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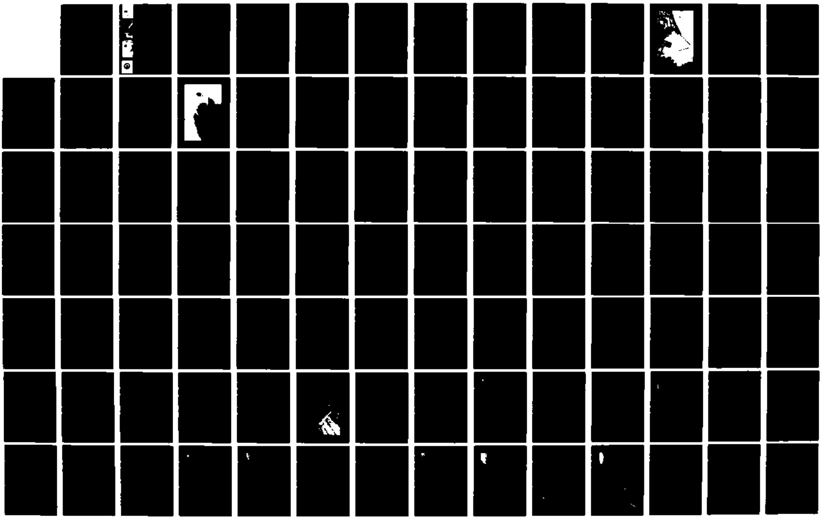

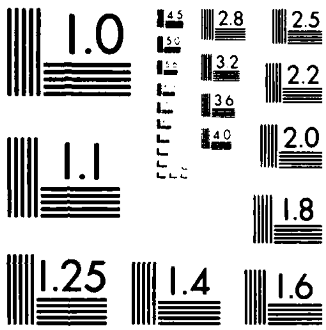

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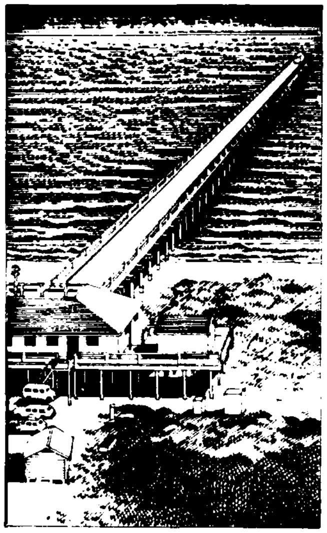

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TECHNICAL REPORT CERC-84-3

BARCELONA HARBOR, NEW YORK DESIGN FOR HARBOR IMPROVEMENTS

HYDRAULIC MODEL INVESTIGATION

by

Robert R. Bottin, Jr.

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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Final Report

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Harbors--New York--Models (LC)
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A 1:60-scale (undistorted) hydraulic model of Barcelona Harbor, New York, [illegible] 2,000 ft of the New York shoreline and sufficient offshore bathymetry in Lake Erie to permit generation of the required test waves, was used to investigate the design of certain proposed improvements with respect to wave action. Proposed improvements consisted of rubble-mound breakwater extensions; rubble-mound absorbers installed along the harbor sides of the existing east and west breakwaters and the lakeward face of the city dock; rubble-mound spurs installed southerly of the lakeward heads of the existing breakwaters; and a parapet wall installed on the existing west breakwater. Two 60-ft-long wave generators and an Automated Data Acquisition and Control System were utilized in model operation. Initially, an optimum improvement plan was selected based on the results of wave-height tests using monochromatic waves. It was concluded from these test results that:

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ABSTRACT (Continued).

a. For existing conditions, without the vertical-walled city dock (Base Test 1), rough and turbulent wave conditions existed in the harbor during periods of storm wave attack. Wave heights exceeding 3.0 ft in the mooring area and inner harbor for several test waves occurred during boating season.

b. Installation of the vertical-walled city dock (Base Test 2), in general, increased wave heights in the harbor with values exceeding 4.0 ft in the mooring area and inner harbor for several test waves occurring during boating season.

c. For existing conditions (Base Test 1 and Base Test 2), excessive energy entered the harbor through the navigation entrance, through the opening between the east breakwater and the shore, and due to overtopping of the existing breakwaters.

d. Initial wave-height measurements (Plans 1-6) indicated that absorbers inside the harbor and shoreward extensions of the east breakwater would not reduce wave heights in the harbor to acceptable levels, and that a breakwater extension at the entrance (Plan 6) would be required to prevent energy from entering the harbor.

e. With the original west breakwater extension and absorber of Plan 6, test results indicated that the city dock absorber (Plan 8) or a 125-ft-long shoreward east breakwater extension (Plan 12) would yield similar wave conditions in the mooring area.

f. Of the improvement plans tested with the initial west jetty extension (Plans 6-21), Plan 12 (300-ft-long lakeward west breakwater extension, west breakwater absorber, and 125-ft-long shoreward east breakwater extension) appeared to be optimum with respect to wave protection and costs; however, the entrance would be somewhat restricted.

g. For the Plan 12 harbor configuration, the 2.0-ft wave-height criterion in the mooring area will be exceeded by 0.4 ft for summer wave conditions from west with a 20-year recurrence interval. A 180-ft-long parapet wall installed on the west breakwater (Plan 15 or 16) will reduce wave heights to 2.0 ft for these incident wave conditions.

h. The installation of breakwater spurs inside the breakwaters (Plan 24), as an alternate to lakeward breakwater extensions, will not reduce wave heights in the mooring area to acceptable levels.

i. Parallel extensions of the east and west breakwaters (Plan 25) will provide adequate wave protection in the mooring area; however, cumulative lengths of these extensions exceed the length required for a curved west extension, resulting in a more costly structure.

j. The crest elevation of the west breakwater extension can be reduced from +13 ft to +11 ft (Plan 31) and still provide adequate wave protection in the mooring area.

k. Of the improvement plans tested with a west jetty extension oriented to provide a wider entrance, Plan 42 (250-ft-long lakeward west breakwater extension, west breakwater absorber, and 150-ft-long shoreward east breakwater extension) appeared to be optimum with respect to wave protection, ease of navigation, and construction costs.

l. For the Plan 42 harbor configuration, the 2.0-ft wave-height criterion in the mooring area will be exceeded by 0.3 ft for summer wave conditions from west with a 20-year recurrence interval and 0.2 ft for fall wave conditions from unrefracted northeast with a 20-year recurrence interval. To reduce wave heights to 2.0 ft in the mooring area, a 180-ft-long parapet wall installed on the west breakwater (Plan 15 or 16) is required for test waves from west; and a 25-ft-long shoreward extension of the east breakwater (Plan 41) is required for test waves from the unrefracted northeast direction.

m. The absorber installed adjacent to the west breakwater not only damps wave energy entering through the harbor openings, but also dissipates wave energy entering the harbor due to overtopping of the west breakwater. The removal of four 100-ft sections of this absorber (Plan 58), however, will have an insignificant impact on wave heights in the mooring area.

n. With the vertical-walled city dock removed from the harbor, the 150-ft-long shoreward extension of the east breakwater (Plan 42) can be removed without sacrificing wave protection in the mooring area.

Based on the results of the spectral wave tests (detailed in Appendix B), it was concluded that:

a. For the optimum improvement plan (Plan 58), wave heights in the mooring area were well within the established wave-height criterion for the spectral wave conditions tested.

b. A comparison of monochromatic and spectral wave conditions indicated that monochromatic waves resulted in slightly larger wave heights throughout the harbor, and monochromatic wave test results may be considered slightly conservative.

PREFACE

A request for a model investigation of Barcelona Harbor, New York, was initiated by the District Engineer, US Army Engineer District, Buffalo (NCB), in a letter to the Division Engineer, US Army Engineer Division, North Central (NCD), dated 15 June 1983. Funds for the US Army Engineer Waterways Experiment Station (WES) to conduct the study were authorized on 11 July and 16 August 1983.

This investigation was the second model study of wave action in Barcelona Harbor conducted by WES. The first was completed in 1958 and reported in WES Technical Report No. 2-523, "Wave Action and Breakwater Location, Harbor of Refuge for Light-Draft Vessels, Barcelona, New York," dated September 1959.

The model study was conducted during the period August 1983-January 1984 by personnel of the Wave Processes Branch (WPB), Wave Dynamics Division (WDD), Coastal Engineering Research Center (CERC), WES, under the direction of Dr. R. W. Whalin, Chief of CERC; Dr. L. E. Link, Jr., Assistant Chief of CERC; Mr. C. E. Chatham, Jr., Chief of WDD; and Mr. D. G. Outlaw, Chief of WPB. The tests were conducted by Mr. M. G. Mize, Civil Engineering Technician, Mr. E. R. Smith, Civil Engineer, Ms. M. L. Hampton, Computer Technician, and Mr. L. L. Friar, Electronics Technician, under the supervision of Mr. R. R. Bottin, Jr., Project Manager. Dr. R. E. Jensen, Research Hydraulic Engineer, developed the wave spectra at the site and Mr. K. A. Turner, Computer Specialist, programmed the spectral wave generator. This report was prepared by Mr. Bottin.

Prior to the model investigation, Messrs. Bottin and Mize met with Mr. Tom Bender from NCB and visited the prototype site. During the course of the study, liaison between NCB and WES was maintained by means of conferences, telephone communications, and monthly progress reports.

The following personnel visited WES to observe model operation and/or participate in conferences during the course of the model investigation.

Mr. Charlie Johnson	NCD	Mr. Doug Richmond	Westfield, N. Y.
Mr. Don Liddell	NCB	Mr. James Monroe	Westfield, N. Y.
Mr. Tom Bender	NCB	Mr. Don Briggs	Westfield, N. Y.
Mr. Denton Clark	NCB		

Commander and Director of WES during the conduct of this investigation and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

US 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 (US statute)	1.609344	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles (US statute)	2.589988	square kilometres
tons (2,000 lb, mass)	907.1847	kilograms

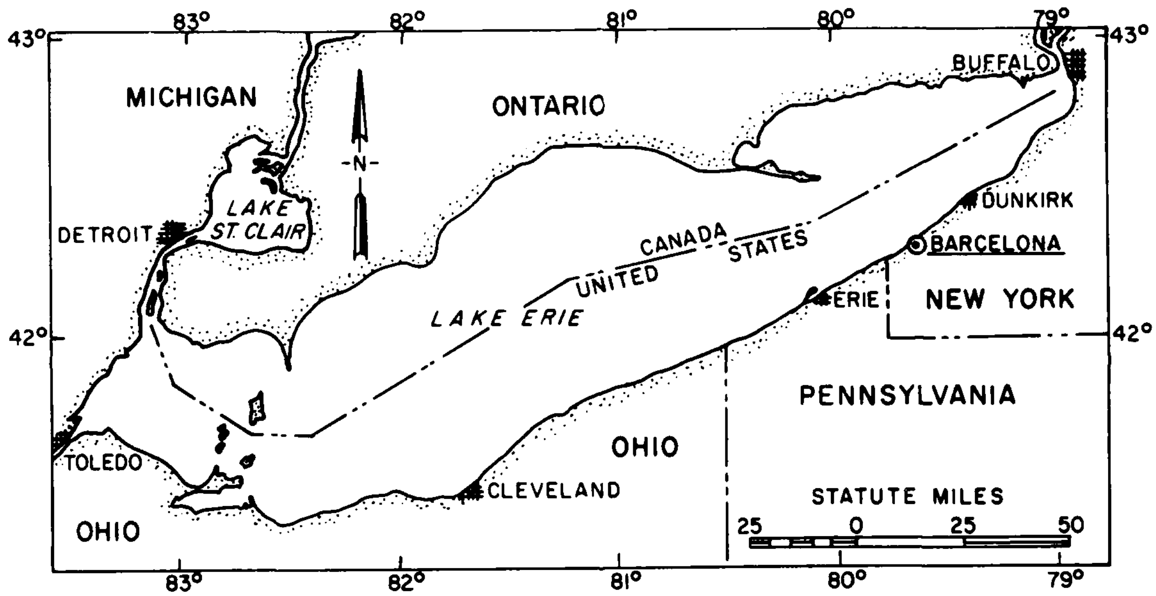

Figure 1. Project location

BARCELONA HARBOR, NEW YORK

DESIGN FOR HARBOR IMPROVEMENTS

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Barcelona Harbor is located in the town of Westfield, Chautauqua County, N. Y., and situated on the south shore of Lake Erie approximately 17 miles* southwest of Dunkirk, N. Y., and 29 miles northeast of Erie, Pa. (Figure 1). The harbor provides both commercial and recreational activities to the area. Four owner-operated commercial fishing vessels (ranging in length from 30 to 42 ft) operate out of the harbor. Approximately 41 tons of fresh fish (perch and pike) are harvested annually with an estimated value of $83,000 (US Army Engineer District, Buffalo, 1982). Recreational facilities include the Monroe Marina, municipal launching ramp, and a public wharf. The Monroe Marina provides approximately 35 moorings for recreational boats while the other facilities are used extensively by the general public.

2. The existing project (Figure 2) was authorized by the 1945 River and Harbor Act (US Army Engineer District, Buffalo, 1958). Construction of the harbor was completed in 1960 and included a 9-ft-high,** 693-ft-long east breakwater and an 11-ft-high, 790-ft-long west breakwater with a 175-ft-long shore arm. The breakwaters are concrete-capped cellular steel sheet-pile structures and the shore arm is a single row of steel sheet piling. The entrance gap between the lakeward ends of the breakwaters is 150 ft wide. The project also includes an 8-ft-deep, 100-ft-wide entrance channel leading to an 8-ft-deep, 800-ft-long harbor basin ranging from 125 to 350 ft in width.

The Problem

3. The design of the existing harbor is inadequate to meet the

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

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

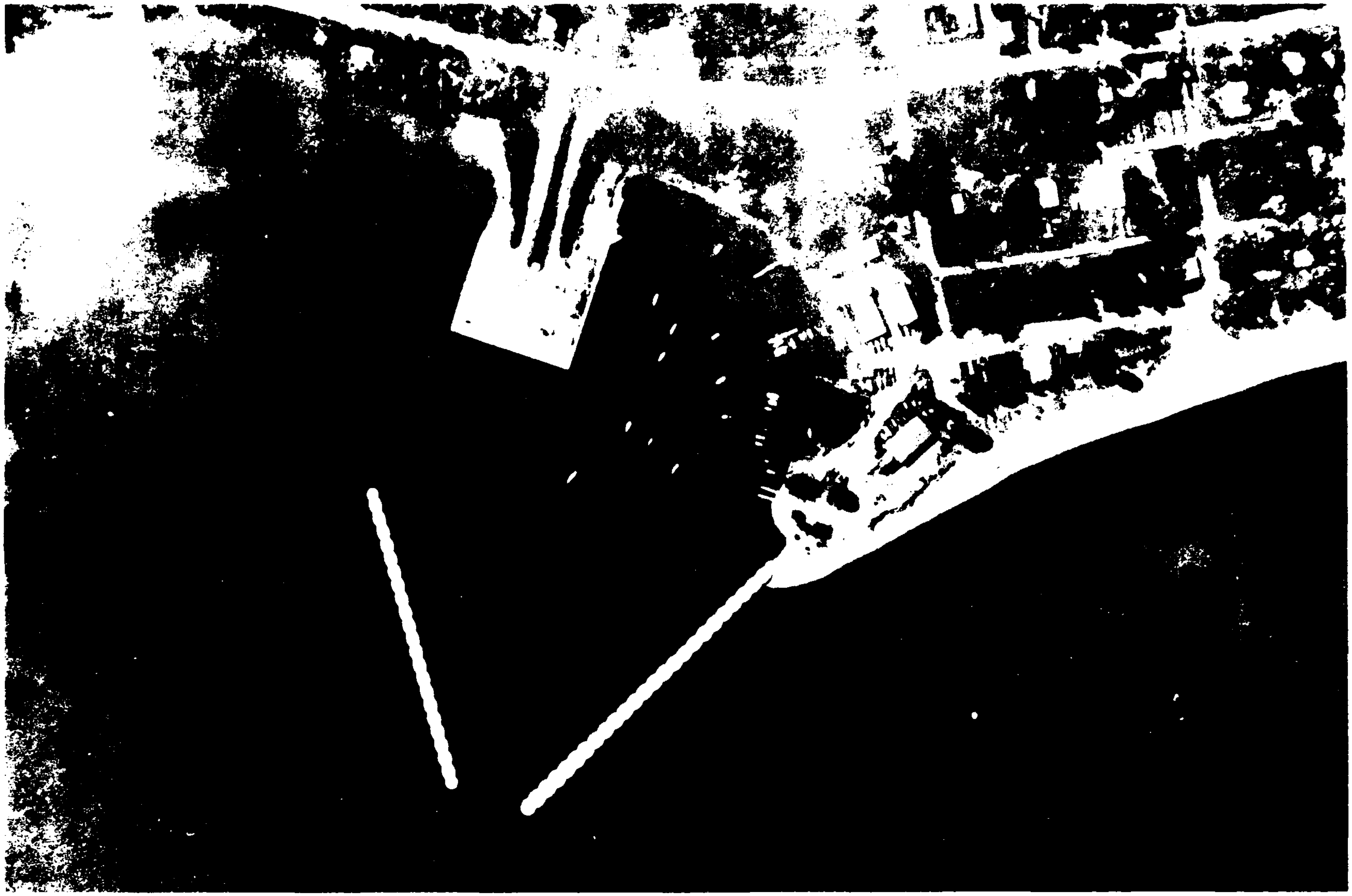

Figure 2. Aerial view of Barcelona Harbor

requirements of a harbor-of-refuge during storm activity. Waves propagating into the harbor reflect off the vertical cellular breakwaters and the vertical-faced public wharf resulting in a confused wave climate inside the harbor of standing and multidirectional waves. The 2-ft design wave height established for the mooring area (harbor-of-refuge standards) is frequently exceeded, and 3- to 4-ft wave heights are not uncommon in the harbor. These excessive wave conditions are hazardous and have resulted in numerous cases of heavy damages experienced by boats moored in the harbor. Also, the use of the present harbor for recreation is limited and unattractive due to the excessive wave action experienced.

4. In summary, wave conditions make Barcelona Harbor unsafe as a harbor-of-refuge for small boats, resulting in no adequate small-boat refuge between Dunkirk, N. Y., and Erie, Pa., a distance of 56 miles. Storm condit[illegible] 'so result in an unsafe harbor for permanently moored craft resulting [illegible] lack of adequately protected permanent mooring and docking facilities to accommodate the growing demand for such facilities in the Westfield area.

Proposed Improvements

5. Possible improvements for wave protection at Barcelona Harbor, as considered in the 1982 US Army Engineer District, Buffalo (NCB), Reconnaissance Report, consist of one or more of the following alternatives:

a. Construction of two 200-ft-long rubble-mound extensions of the lakeward ends of the existing east and west breakwaters parallel to the existing entrance channel.

b. Construction of a 300-ft rubble-mound wave absorber along the northerly face of the existing public wharf.

c. Construction of a 300-ft-long rubble-mound extension of the shoreward end of the east breakwater.

d. Construction of rubble-mound absorbers placed along the harbor sides of the east and west breakwaters.

e. Construction of two rubble-mound spurs placed approximately 200 ft south of the lakeward heads of the east and west breakwaters. The west and east spurs would be about 100 and 150 ft long, respectively.

Purpose of the Model Study

6. At the request of NCB, a hydraulic model investigation was conducted

by the US Army Engineer Waterways Experiment Station (WES) to:

a. Determine wave conditions in the harbor as it now exists, both with and without the vertical-faced public wharf.

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

c. Develop remedial plans, as necessary, for the alleviation of undesirable wave conditions.

d. Determine if suitable design modifications of the proposed plans could be made that would significantly reduce construction costs without sacrificing adequate wave protection.

e. Determine if the optimum improvement plan (as determined by monchromatic wave-height tests) would provide the desired wave protection for spectral wave conditions.

Wave-Height Criteria

7. Completely reliable criteria have not yet been developed for ensuring satisfactory navigation and mooring conditions in small-craft harbors during attack by waves. For this study, however, NCB specified that for any of the various improvement plans to be acceptable, maximum wave heights were not to exceed 2.0 ft (harbor-of-refuge standards) in the mooring area for waves occurring during the boating season (spring, summer, and fall).

PART II: THE MODEL

Design of Model

8. The Barcelona Harbor model (Figure 3) was constructed to an undistorted linear scale of 1:60, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.

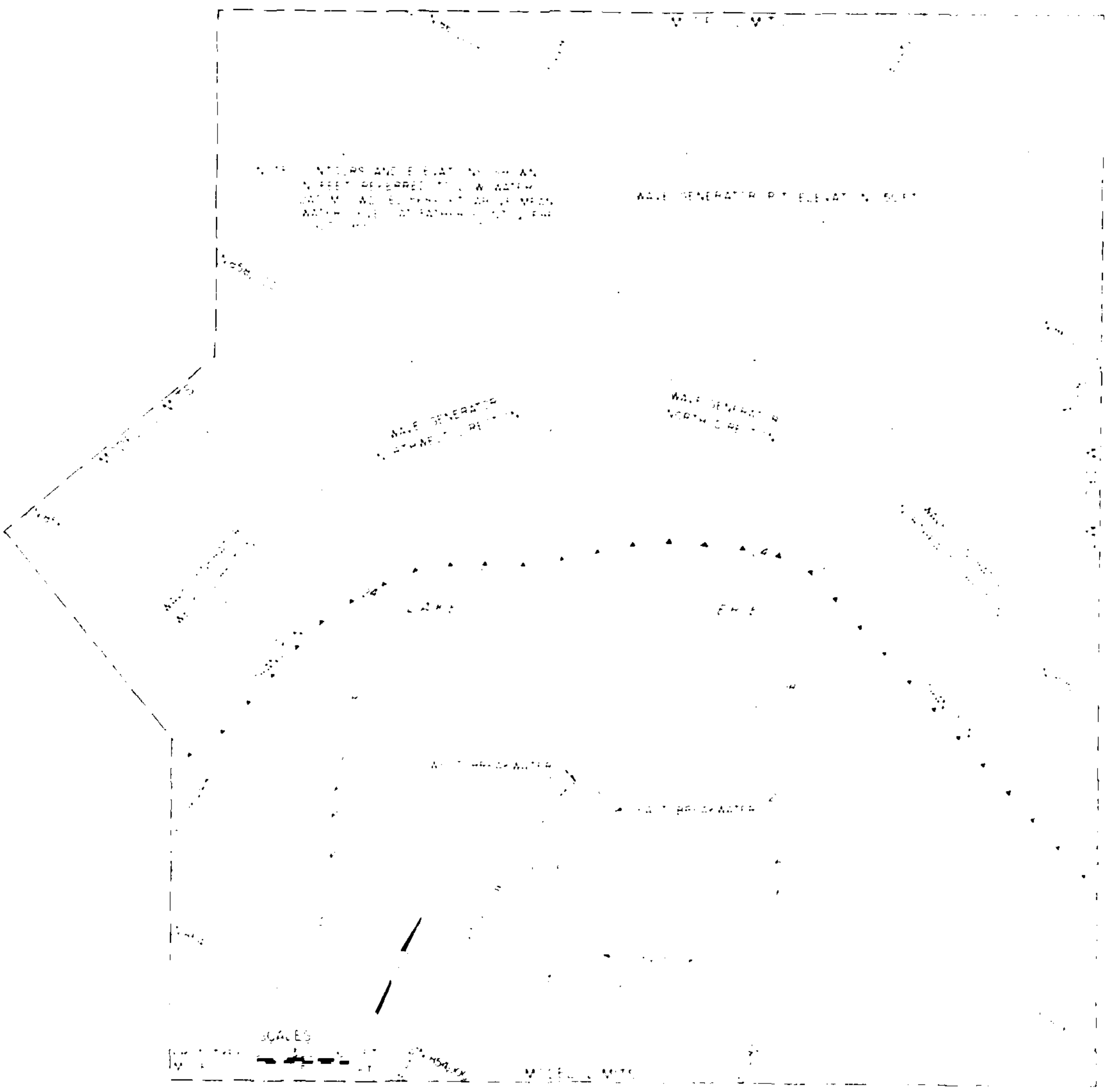

Figure 3. Model layout

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Model:Prototype Scale Relation
Length	L**	$L_r = 1:60$
Area	L^2	$A_r = L_3^2 = 1:3,600$
Volume	L^3	$\forall_r = L_r^3 = 1:216,000$
Time	T	$T_r = L_r^{1/2} = 1:7.75$
Velocity	L/T	$V_r = L_r^{1/2} = 1:7.75$

* Dimensions are in terms of length and time.
** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix C).

9. Proposed improvement plans tested in the model of Barcelona Harbor included the use of rubble-mound breakwaters and absorbers. Based on past experience, 1:60-scale model structures should not create sufficient scale effects to warrant geometric distortion of rock sizes in order to ensure proper transmission and reflection of wave energy. Therefore rock size selection was based on linear scale relations and an assumed specific weight of 165 lb/ft^3 for the prototype rock.

The Model and Appurtenances

10. The model, which was molded in cement mortar, reproduced approximately 7,000 ft of the Lake Erie shoreline, Barcelona Harbor, and underwater contours in the lake to an offshore depth of 24 ft with a sloping transition

to the wave generator pit elevation of -50 ft. The total area reproduced in the model was approximately 11,650 sq ft, representing about 1.5 square miles in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on low water datum (lwd), el 568.6 above mean water level at Father Point, Quebec (International Great Lakes Datum 1955). Horizontal control was referenced to a local prototype grid system.

11. Monochromatic model waves were generated by a 60-ft-long mechanical 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 frequency of the 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 directions. After an optimum test plan was selected, it was subjected to spectral wave conditions. Spectral waves were generated by a 60-ft-long electrohydraulic wave generator with a trapezoidal-shaped vertical-motion plunger. This generator utilized a hydraulic power supply and was controlled by a computer-generated command signal.

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 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 then was 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 damp any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

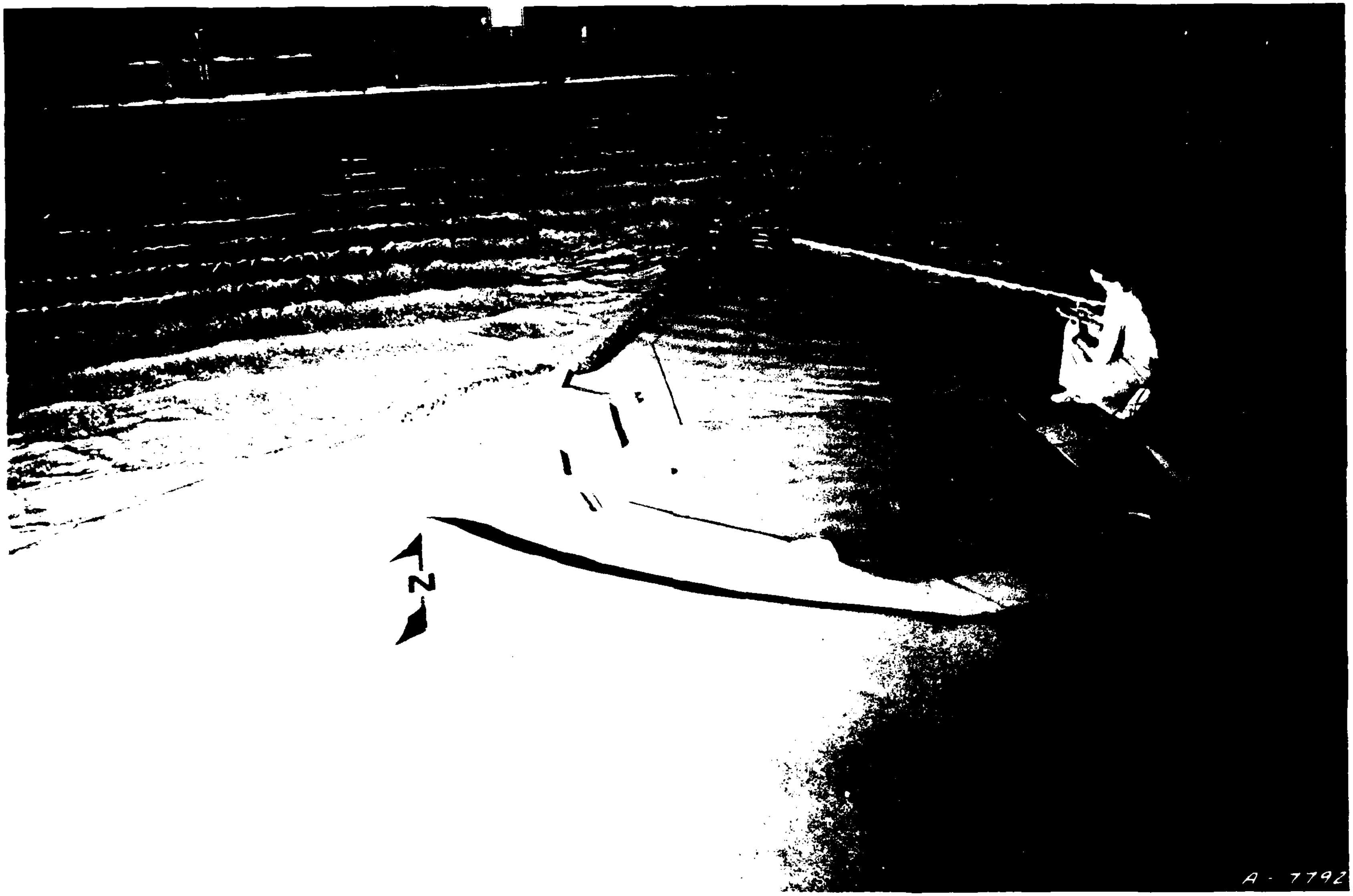

Figure 4. General view of model

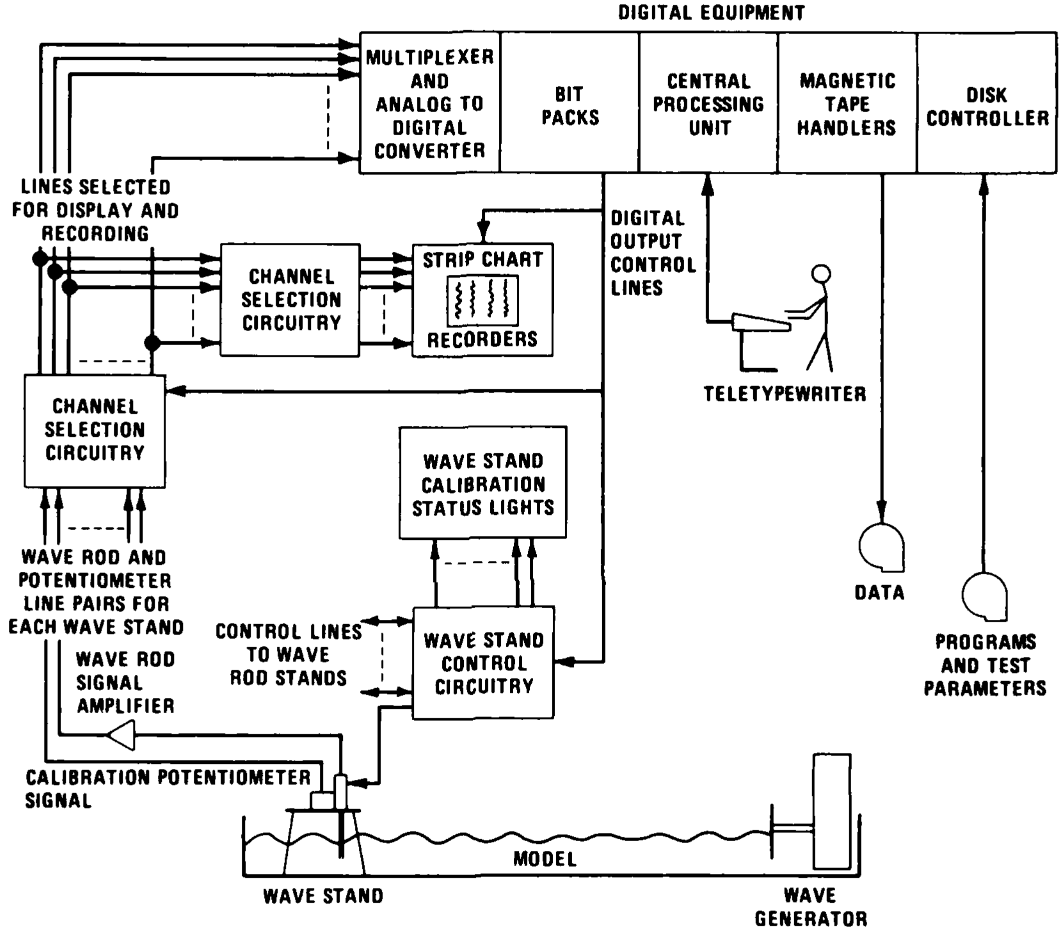

Figure 5. Automated Data Acquisition and Control System (ADACS)

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

14. Still-water levels (swl's) 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 of the Great Lakes fluctuate from year to year and from month to month. Also, at any given location, the water level can vary from day to day and from hour to hour. Continuous records of the levels of the Great Lakes, tabulated since 1860, indicate that the usual pattern of seasonal variations of water levels consists of highs in summer and lows in late winter. The highest and lowest monthly average levels in Lake Erie usually occur in June and February, respectively. During the period of record (1860-1952), the average lake level of Lake Erie was +1.8 ft for the entire year and +2.1 ft for the ice-free period (April through November). The highest 1-month average level of +4.2 ft occurred in May 1952, and the lowest 1-month average level of -1.1 ft occurred in February 1936 (Saville 1953). The seasonal variation in the mean monthly level of Lake Erie usually ranges between 1 and 2 ft with an average variation of 1.6 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 differential barometric pressures, and are superimposed on the longer period variations in lake level. 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; therefore the probability that a high lake level and large wind tide or seiche will occur simultaneously is relatively small.

17. Lake levels of +3.0, +4.0, +5.0, +5.5, and +6.5 ft were selected by NCB for use during model testing. These water levels correspond to various

seasons of the year and direction of wave attack as shown in the following tabulation:

Wave Direction	Design Lake Levels, ft Third Quarter Jul-Sep	Design Lake Levels, ft Fourth Quarter Oct-Dec
West	+6.5	+5.5
Northwest	+5.0	+4.0
North	+5.0	+4.0
Northeast	+4.0	+3.0

The design lake levels selected are equivalent to the 10-year frequency annual mean lake level for the particular season plus a short-period peak rise having a 1-year recurrence interval. Short-period rises of 2.5, 1.0, 1.0, and 0.0 ft were used for test waves from west, northwest, north, and northeast, respectively. In addition, NCB requested that model testing be conducted with a +3.0 ft swl for waves from all test directions. This value would represent less severe conditions that occur more frequently at Barcelona Harbor during the boating season.

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, and the water distance (fetch) over which the wind blows. 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 generating 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 the 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 a 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 (to the first order of approximation). 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 along the wave crest, 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 $H/H_o = K_s\ (b_o/b)^{1/2}$. The quantity $(b_o/b)^{1/2}$ is the refraction coefficient, K_r ; 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, a function of wavelength and water depth, can be obtained from USACERC (1977). For this study, refraction diagrams were prepared for representative wave periods from the critical directions of approach using computer facilities at WES and are detailed 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 Barcelona Harbor area. However, statistical deepwater wave hindcast data representative of this area were obtained from Resio and Vincent (1976a) shoreline grid point 21. The numerical wind and wave models used to produce this data are described in Resio and Vincent (1976b, 1977a, 1977b, and 1978). Resio and

Vincent (1976a) cover deepwater waves approaching from three angular sectors at the site (Figure 6). 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 most waves used during model testing were representative of wave conditions occurring during the navigation (boating) season. In addition, maximum wave heights for the winter season (20-year recurrence intervals) 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 Azimuth, deg	Wave Period sec	Deepwater Wave Height ft	Shallow-Water Wave Height ft	Recurrence Interval Years (season)*	swl
West	287	7.1	6.9	6.3	5 (S)	+6.5
		9.2	12.1	12.0	5 (F)	+5.5
		7.7	4.0	3.8		+6.5
			8.2	7.9	20 (S)	+6.5
		9.9	6.0	6.2		+5.5
			13.4	13.9	20 (F)	+5.5
		10.1	14.1	14.7	20 (W)	+6.5
Northwest	316	5.7	4.9	4.8	5 (S)	+5.0
		6.9	8.9	8.3	5 (F)	+4.0
		6.2	6.6	6.3	20 (S)	+5.0
		7.5	5.0	4.6		+4.0
			10.8	9.9	20 (F)	+4.0
		7.8	11.5	10.5	20 (W)	+5.0
North	347	5.7	4.9	4.6	5 (S)	+5.0
		6.9	8.9	7.9	5 (F)	+4.0
		6.2	6.6	6.1	10 (S)	+5.0
		7.5	5.0	4.5		+4.0
			10.8	9.6	20 (F)	+4.0
		7.8	11.5	10.2	20 (W)	+5.0
Northeast	20	4.9	3.6	2.8	5 (S)	+4.0
		6.4	6.9	5.0	5 (F)	+3.0
		5.9	5.2	4.0	20 (S)	+4.0
		6.7	4.0	2.9		+3.0
			7.9	5.7	20 (F)	+3.0
		6.9	8.2	5.8	20 (W)	+4.0

* S - summer, F - fall, and W - winter seasons.

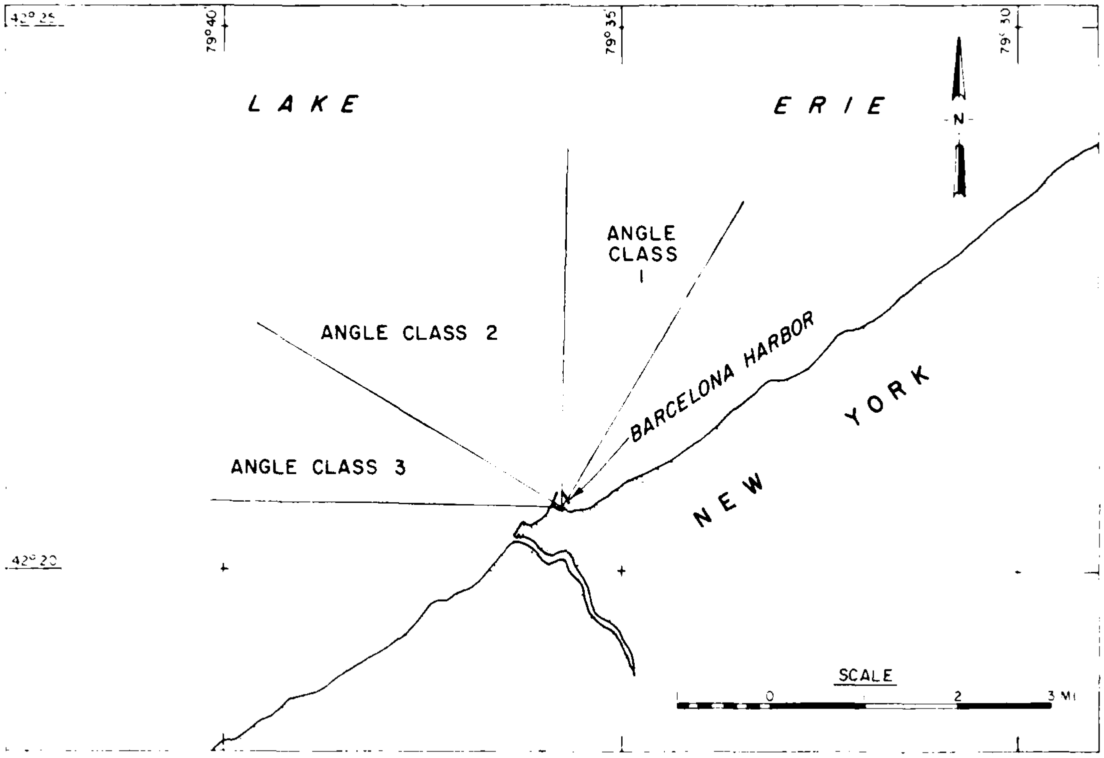

Figure 6. Wave hindcast angle classes

21. In addition to the above test waves, NCB also requested that wave characteristics obtained by Jensen (1984) be used for model testing. The following test waves represent values with a 1-year recurrence interval occurring during the May-October season and were tested in the model with a +3.0 ft swl.

Deepwater Direction	Shallow-Water Azimuth, deg	Wave Period sec	Deepwater Wave Height ft	Shallow-Water Wave Height ft
West	287	5.2	3.9	3.7
Northwest	316	6.2	6.3	6.0
North	347	5.9	5.5	5.1
Northeast	20	5.9	5.6	4.3

22. During the conduct of model testing, test waves from northeast (20 deg) also were tested from an unrefracted northeast direction (45 deg). This actually represented deepwater waves approaching from a more easterly direction than northeast (refracted to due northeast, 45 deg). Waves from this direction potentially could enter the harbor through the opening between the east breakwater and the public wharf (city dock).

Analysis of Model Data

23. The relative merits of the various plans tested were evaluated by:

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

   b. Visual observations and photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves recorded at each gage location was computed. Computed wave heights then were adjusted to compensate for excess model wave-height attenuation due to viscous bottom friction by application of Keulegan's equation (Keulegan 1950). From this equation, reduction of wave heights in the model (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel.

PART IV: TESTS AND RESULTS

The Tests

Base tests

24. Prior to tests of the various improvement plans, comprehensive tests were conducted for two base test conditions. Base Test 1 (Plate 1) consisted of the existing harbor without the vertical-walled city dock and Base Test 2 (Plate 2) included the city dock. Wave-height data were obtained for Base Test 1 and Base Test 2 at various locations in the harbor (Plates 1 and 2) for the test waves listed in paragraphs 20 and 21. Wave pattern photographs also were secured for representative waves from the selected test directions.

Improvement plans

25. Wave-height tests were conducted for 58 test plan variations. These variations consisted of changes in the lengths, alignments, and cross sections of lakeward breakwater extensions; shoreward extensions of the east breakwater; absorbers on the harbor sides of the breakwaters; the installation of a parapet wall on the west breakwater; and an absorber along the vertical-faced city dock. Wave pattern photographs were obtained of all the test plans. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are shown in Plates 3-28.

a. Plan 1 (Plate 3) consisted of a 280-ft-long absorber placed on the lakeward face of the vertical-walled city dock. The absorber crest elevation was +6 ft.

b. Plan 2 (Plate 3) entailed the elements of Plan 1 with a 300-ft-long shoreward rubble-mound extension of the existing east breakwater. The crest elevation of the extension was +8 ft.

c. Plan 3 (Plate 3) involved the elements of Plan 2 with a 150-ft-long absorber installed at an elevation of +9 ft along the inside of the head of the west breakwater.

d. Plan 4 (Plate 3) included the elements of Plan 3 with a 150-ft-long absorber installed along the inside of the head of the east breakwater at an elevation of +9 ft.

e. Plan 5 (Plate 4) consisted of the elements of Plan 4 with an additional 640-ft-long absorber (crest el +8 ft) installed along the inside of the west breakwater trunk.

f. Plan 6 (Plate 4) entailed the elements of Plan 5 with a 300-ft-long lakeward, curved rubble-mound extension of the west breakwater installed at an elevation of +13 ft.

g. Plan 7 (Plate 5) included the elements of Plan 6 with the 150-ft-long absorber at the head of the east breakwater removed.

h. Plan 8 (Plate 5) involved the elements of Plan 7 with the 300-ft-long shoreward extension of the east breakwater removed.

i. Plan 9 (Plate 5) consisted of the elements of Plan 8 with the 280-ft-long absorber on the city dock removed.

j. Plan 10 (Plate 6) involved the elements of Plan 8 with 240 ft of the absorber at the shoreward end of the west breakwater removed.

k. Plan 11 (Plate 7) included the elements of Plan 9 with a 100-ft-long shoreward rubble-mound extension (crest el +8 ft) of the east breakwater.

l. Plan 12 (Plates 7 and 8) entailed the elements of Plan 9 with a 125-ft-long shoreward rubble-mound extension (crest el +8 ft) of the east breakwater.

m. Plan 13 (Plate 9) consisted of the elements of Plan 12 with a 4-ft-high, 790-ft-long parapet wall installed on the west breakwater. The shoreward 180-ft-long section of the parapet wall was installed at an elevation of +13 ft and the remaining portion at el +15 ft.

n. Plan 14 (Plate 9) entailed the elements of Plan 12 with a 4-ft-high, 180-ft-long parapet wall installed on the shoreward end of the cellular breakwater. The breakwater elevation of +9 ft resulted in a parapet elevation of +13 ft.

o. Plan 15 (Plate 10) included the elements of Plan 12 with a 4-ft-high, 180-ft-long parapet wall installed on the shoreward end of the el +11 ft section of the west breakwater resulting in a parapet elevation of +15 ft.

p. Plan 16 (Plate 10) involved the elements of Plan 15 but the 180-ft-long parapet wall was moved to the lakeward side of the west breakwater.

q. Plan 17 (Plate 11) consisted of the elements of Plan 16 but the 125-ft-long shoreward extension of the east breakwater was removed and the 280-ft-long absorber adjacent to the lakeward face of the city dock was reinstalled.

r. Plan 18 (Plate 11) entailed the elements of Plan 17 with the 180-ft-long parapet wall removed.

s. Plan 19 (Plate 12) involved the elements of Plan 18 with the 125-ft-long shoreward east breakwater extension reinstalled.

t. Plan 20 (Plate 12) included the elements of Plan 19 with the 180-ft-long parapet wall of Plan 16 reinstalled.

u. Plan 21 (Plate 13) consisted of the elements of Plan 12 with a 693-ft-long absorber along the inside of the east breakwater and a 280-ft-long absorber along the vertical face of the city dock.

v. Plan 22 (Plate 14) entailed the elements of Plan 12 but the 300-ft-long lakeward west breakwater extension was removed.

w. Plan 23 (Plate 14) included the elements of Plan 22 with the 695-ft-long absorber along the inside of the east breakwater.

x. Plan 24 (Plate 14) involved the elements of Plan 23 with a 100-ft-long west spur and a 150-ft-long east spur installed. The crest elevation of these spur breakwaters was +8.5 ft.

y. Plan 25 (Plate 15) consisted of the elements of Plan 23 with 200-ft-long parallel breakwater extensions of the east and west breakwaters. These extensions were parallel to the entrance channel and installed with a crest elevation of +13 ft. The 280-ft-long dock absorber also was reinstalled.

z. Plan 26 (Plate 16) consisted of the elements of Plan 12 but the 300-ft-long west breakwater extension was reduced to 250 ft in length.

aa. Plan 27 (Plate 16) involved the elements of Plan 26 but the 125-ft-long shoreward extension of the east breakwater was reduced to 100 ft in length.

bb. Plan 28 (Plate 17) included the elements of Plan 27 but the curved 250-ft-long west breakwater extension was replaced with a 325-ft-long dogleg extension installed with a crest elevation of +13 ft.

cc. Plan 29 (Plate 18) entailed the elements of Plan 27 but the curved 250-ft-long west breakwater extension was replaced with a 285-ft-long extension (el +13 ft) on a different alignment. The lakeward cell of the cellular sheet-pile east breakwater was removed.

dd. Plan 30 (Plate 19) consisted of the elements of Plan 29 but a curved 270-ft-long west breakwater extension (el +13 ft) was installed on a different orientation and the two lakeward cells of the cellular sheet-pile east structure were removed.

ee. Plan 31 (Plate 19) involved the elements of Plan 30 but the crest elevation of the 270-ft-long west breakwater extension was reduced from +13 ft to +11 ft.

ff. Plan 32 (Plate 19) included the elements of Plan 31 but the 100-ft-long shoreward extension of the east breakwater was extended to 125 ft in length.

gg. Plan 33 (Plate 19) entailed the elements of Plan 32 but the shoreward extension of the east breakwater was increased to 150 ft in length.

hh. Plan 34 (Plate 20) consisted of a 250-ft-long rubble-mound lakeward extension of the west breakwater (el +11 ft), a 790-ft-long rubble absorber (el +8 ft) along the inside of the existing west breakwater, and a 125-ft-long rubble-mound shoreward extension of the east breakwater (el +8 ft).

ii. Plan 35 (Plate 20) entailed the elements of Plan 34 but the 250-ft-long west breakwater extension was increased to 310 ft in length.

jj. Plan 36 (Plate 20) involved the elements of Plan 35 but the outer 60-ft-long section of the west breakwater extension was oriented slightly lakeward.

kk. Plan 37 (Plate 21) included the elements of Plan 36 but the 125-ft-long extension of the east breakwater was increased to 150 ft in length.

ll. Plan 38 (Plate 21) involved the elements of Plan 36 but the 125-ft-long extension of the east breakwater was increased to 175 ft in length.

mm. Plan 39 (Plate 21) entailed the elements of Plan 36 but the 125-ft-long extension of the east breakwater was increased to 200 ft in length.

nn. Plan 40 (Plate 22) consisted of the elements of Plan 34 with a 200-ft-long extension of the east breakwater.

oo. Plan 41 (Plate 22) entailed the elements of Plan 34 with a 175-ft-long extension of the east breakwater.

pp. Plan 42 (Plate 22) included the elements of Plan 34 with a 150-ft-long extension of the east breakwater.

qq. Plan 43 (Plate 23) consisted of the elements of Plan 42 with an additional layer of stone placed on a 90-ft-long section of the absorber at the lakeward end of the west breakwater.

rr. Plan 44 (Plate 23) involved the elements of Plan 43 but the east breakwater extension was increased to 175 ft in length.

ss. Plan 45 (Plate 23) entailed the elements of Plan 44 but the east breakwater extension was increased to 200 ft in length.

tt. Plan 46 (Plate 24) consisted of the elements of Plan 42 with 200 ft of the absorber adjacent to the west breakwater removed from the shoreward end of the structure.

uu. Plan 47 (Plate 24) included the elements of Plan 42 with 400 ft of the absorber adjacent to the west breakwater removed from the shoreward end of the structure.

vv. Plan 48 (Plate 25) consisted of the elements of Plan 42 with the vertical-walled city dock removed.

ww. Plan 49 (Plate 25) encompassed the elements of Plan 48 but the 150-ft-long east breakwater extension was reduced to 100 ft in length.

xx. Plan 50 (Plate 25) involved the elements of Plan 48 but the 150-ft-long east breakwater extension was reduced to 50 ft in length.

yy. Plan 51 (Plate 26) entailed the elements of Plan 48 but the 150-ft-long east breakwater extension was removed.

zz. Plan 52 (Plate 26) consisted of the elements of Plan 51 but the 250-ft-long west breakwater extension was reduced to 225 ft in length.

aaa. Plan 53 (Plate 26) included the elements of Plan 51 but the 250-ft-long west breakwater extension was reduced to 200 ft in length.

bbb. Plan 54 (Plate 26) encompassed the elements of Plan 51 but the 250-ft-long west breakwater extension was reduced to 175 ft in length.

ccc. Plan 55 (Plate 26) involved the elements of Plan 51 but the 250-ft-long west breakwater extension was reduced to 150 ft in length.

ddd. Plan 56 (Plate 27) included the elements of Plan 55 but a total of 400 ft of the absorber adjacent the west breakwater was removed. Four 100-ft-long sections were removed resulting in a segmented absorber.

eee. Plan 57 (Plate 27) consisted of the elements of Plan 55 but the 150-ft-long west breakwater extension was increased to 225 ft in length.

fff. Plan 58 (Plate 28) encompassed the elements of Plan 42 (the vertical-faced city dock installed) but four 100-ft-long sections of the west breakwater absorber were removed resulting in a segmented structure.

Wave-height tests

26. Wave-height tests were conducted for the various improvement plans 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., west, northeast). However, the optimum test plan was tested comprehensively for test waves from all test directions. Wave gage locations for each improvement plan are shown in Plates 3-28.

Videotape

27. Videotape footage of the Barcelona Harbor model was secured for existing conditions (Base Test 2) and Plan 42 showing the basin under attack by storm waves approaching from the north test direction. This footage was forwarded to NCB for use in briefings, public meetings, etc.

Base Test Results

28. Results of wave-height tests conducted for Base Test 1 are presented in Table 3. Maximum wave heights obtained during boating season were 12.6 ft in the entrance (gage 2) for 7.5-sec, 9.6-ft test waves from north; 3.7 ft in

the mooring area (gage 4) for 7.5-sec, 9.6-ft test waves from north; 3.5 ft in the inner harbor (gage 9) for 6.9-sec, 7.9-ft test waves from north; and 5.3 ft adjacent to the proposed city dock location (gage 12) for 9.9-sec, 6.2-ft test waves from west. The 2.0-ft wave-height criterion in the mooring area (gages 4-8) was exceeded for test waves from all test directions. Visual observations revealed wave energy entering the harbor from the entrance, through the gap shoreward of the east breakwater, and by overtopping of both the east and west breakwaters. Typical wave patterns for Base Test 1 are shown in Photos 1-23.

29. Design wave-height information was obtained along the center lines of the proposed improvement structures for Base Test 1 for the alternate gage locations shown in Plate 1. These data are presented in Table 4. Maximum wave heights were 13.1 ft immediately lakeward of the entrance (gage 3A) for 7.5-sec, 9.6-ft test waves from north; 7.3 ft shoreward of the east breakwater (gage 10A) for 7.7-sec, 7.9-ft test waves from west; 8.8 ft along the harbor side of the west breakwater (gage 4A) for 6.9-sec, 5.8-ft test waves from northeast; and 11.2 ft along the harbor side of the east breakwater (gage 5A) for 9.9-sec, 13.9-ft, and 10.1-sec, 14.7-ft test waves from west.

30. Wave-height measurements secured for Base Test 2 for test waves from the various directions are presented in Table 5. Maximum wave heights obtained during boating season were 12.4 ft in the entrance (gage 2) for 7.5-sec, 9.6-ft test waves from north; 4.7 ft in the mooring area (gage 4) for 7.5-sec, 9.6-ft test waves from north; 4.6 ft in the inner harbor (gage 9) for 7.5-sec, 9.6-ft test waves from north; and 6.6 ft adjacent to the city dock (gage 12) for 9.9-sec, 13.9-ft test waves from west. Wave conditions throughout the entire harbor, in general, increased as a result of the installation of the vertical-faced city dock. Typical wave patterns for Base Test 2 are shown in Photos 24-47.

Improvement Plan Results

31. In evaluating test results, the relative merits of various plans were based on an analysis of measured wave heights in the mooring area. Model wave heights (significant wave height of $H_{1/3}$) were tabulated to show measured values at selected locations.

Plans 1-12 (test waves from northeast)

32. Wave heights obtained for Plans 1-5 for representative test waves from northeast are presented in Table 6. Maximum wave heights in the mooring area were 5.2, 4.5, 3.2, 3.2, and 2.8 ft for Plans 1-5, respectively. The 2.0-ft wave-height criterion was not satisfied for any of these improvement plans. The installation of absorber along the city dock (Plan 1) and the shoreward extension of the east breakwater (Plan 2) damped or prevented most wave energy from entering the harbor in the gap between the city dock and the shoreward end of the east structure. Test results and visual observations indicated a significant amount of wave energy entering the harbor through the entrance. The installation of the absorbers of Plans 3-5 reduced wave activity in the harbor but still did not meet the specified wave-height criterion. Wave pattern photographs obtained for Plans 1-5 are shown in Photos 48-52.

33. Results of wave-height measurements secured for Plans 6-12 for test waves from northeast are presented in Table 7. Maximum wave heights obtained in the mooring area were 0.9, 1.0, 1.6, 2.4, 2.2, 2.0, and 1.6 ft for Plans 6-12, respectively. Only Plans 9 and 10 exceeded the established 2.0-ft wave-height criterion. The west breakwater extension of Plan 6 significantly reduced wave heights in the harbor (less than 1 ft in the mooring area). The removal of the head absorber (Plan 7) and the shoreward extension (Plan 8) of the east breakwater resulted in wave heights that were still within the criterion. Further removal of the city dock absorber (Plan 9) or a portion of the west breakwater absorber (Plan 10), however, resulted in wave heights exceeding the criterion in the mooring area. With the city dock absorber removed (Plan 9), incremental shoreward extensions of the east breakwater reduced wave heights to an acceptable level. Test results for waves from northeast indicated that the city dock absorber without the shoreward extension of the east breakwater (Plan 8) would yield similar wave conditions in the mooring area as a 125-ft-long east breakwater shoreward extension without the city dock absorber (Plan 12). Both Plans 8 and 12 resulted in a maximum wave height in the mooring area of 1.6 ft. Wave pattern photographs obtained for Plans 6-12 for test waves from northeast are shown in Photos 53-59.

34. Wave-height tests were conducted for Plans 8, 9, and 12 for test waves from an unrefracted northeast direction (45-deg azimuth). This represents waves that may approach from a more easterly direction than refracted northeast and results in wave energy that could potentially enter the harbor

shoreward of the east breakwater. Results of these tests are shown in Table 8. Maximum wave heights in the mooring area were 1.8, 2.3, and 1.8 ft for Plans 8, 9, and 12, respectively. The improvement plan configuration without the city dock absorber or the shoreward east breakwater extension (Plan 9) resulted in wave heights exceeding the criterion in the mooring area. The installation of either the city dock absorber (Plan 9) or the 125-ft-long east breakwater extension (Plan 12) resulted in maximum wave heights of 1.8 ft in the mooring area.

Plans 12-20 (test waves from west)

35. Results of wave-height measurements with Plans 12-16 installed for representative test waves from west are presented in Table 9. Maximum wave heights obtained in the mooring area 2.4, 1.3, 2.4, 1.9, and 2.0 ft for Plans 12-16, respectively. The improvement plan configuration without a parapet wall (Plan 12) yielded maximum wave heights in the mooring area of 2.4 ft for summer wave conditions with a 20-year recurrence interval and a +6.5 ft swl. The installation of the 4-ft-high parapet along the entire west structure (Plan 13) reduced maximum wave heights in the mooring area to 1.3 ft. The installation of the parapet wall only on the existing +9 ft elevation shoreward portion of west breakwater, however, resulted in maximum wave heights of 2.4 ft in the mooring area. To reduce wave heights to a maximum of 2 ft in the mooring area for test waves from west, a 180-ft-long parapet wall installed on the +11 ft elevation shoreward portion of the west breakwater was required. This parapet could be installed on the harbor side (Plan 15) or the lakeward site (Plan 16) of the structure. Typical wave patterns for Plans 12-16 for test waves from west are shown in Photos 60-64.

36. Wave-height data for Plans 17-20 are presented in Table 10 for representative test waves from west. Maximum wave heights were 2.4, 2.7, 2.2, and 2.0 ft in the mooring area for Plans 17-20, respectively. When the east shoreward extension was removed and the city dock absorber installed (Plan 17), maximum wave heights in the mooring area increased to 2.4 ft. The removal of the 180-ft-long parapet (Plan 18) further increased maximum wave heights to 2.7 ft. Reinstallation of the east breakwater extension (Plan 19) reduced maximum wave heights to 2.2 ft, and reinstallation of the 180-ft-long parapet (Plan 20) further reduced maximum wave heights in the mooring area to 2.0 ft. These tests indicate that the installation of the absorber on the city dock had little effect on wave heights in the mooring area for waves from this direction.

Wave pattern photographs for representative test waves from west for Plans 17-20 are shown in Photos 65-68.

Plan 12 (test waves from all directions)

37. Wave-height tests were conducted for Plan 12 for test waves from all directions and results are presented in Table 11. Prior to these tests, wave gages 1, 2, 11, and 12 were moved to new locations as shown in Plate 8. Maximum wave heights obtained were 8.6 ft in the entrance (gage 1) for 7.5-sec, 9.6-ft test waves from north; 2.4 ft in the mooring area (gage 5) for 7.7-sec, 7.9-ft test waves from west; 1.7 ft in the inner harbor (gage 9) for 7.7-sec, 7.9-ft waves from northeast; and 4.0 ft adjacent to the city dock (gage 12) for 6.4-sec, 5-ft waves from northeast for waves occurring during boating season. The established wave-height criterion was exceeded only by summer wave conditions with a 20-year recurrence interval and a +6.5 swl.

Plans 21-25 (test waves from north)

38. Wave heights obtained for Plans 21-25 for representative test waves from north are presented in Table 12. Maximum wave heights in the mooring area were 1.1, 3.6, 3.2, 3.4, and 1.2 ft, respectively, for Plans 21-25. The lakeward breakwater extensions of Plans 21 and 25 provided relatively calm conditions not only in the mooring area but in the entire harbor. Neither the breakwater absorbers (Plans 22 and 23) nor the breakwater spurs (Plan 24) without lakeward extensions were effective in reducing wave heights in the mooring area to desired levels. Typical wave patterns for Plans 21-25 for representative test waves from north are shown in Photos 69-73.

Plans 26-31 (test waves from northeast)

39. Wave-height test results for Plans 26-31 for representative test waves from northeast are presented in Table 13. Maximum wave heights in the mooring area were 2.0, 2.1, 2.2, 2.1, 1.7, and 2.0 ft for Plans 26-31, respectively. Reduction of the west breakwater extension by 50 ft in length (Plan 26) resulted in wave heights within the established criterion, but further reduction of the east breakwater shoreward extension by 25 ft in length (Plan 27) resulted in wave heights that exceeded the criterion by 0.1 ft. At this point, it was determined by NCB that the entrance width of most of the various test plans was too narrow; therefore the next series of the test plans involved breakwater configurations that included wider entrances. The 325-ft-long and 285-ft-long west breakwater extensions of Plans 28 and 29, respectively, resulted in wave heights that only slightly exceeded the specified

criterion, while the 270-ft-long west extension orientation of Plan 30 produced wave heights well within the established criterion. A reduction of the breakwater extension crest elevation from +13 ft to +11 ft (Plan 31) resulted in wave heights still within the criterion. Typical wave patterns for Plans 26-31 for test waves from northeast are shown in Photos 74-79.

Plans 31-33 (test waves from unrefracted northeast)

40. Wave-height data for Plans 31-33 for test waves from the unrefracted northeast direction (45 deg) are presented in Table 14. Maximum wave heights obtained in the mooring area were 2.3, 2.2, and 2.2 ft, respectively, for Plans 31-33. Slight increases of the east breakwater shoreward extension (Plans 32 and 33) had little effect on wave heights in the mooring area, and it appeared that significant wave energy was approaching through the entrance. Wave pattern photographs obtained for Plans 31-33 for test waves from the unrefracted northeast direction are shown in Photos 80-82.

Plan 34 (test waves from all directions)

41. Results of wave-height tests for Plan 34 for representative test waves from all directions are presented in Table 15. Maximum wave heights obtained for boating season conditions were 8.8 ft in the entrance (gage 1); 2.5 ft in the mooring area (gage 6); 1.3 ft in the inner harbor (gage 9) all for 6.7-sec, 5.7-ft test waves from the unrefracted northeast direction; and 3.5 ft adjacent to the city dock (gage 12) for 7.5-sec, 9.6-ft test waves from north. The 2-ft wave-height criterion in the mooring area was exceeded by 7.7-sec, 7.9-ft test waves from west with a +6.5 ft swl and 6.7-sec, 5.7-ft test waves from unrefracted northeast with a +3.0 ft swl. These test waves from west exceeded the criterion by 0.3 ft and represented summer wave conditions with a 20-year recurrence interval while test waves from the unrefracted northeast direction exceeded the criterion by 0.5 ft and represented fall wave conditions with a 20-year recurrence interval.

Plans 34-45 (test waves from unrefracted northeast)

42. Wave-height test results for Plans 34-45 for test waves from the unrefracted northeast direction are presented in Table 16. Maximum wave heights in the mooring area were 2.5, 1.6, 2.2, 2.2, 2.1, 1.4, 2.0, 2.0, 2.2, 2.2, 1.9, and 1.8 ft, respectively, for Plans 34-45. The curved 60-ft west extension of Plan 35 reduced wave heights to well within the established

criterion; however, it also decreased the entrance opening which could possibly interfere with navigation. The 60-ft extension oriented more lakeward (Plan 36) resulted in wave heights 0.2 ft in excess of the criterion. The 200-ft-long shoreward extension of the east breakwater along with the 60-ft-long west extension (Plan 39) reduced wave heights in the mooring area to 1.4 ft (well within the criterion). The removal of the 60-ft-long west extension (Plan 40) resulted in 2.0-ft wave heights in the mooring area. Reductions in length of the shoreward extension (Plans 41 and 42) indicated that the 175-ft-long east breakwater extension of Plan 41 also would result in wave heights in the mooring area (2.0 ft) within the criterion. The 150-ft-long east extension of Plan 42 resulted in wave heights that exceeded the criterion by 0.2 ft for wave conditions occurring in the fall with a 20-year recurrence interval. Test results for the additional layer of absorber on the west breakwater and the various east breakwater extension lengths of Plans 43-45 revealed that wave heights in the mooring area would be reduced slightly, but a 175-ft east breakwater extension (Plan 44) would still be required to satisfy the criterion. Typical wave patterns for Plans 34-45 for representative test waves from the unrefracted northeast direction are shown in Photos 83-94. After evaluation of the plans tested thus far, considering wave protection and construction costs, Plan 42 was selected for additional testing.

Plan 42 (test waves from all directions)

43. Results of wave-height tests for Plan 42 from all directions are presented in Table 17. Maximum wave heights obtained were 8.5 ft in the entrance (gage 1) for 6.7-sec, 5.7-ft test waves from the unrefracted northeast direction; 2.3 ft in the mooring area (gage 5) for 7.7-sec, 7.9-ft test waves from west; 1.3 ft in the inner harbor (gage 9) for 9.9-sec, 13.9-ft test waves from west and 7.5-sec, 9.6-ft test waves from north; and 4.8 ft adjacent to the city dock (gage 12) for 6.4-sec, 5.0-ft test waves from northeast for waves occurring during boating season. Considering all the boating season wave conditions, the wave-height criterion for Plan 42 was exceeded by 0.3 ft for 20-year waves from west for summer conditions and by 0.2 ft for 20-year waves from the unrefracted northeast direction for fall conditions. Considering construction costs, ease of navigation, and wave protection provided, Plan 42 appeared to be the optimum improvement plan. Typical wave patterns for Plan 42 are shown in Photos 95-108.

Plans 46 and 47 (test waves from west and unrefracted northeast)

44. Wave-height test results for Plans 46 and 47 are presented in Tables 18 and 19 for the west and unrefracted northeast directions. Maximum wave heights in the mooring area for Plans 46 and 47, respectively, were 2.3 and 2.7 ft for test waves from west; and 2.3 and 2.4 ft for test waves from the unrefracted northeast direction. The incremental removal of the absorber adjacent to the west breakwater (Plans 46 and 47) resulted in only a small increase of wave heights in the mooring area for test waves from the unrefracted northeast direction; however, test waves from west overtopping the west breakwater resulted in larger increases of wave heights in the mooring area. Wave energy associated with waves overtopping the west breakwater was not dissipated in areas where the absorber was removed. Wave pattern photographs obtained for Plans 46 and 47 are shown in Photos 109-112 for the west and unrefracted northeast directions.

Plans 48-51 (test waves from unrefracted northeast)

45. Results of wave-height tests for Plans 48-51 for test waves from the unrefracted northeast direction are presented in Table 20. Maximum wave heights obtained in the mooring area were 1.5, 1.6, 1.6, and 1.7 ft for Plans 48-51, respectively. The wave-height criterion was met for all these test plans. These tests indicated that with the vertical-walled city dock removed from the harbor, shoreward extensions of the east breakwater would not be necessary for test waves from the unrefracted northeast direction. Typical wave patterns for Plans 48-51 for waves from the unrefracted northeast direction are shown in Photos 113-116.

Plans 51-55 (test waves from north)

46. Wave-height measurements obtained for Plans 51-55 for test waves from north are presented in Table 21. Maximum wave heights in the mooring area were 1.6, 1.6, 1.6, 1.7, and 1.9 ft for Plans 51-55, respectively. All these plans resulted in wave heights within the 2.0-ft criterion in the mooring area. Wave patterns for Plans 51-55 for test waves from north are shown in Photos 117-121.

Plans 55 and 56 (test waves from unrefracted northeast)

47. Wave heights for Plans 55 and 56 are presented in Table 22 for test

waves from unrefracted northeast direction. Maximum wave heights were 2.1 and 2.2 ft, respectively, in the mooring area for Plans 55 and 56. The removal of the four 100-ft-long sections of the absorber adjacent to the west breakwater (Plan 56) appeared to have an insignificant impact on wave heights in the mooring area. Wave patterns obtained for Plans 55 and 56 for test waves from the unrefracted northeast direction are shown in Photos 122 and 123.

Plans 51-53, 55, and 56
(test waves from northeast)

48. Results of wave-height tests for Plans 51-53 and Plans 55 and 56 for test waves from northeast are presented in Table 23. Maximum wave heights obtained in the mooring area were 2.0, 2.0, 2.1, 2.7, and 2.6 ft, respectively, for Plans 51, 52, 53, 55, and 56. Both the 250- and 225-ft-long west breakwater extensions of Plans 51 and 52 resulted in wave heights within the 2.0-ft criterion. The segmented west breakwater absorber plan (Plan 56) reduced wave heights in the mooring area by 0.1 ft as opposed to the plan with the continuous absorber (Plan 55). Typical wave patterns for Plans 51-53, 55, and 56 for test waves from northeast are shown in Photos 124-128.

Plans 52 and 57 (test waves from west)

49. Wave heights with Plans 52 and 57 installed for test waves from west are presented in Table 24. Maximum wave heights in the mooring area were 2.1 and 2.2 ft for Plans 52 and 57, respectively. The removal of the four 100-ft-long sections of the west breakwater absorber (Plan 57) resulted in wave heights in the mooring area increasing by 0.1 ft. Wave patterns obtained for Plans 52 and 57 for test waves from west are shown in Photos 129 and 130.

Plan 58 (test waves from west, north,
northeast, and unrefracted northeast)

50. Results of wave-height tests for Plan 58 are presented in Table 25. Maximum wave heights in the mooring area were 2.2, 1.6, 2.0, and 2.2 ft for 20-year waves from the west, north, northeast, and unrefracted northeast test directions, respectively. Test results indicated that the segmented west breakwater absorber of Plan 58 yielded similar values in the mooring area as the continuous west breakwater absorber of Plan 42. Wave patterns obtained for Plan 58 are shown in Photos 131-134.

PART V: CONCLUSIONS

51. Based on the results of the hydraulic model investigation reported herein (with monochromatic wave conditions), it was concluded that:

<u>a</u>. For existing conditions, without the vertical-walled city dock (Base Test 1), rough and turbulent wave conditions existed in the harbor during periods of storm wave attack. Wave heights exceeding 3.0 ft in the mooring area and inner harbor for several test waves occurred during boating season.

<u>b</u>. Installation of the vertical-walled city dock (Base Test 2), in general, increased wave heights in the harbor with values exceeding 4.0 ft in the mooring area and inner harbor for several test waves occurring during boating season.

<u>c</u>. For existing conditions (Base Test 1 and Base Test 2), excessive energy entered the harbor through the navigation entrance, through the opening between the east breakwater and the shore, and due to overtopping of the existing breakwaters.

<u>d</u>. Initial wave-height measurements (Plans 1-6) indicated that absorbers inside the harbor and shoreward extensions of the east breakwater would not reduce wave heights in the harbor to acceptable levels, and that a breakwater extension at the entrance (Plan 6) would be required to prevent energy from entering the harbor.

<u>e</u>. With the original west breakwater extension and absorber of Plan 6, test results indicated that the city dock absorber (Plan 8) or a 125-ft-long shoreward east breakwater extension (Plan 12), would yield similar wave conditions in the mooring area.

<u>f</u>. Of the improvement plans tested with the initial west jetty extension (Plans 6-21), Plan 12 (300-ft-long lakeward west breakwater extension, west breakwater absorber, and 125-ft-long shoreward east breakwater extension) appeared to be optimum with respect to wave protection and costs; however, the entrance would be somewhat restricted.

<u>g</u>. For the Plan 12 harbor configuration, the 2.0-ft wave-height criterion in the mooring area will be exceeded by 0.4 ft for summer wave conditions from west with a 20-year recurrence interval. A 180-ft-long parapet wall installed on the west breakwater (Plan 15 or 16) will reduce wave heights to 2.0 ft for these incident wave conditions.

<u>h</u>. The installation of breakwater spurs inside the breakwaters (Plan 24), as an alternate to lakeward breakwater extensions, will not reduce wave heights in the mooring area to acceptable levels.

<u>i</u>. Parallel extensions of the east and west breakwaters (Plan 25) will provide adequate wave protection in the mooring area; however, cumulative lengths of these extensions exceed the

length required for a curved west extension, resulting in a more costly structure.

j. The crest elevation of the west breakwater extension can be reduced from +13 ft to +11 ft (Plan 31) and still provide adequate wave protection in the mooring area.

k. Of the improvement plans tested with a west jetty extension oriented to provide a wider entrance, Plan 42 (250-ft-long lakeward west breakwater extension, west breakwater absorber, and 150-ft-long shoreward east breakwater extension) appeared to be optimum with respect to wave protection, ease of navigation, and construction costs.

l. For the Plan 42 harbor configuration, the 2.0-ft wave-height criterion in the mooring area will be exceeded by 0.3 ft for summer wave conditions from west with a 20-year recurrence interval and 0.2 ft for fall wave conditions from the unrefracted northeast direction with a 20-year recurrence interval. To reduce wave heights to 2.0 ft in the mooring area, a 180-ft-long parapet wall installed on the west breakwater (Plan 15 or 16) is required for test waves from west; and a 25-ft-long shoreward extension of the east breakwater (Plan 41) is required for test waves from the unrefracted northeast direction.

m. The absorber installed adjacent to the west breakwater not only damps wave energy entering through the harbor openings, but also dissipates wave energy entering the harbor due to overtopping of the west breakwater. The removal of four 100-ft sections of this absorber (Plan 58), however, will have an insignificant impact on wave heights in the mooring area.

n. With the vertical-walled city dock removed from the harbor, the 150-ft-long shoreward extension of the east breakwater (Plan 42) can be removed without sacrificing wave protection in the mooring area.

52. Based on the results of the spectral wave tests (detailed in Appendix B), it was concluded that:

a. For the optimum improvement plan (Plan 58), wave heights in the mooring area were well within the established wave-height criterion for the spectral wave conditions tested.

b. A comparison of monochromatic and spectral wave conditions indicated that monochromatic waves resulted in slightly larger wave heights throughout the harbor, and monochromatic wave test results may be considered slightly conservative.

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Table 1

Wave Heights for All Approach Angles and Seasons

Recurrence Interval, year	Wave Height, ft Angle Class 1	Angle Class 2	Angle Class 3
	Winter		
5	4.9	9.2	12.5
10	6.6	10.5	13.1
20	8.2	11.5	14.1
50	10.5	13.1	15.1
100	12.1	14.4	15.7
	Spring		
5	3.6	3.3	7.2
10	3.9	4.3	8.5
20	4.3	5.6	9.5
50	5.9	6.9	11.2
100	7.2	8.2	12.5
	Summer		
5	3.6	4.9	6.9
10	4.3	5.9	7.5
20	5.2	6.6	8.2
50	7.5	7.2	8.9
100	9.2	7.5	9.2
	Fall		
5	6.9	8.9	12.1
10	7.5	9.8	12.8
20	7.9	10.8	13.4
50	8.5	12.1	14.4
100	9.2	13.1	15.4

Table 2

Significant Period by Angle Class and Wave Height

Wave Height ft	Significant Period, sec Angle Class 1	Angle Class 2	Angle Class 3
1	2.3	2.2	2.6
2	3.6	3.5	3.9
3	4.5	4.4	4.9
4	5.2	5.1	5.7
5	5.8	5.7	6.3
6	6.1	6.0	6.7
7	6.4	6.3	7.1
8	6.8	6.6	7.5
9	7.1	6.9	7.9
10	7.4	7.2	8.4
11	7.7	7.5	8.8
12	8.0	7.8	9.2
13	8.4	8.1	9.6
14	8.7	8.4	10.0
15	9.0	8.7	10.4
16	9.3	9.0	10.8
17	9.6	9.3	11.2
18	10.0	9.6	11.6
19	10.3	9.9	12.0
20	10.6	10.2	12.5
21	10.9	10.5	12.9
22	11.2	10.8	13.3
23	11.6	11.1	13.7
24	11.9	11.4	14.1
25	12.2	11.7	14.5

Table 3

Wave Heights for Base Test 1

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
						+3.0 ft swl										
West	5.2	3.7	3.6	2.6	0.5	0.4	0.4	0.5	0.4	0.3	0.5	0.4	0.8	0.7	1.2	1.1
						+5.5 ft swl										
	9.2	12.0	9.5	9.6	3.4	2.7	2.9	2.4	2.0	2.1	2.4	3.6	4.9	5.1	4.1	5.3
	9.9	6.2	10.9	9.7	3.5	2.7	2.7	1.8	2.0	1.7	1.9	2.6	3.3	5.3	3.9	4.2
		13.9	10.8	8.6	3.8	2.4	3.4	2.1	1.8	2.1	1.8	3.2	3.6	4.3	4.4	4.4
						+6.5 ft swl										
	7.1	6.3	9.3	7.9	2.1	1.3	2.3	1.4	1.0	1.1	0.9	1.6	2.7	1.7	3.5	3.0
	7.7	3.8	5.9	5.2	1.1	1.1	1.0	0.8	0.9	1.3	0.9	1.7	2.1	2.6	2.3	3.3
		7.9	10.5	10.2	3.0	2.4	2.8	2.5	1.4	2.2	2.3	2.8	3.2	3.6	3.1	4.0
	10.1	14.7	13.0	8.6	3.1	3.0	3.2	2.7	2.1	2.4	2.1	2.6	4.1	4.2	4.2	4.5
						+3.0 ft swl										
Northwest	6.2	6.0	8.0	10.3	2.8	2.1	1.6	2.5	1.5	1.4	2.5	1.4	2.5	1.9	2.3	3.1
						+4.0 ft swl										
	6.9	8.3	8.9	10.4	3.8	1.9	2.3	2.5	1.7	2.2	2.2	2.4	2.1	4.1	3.5	4.6
	7.5	4.6	4.7	8.8	2.4	2.0	2.5	1.3	1.4	1.7	1.3	2.2	3.2	2.3	3.5	3.7
		9.9	9.2	5.9	2.3	2.1	1.7	1.4	1.2	1.1	1.6	1.6	2.1	3.0	5.0	4.4

(Continued)

Table 3 (Continued)

	Test Wave		Wave Height, ft													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.0 ft swl									
	5.7	4.8	4.5	6.6	1.1	1.1	1.7	1.0	0.6	1.1	1.1	1.7	2.6	2.1	3.8	3.8
	6.2	6.3	7.1	10.4	2.1	3.3	2.7	1.8	1.4	2.1	1.8	2.0	3.3	2.5	3.0	3.3
	7.8	10.5	9.6	10.9	2.7	1.7	2.5	3.0	1.6	2.8	2.1	2.7	2.8	3.5	4.1	4.0
							+3.0 ft swl									
North	5.9	5.1	5.6	7.7	3.7	2.2	2.5	2.4	1.7	1.2	3.1	1.6	2.7	2.3	2.5	2.5
							+4.0 ft swl									
	6.9	7.9	8.2	10.4	4.8	2.4	3.6	4.1	2.5	3.1	3.5	2.8	4.0	3.0	3.2	4.2
	7.5	4.5	5.6	10.4	2.8	2.1	2.3	2.0	1.5	1.8	2.1	2.6	3.5	3.4	3.3	4.0
		9.6	8.3	12.6	3.1	3.7	2.9	2.9	2.4	1.9	3.4	2.2	3.7	3.7	4.5	4.7
							+5.0 ft swl									
	5.7	4.6	3.8	4.3	2.5	2.2	2.2	2.4	1.4	1.8	1.4	2.2	1.6	2.8	3.6	2.2
	6.2	6.1	6.8	11.9	4.9	2.3	3.3	3.3	2.7	2.2	2.3	4.0	4.3	3.5	5.5	3.8
	7.8	10.2	13.3	9.5	3.7	3.0	3.1	3.4	2.8	3.2	3.9	4.1	5.8	4.6	3.6	5.6
							+3.0 ft swl									
Northeast	5.9	4.3	4.7	6.0	3.2	3.1	2.6	2.6	1.9	1.5	3.2	1.7	1.5	2.7	2.4	2.1
	6.4	5.0	5.7	7.8	3.6	2.5	2.9	3.2	1.9	1.8	2.2	2.1	2.8	3.5	3.3	2.6
	6.7	2.9	3.9	5.1	2.4	2.5	1.9	2.4	1.5	1.2	1.1	2.8	2.7	2.3	2.5	2.7
		5.7	6.7	11.0	4.6	2.6	3.2	4.1	2.5	2.0	2.6	2.7	2.2	2.4	3.4	2.3

(Continued)

Table 3 (Concluded)

	Test Wave		Wave Height, ft													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+4.0 ft swl									
	4.9	2.8	3.2	4.5	2.2	1.3	1.4	1.7	0.9	0.7	1.9	1.1	1.3	1.8	2.3	1.8
	5.9	4.0	4.9	5.5	3.3	3.4	2.2	2.1	2.4	1.8	1.9	1.9	2.0	3.3	5.2	3.1
	6.9	5.8	8.1	9.5	5.4	3.1	3.6	5.2	3.4	4.1	3.2	3.0	4.2	3.6	3.8	2.5

(Sheet 3 of 3)

Table 4

Wave Heights at Various Locations Along Center Lines of Proposed Structures for Base Test 1

Direction	Test Wave Period sec	Test Wave Height ft	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 8A	Gage 9A	Gage 10A
			Wave Height, ft (Structures Not in Place)									
					+5.5 ft swl							
West	9.9	13.9	10.2	11.8	10.8	6.3	11.2	4.6	8.9	4.1	6.8	4.1
					+6.5 ft swl							
	7.7	7.9	9.8	12.9	9.3	5.3	9.7	4.8	8.7	4.5	8.0	7.3
	10.1	14.7	10.9	10.9	10.9	5.5	11.2	5.1	8.0	3.7	8.0	5.6
					+4.0 ft swl							
Northwest	7.5	9.9	8.2	10.2	7.0	5.1	9.6	3.3	6.4	3.3	4.6	4.7
					+5.0 ft swl							
	6.2	6.3	8.5	8.5	10.4	3.5	9.4	2.6	6.8	3.4	4.1	3.2
	7.8	10.5	8.7	12.1	9.2	5.0	10.0	4.2	8.1	3.7	6.0	5.3
					+4.0 ft swl							
North	7.5	9.6	11.5	11.4	13.1	6.6	8.7	5.8	5.5	6.6	4.7	3.4
					+5.0 ft swl							
	6.2	6.1	6.9	7.4	6.3	3.7	6.4	3.7	5.5	4.7	4.6	4.7
	7.8	10.2	10.0	10.3	9.7	6.2	9.7	5.6	7.9	5.4	5.2	5.5
					+3.0 ft swl							
Northeast	6.7	5.7	8.8	9.7	8.5	6.0	3.9	6.3	2.5	3.6	1.2	3.6
					+4.0 ft swl							
	5.9	4.0	5.9	5.0	5.8	7.0	3.6	6.9	2.9	5.5	3.1	5.4
	6.9	5.8	9.3	11.7	8.5	8.8	5.3	6.2	2.5	3.6	2.1	6.1

Table 5

Wave Heights for Base Test 2

Direction	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
								Wave Height, ft								
						+3.0 ft swl										
West	5.2	3.7	4.3	2.5	0.9	0.6	0.4	0.5	0.4	0.4	0.4	0.4	0.9	0.6	1.7	1.0
						+5.5 ft swl										
	9.2	12.0	10.5	11.1	4.4	2.7	3.2	2.4	2.4	2.4	3.0	2.7	4.8	6.1	5.1	6.3
	9.9	6.2	10.0	7.6	3.1	2.5	2.2	1.8	1.8	1.8	1.6	2.5	3.5	5.8	4.5	6.8
		13.9	11.4	9.7	3.5	3.0	2.9	2.1	2.1	2.1	1.9	2.8	5.3	6.6	5.9	5.5
						+6.5 ft swl										
	7.1	6.3	8.6	7.5	2.0	2.0	2.6	1.3	1.2	1.3	1.1	1.5	3.6	3.5	4.5	3.7
	7.7	3.8	6.1	4.2	1.0	1.0	1.1	1.0	0.6	0.7	0.7	0.8	1.9	3.3	2.6	3.0
		7.9	11.4	11.2	3.5	3.0	4.0	2.3	1.7	2.6	2.4	3.3	4.4	6.0	4.0	4.2
	10.1	14.7	11.2	10.1	4.6	3.1	3.7	2.6	2.4	2.4	1.8	3.5	4.7	7.5	5.8	6.7
						+3.0 ft swl										
Northwest	6.2	6.0	9.0	10.4	2.4	2.6	3.5	2.1	1.9	1.5	1.5	1.9	3.1	2.7	2.8	4.2
						+4.0 ft swl										
	6.9	8.3	8.0	10.5	4.1	2.4	3.5	3.3	2.1	2.5	2.7	3.2	3.1	4.1	5.4	5.4
	7.5	4.6	6.0	6.8	2.4	2.0	2.2	1.7	1.7	2.3	1.2	2.7	3.2	4.5	5.6	4.5
		9.9	9.4	7.4	3.0	2.3	3.0	2.4	1.3	1.9	2.0	2.0	3.1	4.0	6.5	4.9

(Continued)

(Sheet 1 of 3)

Table 5 (Continued)

	Test Wave		Wave Height, ft													
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.0 ft swl									
	5.7	4.8	4.7	6.9	2.9	1.2	1.9	1.1	0.7	1.6	1.4	2.5	3.0	3.5	4.6	4.1
	6.2	6.3	7.2	9.8	3.5	4.2	3.5	2.8	2.4	2.4	2.8	3.6	5.2	3.7	3.8	5.3
	7.8	10.5	11.3	9.1	2.8	2.5	3.7	2.0	1.6	2.5	1.9	3.7	4.0	5.5	5.0	5.1
							+3.0 ft swl									
North	5.9	5.1	4.9	3.2	4.2	1.9	2.2	2.5	1.9	1.4	3.2	2.3	2.0	2.8	2.9	3.8
							+4.0 ft swl									
	6.9	7.9	8.7	10.9	4.4	3.1	3.9	3.9	2.4	3.3	2.9	5.3	5.1	3.7	3.8	4.3
	7.5	4.5	5.1	5.4	3.5	2.3	2.8	2.3	1.9	2.1	1.9	3.1	6.3	2.9	2.4	2.6
		9.6	11.7	12.4	5.4	4.7	4.4	4.5	3.2	3.9	4.6	5.4	5.1	5.2	5.1	4.9
							+5.0 ft swl									
	5.7	4.6	4.4	2.3	3.4	2.6	2.7	2.5	1.8	1.5	1.7	1.6	2.9	3.7	3.9	3.3
	6.2	6.1	7.7	6.6	4.0	1.6	3.7	3.5	2.4	1.9	2.4	2.9	5.1	5.0	3.7	6.4
	7.8	10.2	11.2	13.8	5.6	4.4	5.2	4.6	3.8	4.3	5.0	5.1	6.1	6.4	5.6	6.1
							+3.0 ft swl									
Northeast	5.9	4.3	5.1	7.2	3.4	3.6	3.1	3.0	2.3	1.4	3.6	1.2	1.7	3.4	2.2	2.6
	6.4	5.0	6.0	8.5	3.6	2.9	3.8	4.3	1.9	2.0	2.2	1.7	3.0	3.3	3.4	3.5
	6.7	2.9	4.4	5.6	3.2	3.1	2.2	1.9	2.0	1.3	1.5	1.1	2.4	4.1	2.6	4.5
		5.7	8.1	9.3	4.5	4.3	4.0	4.0	2.7	3.8	2.3	4.0	3.6	2.8	5.0	3.4

(Continued)

Table 5 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
+4.0 ft swl																
	4.9	2.8	3.2	3.9	2.4	1.6	2.8	0.9	0.6	0.6	1.0	0.6	1.3	1.4	3.2	2.9
	5.9	4.0	5.6	6.2	3.6	3.9	3.0	2.2	2.4	1.4	2.3	1.5	2.2	2.5	5.7	3.7
	6.9	5.8	8.2	8.1	6.1	3.1	4.5	4.6	3.4	2.9	3.2	3.7	4.1	3.7	3.8	3.1

Table 6

Wave Heights for Plans 1-5 for Test Waves from Northeast

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
+3.0 ft swl																
1	5.9	4.3	6.1	7.6	4.1	3.2	2.7	3.8	2.7	1.6	3.4	0.8	1.4	2.4	3.0	3.2
	6.4	5.0	7.1	8.4	4.5	3.4	2.9	4.4	2.6	2.2	2.9	1.4	3.3	3.1	3.0	3.4
	6.7	5.7	8.6	9.6	5.8	3.9	4.0	5.2	3.5	3.3	3.8	4.0	4.1	3.9	4.3	4.6
2	5.9	4.3	6.2	7.5	4.2	3.7	2.9	3.3	2.5	1.3	3.7	1.1	1.1	1.5	2.7	3.3
	6.4	5.0	7.2	8.8	3.4	3.1	3.1	3.9	2.0	2.1	2.6	1.9	1.6	2.2	2.5	4.0
	6.7	5.7	8.7	9.6	5.0	3.6	4.1	4.5	2.5	2.4	3.4	2.3	1.7	1.5	2.5	4.0
3	5.9	4.3	5.7	7.5	3.9	1.4	2.4	2.6	2.0	1.4	3.4	1.3	1.0	1.8	2.2	3.3
	6.4	5.0	6.9	8.7	3.9	1.8	2.4	2.7	1.3	2.0	2.0	2.1	1.5	2.1	2.3	3.3
	6.7	5.7	8.5	9.4	4.5	2.3	3.0	3.2	2.1	1.7	2.4	2.7	2.3	1.9	1.8	3.8
4	5.9	4.3	5.9	7.1	3.6	1.3	2.0	2.4	1.7	1.1	2.8	1.2	0.9	1.2	1.6	2.2
	6.4	5.0	7.0	8.3	3.9	1.7	2.3	2.9	1.3	1.8	1.9	1.4	1.3	1.7	1.8	2.4
	6.7	5.7	9.0	9.6	4.7	2.5	3.2	3.1	1.5	1.8	2.4	2.2	1.1	1.9	2.0	2.8
5	5.9	4.3	6.1	7.2	3.2	1.6	2.0	1.9	2.1	1.4	3.0	1.6	1.0	1.3	1.5	1.7
	6.4	5.0	6.7	8.2	2.9	1.7	1.9	2.4	1.7	1.5	1.9	1.9	1.0	1.6	1.9	2.5
	6.7	5.7	9.1	9.8	3.8	1.8	2.6	2.8	1.7	1.6	2.1	2.0	1.2	1.1	1.7	2.7
+4.0 ft swl																
1	5.9	4.0	5.9	6.4	3.7	3.3	2.4	2.2	2.8	2.4	2.2	1.7	1.4	2.9	6.4	3.8
2	5.9	4.0	5.6	6.5	4.0	3.7	2.7	2.0	2.4	1.7	2.2	1.6	1.1	2.4	2.0	3.8

Table 7

Wave Heights for Plans 6-12 for Test Waves from Northeast, +3.0 ft swl

	Test Wave		Wave Height, ft													
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
6	5.9	4.3	5.3	2.3	1.1	0.6	0.6	0.6	0.6	0.5	0.7	0.5	0.3	0.8	0.5	0.6
	6.4	5.0	7.2	3.1	1.2	0.7	0.6	0.7	0.5	0.5	0.4	0.7	0.5	1.1	0.7	1.0
	6.7	5.7	9.3	3.8	1.1	0.6	0.9	0.9	0.6	0.5	0.5	0.7	0.4	0.9	0.6	1.0
7	6.4	5.0	6.7	3.7	1.4	0.8	0.9	0.8	0.8	0.5	0.7	0.8	0.4	1.1	1.1	1.3
	6.7	5.7	9.2	4.2	1.4	0.8	0.9	1.0	0.7	0.6	0.6	1.0	0.6	0.8	0.8	0.9
8	6.4	5.0	6.8	3.7	1.7	0.9	1.4	1.4	1.2	1.4	1.5	1.1	1.6	2.8	3.1	1.5
	6.7	5.7	9.2	2.9	1.6	1.0	1.6	1.6	1.5	1.4	1.3	0.9	1.8	2.9	3.1	1.7
9	6.4	5.0	7.3	4.4	2.0	1.3	2.4	2.1	1.5	1.6	2.0	1.3	2.3	3.8	4.2	2.2
	6.7	5.7	9.2	3.9	1.8	1.3	2.0	2.2	1.9	1.5	1.7	1.5	1.8	3.5	3.4	2.1
10	6.4	5.0	7.1	4.1	1.8	1.6	2.1	1.5	1.3	1.3	1.5	1.3	1.8	2.9	3.6	1.9
	6.7	5.7	9.1	3.0	1.4	2.2	1.4	1.8	2.1	1.6	1.7	1.1	2.0	2.7	3.4	1.4
11	6.4	5.0	7.2	3.7	1.6	1.1	1.2	1.9	0.9	0.8	1.2	0.9	0.9	1.6	2.0	1.3
	6.7	5.7	9.5	4.1	1.5	0.9	1.3	2.0	1.4	1.1	1.2	1.4	1.9	1.5	2.2	1.3
12	6.7	5.7	8.7	3.4	1.5	1.2	1.2	1.6	1.3	1.3	1.2	1.1	1.9	1.6	2.0	1.4

Table 8

Wave Heights for Plans 8, 9, and 12 for Test Waves from the

Unrefracted Northeast Direction, +3.0 ft swl

	Test Wave		Wave Height, ft													
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
8	6.7	5.7	9.0	4.8	1.7	1.0	1.5	1.6	1.7	1.8	1.3	1.4	2.8	2.8	3.1	1.8
9	6.7	5.7	8.9	4.9	1.7	1.3	2.3	1.8	1.4	1.7	1.3	1.9	4.0	4.2	3.6	3.1
12	6.7	5.7	8.8	5.2	1.7	1.3	1.8	1.8	1.2	1.3	1.1	1.5	1.7	2.9	2.5	2.4

Table 9

Wave Heights for Plans 12-16 for Test Waves from West

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.5 ft swl									
12	9.2	12.0	11.4	4.2	2.4	1.7	2.0	1.4	1.3	1.6	1.2	2.0	2.7	2.1	1.9	3.2
	9.9	13.9	12.2	4.1	2.3	1.8	2.0	1.5	1.1	1.4	1.1	1.9	2.5	2.8	2.8	4.1
13	9.2	12.0	11.8	3.5	1.2	1.1	1.3	0.9	0.6	0.9	0.7	1.1	1.5	1.8	2.2	1.8
	9.9	13.9	11.8	3.7	1.4	1.1	1.3	1.1	0.7	1.1	0.9	1.1	1.4	1.6	2.7	2.4
14	9.2	12.0	11.6	4.9	2.6	1.8	1.9	1.6	1.0	1.4	1.2	1.9	2.4	2.6	2.8	3.0
	9.9	13.9	12.0	4.2	2.6	1.4	1.9	1.5	1.0	1.3	1.1	1.7	2.6	2.4	2.6	4.5
15	9.2	12.0	11.4	4.4	2.8	1.8	1.9	1.4	1.1	1.3	1.1	2.0	2.3	3.0	2.7	3.4
	9.9	13.9	11.8	3.7	2.1	1.4	1.9	1.4	1.2	1.5	1.2	2.0	2.5	2.6	2.7	4.2
16	9.2	12.0	11.5	4.4	2.5	2.0	2.0	1.4	1.2	1.3	1.2	2.0	2.6	3.1	2.8	3.6
	9.9	13.9	12.2	3.4	2.2	1.6	1.8	1.4	1.1	1.3	1.1	1.7	2.0	2.8	2.7	4.0
							+6.5 ft swl									
12	7.7	7.9	9.7	3.8	3.1	1.9	2.4	1.5	1.1	1.5	1.7	1.7	1.7	2.4	2.7	2.7
13	7.7	7.9	9.8	3.3	1.7	0.8	1.3	1.1	0.6	0.8	0.7	0.7	1.2	1.7	2.2	1.9
14	7.7	7.9	9.6	3.6	3.2	1.2	2.4	1.5	1.0	1.5	1.6	1.7	1.7	2.5	2.7	2.2
15	7.7	7.9	9.5	3.5	2.9	1.3	1.9	1.3	1.0	1.3	1.5	1.4	1.4	2.4	2.4	[illegible]
16	7.7	7.9	9.5	3.6	3.1	1.4	1.9	1.4	0.9	1.1	1.2	1.3	1.4	2.2	2.0	2.4

Table 10

Wave Heights for Plans 17-20 for Test Waves from West

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.5 ft swl									
17	9.2	12.0	11.2	4.7	2.8	1.6	1.8	1.6	1.2	1.4	1.6	1.7	1.9	2.5	4.3	3.1
	9.9	13.9	12.6	3.7	2.2	1.6	1.8	1.5	1.3	1.4	1.2	1.6	2.1	2.7	4.4	3.4
18	9.2	12.0	11.6	4.7	2.5	2.0	2.4	1.7	1.3	1.6	1.3	2.1	2.2	3.1	3.5	3.1
	9.9	13.9	12.1	3.6	2.5	2.3	2.6	1.7	1.3	1.7	1.3	1.9	2.0	2.7	3.6	3.9
19	9.2	12.0	11.2	4.6	2.4	1.7	1.9	1.3	1.0	1.2	1.0	1.4	1.9	2.6	2.4	3.1
	9.9	13.9	12.1	3.3	2.6	2.0	2.1	1.5	1.4	1.5	1.3	1.9	1.9	2.1	2.9	3.6
20	9.2	12.0	11.5	4.7	2.5	1.5	1.8	1.4	1.0	1.2	1.1	1.7	1.7	2.5	2.2	2.8
	9.9	13.9	12.5	3.4	2.3	1.3	1.5	1.2	1.0	1.2	1.0	1.4	1.6	2.0	2.8	3.5
							+6.5 ft swl									
17	7.7	7.9	10.3	4.0	3.5	1.7	2.4	1.7	1.3	1.8	1.7	1.9	2.2	3.1	2.7	3.1
18	7.7	7.9	10.0	4.0	3.7	1.9	2.7	1.8	1.3	2.0	2.0	2.0	2.3	2.8	3.7	3.6
19	7.7	7.9	9.8	3.7	3.3	1.5	2.2	1.4	1.0	1.5	1.3	1.5	1.7	2.3	3.0	2.1
20	7.7	7.9	10.0	3.6	3.2	1.3	2.0	1.3	1.0	1.1	1.1	1.1	1.3	2.4	2.5	2.3

Table 11

Wave Heights for Plan 12

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
West	[illegible]	3.7	0.8	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.4	0.2
							+5.5 ft swl									
	9.2	12.0	4.1	3.6	2.4	1.7	2.0	1.4	1.3	1.6	1.2	2.0	2.7	3.6	2.7	3.2
	9.9	6.2	2.7	1.9	1.7	1.5	1.4	1.2	1.0	1.3	0.8	1.4	1.6	2.1	2.6	2.5
		13.9	4.3	2.5	2.3	1.8	2.0	1.5	1.1	1.4	1.1	1.9	2.5	3.2	2.8	4.1
							+6.5 ft swl									
	7.1	6.3	2.5	2.6	1.7	1.8	1.9	1.3	0.7	1.2	1.0	1.1	2.9	3.0	2.1	2.2
	7.7	3.8	1.6	0.7	0.4	0.5	0.5	0.5	0.5	0.6	0.5	0.8	1.1	1.8	1.0	1.2
		7.9	4.1	3.5	3.1	1.9	2.4	1.5	1.1	1.5	1.7	1.7	1.7	2.6	2.9	2.7
	10.1	14.7	5.3	3.7	3.0	2.5	2.8	2.2	1.7	2.0	1.4	2.4	3.9	3.6	3.3	4.8
							+3.0 ft swl									
Northwest	6.2	6.0	1.9	0.4	0.4	0.3	0.5	0.3	0.2	0.3	0.3	0.4	0.4	1.3	1.0	0.8
							+4.0 ft swl									
	6.9	8.3	3.5	1.2	1.0	0.7	1.0	0.7	0.5	0.6	0.4	0.6	1.0	1.9	[illegible]	1.2
	7.5	4.6	2.3	0.6	0.5	0.3	0.4	0.3	0.2	0.3	0.2	0.3	1.0	1.1	[illegible]	0.6
		9.9	3.1	1.1	0.8	0.7	0.8	0.7	0.5	0.5	0.4	0.7	1.0	1.6	[illegible]	0.9

(Continued)

(Sheet 1 of 3)

Table 11 (Continued)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.0 ft swl									
	5.7	4.8	1.6	0.6	0.4	0.6	0.6	0.5	0.3	0.3	0.4	0.4	0.6	0.7	1.3	0.7
	6.2	6.3	2.1	0.7	0.8	0.8	0.8	0.7	0.5	0.6	0.4	0.6	1.2	1.8	1.7	1.0
	7.8	10.5	3.2	1.7	1.8	1.1	1.6	1.0	0.8	1.0	0.8	1.3	2.0	2.6	2.5	1.9
							+3.0 ft swl									
North	5.9	5.1	3.1	1.5	1.0	0.7	0.8	0.5	0.6	0.5	0.6	0.4	1.2	2.1	1.4	1.1
							+4.0 ft swl									
	6.9	7.9	5.4	2.9	1.5	1.0	1.3	1.2	1.0	1.1	1.0	1.3	2.3	2.7	2.3	2.6
	7.5	4.5	3.8	1.8	0.9	0.5	0.9	0.6	0.9	1.1	0.7	0.5	1.3	2.3	2.0	1.5
		9.6	8.6	3.2	1.6	1.2	1.4	1.5	1.3	1.0	1.3	1.5	2.9	3.5	3.0	3.3
							+5.0 ft swl									
	5.7	4.6	2.9	1.3	0.9	0.8	0.9	1.1	0.5	0.9	0.6	0.6	0.9	3.2	1.6	1.3
	6.2	6.1	3.8	1.6	1.2	1.0	1.1	1.1	0.8	0.9	1.0	1.2	2.1	2.6	2.3	1.5
	7.8	10.2	6.8	2.5	1.9	1.9	2.1	1.8	1.1	1.4	1.7	2.8	4.3	3.2	2.3	1.7
							+3.0 ft swl									
Northeast	5.9	4.3	3.8	2.4	1.5	1.0	1.2	1.0	0.9	0.8	1.6	0.7	1.4	1.4	2.2	1.3
	6.4	5.0	5.0	2.4	1.5	0.7	1.2	1.3	0.8	0.8	0.8	1.0	2.3	4.0	1.9	1.3
	6.7	2.9	4.5	1.5	1.0	0.6	1.1	0.6	0.6	0.7	0.6	0.9	0.5	2.4	1.6	1.2
		5.7	5.0	2.5	1.5	1.2	1.2	1.6	1.3	1.3	1.2	1.1	1.9	2.7	2.2	1.4

(Continued)

Table 11 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
						+4.0 ft swl										
	4.9	2.8	2.8	1.7	0.7	0.8	0.3	0.4	0.4	0.4	1.0	0.7	0.5	1.0	1.8	1.1
	5.9	4.0	4.1	2.2	1.7	0.7	1.1	0.9	0.9	0.8	0.9	0.7	1.3	2.2	1.8	2.0
	6.9	5.8	6.7	2.7	1.6	1.0	1.8	1.8	1.0	1.2	2.1	1.8	4.2	2.6	3.1	1.6
						+3.0 ft swl										
Northeast (unrefracted)	5.9	4.3	2.7	1.5	0.7	0.6	1.1	0.7	0.6	0.3	0.9	0.3	1.1	1.2	1.5	0.9
	6.4	5.0	4.8	2.7	2.1	1.1	1.4	1.4	1.2	0.7	1.0	1.2	1.4	2.2	2.5	1.6
	6.7	2.9	3.4	1.5	1.1	0.9	0.8	0.5	0.4	0.5	0.5	1.0	1.1	2.1	1.6	0.7
		5.7	6.1	3.0	1.7	1.3	1.8	1.8	1.2	1.3	1.1	1.5	1.7	2.9	2.5	2.4
						+4.0 ft swl										
	4.9	2.8	1.7	1.2	0.7	0.5	0.3	0.5	0.4	0.3	1.0	0.4	0.5	0.7	0.9	0.2
	5.9	4.0	3.7	2.7	1.5	0.6	1.5	0.7	1.0	0.4	0.8	0.4	1.2	1.2	2.7	1.9
	6.9	5.8	6.3	3.3	2.5	1.1	1.8	1.5	1.2	1.2	1.3	1.3	1.9	3.3	2.5	2.2

