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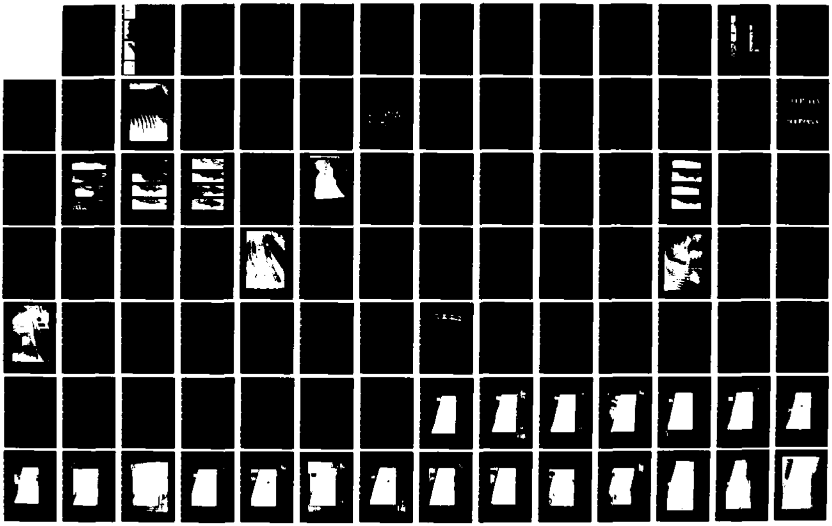

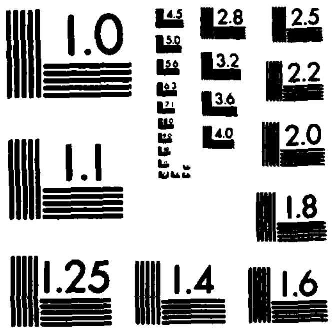

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TECHNICAL REPORT HL-83-15

DESIGN FOR PREVENTION OF BEACH EROSION AT PRESQUE ISLE BEACHES, ERIE, PENNSYLVANIA

Hydraulic Model Investigation

by

William C. Seabergh

Hydraulics Laboratory

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June 1983

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for U. S. Army Engineer District, Buffalo
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Presque Isle Peninsula, Erie, Pennsylvania, is a recurved sand spit with a lakeward perimeter of 9 miles that extends a protective arm around Erie Harbor. The peninsula provides 11 recreational beaches facing Lake Erie which are part of a State park that occupies almost the entire peninsula and contains an ecological reservation and numerous recreational facilities. Over the past 150 years, the integrity of the peninsula has been threatened by erosion of the beaches due to a decreasing sand supply, and numerous efforts to halt this erosion have been ineffective.

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20. ABSTRACT (Continued).

A 1:50-scale (undistorted) physical hydraulic model was constructed to aid in evaluating the use of detached offshore breakwaters as a preventive measure against shoreline erosion. The model reproduced a 9,400-ft length of shoreline which included State Park Beaches 4, 5, and 6. These beaches contained a section of shoreline with an existing groin field and a reach of shoreline with few shoreline structures as it was desired to study the interaction of the proposed structures with both types of beaches.

Three prototype offshore breakwaters had been constructed at Beach 10 at Presque Isle in 1978. An examination of this reach of shoreline was made with a movable-bed model to determine the suitable modeling materials and techniques to be used in the study. After a series of tests, a 0.78-mm-median-diameter coal sediment (specific gravity = 1.35) satisfactorily reproduced shoreline development in the region of the breakwaters. Tests of the proposed offshore breakwaters at Beaches 4, 5, and 6 then were conducted using coal for sediment tracer tests and in beach-fill tests. Wave-generated current patterns also were observed. Testing of existing conditions indicated that for waves oblique to the shoreline, strong longshore currents were generated within the 1,000-ft groin cells and were deflected offshore by the groins. Sediment tracer tended to move offshore at the groins and then move alongshore on the shoreward face and trough of the main offshore bar.

Various offshore breakwater plans were tested. The 350-ft spacing between 150-ft-long offshore breakwaters produced very satisfactory results within the reach of the groin field, outside the groin field, and with the groins removed. Generally, tombolo development was easily initiated. The extent of tombolo development, i.e., whether or not it would attach to the offshore breakwater, was a function of many variables including the proximity to groins, water level, wave height and period, crown elevation of the structure, distance of the breakwater from the initial shoreline, and supply of sediment. Once a tombolo had attached to the breakwater, high water levels and waves overtopping the breakwater were required to erode the tombolo beachline back from the offshore breakwater. The strong longshore current systems noted in the base tests were replaced by slower eddy-like currents behind the breakwaters. Currents moving lakeward between the breakwaters for relatively large wave conditions were diffused. Sediment tracer and beach-fill tests indicated that most sediment was retained shoreward of the line formed by the offshore breakwaters. When tombolos were fully built behind the breakwaters, bypassing on the lakeward side of the breakwater was noted.

PREFACE

A request for a model investigation of a portion of Presque Isle Peninsula, Erie, Pennsylvania, was initiated by the District Engineer, U. S. Army Engineer District, Buffalo (NCB). The study was authorized by the Office, Chief of Engineers, U. S. Army, and funds for the U. S. Army Engineer Waterways Experiment Station (WES) to conduct the study were authorized by NCB on 16 November 1979.

The model study was conducted during the period May 1980-February 1982 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory; Mr. F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; and Dr. R. W. Whalin and Mr. C. E. Chatham, Jr., former and acting Chiefs of the Wave Dynamics Division. Testing was performed by Messrs. E. F. Lane, J. W. McCoy, L. A. Barnes, and M. G. Mize, Engineering Technicians, with the assistance of Mr. R. E. Ankeny, Computer Technician, under the supervision of Mr. W. C. Seabergh, Project Engineer. This report was prepared by Mr. Seabergh.

During the course of the investigation, liaison was maintained with NCB by means of monthly progress reports, telephone communications, and conferences. The following personnel visited WES to observe model operation and participate in conferences during the course of the study: Mr. Bob Adams, State of Pennsylvania; Messrs. Larry Hiipakka, Charlie Johnson, and Stan Boc, North Central Division; Messrs. Don Liddell, Denton Clark, Jr., Richard Gorecki, J. A. Foley, Rao Yalamonchili, George Brooks, Ken Hallock, Dick Aguglia, and Ms. Joan Pope, NCB; and Dr. Dag Nummedal, Consultant for NCB.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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

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

Multiply	By	To Obtain
acres	0.4047	hectares
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
tons (2,000 lb, mass)	907.1847	kilograms

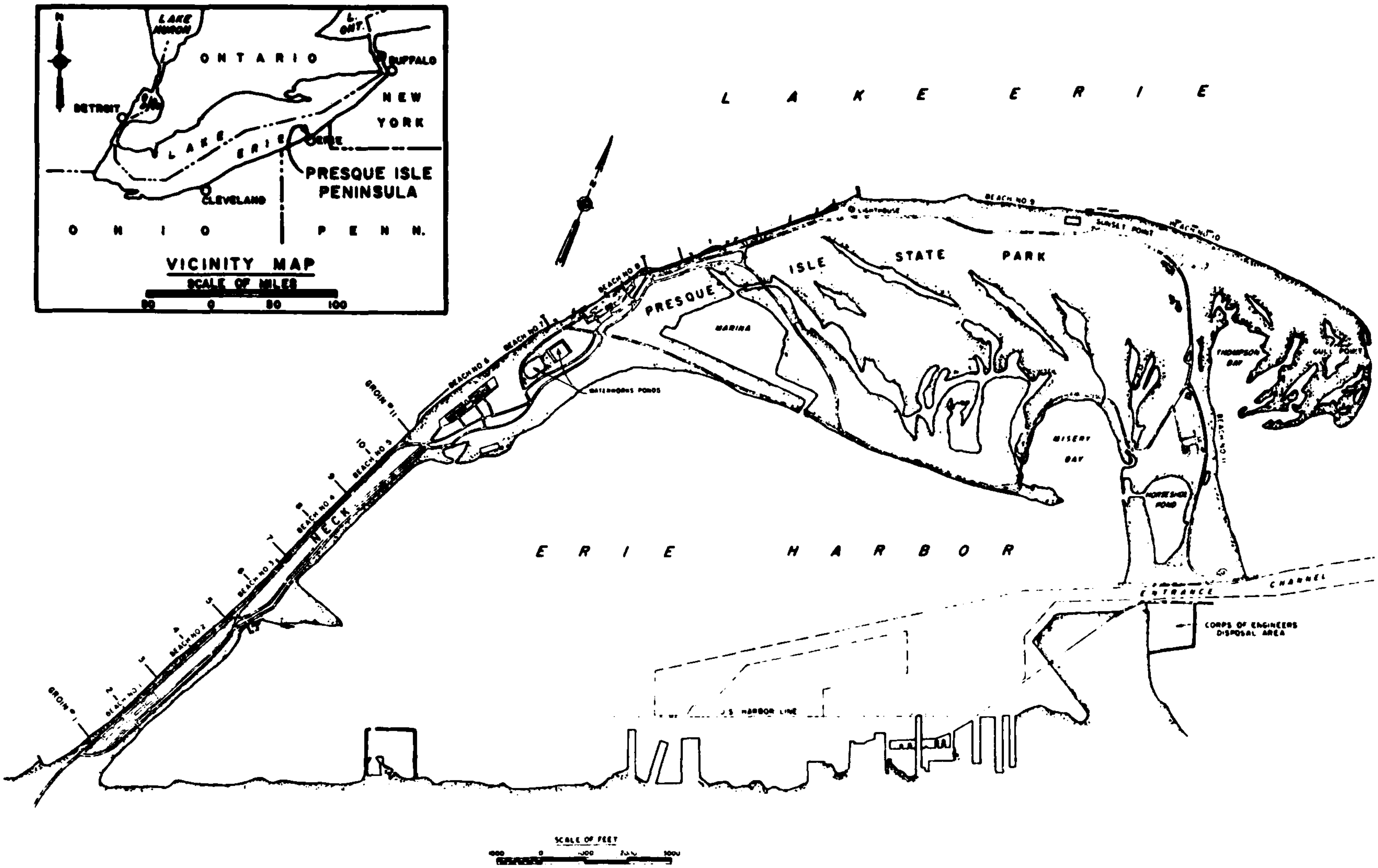

Figure 1. Vicinity and location maps

DESIGN FOR PREVENTION OF BEACH EROSION AT PRESQUE ISLE BEACHES, ERIE, PENNSYLVANIA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Presque Isle Peninsula is a recurved sand spit with a lakeward perimeter of approximately 9 miles* extending a protective arm around Erie Harbor, Erie, Pennsylvania (see Figure 1). It is located on the south shore of Lake Erie, 78 miles southwest of Buffalo, New York, and 102 miles northeast of Cleveland, Ohio. The Lake Erie side of the peninsula is fronted with 11 recreational beaches which are heavily used during the summer season and which are a part of the Pennsylvania Park Service. Presque Isle State Park, containing 3,200 acres, has averaged 3,800,000 visitors annually for the past 10 years. Also located in the park are facilities for boating, hiking, fishing, and bird-watching and extensive acreages for botanical and ecological studies.

2. Presque Isle Peninsula is unique along the south shore of Lake Erie. Historically, it is hypothesized (USAED, Buffalo, 1980) that the peninsula evolved on a glacial morainal till platform which developed about 12,800 years ago. The platform is 12 miles long and 3-1/2 miles wide and about 25 to 30 ft below low water datum (lwd). Presque Isle now occupies the eastern portion of the platform as predominantly westerly waves have caused the peninsula to migrate across the platform and slump off the eastern edge.

The Problem

3. As noted from the tendency for the peninsula to migrate easterly along the coast, and due to a diminishing supply of sand feeding the peninsula, erosion problems would be expected to develop along the peninsula's beaches.

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

From the early 1800's when Erie Harbor was first developed, shore protection along the neck of the peninsula, where it joins the mainland on the west, has been required in order to prevent breaching and thus opening the harbor to wave action from the lake. Breaks up to 1 mile wide developed until preventive measures such as cribwork breakwaters filled with stone and brush weighted with stone were placed along the shoreline in the 1836-1864 period. However, even these failed in a short period of time and efforts have continued to the present to prevent breaching of the neck as part of the project for improvement of Erie Harbor.

4. Severe beach erosion along the entire peninsula in the 1950's led to the cooperative beach protection program between the State of Pennsylvania and the Federal Government authorized in 1954. This program included improvement of some existing groin structures, construction of 10 sheet-pile groins, and the placement of 4,150,000 cu yd of sand beach fill. Figure 2a shows the Beaches 4, 5, and 6 shoreline. Additional beach fill has been periodically required up to the present. The basic problem under study is to maintain beaches along the peninsula which will protect Erie Harbor, provide recreational areas, and maintain the integrity of the peninsula.

Proposed Improvements

5. A number of alternative solutions have been investigated by the U. S. Army Engineer District, Buffalo (NCB), in order to control beach erosion at Presque Isle. These alternatives included additional groins, full breakwaters, segmented offshore breakwaters, a sand trap recirculation scheme, and a "no action" alternative. After detailed investigation by NCB, the recommended plan included the following elements:

- a. Placement of an estimated 500,000 cu yd of sand fill to provide a beach berm with an average width of 60 ft and crest elevation of 10.0 ft above lwd.
- b. Construction of 58 offshore rubble-mound breakwater segments aligned parallel to the shoreline.
- c. Annual replenishment of approximately 38,000 cu yd of sand fill in order to maintain the minimum design beach dimensions.

(a) April 18, 1979, Beaches 4, 5, and 6

(b) July 12, 1978, Beach 10 with three experimental offshore breakwaters

Figure 2. Shoreline at Beaches 4, 5, 6, and 10

Purpose of the Model Study

6. The model study was conducted to examine the NCB's recommended plan and, if necessary, refine and optimize breakwater parameters such as length, height, distance between breakwaters, distance offshore, and orientation. Also of interest was the interaction of the offshore breakwaters with existing shore protection structures such as the numerous groins along the peninsula and the effects of the structures on the littoral processes. To aid in developing modeling capability, an initial test series was developed to examine three experimental breakwaters that had been constructed at Beach 10 (Figure 2b) in 1978.

