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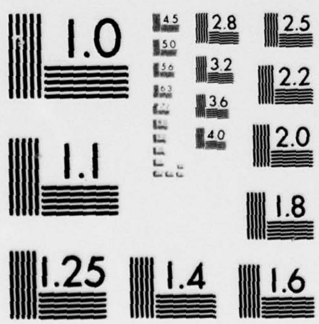

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TECHNICAL REPORT H-77-1

DESIGN FOR SMALL-BOAT HARBOR IMPROVEMENTS, PORT WASHINGTON HARBOR, WISCONSIN

Hydraulic Model Investigation

by

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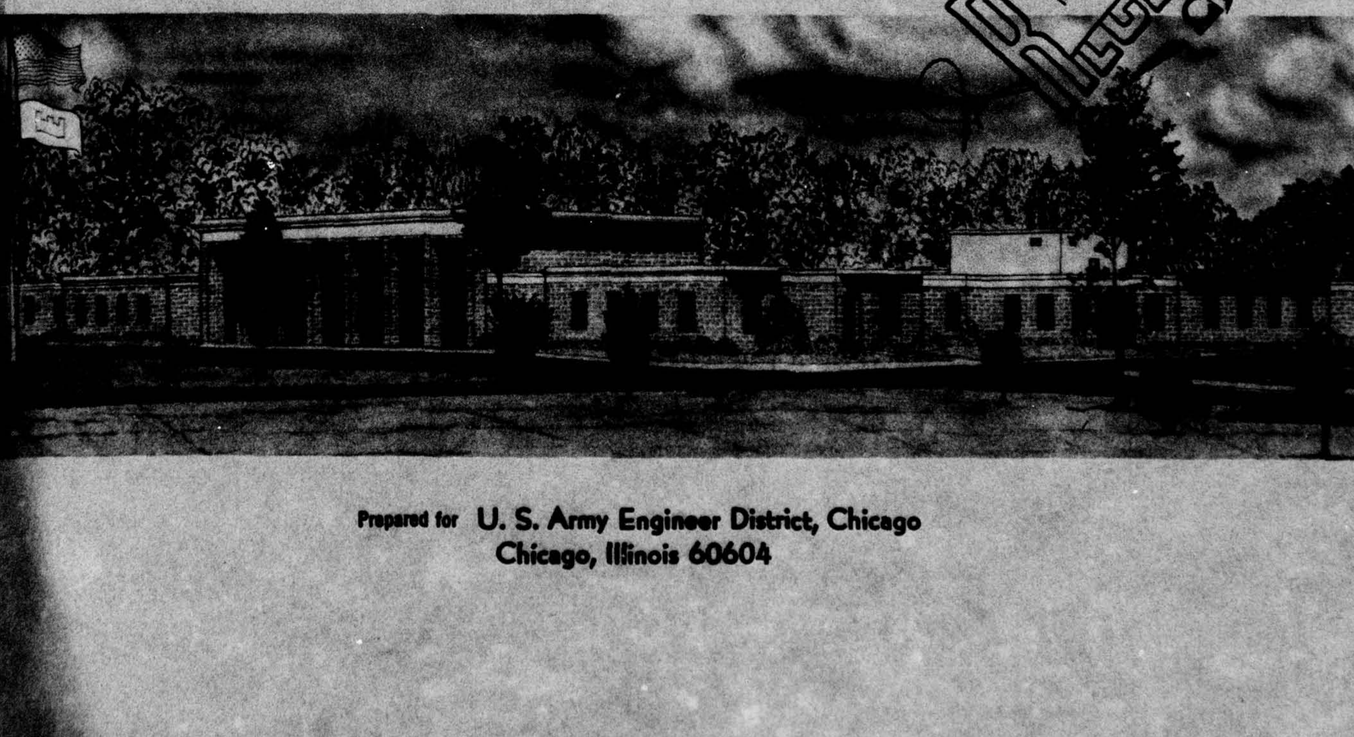
February 1977
Final Report



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 1:75-scale undistorted hydraulic model reproducing Port Washington Harbor, approximately 2600 ft of shoreline on each side of the harbor, and sufficient offshore area in Lake Michigan to permit generation of the required test waves was used to investigate the design of certain proposed improvements with respect to wave action. The proposed improvement plan consisted of (a) new rubble-mound breakwaters within the existing harbor aggregating about 1330 ft in length and arranged to form a protected harbor of approximately

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20. ABSTRACT (Continued)

13.5 acres; (b) a 10-ft-deep, 150-ft-wide entrance channel; (c) a 10-ft-deep anchorage-maneuvering area about 3.5 acres in extent; (d) an 8-ft-deep, 72-ft-wide launching ramp channel extending from the anchorage-manuevering area to a launching ramp; (e) a 500-ft-long wave absorber adjacent to the existing north breakwater; and (f) safety railings on the new breakwaters. A 50-ft-long wave generator, a centrifugal pump and flow meter, and an Automated Data Acquisition and Control System were utilized in model operation. It was concluded from test results that:

a. Existing conditions are characterized by very rough and turbulent waves in the vicinity of the proposed harbor during periods of severe wave attack.

b. The proposed improvement plan (plan 1) was considered inadequate in that wave heights exceeded the established wave-height criteria (a maximum of 2.0 ft in the turning basin and 1.0 ft in the mooring area) for all directions due to overtopping of the existing north breakwater and overtopping of the transmission through the proposed east and west breakwaters.

c. Of the improvement plans tested involving modifications to the north breakwater (adjacent to the proposed harbor), the concrete parapet wall (elevation of +12 ft lwd) in conjunction with wave absorber inside the breakwater (elevation of +4 ft lwd and 6 ft berm width) was determined to be optimal, considering wave protection afforded and cost.

d. To achieve the established wave-height criteria in the proposed small-boat harbor, it was determined that the crown elevations of the east and west breakwaters must be raised and/or an impervious center must be added.

e. Rubble-mound breakwater heads (plan 3) will reduce wave heights in the proposed small-boat harbor entrance somewhat; however, increasing the width of the entrance from 150 to 200 ft (plan 4) will increase wave heights in the entrance significantly.

f. The zigzag west breakwater alignment (plan 7A) resulted in smaller wave heights at the coal wharf (S 37°10' E direction) than did the straight west breakwater alignments (plans 6 and 8); however, maximum wave heights obtained at the coal wharf for plans 6 and 8 were comparable to those obtained for existing conditions, considering all directions tested.

g. Removal of 185 ft from the shore end of the west breakwater (plan 8) will improve wave-induced circulation without increasing wave heights in the proposed small-boat harbor.

h. Construction of the proposed small-boat harbor will have no adverse effects on the existing inner slips of the harbor.

i. Filling in approximately one third of the existing north slip (as requested by the city of Port Washington) (plan 9) will result in increased standing wave heights in the north slip.

j. The proposed small-boat harbor had no adverse effect on the circulation patterns from the Wisconsin Power and Electric Company water discharge, and the warm water discharge did not enter the proposed small-boat basin to any appreciable extent for the proposed improvement plans.

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PREFACE

A request for a model investigation of Port Washington Harbor, Wisconsin, was initiated by the District Engineer, U. S. Army Engineer District, Chicago (NCC). Authorization for the U. S. Army Engineer Waterways Experiment Station (WES) to perform the study was granted by the Office, Chief of Engineers. Funds were authorized by NCC on 27 June 1975 and 19 April 1976.

The model study was conducted at WES during the period June-November 1976 in the Wave Dynamics Division (WDD) of the Hydraulics Laboratory (HL) under the direction of Mr. H. B. Simmons, Chief of the HL, and Dr. R. W. Whalin, Chief of the WDD. The tests were conducted by Mr. R. R. Bottin, Jr., Project Engineer, with the assistance of Messrs. L. A. Barnes, P. Chamberlain, C. W. Coe, and R. E. Ankeny, under the supervision of Mr. C. E. Chatham, Jr., Chief of the Harbor Wave Action Branch. This report was prepared by Mr. Bottin.

Prior to the model investigation Messrs. Chatham and Bottin visited the NCC office and Port Washington Harbor to confer with representatives of NCC and to inspect the prototype harbor. During the course of the investigation, liaison between NCC and WES was maintained by means of conferences, telephone communications, and monthly progress reports.

Mr. Charlie Johnson of U. S. Army Engineer Division, North Central (NCD), and Messrs. Norm Arno and Jim Mazanec of NCC visited WES to observe model operation and participate in conferences during the course of the model study.

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

This investigation was the third model study of wave action in Port Washington Harbor conducted by the WES. The first was completed in 1935 and reported in WES TM No. 87-1, "Model Study of Proposed Improvements to the Harbor of Port Washington, Wisconsin," dated November 1935, and the second was completed in 1950 and reported in

WES TM No. 2-334, "Wave Action and Breakwater Location, Port Washington Harbor, Wisconsin," dated November 1951.

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
miles (U. S. statute)	1.609344	kilometres
acres	4047.0	square metres
square feet	0.092903	square metres
square miles	2.58999	square kilometres
feet per second	0.3048	metres per second
miles per hour	1.609344	kilometres per hour
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2000 lb, mass)	907.1847	kilograms
gallons per minute	0.06308	cubic decimeters per second

DESIGN FOR SMALL-BOAT HARBOR IMPROVEMENTS

PORT WASHINGTON HARBOR, WASHINGTON

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

Existing conditions

1. Port Washington, Wisconsin, is on the west shore of Lake Michigan about 29 miles* north of Milwaukee, Wisconsin, and 27 miles south of Sheboygan, Wisconsin (Figure 1). The city, which had a population of 8700 in 1970,[1] is a trading center and the seat of Ozaukee County. The downtown portions of the business and manufacturing sections have been developed around the harbor.

2. Port Washington Harbor (Figure 2) is entirely artificial and is located at the outlet of a small stream known as Sauk Creek. The harbor area comprises approximately 60 acres and is enclosed by a 3500-ft-long breakwater system. The outer harbor is maintained at a project depth of 21 ft and the inner harbor, or slip area, is maintained at a project depth of 18 ft.

Proposed improvements

3. Proposed improvements to the small-boat harbor within the existing deep-draft harbor at Port Washington consist of the following:

- a. New east and west breakwaters with lengths of 320 and 1010 ft, respectively, arranged to form a protected harbor of approximately 13.5 acres. These breakwaters will be rubble-mound structures with two steel sheet-pile cells used as each breakwater head.
- b. A 10-ft-deep, 150-ft-wide entrance channel.
- c. A 10-ft-deep anchorage-maneuvering area approximately 3.5 acres in extent.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 5.

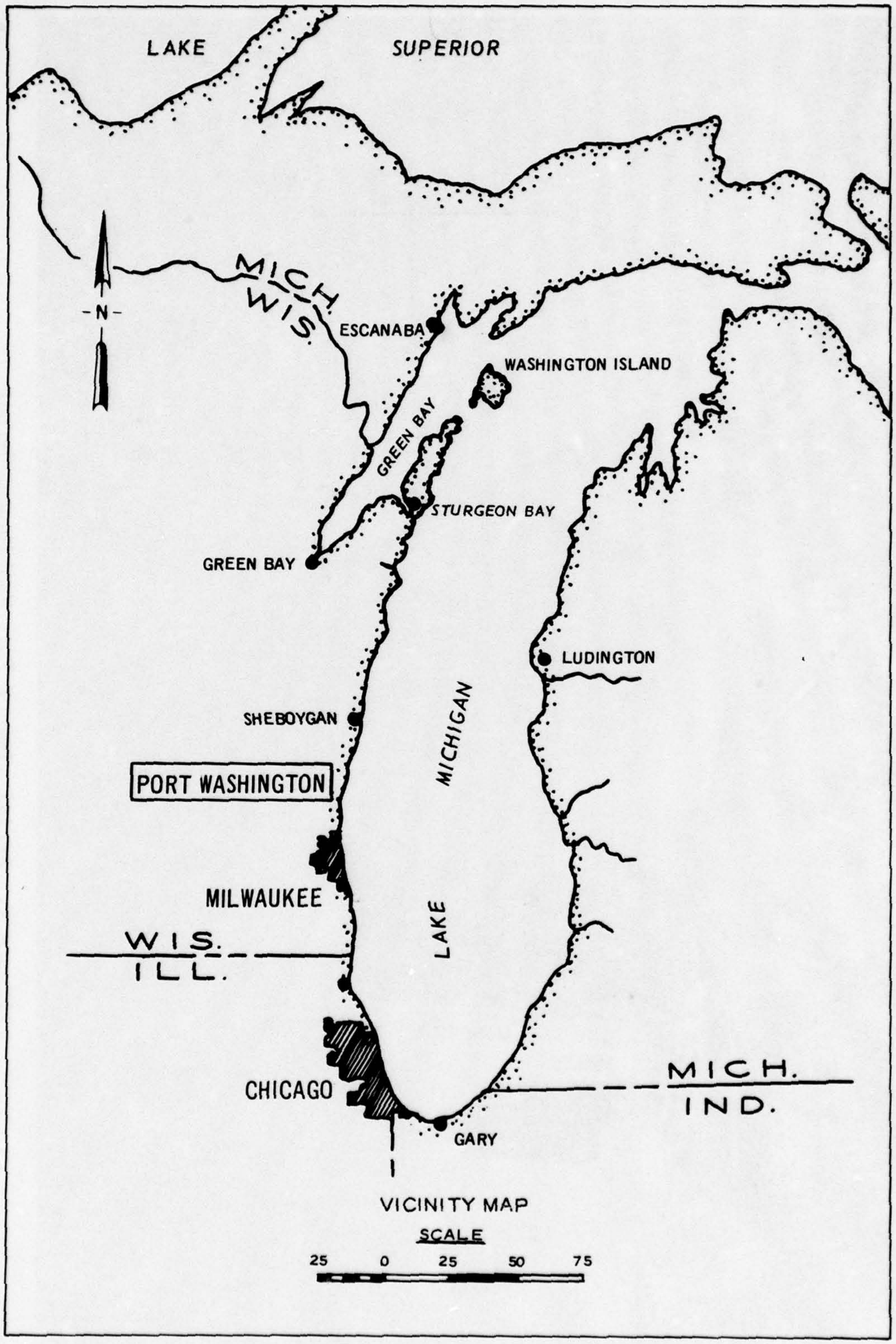

Figure 1. Project location

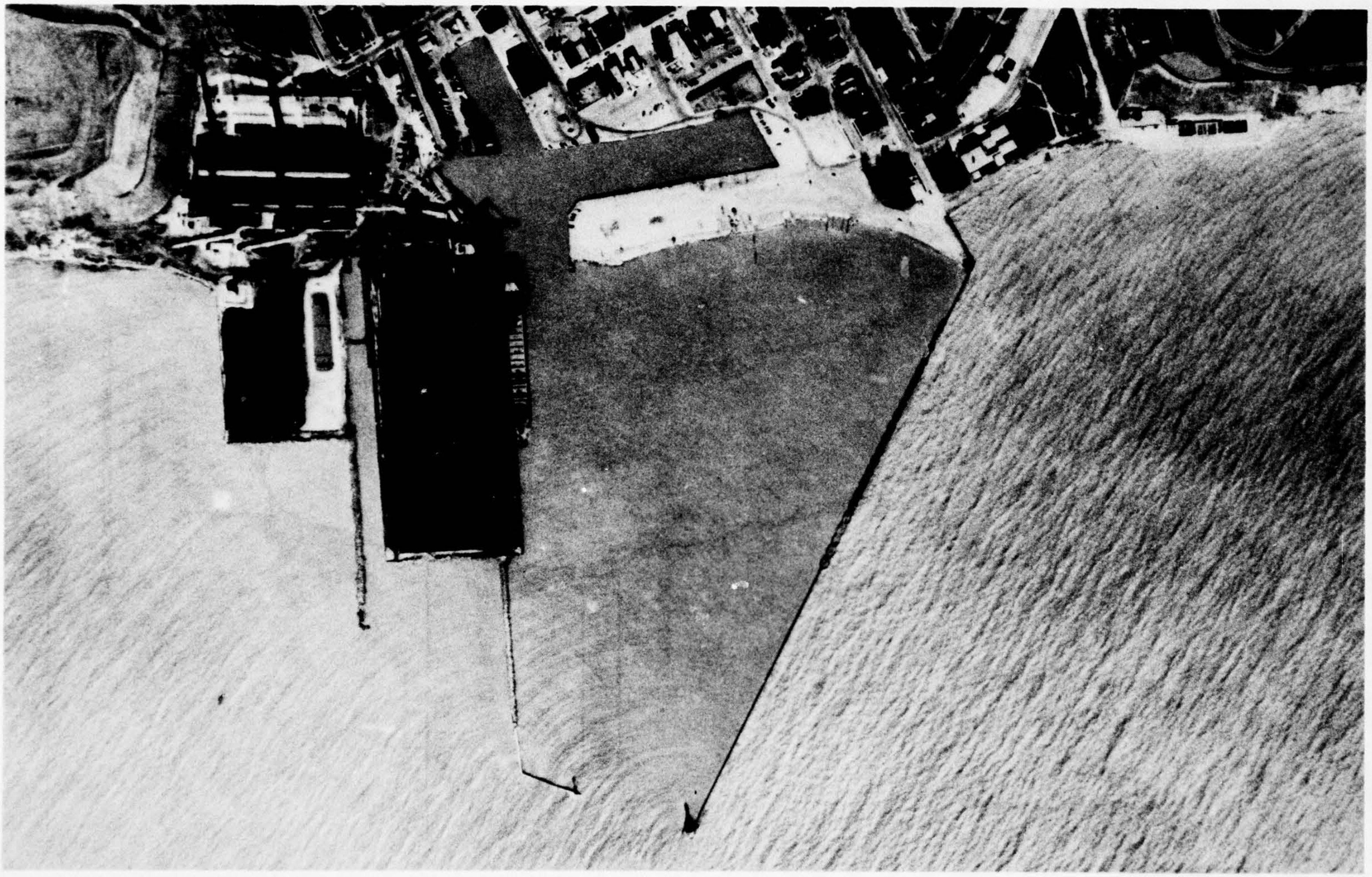

Figure 2. Aerial view of Port Washington Harbor

d. An 8-ft-deep, 72-ft-wide launching ramp channel extending from the anchorage-maneuvering area to a launching ramp.

e. A 500-ft-long rubble-mound wave absorber, adjacent to the existing north breakwater and extending northwesterly from the new east breakwater at its junction with the north breakwater.

f. Safety railings on the new east and west breakwaters.

The Problem

4. Port Washington Harbor is exposed to waves generated by storms from northeast clockwise to south-southeast. Waves caused by storms from these directions have caused considerable damage to harbor facilities and recreational boats, and created difficulties for ships and recreational craft navigating the harbor entrance. Violent wave action, caused by waves reflected from vertical steel sheet-pile bulkheads, has resulted in wave heights up to 12 ft in the slip areas of the inner harbor. Anchorage in the outer basin is not safe for small boats because of the lack of adequate wave protection. These conditions make the harbor unsafe as a harbor-of-refuge for small boats, resulting in no adequate small-boat refuge between Milwaukee and Sheboygan, a distance of 56 miles. In addition, there is a lack of adequately protected permanent mooring and docking facilities to accommodate the great demand for such facilities in the Port Washington area.

Purpose of Model Study

5. At the request of the U. S. Army Engineer District, Chicago (NCC), a hydraulic model study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) to:

a. Determine whether the proposed harbor improvements would provide adequate wave protection for small boats moored in the harbor.

b. Develop remedial plans necessary for the alleviation of undesirable wave conditions.

c. Determine methods to provide adequate circulation in the proposed harbor.

d. Determine whether suitable design modifications of the proposed plan could be made that would reduce construction costs significantly and still provide adequate wave protection.

e. Determine if waves reflected from the west breakwater had an adverse effect on wave heights at the Wisconsin Electric Power Company coal wharf.

Wave-Height Criteria

6. Completely reliable criteria have not yet been developed for ensuring that satisfactory navigation and mooring conditions will be obtained in small-craft harbors during attacks by waves. However, for the study reported herein, the U. S. Army Engineer Division, North Central (NCD), specified that for an improvement plan to be acceptable, heights for waves occurring during the boating season (spring and summer) should not exceed 2.0 ft in the turning basin of the harbor and 1.0 ft in the mooring area. In addition, wave heights not exceeding 0.5 ft were desired in the mooring area for some test plans as a basis for plan formulation studies.

PART II: THE MODEL

Design of the Model

7. The Port Washington Harbor model (Figure 3) was constructed to a linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

- a. The depth of water required in the model to prevent excessive bottom friction effects.
- b. The absolute size of model waves.
- c. Available shelter dimensions and the area required for constructing the model.
- d. Efficiency of model operation.
- e. Capabilities of available wave-generating and wave-measuring equipment.
- f. Cost of model construction.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law.[2] The scale relations used for the design and operation of the model were as follows:

Characteristic	Dimension*,**	Model:Prototype Scale Relation
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$V = L_r^3 = 1:421,875$
Time	T	$T = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$
Discharge	L^3/T	$Q_r = L_r^{5/2} = 1:48,715$

* Dimensions are in terms of length L and time T .
** For convenience, symbols and unusual abbreviations are listed and defined in Appendix B.

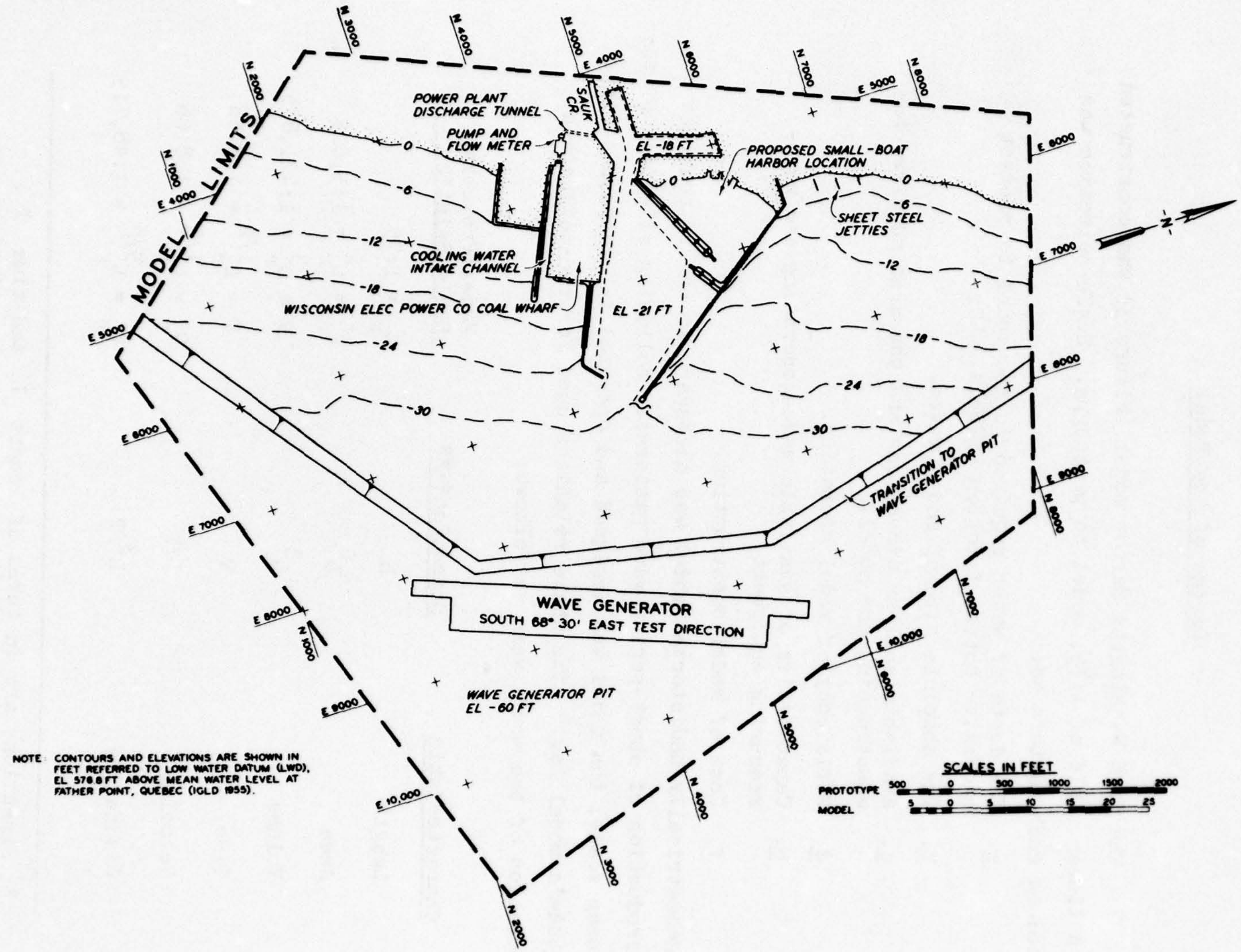

Figure 3. Model layout

8. The proposed improvement plans for Port Washington Harbor included the use of rubble-mound breakwaters and wave absorbers. Portions of the existing breakwaters are rubble-mound structures. Past experience and experimental research have shown that considerable wave energy passes through the interstices of this type of structure; thus, transmission and absorption of wave energy became a matter of concern in the design of the 1:75-scale model. In small-scale harbor models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than do geometrically similar prototype structures.[3] Also, transmission of wave energy through the breakwater is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations[4,5] at WES, this adjustment was made by determining the wave energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A breakwater section was then developed for the small-scale three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, based on previous findings for breakwaters and wave conditions similar to those at Port Washington, it was determined that a close approximation of the correct wave energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:75-scale model to approximately 1.5 times that required for geometric similarity. Accordingly, in constructing the breakwater structures in the Port Washington model, rock sizes were computed linearly by scale and then multiplied by 1.5 to determine the actual sizes used in the model. Portions of the existing Port Washington breakwaters are constructed of steel sheet-piling and concrete. In the model study these structures were considered to be impervious and were constructed of sheet metal.

The Model and Appurtenances

9. The model, which was molded in cement mortar, reproduced the

existing Port Washington Harbor, approximately 2600 ft of the Lake Michigan shoreline on each side of the harbor, and underwater contours in Lake Michigan to an offshore depth of 35 ft with a sloping transition to the wave generator pit elevation* of -60 ft. The total area reproduced in the model was approximately 8660 sq ft, representing about 1.75 sq miles in the prototype. Figure 4 is a general view of the model. Vertical control for model construction was based on low water datum (lwd), the elevation of which is 576.8 ft above mean water level at Father Point, Quebec (International Great Lakes Datum, 1955).[1] Horizontal control was referenced to a local prototype grid system.

10. Model waves were generated by a 50-ft-long wave generator with a trapezoidal-shaped, vertical-motion plunger. The vertical movement of the plunger caused a periodic displacement of water incident to this motion. The length of the stroke and the period of vertical motion were variable over the range necessary to generate waves with the required characteristics. In addition, the wave generator was mounted on retractable casters, which enabled it to be positioned to generate waves from the required test directions.

11. A water-circulating system (Figure 3) consisting of intake and discharge pipes, a centrifugal pump, and a flowmeter were used in the model to reproduce to scale the intake and discharge of cooling water from the Wisconsin Electric Power Company plant. This plant discharges about 550,000 gpm into the harbor when operating five 80,000-kw generating units (about 80 percent of the time). The corresponding scaled value of 11.3 gpm was reproduced during all model tests. Water was pumped from the intake channel and discharged at the northwest limit of the coal wharf adjacent to the mouth of Sauk Creek.

12. An Automated Data Acquisition and Control System (ADACS) designed and constructed at WES (Figure 5) was used to secure wave-height data at selected locations in the model. Basically, through the use of a minicomputer, ADACS recorded onto magnetic tape the

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* All elevations (el) cited herein are in feet referred to low water datum (lwd).

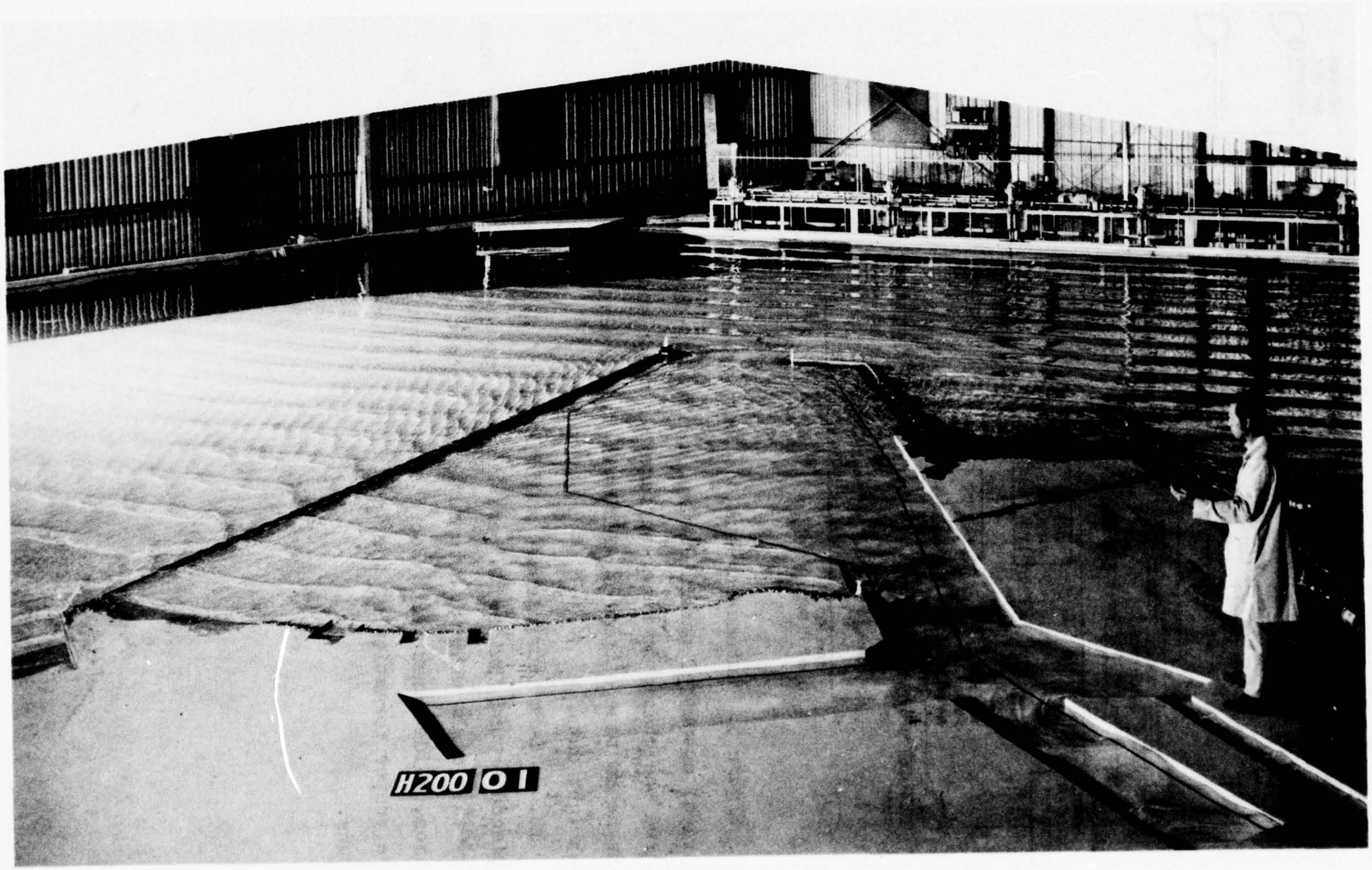

Figure 4. General view of model

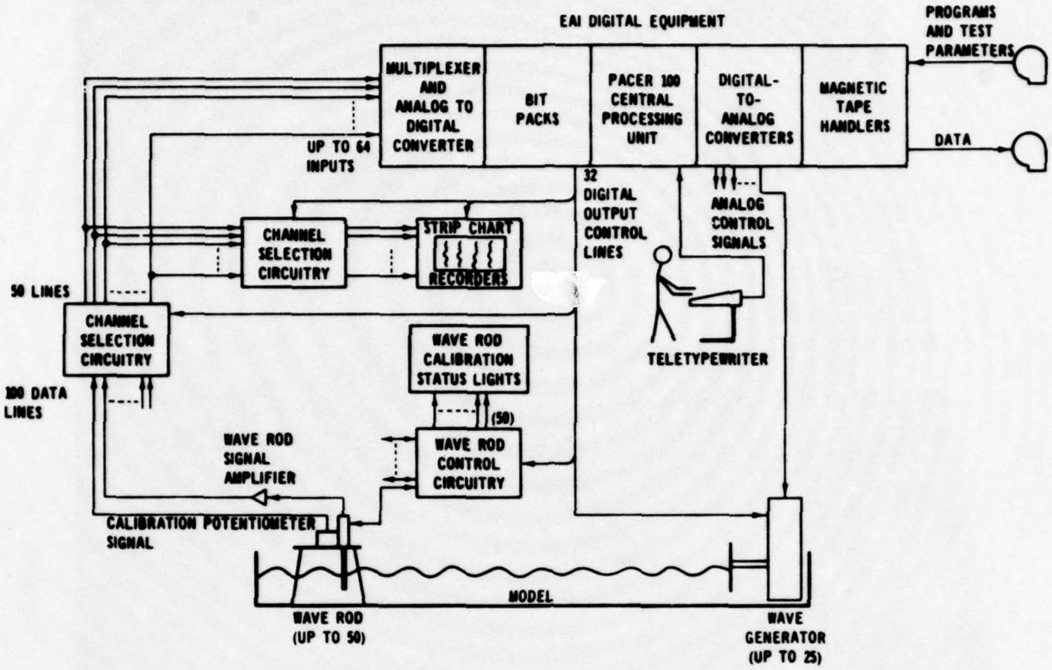

Figure 5. Automated Data Acquisition and Control System

electrical output of parallel-wire, resistance-type wave gages that measured the change in water-surface elevation with respect to time. The magnetic tape output of ADACS was then analyzed to obtain the wave-height data.

13. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides to ensure proper formation of the wave train incident to the model contours.

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

14. Still-water levels (swl) for harbor wave-action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the harbor area, the overtopping of harbor structures by the waves, the reflection of wave energy from harbor structures, and the transmission of wave energy through porous structures.

15. Water levels on the Great Lakes vary from year to year and from month to month. In many locations the water level can fluctuate daily or hourly. Since 1860, continuous records of water levels on the Great Lakes have been recorded and maintained. Typical seasonal variations of the lakes consist of high stages in the summer months and low stages in the winter months. For Lake Michigan the higher levels usually occur in July and the lower levels in February. During the period of record (1860-1973) the average lake level of Lake Michigan was +1.9 ft.[1] The highest one-month average level of +5.14 ft occurred in June 1886 and the lowest one-month average level of -1.45 ft occurred in March 1964. The greatest annual fluctuation as shown by the highest and lowest monthly means of any year was 2.23 ft, and the least annual fluctuation was 0.36 ft.

16. Seasonal and longer variations in the levels of the Great Lakes are caused by variations in precipitation and other factors that affect the actual quantities of water in the lakes. Wind tides and seiches are relatively short-period fluctuations caused by the tractive force of wind blowing over the water surface and by differential barometric pressures and are superimposed on the longer period variations in the lake level. Short-period fluctuations for the Milwaukee Harbor (29 miles south of Port Washington) indicate that a rise of 1.3 ft will occur once each year.[6] Large short-period rises in local

water level are associated with the most severe storms, which generally occur in the winter when the lake level is usually low; thus the probability that a high lake level and a large wind tide or seiche will occur simultaneously is relatively small.

17. An swl of +3.9 ft lwd was selected for use during model testing. This value was obtained from lake stage frequency curves (furnished by NCC) for Milwaukee and Sturgeon Bay, Wisconsin (Plate 1), for a 10-year recurrence interval during boating season (May-October).

Factors influencing selection of test wave characteristics

18. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, the water distance (fetch) over which the wind blows, and water depth. Selection of test wave conditions entails evaluation of such factors as:

- a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generated area) for various directions from which waves can attack the problem area.
- b. The frequency of occurrence and duration of storm winds from the different directions.
- c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.
- d. The alignments, lengths, and locations of various reflecting surfaces inside the harbor.
- e. The refraction of waves caused by differentials in depth in the area lakeward of the harbor, which may create either a concentration or diffusion of wave energy at the harbor site.

Wave refraction

19. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period. The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction can be determined by plotting refraction diagrams and calculating refraction coefficients. These diagrams are constructed by plotting the position of wave orthogonals (lines drawn perpendicular to wave crests) from deep water into shallow water. If it is assumed that the waves do not break and that there is no lateral flow of energy, the ratio between the wave height in deep water H_o and the wave height at any point in shallow water H is inversely proportional to the square root of the ratio of the corresponding orthogonal spacings b_o and b, or $H/H_o = K_s(b_o/b)^{1/2}$, where $(b_o/b)^{1/2}$ is the refraction coefficient K_r, and K_s is the shoaling coefficient. Thus, the refraction coefficient multiplied by the shoaling coefficient gives a conversion factor for transfer of deepwater wave heights to shallow-water values. The shoaling coefficient, which is a function of wave length and water depth, can be obtained from Reference 7. For this study, wave refraction diagrams were prepared for representative wave periods from the critical directions of approach using computer facilities at WES; details of the analysis are given in Appendix A.

Prototype wave data and selection of test waves

20. Measured prototype wave data on which a comprehensive statistical analysis of wave conditions could be based were unavailable for the Port Washington area. However, statistical deepwater wave hindcast data for this area were obtained from Reference 8. Reference 8 covers deepwater waves approaching from three angular sectors at the site as shown in Plate 2. Table 1 gives the significant wave heights for all approach angles and seasons combined for recurrence intervals of 5, 10, 20, 50, and 100 years. Table 2 shows significant wave period by

angle class and wave height. The characteristics of waves used during model testing were representative of wave conditions occurring during spring and summer (boating season). Maximum wave heights for spring and summer conditions were obtained for a 20-year recurrence interval. These test waves were used to design the proposed small-boat harbor. In addition, maximum wave heights for the entire year (20-year recurrence interval) were tested to aid in design of the proposed breakwaters. Model test waves were selected from Tables 1 and 2 and converted to shallow-water values by application of refraction and shoaling coefficients as shown in the following tabulation:

Deepwater Direction	Shallow-water Direction	Wave Period Sec	Deepwater Wave Height, ft	Shallow-water Wave Height, ft	Recurrence Interval Year
NE & ENE	N76°20'E	6.0	4.7	4.3	5.1
		7.7	5.0	4.2	6.9
		7.7	9.2	7.7	20
		10.4*	17.1*	14.7*	20
E	S85°50'E	5.5	4.0	3.8	0.33
		7.3	6.0	5.3	6.6
		7.3	10.8	9.6	20
		8.2*	14.8*	12.7*	20
ESE	S68°30'E	5.5	4.0	3.8	0.33
		7.3	6.0	5.5	6.6
		7.3	10.8	9.9	20
		8.2*	14.8*	13.5*	20
SE	S50°45'E	5.5	4.0	3.8	0.33
		7.3	6.0	5.5	6.6
		7.3	10.8	9.9	20
		8.2*	14.8*	13.6*	20
SSE	S37°10'E	6.0	4.4	3.7	1.6
		8.3	4.0	3.4	5.3
		8.3	8.0	6.9	5.4
		8.3	12.1	10.4	20
		9.4*	15.7*	13.8*	20

* Wave characteristics for the entire year. All others for spring and summer only.

The shallow-water wave directions were taken to be the average directions of the refracted waves for the significant wave periods noted from each deepwater wave direction.

Analysis of Model Data

21. Relative merits of the various plans were evaluated by:

   a. Comparison of wave heights at selected locations in the harbor.

   b. Comparison of current patterns and magnitudes.

   c. Visual observations and wave pattern photographs.

In analyzing the wave-height data, the average height of the highest one third of the waves recorded at each gage location was selected. All wave heights thus selected were then adjusted to compensate for wave height attenuation due to viscous bottom friction in the model by application of Keulegan's equation.[9] From this equation, reduction of wave heights in the model can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel. Current magnitudes were obtained by timing the progress of an injected dye tracer relative to a known distance on the model surface.

PART IV: TESTS AND RESULTS

The Tests

Existing conditions

22. Prior to tests of various improvement plans, comprehensive tests were conducted for existing conditions. Wave-height data were obtained at various locations inside the harbor (Plate 3) for the test directions listed in paragraph 20. Wave-induced current patterns and magnitudes and wave pattern photographs also were secured for representative waves from the five selected test directions.

Improvement plans

23. Wave-height tests were conducted for 32 variations of the originally proposed harbor design. These variations consisted of modifications to that portion of the existing north breakwater adjacent to the proposed small-boat harbor and to the proposed east and west breakwaters. Modifications to the north breakwater included raising the crown elevation, installing absorber plans as alternatives to raising the crown elevation, installing absorber plans in conjunction with raising the crown elevation, using the existing breakwater as a core for a rubble-mound structure, and installing a concrete parapet wall on the existing breakwater both with and without wave absorber. Modifications to the proposed east and west breakwaters consisted of changes in the crown elevation, alignments, breakwater heads, cross sections of the structures, and the lengths. Wave pattern photographs and current patterns and magnitudes were obtained for the originally proposed plan and the more important improvement plans. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are presented in Plates 4-12. Typical breakwater and absorber sections are shown in Plates 13-15 for existing conditions and plans 1-9.

a. Plan 1 (Plate 4) consisted of the originally proposed harbor design. This plan included a 1010-ft-long west breakwater; a 320-ft-long east breakwater; a 150-ft-wide, 10-ft-deep entrance channel; a 10-ft-deep anchorage maneuvering area, approximately 3.5 acres in extent; a 72-ft-wide, 8-ft-deep launching ramp channel extending from the anchorage-maneuvering area to a launching ramp; and a 500-ft-long rubble-mound wave absorber, adjacent to the existing north breakwater and extending northwesterly from the new east breakwater at its junction with the north breakwater.

b. Plan 1A (Plate 4) consisted of the elements of plan 1 but the wave absorber was removed.

c. Plan 1B (Plate 4) entailed the elements of plan 1A with the crown elevation of the north breakwater raised to +9 ft.

d. Plan 1C (Plate 4) involved the elements of plan 1A with the crown elevation of the north breakwater raised to +11 ft.

e. Plan 1D (Plate 4) consisted of the elements of plan 1A with the crown elevation of the north breakwater raised to +13 ft.

f. Plan 1E (Plate 4) entailed the elements of plan 1A with the crown elevation of the north breakwater raised to +15 ft.

g. Plan 1F (Plate 5) involved the elements of plan 1A with a 900-ft-long wave absorber installed inside the harbor adjacent to the north breakwater with an elevation of +7 ft and a berm width of 6 ft.

h. Plan 1G (Plate 5) consisted of the elements of plan 1F except the absorber berm width was 12 ft.

i. Plan 1H (Plate 5) entailed the elements of plan 1F but the absorber berm width was 18 ft.

j. Plan 1I (Plate 5) involved the elements of plan 1F except a 950-ft wave absorber was installed outside the harbor, adjacent to the north breakwater.

k. Plan 1J (Plate 5) consisted of the elements of plan 1I but the absorber berm width was 12 ft.

l. Plan 1K (Plate 5) entailed the elements of plan 1I except the absorber berm width was 18 ft.

m. Plan 1L (Plate 5) involved the elements of plans 1F and 1J, resulting in a combined absorber berm width (both inside and outside the harbor) of 18 ft.

n. Plan 1M (Plate 5) consisted of the elements of plans 1F and 1K resulting in a combined absorber berm width of 24 ft.

o. Plan 1N (Plate 5) entailed the elements of plans 1G and

1K resulting in a combined absorber berm width of 30 ft.

p. Plan 1O (Plate 5) involved the elements of plan 1B with wave absorber installed inside the harbor adjacent to the north breakwater with an elevation of +9 ft and a berm width of 6 ft.

q. Plan 1P (Plate 5) consisted of the elements of plan 1C with wave absorber installed inside the harbor adjacent to the north breakwater with an elevation of +11 ft and a berm width of 6 ft.

r. Plan 1Q (Plate 5) entailed the elements of plan 1E with wave absorber installed inside the harbor adjacent to the north breakwater with an elevation of +15 ft and a berm width of 6 ft.

s. Plan 1R (Plate 6) involved using the existing north breakwater as a core for a rubble-mound structure. Wave absorbers with a 6-ft berm width and an elevation of +7 ft were installed on each side of the breakwater. One layer of armor stone was placed on top of the existing breakwater and absorbers, resulting in a crown elevation of +10 ft.

t. Plan 1S (Plate 6) consisted of the elements of plan 1R but two layers of armor stone were placed on top of the existing breakwater and absorbers, resulting in a crown elevation of +13 ft.

u. Plan 2 (Plate 6) entailed the elements of plan 1R with the east and west breakwaters raised to a crown elevation of +10 ft.

v. Plan 2A (Plate 6) involved the elements of plan 1R with the east and west breakwaters raised to a crown elevation of +12 ft.

w. Plan 3 (Plate 7) consisted of the elements of plan 2A but the cellular sheet-pile heads of the east and west breakwaters were replaced with rubble-mound heads.

x. Plan 4 (Plate 7) entailed the elements of plan 3 except the east breakwater was shifted lakeward increasing the width of the entrance channel from 150 to 200 ft.

y. Plan 5 (Plate 8) involved the elements of plan 3 but an 825-ft-long concrete parapet wall was installed on the north breakwater to an elevation of +12 ft and the wave absorber adjacent to the north breakwater was removed. In addition, the outer 150 ft of the north sheet pile shore connection was raised to an elevation of +12 ft.

z. Plan 5A (Plate 8) consisted of the elements of plan 5 with wave absorber installed adjacent to the north breakwater inside the harbor with an elevation of +4 ft and a berm width of 6 ft.

aa. Plan 5B (Plate 8) entailed the elements of plan 5A except the concrete parapet wall was raised to an elevation of +14 ft.

bb. Plan 6 (Plate 9) involved the elements of plan 5A but the east and west breakwaters were constructed with crown elevations of +10 and +8 ft, respectively, with impervious sheet-pile centers.

cc. Plan 6A (Plate 9) consisted of the elements of plan 6 except the east and west breakwaters were constructed with crown elevations of +12 and +10 ft, respectively.

dd. Plan 7 (Plate 10) entailed the elements of plan 6 but the west breakwater was constructed in a zig-zag alignment. The zig-zag section of this breakwater did not include an impervious sheet-pile center.

ee. Plan 7A (Plate 10) involved the elements of plan 7 except the zig-zag section of the west breakwater did include an impervious sheet-pile center.

ff. Plan 8 (Plate 11) consisted of the elements of plan 6 but the east breakwater was constructed to a crown elevation of +12 ft without an impervious sheet-pile center, and 185 ft of the shore end of the west breakwater was removed.

gg. Plan 9 (Plate 12) entailed the elements of plan 8 but approximately one third of the existing north slip was filled in. This plan is a proposal by the city of Port Washington.

Wave-height tests

24. Wave-height tests for the various improvement plans were conducted using test waves from one or more of the test directions listed in paragraph 20. Tests involving certain proposed improvement plans were limited to the most critical direction of wave approach (i.e., the N76°20'E test direction involving modifications to the north breakwater and the S37°10'E direction involving changes to the proposed east and west breakwaters). However, major plans of improvement were tested comprehensively for the test waves from all five test directions (i.e., N76°20'E, S85°50'E, S68°30'E, S50°45'E, and S37°10'E). Wave gage locations for each improvement plan are shown in Plates 4-12.

Current pattern and magnitude tests

25. Wave-induced current patterns and magnitudes were determined at selected locations by timing the progress of a dye tracer relative

to a known distance on the model floor. These tests were conducted for the major improvement plans using test waves from one or more of the test directions listed in paragraph 20.

Movie

26. A 20-min movie of Port Washington Small-Boat Harbor model was secured for existing conditions and plan 8 and forwarded to NCC for use in public meetings. Included in the movie footage were the following:

- a. A general view of Port Washington Harbor model (existing conditions, plan 8).
- b. Discharge from the Wisconsin Electric Power Company plant (existing conditions).
- c. The north breakwater (adjacent to the proposed harbor) under attack by 6-sec, 4.3-ft and 7.7-sec, 7.7-ft waves from N76°20'E (existing conditions, plan 8).
- d. Excitation of the inner slips by 5.5-sec, 3.8-ft and 7.3-sec, 9.9-ft waves from S68°30'E (existing conditions).
- e. Wave conditions at the coal wharf for 5.5-sec, 3.8-ft and 7.3-sec, 9.9-ft waves from S68°30'E (plan 8).
- f. The proposed small-boat harbor site under attack by 6-sec, 3.7-ft and 8.3-sec, 10.4-ft waves from S37°10'E (existing conditions, plan 8).

Igloo wave absorber tests

27. Igloo wave absorber tests (sponsored by Nippon Tetrapod Company, Ltd.) were conducted with Igloo absorber units installed at various locations in the slip areas of the existing harbor. Tests were also conducted using Igloo absorber units as alternatives to the rubble-mound breakwater and wave absorber in the proposed small-boat harbor. Results of these tests are presented in Reference 10.

Test Results

28. In evaluating test results, the relative merits of each plan were based on an analysis of measured wave heights and wave-induced current patterns and magnitudes. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations. Most wave-induced current patterns and magnitudes were

superimposed on wave pattern photographs for the corresponding plan and wave condition tested; however, some current patterns and magnitudes were plotted on plates for the plan and wave condition tested.

Existing conditions

29. Initial wave-height measurements obtained for existing conditions (gages 1-15) are presented in Table 3. Maximum wave heights recorded for spring and summer wave conditions were 14.8 ft in the entrance to the existing deep draft harbor (gage 1) for 7.3-sec, 9.9-ft test waves from S68°30'E, 12.2 ft at the entrance to the proposed small-boat harbor (gage 6) for 8.3-sec, 10.4-ft test waves from S37°10'E; 8.4 ft in the proposed mooring area (gage 10) for 8.3-sec, 6.9-ft test waves from S37°10'E; and 13.3 ft in the inner slip area of the existing harbor (gage 14) for 7.3-sec, 9.9-ft test waves from S68°30'E.

30. Wave heights obtained for existing conditions at the coal wharf (gages 16-24) are presented in Table 4 for the N76°20'E, S68°30'E, and S37°10'E test directions. Maximum wave heights obtained were 23.6, 15.3, and 12.4 ft for the N76°20'E, S68°30'E, and S37°10'E test directions, respectively.

31. Wave-height data collected for existing conditions in the inner slip areas (gages 27-41) are presented in Table 5 for the S68°30'E test direction. Maximum wave heights recorded were 14.5 and 15.0 ft in the corners of the west and north slips, respectively.

32. Wave-induced current patterns and magnitudes secured for existing conditions are shown in Photos 1-15. Current velocities in the vicinity of the proposed mooring area ranged from 0.1 to 3.9 fps. Typical wave patterns for existing conditions also are shown in Photos 1-15.

33. Using wave heights collected for existing conditions in the vicinity of the proposed breakwater structures, armor stone sizes were calculated by WES personnel using design procedures from Reference 7. Based on a 10.6-ft design wave, the following stone sizes are required for stability and were used in the model: armor layer, 4.2 tons; first underlayer, 842 lb; and core stone, 42 lb. In addition, wave heights were measured outside the north breakwater, and a 10.3-ft wave height was obtained for 10.4-sec, 14.7-ft test waves from N76°20'E to aid in

the design of various modifications to that portion of the north breakwater adjacent to the proposed harbor.

Improvement plans

34. Results of wave-height tests with plan 1 installed in the model are presented in Table 6. Maximum wave heights obtained were 11.6 ft in the entrance to the existing deep draft harbor (gage 1) for 7.3-sec, 9.9-ft test waves from S68°30'E; 6.5 ft in the entrance to the proposed small-boat harbor (gage 6) for 8.3-sec, 10.4-ft test waves from S37°10'E; 3.4 ft in the turning basin of the proposed harbor (gage 7) for 7.3-sec, 9.6-ft test waves from S85°50'E; 3.2 ft in the proposed mooring area (gage 10) for 7.3-sec, 9.6-ft test waves from S85°50'E; and 10.5 ft in the inner slip areas of the existing harbor (gage 14) for 7.3-sec, 9.6-ft test waves from S85°50'E. Typical wave patterns for representative test waves from various directions with plan 1 installed in the model are shown in Photos 16-27.

35. Results of wave-height tests with plans 1A-1E installed are presented in Table 7 for the N76°20'E test direction. Maximum wave heights obtained in the turning basin (gages 7-9) for plans 1A-1E were 4.4, 3.2, 2.1, 1.6, and 1.1 ft, respectively, while maximum wave heights obtained in the mooring area (gages 10-11) were 2.2, 1.5, 1.1, 0.9, and 0.7 ft, respectively. Curves depicting maximum wave heights in the turning basin and mooring area versus crown elevation of the north breakwater are shown in Plate 16. A crown elevation of +13 ft (plan 1D) was required to achieve the established wave-height criteria (a maximum of 2.0 ft in the turning basin and 1.0 ft in the mooring area).

36. Wave-height measurements collected for plans 1F-1H are presented in Table 8 for the N76°20'E test direction. Maximum wave heights obtained were 2.2, 2.0, and 1.6 ft in the turning basin and 2.6, 2.2, and 1.6 ft in the mooring area for plans 1F-1H, respectively. Curves representing maximum wave heights in the turning basin and mooring area versus the wave absorber berm width inside the north breakwater are shown in Plate 17. The wave-height criterion in the mooring area was exceeded for plans 1F-1H.

37. Results of wave-height tests with plans 1I-1K installed in

the model are presented in Table 8 for the N76°20'E test direction. Maximum wave heights secured for plans 1I-1K were 3.0, 1.8, and 1.5 ft and 1.9, 1.6, and 1.3 ft in the turning basin and mooring area, respectively. Curves depicting maximum wave heights in the turning basin and mooring area versus the wave absorber berm width outside the breakwater are presented in Plate 18. Again the wave-height criterion in the mooring area was exceeded for plans 1I-1K.

38. Wave-height measurements obtained with plans 1L-1N installed are presented in Table 9 for the N76°20'E test direction. Maximum wave heights were 1.5, 1.1, and 1.0 ft in the turning basin and 1.5, 1.0, and 0.8 ft in the mooring area for plans 1L-1N, respectively. Curves showing maximum wave heights in the turning basin and mooring area versus the combined absorber width (inside and outside the north breakwater) are presented in Plate 19. A combined berm width of 24 ft (plan 1M) was necessary to achieve the established wave-height criteria.

39. Results of wave-height tests for plans 1O-1Q are presented in Table 9 for the N76°20'E test direction. Maximum wave heights recorded in the turning basin were 1.5, 0.6, and 0.3 ft while maximum wave heights obtained in the mooring area were 1.2, 0.5, and 0.4 ft for plans 1O-1Q, respectively. Curves plotted showing maximum wave heights in the turning basin and mooring area versus the crown elevation of the north breakwater and absorber are presented in Plate 20. Plan 1P (+11 ft breakwater crown elevation in conjunction with +11 ft absorber elevation installed inside breakwater) satisfied the established wave-height criteria.

40. Wave heights obtained for plans 1R and 1S are presented in Table 9 for the N76°20'E test direction. Maximum wave heights obtained in the turning basin were 0.5 and 0.5 ft for plans 1R and 1S, respectively; and maximum wave heights in the mooring area were 0.7 and 0.6 ft. Wave heights obtained for both plans 1R and 1S were within the established wave-height criteria.

41. Results of wave-height tests for plans 1R, 2, and 2A are presented in Table 10 for test waves from the S37°10'E test direction. Maximum wave heights obtained in the turning basin were 1.4, 1.1, and

1.0 ft, while maximum wave heights recorded in the mooring area were 1.3, 1.2, and 0.4 ft for plans 1R, 2, and 2A, respectively. Plan 2A (east and west breakwater crown elevation of +12 ft) met the established wave-height criteria. Visual observations indicated that most wave energy entering the harbor for plans 1R and 2 (+8 and +10 ft breakwater crown elevation, respectively) was due to transmission through the structures, although slight overtopping was observed for plan 1R.

42. Wave-height measurements obtained for plan 3 are shown in Table 10 for the S37°10'E test direction. The maximum wave height obtained in the entrance of the proposed small-boat harbor (gage 6) was 3.0 ft as opposed to 3.9 ft for plan 2A (sheet-pile heads). Therefore, rubble-mound heads were used on the east and west breakwaters for all subsequent test plans.

43. Results of wave-height tests with plan 4 installed in the model are presented in Table 10 for the S37°10'E test direction. Maximum wave heights recorded in the proposed entrance were 5.3 ft, and maximum wave heights in the proposed turning basin and mooring area were 1.4 and 0.6 ft, respectively. Thus, increasing the channel width substantially increased wave heights in the entrance channel.

44. Wave heights obtained for plans 5-5B are presented in Table 11 for the N76°20'E test direction. Maximum wave heights obtained in the turning basin were 2.0, 1.6, and 0.6 ft, while maximum wave heights recorded in the mooring area were 1.0, 0.9, and 0.6 ft for plans 5-5B, respectively. Plans 5-5B satisfied the established wave-height criteria.

45. Results of wave-height tests conducted for plans 6 and 6A are shown in Table 11 for test waves from S37°10'E. Maximum wave heights in the turning basin were 1.3 and 0.8 ft, and maximum wave heights in the mooring area were 0.9 and 0.4 ft for plans 6 and 6A, respectively. Plans 6 and 6A met the established wave-height criteria and plan 6 was subjected to further testing.

46. Comprehensive wave-height measurements obtained for plan 6 are presented in Table 12 for all test directions. Maximum wave heights obtained were 13.8 ft in the entrance to the existing deep draft harbor (gage 1) for 8.3-sec, 10.4-ft test waves from S37°10'E; 4.6 ft in the

proposed small-boat harbor entrance (gage 6) for 8.3-sec, 10.4-ft test waves from S37°10'E; 1.3 ft in the turning basin of the proposed harbor (gages 7 and 8) for 7.3-sec, 9.6-ft test waves from S85°50'E and 8.3-sec, 10.4-ft test waves from S37°10'E; 0.9 ft in the proposed mooring area (gages 10 and 11) for 7.3-sec, 9.6-ft test waves from S85°50'E and 8.3-sec, 10.4-ft test waves from S37°10'E; and 10.1 ft in the inner slip areas of the existing harbor (gage 14) for 7.3-sec, 9.9-ft test waves from S68°30'E.

47. Additional wave-height tests were conducted with plan 6 installed to determine wave conditions at the coal dock (gages 16-24) due to waves reflected from the west breakwater. These test results are shown in Table 13 for the S68°30'E and S37°10'E test directions. Maximum wave heights obtained were 16.0 and 15.6 ft for the S68°30'E and S37°10'E test directions, respectively.

48. Wave-induced current patterns and magnitudes secured for plan 6 are shown in Plates 21-23 for the S37°10'E test direction. Maximum velocities recorded were 1.2 fps at the entrance of the small-boat harbor and 0.6 fps in the mooring area for 9.4-sec, 13.8-ft test waves. All tests indicated a weak current movement from the mooring area to the entrance of the harbor. An area of poor circulation and flushing was observed in the northern portion of the proposed harbor between the existing north breakwater and the boat launching ramp channel.

49. Results of wave-height tests with plans 7 and 7A installed are presented in Table 11 for test waves from S37°10'E. Maximum wave heights in the turning basin were 1.8 and 1.1 ft, while maximum wave heights in the mooring area were 2.1 and 0.7 ft for plans 7 and 7A, respectively. Wave heights for plan 7A were within the established criteria; therefore, plan 7A was subjected to further testing.

50. Results of comprehensive wave-height tests with plan 7A installed in the model are presented in Table 14 for all test directions. Maximum wave heights for spring and summer wave conditions were 13.1 ft in the entrance to the existing deep draft harbor (gage 1) for 7.3-sec, 9.9-ft test waves from S50°45'E; 5.3 ft in the proposed harbor entrance (gage 6) for 8.3-sec, 10.4-ft test waves from S37°10'E; 1.8 ft in the

turning basin of the proposed harbor (gage 7) for 7.3-sec, 9.6-ft test waves from S85°50'E; 1.0 ft in the proposed mooring area (gage 10) for 7.3-sec, 9.6-ft test waves from S85°50'E; and 10.5 ft in the inner slip areas of the existing harbor (gage 14) for 7.3-sec, 9.9-ft test waves from S50°45'E.

51. Results of wave-height tests conducted for plan 7A at the coal wharf (gages 16-24) are presented in Table 13 for the S68°30'E and S37°10'E test directions. Maximum wave heights recorded were 15.8 and 13.7 ft for the S68°30'E and S37°10'E test directions, respectively.

52. Current patterns and magnitudes secured for plan 7A are shown in Plates 24-27 for test waves from S68°30'E and S37°10'E. Maximum velocities obtained were 1.0 fps in the proposed entrance for 8.3-sec, 10.4-ft test waves from S37°10'E and 0.5 fps in the mooring area for 7.3-sec, 9.9-ft test waves from S68°30'E. In general, current movement was from the mooring area to the entrance of the proposed harbor, and an area of poor circulation and flushing was noted between the boat launching ramp channel and the north breakwater.

53. Results of wave-height tests with plan 8 installed in the model are presented in Table 15 for all test directions. Maximum wave heights obtained for spring and summer wave conditions were 5.3 ft in the entrance to the proposed small-boat harbor (gage 6) for 8.3-sec, 10.4-ft test waves from S37°10'E; 1.8 ft in the turning basin of the proposed harbor (gage 7) for 7.3-sec, 9.6-ft test waves from S85°50'E and 8.3-sec, 10.4-ft test waves from S37°10'E; and 1.0 ft in the proposed mooring area (gage 10) for 7.3-sec, 9.6-ft waves from S85°50'E. The maximum wave height recorded at the coal wharf (gage 18) for incident wave conditions representative of the entire year was 22.4 ft for 10.4-sec, 14.7-ft test waves from N76°20'E.

54. Wave heights obtained at the heads of the east breakwater (gage 25) and the shoreward head of the west breakwater (gage 26) are also shown in Table 15. The lakeward head of the west breakwater was protected by the east breakwater. Maximum wave heights obtained for design purposes were 10.8 and 9.8 ft for the east and west breakwater heads, respectively.

55. Results of wave-height tests obtained for plan 8 in the inner slip areas of the existing harbor (gages 27-41) are presented in Table 16 for the S68°30'E test direction. Maximum wave heights collected were 16.3 and 17.0 ft in the corners of the west (gage 31) and north (gage 41) slips, respectively.

56. Wave-induced current patterns and magnitudes secured for plan 8 are shown in Photos 28-47 for all test directions. Maximum velocities recorded were 1.4 fps in the entrance to the small-boat harbor for 8.3-sec, 10.4-ft test waves from S37°10'E and 2.2 fps in the mooring area for 7.3-sec, 9.9-ft test waves from S68°30'E. All tests indicated current movement from the mooring area to the entrance of the harbor. For the smaller test waves, however, an area of poor circulation and flushing was observed between the boat launching ramp channel and the north breakwater. Typical wave patterns for plan 8 are also shown in Photos 28-47.

57. Results of wave-height tests with plan 9 installed are presented in Table 16 for the S68°30'E test direction. Maximum wave heights recorded in the existing west slip were 16.1 ft for 8.2-sec, 13.5-ft test waves, and those obtained in the existing north slip were 21.4 ft for 7.3-sec, 9.9-ft test waves.

Discussion of test results

58. Test results obtained for existing conditions revealed rough and turbulent wave conditions in the vicinity of the proposed harbor. Also, extremely large wave heights were obtained along the coal wharf and in the inner slip areas of the existing harbor due to standing waves caused by reflections off the vertical steel sheet-pile bulkhead walls.

59. Test results obtained for the originally proposed plan of improvement (plan 1) indicated that wave-heights obtained in the proposed harbor exceeded the established criteria (a maximum of 2.0 ft in the turning basin and 1.0 ft in the mooring area) for all test directions. Observations revealed this was due to overtopping of the existing north breakwater (adjacent to the harbor) and overtopping of and transmission through the proposed east and west breakwaters.

60. A comparison of plans 1A-1S and 5-5B (plans involving

modifications to the north breakwater) reveals that several of the plans met the required wave-height criteria; however, considering cost and wave protection afforded, plan 5A was considered the optimum.

61. An examination of wave-height data in the entrance to the proposed harbor for plans 2A, 3, and 4 indicated that rubble-mound breakwater heads (plan 3) would reduce wave heights in the entrance; however, increasing the channel width from 150 to 200 ft (plan 4) would increase wave heights in the entrance.

62. To achieve the established wave-height criteria in the proposed harbor, it was determined that modifications must be made to the east and west breakwaters. These modifications consisted of raising the crown elevation of the structures and/or installing an impervious center. Considering the plans tested with respect to economics and wave protection, the plan 8 structures (elevations of +12 ft east breakwater and +8 ft west breakwater with impervious center) were determined to be optimum.

63. The removal of 185 ft from the shore end of the west breakwater (plan 8) increased wave-induced current magnitudes in the harbor mooring area over the shore-connected breakwater (plans 6 and 7A) and should aid in harbor flushing. The removal of this breakwater did not increase wave heights in the proposed harbor.