Table 12

Wave Heights for Plans 21-25 for Test Waves from North

Plan	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
								+4.0 ft swl								
21	6.9	7.9	5.2	1.9	1.0	0.5	0.7	0.8	0.6	0.7	0.7	0.6	1.0	1.4	2.0	0.9
	7.5	9.6	5.9	1.5	0.8	0.5	0.7	0.6	0.8	0.6	0.6	0.5	0.6	1.4	1.3	0.8
22	6.9	7.9	9.4	11.6	4.3	2.3	3.6	3.2	2.5	2.2	3.2	4.1	4.1	4.6	3.7	5.3
	7.5	9.6	9.8	8.9	4.0	2.3	3.5	3.2	2.4	2.5	3.2	4.2	4.3	6.0	3.8	4.6
23	6.9	7.9	9.8	10.9	2.9	1.2	2.0	1.9	1.8	1.3	1.7	1.7	2.9	4.4	2.9	4.3
	7.5	9.6	10.2	9.1	4.1	2.4	3.2	2.9	2.1	1.9	2.8	2.3	3.8	4.8	3.3	4.1
24	6.9	7.9	10.1	10.0	2.1	1.1	2.0	1.8	1.2	1.2	1.3	1.3	2.5	[illegible]	2.9	2.0
	7.5	9.6	11.0	11.8	4.0	2.3	3.4	2.7	2.2	2.0	3.4	2.7	3.4	4.0	2.3	2.4
25	6.9	7.9	10.7	4.0	1.7	0.8	1.2	1.1	0.7	1.1	1.2	1.5	1.1	1.5	1.9	1.7
	7.5	9.6	10.8	2.7	1.3	0.6	1.2	1.1	1.0	1.1	0.8	0.8	1.0	2.1	2.3	1.1
								+5.0 ft swl								
21	5.7	4.6	3.0	1.2	0.8	0.5	0.5	0.6	0.6	0.5	0.3	0.5	0.5	2.1	1.1	0.6
	6.2	6.1	3.8	1.9	0.9	0.7	0.7	1.1	0.9	0.8	0.7	0.8	0.8	1.5	2.2	0.8
22	6.2	6.1	6.7	8.9	3.4	1.6	2.9	2.7	1.8	1.7	1.8	1.5	3.3	4.4	3.2	5.0
23	6.2	6.1	6.7	8.4	3.3	1.9	2.7	2.4	1.7	1.8	2.0	1.5	2.4	5.7	2.5	3.1
24	6.2	6.1	6.8	9.4	3.5	1.9	2.8	2.1	1.7	2.3	2.7	2.0	2.7	5.1	2.9	2.2
25	6.2	6.1	7.2	1.8	0.9	0.9	0.8	1.2	0.9	0.9	1.1	0.7	1.0	2.2	2.3	0.9

Table 13

Wave Heights for Plans 26-31 for Test Waves from Northeast

	Test Wave		Wave Height, ft													
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
26	6.7	5.7	7.1	3.5	2.2	1.5	1.6	1.5	1.1	1.5	1.3	1.8	2.4	2.0	2.1	2.0
27	6.7	5.7	7.0	3.5	2.3	1.5	2.0	1.9	1.3	1.5	1.5	1.8	2.9	2.8	2.9	2.4
28	6.7	5.7	5.8	2.6	1.7	1.0	1.5	1.5	1.2	1.2	1.0	0.8	2.3	1.9	2.3	2.0
29	6.7	5.7	5.9	2.2	1.2	1.0	1.2	1.4	0.8	1.3	1.0	1.2	2.9	2.9	2.2	2.1
30	6.7	5.7	4.7	2.7	1.8	1.2	1.6	1.2	1.4	1.5	1.2	1.4	2.7	2.4	2.1	1.9
31	6.7	5.7	4.2	1.9	1.0	0.9	1.2	1.0	1.1	1.0	0.9	1.1	2.2	2.5	2.0	1.9
							+4.0 ft swl									
26	5.9	4.0	3.5	2.9	2.0	1.3	2.0	1.6	1.2	0.9	0.8	0.8	1.4	2.6	2.9	2.6
27	5.9	4.0	3.7	2.9	1.7	1.3	2.1	1.7	1.7	1.1	0.9	1.0	2.2	2.6	3.4	2.4
28	5.9	4.0	5.1	3.2	2.0	1.4	2.2	1.6	1.8	1.5	1.1	1.2	2.7	2.4	3.3	2.1
29	5.9	4.0	5.8	3.0	2.0	2.0	2.1	1.8	1.3	1.1	1.1	1.0	2.6	4.3	2.0	1.5
30	5.9	4.0	3.7	2.4	1.6	1.6	1.7	1.4	1.1	1.1	1.2	0.4	1.8	3.2	2.3	1.6
31	5.9	4.0	4.6	2.5	1.5	1.8	2.0	0.8	1.2	1.2	1.0	0.9	2.0	4.1	3.2	1.4

Table 14

Wave Heights for Plans 31-33 for Test Waves from the Unrefracted Northeast Direction

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
31	6.7	5.7	6.7	3.9	2.5	1.3	2.0	2.3	1.4	0.9	1.3	1.2	1.9	3.6	2.6	1.8
32	6.7	5.7	6.6	4.1	2.5	1.3	1.9	2.2	1.5	0.9	1.2	1.3	2.0	3.4	2.5	1.8
33	6.7	5.7	7.2	3.6	2.3	1.7	2.2	2.0	1.4	0.9	1.3	1.5	1.7	3.1	1.7	1.9
							+4.0 ft swl									
31	5.9	4.0	4.6	2.6	1.2	1.0	1.4	0.9	1.3	0.4	0.7	0.5	1.2	2.3	2.4	2.3
32	5.9	4.0	5.0	2.4	1.5	0.8	0.9	1.0	1.2	0.4	0.9	0.5	1.2	2.2	1.6	2.2

Table 15

Wave Heights for Plan 34

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
						+5.5 ft swl										
West	9.9	13.9	3.6	2.8	2.2	1.9	2.0	1.6	1.0	1.3	1.1	1.7	2.9	3.3	2.8	3.3
						+6.5 ft swl										
	7.7	7.9	3.8	3.6	3.0	1.9	2.3	1.4	1.0	1.6	1.1	1.9	2.5	3.0	2.3	2.9
						+4.0 ft swl										
North	7.5	9.6	6.5	2.8	1.8	0.9	1.4	1.2	1.1	0.9	1.0	1.4	2.3	3.5	1.9	1.9
						+5.0 ft swl										
	6.2	6.1	3.8	2.1	1.3	0.9	1.0	0.8	0.6	1.0	1.0	1.1	1.4	2.3	1.4	1.5
						+3.0 ft swl										
Northeast	6.7	5.7	5.8	3.2	2.2	1.1	1.7	1.8	1.3	1.0	1.1	1.1	2.3	3.1	2.1	1.9
						+4.0 ft swl										
	5.9	4.0	5.1	3.1	2.1	1.2	1.2	1.3	1.2	0.7	1.1	0.8	0.9	2.7	1.1	2.4
						+3.0 ft swl										
Northeast (unrefracted)	6.7	5.7	8.8	4.8	2.3	1.5	1.9	2.5	1.0	1.2	1.3	1.5	1.9	3.2	2.0	3.7
						+4.0 ft swl										
	5.9	4.0	4.4	2.6	1.8	0.6	1.0	1.0	0.9	0.7	1.1	0.5	0.7	1.6	1.6	2.4

Table 16

Wave Heights for Plans 34-45 for Test Waves from the

Unrefracted Northeast Direction, +3.0 ft swl

	Test Wave		Wave Height, ft													
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
34	6.7	5.7	8.8	4.8	2.3	1.5	1.9	2.5	1.0	1.2	1.3	1.5	1.9	3.2	2.0	3.7
35	6.7	5.7	5.1	2.7	1.6	1.2	1.3	1.6	0.8	1.0	0.9	1.1	1.6	2.8	1.6	2.2
36	6.7	5.7	5.8	3.2	1.9	1.2	1.0	2.2	0.8	1.0	1.0	1.1	1.8	2.4	2.2	2.2
37	6.7	5.7	5.6	3.2	1.8	1.2	1.2	2.2	0.9	1.0	1.0	1.2	1.6	2.2	2.0	2.2
38	6.7	5.7	4.7	3.1	1.7	1.1	1.6	2.1	0.8	1.0	0.9	1.4	1.7	2.4	1.4	2.1
39	6.7	5.7	5.2	3.2	1.8	1.2	1.4	1.2	1.0	0.7	1.0	1.5	1.7	3.0	1.0	1.8
40	6.7	5.7	8.4	5.0	2.6	1.6	2.0	1.5	1.4	1.0	1.3	1.8	1.2	3.4	1.9	3.2
41	6.7	5.7	8.7	4.5	2.0	1.6	2.0	1.8	0.9	1.2	1.1	1.8	1.7	3.3	1.9	3.2
42	6.7	5.7	8.5	4.4	2.0	1.6	1.9	2.2	1.0	1.3	1.3	1.6	1.7	3.4	2.0	3.4
43	6.7	5.7	8.2	4.4	2.7	1.5	1.6	2.2	1.3	1.	1.5	1.6	1.7	3.1	2.3	3.4
44	6.7	5.7	8.5	4.5	2.4	1.7	1.9	1.7	1.2	1.1	1.3	1.9	1.3	3.2	1.9	3.1
45	6.7	5.7	8.7	3.8	2.0	1.5	1.8	1.5	1.2	0.9	1.1	1.5	1.7	3.9	1.6	2.7

Table 17

Wave Heights for Plan 42

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
West	5.2	3.7	1.0	0.3	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2
							+5.5 ft swl									
	9.2	12.0	3.4	3.5	2.7	1.9	2.0	1.4	1.1	1.4	1.1	1.9	2.8	3.6	2.2	2.7
	9.9	6.2	4.4	2.9	1.9	1.9	1.6	1.3	1.2	1.0	1.2	1.5	3.1	4.2	2.5	2.7
		13.9	3.9	3.0	2.8	2.0	2.0	1.7	1.2	1.6	1.3	1.8	3.7	3.9	2.8	4.5
							+6.5 ft swl									
	7.1	6.3	3.1	1.8	1.4	1.4	1.5	1.4	0.8	1.1	0.8	1.3	2.0	2.0	2.2	1.8
	7.7	3.8	1.1	0.9	0.5	0.3	0.4	0.4	0.3	0.5	0.3	0.3	0.7	1.7	0.7	1.0
		7.9	3.4	2.2	1.7	2.0	2.3	1.9	1.0	1.5	1.1	1.6	2.2	3.4	2.1	3.2
	10.1	14.7	6.1	4.3	3.2	2.0	3.1	2.0	1.6	2.2	1.5	2.3	4.0	5.2	3.4	4.3
							+3.0 ft swl									
Northwest	6.2	6.0	1.9	0.8	0.4	0.3	0.4	0.3	0.3	0.3	0.3	0.2	0.5	1.2	0.6	0.5
							+4.0 ft swl									
	6.9	8.3	2.3	1.1	1.1	0.6	0.8	0.7	0.5	0.7	0.5	0.5	1.3	2.0	1.6	0.9
	7.5	4.6	3.2	0.8	0.6	0.5	0.7	0.6	0.5	0.6	0.4	0.4	1.1	1.9	1.1	0.4
		9.9	2.5	1.2	0.8	0.8	1.0	1.0	0.6	0.7	0.6	0.8	1.7	2.4	1.5	1.4

(Continued)

(Sheet 1 of 3)

Table 17 (Continued)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.0 ft swl									
	5.7	4.8	2.1	1.0	0.5	0.5	0.7	0.4	0.3	0.[illegible]	0.3	0.3	0.5	0.8	1.0	0.6
	6.2	6.3	2.4	1.0	0.8	1.1	1.2	0.7	0.8	0.5	0.6	0.4	1.3	3.2	1.6	0.8
	7.8	10.5	3.6	1.4	1.3	1.5	1.3	1.1	0.7	1.1	0.8	1.2	2.3	3.7	1.7	1.7
							+3.0 ft swl									
North	5.9	5.1	2.8	1.5	0.8	0.5	0.6	0.6	0.5	0.6	0.7	0.4	0.6	1.8	0.9	1.2
							+4.0 ft swl									
	6.9	7.9	6.4	2.1	1.4	0.9	0.9	1.1	0.8	1.0	0.8	0.8	1.9	2.7	2.1	2.0
	7.5	4.5	4.2	1.8	1.1	0.5	1.0	0.9	0.8	1.0	0.7	0.6	1.1	3.5	1.4	1.5
		9.6	6.7	2.5	1.7	1.2	1.9	1.5	1.2	1.0	1.3	1.0	2.6	4.0	2.1	2.0
							+5.0 ft swl									
	5.7	4.6	2.8	1.3	1.0	0.8	0.6	0.7	0.6	0.7	0.5	0.5	0.9	2.5	0.8	1.1
	6.2	6.1	3.8	2.0	1.3	0.7	1.0	1.2	0.6	0.8	0.8	0.8	1.2	3.2	1.5	1.6
	7.8	10.2	6.3	2.5	1.4	1.3	2.2	1.6	1.2	1.3	1.3	1.7	3.1	5.2	2.1	1.7
							+3.0 ft swl									
Northeast	5.9	4.3	4.8	2.2	1.4	0.8	0.9	1.1	0.9	0.6	1.1	0.7	1.5	3.2	1.6	1.8
	6.4	[illegible].0	6.3	3.1	2.0	1.0	1.1	2.1	1.2	0.9	1.0	1.0	1.7	4.8	1.2	1.5
	6.7	2.9	4.6	2.3	1.2	0.7	1.0	1.2	0.7	0.7	0.6	1.0	0.9	2.6	0.9	1.7
		5.7	6.6	2.3	1.8	0.8	1.2	1.7	1.0	0.9	1.0	1.0	2.0	3.2	1.8	1.5

(Continued)

(Sheet 2 of 3)

Table 17 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+4.0 ft swl									
	4.9	2.8	2.2	1.4	0.9	0.5	0.9	0.5	0.8	0.4	0.8	0.3	0.4	1.[illegible]	1.1	0.6
	5.9	4.0	4.8	2.4	1.8	1.2	1.2	1.1	0.9	0.9	1.0	1.0	1.2	3.9	1.4	2.1
	6.9	5.8	7.6	3.1	2.1	1.2	1.8	1.6	0.9	1.1	1.6	1.6	2.2	2.8	1.9	2.0
							+3.0 ft swl									
Northeast	5.9	4.3	4.4	2.2	1.3	0.8	1.3	0.9	0.9	0.5	1.2	0.7	1.1	2.1	1.1	1.2
(unre-	6.4	5.0	3.9	3.1	2.1	0.9	1.0	1.5	1.3	0.9	1.0	1.3	1.2	2.4	1.0	1.6
fracted)	6.7	2.9	2.1	1.6	1.0	0.5	0.6	0.7	0.6	0.3	0.3	0.8	0.3	1.1	0.6	1.0
		5.7	8.5	4.4	2.0	1.6	1.9	2.2	1.0	1.3	1.3	1.6	1.7	3.4	2.0	3.4
							+4.0 ft swl									
	4.9	2.8	2.2	1.2	0.8	0.5	0.5	0.3	0.6	0.4	0.7	0.3	0.1	0.5	0.7	0.2
	5.9	4.0	4.0	2.4	1.6	0.8	0.8	0.9	0.9	0.8	1.1	0.7	0.9	1.5	0.8	1.5
	6.9	5.8	6.3	3.9	2.6	1.1	2.5	2.3	1.5	1.3	1.4	1.4	2.5	3.3	2.0	2.8

Table 18

Wave Heights for Plans 46 and 47 for Test Waves from West

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+5.5 ft swl									
46	9.9	13.9	3.5	2.9	2.8	2.5	2.1	2.1	1.4	2.0	1.2	2.4	2.9	3.0	3.1	3.7
47			3.8	2.7	2.8	2.5	2.7	2.0	1.3	1.6	1.2	2.0	3.2	3.8	2.9	4.3
							+6.5 ft swl									
46	7.7	7.9	3.5	2.2	1.8	2.4	2.3	2.0	1.0	1.6	1.0	1.7	2.7	3.4	1.9	2.9
47			4.6	3.6	2.8	1.9	2.7	1.7	1.1	1.6	1.3	1.7	2.5	3.9	3.0	2.5

Table 19

Wave Heights for Plans 46 and 47 for Test Waves from the Unrefracted Northeast Direction

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
46	6.7	5.7	7.2	4.0	2.1	1.8	2.3	1.9	1.3	1.1	1.2	1.9	1.7	3.6	1.8	2.9
47			7.3	4.4	2.4	2.1	2.4	1.9	1.7	1.2	1.5	2.3	1.9	3.7	2.0	3.0

Table 20

Wave Heights for Plans 48-51 for Test Waves from the Unrefracted Northeast Direction

Plan	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
48	6.7	5.7	8.0	4.0	2.1	1.1	1.5	1.5	1.1	1.1	1.5	2.0	1.3	3.0	2.2	2.0
49			8.0	4.0	2.0	1.1	1.3	1.5	1.6	1.3	1.3	2.1	0.9	3.0	2.1	1.9
50			7.8	3.9	2.2	1.0	1.5	1.6	1.5	1.4	1.4	1.8	1.6	2.9	2.3	2.1
51			8.0	4.4	2.1	1.3	1.6	1.7	1.5	1.6	1.8	2.0	1.5	2.8	3.1	1.9

Table 21

Wave Heights for Plans 51-55 for Test Waves from North

Plan	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+4.0 ft swl									
51	7.5	9.6	8.6	3.2	1.6	1.1	1.1	1.2	1.0	1.6	1.8	2.5	3.0	2.7	3.1	2.5
52			8.5	3.5	1.8	1.1	1.2	1.5	1.4	1.6	1.9	2.9	2.7	3.4	3.4	2.8
53			8.8	3.4	1.9	1.0	1.3	1.4	1.3	1.6	2.1	2.1	2.4	3.1	3.1	2.7
54			8.5	3.3	2.4	1.1	1.6	1.4	1.4	1.7	2.0	2.1	2.6	3.6	3.0	2.7
55			8.5	4.6	2.8	1.3	1.8	1.9	1.5	1.6	2.1	2.4	2.4	3.9	3.2	2.8

Table 22

Wave Heights for Plans 55-56 for Test Waves from the Unrefracted Northeast Direction

Plan	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
55	6.7	5.7	8.1	4.1	2.0	1.3	1.7	2.1	1.9	1.8	1.8	1.4	1.2	3.3	2.2	2.3
56			8.3	3.7	2.5	1.1	2.2	1.9	1.4	1.4	1.8	1.8	1.4	4.1	2.3	2.3

Table 23

Wave Heights for Plans 51-53 and Plans 55-56 for Test Waves from Northeast

Plan	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
51	6.7	5.7	6.5	2.6	1.6	0.7	1.0	1.3	1.4	2.0	2.1	2.4	1.9	2.2	2.9	1.6
52			8.5	4.4	2.4	1.1	1.8	1.4	1.7	2.0	2.6	2.0	2.1	2.6	2.9	2.6
53			9.9	4.5	2.5	1.1	1.7	1.5	1.7	2.1	2.1	2.6	2.0	2.6	2.8	2.9
55			11.8	5.8	2.9	1.4	2.5	2.7	2.3	1.7	1.9	1.8	1.9	2.4	2.4	3.1
56			12.2	5.6	3.1	1.2	2.6	2.3	2.0	2.1	2.1	1.7	2.9	3.1	2.1	2.7

Table 24

Wave Heights for Plans 52 and 57 for Test Waves from West

	Test Wave		Wave Height, ft													
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
								+5.5 ft swl								
52	9.9	13.9	4.1	4.2	3.0	1.7	2.1	1.9	1.4	1.7	1.6	2.4	2.4	3.0	2.7	3.5
57			4.0	3.8	3.2	1.7	2.2	1.7	1.3	2.2	1.6	2.9	2.3	3.3	3.0	4.2
								+6.5 ft swl								
52	7.7	7.9	4.3	3.1	2.2	1.5	2.0	1.5	1.2	1.4	1.6	[illegible]	2.1	2.3	2.6	2.7
57			4.4	2.5	2.0	1.8	2.1	1.7	[illegible]	1.5	1.2	1.6	2.1	2.2	2.4	2.8

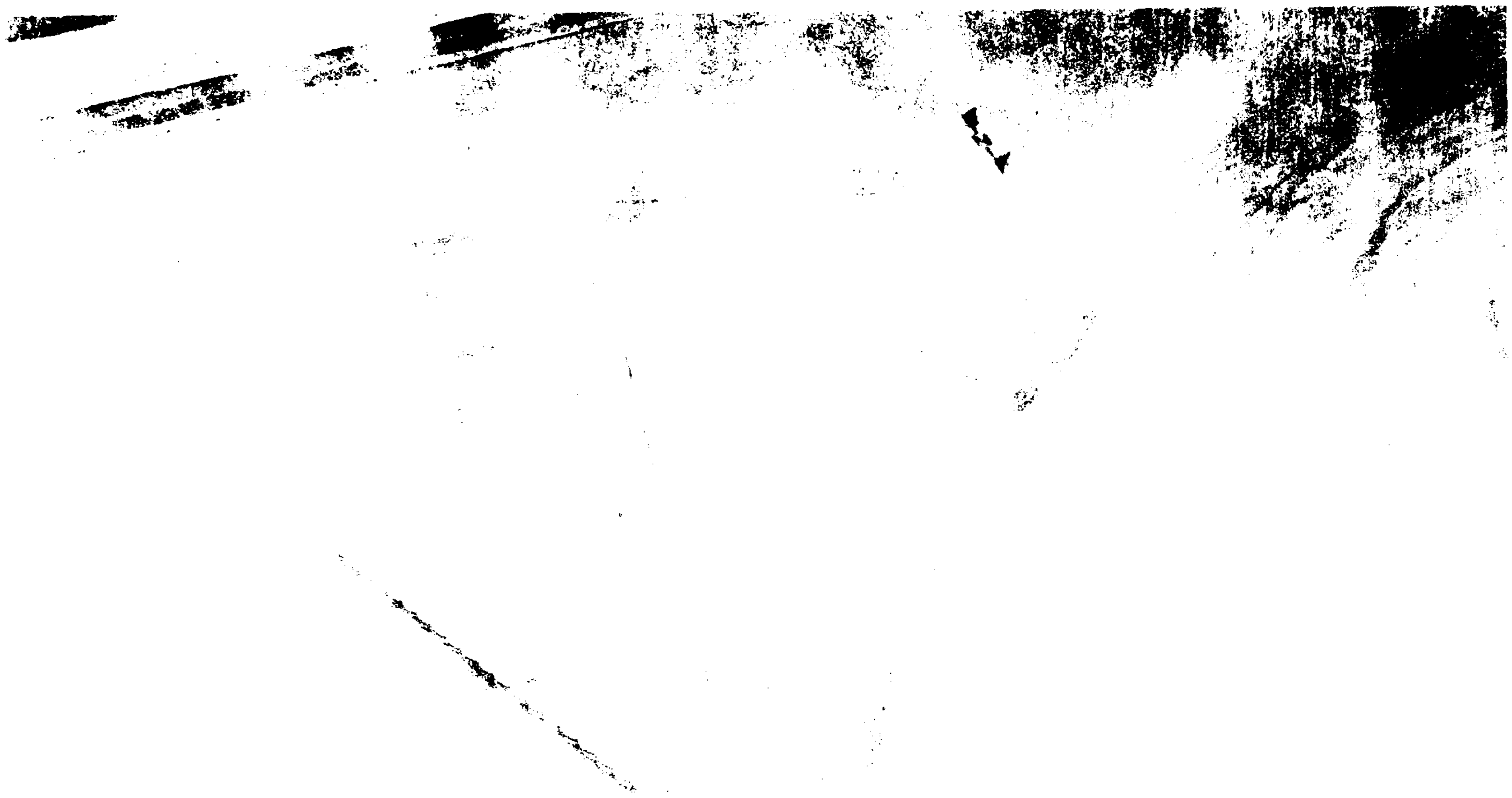
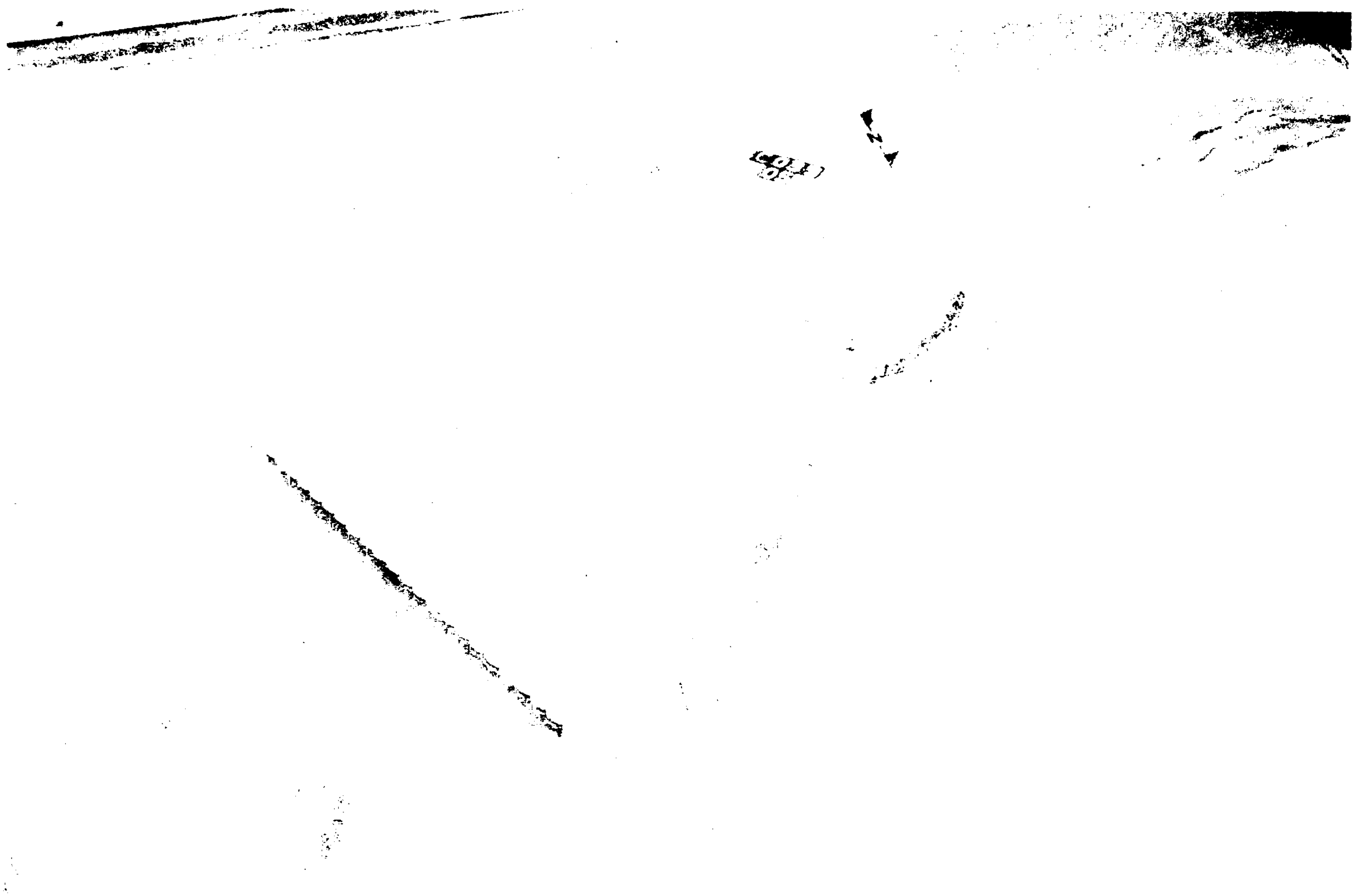


Photo 2. Typical wave patterns for Base Test 1; 9.2-sec, 12-ft waves from west; +5.5 ft swl



...oto 3. ...ypical wave pa... -sec, 13.9-ft wa... from west; ... ft swl

Photo 4. Typical wave patterns for Base Test 1; 7.1-sec, 6.3-ft waves from west; +6.5 ft swl

Photo 5. Typical wave patterns for Base Test 1; [illegible]-sec, [illegible]-ft waves from [illegible] ft swl

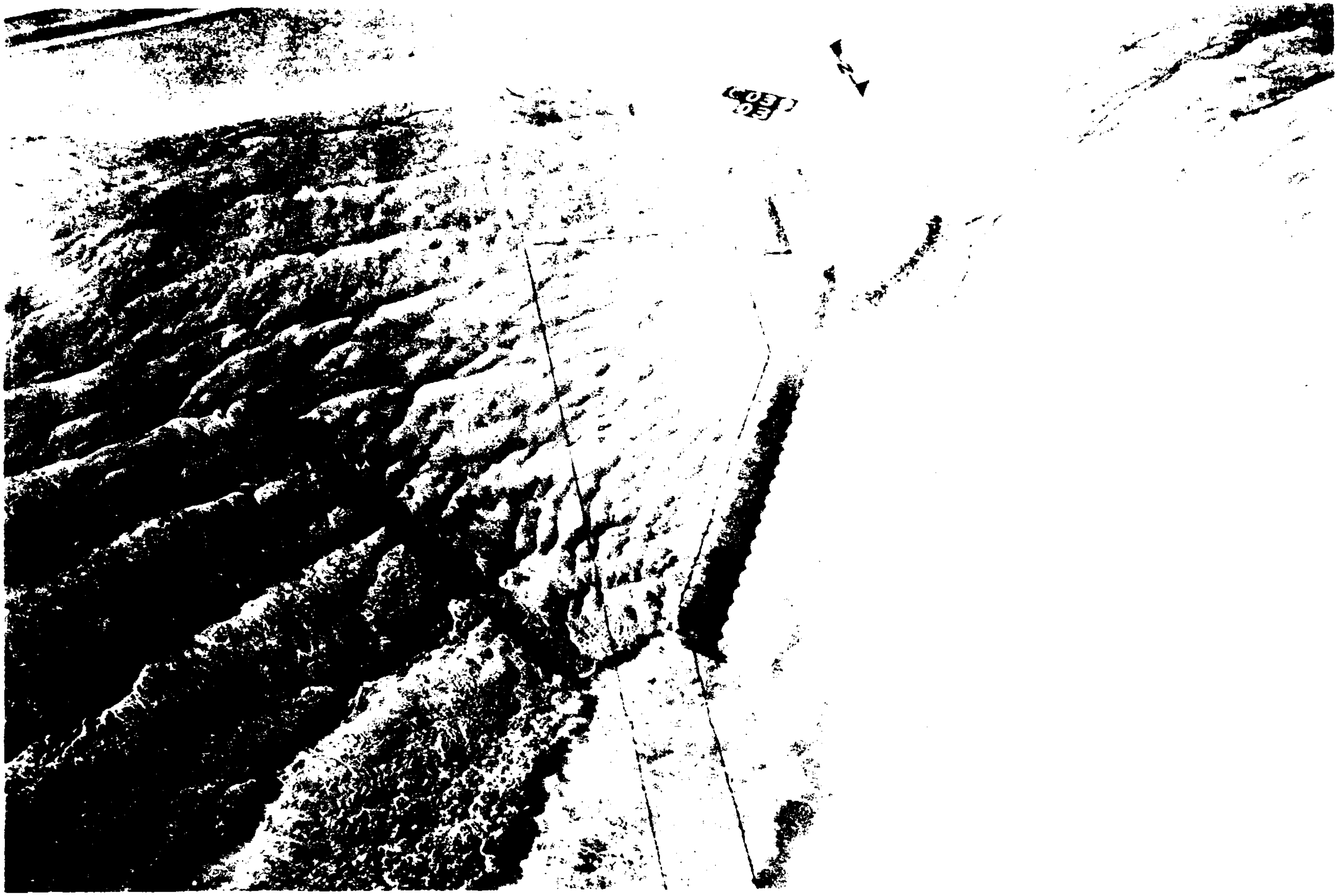


Photo 6. Typical wave patterns for Base Test 1; 10.1-sec, 14.7-ft waves from west; +6.5 ft swl

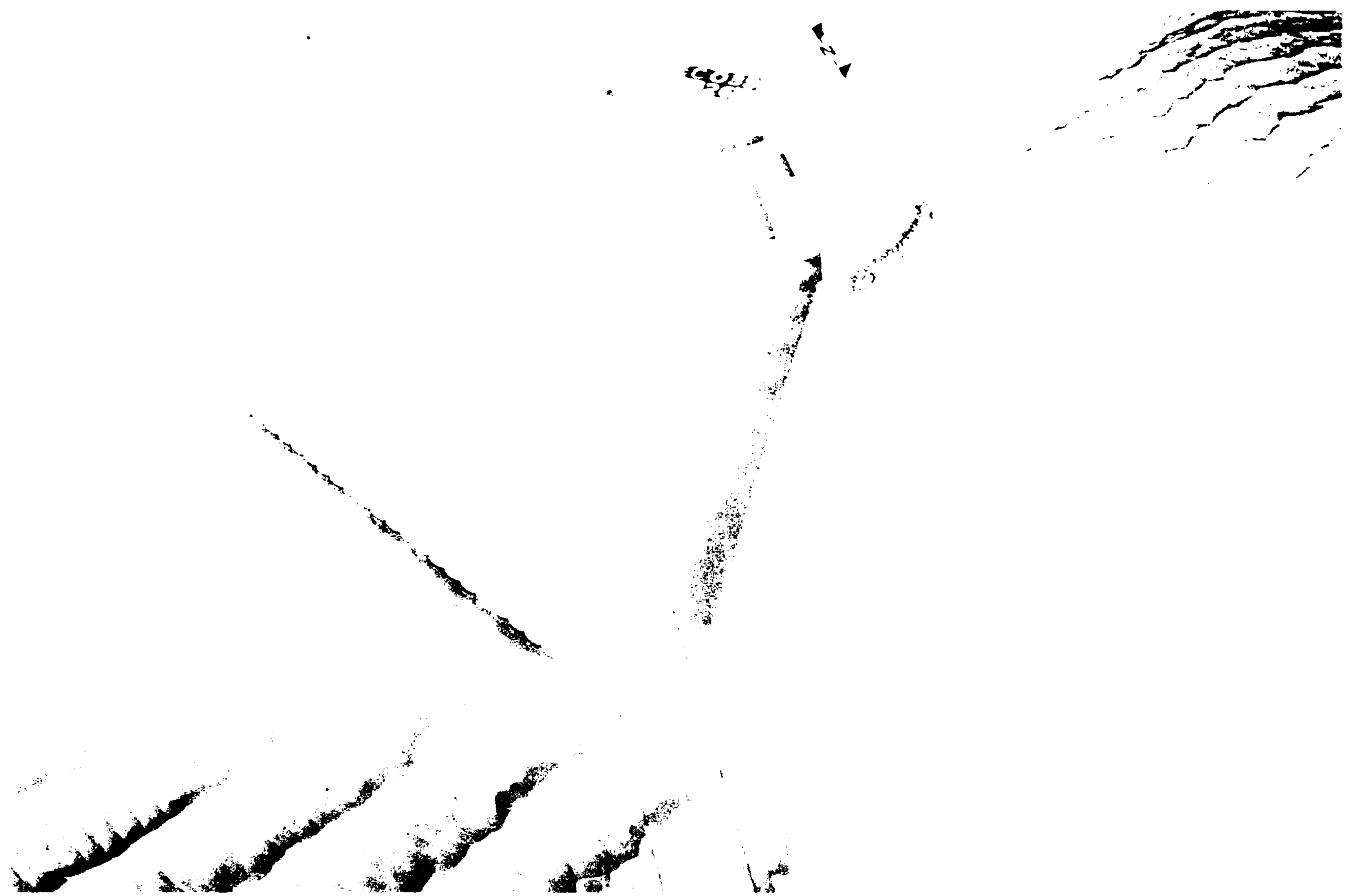


Photo 7. Typical wave patterns for Base Test 1; 6.2-sec, 6-ft waves from northwest; +3.0 ft swl

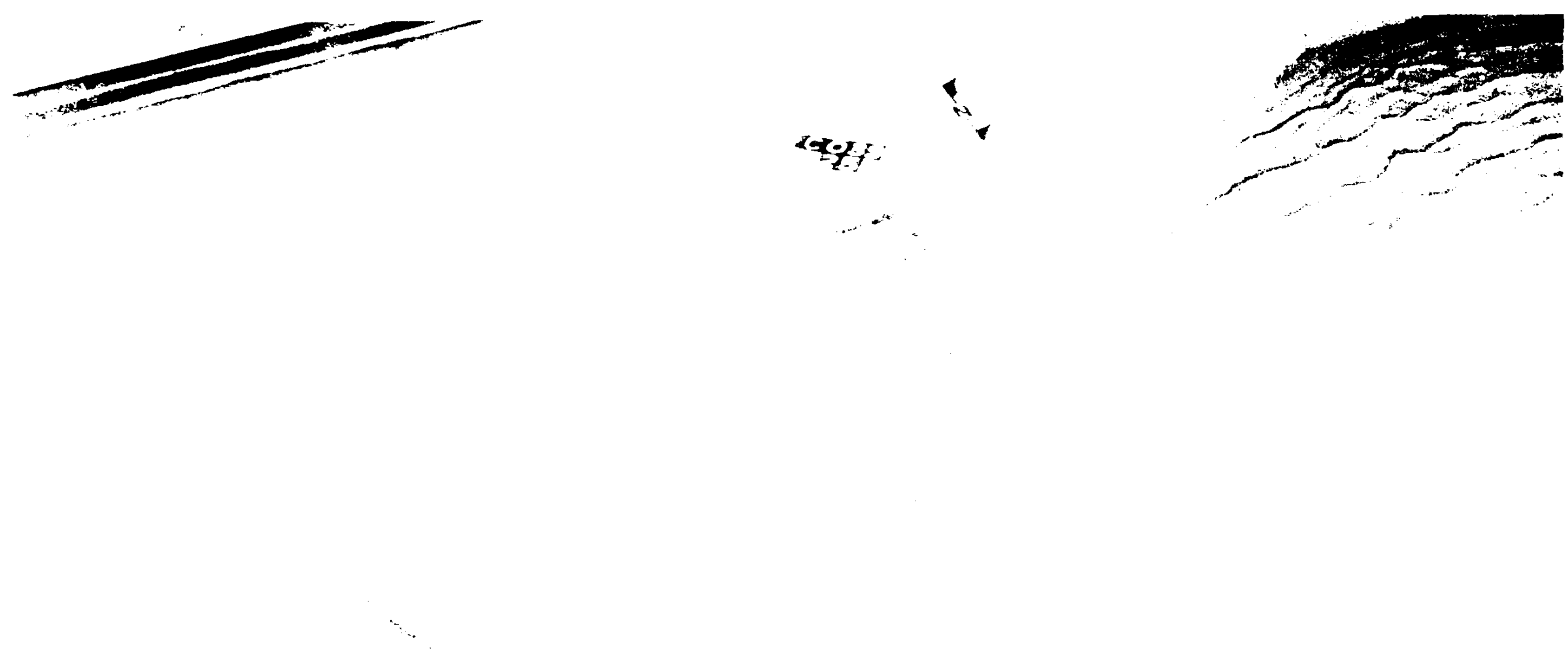


Photo 8. Typical wave patterns for Base Test 1; 6.9-sec, 8.3-ft waves from northwest; +4.0 ft swl

Photo 9. Typical wave patterns for Base Test 1; 7.5-sec, 9.9-ft waves from northwest; +4.0 ft swl

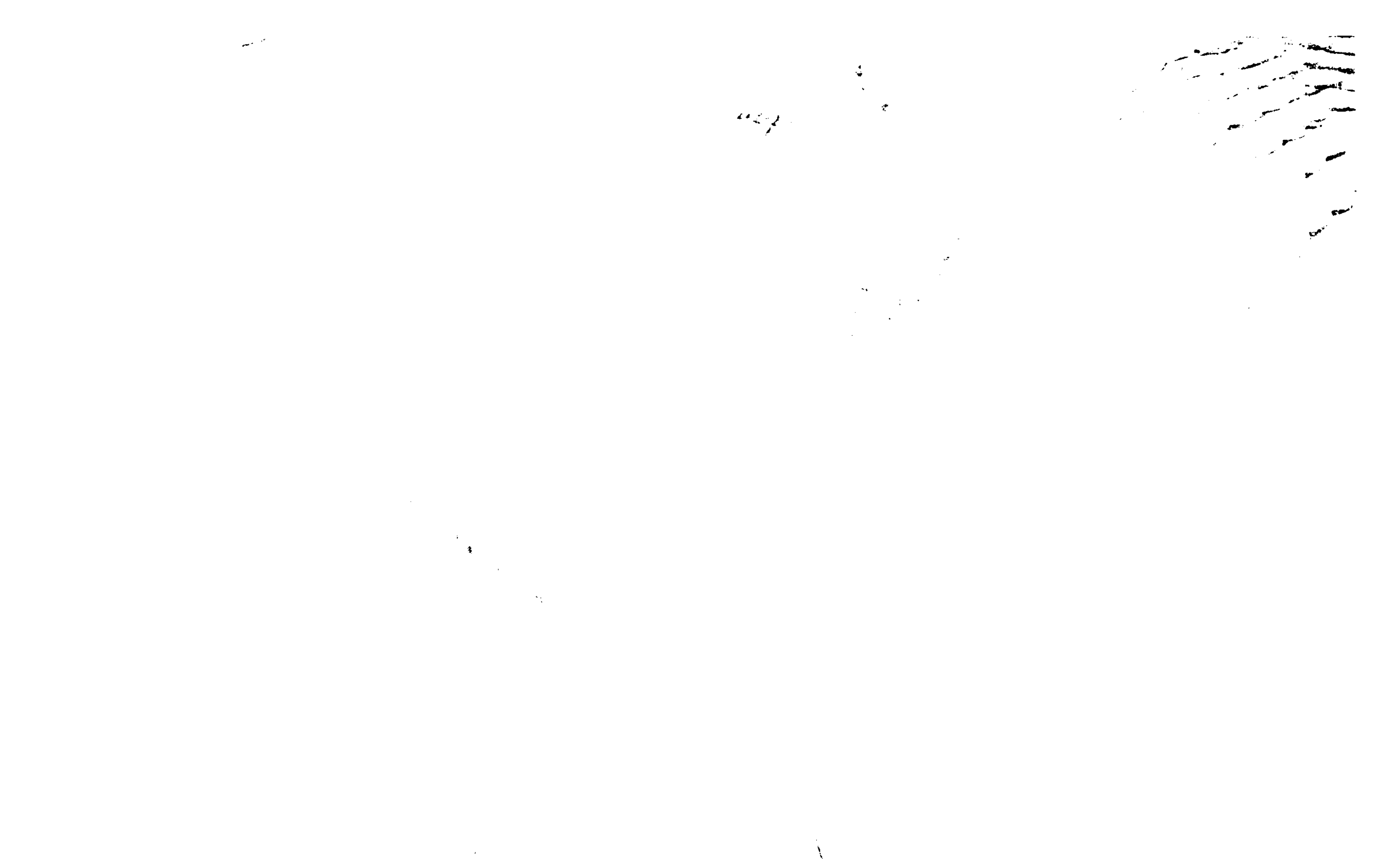


Photo 10. Typical wave patterns for Base Test 1; 5.7-sec, 4.8-ft waves from northwest; +5.0 ft swl

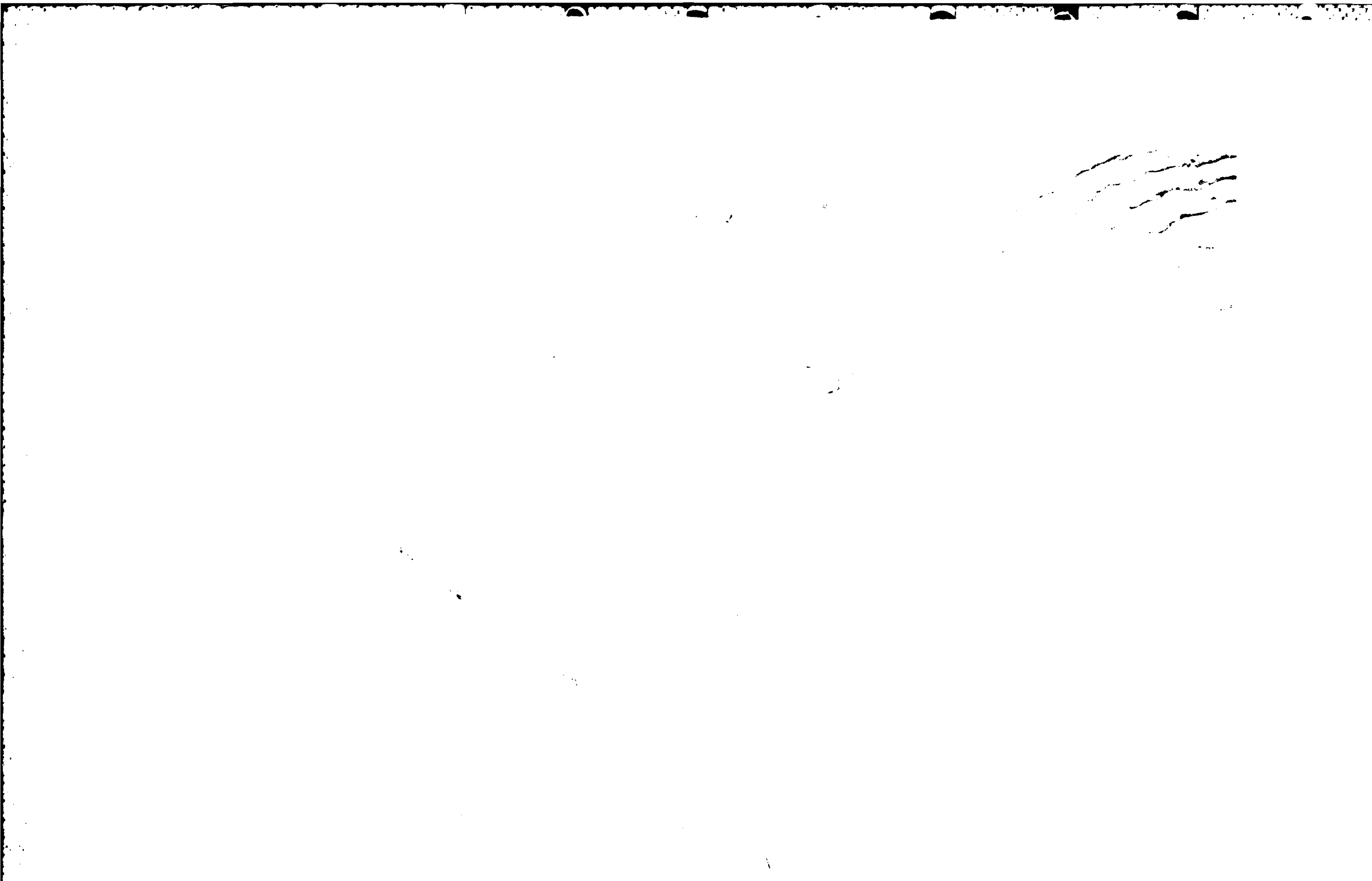


Photo 11. Typical wave patterns for Base Test 1; 6.2-sec, 6.3-ft waves from northwest; +5.0 ft swl

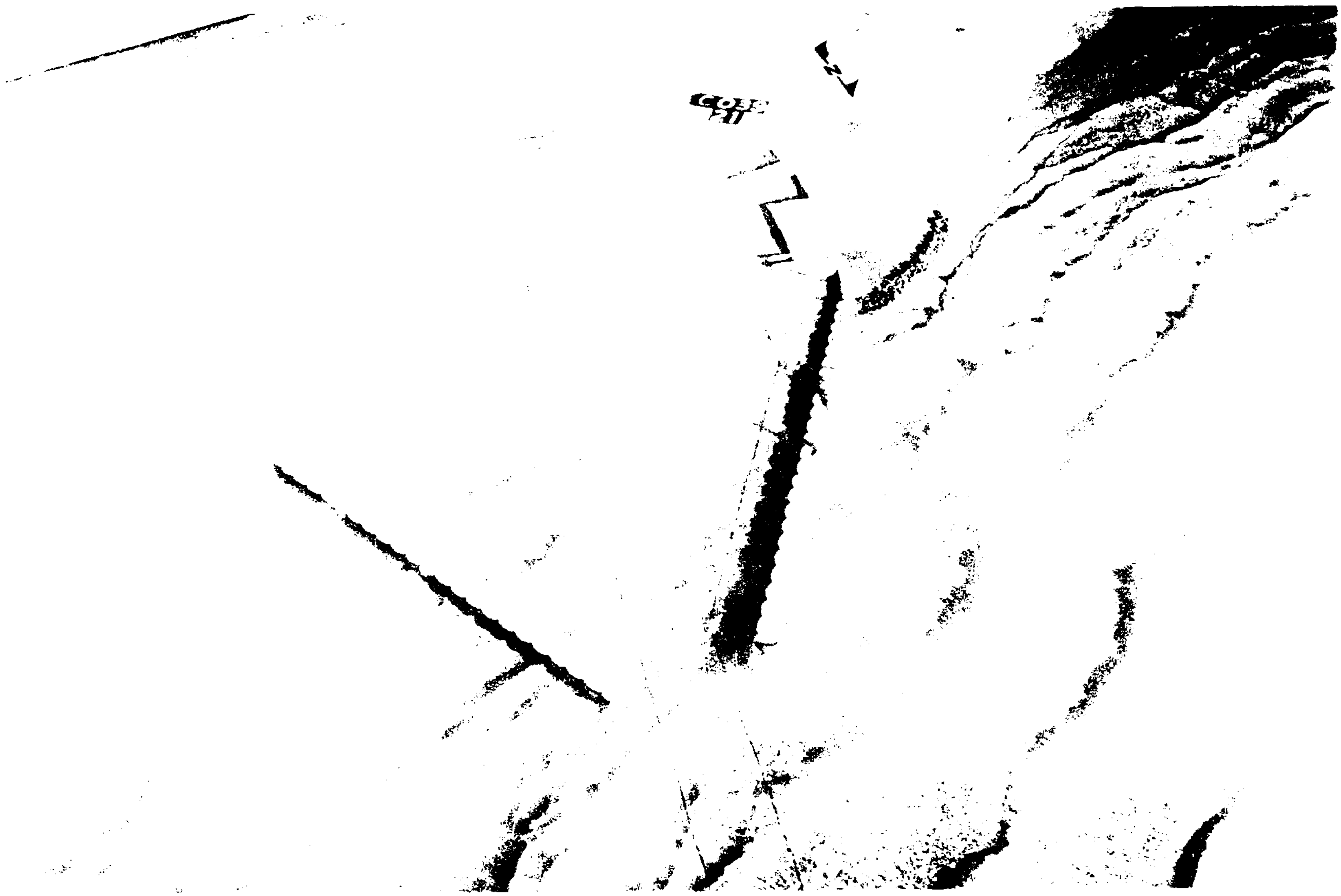


Photo 12. Typical wave patterns for Base Test 1; 7.8-sec, 10.5-ft waves from northwest; +5.0 ft swl

Photo 15. Typical wave patterns for base Test 1; 5.9-sec, 5.1-ft waves from north; +3.0 ft swl

Photo 14. Typical wave patterns for Base Test 1; 6.9-sec, 7.9-ft waves from north; +4.0 ft swl

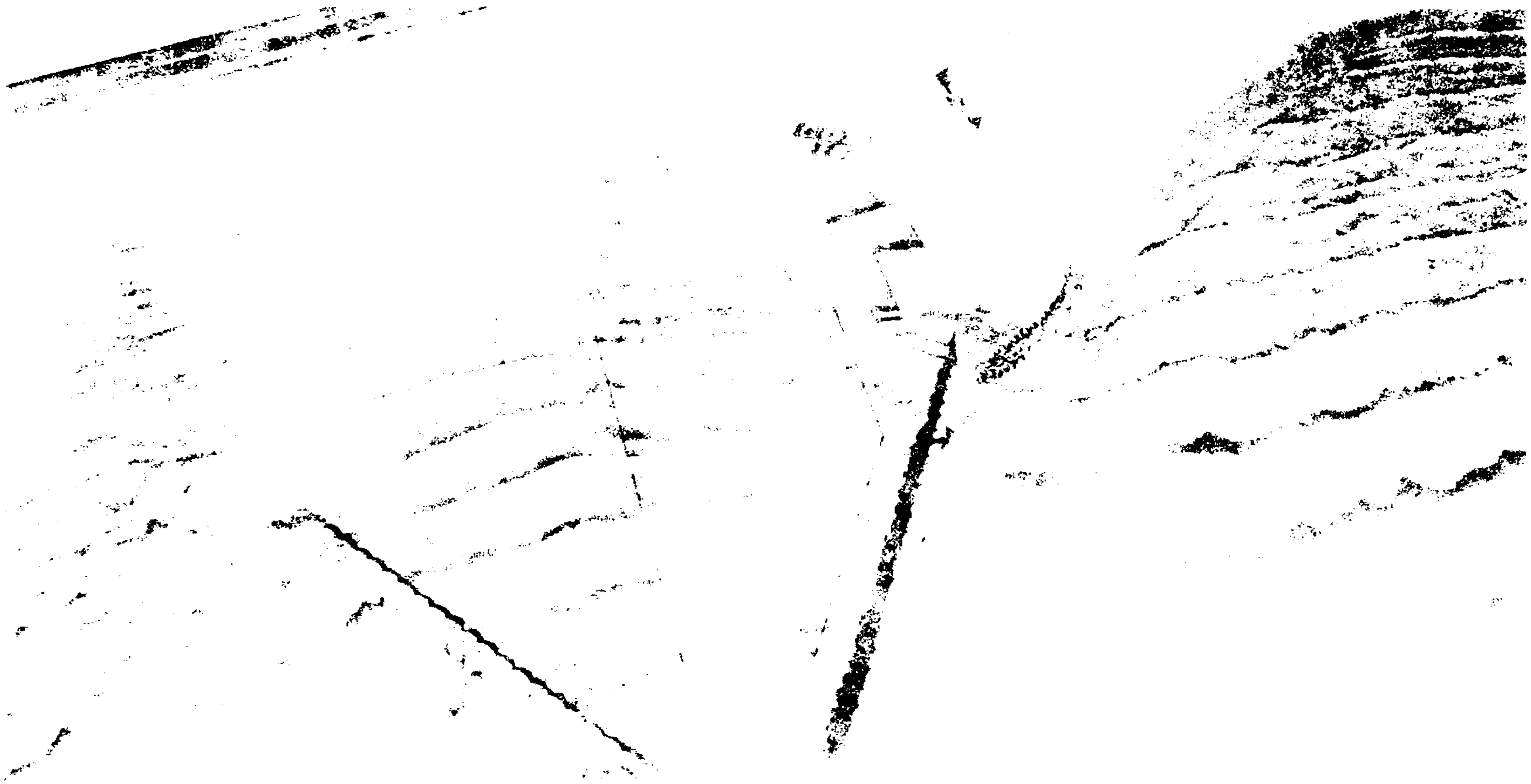
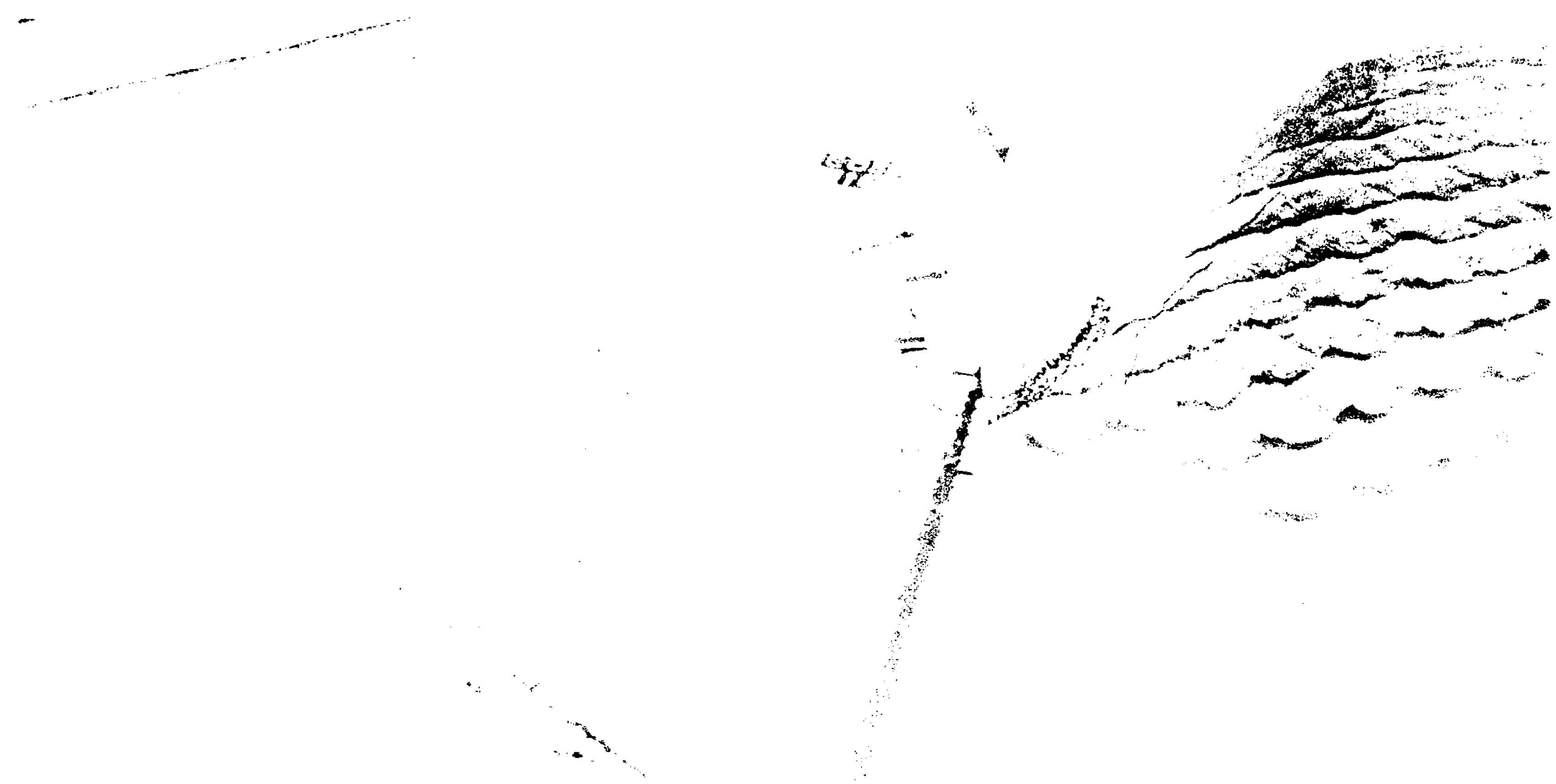


Photo 15. Typical wave patterns for Base Test 1; 7.5-sec, 9.6-ft waves from north; +[illegible].0 ft swl



[illegible] wave patterns for base test [illegible]; [illegible]-sec, [illegible]-ft waves from north; [illegible] ft [illegible]

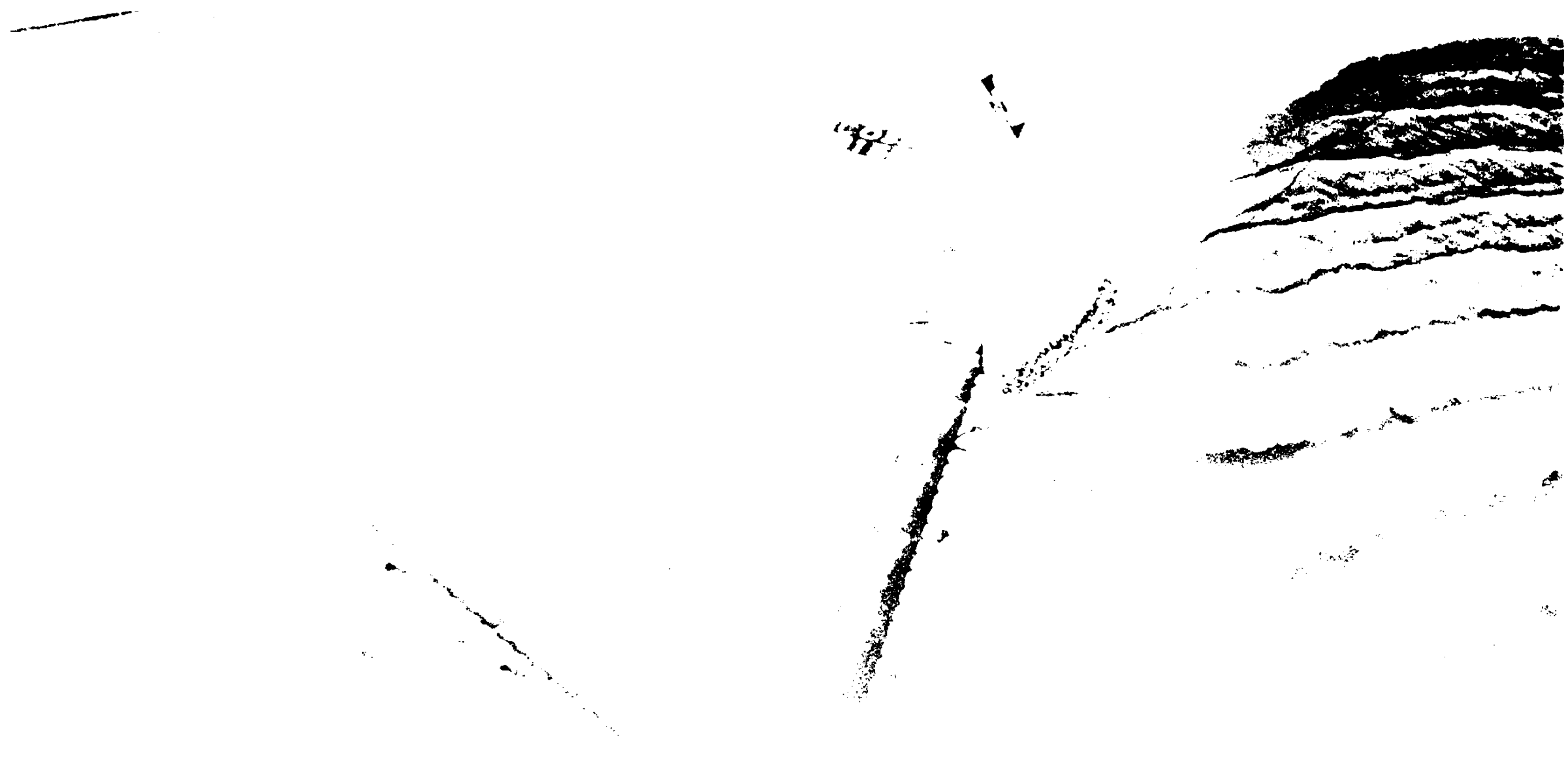


Photo [illegible] [illegible] wave patterns for Base Test [illegible]: [illegible]-sec, [illegible]-ft waves from north; [illegible]

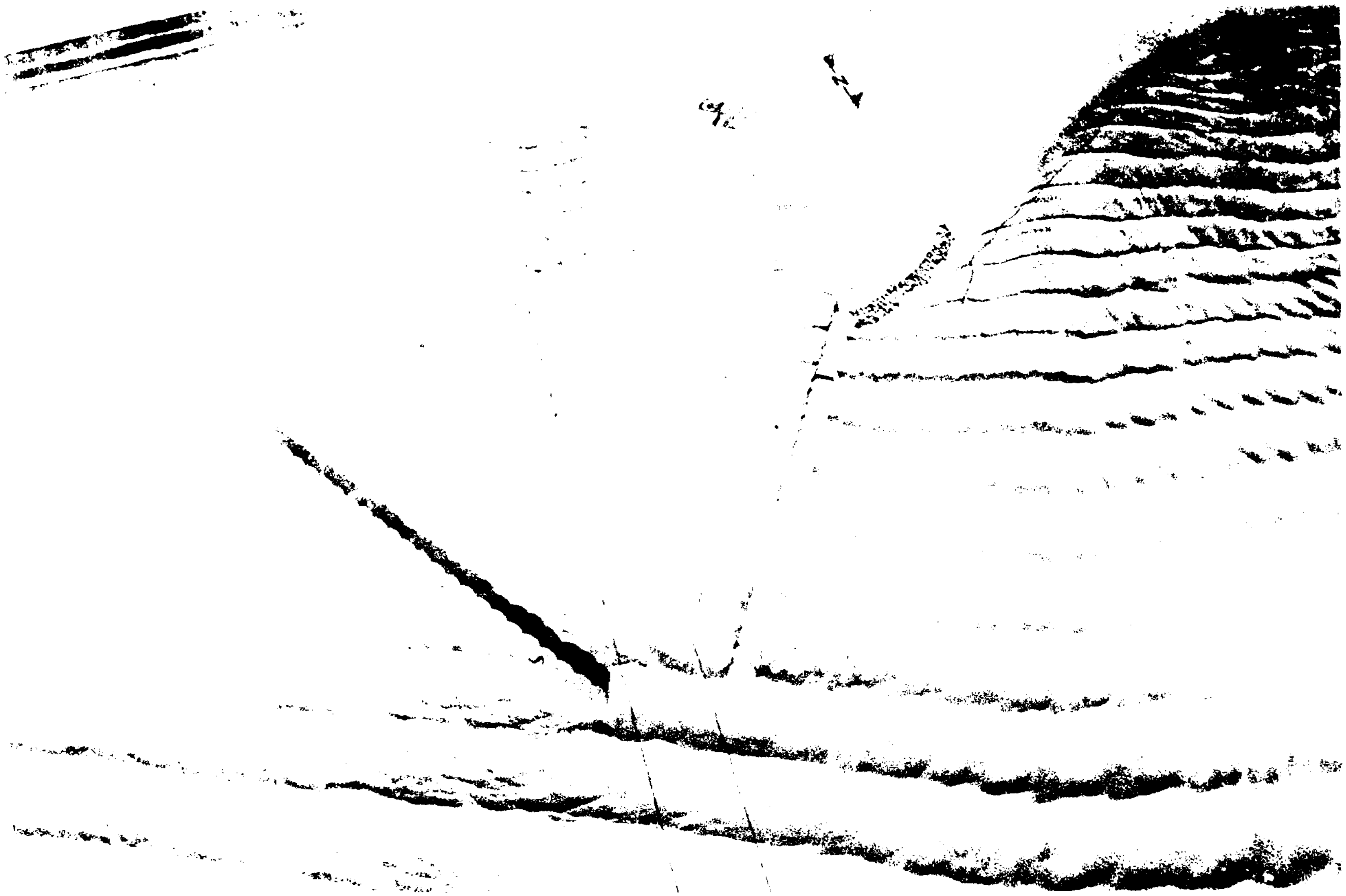
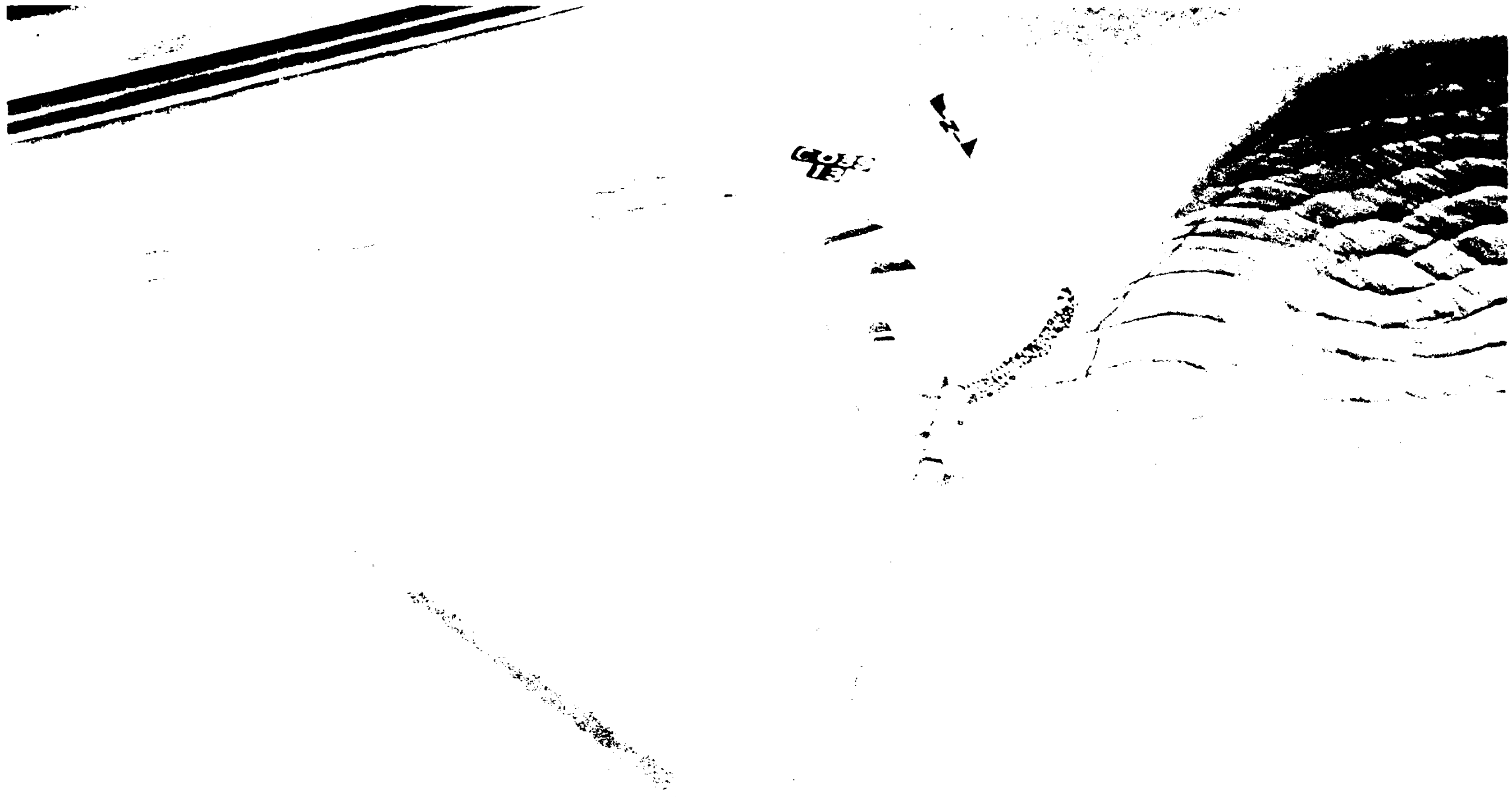


Photo 18. Typical wave patterns for Base Test 1; 5.9-sec, 4.3-ft waves from northeast; +3.0 ft swl



oto 19. Typical wave patterns [illegible] Test 1; 6.4-sec, 5-ft waves from northeast; +3.0 ft sw

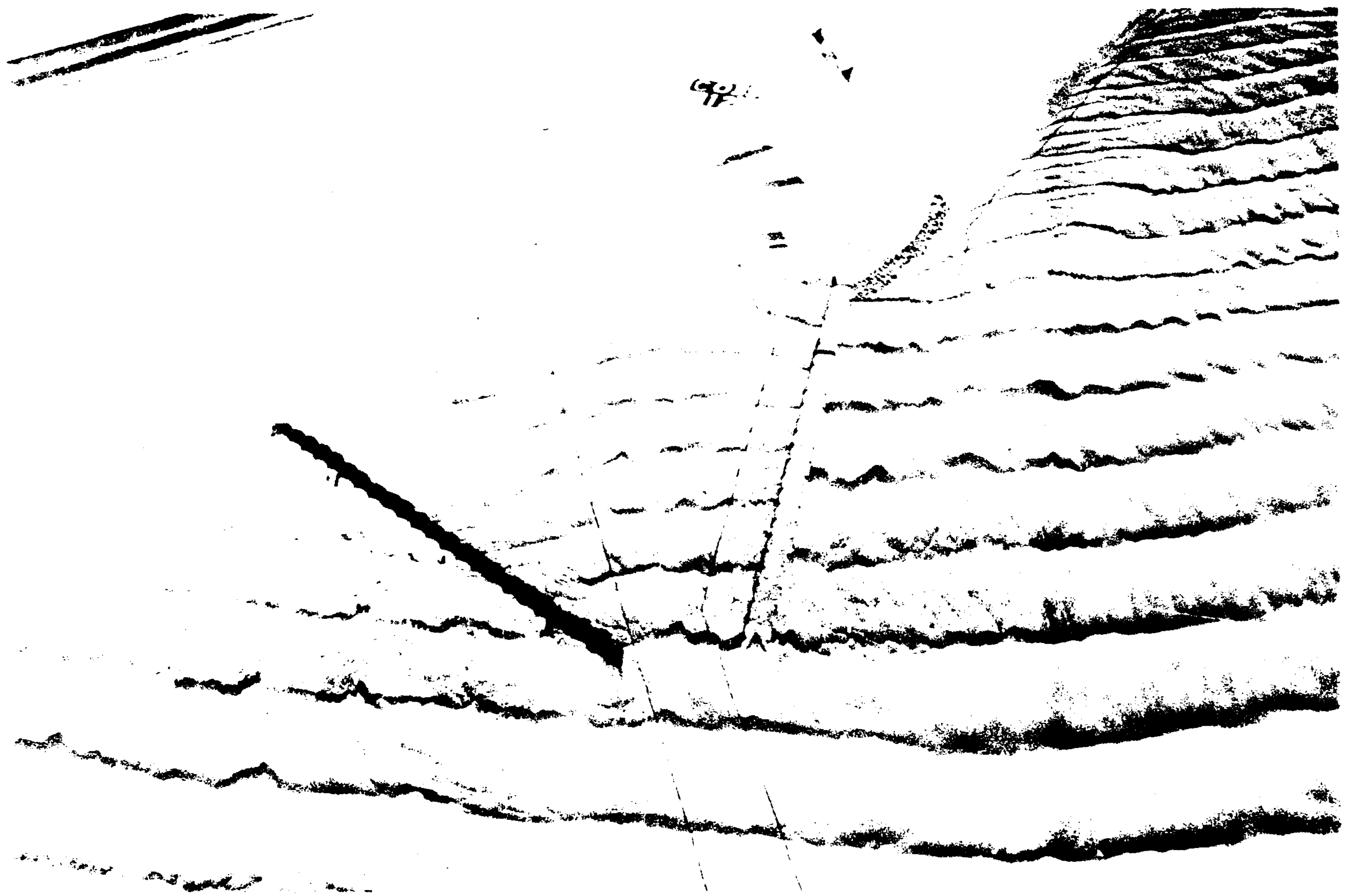


Photo 20. Typical wave patterns for Base Test 1; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

Photo 21. Typical wave patterns for Base Test 1; 4.0-sec, 2.8-ft waves from northeast; +4.0 ft swl

Photo 22. Typical wave patterns for Base Test 1; 5.9-sec, 4-ft waves from northeast; +4.0 ft swl

Photo 23. Typical wave patterns for Base Test 1; 6.9-sec, 5.8-ft waves from northeast; +4.0 ft swl

Photo 24. Typical wave patterns for Base Test 2; 5.2-sec, 3.7-ft waves from west; +3.0 ft swl

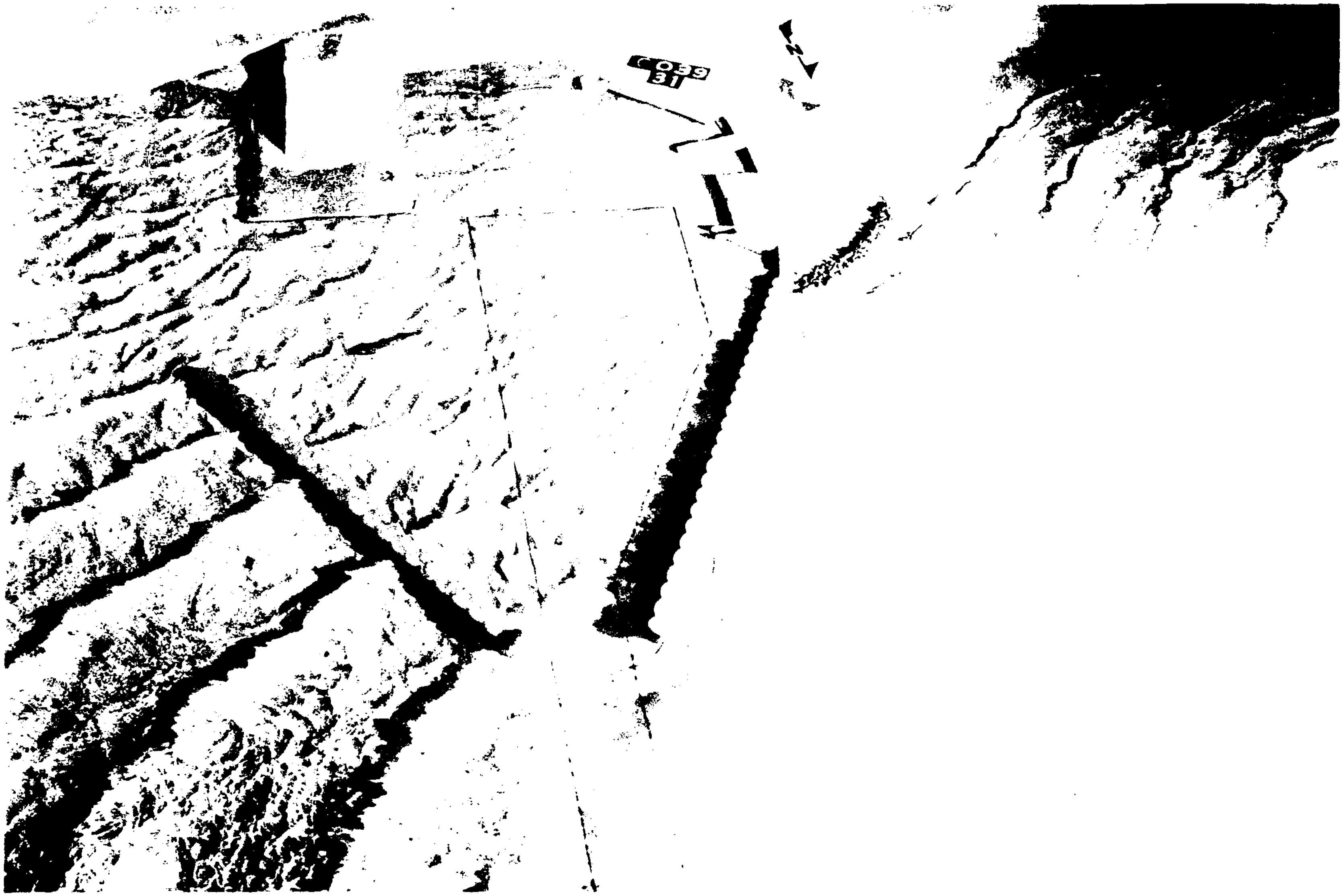


Photo 25. Typical wave patterns for Base Test 2; 9.2-sec, 12-ft waves from west; +5.5 ft swl

Photo 26. Typical wave patterns for Base Test 2; 9.9-sec, 13.9-ft waves from west; [illegible] ft swl

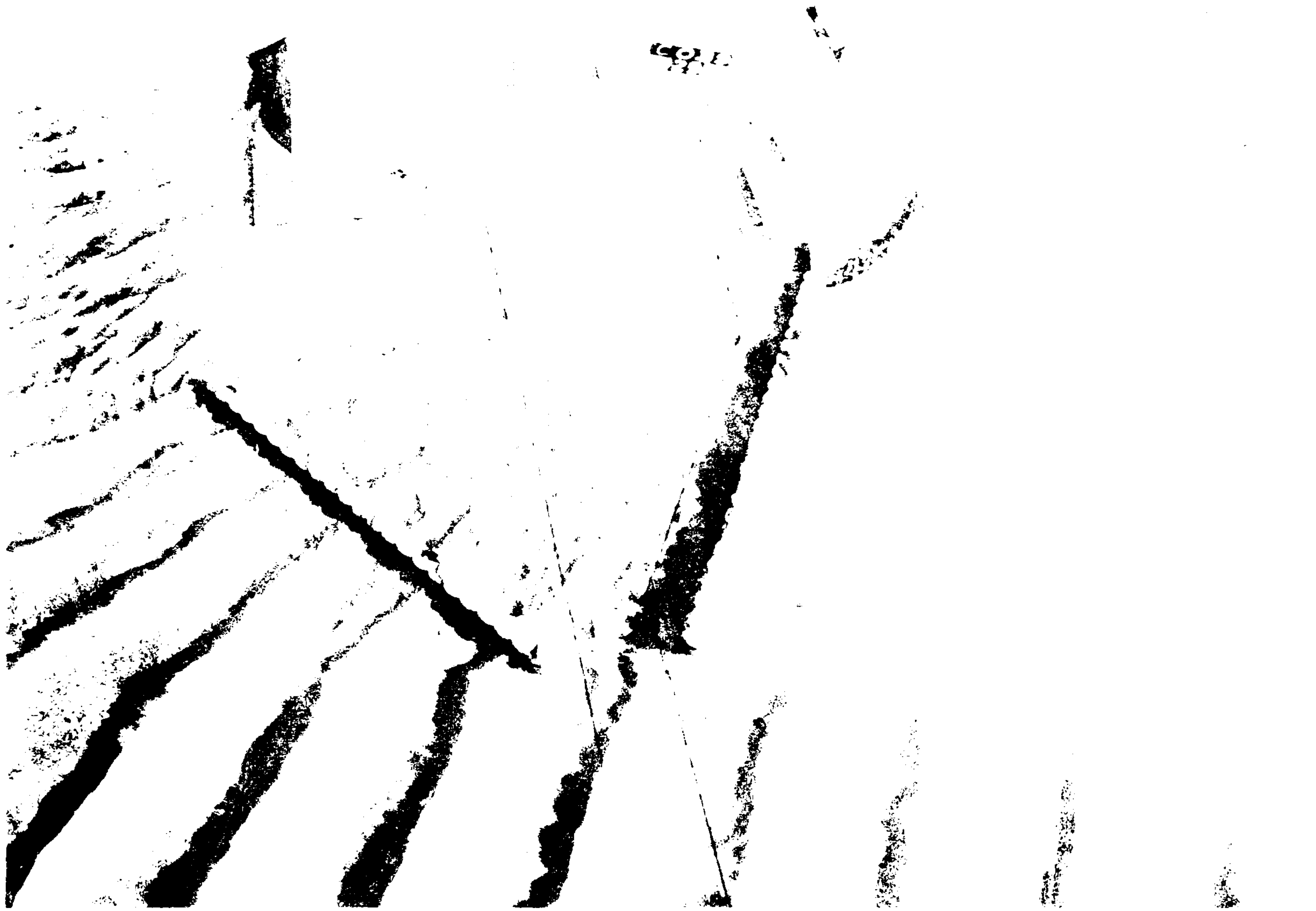
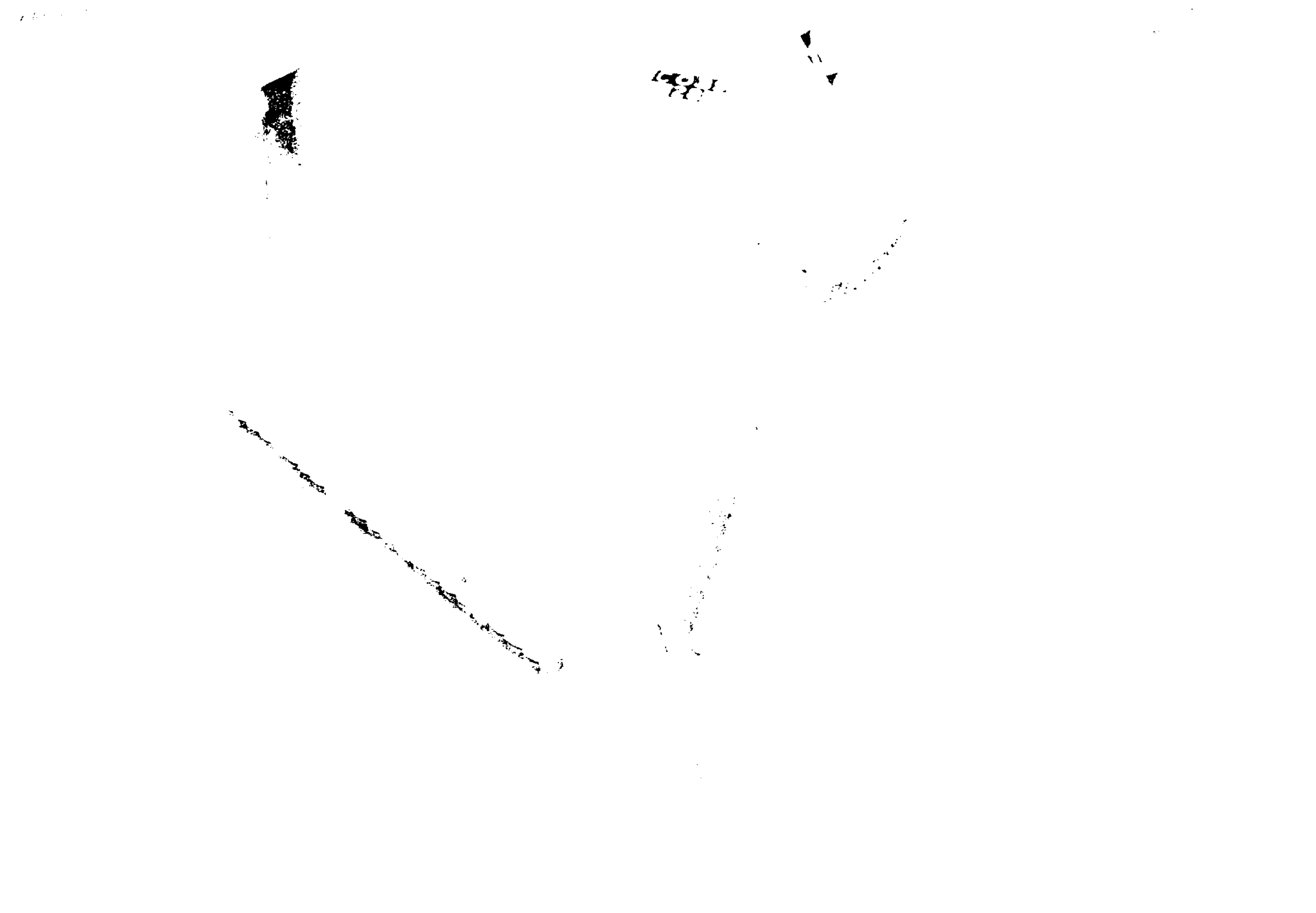


Photo 17. Typical wave patterns for Base Test 2; 7.1-sec, 6.3-ft waves from west; 46.5 ft swl



[illegible] patterns for [illegible]; [illegible] from west; [illegible]

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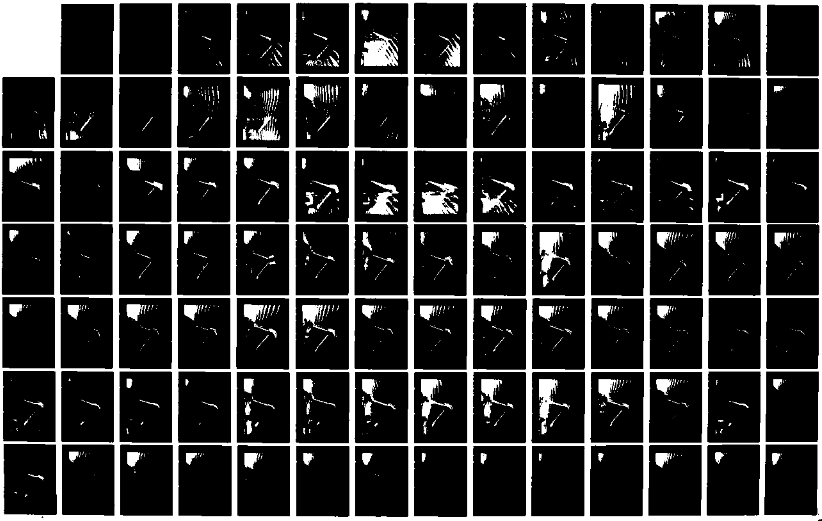

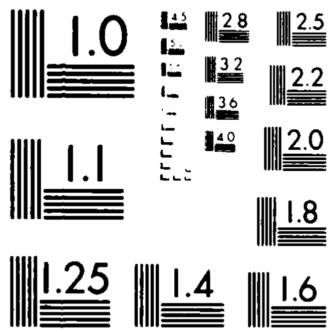

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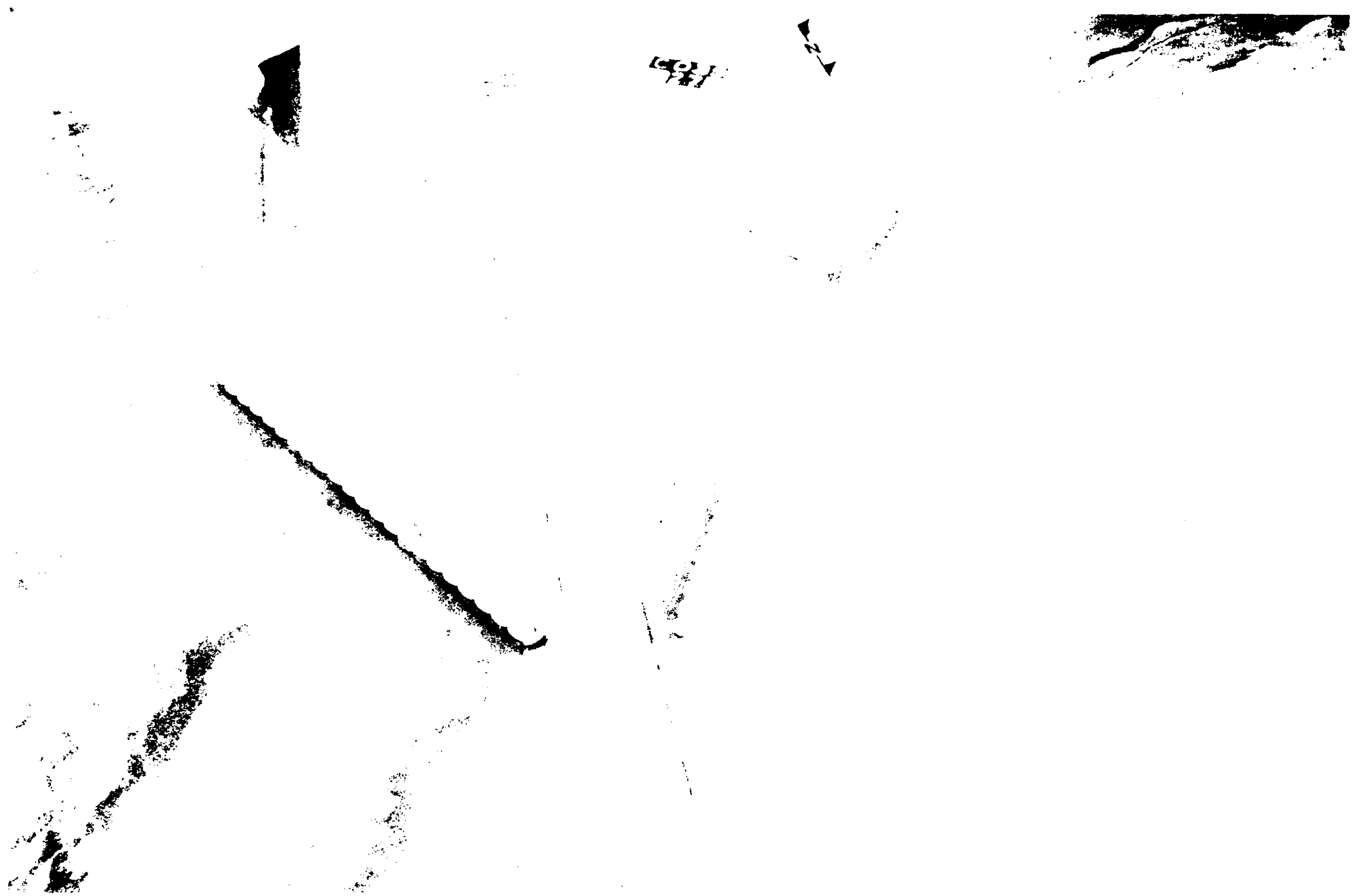

Photo 29. Typical wave patterns for Base Test 2; 10.1-sec, 14.7-ft waves from west; +6.5 ft swl

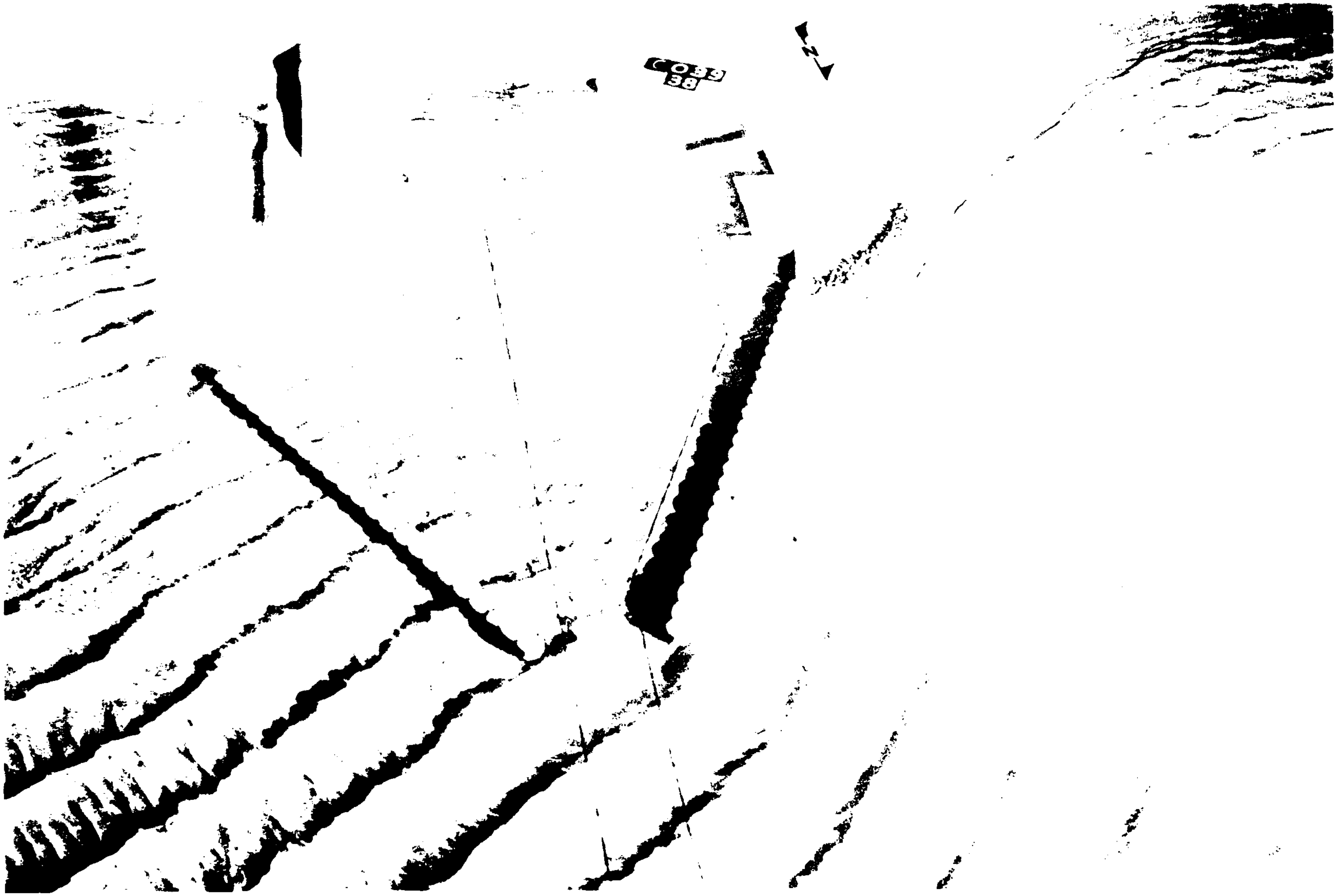

Photo 30. Typical wave patterns for Base Test 2; 6.2-sec, 6-ft waves from northwest; +3.0 ft swl

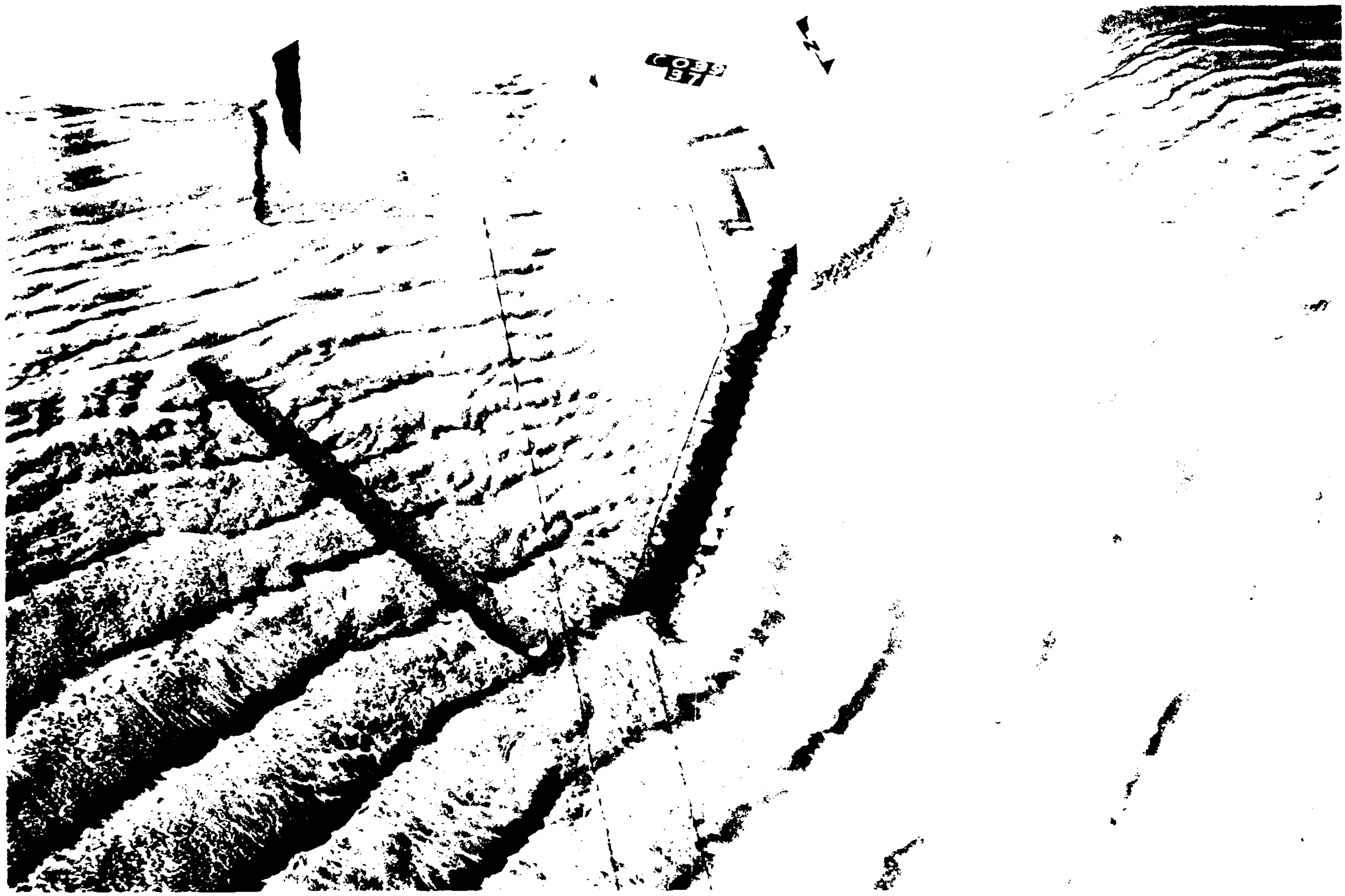

Photo 31. Typical wave patterns for Base Test 2; 6.9-sec, 8.3-ft waves from northwest; +4.0 ft swl

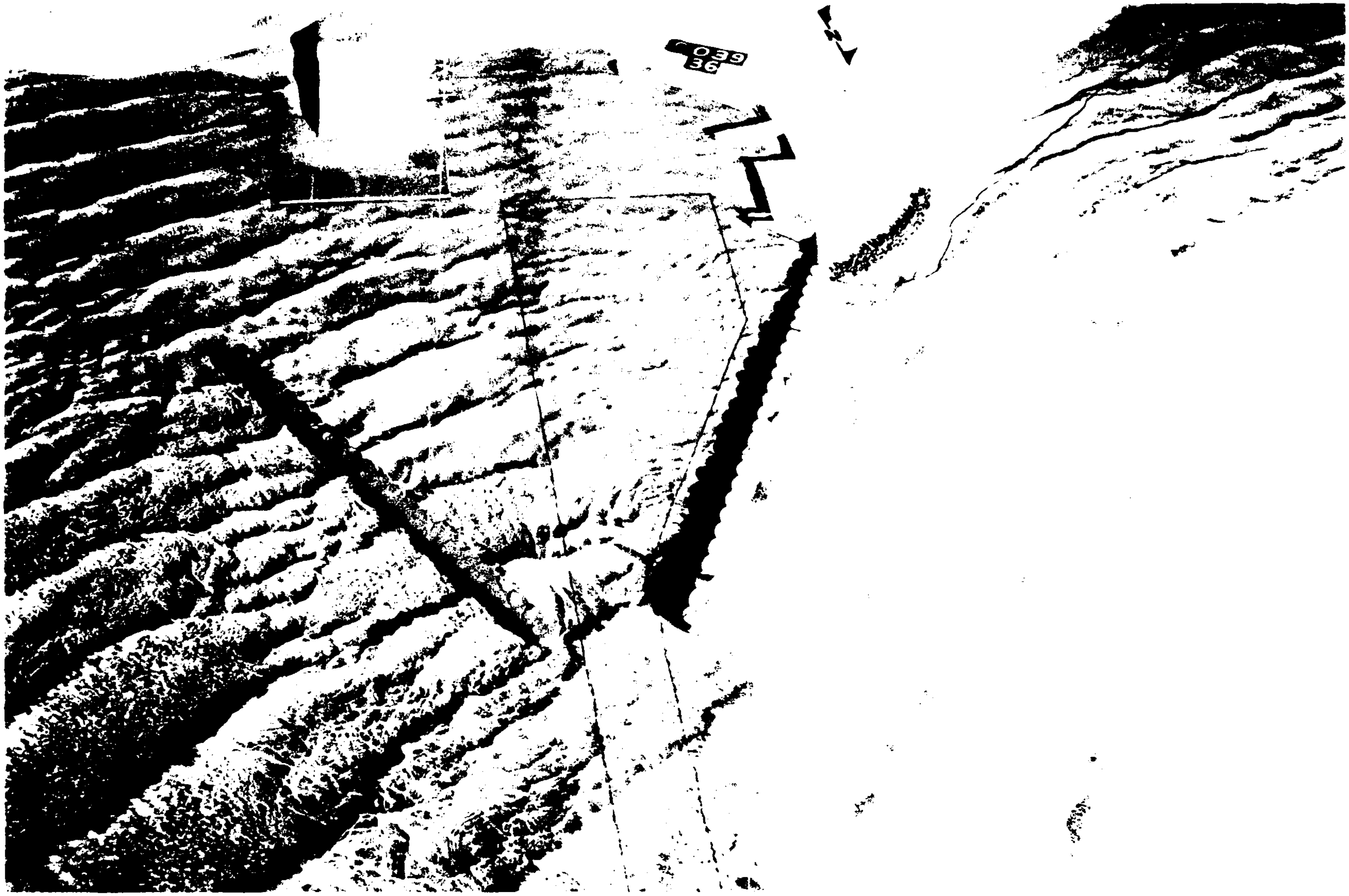

Photo 32. Typical wave patterns for Base Test 2; 7.5-sec, 9.9-ft waves from northwest; +4.0 ft swl

Photo 33. Typical wave patterns for Base Test 2; 5.7-sec, 4.8-ft waves from northwest; +5.0 ft swl