PART II: THE MODEL

Description

7. The Presque Isle model was constructed in a 188-ft-long by 139-ft-wide by 2-ft-deep concrete basin to a 1:50 (undistorted) scale. About 9,400 ft of prototype shoreline at State Park Beaches 4, 5, and 6 was modeled in concrete mortar. The beachline included both a region with a groin system and a segment of beach without significant shore protection structures as shown in Figure 2. The model bed was molded to the July 1979 bathymetric condition with the Lake Erie contours accurately molded to -20 ft lwd and a sloping transition to the basin bottom of -50 ft lwd (Figures 3 and 4). For the 1:50-geometric-model scale, the following relations were computed based on the Froudian law of similitude:

Characteristic	Scale Relation
Horizontal distance	L_h = 1:50
Vertical distance	L_v = 1:50
Area	L_h^2 = 1:2,500
Volume	$L_h^2 L_v$ = 1:125,000
Velocity	$L_v^{1/2}$ = 1:7.07
Time - Wind wave	$L_v/L_v^{1/2}$ = 1:7.07
Slope	L_v/L_h = 1:1

Model Appurtenances

8. The model was equipped with the necessary appurtenances to reproduce and measure all required phenomena including water levels, waves, and wave-generated currents. Wave action was reproduced in the model with a 120-ft-long vertical plunger type wave generator which could be quickly adjusted to reproduce the required wave height and period. Retractable wheels permitted it to be moved to different positions. Wave data were collected with an automated data aquisition and control system (ADACS). Through the use of a minicomputer, ADACS recorded onto magnetic tape the electrical output of parallel

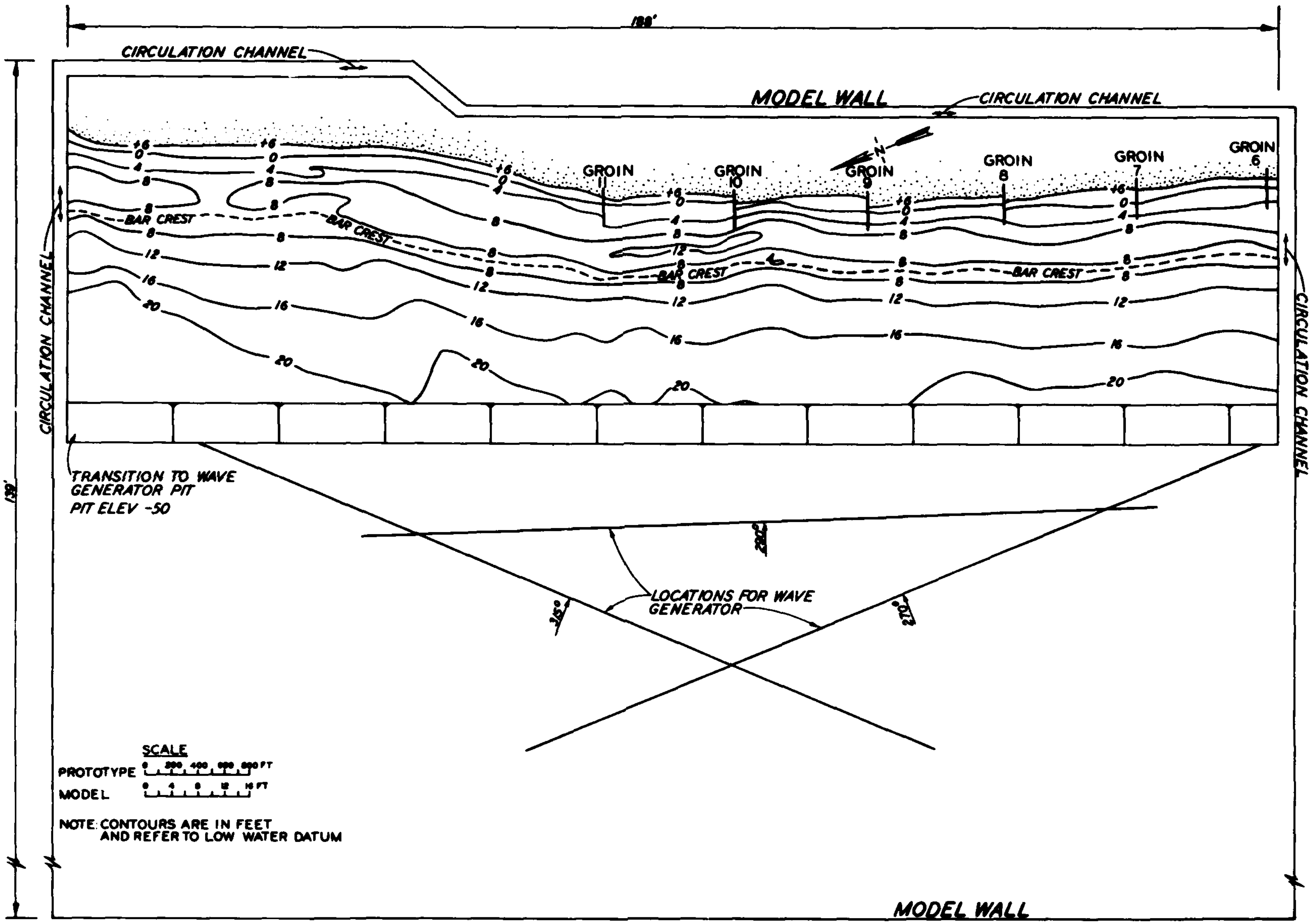


Figure 3. Presque Isle model layout

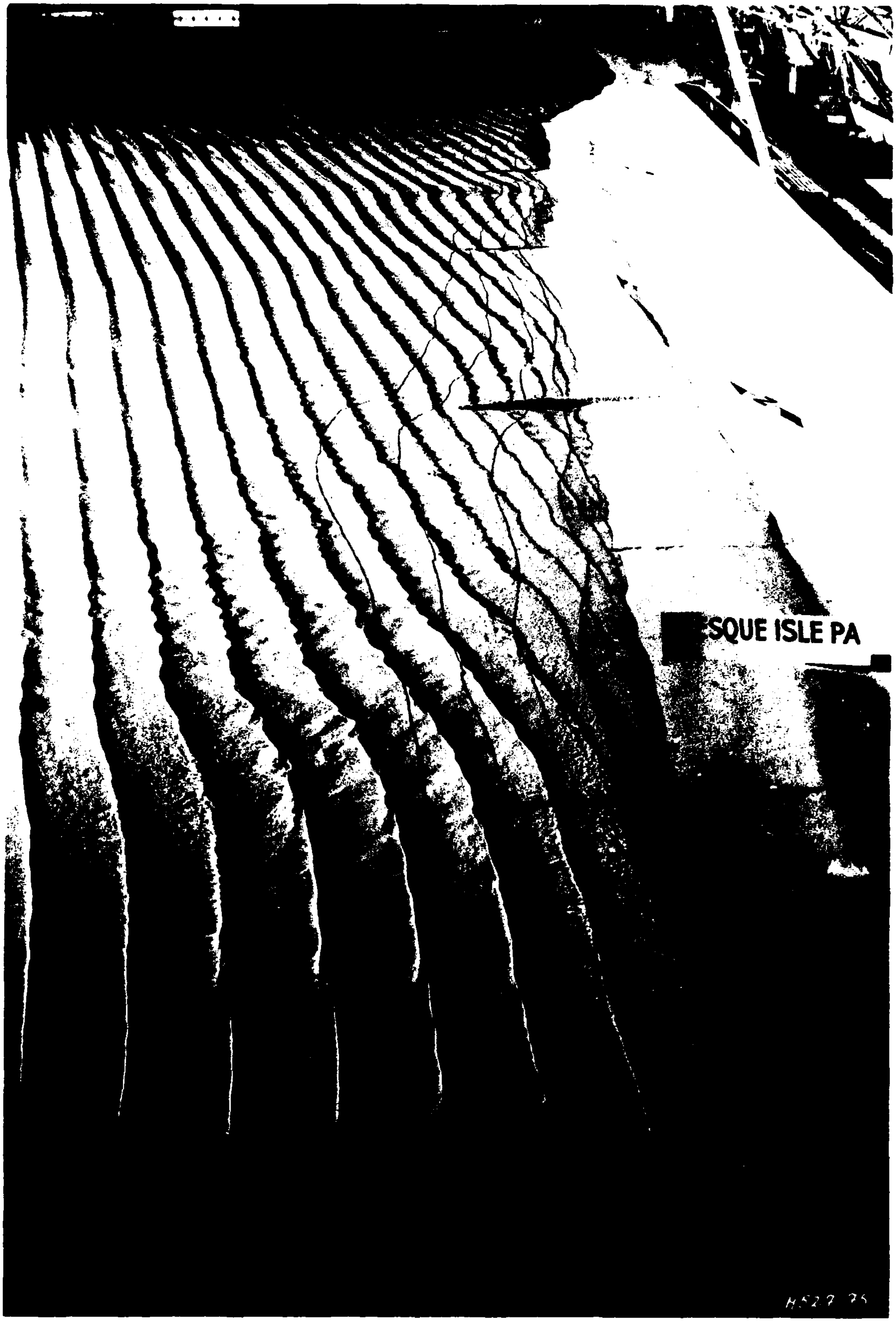


Figure 4. Presque Isle model

wire resistance type sensors as the water surface varied with time. The magnetic tape output of ADACS then was analyzed by the computer and tables of wave height printed. Solid layers of fiber wave absorber were placed along the inside of the model walls to damp wave energy that might be reflected. A circulation channel (Figure 3) behind the beach recirculated longshore currents to the updrift beaches to minimize basin circulation effects. Still-water levels were read with a manual point gage accurate to 0.001 ft (0.05 ft prototype). Wave-generated currents were measured by injecting dye in the water column and timing the travel of the dye patch over a known distance. An overhead photo system of 70-mm cameras was used to record test data.

Model Structures

9. The sheet-pile groins (groins 7, 9, 10, and 11) were constructed of galvanized metal and located in the model from prototype maps and survey data. The shoreward 60 ft had a crest elevation of +10 ft lwd, then sloped from +10 to 0 ft lwd over the lakeward portion of the structure. Groin 8 is a compactly placed stone structure in the prototype and was molded of concrete in the model with its surface scored to represent the individually placed stones. The offshore breakwaters used in the study were scaled from NCB's design drawings (Figure 5). Each size stone was geometrically scaled by the 1:50 model scale since laboratory testing by Dai and Jackson (1966) and Ball and Brasfeild (1967) ascertained that wave reflection and transmission characteristics of the rock rubble-mound structure would be correctly reproduced (i.e., negligible scale effects).

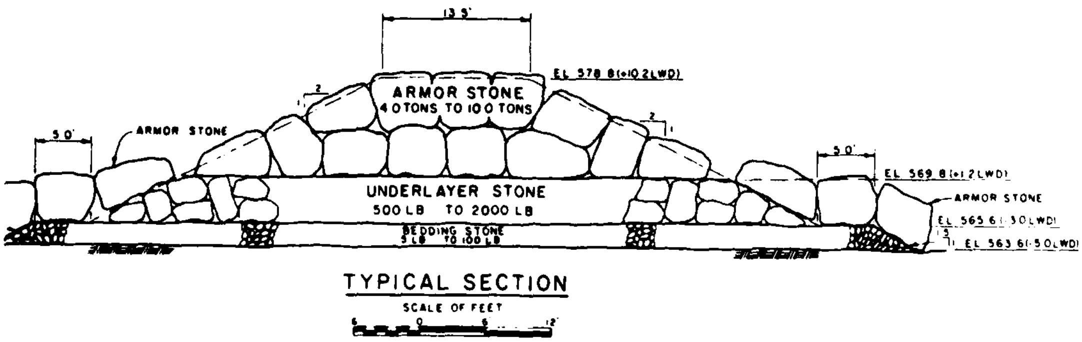


Figure 5. Proposed offshore breakwater cross section

PART III: PROTOTYPE ENVIRONMENTAL PARAMETERS AND MODEL TEST CONDITIONS

10. Lake Erie water levels can vary significantly in both the long term and the short term. Long-term variations are due to changes in the total volume of water in the lake resulting from change of inflow, precipitation, and evaporation. The lwd for Lake Erie is 568.6 ft (International Great Lakes Datum of 1955). The mean water level is 570.5 ft (+1.9 ft) and monthly means have fluctuated from 573.5 ft (June 1973) to 567.5 ft (December 1934) in the 1860-1979 time period. Table 1 shows the average daily water levels for 1979 at the Erie, Pennsylvania, gage, located on the east side of the peninsula at the Coast Guard Station near the harbor entrance. The yearly mean monthly low was in February at 570.3 ft and the high was in June at 572.16 ft, a difference of 1.86 ft.

11. Short-term water-level variations can occur hourly due to wind stress on the water surface (by seiching or local setup) and gravitational tides. Tides are small, about 0.1 to 0.2 ft (Platzman and Rao 1964). Seiche oscillations are caused when winds subside and wind setup cannot be maintained, initiating basin oscillations. Oscillations of the first mode along the longitudinal axis of the lake as great as 13.9 ft have been observed at the extreme ends of Lake Erie (difference between Buffalo and Toledo (Hunt and Bajorunas 1958)). A difference of 9 ft has a 2-year recurrence interval (Irish and Platzman 1962). Since Presque Isle is about halfway from the center of the midpoint in the longitudinal axis between Toledo and Buffalo, maximum variations due to lake seiching for the fundamental mode would be approximately one-half the maximum seiching at the endpoints (Buffalo and Toledo). An examination of Table 1, showing 1979 water-level variations, indicates an instantaneous maximum lake level of 575.9 ft (+7.3 ft lwd) on 6 April and an instantaneous minimum of 569.33 (+0.7 ft lwd) on 25 February, probably the results of short-term phenomena. One might expect local wind and wave setup to cause elevations on the beach side of Presque Isle to be greater than the recorded elevation at the Coast Guard Station on the leeward side of the peninsula, away from the predominant westerly winds, when strong wind conditions exist.

12. Water-level elevations selected for testing were 0.0, +3.0, and +6.9 ft lwd. This would cover, respectively, an extreme low condition, an

average condition, and a high water elevation usually associated with storm conditions.