64. An examination of wave heights obtained at the coal wharf for existing conditions and plans 6, 7A, and 8 (Table 17) revealed that the zigzag west breakwater alignment (plan 7A) resulted in smaller wave heights for the S37°10'E direction than did the straight west breakwater alignments (plans 6 and 8); however, maximum wave heights obtained at the coal wharf for plans 6 and 8 were comparable to those obtained for existing conditions, considering all directions tested. Wave heights at the coal dock were plotted graphically for existing conditions and plans 6, 7A, and 8 and are shown in plates 28-36.

65. A comparison of wave heights obtained in the inner slips of the existing harbor for existing conditions and plans 8 and 9 (Table 18) indicates generally that plan 8 reduced wave heights along the center line of the slips while plan 9 increased wave heights, particularly at

the end of the north slip. Wave heights at the center line of the west and north slips for existing conditions and plans 8 and 9 were plotted graphically and are shown in Plates 37-40.

66. Visual observations of circulation patterns from the Wisconsin Power and Electric Company revealed the formation of eddies in the area between the mouth of Sauk Creek and the entrance to the north slip for existing conditions and the various test plans. For plan 8 (185-ft opening between the west breakwater and the shore) the discharge from the power plant did not enter the proposed small-boat harbor to any appreciable extent.

67. After completion of this study but prior to publication of this report, the wave hindcast data contained in Reference 8 (which was in publication at the time) were modified. The results of this modification are shown in the following tabulation:

		Maximum Wave, 20-Year Recurrence Interval					
		Preliminary Hindcast			Final Hindcast		
Angle Class	Season	Period *sec*	Deep-water Height *ft*	Shallow Water Height *ft*	Period *sec*	Deep-water Height *ft*	Shallow Water Height *ft*
1	Spring and summer	8.3	12.1	10.4	7.9	10.5	9.0
	Full year	9.4	15.7	13.8	9.0	14.4	12.7
2	Spring and summer	7.3	10.8	9.9	6.8	8.5	7.8
	Full year	8.2	14.8	13.6	7.7	12.8	11.8
3	Spring and summer	7.7	9.2	7.7	7.6	8.9	7.5
	Full year	10.4	17.1	14.7	9.3	13.8	11.9

As can be seen above, the modification resulted in a reduction in both wave period and wave height for all angle classes. The test data contained in this report were reexamined in light of these reductions with the following conclusions:

- a. The elevation of the concrete parapet wall of the existing north breakwater was primarily based on the 7.7-sec, 7.7-ft wave for spring and summer from N 76°20' E (angle class 3). Since this wave was only reduced 0.1 sec and 0.2 ft, the height obtained is still valid.
- b. The design wave suggested for the proposed interior breakwaters (10.6 ft) was based on the worst waves from S 50°45' E

(heights in the vicinity of the structure ranged from 6.7 to 10.8 ft) and S 37°10' E (heights in the vicinity of the structure ranged from 6.8 to 12.2 ft). The reduced incident waves will still result in wave heights in excess of 10 ft at the proposed structure, and the 10.6-ft design wave is still suggested.

c. The reduced incident waves from the S 37°10' E test direction will still result in excessive wave heights in the mooring area of the proposed harbor due to transmission through and/or overtopping of the interior breakwaters as originally proposed. It therefore will still be necessary to either raise the crown elevation or seal these structures.

d. While the maximum wave periods and heights used for the 20-year recurrence interval were somewhat larger than those now given in Reference 8, the basic recommendations of this report are still the same. The only difference is that the resulting harbor design is slightly more conservative (i.e., the recurrence interval of the maximum waves used is greater than 20 years).

PART V: CONCLUSIONS

67. Based on the results of the hydraulic model investigation reported herein, it is concluded that:

a. Existing conditions are characterized by very rough and turbulent waves in the vicinity of the proposed harbor during periods of severe wave attack.

b. The proposed improvement plan (plan 1) was considered inadequate, in that wave heights exceeded the established wave-height criteria (a maximum of 2.0 ft in the turning basin and 1.0 ft in the mooring area) for all directions due to overtopping of the existing north breakwater and overtopping of and transmission through the proposed east and west breakwaters.

c. Of the improvement plans tested involving modifications to the north breakwater (adjacent to the proposed harbor), the concrete parapet wall (elevation of +12 ft) in conjunction with wave absorber inside the breakwater (elevation of +4 ft and 6-ft berm width) was determined to be optimal, considering wave protection afforded and cost.

d. To achieve the established wave-height criteria in the proposed small-boat harbor, it was determined that the crown elevations of the east and west breakwaters must be raised and/or an impervious center must be added.

e. Rubble-mound breakwater heads (plan 3) will reduce wave heights in the proposed small-boat harbor entrance somewhat; however, increasing the width of the entrance from 150 to 200 ft (plan 4) will increase wave heights in the entrance significantly.

f. The zigzag west breakwater alignment (plan 7A) resulted in smaller wave heights at the coal wharf (S37°10'E direction) than did the straight west breakwater alignments (plans 6 and 8); however, maximum wave heights obtained at the coal wharf for plans 6 and 8 were comparable to those obtained for existing conditions, considering all directions tested.

g. Removal of 185 ft from the shore end of the west breakwater (plan 8) will improve wave-induced circulation without increasing wave heights in the proposed small-boat harbor.

h. Construction of the proposed small-boat harbor will have no adverse effects on the existing inner slips of the harbor.

i. Filling in approximately one third of the existing north slip (as requested by the city of Port Washington) (plan 9) will result in increased standing wave heights in the north slip.

j. The proposed small-boat harbor had no adverse effect on the circulation patterns from the Wisconsin Power and Electric Company water discharge, and the warm water discharge did not enter the proposed small-boat basin to any appreciable extent for the proposed improvement plans.

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Table 1

Wave Heights, ft, for All Approach Angles and Seasons

Recurrence Interval	Angle Class 1	2	3
		Winter	
5	10.8	13.1	11.5
10	13.4	13.8	13.8
20	15.7	14.1	17.1
50	18.7	14.8	21.6
100	20.7	15.1	25.3
		Spring	
5	7.9	8.5	4.6
10	9.2	9.5	6.6
20	11.5	10.8	8.5
50	14.1	12.8	10.5
100	15.7	13.4	12.1
		Summer	
5	8.2	3.9	4.3
10	9.5	4.9	7.2
20	12.1	5.9	9.2
50	14.4	7.9	11.8
100	16.7	9.2	14.8
		Fall	
5	13.4	10.8	10.8
10	14.8	12.1	12.8
20	15.7	14.8	14.8
50	18.0	16.4	16.1
100	19.7	19.0	18.4

Table 2

Significant Period, sec, by Angle Class and Wave Height

Wave Height	Angle Class		
ft	1	2	3
1	4.2	4.3	3.8
2	4.8	4.8	4.5
3	5.2	5.2	5.0
4	5.8	5.6	5.6
5	6.3	6.0	6.2
6	6.6	6.2	6.6
7	6.9	6.4	6.9
8	7.2	6.7	7.3
9	7.5	6.9	7.6
10	7.8	7.1	8.0
11	8.0	7.3	8.3
12	8.3	7.5	8.7
13	8.6	7.8	9.0
14	8.9	8.0	9.4
15	9.2	8.2	9.7
16	9.5	8.4	10.1
17	9.8	8.6	10.4
18	10.1	8.9	10.8
19	10.4	9.1	11.1
20	10.7	9.3	11.5
21	10.9	9.5	11.8
22	11.2	9.7	12.2
23	11.5	10.0	12.5
24	11.8	10.2	12.9
25	12.1	10.4	13.2

Table 3

Wave Heights Obtained for Existing Conditions

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N76°20'E	6.0	4.3	4.3	1.2	0.8	1.2	1.5	0.9	1.2	0.6	1.4	0.9	0.8	0.9	1.1	1.4	0.2
	7.7	4.2	2.9	1.7	2.0	1.8	2.2	1.2	1.8	1.9	1.5	1.7	1.3	1.8	0.9	2.7	1.2
		7.7	5.3	3.8	4.3	6.3	6.0	4.0	3.2	3.2	4.9	4.4	4.2	2.6	2.7	5.0	2.9
	10.4*	14.7	16.4	9.9	10.3	7.7	6.9	6.7	7.0	5.5	8.5	6.4	6.4	6.1	5.3	5.3	6.5
S85°50'E	5.5	3.8	4.3	1.5	1.0	1.2	1.1	0.4	0.8	0.7	1.1	1.5	1.5	1.1	0.4	1.3	0.7
	7.3	5.3	7.7	3.5	4.9	4.7	6.0	2.7	2.8	5.0	2.2	4.3	3.0	4.2	4.3	3.1	2.2
		9.6	12.2	5.3	8.0	7.9	9.1	6.1	5.0	4.4	8.0	6.3	5.1	7.6	4.5	9.4	5.6
	8.2*	12.7	13.5	8.5	12.2	8.2	9.0	7.3	6.3	5.3	8.5	6.6	6.5	8.5	5.6	7.5	10.1
S68°30'E	5.5	3.8	3.2	2.0	2.2	2.4	2.9	0.5	2.1	0.8	2.0	1.8	2.2	3.7	1.9	3.3	1.1
	7.3	5.5	6.3	4.3	5.0	6.3	5.9	1.7	3.2	2.9	3.1	3.4	3.0	7.5	4.0	12.2	2.7
		9.9	14.8	8.7	10.1	11.9	10.8	4.5	3.8	4.8	7.9	5.2	6.4	11.4	6.8	13.3	5.4
	8.2*	13.5	19.9	12.8	10.9	9.9	11.4	8.8	4.9	6.0	8.5	6.9	6.1	11.6	6.6	7.1	13.2
S50°45'E	5.5	3.8	5.5	4.1	1.2	1.8	1.4	1.5	2.7	1.5	2.0	3.0	4.5	1.8	0.6	1.5	1.4
	7.3	5.5	6.1	4.2	3.7	4.8	4.8	3.8	2.9	4.4	3.4	4.6	4.7	4.2	4.7	6.8	2.1
		9.9	12.2	10.1	7.2	8.9	9.3	7.4	6.1	7.7	7.8	6.4	5.2	8.7	6.4	10.3	3.8
	8.2*	13.6	19.4	12.8	8.9	8.1	9.3	8.6	10.8	7.4	8.5	6.9	6.7	9.8	5.7	5.9	10.8
S37°10'E	6.0	3.7	4.1	2.0	1.3	1.3	1.2	2.4	1.9	1.8	3.5	2.3	3.3	1.7	0.7	0.6	0.5
	8.3	3.4	2.5	2.2	1.2	2.0	1.6	1.8	3.5	3.6	1.5	1.8	4.8	3.3	1.1	1.7	0.8
		6.9	6.7	6.3	4.2	3.5	3.8	7.3	7.7	7.7	8.5	8.4	8.3	6.7	2.5	2.9	3.5
		10.4	14.7	8.9	4.4	5.5	4.5	12.2	9.8	6.8	10.4	6.8	7.5	5.4	3.6	3.5	6.5
	9.4*	13.8	21.8	16.7	5.8	7.9	8.2	9.6	9.5	8.4	9.7	6.9	6.1	7.9	6.0	6.7	6.6

* Wave conditions for entire year, 20-year recurrence interval.

Table 4

Wave Heights Obtained at Coal Wharf for Existing Conditions

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 16	17	18	19	20	21	22	23	24
N76°20'E	7.7	4.2	4.2	4.2	4.7	5.8	4.1	3.2	4.1	2.6	1.9
		7.7	7.7	6.8	9.3	9.5	7.8	5.3	4.7	5.8	4.5
	10.4*	14.7	10.2	12.4	19.7	23.6	21.7	17.2	11.7	10.9	15.4
S68°30'E	7.3	5.5	7.1	7.4	9.8	6.5	5.9	7.8	6.7	8.9	8.0
		9.9	10.0	14.5	15.0	12.5	14.6	15.3	12.6	12.7	11.3
	8.2*	13.5	10.9	12.2	13.3	15.1	9.8	8.5	10.8	14.7	15.2
S37°10'E	8.3	3.4	1.9	2.7	4.1	3.6	5.2	4.1	2.6	3.3	4.2
		10.4	4.8	6.3	6.6	6.7	7.6	6.4	8.2	11.4	8.3
	9.4*	13.8	10.4	10.3	8.6	8.4	8.8	10.7	12.4	11.6	9.2

* Wave conditions for entire year, 20-year recurrence interval.

Table 5

Wave Heights Obtained in Inner Slip Areas of Existing Harbor for Existing Conditions

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
S68°30'E	5.5	3.8	4.7	1.9	4.5	3.2	5.9	4.7	1.9	1.5	2.1	5.5	1.9	1.5	2.1	4.1	2.9
	7.3	5.5	7.8	4.6	5.6	8.1	10.6	4.1	9.0	6.4	9.0	8.4	6.6	8.1	4.6	5.2	10.1
		9.9	10.5	6.5	6.4	12.2	14.6	8.1	12.3	11.4	13.0	11.7	14.6	9.4	6.8	9.5	15.0
	8.2*	13.5	11.5	8.2	9.9	12.7	14.2	14.5	9.4	7.0	9.2	7.6	7.3	10.5	8.4	14.4	9.1

* Wave conditions for entire year, 20-year recurrence interval.

Table 6

Wave Heights Obtained with Plan 1

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N76°20'E	6.0	4.3	3.2	1.0	0.9	0.8	0.8	0.2	0.1	0.5	0.3	0.5	0.2	0.5	0.5	1.0	0.4
	7.7	4.2	2.9	1.5	1.5	2.4	2.3	1.0	0.6	1.1	0.3	1.3	0.6	1.2	0.5	3.1	2.4
		7.7	5.3	4.0	4.4	8.1	5.7	1.2	2.4	3.1	1.6	2.2	1.5	4.8	2.4	8.2	5.3
S85°50'E	5.5	3.8	3.2	1.4	0.6	0.8	1.0	0.4	0.3	0.2	0.2	0.2	0.3	1.3	0.3	1.4	0.6
	7.3	5.3	6.0	4.1	4.2	6.1	4.2	1.8	1.7	1.4	0.7	2.2	0.6	4.5	4.7	5.8	2.9
		9.6	9.9	8.8	8.3	8.7	8.4	3.7	3.4	2.9	1.6	3.2	1.8	9.1	5.1	10.5	6.2
S68°30'E	5.5	3.8	3.9	2.6	3.2	1.4	3.3	1.0	0.7	0.4	0.4	0.4	0.5	4.1	1.7	4.0	1.7
	7.3	5.5	5.9	4.6	4.1	5.5	6.0	2.2	0.5	1.3	0.5	1.0	0.6	4.9	5.0	4.0	4.3
		9.9	11.6	8.3	9.1	10.2	9.5	3.6	1.1	1.7	0.9	1.2	0.8	7.8	6.1	8.8	6.4
S50°45'E	5.5	3.8	4.3	2.8	0.7	2.9	1.2	1.6	0.5	0.1	0.6	0.5	0.6	1.0	0.3	2.5	1.3
	7.3	5.5	5.7	5.4	3.0	4.1	4.3	2.4	1.1	1.3	0.5	1.3	0.8	3.2	2.2	3.5	4.0
		9.9	10.0	9.6	5.8	5.5	7.1	5.9	0.9	1.0	1.1	1.2	1.0	5.7	6.6	6.8	4.8
S37°10'E	6.0	3.7	3.6	2.6	2.1	1.6	1.3	0.7	0.2	0.7	0.6	0.2	0.5	1.0	1.3	1.1	0.3
	8.3	3.4	2.4	1.8	1.2	2.4	0.8	1.3	0.3	0.5	1.2	0.9	0.7	2.4	0.6	1.0	0.9
		6.9	5.4	4.7	3.3	4.4	3.0	3.4	0.7	1.1	0.7	1.5	1.1	5.4	2.0	2.4	3.3
		10.4	10.5	9.9	4.4	7.6	6.2	6.5	1.8	1.3	1.6	1.7	1.4	6.4	3.0	4.2	5.8

Table 7

Wave Heights Obtained in Proposed Harbor for Plans 1A-1E

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 6	7	8	9	10	11
			Plan 1A					
N76°20'E	6.0	4.3	0.2	0.4	0.3	0.3	0.2	0.3
	7.7	4.2	0.9	1.4	0.9	0.3	1.4	0.6
		7.7	1.6	4.4	3.7	2.0	2.2	2.1
			Plan 1B					
N76°20'E	7.7	4.2	0.8	0.6	0.5	0.3	0.2	0.2
		7.7	1.7	3.2	2.6	1.4	1.5	1.3
			Plan 1C					
N76°20'E	7.7	4.2	0.6	0.4	0.3	0.4	0.3	0.4
		7.7	1.9	2.1	1.7	1.0	0.9	1.1
			Plan 1D					
N76°20'E	7.7	7.7	1.8	1.6	1.6	0.8	0.9	0.9
			Plan 1E					
N76°20'E	7.7	7.7	1.8	0.9	1.1	0.4	0.7	0.6

Table 8

Wave Heights Obtained in Proposed Harbor for Plans 1F-1K

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 6	7	8	9	10	11
			Plan 1F					
N76°20'E	7.7	4.2	0.6	0.7	0.4	0.4	0.5	0.2
		7.7	1.8	1.9	2.2	0.9	2.6	0.9
			Plan 1G					
N76°20'E	7.7	7.7	1.9	2.0	1.7	0.8	2.2	0.8
			Plan 1H					
N76°20'E	7.7	7.7	1.5	1.6	1.3	0.7	1.6	0.8
			Plan 1I					
N76°20'E	7.7	4.2	0.9	0.8	0.8	0.3	0.7	0.3
		7.7	1.6	2.3	3.0	1.5	1.9	0.9
			Plan 1J					
N76°20'E	7.7	4.2	0.7	0.7	0.2	0.2	0.2	0.3
		7.7	1.5	1.8	1.8	0.9	1.6	1.0
			Plan 1K					
N76°20'E	7.7	7.7	1.5	1.4	1.5	0.5	1.3	0.9

Table 9

Wave Heights Obtained in Proposed Harbor for Plans 1L-1S

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 6	7	8	9	10	11
				Plan 1L				
N76°20'E	7.7	7.7	1.4	1.5	1.3	0.6	1.5	1.0
				Plan 1M				
N76°20'E	7.7	7.7	1.5	1.1	0.7	0.4	1.0	0.8
				Plan 1N				
N76°20'E	7.7	7.7	1.6	1.0	0.5	0.4	0.8	0.7
				Plan 1O				
N76°20'E	7.7	7.7	1.8	1.2	1.5	0.5	1.2	0.8
				Plan 1P				
N76°20'E	7.7	7.7	1.9	0.6	0.4	0.3	0.4	0.5
				Plan 1Q				
N76°20'E	7.7	7.7	1.9	0.3	0.2	0.3	0.4	0.3
				Plan 1R				
N76°20'E	7.7	7.7	1.6	0.5	0.4	0.4	0.7	0.5
				Plan 1S				
N76°20'E	7.7	7.7	1.6	0.4	0.4	0.5	0.6	0.5

Table 10

Wave Heights Obtained in Proposed

Harbor for Plans 1R, 2, 2A, 3, and 4

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 6	7	8	9	10	11
			Plan 1R					
S37°10'E	6.0	3.7	0.9	0.6	0.5	0.5	0.5	0.6
	8.3	3.4	1.2	0.5	0.3	0.5	0.3	0.8
		6.9	3.2	0.7	0.4	1.0	0.7	1.0
		10.4	5.2	1.4	0.7	1.3	1.1	1.3
			Plan 2					
S37°10'E	8.3	3.4	1.1	0.5	0.3	0.3	0.3	0.6
		6.9	3.0	1.0	0.4	0.7	0.5	0.9
		10.4	4.9	1.1	0.5	0.9	0.6	1.2
			Plan 2A					
S37°10'E	8.3	6.9	2.4	0.9	0.2	0.2	0.1	0.4
		10.4	3.9	1.0	0.3	0.3	0.1	0.4
			Plan 3					
S37°10'E	8.3	6.9	1.8	0.6	0.2	0.3	0.2	0.4
		10.4	3.0	0.8	0.3	0.4	0.3	0.5
			Plan 4					
S37°10'E	8.3	6.9	2.1	0.7	0.2	0.3	0.2	0.5
		10.4	5.3	1.4	0.3	0.6	0.3	0.6

Table 11

Wave Heights Obtained in Proposed Harbor

for Plans 5-5B, 6, 6A, 7, and 7A

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 6	7	8	9	10	11
			Plan 5					
N76°20'E	6.0	4.3	0.6	0.3	0.1	0.1	0.1	0.2
	7.7	4.2	0.5	0.2	0.3	0.2	0.2	0.4
		7.7	0.8	1.0	2.0	0.6	0.9	1.0
			Plan 5A					
N76°20'E	7.7	7.7	0.8	0.8	1.6	0.5	0.9	0.9
			Plan 5B					
N76°20'E	7.7	7.7	0.9	0.4	0.6	0.4	0.6	0.6
			Plan 6					
S37°10'E	6.0	3.7	1.0	0.4	0.2	0.2	0.2	0.2
	8.3	3.4	1.7	0.5	0.2	0.2	0.2	0.3
		6.9	3.8	0.9	0.2	0.4	0.3	0.4
		10.4	4.6	1.3	0.4	0.7	0.7	0.9
			Plan 6A					
S37°10'E	8.3	10.4	3.2	0.8	0.3	0.4	0.4	0.4
			Plan 7					
S37°10'E	6.0	3.7	1.1	0.4	0.2	0.4	0.8	0.3
	8.3	3.4	2.3	0.4	0.5	0.8	0.5	0.8
		6.9	4.2	0.7	0.4	1.1	1.1	1.3
		10.4	5.9	0.9	0.5	1.8	2.1	1.9
			Plan 7A					
S37°10'E	6.0	3.7	0.9	0.3	0.2	0.1	0.2	0.1
	8.3	3.4	1.9	0.3	0.1	0.1	0.1	0.1
		6.9	3.2	0.7	0.1	0.2	0.3	0.2
		10.4	5.3	1.1	0.3	0.5	0.4	0.7

Table 12

Wave Heights Obtained with Plan 6

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N76°20'E	6.0	4.3	3.6	1.1	0.7	1.0	1.0	0.2	0.1	0.1	0.1	0.1	0.1	2.3	0.4	1.1	0.6
	7.7	4.2	2.8	1.8	3.4	2.5	2.9	0.7	0.2	0.1	0.1	0.1	0.1	2.0	0.9	3.4	1.1
		7.7	4.4	3.9	6.4	5.5	5.5	0.9	0.5	1.0	0.5	0.6	0.4	5.2	3.5	5.5	4.1
S85°50'E	5.5	3.8	3.5	1.3	0.5	1.2	1.4	0.2	0.1	0.1	0.1	0.1	0.1	1.6	0.5	2.3	0.8
	7.3	5.3	5.7	3.2	4.7	4.0	4.2	0.7	0.2	0.1	0.1	0.1	0.1	5.6	3.5	6.8	2.8
		9.6	10.3	5.5	10.8	9.5	9.4	2.5	1.3	1.3	0.7	0.9	0.5	8.8	5.9	9.3	6.6
S68°30'E	5.5	3.8	3.9	2.2	1.3	2.5	3.1	1.1	0.4	0.2	0.1	0.1	0.1	3.3	1.8	4.1	2.5
	7.3	5.5	5.5	4.2	5.2	6.5	5.7	0.9	0.3	0.1	0.1	0.2	0.1	7.1	5.2	8.5	3.7
		9.9	11.8	8.7	8.8	12.5	11.3	2.2	0.6	0.2	0.2	0.2	0.2	11.3	6.8	10.1	6.2
S50°45'E	5.5	3.8	3.9	3.4	2.1	1.9	1.2	1.0	0.5	0.2	0.1	0.1	0.1	3.4	1.6	1.3	1.6
	7.3	5.5	5.1	5.0	3.4	5.5	5.4	1.9	0.6	0.2	0.2	0.3	0.2	4.3	2.1	3.7	4.2
		9.9	11.1	9.9	7.2	8.4	7.4	3.7	1.1	0.3	0.3	0.4	0.3	6.8	5.8	6.8	6.2
S37°10'E	6.0	3.7	3.8	2.7	1.7	0.6	1.0	1.0	0.4	0.2	0.2	0.2	0.2	0.5	0.6	1.1	0.3
	8.3	3.4	3.2	2.5	2.3	2.3	1.4	1.7	0.5	0.2	0.2	0.2	0.3	3.9	1.1	1.5	1.6
		6.9	7.8	5.8	3.2	4.7	3.2	3.8	0.9	0.2	0.4	0.3	0.4	4.5	2.3	3.2	2.8
		10.4	13.8	9.4	5.1	7.2	5.7	4.6	1.3	0.4	0.7	0.7	0.9	4.4	3.6	4.5	5.4

Table 13

Wave Heights Obtained at Coal Wharf for Plans 6 and 7A

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 16	17	18	19	20	21	22	23	24
Plan 6											
S68°30'E	7.3	5.5	6.4	7.1	8.9	5.8	6.6	9.4	6.3	8.3	6.8
		9.9	9.8	13.5	13.0	11.7	15.5	12.6	11.3	11.8	10.6
	8.2*	13.5	11.8	12.5	14.2	11.8	9.4	11.5	12.8	16.0	15.1
S37°10'E	8.3	3.4	2.0	1.6	1.5	3.7	3.5	2.2	2.0	1.6	1.6
		10.4	10.6	7.7	6.6	3.7	7.3	9.1	6.5	6.1	5.1
	9.4*	13.8	8.6	12.4	15.5	12.5	15.6	13.2	11.3	11.8	7.5
Plan 7A											
S68°30'E	7.3	5.5	5.2	8.4	8.3	5.9	6.4	6.6	5.6	6.2	9.1
		9.9	10.8	12.6	12.8	10.0	11.2	13.1	10.5	14.2	13.2
	8.2*	13.5	11.0	11.1	10.5	10.1	11.7	14.7	12.9	14.0	15.8
S37°10'E	8.3	3.4	2.3	1.3	1.9	3.1	3.7	1.9	1.3	1.5	2.9
		10.4	3.8	5.2	6.4	6.1	6.0	5.9	7.2	7.8	7.6
	9.4*	13.8	9.8	10.8	11.2	10.1	12.6	13.7	10.7	11.7	10.2

* Wave conditions for entire year, 20-year recurrence interval.

Table 14

Wave Heights Obtained with Plan 7A

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N76°20'E	6.0	4.3	3.8	1.4	0.8	0.9	1.0	0.3	0.1	0.1	0.1	0.1	0.1	2.3	0.4	1.1	0.7
	7.7	4.2	3.8	2.7	2.7	1.3	2.5	0.3	0.1	0.1	0.1	0.1	0.1	2.3	1.6	3.0	1.5
		7.7	6.0	4.0	5.4	5.1	3.3	1.1	0.6	1.1	0.5	0.6	0.5	5.0	4.4	5.7	4.4
	10.4*	14.7	11.8	11.3	9.1	8.9	7.0	4.1	3.1	2.5	1.6	1.7	1.3	5.8	4.4	5.9	6.3
S85°50'E	5.5	3.8	3.2	1.2	0.7	1.5	1.6	1.5	0.1	0.1	0.1	0.1	0.1	1.3	0.7	3.1	1.3
	7.3	5.3	5.3	2.7	3.5	4.2	4.4	0.7	0.1	0.2	0.1	0.1	0.1	8.9	4.1	4.6	4.4
		9.6	9.1	6.5	9.2	8.5	8.2	2.9	1.8	1.4	0.9	1.0	0.7	10.4	5.3	9.5	8.3
	8.2*	12.7	11.6	7.2	9.0	11.2	8.0	4.5	1.5	1.4	0.6	0.7	0.9	9.3	6.2	8.1	9.8
S68°30'E	5.5	3.8	4.1	3.3	1.7	2.7	4.4	0.3	0.1	0.1	0.1	0.1	0.1	2.8	1.7	5.9	2.6
	7.3	5.5	6.1	3.6	4.3	5.2	5.7	1.1	0.2	0.2	0.2	0.2	0.1	8.9	3.3	5.3	5.2
		9.9	12.6	9.9	7.0	9.7	7.9	2.4	0.6	0.4	0.3	0.3	0.3	10.9	5.4	7.4	7.7
	8.2*	13.5	17.9	13.1	12.1	10.9	12.0	4.7	1.1	0.5	0.7	0.7	0.7	9.8	8.2	7.3	9.8
S50°45'E	5.5	3.8	3.3	4.0	1.2	0.8	1.5	0.5	0.1	0.1	0.1	0.1	0.2	1.7	0.9	2.1	1.6
	7.3	5.5	5.7	3.8	2.7	4.8	3.9	1.7	0.5	0.3	0.1	0.3	0.2	4.0	3.1	7.0	2.3
		9.9	13.1	9.3	5.7	8.9	6.4	3.5	0.9	0.4	0.4	0.5	0.3	10.1	5.6	10.5	4.1
	8.2*	13.6	19.7	16.1	8.1	7.8	8.1	6.4	1.2	0.6	0.9	1.2	1.5	12.5	9.0	7.1	14.0
S37°10'E	6.0	3.7	2.4	1.5	0.9	1.4	0.5	0.9	0.3	0.2	0.1	0.2	0.1	1.5	0.8	0.4	0.5
	8.3	3.4	3.4	2.4	0.9	0.8	0.9	1.9	0.3	0.1	0.1	0.1	0.1	2.4	0.4	4.2	0.9
		6.9	7.1	5.0	2.3	1.9	2.9	3.2	0.7	0.1	0.2	0.3	0.2	5.7	1.2	6.4	2.6
		10.4	11.9	9.3	3.8	2.8	6.3	5.3	1.1	0.3	0.5	0.4	0.7	8.5	3.2	8.4	4.5
	9.4*	13.8	21.8	14.8	6.1	6.6	8.3	4.0	1.1	0.6	1.3	1.3	1.2	10.1	4.8	6.6	7.6

* Wave conditions for entire year, 20-year recurrence interval.

Table 15

Wave Heights Obtained with Plan 8

Test Direction	Test Wave Period sec	Test Wave Height ft	6	7	8	9	10	11	18	19	20	21	22	23	24	25	26
			Wave Height, ft, at Gage														
N76°20'E	6.0	4.3	0.2	0.2	0.1	0.1	0.1	0.1	1.2	0.7	1.3	1.3	0.9	0.6	0.5	0.8	1.5
	7.7	4.2	0.7	0.2	0.1	0.1	0.1	0.4	3.6	6.2	4.7	2.5	4.4	1.6	1.4	0.7	2.2
		7.7	0.9	0.9	0.8	0.3	0.5	0.5	8.7	8.0	6.6	4.4	4.9	3.1	4.6	2.0	4.0
	10.4*	14.7	3.3	3.9	1.3	1.2	1.3	1.5	22.4	22.0	15.6	12.8	9.8	9.5	13.1	7.8	9.8
S85°50'E	5.5	3.8	0.2	0.2	0.1	0.1	0.1	0.1	3.0	2.3	1.7	1.4	2.2	1.9	2.1	0.4	1.8
	7.3	5.3	0.7	0.3	0.1	0.1	0.3	0.3	6.5	3.9	5.7	6.4	7.4	5.3	5.0	1.4	2.5
		9.6	2.4	1.8	0.8	0.9	1.0	0.6	14.1	14.3	14.9	13.8	10.6	7.3	9.9	5.9	6.4
	8.2*	12.7	3.5	2.2	1.0	1.2	1.3	1.1	21.1	17.3	10.5	10.6	13.6	13.1	10.6	8.9	8.1
S68°30'E	5.5	3.8	0.4	0.3	0.1	0.2	0.2	0.4	4.2	4.3	3.6	3.8	4.2	3.1	5.9	0.9	3.5
	7.3	5.5	2.0	0.9	0.2	0.3	0.3	0.4	8.7	7.1	6.8	8.4	7.2	7.3	7.8	1.9	3.7
		9.9	2.9	0.9	0.3	0.3	0.6	0.4	15.2	13.4	13.0	13.8	11.2	10.2	12.0	5.5	5.3
	8.2*	13.5	4.6	1.3	0.3	0.6	0.8	0.7	13.0	12.4	11.7	13.9	14.0	14.2	13.3	10.4	8.7
S50°45'E	5.5	3.8	0.8	0.2	0.2	0.2	0.1	0.3	2.4	2.3	2.1	1.8	1.7	1.0	2.2	1.5	2.8
	7.3	5.5	2.2	0.8	0.2	0.2	0.4	0.4	7.2	6.1	7.0	8.5	5.7	5.3	5.9	2.4	4.4
		9.9	3.9	1.2	0.3	0.4	0.7	0.4	9.0	10.8	10.7	11.9	10.0	10.2	11.3	5.7	4.8
	8.2*	13.6	5.3	1.7	0.4	0.9	0.8	0.7	9.4	10.7	11.3	9.7	11.0	10.9	11.6	10.1	6.2
S37°10'E	6.0	3.7	1.2	0.5	0.3	0.2	0.3	0.2	1.2	0.7	1.5	2.5	2.3	1.9	1.1	2.3	1.6
	8.3	3.4	1.0	0.2	0.1	0.3	0.2	0.2	1.3	3.9	3.5	2.5	2.1	1.0	1.5	1.3	1.7
		6.9	3.1	0.8	0.3	0.6	0.6	0.5	3.1	8.6	7.8	3.5	3.5	3.9	5.1	5.5	4.4
		10.4	5.3	1.8	0.5	0.7	0.9	0.6	5.3	5.9	7.5	7.2	6.3	6.5	7.2	10.8	5.7
	9.4*	13.8	3.5	1.4	0.8	1.1	1.1	1.5	15.4	10.2	12.1	12.7	11.4	9.1	10.0	9.0	8.4

* Wave conditions for entire year, 20-year recurrence interval.

Table 16

Wave Heights Obtained in Inner Slip Areas of Existing Harbor for Plans 8 and 9

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
								Plan 8									
S68°30'E	5.5	3.8	4.0	3.4	4.7	4.8	4.1	3.8	2.3	1.8	2.8	1.1	2.3	2.0	2.2	3.7	2.7
	7.3	5.5	6.7	4.4	6.7	8.1	11.2	4.1	8.9	6.8	6.5	8.8	5.2	7.7	5.6	6.4	8.4
		9.9	9.7	9.6	9.1	12.2	13.8	9.1	12.0	12.2	9.4	11.6	13.0	8.6	7.5	12.1	14.4
	8.2*	13.5	10.9	8.0	10.1	11.9	16.3	13.5	7.1	7.3	6.9	7.5	6.3	8.9	10.1	17.0	13.1
								Plan 9									
S68°30'E	5.5	3.8	4.4	2.6	5.0	3.8	3.2	4.0	2.9	2.4	4.8	2.9	3.0	-	-	3.9	2.7
	7.3	5.5	7.3	5.9	5.6	7.3	9.8	5.0	4.4	6.4	10.9	4.2	13.0	-	-	13.1	5.1
		9.9	9.9	10.1	9.0	10.1	11.5	8.8	11.8	10.0	15.9	7.8	20.1	-	-	21.4	9.5
	8.2*	13.5	12.8	9.2	10.1	16.1	12.9	12.9	7.7	10.7	7.6	9.1	10.1	-	-	13.3	17.0

* Wave conditions for entire year, 20-year recurrence interval.

Table 17

Wave Heights Obtained at Coal Wharf for Existing Conditions and Plans 6, 7A, and 8

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 16	17	18	19	20	21	22	23	24
			Existing Conditions								
N76°20'E	7.7	4.2	4.2	4.2	4.7	5.8	4.1	3.2	4.1	2.6	1.9
		7.7	7.7	6.8	9.3	9.5	7.8	5.3	4.7	5.8	4.5
	10.4*	14.7	10.2	12.4	19.7	23.6	21.7	17.2	11.7	10.9	15.4
S68°30'E	7.3	5.5	7.1	7.4	9.8	6.5	5.9	7.8	6.7	8.9	8.0
		9.9	10.0	14.5	15.0	12.5	14.6	15.3	12.6	12.7	11.3
	8.2*	13.5	10.9	12.2	13.3	15.1	9.8	8.5	10.8	14.7	15.2
S37°10'E	8.3	3.4	1.9	2.7	4.1	3.6	5.2	4.1	2.6	3.3	4.2
		10.4	4.8	6.3	6.6	6.7	7.6	6.4	8.2	11.4	8.3
	9.4*	13.8	10.4	10.3	8.6	8.4	8.8	10.7	12.4	11.6	9.2
			Plan 6								
S68°30'E	7.3	5.5	6.4	7.1	8.9	5.8	6.6	9.4	6.3	8.3	6.8
		9.9	9.8	13.5	13.0	11.7	15.5	12.6	11.3	11.8	10.6
	8.2*	13.5	11.8	12.5	14.2	11.8	9.4	11.5	12.8	16.0	15.1
S37°10'E	8.3	3.4	2.0	1.6	1.5	3.7	3.5	2.2	2.0	1.6	1.6
		10.4	10.6	7.7	6.6	3.7	7.3	9.1	6.5	6.1	5.1
	9.4*	13.8	8.6	12.4	15.5	12.5	15.6	13.2	11.3	11.8	7.5
			Plan 7A								
S68°30'E	7.3	5.5	5.2	8.4	8.3	5.9	6.4	6.6	5.6	6.2	9.1
		9.9	10.8	12.6	12.8	10.0	11.2	13.1	10.5	14.2	13.2
	8.2*	13.5	11.0	11.1	10.5	10.1	11.7	14.7	12.9	14.0	15.8
S37°10'E	8.3	3.4	2.3	1.3	1.9	3.1	3.7	1.9	1.3	1.5	2.9
		10.4	3.8	5.2	6.4	6.1	6.0	5.9	7.2	7.8	7.6
	9.4*	13.8	9.8	10.8	11.2	10.1	12.6	13.7	10.7	11.7	10.2
			Plan 8								
N76°20'E	7.7	4.2	-	-	3.6	6.2	4.7	2.5	4.4	1.6	1.4
		7.7	-	-	8.7	8.0	6.6	4.4	4.9	3.1	4.6
	10.4*	14.7	-	-	22.4	22.0	15.6	12.8	9.8	9.5	13.1
S68°30'E	7.3	5.5	-	-	8.7	7.1	6.8	8.4	7.2	7.3	7.8
		9.9	-	-	15.2	13.4	13.0	13.8	11.2	10.2	12.0
	8.2*	13.5	-	-	13.0	12.4	11.7	13.9	14.0	14.2	13.3
S37°10'E	8.3	3.4	-	-	1.3	3.9	3.5	2.5	2.1	1.0	1.5
		10.4	-	-	5.3	5.9	7.5	7.2	6.3	6.5	7.2
	9.4*	13.8	-	-	15.4	10.2	12.1	12.7	11.4	9.1	10.0

* Wave conditions for entire year, 20-year recurrence interval.

Table 18

Wave Heights Obtained in Inner Slip Areas of Existing Harbor

for Existing Conditions and Plans 8 and 9

Test Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft, at Gage 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Existing Conditions																	
S68°30'E	5.5	3.8	4.7	1.9	4.5	3.2	5.9	4.7	1.9	1.5	2.1	5.5	1.9	1.5	2.1	4.1	2.9
	7.3	5.5	7.8	4.6	5.6	8.1	10.6	4.1	9.0	6.4	9.0	8.4	6.6	8.1	4.6	5.2	10.1
		9.9	10.5	6.5	6.4	12.2	14.6	8.1	12.3	11.4	13.0	11.7	14.6	9.4	6.8	9.5	15.0
	8.2*	13.5	11.5	8.2	9.9	12.7	14.2	14.5	9.4	7.0	9.2	7.6	7.3	10.5	8.4	14.4	9.1
Plan 8																	
S68°30'E	5.5	3.8	4.0	3.4	4.7	4.8	4.1	3.8	2.3	1.8	2.8	1.1	2.3	2.0	2.2	3.7	2.7
	7.3	5.5	6.7	4.4	6.7	8.1	11.2	4.1	8.9	6.8	6.5	8.8	5.2	7.7	5.6	6.4	8.4
		9.9	9.7	9.6	9.1	12.2	13.8	9.1	12.0	12.2	9.4	11.6	13.0	8.6	7.5	12.1	14.4
	8.2*	13.5	10.9	8.0	10.1	11.9	16.3	13.5	7.1	7.3	6.9	7.5	6.3	8.9	10.1	17.0	13.1
Plan 9																	
S68°30'E	5.5	3.8	4.4	2.6	5.0	3.8	3.2	4.0	2.9	2.4	4.8	2.9	3.0	-	-	3.9	2.7
	7.3	5.5	7.3	5.9	5.6	7.3	9.8	5.0	4.4	6.4	10.9	4.2	13.0	-	-	13.1	5.1
		9.9	9.9	10.1	9.0	10.1	11.5	8.8	11.8	10.0	15.9	7.8	20.1	-	-	21.4	9.3
	8.2*	13.5	12.8	9.2	10.1	16.1	12.9	12.9	7.7	10.7	7.6	9.1	10.1	-	-	13.3	17.0

* Wave conditions for entire year, 20-year recurrence interval.

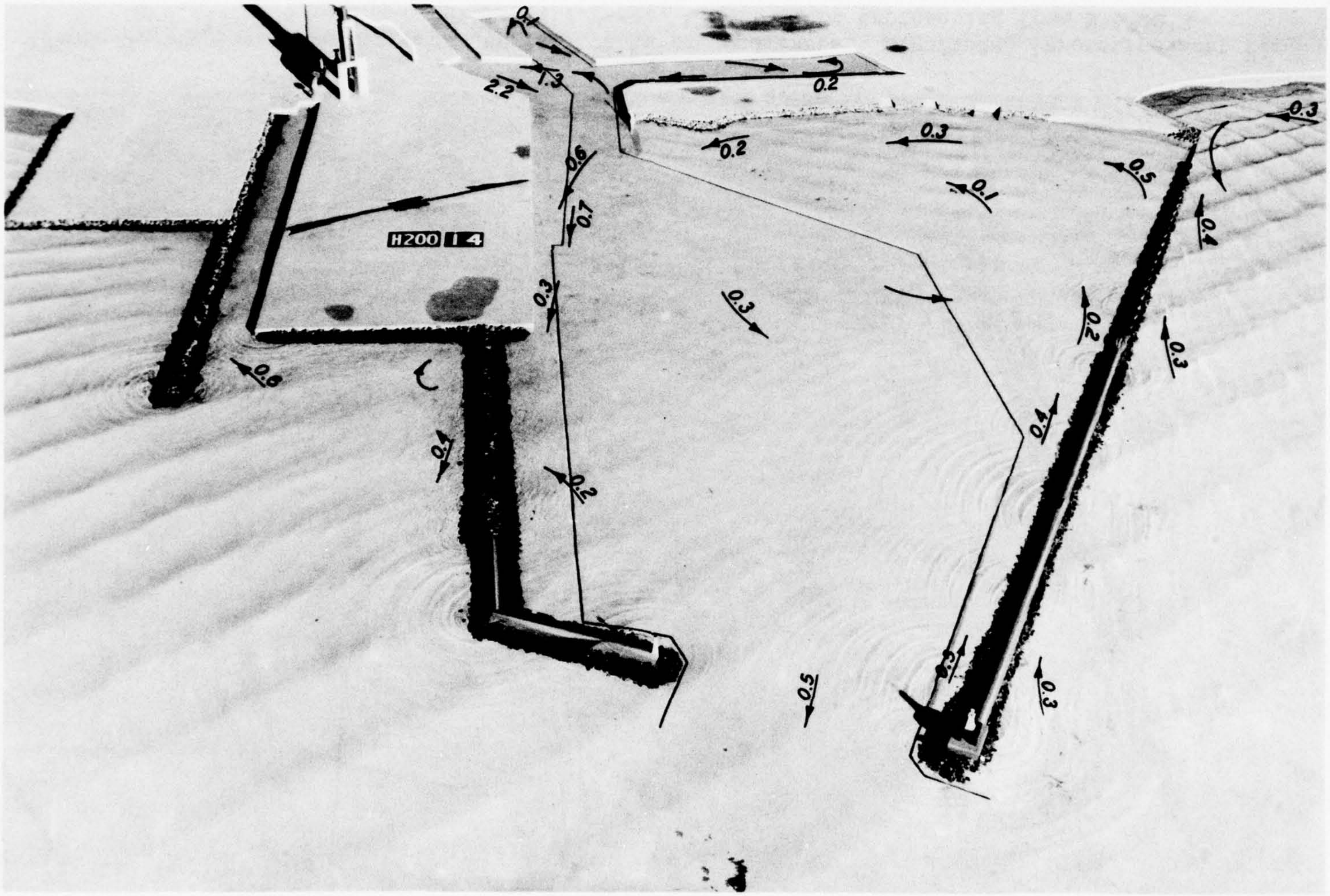

Photo 1. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 6-sec, 4.3-ft waves approaching from N76°20'E

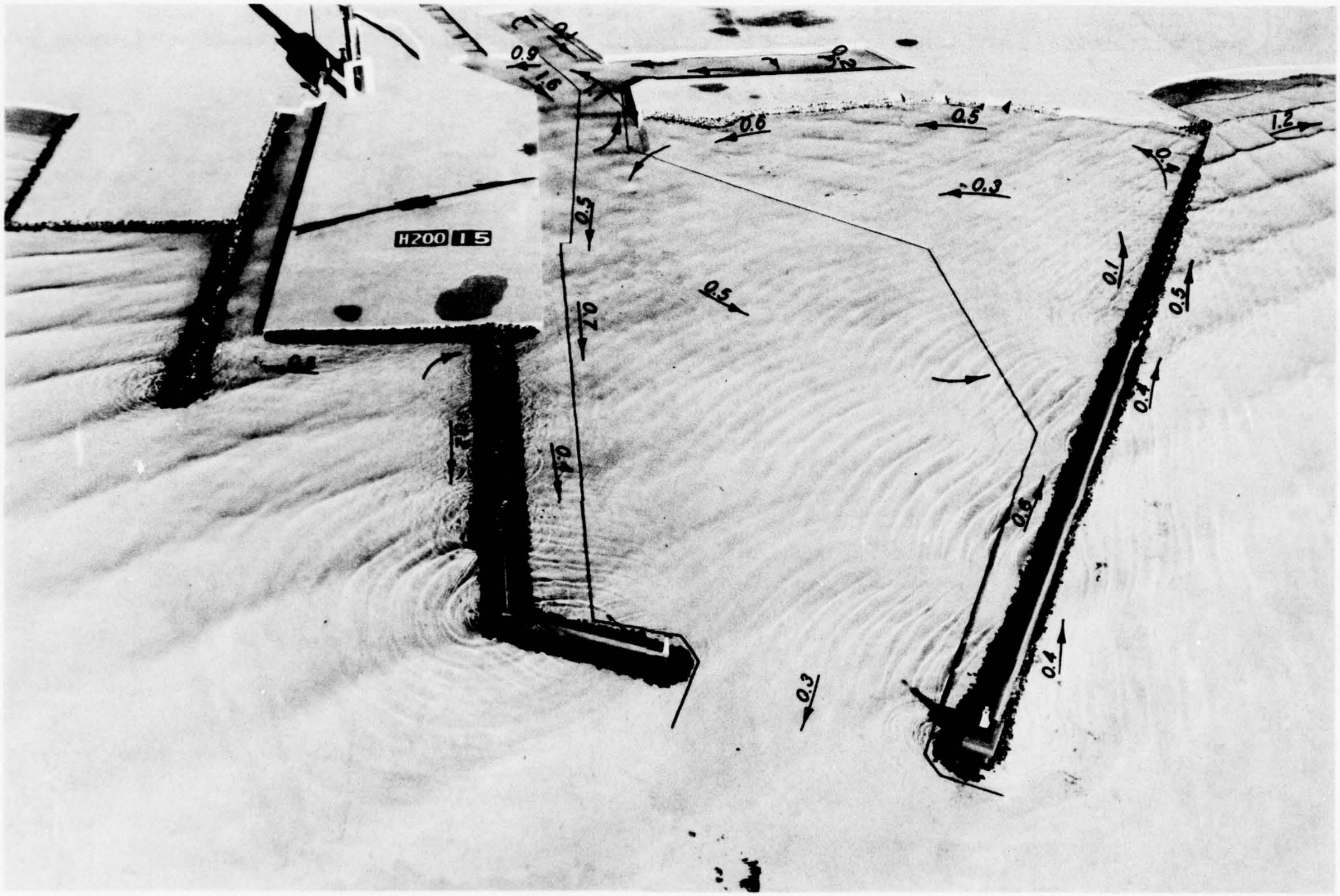

Photo 2. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.7-sec, 4.2-ft waves approaching from N76°20'E

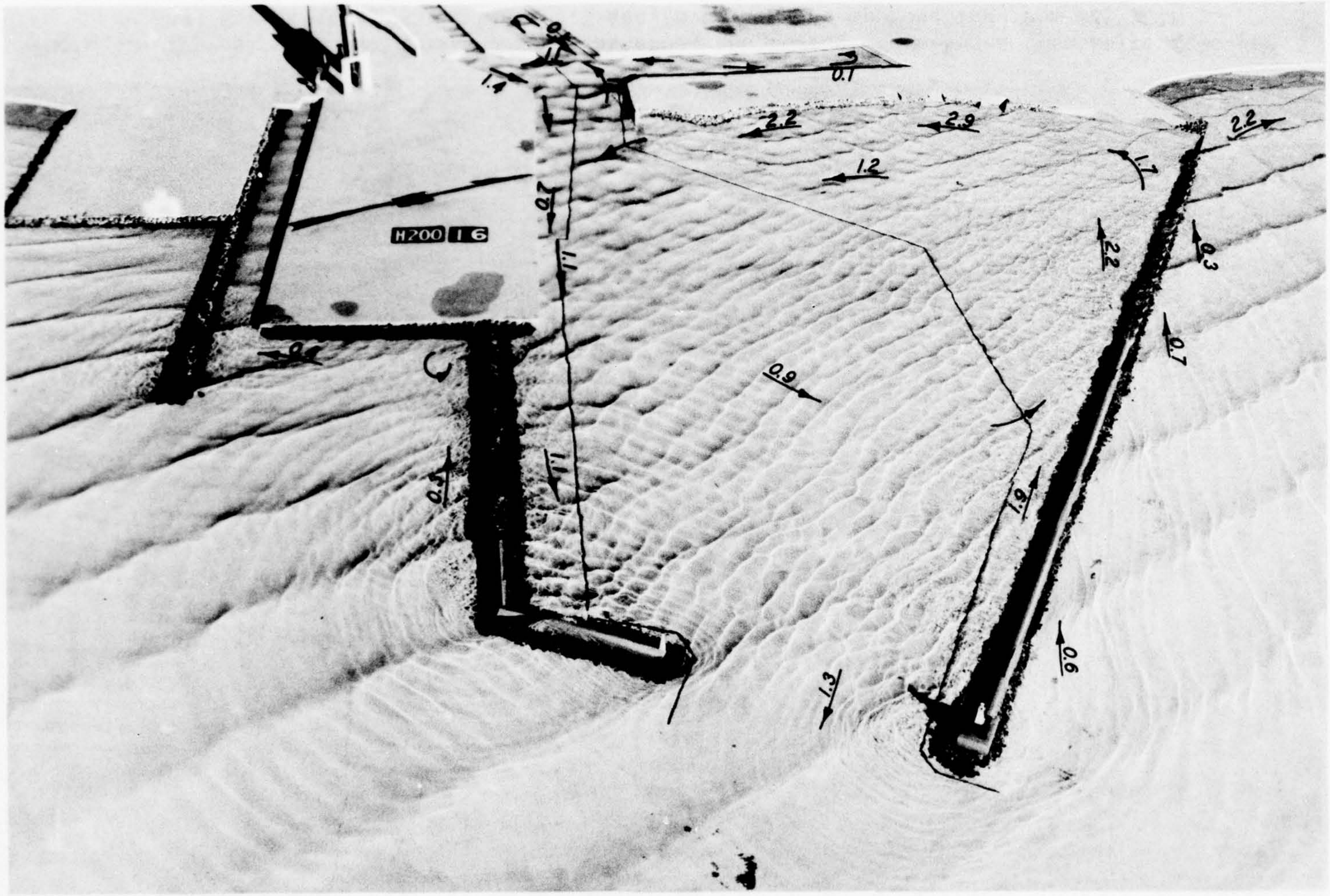

Photo 3. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.7-sec, 7.7-ft waves approaching from N76°20'E

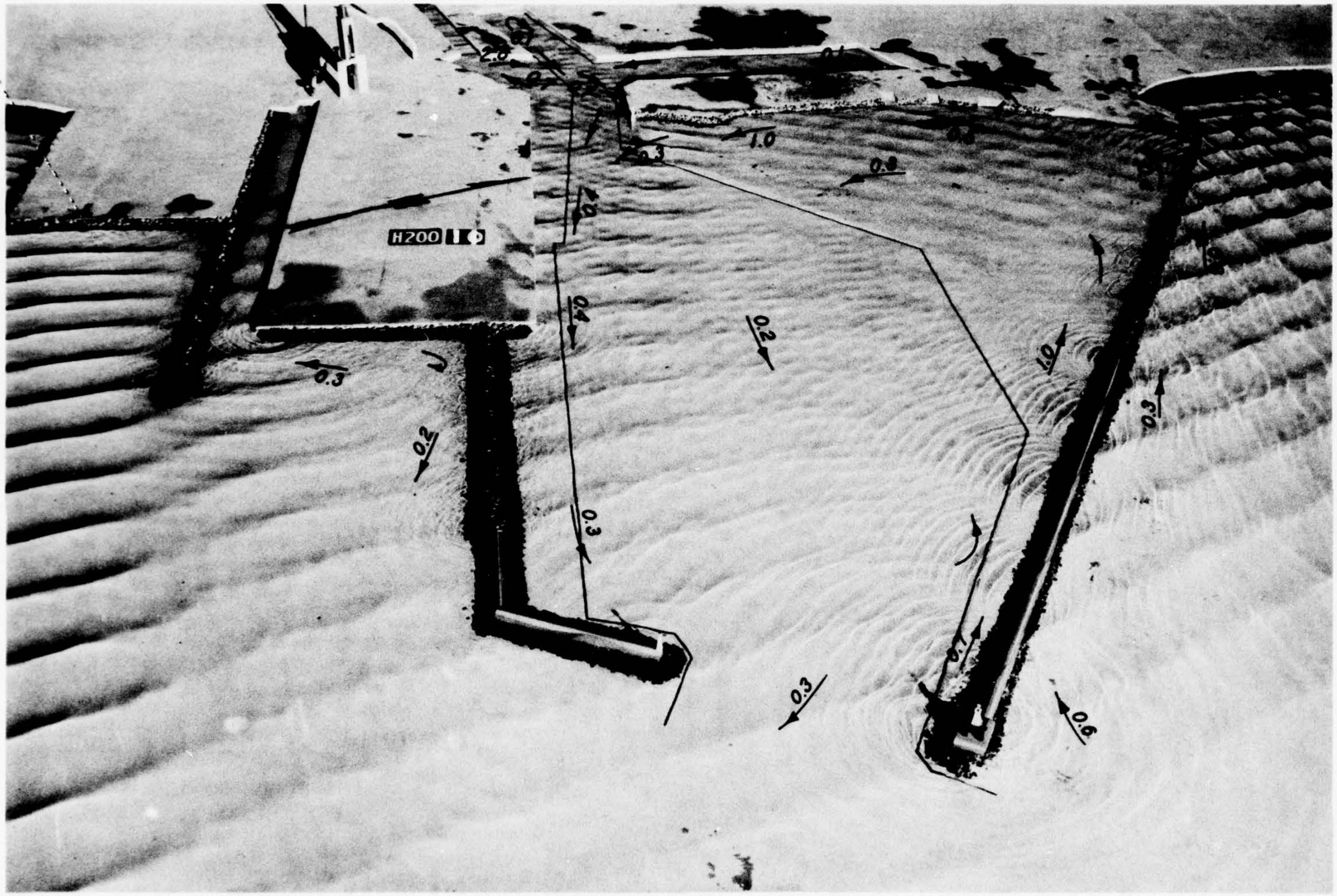

Photo 4. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5.5-sec, 3.8-ft waves approaching from S85°50'E

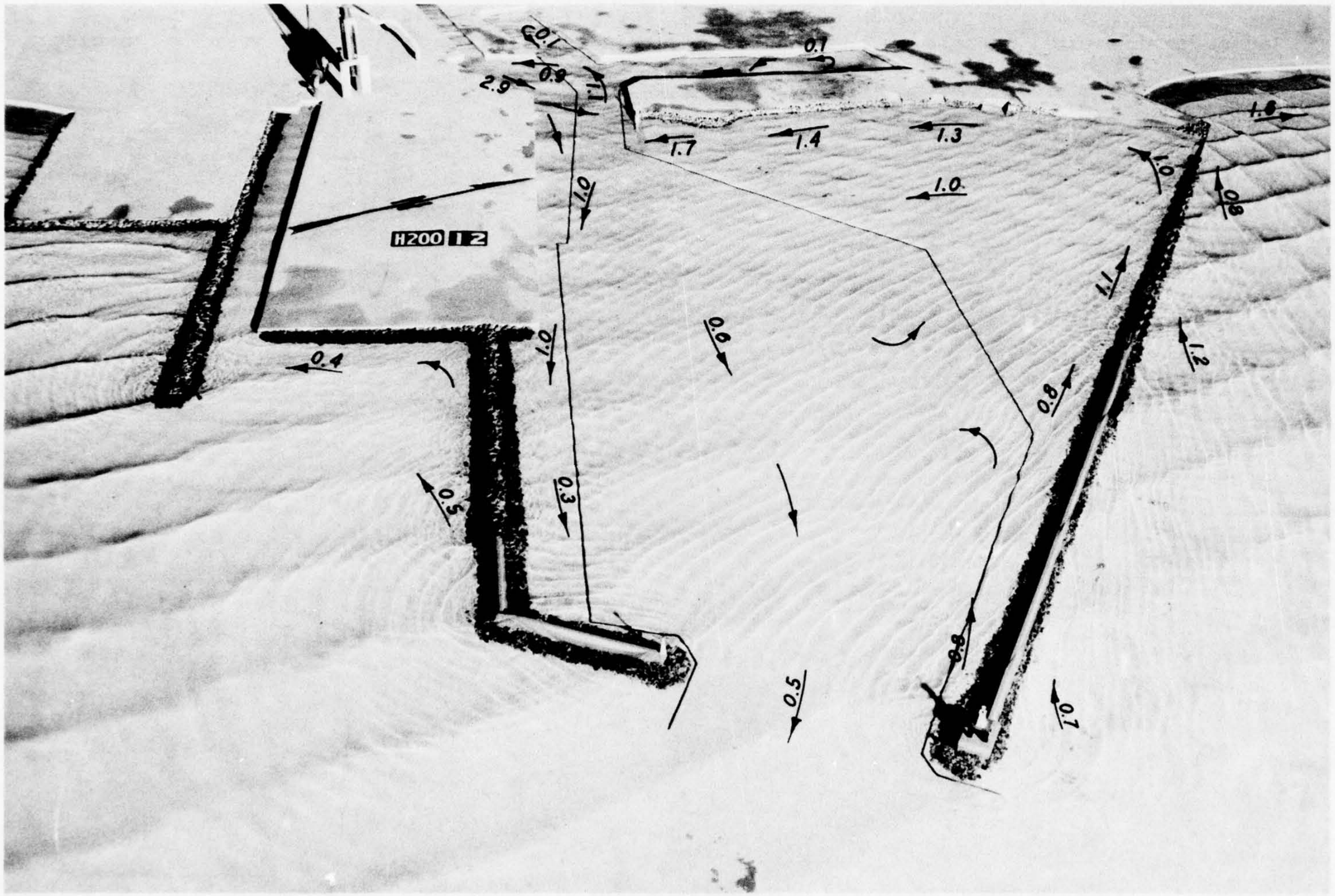

Photo 5. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 5.3-ft waves approaching from S85°50'E

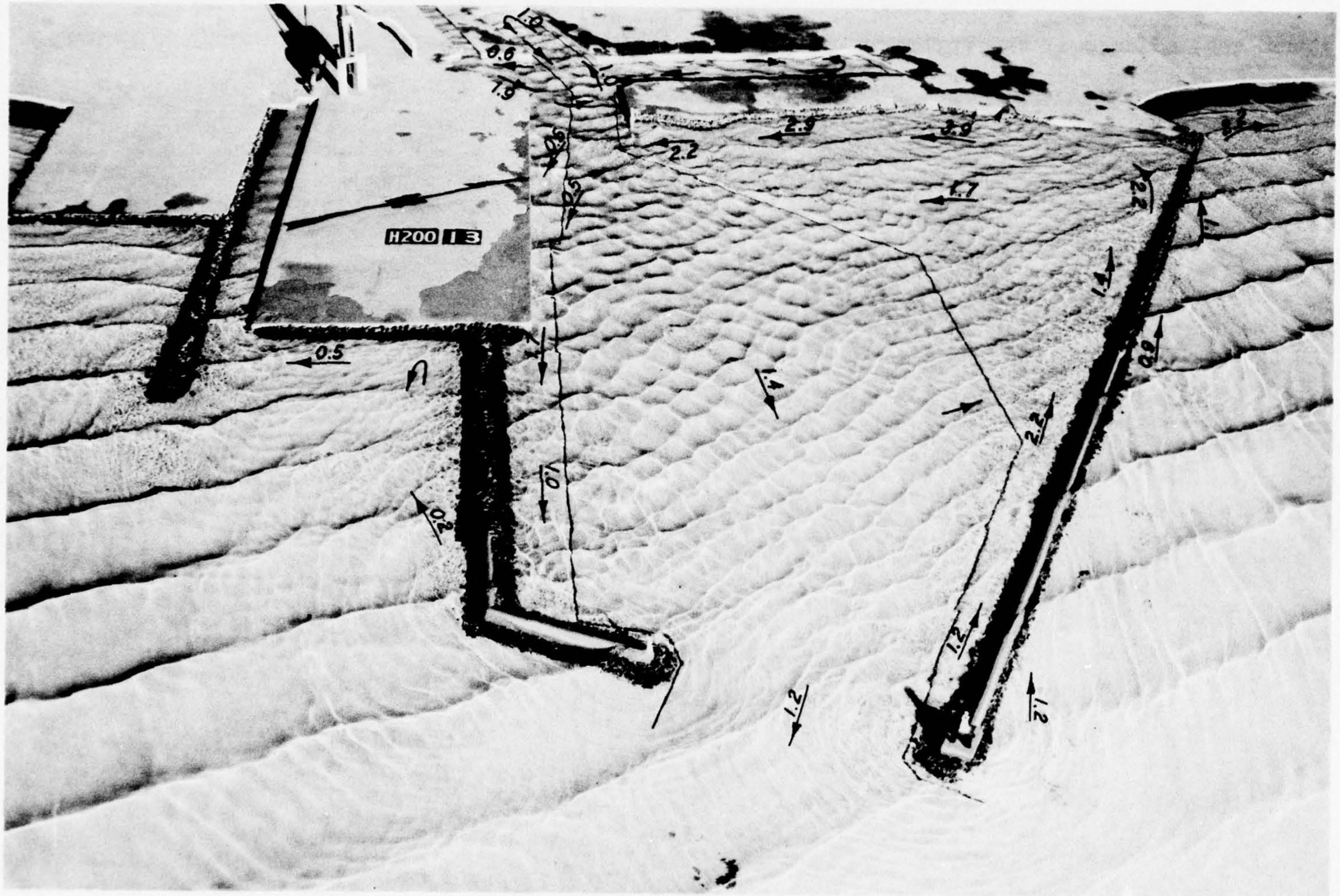

Photo 6. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 9.6-ft waves approaching from S85°50'E