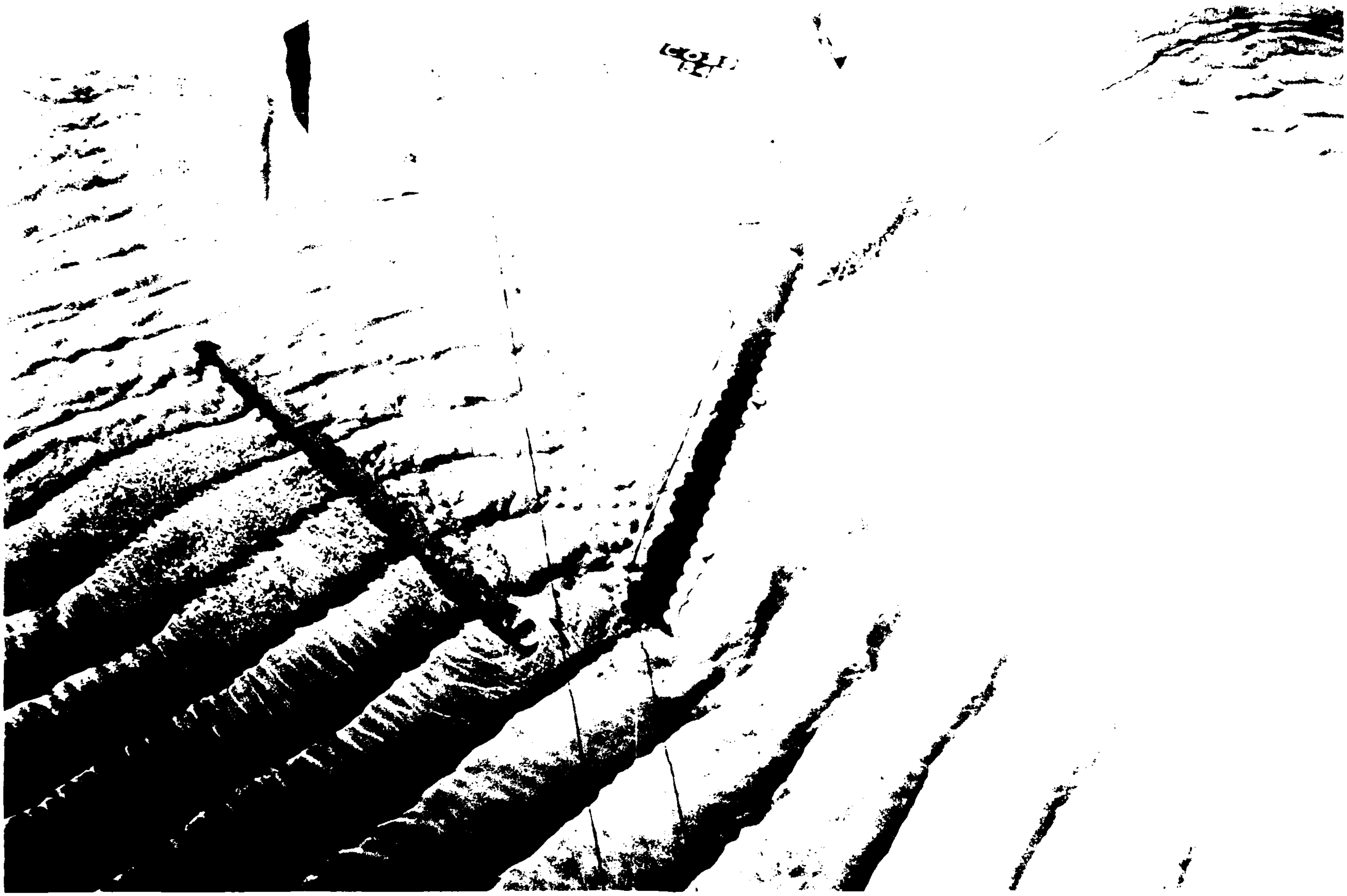

Photo 34. Typical wave patterns for Base Test 2; 6.2-sec, 6.3-ft waves from northwest; +5.0 ft swl

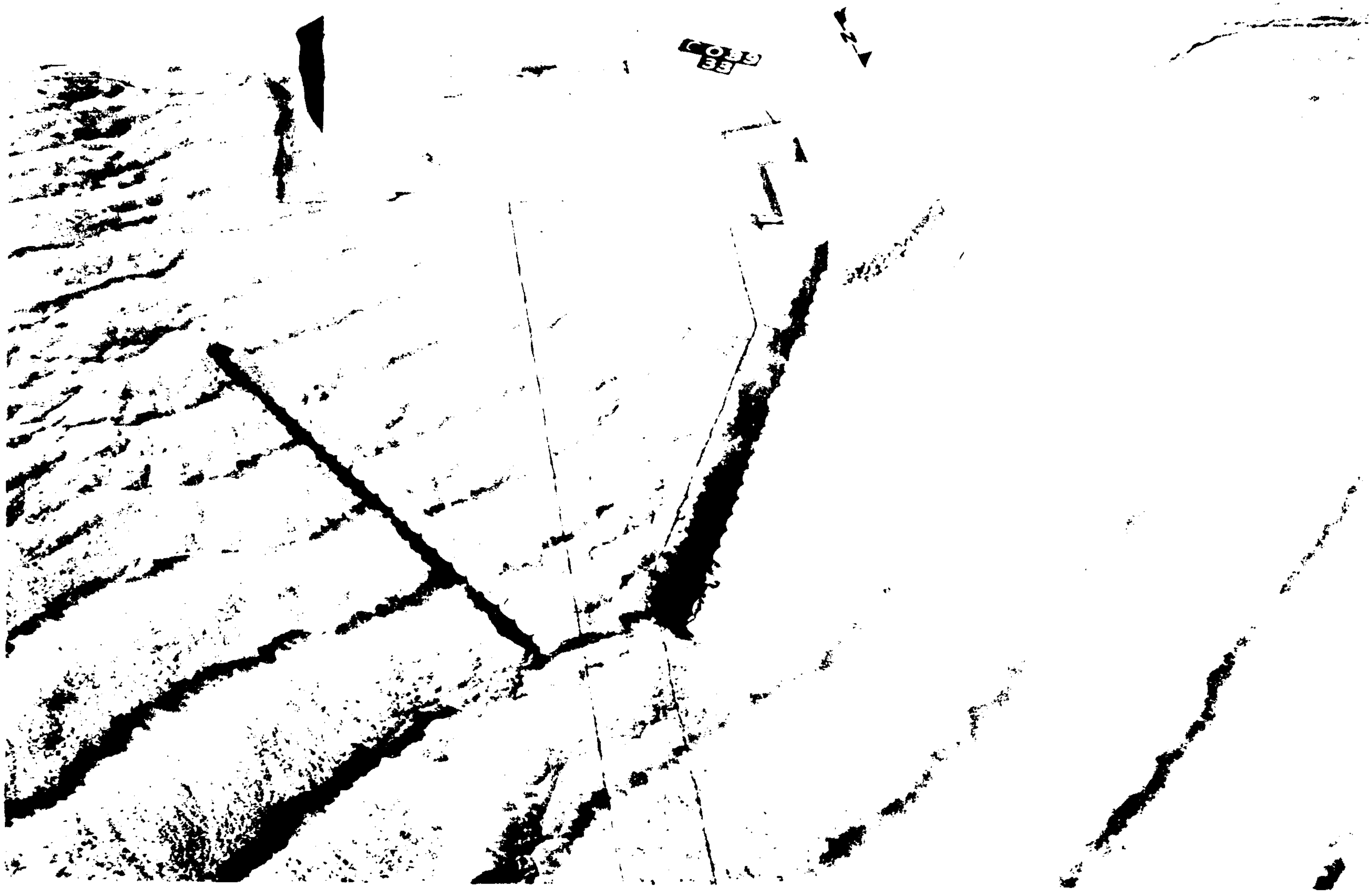

Photo 35. Typical wave patterns for Base Test 2; 7.8-sec, 10.5-ft waves from northwest; +5.0 ft swl

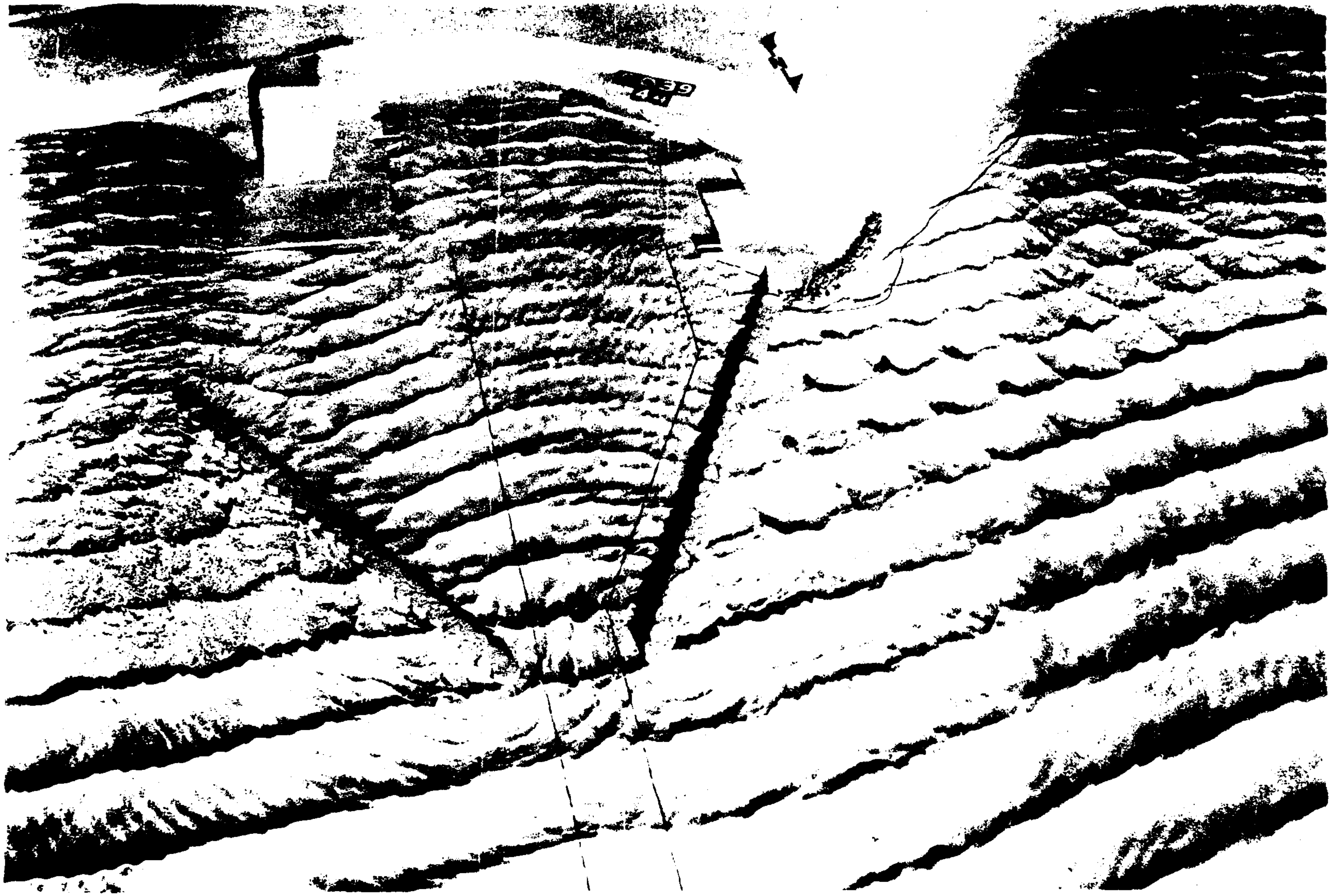

Photo 36. Typical wave patterns for Base Test 2; 5.9-sec, 5.1-ft waves from north; +3.0 ft swl

Photo 37. Typical wave patterns for Base Test 2; 6.9-sec, 7.9-ft waves from north; +4.0 ft swl

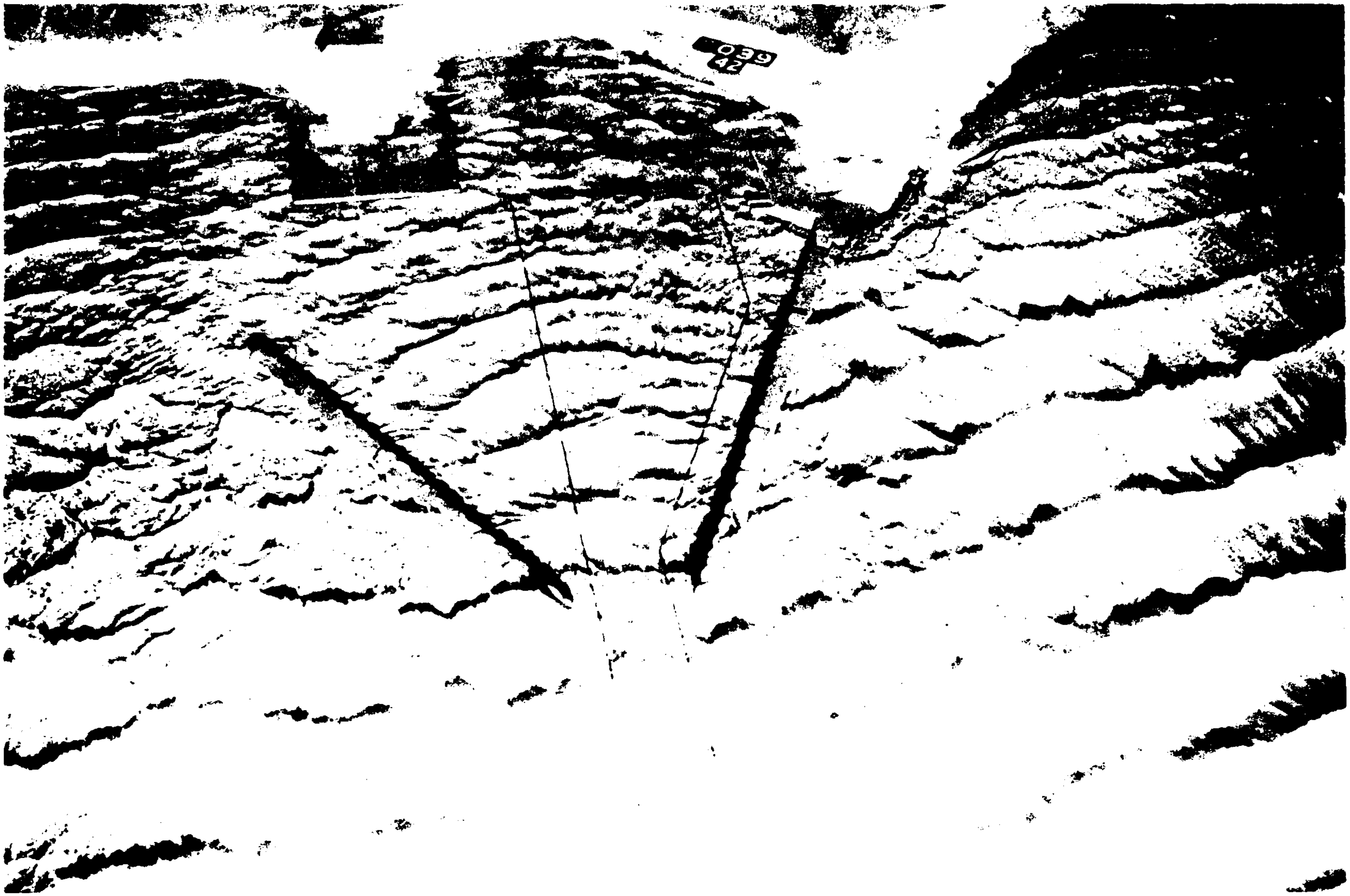

Photo 38. Typical wave patterns for Base Test 2; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

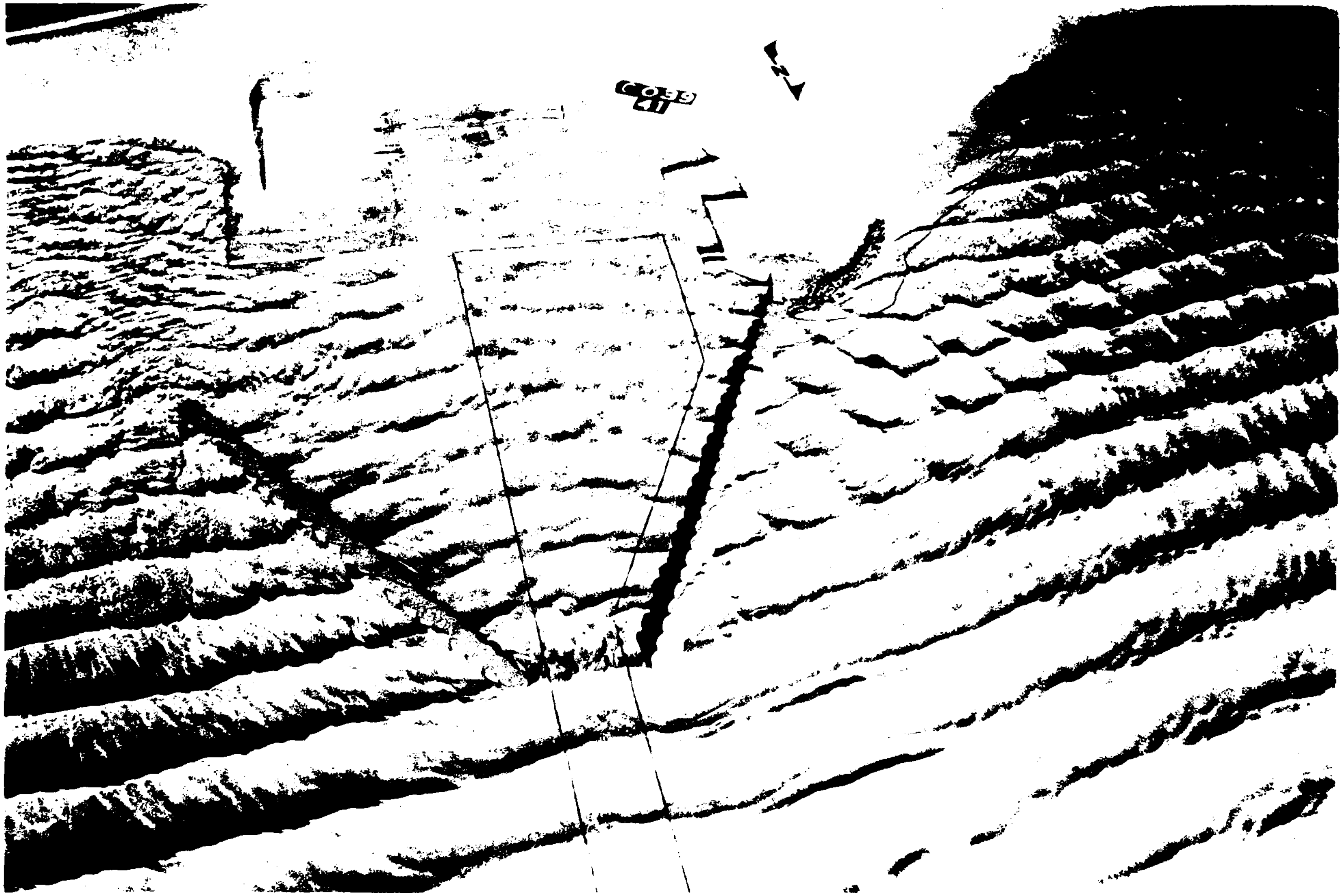

Photo 29. Typical wave patterns for Base Test 2; 5.7-sec, 4.6-ft waves from north; +5.0 ft swl

Photo 40. Typical wave patterns for Base Test 2; 6.2-sec, 6.1-ft waves from north; +5.0 ft swl

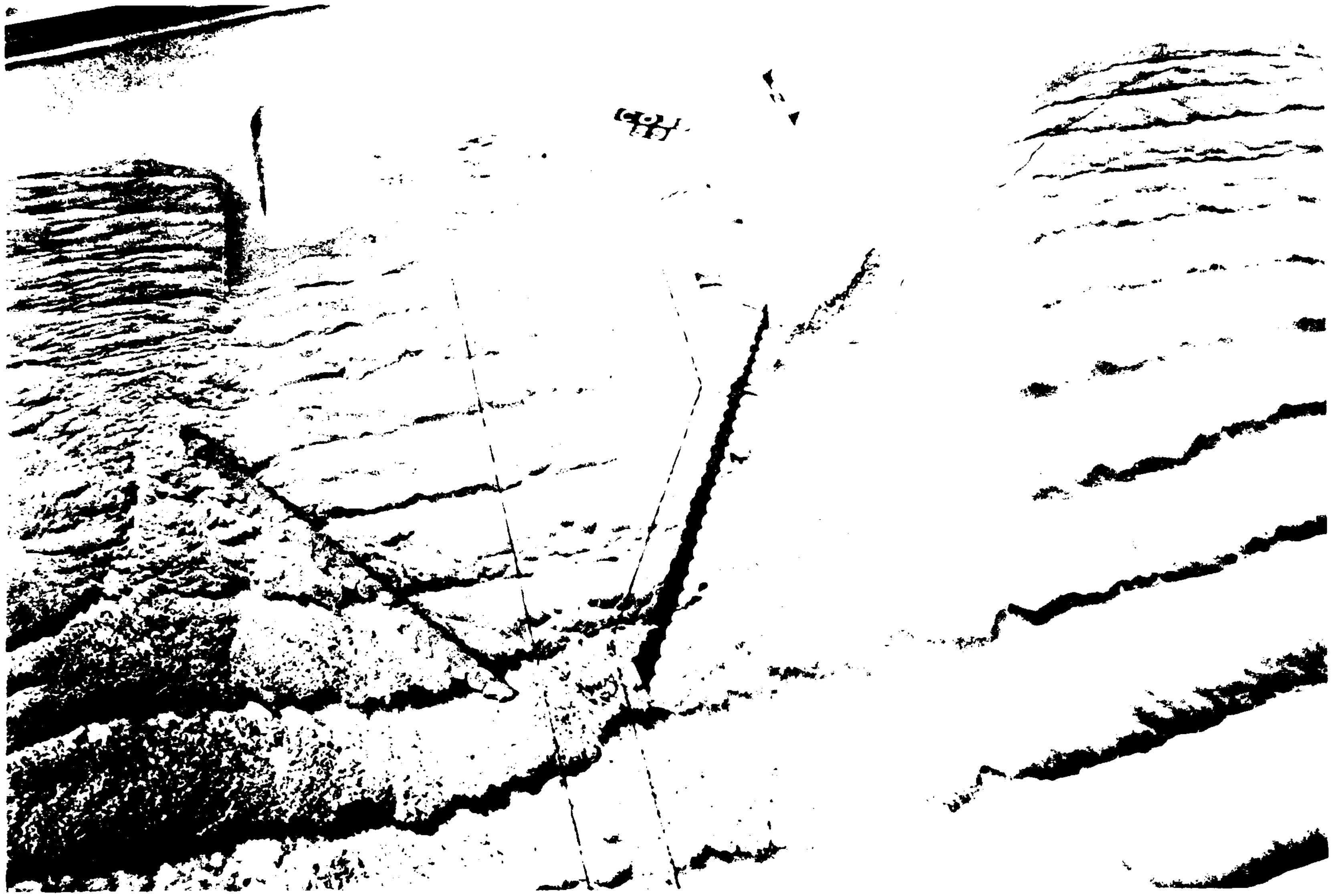

Photo 41. Typical wave patterns for Base Test 2; 7.8-sec, 10.2-ft waves from north; +5.0 ft swl

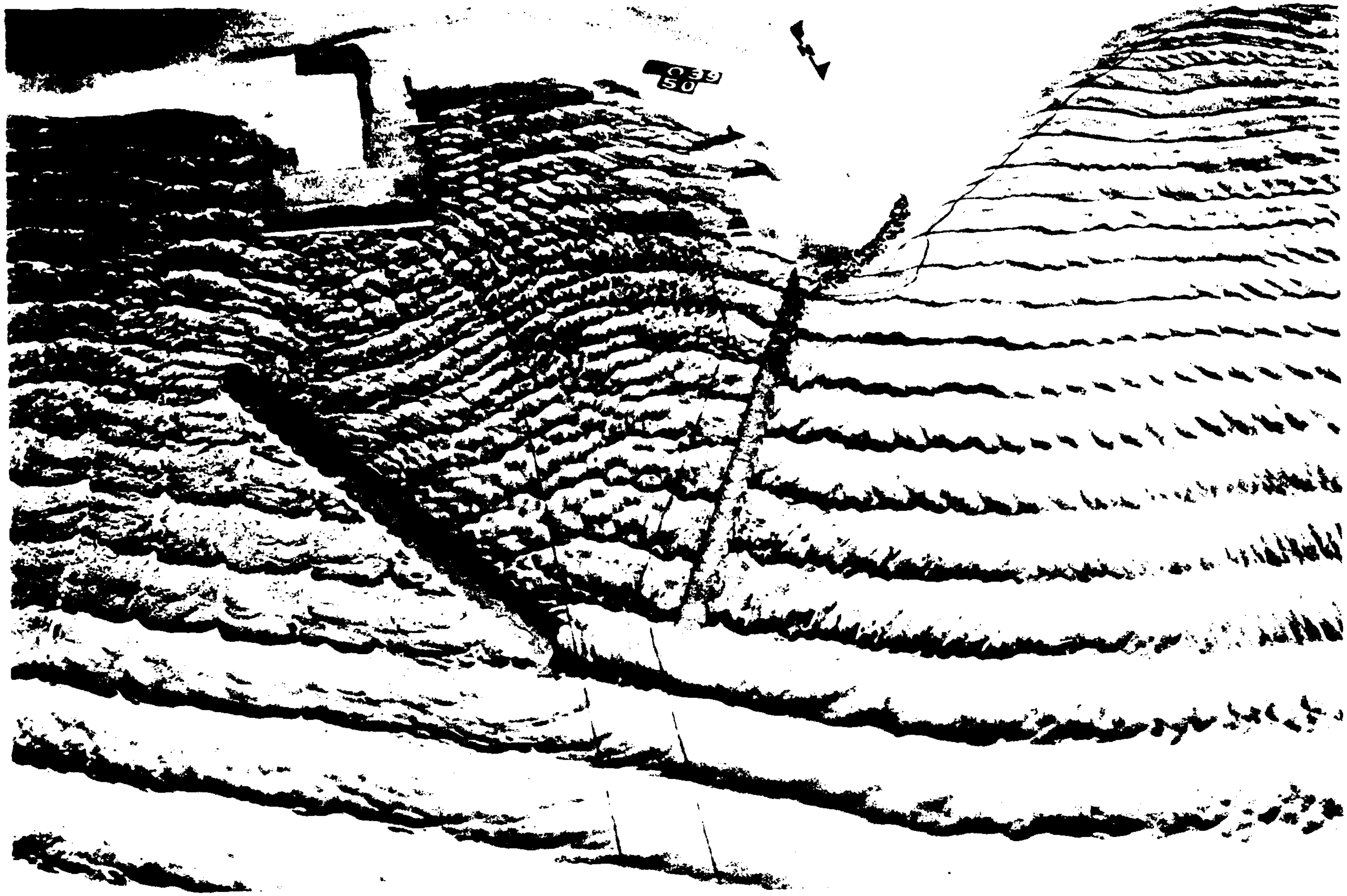

Photo 42. Typical wave patterns for Base Test 2; 5.9-sec, 4.3-ft waves from northeast; +3.0 ft swl

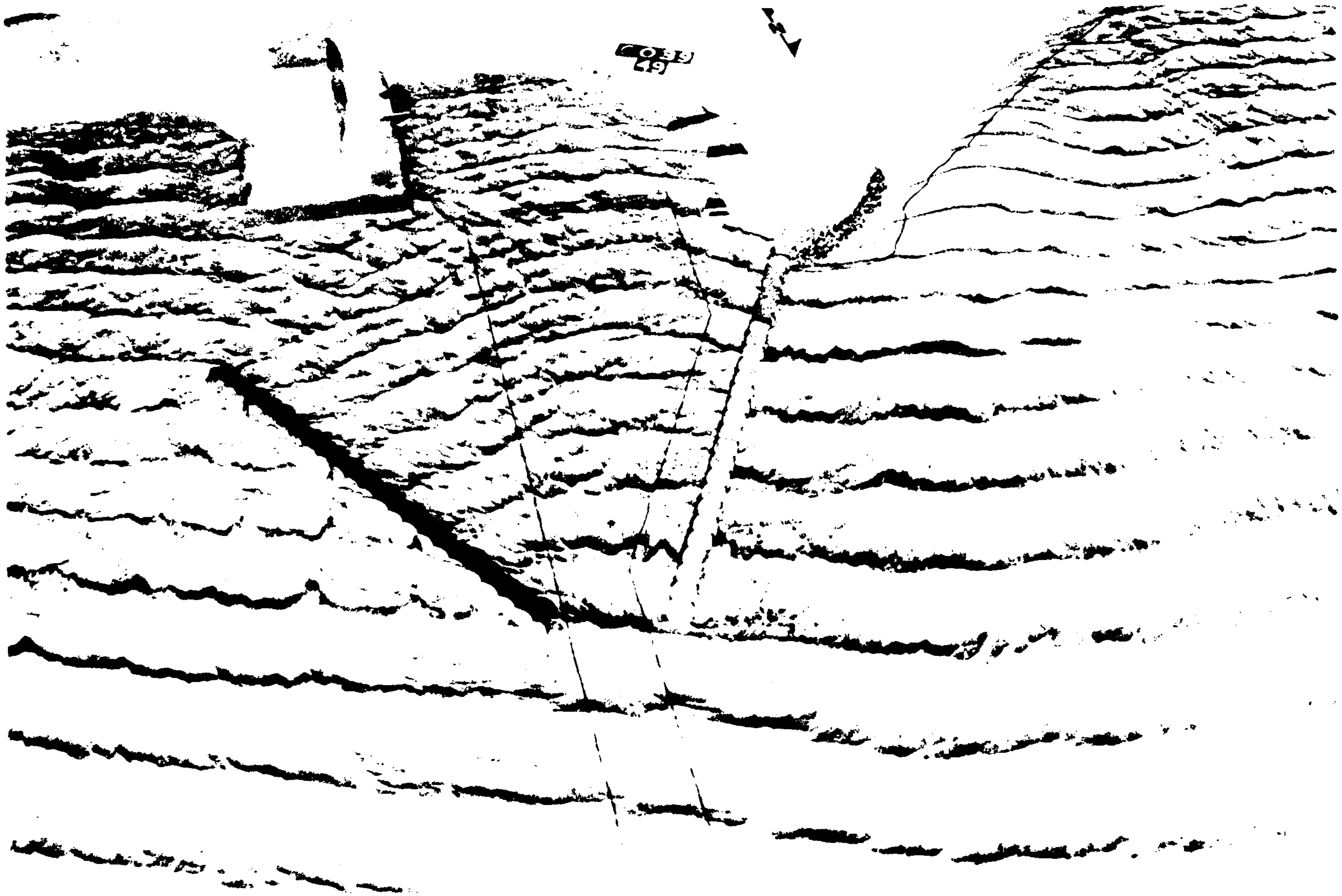

Photo 43. Typical wave patterns for Base Test 2; 6.4-sec, 5-ft waves from northeast; +3.0 ft swl

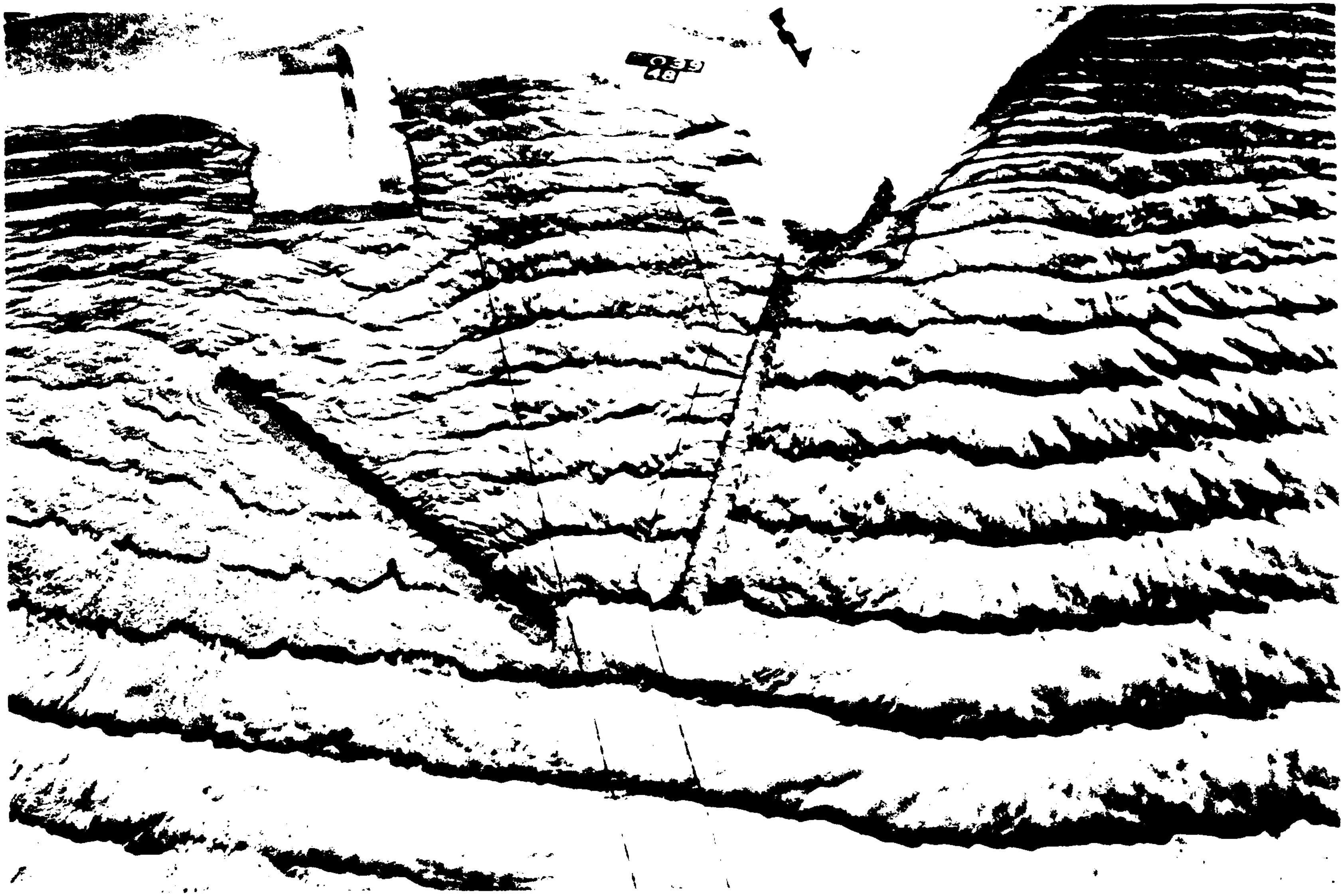

Photo 44. Typical wave patterns for Base Test 2; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

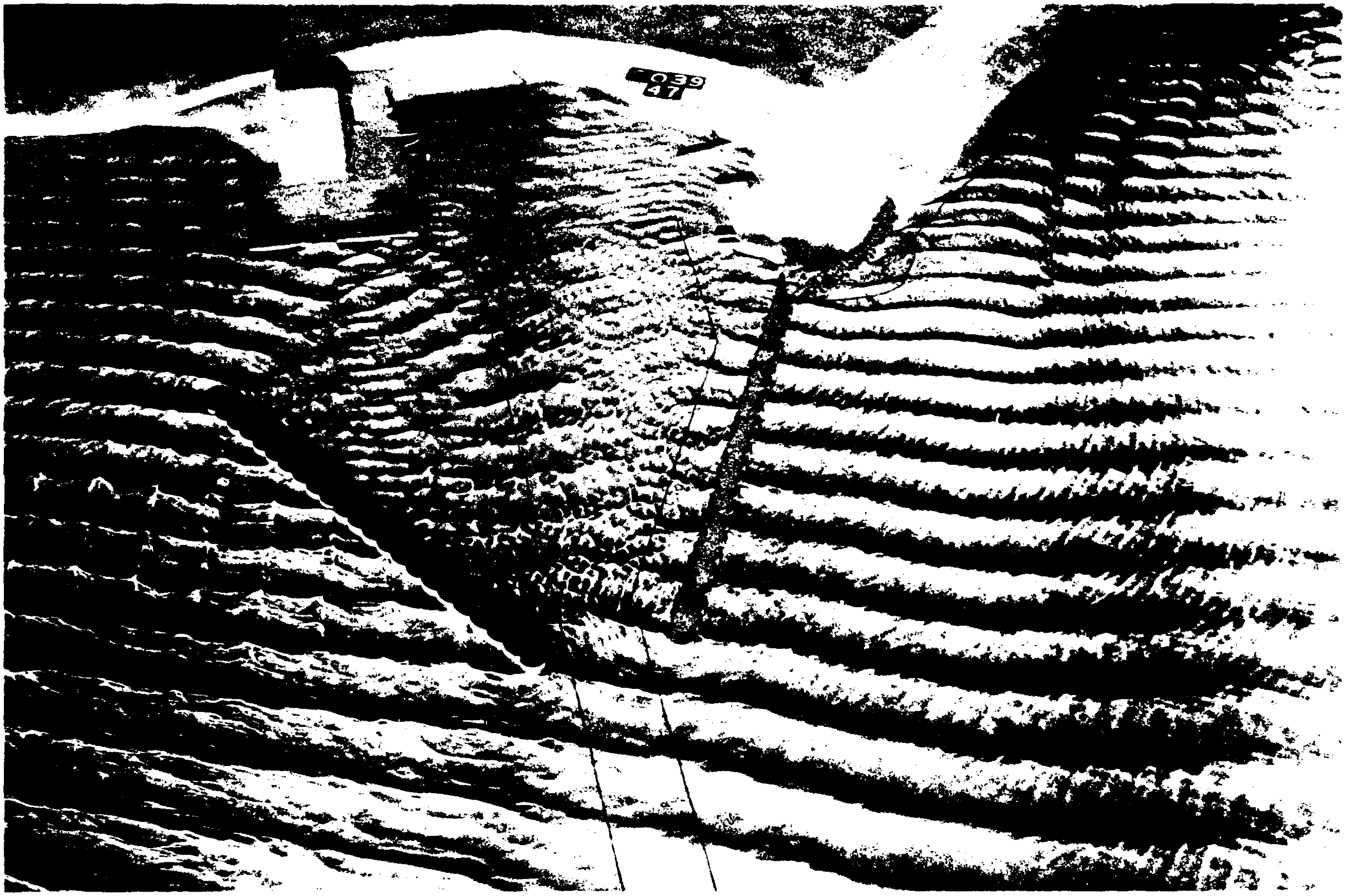

Photo 45. Typical wave patterns for Base Test 2; 4.9-sec, 2.8-ft waves from northeast; +4.0 ft swl

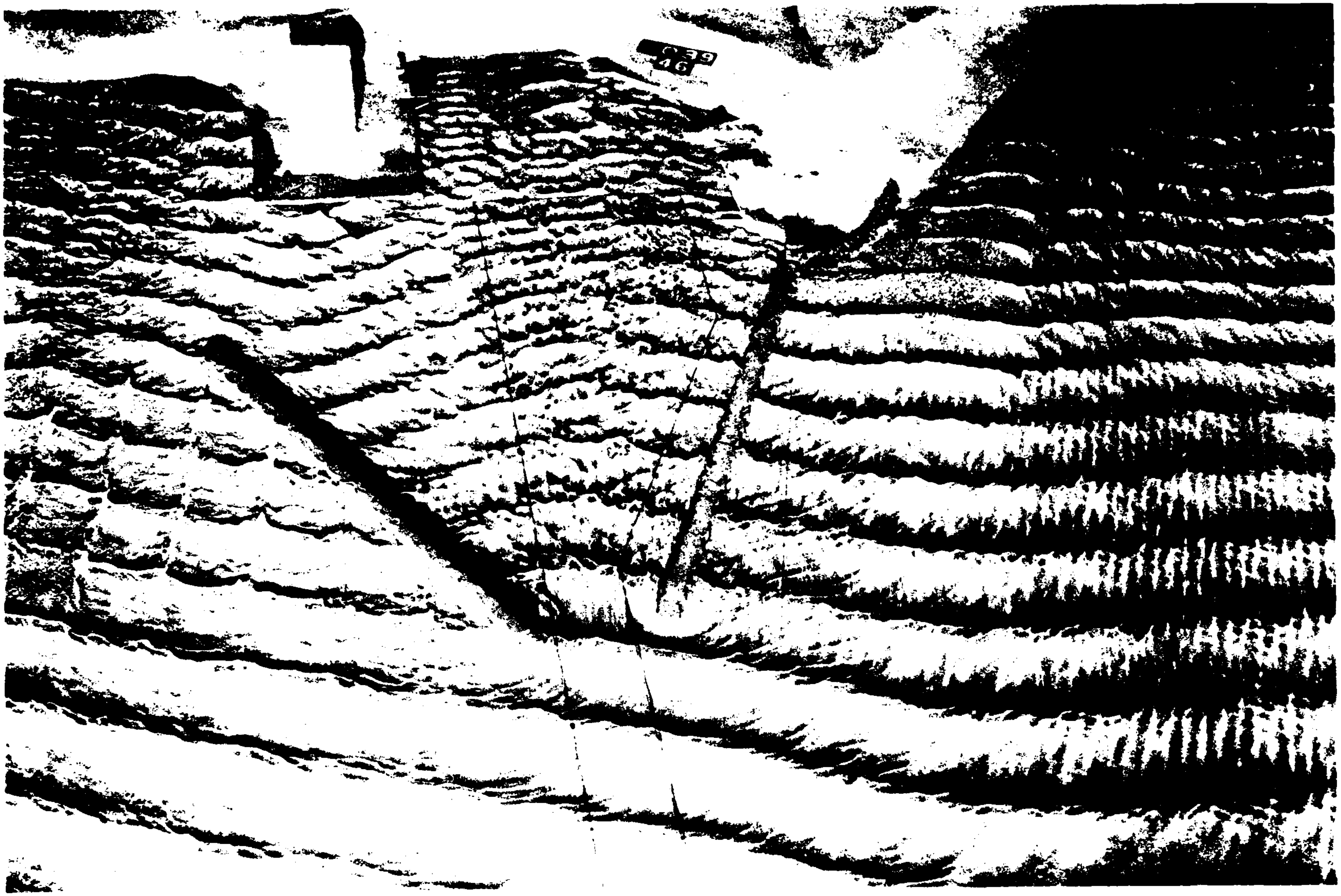

Photo 46. Typical wave patterns for Base Test 2; 5.9-sec, 4-ft waves from northeast; +4.0 ft swl

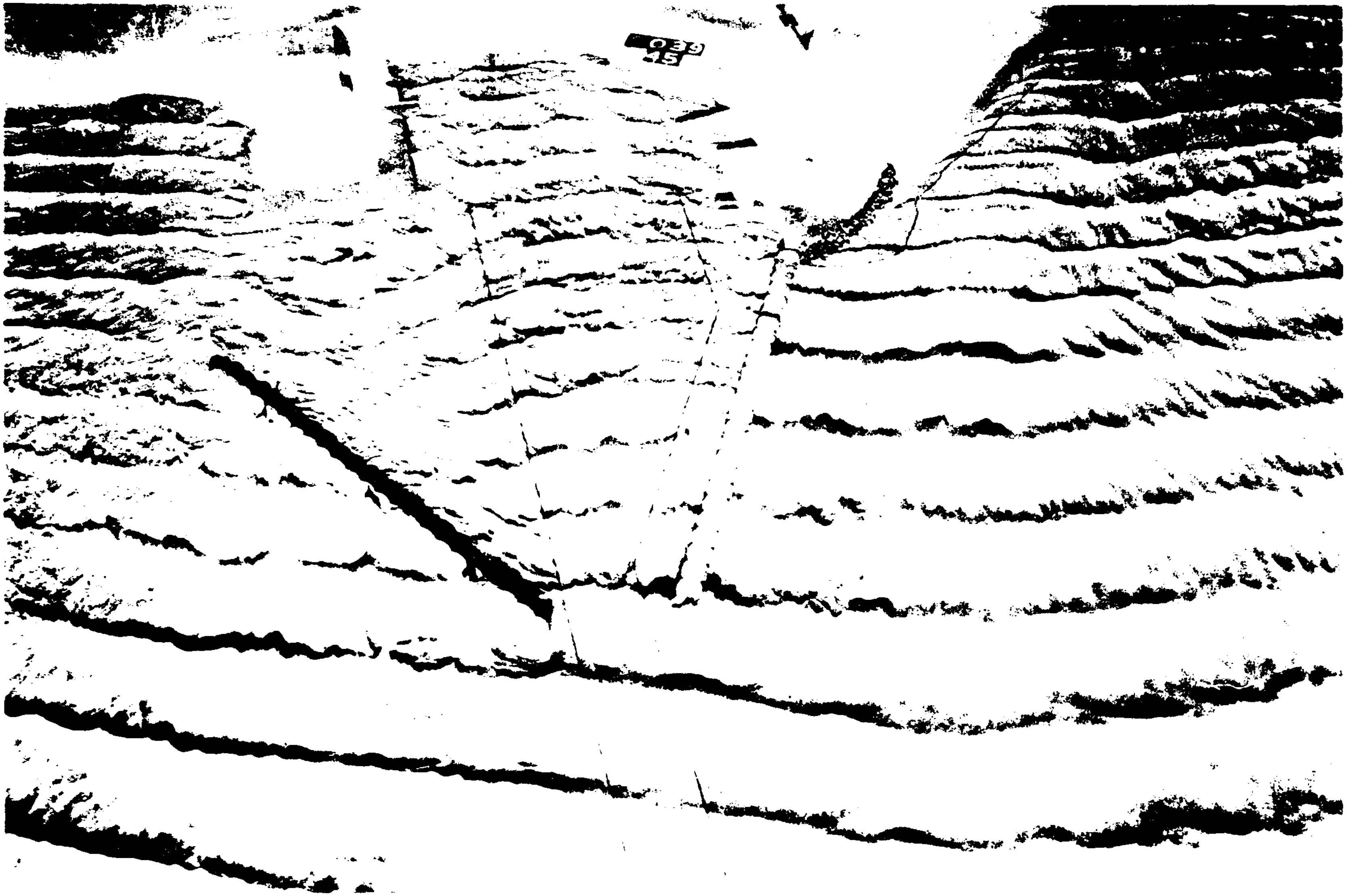

Photo 47. Typical wave patterns for Base Test 2; 6.9-sec, 5.8-ft waves from northeast; +4.0 ft swl

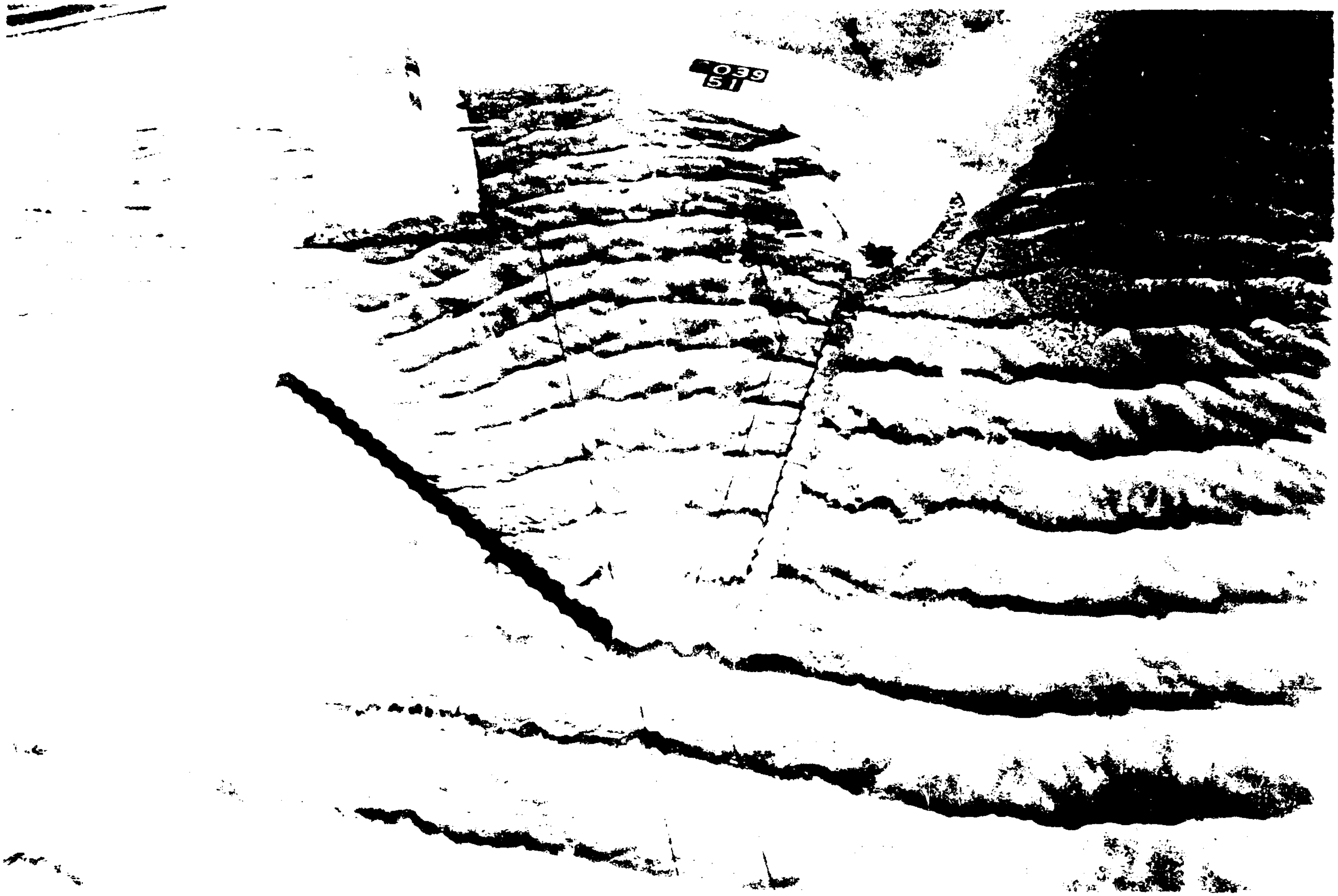

Photo [illegible]. Typical wave patterns for Plan 1; 6.7-sec, 5.7-ft waves from northeast; +3.0 [illegible]

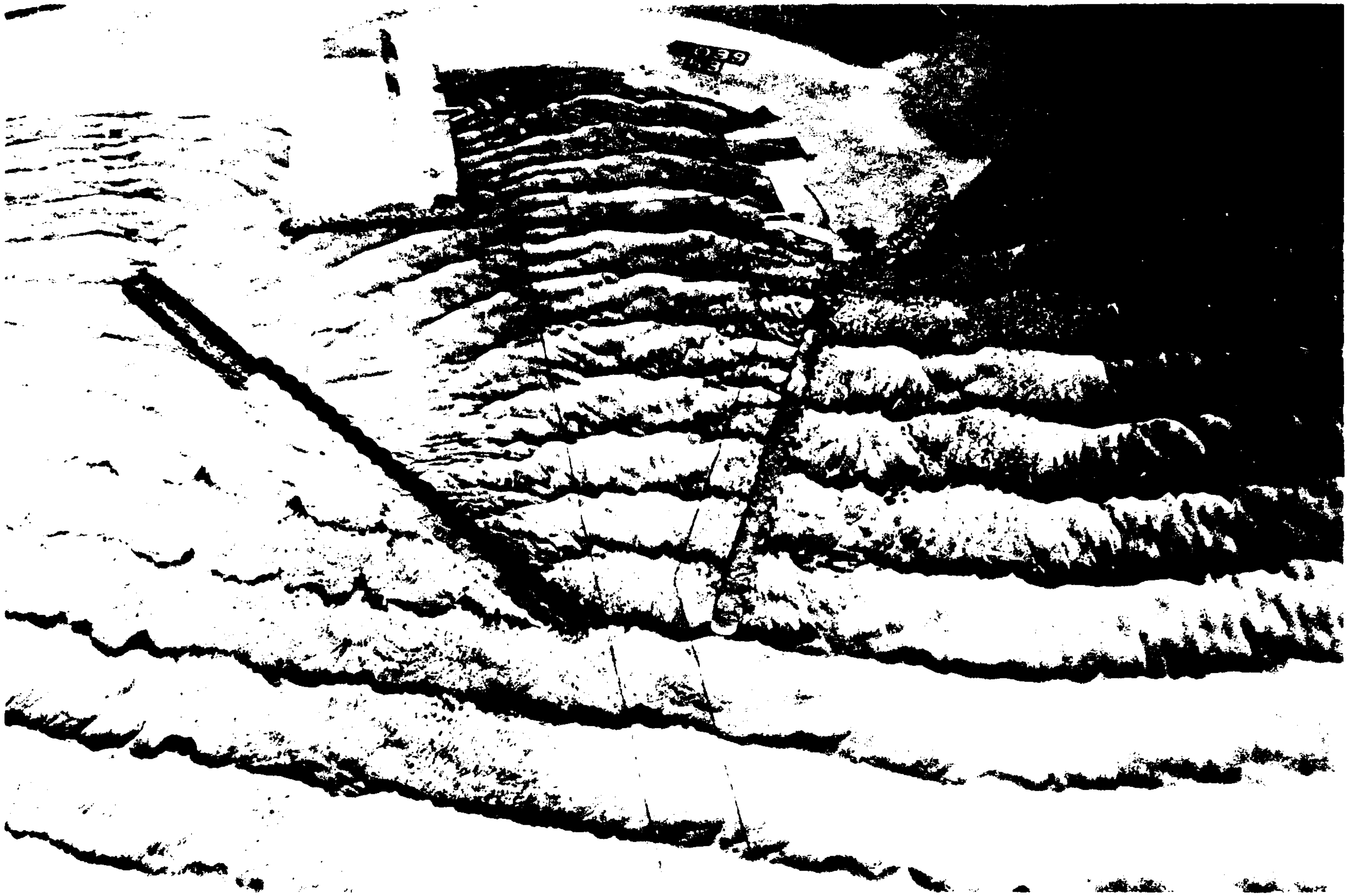

Photo 39. Typical wave patterns for Plan 2; 6.7-sec, 5.7-ft waves from northeast; +5.0 ft swl

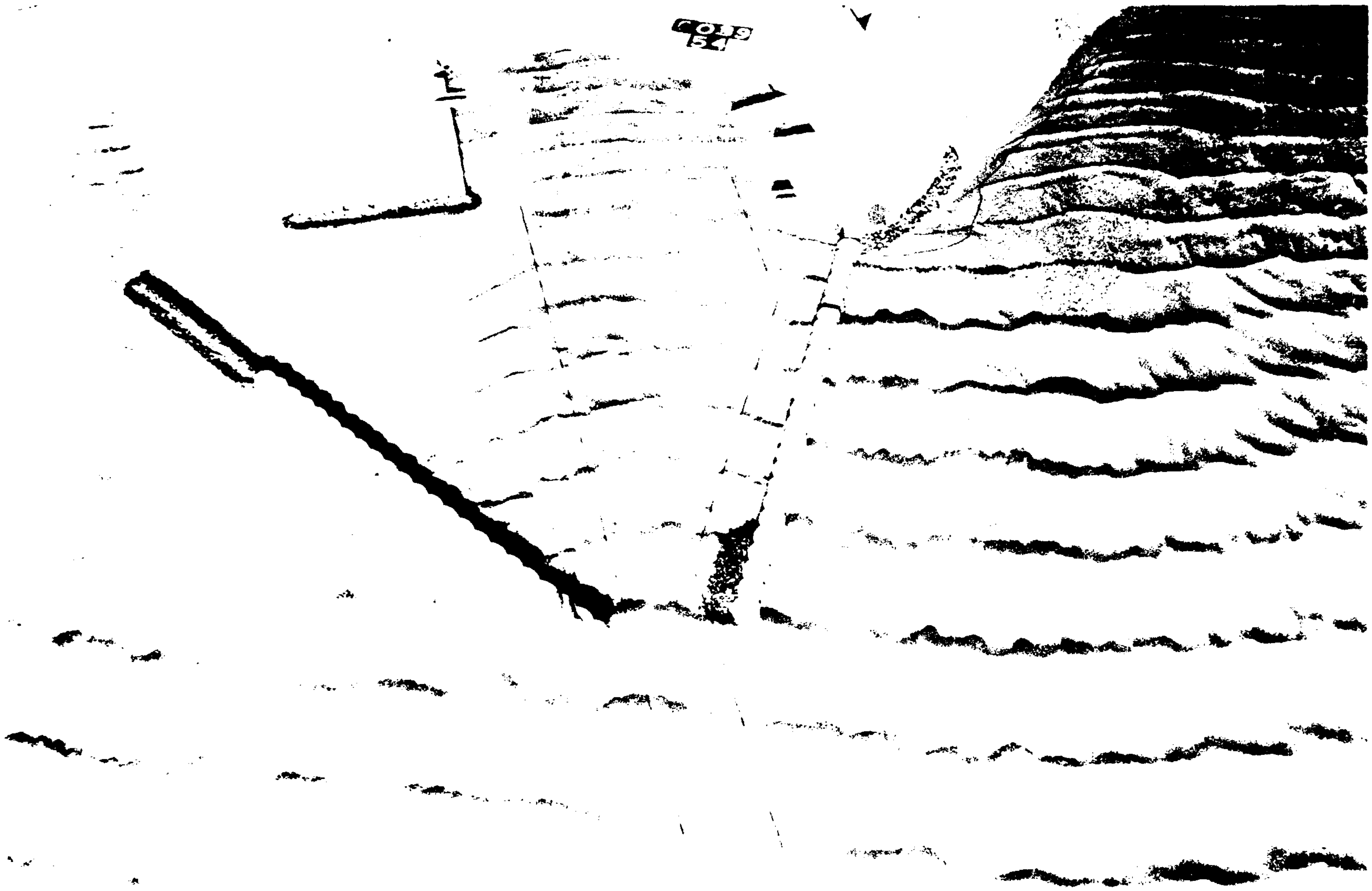

Photo 50. Typical wave patterns for Plan 3; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

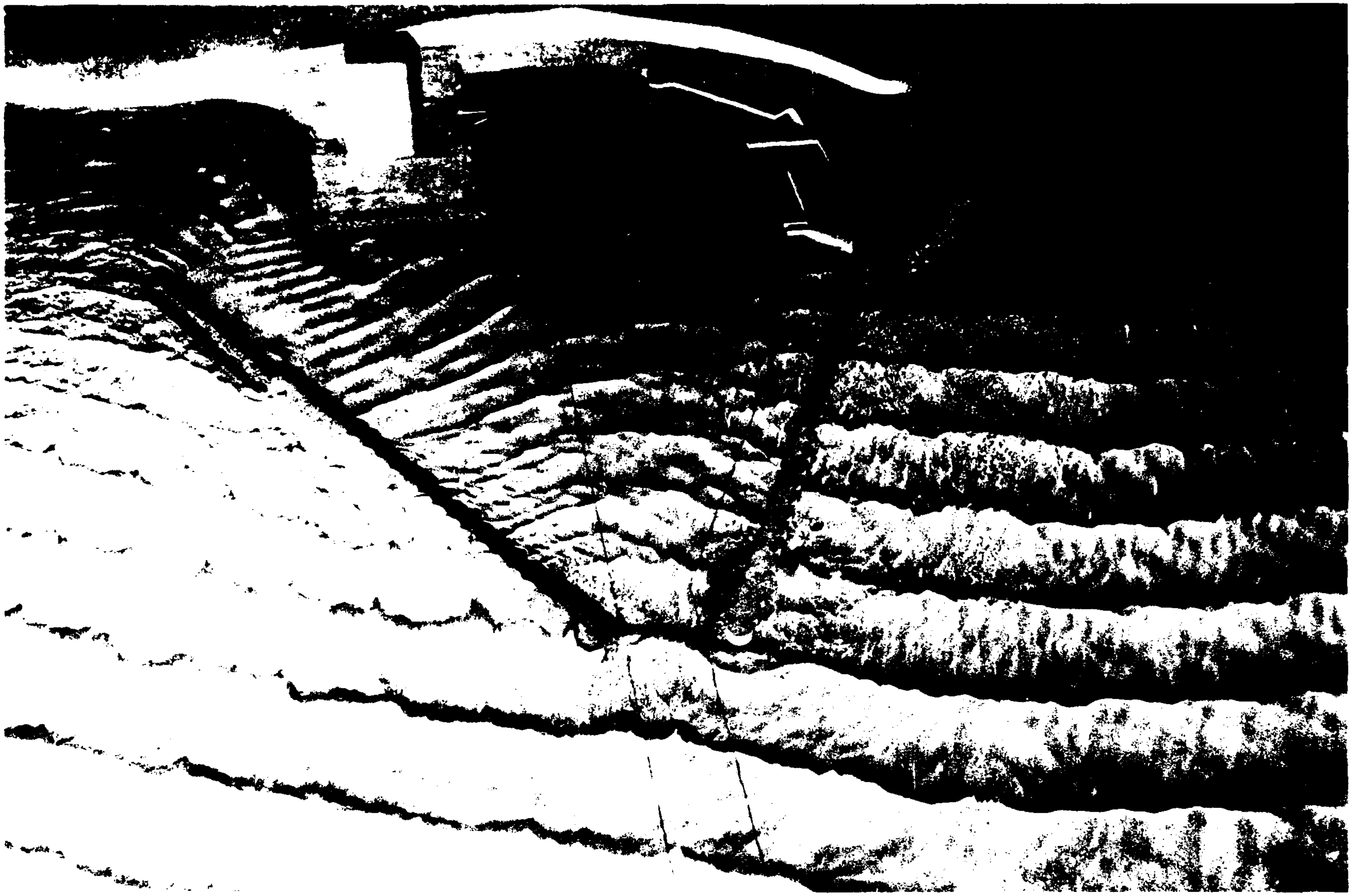

Photo 51. Typical wave patterns for Plan 4; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

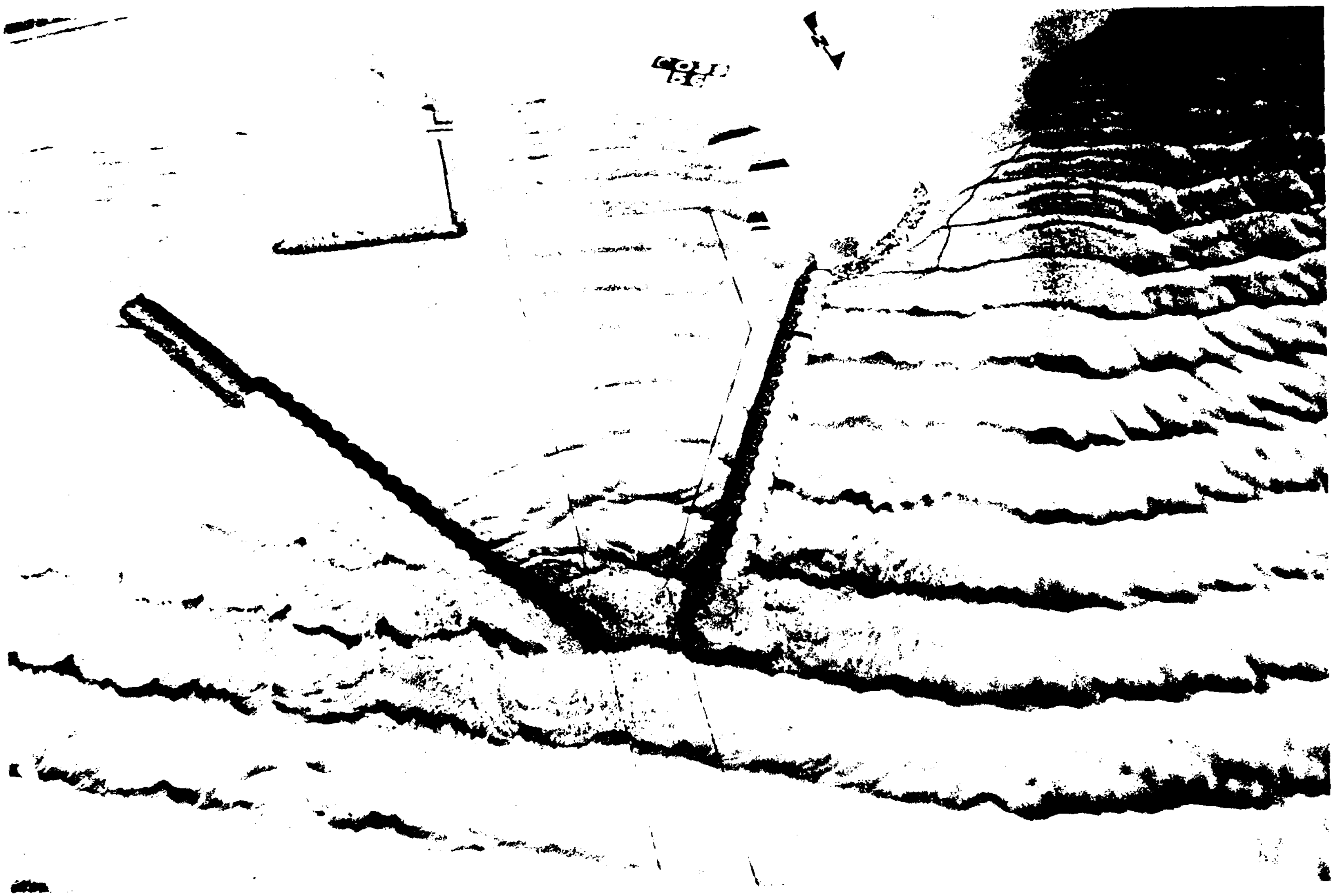

Photo 52. Typical wave patterns for Plan 5; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

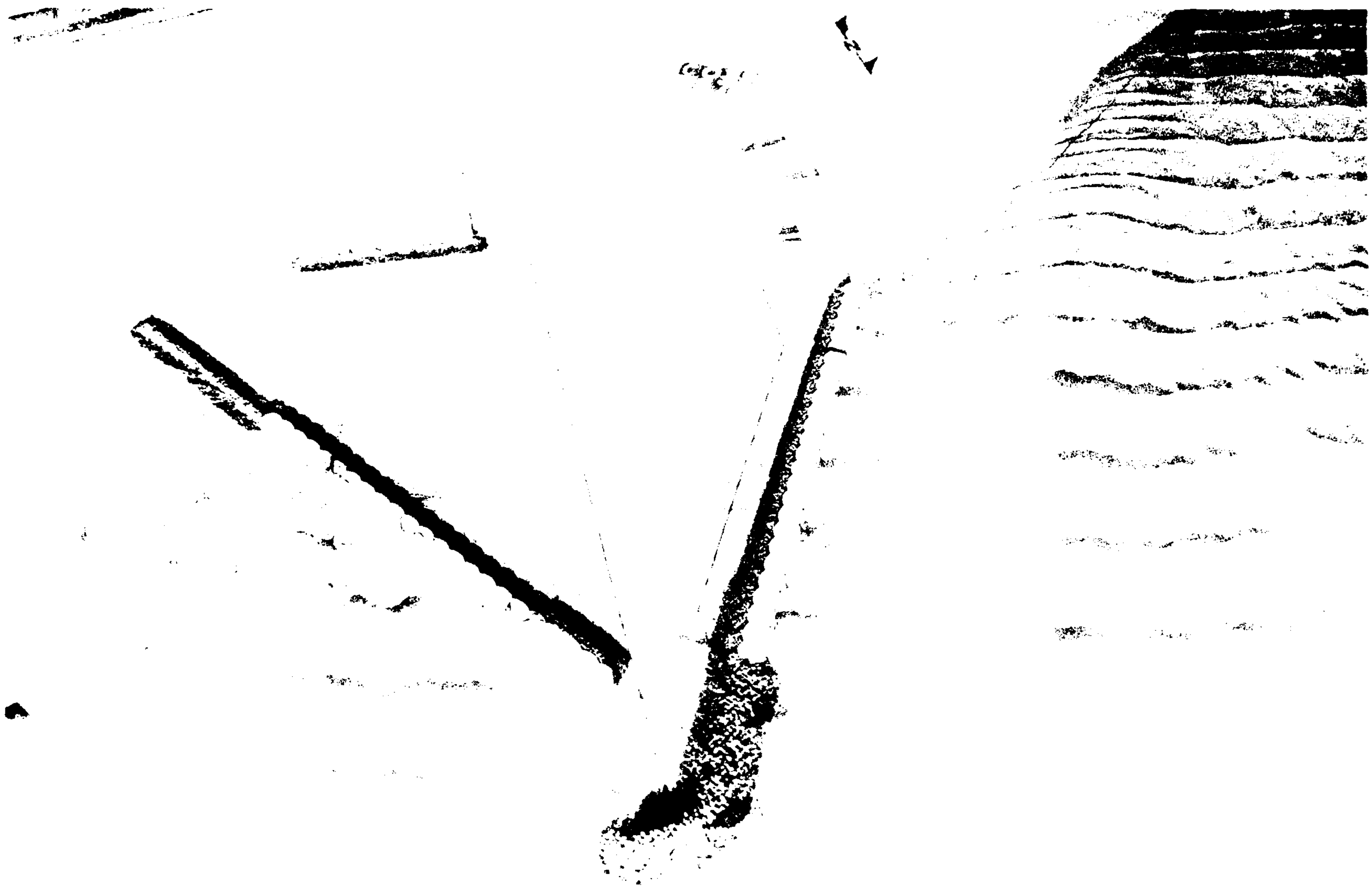

Photo 53. Typical wave patterns for Plan 6; 6.7-sec, [illegible]

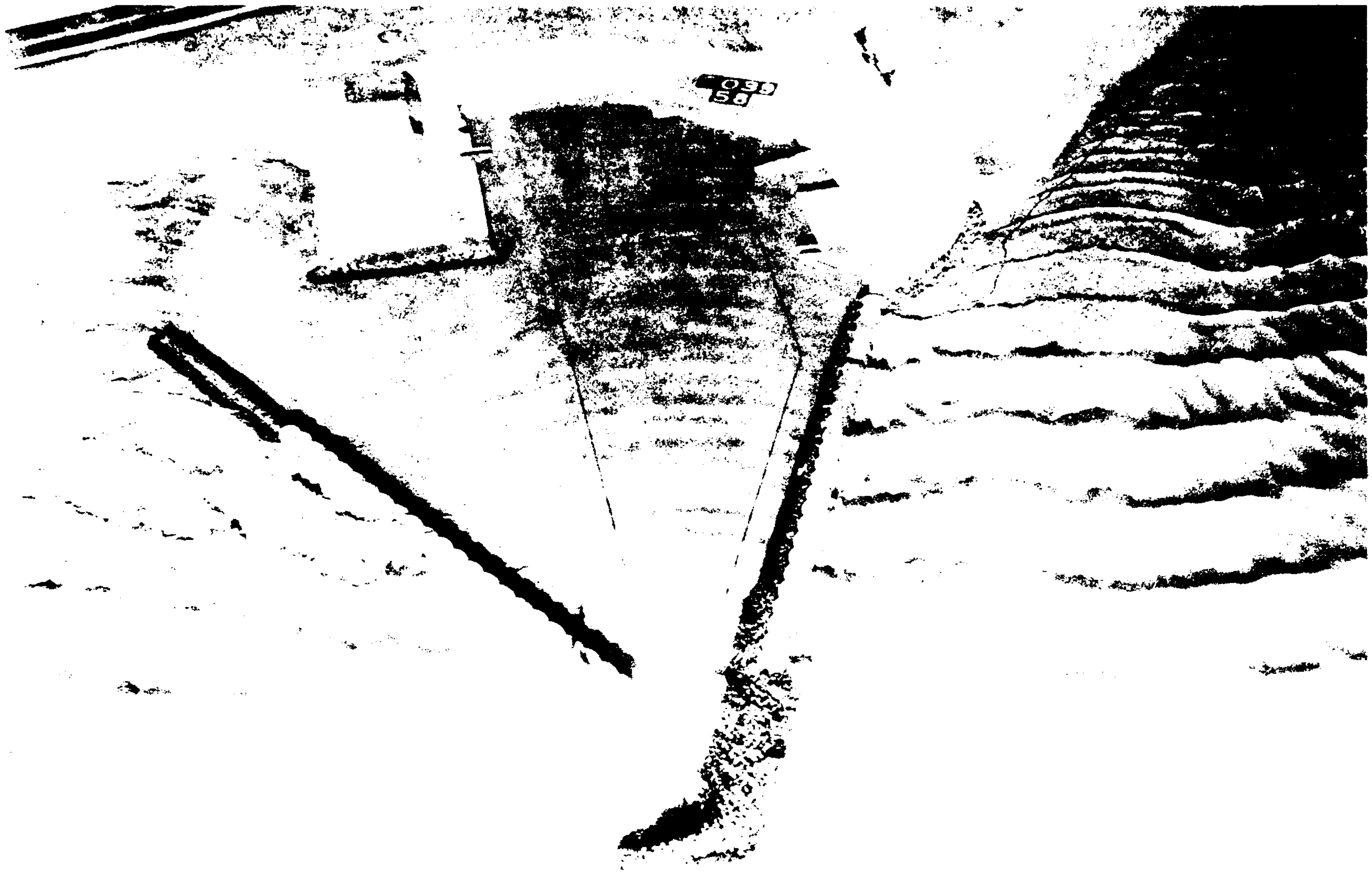

Photo 54. Typical wave patterns for Plan 7; 6.7-sec, 5.7-ft waves from northeast; +5.0 ft swl

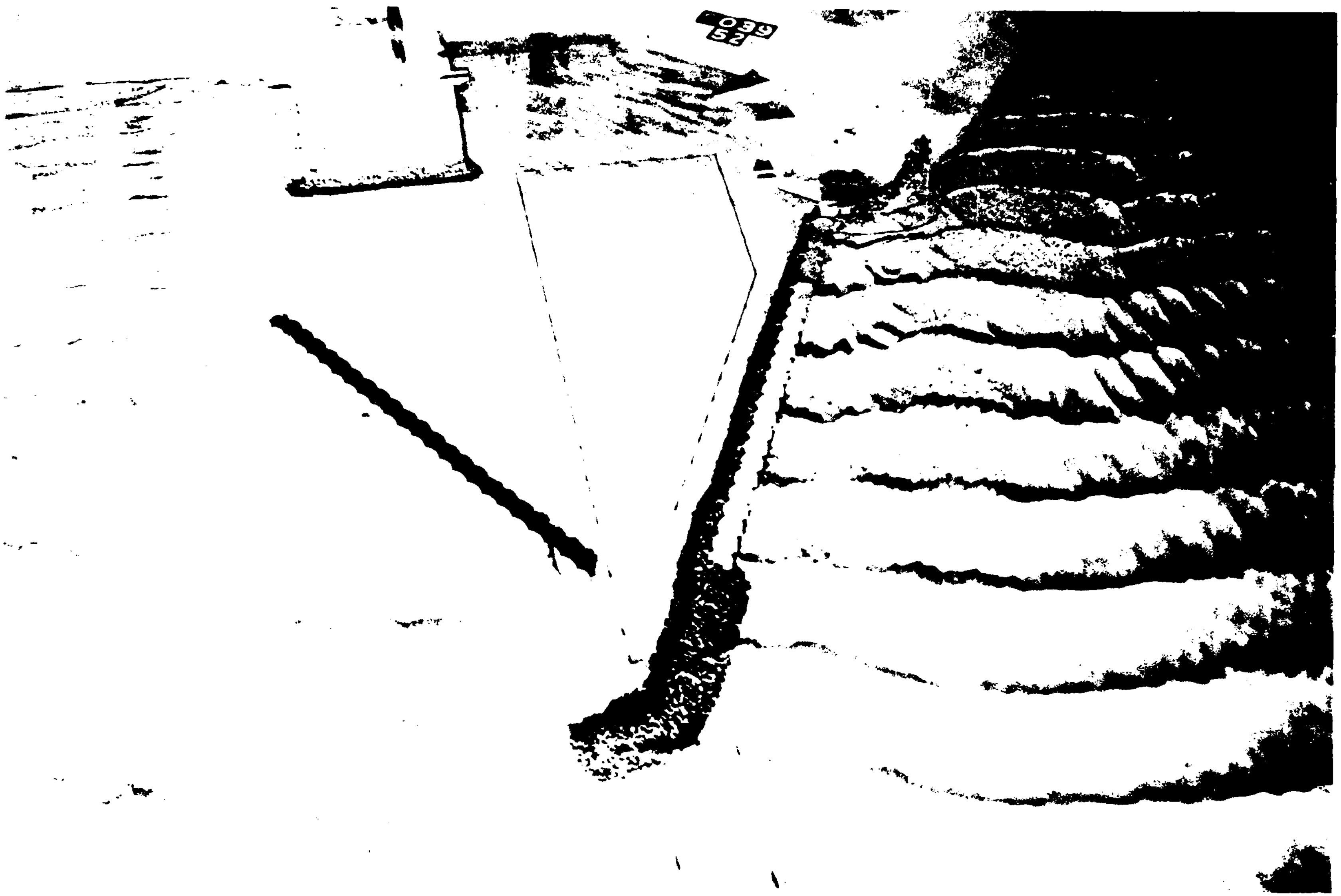

Photo 55. Typical wave patterns for Plan 8; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

Photo 56. Typical wave patterns for Plan 9; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

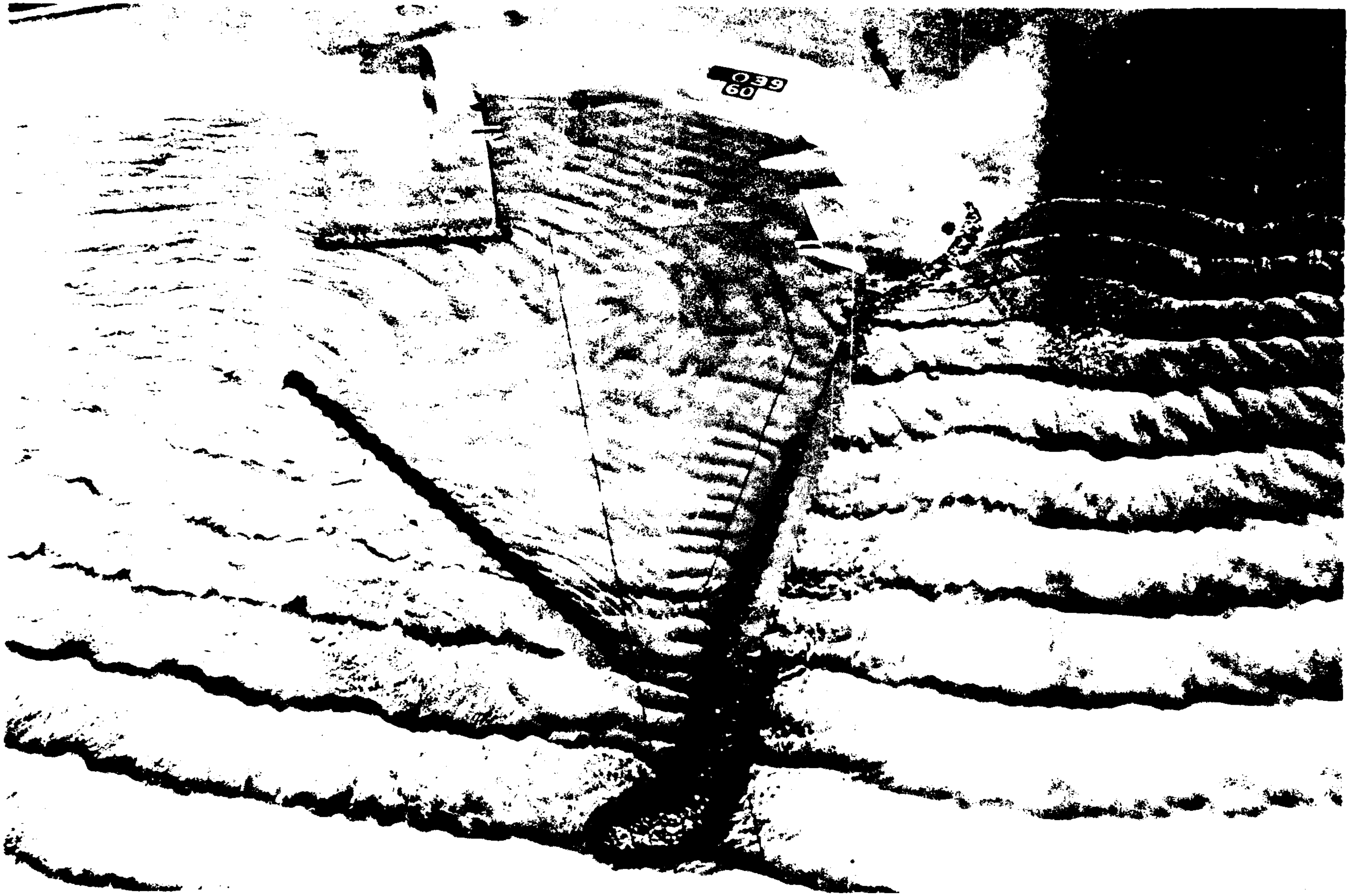

Photo 57. Typical wave patterns for Plan 10; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

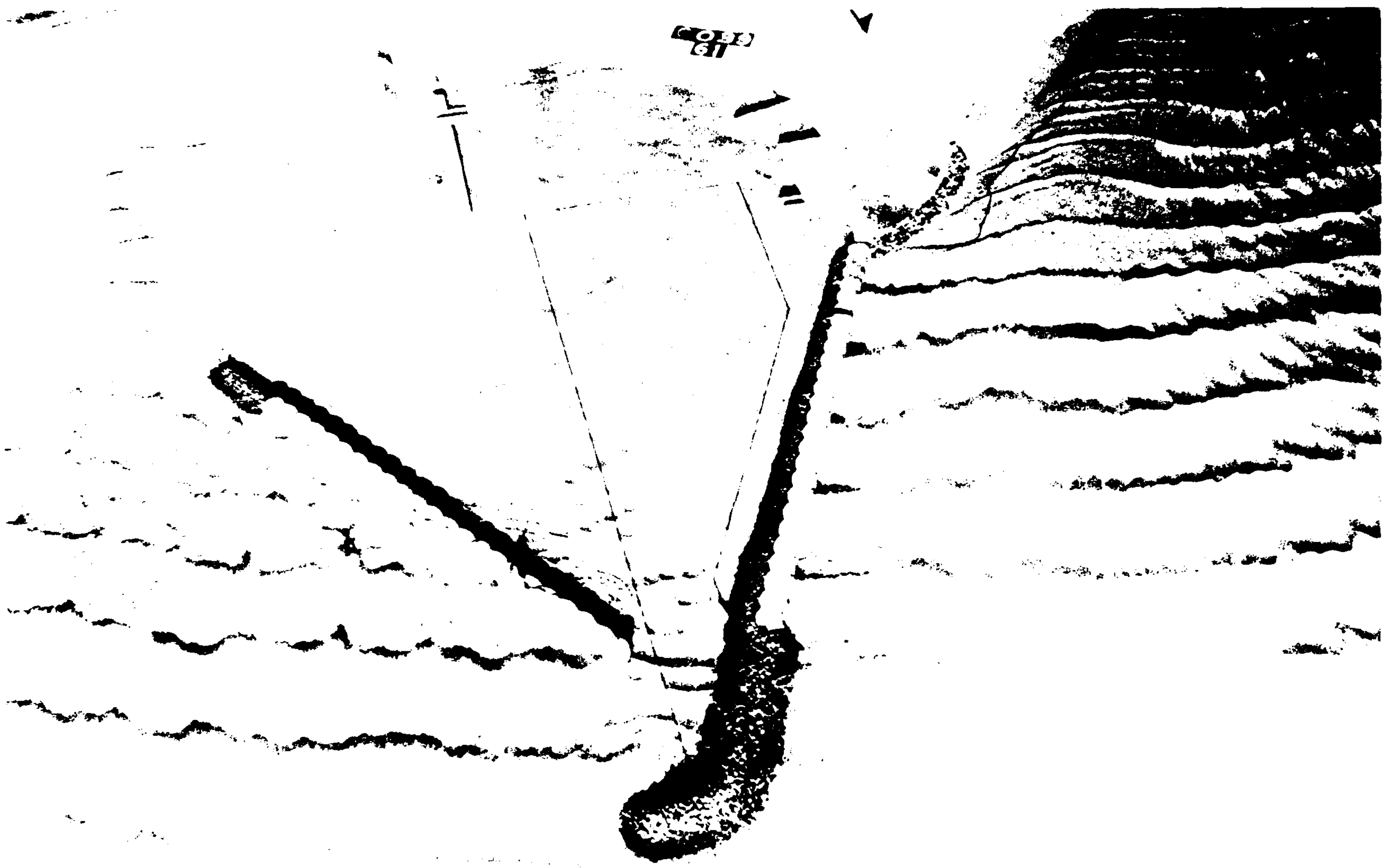

Photo 58. Typical wave patterns for Plan 11; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

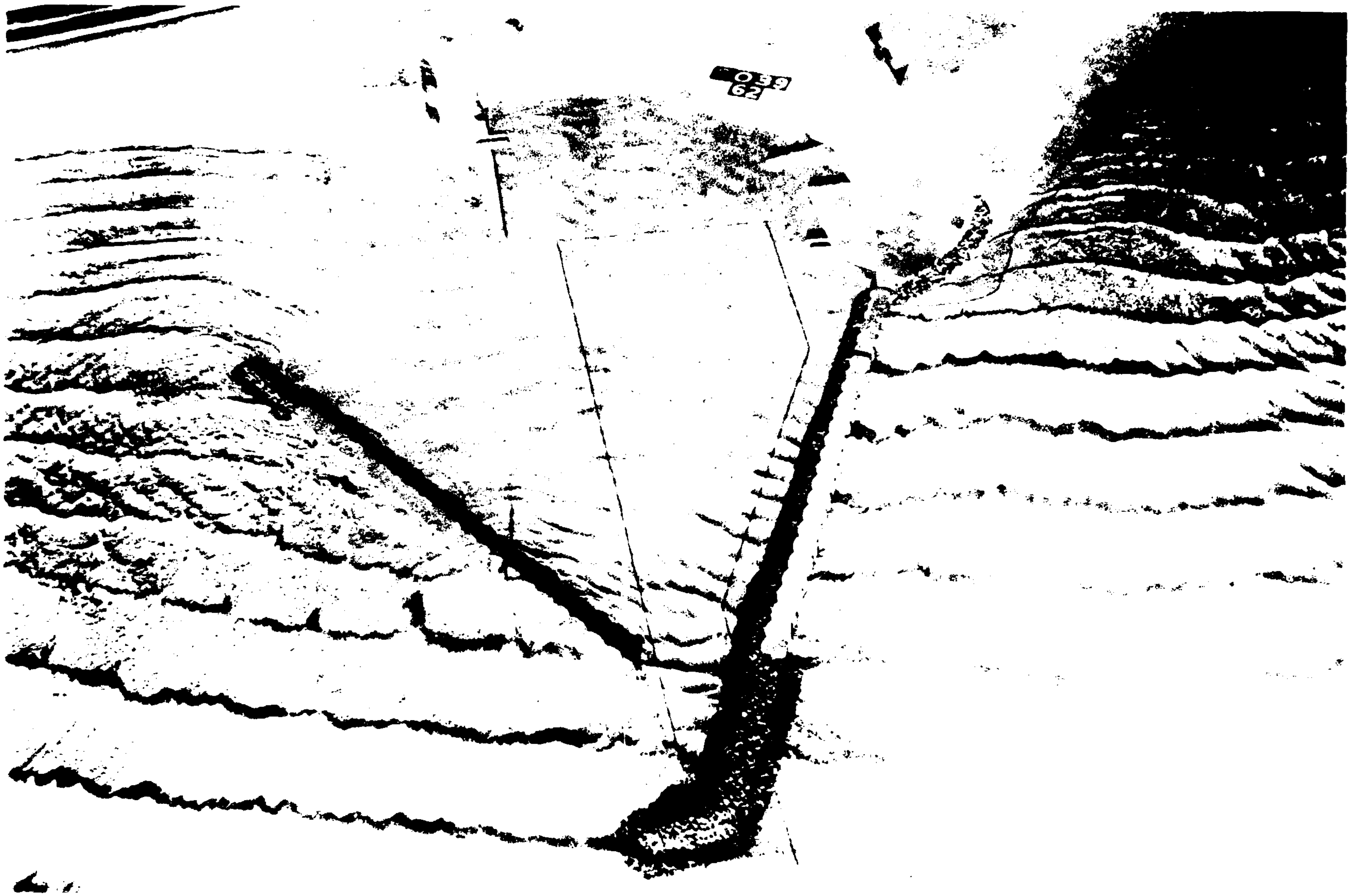

Photo 59. Typical wave patterns for Plan 12; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

Photo 60. Typical wave patterns for Plan 12; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

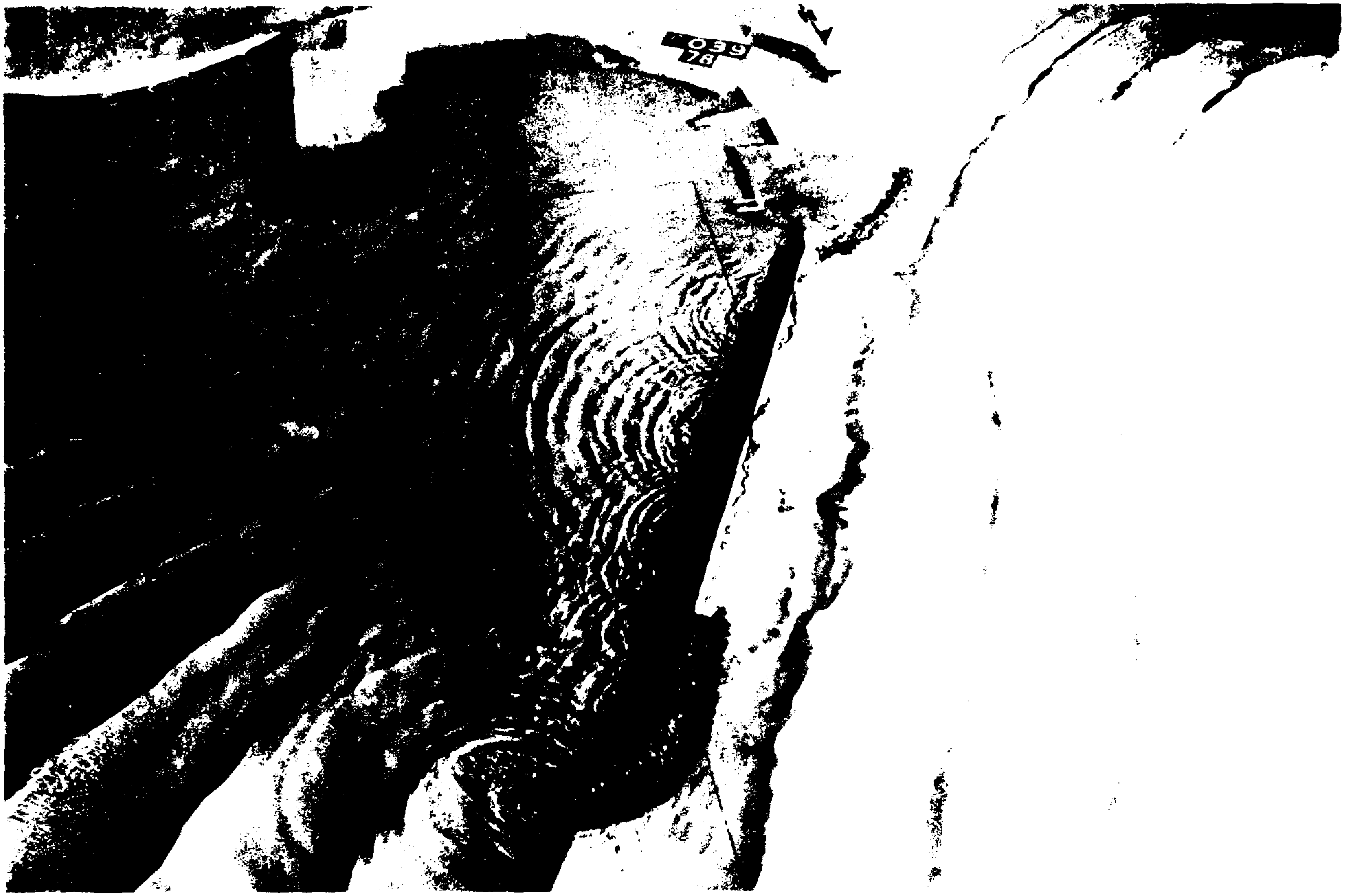

Photo 61. Typical wave patterns for Plan 13; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 62. Typical wave patterns for Plan 14; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

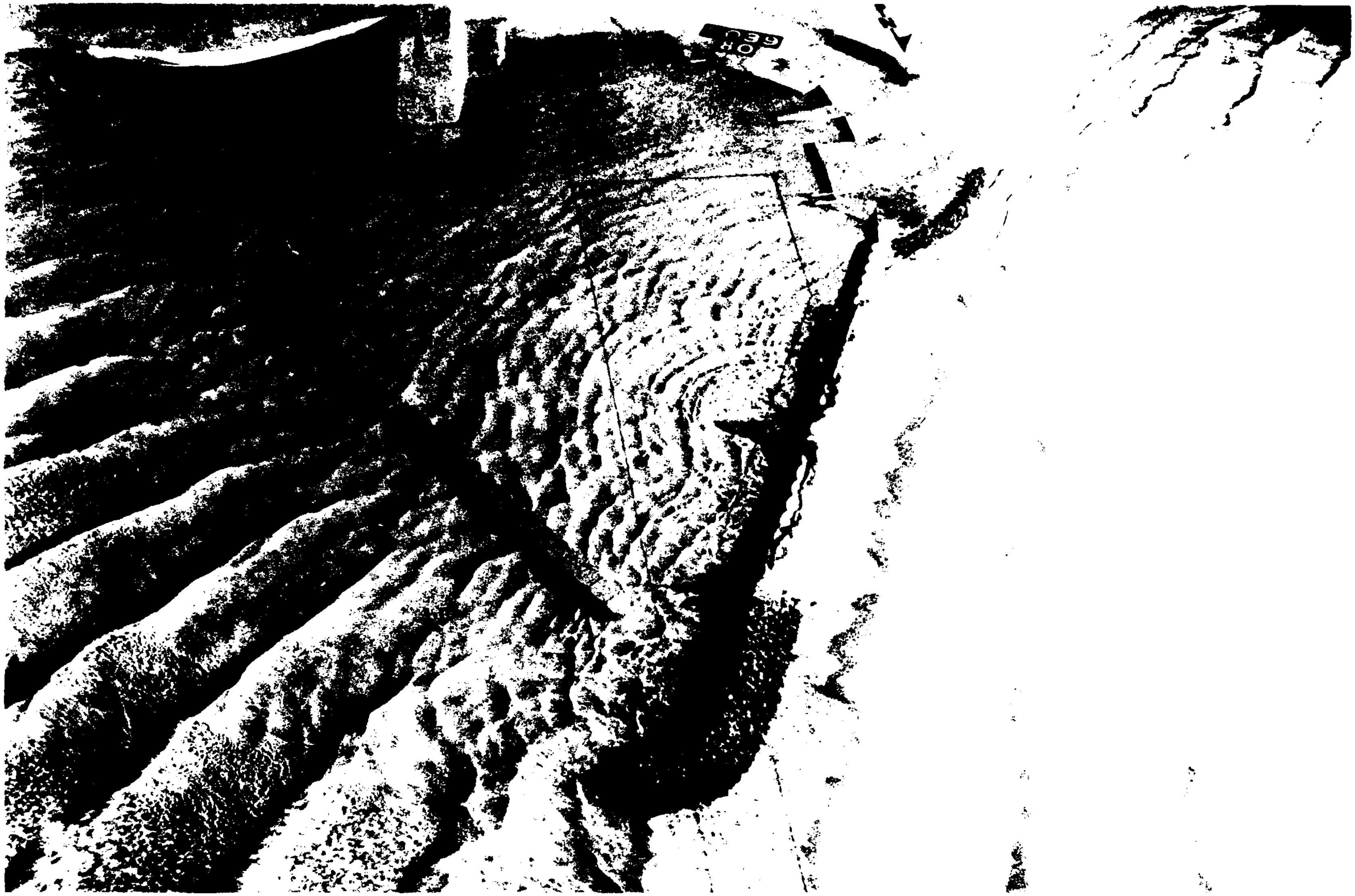

Photo 63. Typical wave patterns for Plan 15; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 64. Typical wave patterns for Plan 16; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 65. Typical wave patterns for Plan 17; 7.7-sec, 7.9-ft waves from west; +6.3 ft swl

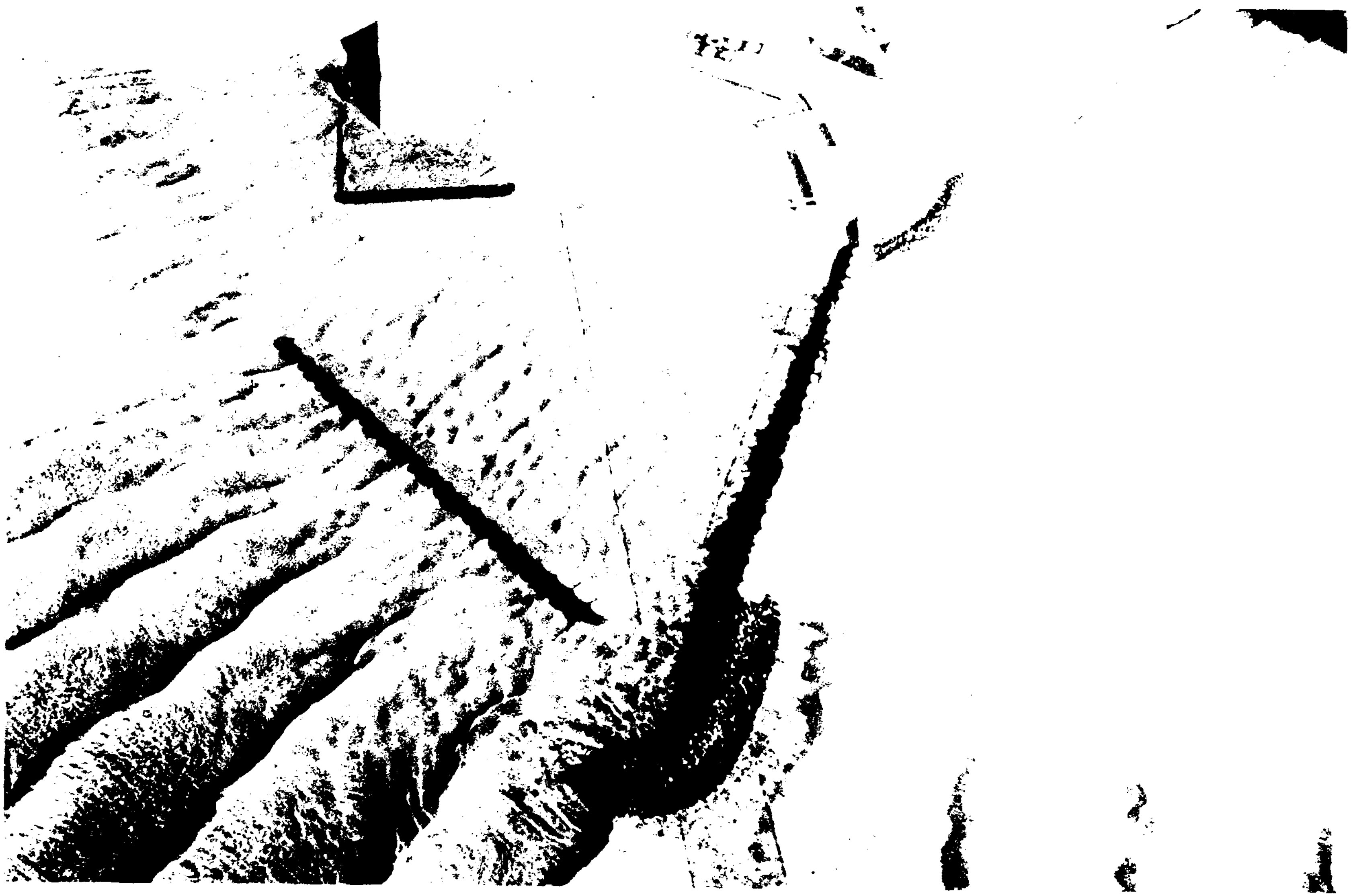

Photo 66. Typical wave patterns for Plan 18; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

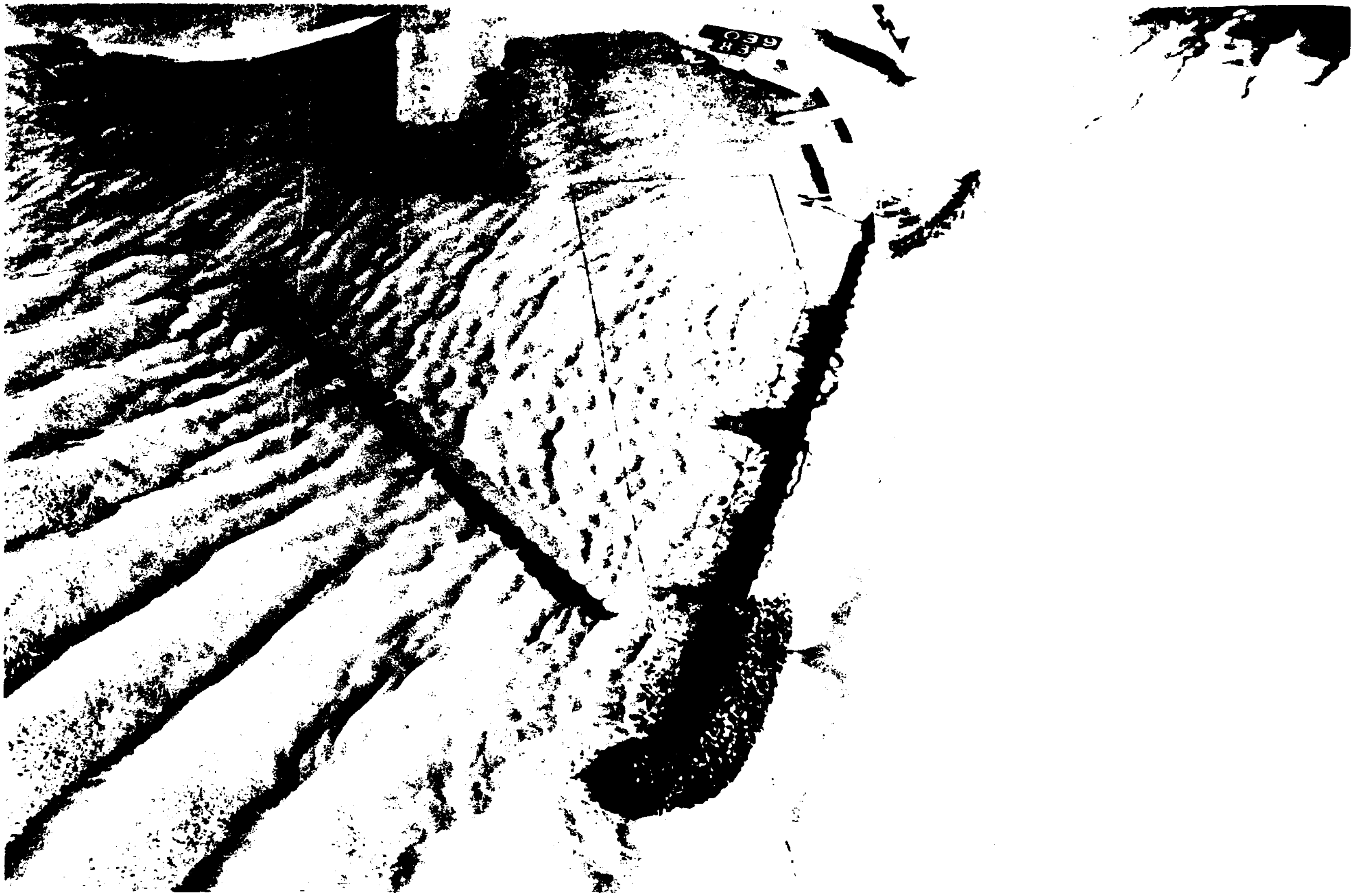

Photo 67. Typical wave patterns for Plan 19; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 68. Typical wave patterns for Plan 20; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 69. Typical wave patterns for Plan [illegible]; 7.5-[illegible], [illegible].0-ft wave from north; +4.0 ft swl

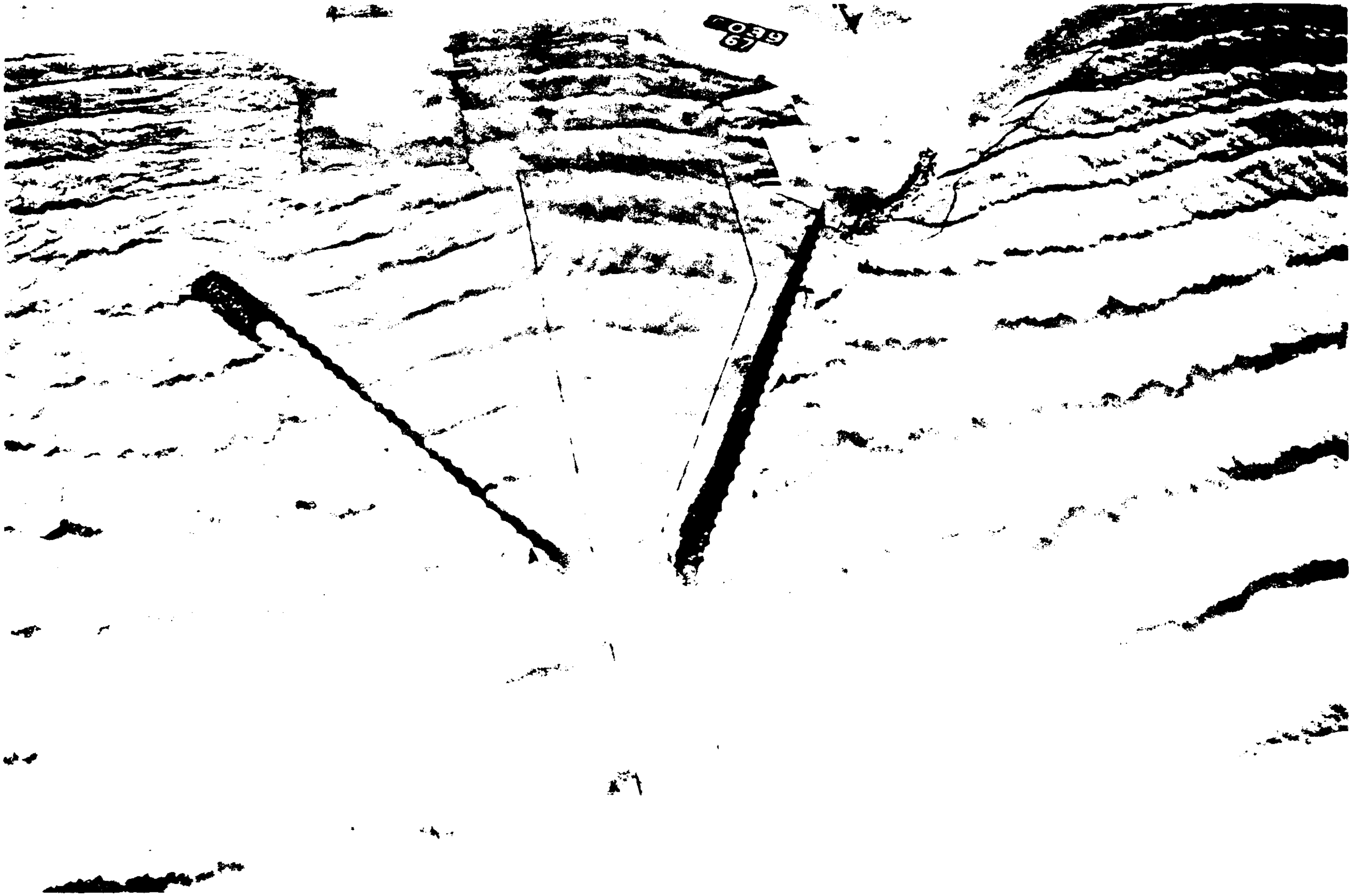

Photo 70. Typical wave patterns for Plan 22; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