Wind Waves

13. Winds blowing over the water surface generate wind waves which significantly determine nearshore and shoreline processes along the Presque Isle beaches. These waves, breaking over offshore bars and at the shoreline, can cause significant currents and turbulence to transport sediment away from the beaches. Therefore, in planning the test program for the model study, it was necessary to select wave dimensions (wave height and period) and wave direction that would represent existing wave conditions at the prototype site. Hindcasting data of Saville (1953) show that waves usually less than 2 ft in height approach Presque Isle 88 percent of the time during the ice-free period (April-November). Wave periods are usually 4 sec or less. Figure 6 shows wave-height and direction data as presented in Saville with the shoreline orientation of the Beach 4-6 region and Beach 10 region shown. The largest waves approach from the west (270 deg azimuth) and west-northwest (292 deg). A plot of total wave energy from each direction as taken from Saville is shown in Figure 7 which indicates that the greatest portion of total energy is from the west (270 deg). Wave information data determined by Resio and Vincent (1976) for design waves are shown in Figure 8. For Presque Isle, angle class 1 contains waves from 65 to 5 deg azimuth, angle class 2 contains waves from 5 to 305 deg, and angle class 3 contains waves from 305 to 245 deg. Figure 9 shows the periods associated with a certain height design wave. As shown in Figure 8, the largest waves are in angle class 8 which encompasses waves from 240 to 305 deg azimuth and occurs in the fall and winter seasons. The winter season (January-March) at Presque Isle normally has ice cover along the shoreline and out into the lake. A limited amount of LEO (Littoral Environment Observations) data also were available. NCB performed extensive wave-refraction studies along the Presque Isle peninsula to provide detailed information on transformation into the shoreline from deeper water. Because of the shallowness of Lake Erie, the wave generator pit elevation of -50 ft lwd could be considered "deep" water. Based on the previously discussed information, the water level and wave conditions shown in Table 2 were selected for the initial test sequence of base conditions at Beaches 4 to 6.

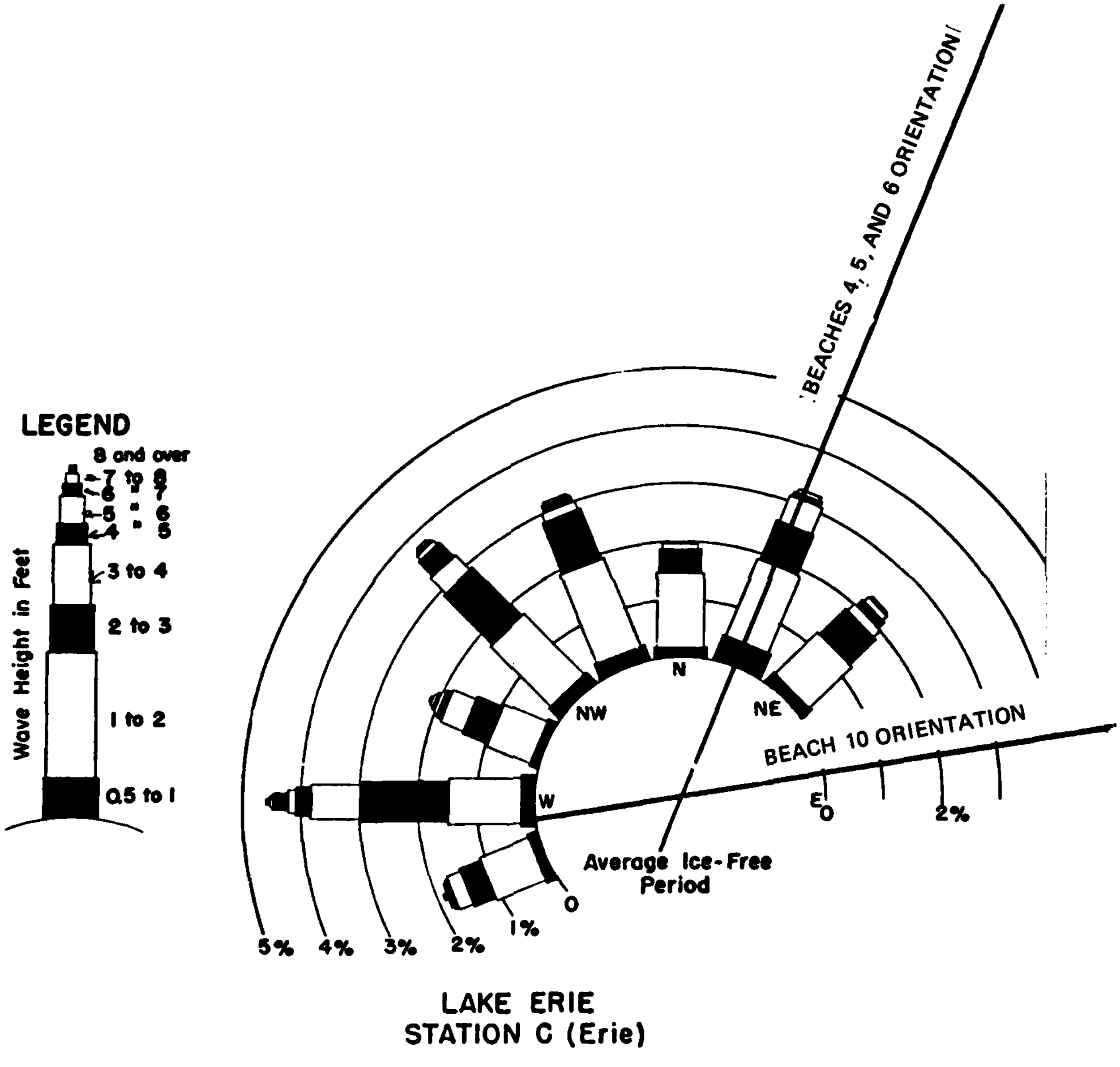


Figure 6. Wave rose showing percent of time waves of different height occur from each direction (Saville 1953)

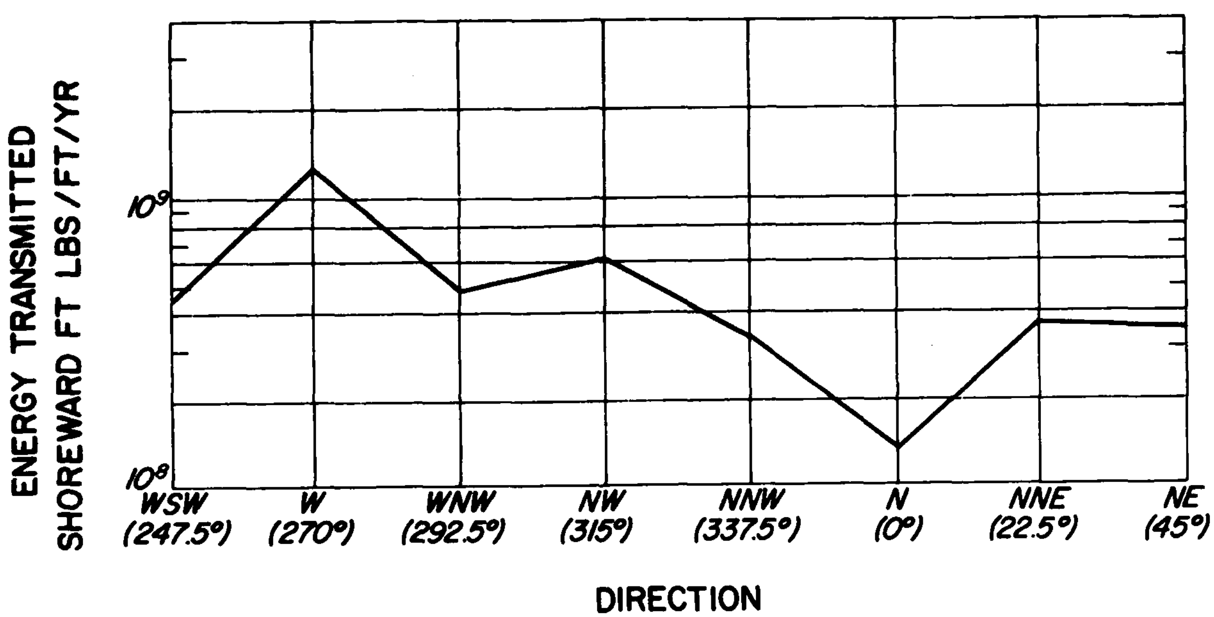


Figure 7. Variation of wave energy with direction (Saville 1953)

TABLE OF EXTREMES ESTIMATES

GRID LOCATION 6,18 LAT=42.27 LON=80.17 ERIE PA

SHORELINE GRID POINT 18

WINTER

ANGLE CLASSES

	1	2	3	ALL
5	4.6(0.8)	7.9(0.6)	12.1(0.3)	12.3(0.8)
10	6.6(1.0)	9.5(0.8)	12.8(0.4)	13.1(1.1)
20	8.2(1.3)	10.8(1.0)	13.4(0.5)	14.0(1.3)
50	10.8(1.6)	12.8(1.3)	14.4(0.6)	15.3(1.6)
100	12.8(1.8)	14.4(1.5)	15.1(0.7)	16.4(1.9)

SPRING

ANGLE CLASSES

	1	2	3	ALL
5	3.6(0.6)	2.6(0.5)	7.2(0.4)	7.3(0.6)
10	3.9(0.8)	3.9(0.6)	8.2(0.6)	8.5(0.8)
20	5.6(1.0)	4.9(0.8)	9.2(0.7)	9.6(1.0)
50	7.2(1.2)	6.6(1.0)	10.8(0.9)	11.2(1.2)
100	8.9(1.4)	7.9(1.1)	11.8(1.0)	12.4(1.4)

SUMMER

ANGLE CLASSES

	1	2	3	ALL
5	3.6(0.9)	4.3(0.6)	6.9(0.6)	7.2(0.9)
10	3.9(1.1)	5.2(0.8)	7.5(0.8)	7.8(1.2)
20	4.3(1.4)	5.9(1.1)	8.2(1.0)	8.4(1.5)
50	5.2(1.8)	6.9(1.3)	8.9(1.2)	9.1(1.8)
100	6.2(2.0)	7.5(1.5)	9.5(1.4)	9.7(2.1)

FALL

ANGLE CLASSES

	1	2	3	ALL
5	6.6(0.2)	8.2(0.5)	11.5(0.3)	11.6(0.5)
10	7.5(0.2)	9.2(0.6)	12.1(0.4)	12.3(0.6)
20	7.9(0.3)	10.5(0.8)	12.8(0.5)	13.1(0.8)
50	8.5(0.4)	11.8(0.9)	13.8(0.6)	14.1(1.0)
100	8.5(0.4)	13.1(1.1)	14.4(0.7)	14.9(1.1)

Figure 8. Extreme design wave estimates (Resio and Vincent 1976)

GRID LOCATION 6,18 LAT=42.27 LON=80.17 ERIE PA

GRID POINT NUMBER 18

SIGNIFICANT PERIOD BY ANGLE CLASS AND WAVE HEIGHT

WAVE HEIGHT (FT)	ANGLE CLASS 1	2	3
1	2.3	2.3	2.4
2	3.6	3.5	3.7
3	4.5	4.4	4.7
4	5.2	5.1	5.4
5	5.7	5.6	6.0
6	6.0	5.9	6.4
7	6.2	6.2	6.8
8	6.5	6.5	7.1
9	6.8	6.8	7.5
10	7.1	7.1	7.9
11	7.3	7.3	8.3
12	7.6	7.6	8.7
13	7.9	7.9	9.0
14	8.1	8.2	9.4
15	8.4	8.5	9.8
16	8.7	8.8	10.2
17	8.9	9.1	10.6
18	9.2	9.4	10.9
19	9.5	9.7	11.3
20	9.8	10.0	11.7
21	10.0	10.2	12.1
22	10.3	10.5	12.5
23	10.6	10.8	12.8
24	10.8	11.1	13.2
25	11.1	11.4	13.6

Figure 9. Periods associated with design wave estimates (Resio and Vincent 1976)

Simulation of Prototype Beach Sediments

14. The primary problem at Presque Isle is erosion of the beaches, and both movable-bed modeling and sediment tracer model tests were selected to examine sedimentation phenomena in detail. Movable-bed modeling involved the use of a model sediment in a fully movable bed, i.e., both scouring and filling could be examined with the model. Sediment tracer tests involved the placement of a lightweight sediment as a thin veneer on the molded concrete beach in order to observe direction of sediment movement and locations of sediment accumulation. Previous U. S. Army Engineer Waterways Experiment Station (WES) studies (e.g., Bottin and Chatham 1975) have successfully used this technique. The criteria of Noda (1971) relating model to prototype ratios of sediment size, sediment specific gravity in water, and the horizontal and vertical model scales have been used as a guide in initially selecting model sediment material. A graphical solution of Noda's model laws is shown in Figure 10 with the associated relationships as shown in the lower right-hand corner. The method assumes a distorted-scale model; however, since an undistorted-scale model had been selected for the study in order to accurately reproduce wave refraction and diffraction simultaneously, a range of sediment scales was determined by substituting the 1:50-scale ratio first for the vertical scale and then for the horizontal scale to determine sediment size scale ratios for the same specific gravity. As crushed coal had previously been successfully used and was available in sufficient quantities, a specific gravity of 1.35 (representing coal) was used to determine a range of sediment size ratios.

15. Prototype sediments to be represented in the model varied from the natural sands of the offshore zone (-1.0 ft lwd and lakeward) with median diameters ranging from 0.11 mm to 0.25 mm, to the coarser sands used for beach fill at the shoreline (1.8-mm median diameter). Using Noda's relationships for the coal with a specific gravity of 1.35, model sediments should be about 2.05 to 2.69 times the prototype size. This called for coal sizes varying from a minimum of 0.22 mm (0.11 mm, S.G. = 2.05) to a maximum of 4.84 mm (1.8 mm, S.G. = 2.69). The uses of various sizes of coal sediment will be discussed in the next section explaining various types of model tests.