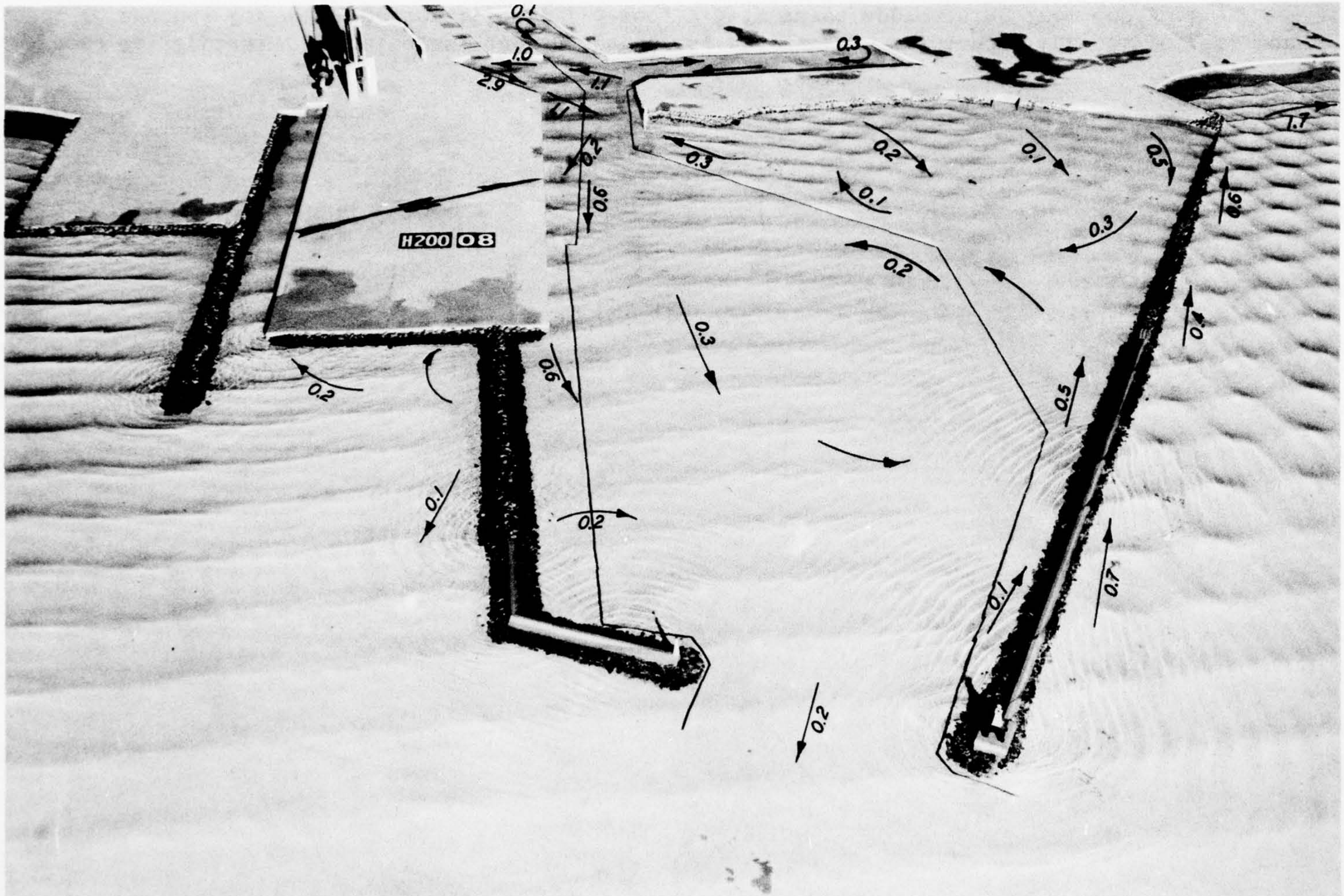

Photo 7. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5.5-sec, 3.8-ft waves approaching from S68°30'E

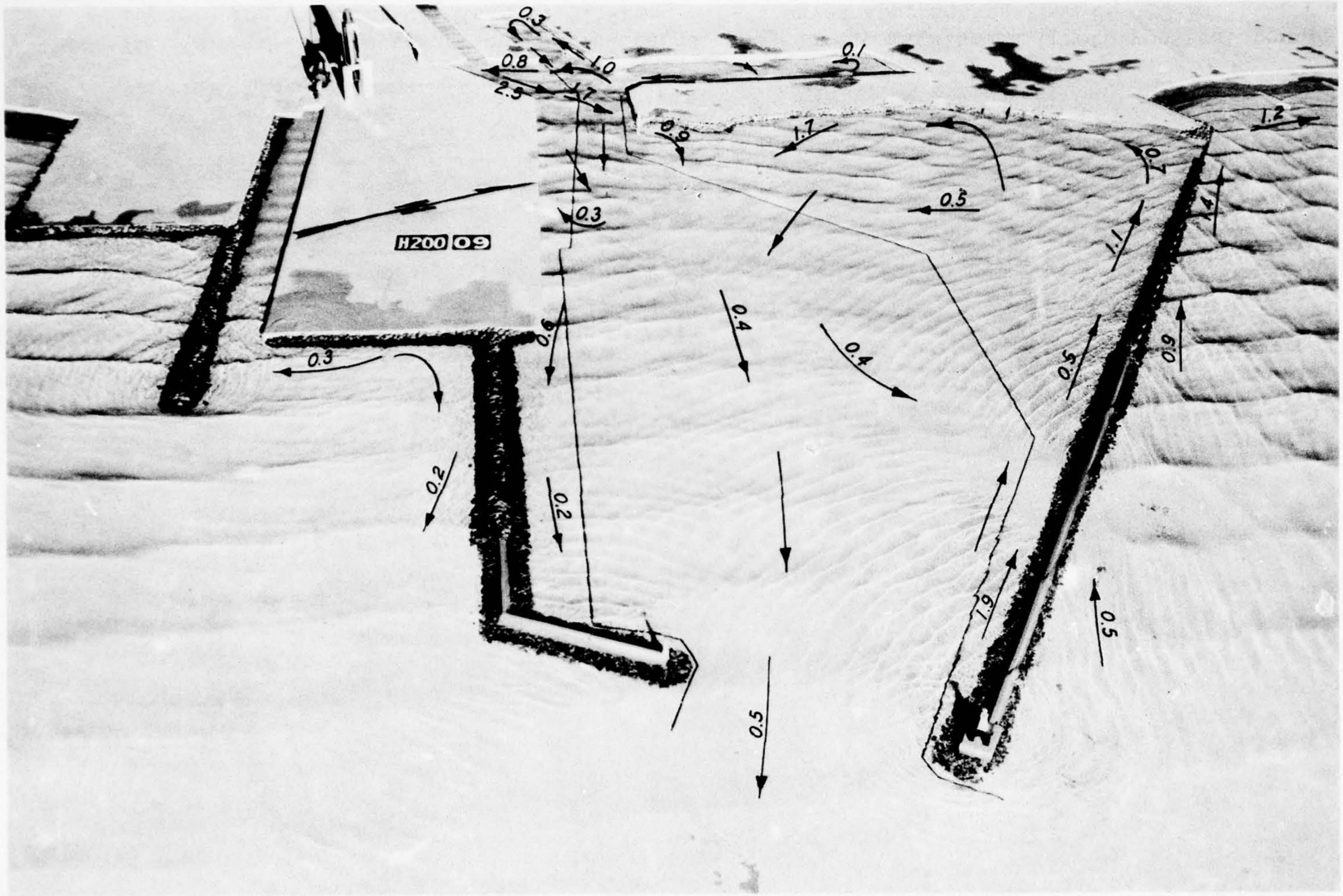

Photo 8. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 5.5-ft waves approaching from S68°30'E

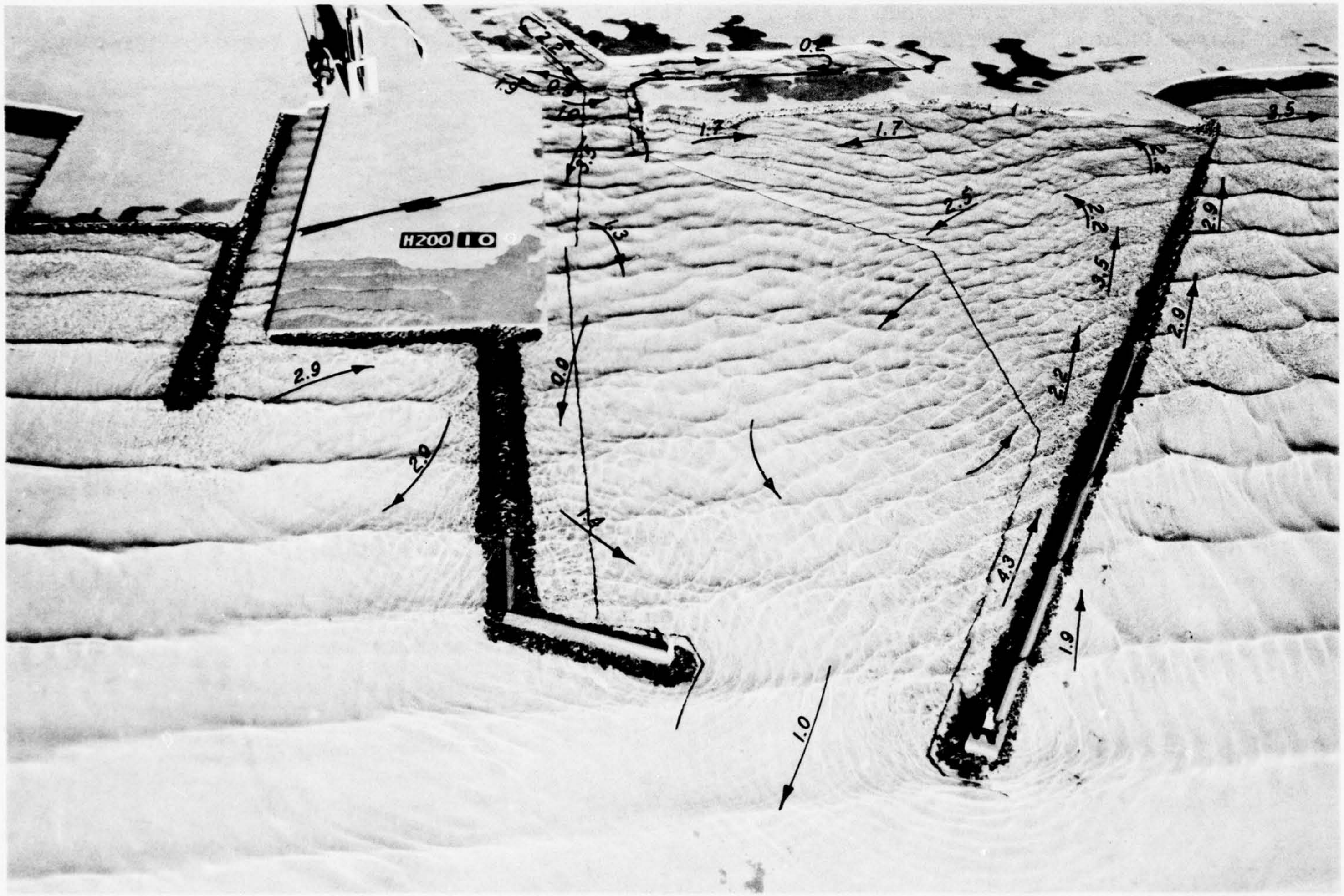

Photo 9. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 9.9-ft waves approaching from S68°30'E

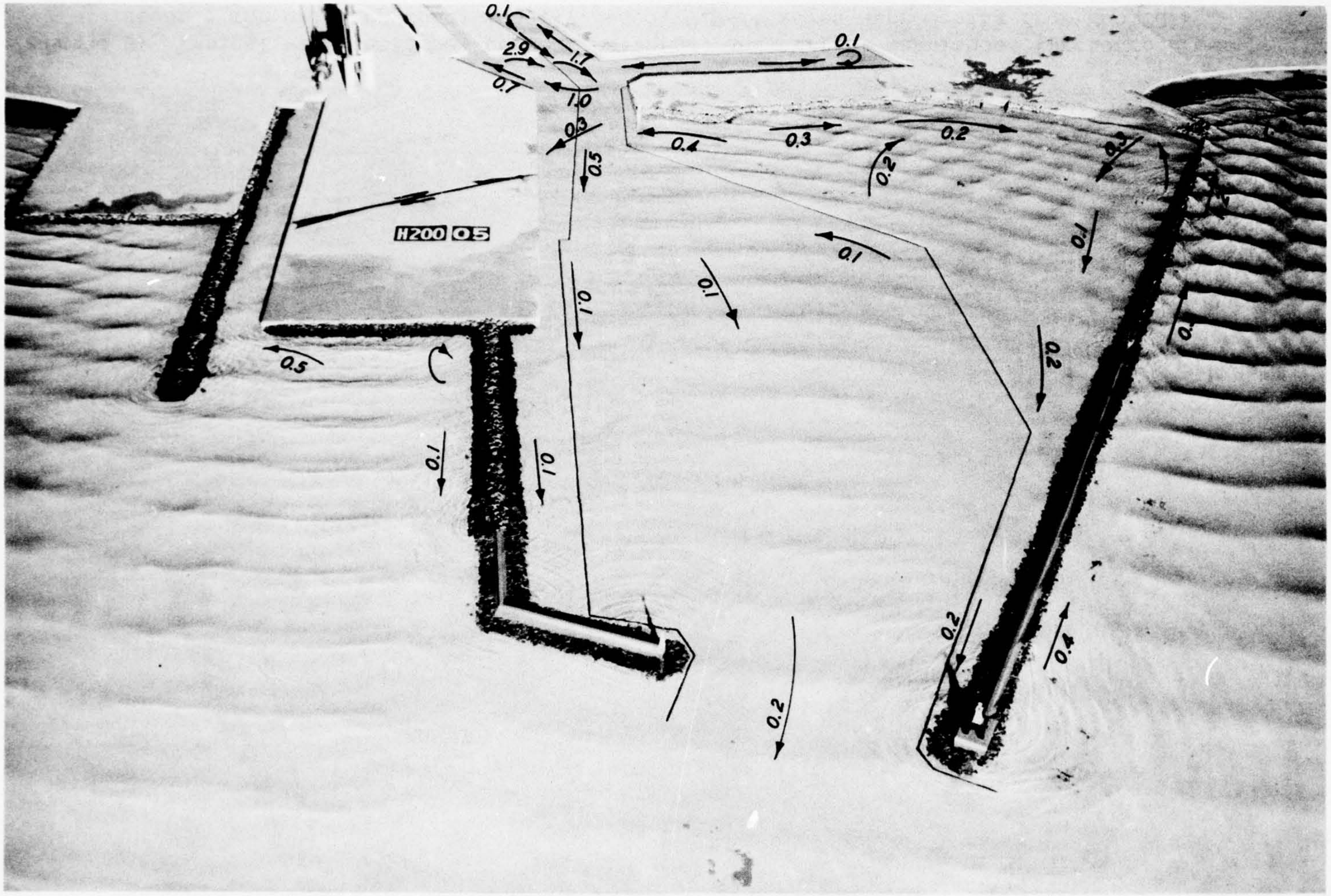

Photo 10. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5.5-sec, 3.8-ft waves approaching from S50°45'E

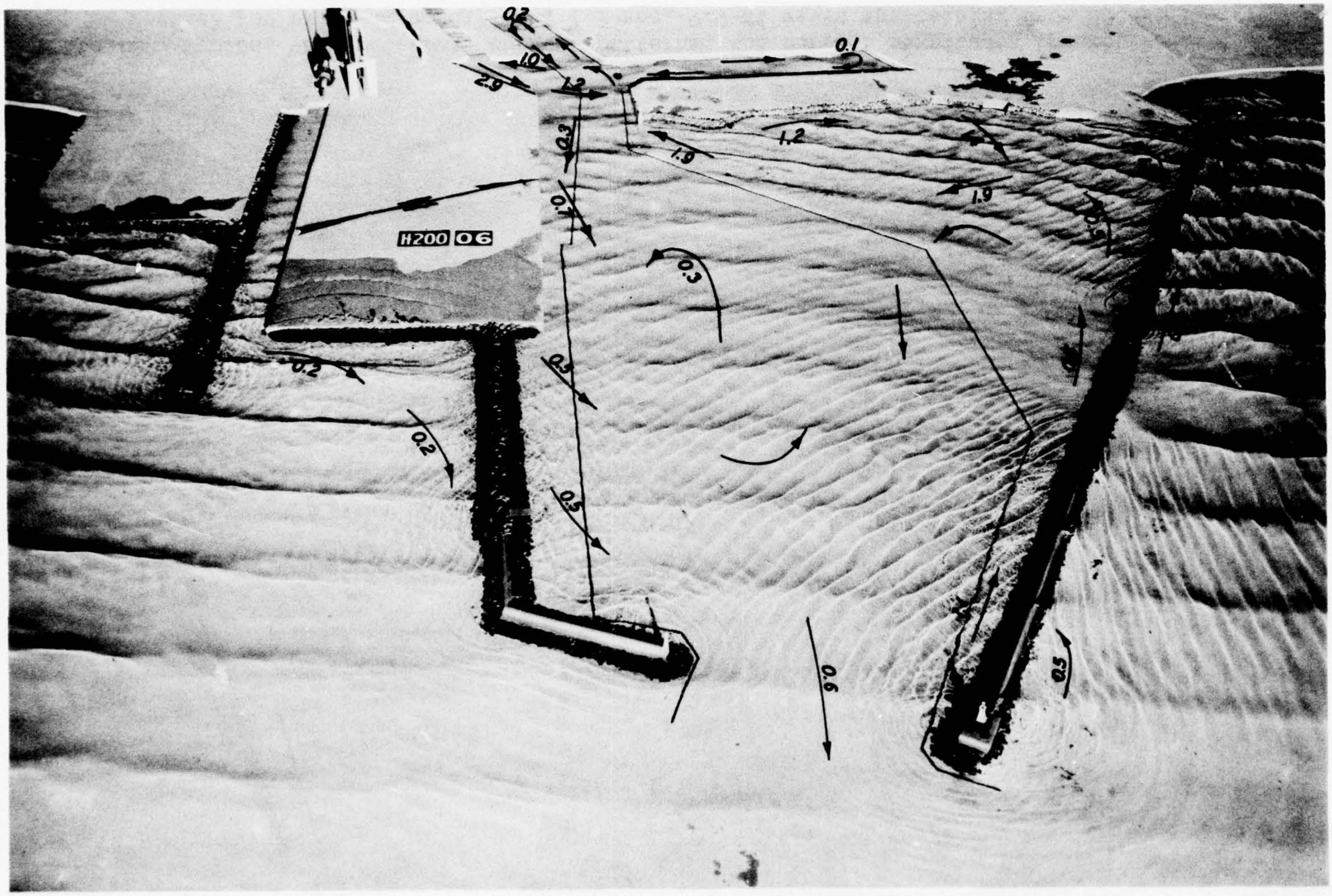

Photo 11. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 5.5-ft waves approaching from S50°45'E

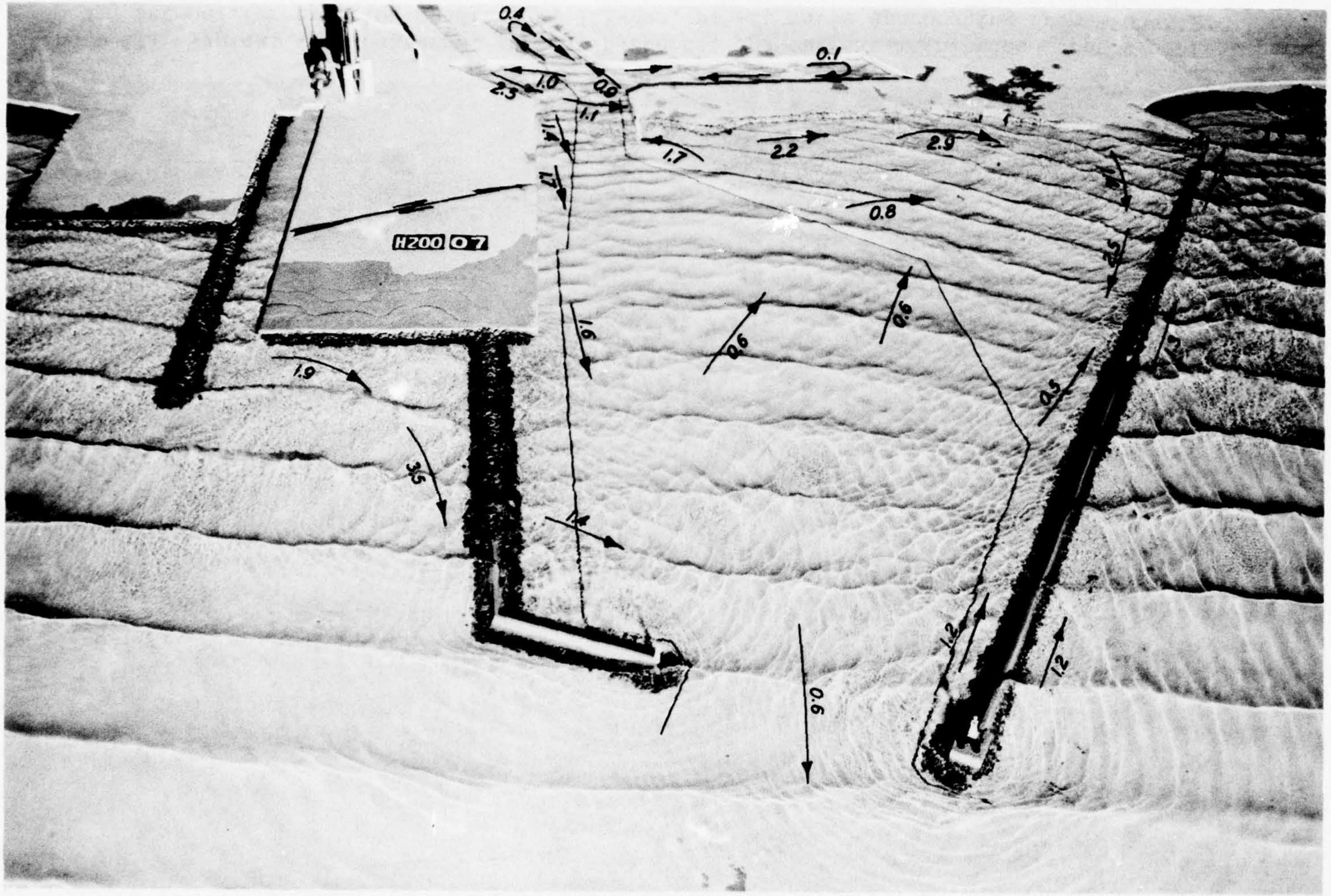

Photo 12. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7.3-sec, 9.9-ft waves approaching from S50°45'E

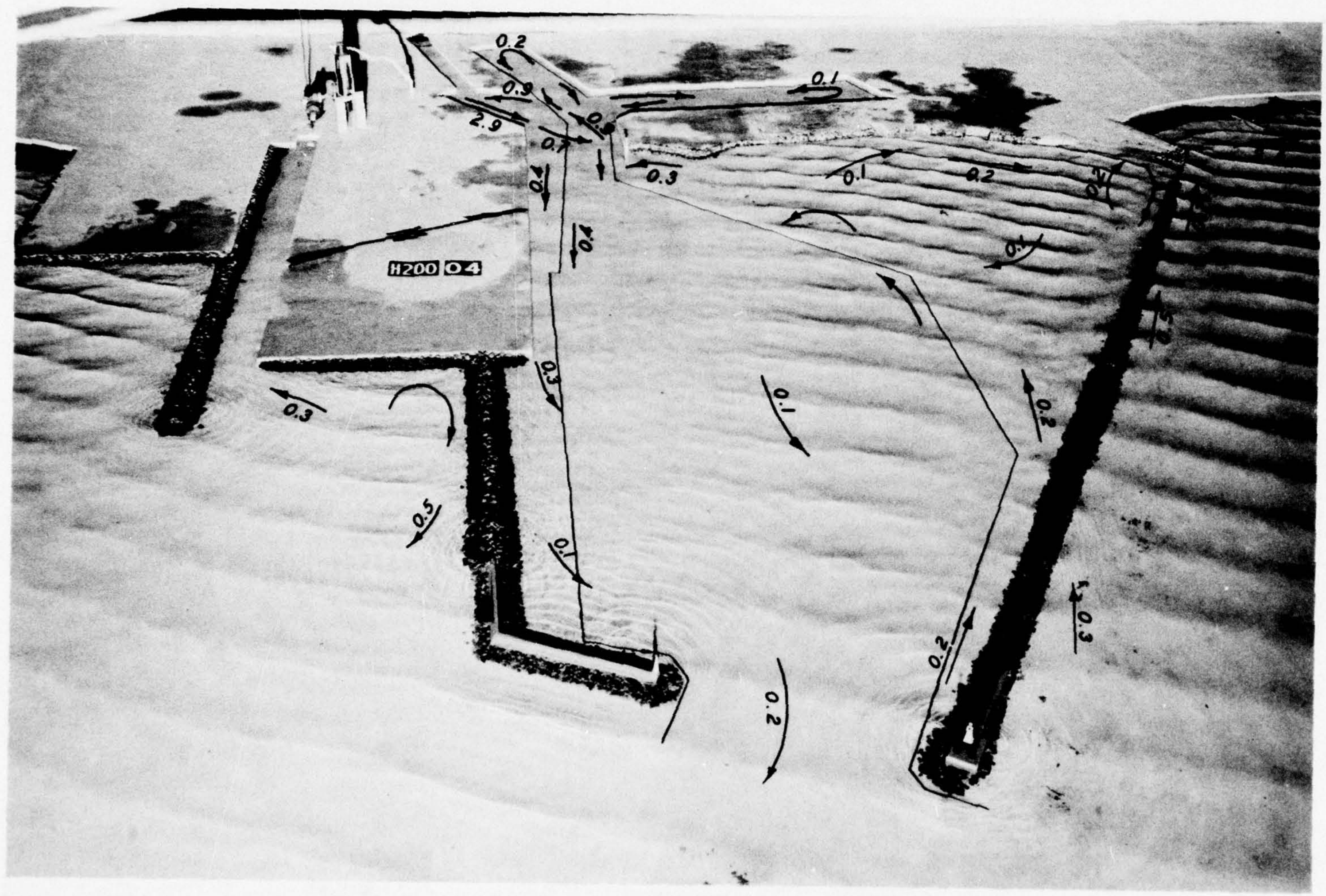

Photo 13. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 6-sec, 3.7-ft waves approaching from S37°10'E

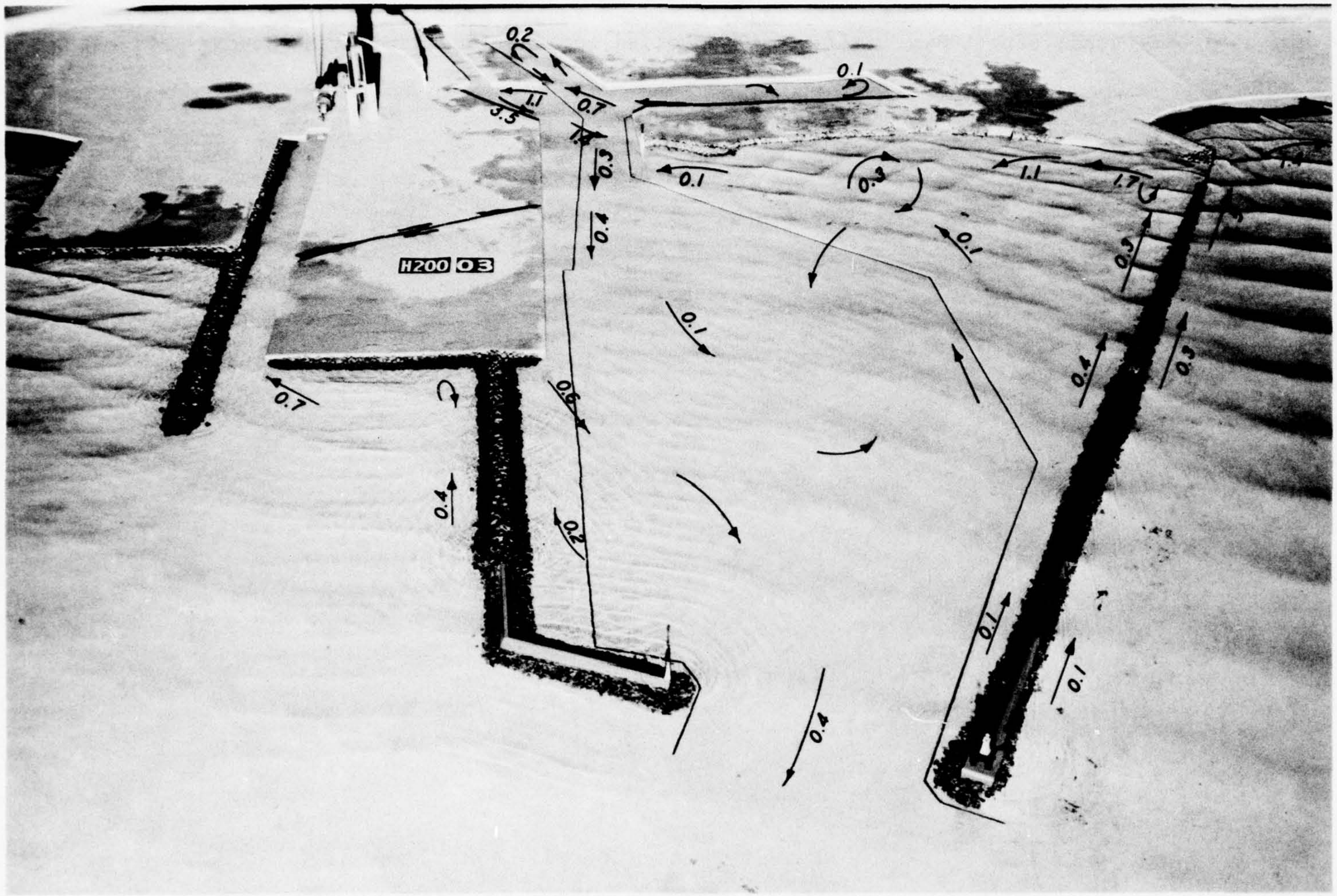

Photo 14. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 8.3-sec, 3.4-ft waves approaching from S37°10'E

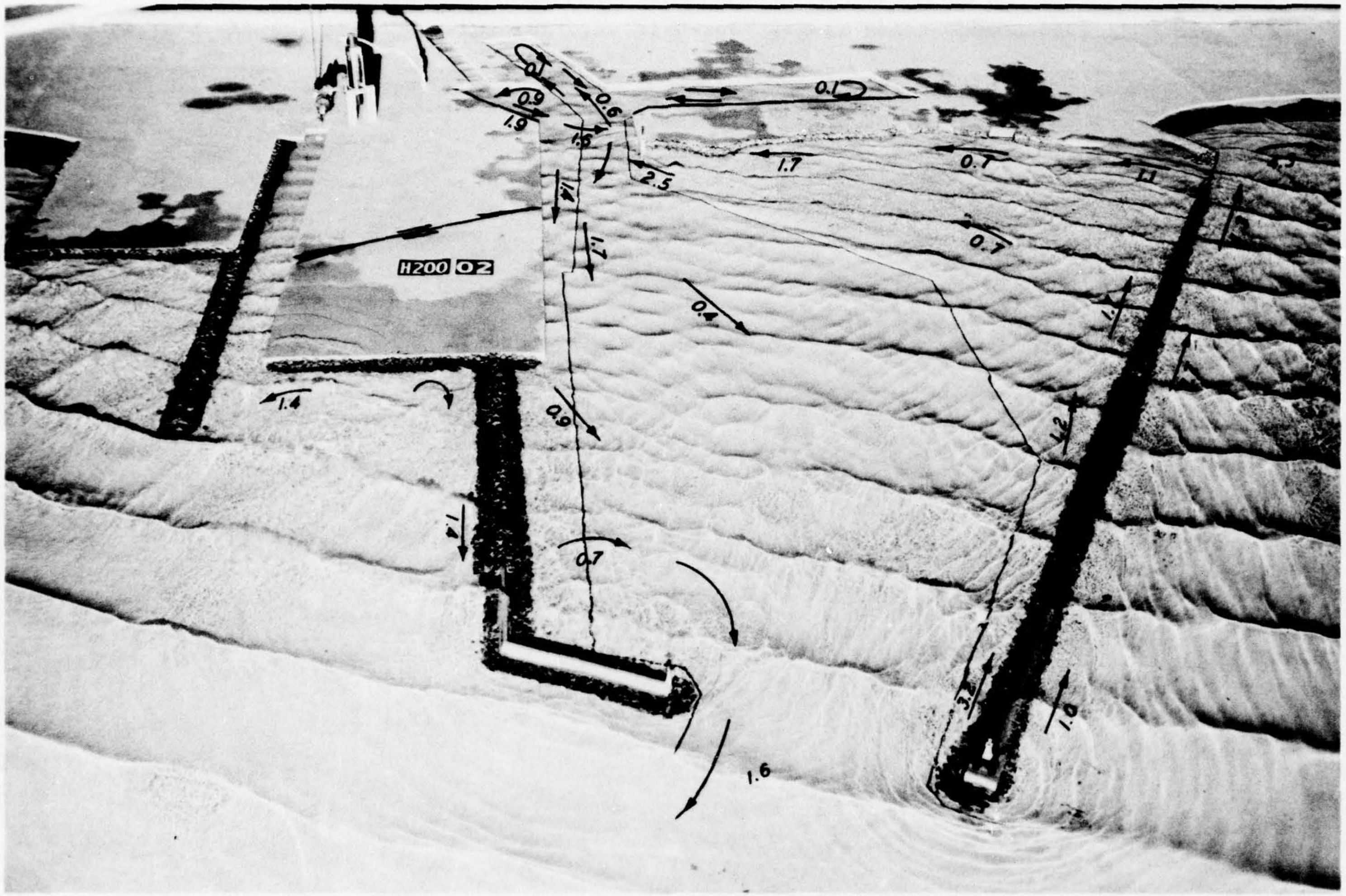

Photo 15. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 8.3-sec, 10.4-ft waves approaching from S37°10'E

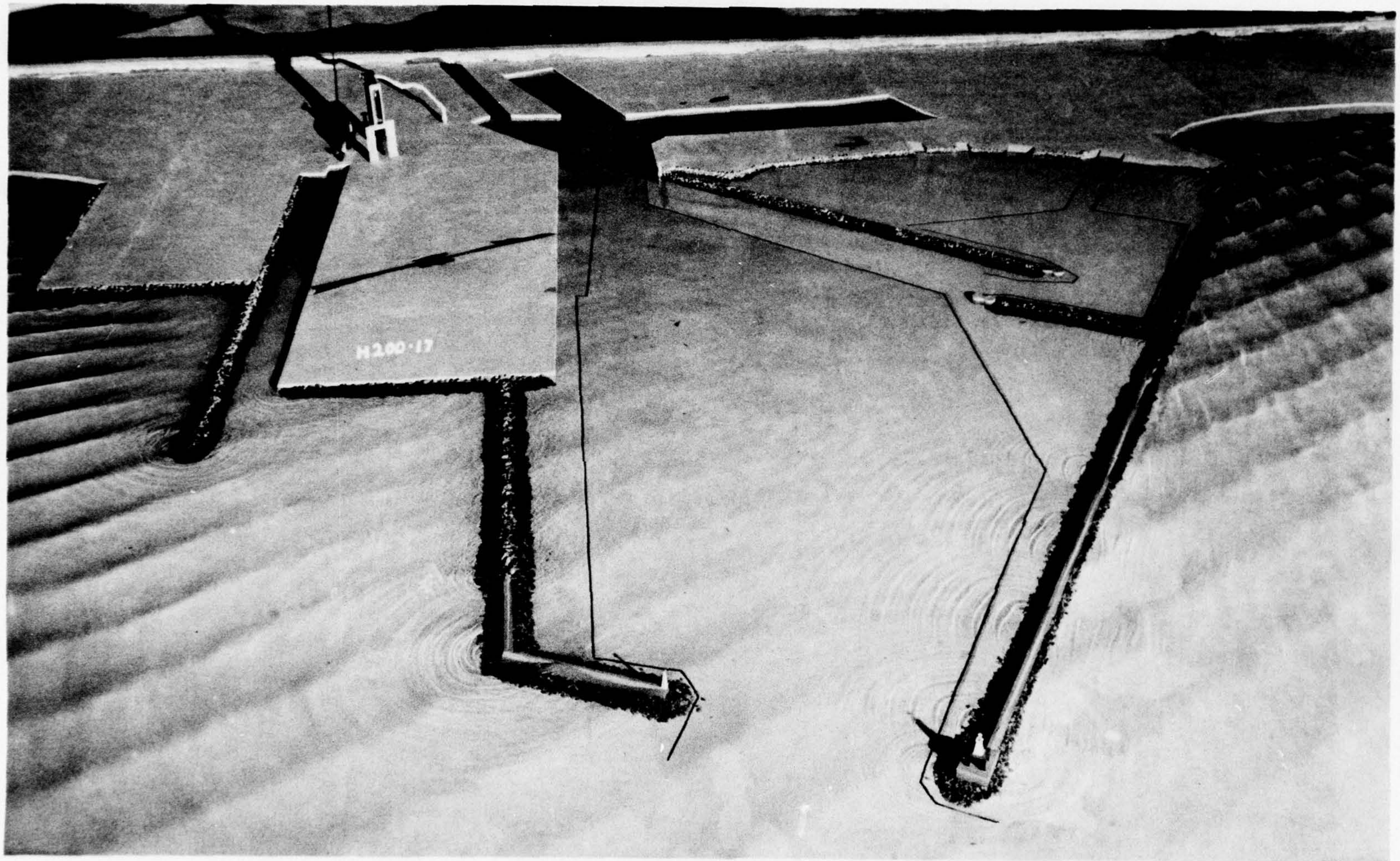

Photo 16. Typical wave patterns for plan 1; 6-sec, 4.3-ft waves approaching from N76°20'E

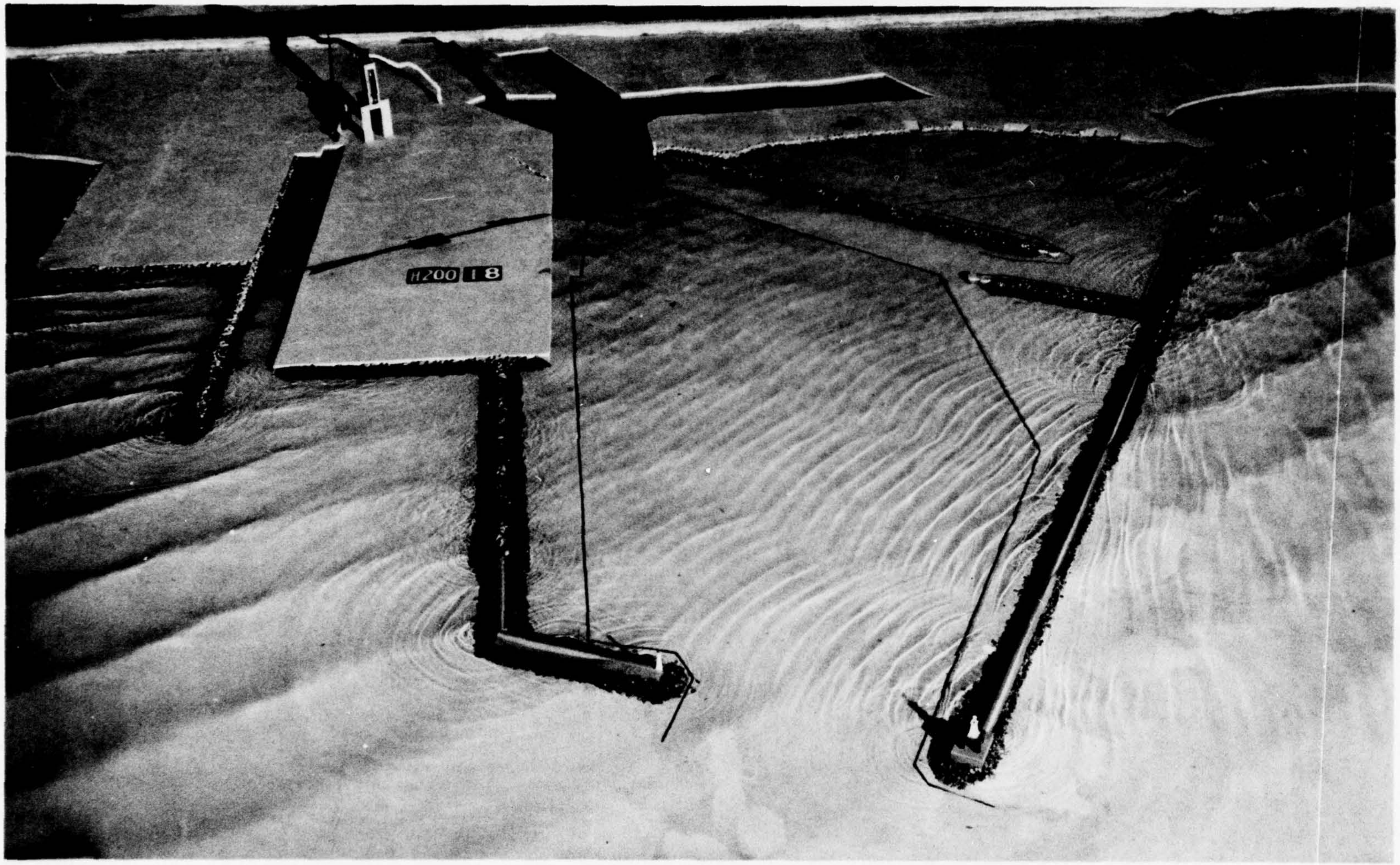

Photo 17. Typical wave patterns for plan 1; 7.7-sec, 4.2-ft waves approaching from N76°20'E

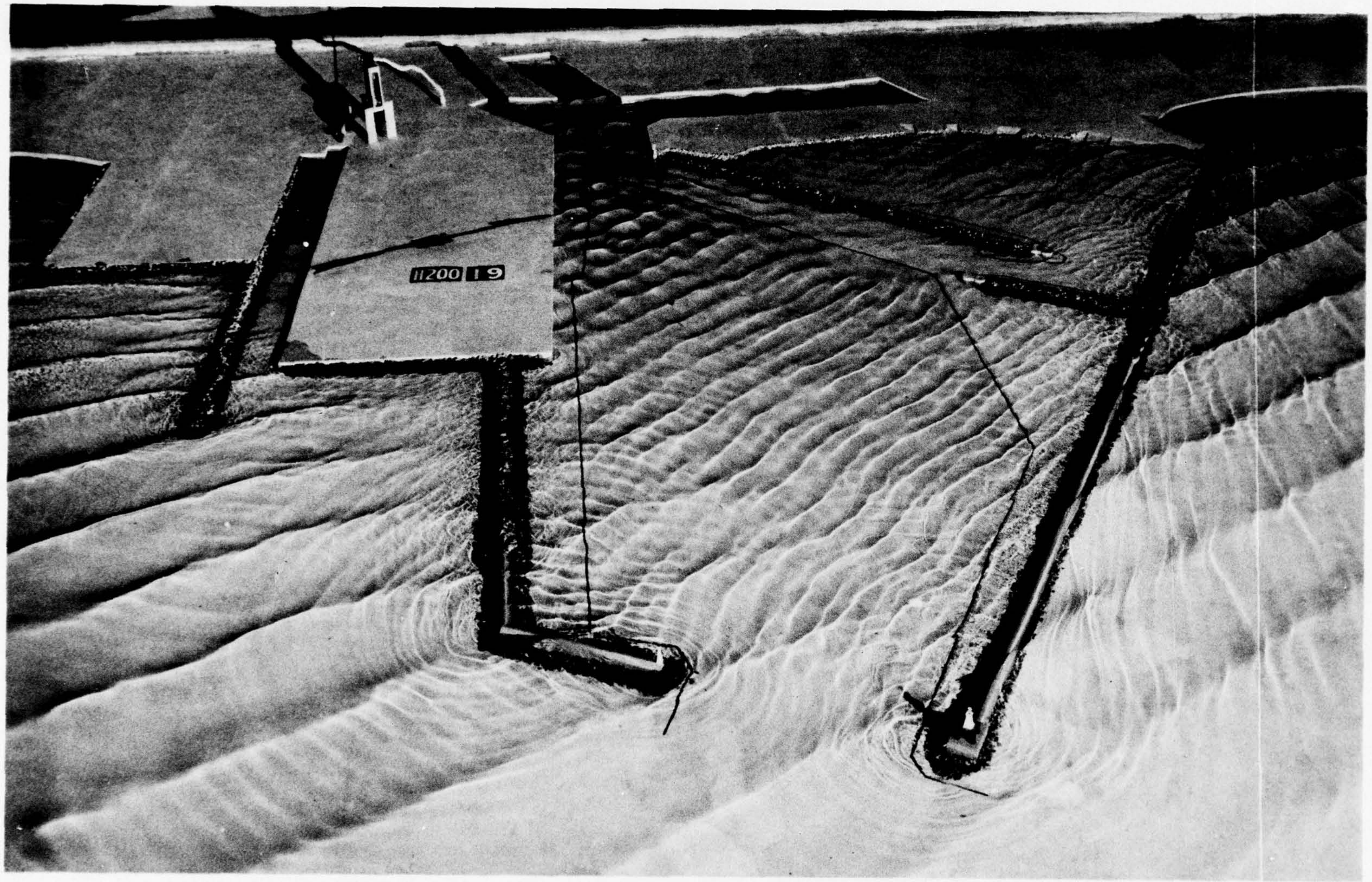

Photo 18. Typical wave patterns for plan 1; 7.7-sec, 7.7-ft waves approaching from N76°20'E

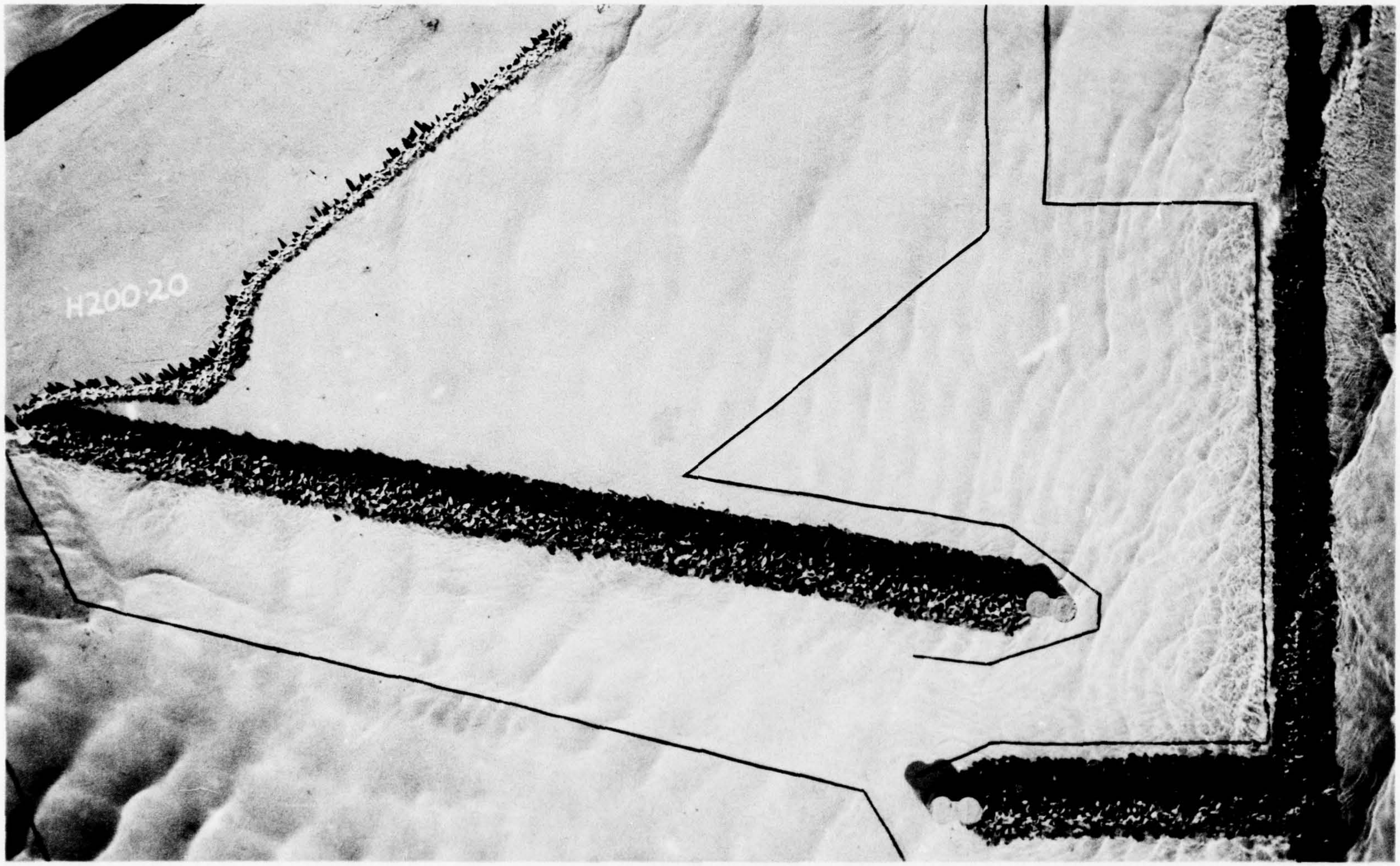

Photo 19. Typical wave patterns in proposed small-boat basin for plan 1; 7.7-sec, 7.7-ft waves approaching from N76°20'E

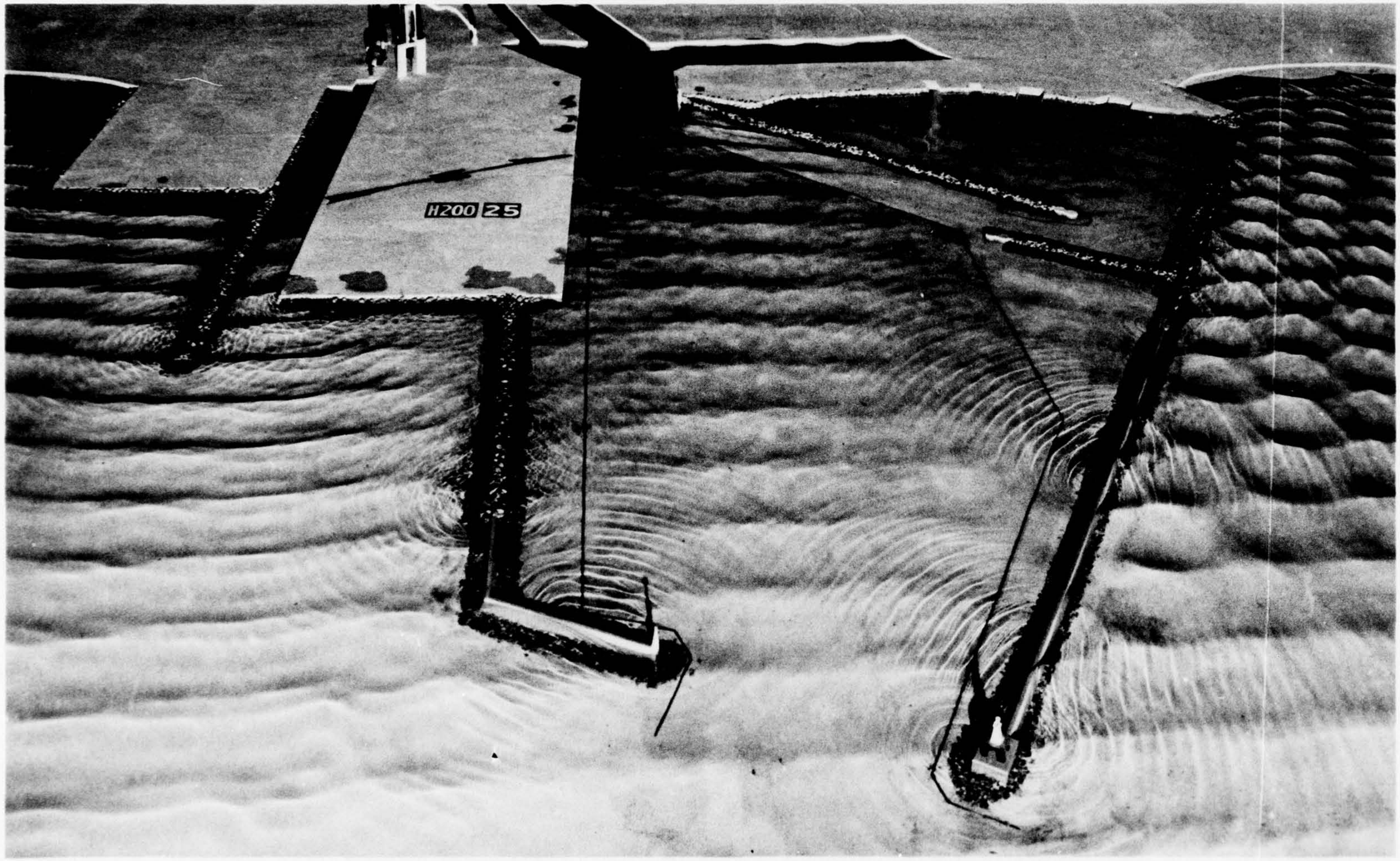

Photo 20. Typical wave patterns for plan 1; 5.5-sec, 3.8-ft waves approaching from S68°30'E

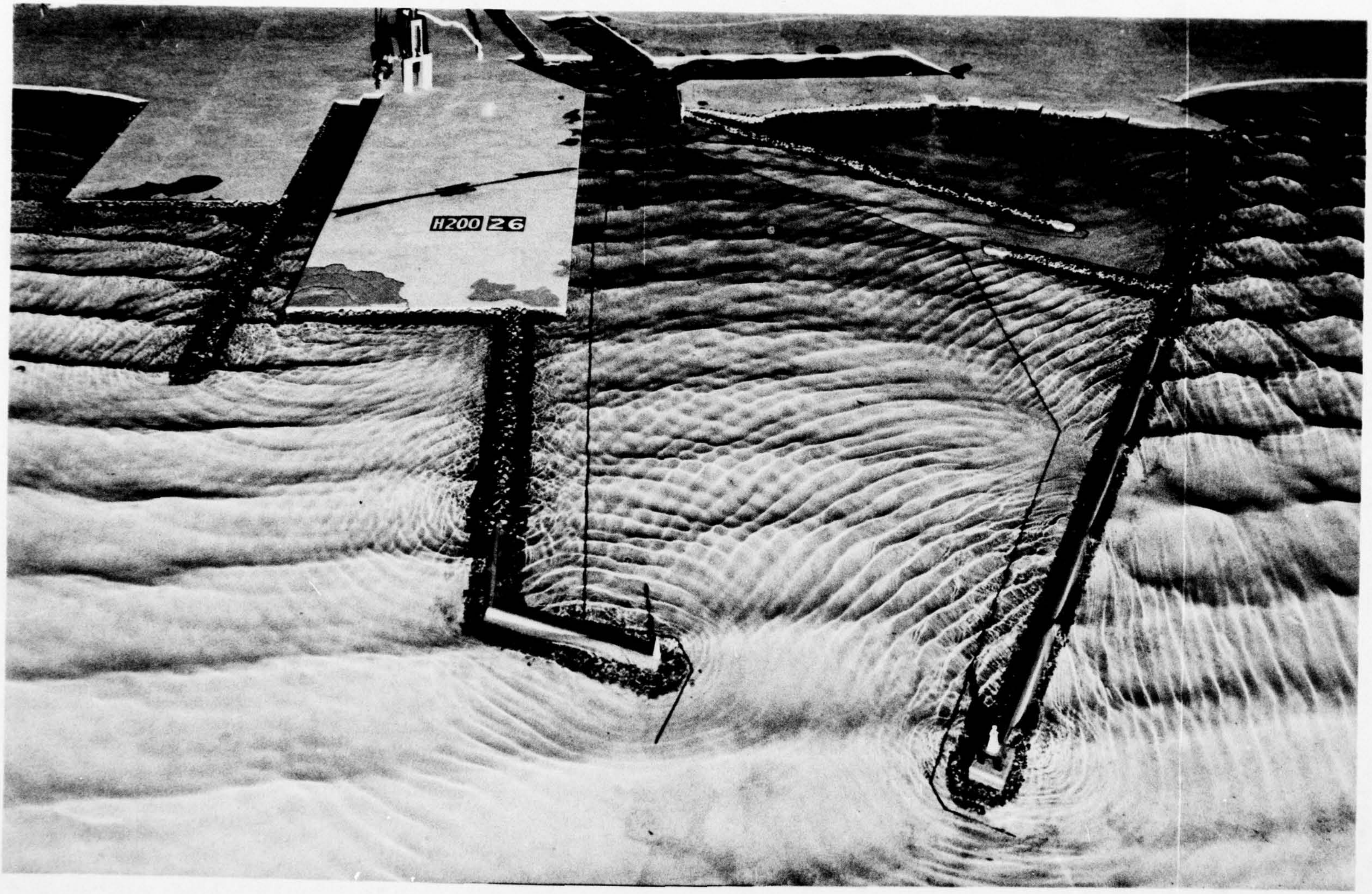

Photo 21. Typical wave patterns for plan 1; 7.3-sec, 5.5-ft waves approaching from S68°30'E

Photo 22. Typical wave patterns for plan 1; 7.3-sec, 9.9-ft waves approaching from S68°30'E

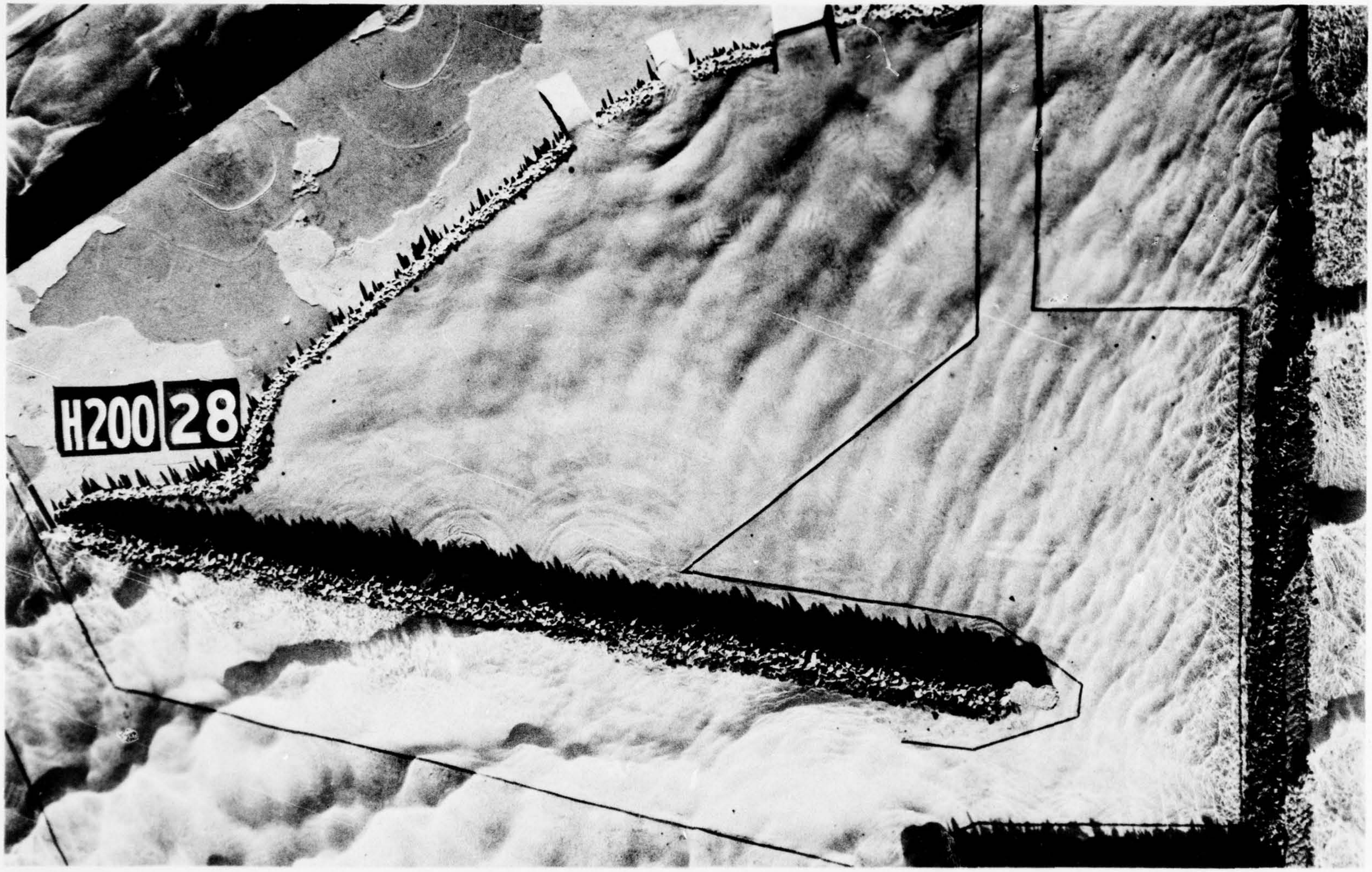

Photo 23. Typical wave patterns in proposed small-boat basin for plan 1; 7.3-sec, 9.9-ft waves approaching from S68°30'E

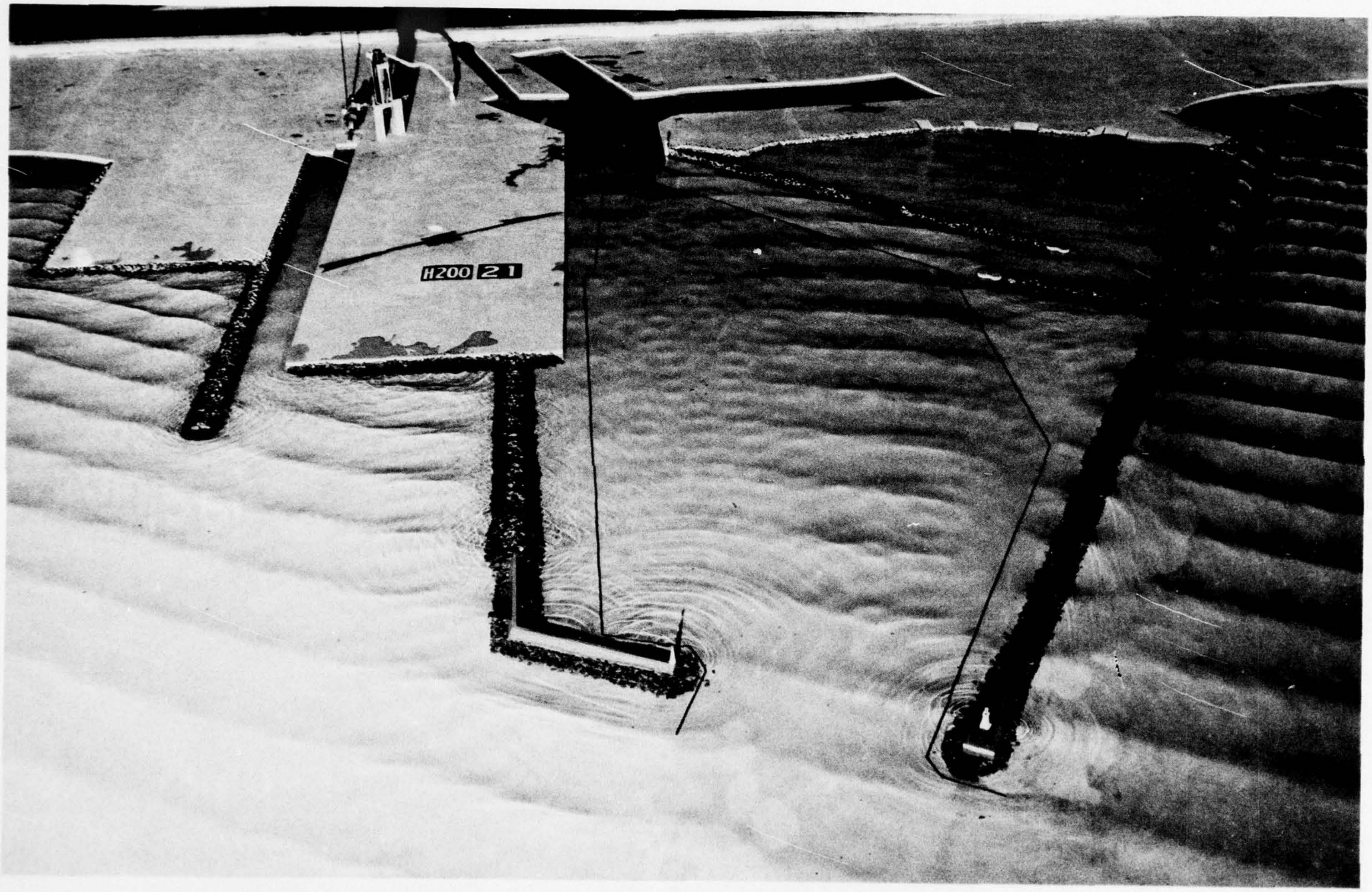

Photo 24. Typical wave patterns for plan 1; 6-sec, 3.7-ft waves approaching from S37°10'E