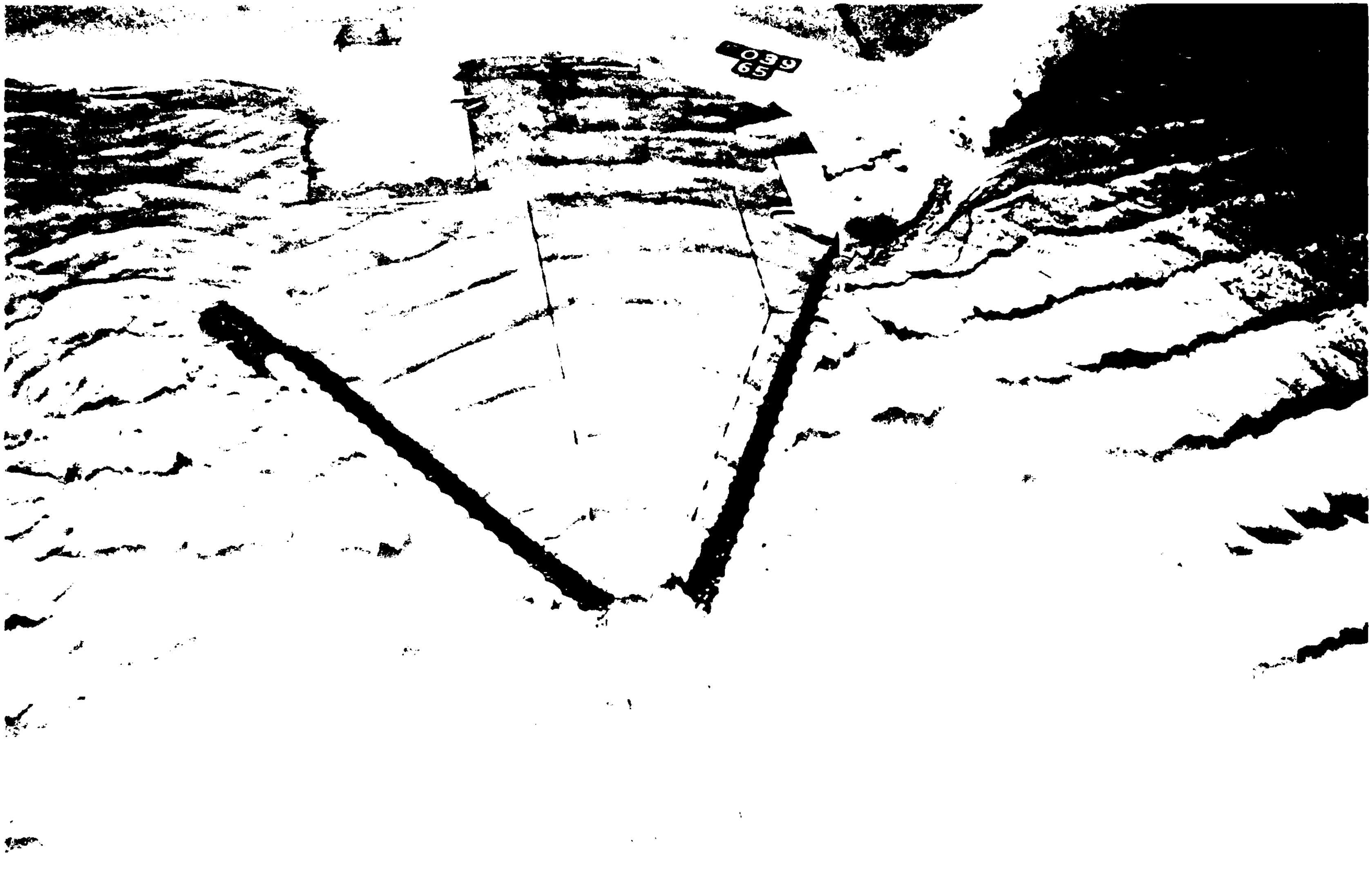

Photo 71. Typical wave patterns for Plan 23; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

Photo 72. Typical wave patterns for Plan 24; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

Photo 73. Typical wave patterns for Plan 25; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

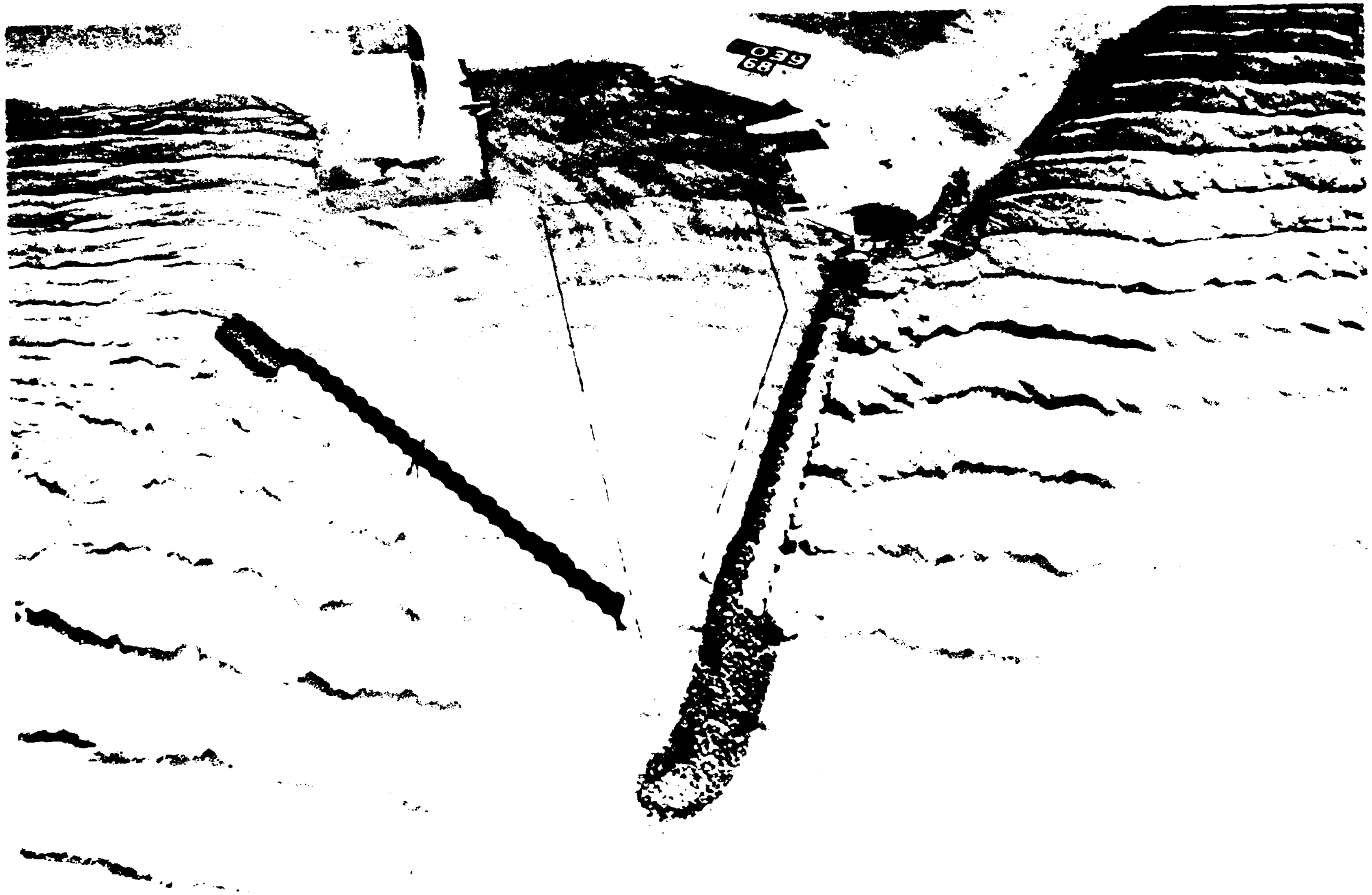

Photo 74. Typical wave patterns for Plan 26; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

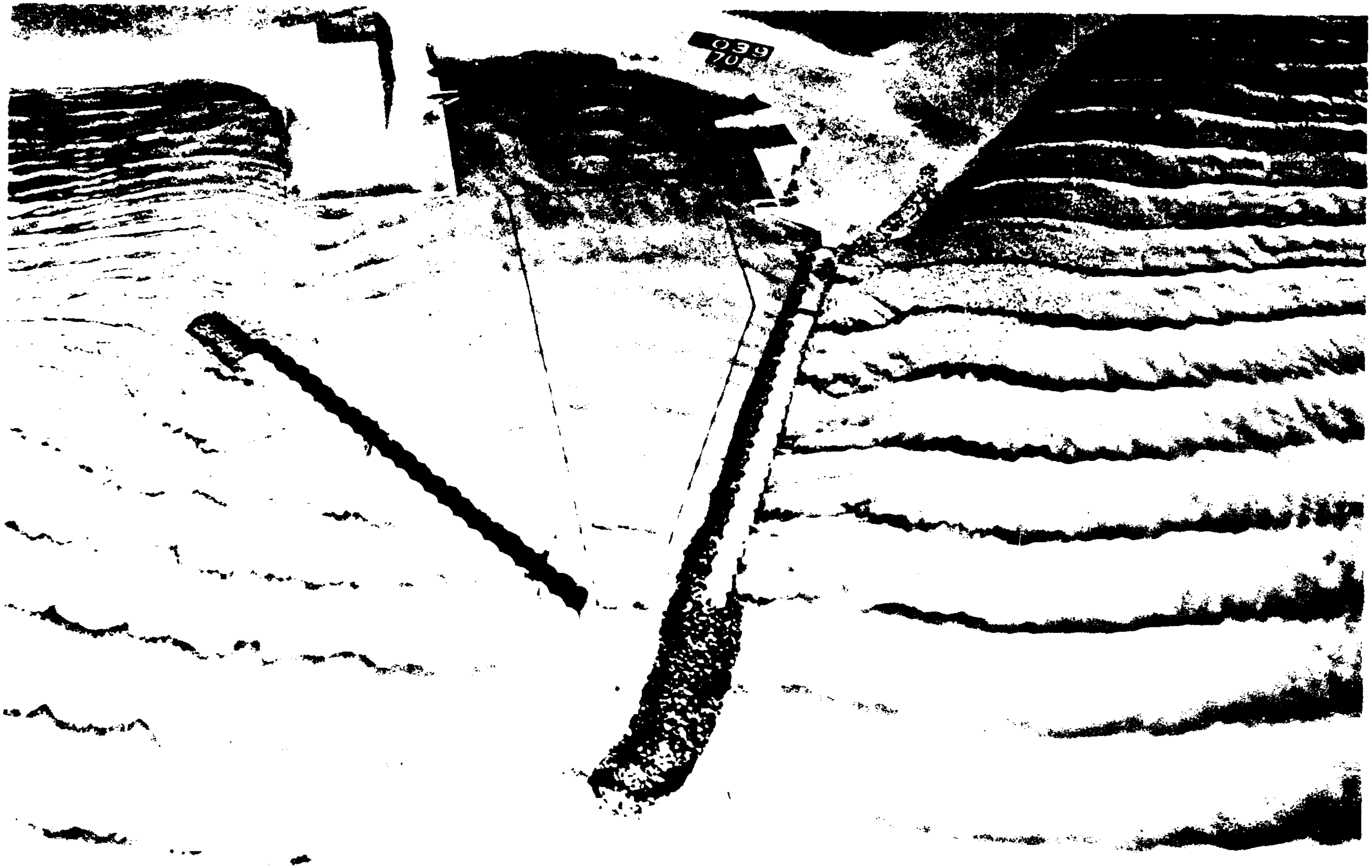

Photo 75. Typical wave patterns for Plan 27; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

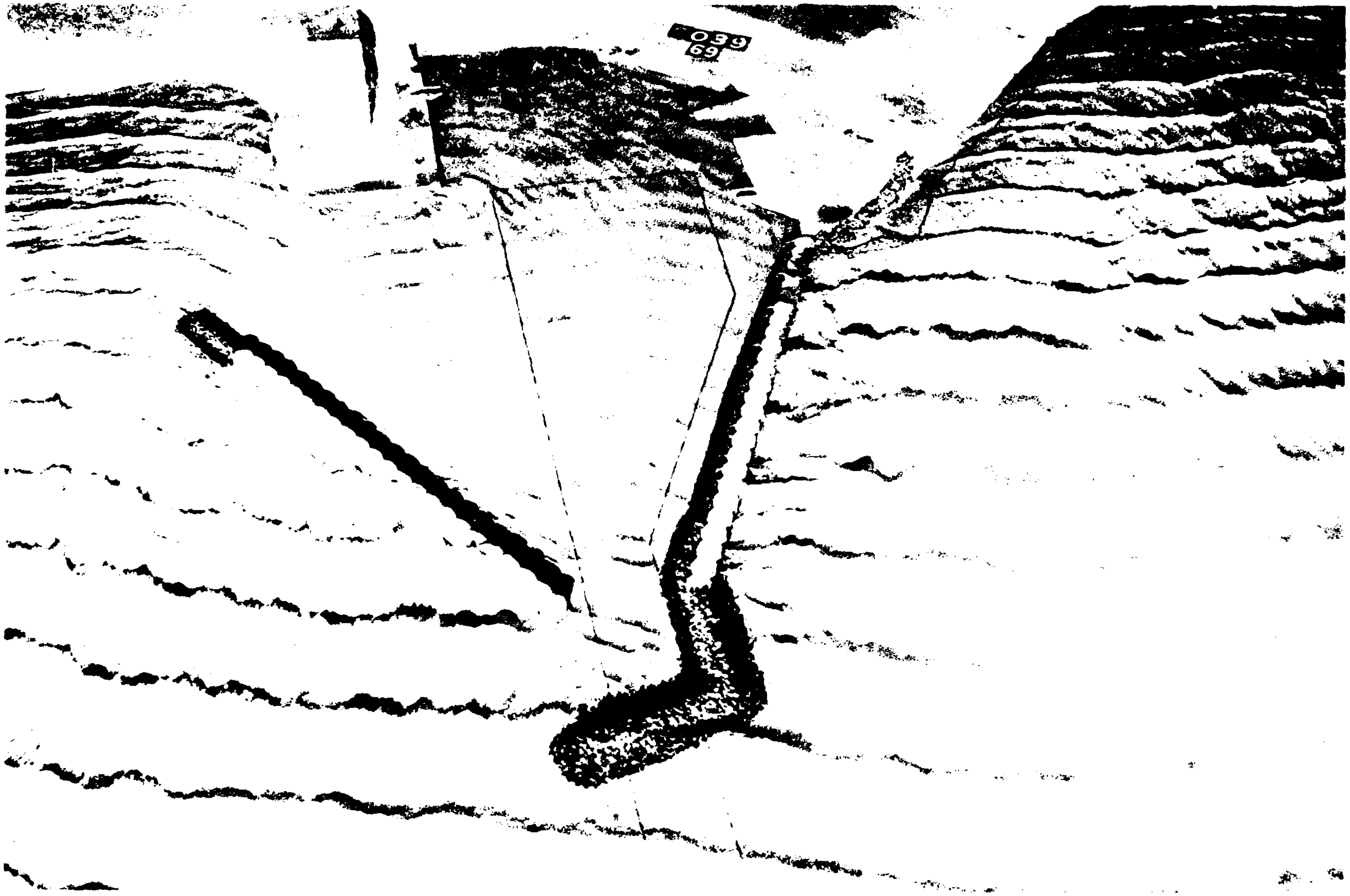

Photo 76. Typical wave patterns for Plan 28; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

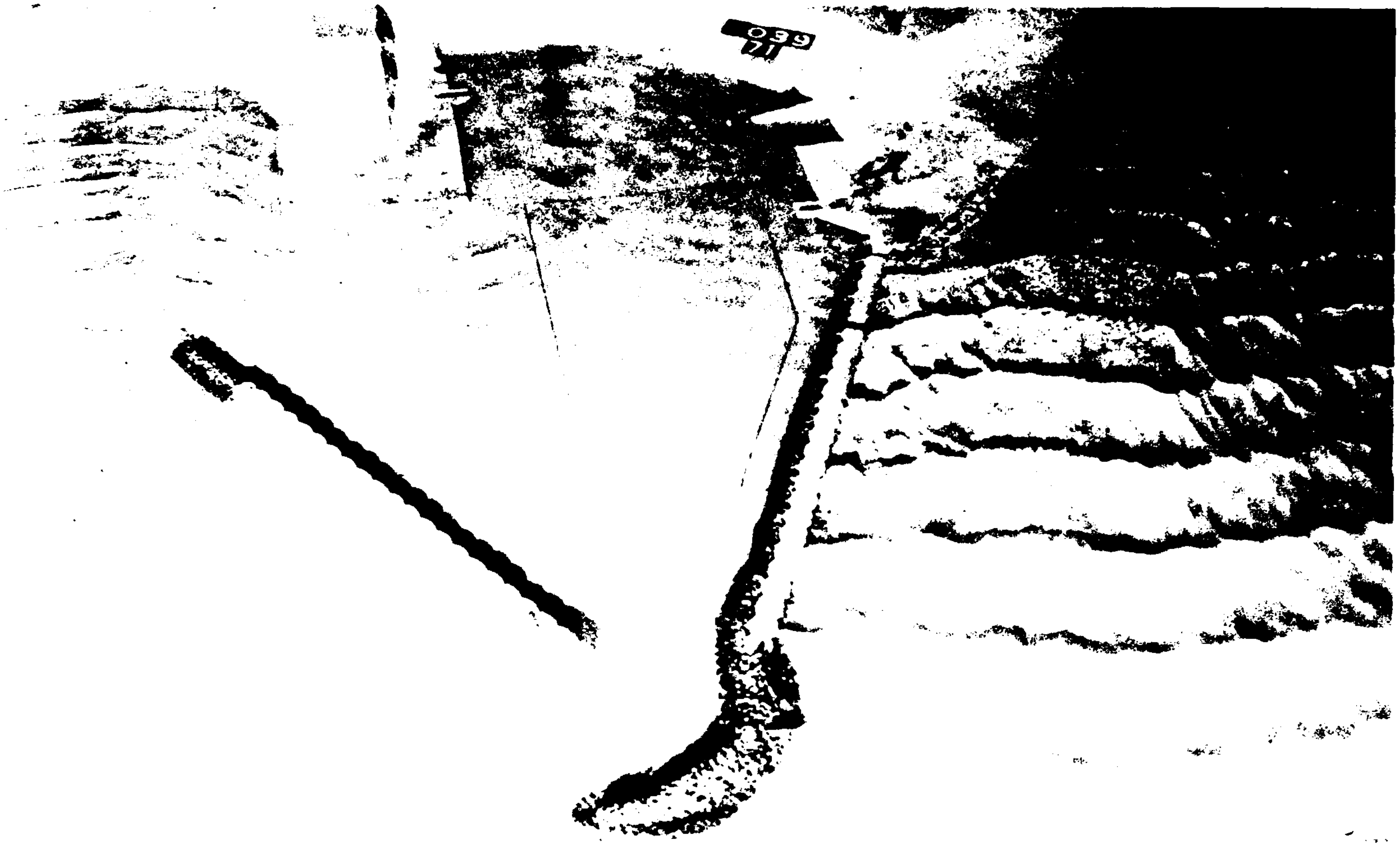

Photo 77. Typical wave patterns for Plan 29; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

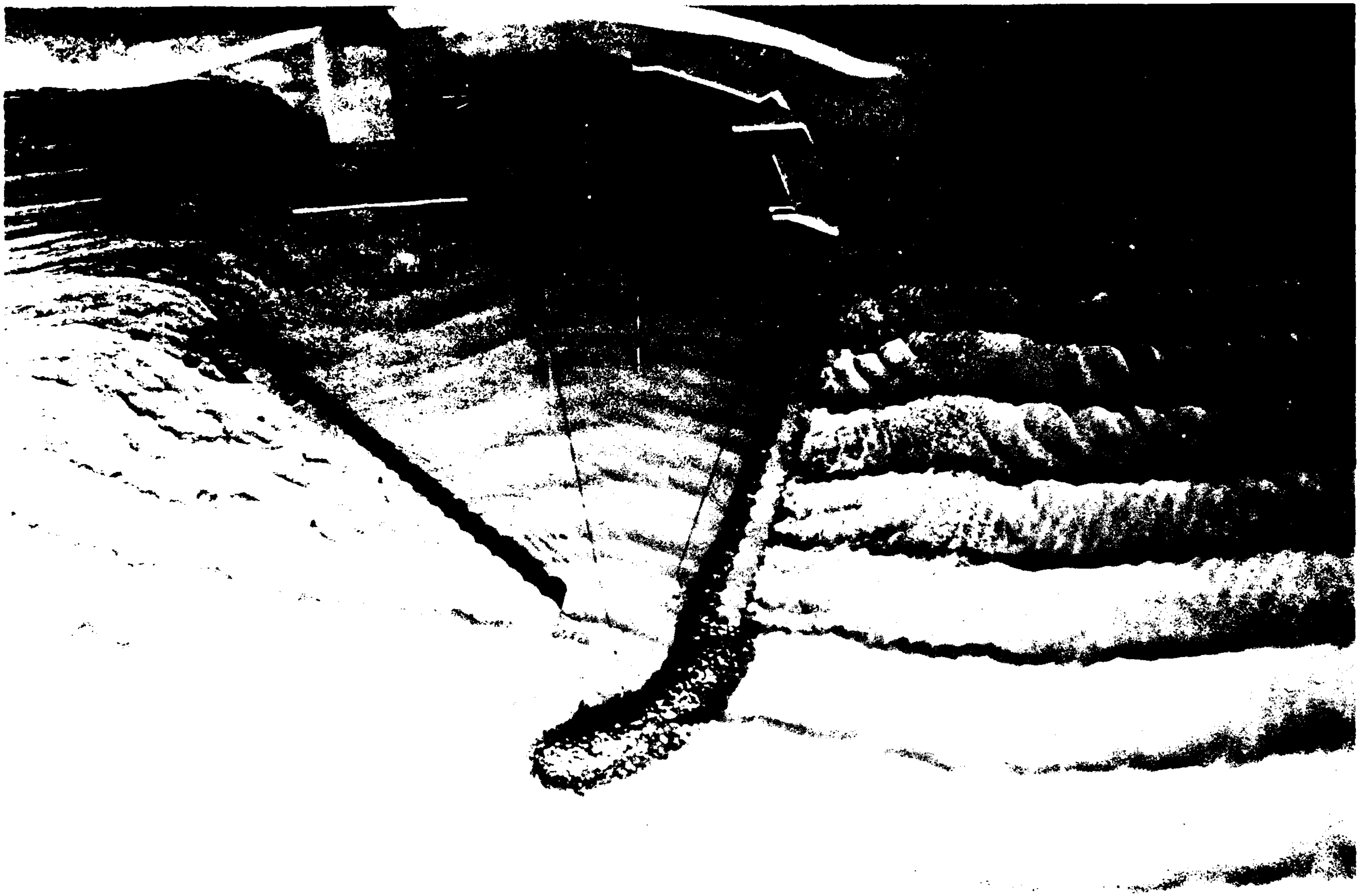

Photo 78. Typical wave patterns for Plan 30; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

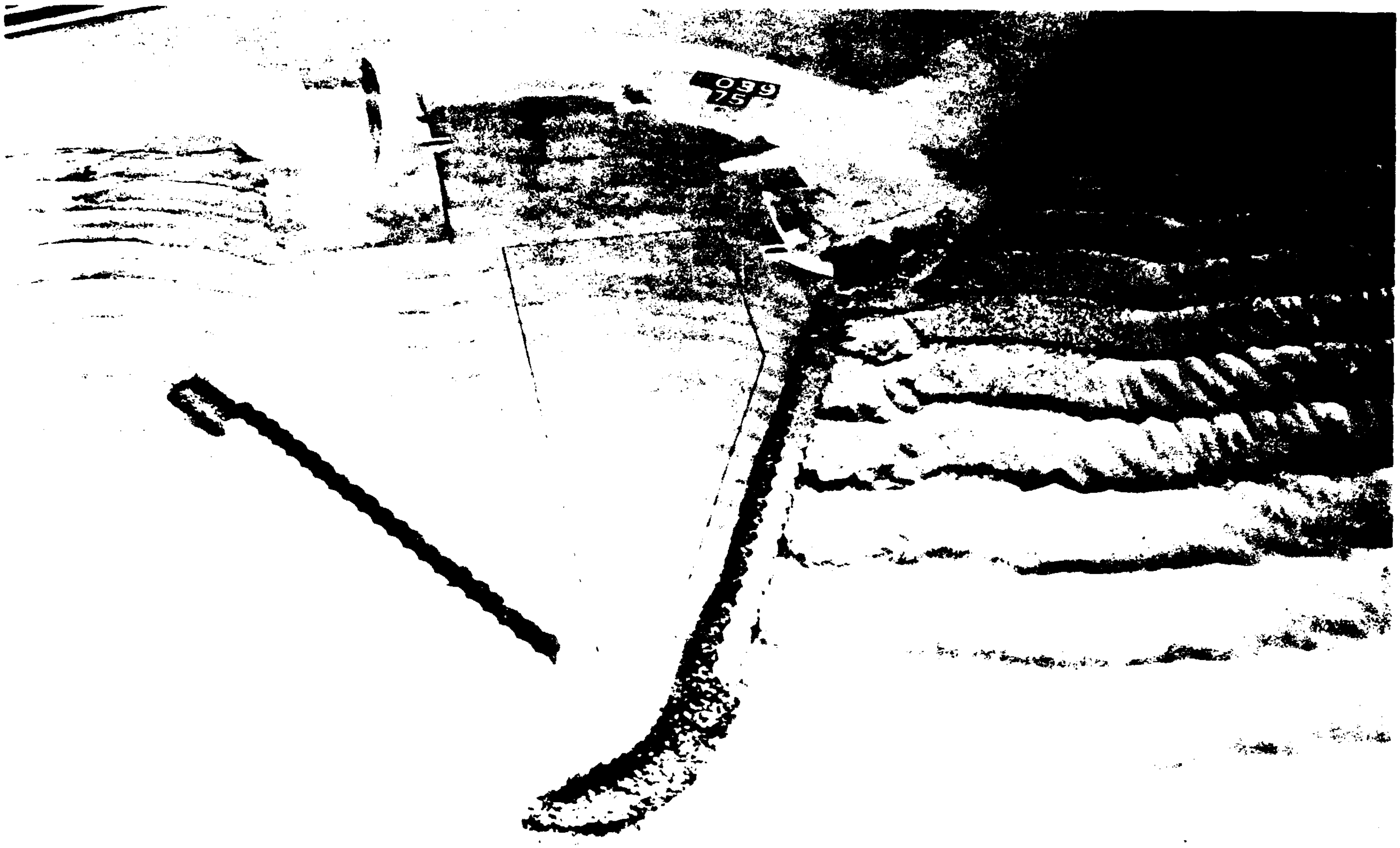

Photo 79. Typical wave patterns for Plan 31; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

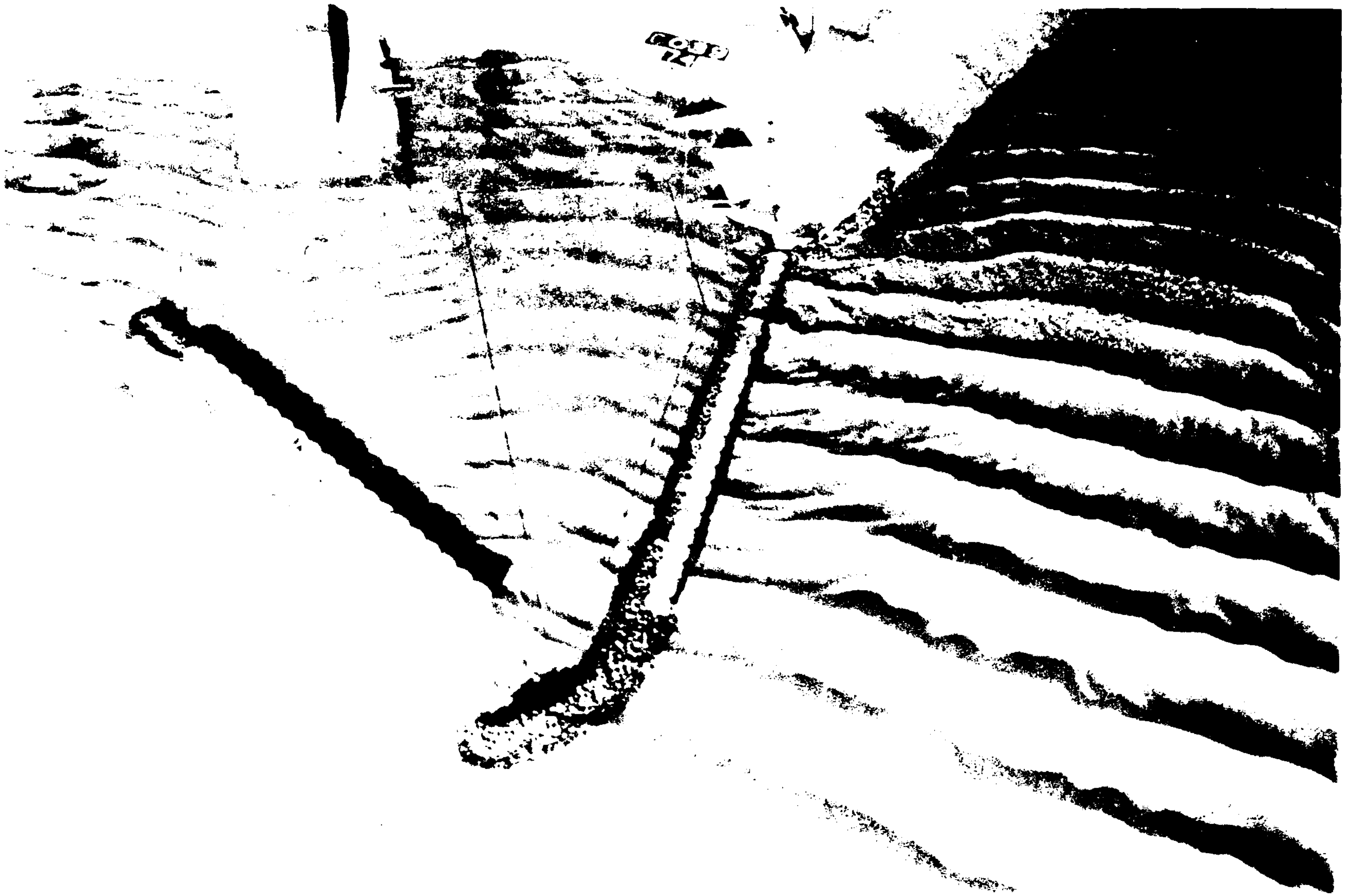

Photo 80. Typical wave patterns for Plan 31; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

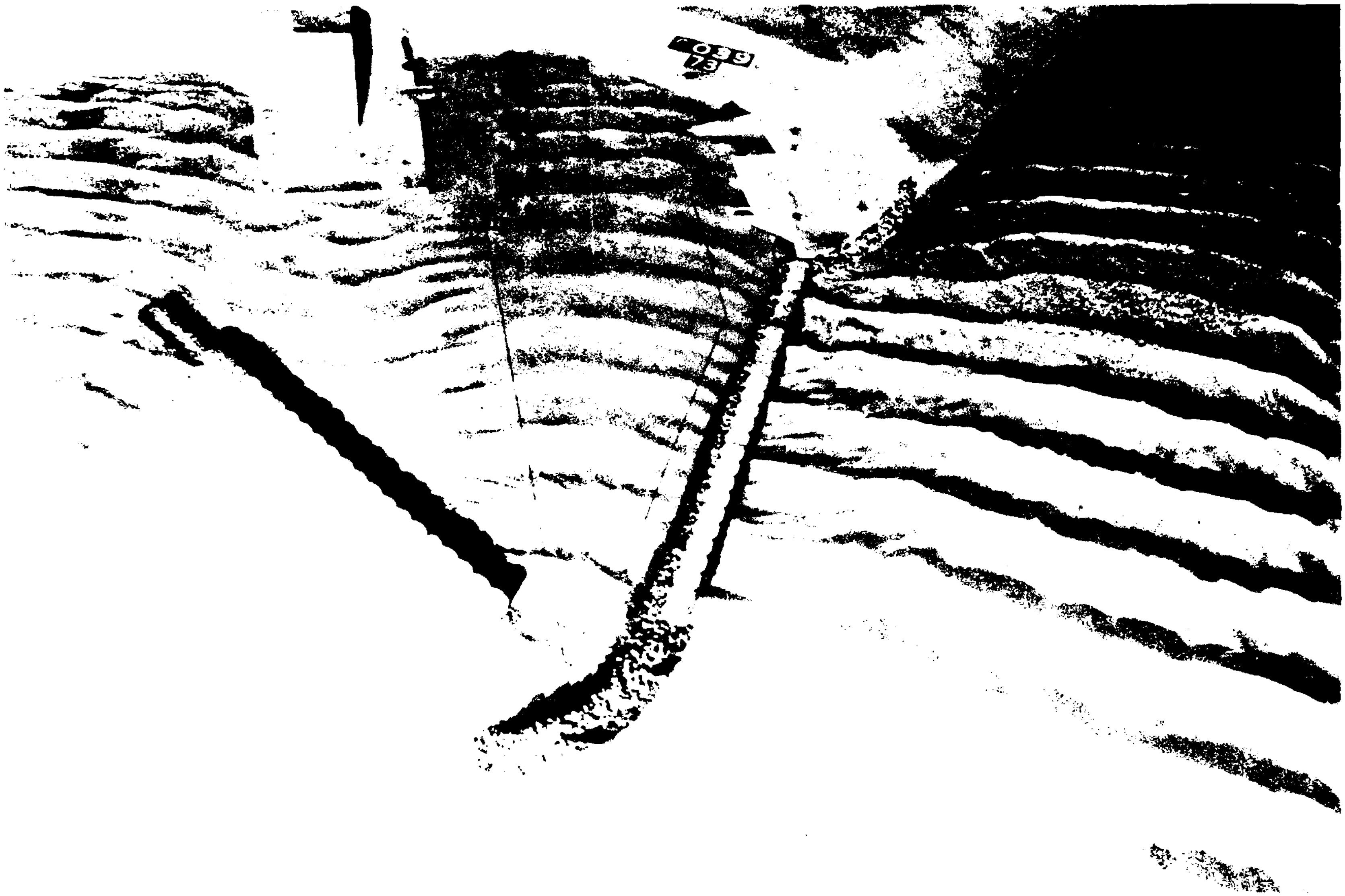

Photo 81. Typical wave patterns for Plan 32; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

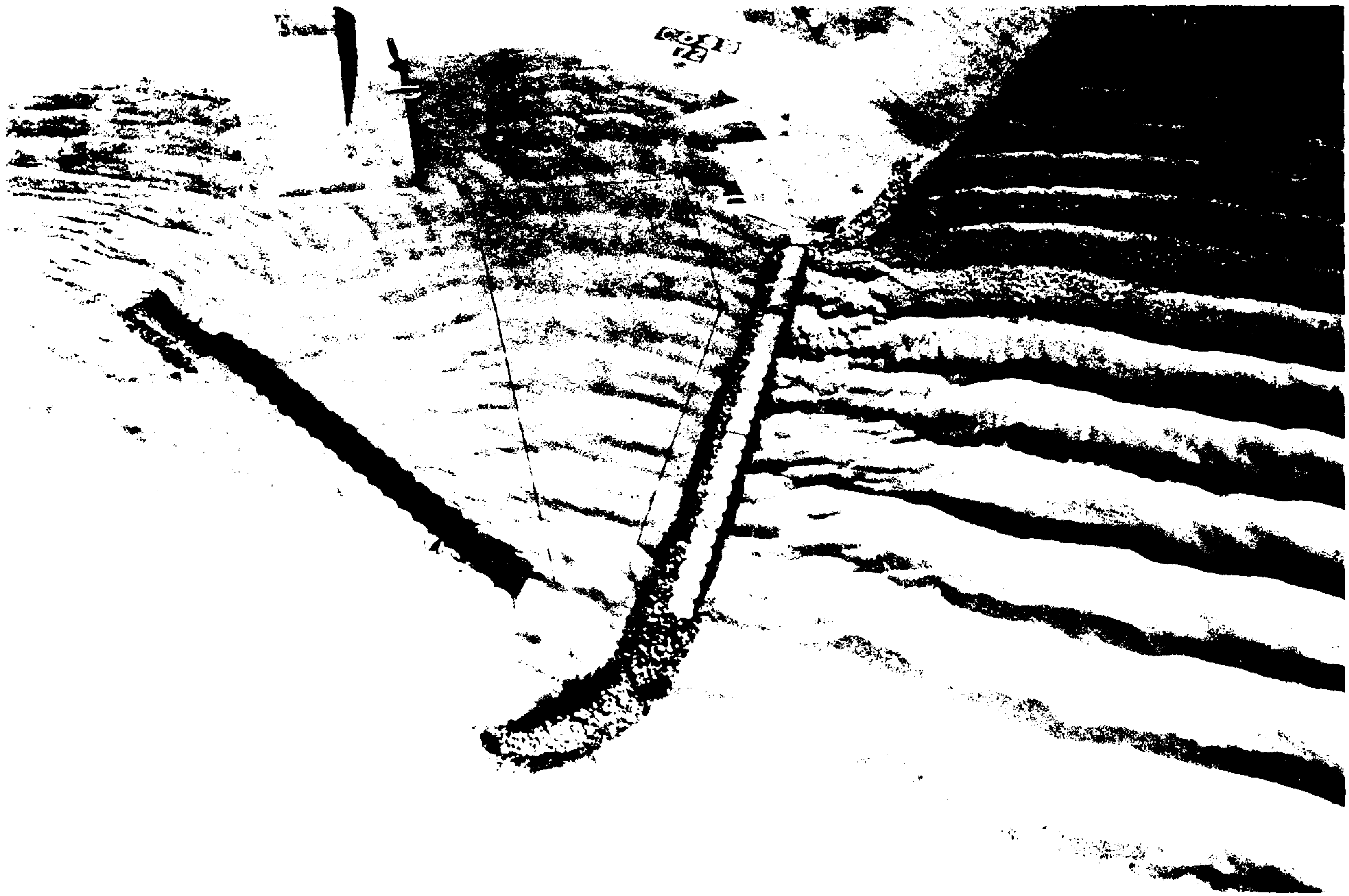

Photo 82. Typical wave patterns for Plan 33; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

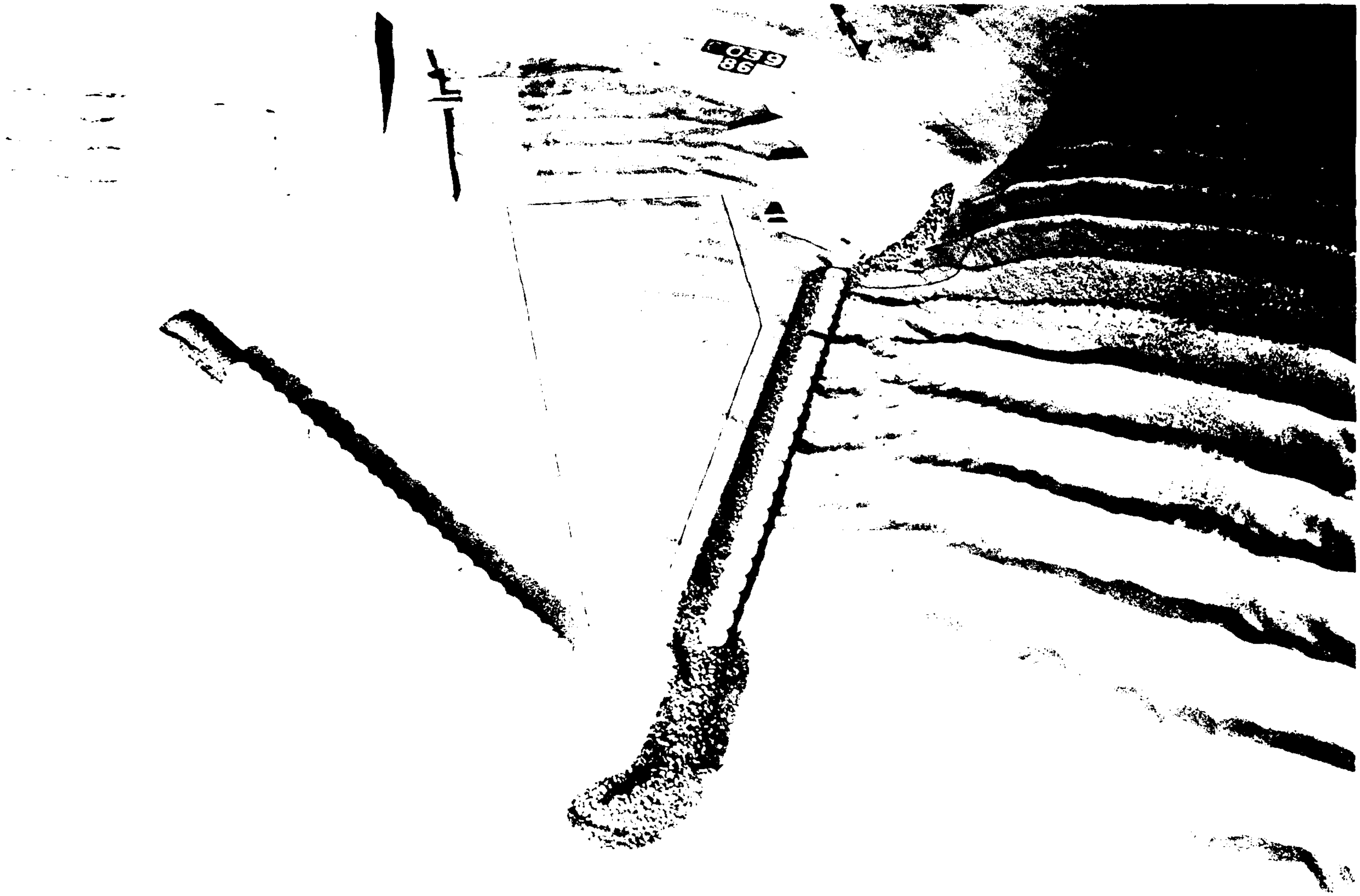

Photo 83. Typical wave patterns for Plan 34; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

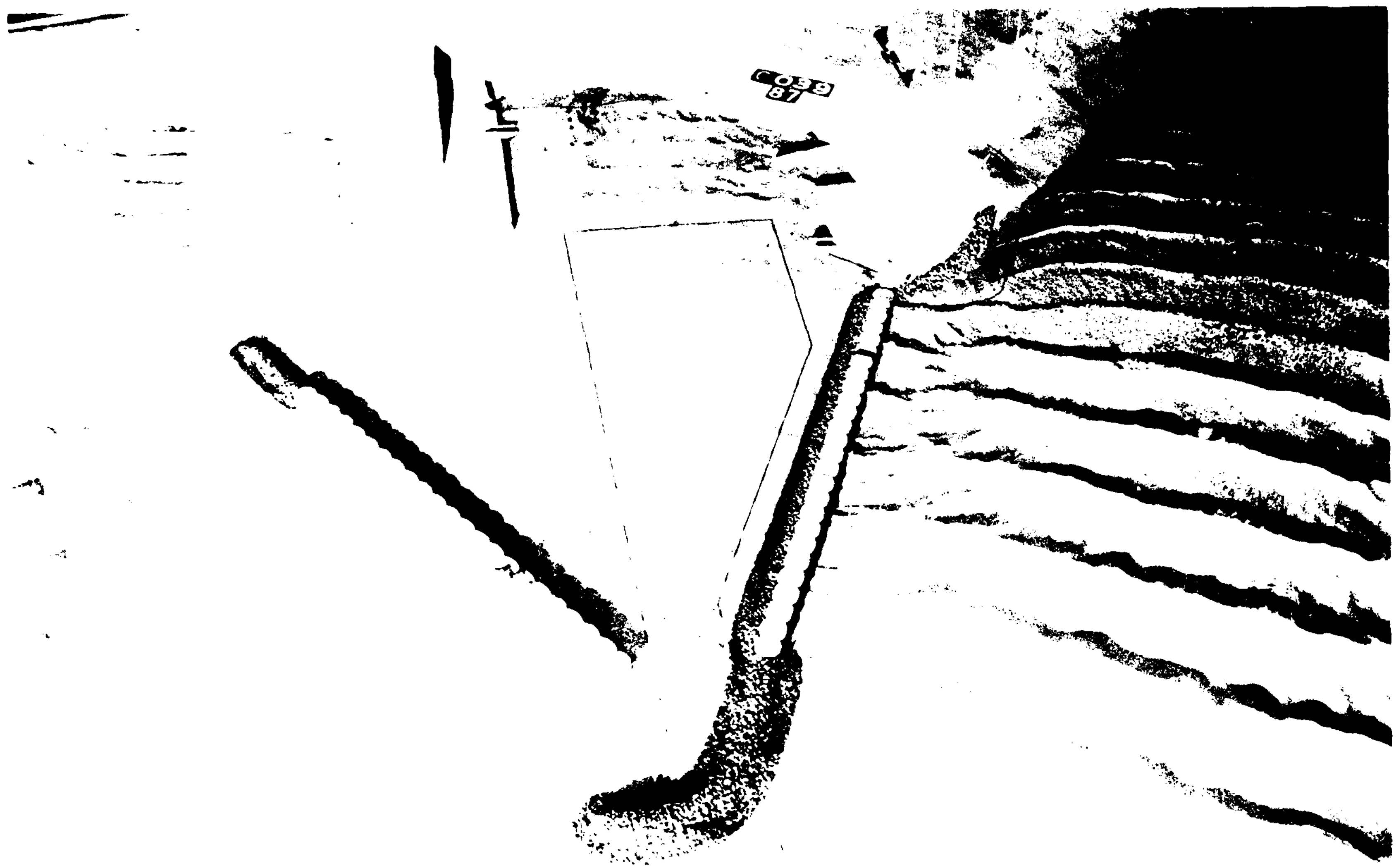

Photo 84. Typical wave patterns for Plan 35; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

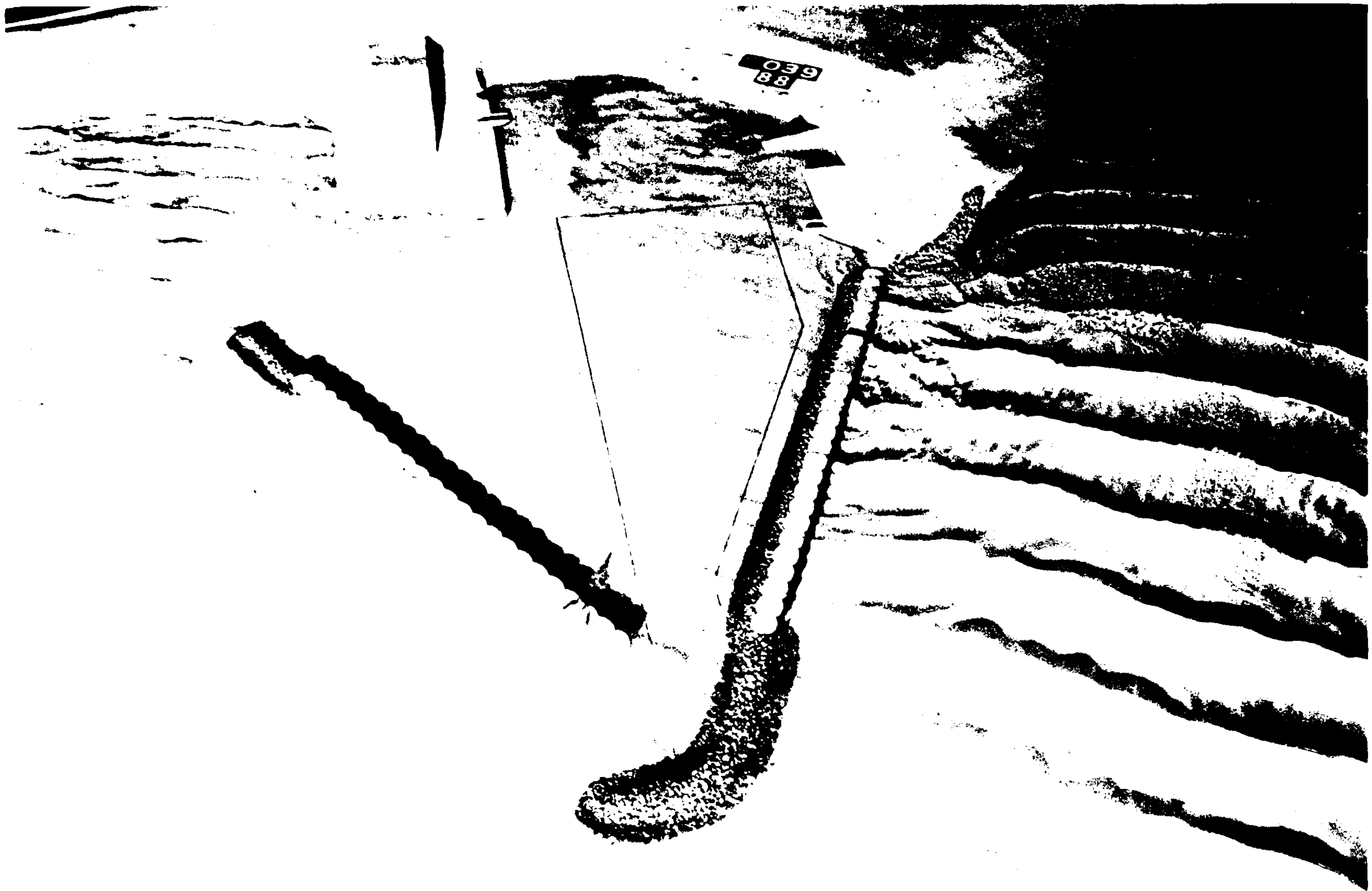

Photo 85. Typical wave patterns for Plan 36; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

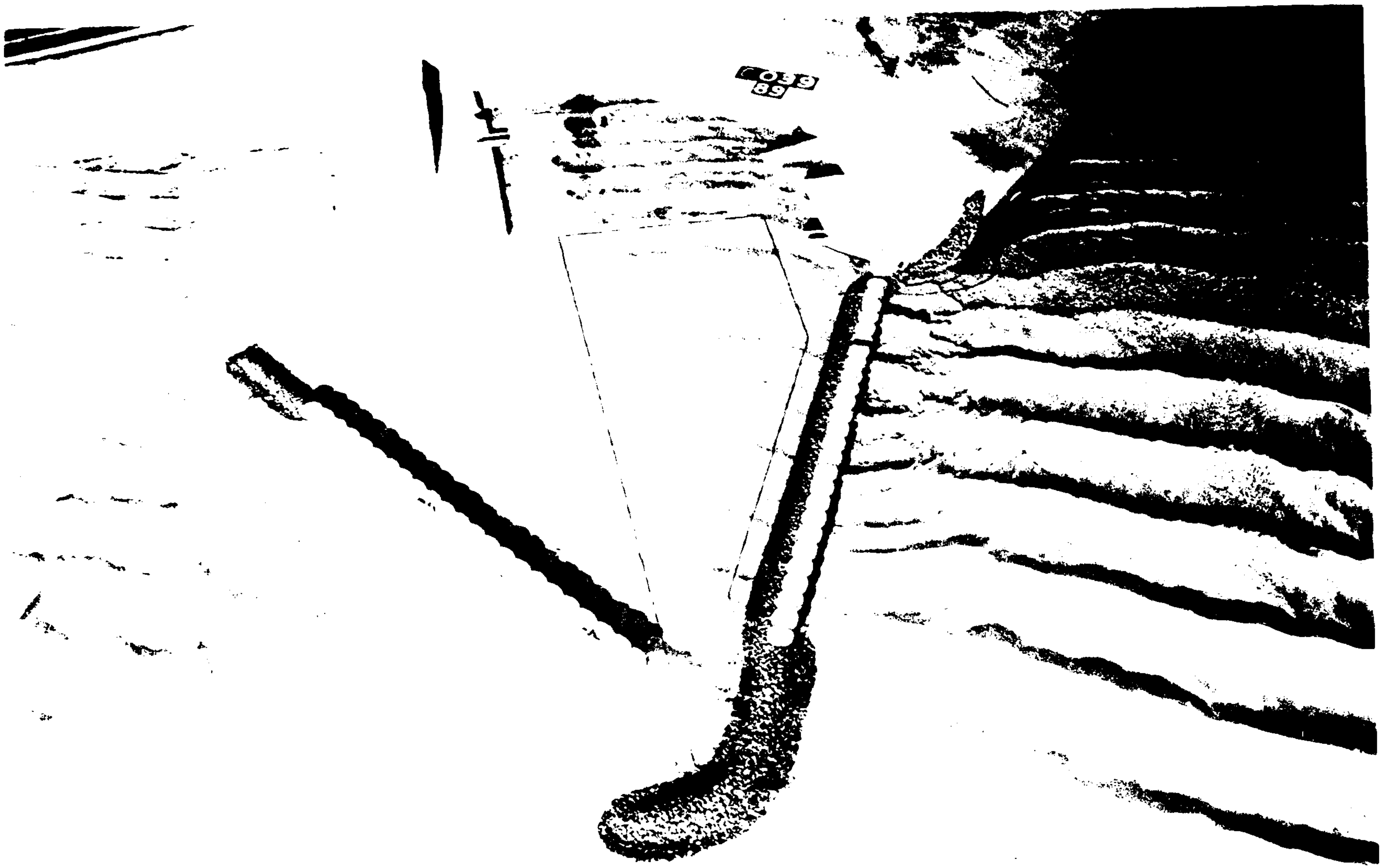

Photo 86. Typical wave patterns for Plan 37; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

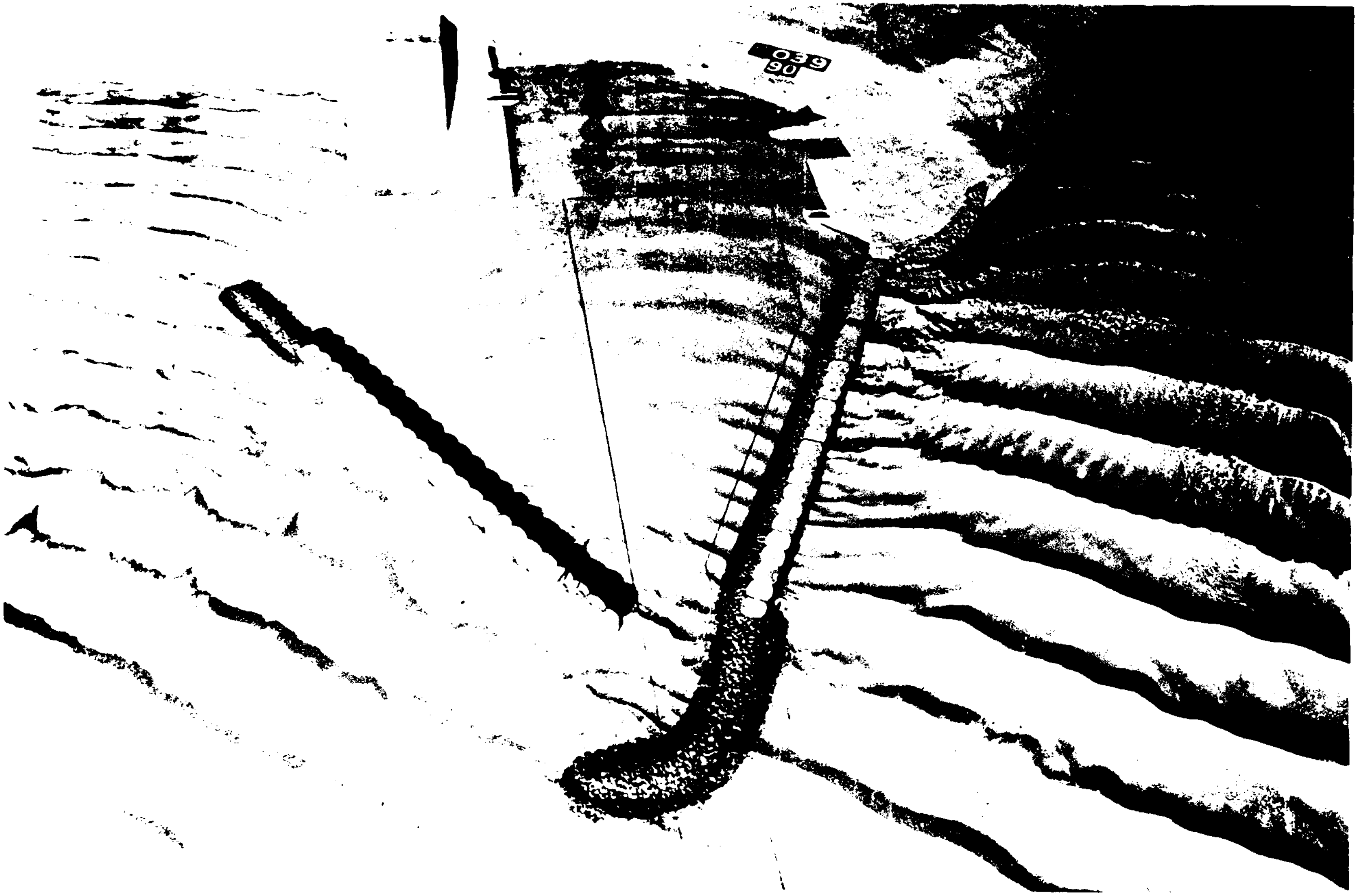

Photo 87. Typical wave patterns for Plan 38; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

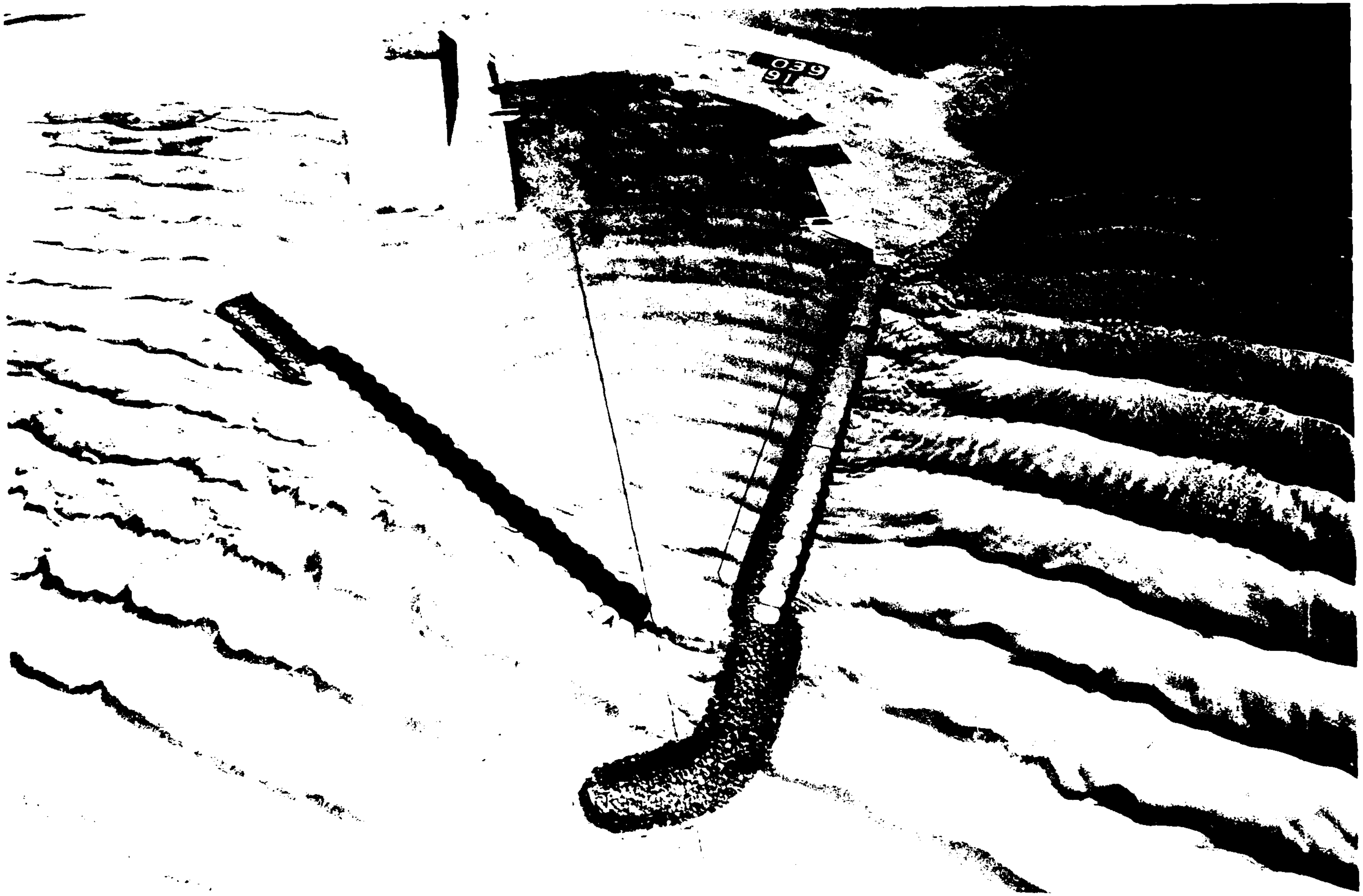

Photo 88. Typical wave patterns for Plan 39; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

Photo 89. Typical wave patterns for Plan 40; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

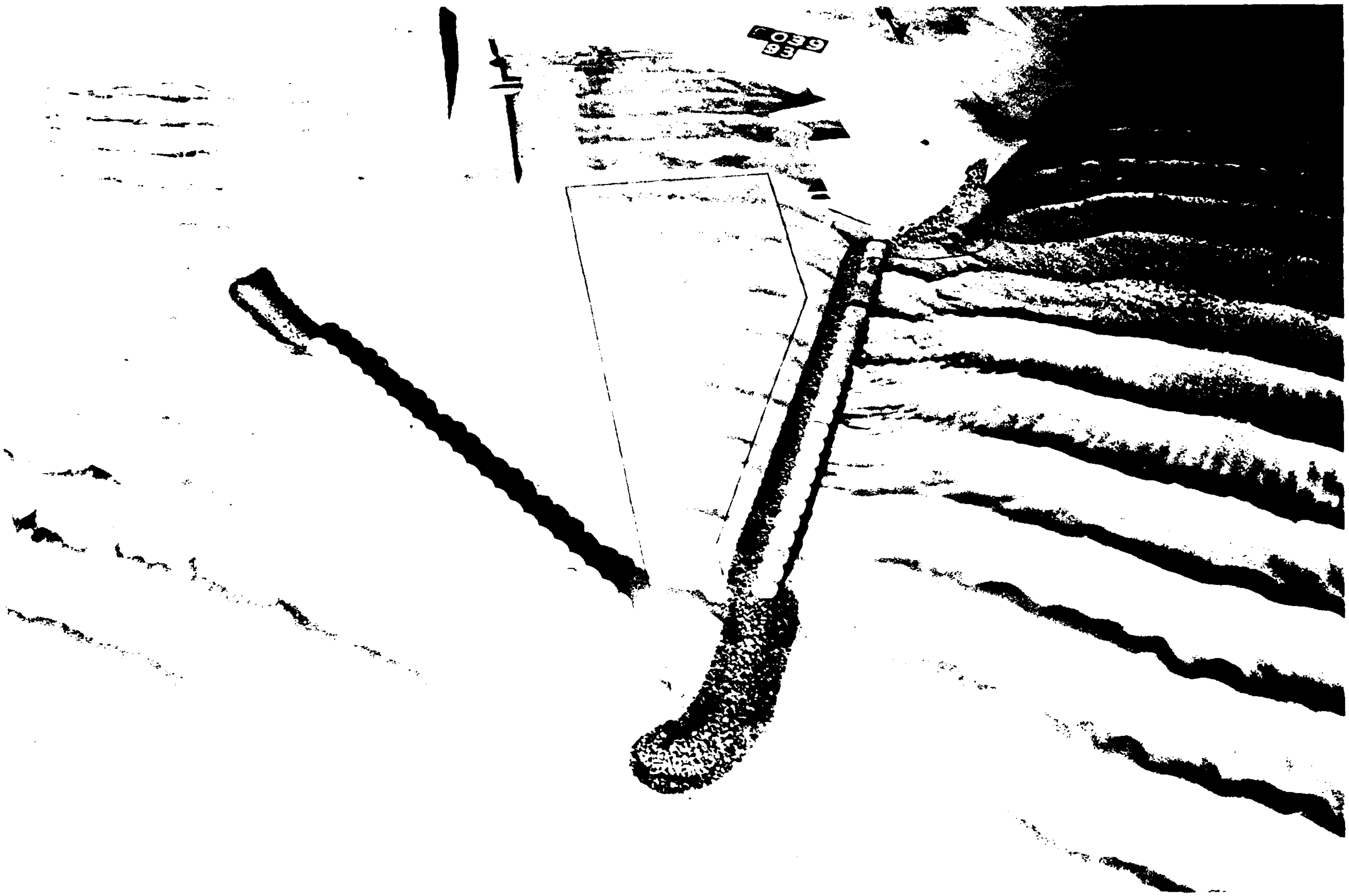

Photo 90. Typical wave patterns for Plan 41; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

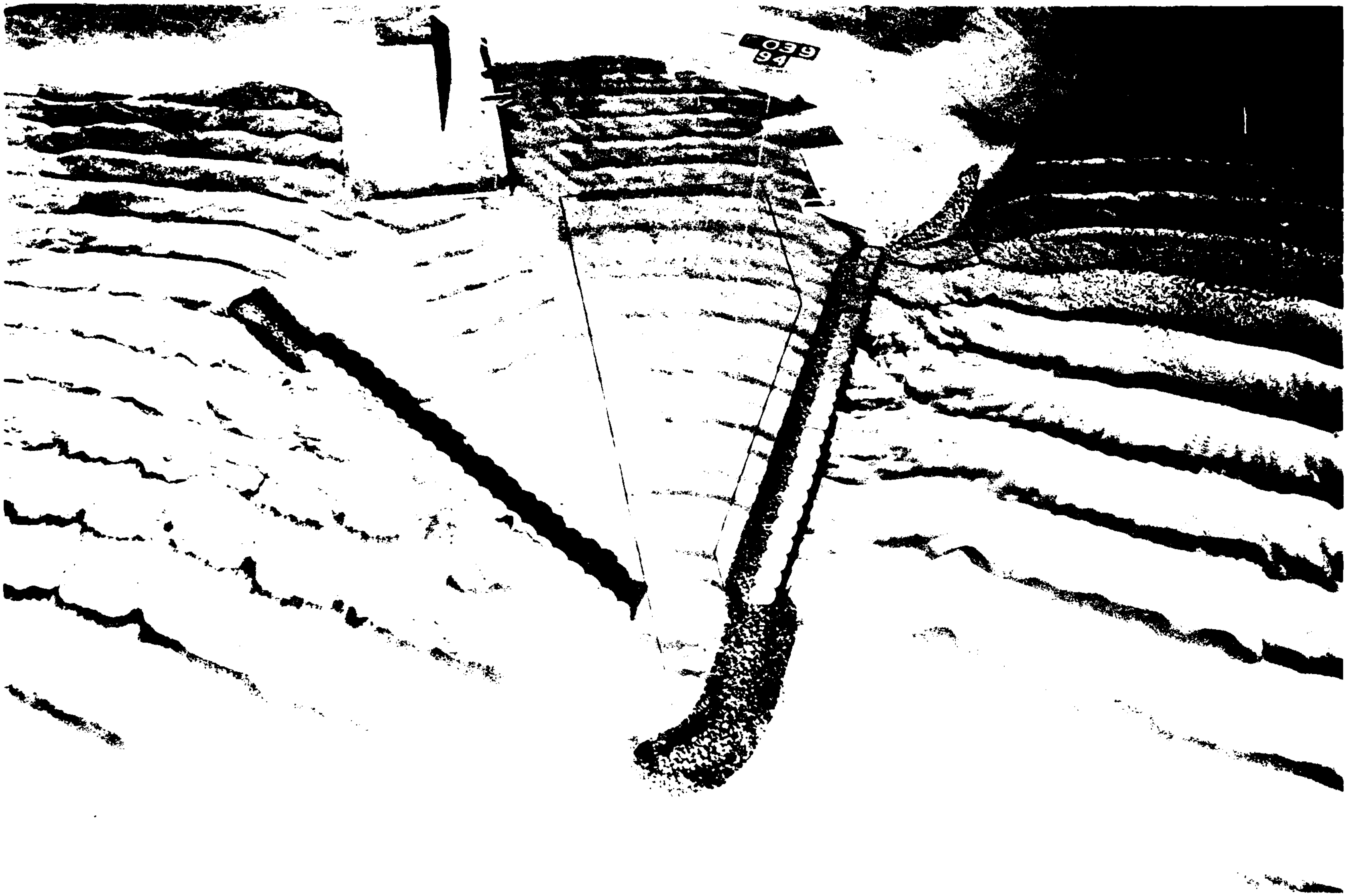

Photo 91. Typical wave patterns for Plan 42; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

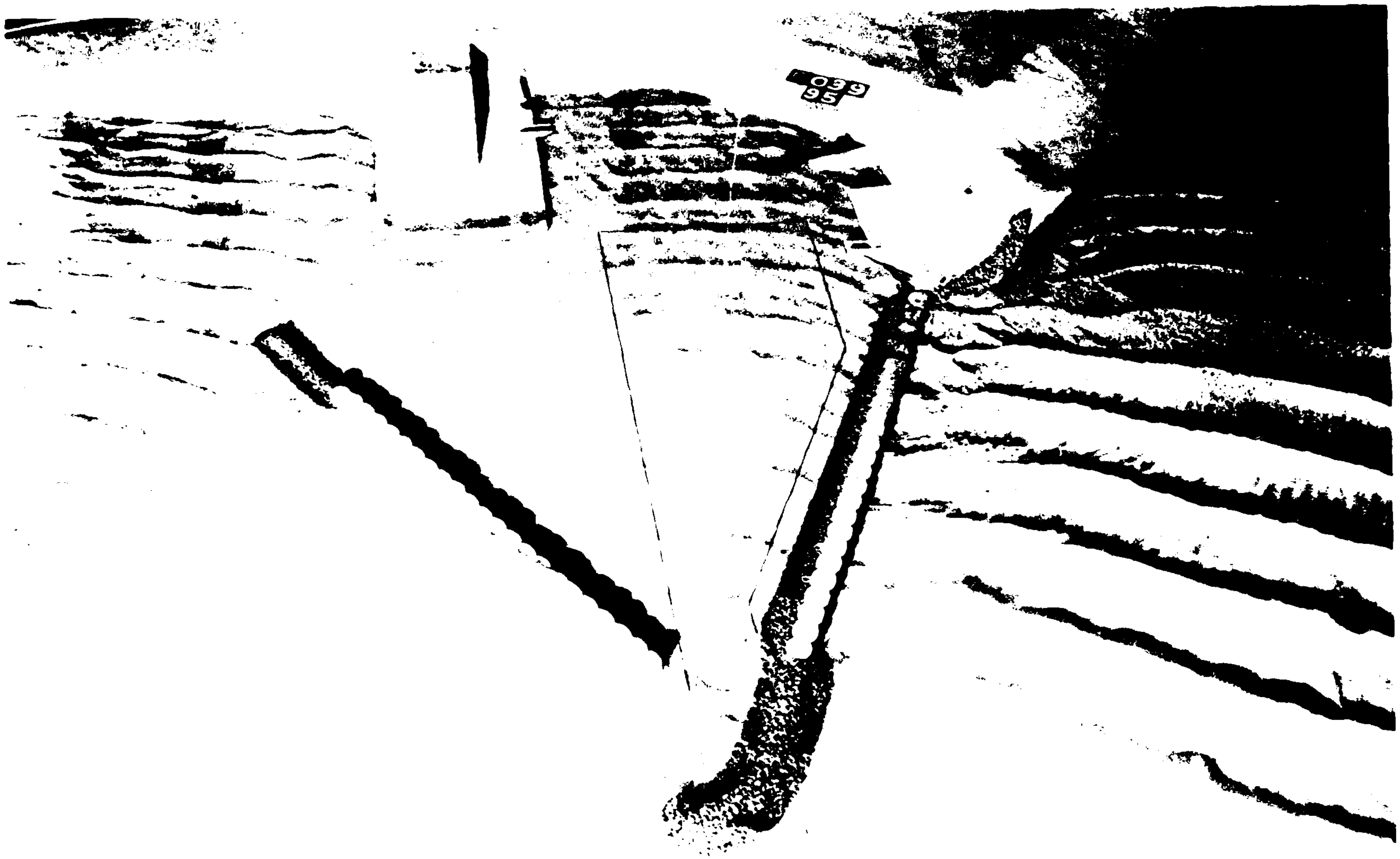

Photo 92. Typical wave patterns for Plan 43; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

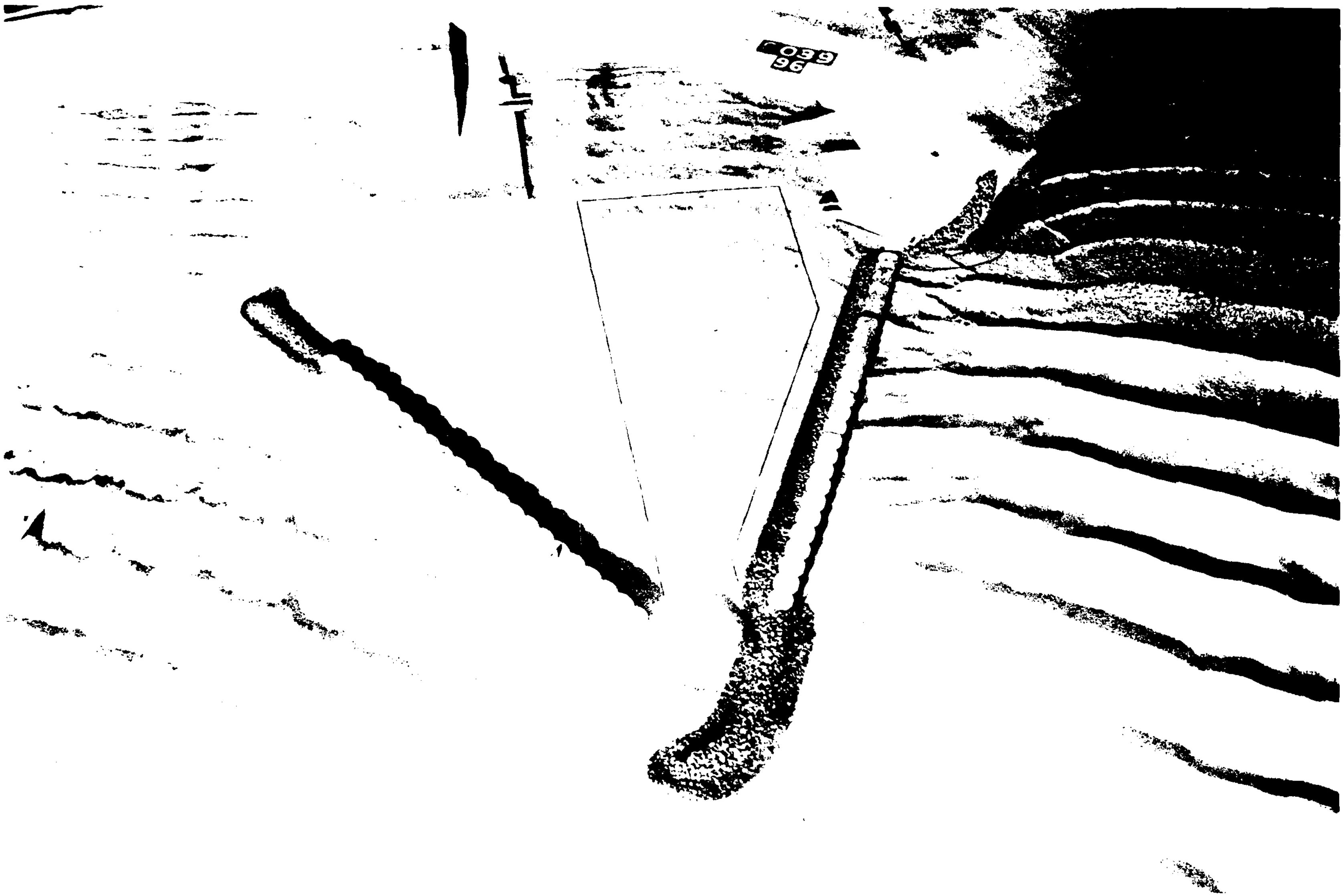

Photo 93. Typical wave patterns for Plan 44; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

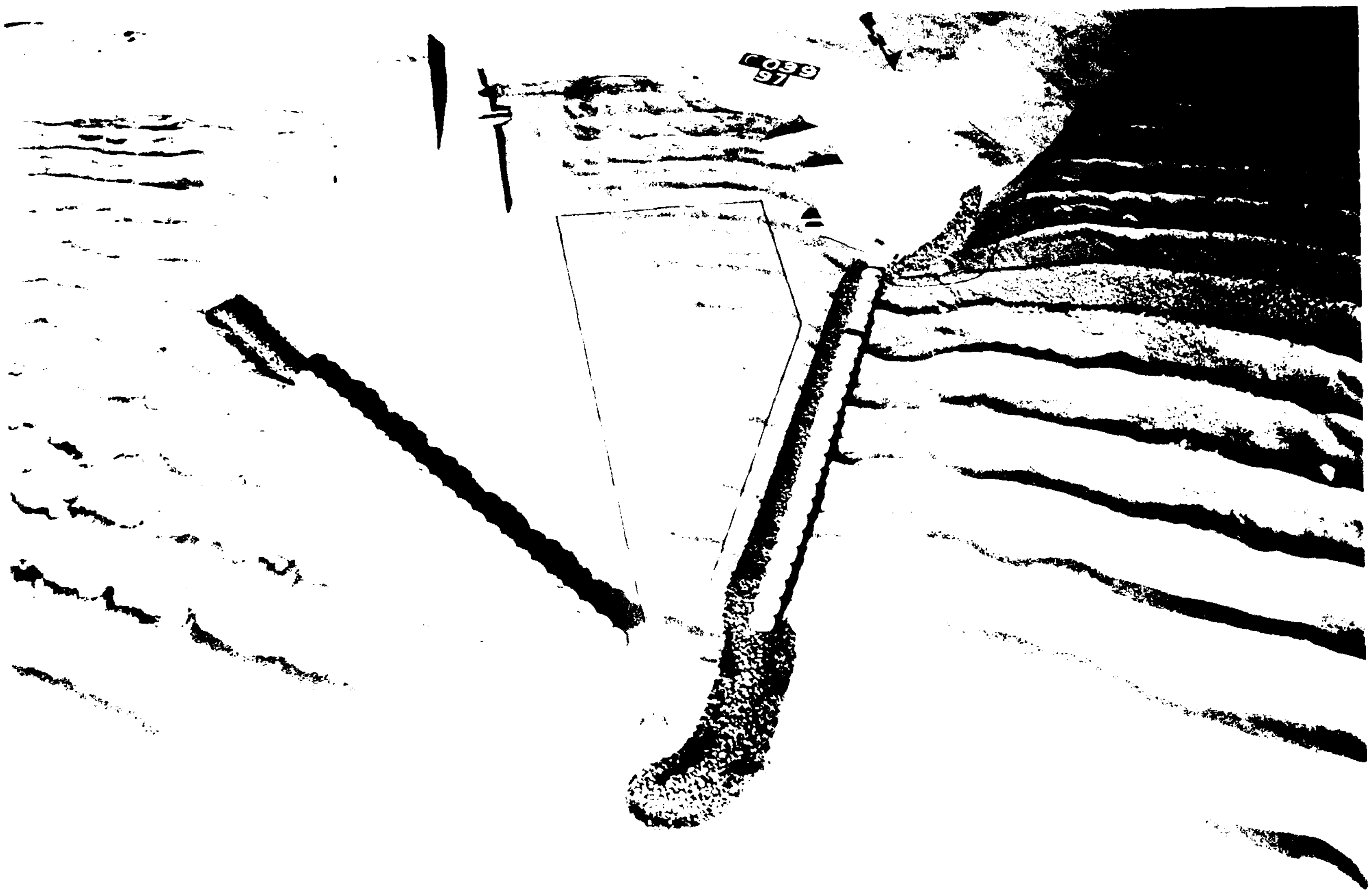

Photo 94. Typical wave patterns for Plan 45; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

Photo 95. Typical wave patterns for Plan 42; [illegible].2-sec, 3.7-ft waves from west; +3.0 ft swl

Photo 96. Typical wave patterns for Plan 42; 9.9-sec, 13.9-ft waves from west; +5.5 ft swl

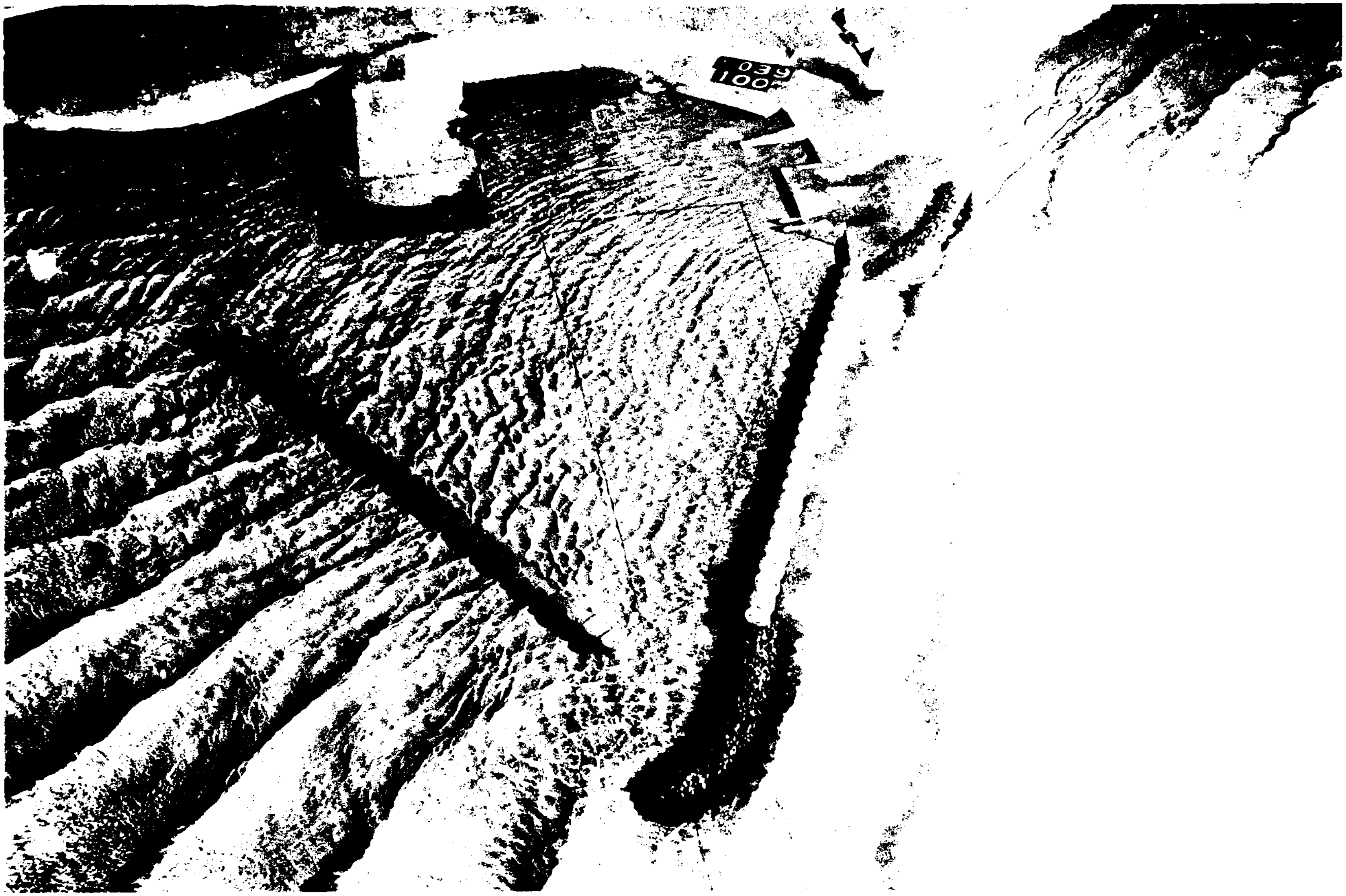

Photo 97. Typical wave patterns for Plan 42; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 98. Typical wave patterns for Plan 42; 6.2-sec, 6.0-ft waves from northwest; +3.0 ft swl

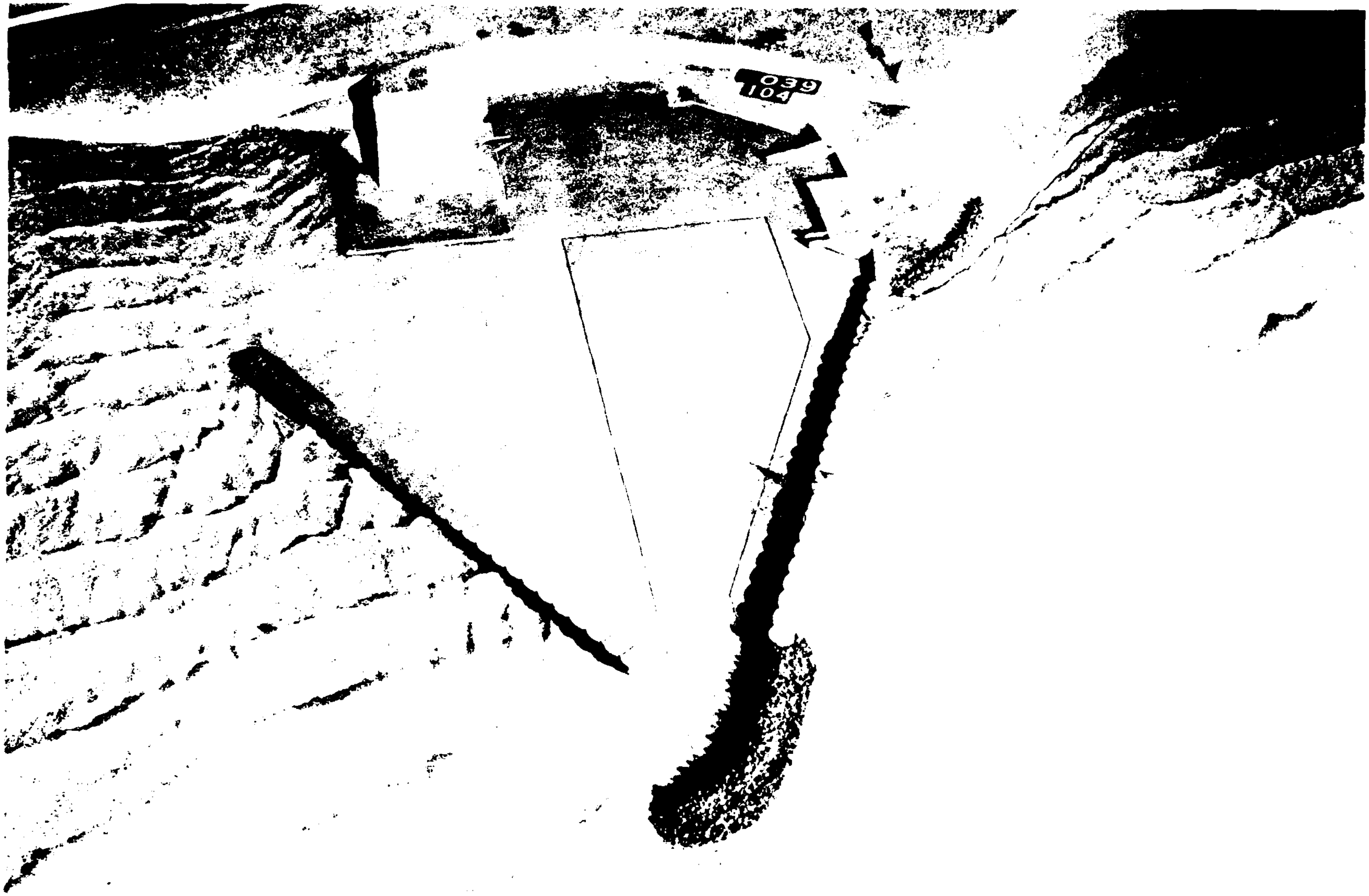

Photo 99. Typical wave patterns for Plan 42; 7.5-sec, 9.9-ft waves from northwest; +4.0 ft swl

Photo 100. Typical wave patterns for Plan 42; 6.2-sec, 6.3-ft waves from northwest; +5.0 ft swl

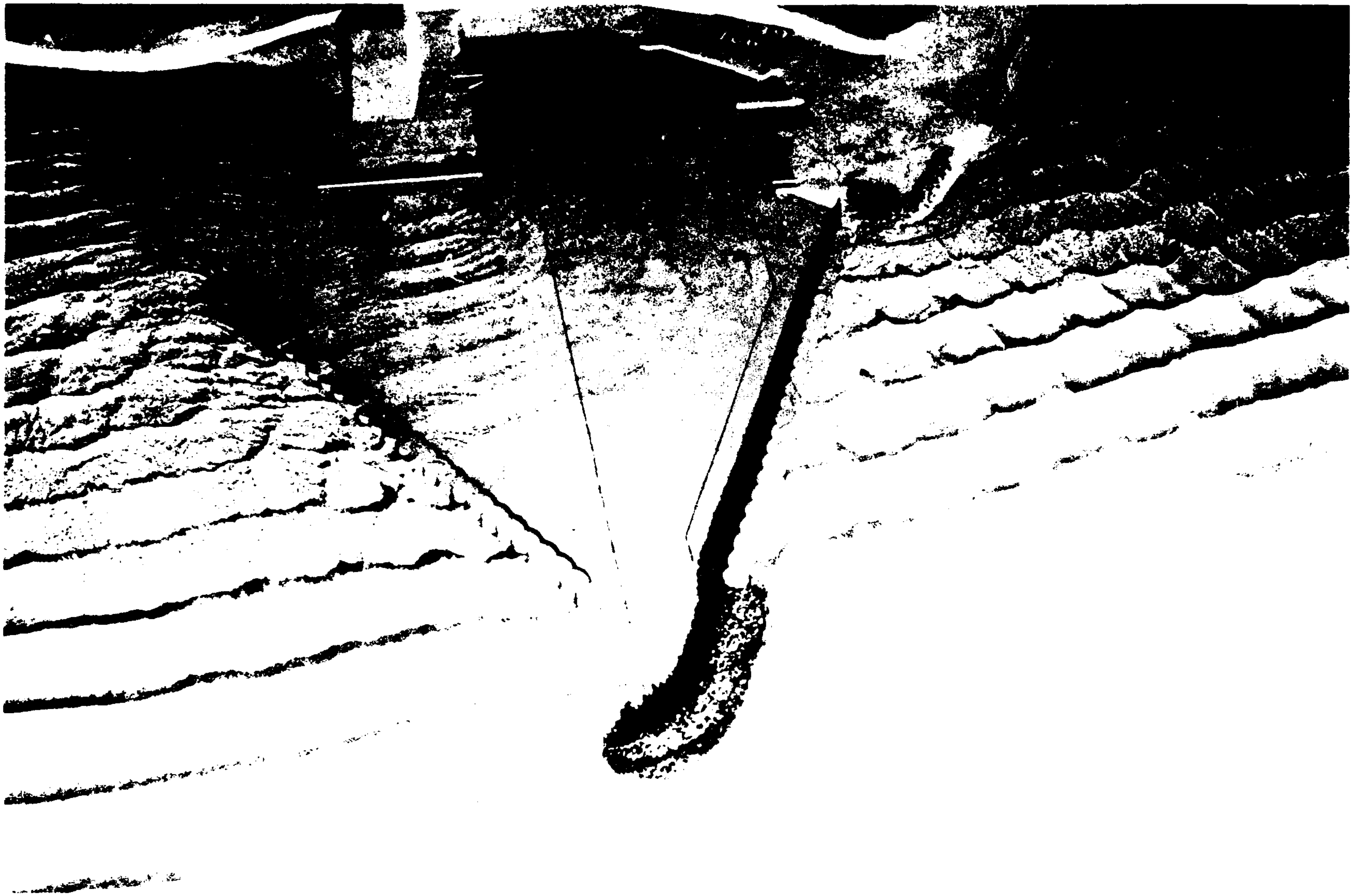

Photo 101. Typical wave patterns for Plan 42; 5.9-sec, 5.1-ft waves from north; +3.0 ft swl

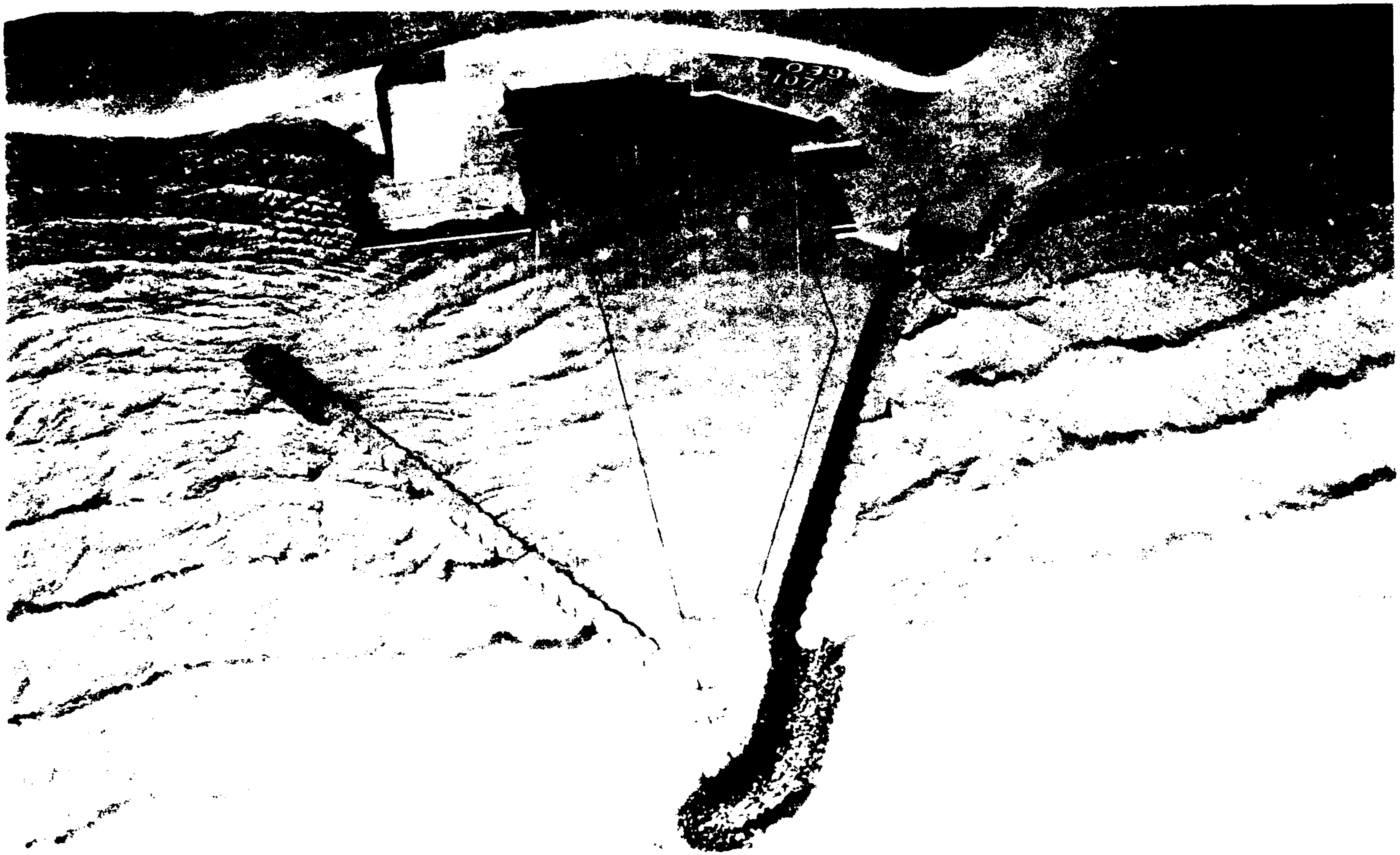

Photo 102. Typical wave patterns for Plan 42; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

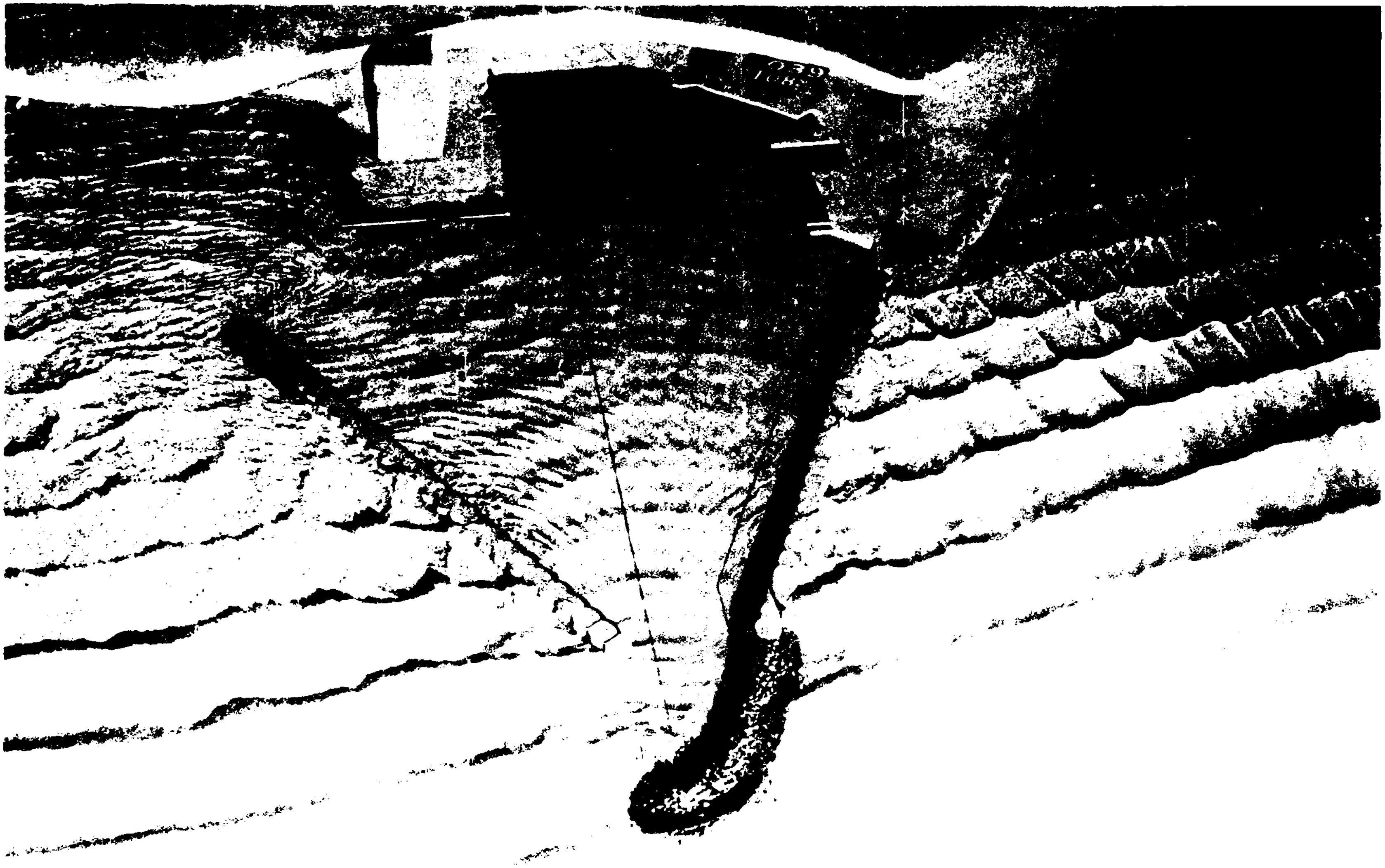

Photo 103. Typical wave patterns for Plan 42; 6.2-sec, 6.1-ft waves from north; +5.0 ft swl

Photo 104. Typical wave patterns for Plan 42; 5.9-sec, 4.3-ft waves from northeast; +3.0 ft swl

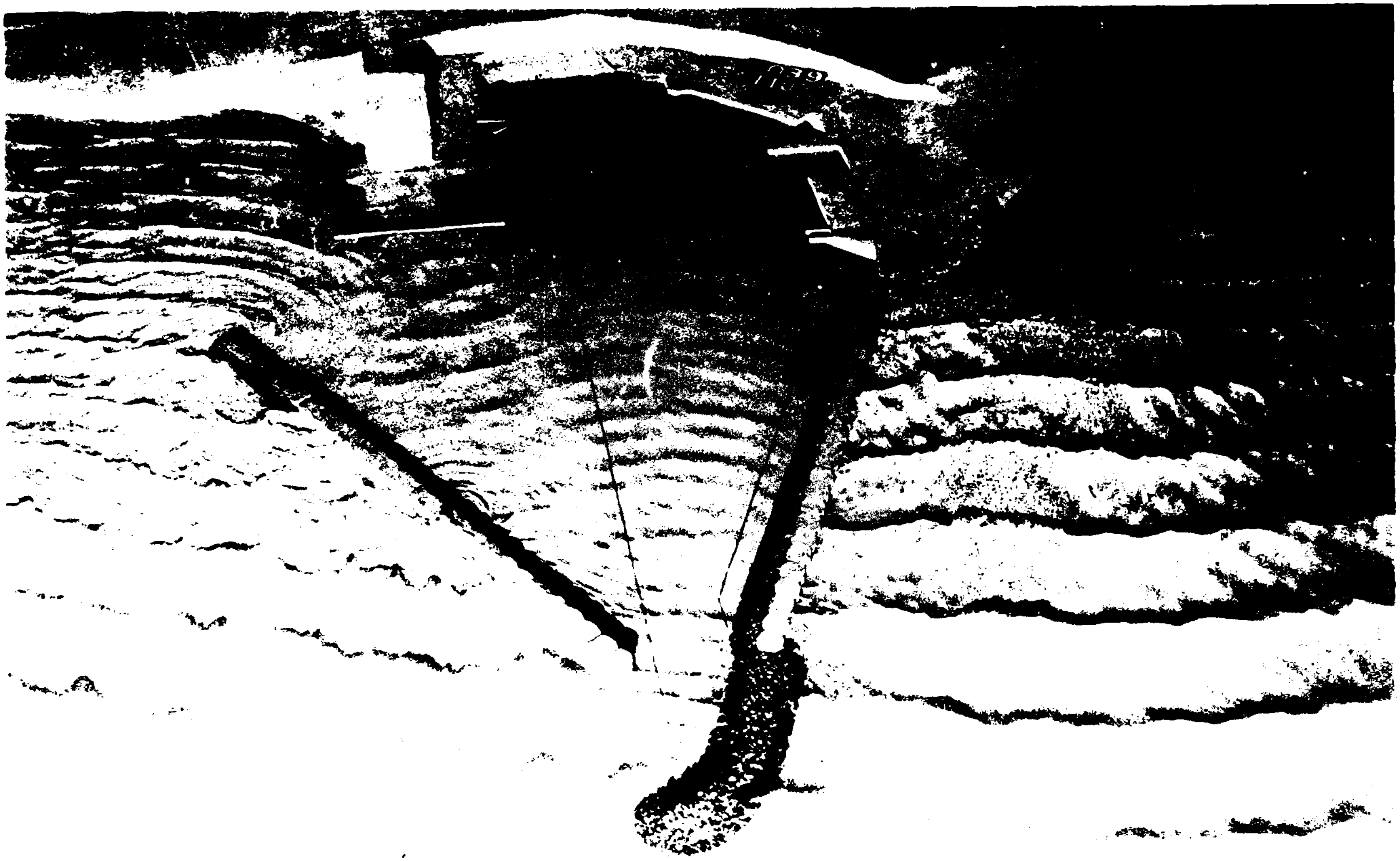

Photo 105. Typical wave patterns for Plan 42; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