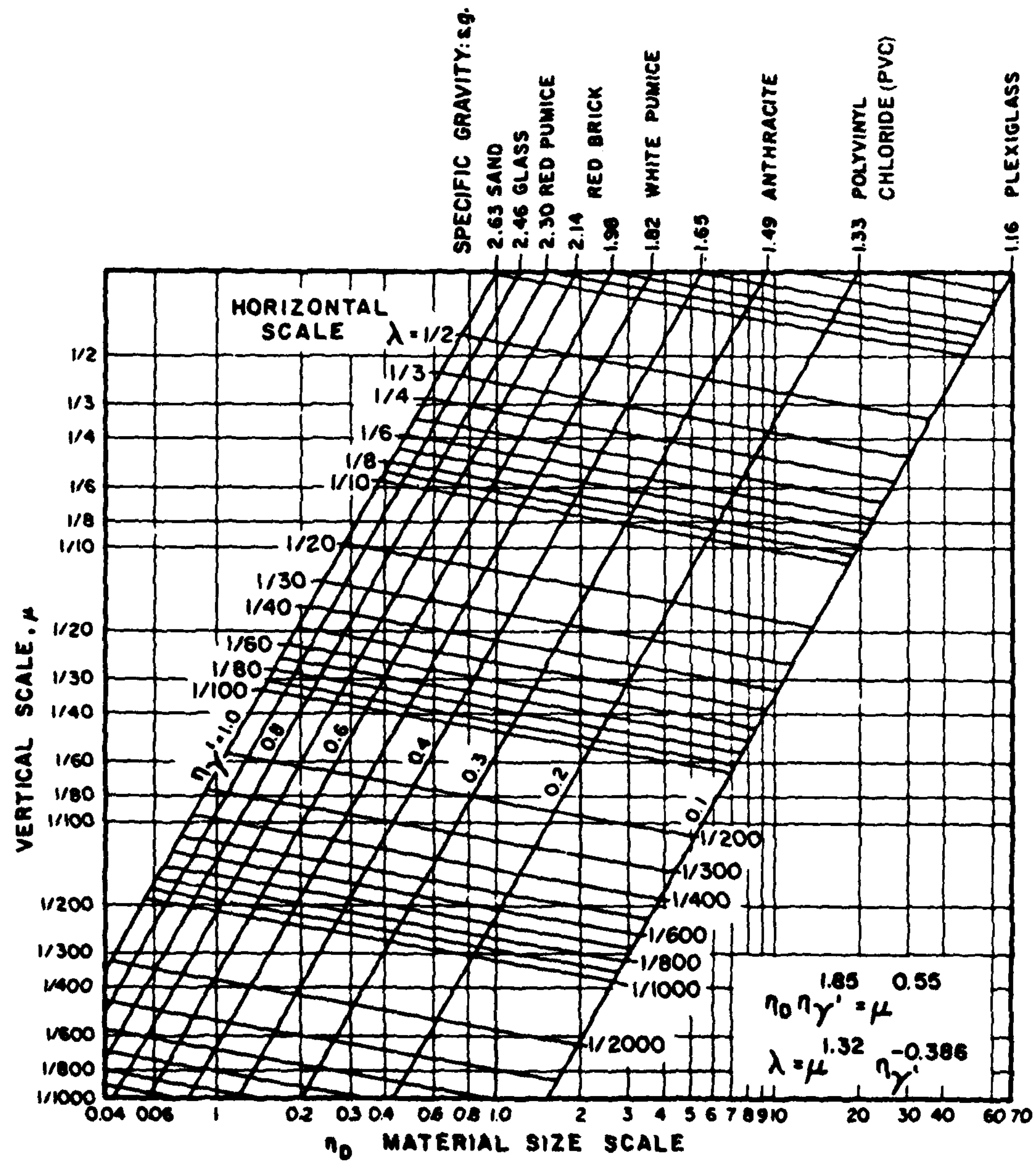


Figure 10. Graphical representation of Noda's model law

PART IV: TESTING AND RESULTS

The Testing Program

16. The basic philosophy for the testing program was based on the three experimental offshore breakwaters constructed at Beach 10 in July 1978 (see Figure 2b) and the reproduction in the model of the well-documented beach evolution shoreward of these breakwaters. A movable-bed model basin was inset in the Beach 4, 5, and 6 region during initial construction of the model to study the prototype experimental breakwaters at Beach 10 (to see how well the beach evolution could be modeled using the selected model sediments and, if necessary, adjust the model parameters of sediment size, wave action, and water level to reproduce the prototype phenomena). After gaining some experience from such testing, it was felt that a better testing program could be conducted in the Beach 4, 5, and 6 region.

17. Testing at the Beach 4, 5, and 6 region for the base condition (existing conditions, 1979) and of various plans for the offshore breakwaters was performed in the fixed-bed model due to the wide variety of test conditions (various combinations of water level, wave height, period, and direction) to be examined and the expense of using a movable-bed model for so many tests. Three types of testing were performed in the fixed-bed model. First, wave-generated current magnitudes and directions were measured along the coastline and adjacent to structures for base and plan conditions. Detailed patterns of nearshore circulation were derived from these data. The second type of test was the sediment tracer test in which lines of coal sediment tracer were placed perpendicular to shore as shown in Figure 11. The coal tracer used was 0.50-mm coal, representing the finer sized sediments in the offshore region (-1.0 ft lwd and lakeward). The test was run for a short-time period to observe and record patterns of movement. The third type test was a beach-fill test in which a larger coal size than that used in the tracer test simulated the larger grained material used for beach fill in the prototype. At the start of the test, a layer of beach fill was placed along the shoreline. As the test progressed and sediment was distributed by the waves, additional sediment was placed along eroded portions of the shoreline. The testing program followed this sequence:

<u>a</u>. Movable-bed tests of the Beach 10 region which has three

a. Pretest

b. Posttest

Figure 11. Sediment tracer placement in model

prototype experimental offshore breakwaters.

b. Base tests of the July 1979 bathymetric conditions at the Beach 4, 5, and 6 region which includes a segment of a major groin field and a segment of nearly structure-free beach.

c. Plan tests at Beaches 4, 5, and 6.

Movable-Bed Modeling of Beach 10: The Experimental Breakwaters

Prototype experimental breakwaters

18. Three offshore breakwaters were constructed at Beach 10 in the spring of 1978 to examine this concept for wave attenuation and beach building at Presque Isle. The 125-ft-long breakwaters were located at the -1.0 ft lwd contour parallel to the shore with gaps of 200 and 300 ft between them. The crest elevation of each breakwater was +6.0 ft lwd. Figure 12 shows a sequence of aerial photographs illustrating beach development behind the breakwaters from 19 May 1978 through 30 October 1981. By the end of 1978, good tombolo development could be noted shoreward of the breakwaters. In the spring of 1979, the tombolos were rounded off, probably due to higher energy waves in the fall and winter coupled with higher water levels due to wind setup and seiching which would permit waves to overtop the breakwaters. The same sequence occurred during the next year (compare 16 November 1979 and 17 April 1980 photographs). Throughput of sediment can be noted on the left side of the 17 April 1980 photograph. Evidently the tombolos did not build up during the summer of 1980 as noted in the 12 September 1980 photograph. However, by the next spring, the 10 April 1981 photograph shows a large tombolo at the westerly breakwater which remained in place through 30 October 1981.

Model experimental breakwater testing

19. The movable-bed test basin was built within the fixed-bed portion of the model as shown in Figure 13. Figure 14 shows the wave directions tested and the configuration of the beach at the start of a test. A total of 18 tests were run. Each test was usually composed of several parts in order to save time on remolding. In the early tests, a variety of wave heights and periods were examined during a given test in order to study the behavior and response of the sediment. In some later tests, only the wave height was varied with the period and water level held constant. Table 2 summarizes these tests. Usually sediment was introduced in the breaker zone at the up-coast boundary by demand. A brief discussion of each test follows.

a. 19 May 78

b. 12 July 78

c. 2 September 78

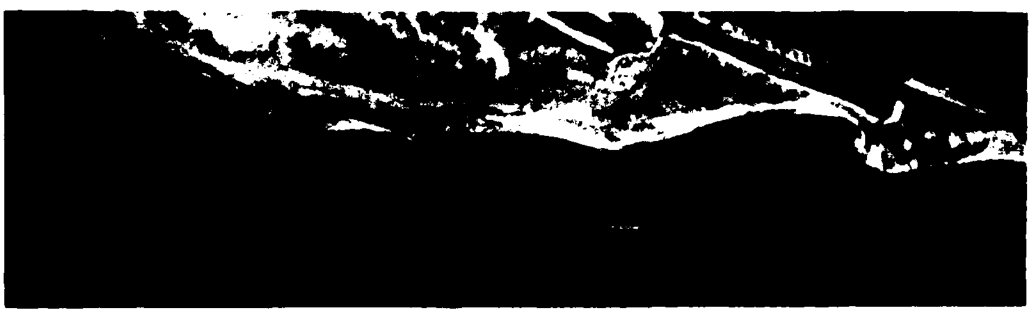
d. 9 November 78

Figure 12. Beach 10 experimental breakwaters, 19 May 78 to 30 October 81 (Sheet 1 of 3)

e. 18 April 79

f. 16 July 79

g. 16 November 79



h. 17 April 80

Figure 12. (Sheet 2 of 3)

i. 12 September 80

j. 10 April 81

k. 7 July 81

l. 30 October 81

Figure 12. (Sheet 3 of 3)

20. Test 1. With a 1.9-ft-lwd water level, 5-sec, 2-ft waves were run for 2 hr from 299 deg (the sharpest wave angle) and tombolos developed as shown in Plate 1. Then 1 hr of 5-sec, 4-ft waves was run and the embayment between the breakwaters built lakeward (Plate 2). Increasing wave height to 8 ft and period to 7 sec caused further shoreline buildup (Plate 3), as all three breakwaters were joined by the beach. Finally a 9-sec, 13-ft wave was run for 0.3 hr (Plate 4). Onshore sediment transport continued to build up the beach.

21. Test 2. The wave generator was moved to 341 deg azimuth, creating a wave about normal to the beach. No photographs were available for this test, but symmetric tombolos were built by the series of waves run as outlined in Table 2. As wave steepness was increased (wave height increased, period held constant), there was continual building of beach behind the breakwaters similar to that seen in Test 1. The water level then was increased to +6.9 ft lwd. At this level, there was considerable wave transmission over the breakwaters, flattening the shoreline which had developed in the previous part of Test 2.

22. Test 3. Plate 5 shows the development after 1.5 hr of a 341-deg, 5-sec, 1.5-ft wave at the +1.9 ft lwd water level. Tombolo development behind the west and east breakwaters has started.

23. Test 4. Plate 6 shows the effect of the 22-deg (see Figure 14), 5-sec, 3-ft wave at the +1.9 ft lwd water level. Initially, a 5-sec, 1.5-ft wave was run, but little movement occurred and the wave height was increased. Tombolos appear detached from the shore but depths between the tombolos and the shore are very shallow. Since the 3-ft wave breaks in deeper water, most sediment movement is somewhat lakeward of the shoreline.

24. Test 5. The wave generator was moved to 313 deg (see Figure 14) and a 5-sec, 3-ft wave at +1.9 ft lwd water level was run. No photographs were taken but onshore sediment movement was too effective. It was decided to raise the water level to +4.0 ft to reduce onshore transport lakeward of the breakwaters. This level was still a reasonable level to use with respect to recent prototype water levels.

25. Test 6. Plate 7 illustrates that the higher water level permitted better development of the tombolos at the shoreline than the lower water level. A problem with erosion at the shoreward boundary of the model developed because of the higher water level as the shoreline between the west and middle breakwaters receded to the fixed-bed portion of the model.

26. Test 7. The wave period was shortened to 4 sec and the water level

Figure 13. Movable-bed model of Beach 10

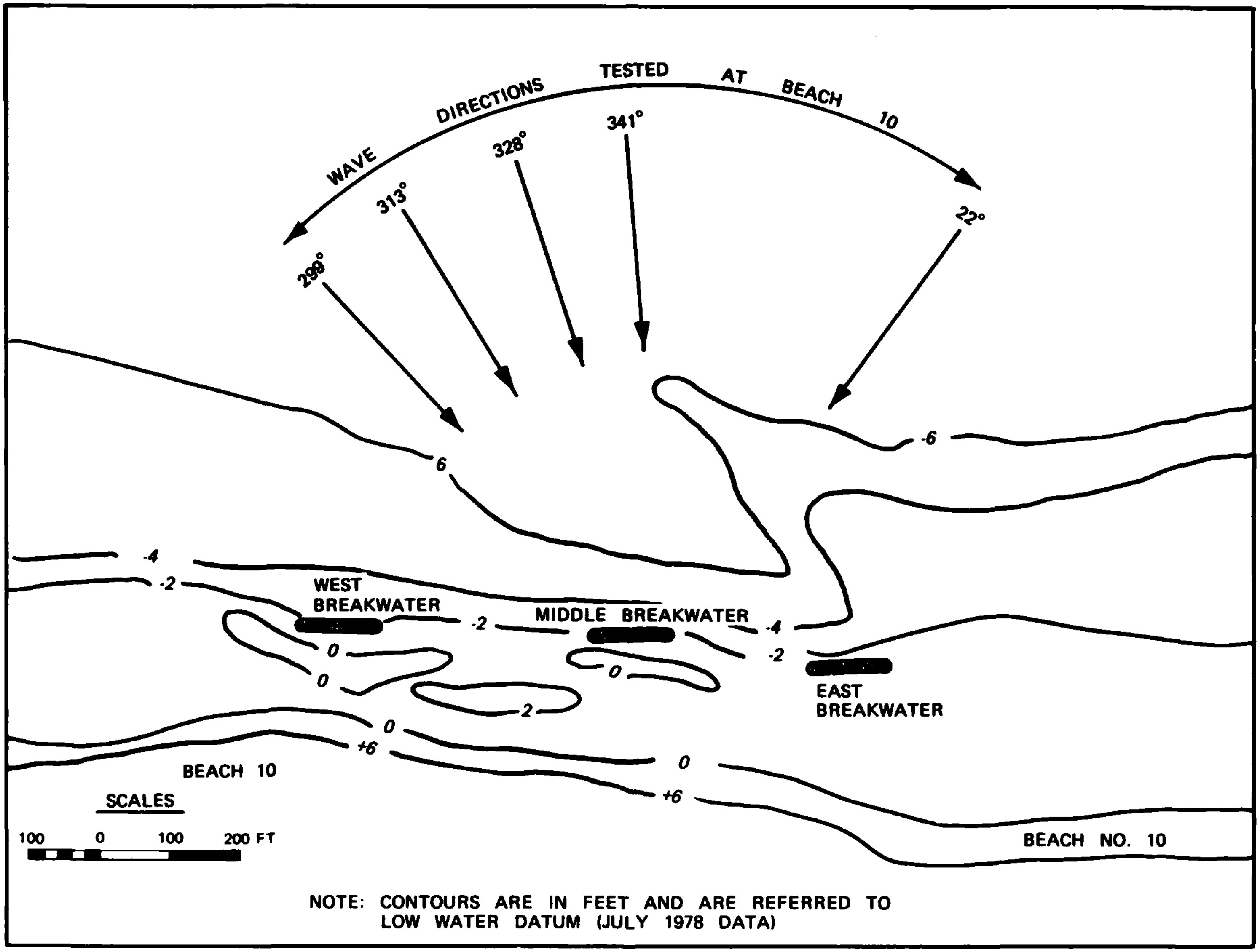


Figure 14. Wave directions tested at Beach 10

retained at +4.0 ft lwd for this test of initially a 1.3-ft wave (Plates 8 and 9) and then a 2.6-ft wave (Plate 10). The latter condition showed good tombolo development behind the breakwaters but problems of erosion at the shoreward boundary in the region between the breakwater occurred. The boundary then was cut back so more beach area could be modeled in the movable-bed coal sediment. Plate 11 shows the increased beach size before starting Test 8.

