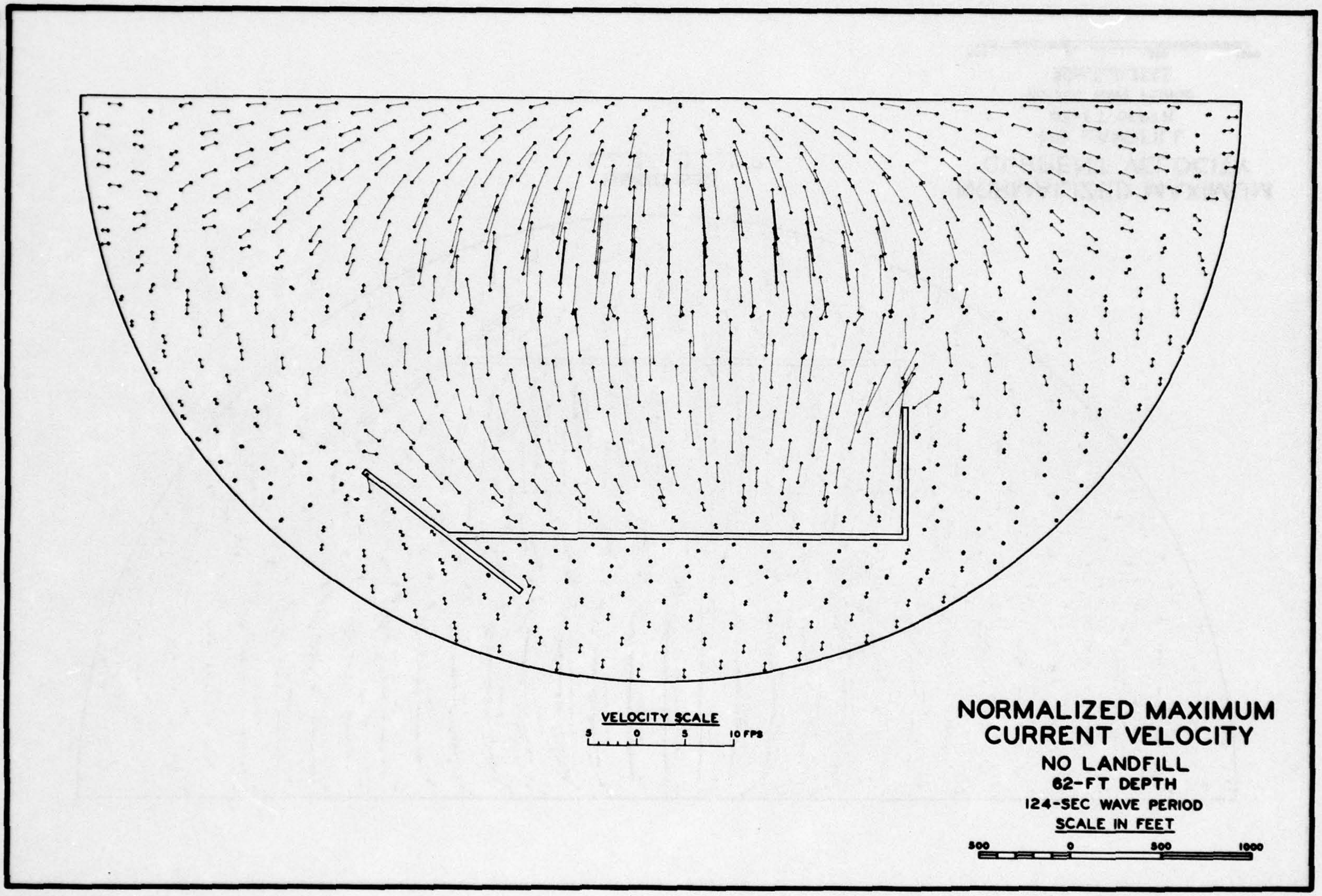


NORMALIZED MAXIMUM
CURRENT VELOCITY

NO LANDFILL
62-FT DEPTH
68-SEC WAVE PERIOD
SCALE IN FEET

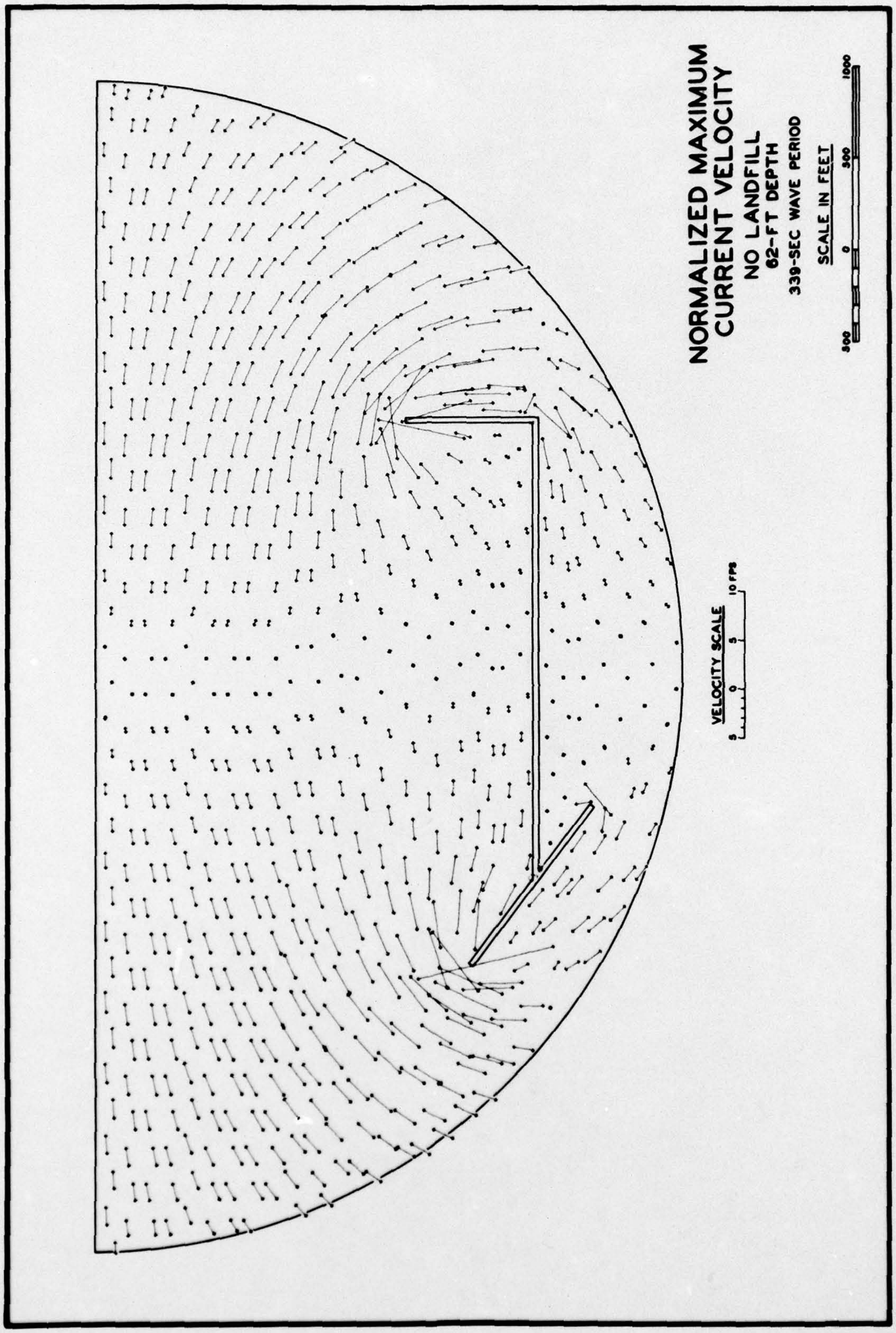
PLATE 13

PLATE 14



NORMALIZED MAXIMUM CURRENT VELOCITY

NO LANDFILL
62-FT DEPTH
124-SEC WAVE PERIOD


NORMALIZED MAXIMUM CURRENT VELOCITY

NO LANDFILL

62-FT DEPTH

339-SEC WAVE PERIOD

PLATE 15

APPENDIX A: NOTATION

a	Boundary of region A
A	Area of region inside a harbor
g	Acceleration due to gravity, 32.2 ft/sec^2
h	Water depth, ft
H_n	Hankel function of the first kind of order n
i	Imaginary number
k	Wave number, ft^{-1}
n	Integer
n_a	Unit vector normal to boundary a
r	Spherical coordinate, ft
t	Time, sec
u	Velocity in x-direction, ft/sec
v	Velocity in y-direction, ft/sec
w	Angular velocity, radians/sec
x	Cartesian coordinate, ft
y	Cartesian coordinate, ft
α_n	Unknown coefficient
∇	Gradient, ft^{-1}
η	Wave amplitude, ft
θ	Spherical coordinate, degrees
ϕ	Total velocity potential, ft^2/sec
ϕ_a	Total velocity potential evaluated on boundary a , ft^2/sec
ϕ_I	Incident velocity potential, ft^2/sec
ϕ_R	Far field velocity potential, ft^2/sec
ϕ_s	Scattered velocity potential, ft^2/sec

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Wanstrath, John J
Long Beach Harbor numerical analysis of harbor oscillations: Report 4: Alternate plans for Pier J completion and tanker terminal project (no landfill), by John J. Wanstrath. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper H-76-20, Report 4)
Prepared for Port of Long Beach, Long Beach, California.

1. Harbor oscillations. 2. Long Beach Harbor. 3. Numerical analysis. 4. Piers (Docks). 5. Tanker terminals. I. Port of Long Beach. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper H-76-20, Report 4)
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