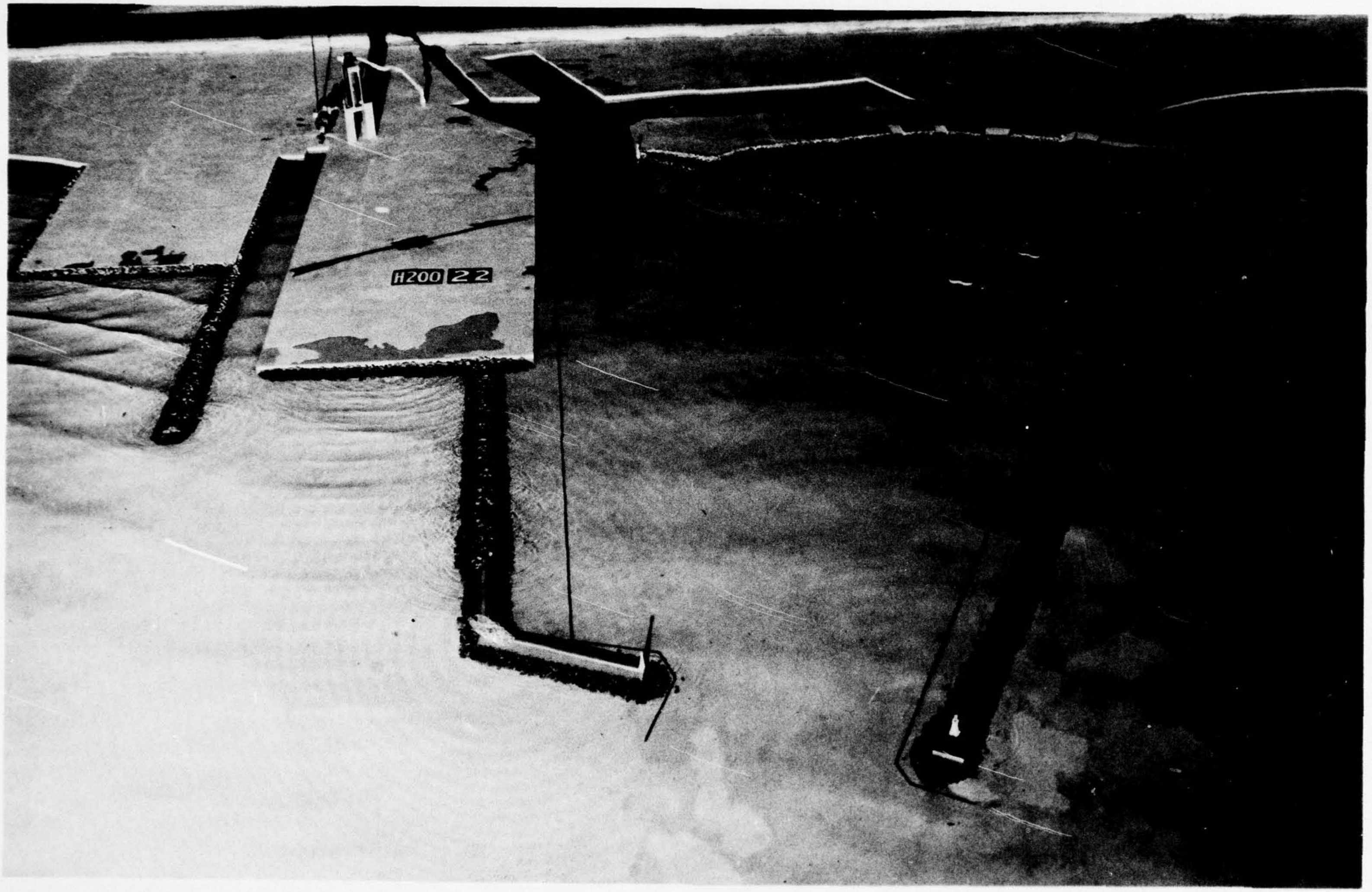

Photo 25. Typical wave patterns for plan 1; 8.3-sec, 3.4-ft waves approaching from S37°10'E

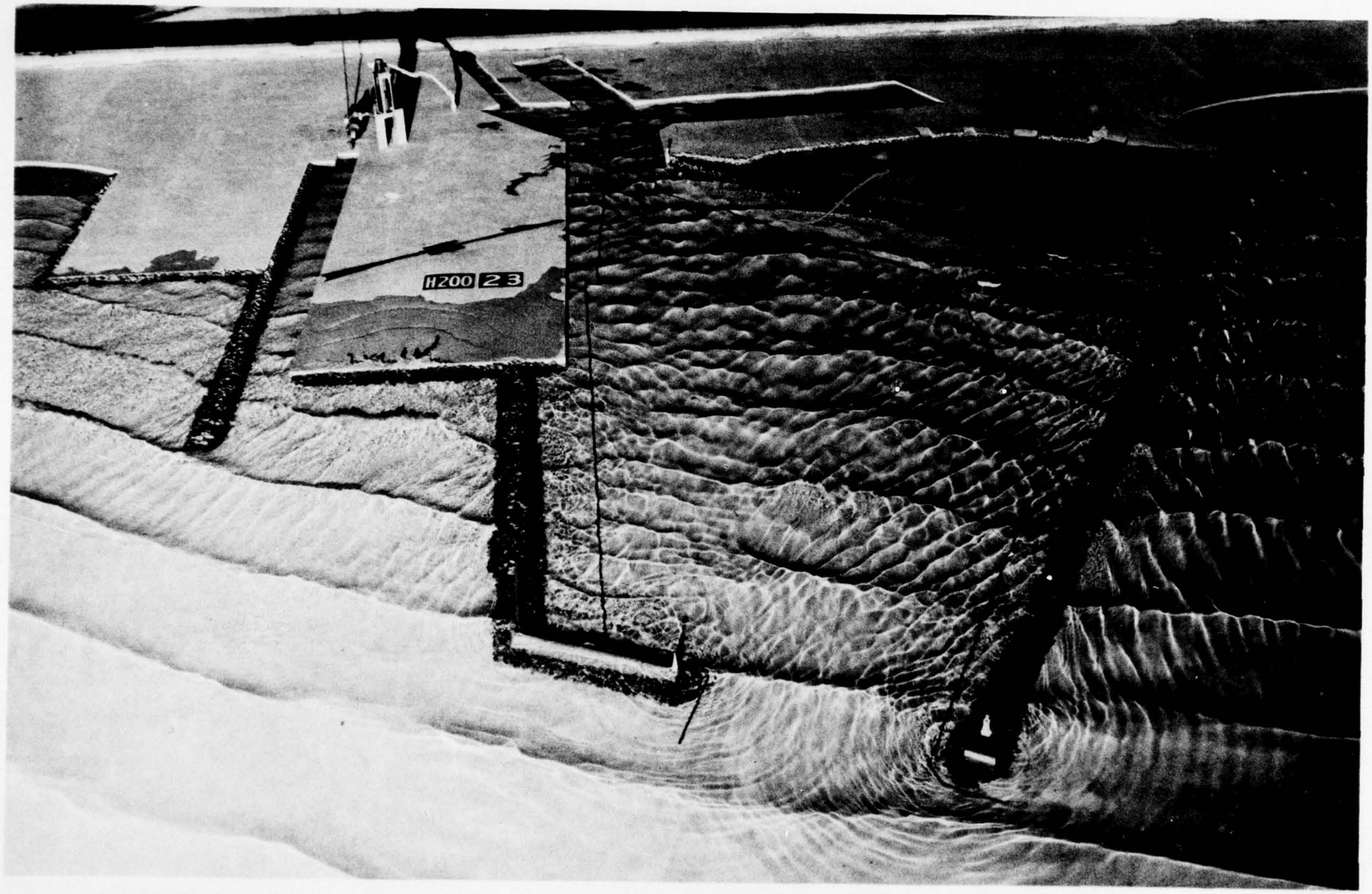

Photo 26. Typical wave patterns for plan 1; 8.3-sec, 10.4-ft waves approaching from S37°10'E

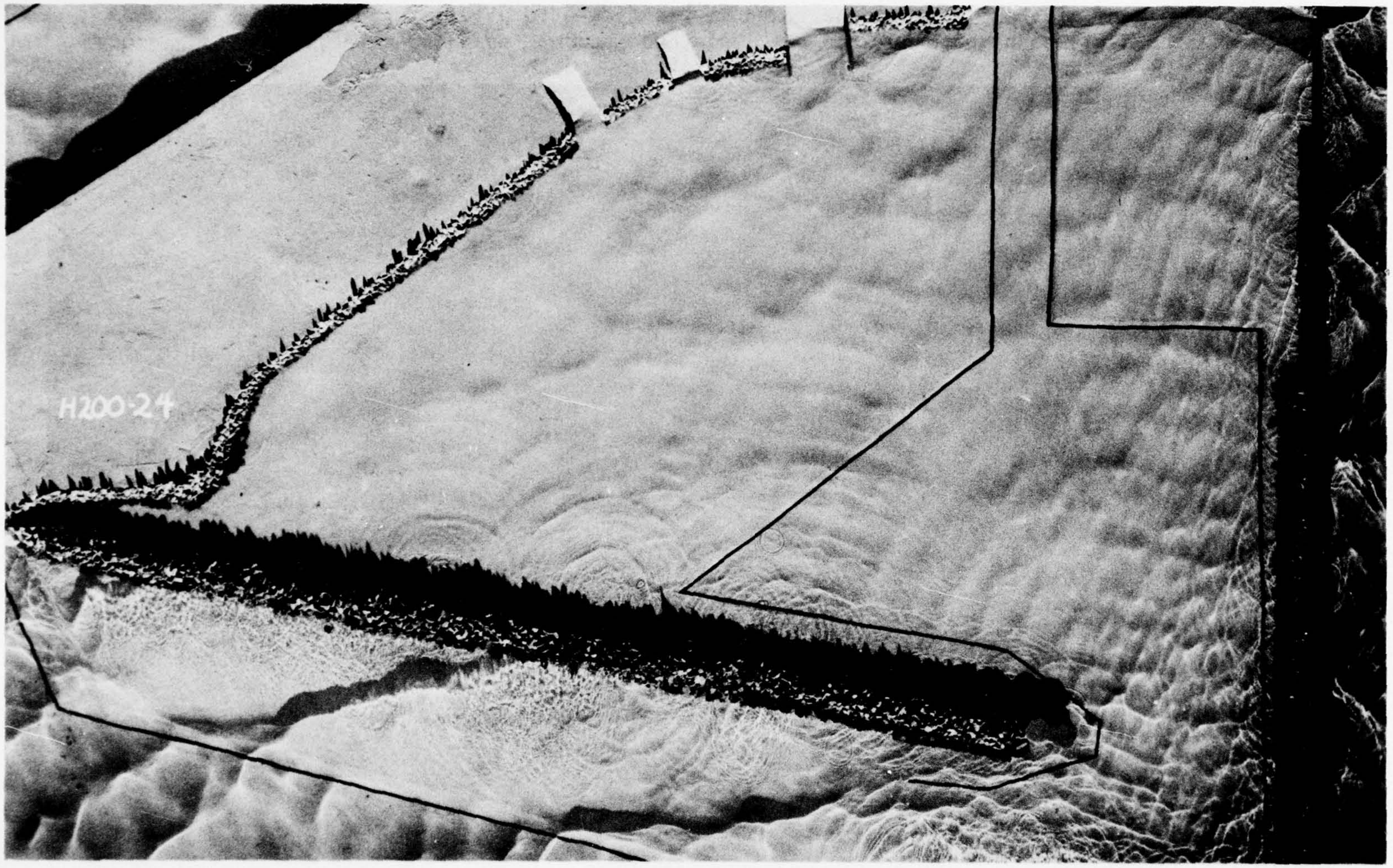

Photo 27. Typical wave patterns in proposed small-boat basin for plan 1; 8.3-sec, 10.4-ft waves approaching from S37°10'E

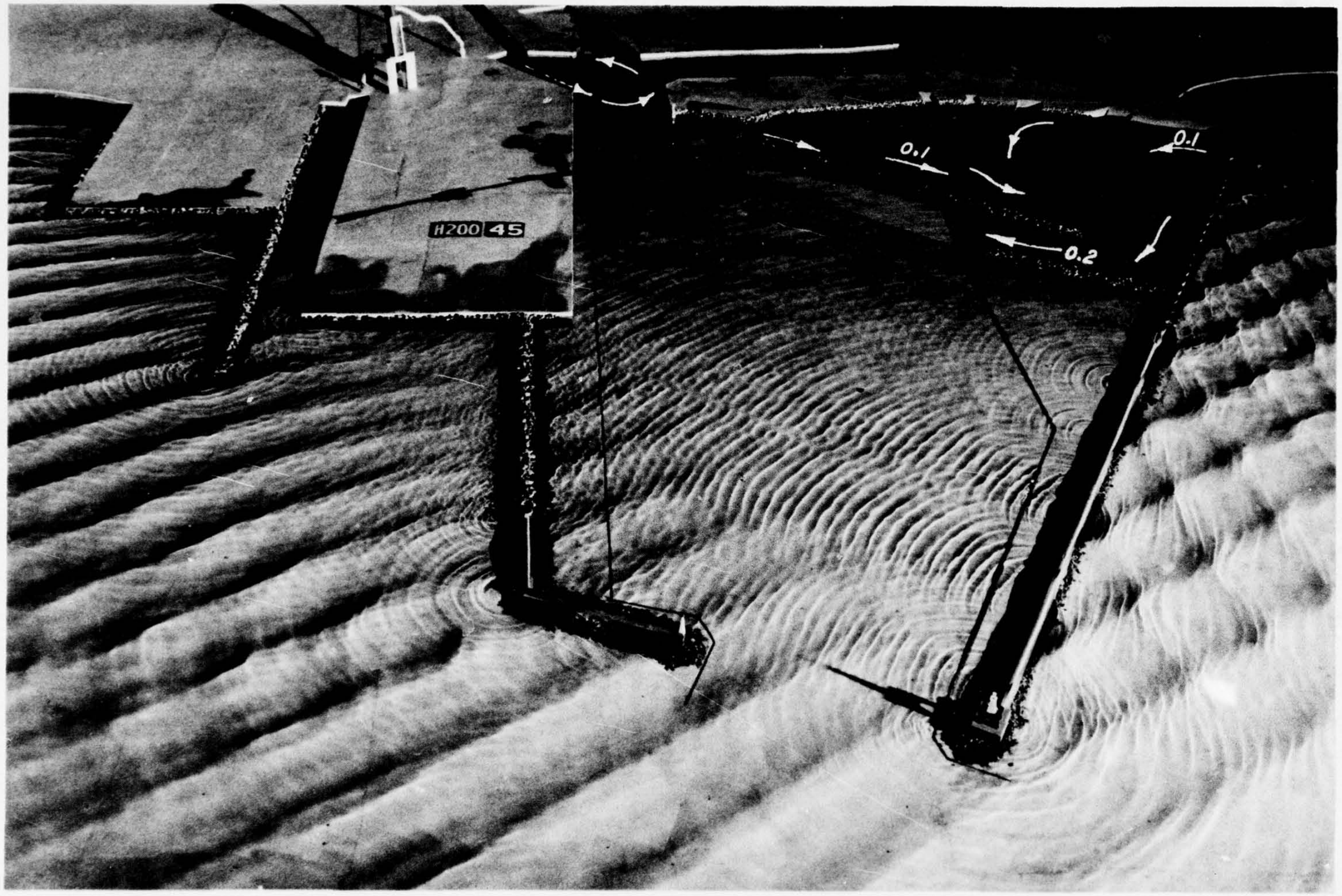

Photo 28. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 6-sec, 4.3-ft waves approaching from N76°20'E

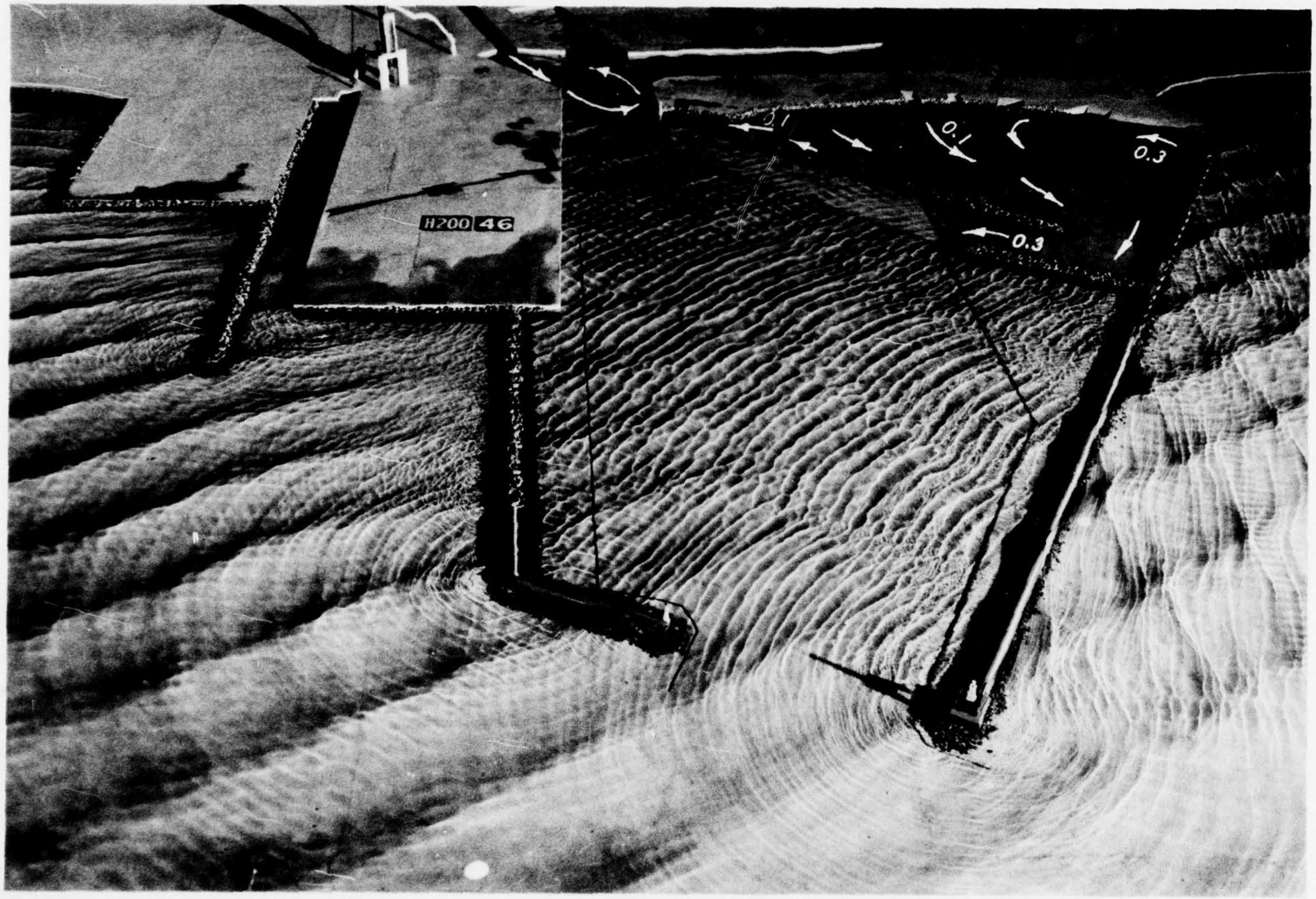

Photo 29. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.7-sec, 4.2-ft waves approaching from N76°20'E

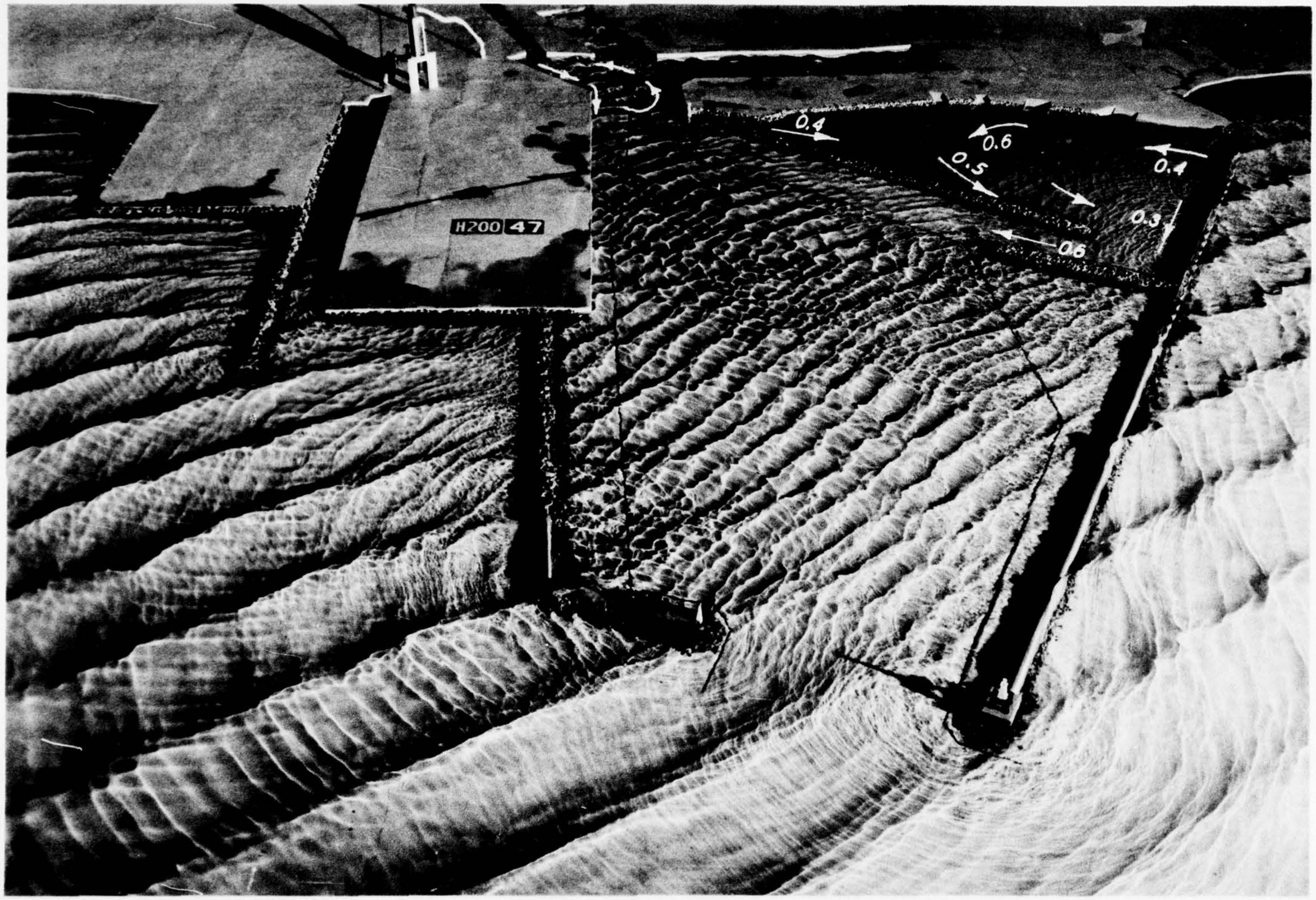

Photo 30. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.7-sec, 7.7-ft waves approaching from N76°20'E

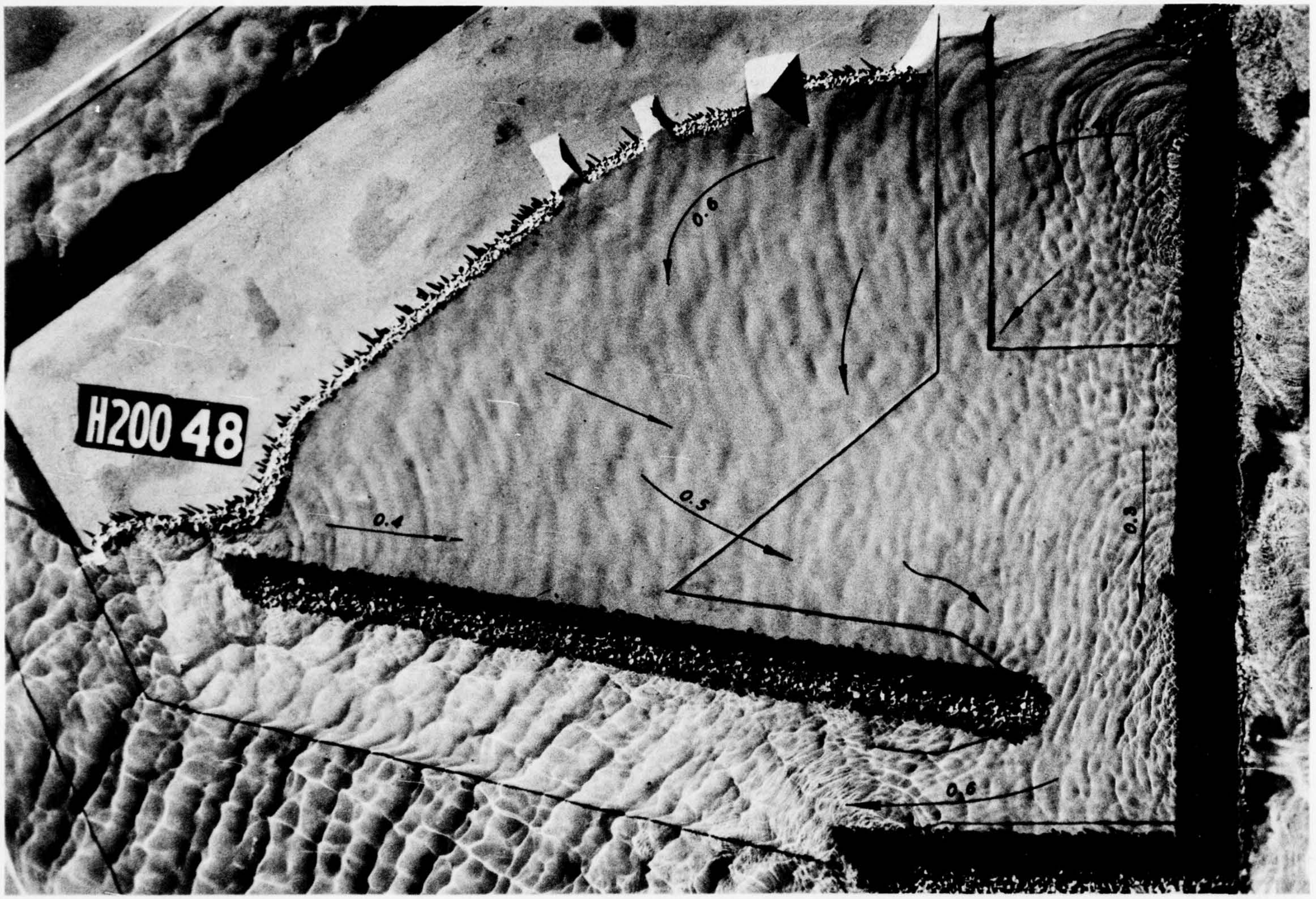

Photo 31. Typical wave patterns, current patterns, and current magnitudes in proposed small-boat harbor (in prototype feet per second) for plan 8; 7.7-sec, 7.7-ft waves approaching from N76°20'E

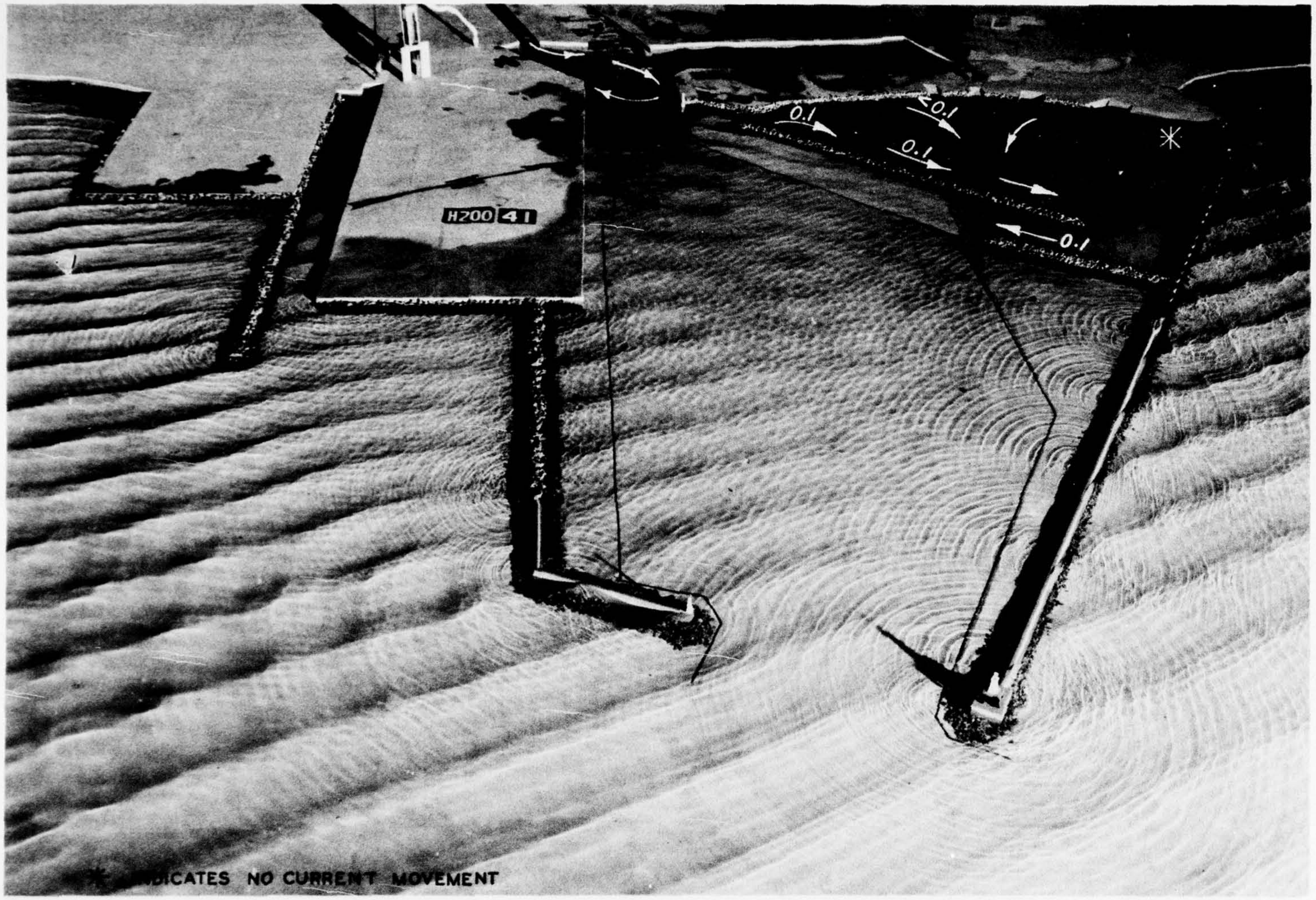

Photo 32. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 5.5-sec, 3.8-ft waves approaching from S85°50'E

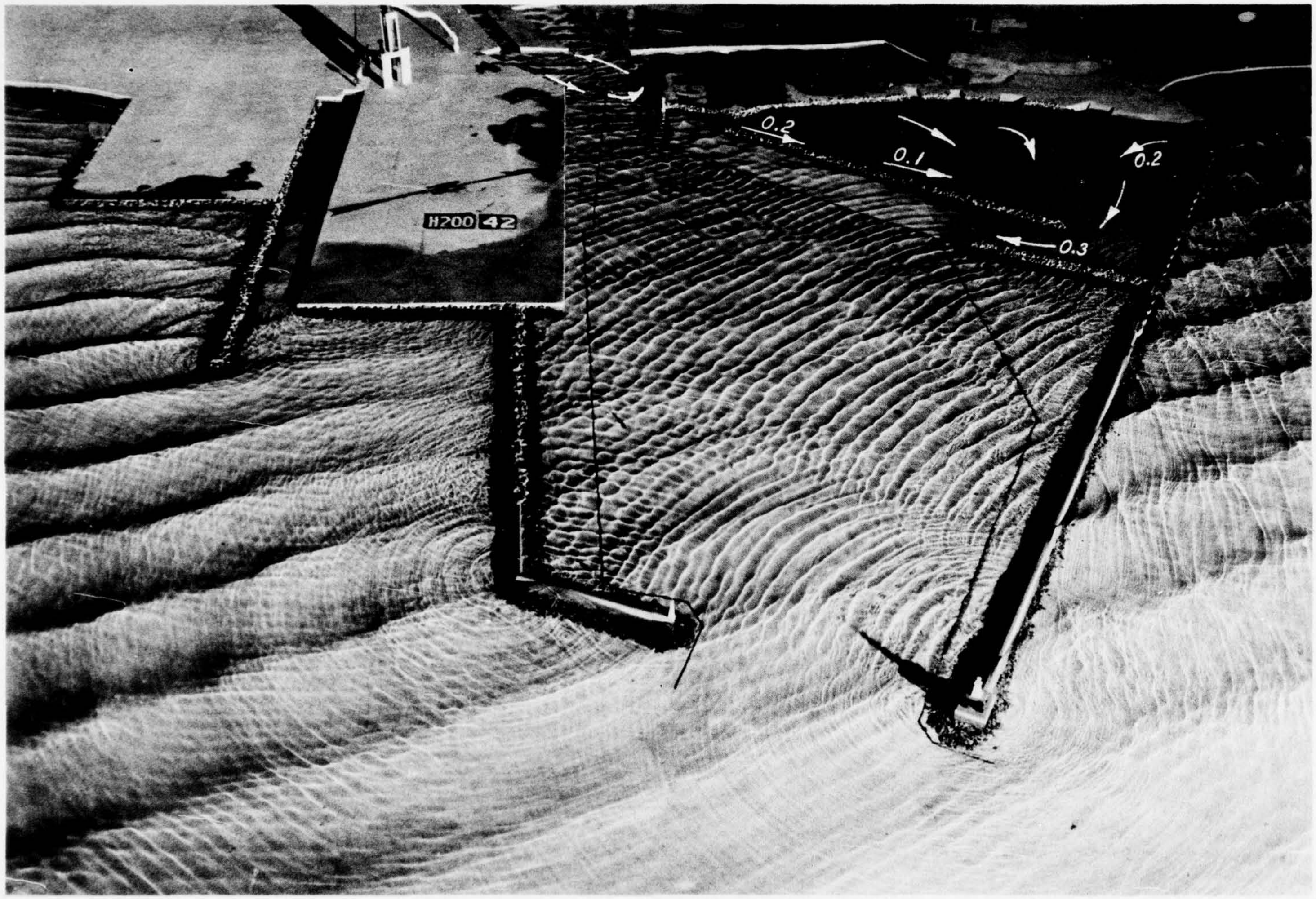

Photo 33. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 5.3-ft waves approaching from S85°50'E

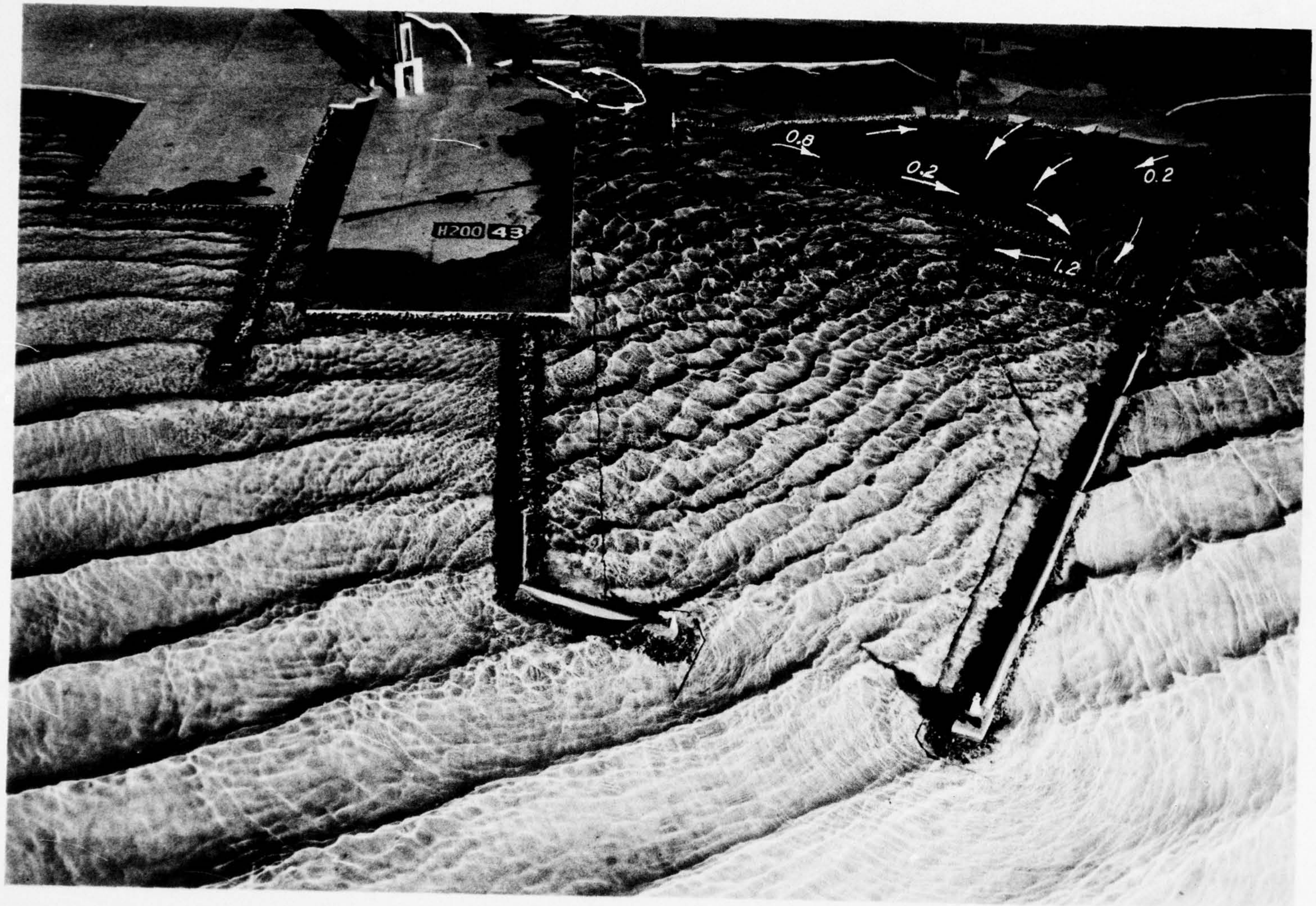

Photo 34. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 9.6-ft waves approaching from S85°50'E

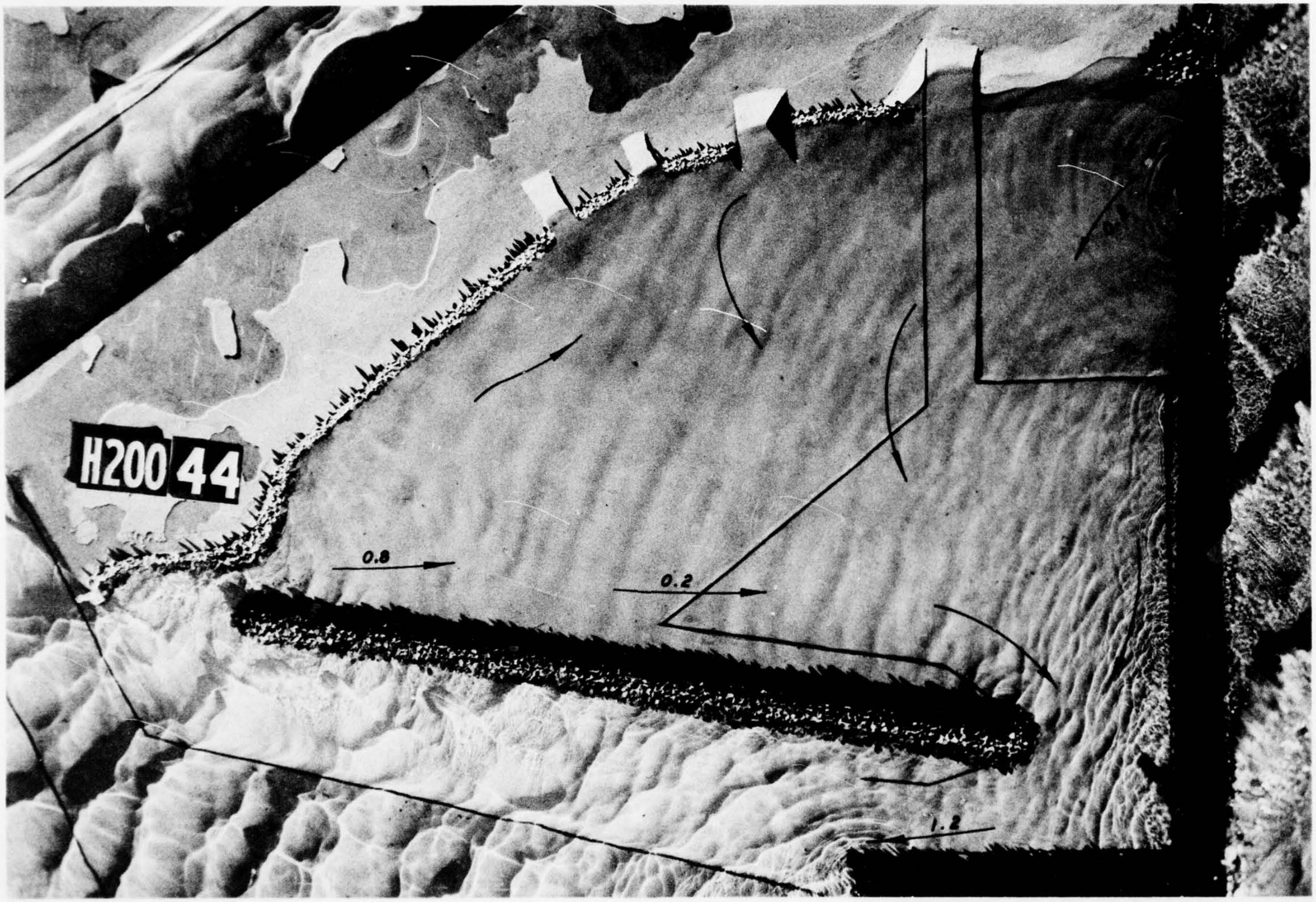

Photo 35. Typical wave patterns, current patterns, and current magnitudes in proposed small-boat basin (in prototype feet per second) for plan 8; 7.3-sec, 9.6-ft waves approaching from S85°50'E

AD-A037 088 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/13
DESIGN FOR SMALL-BOAT HARBOR IMPROVEMENTS; PORT WASHINGTON HARB--ETC(U)
FEB 77 R R BOTTIN

UNCLASSIFIED WES-TR-H-771 NL

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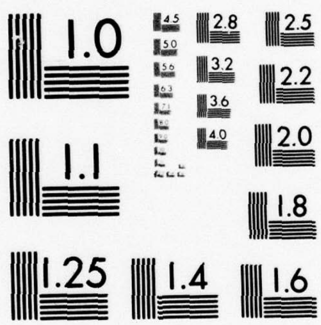


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

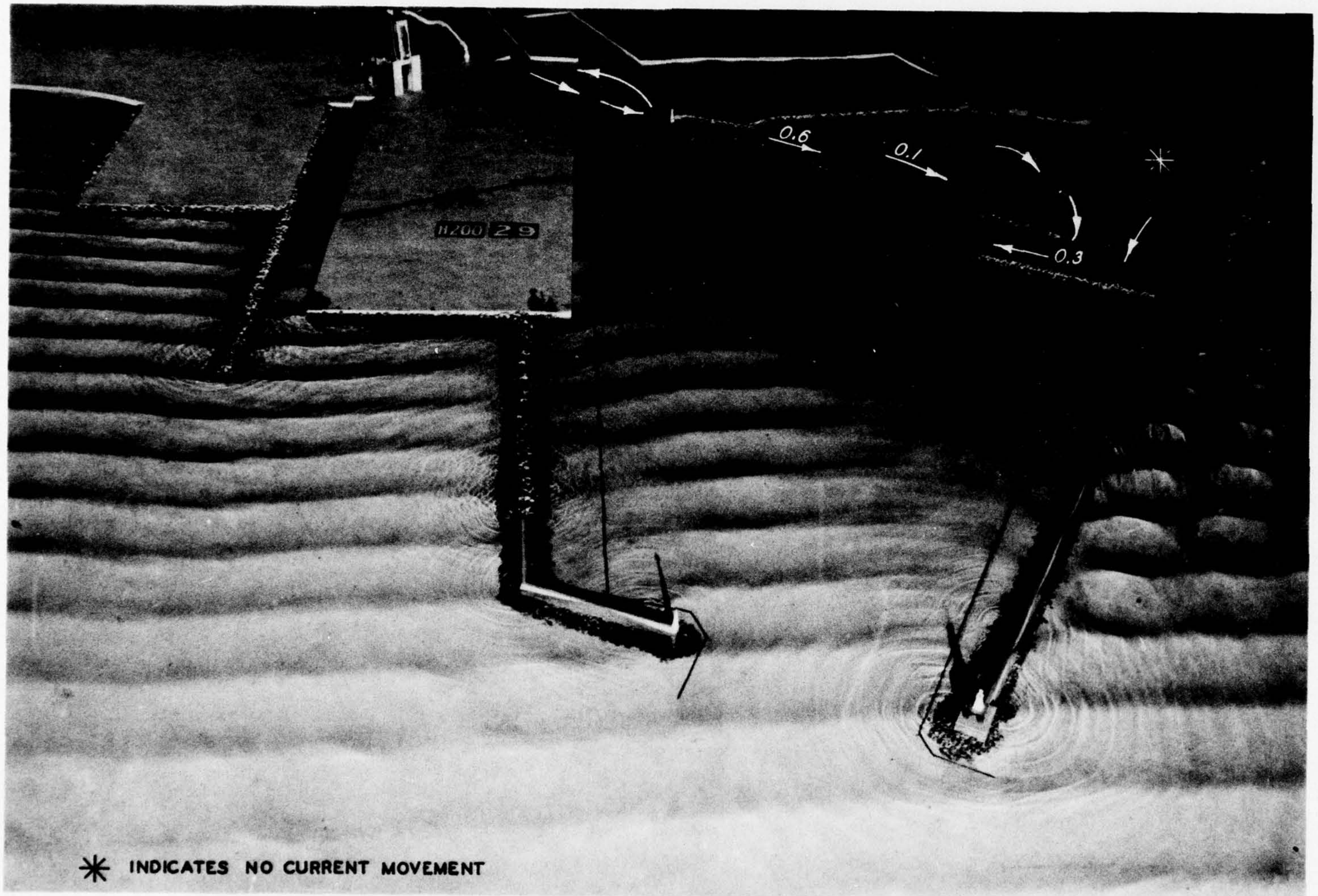


Photo 36. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 5.5-sec, 3.8-ft waves approaching from S68°30'E

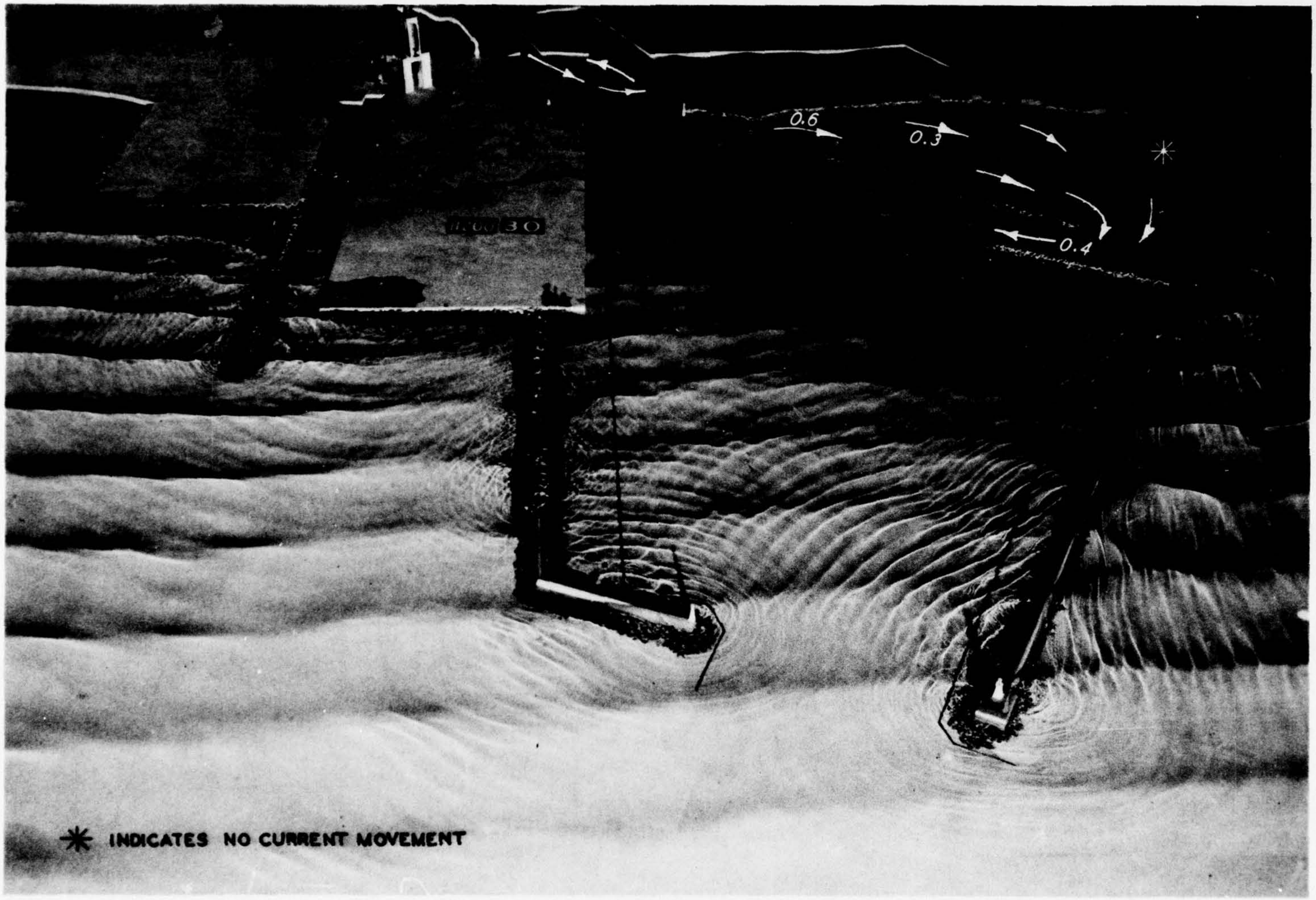


Photo 37. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 5.5-ft waves approaching from S68°30'E

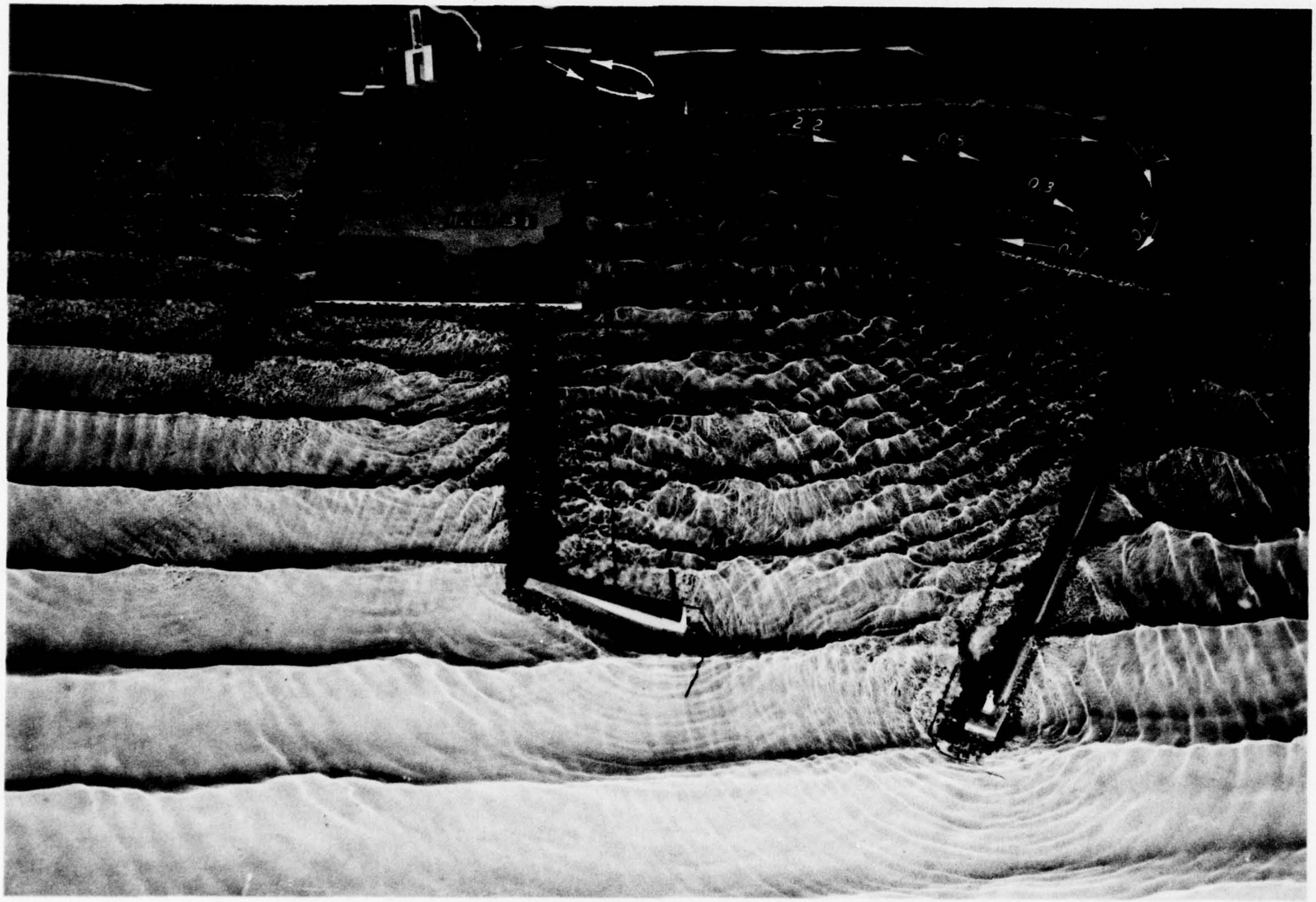


Photo 38. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 9.9-ft waves approaching from S68°30'E

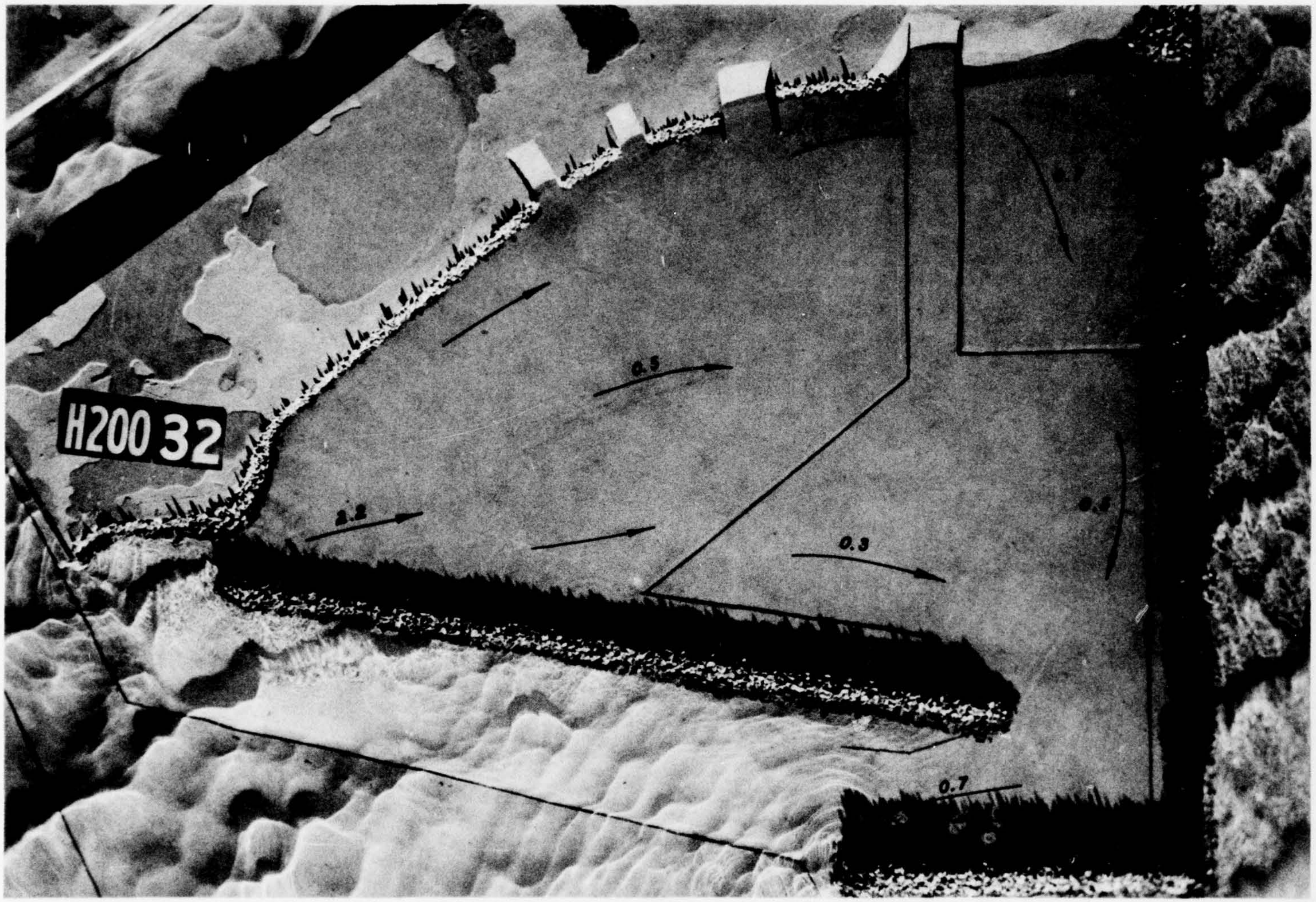


Photo 39. Typical wave patterns, current patterns, and current magnitudes in proposed small-boat basin (in prototype feet per second) for plan 8; 7.3-sec, 9.9-ft waves approaching from S68°30'E

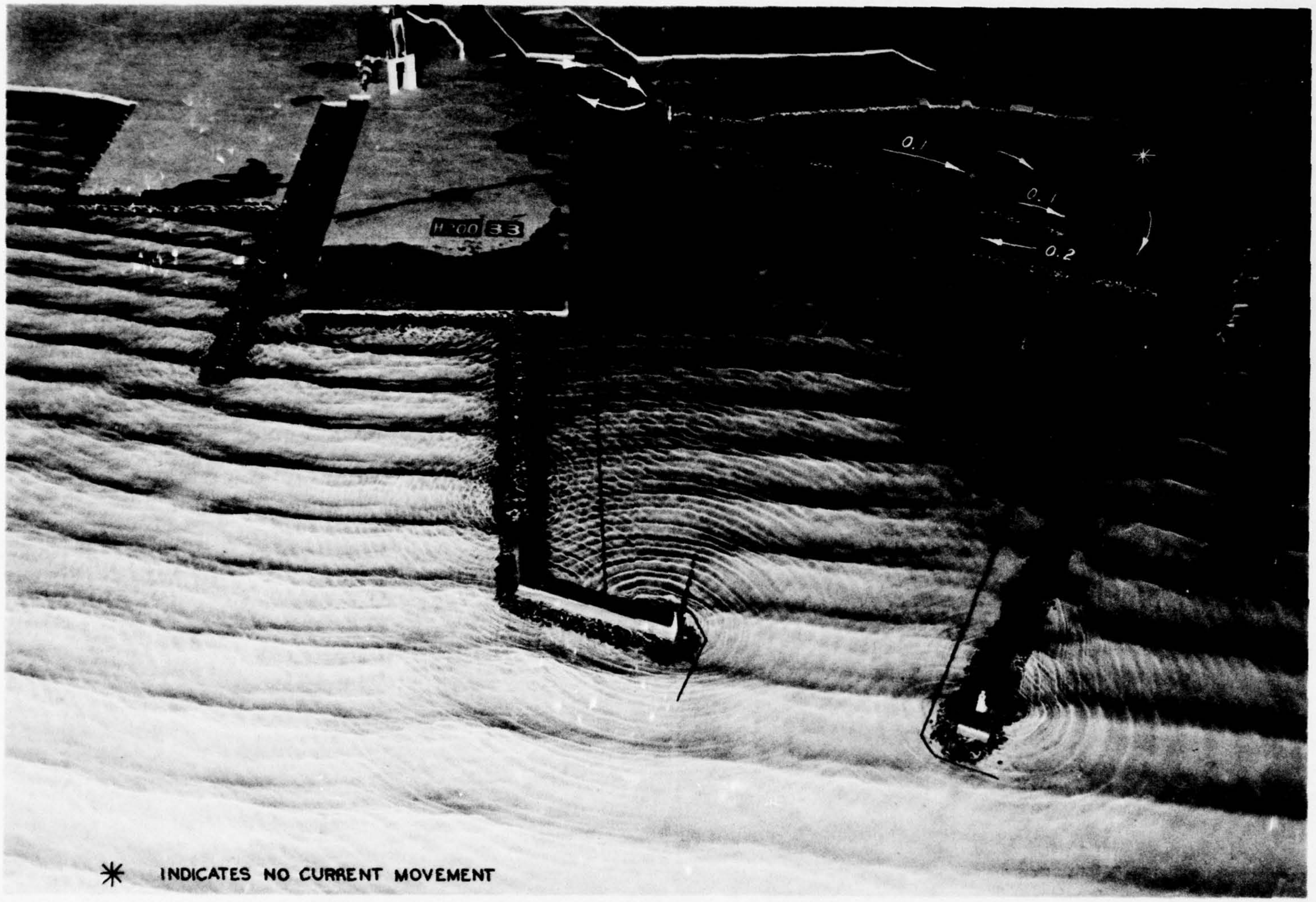


Photo 40. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 5.5-sec, 3.8-ft waves approaching from S50°45'E

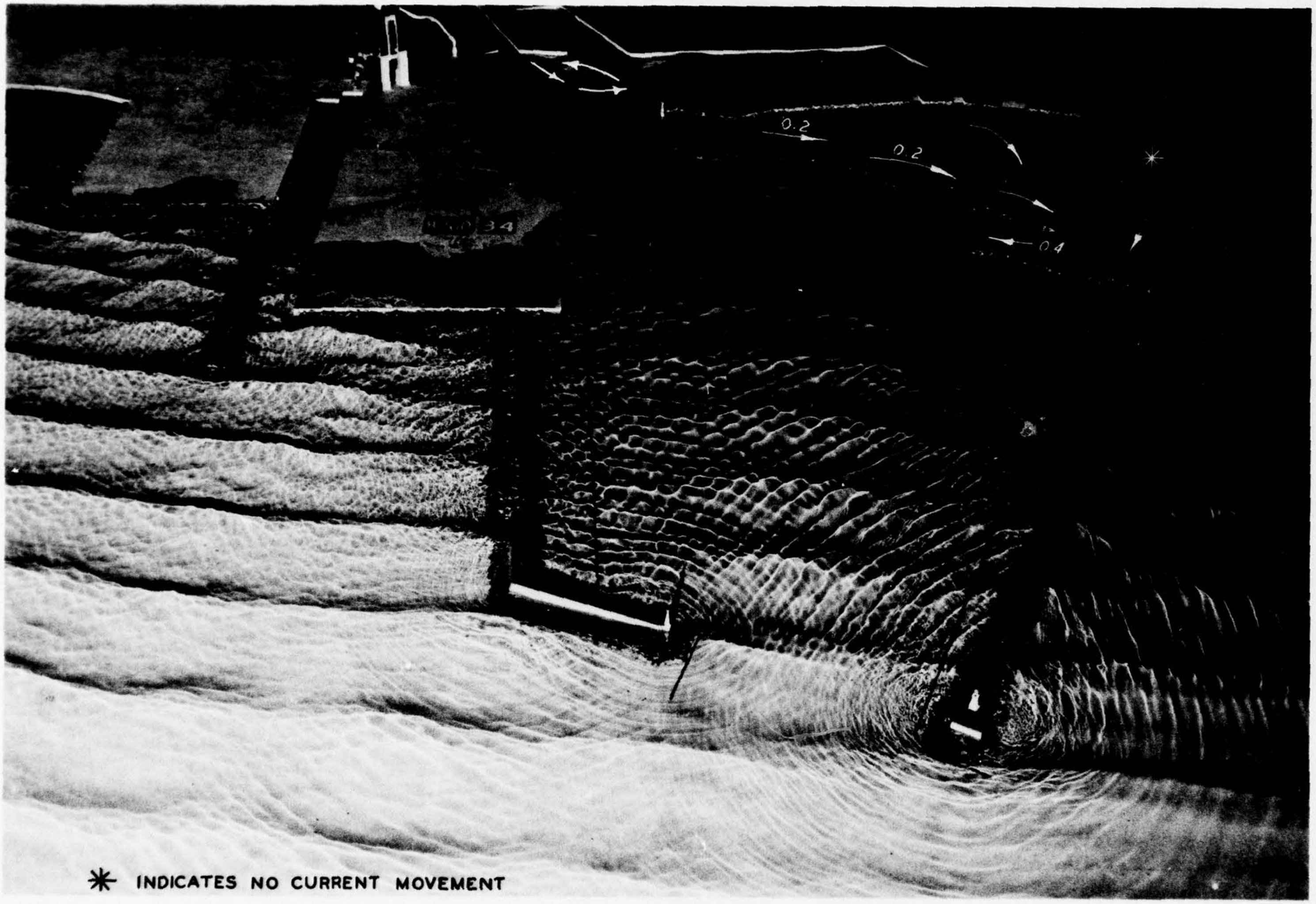


Photo 41. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 5.5-ft waves approaching from S50°45'E