27. Test 8. A 4-sec, 2.1-ft wave from 313-deg azimuth at the +4.0 ft lwd water level was used and Plate 12 shows the Beach 10 area after 2 hr of testing. Very realistic tombolo development occurred (compare with 16 July 1979, Figure 12). The test was continued with a larger 3.2-ft wave, all other conditions held constant, and tombolo development continued (Plate 13). Plate 14 shows the effects of increasing the wave height to 4.2 ft for 1 hr. The tombolo has reached the west breakwater and a tombolo is nearly touching the middle breakwater. Sediment has bypassed the west breakwater, moving eastward along the lakeward face of the breakwater, and has accreted off the tip of the west breakwater between the west and middle breakwaters. After 2 hr of the 4.2-ft waves (Plate 15) there has been considerable accumulation in the embayments between the breakwaters. Part is due to longshore transport moving along the lakeside face of the offshore breakwaters and part is due to onshore transport of the coal particles.

28. Test 9. During this test there was no introduction of model sediment upcoast of the breakwaters. This change was made in order to see the effect on accretion near the structures, which as seen in the previous test had shown heavy accumulations for the larger waves. Also a 5-sec period was used. After 2 hr of a 2.5-ft wave at the +4.0 ft lwd water level, reasonable shoreline development had occurred (Plate 16). Wave height was then increased to 4.0 ft for 0.5 hr (Plate 17) and to 7.0 ft for 2.0 hr (Plate 18). Once again there was strong onshore sediment movement for the large waves.

29. Test 10. The period was reduced to 4 sec and a 2.1-ft wave was run for 4.0 hr (Plate 19). Good tombolo development occurred. Wave height then was increased to 3.2 ft for 2 hr (Plate 20) and the west tombolo attached to the west breakwater. Wave height again was increased, this time to 4.2 ft, and run for 2 hr (Plate 21). The attached tombolo grew wider and finally sediment bypassed on the lake side of the west breakwater and accumulated off the downdrift tip of the west breakwater. This test was similar to Test 8 in the size and sequence of waves but durations were longer for Test 10. However,

there was no feeding of sediment at the upcoast boundary for Test 10 as there was for Test 8 and thus longshore rates of movement were not as great as the Test 8 sequence and not as much filling of the embayments occurred (compare Plates 15 and 21).

30. Test 11. The wave period was reduced to 3.5 sec, the lower limit of wave period for the wave generator used in this study. Plate 22 shows the initial conditions and Plate 23 shows limited movement of the shoreline after 1 hr of a 1.3-ft wave height. With the wave height increased to 2.6 ft, Plate 24 shows shoreline response after 2.5 hr. Response was similar to the 2.1-ft, 4-sec wave after 4 hr (Plate 19). Increasing wave height to 3.9 ft for 0.5 hr (Plate 25) in order to create a cutback of the tombolos resulted in increased building of the west tombolo and slight reductions in the central and east tombolos. Increasing wave height to 5.2 ft caused the west tombolo to reach the breakwater with little change otherwise (Plate 26). The wave height was increased to 6.4 ft and run for 0.5 hr which resulted in increased beach building upcoast of the west tombolo (Plate 27). The water level then was raised to +6.9 ft lwd and the 6.4-ft wave run for 0.5 hr. Plate 28 indicates that erosion behind the breakwaters did occur as a result of wave energy overtopping the breakwaters attacking the tombolos. The Test 11 series illustrated two points. First, the shorter period wave reduced onshore transport somewhat; and second, it appeared that higher water levels and overtopping of the offshore breakwaters were required to cut back the tombolos. Increases in wave height alone did not significantly cut back the tombolos. The higher water levels were necessary to permit sufficient wave energy to attack the tombolos.

31. Test 12. The movable-bed coal sediment was sieved in order to reduce the grain size in an effort to reduce onshore transport of sediment. The median diameter was reduced from 1.2 to 0.9 mm and placed in the model to start Test 12. A variety of conditions were examined during Test 12. Plates 29-33 show a continuous test series of increasing wave height. Durations of large waves were relatively short and significant onshore movement was not evident. During this test, visitors from NCB and U. S. Army Engineer Division, North Central (NCD), were in attendance. The beach was smoothed back and Tests 12-E through 12-J were run (Plates 34-42) to show various conditions. Included in this group of tests was a series of varied water-level sequences with rounding off of tombolos during the high water (+6.9 ft) stage (compare Plates 38 and 42).

32. <u>Test 13.</u> Test 13 was similar to Test 10 except for the sediment size, with the smaller 0.9-mm size in place for Test 13. Plates 43-45 can be compared with Plates 19-21, respectively. Results are similar except the Test 13 series tombolos attach or reach closer to the west and central breakwaters for the first two wave conditions, indicating slightly greater longshore movement for the smaller coal. Observations during testing indicated reduced onshore movement of sediment for the larger wave conditions.

33. <u>Test 14.</u> Wave period was increased to 5 sec and three wave heights were run for this test. Plates 46-48 show that tombolo growth behind the center breakwater was slightly greater than that behind the west breakwater, a somewhat unexpected result, especially when compared with Test 9 (Plate 16) after 2 hr of 2.5-ft, 5-sec waves. The duration of Test 14A was 2 hr longer and the wave height was less (2.1 ft versus 2.5 ft); also the sediment was smaller for Test 14. A combination of these factors might explain the reason for the increased growth rate of the center tombolo over that of the west tombolo for the 313-deg wave.

34. <u>Test 15.</u> The wave angle was flattened to 328 deg (see Figure 14). Plates 49-51 show that this test produced similar results to Test 14, with strong growth behind the central breakwater. At this time, a check of crest elevations of the breakwaters was made and it was noted that the crest of the west and east breakwaters had degraded slightly in the course of work on molding and remolding the movable bed between tests. The crowns were built up to the correct elevation and a test similar to Test 15 was run.

35. <u>Test 16.</u> With the crown elevations corrected, Plates 52-55 show test results indicating increased tombolo development behind the east and west breakwaters, but the trend for the middle breakwater tombolo to lead in accretion was still evident. Plate 55 shows the model flooded to the +6.9 ft lwd water level following Test 16-C. A 5-sec, 6.4-ft wave was run for 1 hr and the photograph on the right side of Plate 55 shows the results of accumulation above the water line.

36. <u>Test 17.</u> Since wave periods shorter than the 5-sec period produced more realistic results and since wave periods lower than 5 sec are more typical of the prototype, the 4-sec period was chosen for the remainder of the movable-bed testing. Therefore, for the 328-deg wave approach, Plates 56-58 show the results of 2.1-, 3.2-, and 4.2-ft waves for durations of 4, 2, and 2 hr, respectively. Results for the 2.1- and 3.2-ft waves look reasonable with respect

to prototype occurrences (see Figure 12, 16 November 1979 photograph). Results after 2 hr of the 4.2-ft wave indicate a filling of the embayments between the breakwaters as a result on onshore transport of the sediment.

37. Test 18. This test was performed to simulate a high energy event on a naturally accreted beach similar to the planform of Test 17. A 2.1-ft, 4-sec wave was run for 4 hr to build up the tombolos as has usually occurred in the summer season in the prototype (Plate 59). The water level then was raised to +6.9 ft and the shoreline was submerged as seen in Plate 60. A 6.6-ft, 4-sec wave was run for 0.2 hr with the resulting high-water shoreline seen in Plate 61. Then with the water level reduced to the normal level, the shoreline is shown in Plate 62. Figure 15 compares model and prototype for late fall and spring conditions. The tombolos have been rounded off and the shoreline east of the breakwaters shows an accumulation as a result of sediment moving through the system.

38. Plates 63-65 show the bathymetries during various phases of a test with the 313-deg wave which was made by lowering the water level to given elevations, photographing the waterline at that level, then compiling all the water levels on a single plate. Plate 63 shows the initial bathymetry; Plate 64 shows the bathymetry after 4 hr of 4-sec, 2.1-ft waves; and Plate 65 shows the final bathymetry after the 2.1-, 3.2-, and 4.2-ft waves had been run.

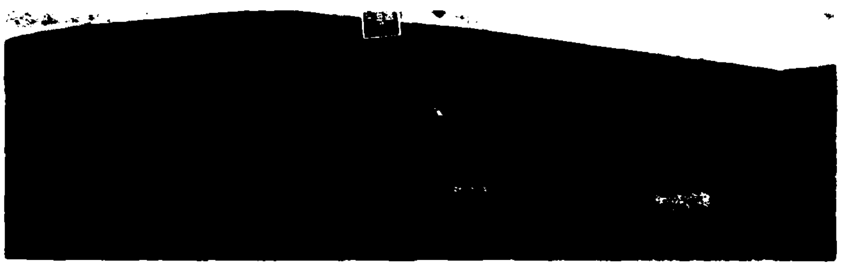
39. The movable-bed testing indicated that good reproduction of the shoreline planform could be obtained using the coal sediment. It was obvious, however, that care must be taken in selection of test conditions and test procedures.

Base Test at Beaches 4-6

40. The movable-bed test section was capped over and was molded in concrete to the July 1979 bathymetry at Beaches 4 through 6 to match the remainder of the model. A series of tests was run for existing conditions (1979) including wave-generated current measurements, sediment tracer movement, and beach-fill tests as described previously. Table 3 shows the selected test conditions (wave direction, height, period, and water level). Wave-generated currents were measured for each condition listed in Table 3. Sediment tracer and beach-fill tests were run for selected test conditions out of those listed in Table 3.

a. Model (accretion of shoreline)

b. Prototype (16 November 1979)



c. Model (erosion of shoreline)

d. Prototype (17 April 1980)

Figure 15. Model-prototype comparison

Base wave-generated current tests

41. Waves breaking along the shoreline generate currents that aid in the movement of sediments along the coast. The examination of these currents is important in determining mechanisms of sediment transport. Also it is important to examine these currents with regard to the safety of swimmers.

42. Plates 66a-75b show Base Test wave-generated currents from the 270-deg wave direction. Most of the plates showing detailed velocity measurements are followed by a plate for the same test conditions which shows dye movement in the surf zone. Plate 66a shows the results for the 2-ft, 4-sec wave at the 0.0 ft lwd. Most of the higher currents are near the shore, with a clockwise eddy on the lee side of groins 7-10, resulting in a lakeward-directed current along the groin. At the downcoast end of each groin cell there is a strong current directed offshore along the groin. There is a reversal of longshore currents to about 600 ft northeast of groin 11, after which the longshore currents become uniform along the portion of coast without groins. Plate 66b shows photographs of the lakeward-directed currents at the downcoast end of each groin cell. The orientation of the beach in the photographs is opposite that of the wave-generated current sketch, so the predominant longshore currents resulting from the 270-deg wave are moving from right to left in the photographs. As wave height is increased, the surf zone is widened and the 7-ft, 4-sec waves break on the outer bar (Plates 67a-67b). For this 2-, 4-, and 7-ft, 4-sec series of waves at 0.0-ft water level, rip currents along the groins are strongest for the 4-ft, 4-sec wave. Since the 7-ft, 4-sec waves break on the outer bar, the surf zone near the shore and groins has slower currents.

43. With the water level increased to +3.0 ft, the 2-, 4-, and 7-ft, 4-sec waves produced current patterns similar to those obtained for the 0.0-ft water level (Plates 69a-71b). Once again the strongest current system along the shore and against the groins was for the 4-ft, 4-sec wave. It was noted for the larger waves (4 and 7 ft) that reversing circulation in cells between groins would occur. Usually the cell between groins 9 and 10 would show a current reversal just offshore of the beachline and sometimes the eddy on the leeside of a groin would be extended farther downcoast. These were probably the result of wave refraction over the irregular bathymetry. As can be noted, the contours undulate in and out from shore along the entire study area.

44. Plates 72a-73b show results of 6-ft, 6-sec and 10-ft, 6-sec waves

from 270 deg and with the water level at +3.0 ft. Currents within the groin cells are stronger for the 6-ft, 6-sec waves while those currents farther offshore near the bar are stronger for the 10-ft, 6-sec wave. Strong rip currents still persist along the downcoast groin of each cell for both wave conditions.

45. Plates 74a-75b show results with the water level at the +6.9 ft elevation. Two wave conditions were run: first a 6-ft, 6-sec wave, then the project design wave height and wave period (a 12-ft, 9-sec wave). The 6-ft, 6.4-sec wave produced strong currents at the shoreline and along the groins. This test (Test 9) can be compared with Test 7 (as the waves are nearly the same) to note the effect of water level on the current system. The higher water level permits higher currents at the shoreline and more reduced currents lakeward of the groin cells when compared with the lower water-level test. Test 10 (Plates 75a and 75b) using the design wave condition shows high velocities along the outer bar and lesser velocities close to shore since the wave breaks three times before reaching the shoreline.

46. Base wave-generated current Tests 11-20 were performed for a 290-deg wave angle which approaches nearly parallel to the average shoreline. The 0.0-ft water level series of tests for the 2-ft, 4-ft, and 7-ft, 4-sec waves are shown in Plates 76a-78b. The dye photographs (Plates 76b, 77b, and 78b), for which a line of dye had been placed along the shoreline and then wave action begun, illustrate initial circulation patterns in the surf zone for the 290-deg wave. Rip currents do not always appear against the groins and the current sketches (Plates 76a, 77a, and 78a) illustrate the complex circulation patterns for waves parallel to the coast. Magnitudes of rip currents were reduced for a given 290-deg wave when compared with the same wave from 270 deg.