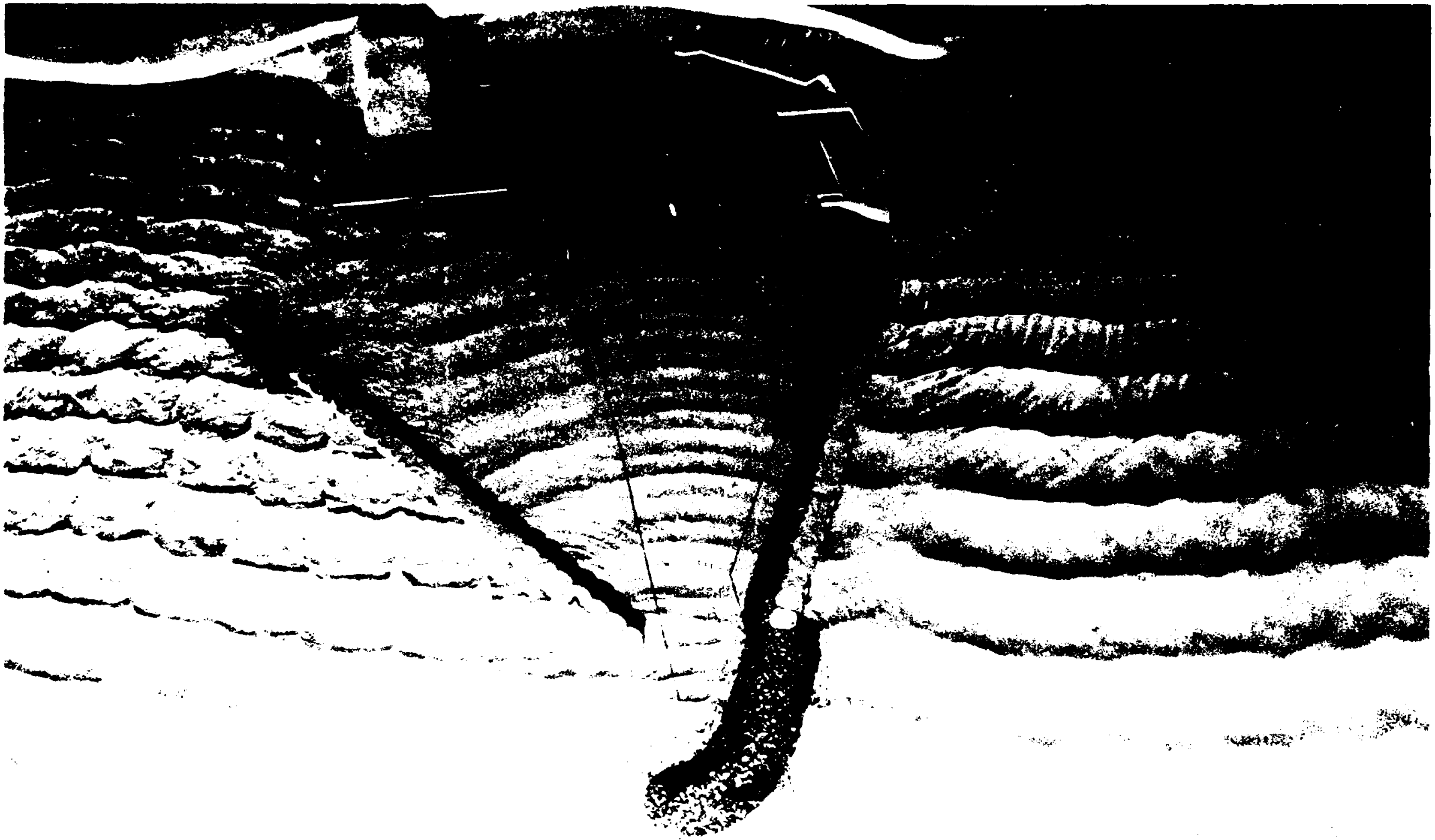

Photo 106. Typical wave patterns for Plan 42; 5.9-sec, 4.0-ft waves from northeast; +4.0 ft swl

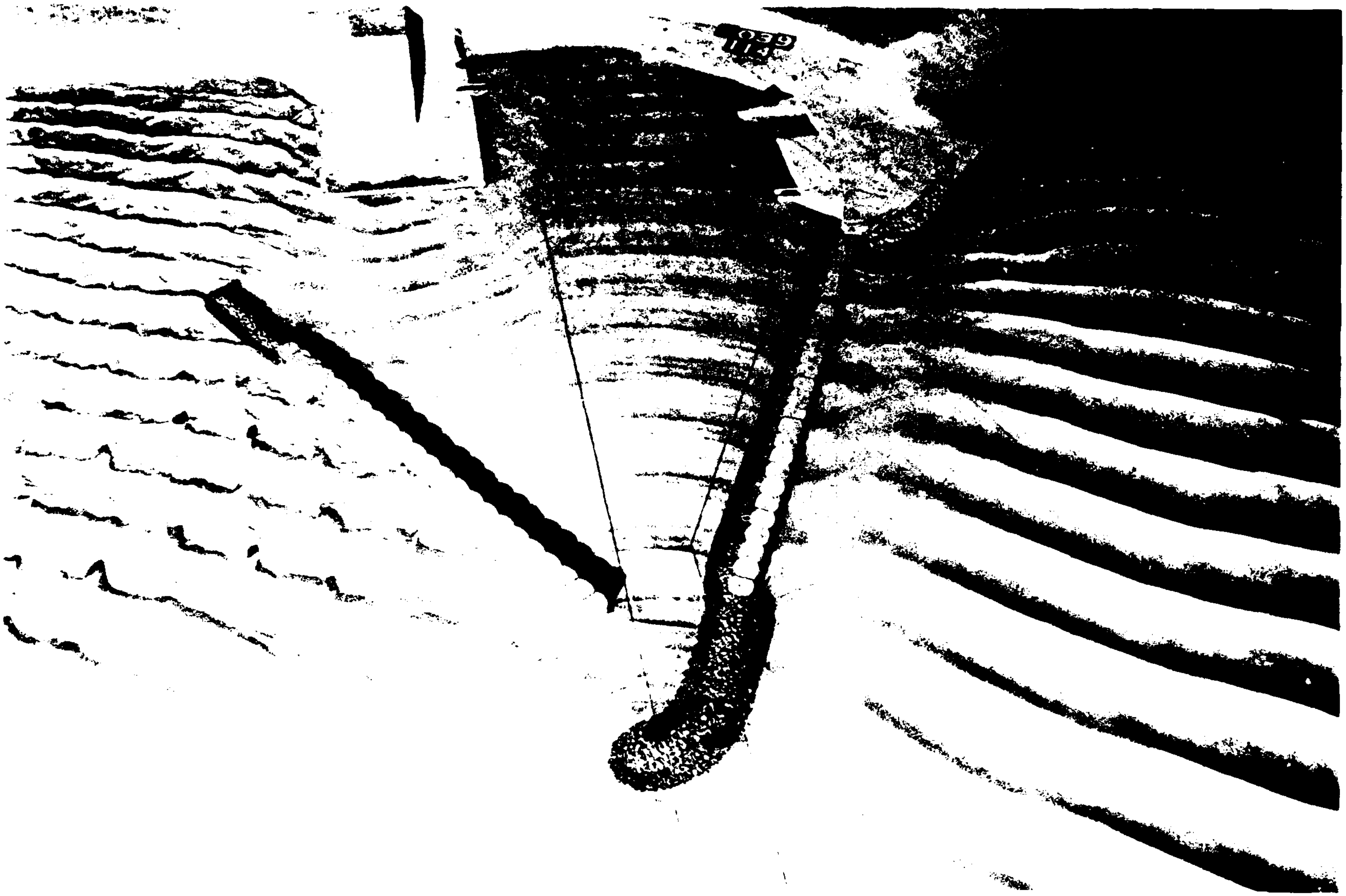

Photo 107. Typical wave patterns for Plan 42; 5.9-sec, 4.3-ft waves from the unrefracted northeast direction; +3.0 ft swl

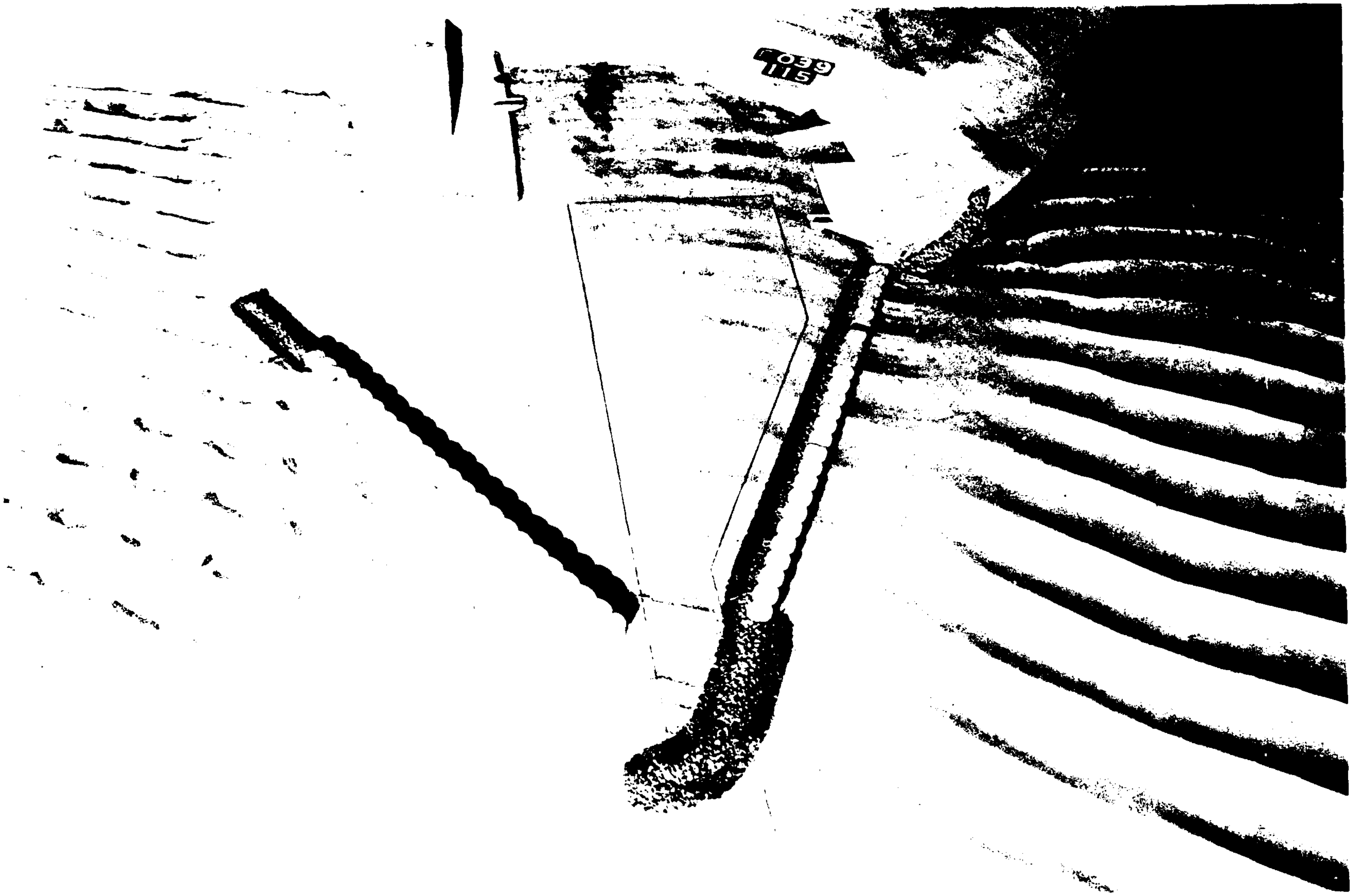

Photo 108. Typical wave patterns for Plan 42; 5.9-sec, 4.0-ft waves from the unrefracted northeast direction; +4.0 ft swl

Photo 109. Typical wave patterns for Plan 46; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

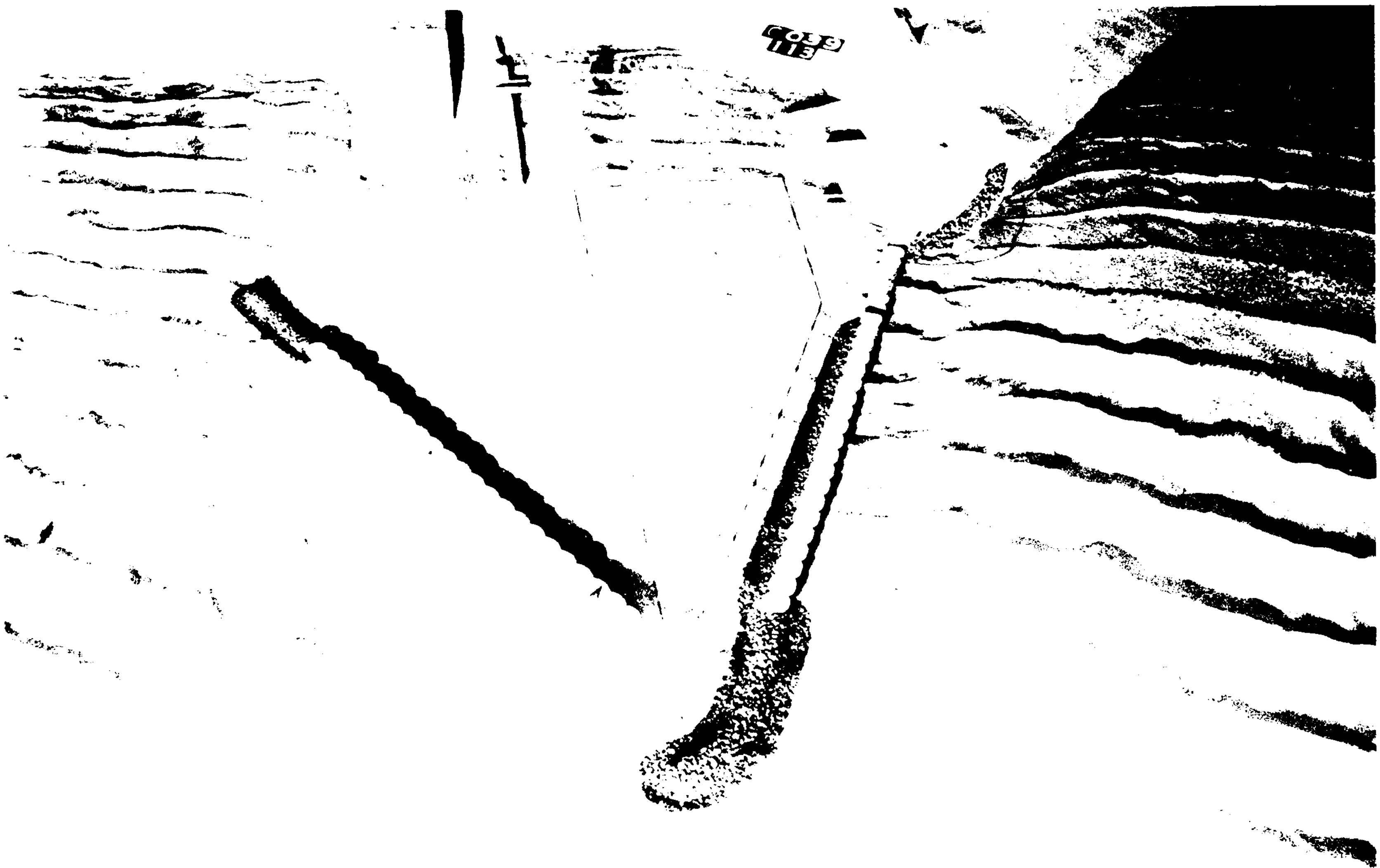

Photo 110. Typical wave patterns for Plan 46; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

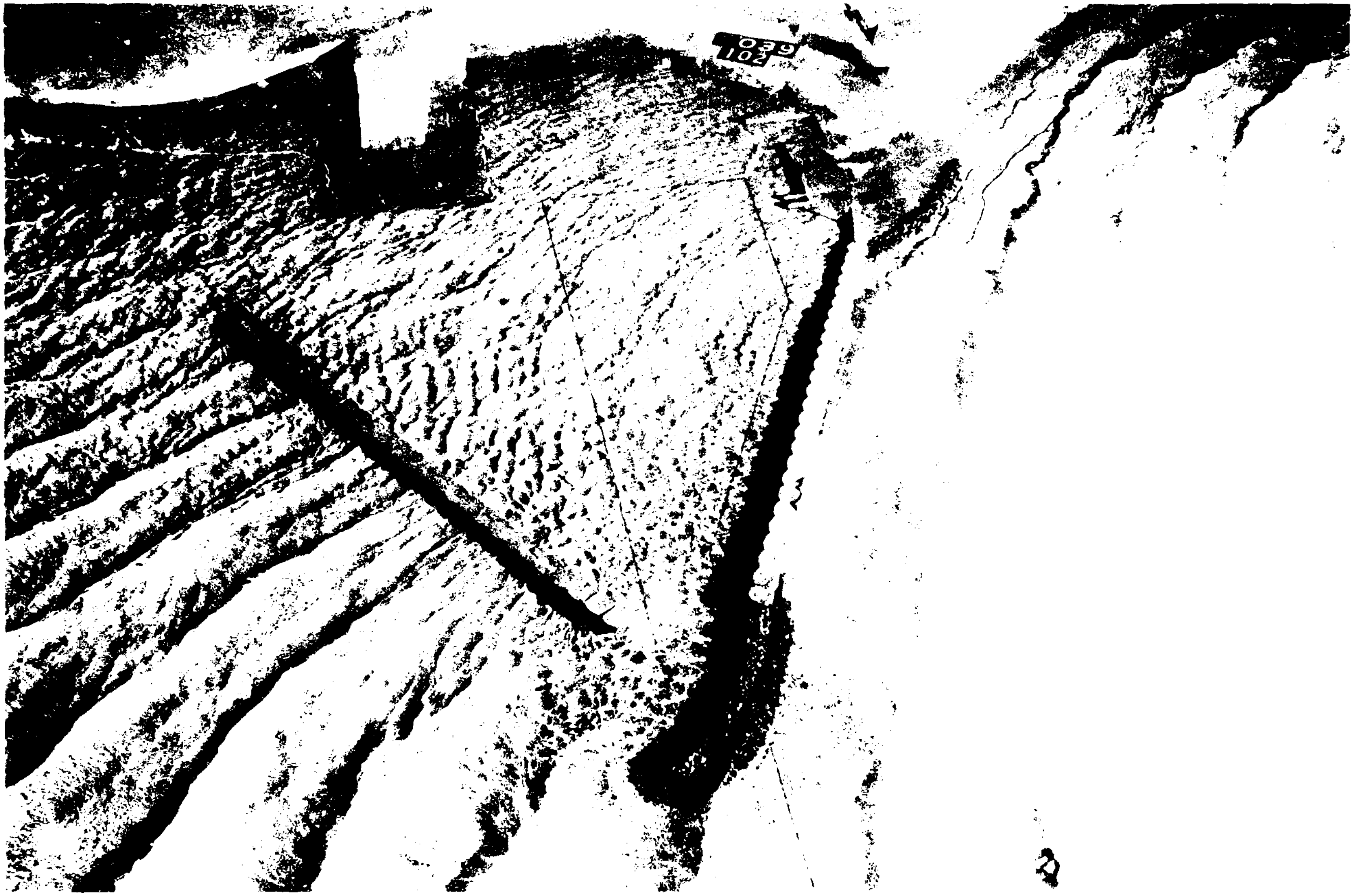

Photo 111. Typical wave patterns for Plan 47; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

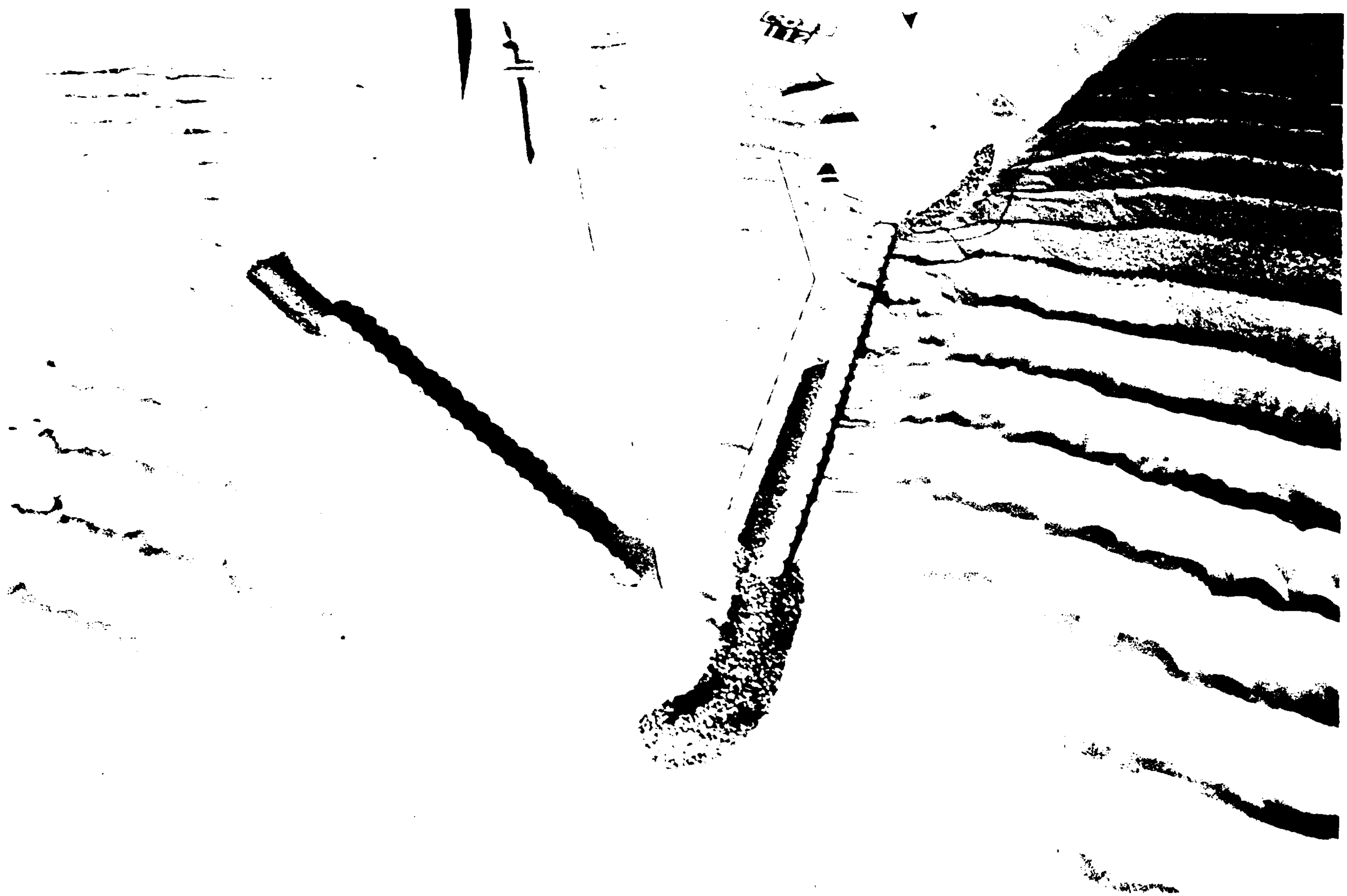

Photo 112. Typical wave patterns for Plan 47; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

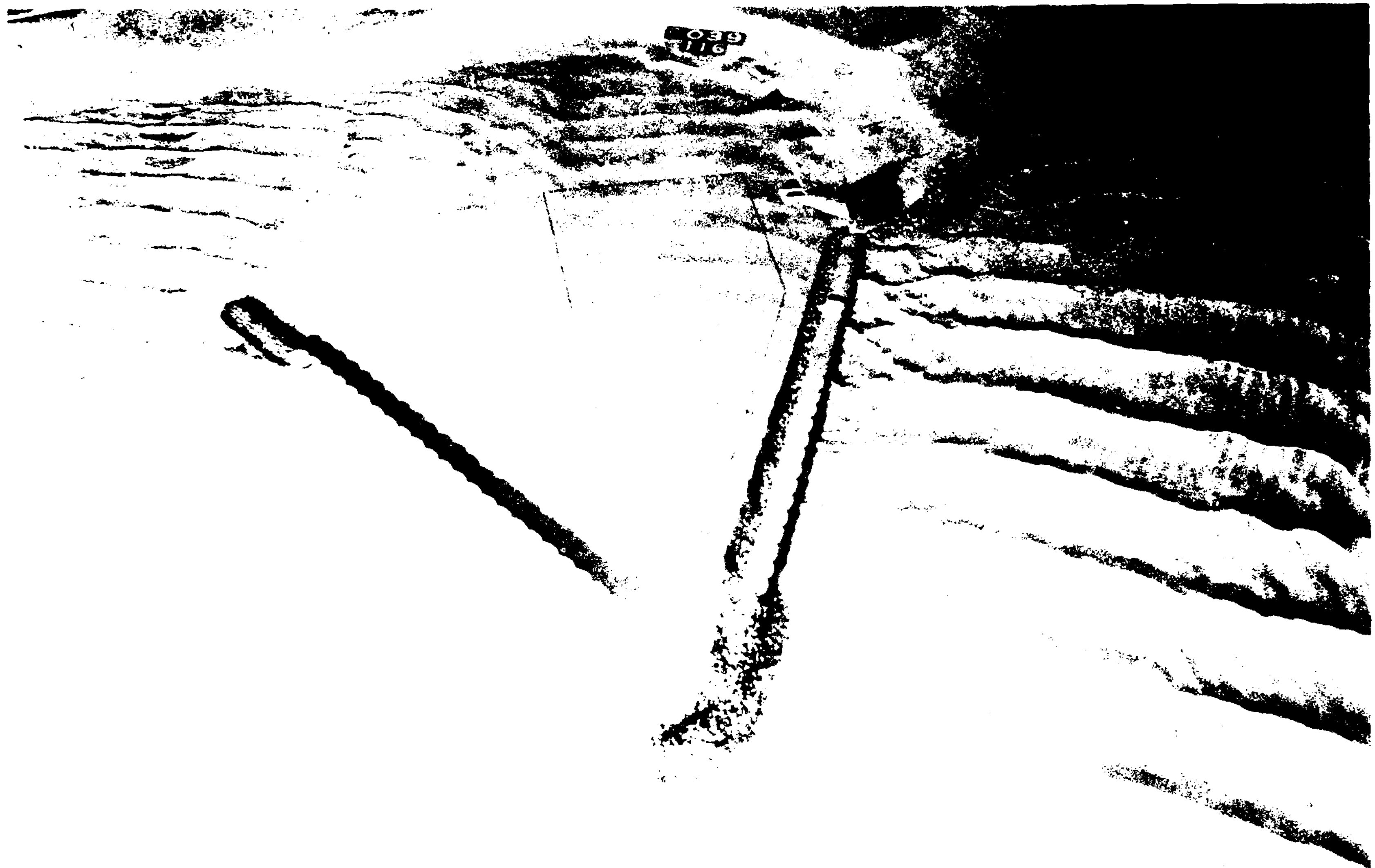

Photo 113. Typical wave patterns for Plan 48; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

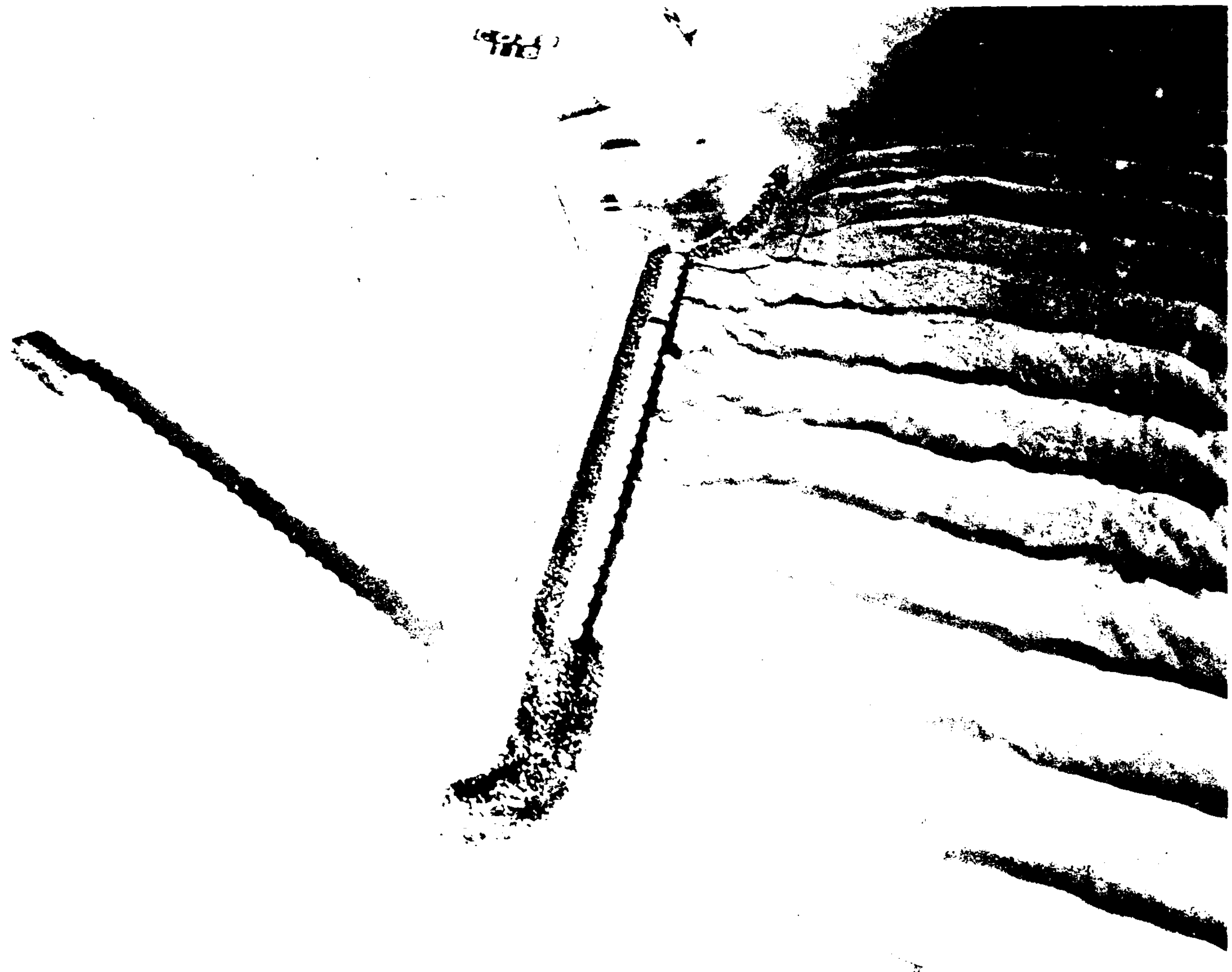

Photo 114. Typical wave patterns for Plan 49; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

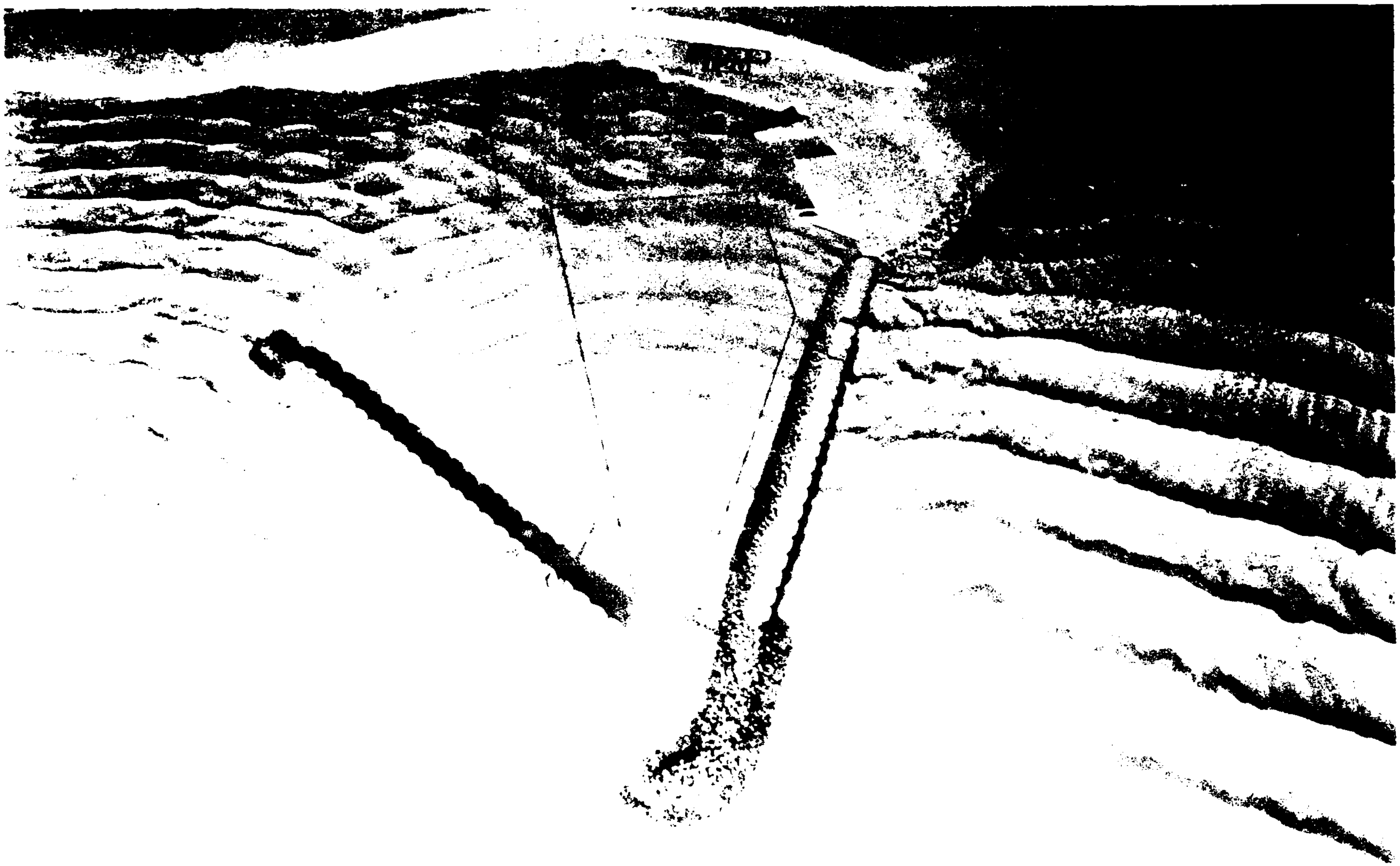

Photo 115. Typical wave patterns for Plan 50; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

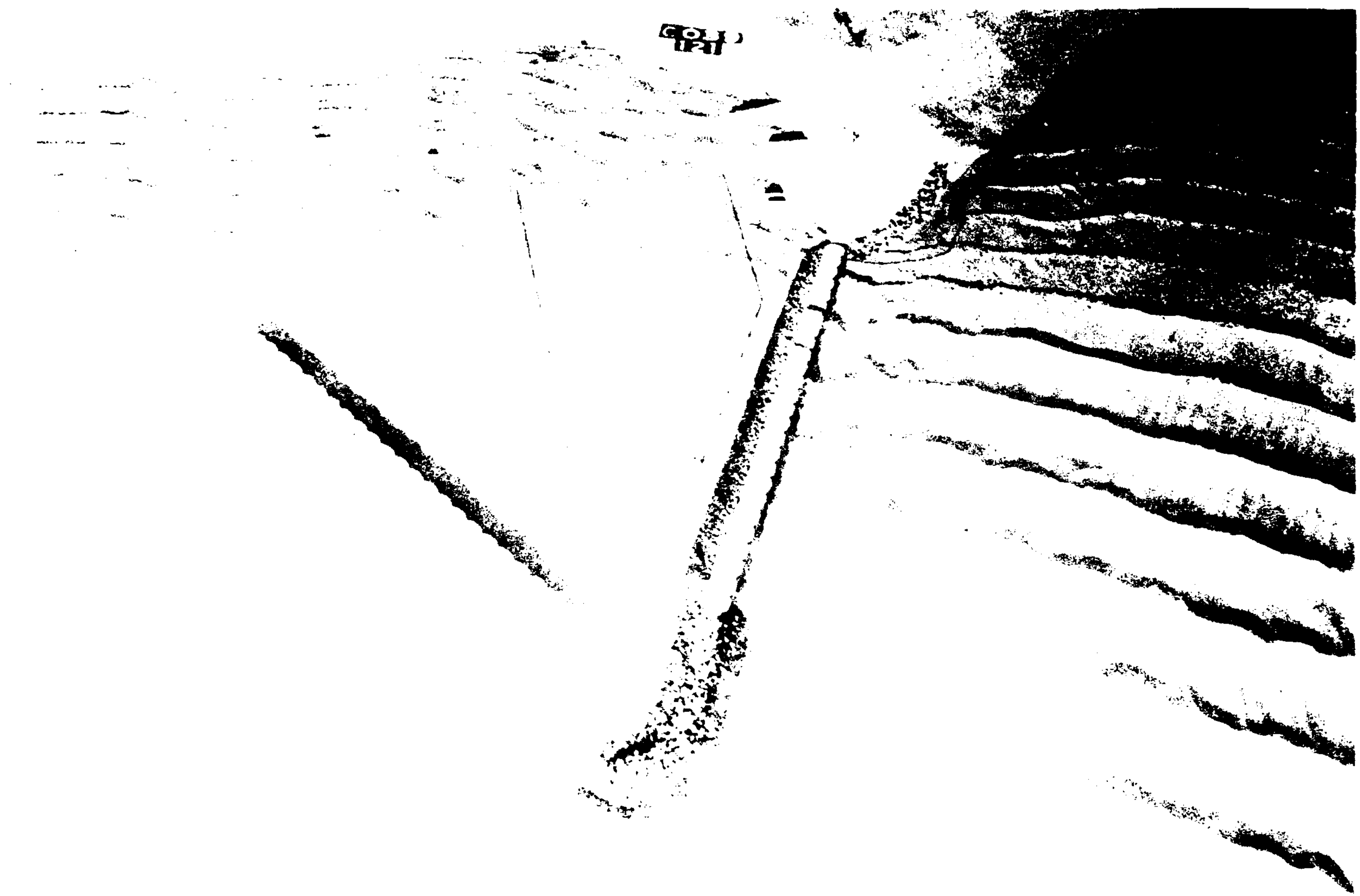

Photo 116. Typical wave patterns for Plan 51; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

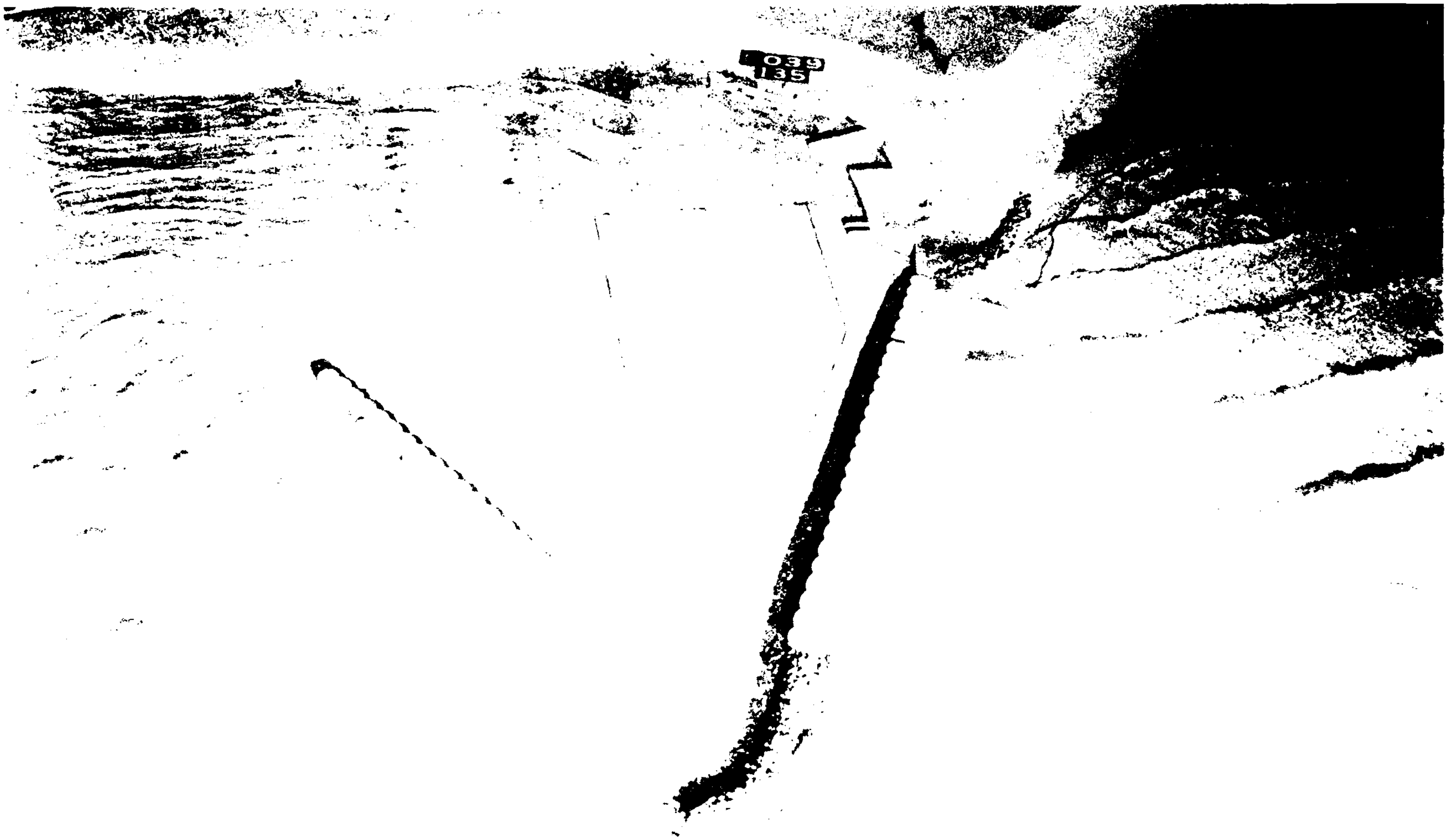

Photo 117. Typical wave patterns for Plan 51; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

Photo 118. Typical wave patterns for Plan 52; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

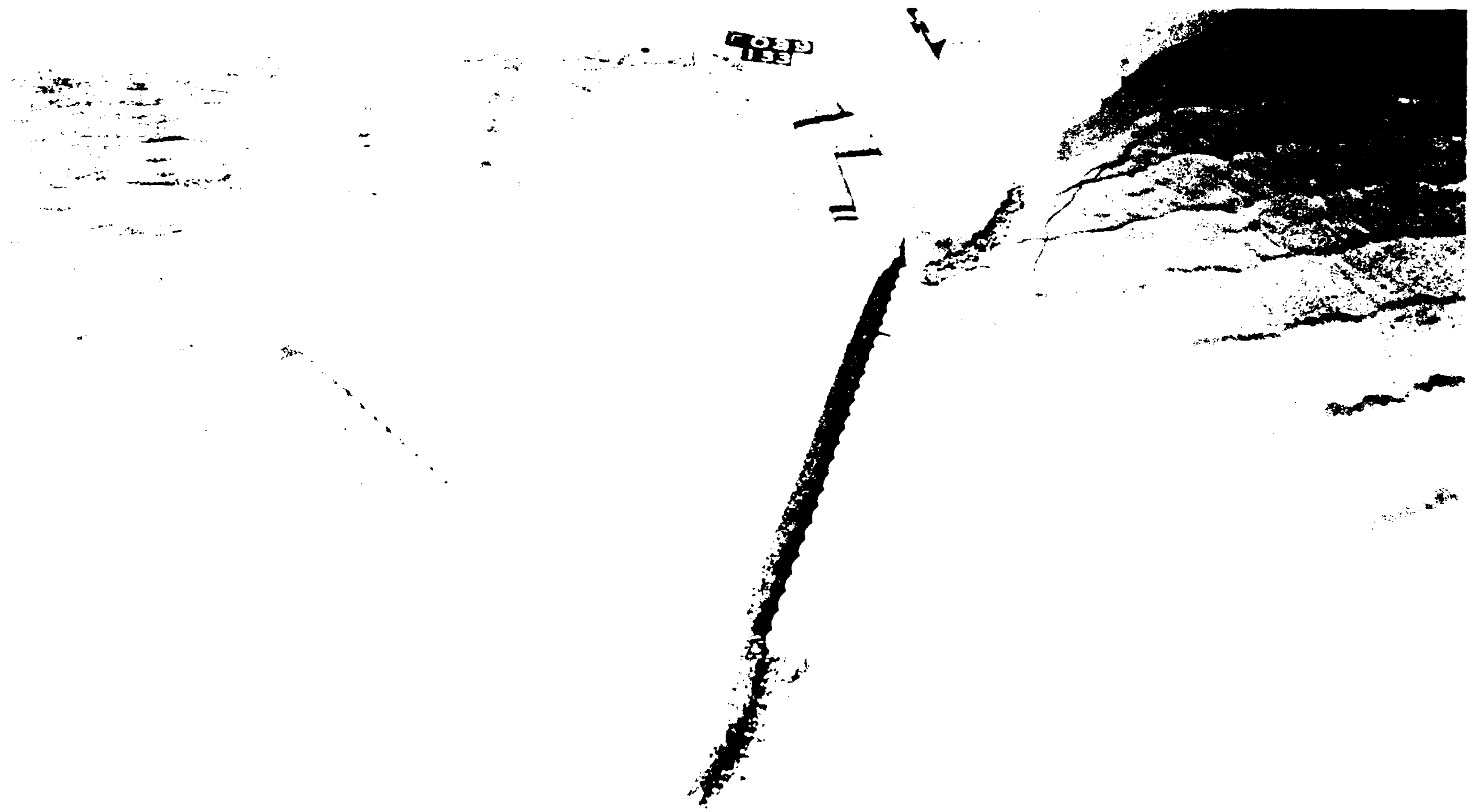

Photo 119. Typical wave patterns for Plan 53; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

Photo 120. Typical wave patterns for Plan 54; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

Photo 121. Typical wave patterns for Plan 55; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

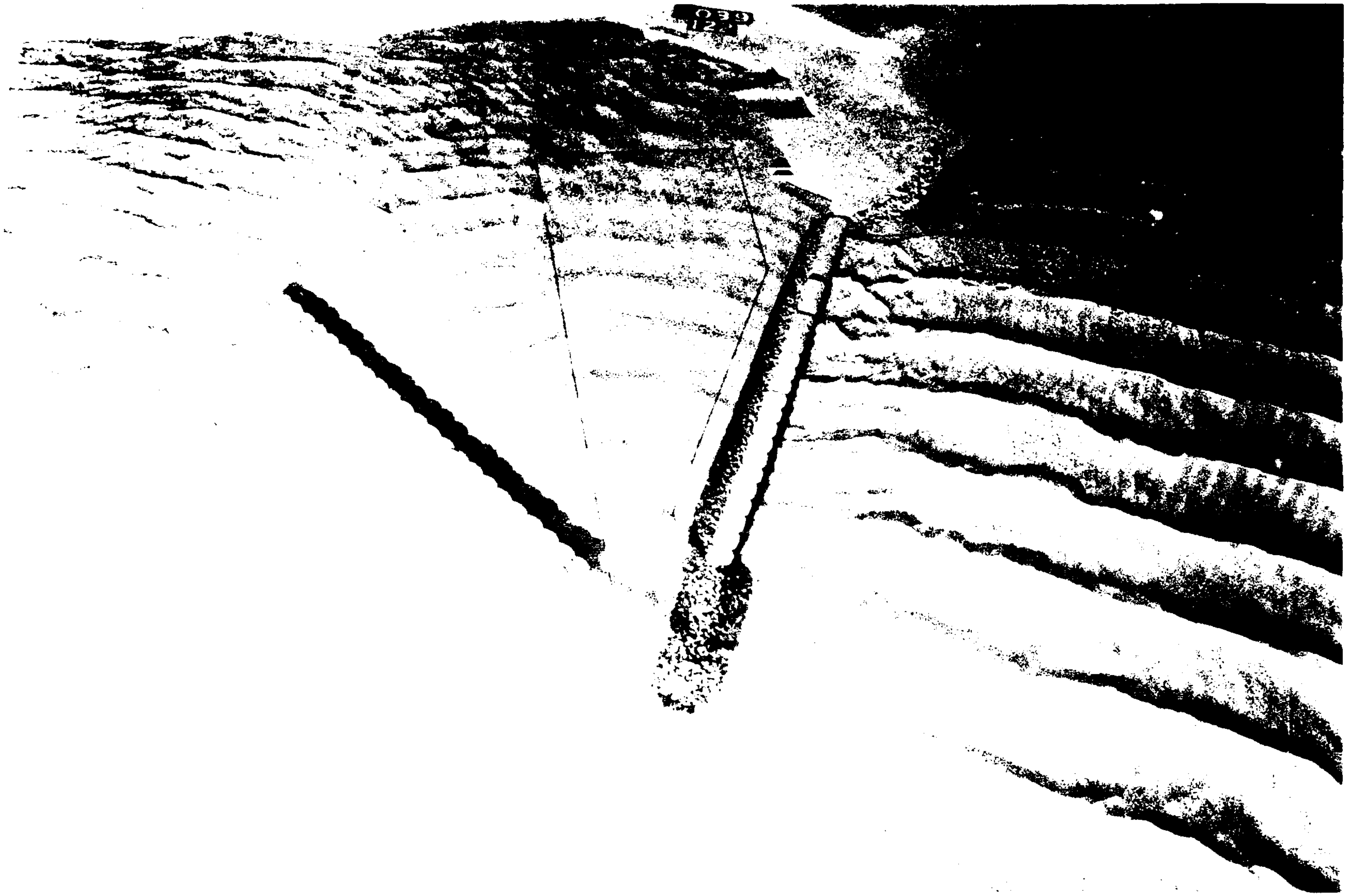

Photo 122. Typical wave patterns for Plan 55; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

Photo 123. Typical wave patterns for Plan 56; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl

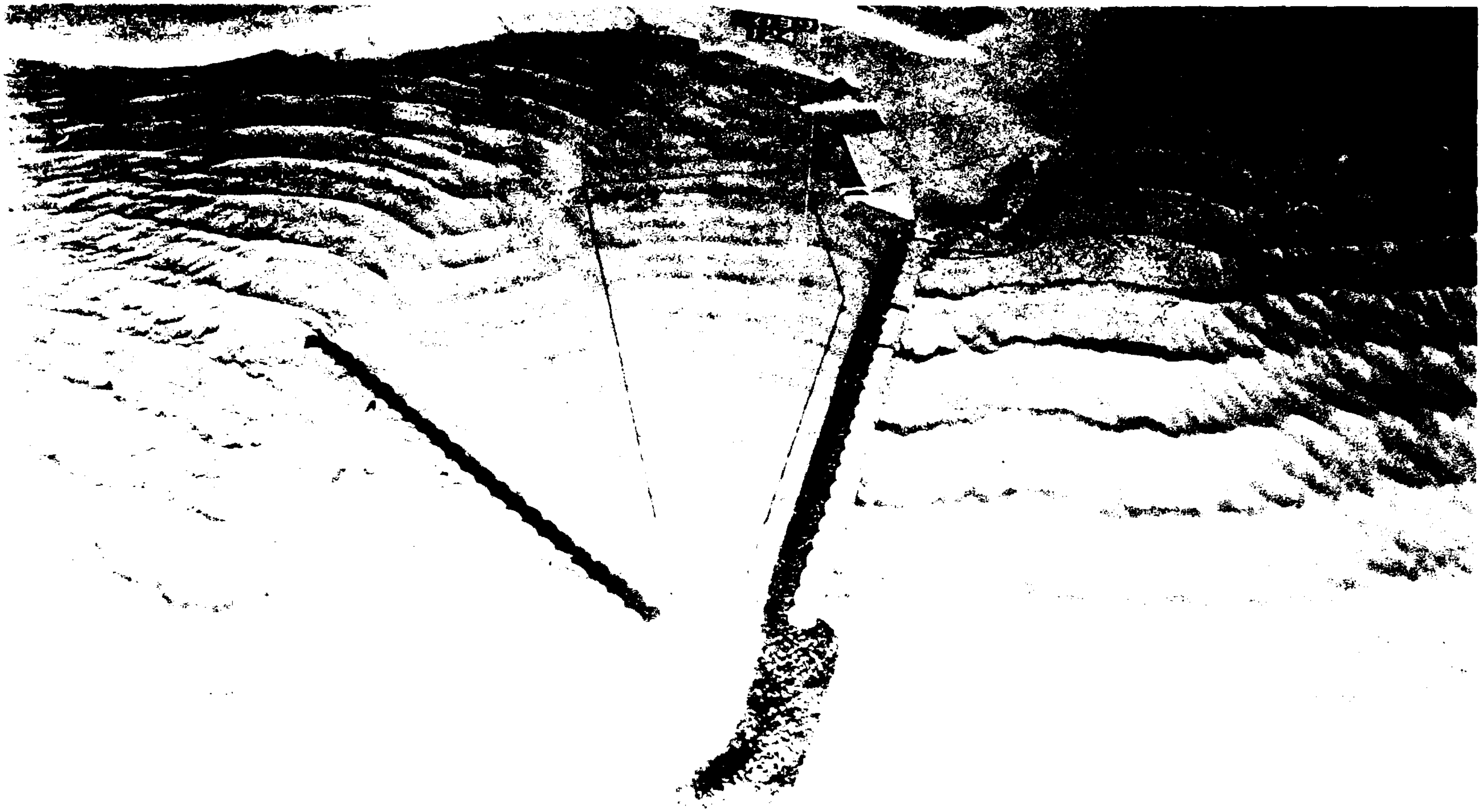

Photo 124. Typical wave patterns for Plan 51; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

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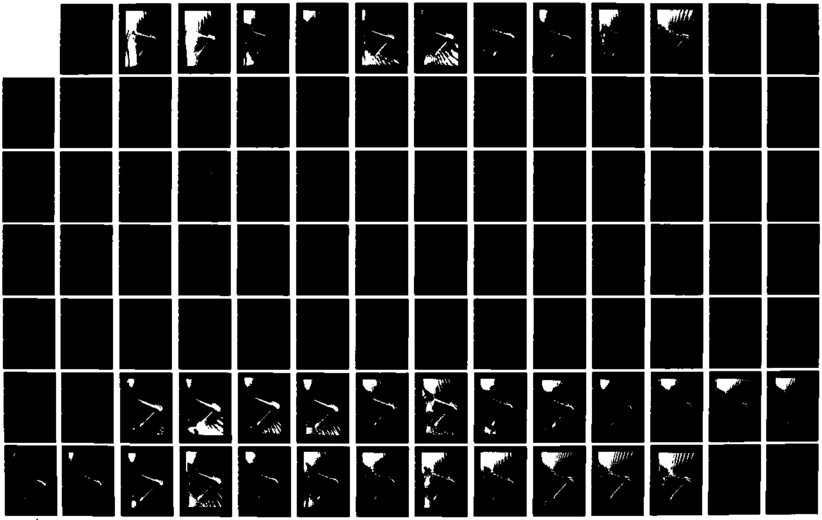

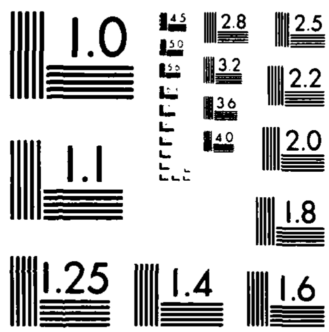

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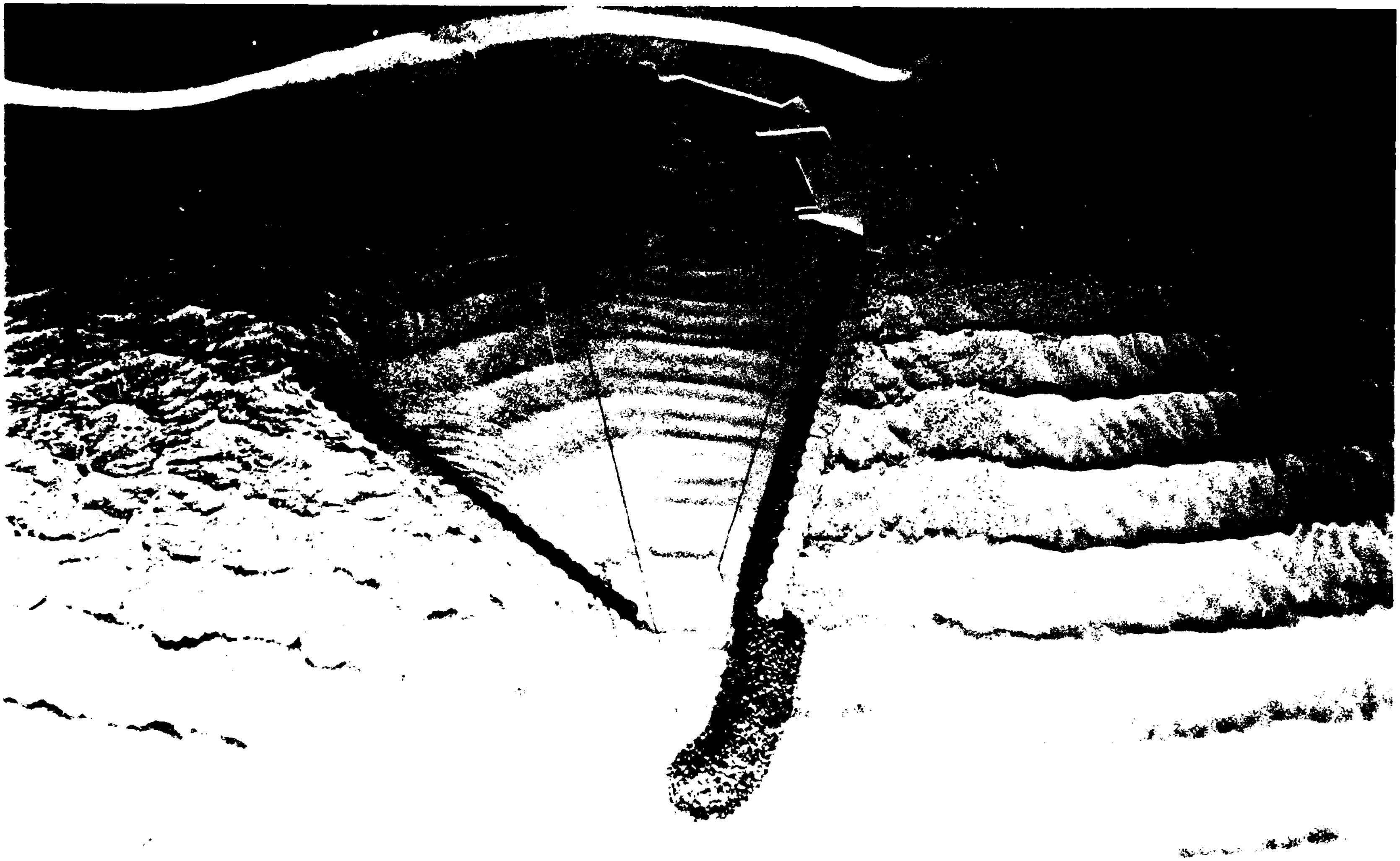


Photo 125. Typical wave patterns for Plan 52; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

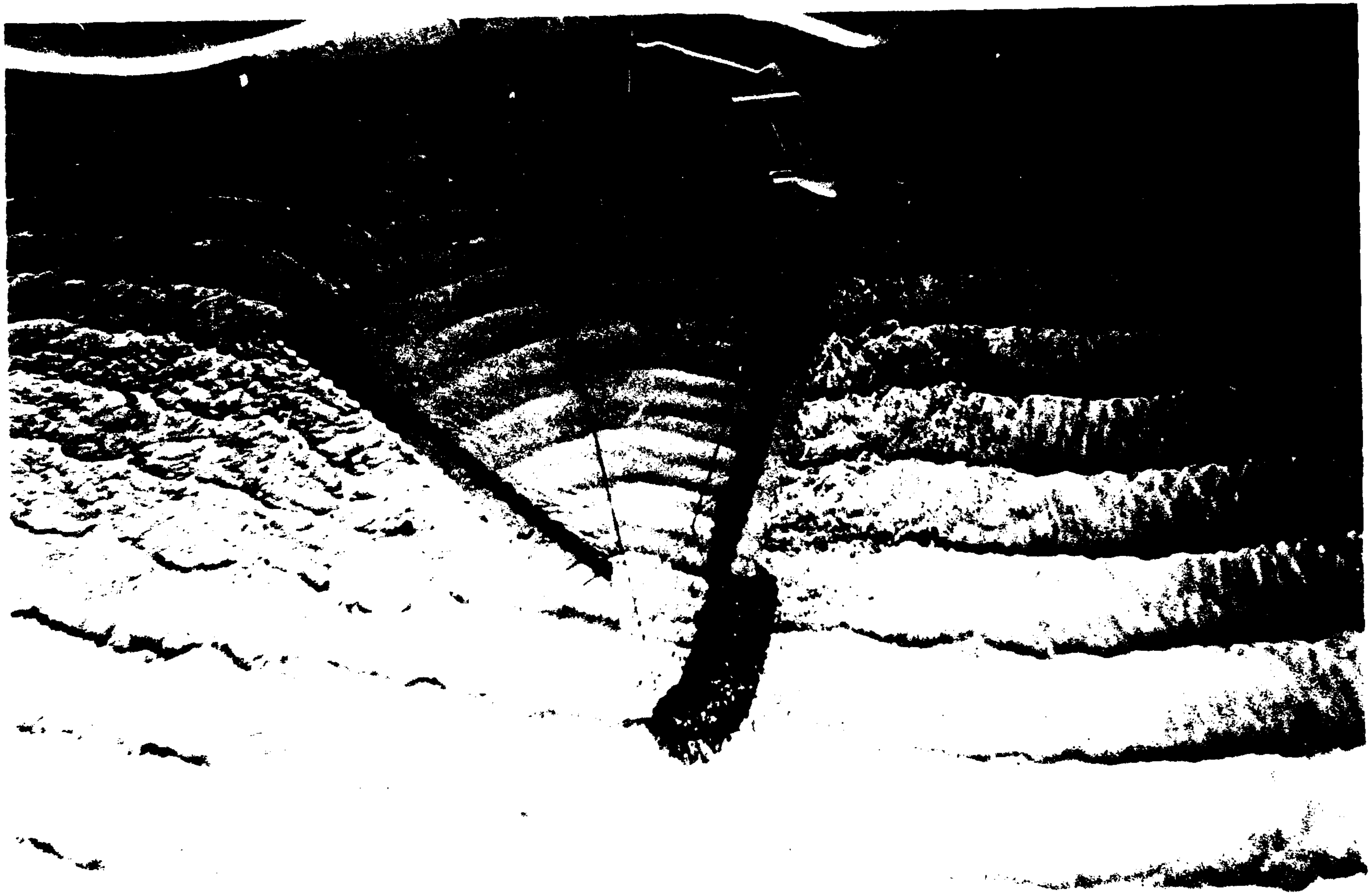


Photo 126. Typical wave patterns for Plan 53; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

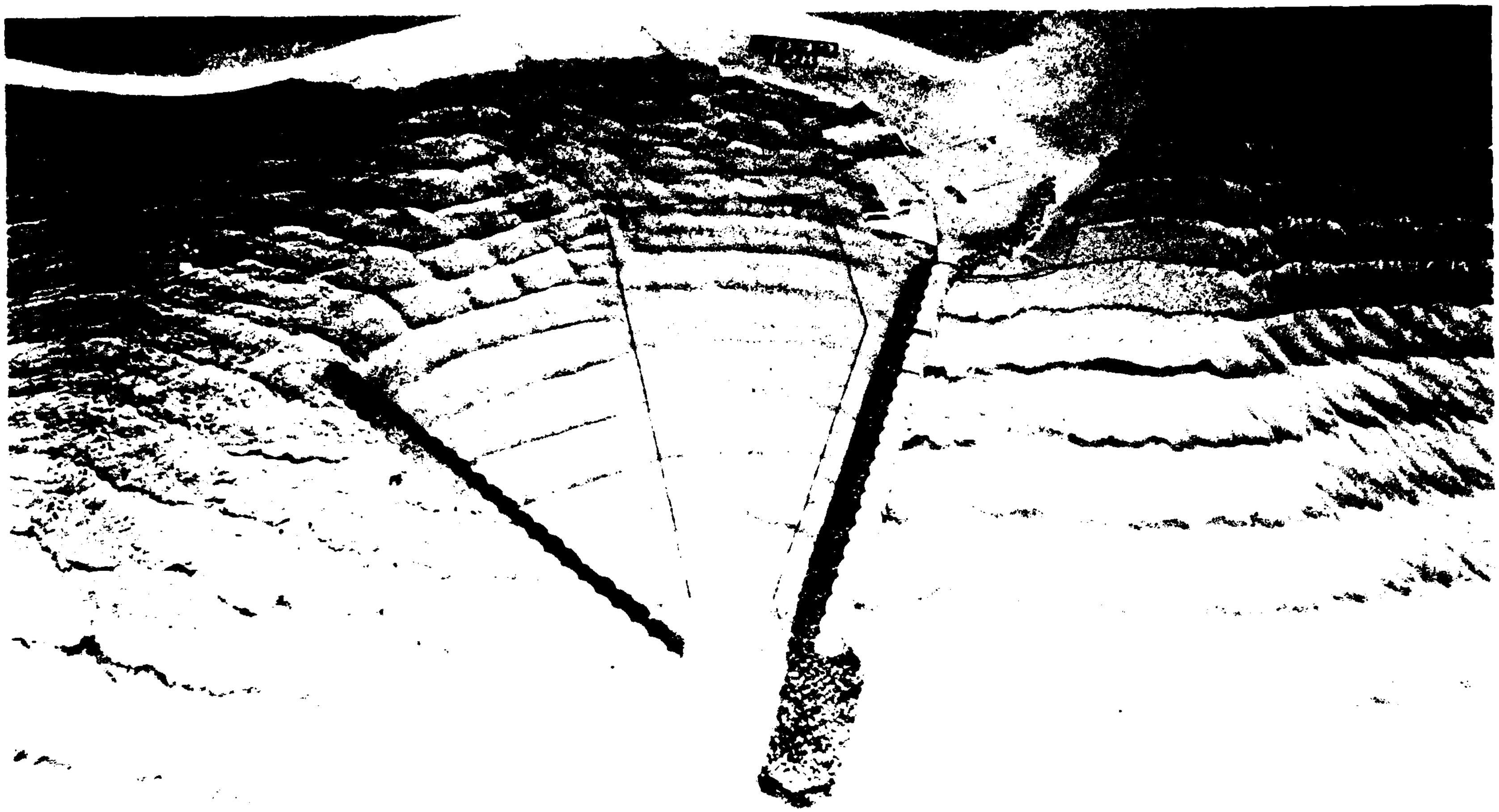


Photo 127. Typical wave patterns for Plan 55; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

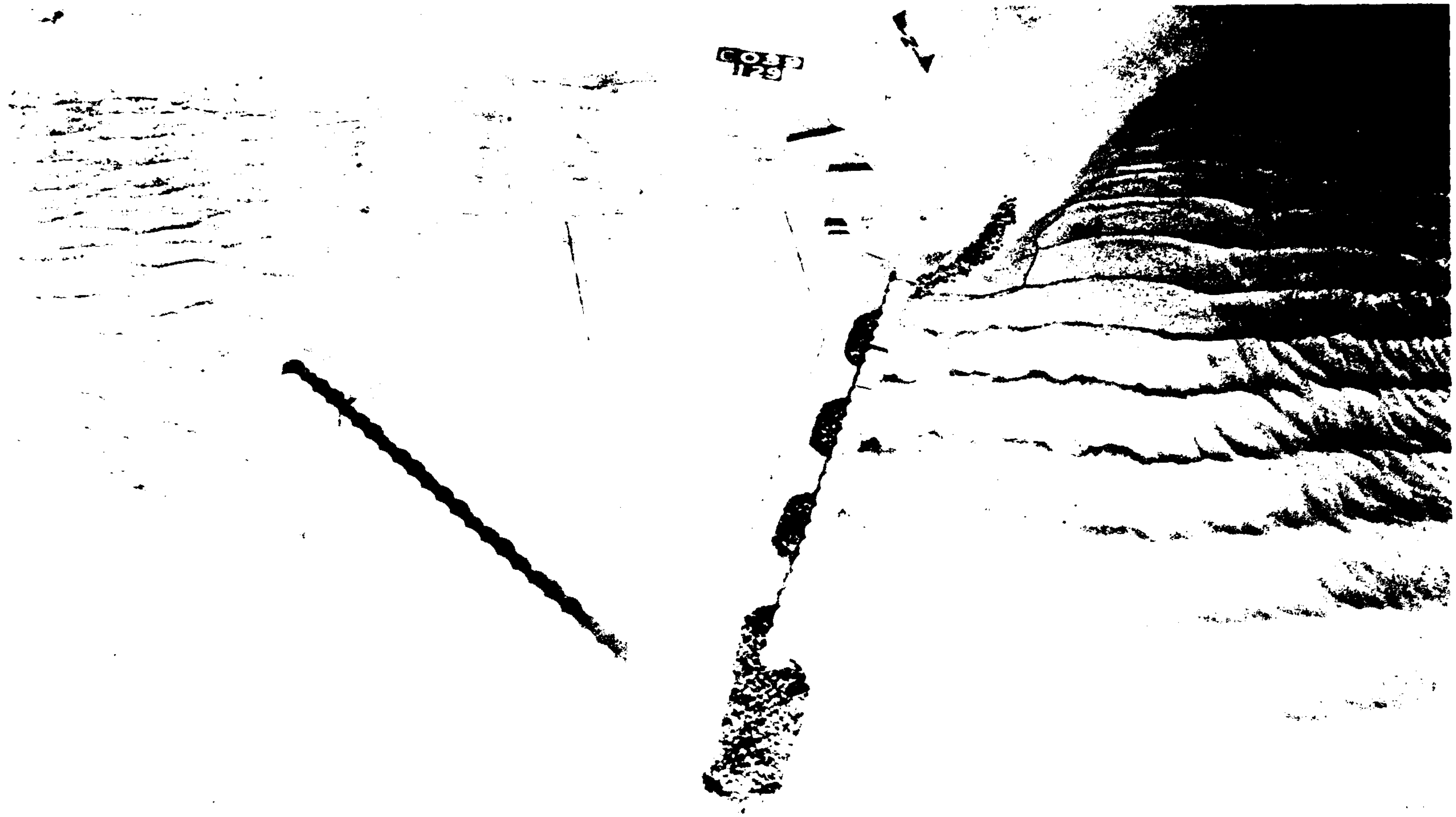


Photo 128. Typical wave patterns for Plan 56; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

Photo 129. Typical wave patterns for Plan 52; 7.7-sec, 7.9-ft waves from west; +6.5ft swl

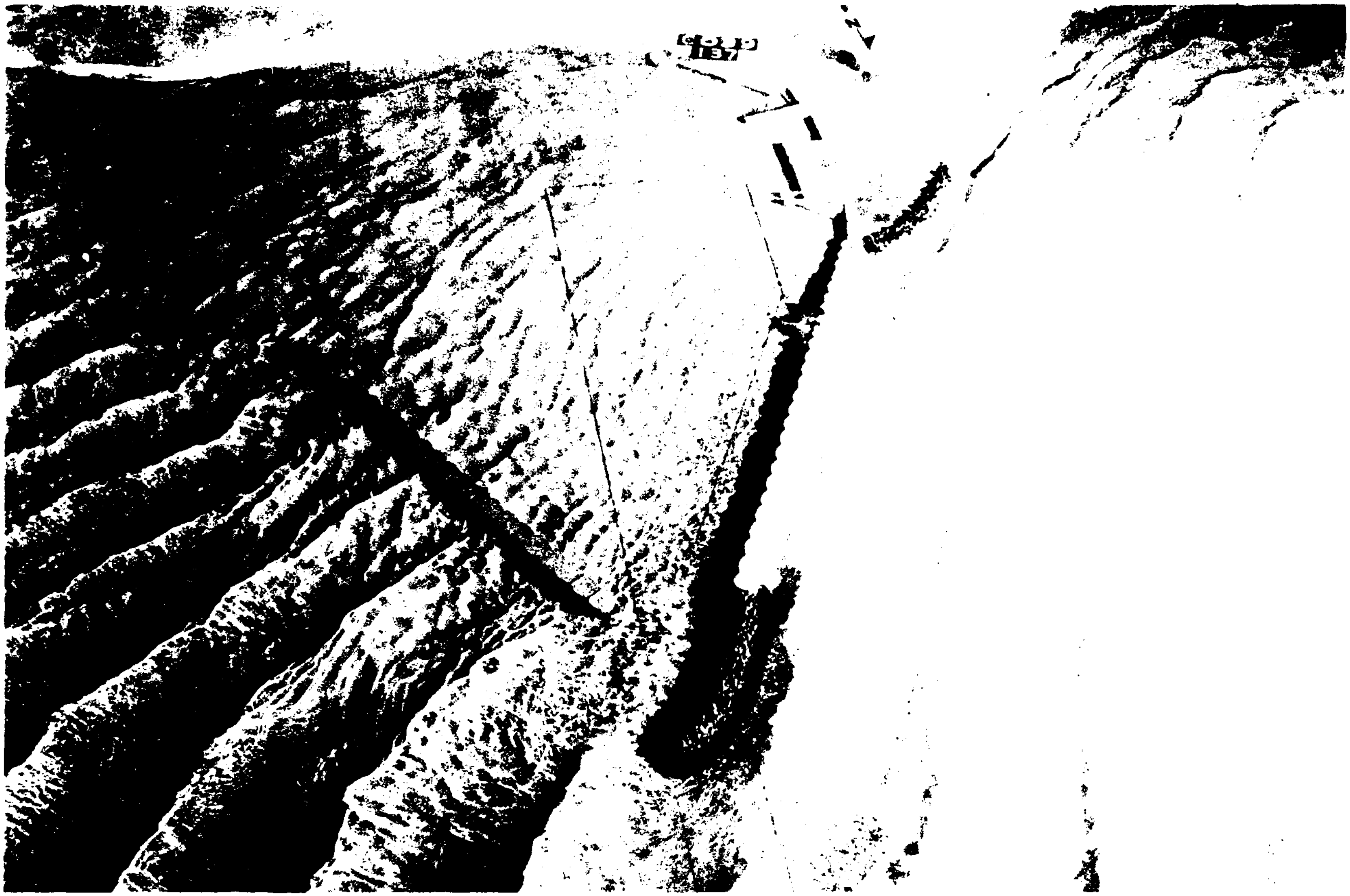


Photo 130. Typical wave patterns for Plan 57; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 131. Typical wave patterns for Plan 58; 7.7-sec, 7.9-ft waves from west; +6.5 ft swl

Photo 132. Typical wave patterns for Plan 58; 7.5-sec, 9.6-ft waves from north; +4.0 ft swl

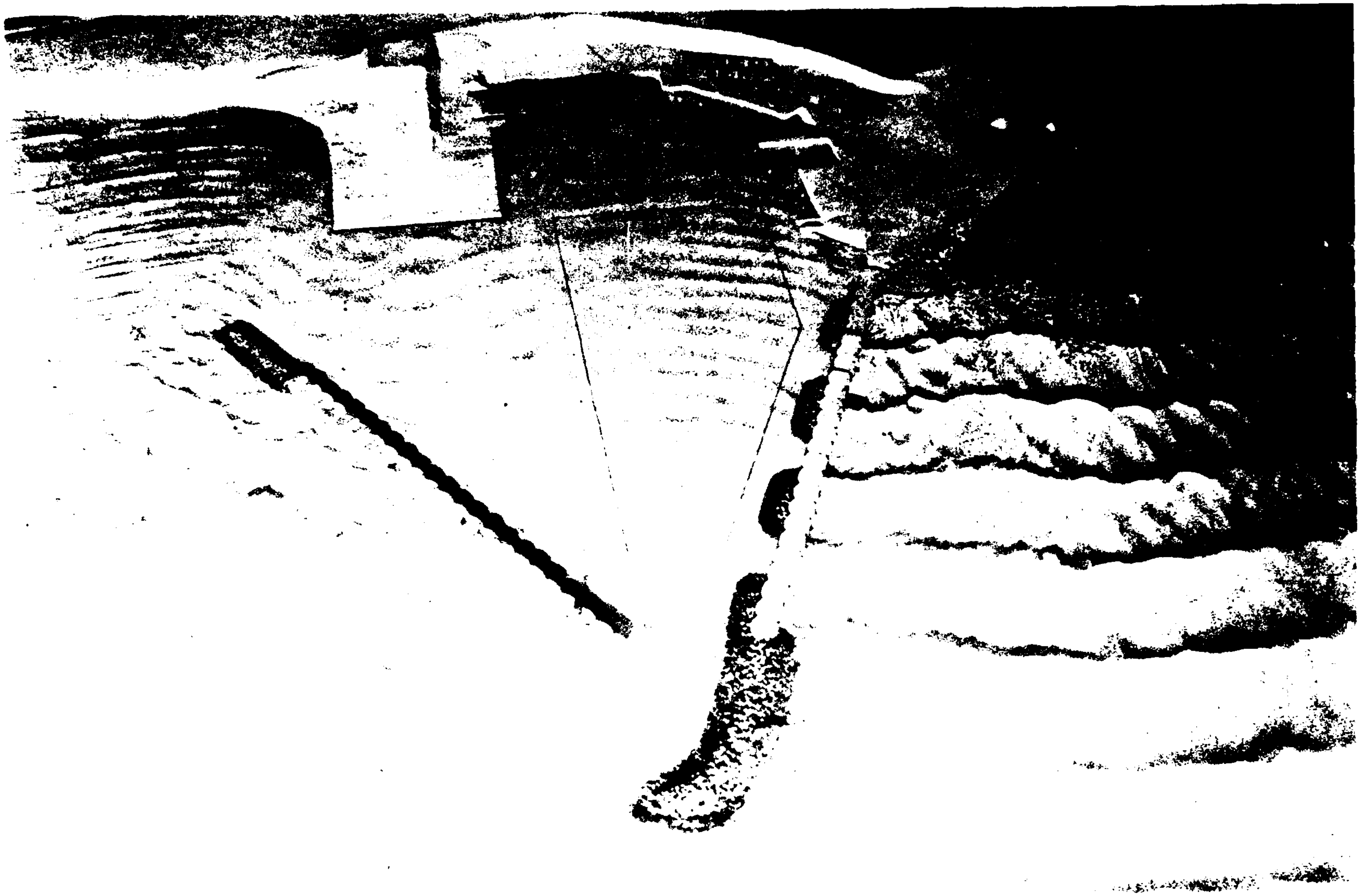


Photo 133. Typical wave patterns for Plan 58; 6.7-sec, 5.7-ft waves from northeast; +3.0 ft swl

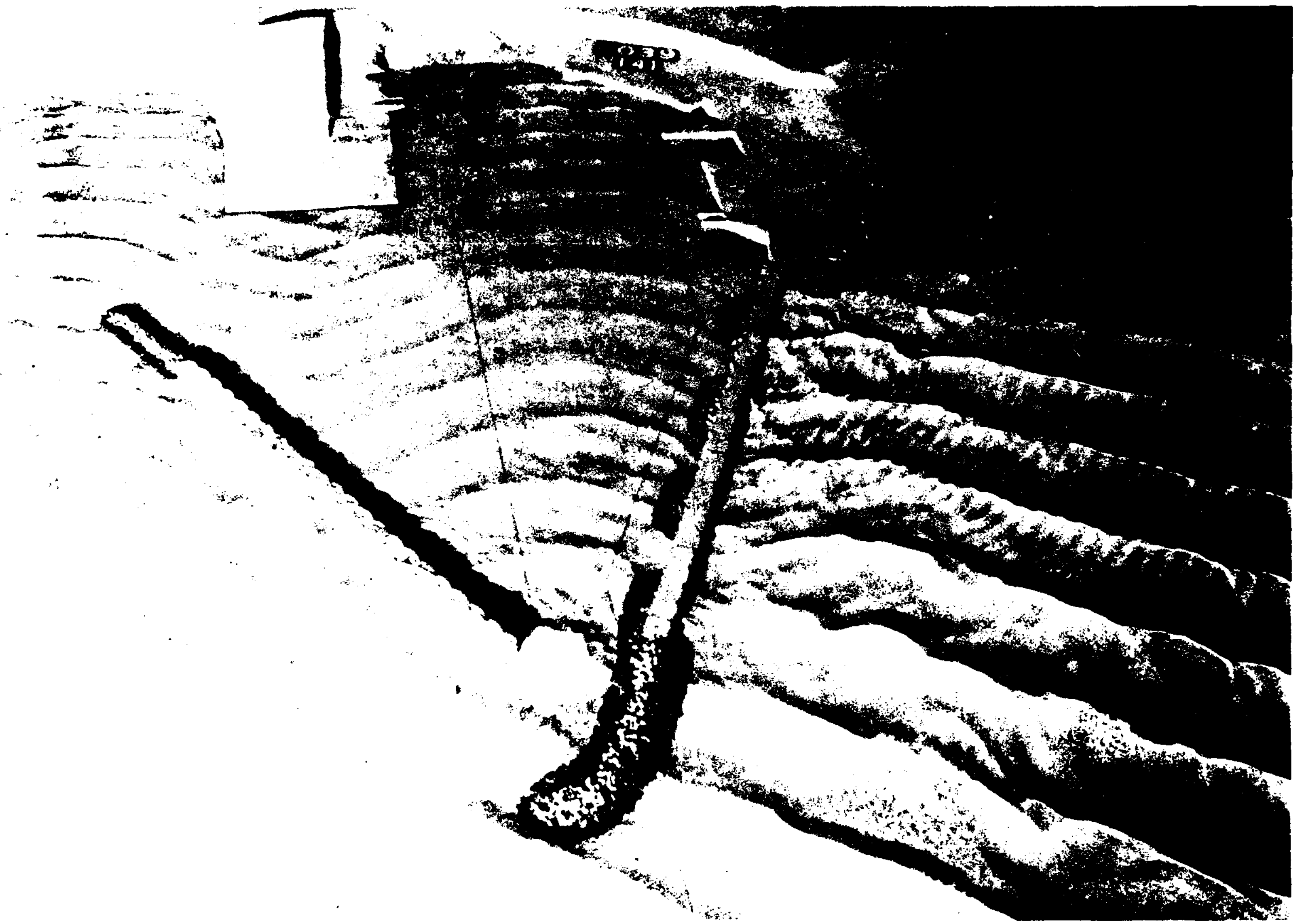
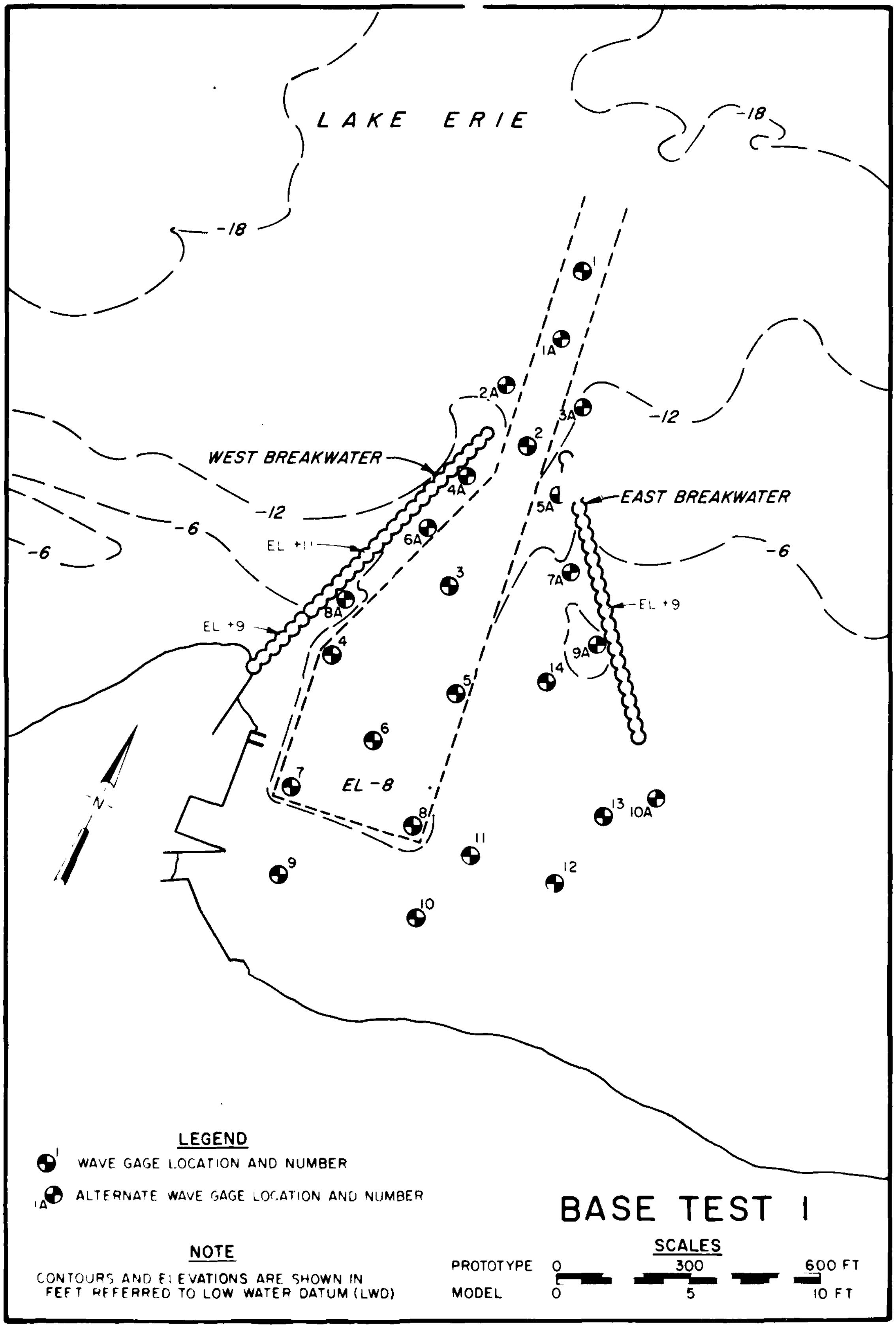
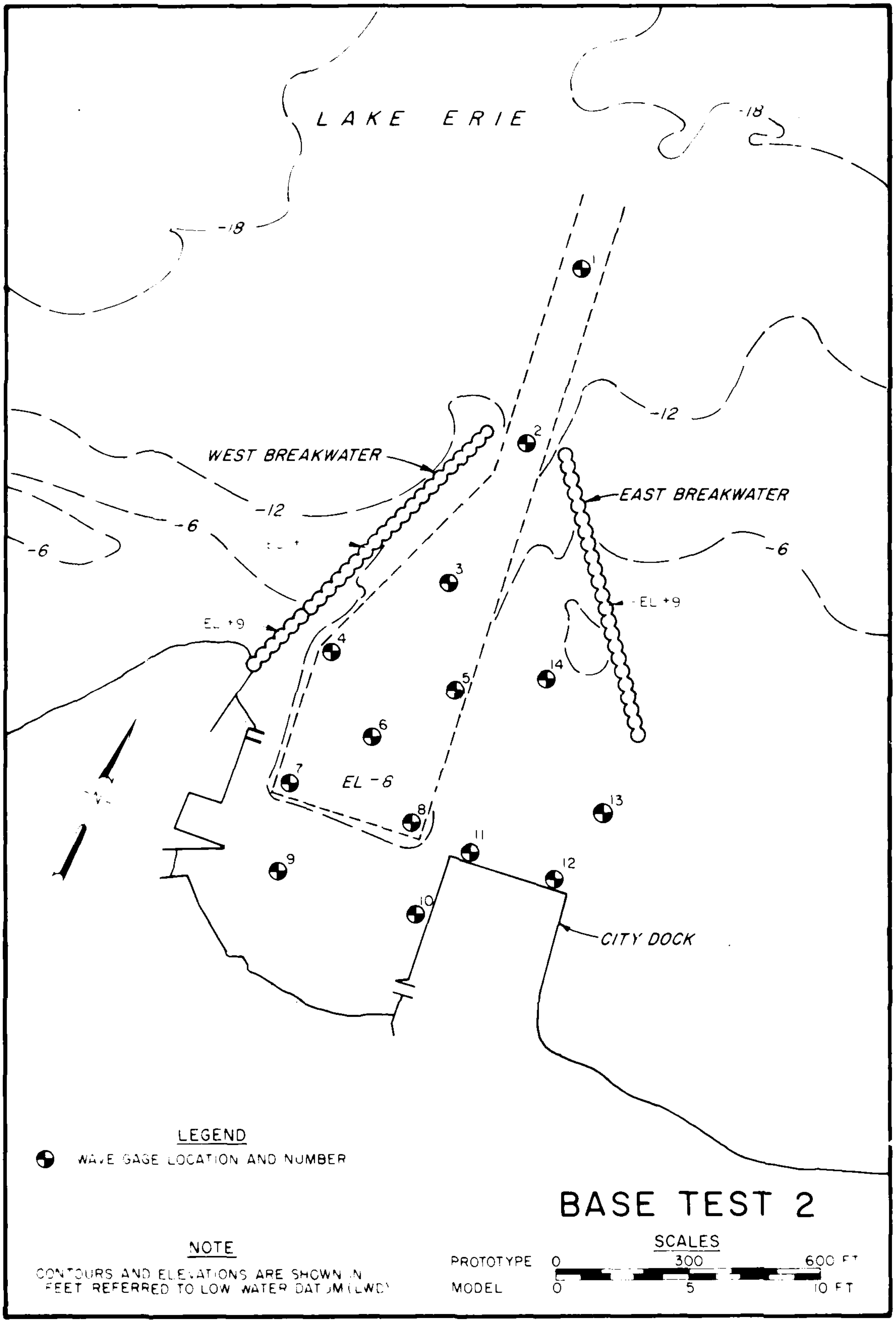


Photo 134. Typical wave patterns for Plan 58; 6.7-sec, 5.7-ft waves from the unrefracted northeast direction; +3.0 ft swl



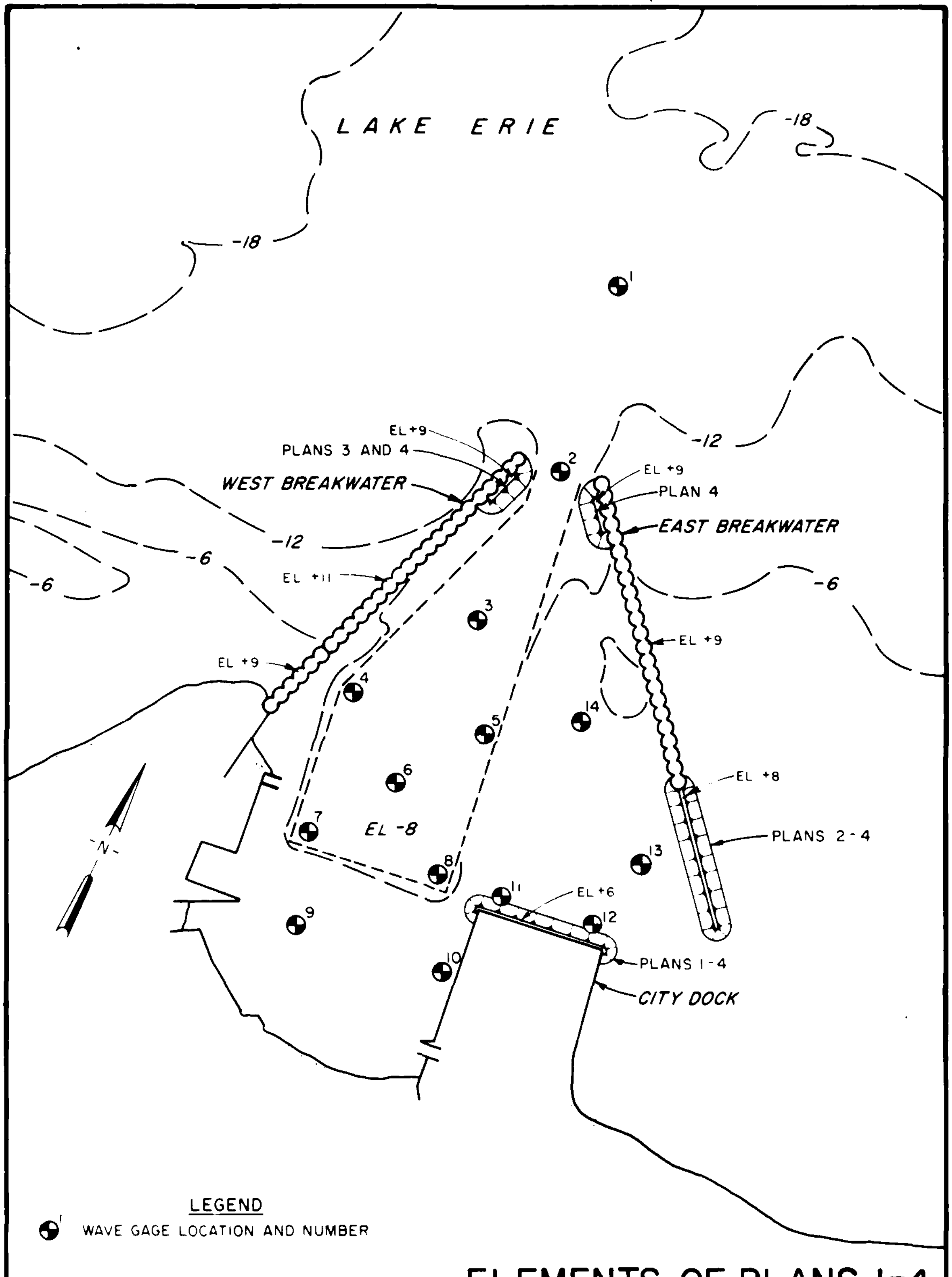
LAKE ERIE
-18
-12
-6
WEST BREAKWATER
EAST BREAKWATER
EL +11
EL +9
EL -8
N
1
1A
2A
2
3A
4A
5A
6A
3
7A
8A
4
9A
14
5
6
7
8
13
10A
11
9
12
10
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
BASE TEST 1
NOTE
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
SCALES
PROTOTYPE 0 300 600 FT
MODEL 0 5 10 FT

PLATE 1



BASE TEST 2

PLATE 2



LEGEND

WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLANS 1-4

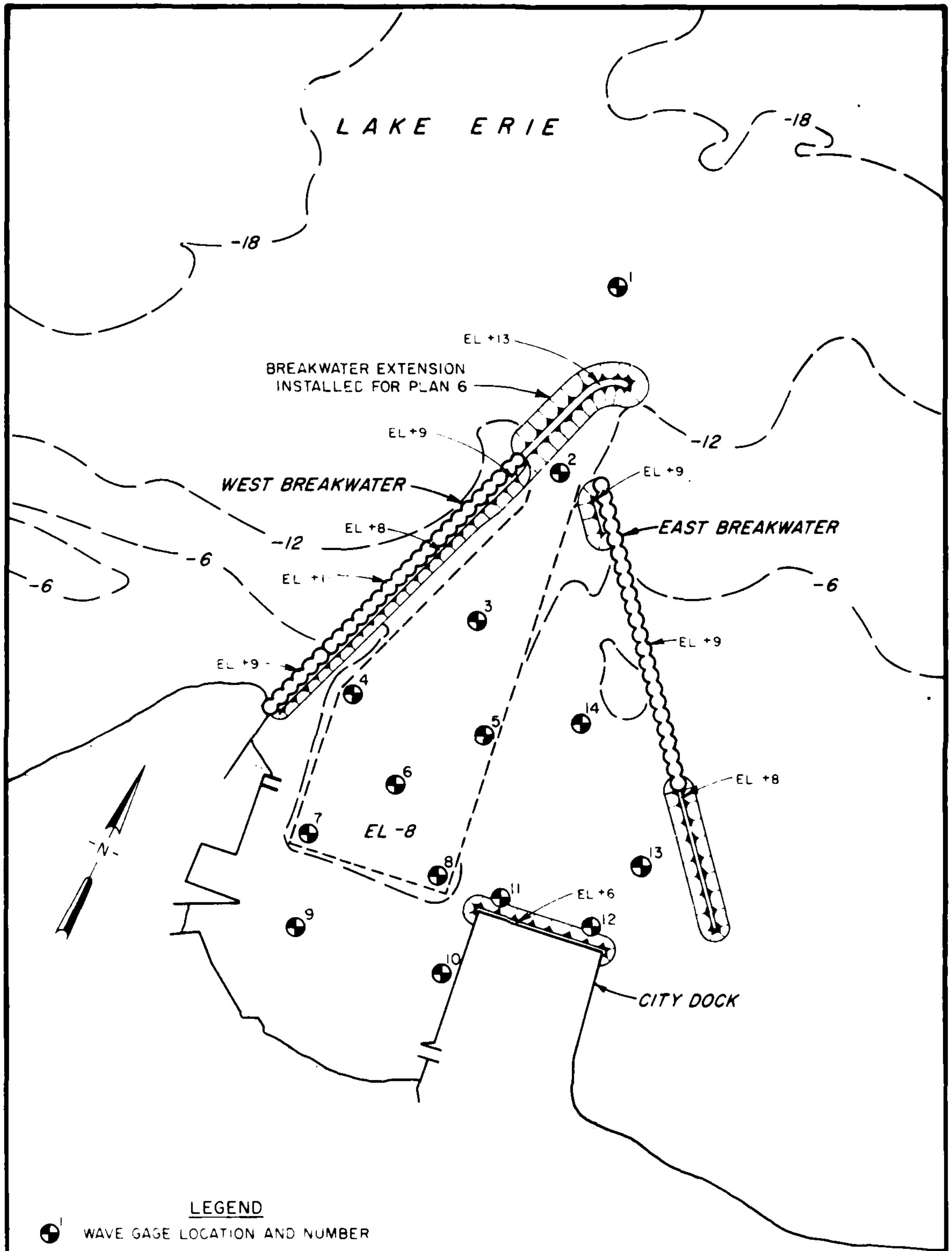
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT



LEGEND

^{1} WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLANS 5 AND 6

NOTE

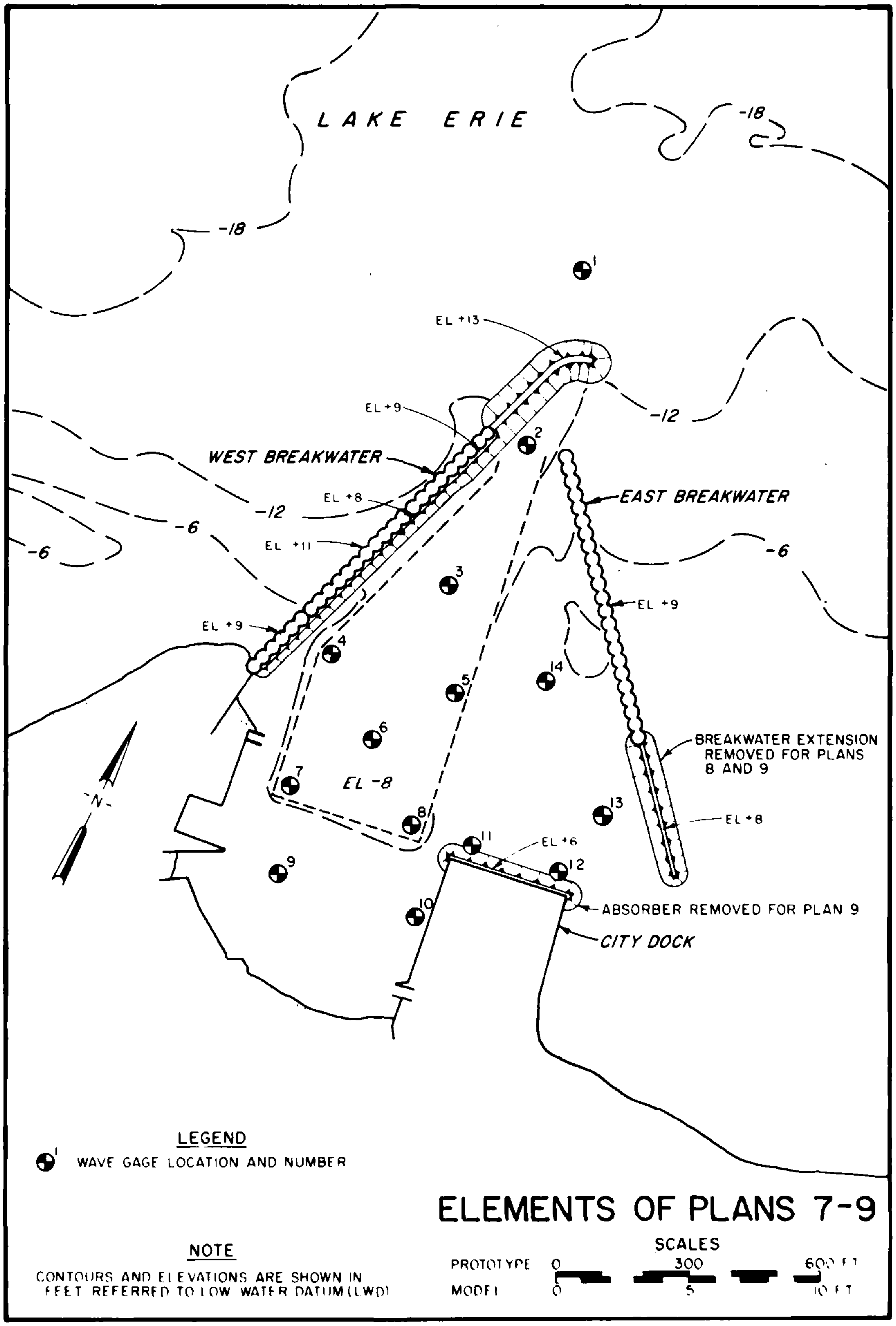
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

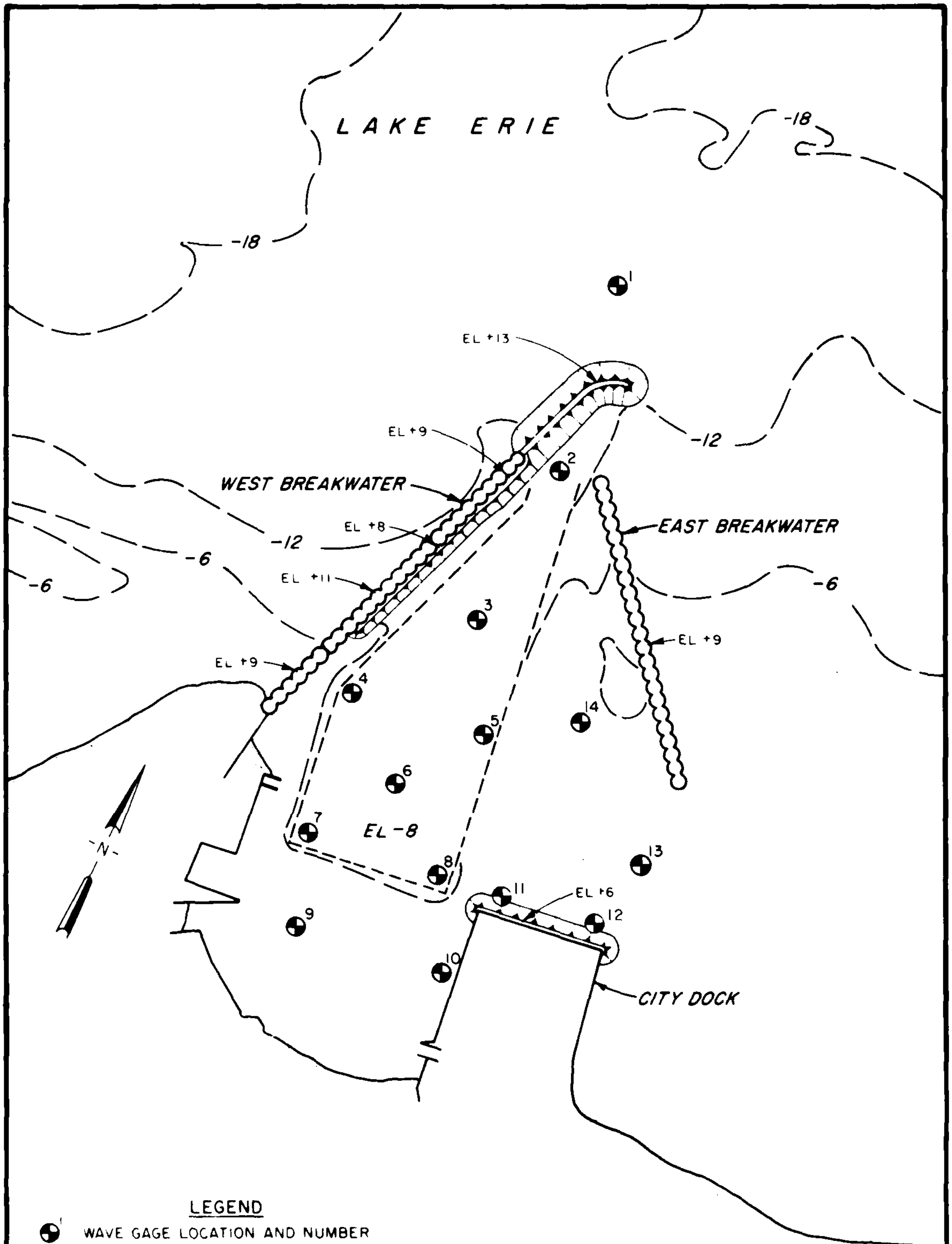
PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT

PLATE 4



ELEMENTS OF PLANS 7-9



LEGEND

WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLAN 10

NOTE

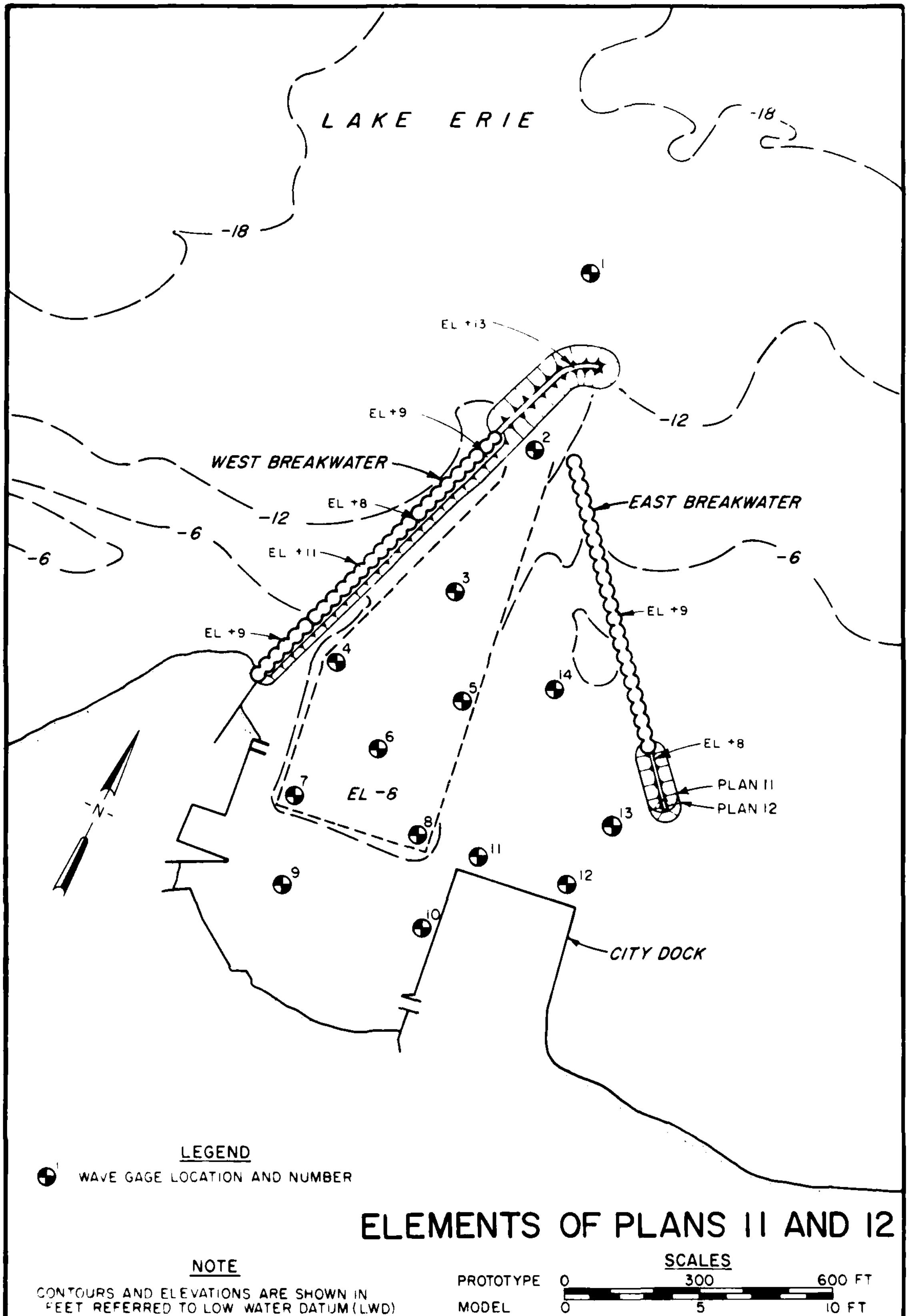
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT

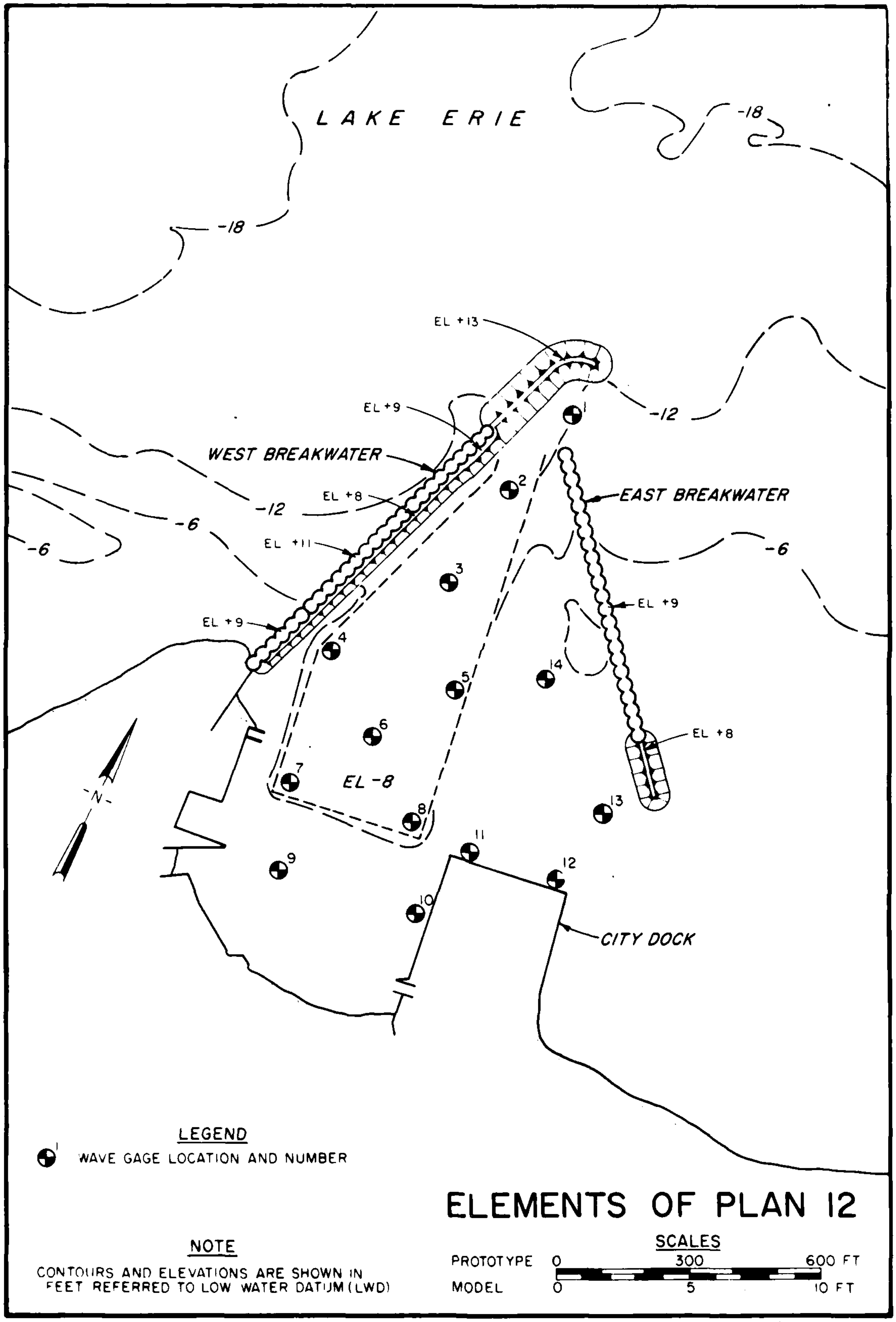
PLATE 6

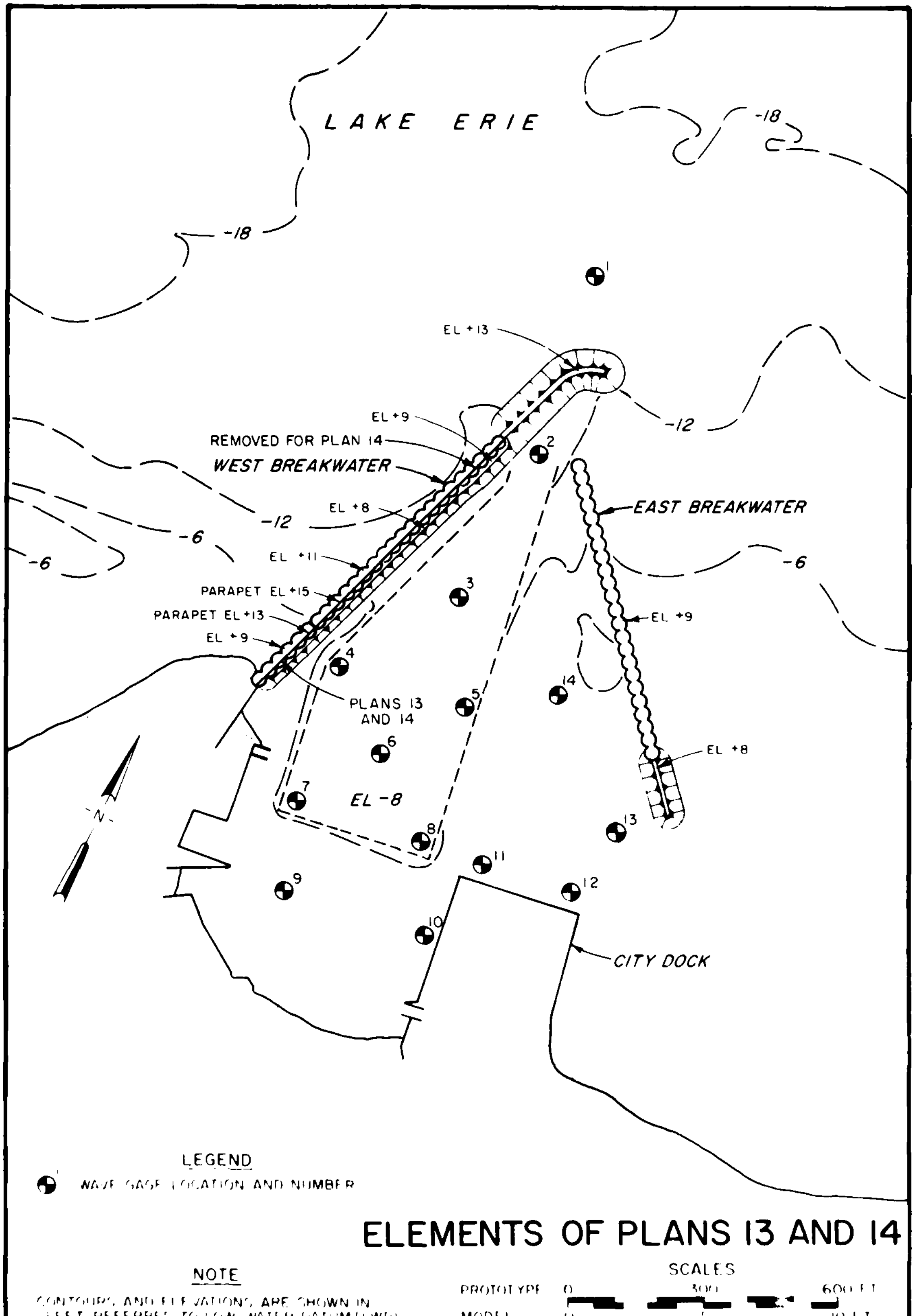


ELEMENTS OF PLANS 11 AND 12

NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

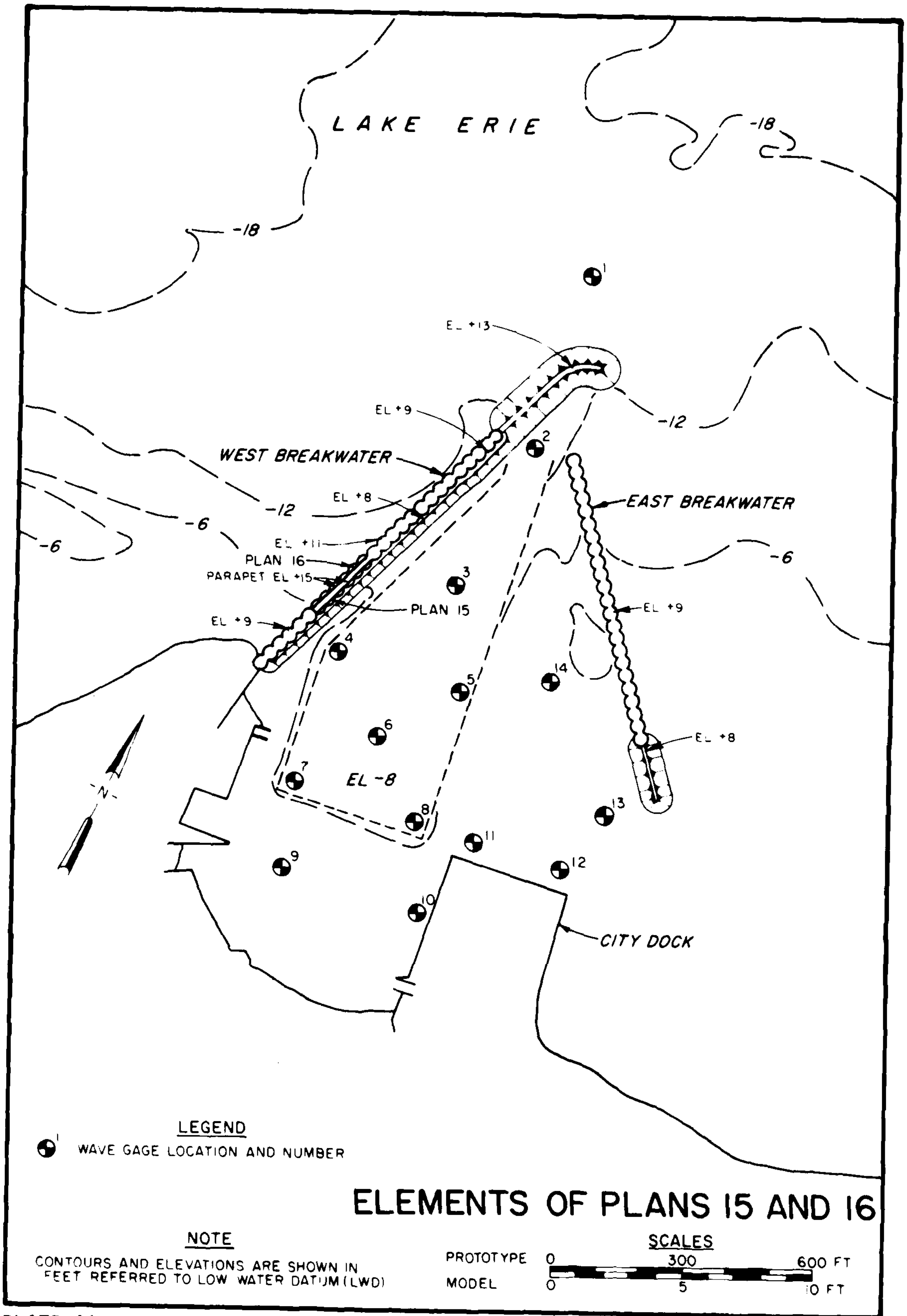

LAKE ERIE
-18
-18
EL +13
EL +9
WEST BREAKWATER
EL +8
-12
-12
-6
-6
-6
EL +11
EL +9
EAST BREAKWATER
EL +9
EL +8
EL -8
N
CITY DOCK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLAN 12
NOTE
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
SCALES
PROTOTYPE 0 300 600 FT
MODEL 0 5 10 FT



ELEMENTS OF PLANS 13 AND 14

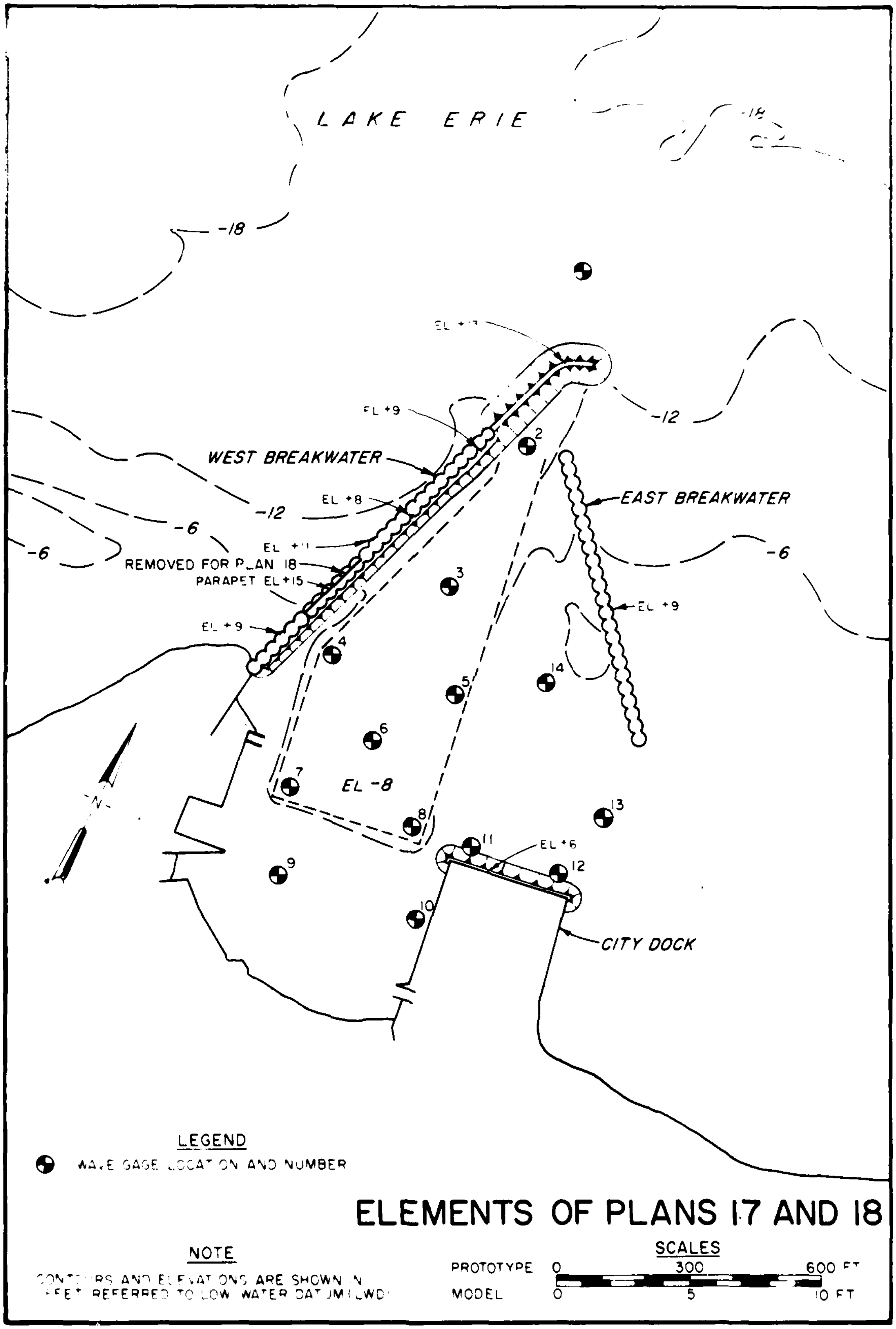
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)



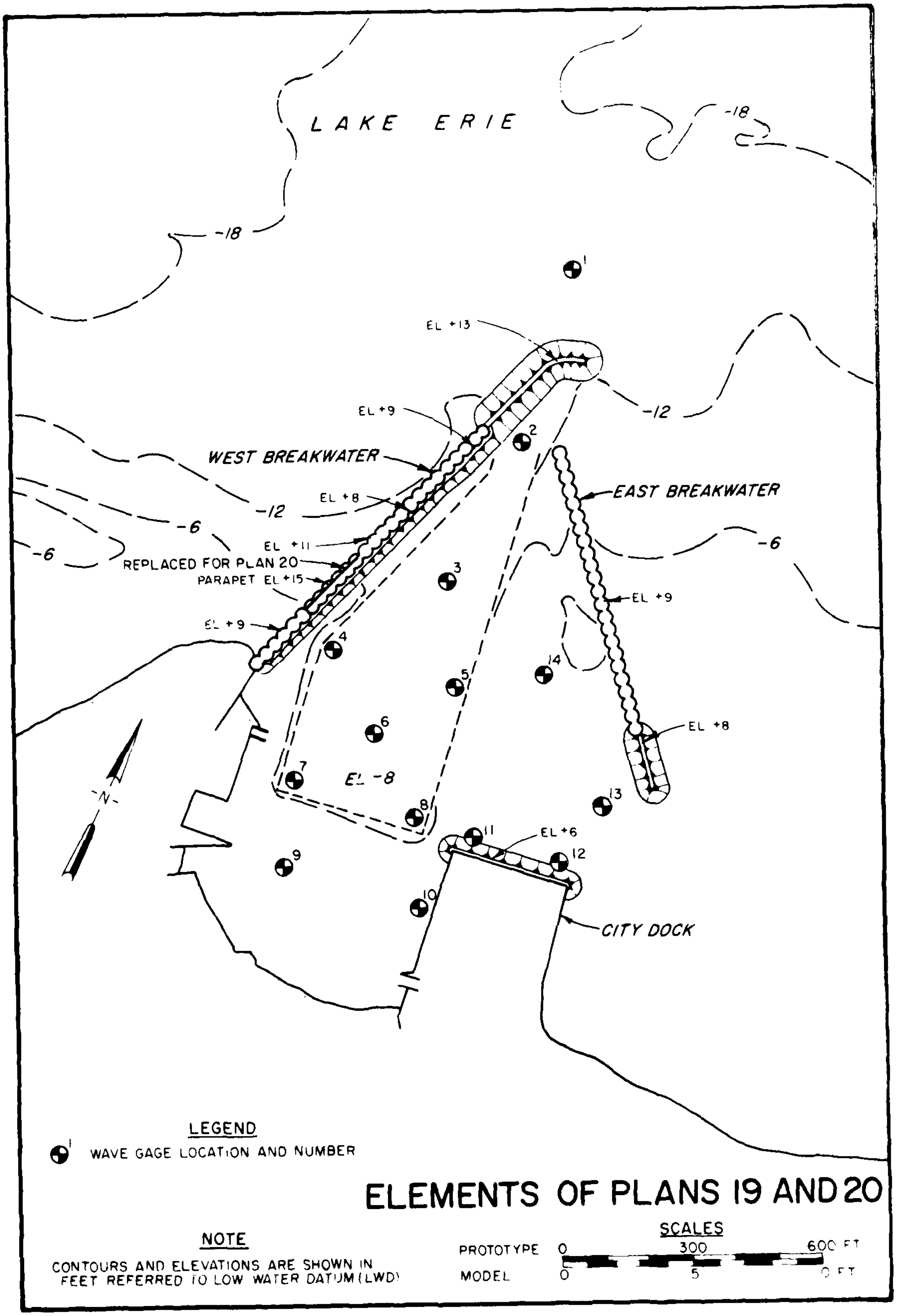
ELEMENTS OF PLANS 15 AND 16

PLATE 10



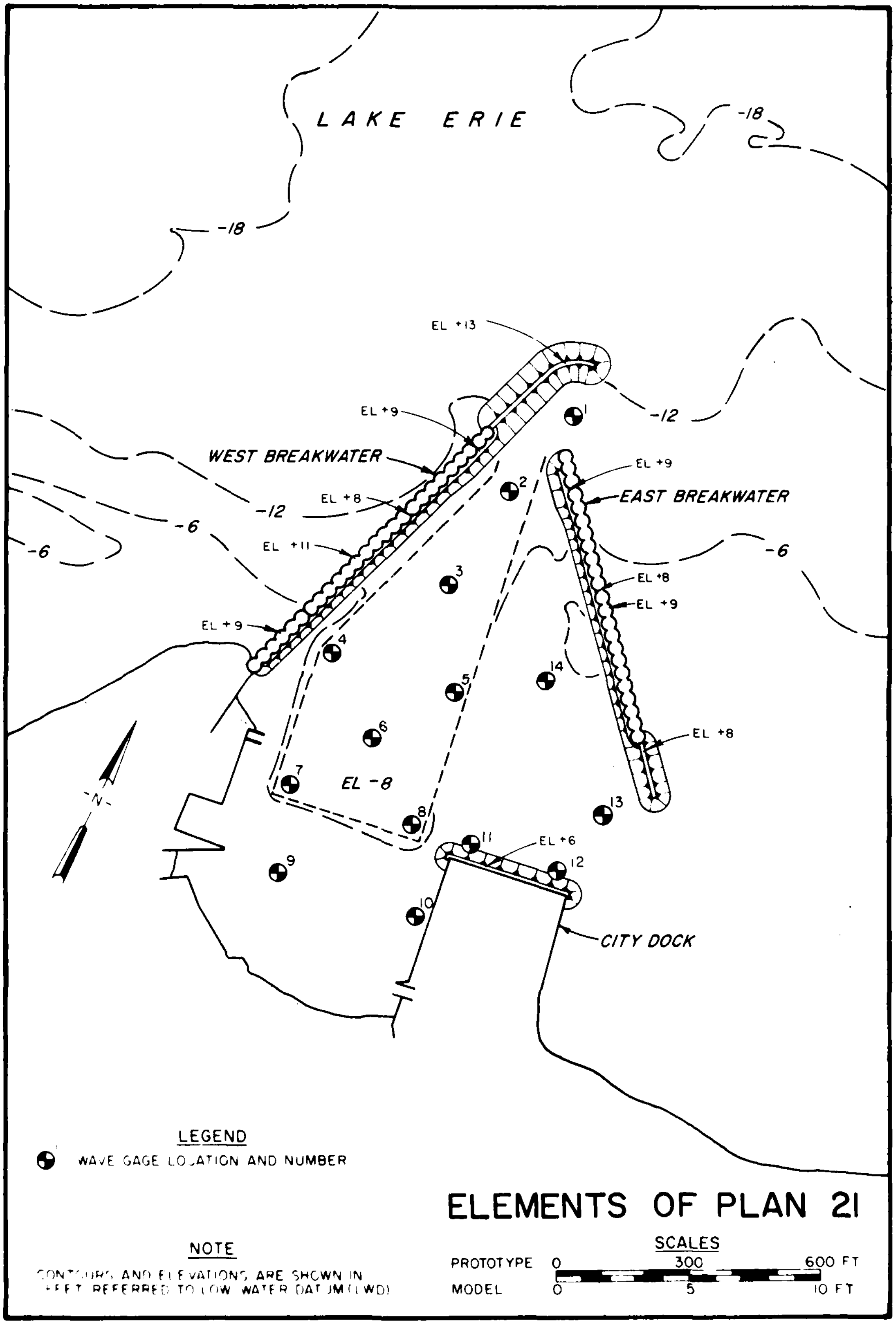
ELEMENTS OF PLANS 17 AND 18

PLATE 11

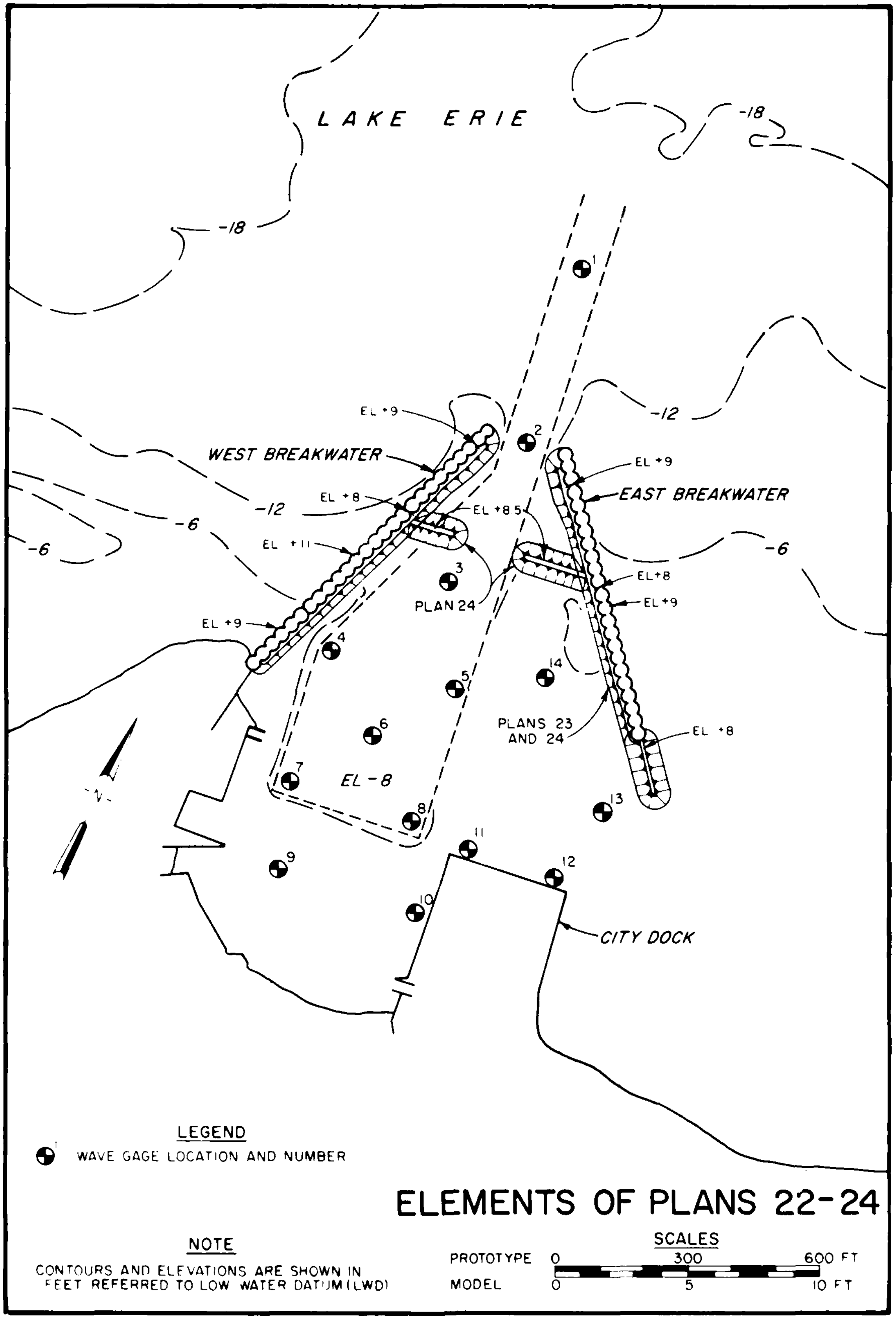


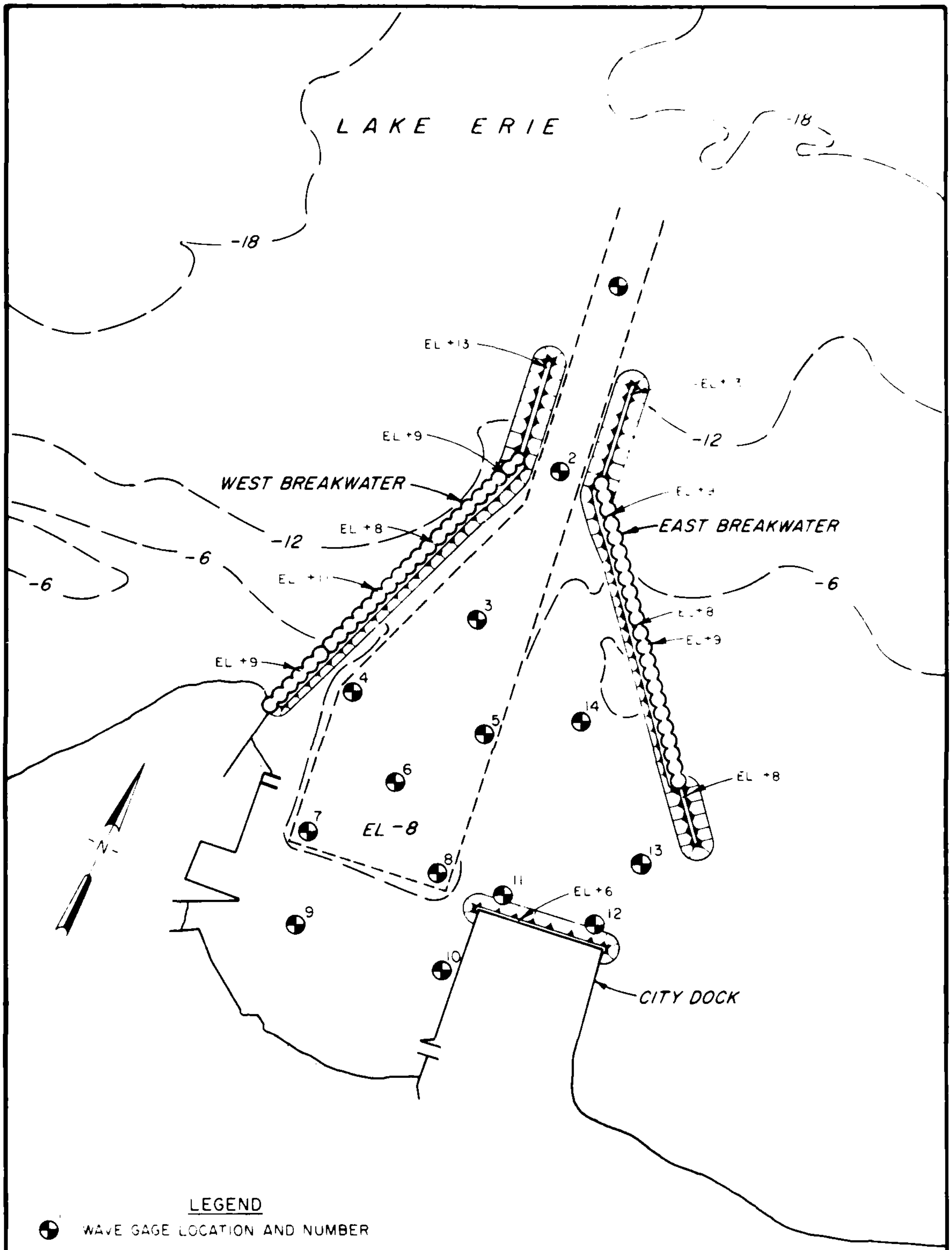
ELEMENTS OF PLANS 19 AND 20

PLATE 12



ELEMENTS OF PLAN 21


LAKE ERIE
-18
-18
-12
-12
-6
-6
-6
EL +9
WEST BREAKWATER
EL +8
EL +8.5
EL +11
EL +9
PLAN 24
EL +9
EAST BREAKWATER
EL+8
EL+9
PLANS 23 AND 24
EL +8
EL -8
CITY DOCK
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLANS 22-24
NOTE
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
SCALES
PROTOTYPE 0 300 600 FT
MODEL 0 5 10 FT



LEGEND

WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLAN 25

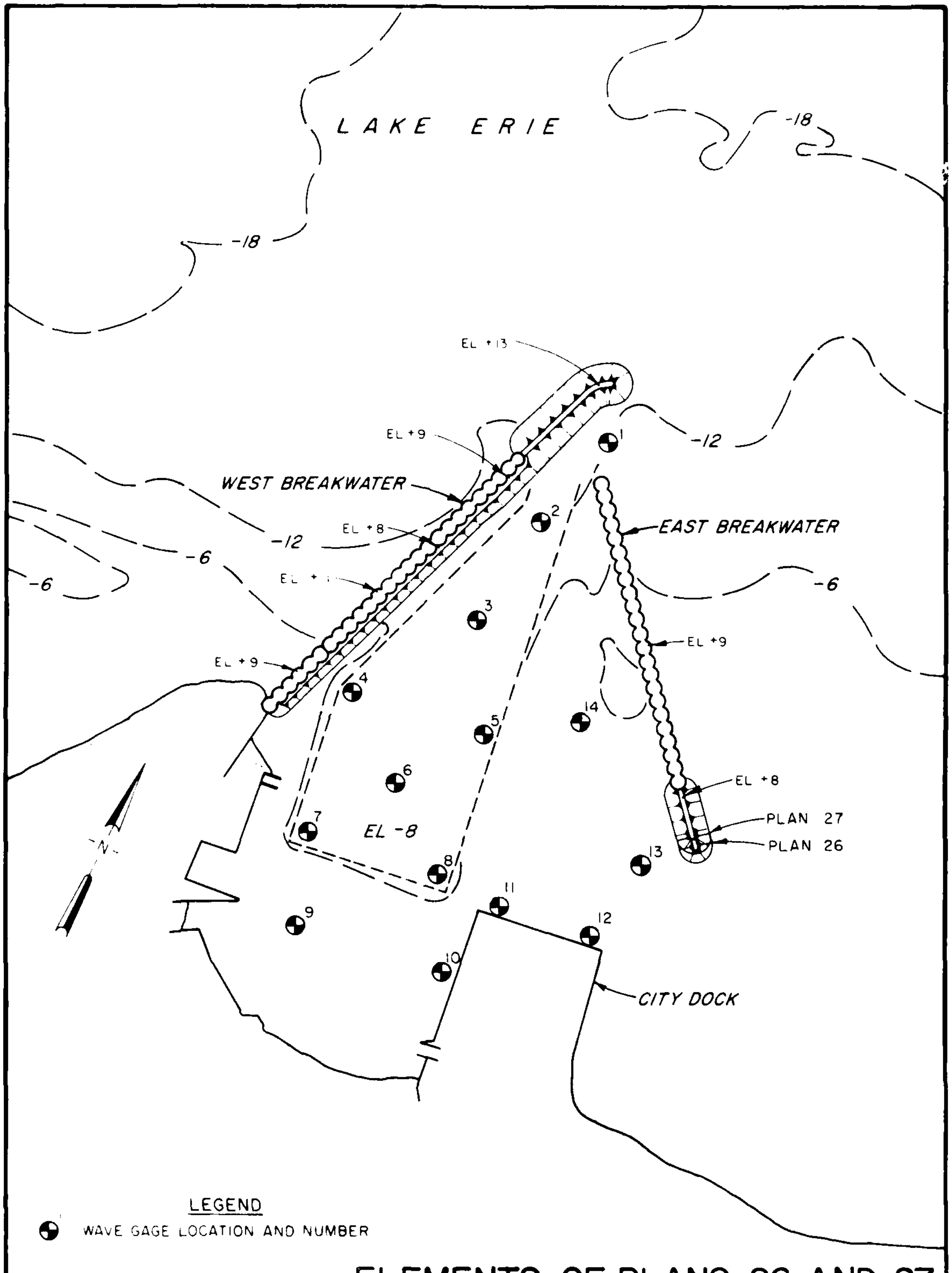
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT



ELEMENTS OF PLANS 26 AND 27

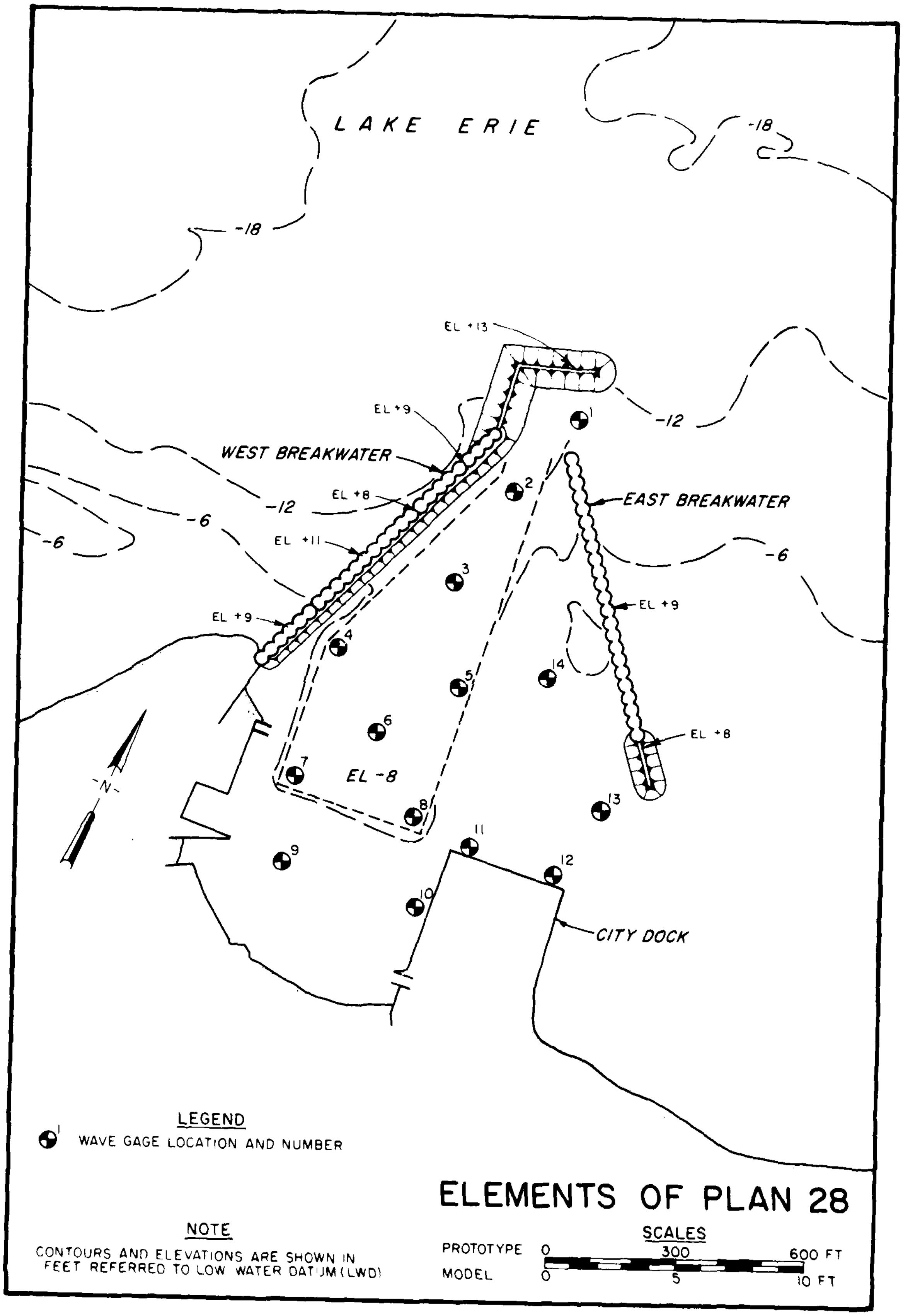
NOTE

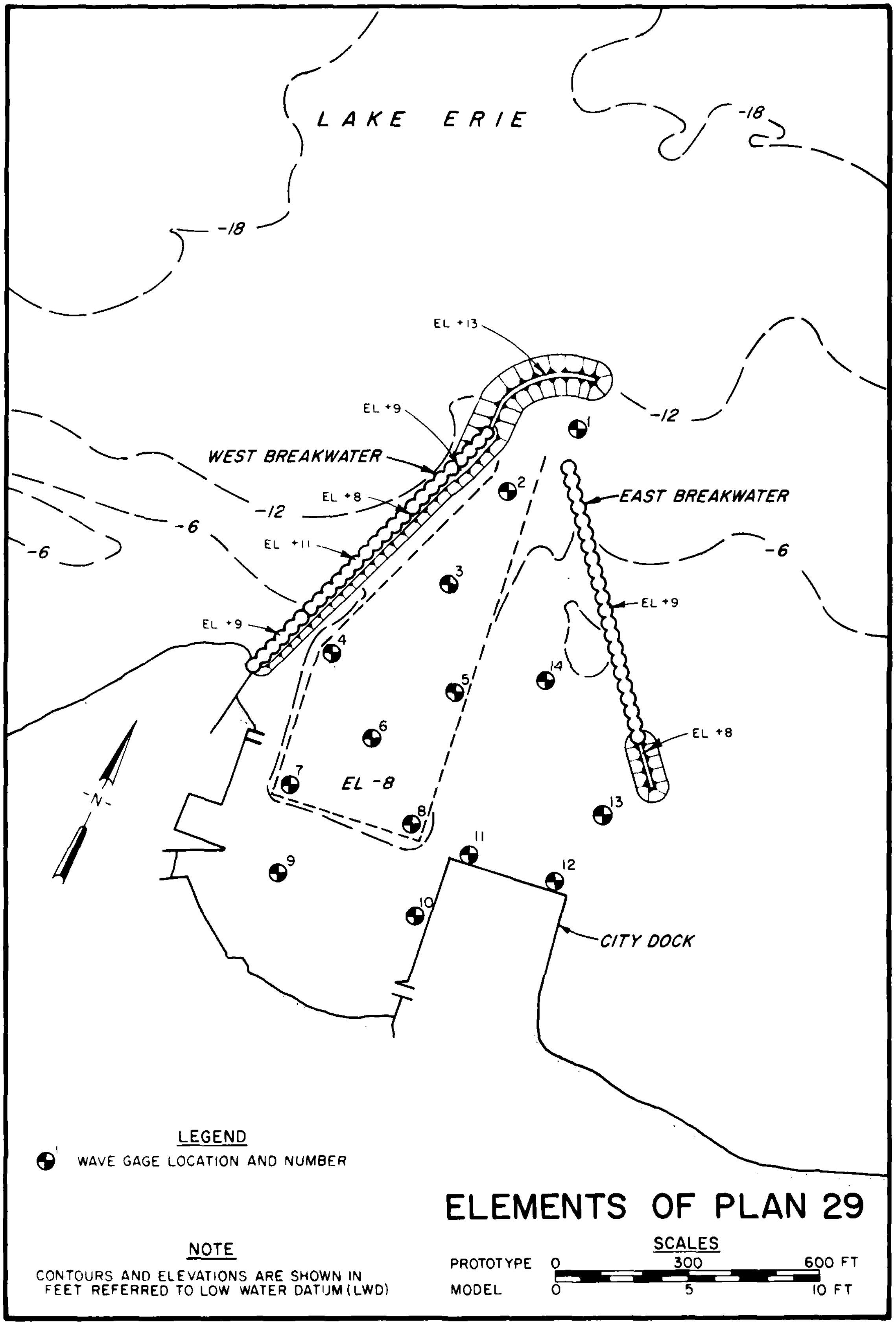
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

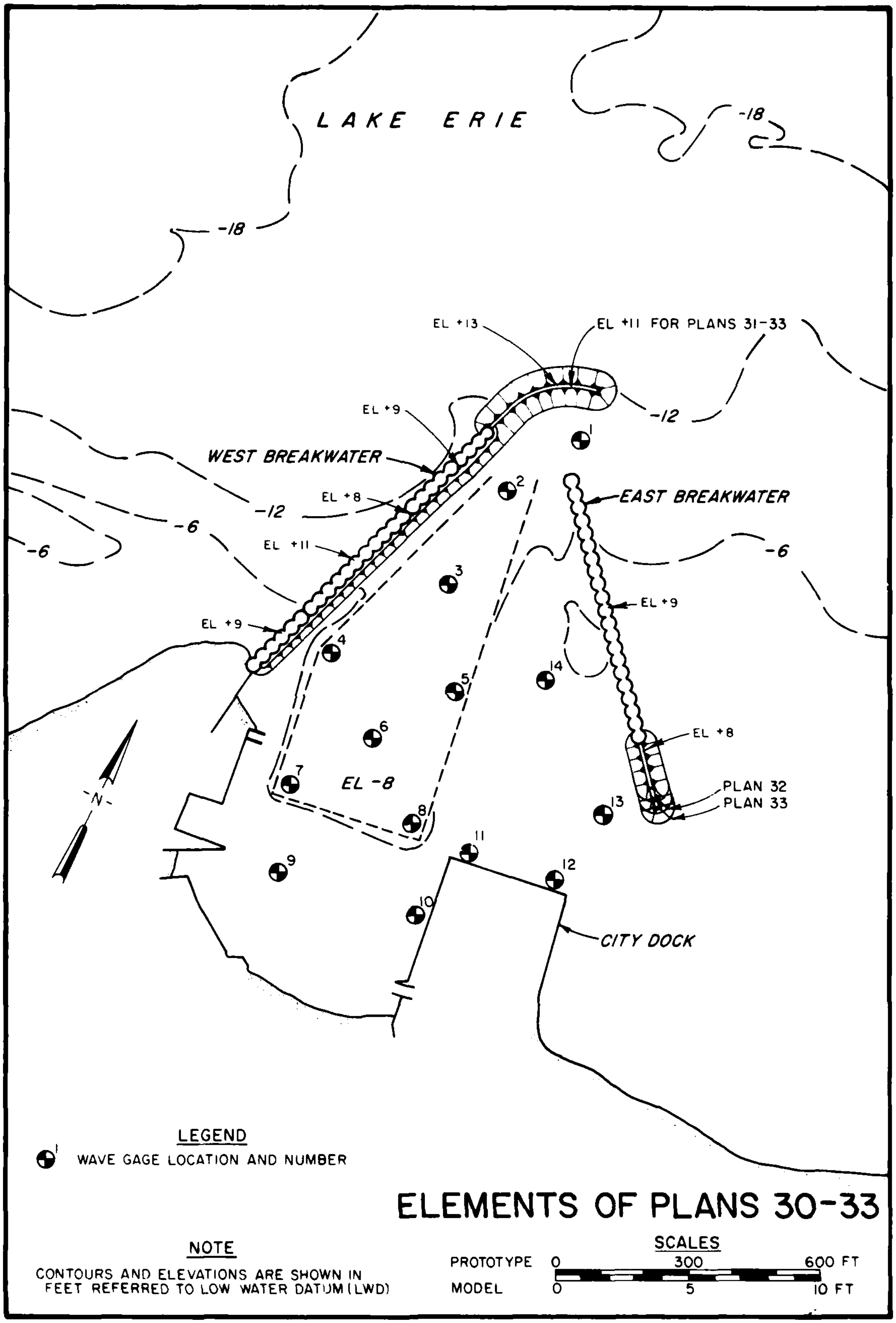
MODEL 0 5 10 FT


LAKE ERIE
-18
-18
-12
-12
-6
-6
-6
EL +13
EL +9
WEST BREAKWATER
EL +8
EL +11
EL +9
EAST BREAKWATER
EL +9
EL +8
EL -8
CITY DOCK
N
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLAN 28
NOTE
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
SCALES
PROTOTYPE 0 300 600 FT
MODEL 0 5 10 FT

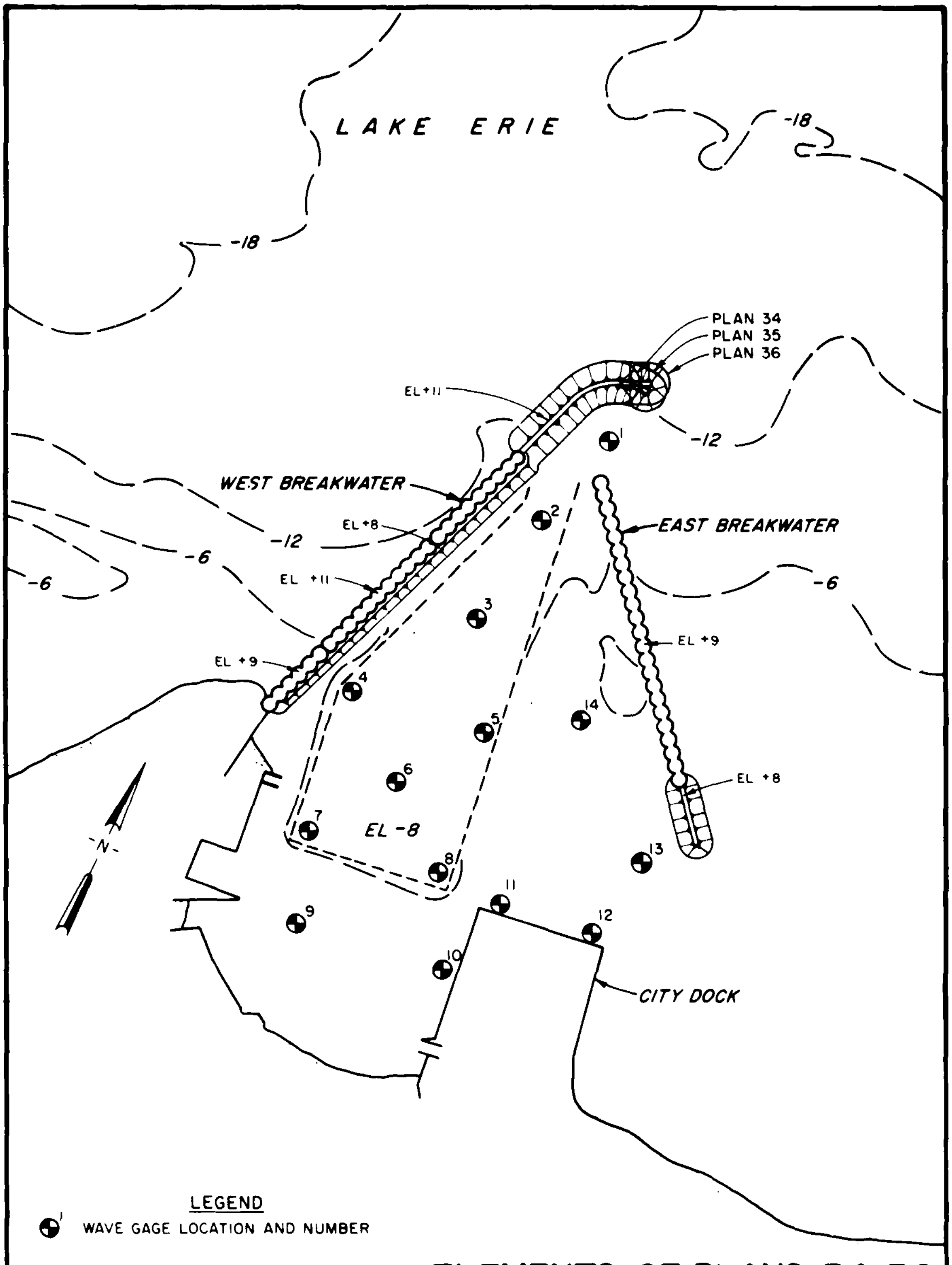


ELEMENTS OF PLAN 29

PLATE 18



ELEMENTS OF PLANS 30-33



LEGEND

WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLANS 34-36

NOTE

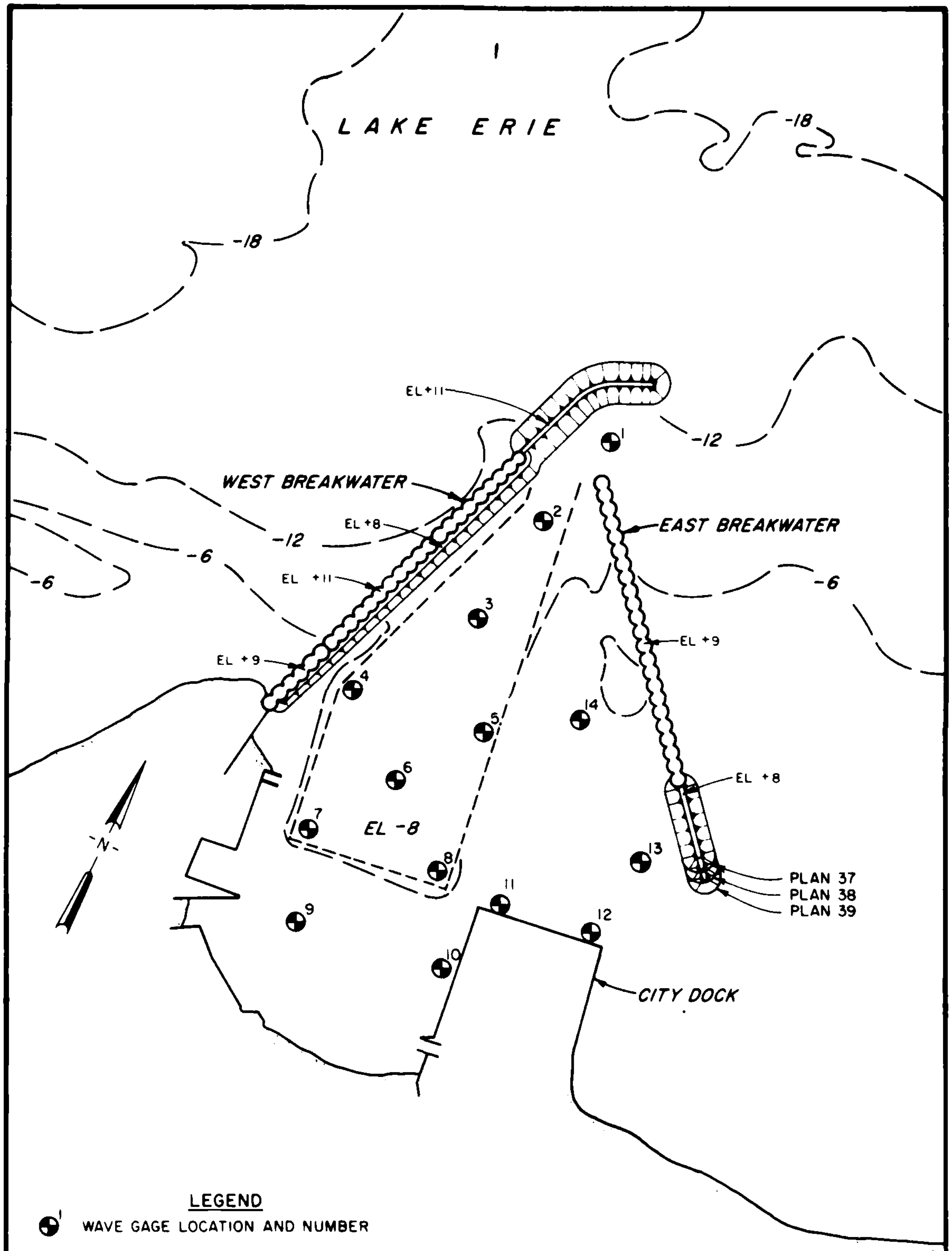
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT

PLATE 20



ELEMENTS OF PLANS 37-39

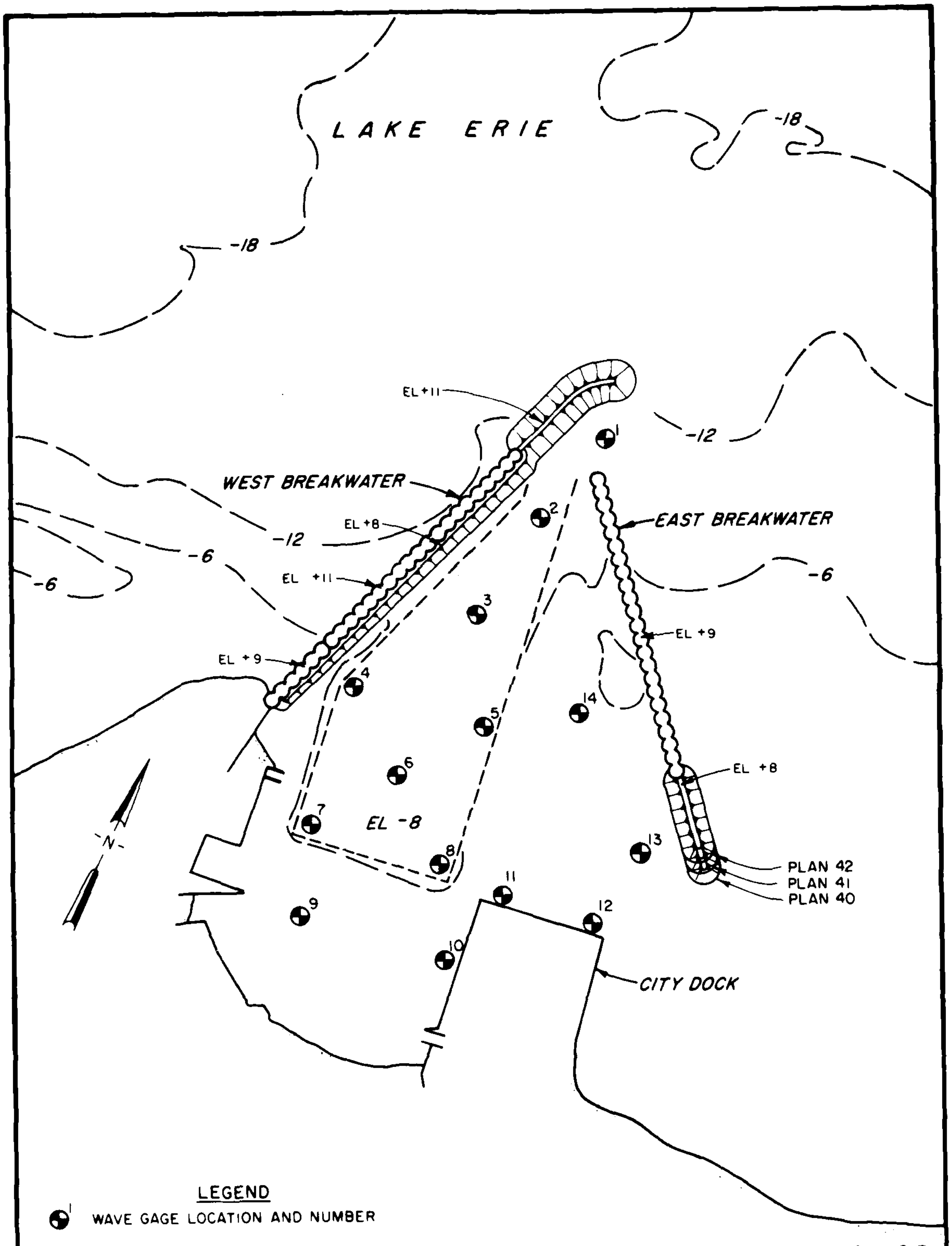
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT



LEGEND

WAVE GAGE LOCATION AND NUMBER

ELEMENTS OF PLANS 40-42

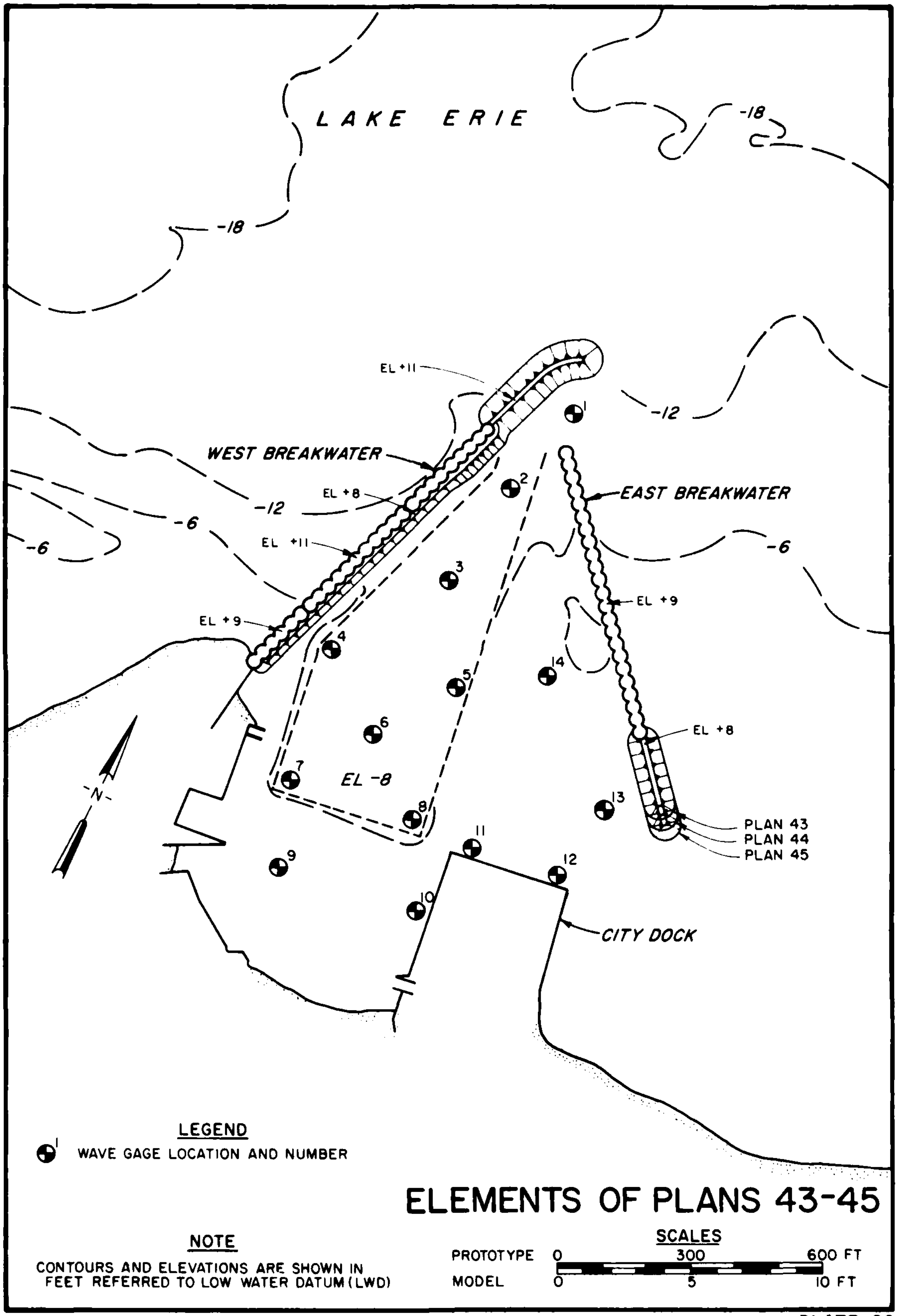
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

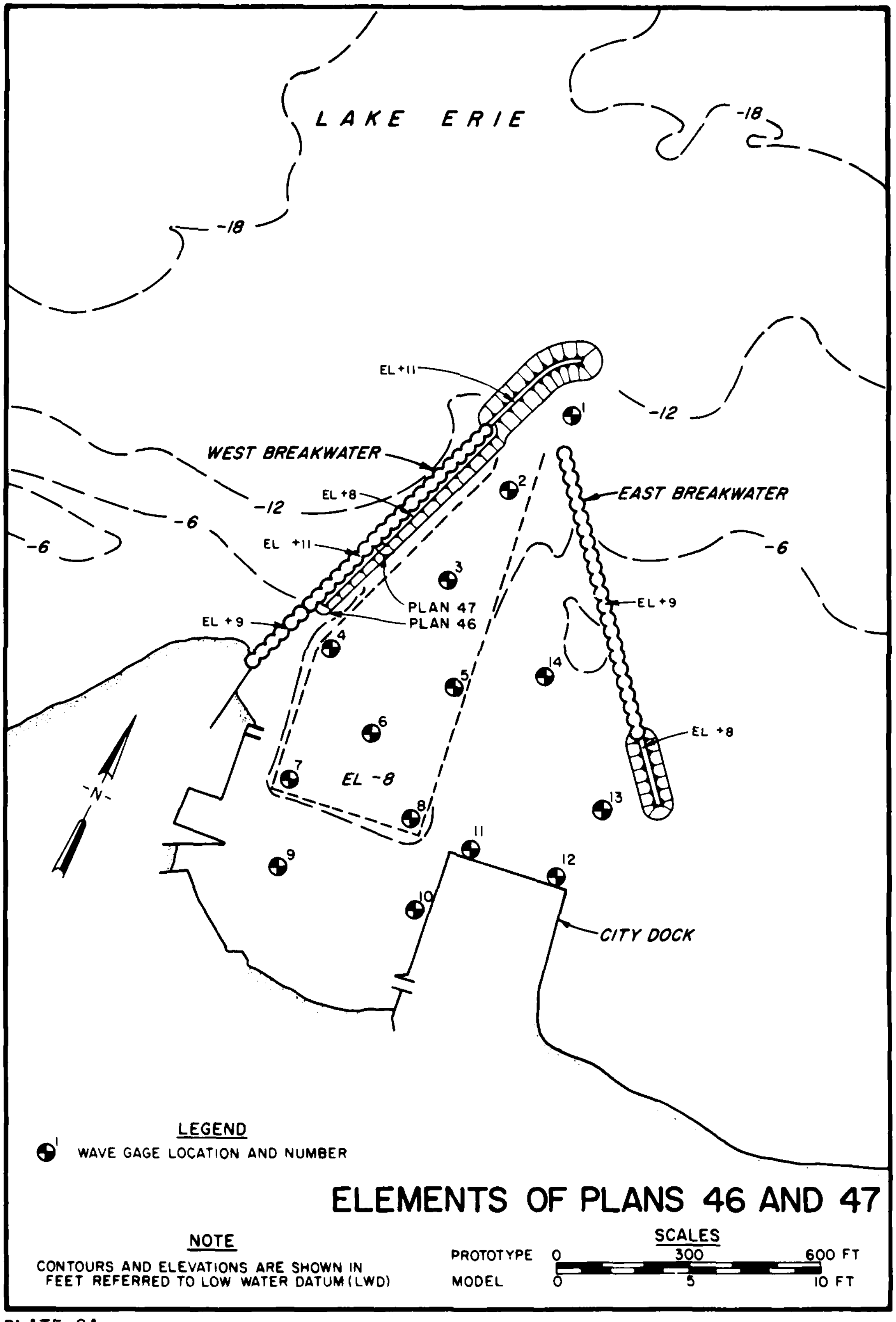
SCALES

PROTOTYPE 0 300 600 FT

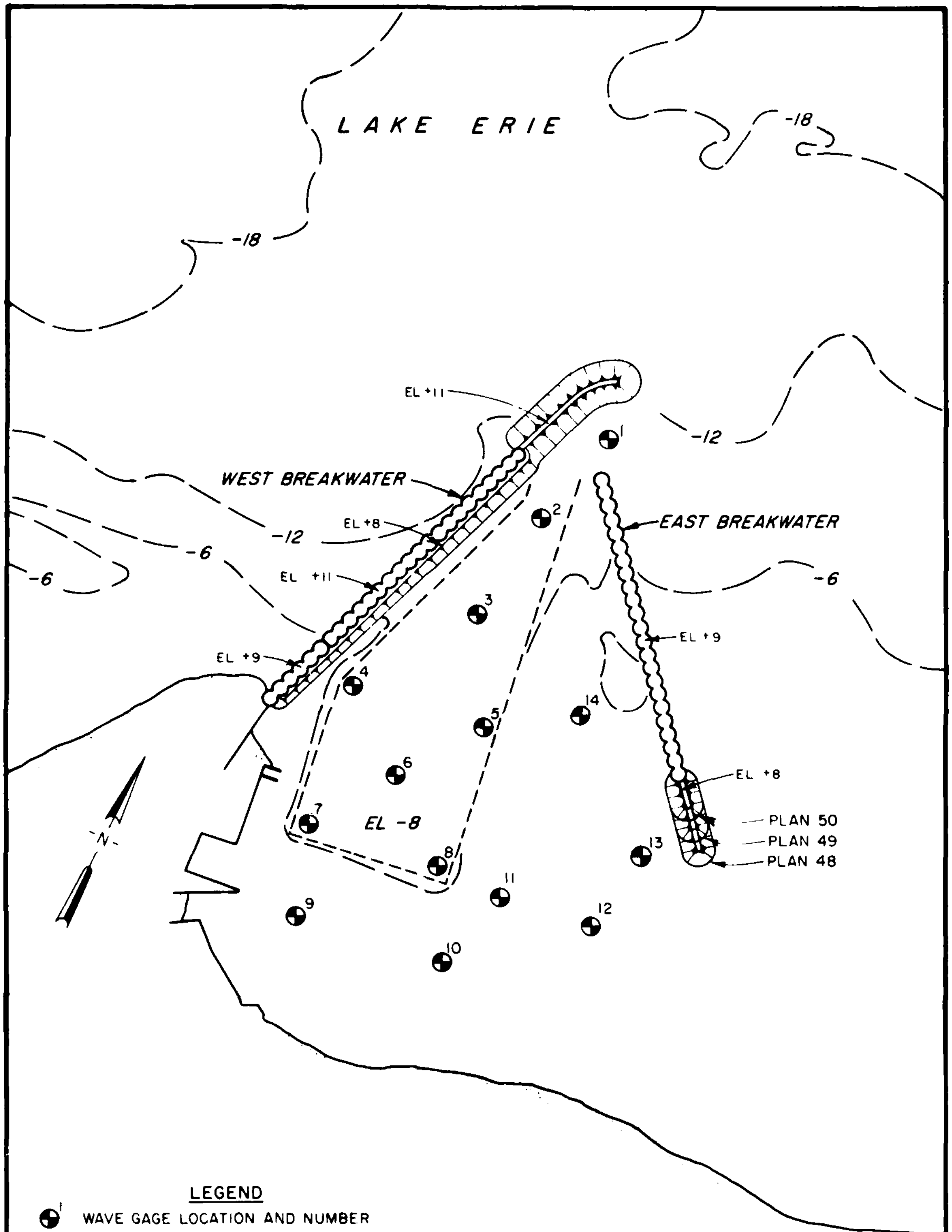
MODEL 0 5 10 FT



ELEMENTS OF PLANS 43-45



ELEMENTS OF PLANS 46 AND 47



ELEMENTS OF PLANS 48-50

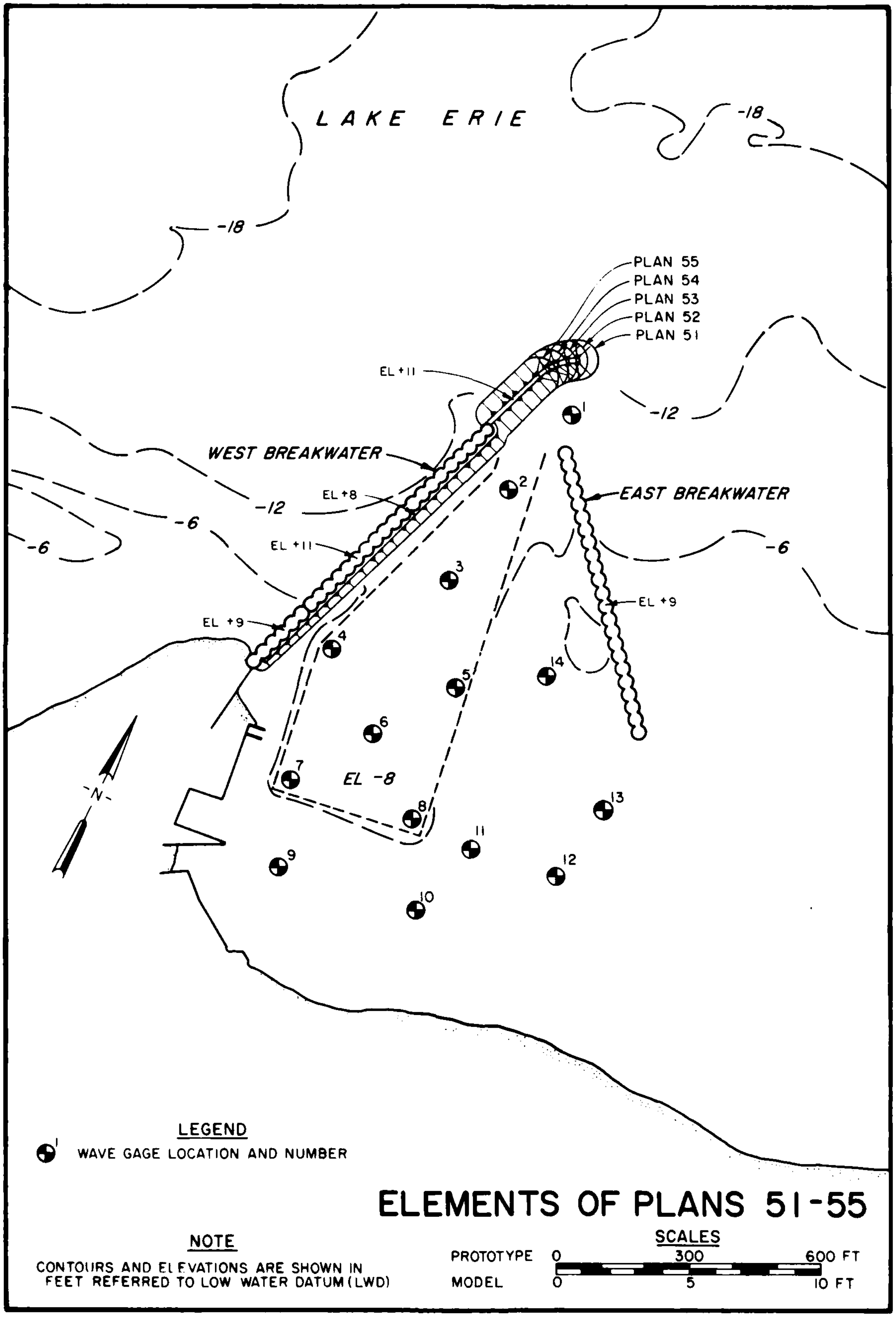
NOTE

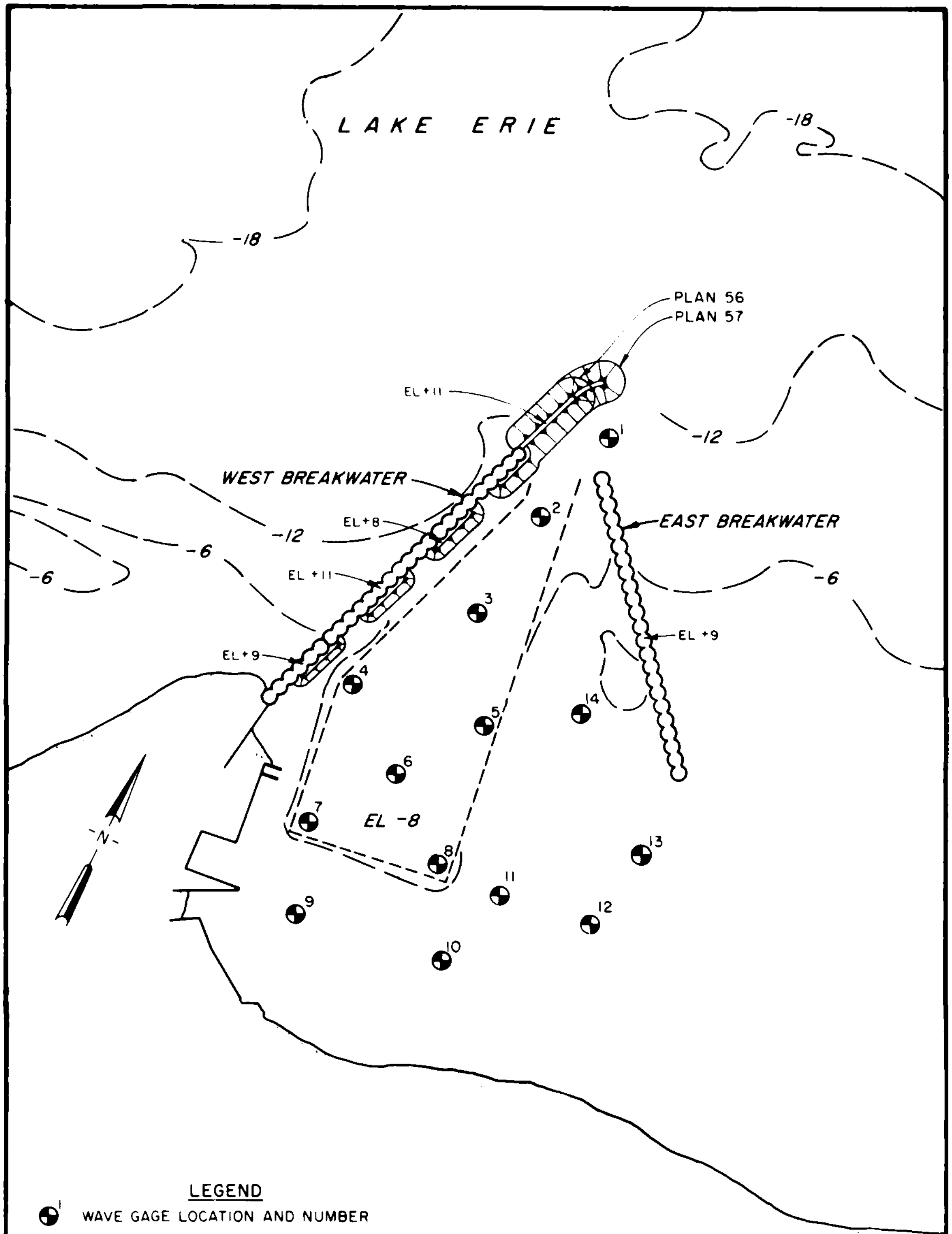
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT


LAKE ERIE
-18
-18
PLAN 55
PLAN 54
PLAN 53
PLAN 52
PLAN 51
EL +11
-12
WEST BREAKWATER
EAST BREAKWATER
EL +8
-12
-6
-6
-6
EL +11
EL +9
EL +9
N
EL -8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLANS 51-55
NOTE
CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)
SCALES
PROTOTYPE 0 300 600 FT
MODEL 0 5 10 FT



ELEMENTS OF PLANS 56 AND 57

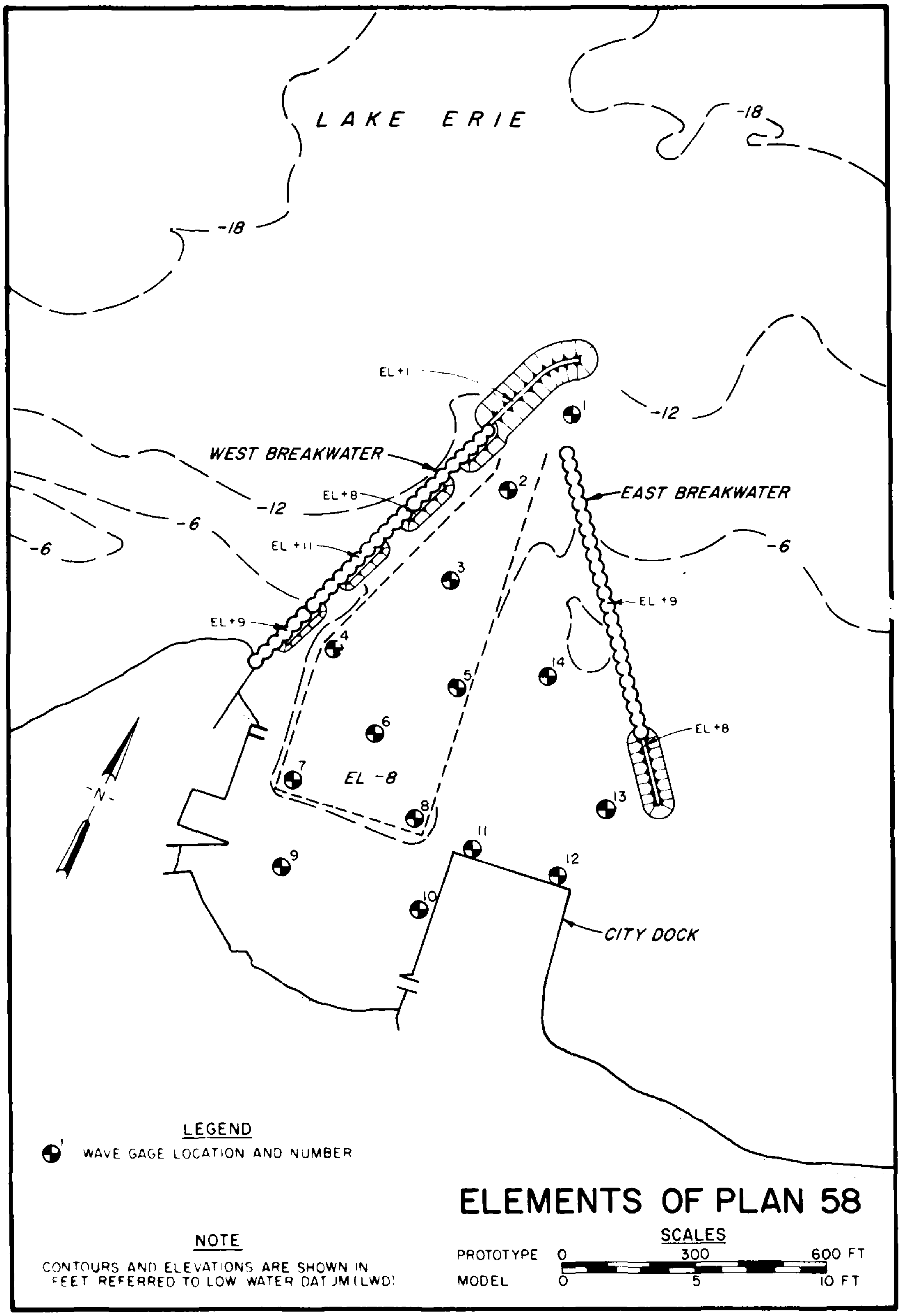
NOTE

CONTOURS AND ELEVATIONS ARE SHOWN IN FEET REFERRED TO LOW WATER DATUM (LWD)

SCALES

PROTOTYPE 0 300 600 FT

MODEL 0 5 10 FT



ELEMENTS OF PLAN 58

APPENDIX A: WAVE REFRACTION ANALYSIS FOR BARCELONA HARBOR

1. Prior to the hydraulic model investigation of Barcelona Harbor, a wave refraction analysis was conducted at the US Army Engineer Waterways Experiment Station (WES) to determine the shallow-water wave height and the 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 (1967)* and modified by WES in 1971. All computations and plotting were done using an Electronic Associates, Inc. (EAI) Pacer 100 minicomputer and Versatec electrostatic 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 given 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 that 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. Since previous research at WES by Whalin (1971, 1972) 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 0.45 were selected as being reasonable values.

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* See References at the end of main text.

3. Refraction diagrams for Barcelona Harbor were produced from a rectangular depth grid (8.0 miles by 5.8 miles) which paralleled the shoreline in the vicinity of the project area and extended lakeward beyond the deepwater wave data gage location (Plate A1) from which wave characteristics were obtained (Resio and Vincent 1976a). Limits of the depth grid used are shown in Plate A1. The grid spacing was 400 ft and depths were taken from the latest lake survey charts. Storm conditions were represented by superimposing a water level of 5.0 ft on the depth grid.

4. Wave orthogonals were produced for 5-, 6-, 7-, 8-, 9-, 10-, and 11-sec waves from west; 5-, 6-, 7-, 8-, and 9-sec waves from northwest and north; and 5-, 6-, 7-, and 8-sec waves from northeast. 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 four 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 0.98, 0.95, 0.92, 0.91, 0.92, 0.93 and 0.94 for 5-, 6-, 7-, 8-, 9-, 10-, and 11-sec wave periods, respectively, were computed for a 55-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 secured at the model contours for each wave period, four wave generator positions were selected for model testing representing the various deepwater directions. The following tabulation shows the deepwater directions and the corresponding shallow-water test directions.

Deepwater Direction, Azimuth, deg	Corresponding Shallow-Water Test Direction, Azimuth, deg
West, 270	287
Northwest, 315	316
North, 360	347
Northeast, 45	20

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 direction.

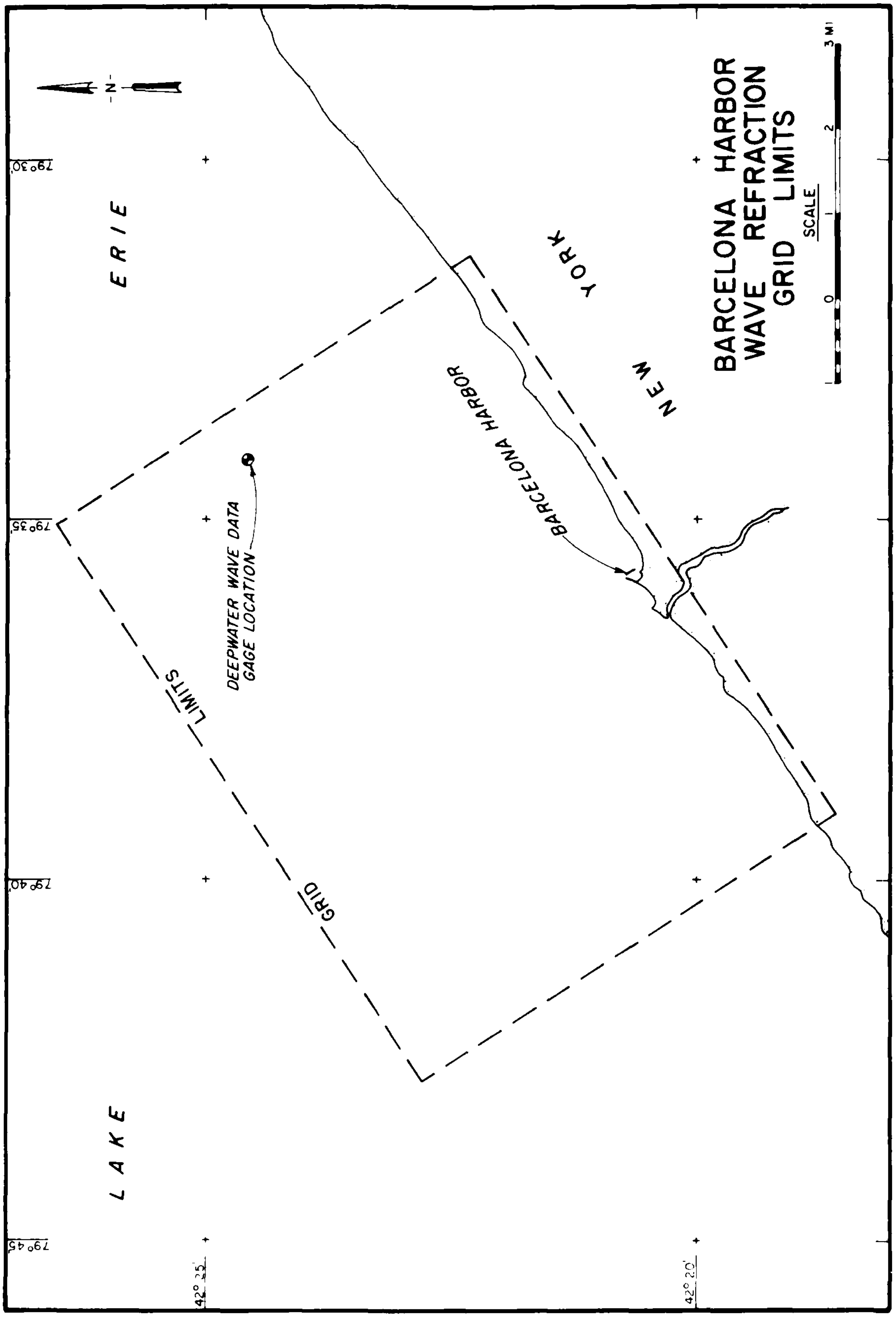
Table A1

Summary of Refraction and Shoaling Analysis for Barcelona Harbor

Deepwater Direction, deg	Wave Period sec	Shallow-Water Azimuth deg	Refraction* Coefficient	Shoaling** Coefficient	Wave-Height Adjustment Factor
West (270)	5	276.4	0.97	0.98	0.95
	6	281.8	0.97	0.95	0.92
	7	285.6	1.00	0.92	0.92
	8	288.5	1.09	0.91	0.99
	9	291.4	1.07	0.92	0.98
	10	292.3	1.12	0.93	1.04
	11	292.5	1.14	0.94	1.07
NW (315)	5	315.1	1.00	0.98	0.98
	6	315.2	1.01	0.95	0.96
	7	315.9	1.01	0.92	0.93
	8	315.9	1.00	0.91	0.91
	9	316.1	0.98	0.92	0.90
North (360)	5	354.2	0.98	0.98	0.96
	6	349.5	0.97	0.95	0.92
	7	345.9	0.97	0.92	0.89
	8	344.0	0.98	0.91	0.89
	9	341.9	0.96	0.92	0.88
NE (45)	5	27.7	0.80	0.98	0.78
	6	21.2	0.80	0.95	0.76
	7	16.1	0.76	0.92	0.70
	8	12.8	0.81	0.91	0.74

* At approximate locations of wave generator in model.