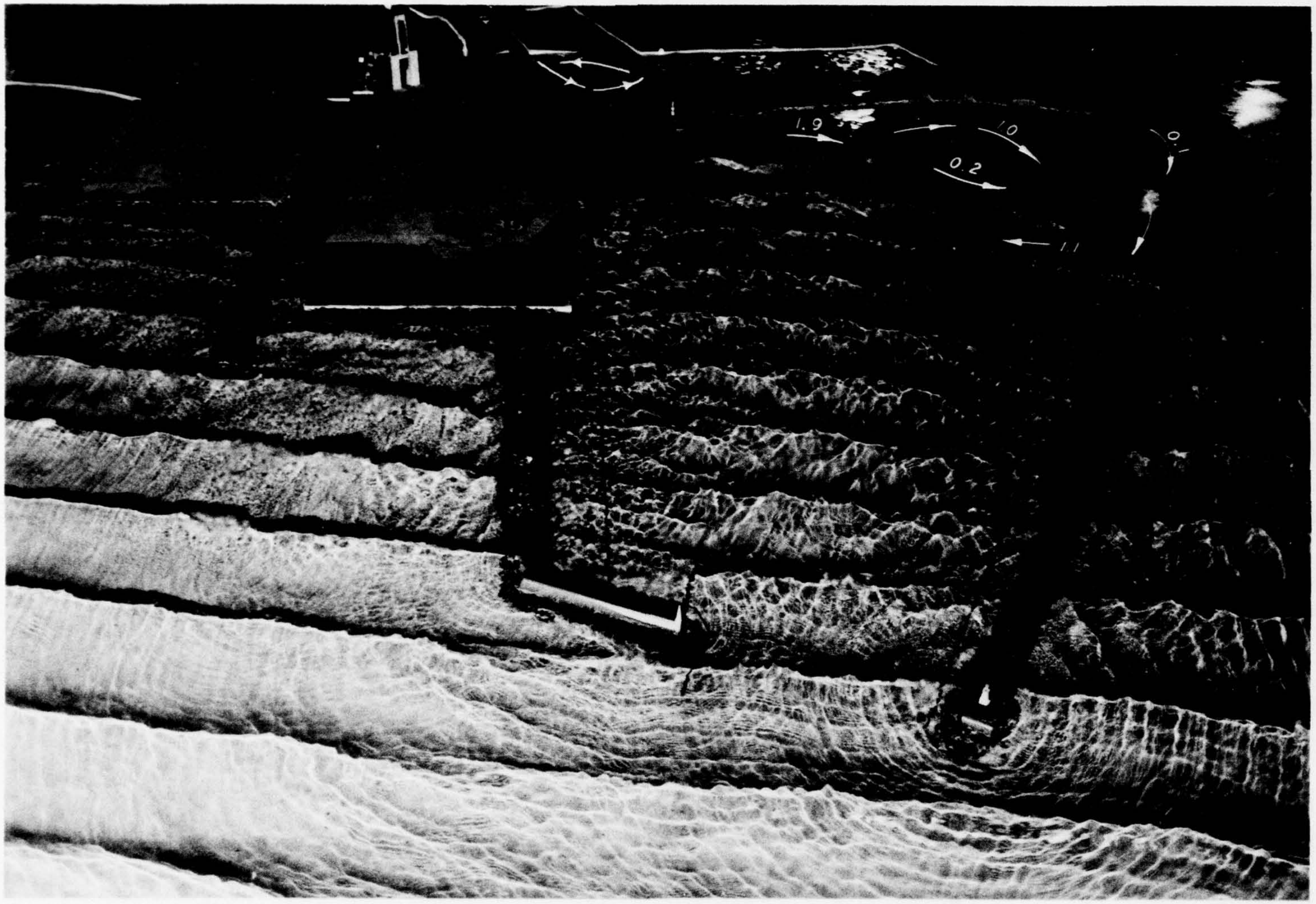


Photo 42. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 7.3-sec, 9.9-ft waves approaching from S50°45'E

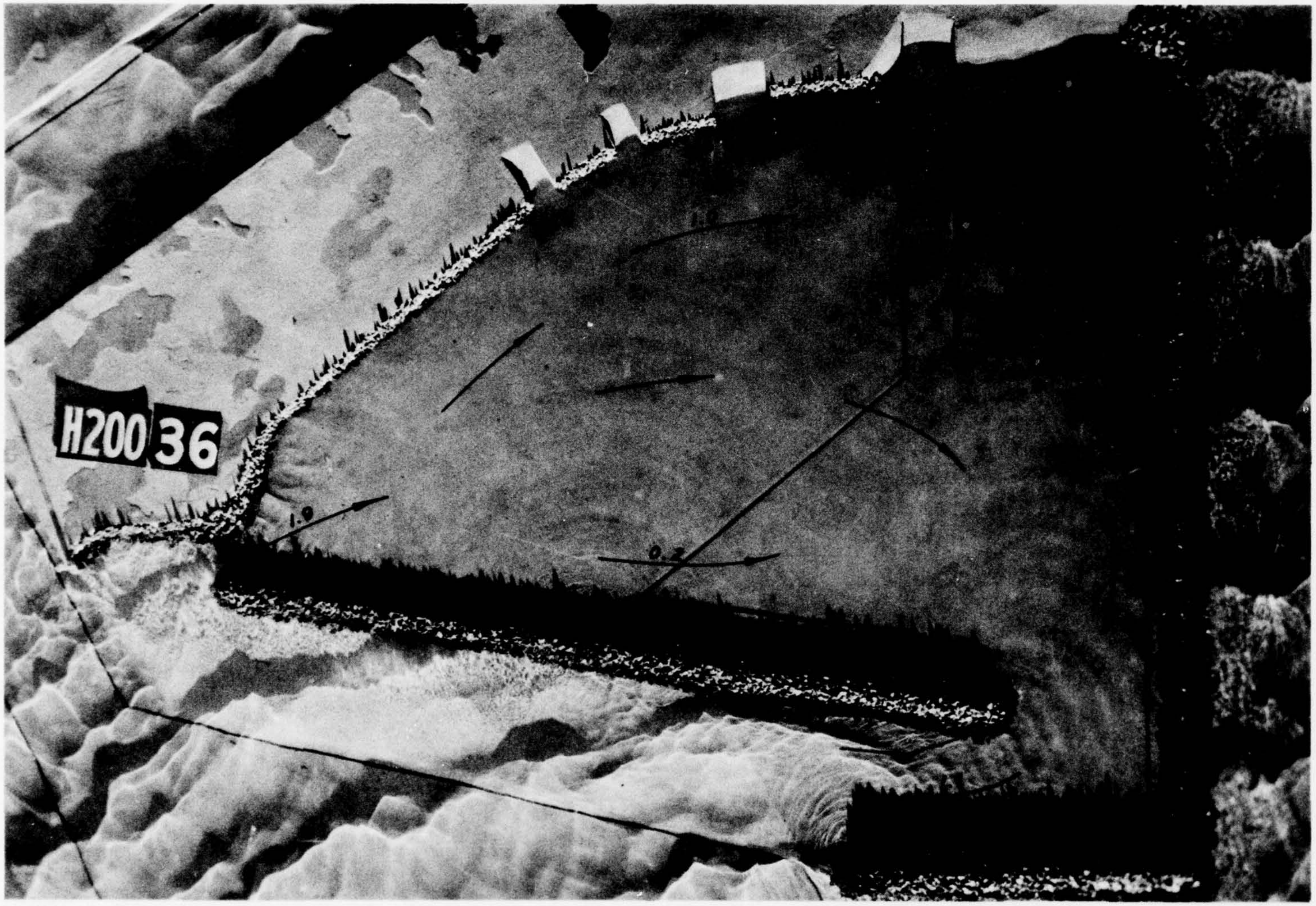


Photo 43. Typical wave patterns, current patterns, and current magnitudes in proposed small-boat basin (in prototype feet per second) for plan 8; 7.3-sec, 9.9-ft waves approaching from S50°45'E

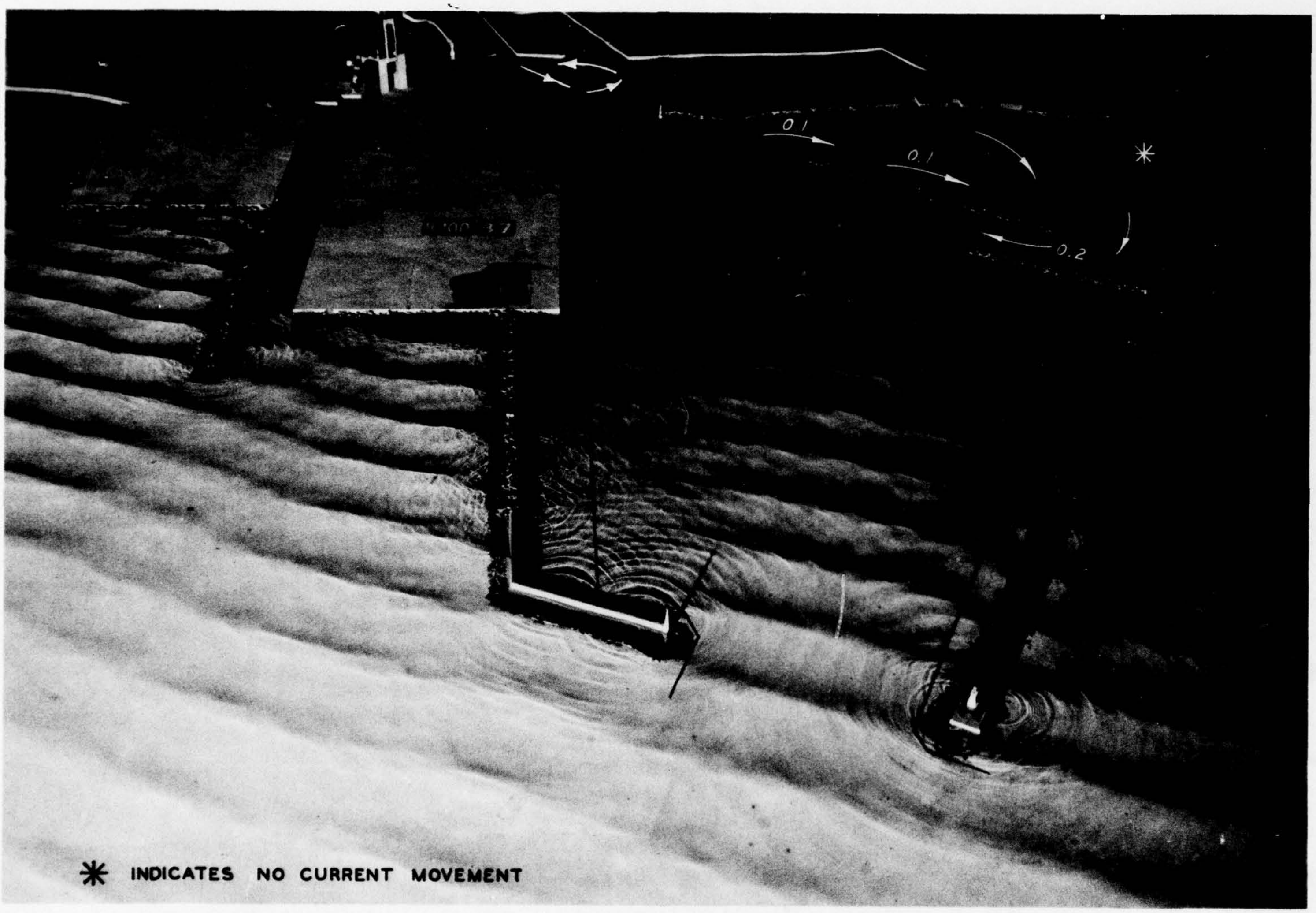


Photo 44. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 6-sec, 3.7-ft waves approaching from S37°10'E

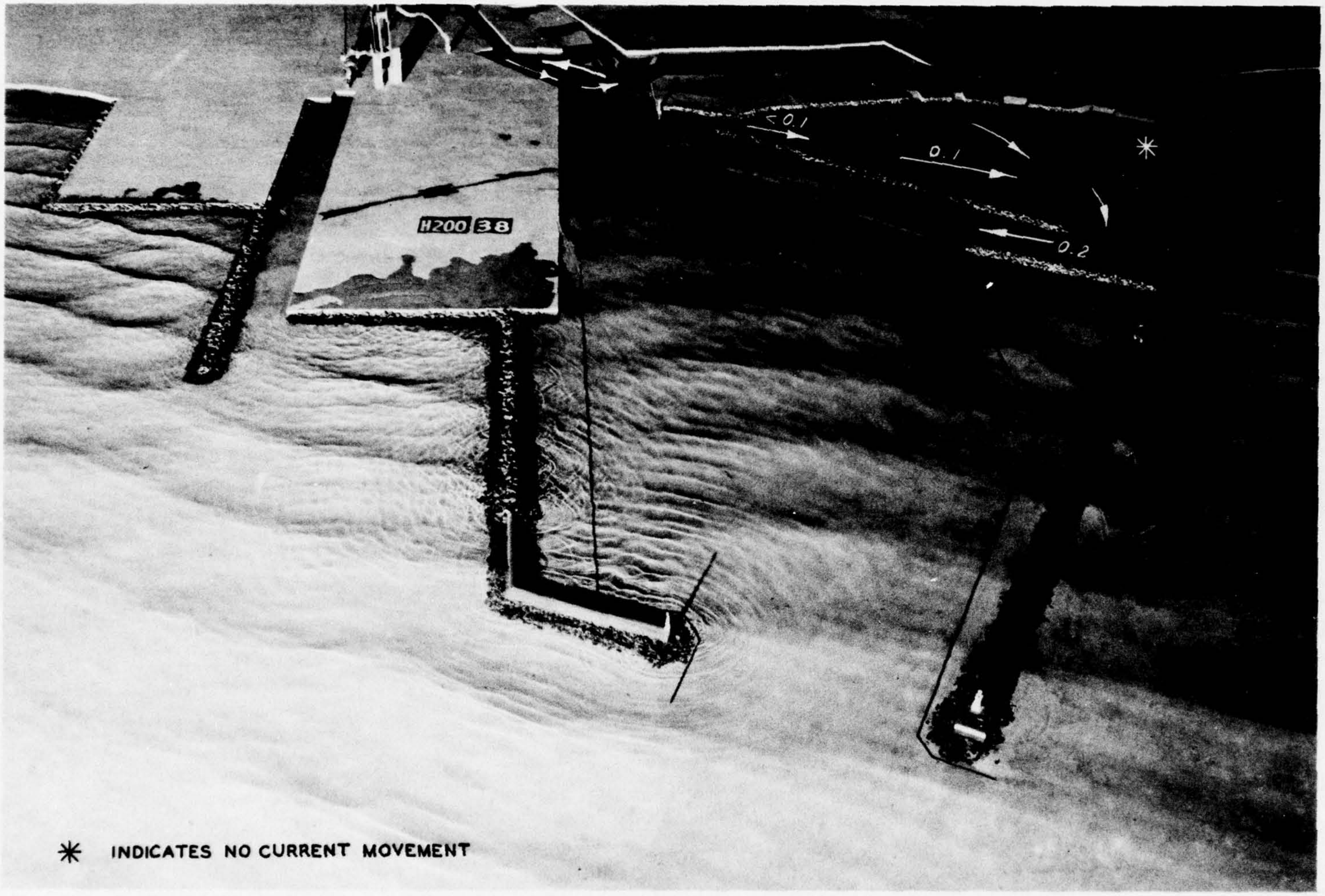


Photo 45. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 8.3-sec, 3.4-ft waves approaching from S37°10'E

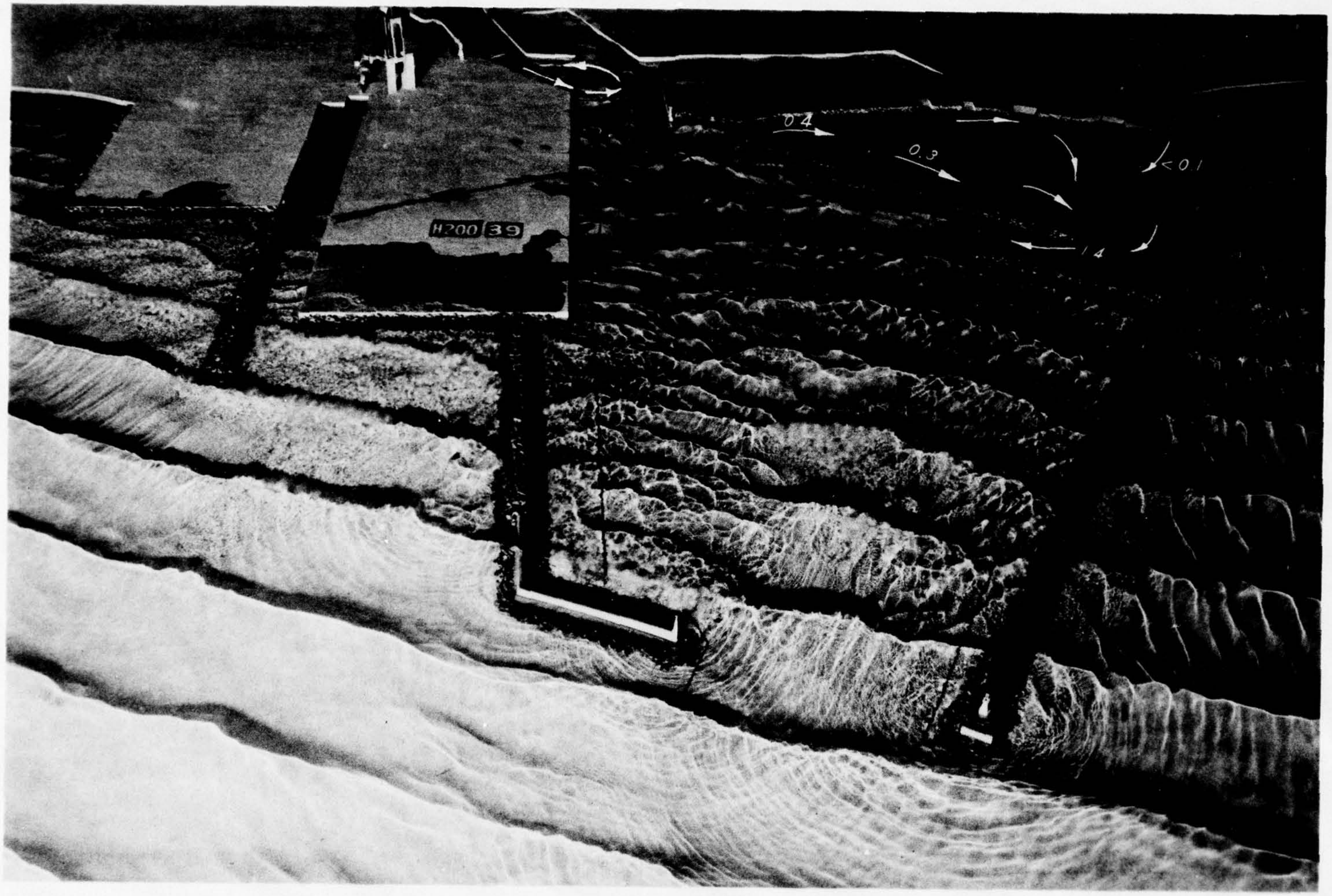


Photo 46. Typical wave patterns, current patterns, and current magnitudes (in prototype feet per second) for plan 8; 8.3-sec, 10.4-ft waves approaching from S37°10'E

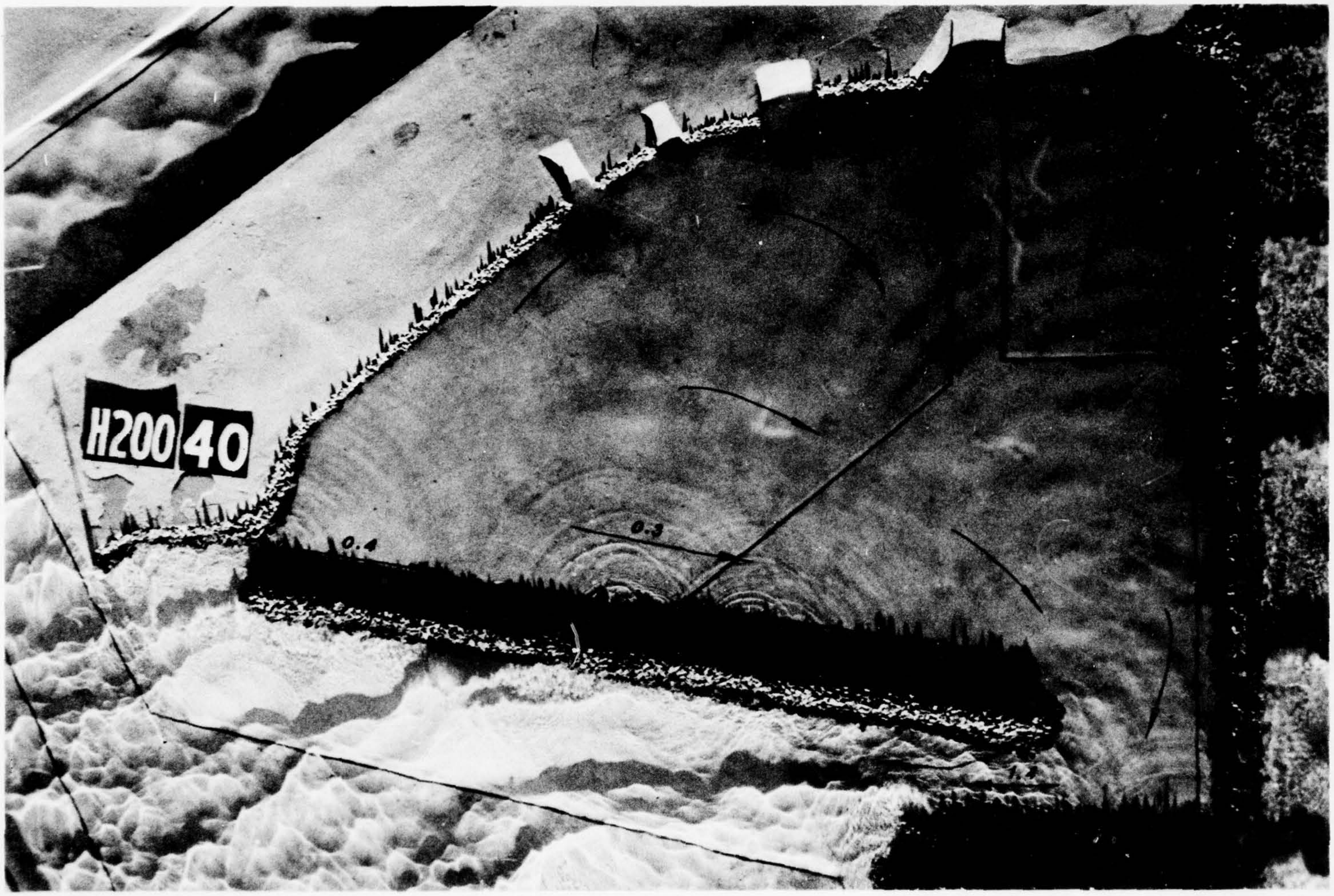
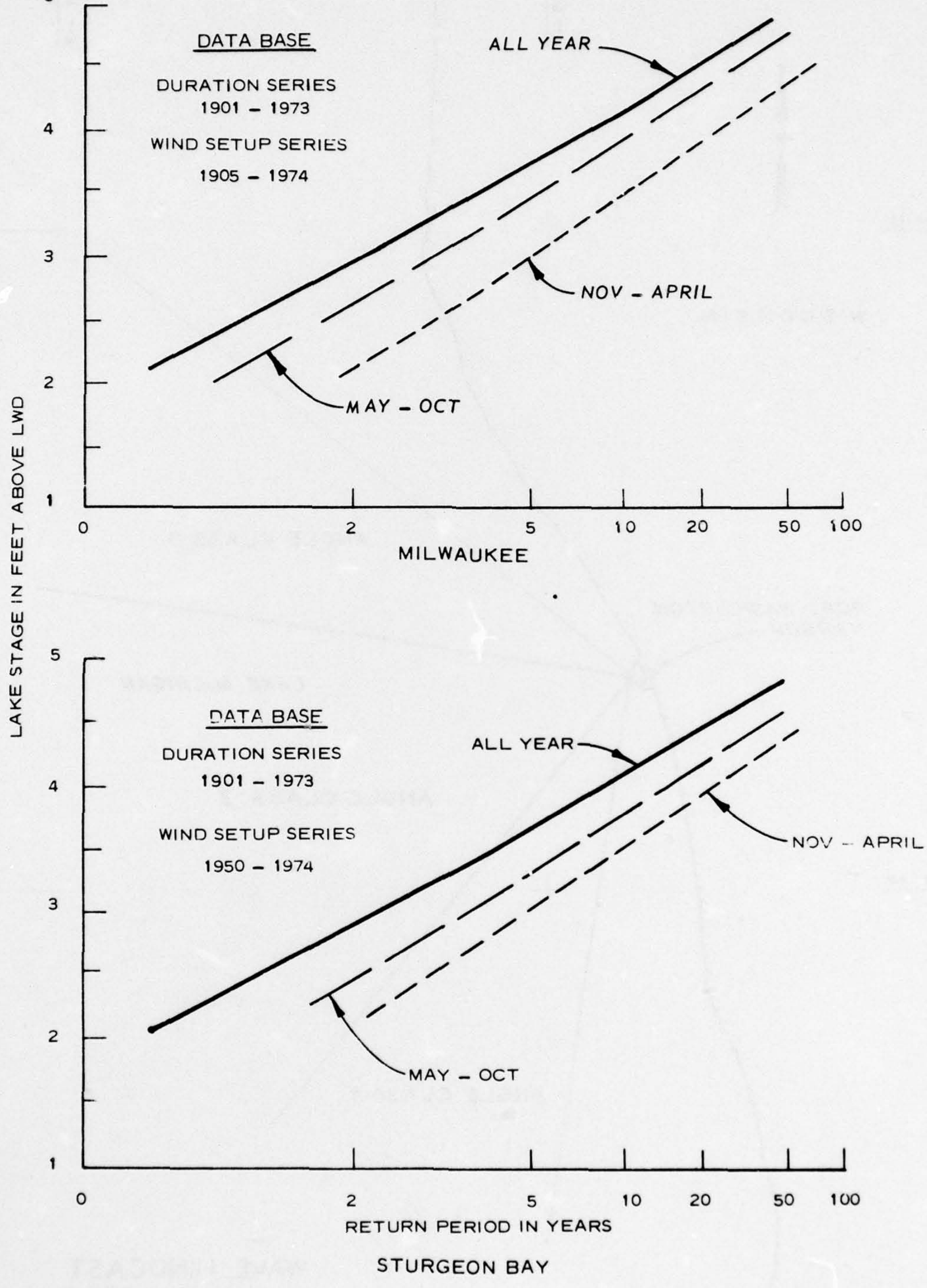


Photo 47. Typical wave patterns, current patterns, and current magnitudes in proposed small-boat basin (in prototype feet per second) for plan 8; 8.3-sec, 10.4-ft waves approaching from S37°10'E

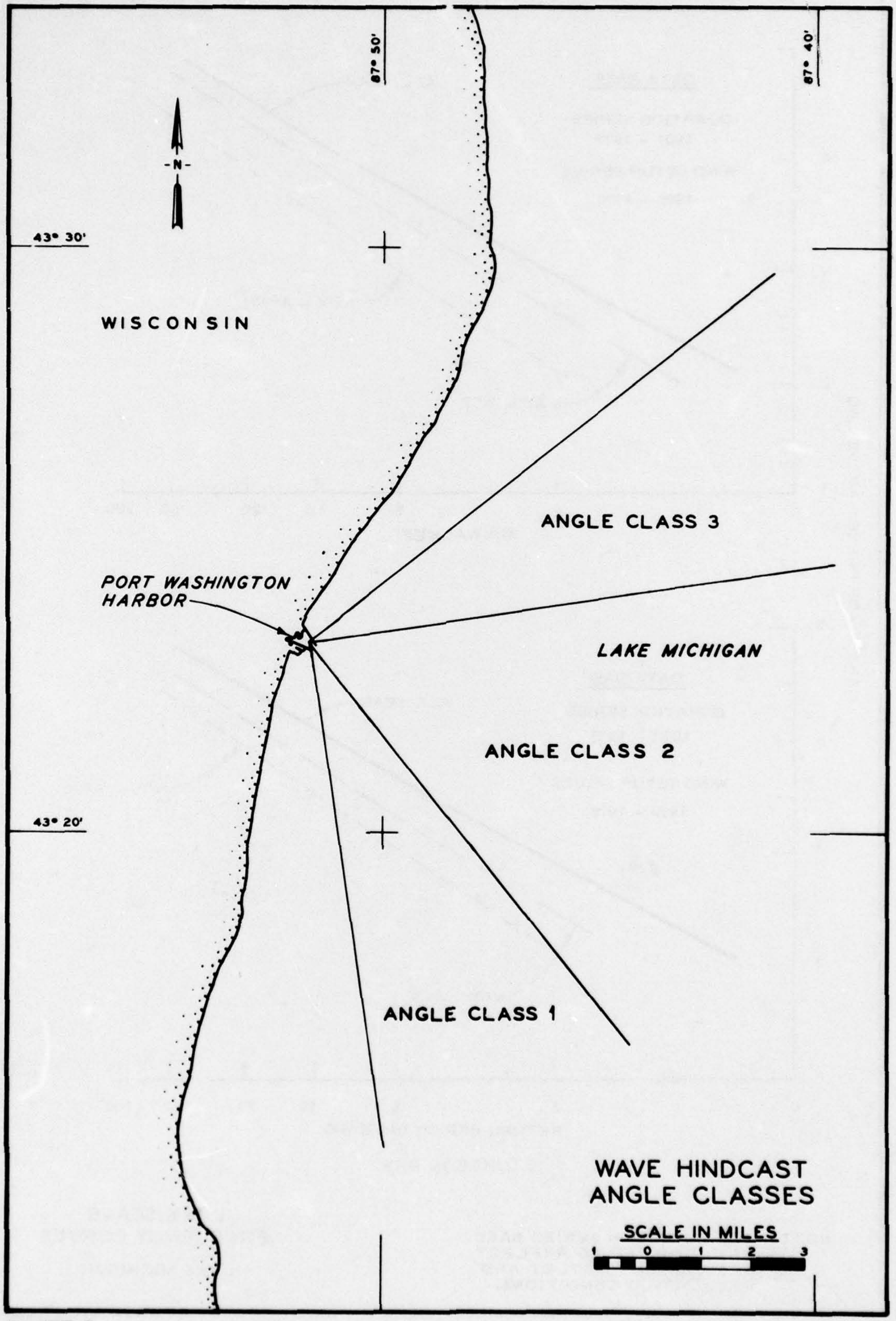


NOTE: THE DURATION SERIES BASE WAS ADJUSTED TO REFLECT PRESENT DAY OUTLET AND REGULATING CONDITIONS.

LAKE STAGE
FREQUENCY CURVES

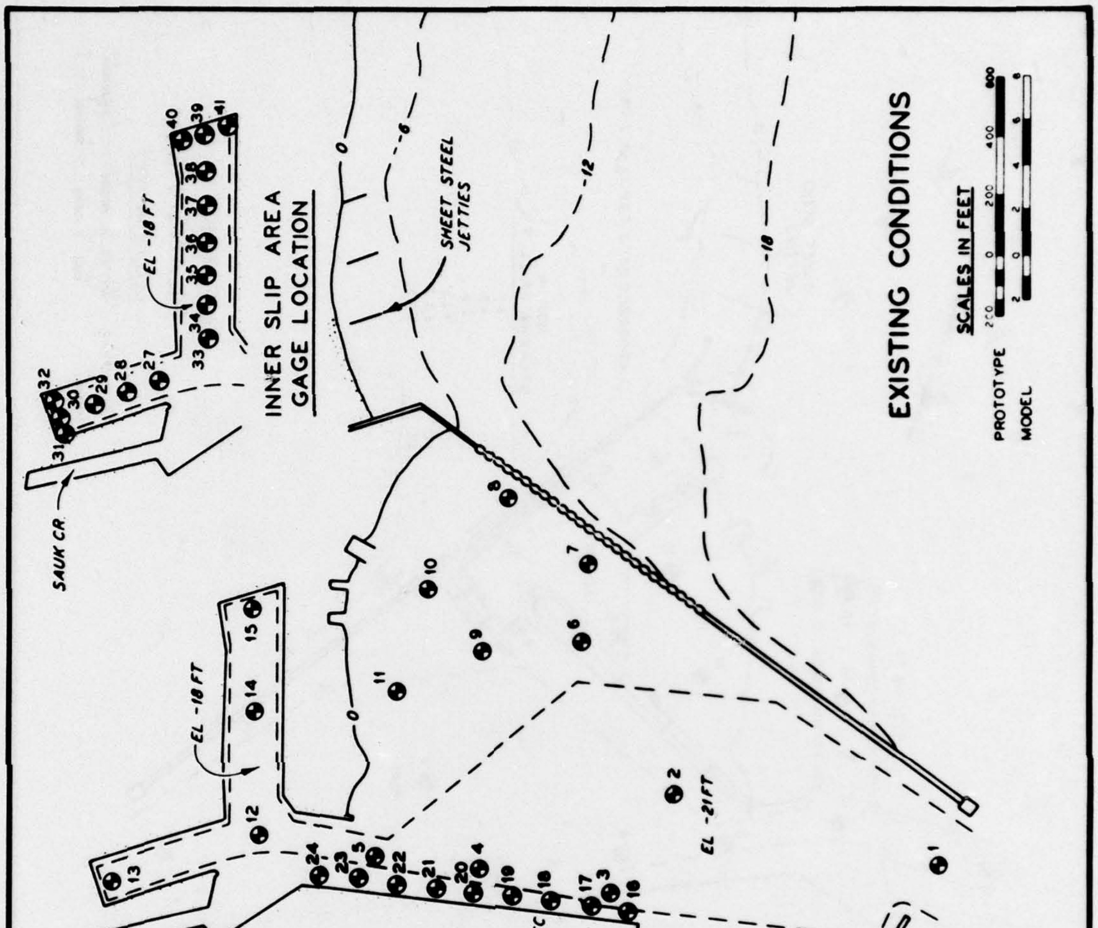
LAKE MICHIGAN

PLATE 1



87° 50'
87° 40'
N
43° 30'
43° 20'
WISCONSIN
PORT WASHINGTON
HARBOR
ANGLE CLASS 3
LAKE MICHIGAN
ANGLE CLASS 2
ANGLE CLASS 1
WAVE HINDCAST
ANGLE CLASSES
SCALE IN MILES
1 0 1 2 3

PLATE 2


EXISTING CONDITIONS
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
WAVE GAGE LOCATION
NOTE CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO LWD
INNER SLIP AREA GAGE LOCATION
SAUK CR.
EL -18 FT
EL -21 FT
SHEET STEEL JETTIES
WISCONSIN ELEC POWER CO COAL WHARF
COOLING WATER INTAKE CHANNEL
N

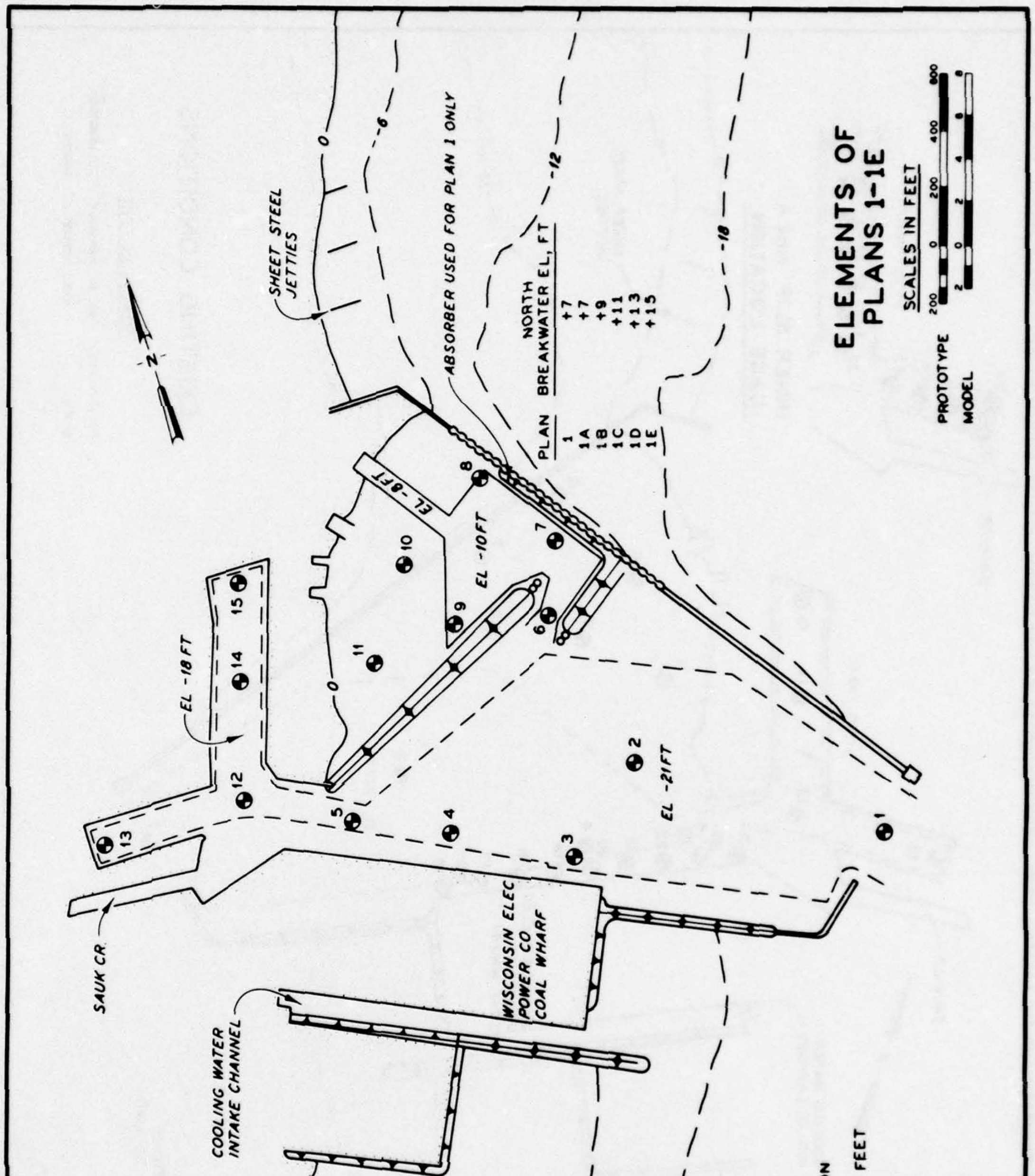
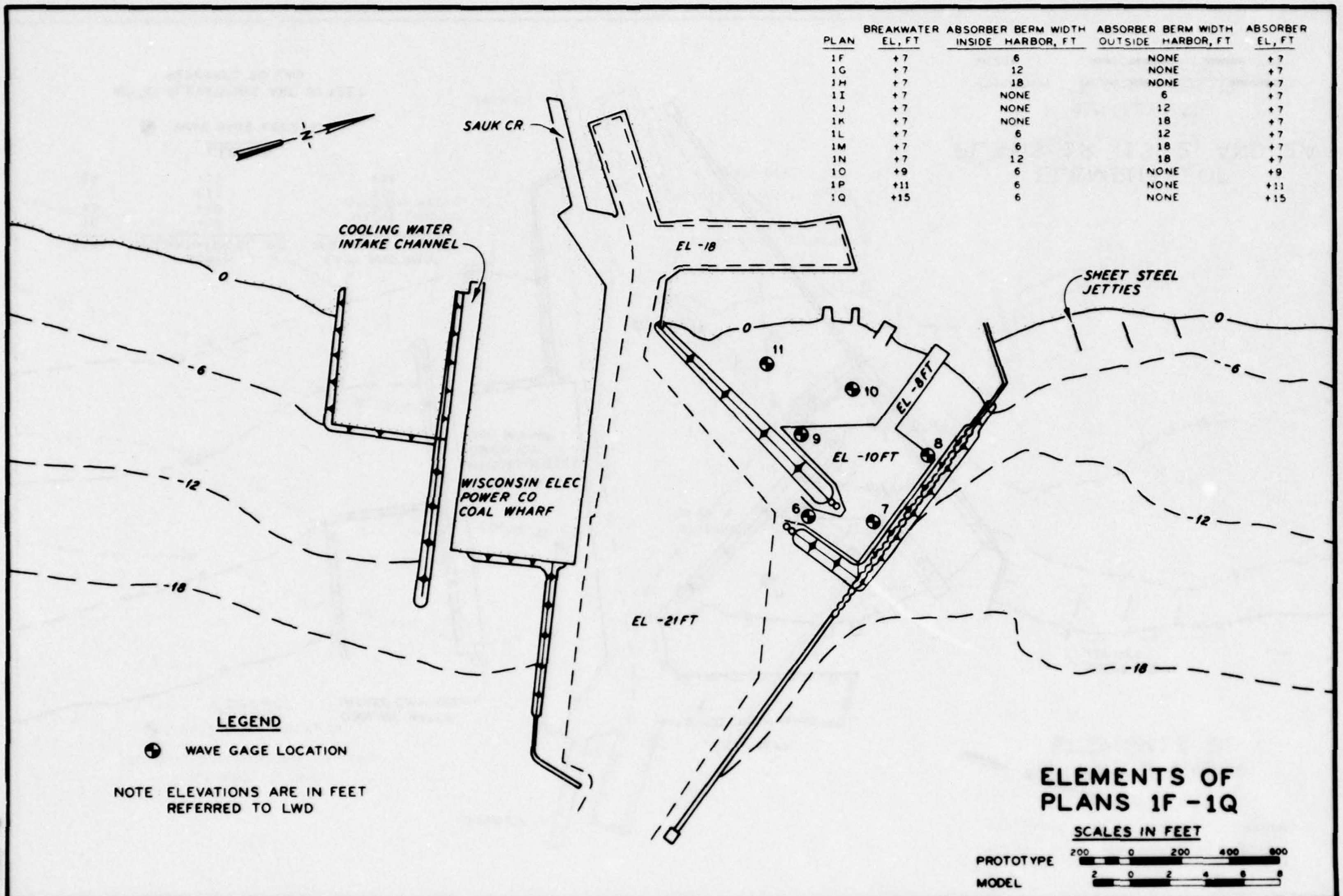

ELEMENTS OF PLANS 1-1E
SCALES IN FEET
PROTOTYPE 200 0 200 400 800
MODEL 2 0 2 4 6 8
PLAN NORTH BREAKWATER EL, FT
1 +7
1A +7
1B +9
1C +11
1D +13
1E +15
SHEET STEEL JETTIES
ABSORBER USED FOR PLAN 1 ONLY
EL -8FT
EL -10FT
EL -18 FT
EL -21FT
SAUK CR.
COOLING WATER INTAKE CHANNEL
WISCONSIN ELEC POWER CO COAL WHARF
LEGEND
WAVE GAGE LOCATION
NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD.

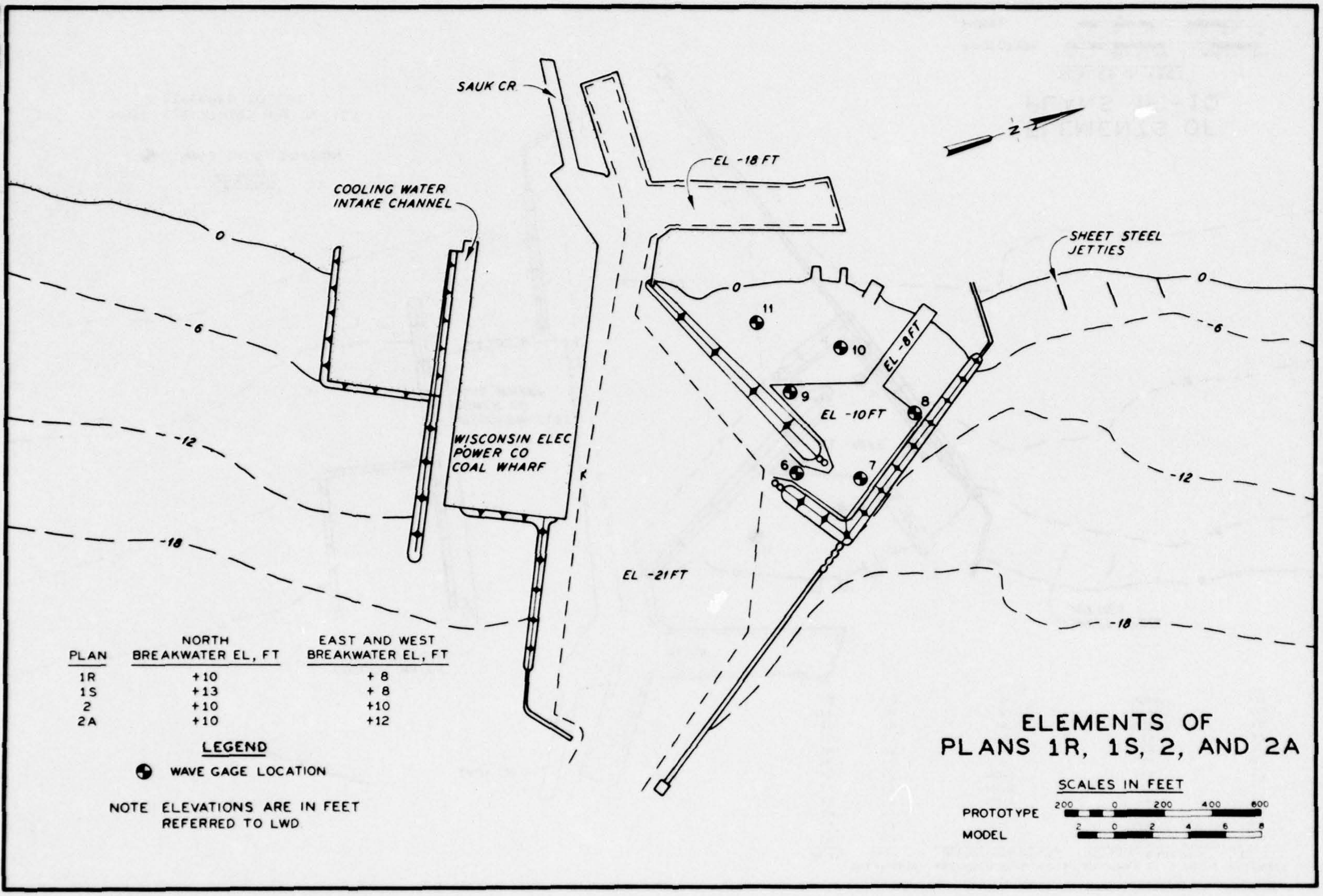
PLATE 4



PLAN	BREAKWATER EL, FT	ABSORBER BERM WIDTH INSIDE HARBOR, FT	ABSORBER BERM WIDTH OUTSIDE HARBOR, FT	ABSORBER EL, FT
1F	+7	6	NONE	+7
1G	+7	12	NONE	+7
1H	+7	18	NONE	+7
1I	+7	NONE	6	+7
1J	+7	NONE	12	+7
1K	+7	NONE	18	+7
1L	+7	6	12	+7
1M	+7	6	18	+7
1N	+7	12	18	+7
1O	+9	6	NONE	+9
1P	+11	6	NONE	+11
1Q	+15	6	NONE	+15

ELEMENTS OF PLANS 1F - 1Q

PLATE 5



PLAN	NORTH BREAKWATER EL, FT	EAST AND WEST BREAKWATER EL, FT
1R	+10	+ 8
1S	+13	+ 8
2	+10	+10
2A	+10	+12

LEGEND

● WAVE GAGE LOCATION

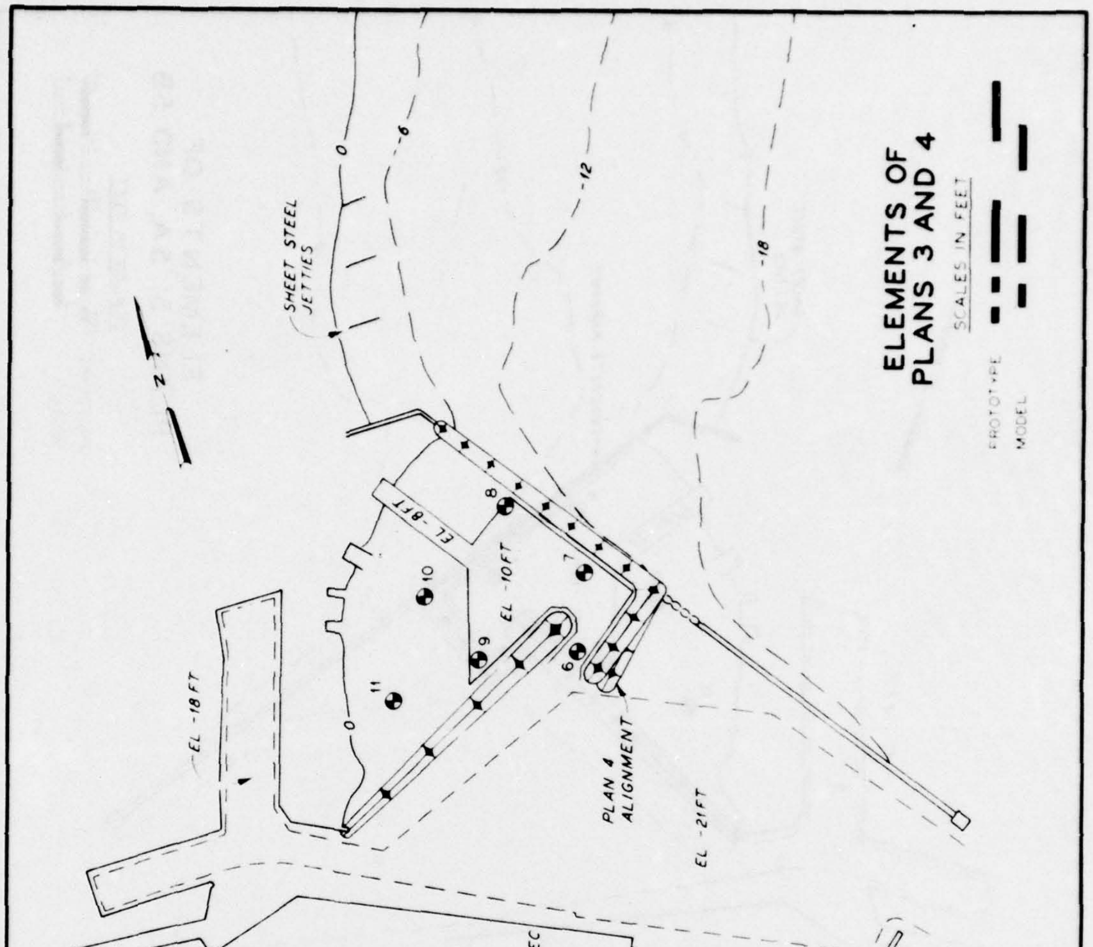
NOTE ELEVATIONS ARE IN FEET REFERRED TO LWD

ELEMENTS OF PLANS 1R, 1S, 2, AND 2A

SCALES IN FEET

PROTOTYPE 200 0 200 400 600

MODEL 2 0 2 4 6 8


ELEMENTS OF
PLANS 3 AND 4
SCALES IN FEET
PROTOTYPE
MODEL
SHEET STEEL JETTIES
N
EL -8 FT
EL -10 FT
EL -18 FT
EL -21 FT
PLAN 4 ALIGNMENT
SAUK CR
WISCONSIN ELEC POWER CO COAL WHARF
COOLING WATER INTAKE CHANNEL
LEGEND
WAVE GAGE LOCATION
NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD.

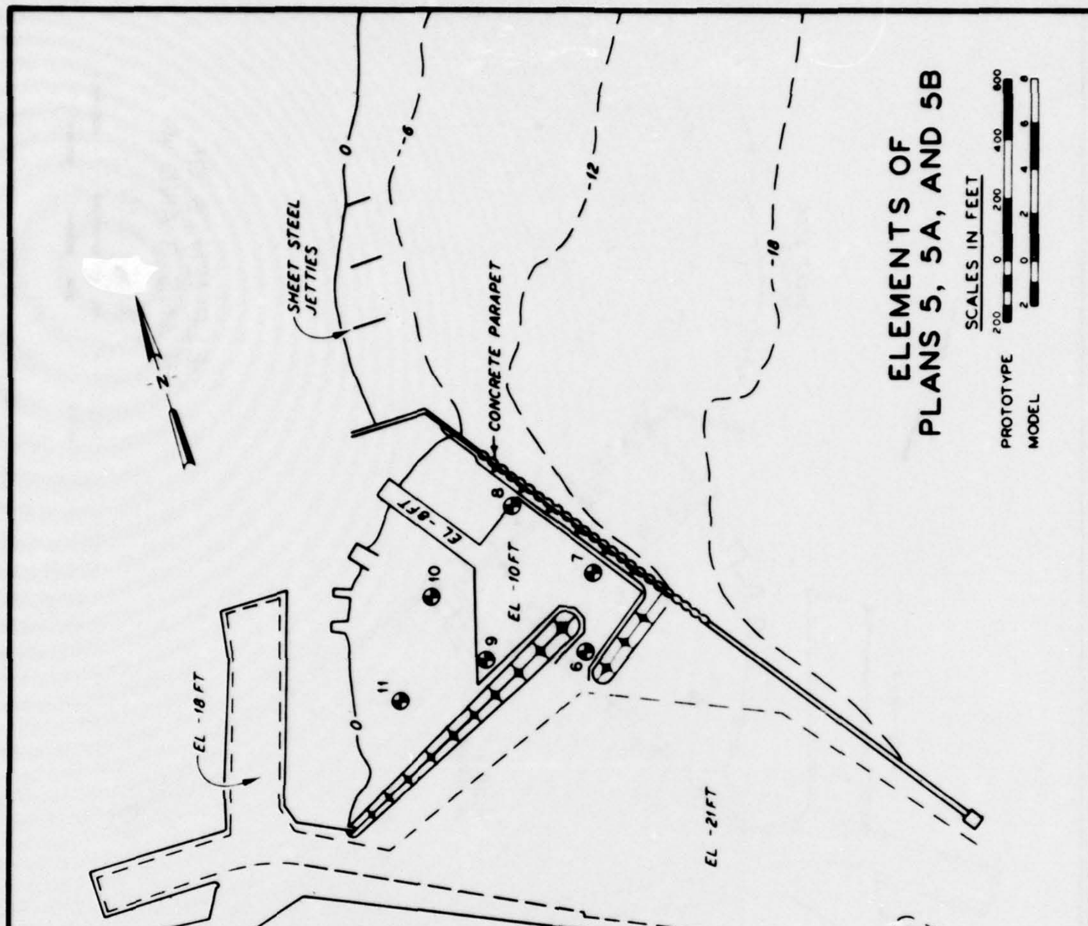
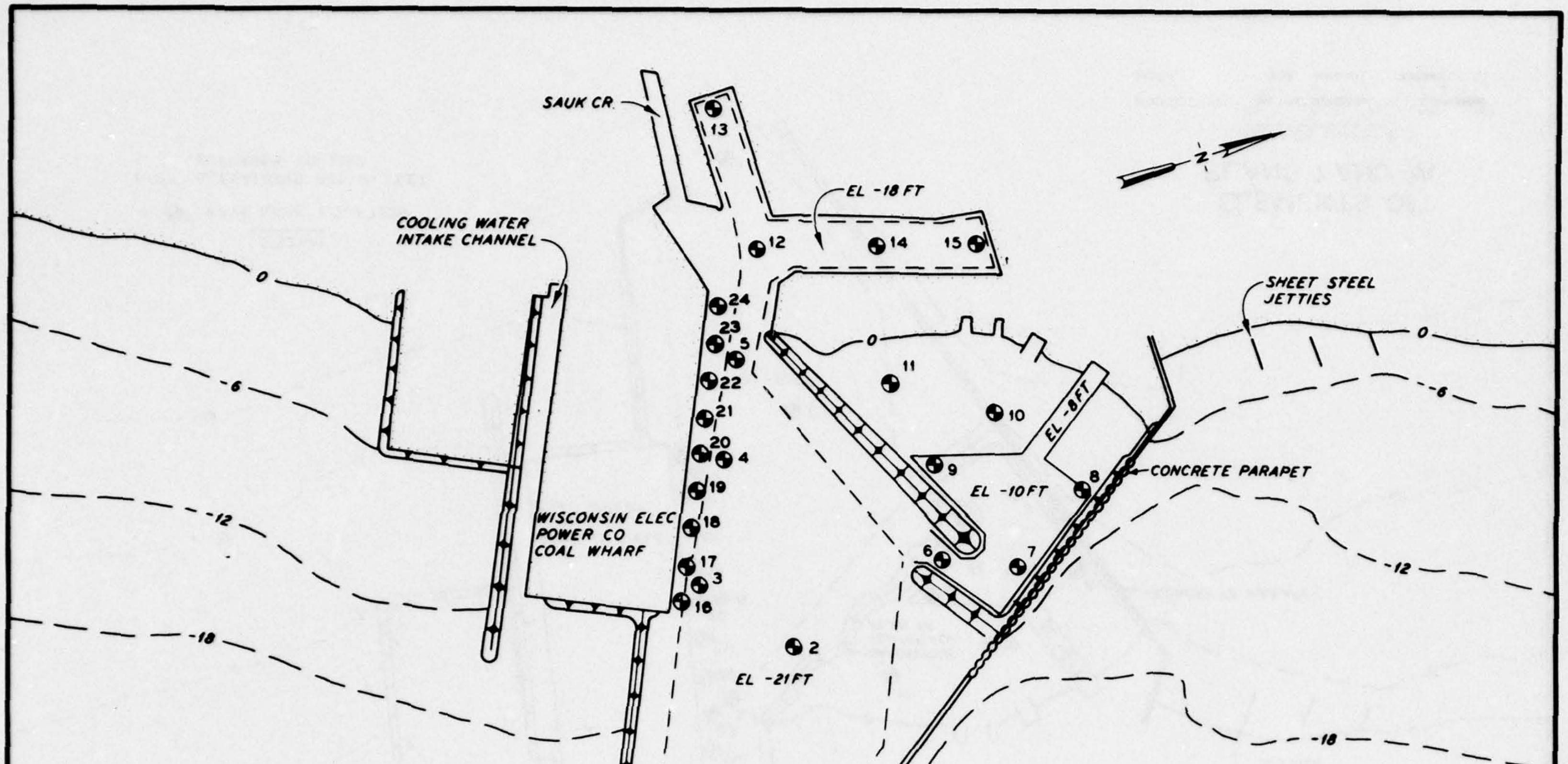

ELEMENTS OF
PLANS 5, 5A, AND 5B
SCALES IN FEET
PROTOTYPE 200 0 200 400 800
MODEL 2 0 2 4 6 8
N
SHEET STEEL JETTIES
CONCRETE PARAPET
EL -8FT
EL -10FT
EL -18 FT
EL -21FT
SAUK CR
WISCONSIN ELEC POWER CO COAL WHARF
COOLING WATER INTAKE CHANNEL
0
-6
-12
-18
6
7
8
9
10
11
PLAN PARAPET EL, FT ABSORBER EL, FT
5 +12 NONE
5A +12 +4
5B +14 +4
LEGEND
WAVE GAGE LOCATION
NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD.