47. With the water level at +3.0 ft lwd, 2-, 4-, and 7-ft, 4-sec waves from 290 deg were tested to obtain wave-generated current magnitudes and patterns (Plates 79a-81b). The 2- and 4-ft waves showed as much variation as the 2- and 4-ft waves run at the lower 0.0-ft water levels. The 7-ft, 4-sec wave produced almost similar circulation patterns at the 0.0 and +3.0 water levels, since the wave broke at about the same location (over the outer bar) for each water level. Current magnitudes were usually strongest at the shoreline. Six- and 10-ft, 6-sec waves were tested at the +3.0 ft water level and indicated strong rip currents emanating from each groin field cell (Plates 82a-83b).

48. Plates 84 and 85 show results of the water level increased to +6.9 ft with the 6.0-ft, 6.4-sec and 12-ft, 9-sec waves reproduced. Strong

circulation patterns are shown to extend lakeward over the outer bar. Strong movement toward the outer bar from the beach is shown to occur at groins 8 and 11 for the smaller of the two waves and at groins 9 and 11 for the larger wave.

49. Base condition wave-generated current results for a 315-deg wave approach are shown in Plates 86a-94b. Generally, there was strong current movement along the shoreline toward the southwest within each groin cell for each wave and water level tested. Currents approaching groin 11 along the open beach were deflected offshore. Eddy areas on the lee side of some groins were more broadly developed for some conditions, as leeward of groin 10 for Test 25 (Plate 90a), Test 26 (Plate 91a), Test 27 (Plate 92a), Test 28 (Plate 93a) and Test 29 (Plate 94a). This was the result of the concavity of the contours in the groin 9-10 cell. Observations made for the 270-deg wave with respect to higher currents offshore along the outer bar then onshore along the shoreline, for the wave heights above 6 ft, also held for the 315-deg waves.

Sediment tracer base tests

50. Plate 95 shows a layout of the 0.5-mm coal sediment tracer before starting a test with waves from 290 deg. Note the shorter lengths of tracer near the groins. For the 270- and 315-deg waves, the shorter lengths were placed only on the downwave or lee side of the groins. The test numbers correlate with the same test conditions used for the Base wave-generated current tests.

51. 270-deg wave approach. Plates 96-101 show Base Test results for the 270-deg wave approach. Plate 96 shows results of the 4-ft, 4-sec wave at 0.0 ft lwd. There was fairly uniform longshore movement of the tracer in each groin cell, with movement past the groin tips for three of the four groins in the study area. There was continuous downcoast alongshore movement of the tracer in the region north of groin 11. There was some onshore movement of tracer in the regions lakeward of the wave breaking zone. The 2-ft, 4-sec, +3.0 ft water-level test (Plate 97) showed uniform longshore movement in each groin cell and the Beach 6 region. There was some offshore movement at the tips of groins 8, 10, and 11. The 4-ft, 4-sec wave (Plate 98) indicated strong longshore movement in the groin cells and along Beach 6, with tracer moving offshore at the tips of each groin. Plate 99 shows the results of the 7-ft, 4-sec wave late in a test (i.e., the photograph was taken much later in the test than previous photographs). Groin cells 8, 9, 10, and 11 have almost completely emptied of tracer. The 10-ft, 6-sec wave (Plate 100) indicated that

the strongest tracer movement was in the offshore area in the trough between the bar crest and the tip of the groins. Strong offshore movement along a groin tip was evident only at groin 11 for this test condition. Once sediment moved past groin 11, it stayed in the offshore trough. The 12-ft, 9-sec wave at the +6.9 ft water level (Plate 101) produced strong longshore movement between the groins and in the offshore zone. Also some tracer was deposited landward of the groin system due to the high runup at this extreme water level.

52. 290-deg wave approach. Base tracer tests for the 290-deg wave are seen in Plates 102-107. Since this wave direction is normal to the shoreline in the Beach 4 and 5 region, the direction of sediment tracer movement is somewhat variable in that region. Since the Beach 6 region recedes at a small angle from the 290-deg wave approach, sediment movement is directed northeasterly as it was for the 270-deg wave approach. Comparison of Plates 102 and 104 shows the effect of water level on the tracer movement. Tracer movement is strong along groins 8 and 10 for the +3.0 ft level and strong along groin 11 for the 0.0-ft level. Movement of tracer along Beach 6 is uniform for both levels. Plate 103 shows that the movement is limited to the shoreline for the 2-ft, 4-sec wave at +3.0 ft water level. Plate 105 indicates that the 7-ft, 4-sec wave at +3.0 ft level produces lakeward tracer movement along groins 7, 8, and 11. The 10-ft, 6-sec wave at the +3.0 ft water level (Plate 106) showed tracer movement in a direct offshore direction for tracer placed lakeward of the groins. There was some alongshore movement of tracer within the groin cells, but movement out of the cells was not strong. The 12-ft, 9-sec wave, +6.9 ft water level (Plate 107) showed strong offshore movement at Beach 5 and the northeastern part of Beach 4. Sediment tracer was also pushed shoreward due to high wave runup.

53. 315-deg wave approach. Plates 108-112 show Base tracer test results for the 315-deg wave direction. For the low water level, Plate 108 shows strong tracer transport both along the inshore beach face and lakeward of the groin tips in the vicinity of the outer bar for the 4-ft, 4-sec wave. At the +3.0 ft water level, movement for a 2-ft, 4-sec wave is concentrated more along the inner shore face (Plate 109), but tracer movement along the groins is not as strong as at the lower water level. The 7-ft, 4-sec wave (Plate 110) produced strong tracer movement along the offshore bar and along the shoreline in each groin cell, with movement lakeward along the downcoast groin in each cell of Beaches 4 and 5. The 10-ft, 6-sec wave (Plate 111) and the 12-ft, 9-sec

wave (Plate 112) produced tracer movement very similar to the previous 7-ft, 4-sec wave.

54. The Base tracer tests indicated that the sediment movement through the groin system and along the open beach was strong for angled waves (270 and 315 deg). The sediment tended to be deflected offshore by the groins toward the offshore bar system. Any sediment which reached the offshore bar tended to stay offshore and travel along the face of the bar or in the trough between the bar crest and the groin tips. Waves approaching parallel to the beach did not produce strong offshore transport except for the large waves that had strong rip currents associated with them which moved tracer lakeward.

55. Beach-fill base tests. These tests were conducted with crushed coal representing beach fill placed at the shoreline. Sediment was continually fed along the beach-waterline interface at areas where sediment was removed by wave action. A 0.9-mm-median-diameter coal was used to represent the rather coarse-grained beach fill placed in the prototype (about 0.8- to 7.0-mm-median diameter). The test was run for a considerable length of time to permit the sediment to redistribute itself along the coast. The study area for these tests was limited to the Beach 5 and 6 region (groin cells 9 and 10, 10 and 11, and the open beach northeast of groin 11) for better control of this manual type of test.

56. 270-deg wave approach. A 4-ft, 4-sec wave at the +3.0 ft water level was selected for testing and run for 5 hr. Photographs were made every 0.5 hr; the final photograph is shown in Plate 113. Feeding of sediment along the shoreline was halted 5 min before the end of the test to permit areas of scour to better show up in the photographs. As noted in Plate 113, the sediment moved lakeward to the downcoast end of each groin cell and tended to shift offshore and move around the tips of groins 10 and 11. The water level then was raised to the +5.0 ft level and a 6-ft, 6-sec wave was run for 2 hr using the previous test as the initial condition for this portion of the test. Sediment was not fed for the first half hour of the test, then sediment was added at the shoreline at places of scour. Results shown in Plate 114 are similar to those of Plate 113 except that more sediment has shifted lakeward and small amounts have moved toward the offshore bar beyond the groins. The model sediment then was picked up and the next test was begun with a clean model bed. A 12-ft, 9-sec wave at the 6.9-ft water level was run for 1.0 hr; the result is shown in Plate 115. Sediment introduced at the waterline moved

lakeward and began to move around the groins. Movement offshore past groin 11 was especially strong.

57. <u>290-deg wave approach.</u> For a 4-ft, 4-sec wave at the +3.0 ft water level, the 5-hr test indicated that most sediment moved off the shoreline and remained in the cell for this straight-in wave approach (Plate 116). Only minor traces of sediment moved offshore beyond the groins. The 6-ft, 6-sec wave at the +5.0 ft water level redistributed the sediment of the previous test (Plate 116) as shown in Plate 117, after 0.5 hr of run time with no beach nourishment. There is a slight increase in movement offshore toward the trough between the groin tips and the offshore bar. Final results of the test after 2 hr, in which the scour regions were continually nourished for the final 1.5 hr of the test, are shown in Plate 118. Sediment was seen to be pushing farther offshore in regions not directly adjacent to groins but some distance away from them. The 12-ft, 9-sec wave at the +6.9 ft water level (Plate 119) produced strong offshore movement at groin 10 with sediment from both adjacent groin cells contributing to this movement.

Plan 1 Testing

58. The Plan 1 system of offshore breakwaters was installed in the model as shown in Figure 16. The spacing between breakwaters and the length of the individual offshore breakwaters were similar to that presented as the segmented breakwater alternative in the NCB's "Final Phase I General Design Memorandum (1980)." A typical section is shown in Figure 5. The crest elevation of each breakwater was +10.2 ft lwd. The original design called for the breakwaters to be placed at the -5 ft lwd contour; however, it was thought that within the groin field for this initial plan, breakwaters should be placed at the tip of each groin, and the breakwater between groins should be placed on a line connecting the groin tips. As shown in Figure 17, this necessitated placing the breakwaters located in the groin field in a slightly greater depth of water than the original design depth. Northeast of groin 11 there was a transition to the -5 ft contour. After closely examining the Base test data, the number of test conditions was reduced for the plan testing. Table 3 shows the conditions and types of tests run for the different plans.

Plan 1 wave-generated currents

59. <u>270-deg wave.</u> Plates 120a-126b show the detailed wave-generated current measurements and the dye photographs for the 270-deg wave approach.

Figure 16. Plan 1 in model

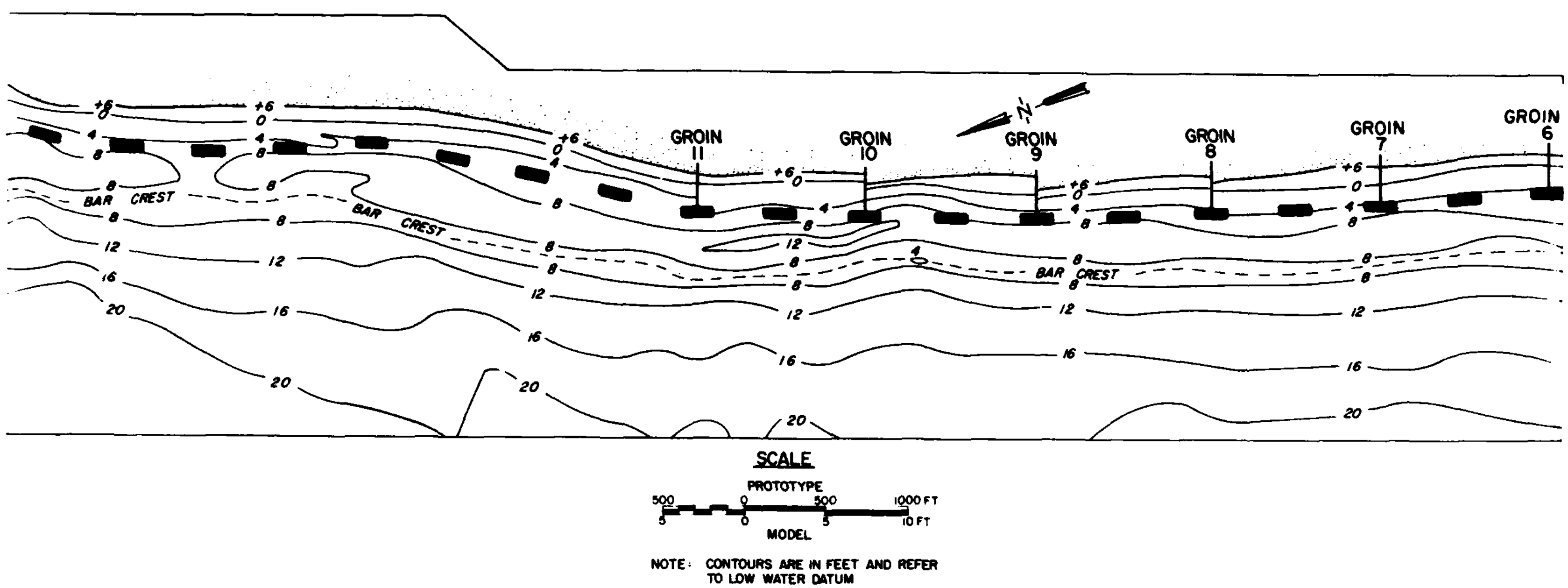


Figure 17. Plan 1 offshore breakwater layout

Plate 120a shows results of the 4-ft, 4-sec wave at the 0.0-ft water level. In some of the cells between groins, currents at the shoreline can alternate direction across the length of the cell up to six times (see region between groins 9 and 10 along the shoreline). Generally, in the region of offshore breakwaters and groins, there was a very slow lakeward current between the upcoast pair of breakwaters and a slightly stronger current on the downcoast end of the groin cell moving lakeward along the upcoast edge of the downcoast breakwater (e.g., examining groin 9 and 10 cell, a current of 0.5 fps is flowing lakeward between the upcoast breakwater and the center breakwater while adjacent to the upcoast side of the downcoast breakwater in this cell, currents of 0.6 and 1.8 fps are moving lakeward). In the open-coast region of Beach 6 in Plate 120a, northeast of groin 11, currents along the shoreline are not quite as fragmented, although behind the more downcoast breakwaters there are current reversals due to the protecting structure. Plate 120b shows a slow lakeward movement of dye extending beyond the breakwaters for the 4-ft, 4-sec wave. Plate 121a shows that patterns behind the breakwaters for the 7-ft, 4-sec wave are similar to those for the 4-ft, 4-sec wave; but lakeward of the structures, the longshore currents are higher due to initial wave breaking on the outer bar. Currents moving out of the downcoast gap between breakwaters for a given groin cell are stronger and oriented in a more alongshore direction than for the smaller wave. Plate 121b shows dye movement for dye initially placed along the shoreline.