** At 55-ft depth (50-ft pit elevation with 5-ft storm conditions superimposed).



BARCELONA HARBOR
WAVE REFRACTION
GRID LIMITS
SCALE
0
1
2
3 MI
N
LAKE ERIE
NEW YORK
BARCELONA HARBOR
DEEPWATER WAVE DATA
GAGE LOCATION
GRID LIMITS
79°30'
79°35'
79°40'
79°45'
42°25'
42°20'

PLATE A1

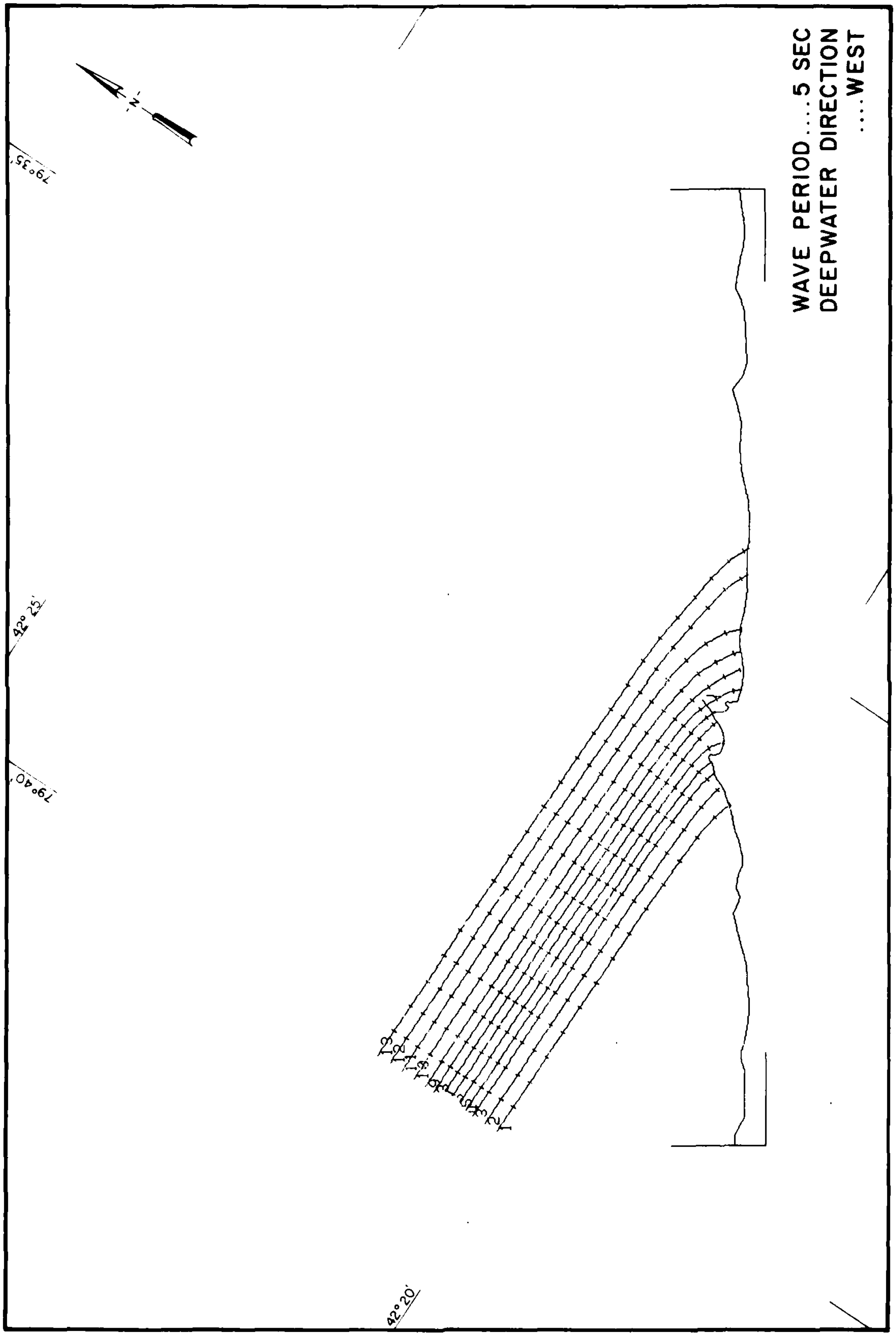

WAVE PERIOD....5 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A2

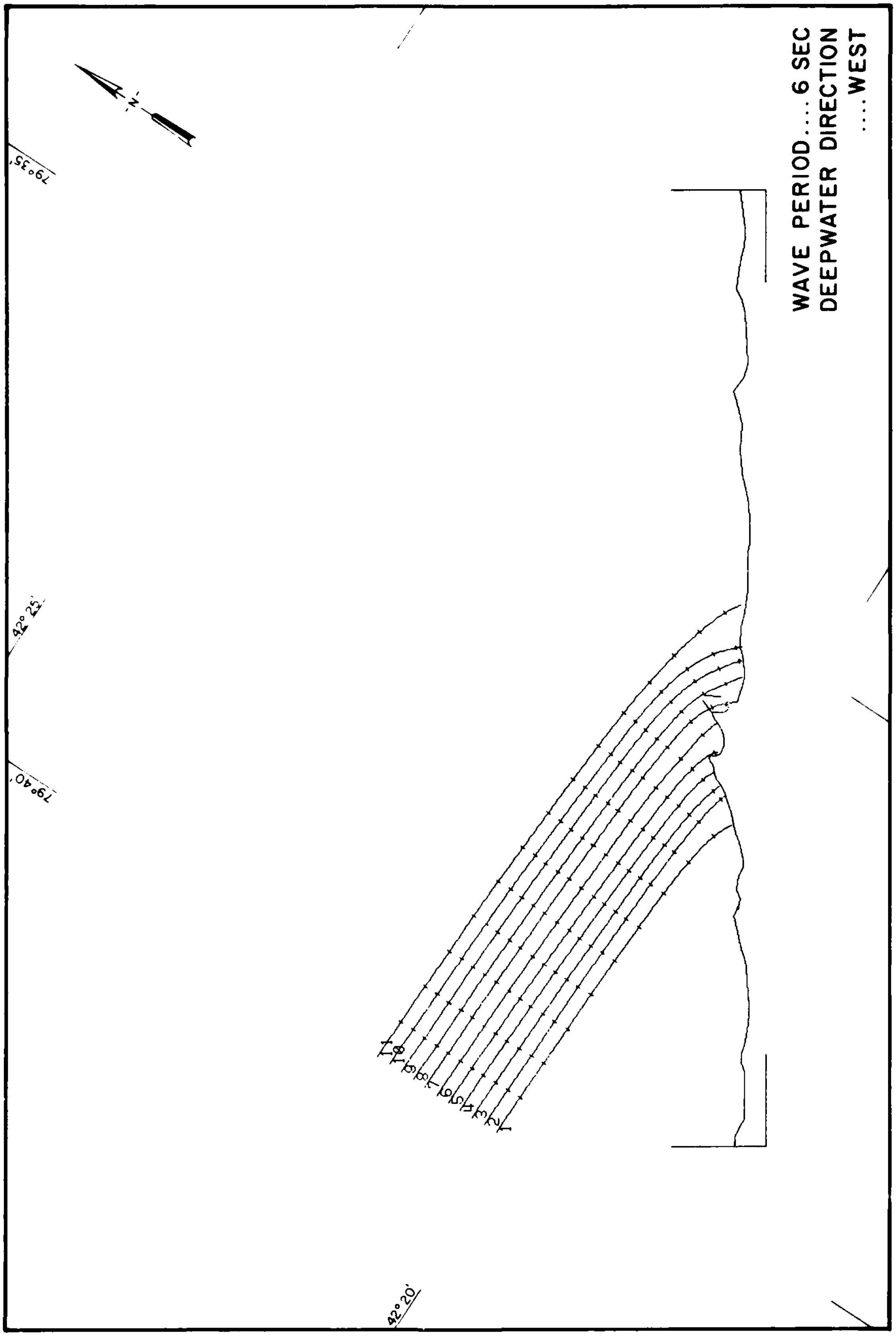
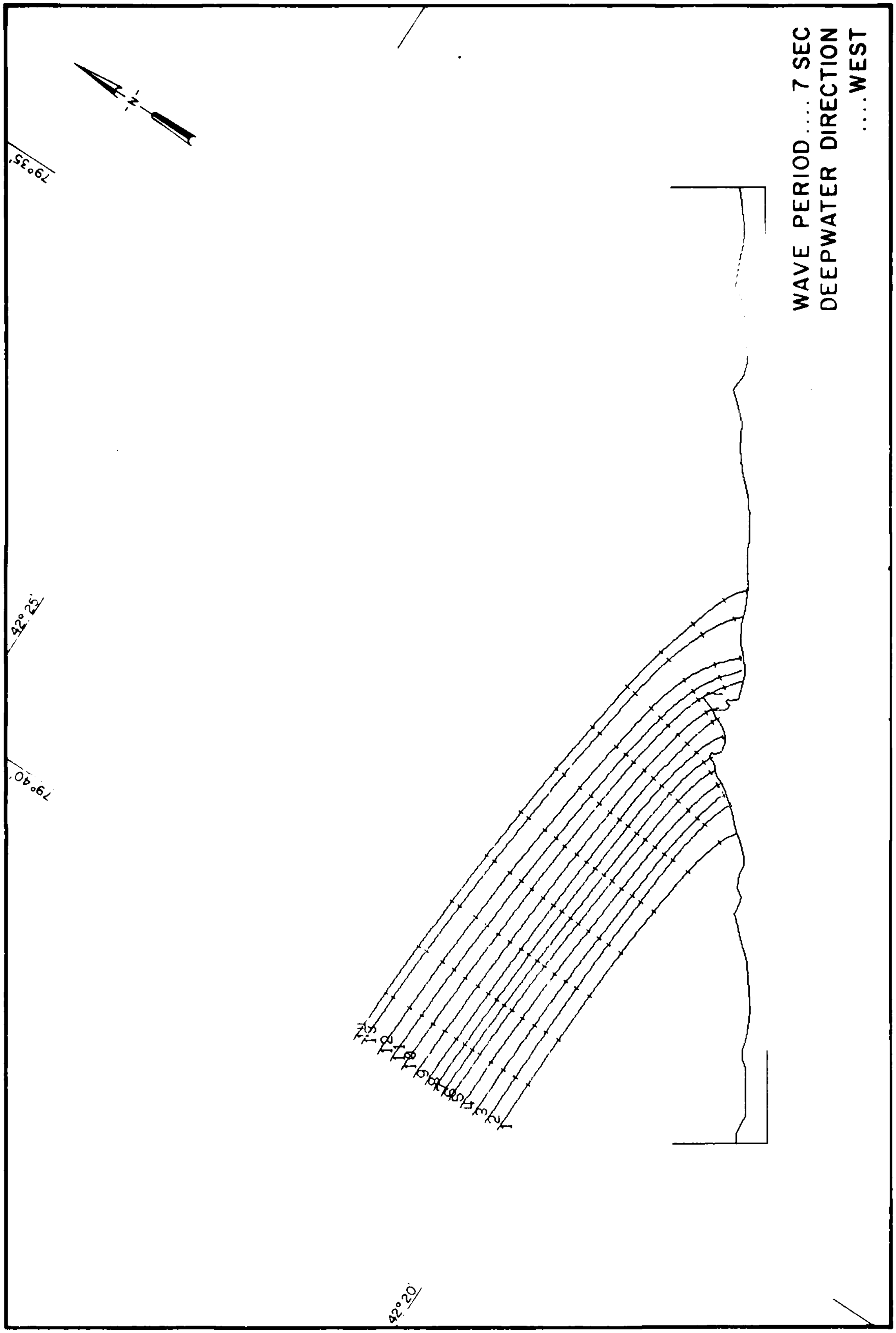

WAVE PERIOD....6 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A3



WAVE PERIOD.... 7 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A4

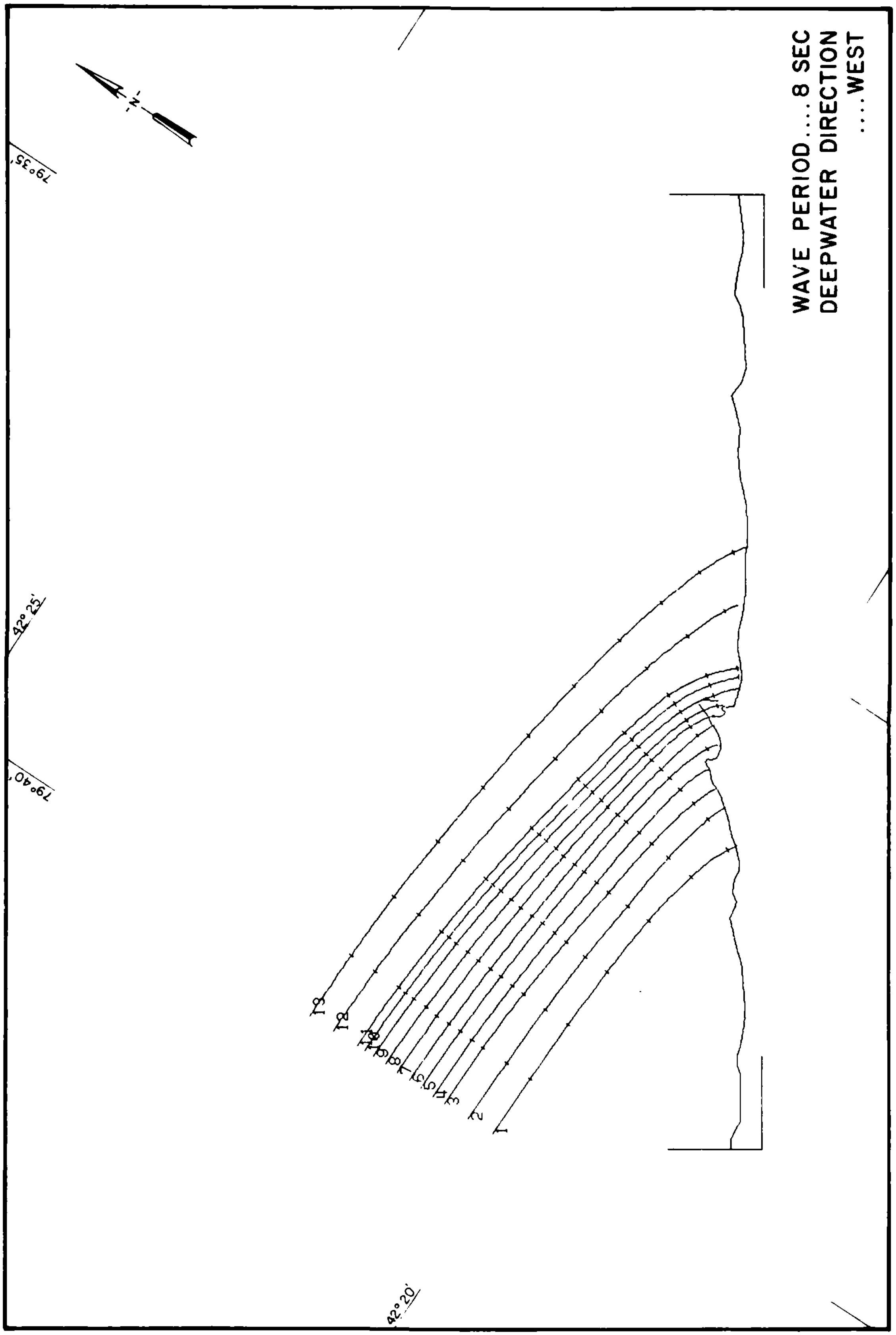
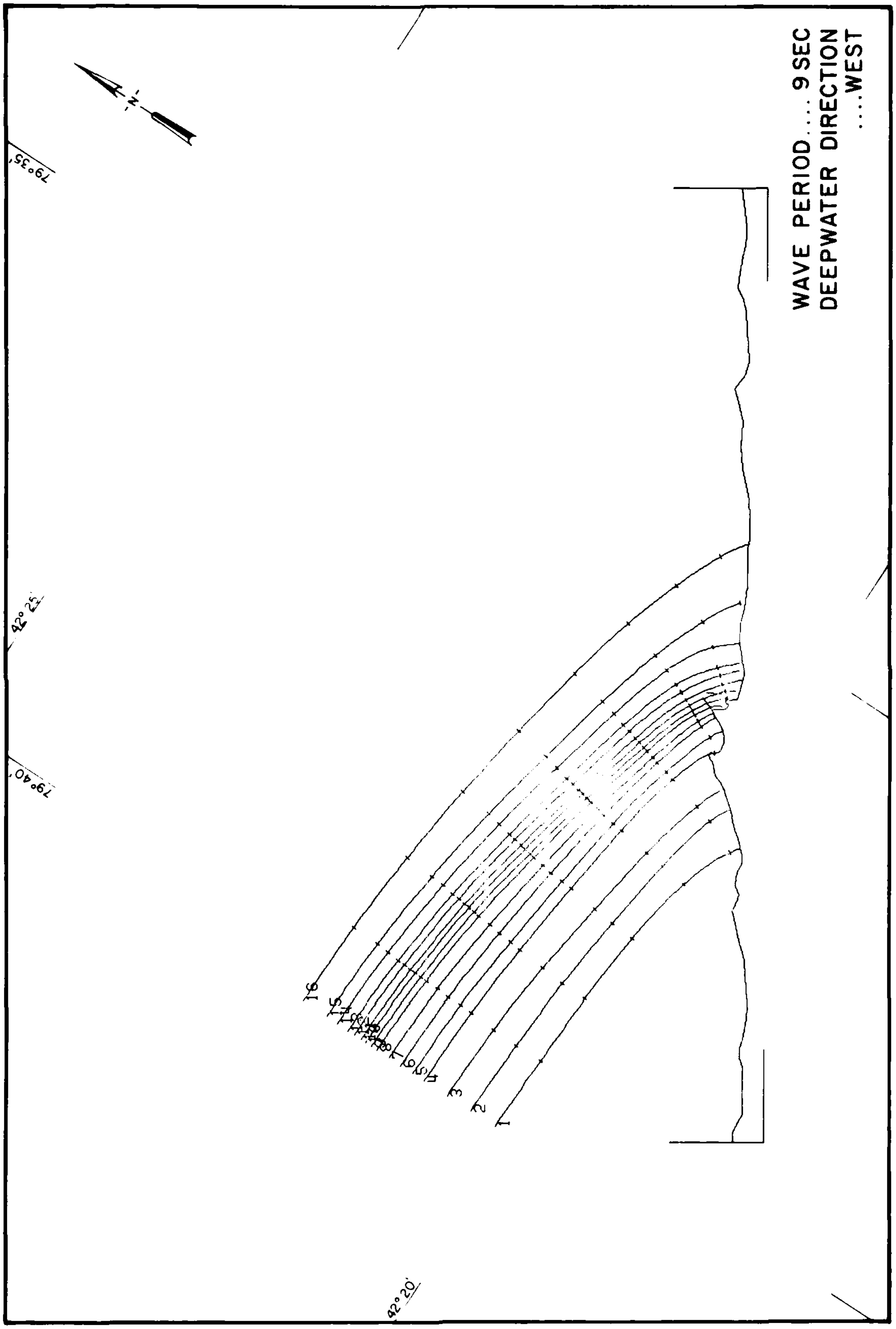

WAVE PERIOD....8 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
79°40'
42°25'
42°20'

PLATE A5



WAVE PERIOD.... 9 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A6

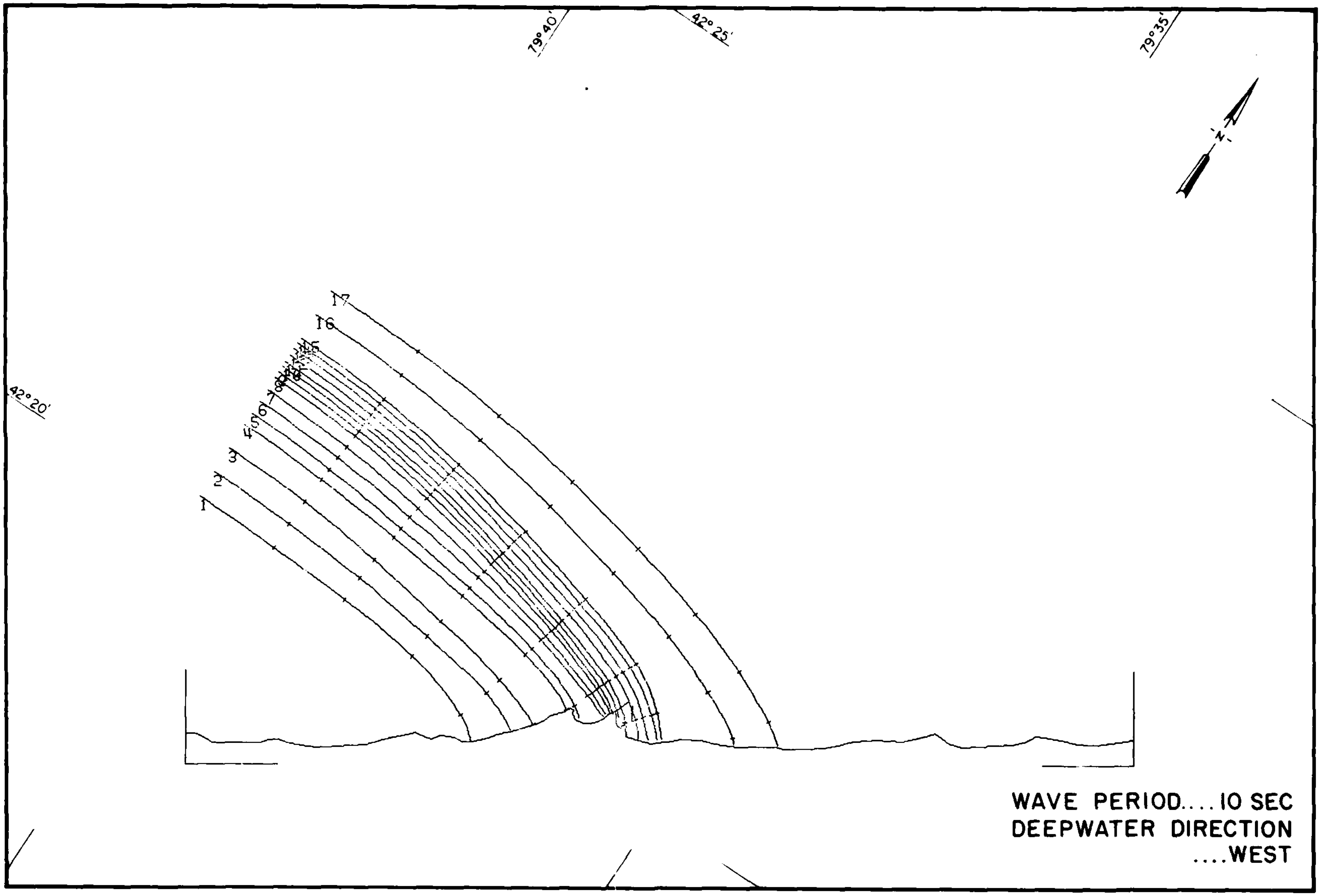

79°40'
42°25'
79°35'
N
42°20'
1
2
3
4
5
6
16
17
WAVE PERIOD....10 SEC
DEEPWATER DIRECTION
....WEST

PLATE A7

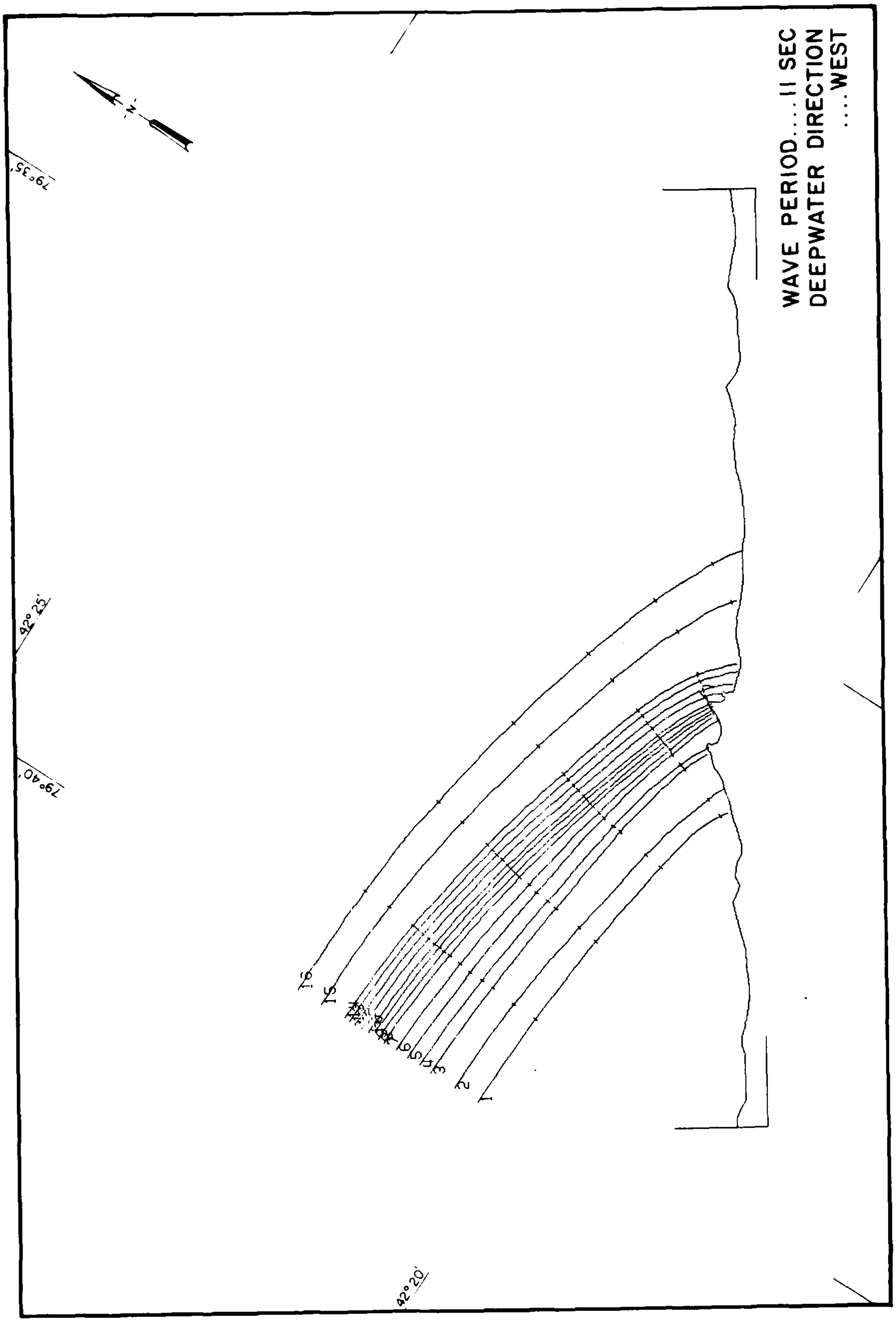

WAVE PERIOD....11 SEC
DEEPWATER DIRECTION
....WEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A8

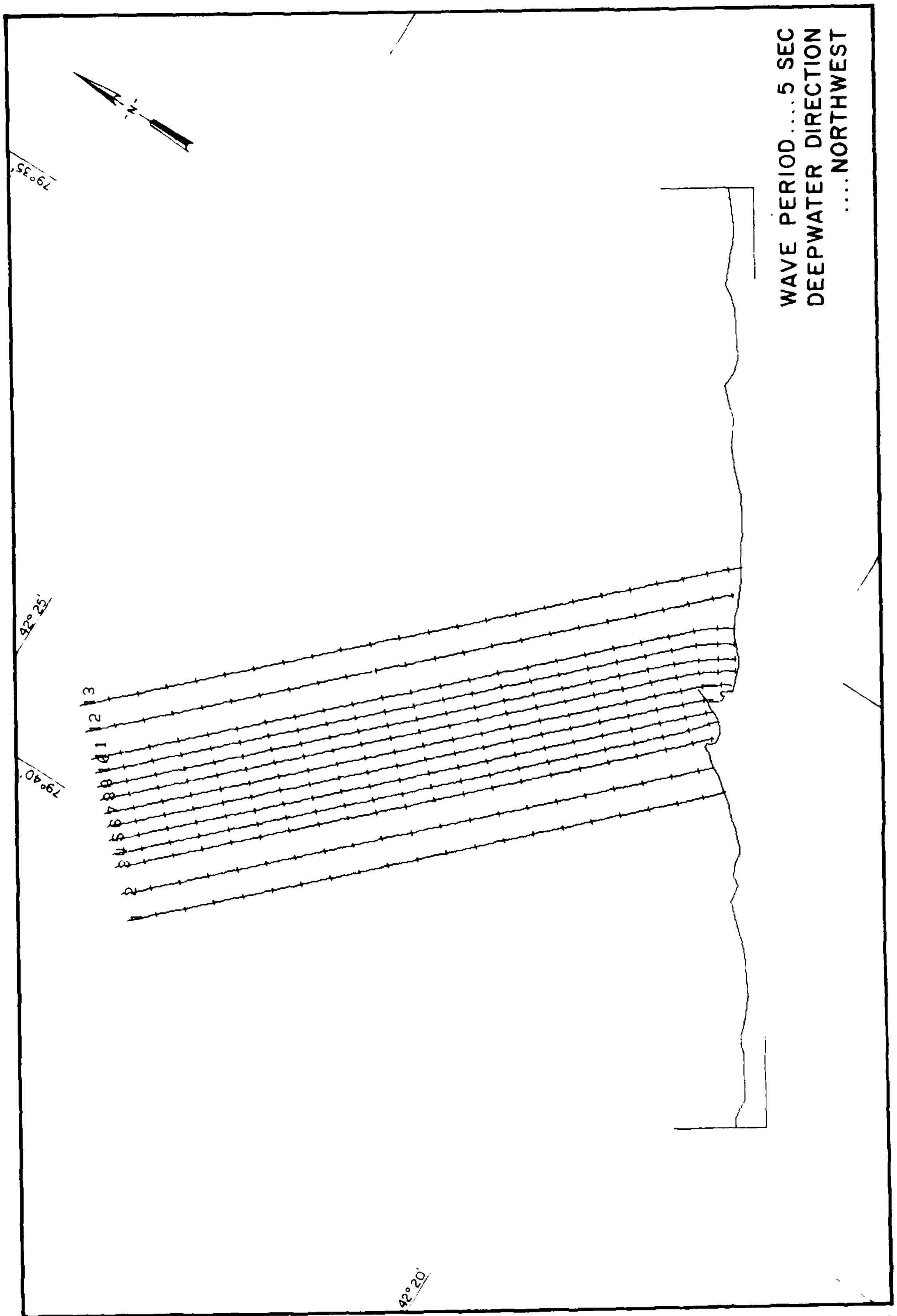

WAVE PERIOD....5 SEC
DEEPWATER DIRECTION
....NORTHWEST
N
79°35'
79°40'
42°25'
42°20'

PLATE A9

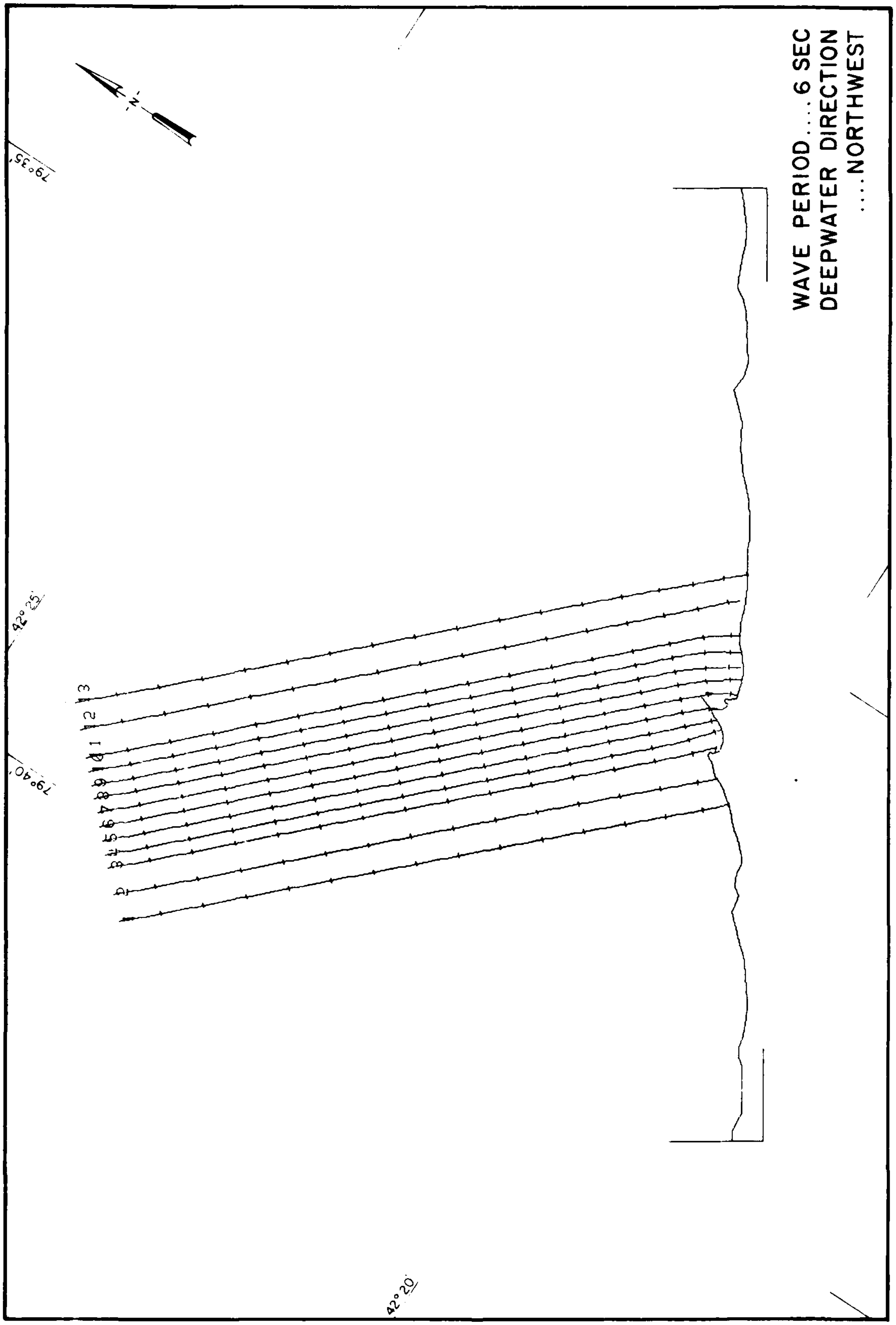

WAVE PERIOD.....6 SEC
DEEPWATER DIRECTION
.....NORTHWEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A10

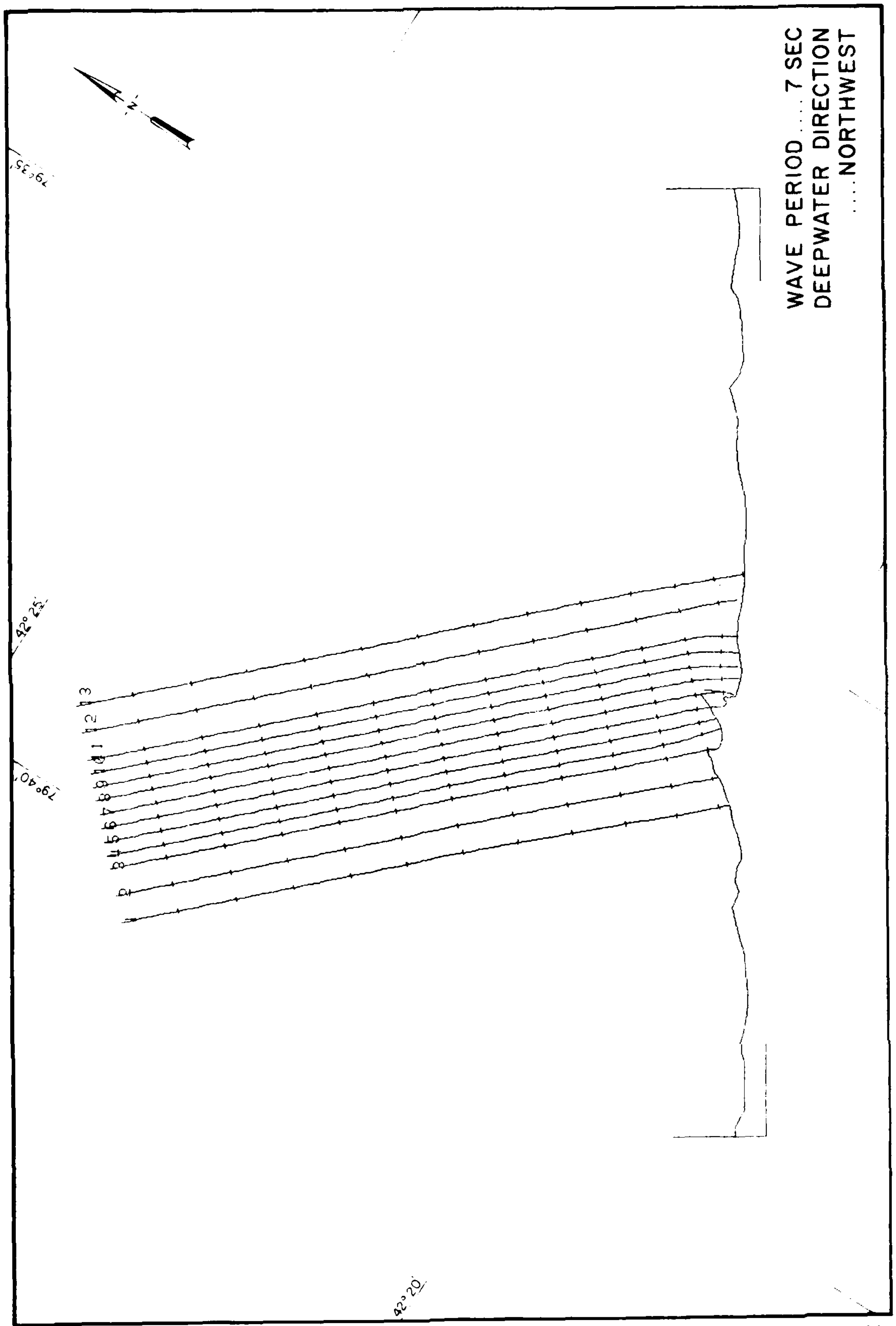

WAVE PERIOD .... 7 SEC
DEEPWATER DIRECTION ....NORTHWEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A11

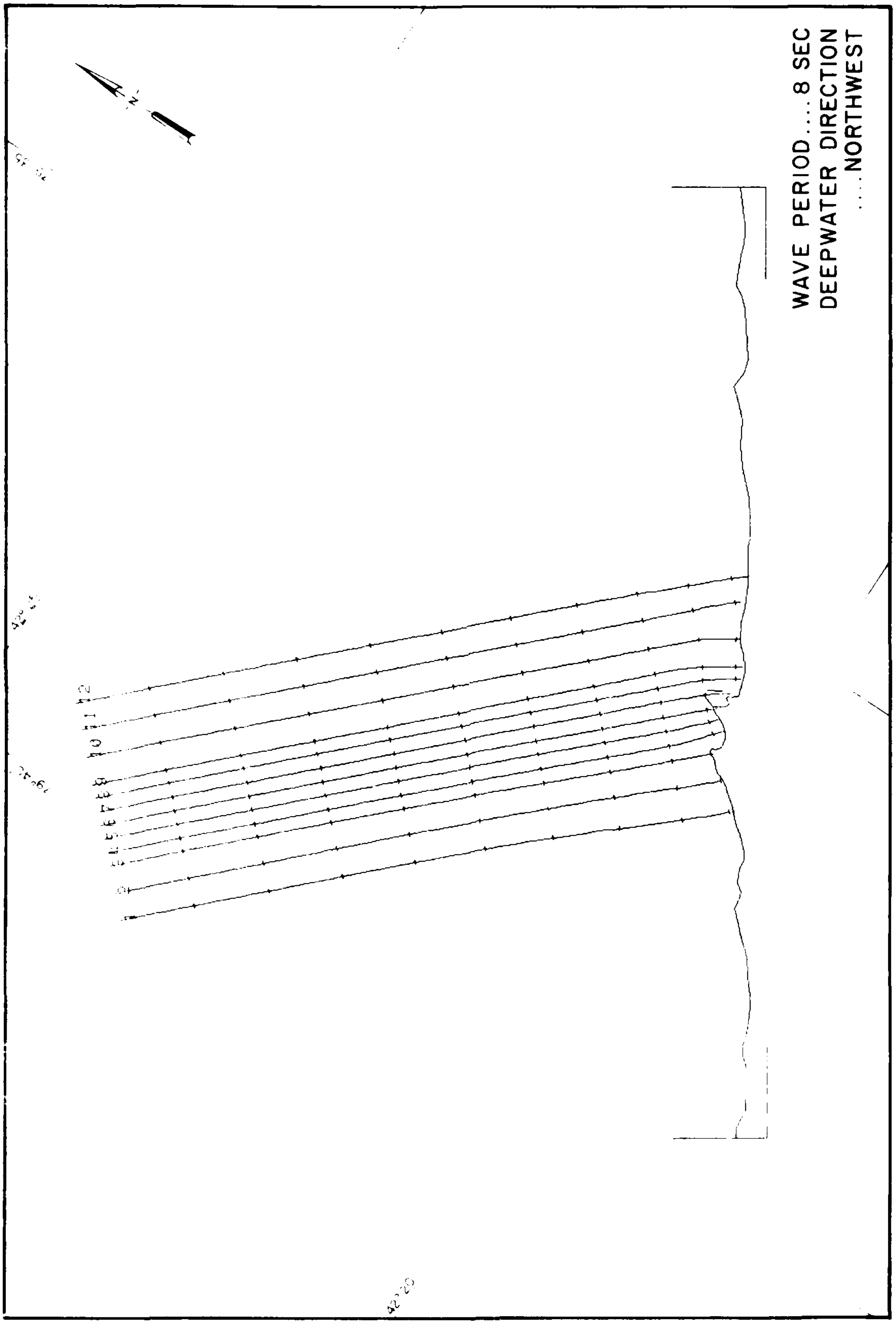


PLATE A12

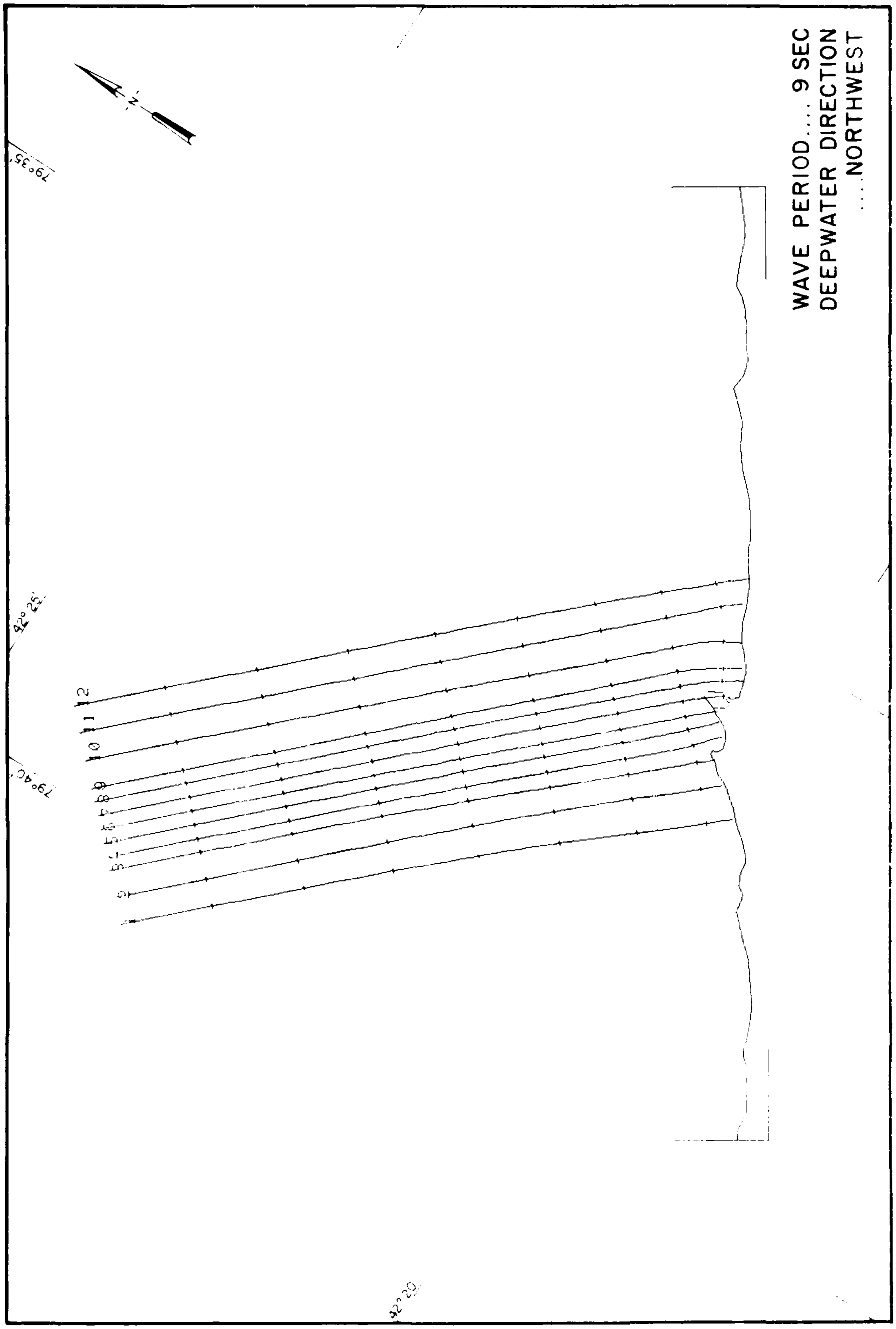

WAVE PERIOD.... 9 SEC
DEEPWATER DIRECTION
....NORTHWEST
N
79°35'
42°25'
79°40'
42°20'

PLATE A13

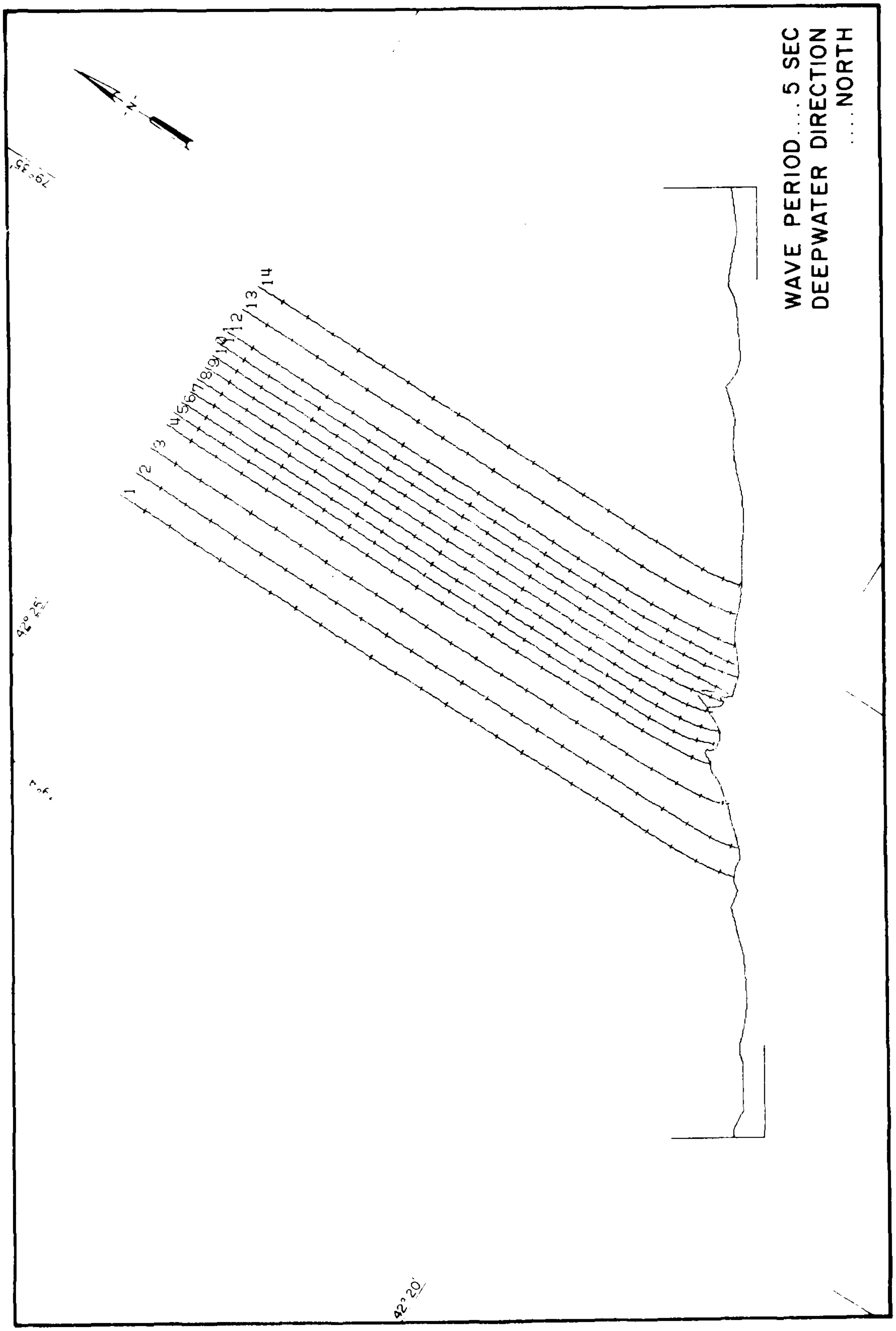

WAVE PERIOD....5 SEC
DEEPWATER DIRECTION
....NORTH
N
79° 35'
42° 25'
42° 20'
1
2
3
4
5
6
7
8
9
10
11
12
13
14

PLATE A14

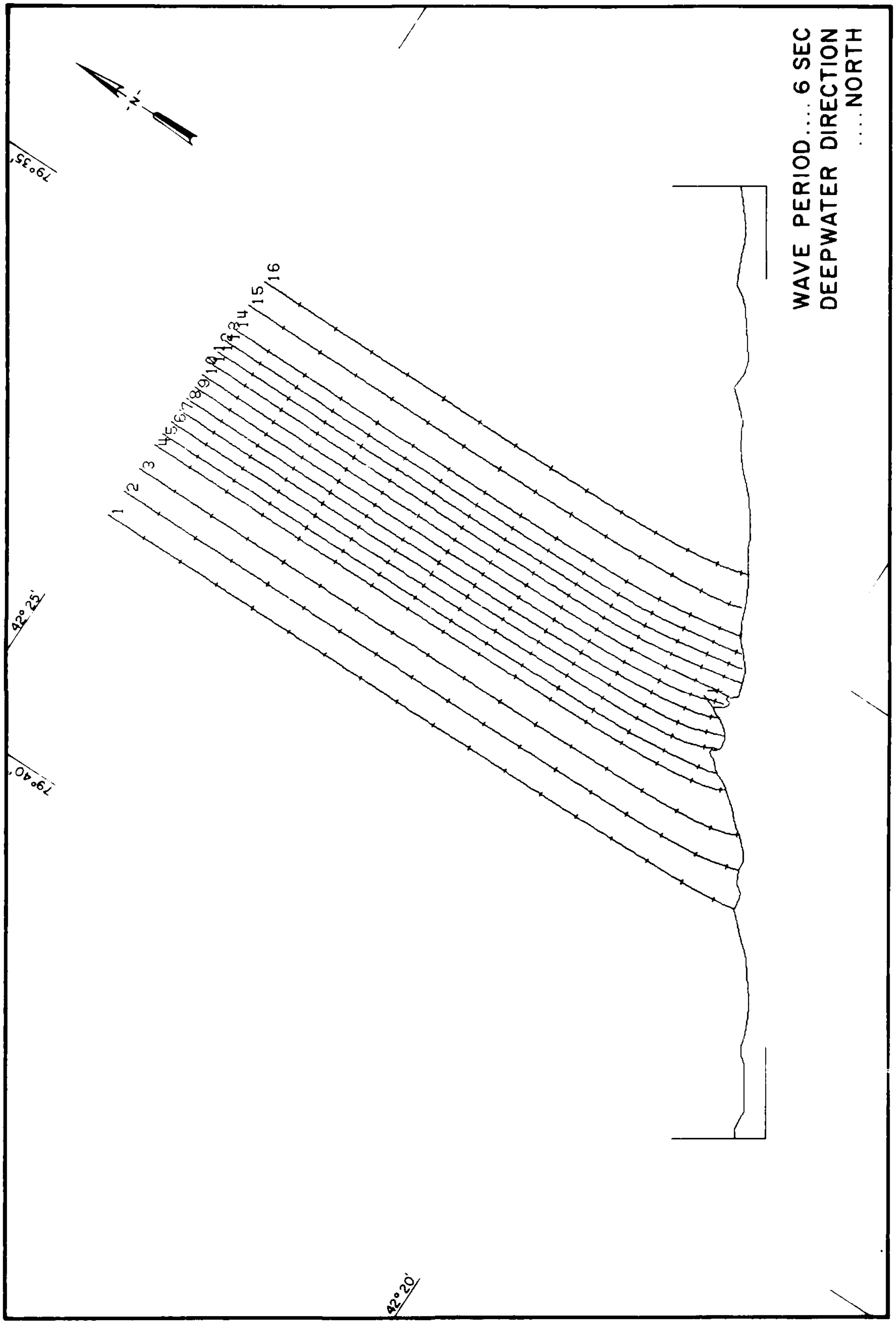

WAVE PERIOD.... 6 SEC
DEEPWATER DIRECTION
....NORTH
N
79°35'
79°40'
42°25'
42°20'
1
2
3
15
16

PLATE A15

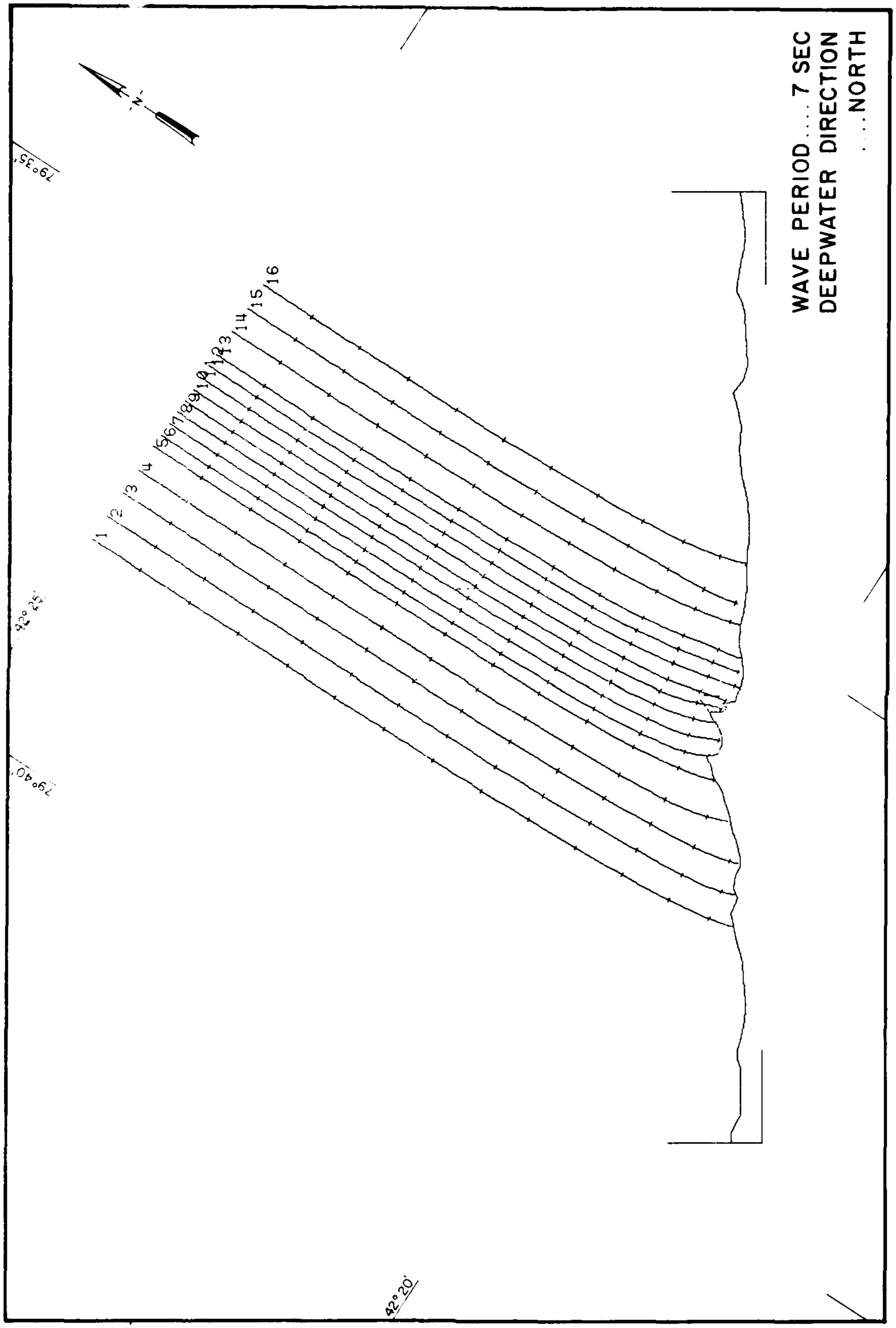

WAVE PERIOD.... 7 SEC
DEEPWATER DIRECTION
....NORTH
N
79°35'
42°25'
79°40'
42°20'

PLATE A16

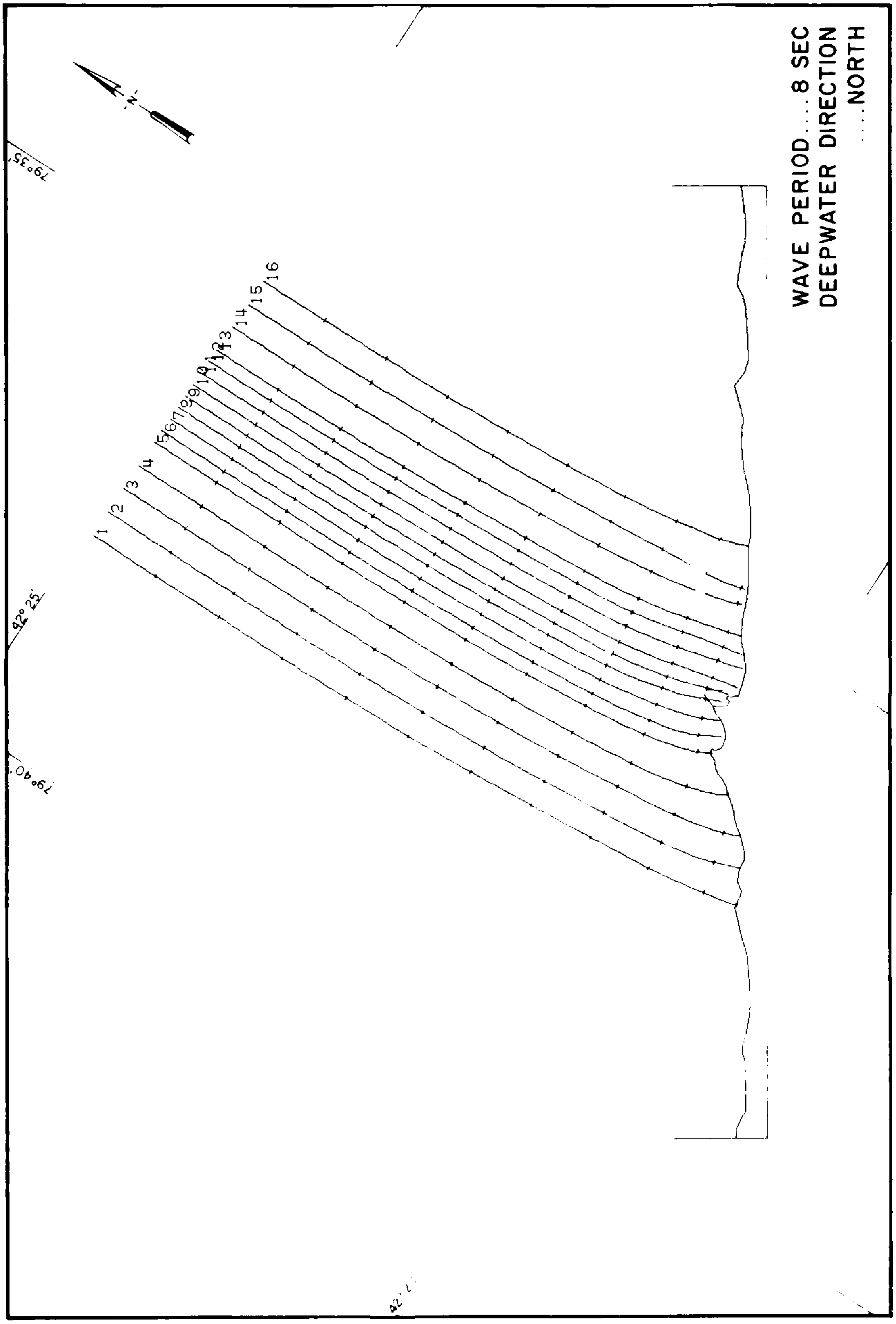
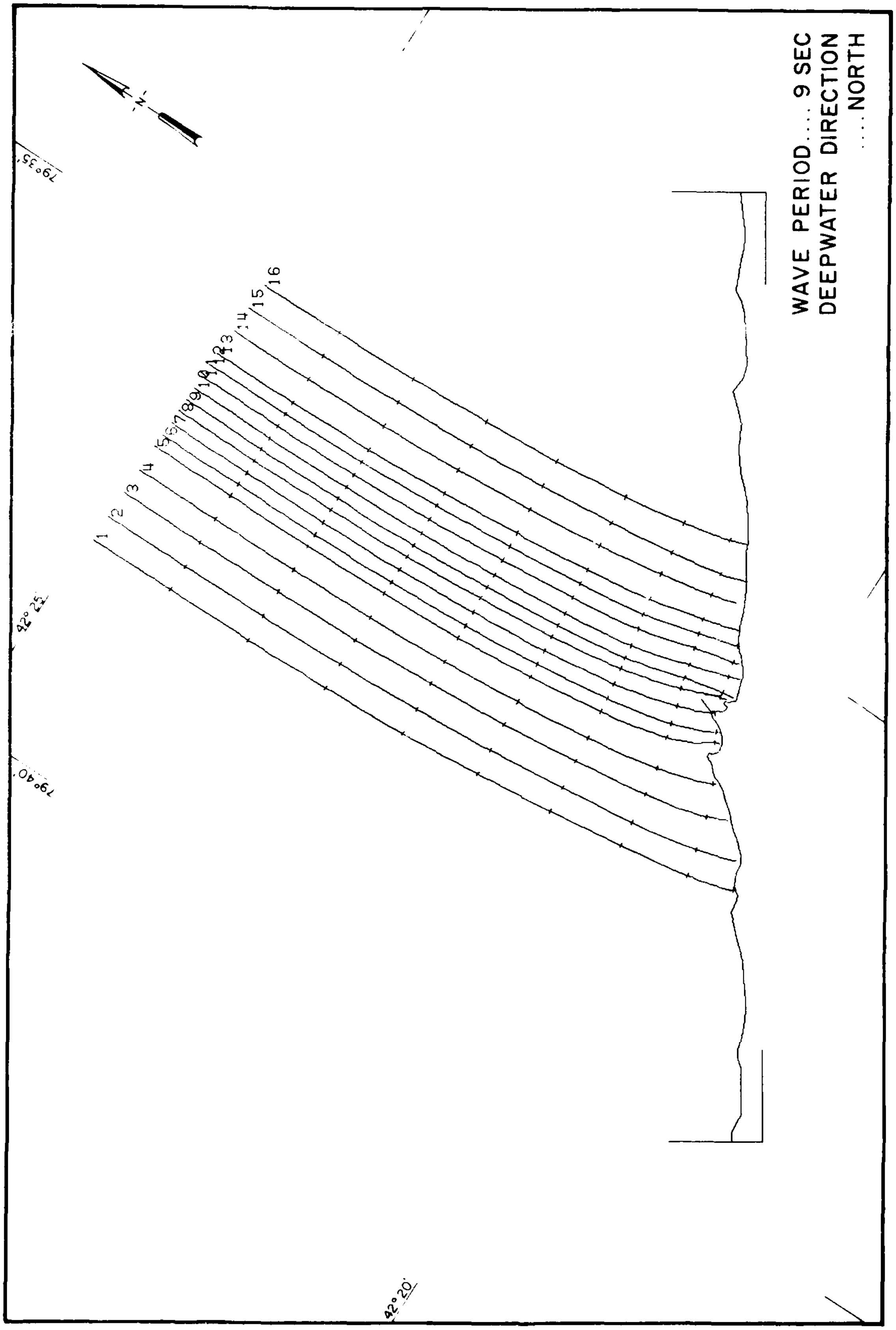

WAVE PERIOD....8 SEC
DEEPWATER DIRECTION
....NORTH
N
79°35'
42°25'
79°40'
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

PLATE A17



WAVE PERIOD.... 9 SEC
DEEPWATER DIRECTION .....NORTH
N
79°35'
42°25'
79°40'
42°20'
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

PLATE A18

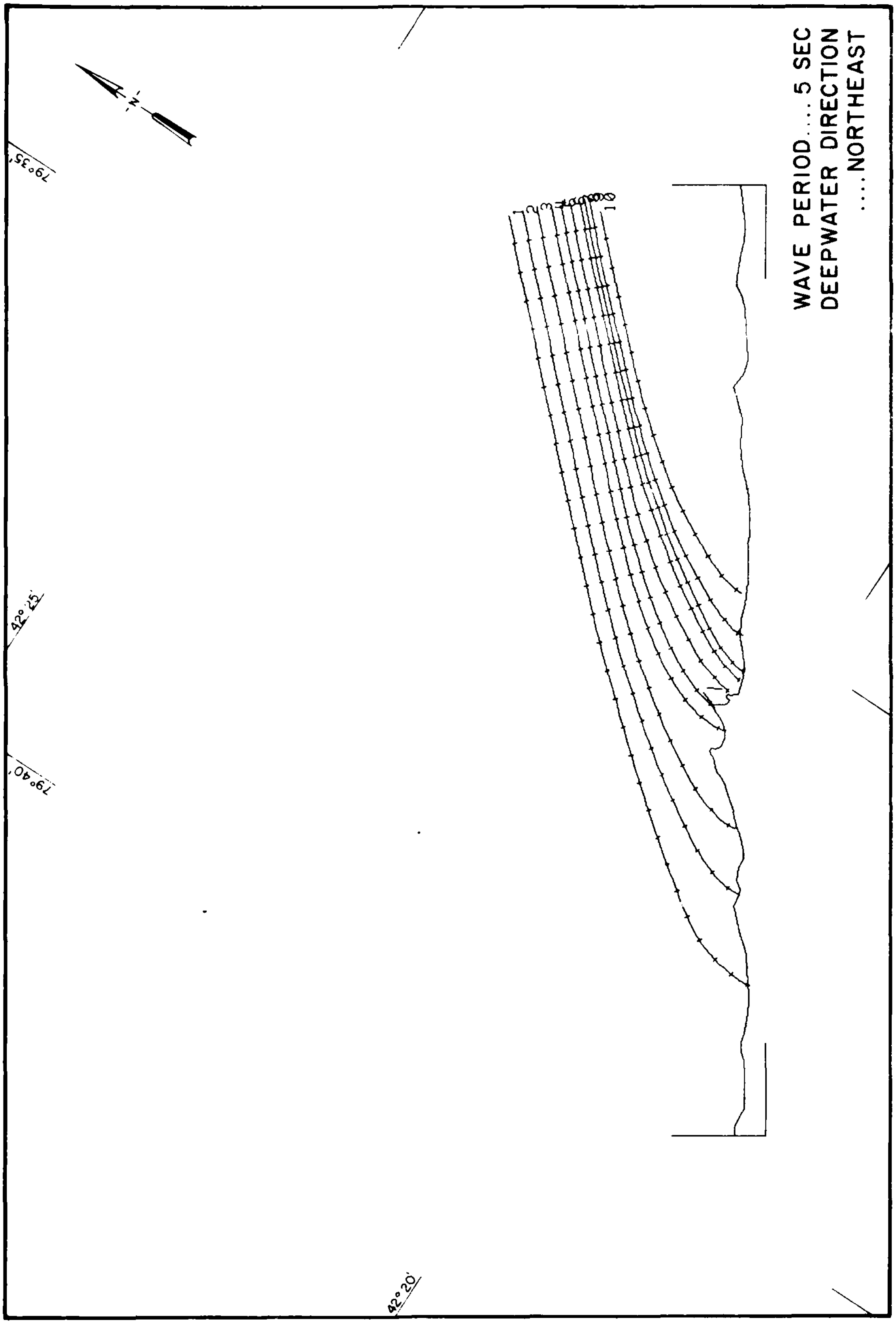

WAVE PERIOD....5 SEC
DEEPWATER DIRECTION
....NORTHEAST
N
79°35'
42°25'
79°40'
42°20'

PLATE A19

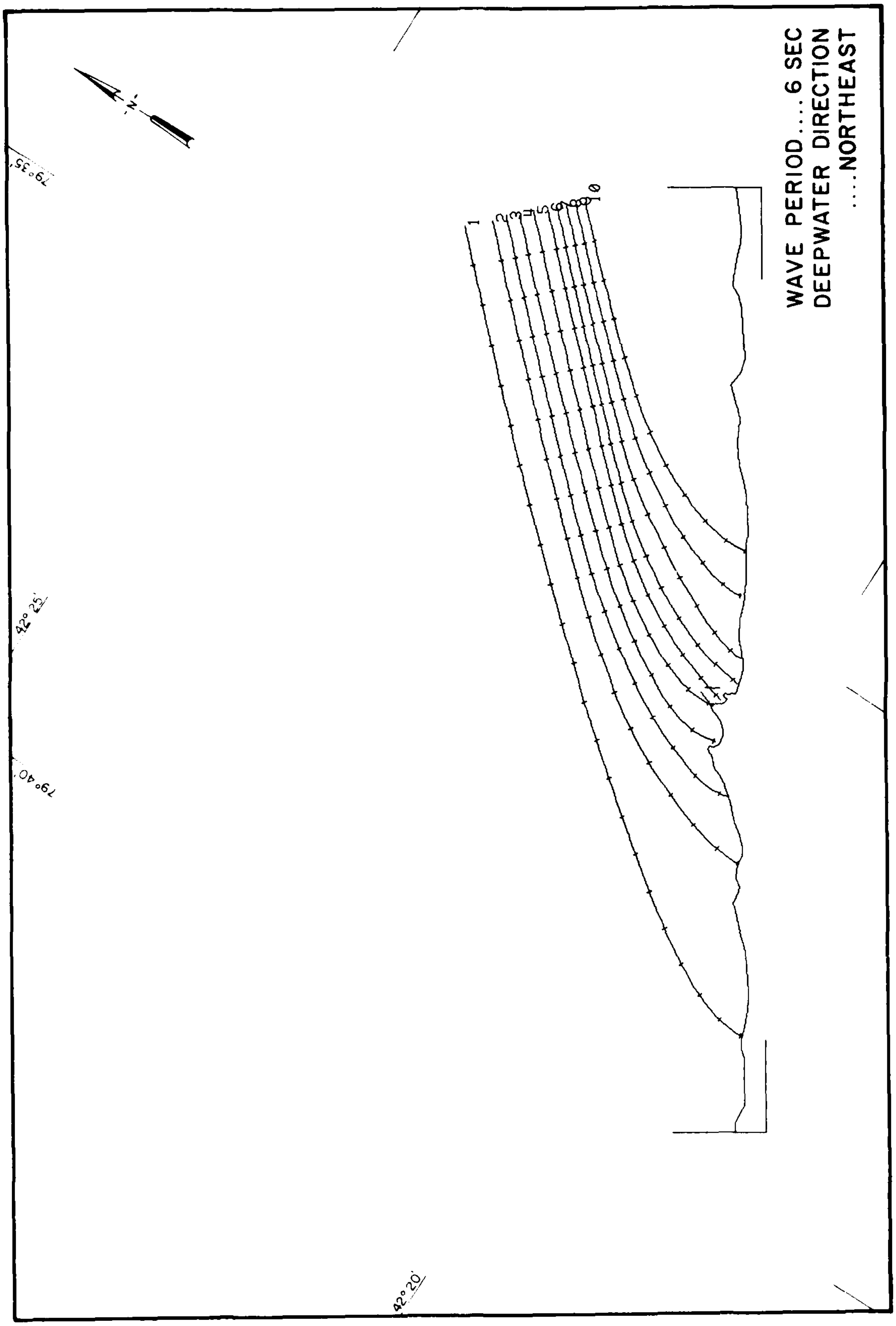

WAVE PERIOD.....6 SEC
DEEPWATER DIRECTION
.....NORTHEAST
N
79°35'
42°25'
79°40'
42°20'

PLATE A20

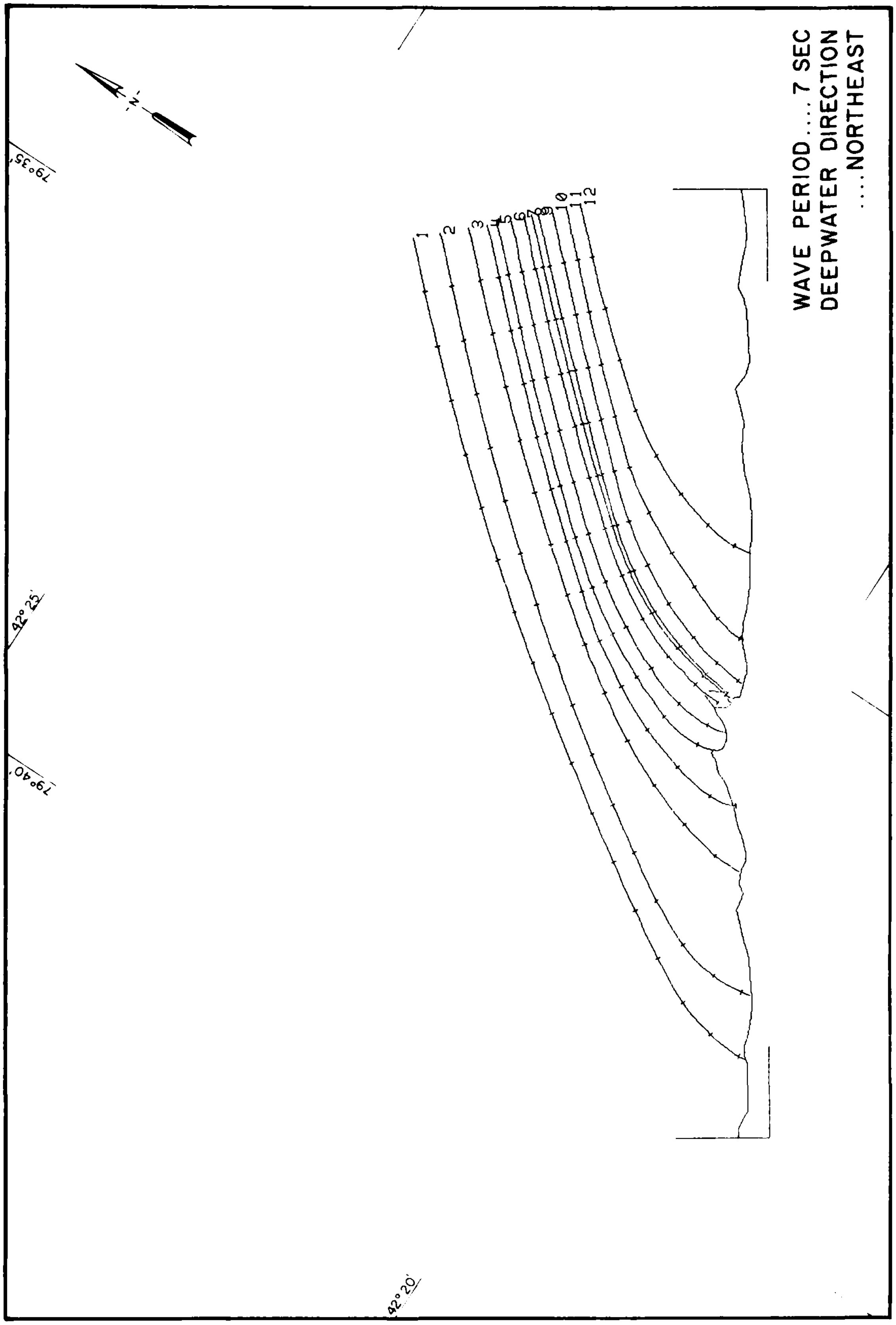

WAVE PERIOD.....7 SEC
DEEPWATER DIRECTION
....NORTHEAST
N
79°35'
42°25'
79°40'
42°20'
1
2
3
4
5
6
7
8
9
10
11
12

PLATE A21

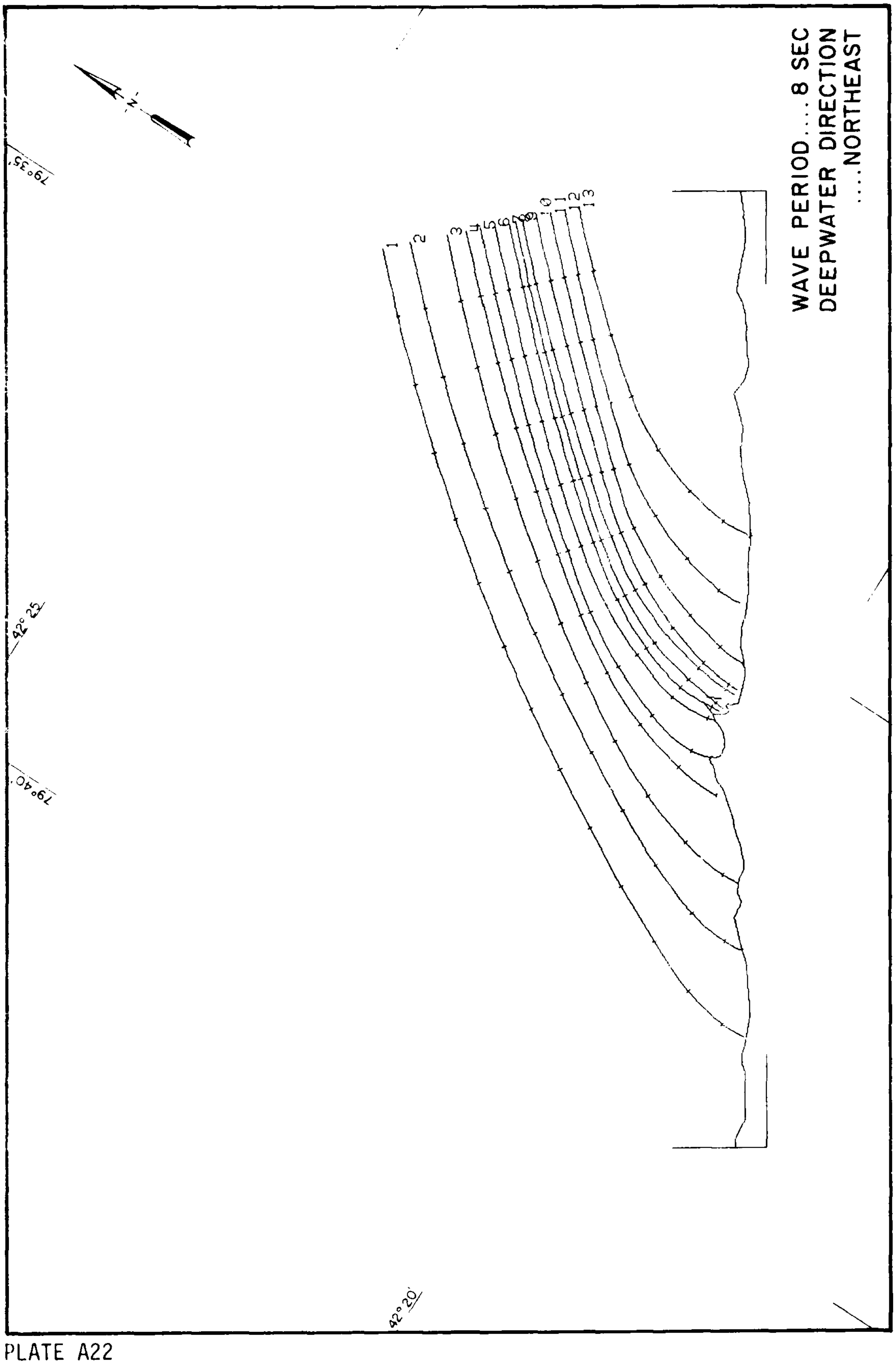

WAVE PERIOD....8 SEC
DEEPWATER DIRECTION
....NORTHEAST
N
79°35'
79°40'
42°25'
42°20'
1
2
3
4
5
6
7
8
9
10
11
12
13

PLATE A22

APPENDIX B: COMPARISON OF SPECTRAL AND MONOCHROMATIC WAVE TESTS FOR BARCELONA HARBOR

1. The optimum improvement plan (Plan 58, Plate 28 in main text) was initially developed in the model investigation using statistical wave hindcast data from Resio and Vincent (1976a).* These test waves were reproduced with a monochromatic wave generator. Subsequent to these model tests, and in order to determine wave heights in the harbor for spectral wave conditions (irregular wave trains propagating into the study area), it was necessary to conduct an additional wave hindcast study for Barcelona Harbor. This study (Jensen 1984), entailed both a wind analysis and spectral analysis of wave conditions for the boating season (May-Oct). The values (significant wave periods and wave heights) obtained for this additional wave hindcast varied somewhat from those obtained in Resio and Vincent (1976a) due to the May-October hindcast period and the intermediate depth water-wave hindcast procedures used. Therefore, to draw direct wave-height comparisons in the harbor between spectral and monochromatic wave conditions, it was necessary to calibrate both the spectral and monochromatic wave generators for design waves with significant wave periods and heights corresponding to the data generated by Jensen (1984).

2. Wave spectra were developed for Barcelona Harbor representing 1- and 25-year recurrence intervals occurring during boating season (May-Oct) for the west, northwest, north, and northeast test directions. Typical 2-ft wave spectra also were developed for the northeast test direction. Model test waves were converted to shallow-water values by application of refraction and shoaling coefficients (described in main text) as shown in the following tabulation:

Deepwater Direction	Shallow-Water Azimuth deg	Wave** Period sec	Deepwater** Wave Height ft	Shallow-Water** Wave Height ft	Recurrence Interval years	Still-Water Level (swl)
West	287	5.2	3.9	3.7	1	+3.0
		5.4	4.7	4.4	25	+6.5
Northwest	316	6.2	6.3	6.0	1	+3.0
		6.9	8.2	7.6	25	+5.0
North	347	5.9	5.5	5.1	1	+3.0
		6.2	6.9	6.3	25	+5.0
Northeast	20	5.0	--	2.0	--	+3.0
		5.9	5.6	4.3	1	+3.0
		6.2	6.9	5.2	25	+4.0

* See References at end of main text.

** Indicates significant wave p riods and wave heights.

3. As in the initial model testing program, test waves from northeast (20 deg) also were tested from an unrefracted northeast direction (45 deg). This represented deepwater waves approaching from a more easterly direction than northeast (refracted to due northeast, 45 deg). Waves approaching from this direction potentially could enter the harbor through the opening between the east breakwater and the public wharf (city dock).

4. Plots depicting the various wave spectra generated are presented in Plates B1-B9. The dashed lines represent the desired spectra while the solid lines represent the spectra generated by the wave generator. Methods employed to generate these design wave conditions, the wind analysis, the numerical shallow-water wave model utilized, and the actual wave hindcast may be obtained from Jensen (1984).

5. Wave heights obtained for spectral wave conditions for Plan 58 are presented in Table B1. Wave heights (H_{m_0} = energy-based on four times the standard deviation of the surface elevation data at each gage, usually equivalent in deep water to the significant wave heights, $H_{1/3}$), were tabulated to show values at selected gage locations. Maximum wave heights were 4.3 ft in the entrance (gage 1) for 6.2-sec, 5.2-ft test waves from northeast; 1.1 ft in the mooring area (gage 5) for 6.2-sec, 5.2-ft test waves from unrefracted northeast; 1.1 ft in the inner harbor (gage 10) for 6.2-sec, 5.2-ft test waves from northeast; and 2.2 ft adjacent to the city dock (gage 12) for 6.2-sec, 5.2-ft test waves from the unrefracted northeast direction. Wave heights in the mooring area (gages 4-8) were well within the established 2.0-ft wave-height criterion. Typical spectral wave patterns for Plan 58 are shown in Photos B1-B12.

6. Results of wave-height tests conducted for monochromatic wave conditions for the test waves listed in paragraph 2 with Plan 58 installed in the model are shown in Table B2. Again, the tabulated values refer to significant wave heights obtained at selected locations. Maximum wave heights obtained were 5.8 ft in the entrance (gage 1) for 6.2-sec, 5.2-ft test waves from the unrefracted northeast direction; 2.0 ft in the mooring area (gage 10) for 6.2-sec, 5.2-ft test waves from the unrefracted northeast direction; and 4.1 ft adjacent to the city dock (gage 12) for 6.2-sec, 5.2-ft test waves from northeast. The 2.0-ft wave-height criterion in the mooring area was not exceeded for any of these test waves. Typical monochromatic wave patterns obtained for Plan 58 are shown in Photos B13-B24.

7. Wave-height data for corresponding spectral and monochromatic wave conditions were plotted graphically, as shown in Plates B10-B16 for comparison purposes. Average wave heights at each gage location for both spectral and monochromatic conditions (considering all test waves, directions, and still-water levels) are presented in Plate B17. Considering all test conditions, monochromatic wave conditions, in general, resulted in slightly larger wave heights in the harbor as opposed to wave heights secured with spectral wave conditions. With the exception of 5-sec, 2-ft test waves from northeast, the uniform monochromatic waves resulted in larger wave heights in the entrance (gage 1) than did the irregular (varying wave period and heights) spectral waves for all test directions. Visual observations and wave pattern photographs indicated that monochromatic wave conditions resulted in substantially more overtopping of the structures than the corresponding spectral waves. For the larger test waves, each monochromatic wave crest overtopped the structures, whereas the irregular spectral waves only occasionally overtopped the structures. It was noted also that wave reflections from the structures and standing wave patterns inside the harbor were more uniform and prominent for monochromatic waves as opposed to corresponding spectral conditions. The large wave heights obtained (particularly adjacent to the city dock) for some of the more severe monochromatic test waves may be attributed to the fact that a fixed gage was placed at an antinodal point in a uniform standing wave system. For the irregular spectral waves, wave patterns were less uniform and less conspicuous in the harbor and maximum wave heights at a fixed location varied from wave to wave.

8. In summary, results of these tests indicated that monochromatic wave conditions resulted in slightly larger wave heights throughout the harbor than for corresponding spectral wave conditions. The established 2.0-ft wave-height criterion in the harbor mooring area was met by both the monochromatic and spectral wave trains. Since the maximum wave height in the mooring area for monochromatic waves was 2.0 ft and the maximum wave height was 1.1 ft for spectral waves, and due to the fact that irregular spectral wave trains more closely represent conditions in the prototype, the results of the monochromatic wave tests may be considered slightly conservative.

Table B1

Wave Heights for Plan 58 for Spectral Wave Conditions

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
West	5.2	3.7	0.7	0.3	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2
							+6.5 ft swl									
	5.4	4.4	1.0	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.2
							+3.0 ft swl									
Northwest	6.2	6.0	1.7	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.7	0.6	0.5
							+5.0 ft swl									
	6.9	7.6	2.4	1.0	0.8	0.6	0.7	0.7	0.8	0.7	0.7	0.8	1.0	1.6	1.3	1.1
							+3.0 ft swl									
North	5.9	5.1	2.0	1.1	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.8	1.3	0.8	0.7
							+5.0 ft swl									
	6.2	6.3	3.1	1.8	1.1	0.7	0.8	0.8	0.8	0.7	0.9	0.8	1.1	2.1	1.4	1.2
							+3.0 ft swl									
Northeast	5.0	2.0	1.5	1.0	0.5	0.3	0.3	0.3	0.3	0.2	0.4	0.2	0.3	0.6	0.4	0.5
	5.9	4.3	3.6	2.0	1.1	0.7	0.7	0.7	0.6	0.5	0.8	0.6	0.9	1.5	1.1	1.1

(Continued)

Table B1 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+4.0 ft swl									
Northeast (Cont)	6.2	5.2	4.3	2.3	1.5	1.0	1.0	0.8	0.9	0.9	1.1	1.6	2.1	1.7	1.6	
							+3.0 ft swl									
Northeast (unre-fracted)	5.0	2.0	1.1	0.6	0.4	0.3	0.2	0.2	0.3	0.1	0.3	0.1	0.1	0.4	0.3	0.3
	5.9	4.3	2.6	1.3	0.8	0.6	0.5	0.5	0.5	0.4	0.6	0.4	0.5	1.1	0.7	0.7
							+4.0 ft swl									
	6.2	5.2	3.8	2.0	1.5	1.0	1.1	1.0	0.9	0.8	1.0	0.9	1.2	2.2	1.7	1.2

Table B2

Wave Heights for Plan 58 for Monochromatic Wave Conditions

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+3.0 ft swl									
West	5.2	3.7	1.2	0.3	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.2
							+6.5 ft swl									
	5.4	4.4	1.6	0.5	0.4	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.3	0.3	0.3	0.1
							+3.0 ft swl									
Northwest	6.2	6.0	2.1	0.9	0.5	0.3	0.4	0.3	0.2	0.3	0.3	0.3	0.3	0.5	0.5	0.3
							+5.0 ft swl									
	6.9	7.6	3.2	1.2	0.8	0.8	1.2	0.5	0.6	0.6	0.6	0.5	1.1	1.9	1.7	1.2
							+3.0 ft swl									
North	5.9	5.1	2.6	1.3	0.8	0.5	0.6	0.5	0.5	0.3	0.5	0.2	0.6	1.2	0.8	0.9
							+5.0 ft swl									
	6.2	6.3	4.2	1.9	1.5	0.7	1.2	1.3	0.6	0.7	1.1	1.0	1.5	4.0	1.7	1.6
							+3.0 ft swl									
Northeast	5.0	2.0	1.4	1.2	0.8	0.5	0.2	0.4	0.5	0.5	0.6	0.2	0.3	1.0	0.3	0.5
	5.9	4.3	4.5	2.5	1.5	0.8	1.0	1.0	1.1	0.8	1.2	0.4	1.7	1.9	1.4	1.7

(Continued)

Table B2 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14
							+4.0 ft swl									
Northeast (Cont)	6.2	5.2	5.5	3.1	1.9	0.9	1.6	2.0	1.1	0.9	0.8	1.0	1.5	4.1	2.2	2.6
							+3.0 ft swl									
Northeast (unre-fracted)	5.0	2.0	0.9	0.8	0.6	0.4	0.1	0.2	0.4	0.2	0.4	0.2	0.1	0.5	0.1	0.2
	5.9	4.3	4.2	2.4	1.4	1.2	1.3	1.1	1.0	0.5	1.0	0.5	1.2	2.7	1.4	1.4
							+4.0 ft swl									
	6.2	5.2	5.8	3.4	2.8	1.6	1.3	1.8	1.5	1.0	1.1	1.3	1.4	3.2	1.5	2.7

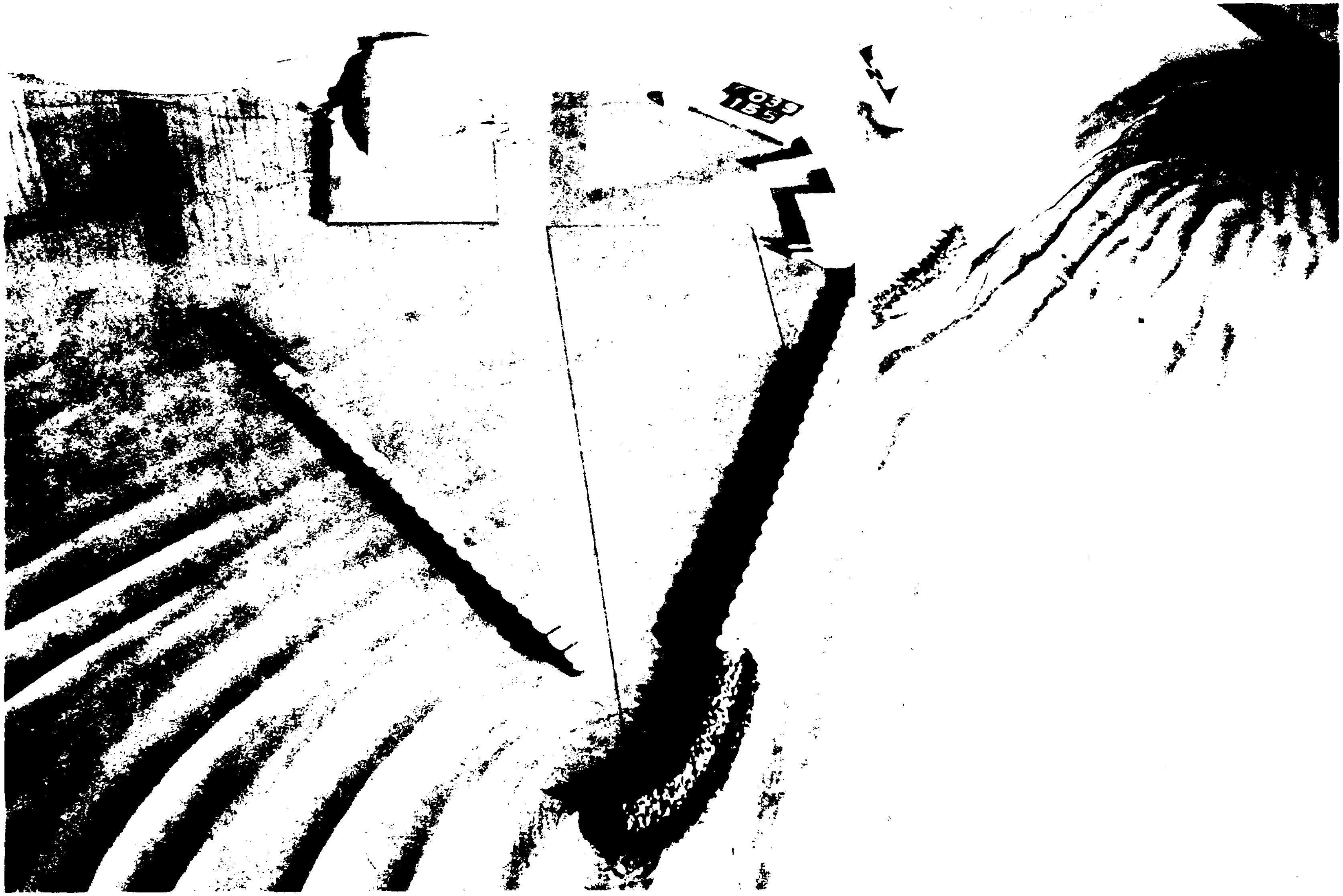


Photo B1. Typical spectral wave patterns for Plan 58; 5.2-sec, 3.7-ft test waves from west; +3.0 ft swl

Photo B2. Typical spectral wave patterns for Plan 58; 5.4-sec, 4.4-ft test waves from west; +6.5 ft swl

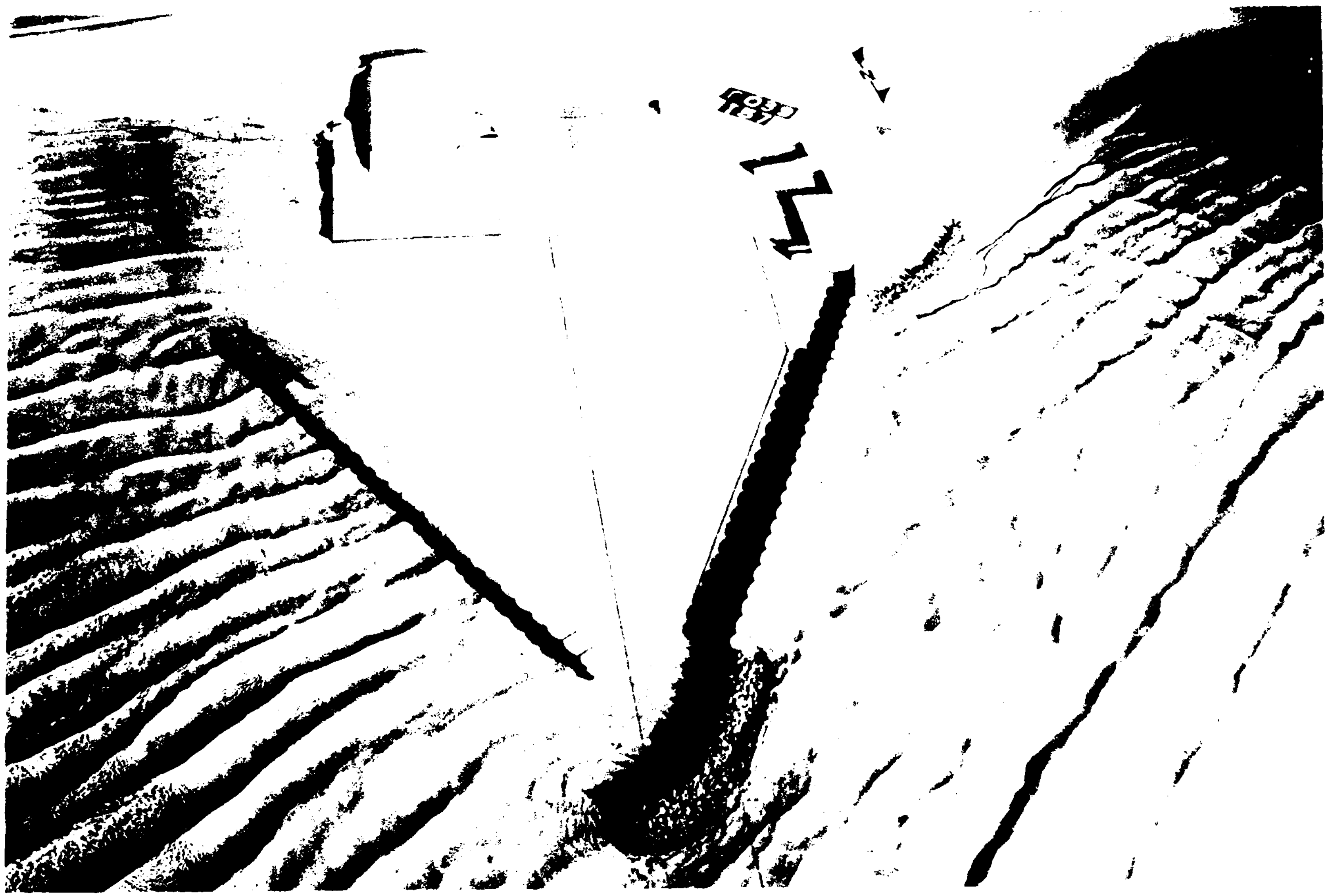


Photo B3. Typical spectral wave patterns for Plan 58; 6.2-sec, 6.0-ft test waves from northwest; +3.0 ft swl

Photo B4. Typical spectral wave patterns for Plan 58; 6.9-sec, 7.6-ft test waves from northwest; +5.0 ft swl

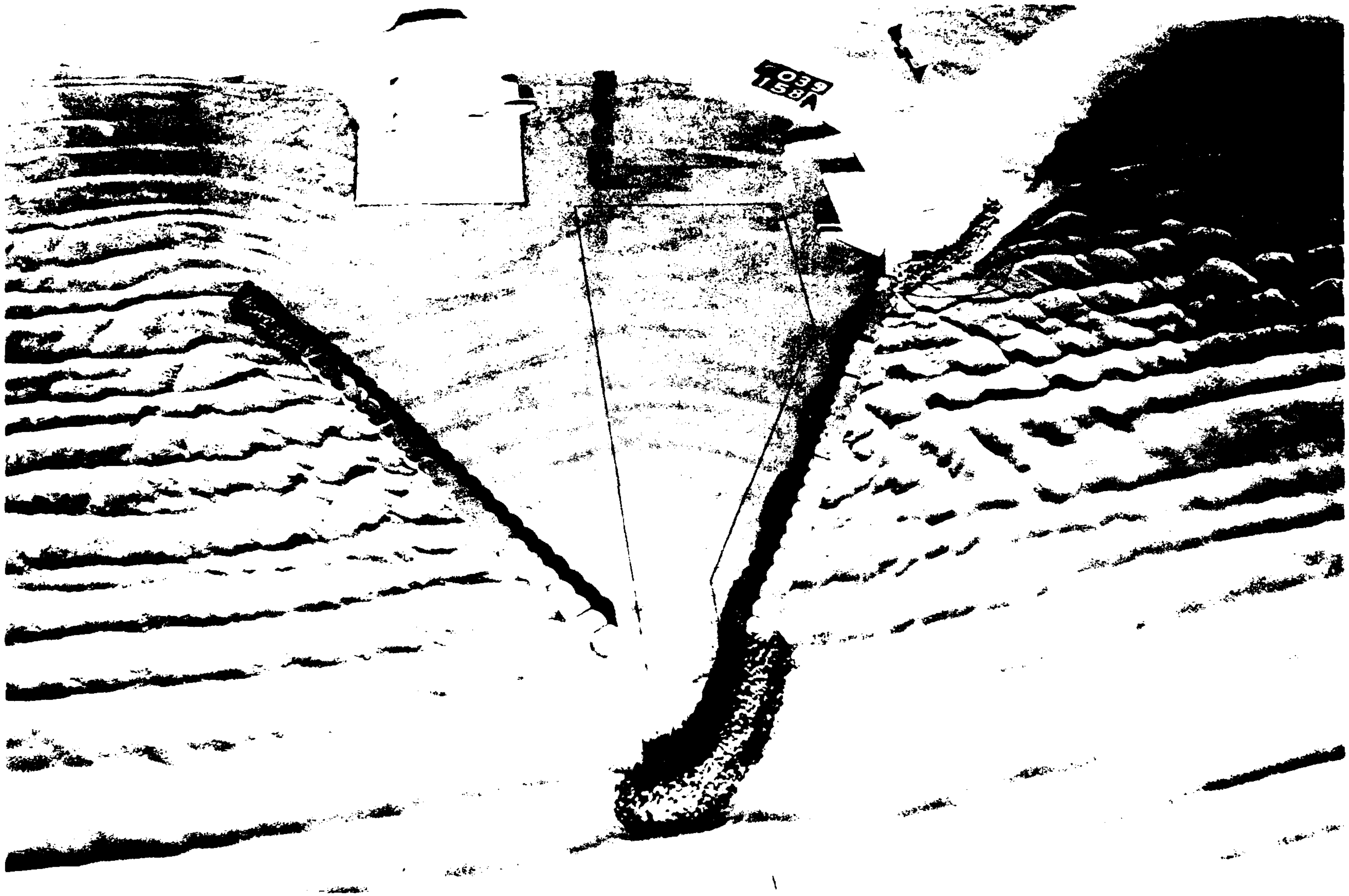


Photo B5. Typical spectral wave patterns for Plan 58; 5.9-sec, 5.1-ft test waves from north; +3.0 ft swl

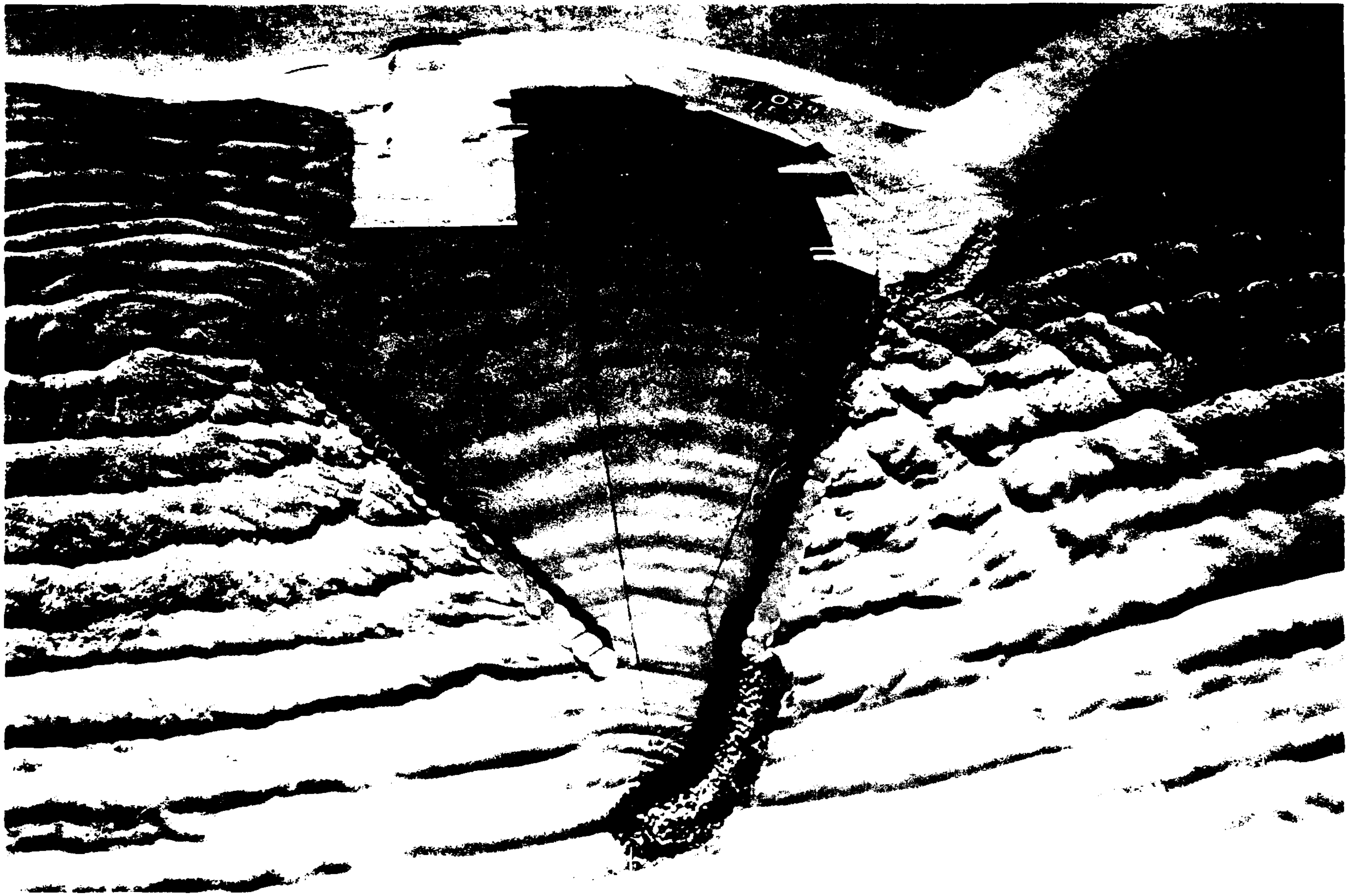


Photo B6. Typical spectral wave patterns for Plan 58; 6.2-sec, 6.3-ft test waves from north; +5.0 ft swl

Photo B7. Typical spectral wave patterns for Plan 58; 5.0-sec, 2.0-ft test waves from northeast; +3.0 ft swl

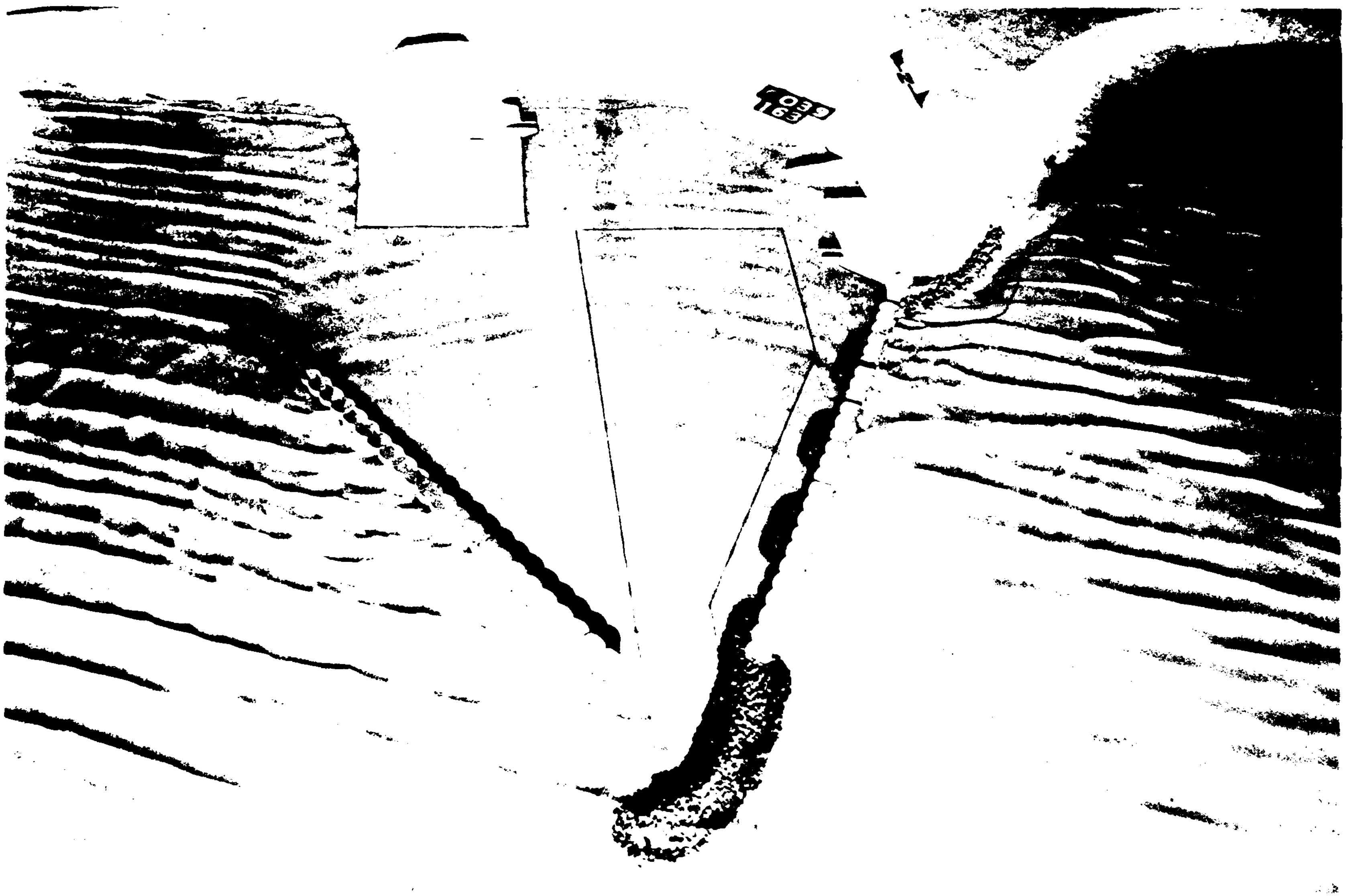


Photo B8. Typical spectral wave patterns for Plan 58; 5.9-sec, 4.3-ft test waves from northeast; +3.0 ft swl

Photo B9. Typical spectral wave patterns for Plan 58; 6.2-sec, 5.2-ft test waves from northeast; +4.0 ft swl

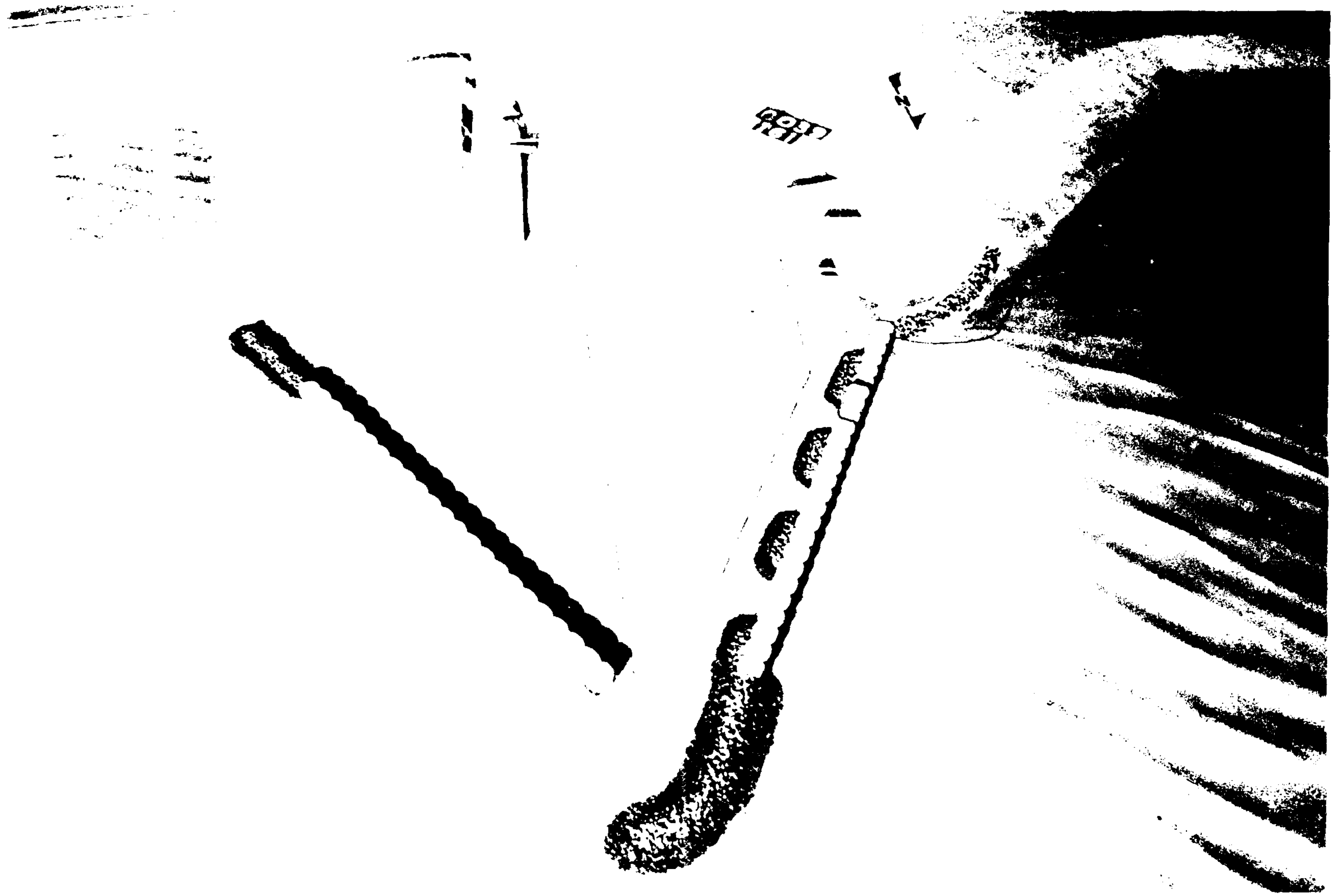


Photo B10. Typical spectral wave patterns for Plan 58; 5.0-sec, 2.0-ft test waves from the unrefracted northeast direction; +3.0 ft swl