PLATE 8



ELEMENTS OF PLANS 6 AND 6A

PLAN	CROWN EL EAST BREAKWATER, FT	CROWN EL WEST BREAKWATER, FT
6	+10	+8
6A	+12	+10

LEGEND

● WAVE GAGE LOCATION

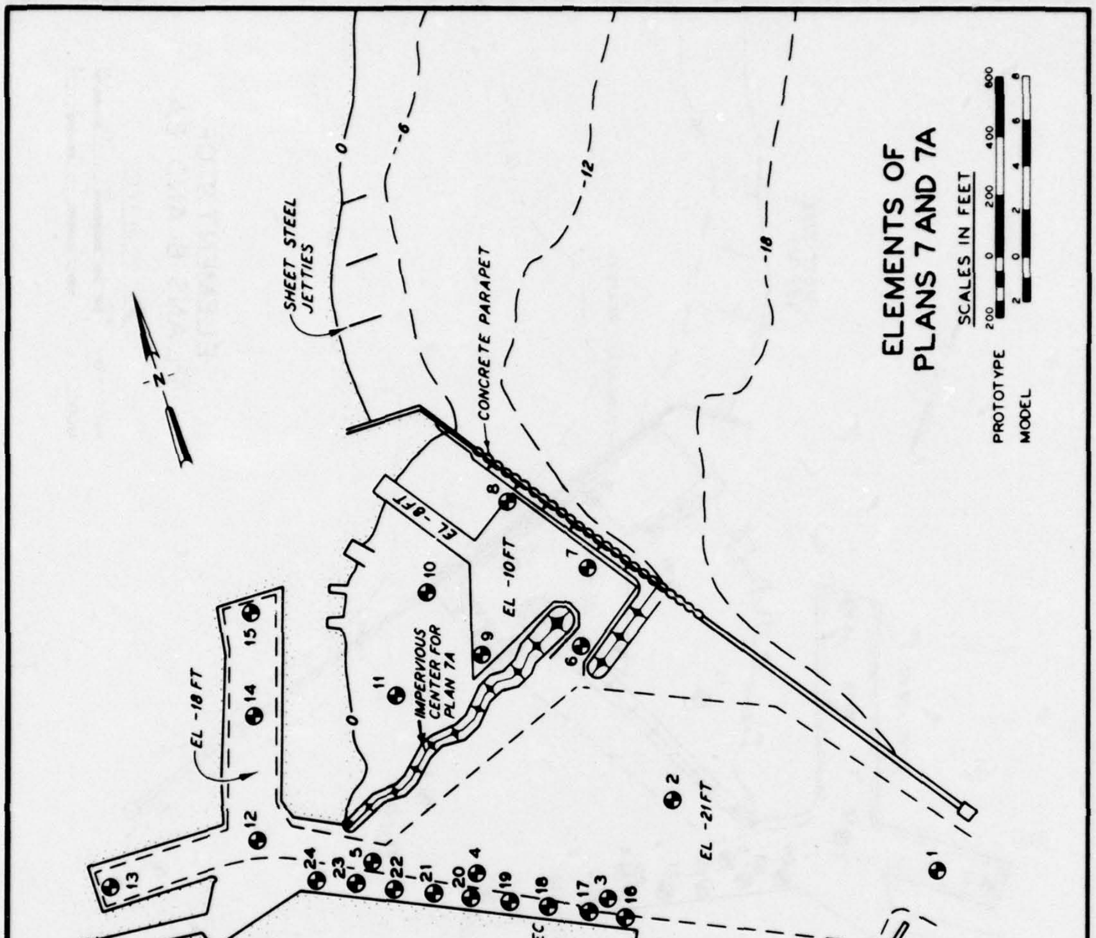
NOTE ELEVATIONS ARE IN FEET REFERRED TO LWD

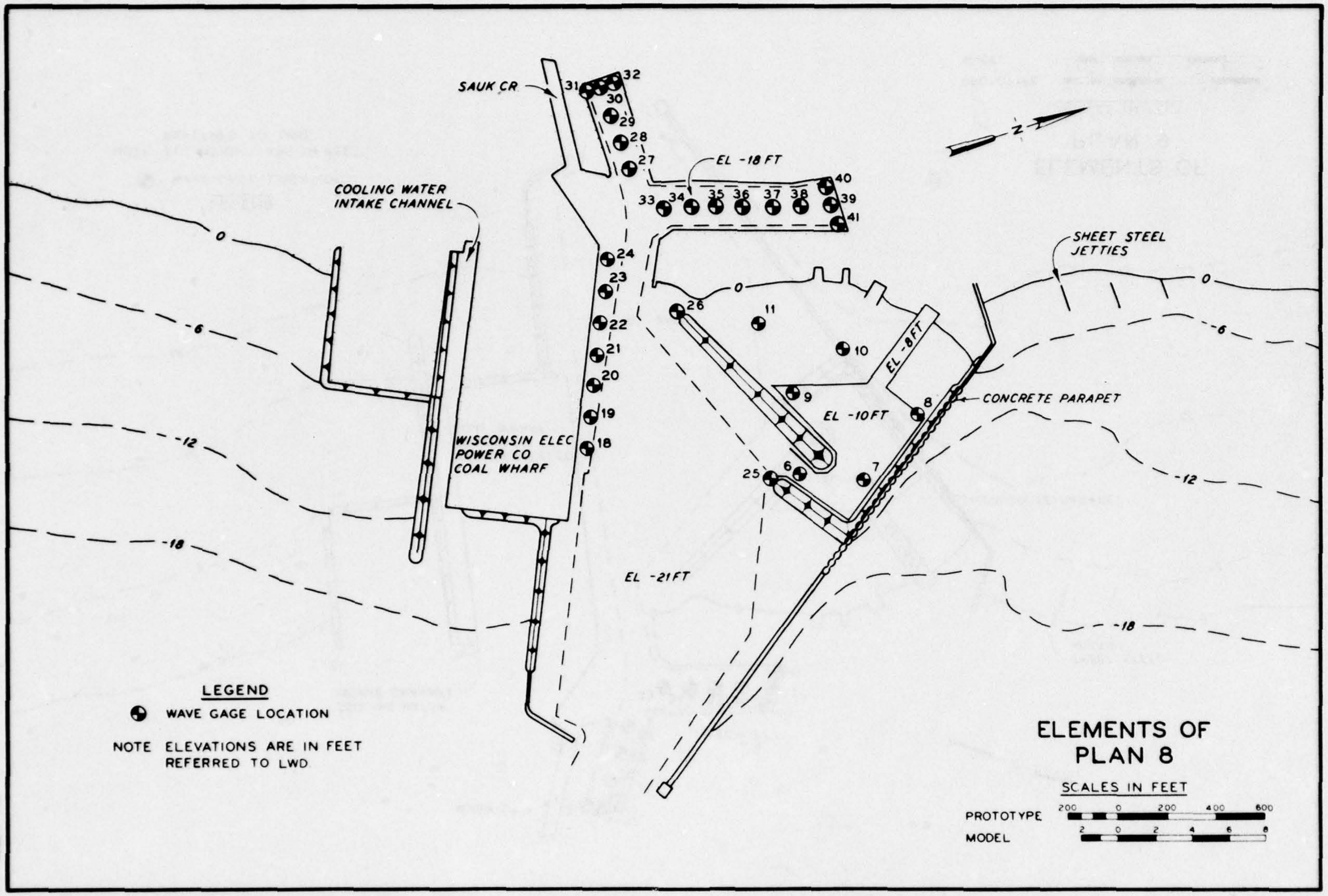
SCALES IN FEET

PROTOTYPE 200 0 200 400 600

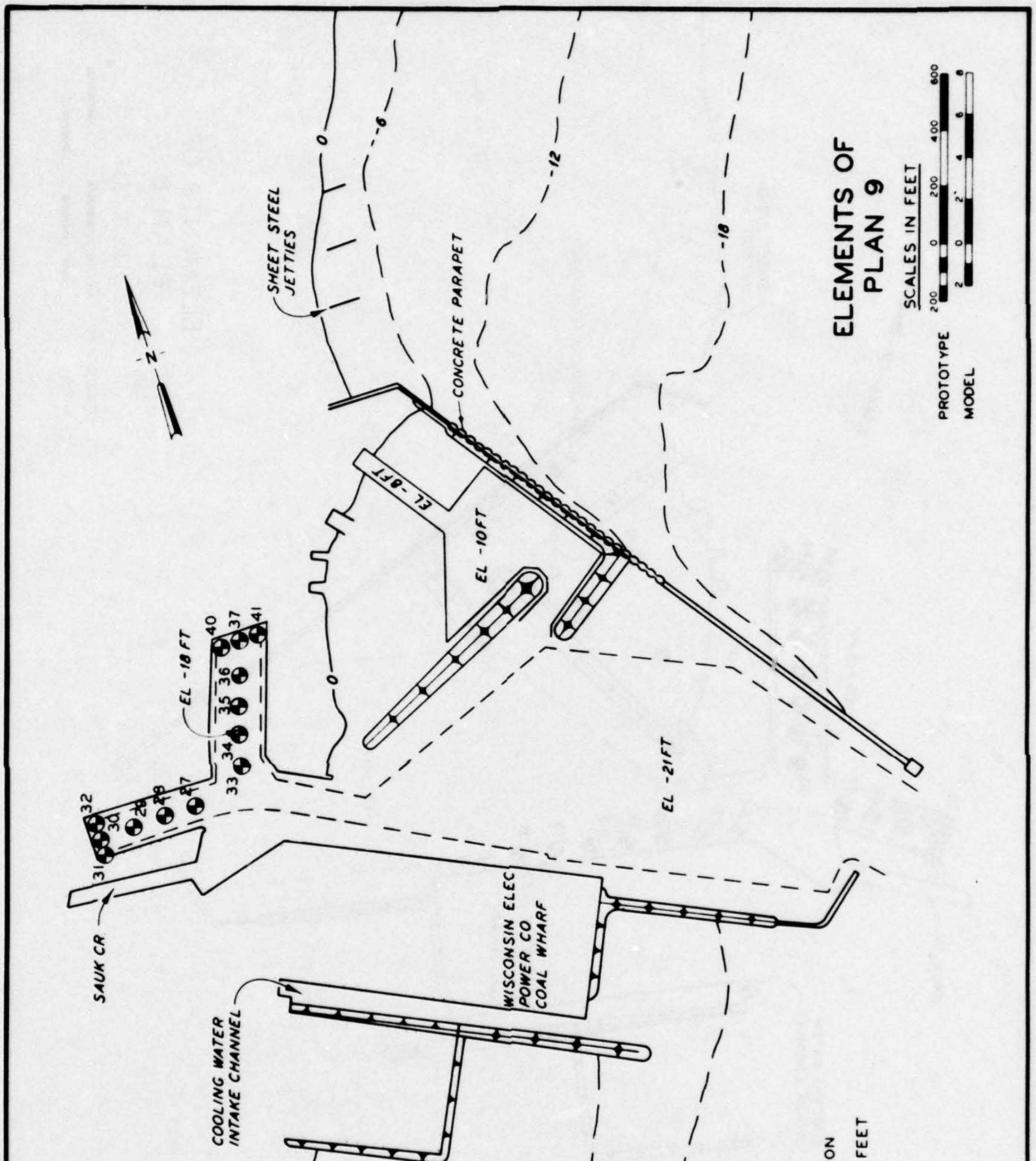
MODEL 2 0 2 4 6 8

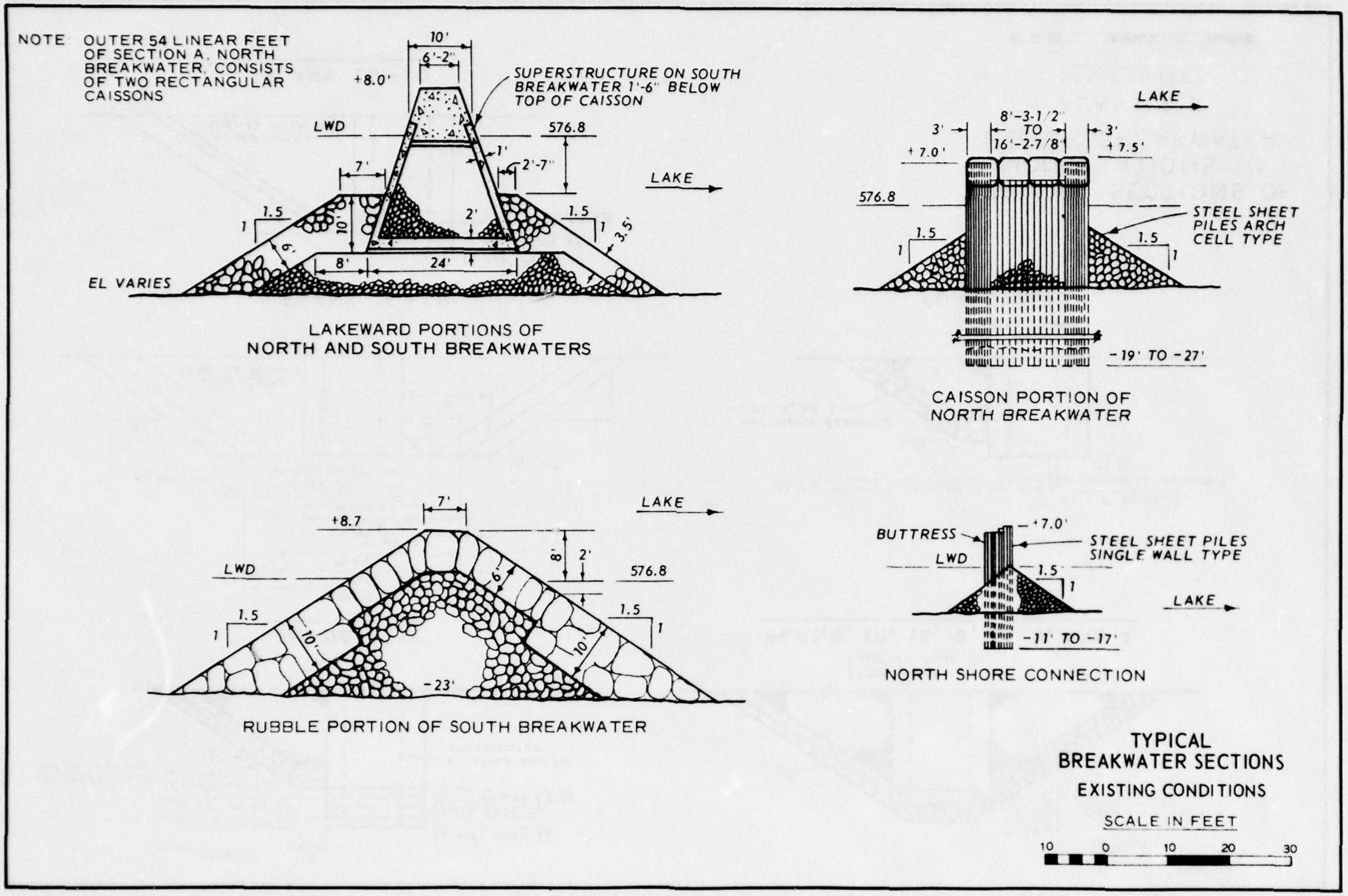
PLATE 9


ELEMENTS OF PLANS 7 AND 7A
SCALES IN FEET
PROTOTYPE 200 0 200 400 600
MODEL 2 0 2 4 6
LEGEND
WAVE GAGE LOCATION
NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD
N
SAUK CR.
COOLING WATER INTAKE CHANNEL
WISCONSIN ELEC POWER CO COAL WHARF
SHEET STEEL JETTIES
CONCRETE PARAPET
IMPERVIOUS CENTER FOR PLAN 7A
EL -18 FT
EL -8 FT
EL -10 FT
EL -21 FT
0
-6
-12
-18
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

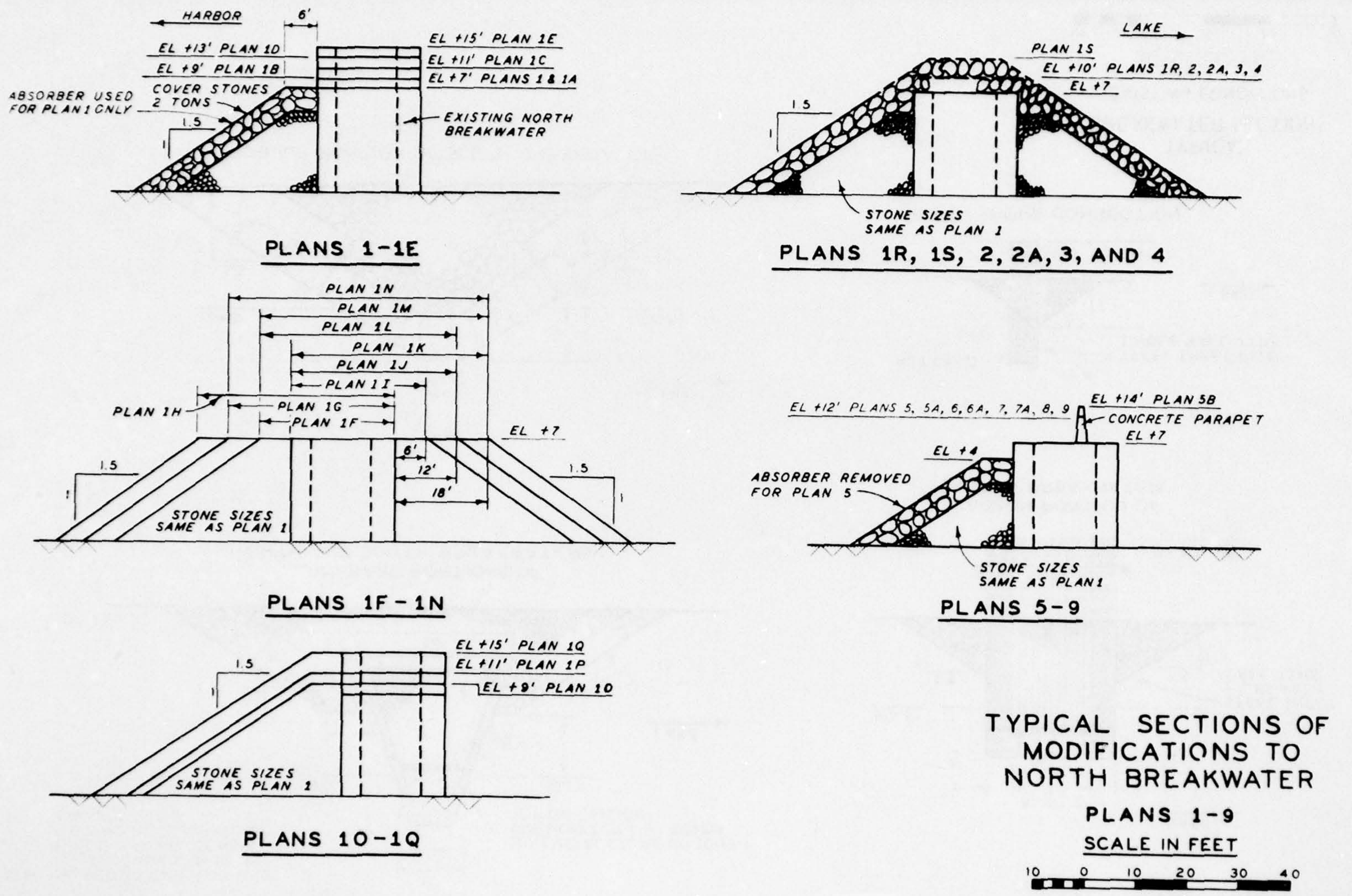


SAUK CR
COOLING WATER
INTAKE CHANNEL
EL -18 FT
SHEET STEEL
JETTIES
CONCRETE PARAPET
EL -8 FT
EL -10 FT
EL -21 FT
WISCONSIN ELEC
POWER CO
COAL WHARF
N
0
-6
-12
-18
1
2
3
4
5
6
7
8
9
10
11
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
LEGEND
WAVE GAGE LOCATION
NOTE ELEVATIONS ARE IN FEET
REFERRED TO LWD.
ELEMENTS OF
PLAN 8
SCALES IN FEET
PROTOTYPE 200 0 200 400 600
MODEL 2 0 2 4 6 8


ELEMENTS OF
PLAN 9
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
WAVE GAGE LOCATION
NOTE ELEVATIONS ARE IN FEET
REFERRED TO LWD
SHEET STEEL
JETTIES
CONCRETE PARAPET
EL -8 FT
EL -10 FT
EL -18 FT
EL -21 FT
SAUK CR
WISCONSIN ELEC
POWER CO
COAL WHARF
COOLING WATER
INTAKE CHANNEL
N
0
-6
-12
-18
31
32
30
28
29
27
33
34
35
36
37
40
41



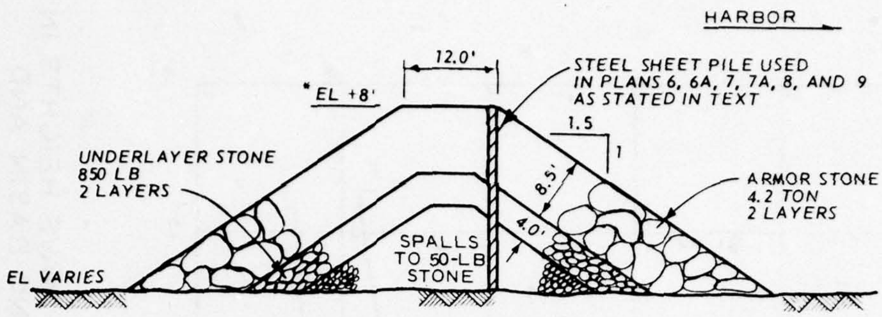
TYPICAL BREAKWATER SECTIONS
EXISTING CONDITIONS



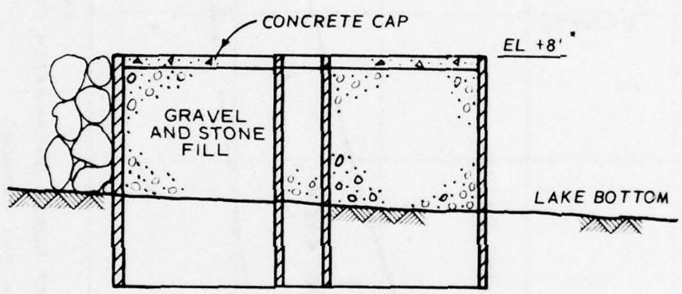
TYPICAL SECTIONS OF MODIFICATIONS TO NORTH BREAKWATER

PLANS 1-9

PLATE 14



NEW EAST AND WEST BREAKWATERS
PLANS 1–9



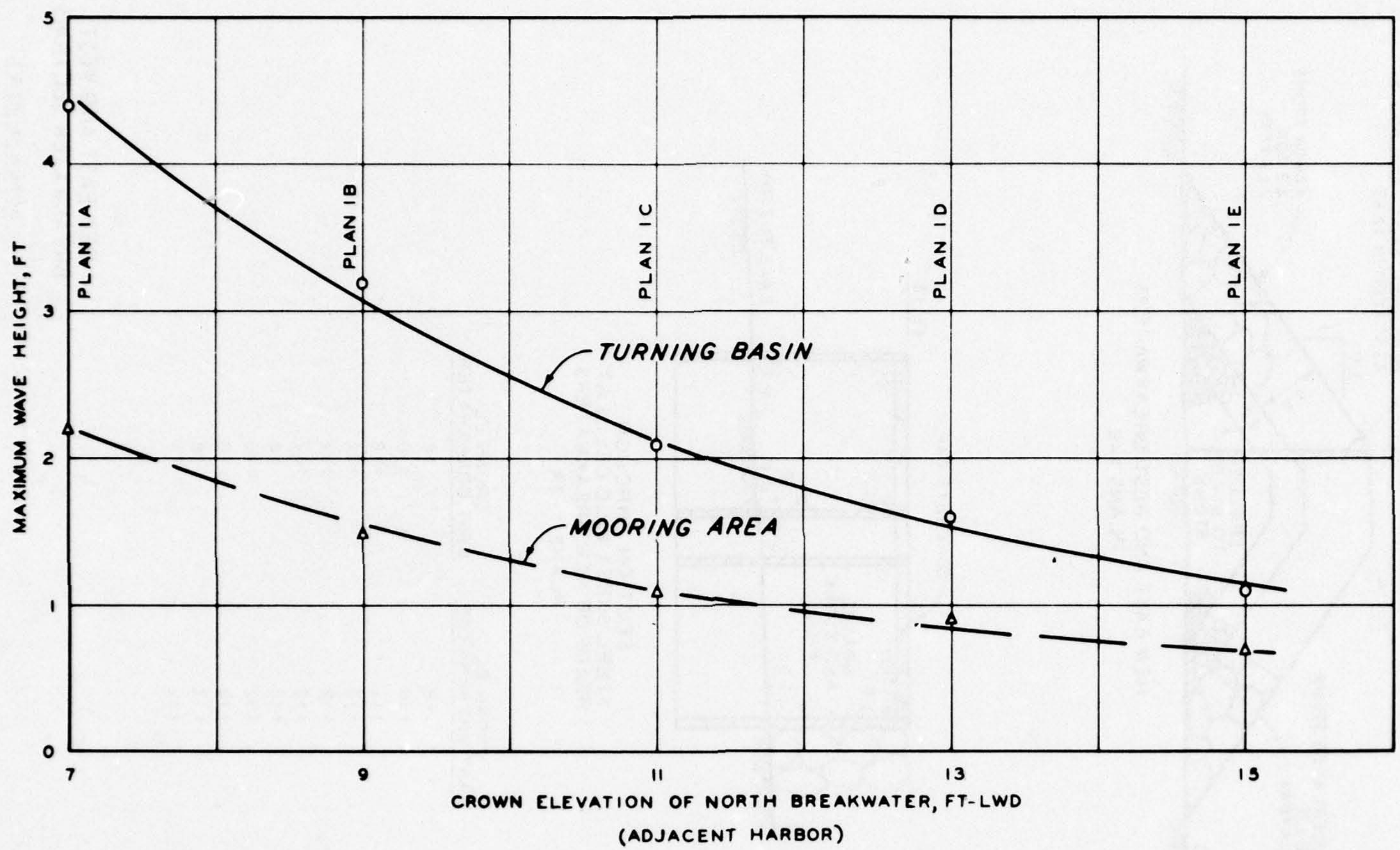
SECTION THROUGH
STEEL SHEET PILE CELLS AT
HEADS OF NEW BREAKWATERS
PLANS 1-2A

* PLAN	CROWN EL EAST BREAKWATER	CROWN EL WEST BREAKWATER
1-1S	+8	+8
2	+10	+10
2A	+12	+12
3	+12	+12
4	+12	+12
5-5B	+12	+12
6	+10	+8
6A	+12	+10
7-7A	+10	+8
8	+12	+8
9	+12	+8

NEW EAST AND WEST BREAKWATER SECTIONS

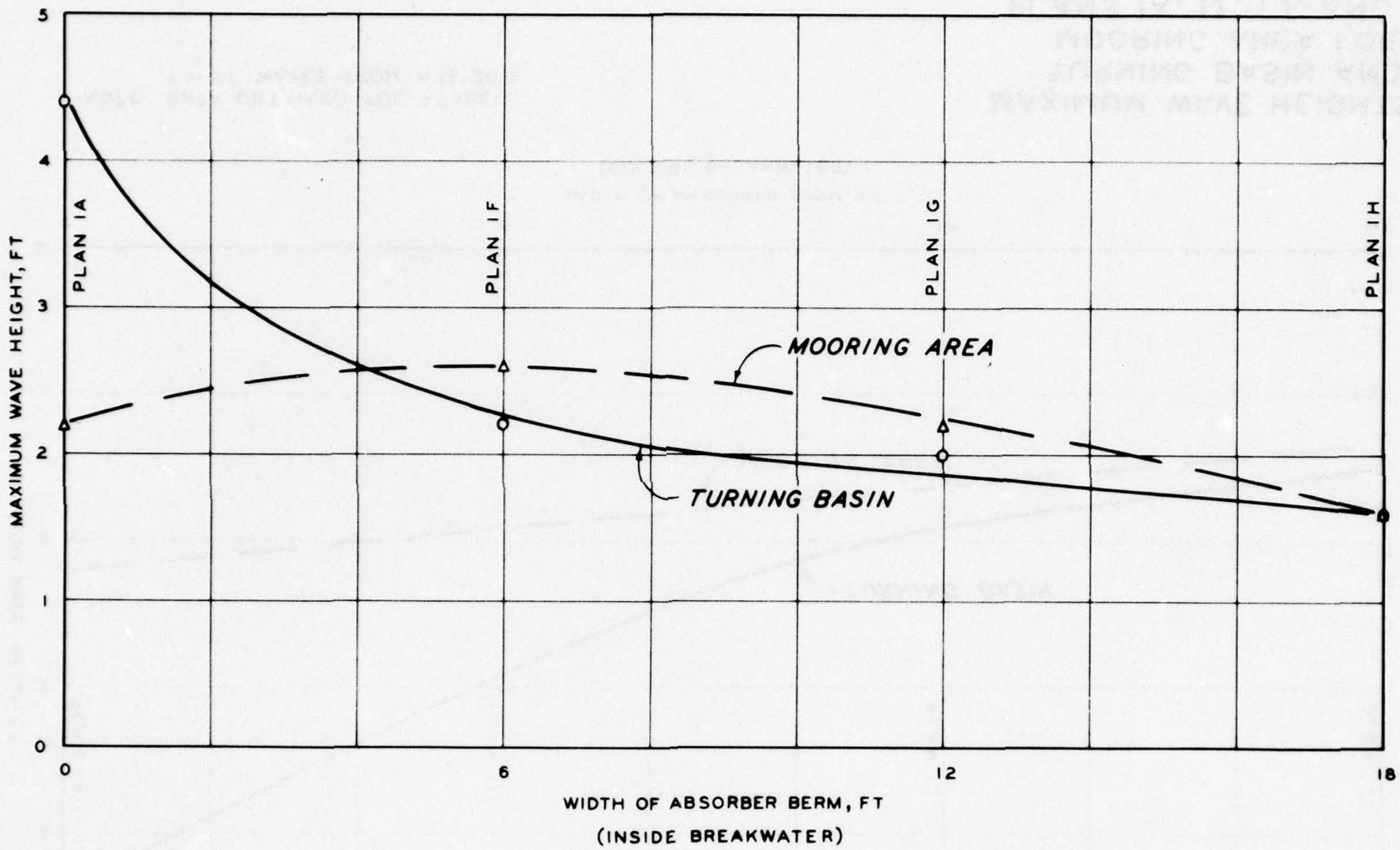
SCALE IN FEET

10 0 10 20



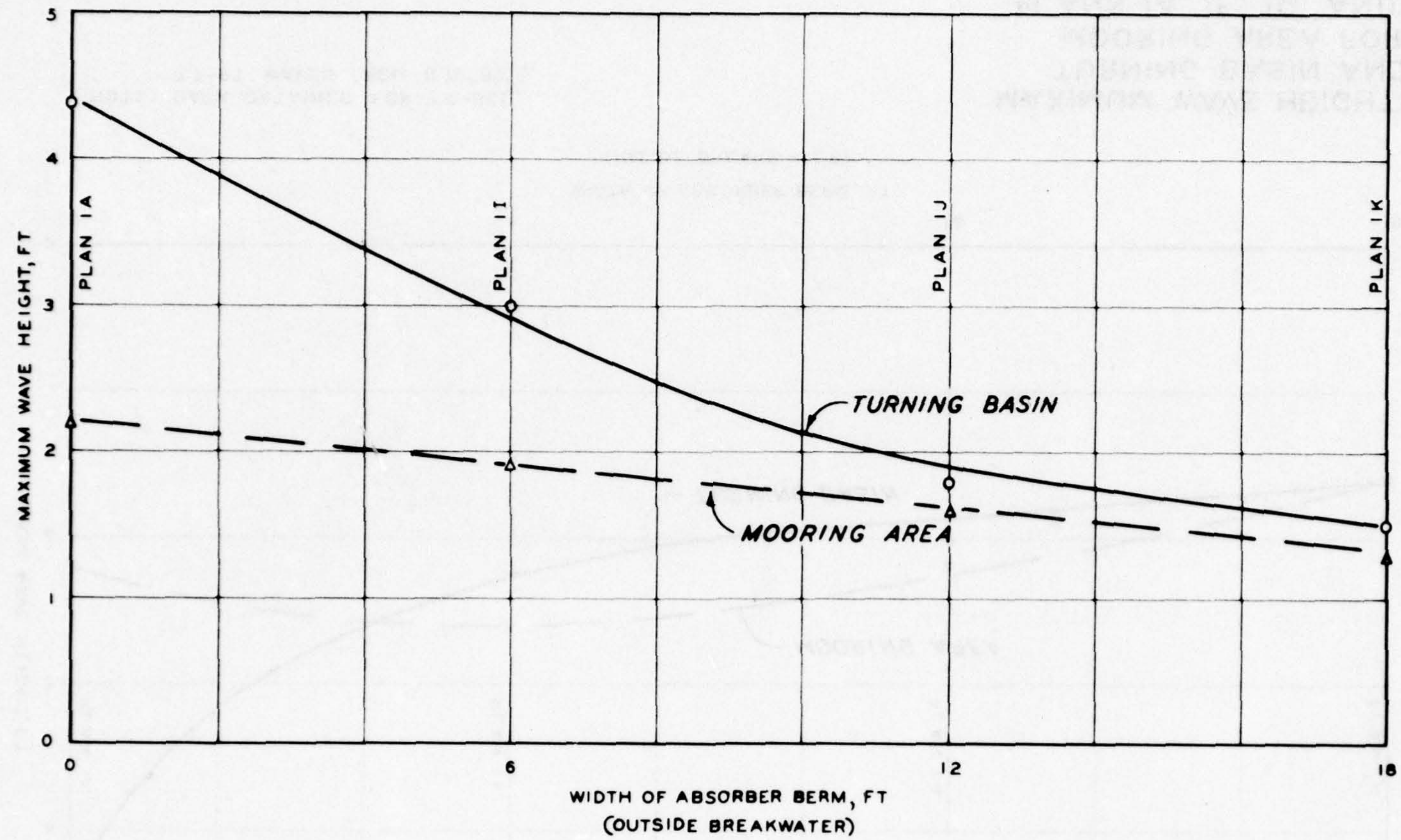
NOTE: DATA OBTAINED FOR 7.7-SEC, 7.7-FT WAVES FROM N 76°20'E.

MAXIMUM WAVE HEIGHTS IN TURNING BASIN AND MOORING AREA FOR PLANS IA, IB, IC, ID, AND IE



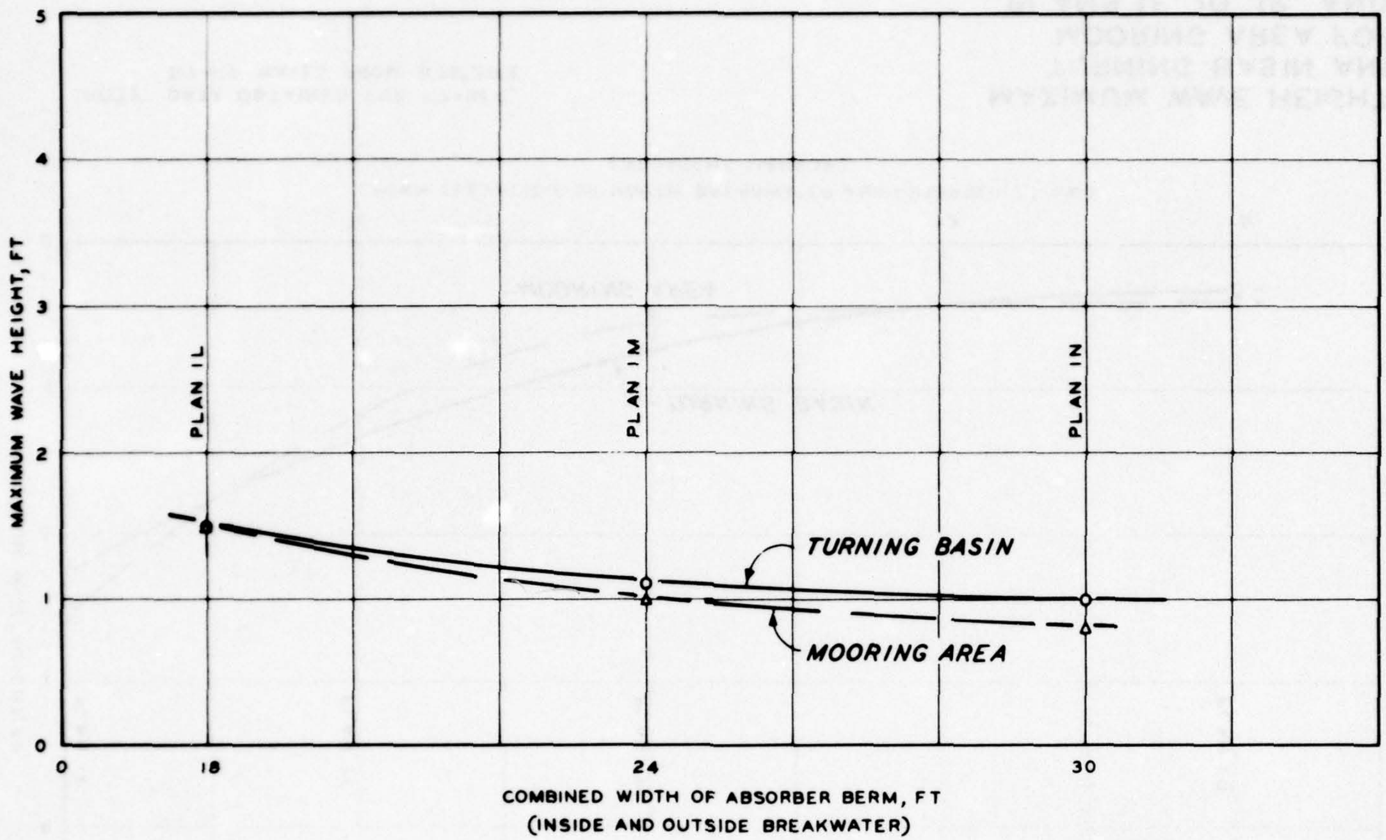
NOTE: DATA OBTAINED FOR 7.7-SEC, 7.7-FT WAVES FROM N 76°20'E.

MAXIMUM WAVE HEIGHTS IN TURNING BASIN AND MOORING AREA FOR PLANS IA, IF, IG, AND IH



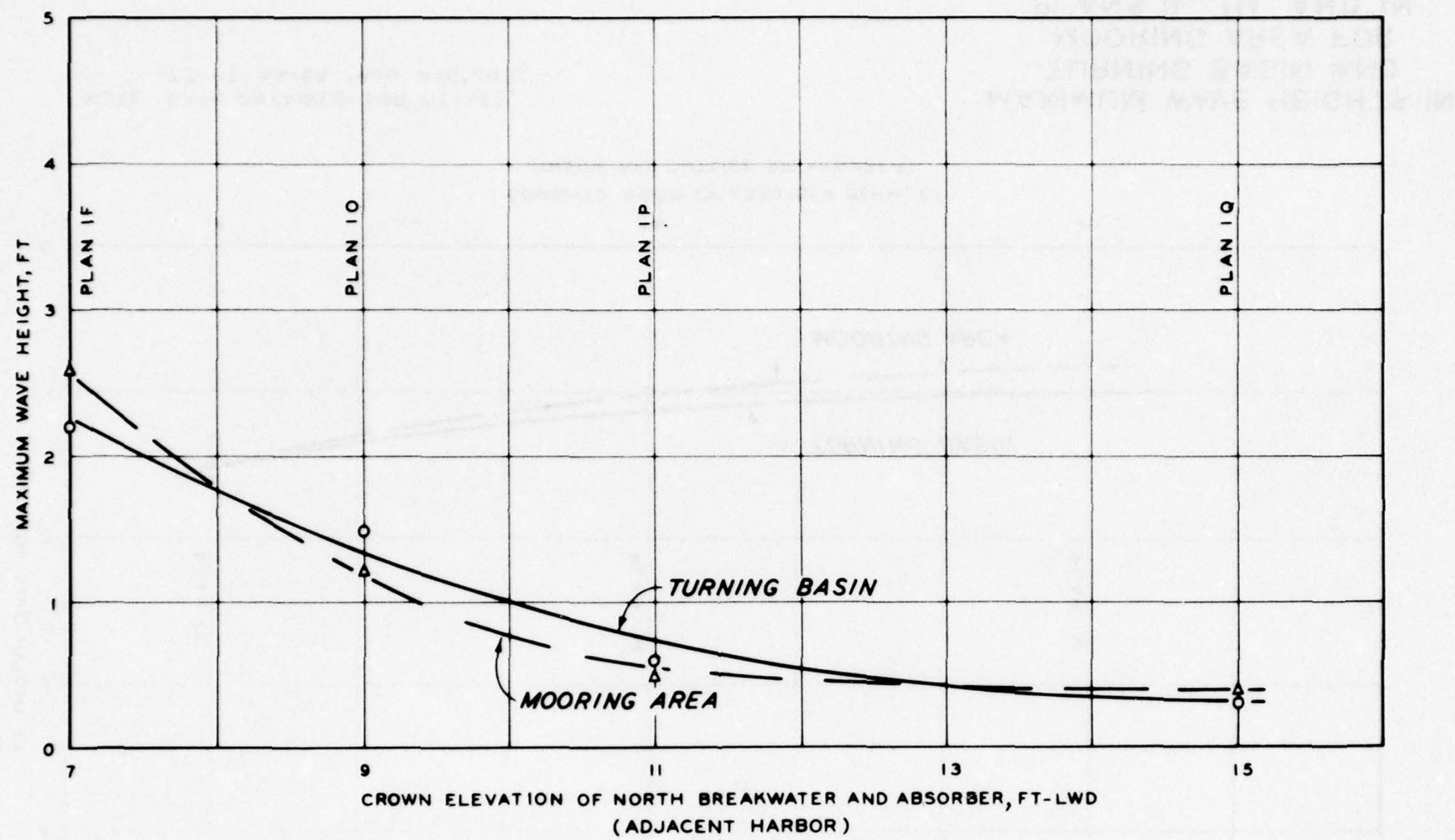
NOTE: DATA OBTAINED FOR 7.7-SEC, 7.7-FT WAVES FROM N76°20'E.

MAXIMUM WAVE HEIGHTS IN TURNING BASIN AND MOORING AREA FOR PLANS IA, II, IJ, AND IK



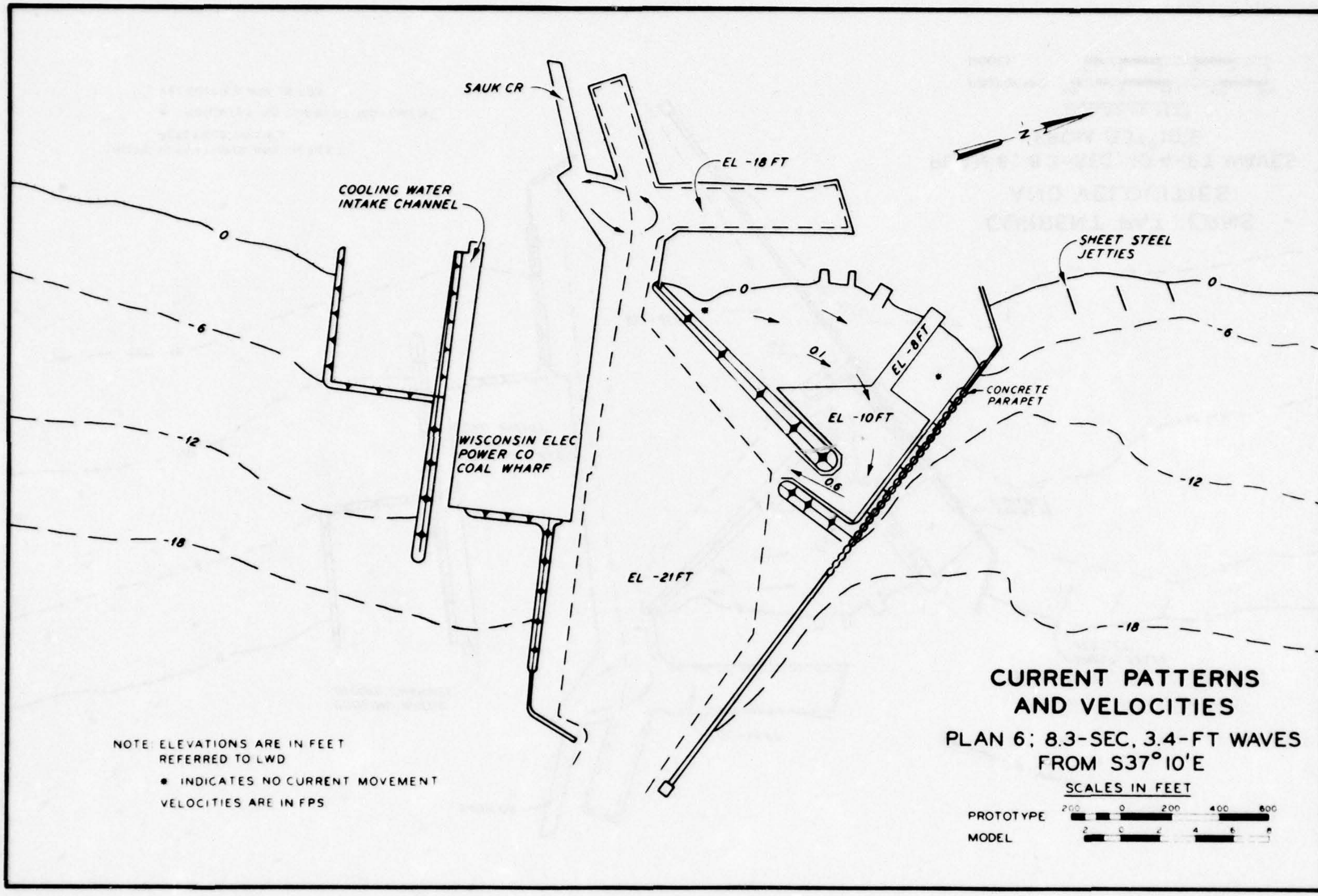
NOTE: DATA OBTAINED FOR 7.7-SEC, 7.7-FT WAVES FROM N76°20'E.

MAXIMUM WAVE HEIGHTS IN TURNING BASIN AND MOORING AREA FOR PLANS IL, IM, AND IN



NOTE: DATA OBTAINED FOR 7.7-SEC, 7.7-FT WAVES FROM N76°20'E.

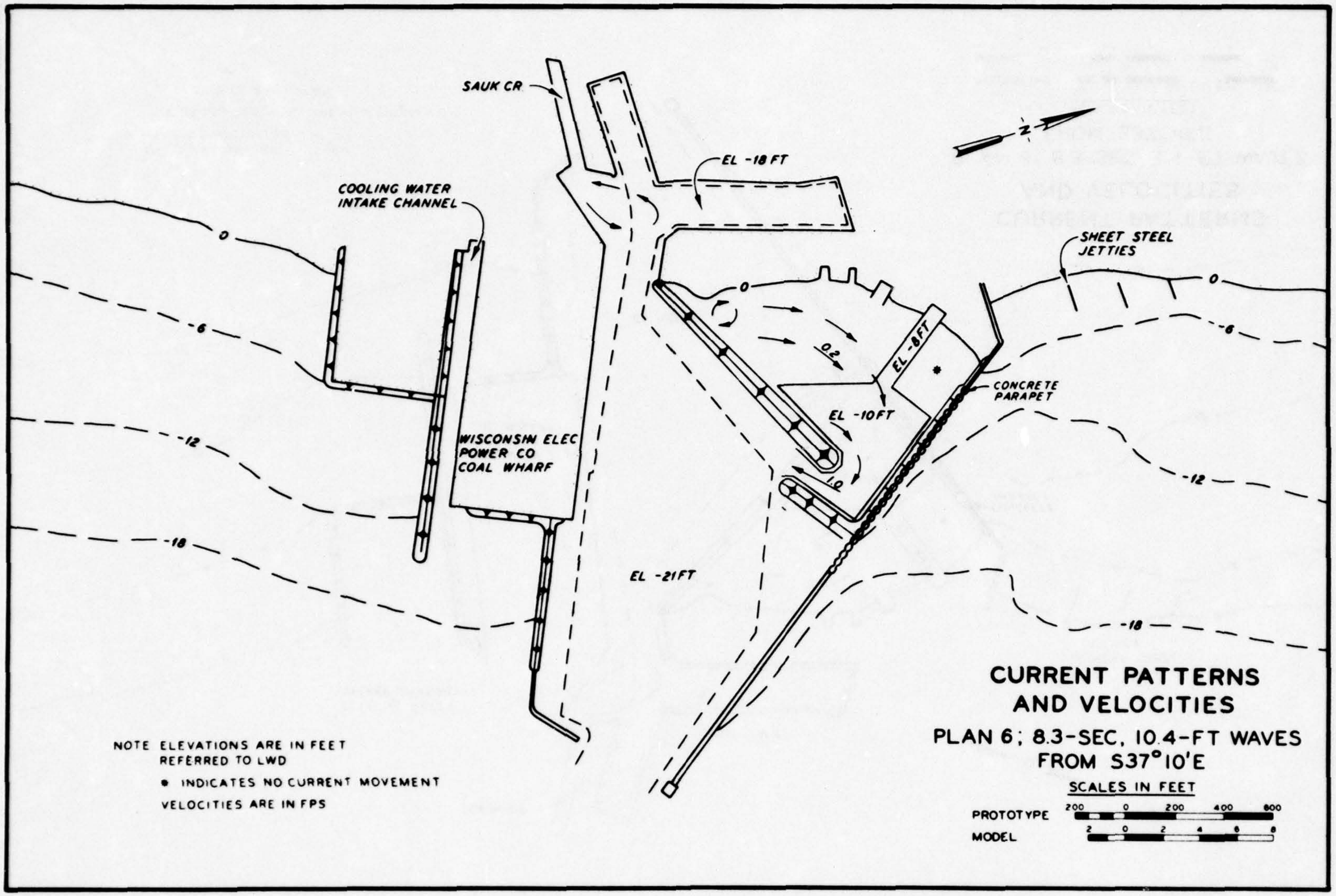
MAXIMUM WAVE HEIGHTS IN TURNING BASIN AND MOORING AREA FOR PLANS 1F, 1O, 1P, AND 1Q



CURRENT PATTERNS AND VELOCITIES

PLAN 6; 8.3-SEC, 3.4-FT WAVES FROM S37°10'E

SCALES IN FEET



CURRENT PATTERNS AND VELOCITIES

PLAN 6; 8.3-SEC, 10.4-FT WAVES FROM S37°10'E

SCALES IN FEET

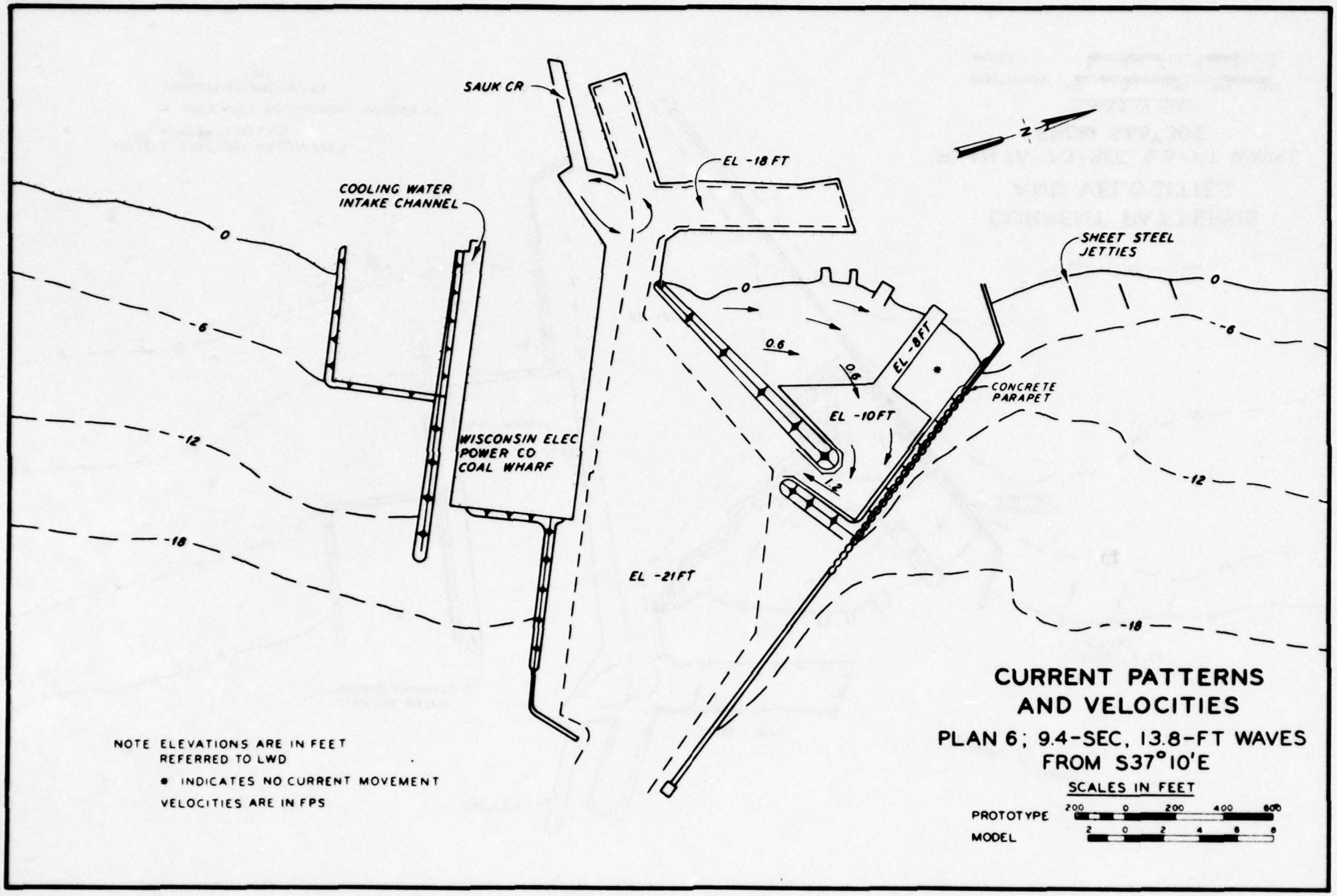
PROTOTYPE 200 0 200 400 600

MODEL 2 0 2 4 6 8

NOTE ELEVATIONS ARE IN FEET REFERRED TO LWD

* INDICATES NO CURRENT MOVEMENT

VELOCITIES ARE IN FPS



CURRENT PATTERNS AND VELOCITIES

PLAN 6; 9.4-SEC, 13.8-FT WAVES FROM S37°10'E

SCALES IN FEET

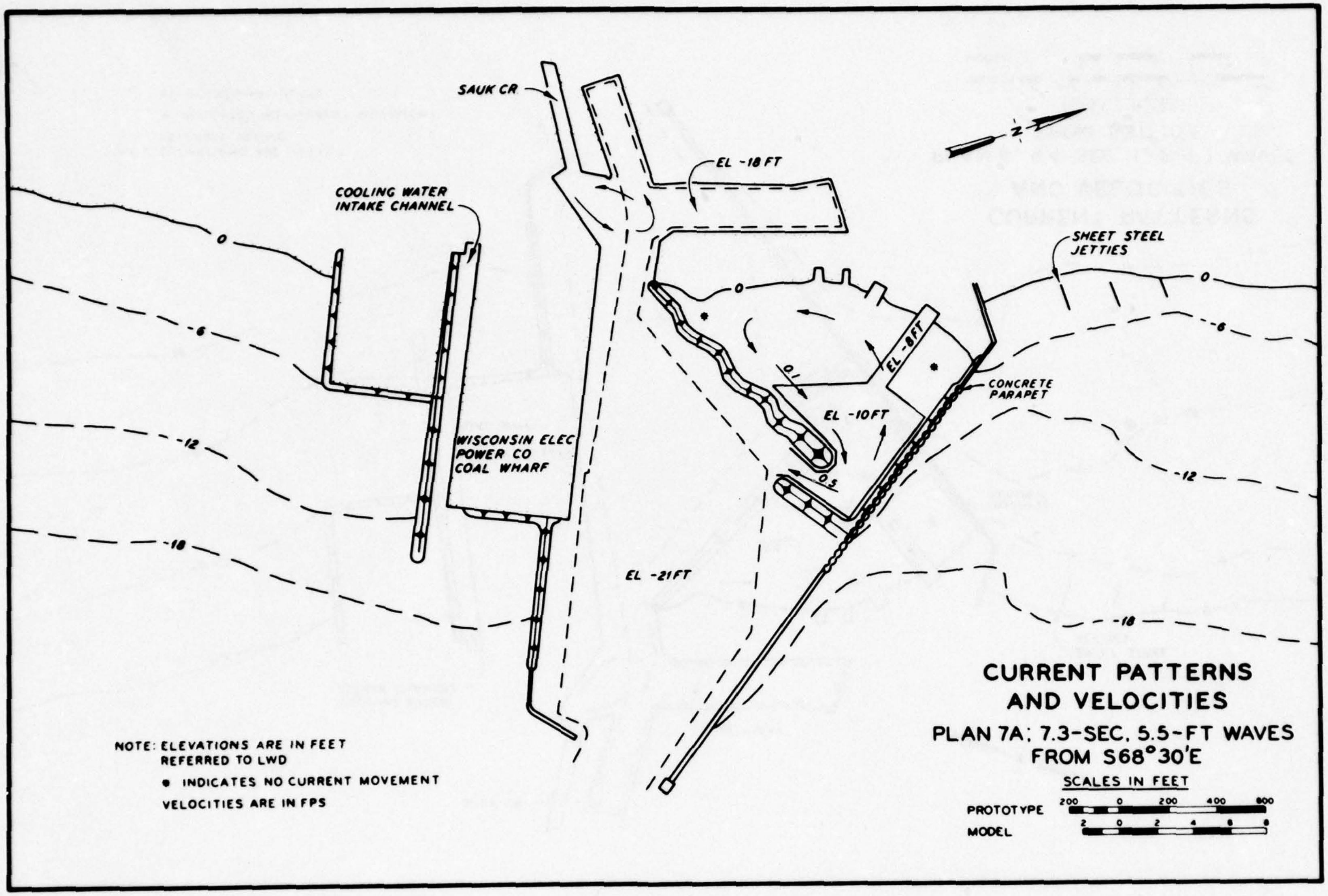
PROTOTYPE 200 0 200 400 600

MODEL 2 0 2 4 6 8

NOTE ELEVATIONS ARE IN FEET REFERRED TO LWD

• INDICATES NO CURRENT MOVEMENT

VELOCITIES ARE IN FPS



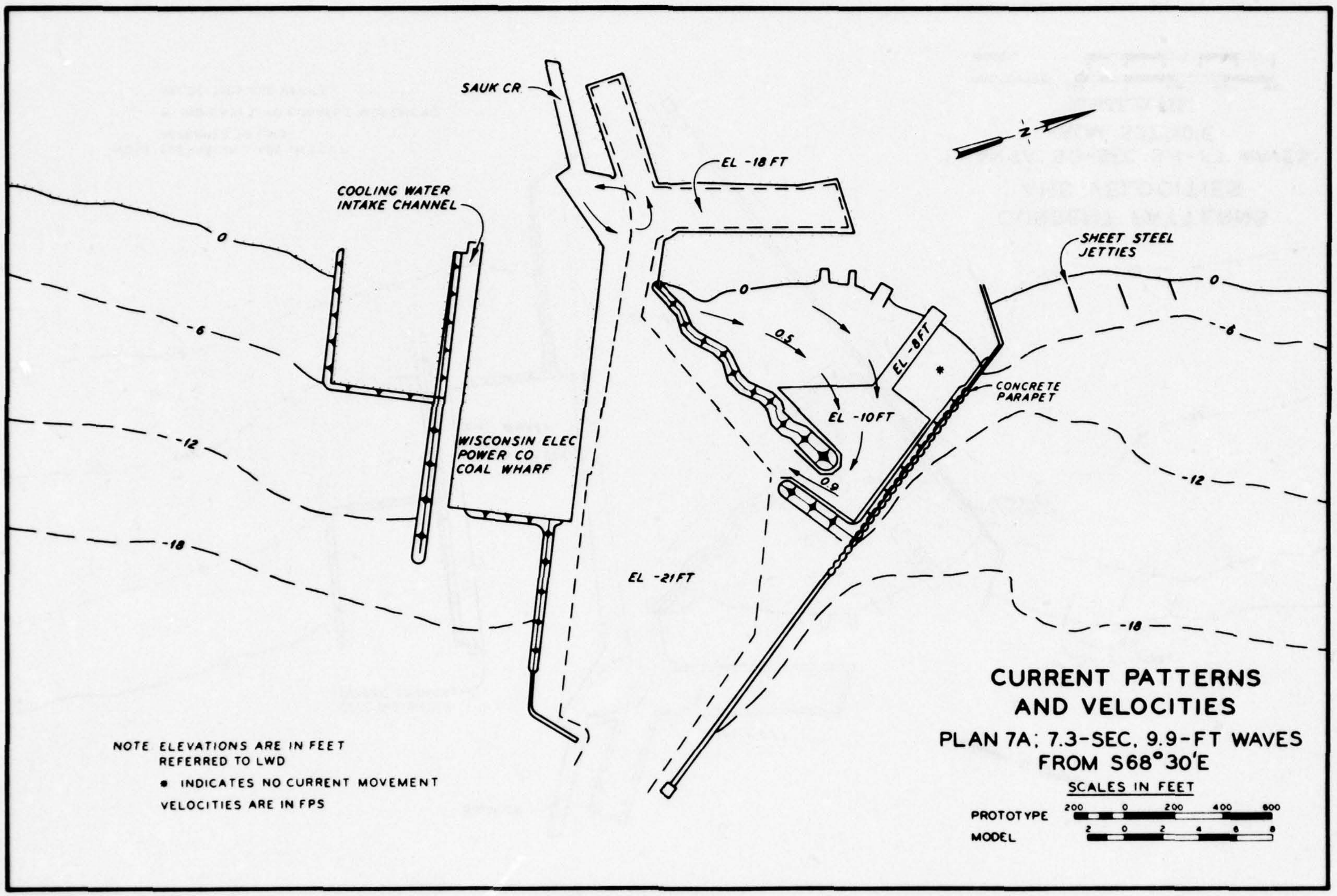
CURRENT PATTERNS AND VELOCITIES

PLAN 7A; 7.3-SEC, 5.5-FT WAVES FROM S68°30'E

NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD
- INDICATES NO CURRENT MOVEMENT

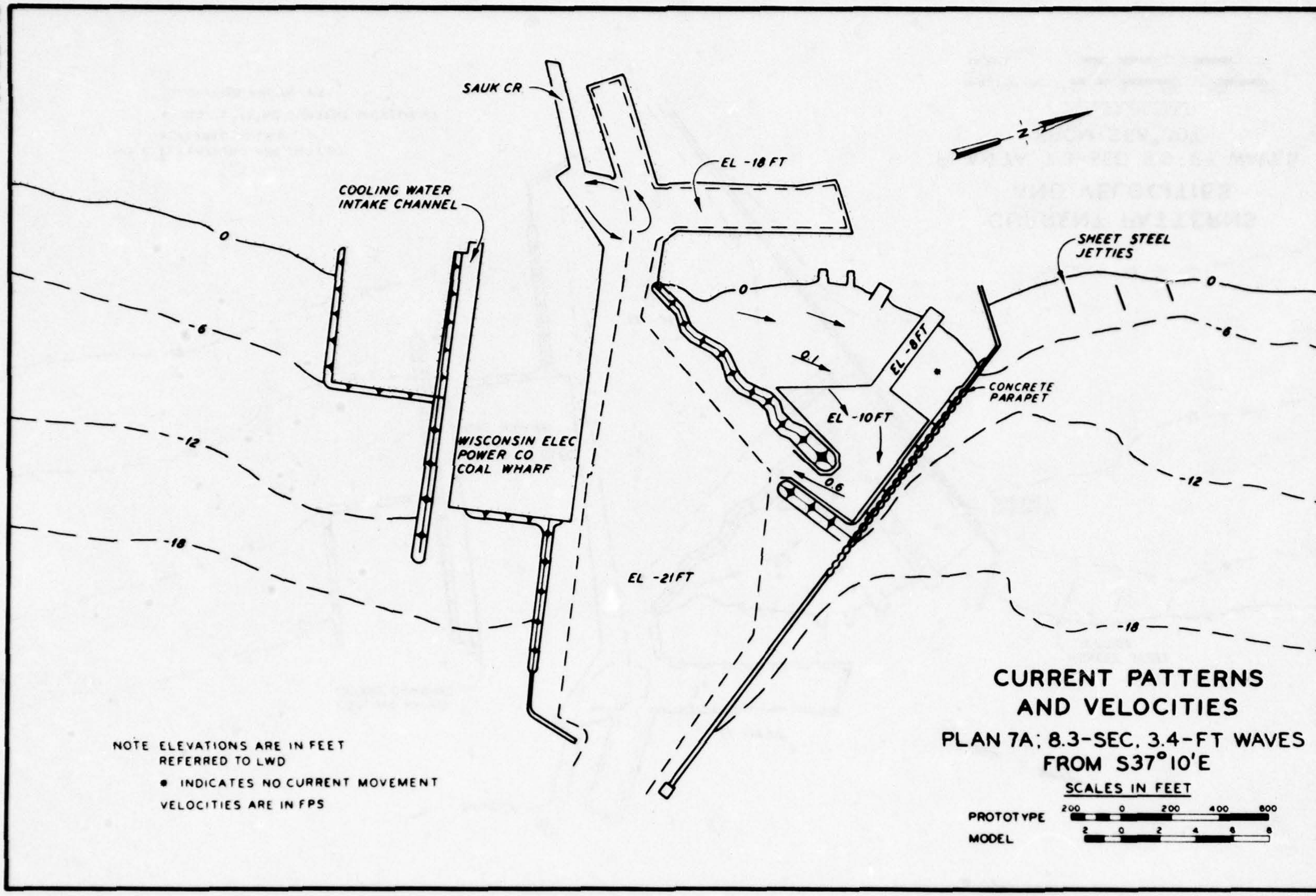
VELOCITIES ARE IN FPS

PLATE 24



CURRENT PATTERNS AND VELOCITIES

PLAN 7A; 7.3-SEC, 9.9-FT WAVES FROM S68°30'E



NOTE ELEVATIONS ARE IN FEET REFERRED TO LWD
• INDICATES NO CURRENT MOVEMENT
VELOCITIES ARE IN FPS

CURRENT PATTERNS AND VELOCITIES

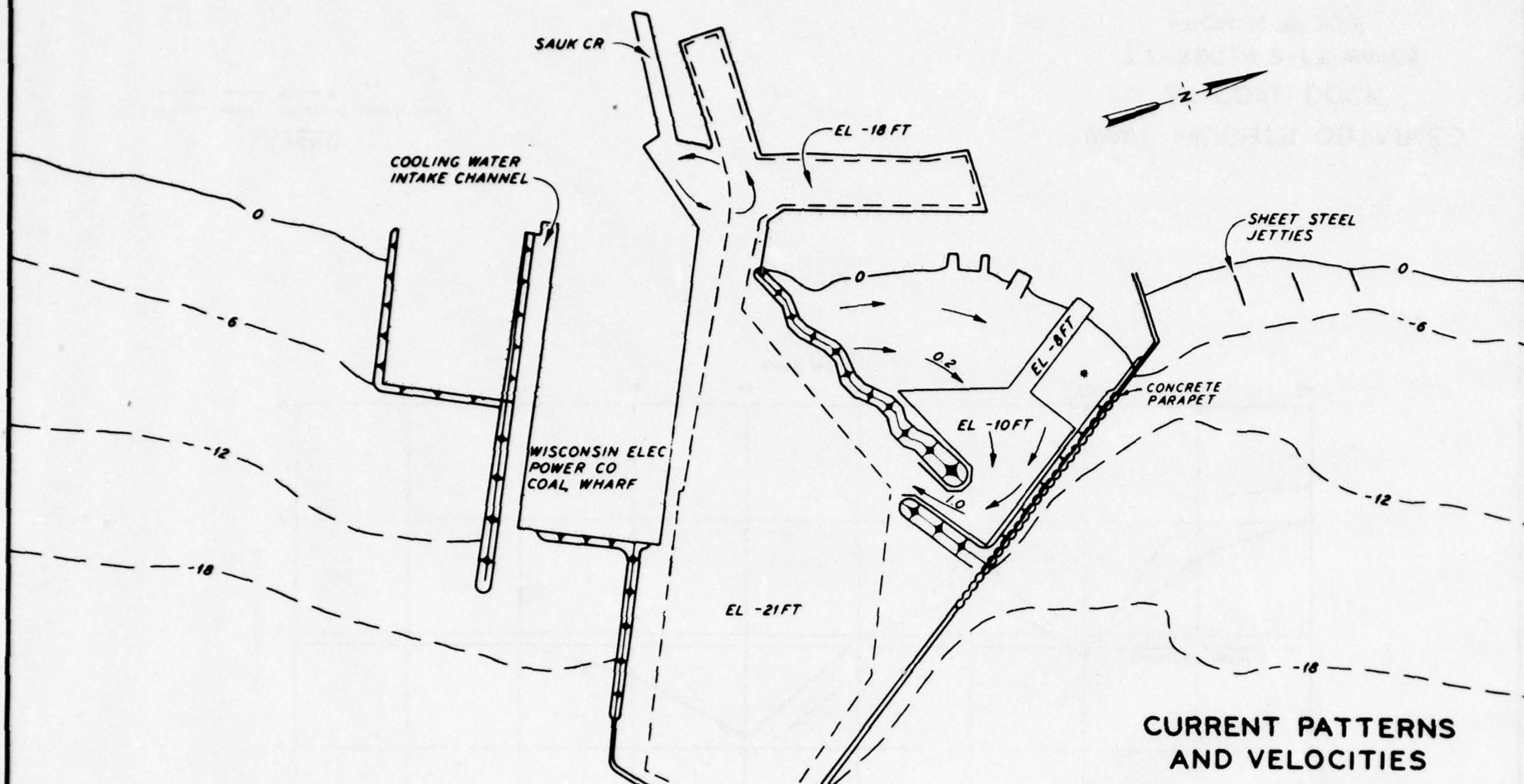
PLAN 7A; 8.3-SEC, 3.4-FT WAVES FROM S37°10'E

SCALES IN FEET

PROTOTYPE 200 0 200 400 600

MODEL 2 0 2 4 6 8

PLATE 26



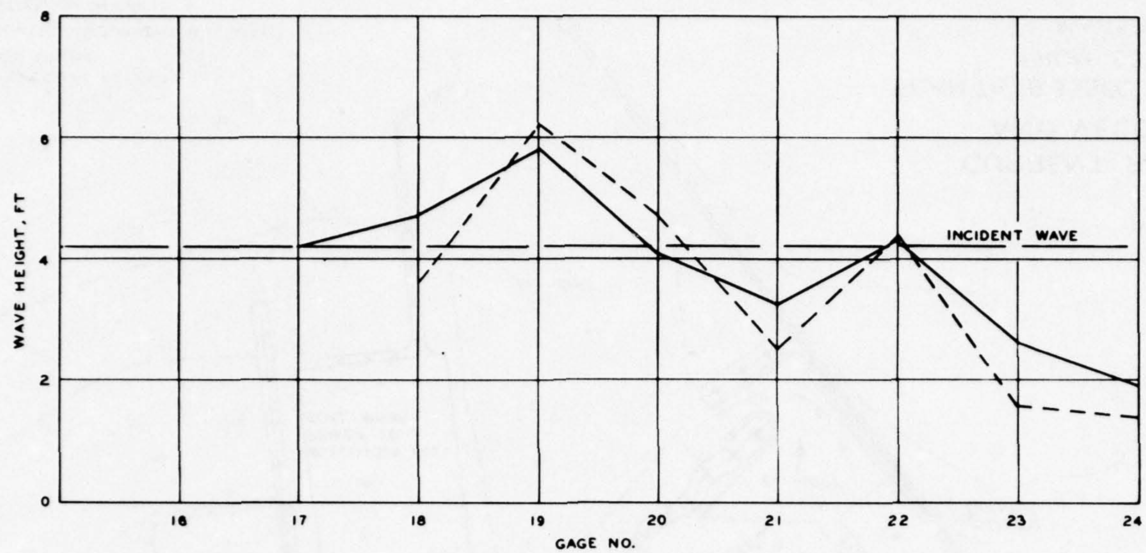
NOTE: ELEVATIONS ARE IN FEET REFERRED TO LWD