60. With the water-level at +3.0 ft, a 2-ft, 4-sec wave showed slow current movement behind the breakwaters. In the groin cell region, there was no outward flow between the upper and middle breakwaters and slow outward currents at the downcoast opening (Plates 122a and 122b). The 4-ft, 4-sec, 7-ft, 4-sec, and 10-ft, 6-sec waves produced somewhat similar current patterns (Plates 123a-125b) at certain locations. Some groin cells showed currents entering the upcoast portion of the cell, between the upcoast and center breakwaters, moving shoreward, then exiting lakeward in the downcoast gap (e.g., Plate 125a, between groins 9 and 10, and 10 and 11). Plate 125b shows dye movement indicating this pattern. In the open-coast area northeast of groin 11, Plates 122a-125b show currents at the upcoast end of each breakwater which moved lakeward, then downcoast parallel to the structure. The 12-ft, 9-sec wave at the +6.9 ft water level produced high longshore currents over the offshore bar area and fairly strong movement behind the breakwaters (Plates 126a

and 126b), although comparable to conditions produced by the smaller waves.

61. <u>290-deg waves.</u> Plates 127a-131b show wave-generated currents for the 290-deg wave approach with Plan 1 installed. The 4-ft, 4-sec wave at the 0.0-ft water level (Plates 127a and 127b) produced a large number of eddying currents in the lee of the breakwater groin system. In the Beach 6 region, longshore currents began moving downcoast due to the change in shoreline angle relative to wave approach angle. The 4-ft, 4-sec wave at the +3.0 ft water level produced about the same effect as at the lower water level with some variation in eddying current patterns shoreward of the breakwaters (Plates 128a and 128b). The 7-ft, 4-sec and 10-ft, 6-sec wave at the +3.0 ft water level produced very similar current patterns and magnitudes behind the breakwaters, but the currents lakeward of the breakwaters were slightly greater for the 10-ft wave (Plates 129a-130b). The 12-ft, 9-sec wave at the +6.9 ft water level produced circulation eddies behind the breakwaters of about the same size and current magnitude as the previous waves for this plan (Plate 131a), although offshore there was a strong lakeward-directed current at groin 10 (Plate 131b).

62. <u>315-deg waves.</u> Plates 132a-134b show Plan 1 current patterns for the 315-deg wave approach. The 4-ft, 4-sec wave at the 0.0-ft water level produced eddying currents in the lee of the breakwater in the groin field. There was an outward flux of the water mass at the downcoast end of each groin-breakwater cell as shown in the dye photographs (Plate 132b). Currents along the Beach 6 area were more uniform along the beach. The 4-ft, 4-sec and 7-ft, 4-sec waves at the +3.0 ft water level produced somewhat similar results as the previous 4-ft, 4-sec wave at the 0.0-ft water level (Plates 133a-134b).

<u>Plan 1 sediment tracer tests</u>

63. Sediment tracer was placed in the model as shown in Plate 135 for the tests with the 270-deg wave. Placement for the 290-deg wave was different only in that a line of tracer was added on the southwest side of each groin, and for the 315-deg wave, tracer was placed only on the southwest side of a groin (the northeast line of tracer, adjacent to a groin, was eliminated).

64. <u>270-deg wave.</u> Plates 136-141 present results of the tracer tests with a 270-deg wave approach. Tracer movement for the 4-ft, 4-sec wave at 0.0-ft water level was primarily limited to tracer located in the gaps between the offshore breakwaters and the region lakeward of the breakwaters (Plate 136). There was some movement out of the groin 10 and 11 cell near groin 11, where

tracer moved directly toward the upcoast tip of the breakwater rather than toward the landward end of the groin. The 2-ft, 4-sec wave at the +3.0 ft water level indicated movement only in the region of the gaps between breakwaters (Plate 137). The 4-sec, 4-ft wave at +3.0 ft water level (Plate 138) indicated similar movement behind the breakwaters as for the test of 0.0-ft water level (Plate 136). Movement of tracer in the nongroin region of Beach 6 indicated a fairly continuous alongshore movement of tracer as compared with discontinuous movement of that for smaller 2-ft, 4-sec wave (Plate 137). The 7-ft, 4-sec wave at the +3.0 ft water level indicated stronger alongshore movement lakeward of the breakwaters than the 4-ft, 4-sec wave (Plate 139), but movement behind the breakwater system was similar to that of the 4-ft, 4-sec wave. The 10-ft, 6-sec wave (Plate 140) set up currents which removed some tracer from behind the breakwater system to the offshore area from between the downcoast gap of a breakwater-groin cell. In the nongroin region, tracer movement was generally alongshore both behind and offshore of the breakwaters. The 12-ft, 9-sec wave at +6.9 ft water level produced strong alongshore movement lakeward of the breakwaters. There was some movement of tracer shoreward from the lakeside of the breakwaters and some offshore movement from behind the breakwaters at groins 8 and 10.

65. <u>290-deg waves.</u> Plates 142-146 present results of the 290-deg wave approach sediment tracer tests. The 4-ft, 4-sec wave at the 0.0-ft water level produced some offshore movement of tracer lakeward of the breakwaters but almost all the tracer shoreward of the breakwaters remained behind the breakwaters (Plate 142). In the Beach 6 region, most tracer moved alongshore with minor amounts migrating lakeward along the southern tips of the breakwaters. The 4-ft, 4-sec wave at the +3.0 ft water level showed less offshore movement of tracer lakeward of the breakwaters than the previous test and was similar in respect to maintaining the tracer shoreward of the breakwaters near the shore (Plate 143). The 7-ft, 4-sec wave at +3.0 ft also tended to retain most of the shoreward placed tracer behind the breakwaters (Plate 144). The 10-ft, 6-sec wave produced similar results as the previous test except for the tracer offshore of the breakwaters, which tended to move farther offshore (Plate 145). The 12-ft, 9-sec wave at the +6.9 ft level showed strong offshore movement of tracer lakeward of the breakwaters and some movement out of the region shoreward of the breakwaters (Plate 146).

66. <u>315-deg waves.</u> The sediment tracer tests for waves from the 315-deg

wave approach are shown in Plates 147-149. The three tests shown produced very similar patterns of movement, with sediment tracer behind the breakwaters remaining in these regions and with tracer in the offshore region moving alongshore.

Plan 1 beach-fill tests

67. 270-deg waves. Plate 150 shows the results of the 4-ft, 4-sec wave at the +3.0 ft water level after 5 hr of testing in which sediment was continually placed along the shoreline in areas of strong movement (primarily in the gap spaces between the breakwaters). As shown in Plate 150, the sediment was redistributed and tombolos were developed behind the breakwaters. The greater portion of sediment had accreted along the shoreline with minor amounts migrating along the lakeward face of the center and downcoast breakwaters of groin cells 9 and 10. In the nongroin region of Beach 6, nearly full tombolo development was noted as the breakwaters in this region are closer to shore. The water level then was raised to +5.0 ft and a 6-ft, 6-sec wave run for 2 hr. Plate 151 shows results that indicated a cutting back of the tombolos developed in the first portion of the test. There was no movement of sediment offshore lakeward of the breakwaters except in the Beach 6 region where there was some offshore movement around the breakwaters. Generally, this movement was in a longshore direction parallel to the long axis of the breakwater, then shoreward on the downdrift side of the breakwater. Plate 152 shows results of the separate test of the 12-ft, 9-sec wave at the +6.9 ft water level. This was not a continuation of the previous test. Once again, even for this severe wave condition, the sediment remained shoreward of the breakwaters (except near the transition region between the groin field and Beach 6, shown on the left side of the lower photograph in Plate 152). Sediment also was overwashed landward onto the beaches due to the high water level and wave runup.

68. 290-deg wave. Beach-fill tests for the 290-deg wave approach are shown in Plates 153-156. The 4-ft, 4-sec wave at the +3.0 ft water level indicated sediment was retained behind the breakwaters (Plate 153) in a typical tombolo beachline not unlike the 270-deg wave for similar conditions (Plate 150). There was even less movement along the lakeward edge of the breakwaters due to the almost normal wave approach to the local shore of Beaches 4 and 5. The 6-ft, 6-sec wave at +5.0 ft water level then was reproduced for 2 hr. Some minor offshore movement of sediment was noted, but most of the tombolos that had formed remained intact. Plates 155 and 156 show hours of

0.5 and 1.0, respectively, of the test with the 12-ft, 9-sec wave at the +6.9 ft water level. There was some offshore movement of sediment from the groin 9 and 10 and 10 and 11 cells, but the greater portion of sediment introduced at the shoreline remained behind the breakwaters.

Plan 2 Testing

69. The Plan 2 system of offshore breakwaters was installed in the model (Figures 18 and 19) although only the groin 9, Beach 6 region was studied in detail in order to reduce data collection. Essentially, the main difference between Plan 1 and Plan 2 was the lateral shift of the line of offshore breakwaters by 250 ft. Spacing between breakwaters and distance offshore was the same as that for Plan 1. The transition region between the last groin (No. 11) and the open section of beach (Beach 6) was somewhat different (i.e., the first offshore breakwater north of groin 11 was in deeper water and closer to groin 11 for the Plan 2 condition than for Plan 1). Tests for Plan 2 are listed in Table 3.

Plan 2 wave-generated current tests

70. 270-deg waves. The 4-ft, 4-sec wave at the 0.0-ft water level produced a fairly uniform longshore current behind the breakwaters in the midsection of each groin cell, with eddying currents adjacent to each groin (Plates 157a and 157b). There was some movement of the water mass out of each gap in the breakwater groin system. Beach 6 results showed fairly uniform longshore currents behind the breakwaters with a current exiting upcoast of each breakwater and paralleling the lake side of the breakwaters. The 4-ft, 4-sec wave at the +3.0 ft water level indicated similar patterns as the previous test except that the eddying currents were slightly stronger (Plates 158a and 158b). The 10-ft, 6-sec wave produced greater eddying behind the breakwater and greater offshore currents extending lakeward of the breakwaters since the wave was breaking in deeper water (Plates 159a and 159b). The 12-ft, 9-sec wave at the +6.9 ft water level indicated currents of moderate value behind the breakwaters in the groin region and strong longshore currents on the outer bar (Plates 160a and 160b).

Plan 2 sediment tracer tests

71. 270-deg waves. Plate 161 shows the sediment tracer placement for the Plan 2 testing. Plate 162 shows results of a 4-ft, 4-sec wave at the 0.0-ft water level. Sediment tracer accumulated behind the offshore