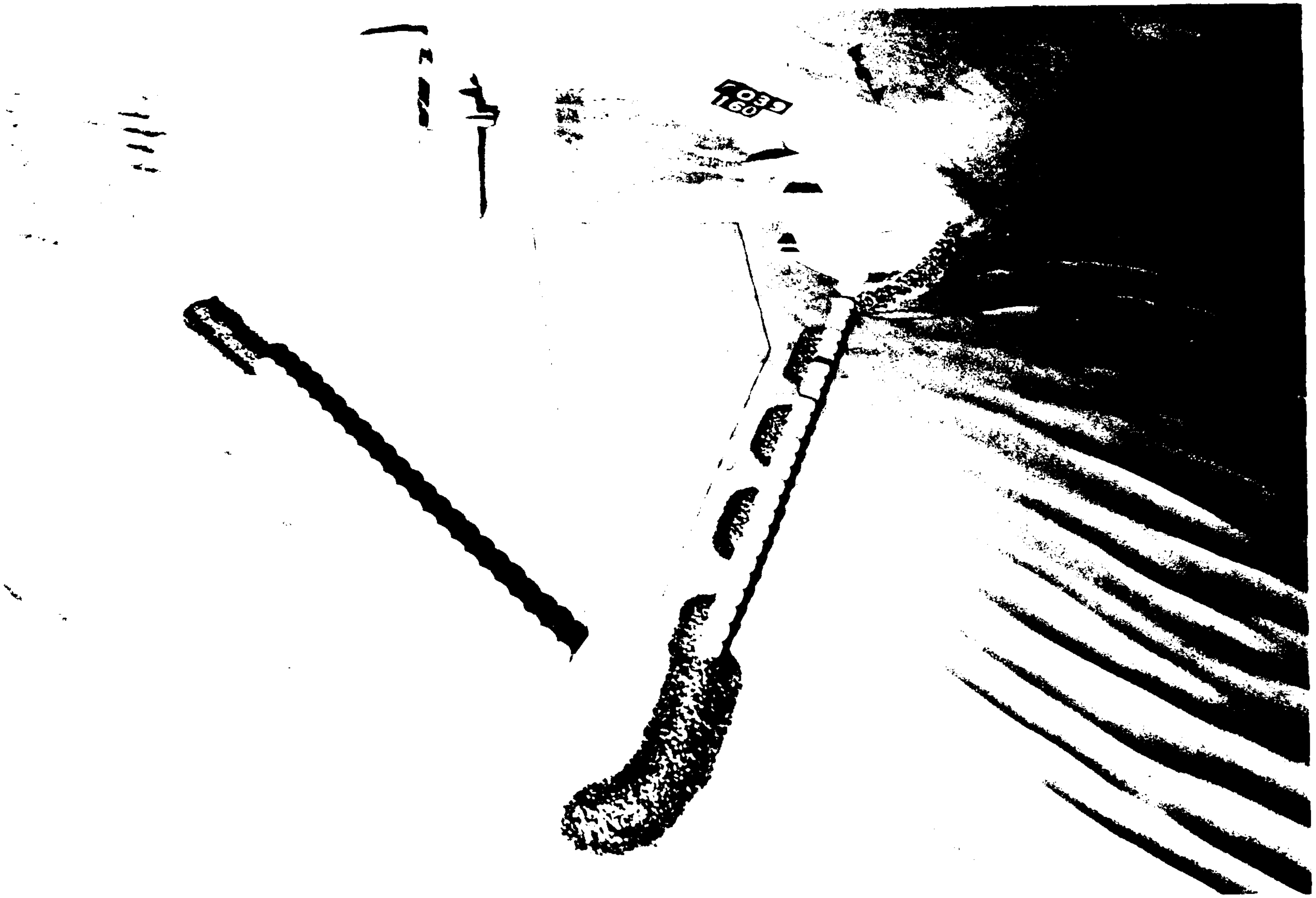


Photo B11. Typical spectral wave patterns for Plan 58; 5.9-sec, 4.3-ft test waves from the unrefracted northeast direction; +3.0 ft swl

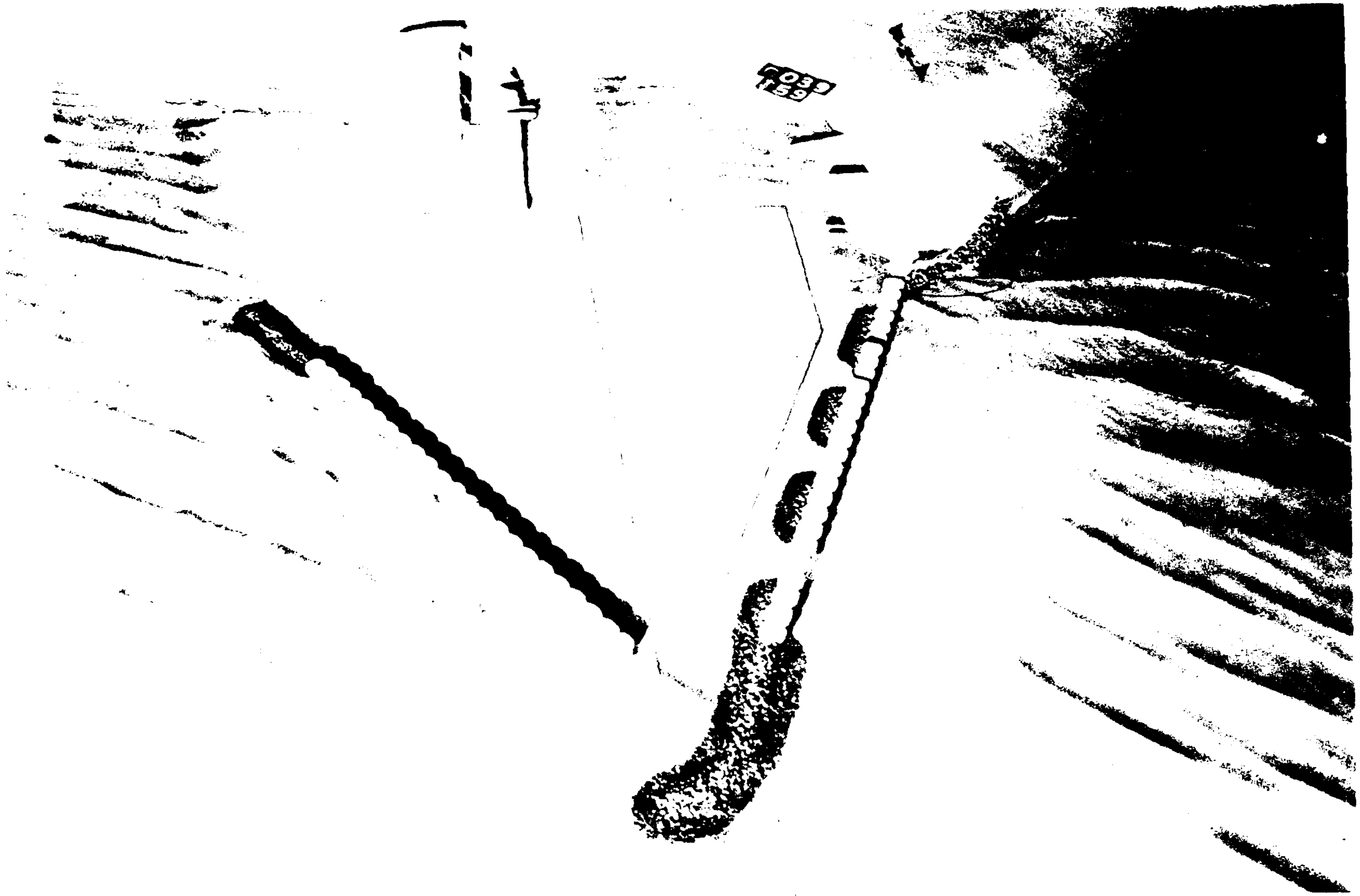


Photo B12. Typical spectral wave patterns for Plan 58; 6.2-sec, 5.2-ft test waves from the unrefracted northeast direction; +4.0 ft swl

Photo B13. Typical monochromatic wave patterns for Plan 58; 5.2-sec, 3.7-ft test waves from west; +3.0 ft swl

Photo B14. Typical monochromatic wave patterns for Plan 58; 5.4-sec, 4.4-ft test waves from west; +6.5 ft swl

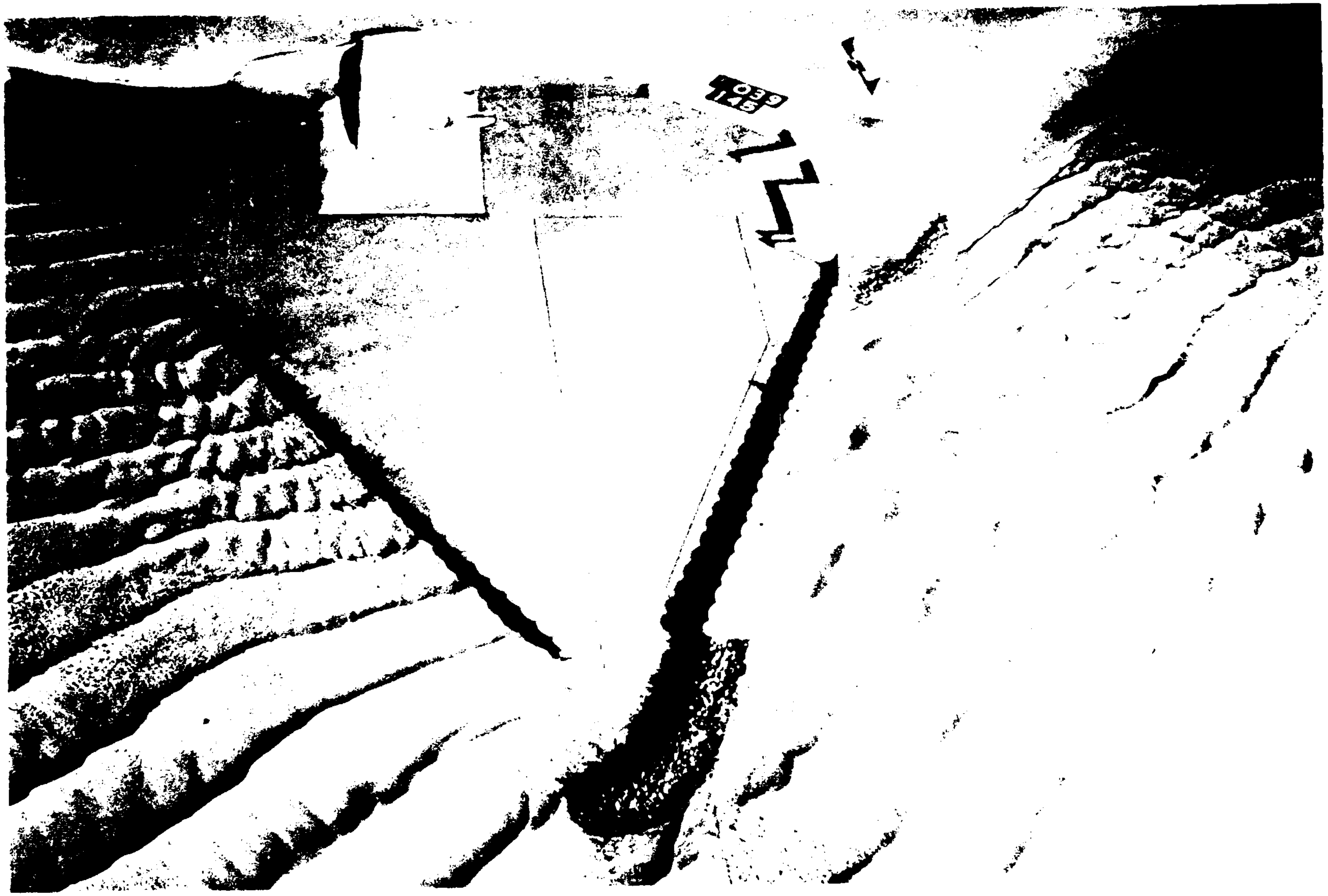


Photo B15. Typical monochromatic wave patterns for Plan 58; 6.2-sec, 6.0-ft test waves from northwest; +3.0 ft swl

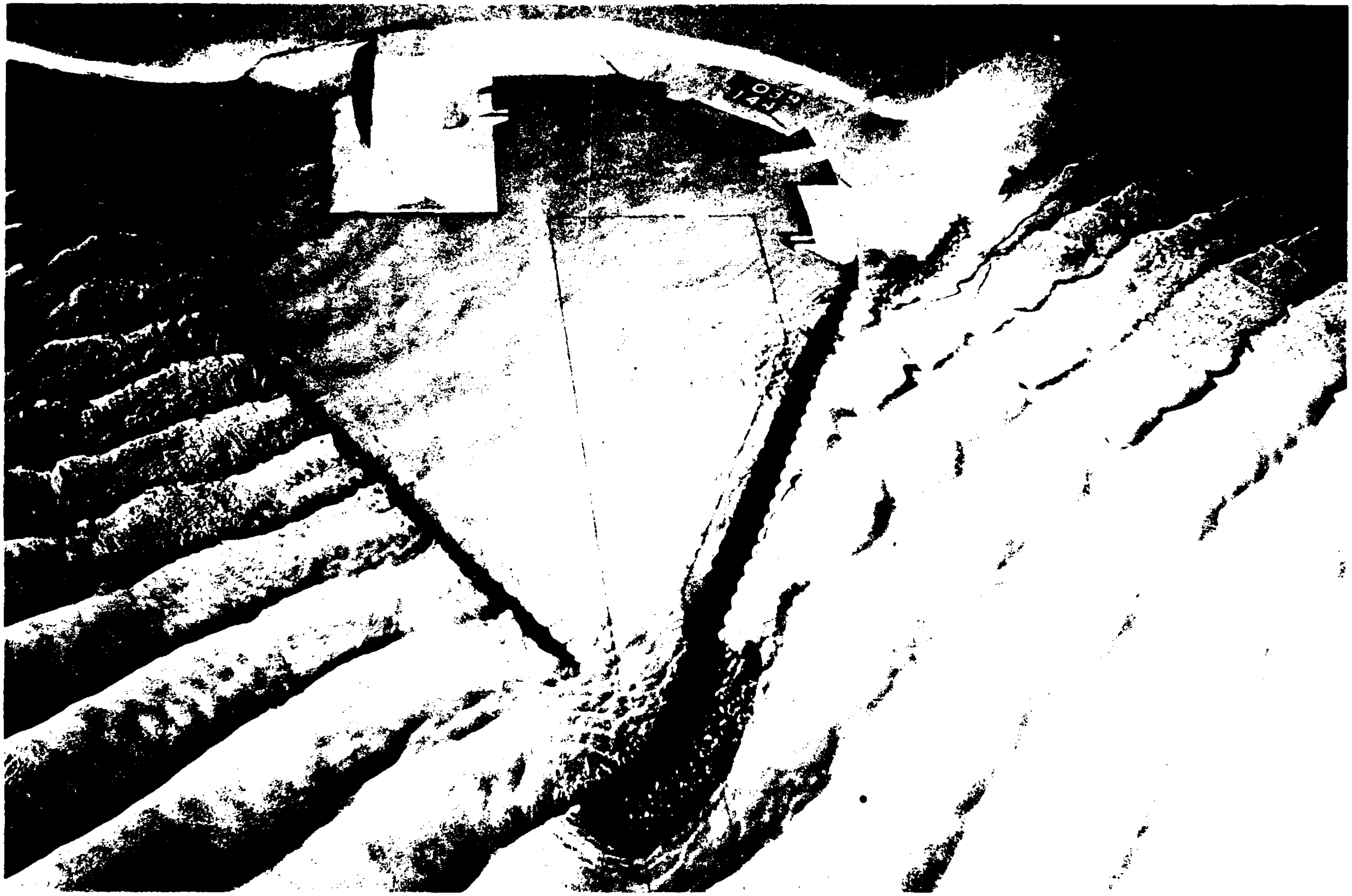


Photo B16. Typical monochromatic wave patterns for Plan 58; 6.9-sec, 7.6-ft test waves from northwest; +5.0 ft swl

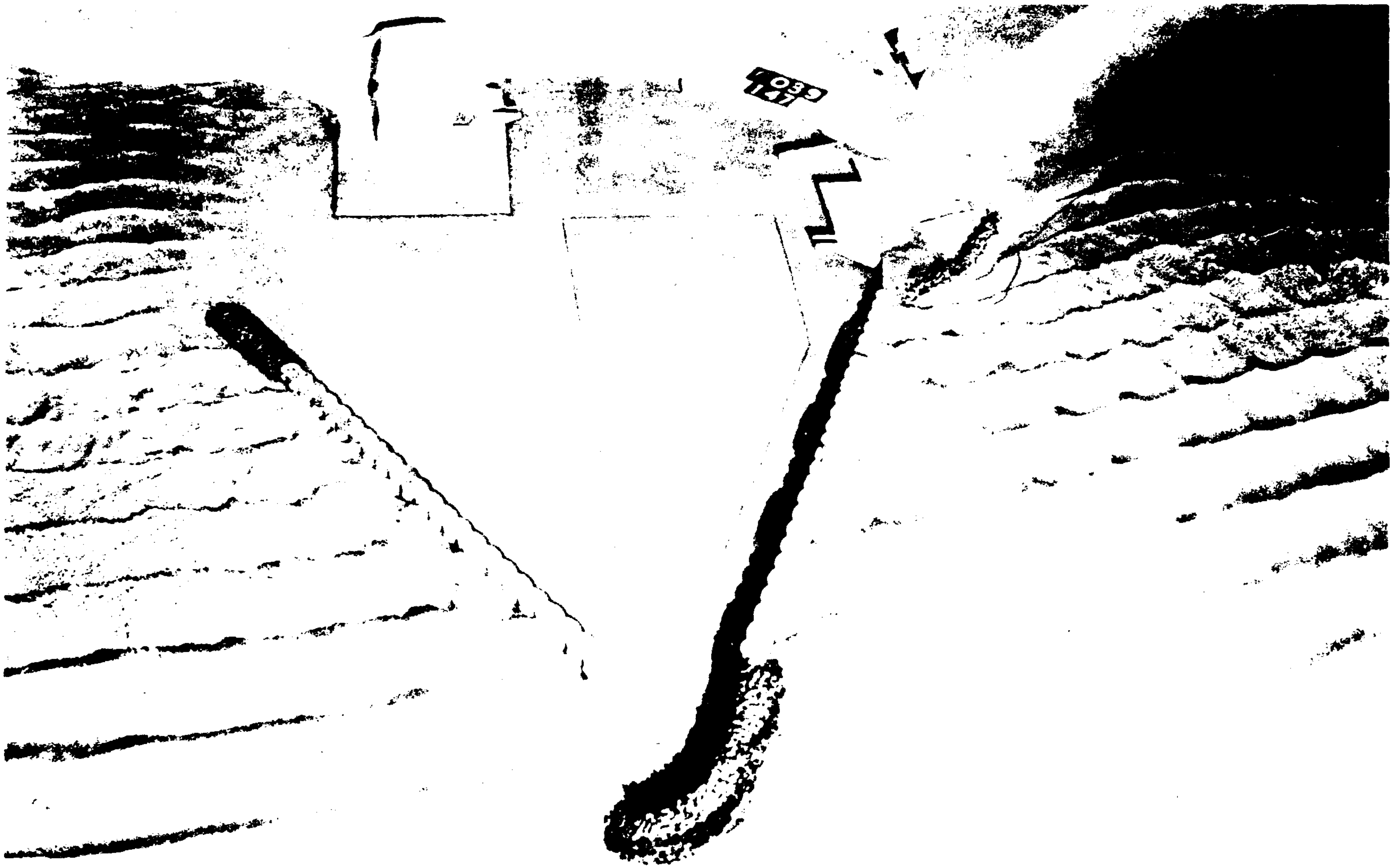


Photo B17. Typical monochromatic wave patterns for Plan 58; 5.9-sec, 5.1-ft test waves from north; +3.0 ft swl

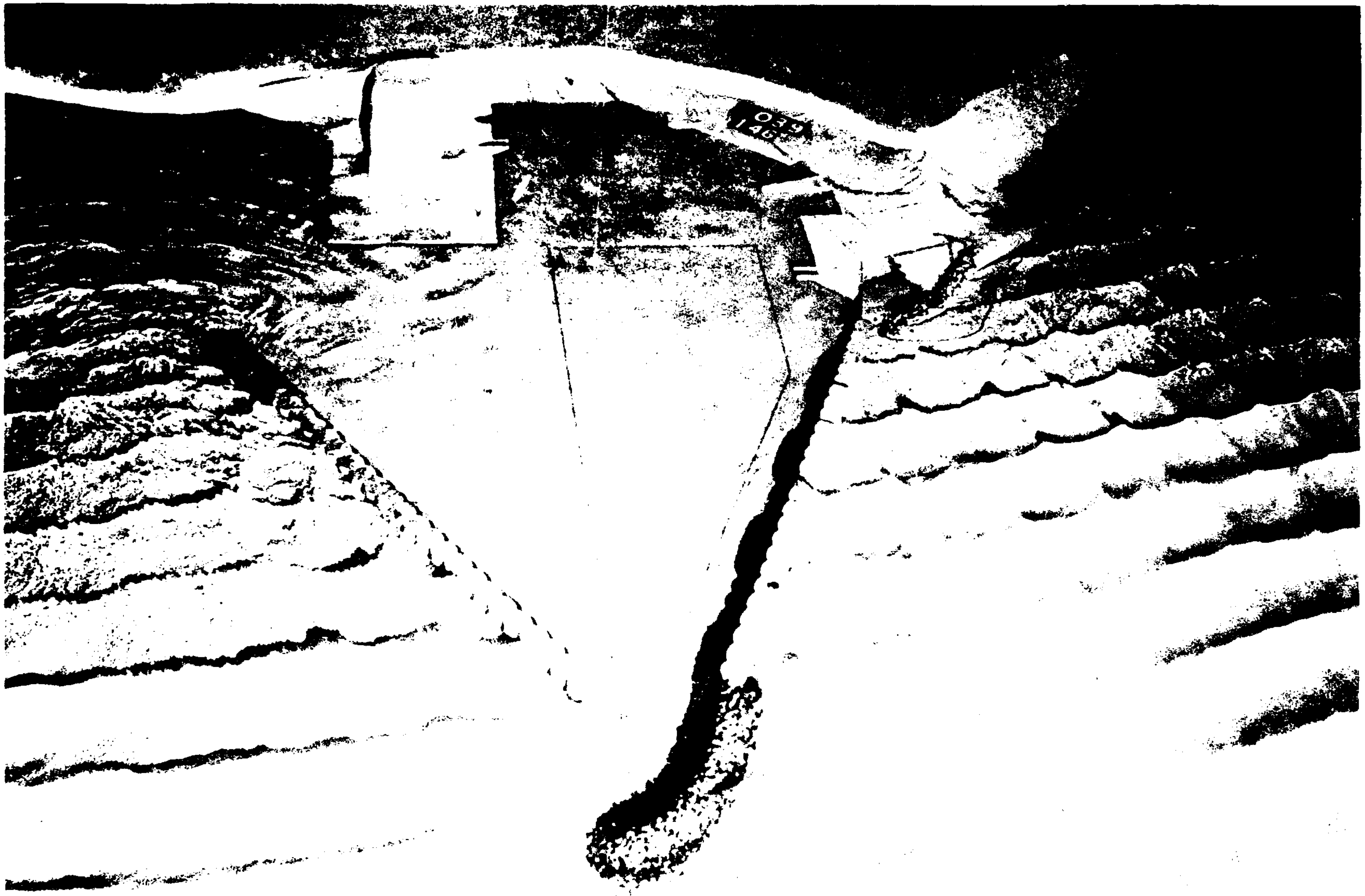


Photo B18. Typical monochromatic wave patterns for Plan 58; 6.2-sec, 6.3-ft test waves from north; +5.0 ft swl

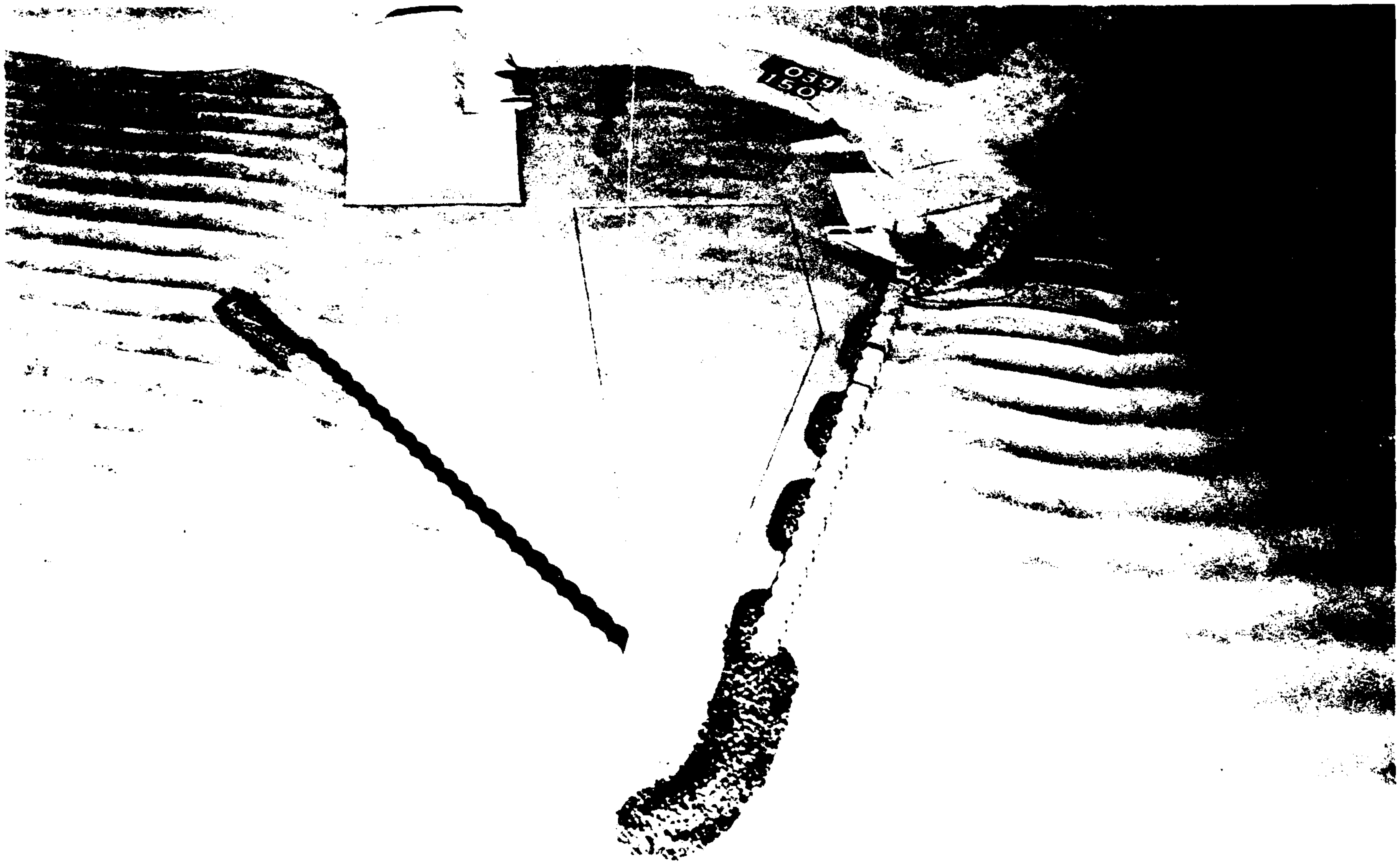


Photo B19. Typical monochromatic wave patterns for Plan 58; 5.0-sec, 2.0-ft test waves from northeast; +3.0 ft swl

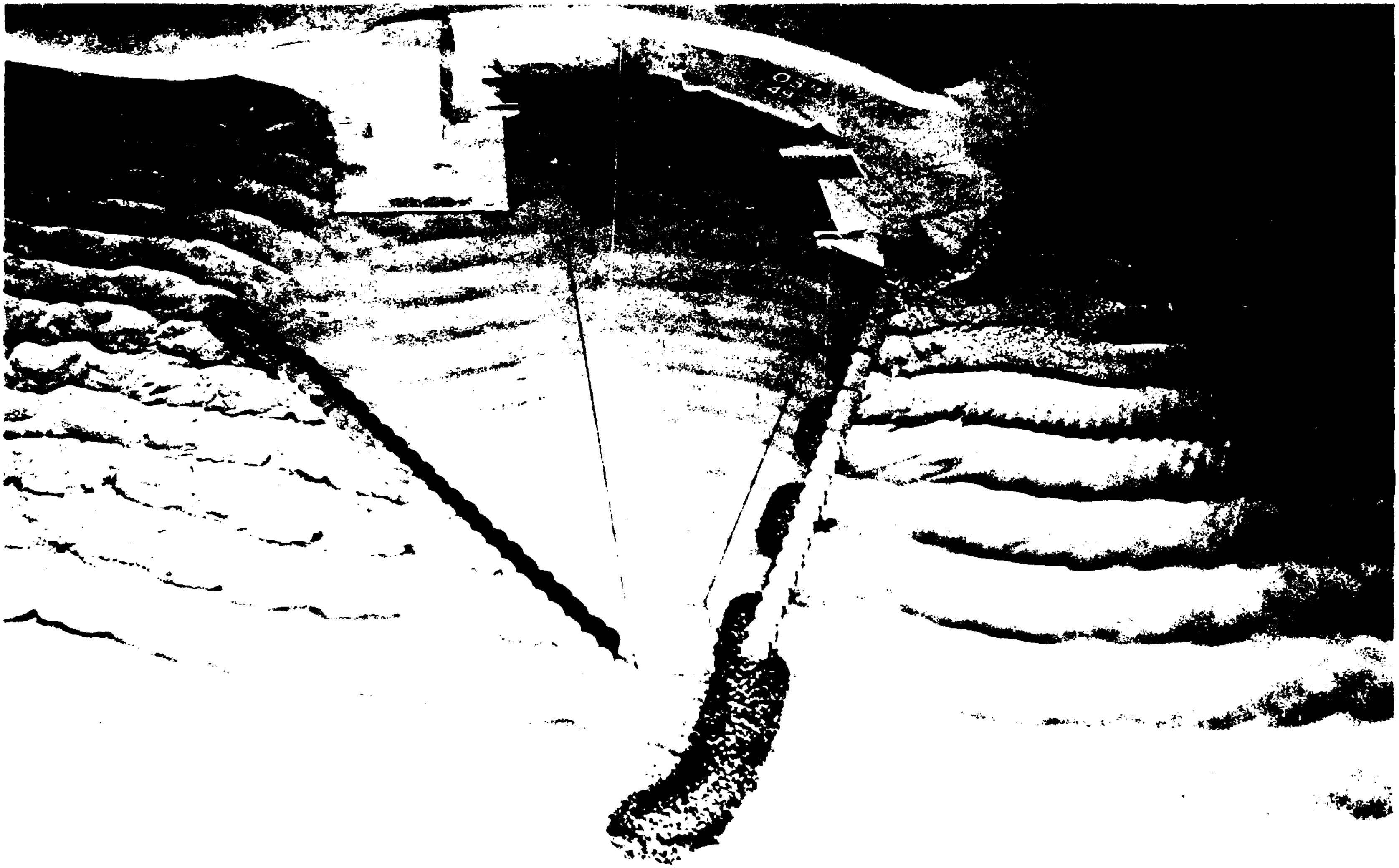


Photo B20. Typical monochromatic wave patterns for Plan 58; 5.9-sec, 4.3-ft test waves from northeast; +3.0 ft swl

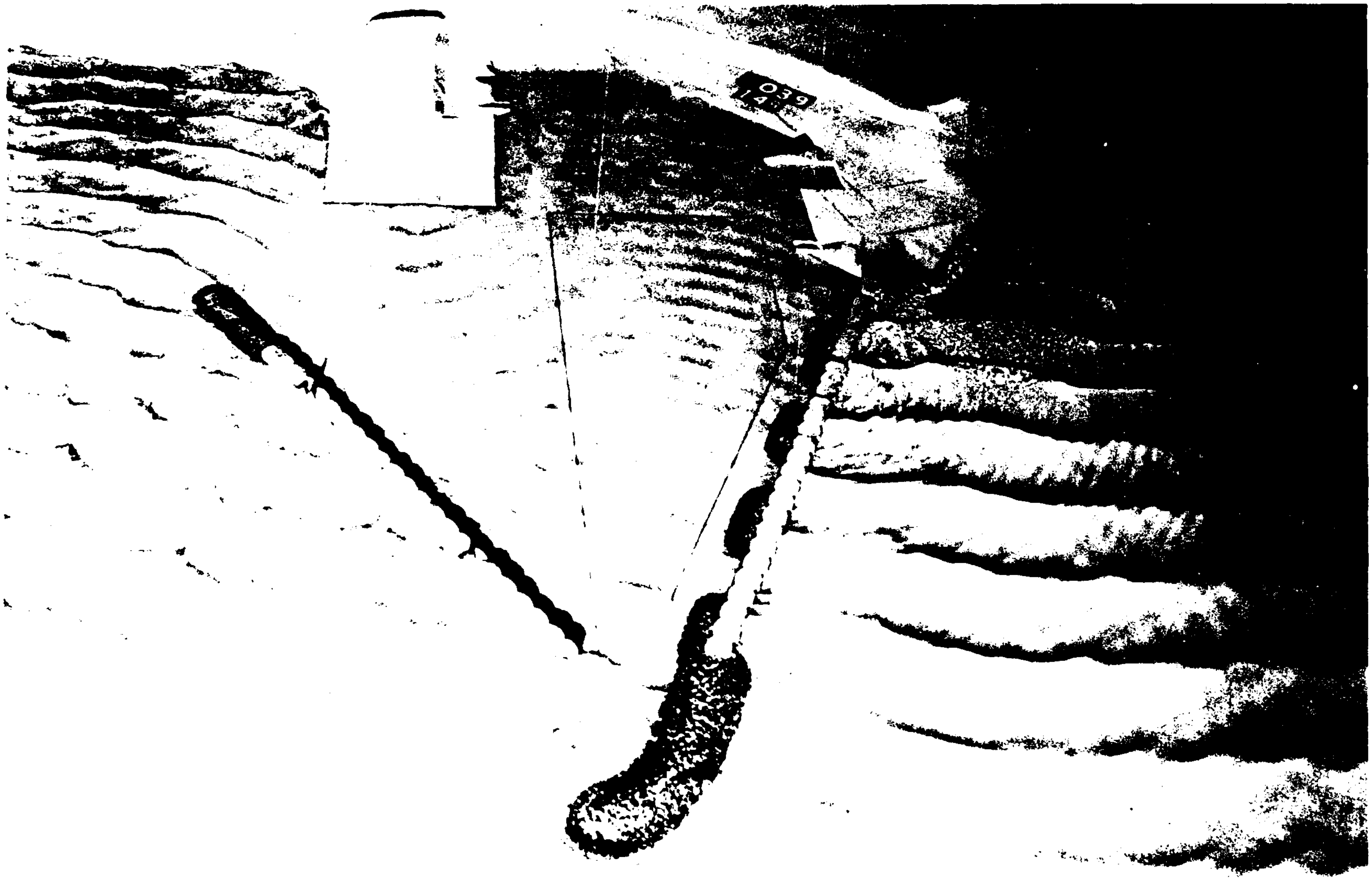


Photo B21. Typical monochromatic wave patterns for Plan 58; 6.2-sec, 5.2-ft test waves from northeast; +4.0 ft swl

Photo B22. Typical monochromatic wave patterns for Plan 58; 5.0-sec, 2.0-ft test waves from unrefracted northeast; +3.0 ft swl

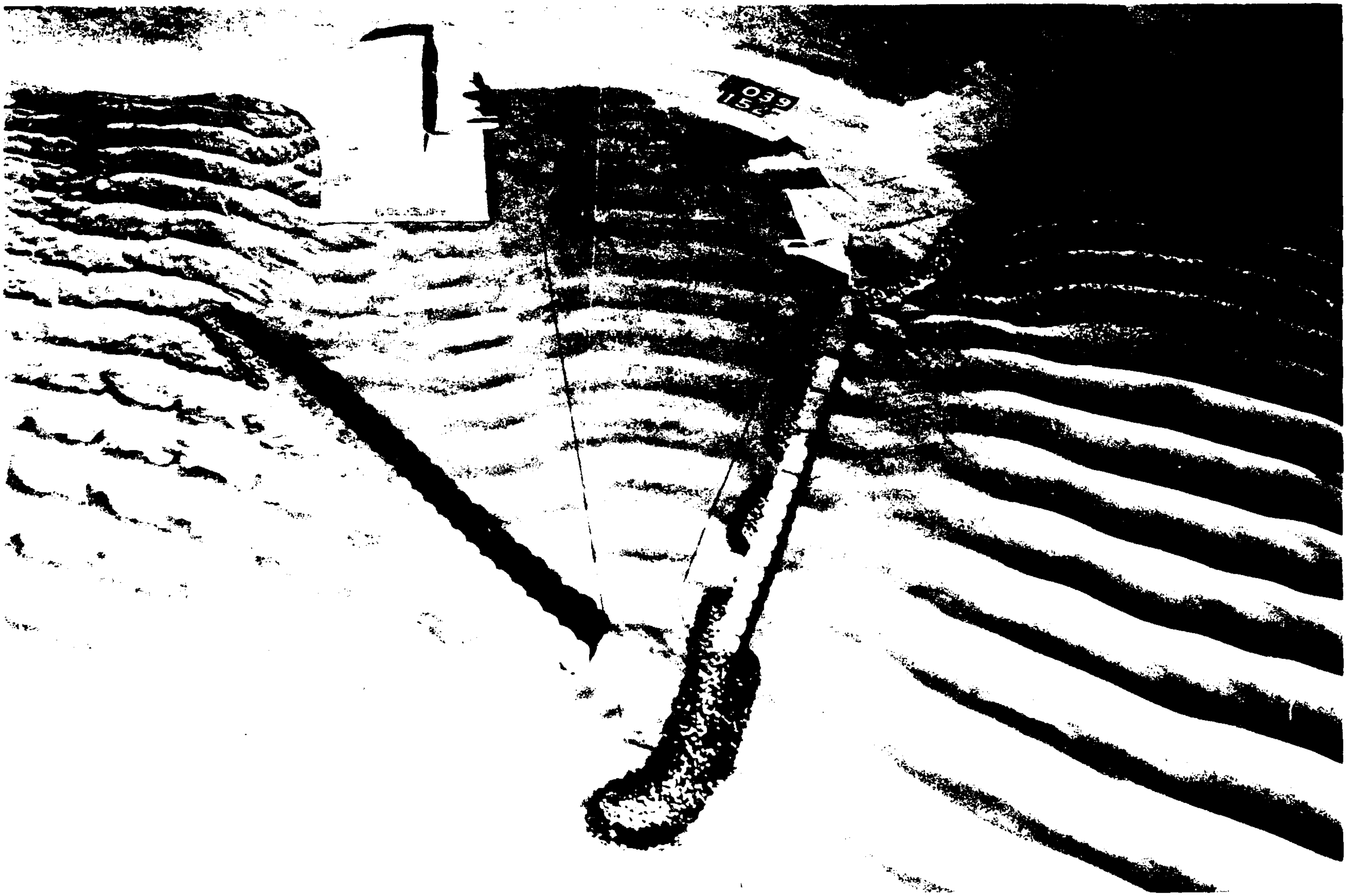


Photo B23. Typical monochromatic wave patterns for Plan 58; 5.9-sec, 4.3-ft test waves from unrefracted northeast; +3.0 ft swl

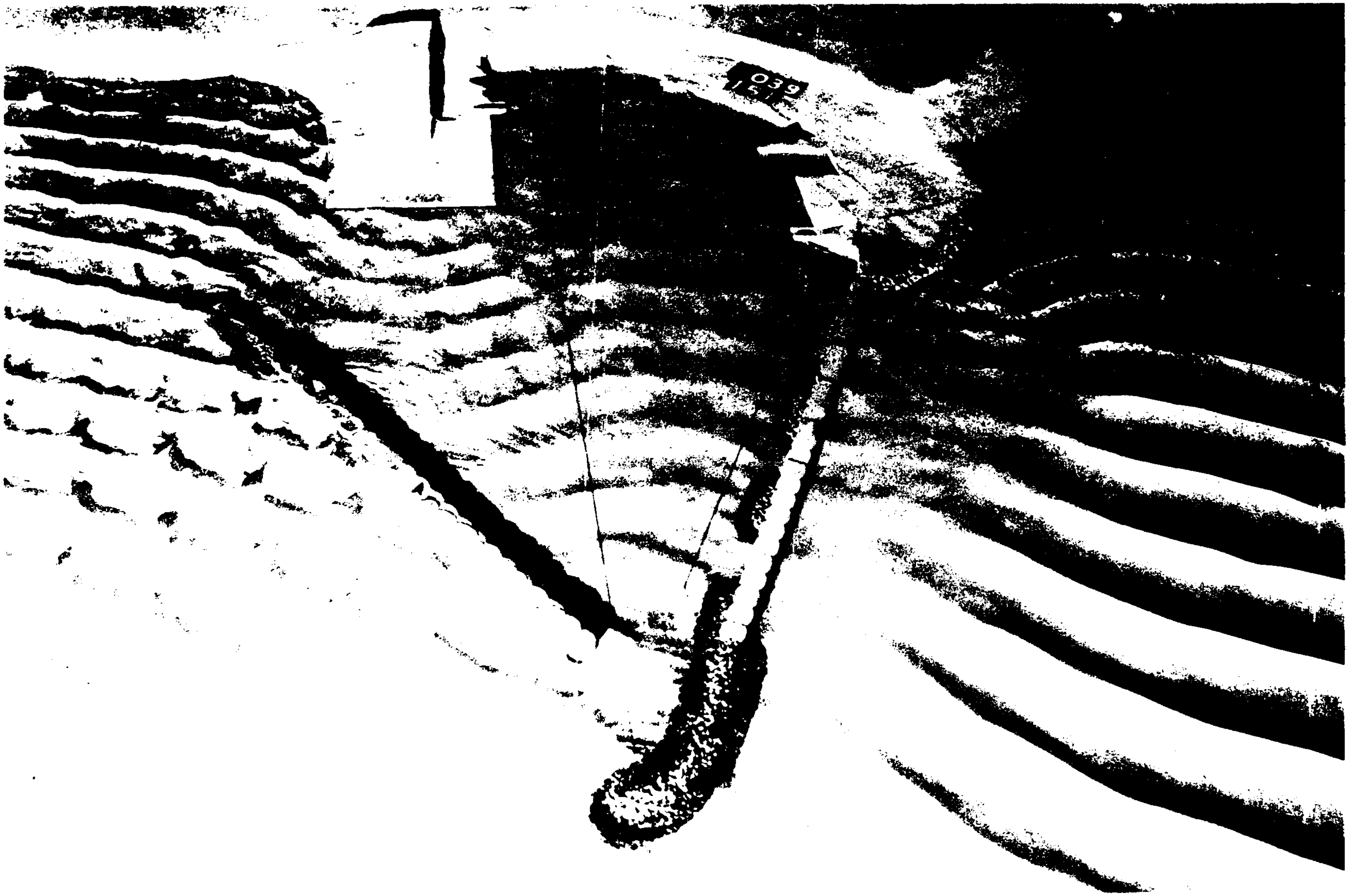
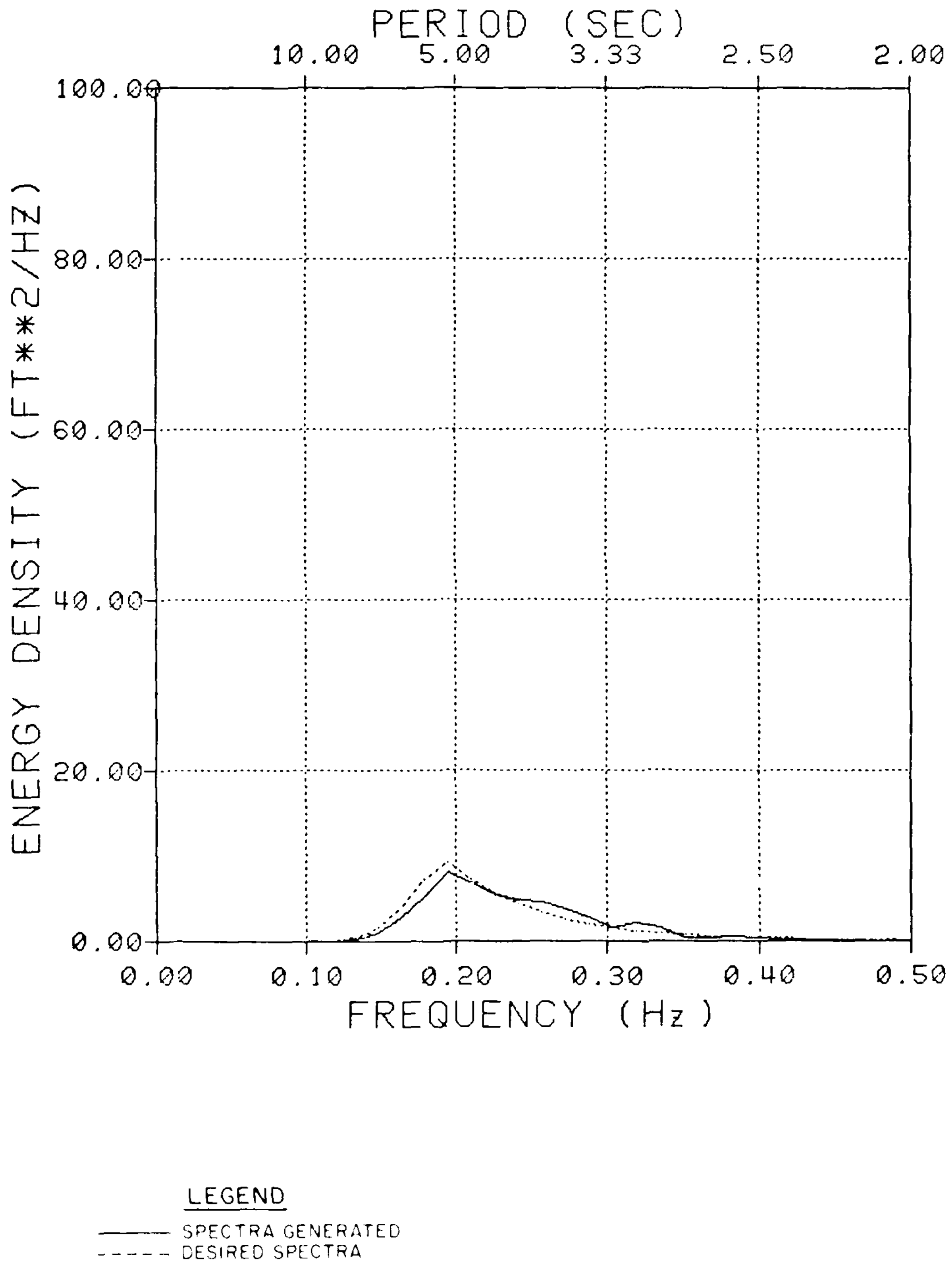


Photo B24. Typical monochromatic wave patterns for Plan 58; 6.2-sec, 5.2-ft test waves from unrefracted northeast; +4.0 ft swl



WAVE SPECTRA PLOTS
5.2-SEC, 3.7-FT WAVES

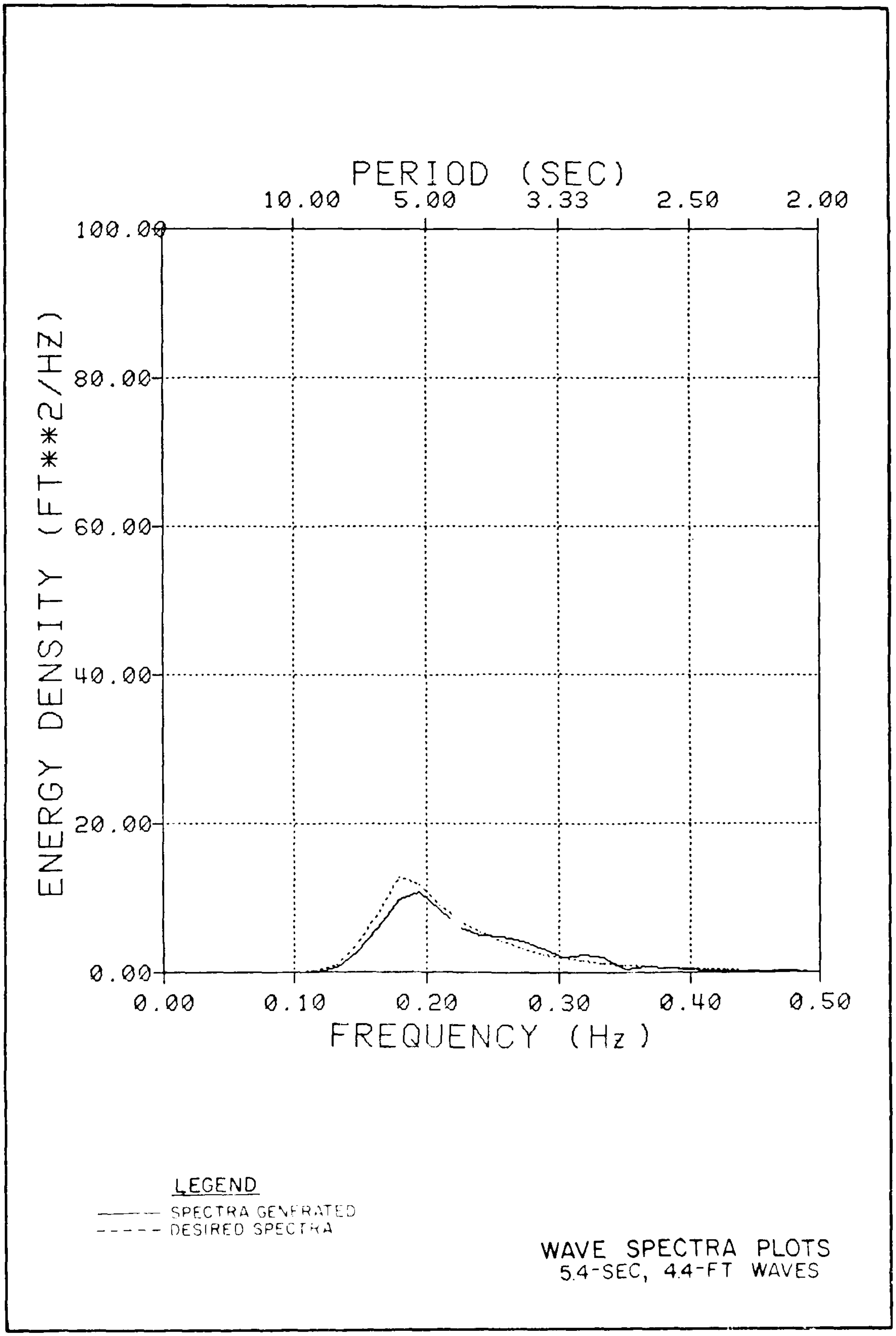
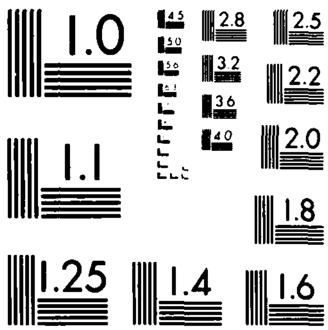

PERIOD (SEC)
10.00
5.00
3.33
2.50
2.00
100.00
80.00
60.00
40.00
20.00
0.00
ENERGY DENSITY (FT**2/HZ)
0.00
0.10
0.20
0.30
0.40
0.50
FREQUENCY (Hz)
LEGEND
SPECTRA GENERATED
DESIRED SPECTRA
WAVE SPECTRA PLOTS
5.4-SEC, 4.4-FT WAVES

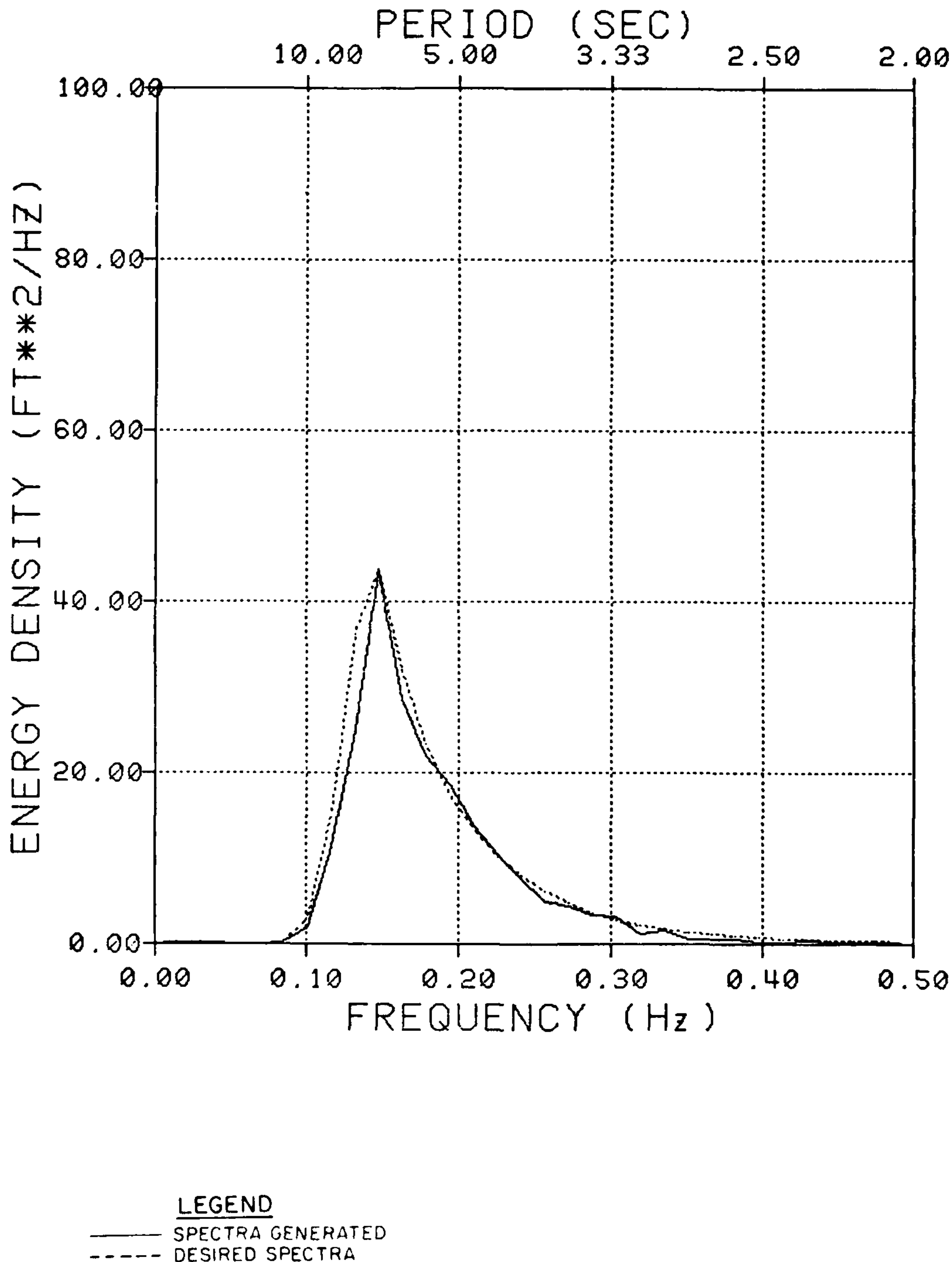
PLATE B2

AD-A149 257 BARCELONA HARBOR NEW YORK DESIGN FOR HARBOR IMPROVEMENTS HYDRAULIC MODEL INVESTIGATION(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS R R BOTTIN 4/4

UNCLASSIFIED AUG 84 CERC-TR-84-3 F/G 13/2 NL

END
FILMED
DTIC

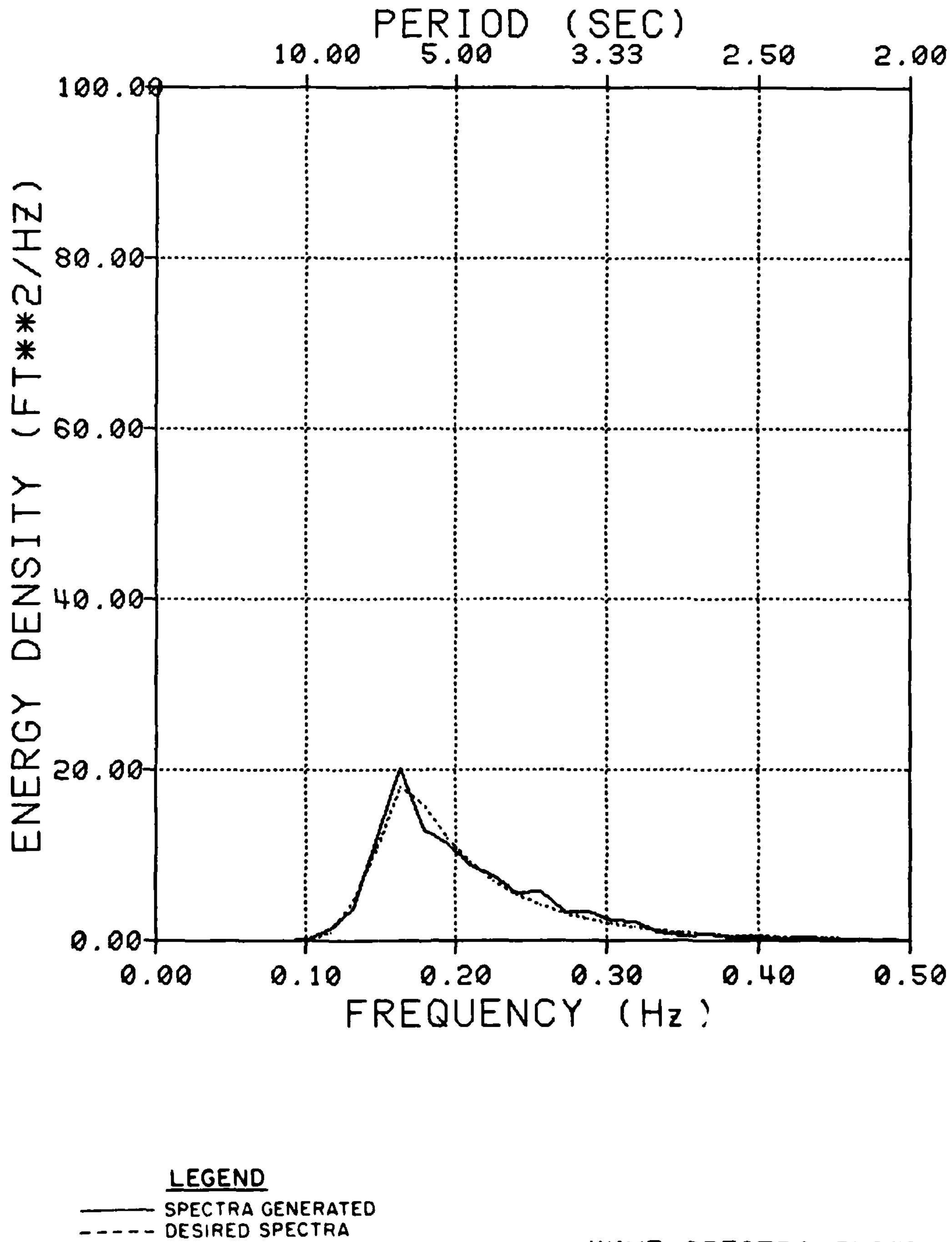

1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6



WAVE SPECTRA PLOTS
6.9-SEC, 7.6-FT WAVES

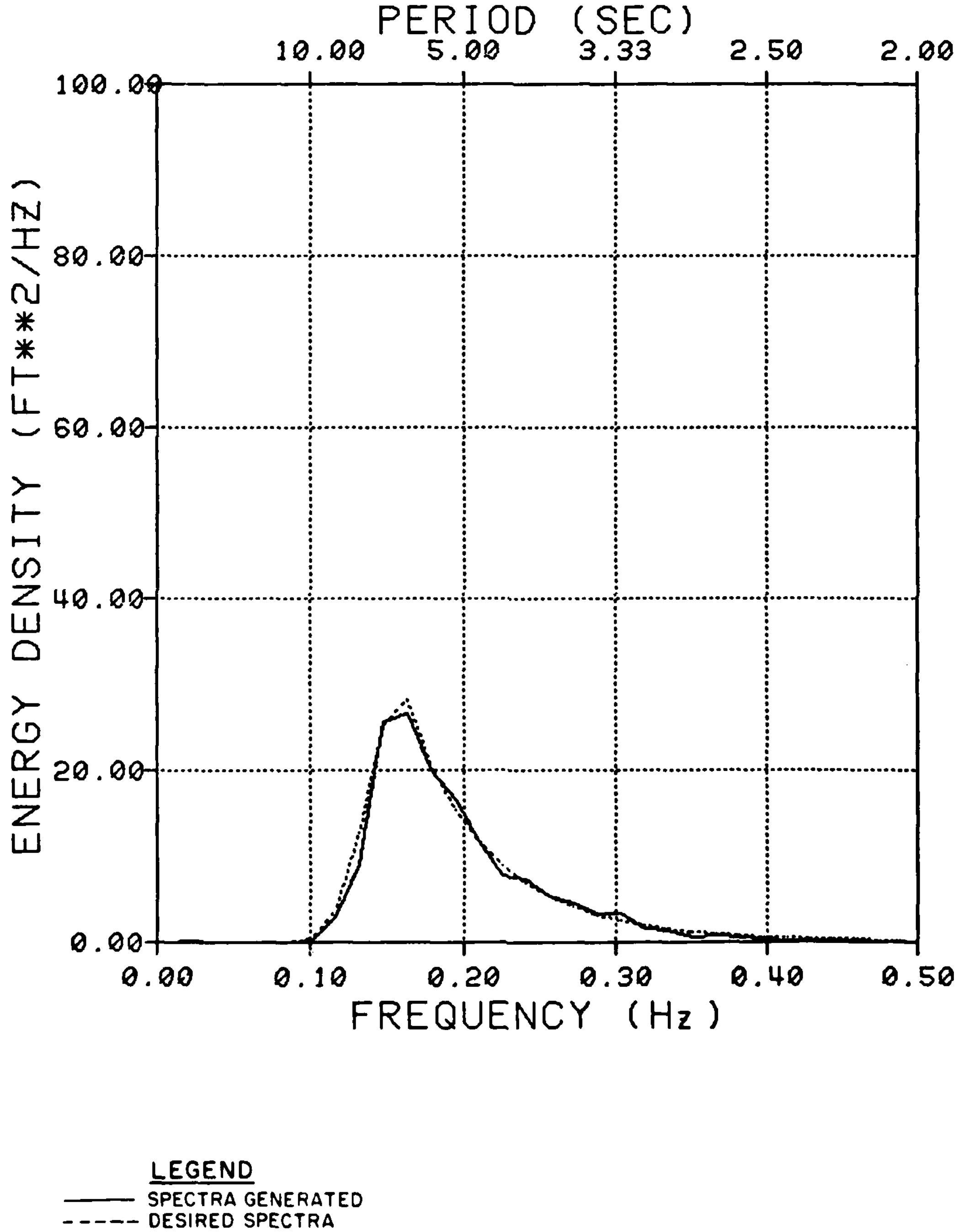
PLATE B4

PREVIOUS PAGE IS BLANK



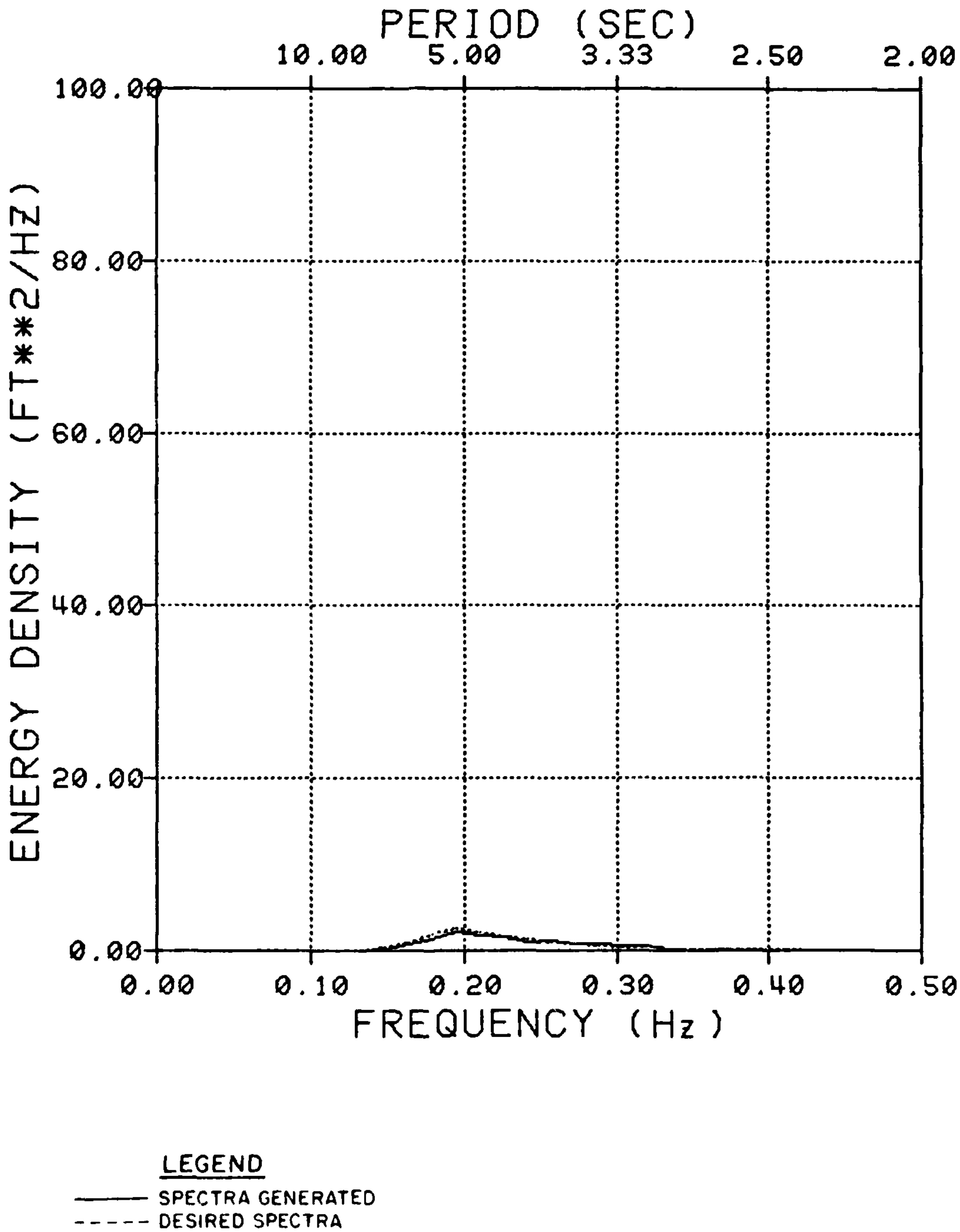
WAVE SPECTRA PLOTS
5.9-SEC, 5.1-FT WAVES

PLATE B5



WAVE SPECTRA PLOTS
6.2-SEC, 6.3-FT WAVES

PLATE B6



WAVE SPECTRA PLOTS
5.0-SEC, 2.0-FT WAVES

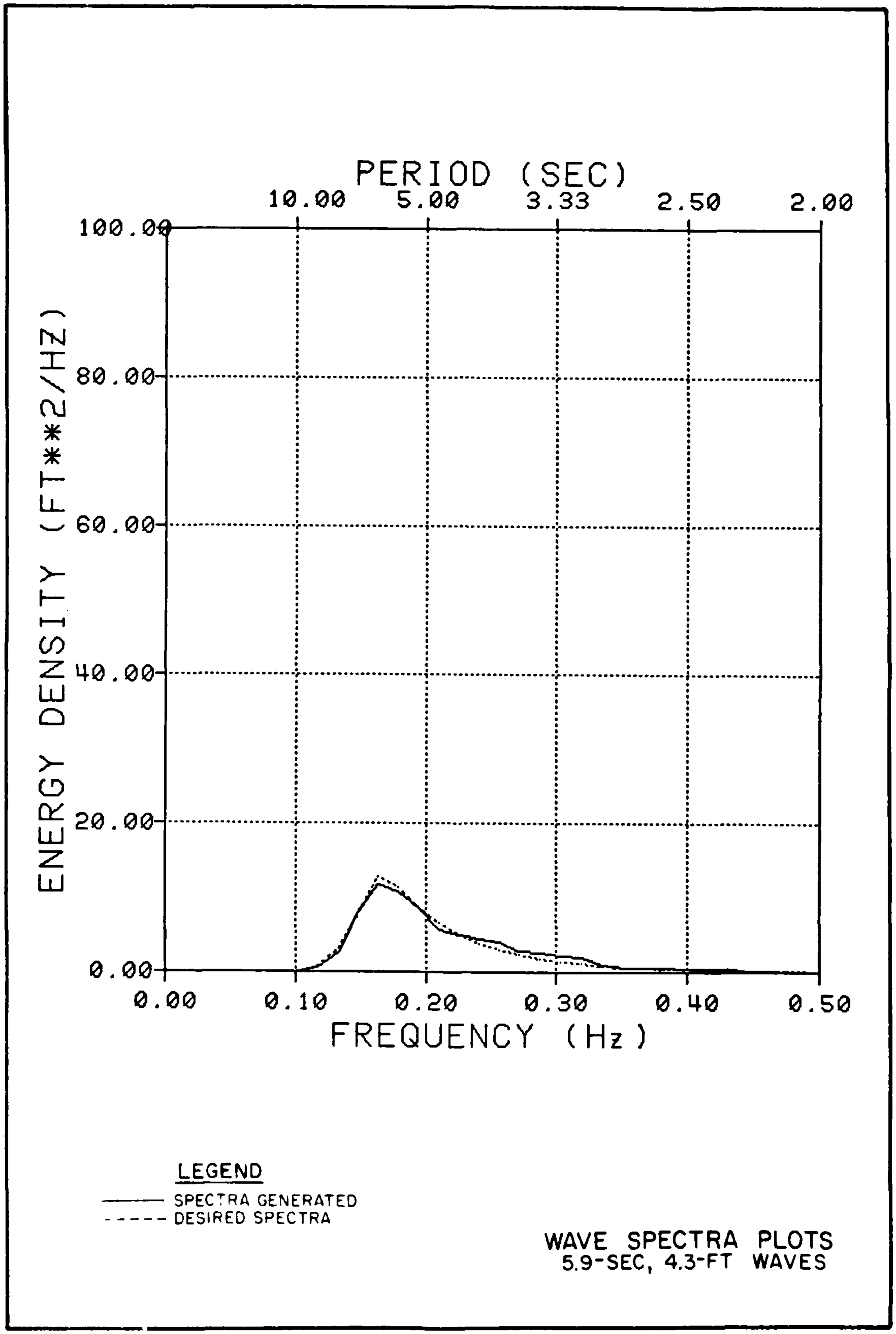
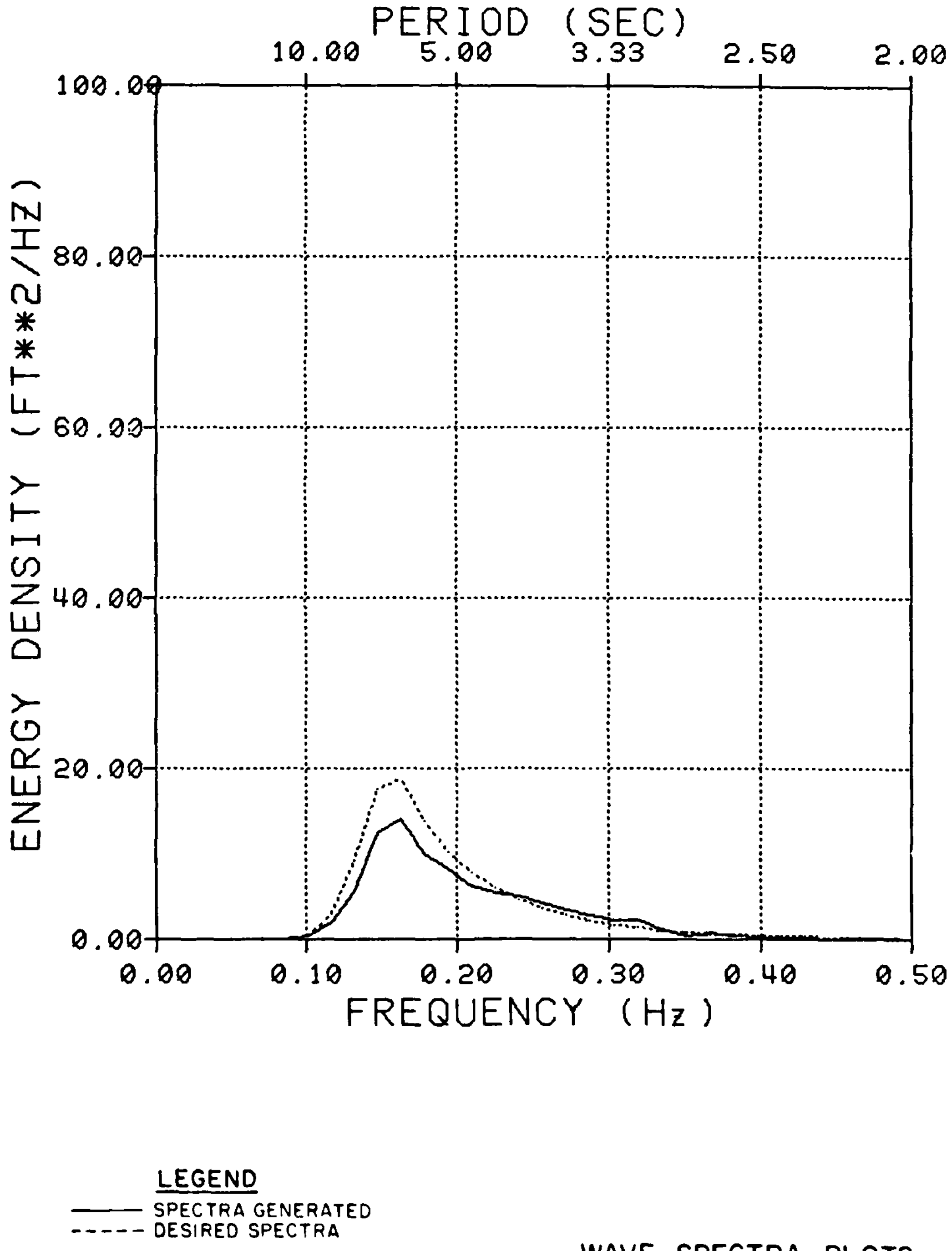
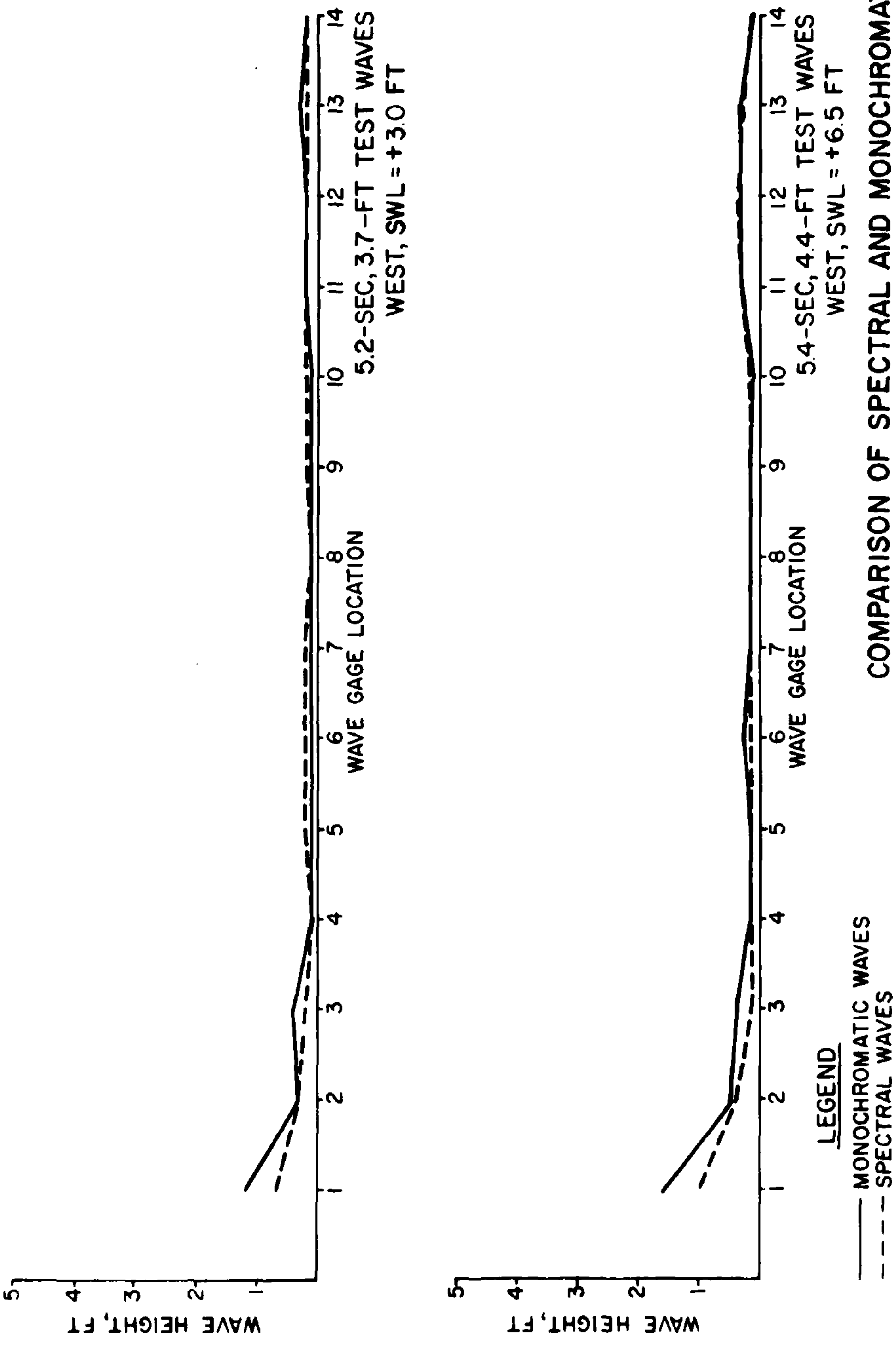

PERIOD (SEC)
10.00
5.00
3.33
2.50
2.00
100.00
80.00
60.00
40.00
20.00
0.00
ENERGY DENSITY (FT**2/HZ)
0.00
0.10
0.20
0.30
0.40
0.50
FREQUENCY (Hz)
LEGEND
SPECTRA GENERATED
DESIRED SPECTRA
WAVE SPECTRA PLOTS
5.9-SEC, 4.3-FT WAVES

PLATE B8

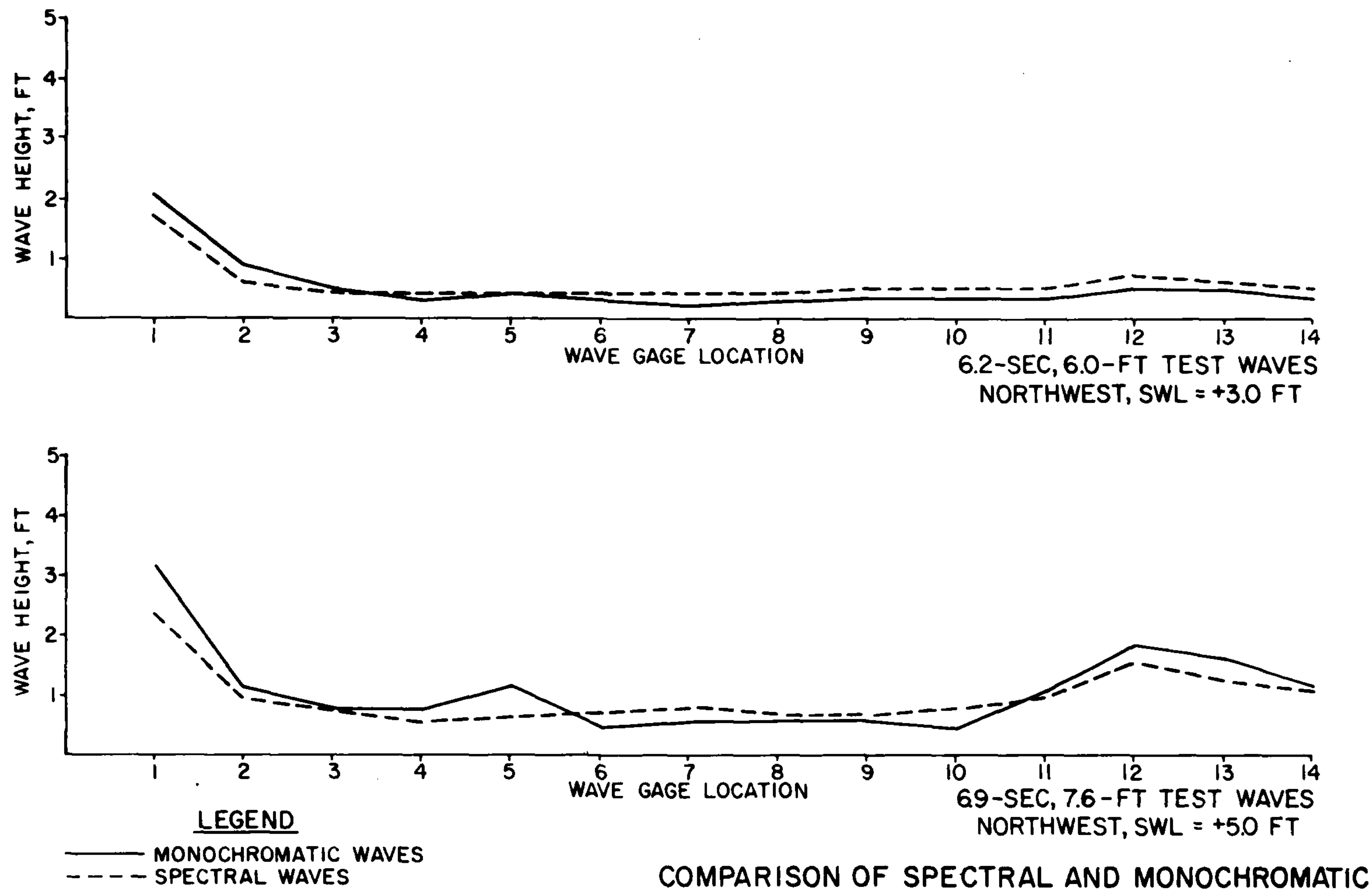


WAVE SPECTRA PLOTS
6.2-SEC, 5.2-FT WAVES

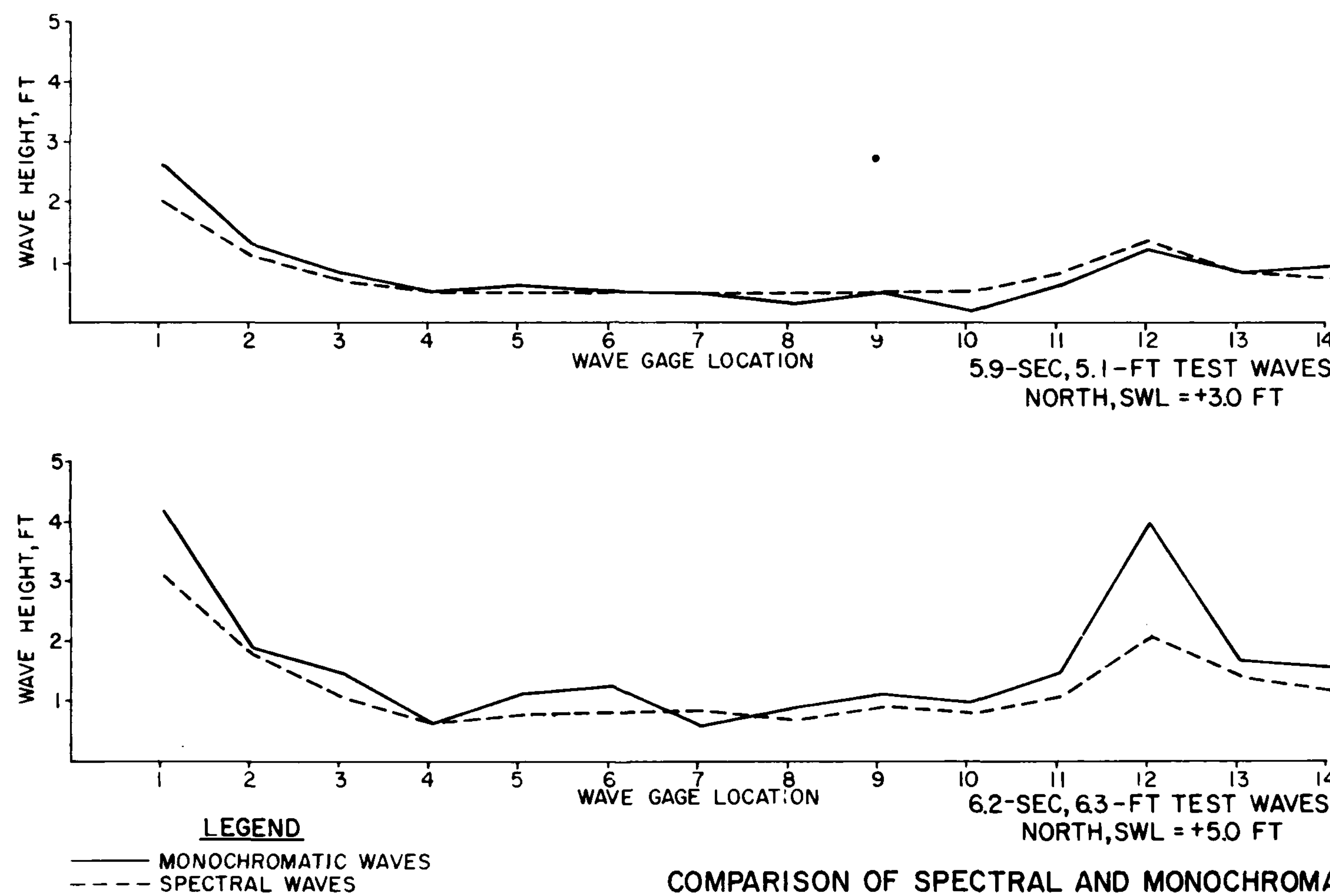
PLATE B9



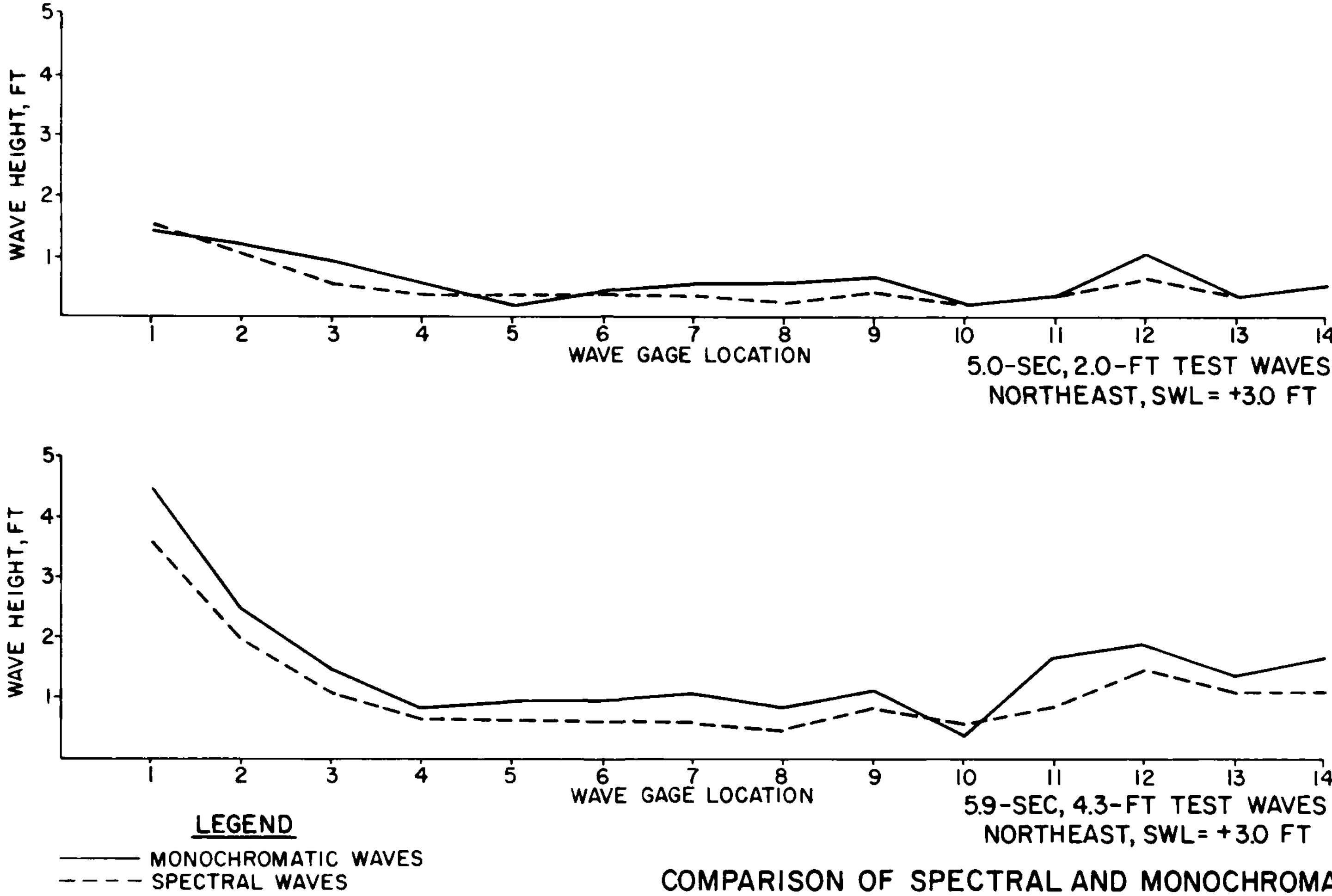
COMPARISON OF SPECTRAL AND MONOCHROMATIC
WAVES FROM WEST
SWL'S = +3.0 AND +6.5 FT



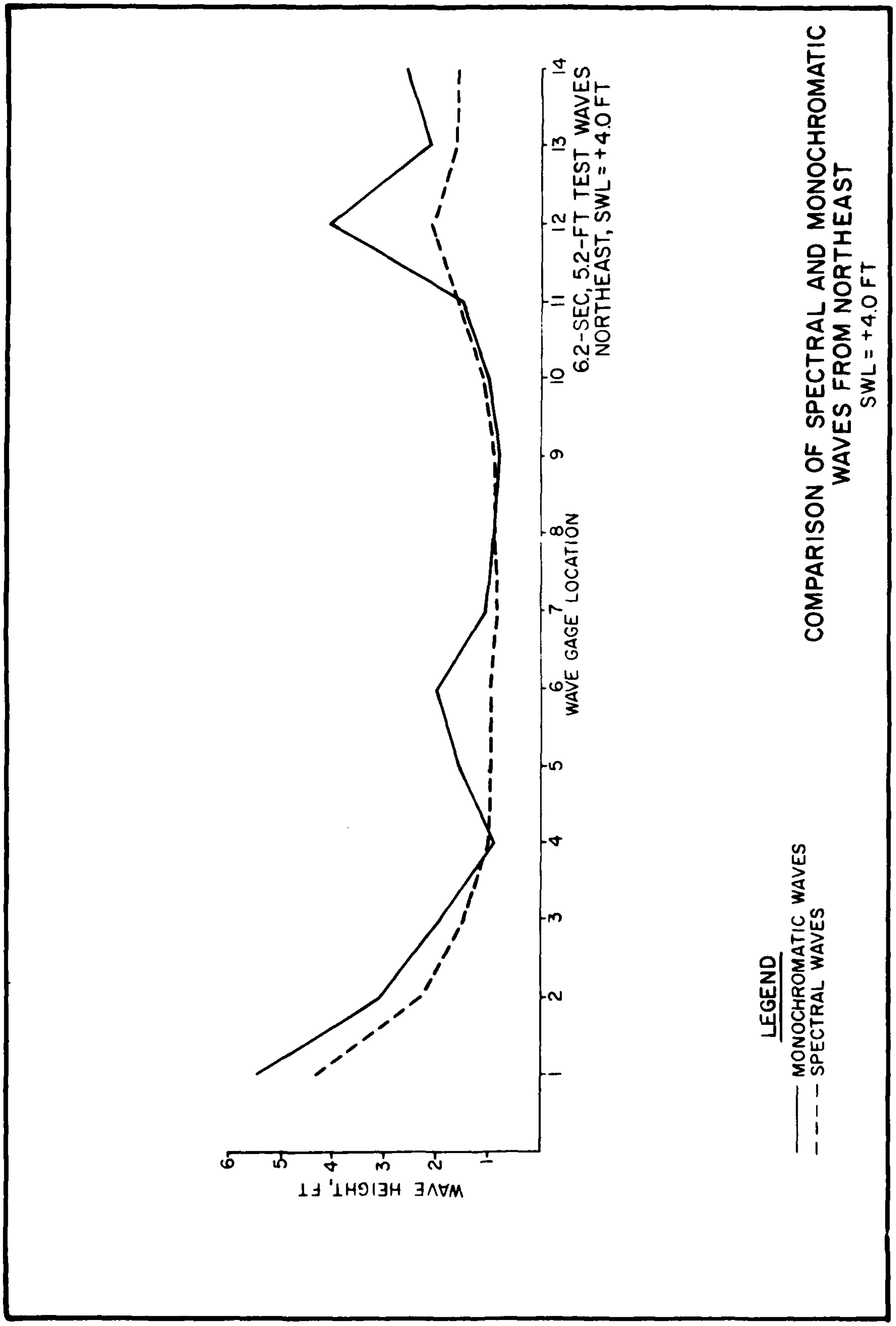
COMPARISON OF SPECTRAL AND MONOCHROMATIC
WAVES FROM NORTHWEST
SWL'S = +3.0 AND +5.0 FT

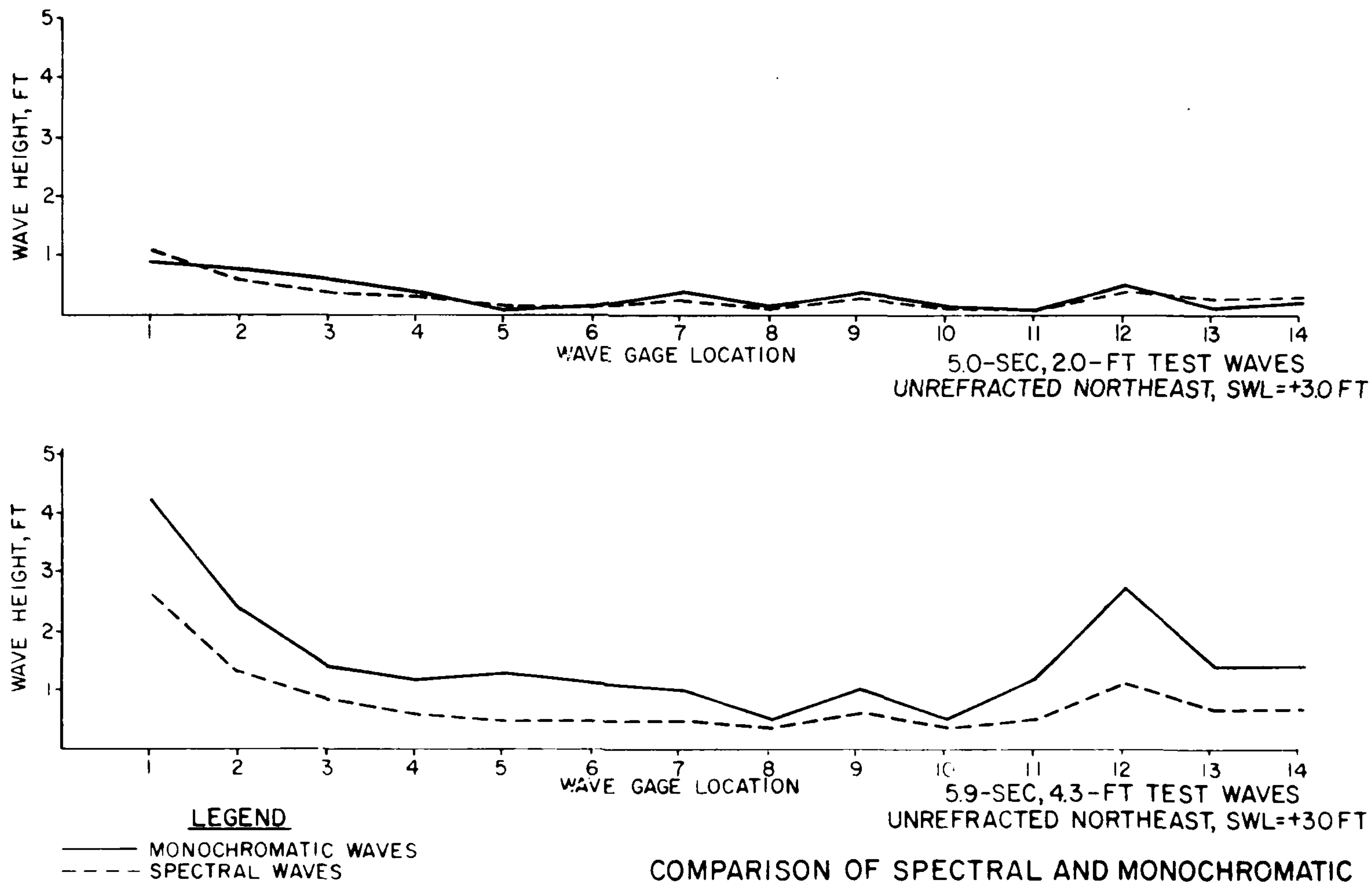


COMPARISON OF SPECTRAL AND MONOCHROMATIC WAVES FROM NORTH
SWL'S = +3.0 AND +5.0 FT

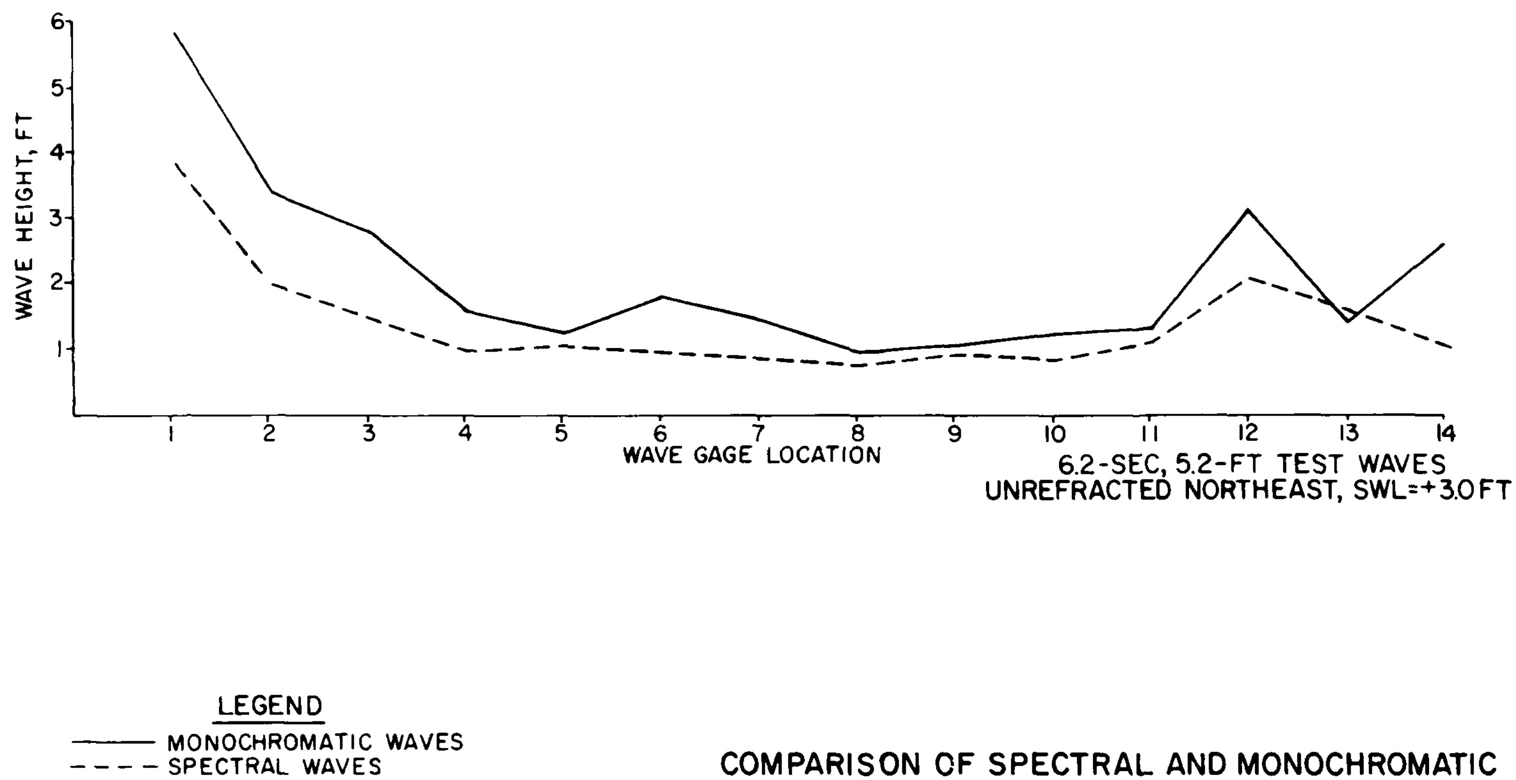


COMPARISON OF SPECTRAL AND MONOCHROMATIC
WAVES FROM NORTHEAST
SWL = +3.0 FT

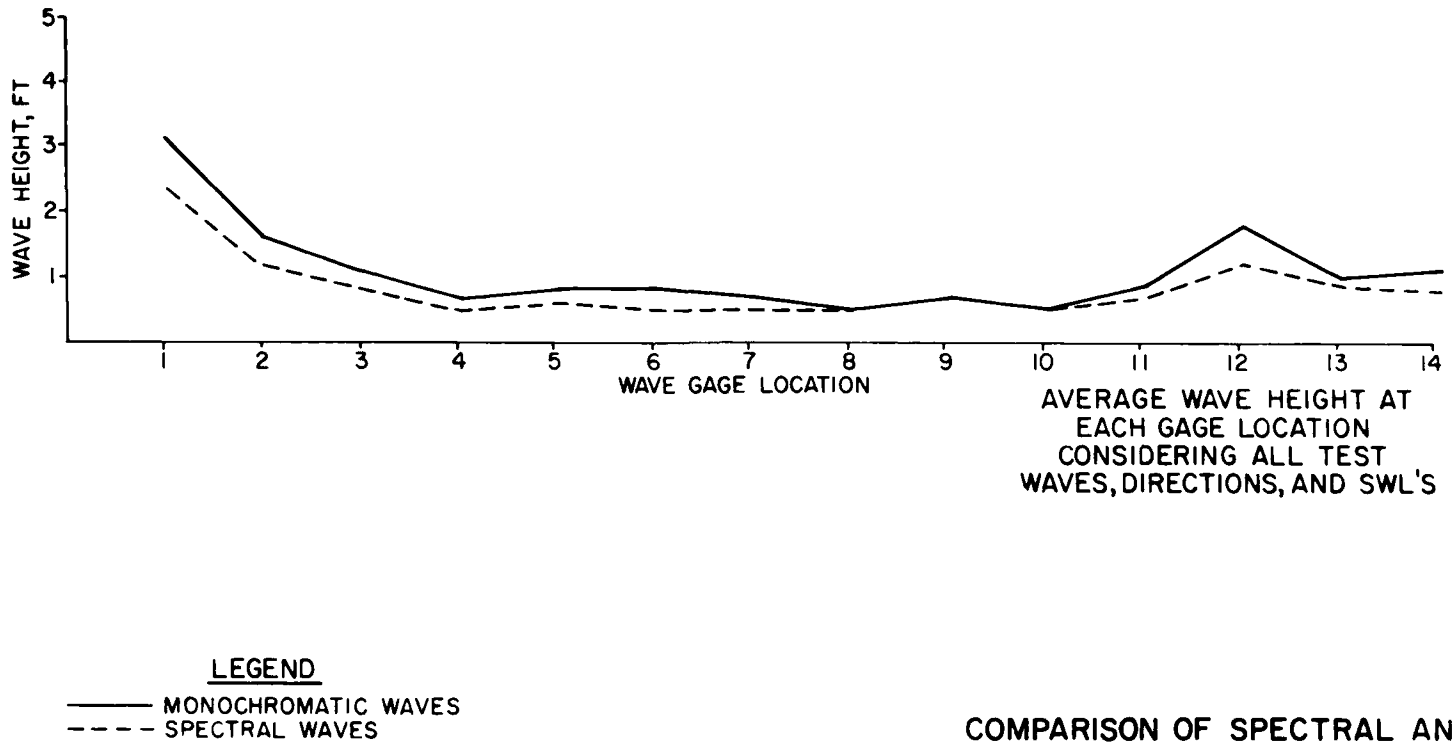

LEGEND
MONOCHROMATIC WAVES
SPECTRAL WAVES
WAVE HEIGHT, FT
WAVE GAGE LOCATION
6.2-SEC, 5.2-FT TEST WAVES
NORTHEAST, SWL = +4.0 FT
COMPARISON OF SPECTRAL AND MONOCHROMATIC
WAVES FROM NORTHEAST
SWL = +4.0 FT



COMPARISON OF SPECTRAL AND MONOCHROMATIC WAVES FROM UNREFRACTED NORTHEAST
SWL = +3.0 FT



COMPARISON OF SPECTRAL AND MONOCHROMATIC
WAVES FROM UNREFRACTED NORTHEAST
SWL = +3.0 FT



COMPARISON OF SPECTRAL AND MONOCHROMATIC WAVES
FOR ALL TEST CONDITIONS

APPENDIX C: 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_{m_o}	Energy-based wave
$H_{1/3}$	Significant wave height
K_r	Refraction coefficient
K_s	Shoaling coefficient
L	Length
T	Time
V	Velocity
$\forall$	Volume

*U.S. GOVERNMENT PRINTING OFFICE:

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