• INDICATES NO CURRENT MOVEMENT

VELOCITIES ARE IN FPS

CURRENT PATTERNS AND VELOCITIES

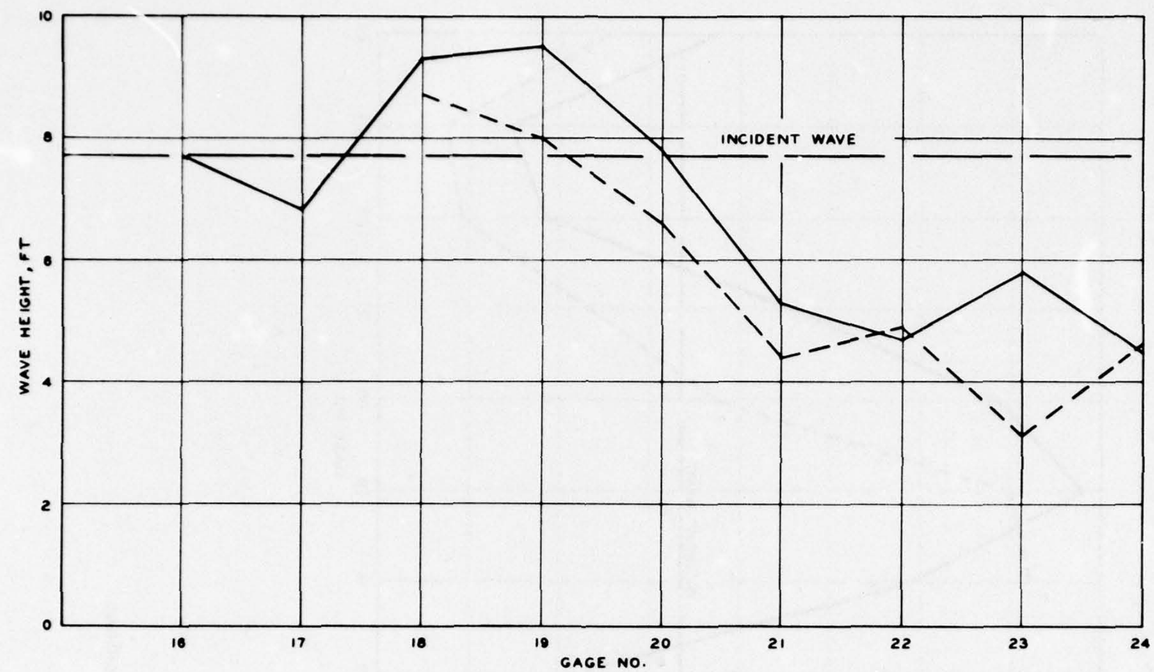
PLAN 7A; 8.3-SEC, 10.4-FT WAVES FROM S37°10'E



LEGEND

——— EXISTING CONDITIONS
– – – PLAN 8

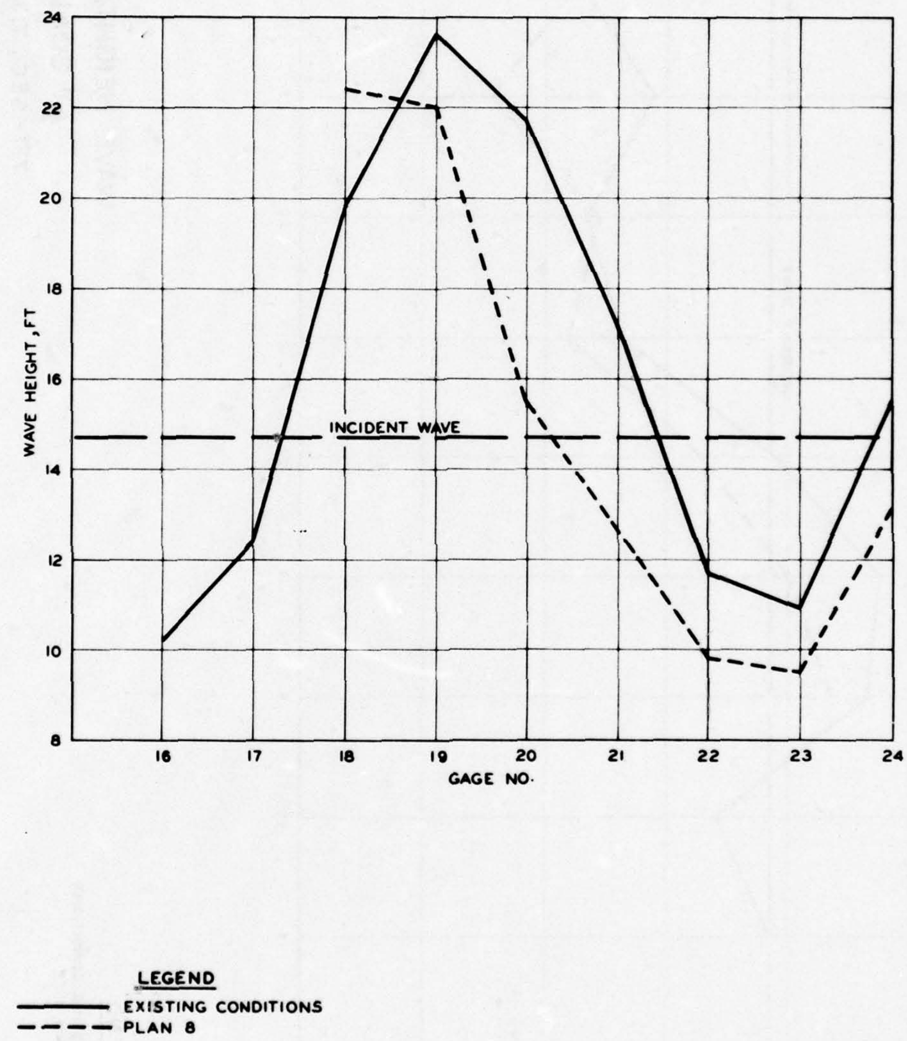
WAVE HEIGHTS OBTAINED
AT COAL DOCK
7.7-SEC, 4.2-FT WAVES
FROM N 76° 20′ E



LEGEND

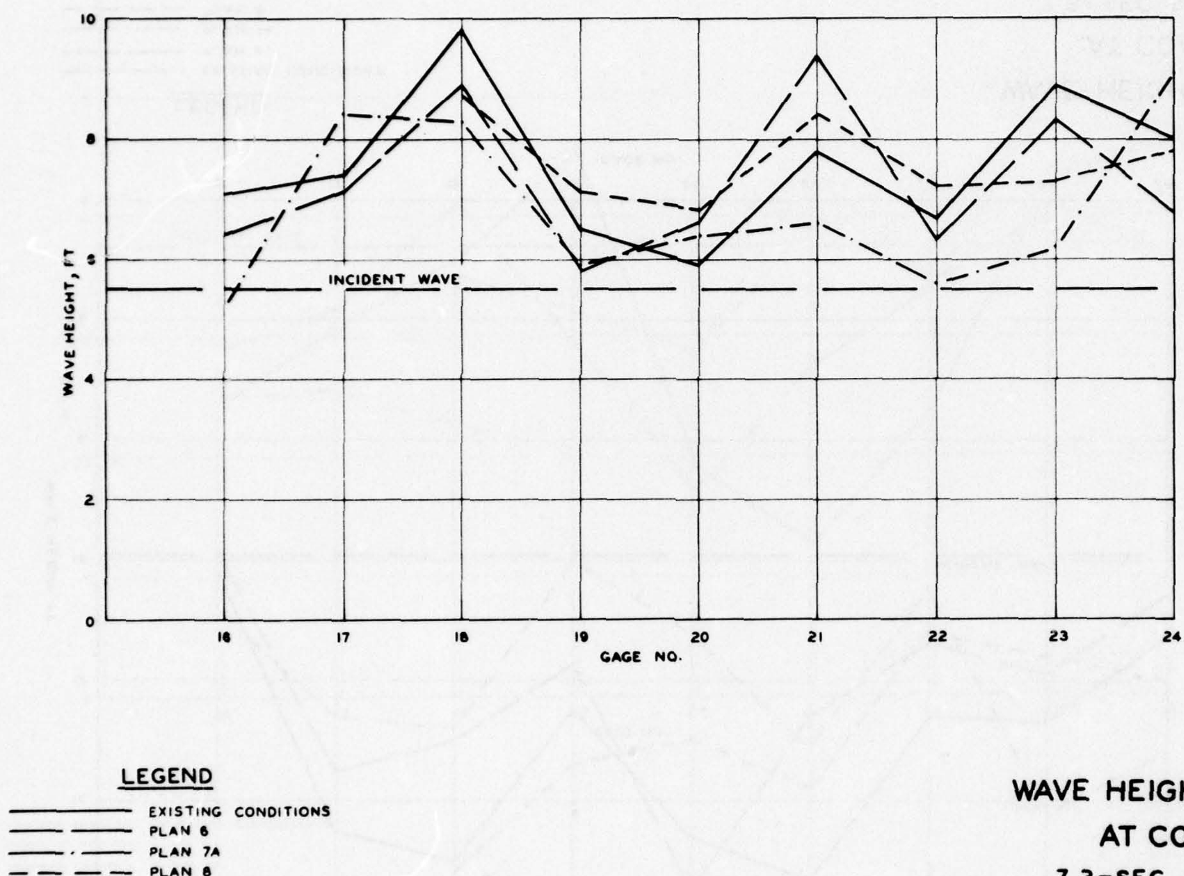
—— EXISTING CONDITIONS
– – – PLAN 8

WAVE HEIGHTS OBTAINED
AT COAL DOCK
7.7-SEC, 7.7-FT WAVES
FROM N 76° 20′E



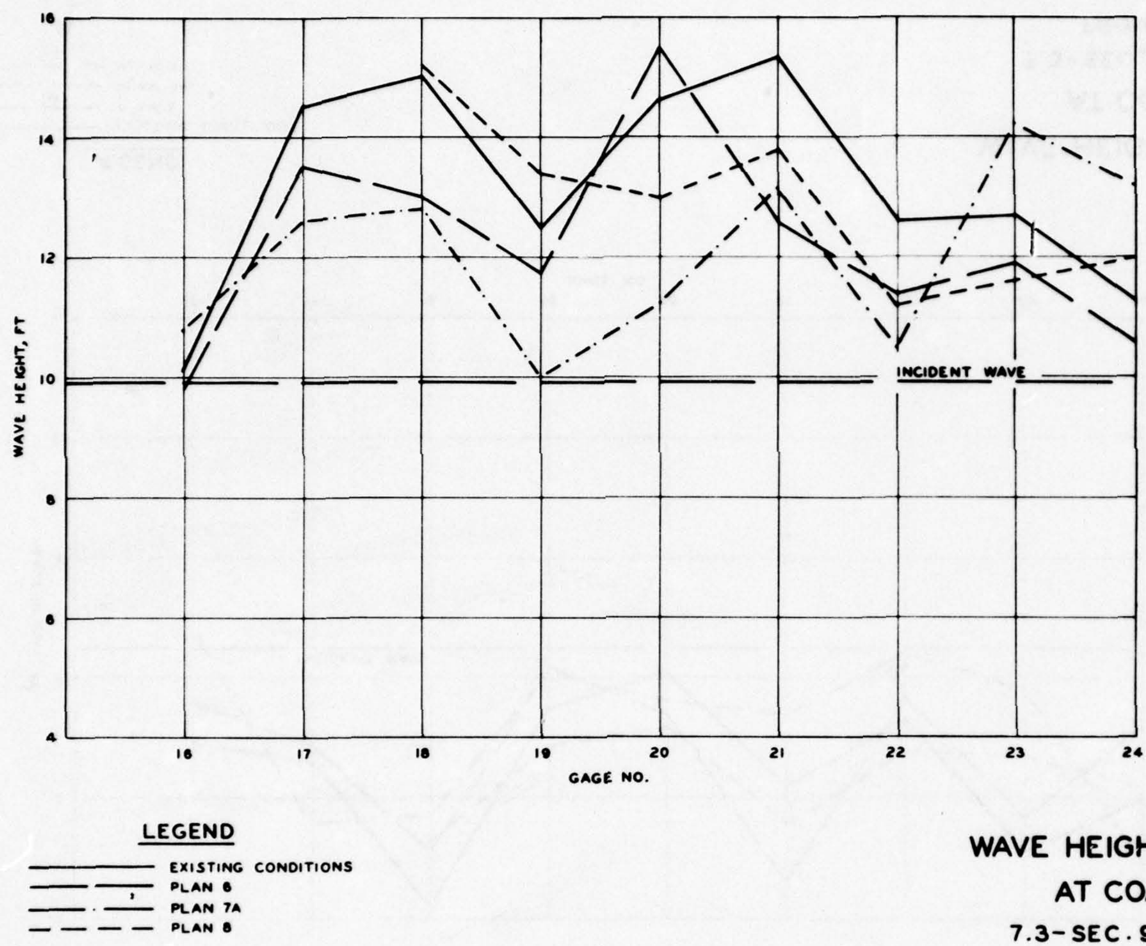
WAVE HEIGHTS OBTAINED AT COAL DOCK

10.4-SEC, 14.7-FT WAVES FROM N76° 20'E



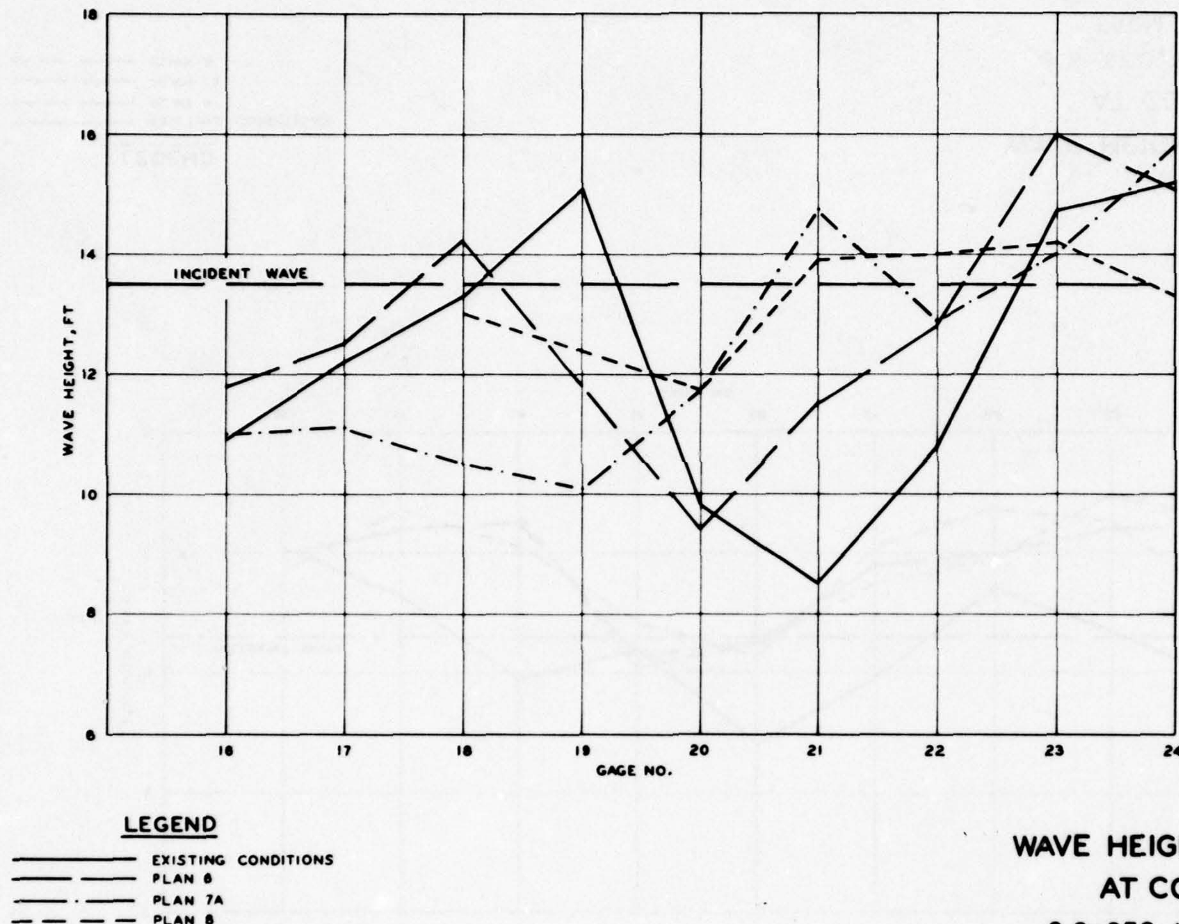
WAVE HEIGHTS OBTAINED AT COAL DOCK

7.3-SEC, 5.5-FT WAVES FROM S 68° 30′E



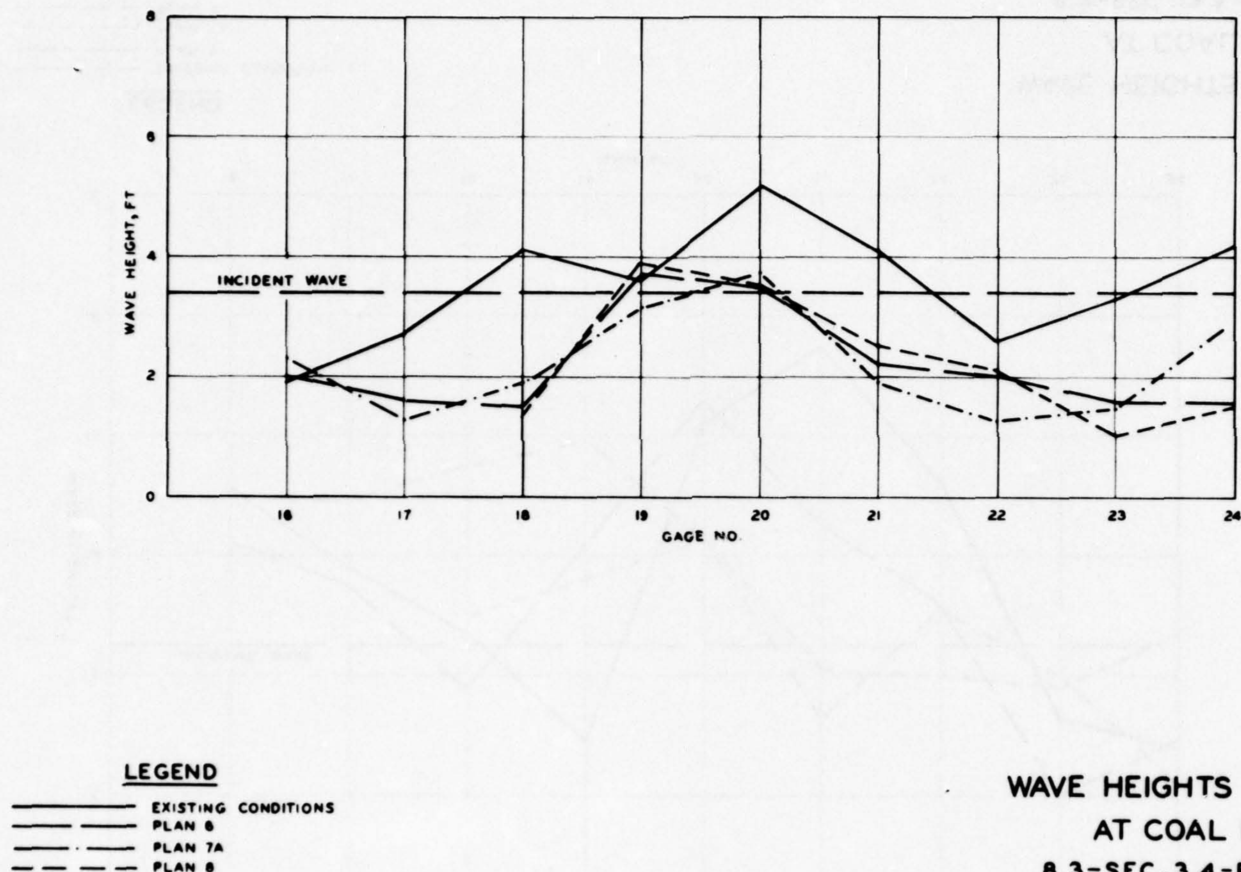
WAVE HEIGHTS OBTAINED AT COAL DOCK

7.3-SEC. 9.9-FT WAVES FROM S 68° 30'E

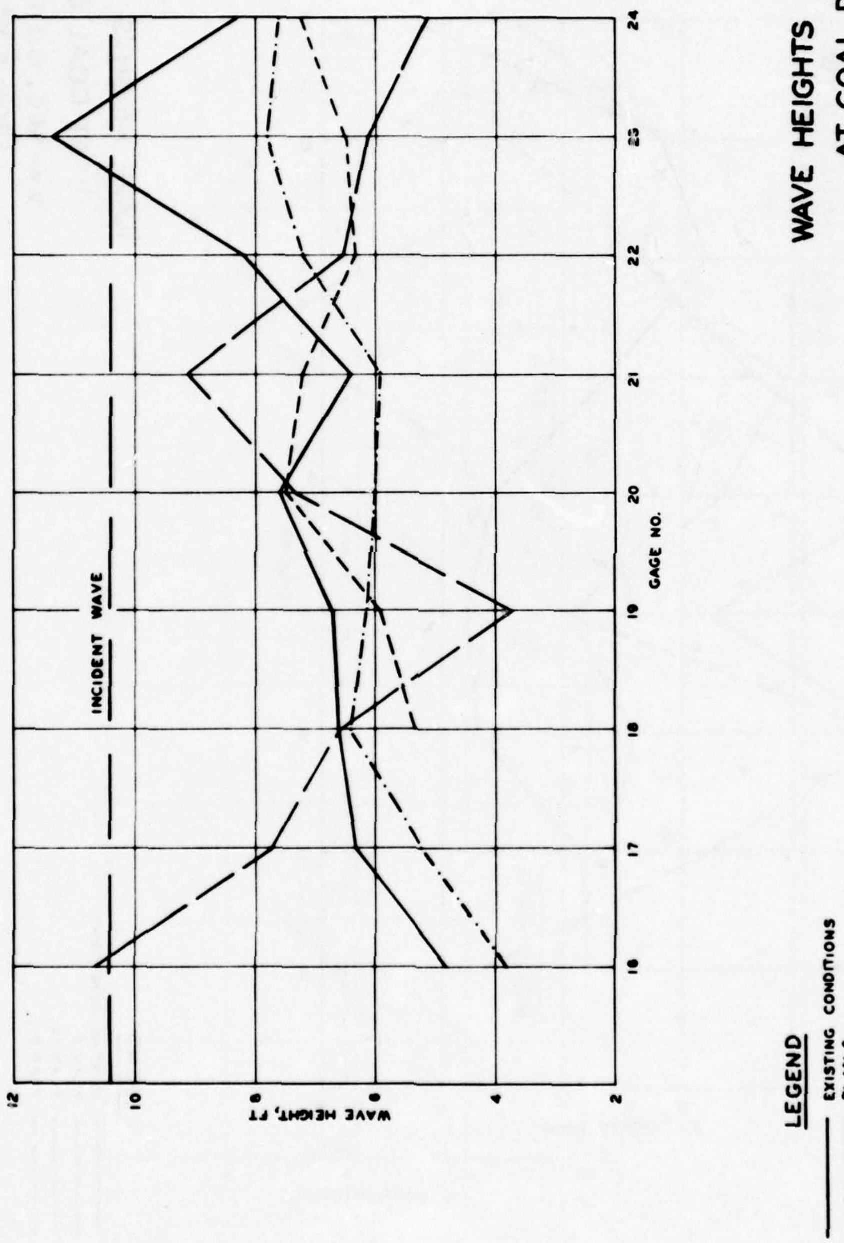


WAVE HEIGHTS OBTAINED
AT COAL DOCK

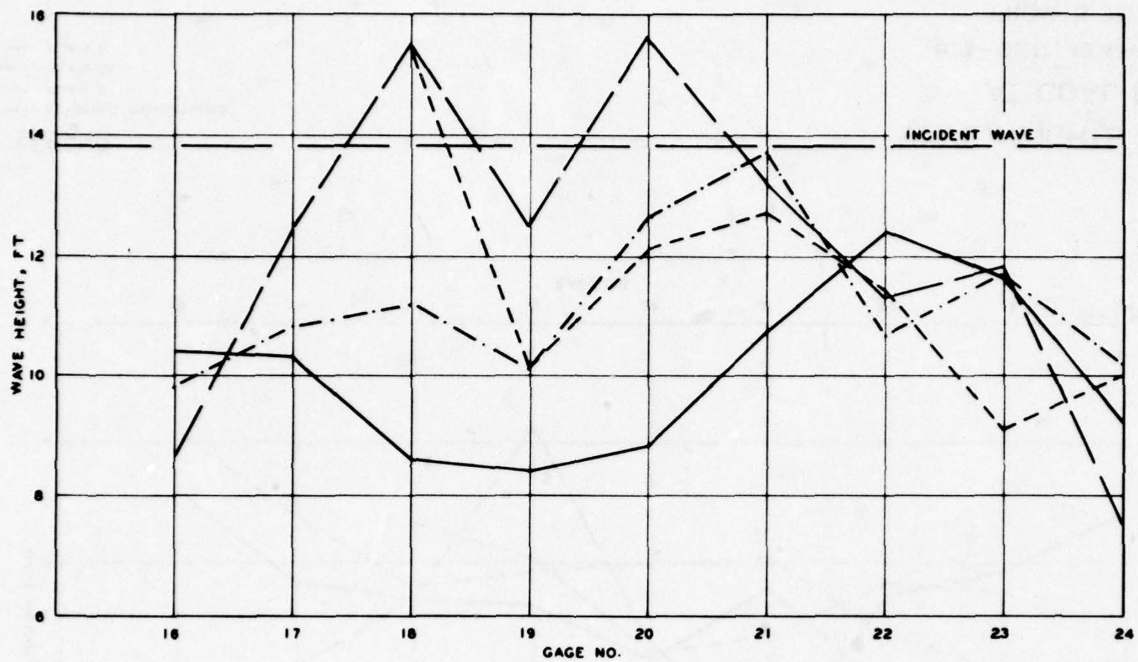
8.2-SEC, 13.5-FT WAVES
FROM S 68° 30′ E



WAVE HEIGHTS OBTAINED
AT COAL DOCK
8.3-SEC, 3.4-FT WAVES
FROM S 37° 10′ E



WAVE HEIGHTS OBTAINED
AT COAL DOCK
8.3-SEC, 10.4-FT WAVES
FROM S 37° 10'E

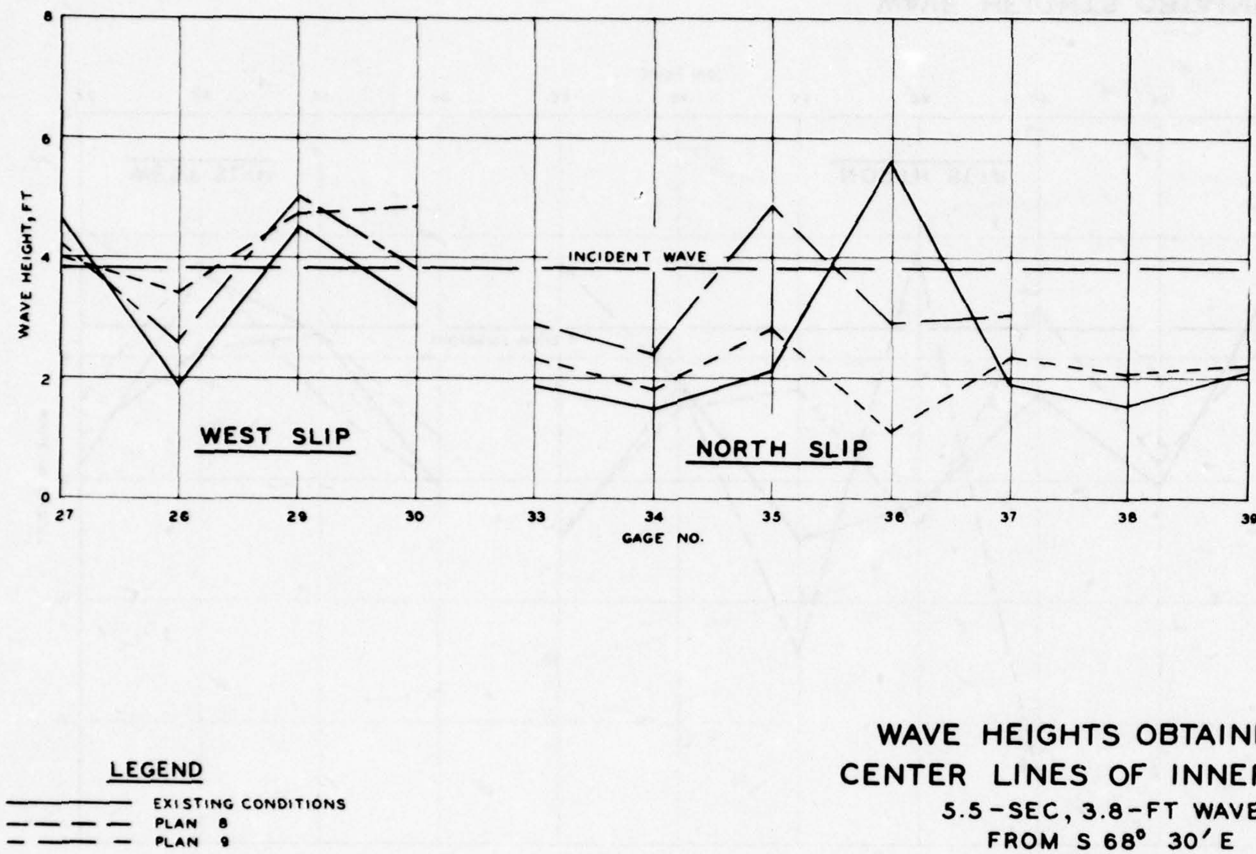


LEGEND

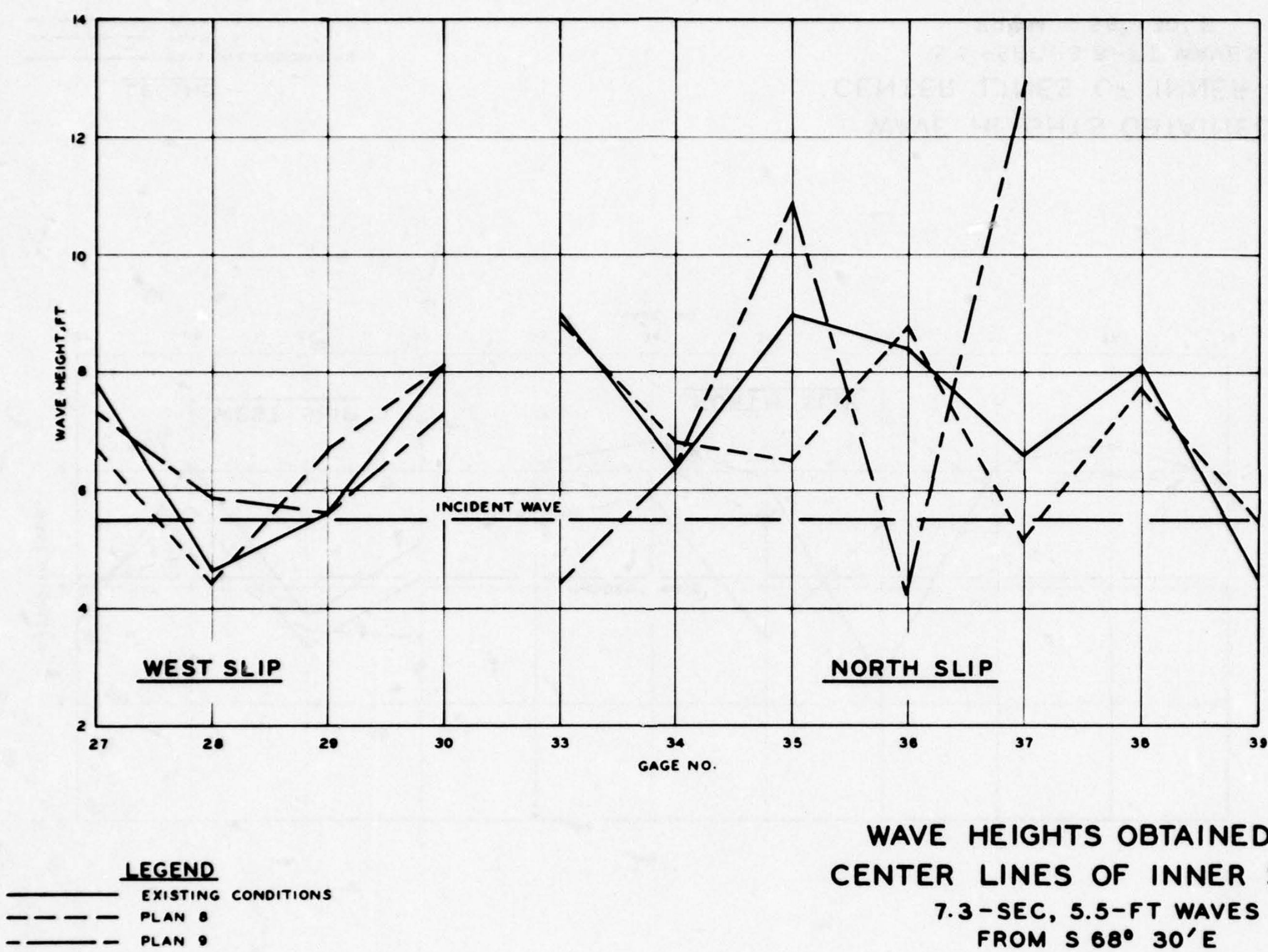
- EXISTING CONDITIONS
- PLAN 6
- PLAN 7A
- PLAN 8

WAVE HEIGHTS OBTAINED AT COAL DOCK

9.4-SEC, 13.8-FT WAVES FROM S 37° 10′E

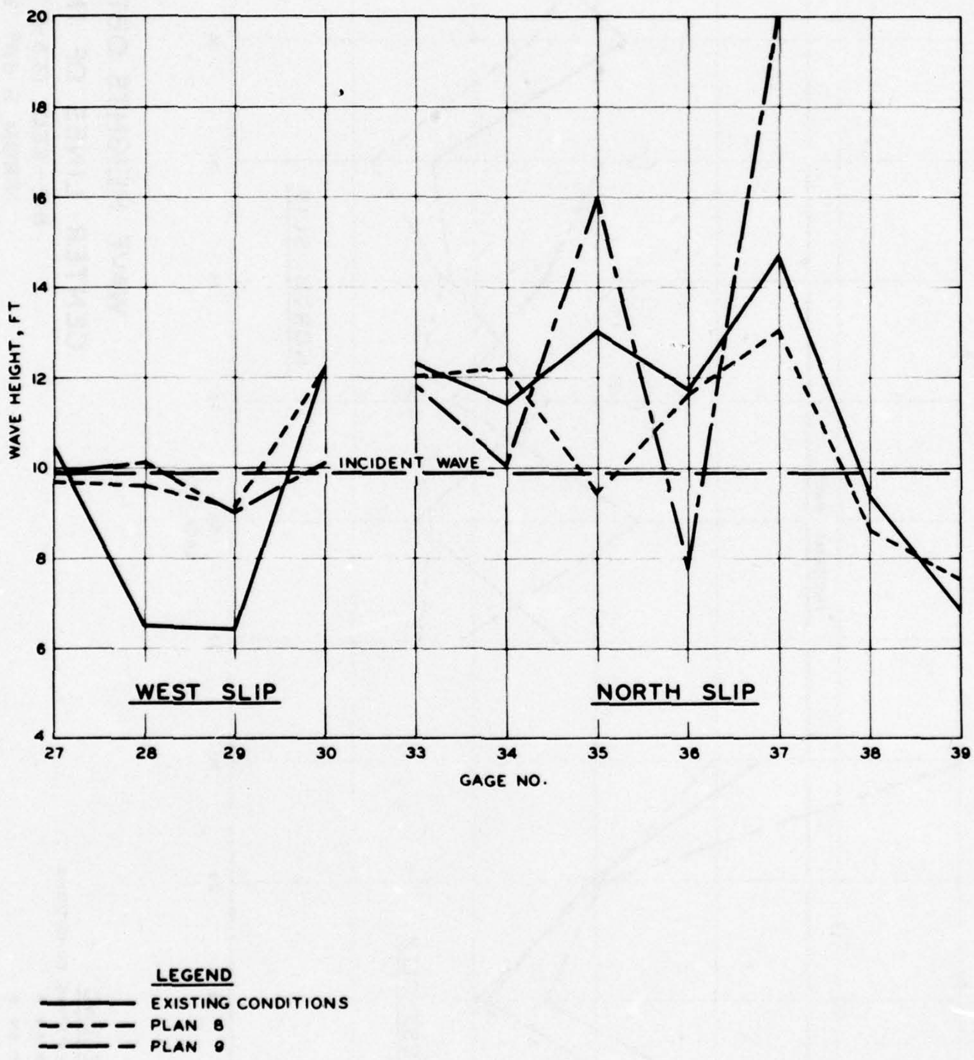


WAVE HEIGHTS OBTAINED AT
CENTER LINES OF INNER SLIPS
5.5-SEC, 3.8-FT WAVES
FROM S 68° 30′ E



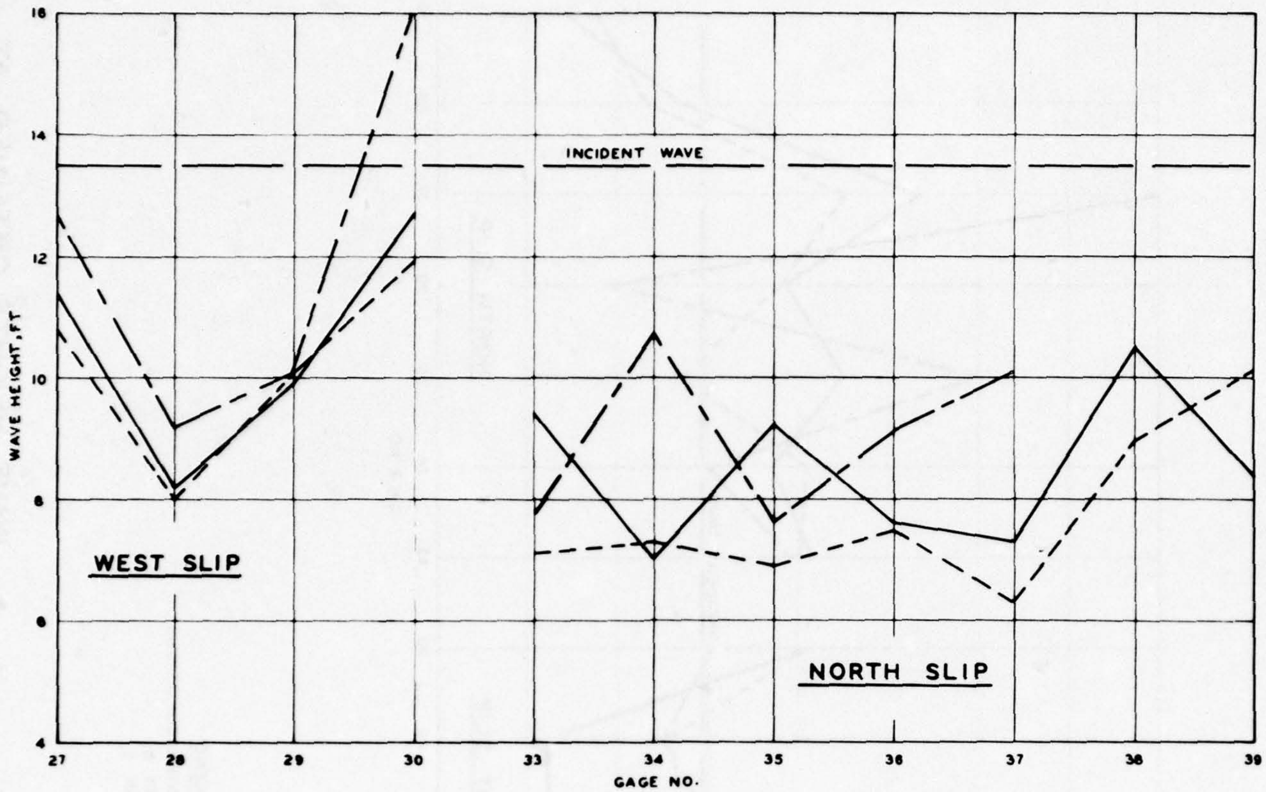
WAVE HEIGHTS OBTAINED AT CENTER LINES OF INNER SLIPS

7.3-SEC, 5.5-FT WAVES FROM S 68° 30′E



WAVE HEIGHTS OBTAINED AT CENTER LINES OF INNER SLIPS

7.3-SEC, 9.9-FT WAVES FROM S 68° 30′ E



LEGEND

- ——— EXISTING CONDITIONS
- – – – PLAN 8
- —— – PLAN 9

WAVE HEIGHTS OBTAINED AT CENTER LINES OF INNER SLIPS

8.2-SEC, 13.5-FT WAVES
FROM S 68° 30′E

APPENDIX A: WAVE REFRACTION ANALYSIS FOR PORT WASHINGTON HARBOR SITE

1. Prior to the hydraulic model investigation of Port Washington Harbor, a wave refraction analysis was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) to determine the shallow-water wave height and refracted wave direction at the model wave generator pit for representative wave periods from the critical directions of deepwater wave approach. This analysis was conducted using a linear wave refraction theory originally developed at Stanford University by Dobson[11]* in 1967 and modified by WES in 1971. All computations and plotting were done using the Honeywell 635 computer and Colcomp drum plotter at WES.

2. In this analysis, the effects of both reflection and diffraction are neglected. These assumptions are valid except in convergence areas where caustics occur and linear theory does not apply. Therefore, the major assumption in determining the wave height at any point on a wave orthogonal, within the limits of the linear theory, is that no energy is transmitted perpendicular to the orthogonal along the wave crest, in which case the height at any point is given by

$$H = H_o K_s K_r$$

where

H_o = wave height in deep water

K_s = shoaling coefficient

K_r = refraction coefficient

This assumption has been shown to be reasonable for mild slopes which induce only gradual bending of the orthogonals. For areas of extreme refraction, failure to consider the flow of energy along the wave crests can lead to significant errors in the computed wave height.

---

* Raised numbers refer to similarly numbered items in the References at the end of main text.

Since previous research at WES by Whalin[12,13] has shown that wave energy will tend to flow along the wave crests in areas of energy concentration, a maximum refraction coefficient of 1.4 and a minimum refraction coefficient of 0.15 were selected as being reasonable values.

3. Refraction diagrams for Port Washington Harbor were produced from a rectangular depth grid (15 miles by 7 miles) which paralleled the shoreline in the vicinity of the harbor and extended lakeward to where depths were sufficient (i.e. equal to one half the deepwater wave length) for wave periods from the various directions. Limits of the depth grid used are shown in Plate A1. The grid spacing was 293 ft and depths were taken from the latest lake survey charts. Storm conditions were represented by superimposing a water level of +3.9 ft on the depth grid.

4. Wave orthogonals were produced for 6-, 7-, 8-, and 9-sec waves from the northeast and east northeast; 6-, 7-, and 8-sec waves from the east, east southeast, and southeast; and 6-, 7-, 8-, and 9-sec waves from the south southeast. The plots obtained are shown in Plates A2-A22.

5. Refraction coefficients and shallow-water orthogonal directions obtained for the various wave periods from the six deepwater wave directions are presented in Table A1. These values represent an average of the orthogonals in the immediate vicinity of the harbor site (approximately the location of the wave generator in the model). Shoaling coefficients of 0.96, 0.93, 0.92, and 0.91 for 6-, 7-, 8-, and 9-sec, respectively, were computed for a 63.9-ft water depth corresponding to the simulated depth at the model wave generator. The wave-height adjustment factor is obtained by multiplying K_r times K_s and can be applied to any deepwater wave height to obtain the corresponding shallow-water value.

6. Based on the refracted directions obtained at the transition from the model wave generator pit (-60 ft) to the model contours, five wave generator positions were selected representing the various deepwater directions as shown:

Deepwater Direction(s)	Selected Shallow-Water Test Direction
NE and ENE	N76°20'E
East	S85°50'E
ESE	S68°30'E
SE	S50°45'E
SSE	S37°10'E

Table A1

Summary of Refraction and Shoaling Analysis for Port Washington Small-Boat Harbor

Deepwater Direction	Wave Period sec	Shallow-Water Azimuth deg	Refraction Coefficient	Shoaling Coefficient	Wave-Height Adjustment Factor
NE (45°)	6	67.88	0.82	0.96	0.79
	7	70.21	0.67	0.93	0.62
	8	72.68	0.58	0.92	0.53
	9	76.34	0.55	0.91	0.50
ENE (67.5°)	6	74.51	0.95	0.96	0.91
	7	78.55	0.90	0.93	0.84
	8	82.58	0.91	0.92	0.84
	9	84.52	0.95	0.91	0.86
E (90°)	6	92.64	0.99	0.96	0.95
	7	94.53	0.97	0.93	0.90
	8	95.87	0.93	0.92	0.86
ESE (112.5°)	6	112.12	1.00	0.96	0.96
	7	111.51	0.99	0.93	0.92
	8	110.74	0.99	0.92	0.91
SE (135°)	6	131.82	1.00	0.96	0.96
	7	129.28	0.99	0.93	0.92
	8	126.64	1.00	0.92	0.92
SSE (157.5°)	6	148.27	0.88	0.96	0.84
	7	144.89	0.90	0.93	0.84
	8	140.86	0.93	0.92	0.86
	9	137.44	0.97	0.91	0.88

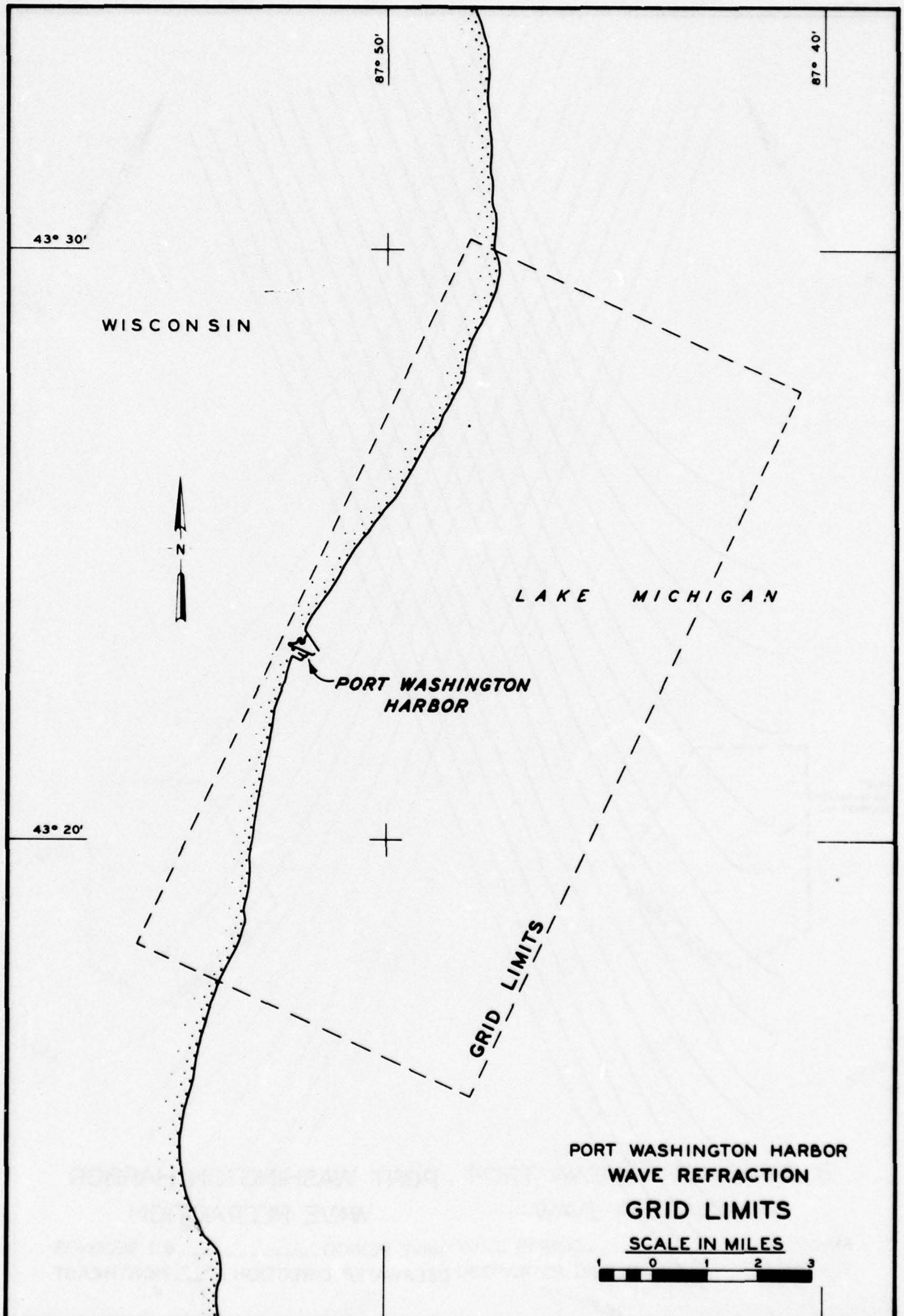

87° 50'
87° 40'
43° 30'
43° 20'
WISCONSIN
N
LAKE MICHIGAN
PORT WASHINGTON HARBOR
GRID LIMITS
PORT WASHINGTON HARBOR
WAVE REFRACTION
GRID LIMITS
SCALE IN MILES
1 0 1 2 3

PLATE A1

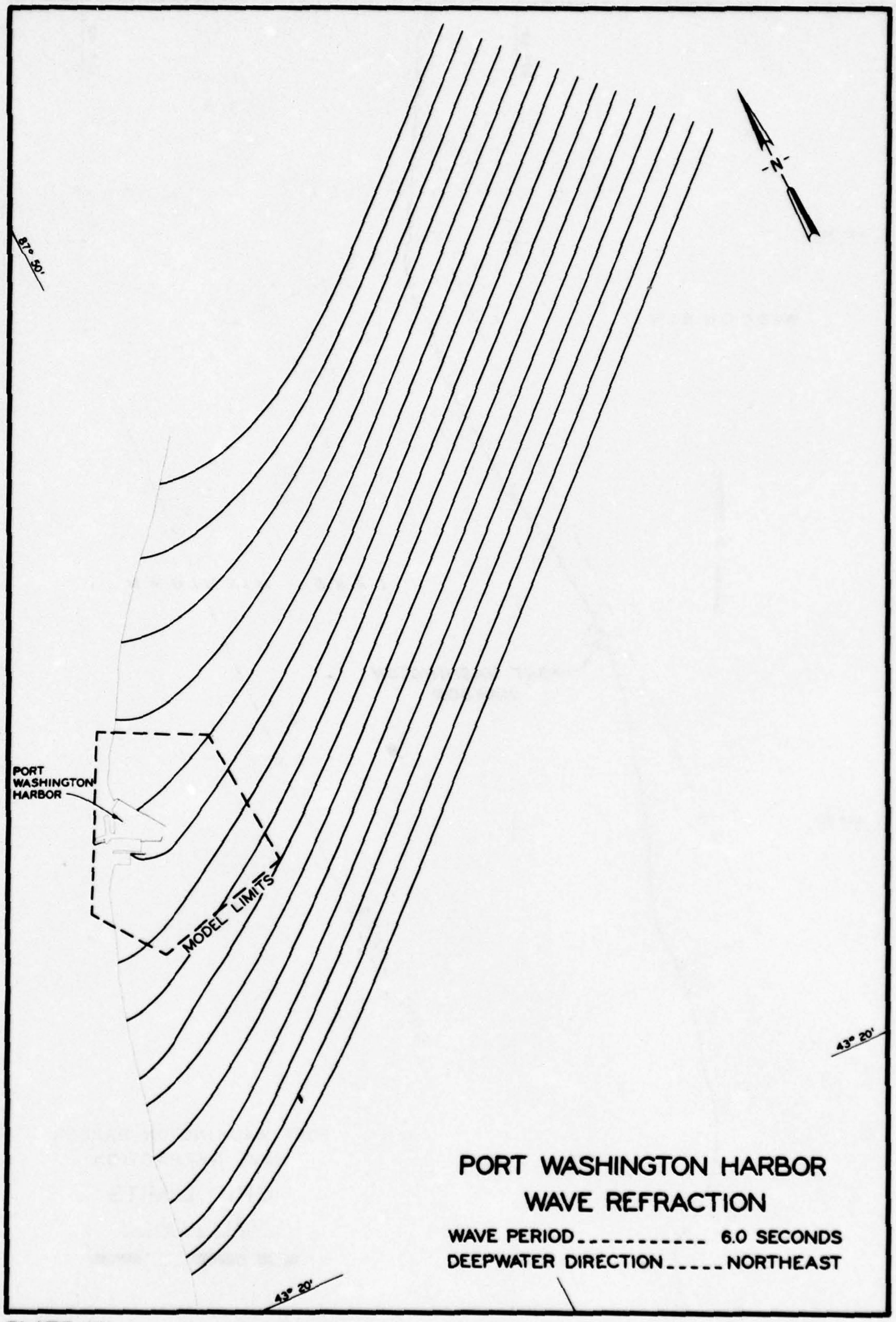

87° 50'
N
PORT WASHINGTON HARBOR
MODEL LIMITS
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD .... 6.0 SECONDS
DEEPWATER DIRECTION ..... NORTHEAST

PLATE A2

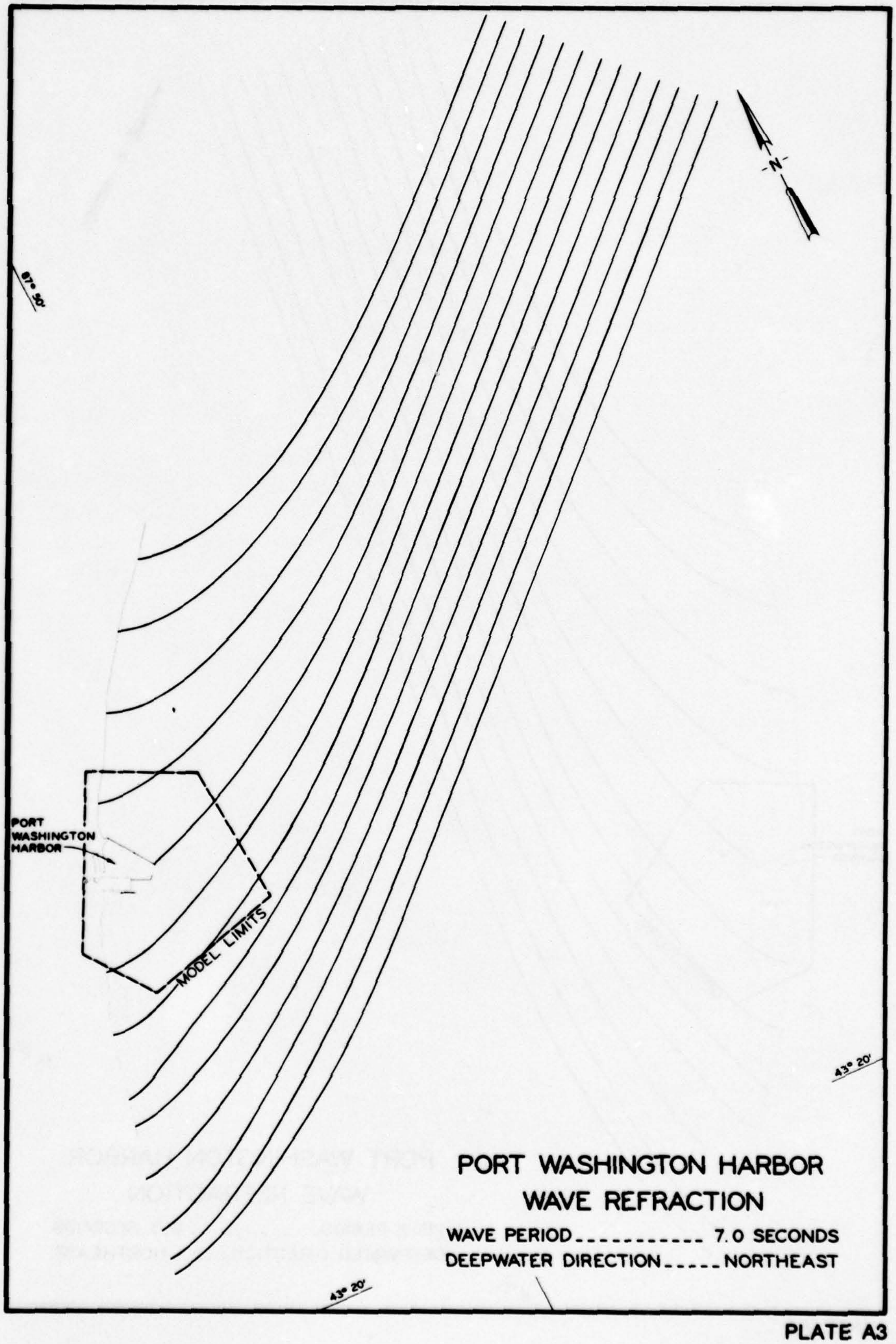
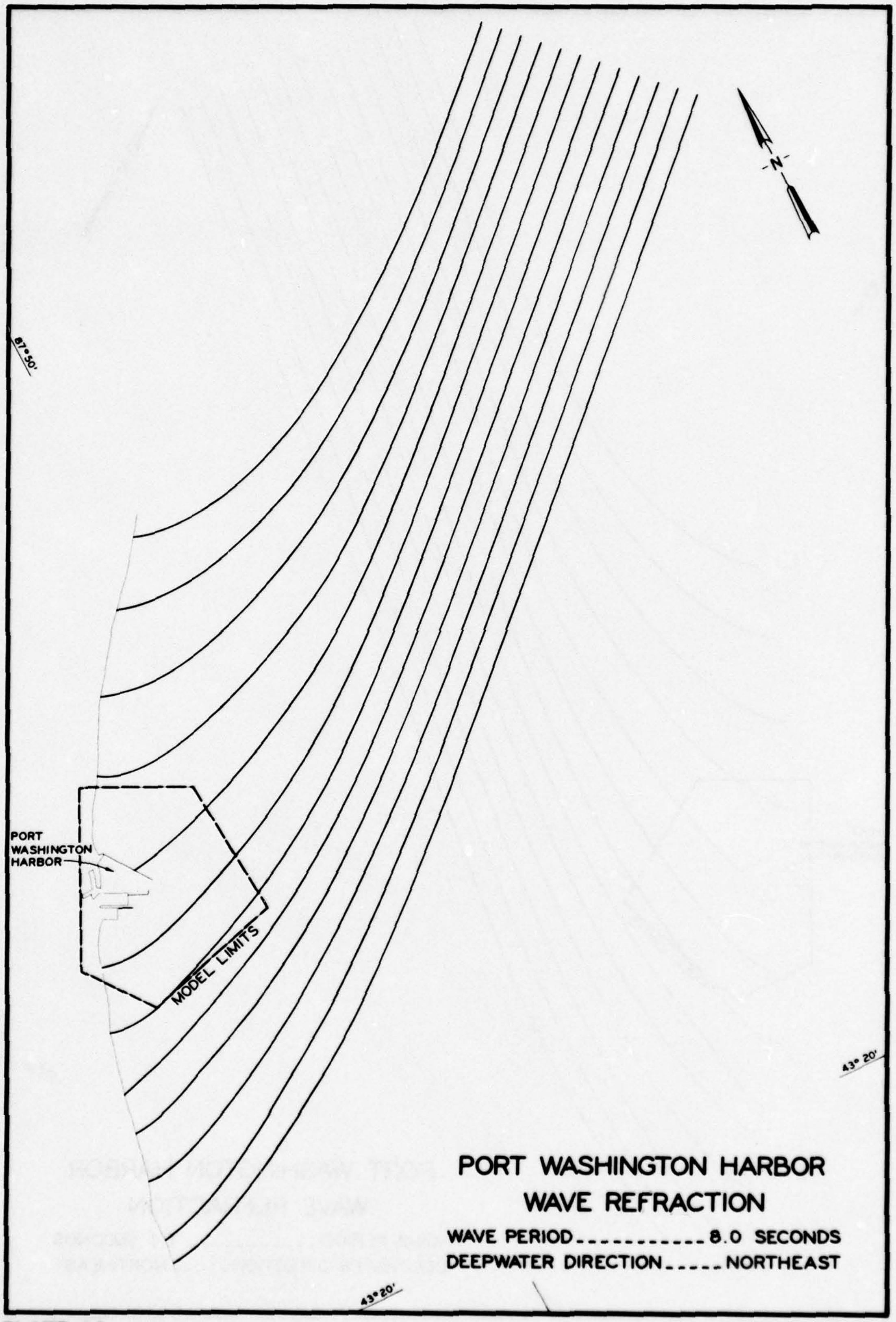
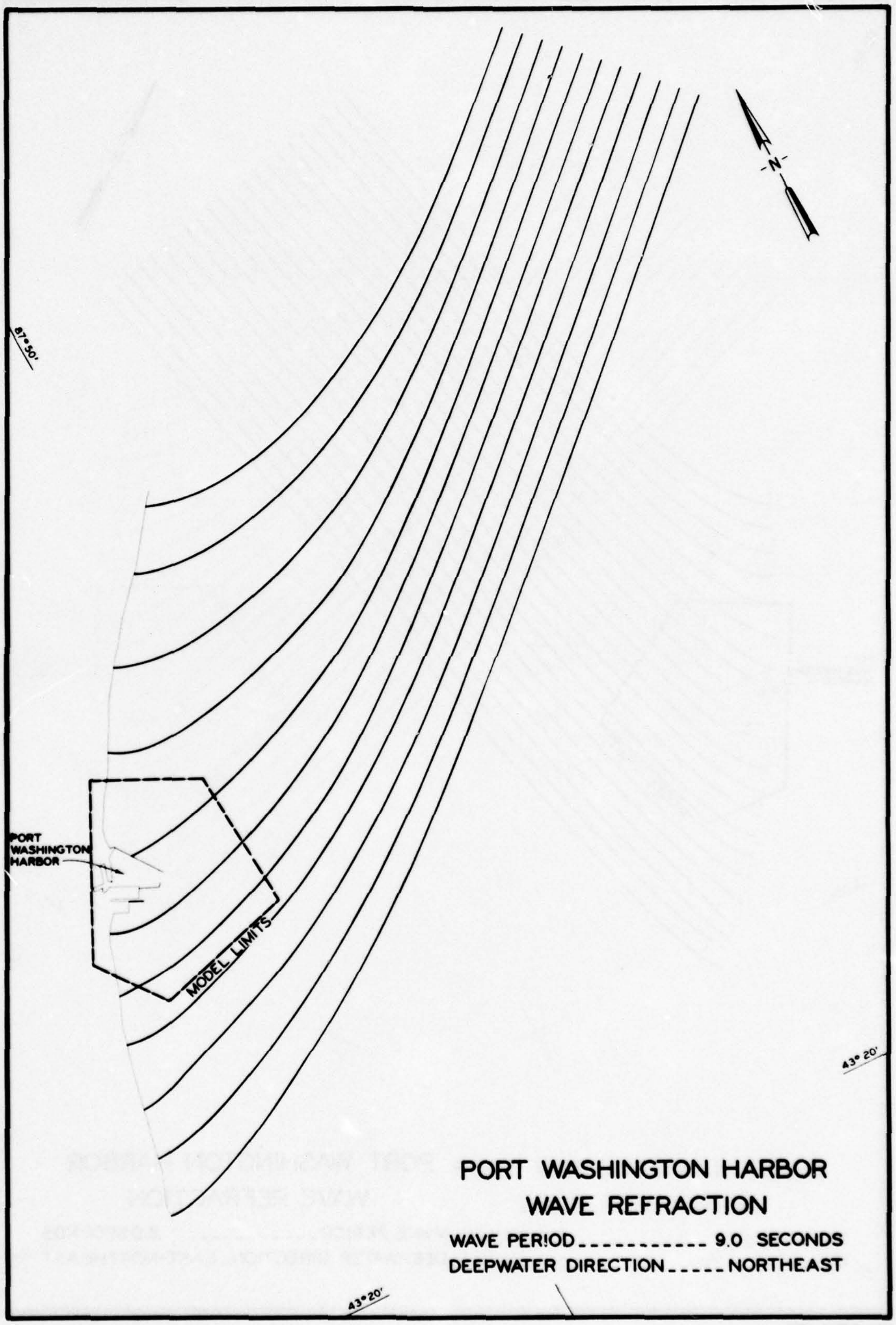

87° 50'
PORT
WASHINGTON
HARBOR
MODEL LIMITS
N
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD .... 7.0 SECONDS
DEEPWATER DIRECTION ..... NORTHEAST

PLATE A3



PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION ..... NORTHEAST

PLATE A4



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 9.0 SECONDS
DEEPWATER DIRECTION ..... NORTHEAST

PLATE A5

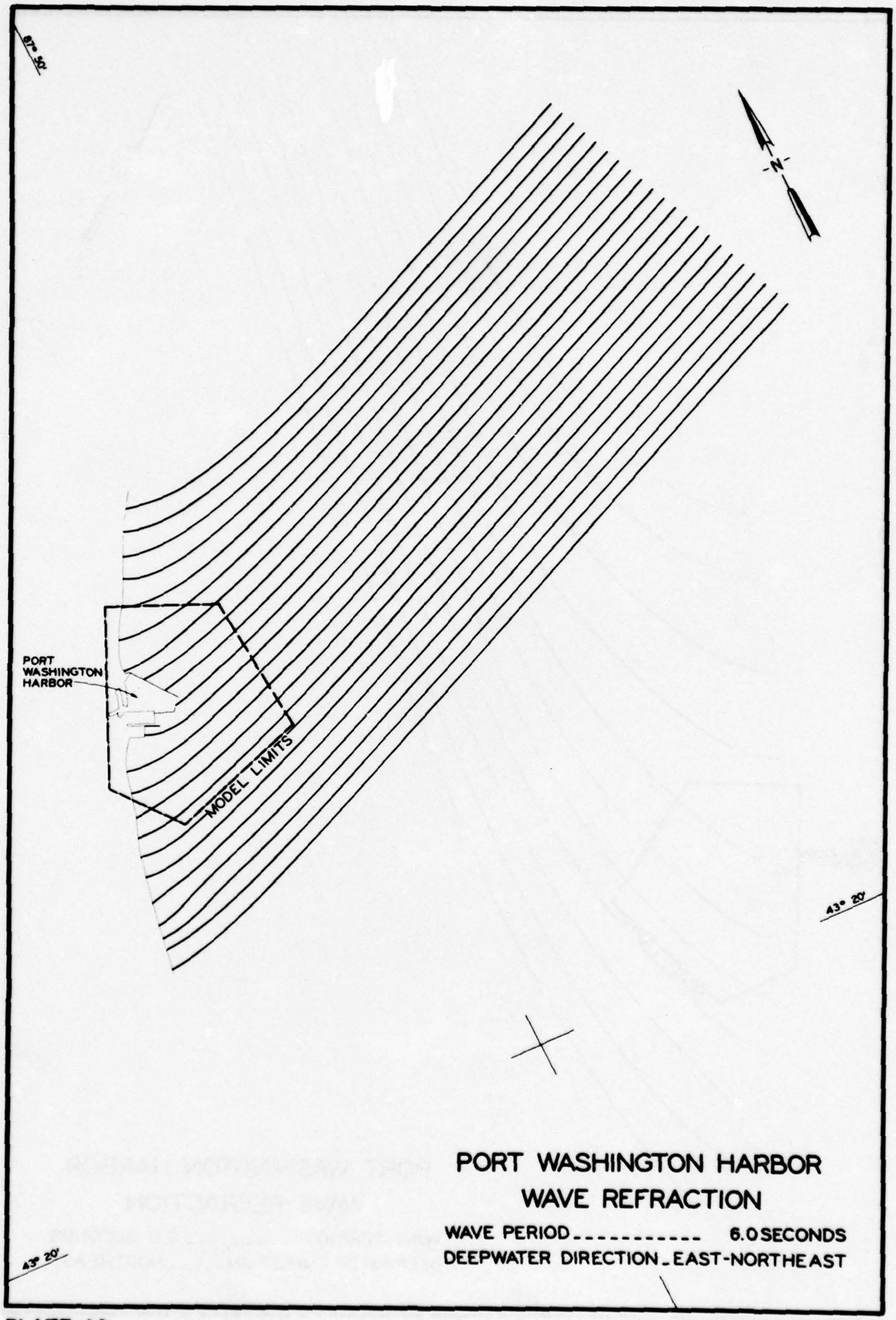
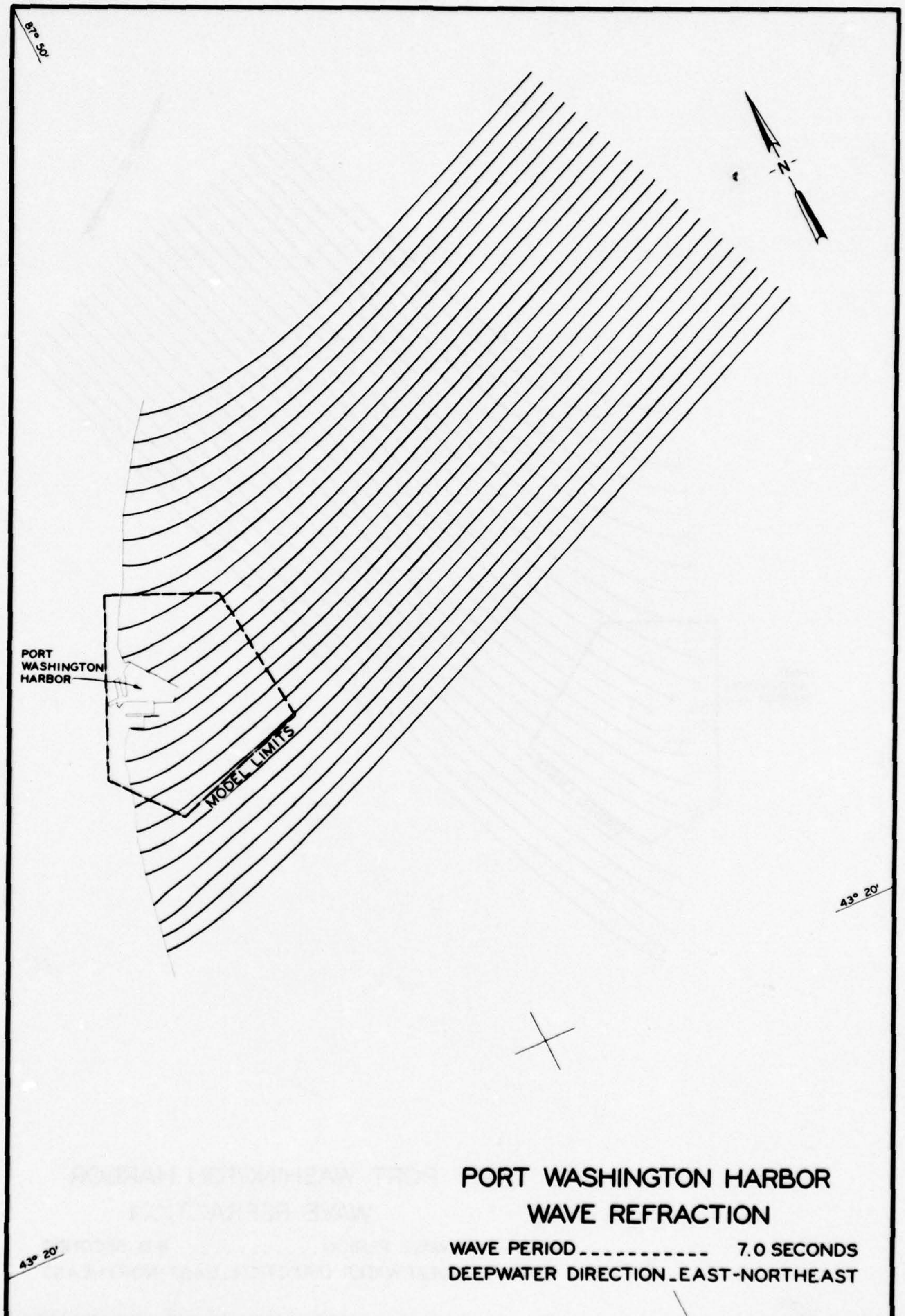

87° 50'
N
PORT WASHINGTON HARBOR
MODEL LIMITS
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD ----------- 6.0 SECONDS
DEEPWATER DIRECTION - EAST-NORTHEAST

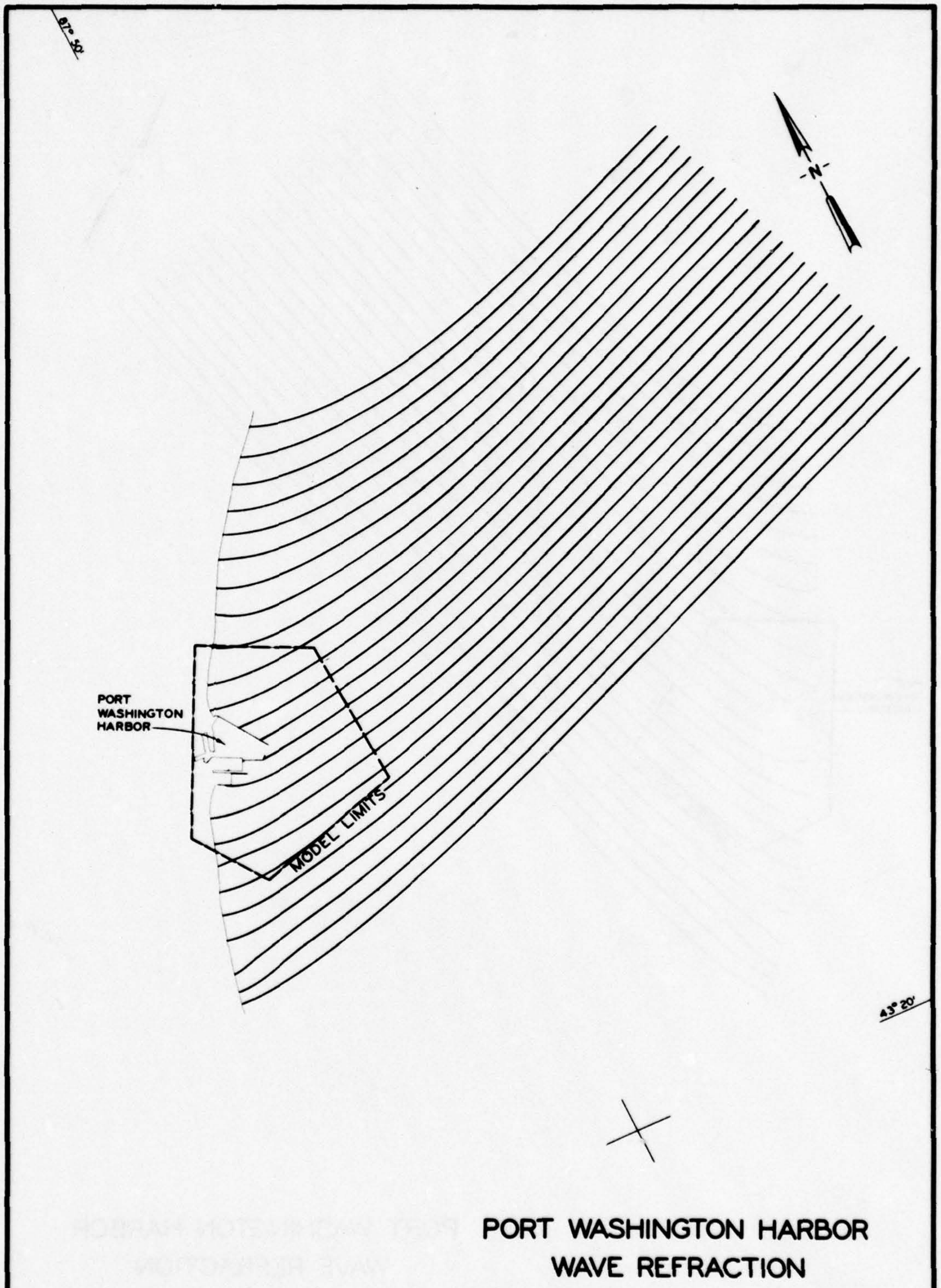
PLATE A6



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD.......... 7.0 SECONDS
DEEPWATER DIRECTION_EAST-NORTHEAST

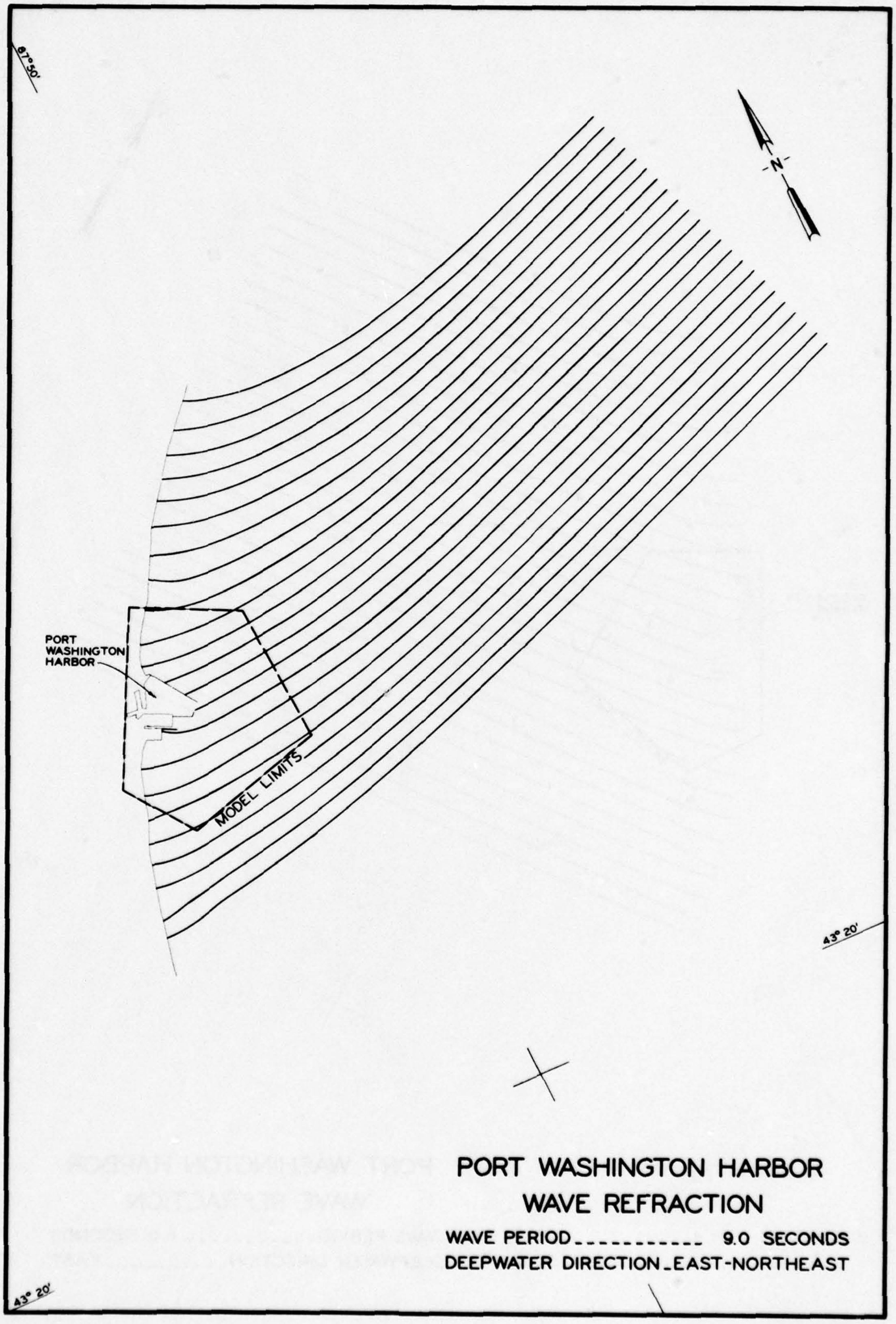
PLATE A7



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION _ EAST-NORTHEAST

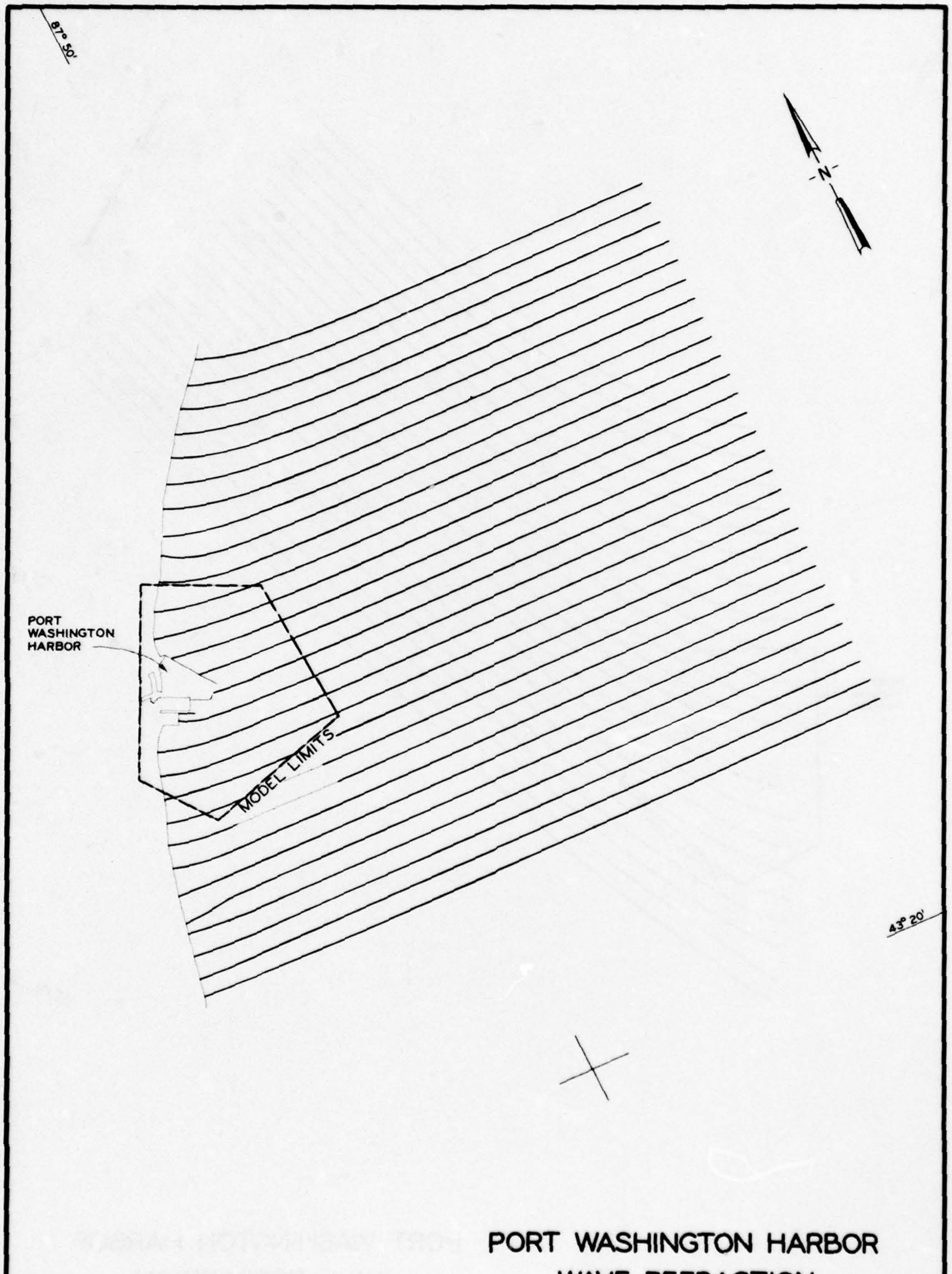
PLATE A8



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD ____________ 9.0 SECONDS
DEEPWATER DIRECTION _ EAST-NORTHEAST

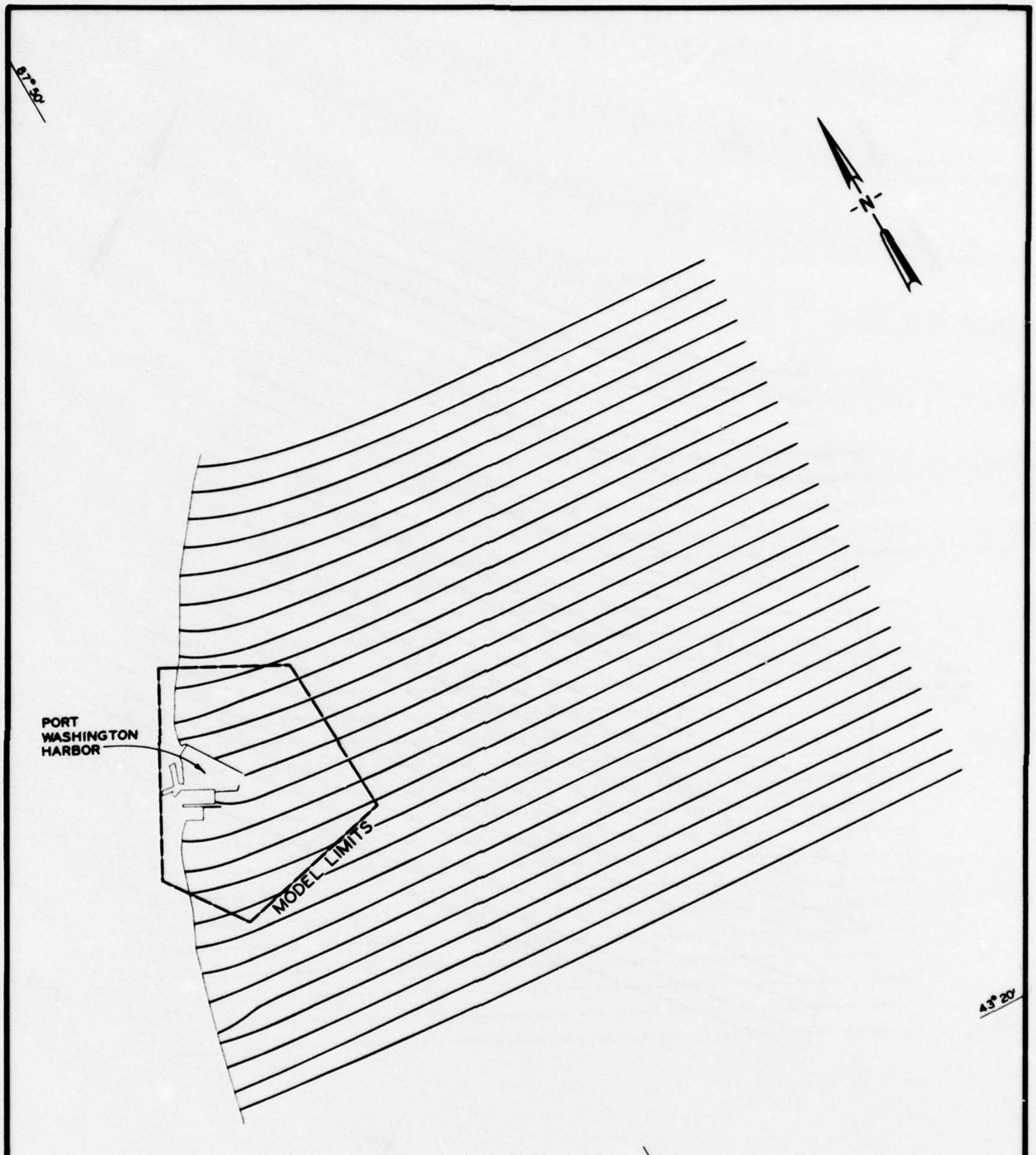
PLATE A9



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 6.0 SECONDS
DEEPWATER DIRECTION .... EAST

PLATE A10



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 7.0 SECONDS
DEEPWATER DIRECTION .... EAST

PLATE A11

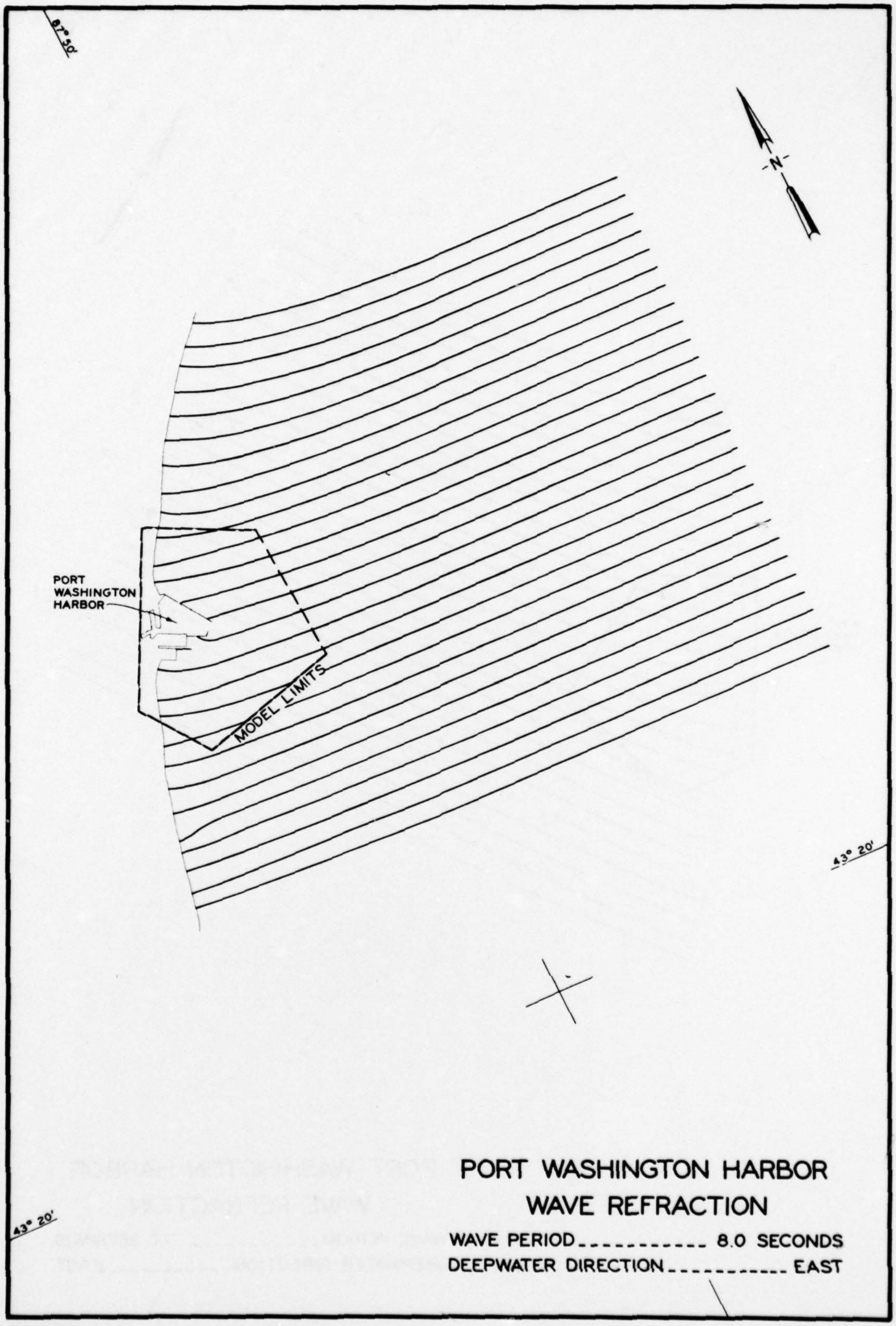
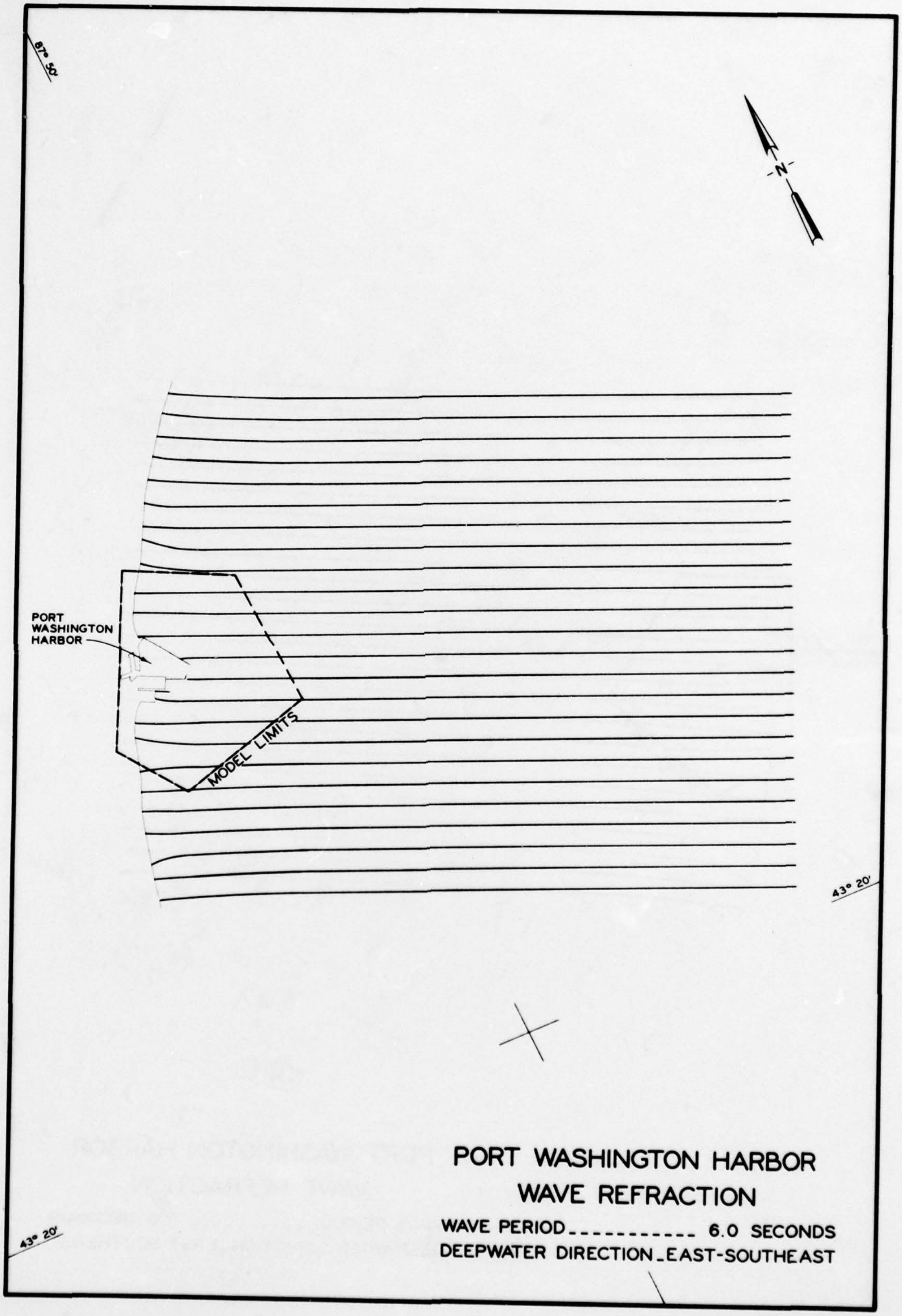

87° 50'
N
PORT WASHINGTON HARBOR
MODEL LIMITS
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION .... EAST

PLATE A12



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD ----------- 6.0 SECONDS
DEEPWATER DIRECTION - EAST-SOUTHEAST

PLATE A13

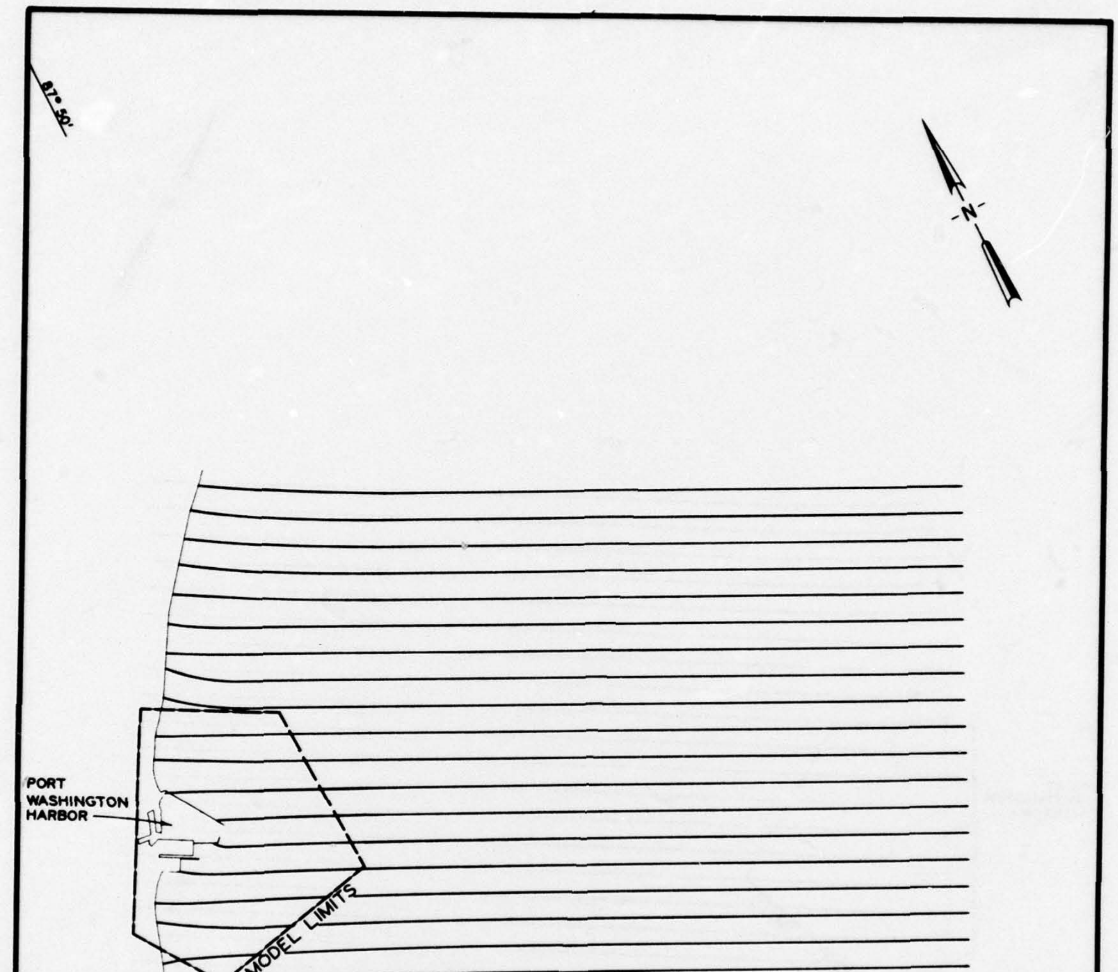
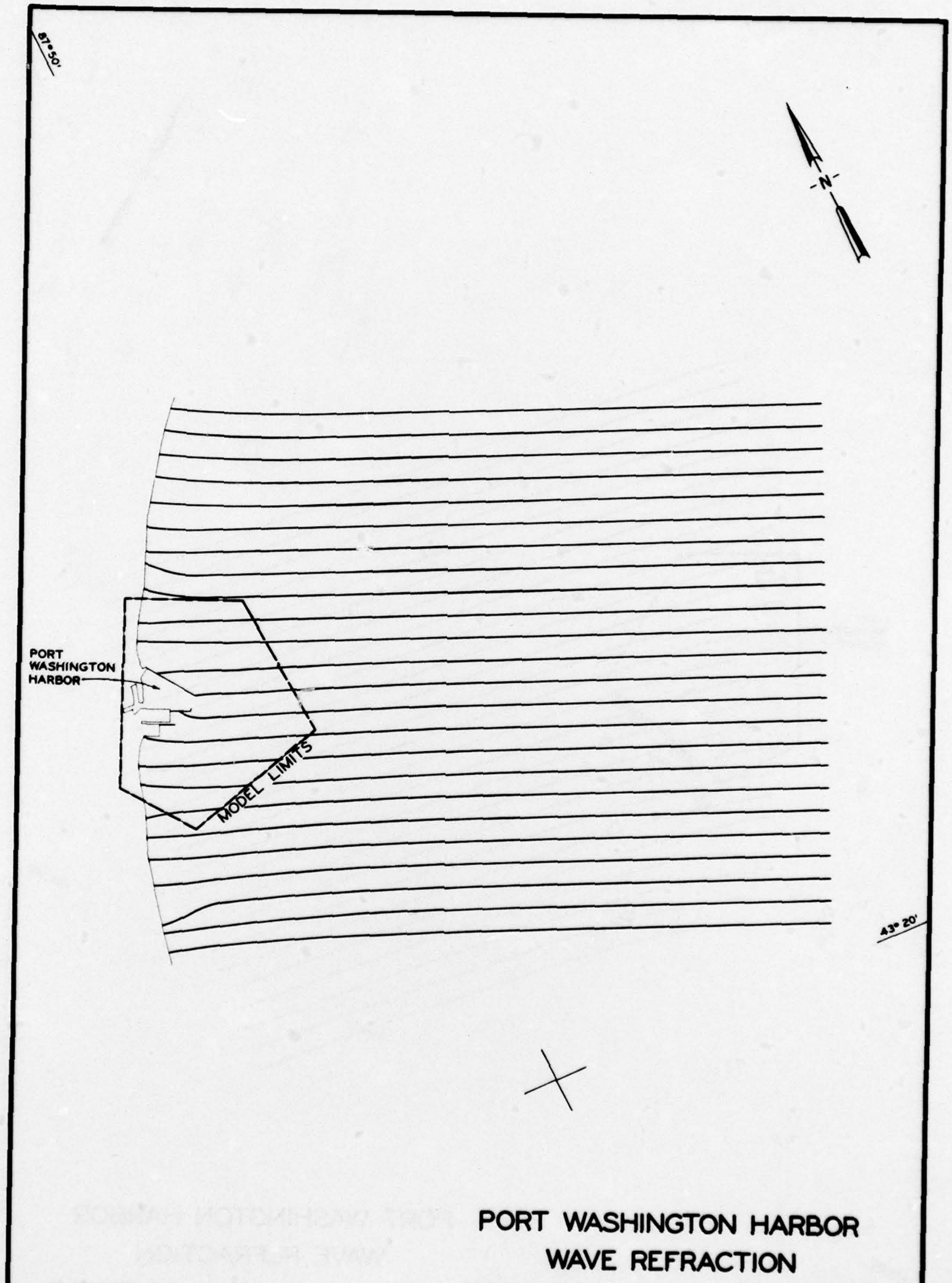
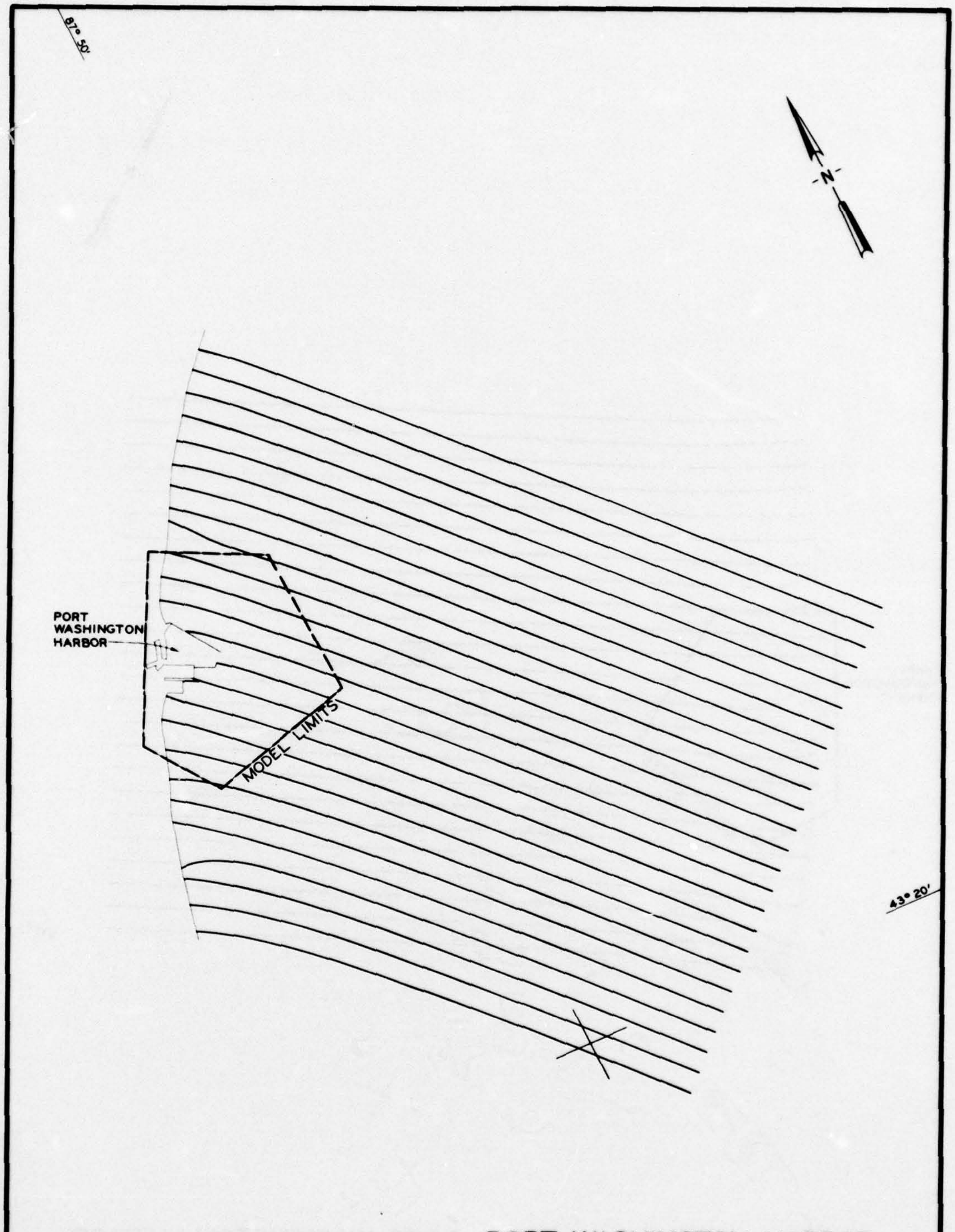

87° 50'
N
PORT
WASHINGTON
HARBOR
MODEL LIMITS
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD........... 7.0 SECONDS
DEEPWATER DIRECTION_EAST-SOUTHEAST

PLATE A14



PORT WASHINGTON HARBOR
WAVE REFRACTION

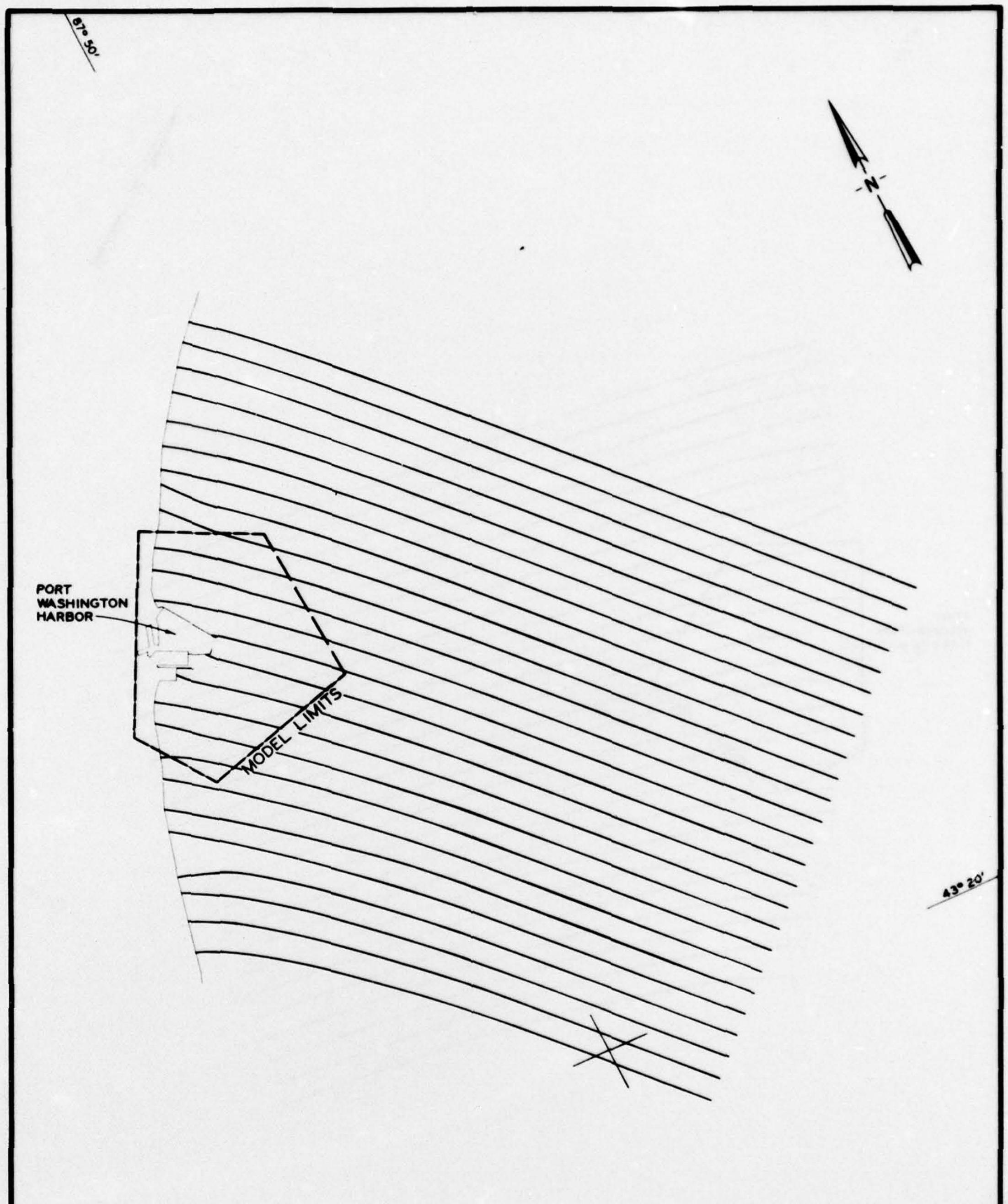
WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION . EAST-SOUTHEAST



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD............ 6.0 SECONDS
DEEPWATER DIRECTION..... SOUTHEAST

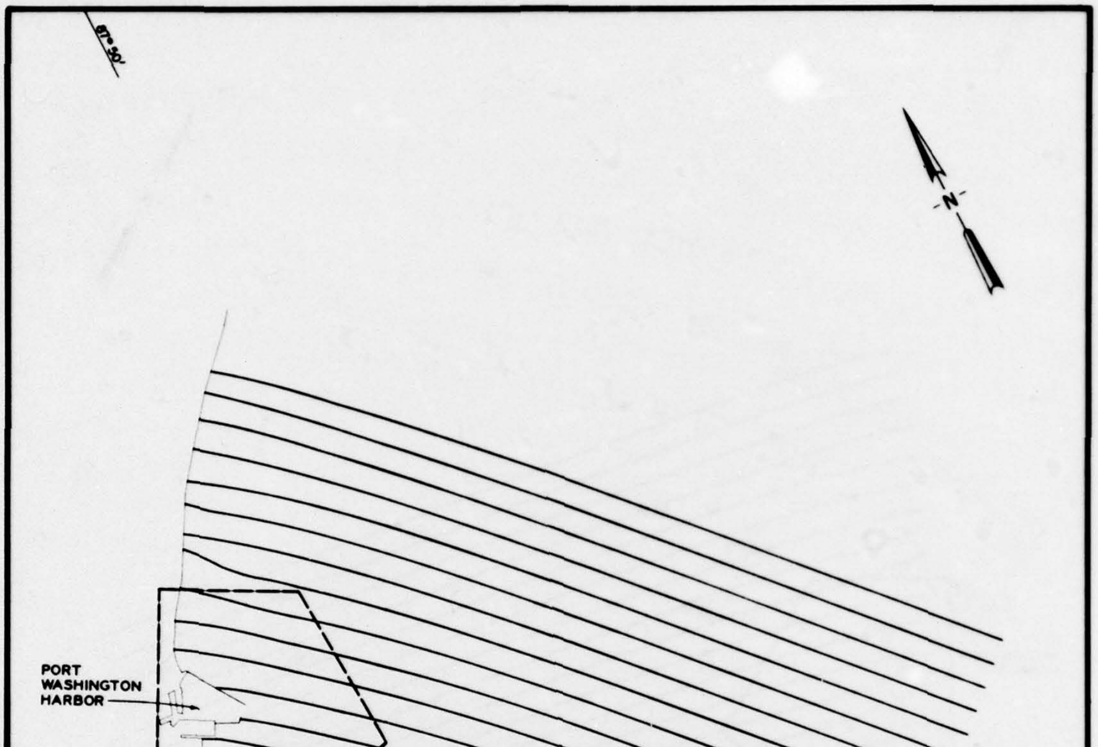
PLATE A16



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD ------------ 7.0 SECONDS
DEEPWATER DIRECTION ----- SOUTHEAST

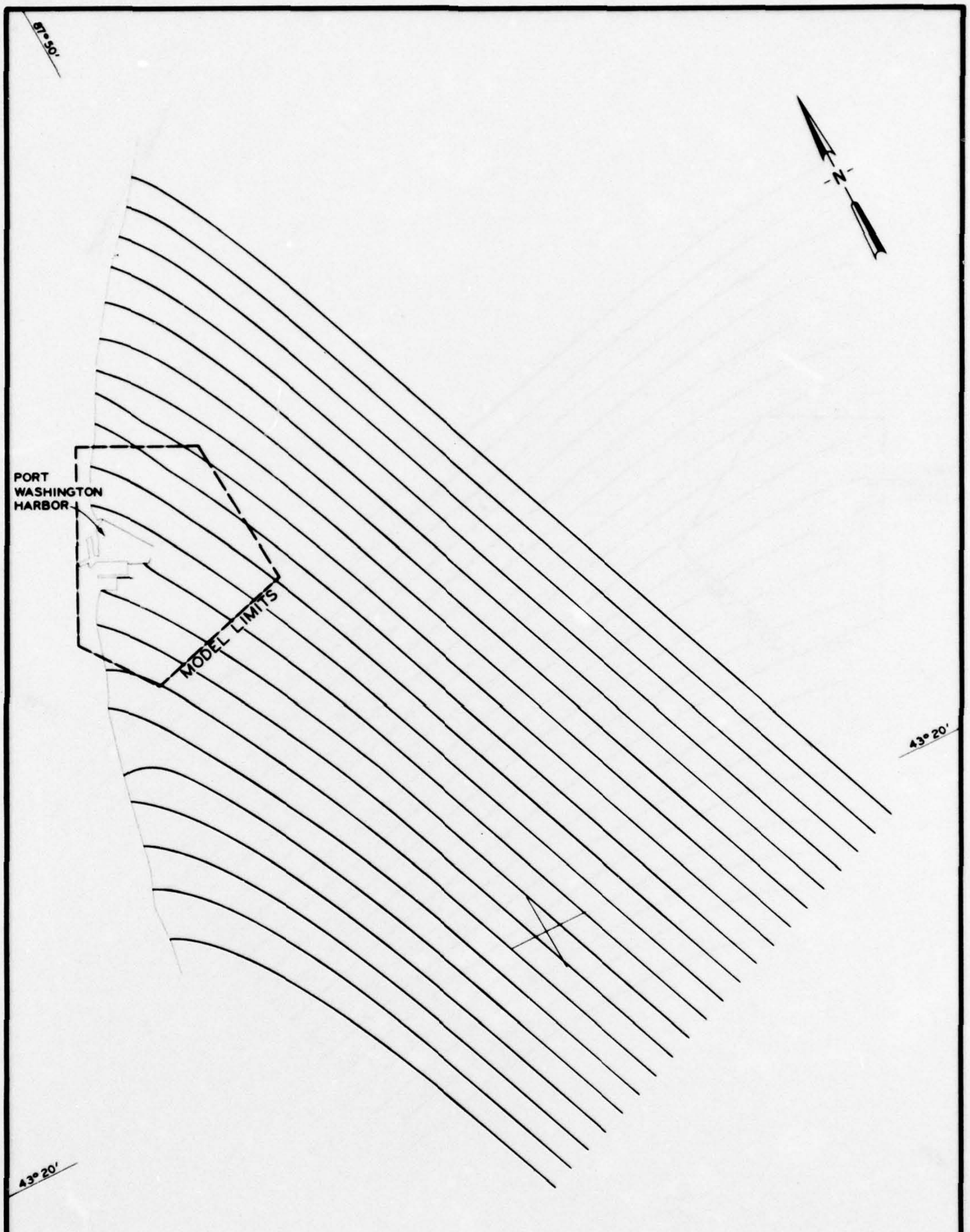
PLATE A17



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION ..... SOUTHEAST

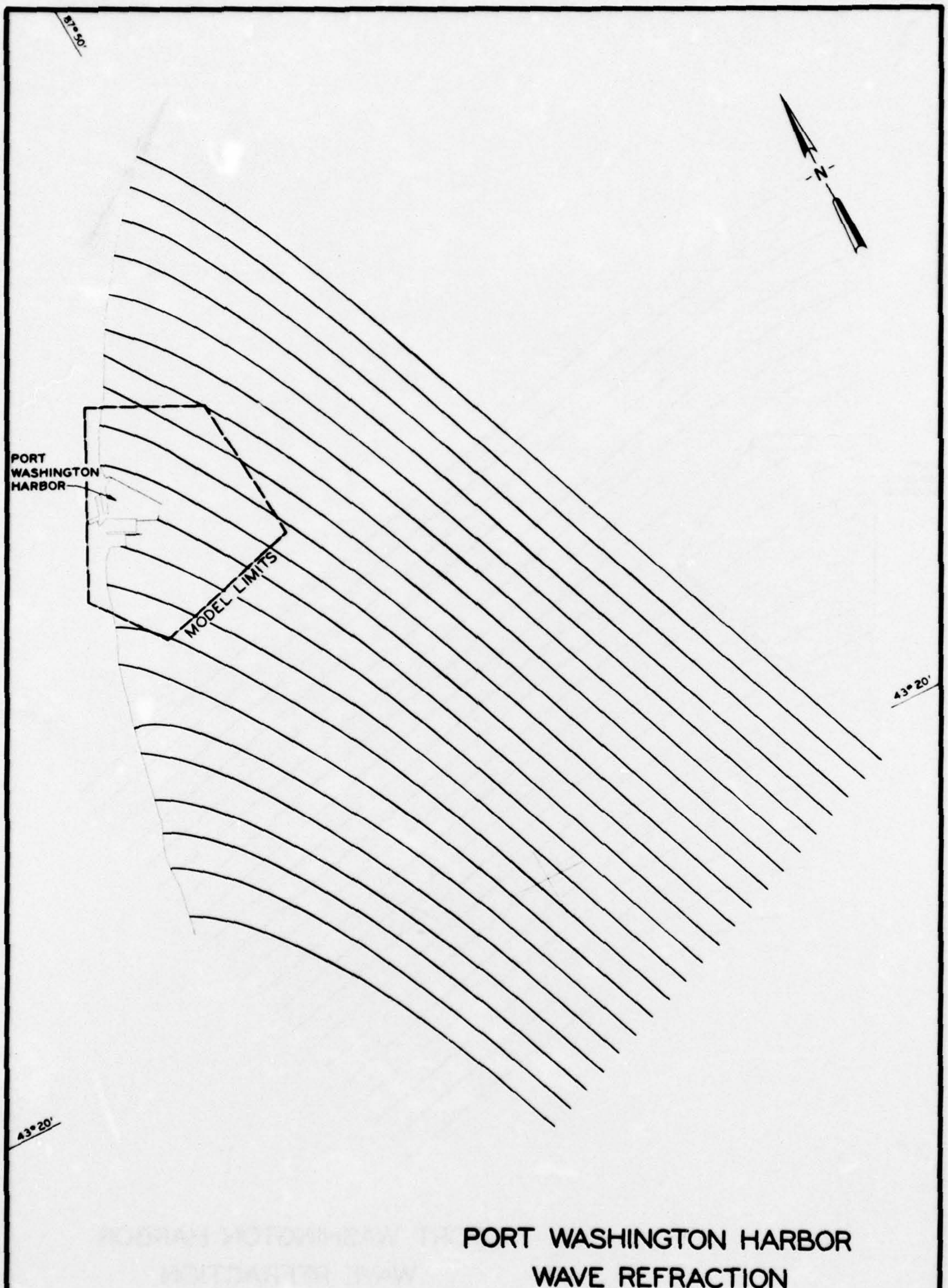
PLATE A18



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 6.0 SECONDS
DEEPWATER DIRECTION - SOUTH-SOUTHEAST

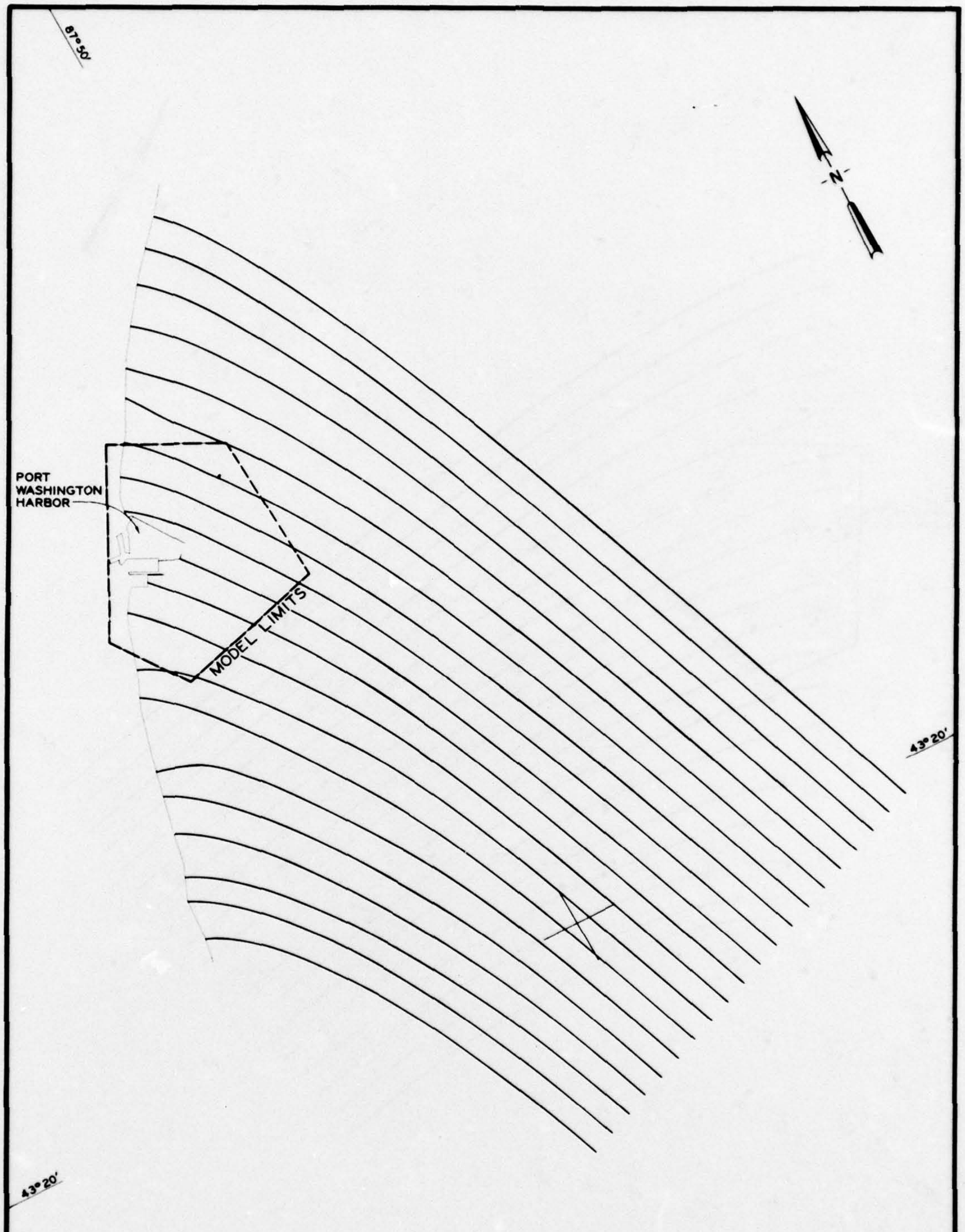
PLATE A19



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 7.0 SECONDS
DEEPWATER DIRECTION_SOUTH-SOUTHEAST

PLATE A20



PORT WASHINGTON HARBOR
WAVE REFRACTION

WAVE PERIOD .... 8.0 SECONDS
DEEPWATER DIRECTION_SOUTH-SOUTHEAST

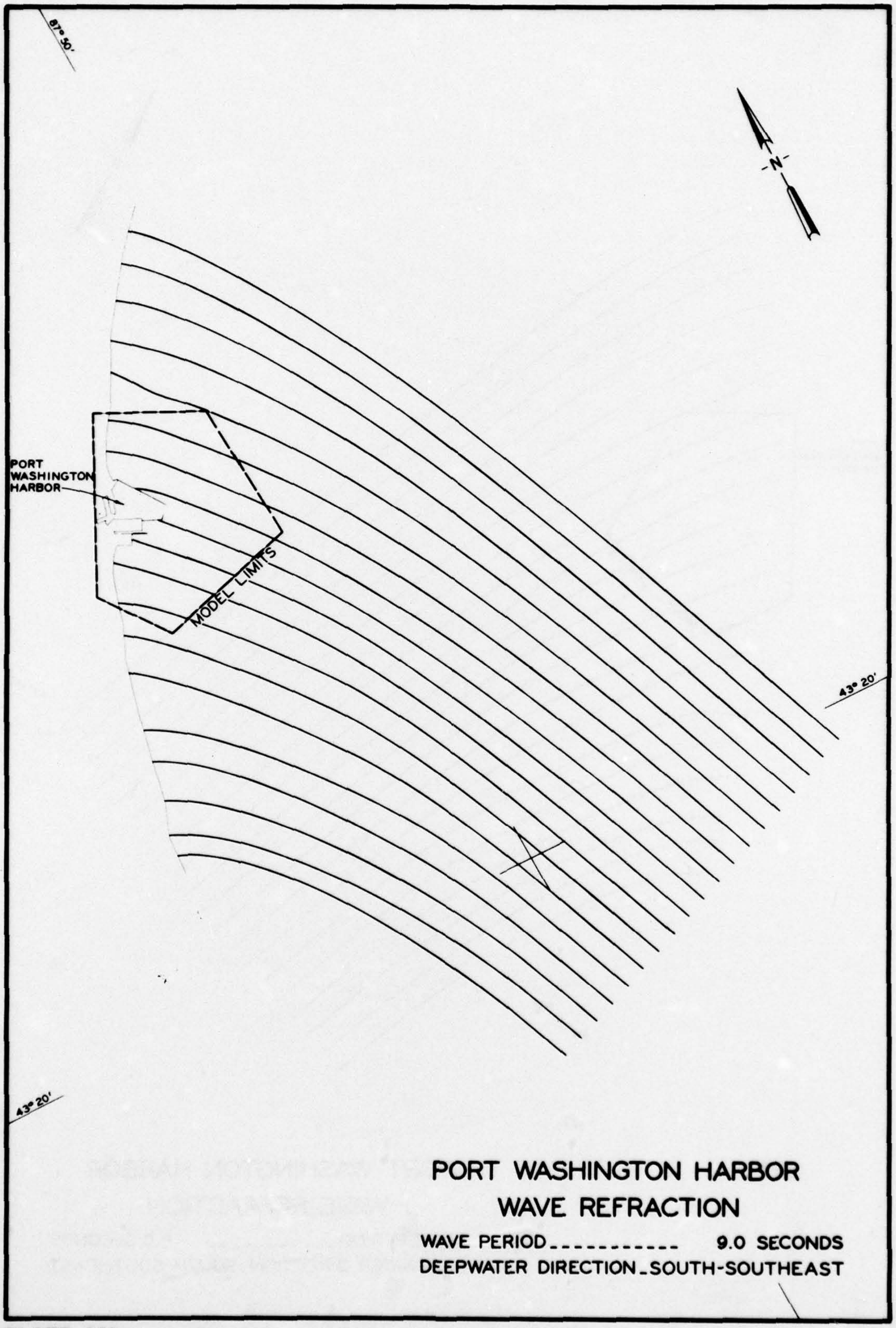

87° 50'
N
PORT WASHINGTON HARBOR
MODEL LIMITS
43° 20'
43° 20'
PORT WASHINGTON HARBOR
WAVE REFRACTION
WAVE PERIOD ----------- 9.0 SECONDS
DEEPWATER DIRECTION SOUTH-SOUTHEAST

PLATE A22

APPENDIX B: NOTATION

A	Area
b	Shallow-water orthogonal spacing
b_o	Deepwater orthogonal spacing
$(b_o/b)^{1/2}$	Refraction coefficient, K_r
H	Shallow-water wave height
H_o	Deepwater wave height
$H_{1/3}$	Significant wave height
K_r	Refraction coefficient
K_s	Shoaling coefficient
L	Length
Q	Discharge
T	Time
V	Velocity
$\forall$	Volume

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.

Bottin, Robert R

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