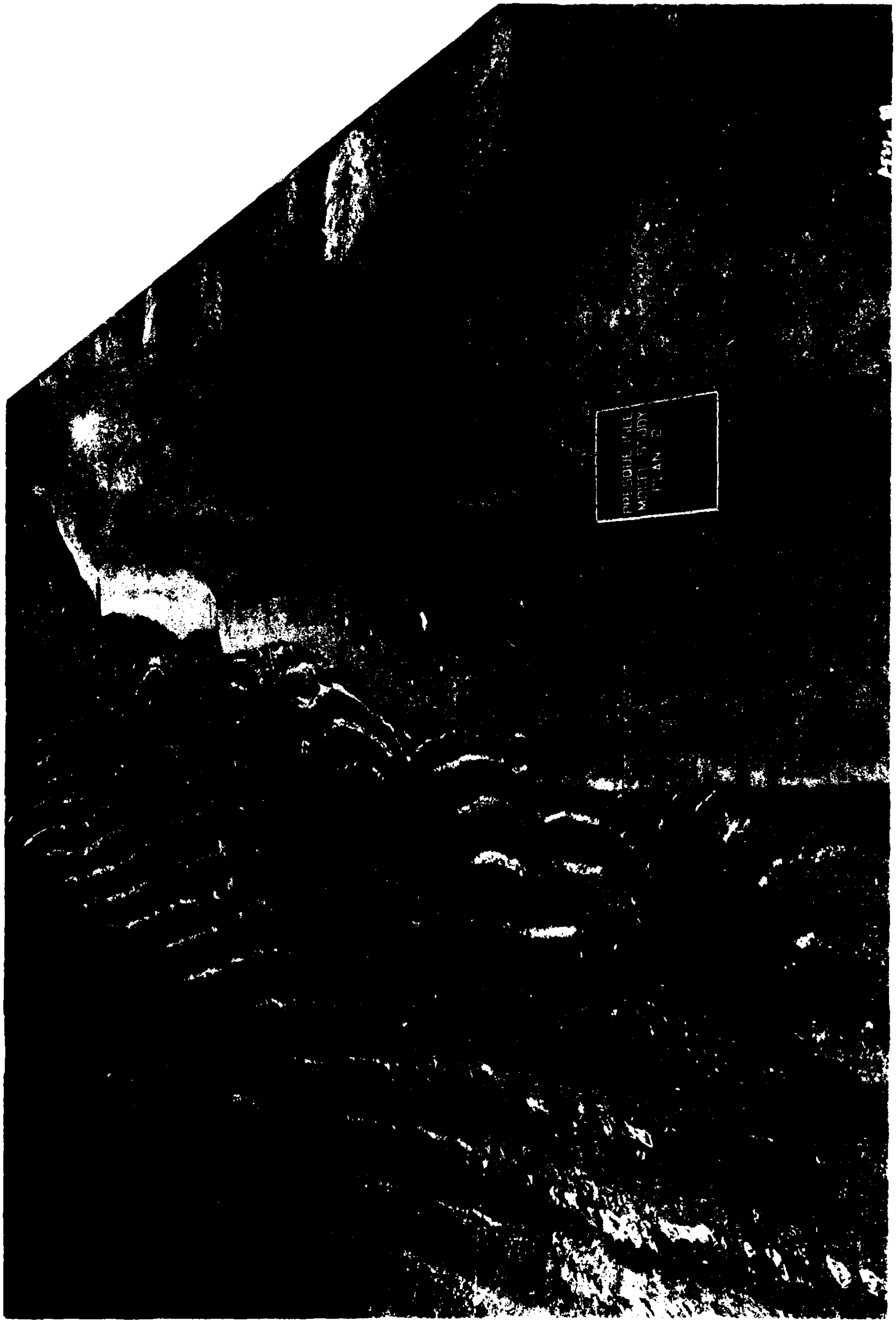


Figure 18. Plan 2 in model

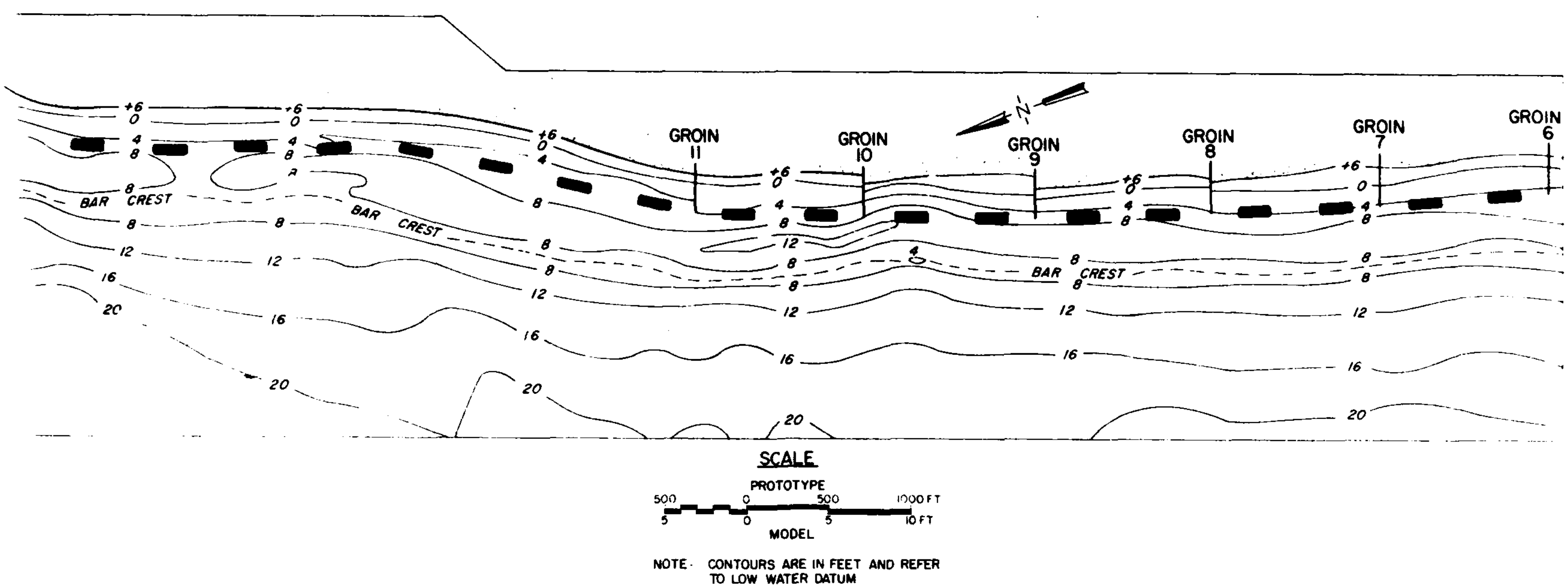


Figure 19. Plan 2 offshore breakwater layout

breakwaters, while that sediment tracer placed offshore moved parallel to the shoreline. The 4-ft, 4-sec wave at the +3.0 ft water level indicated more movement behind the breakwaters at the higher water level than the previous test at 0.0 ft. However, the sediment tracer shoreward of the breakwaters did not move out lakeward of the breakwaters (Plate 163). At the downcoast end of each cell, sediment tracer moved out from behind the breakwater, then curved back in toward the groin. The 10-ft, 6-sec wave indicated that most tracer placed shoreward of the breakwaters remained shoreward except for a small amount moving toward the tip of groin 11 (Plate 164). The 12-ft, 9-sec wave test indicated most tracer remained behind the breakwater with small tracer paths moving lakeward between groin 10 and 11 (Plate 165).

Plan 2 beach-fill tests

72. 270-deg waves. Beach-fill tests were performed in a similar manner as previous beach-fill tests. Plates 166 and 167a-167b show the 4-ft, 4-sec, +3.0 ft water level tests at the halfway point (hour 2.5), and at the conclusion of the test (hour 5), respectively. Good tombolo development behind the breakwaters was noted. Regions adjacent to the groins remained clear of sediment. Plate 168 shows Plan 2 after 2 hr of 6-ft, 6-sec wave attack at the +5.0 ft water level as a continuation of the previously discussed test. Sediment was contained shoreward of the line of the breakwaters except for a minor tracer amount migrating in front of the breakwaters. Results of the 12-ft, 9-sec wave at +6.9 ft are shown in Plates 169a and 169b. There was movement of sediment past groin 10 toward the outer bar, and movement out beyond the breakwater at the Beach 6 region.

Plan 3 Testing

73. The Plan 3 system of offshore breakwaters was placed in the model as shown in Figures 20 and 21. Ideally, all the breakwaters were to be placed at the -5 ft contour as called for in the NCB's design; however, this would produce a serpentine alignment. Instead, the breakwaters between the locations of groins 7 and 11 were placed along a straight line where the depth averaged about 5.0 ft. This was felt appropriate as the shoreline would readjust to the breakwaters in any case. Also the groins were removed. The breakwaters north of the groin 11 location also were placed as close to the -5 ft contour while maintaining a smooth curve in the transition to the different orientation of Beach 6. Center-line spacing of the breakwaters was maintained at 500 ft and

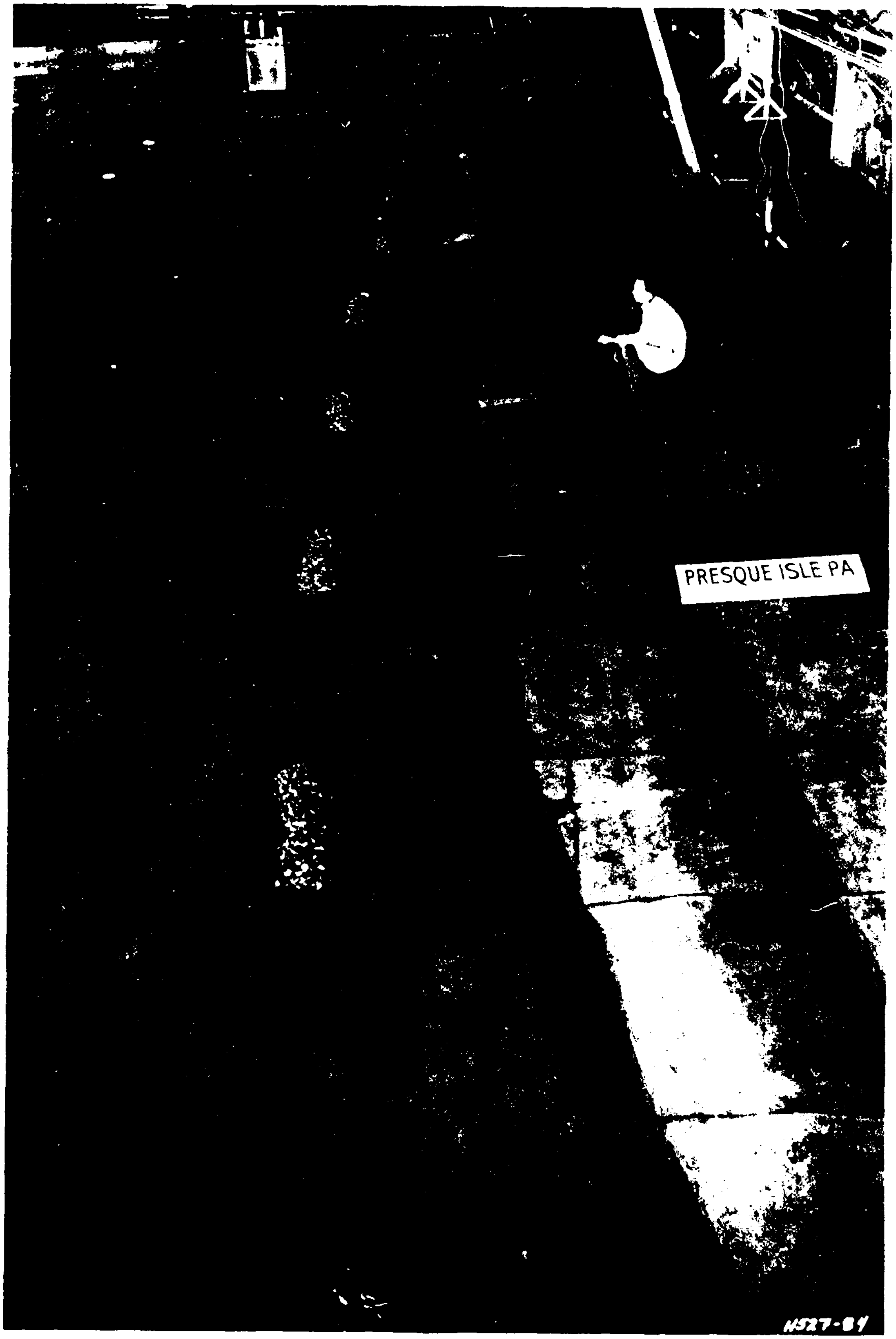


Figure 20. Plan 3 in model

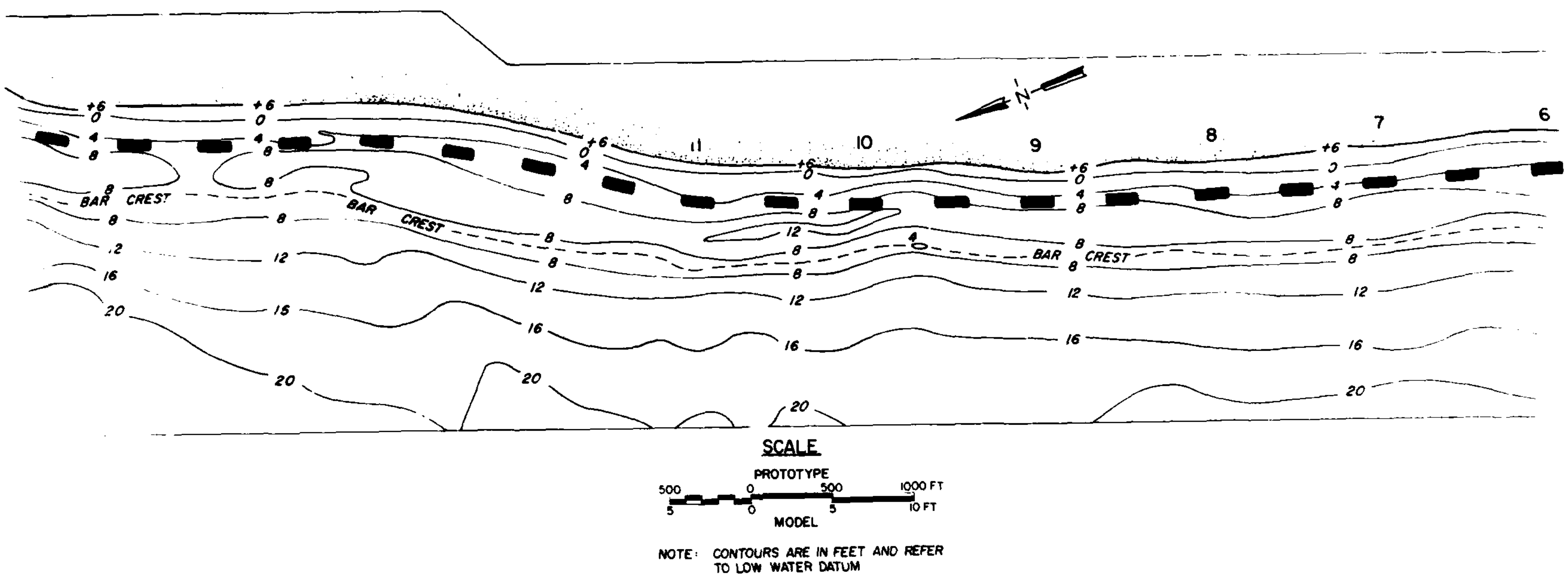


Figure 21. Plan 3 offshore breakwater layout

lateral location along the shoreline was similar to Plan 1.

Plan 3 wave-generated currents

74. 270-deg waves. Currents for the 4-ft, 4-sec wave at +3.0 ft water level indicated that a strong continuous longshore current set up behind the offshore breakwaters (Plate 170a). The dye photographs indicated slow currents emanating upcoast of some breakwaters, then flowing parallel to the lakeside of the structures (Plate 170b). The 12-ft, 9-sec wave at the +6.9 ft water level produced current patterns (Plates 171a and 171b) similar to the previous test.

75. 290-deg waves. Wave-generated current patterns for the 4-ft, 4-sec wave for waves approaching from 290 deg indicated eddying currents at Beaches 4 and 5 and uniformly directed northeasterly longshore currents at Beach 6, where there is an angle between the wave front and the beachline (Plate 172). The 12-ft, 9-sec wave at +6.9 ft indicates patterns similar to the previous test (Plate 173) with about the same magnitude of currents behind the breakwaters but greater currents offshore of the breakwaters.

Plan 3 sediment tracer tests

76. 270-deg waves. Plate 174 shows the layout of sediment tracer for Plan 3. Results of the 4-ft, 4-sec wave at the +3.0 ft water level indicated a tendency for the sediment tracer behind the offshore breakwaters to move alongshore through the system (Plate 175). For the 12-ft, 9-sec wave, some paths of moving tracer from behind the breakwaters are noted (Plate 176).

77. 290-deg waves. Testing of the 4-ft, 4-sec wave at the +3.0 ft water level produced tracer patterns of accretion behind the breakwaters (Plate 177). The 12-ft, 9-sec wave at the +6.9 ft water level (Plate 178) produced tracer patterns indicating strong movement lakeward of the breakwaters but mostly movement toward accumulation shoreward of the breakwaters.

Plan 3 beach-fill tests

78. 270-deg waves. Plates 179 and 180 show results halfway through and at the conclusion, respectively, of the beach fill test for the 4-ft, 4-sec wave at Beaches 5 and 6. Emergent, above-water tombolos existed behind most of the breakwaters and minor migrations of sediment along the lakeside of the offshore breakwaters developed. Plates 181 and 182 show the effect of the 6-ft, 6-sec wave at the +5.0 ft water level after the first half hour of testing and after 2 hr, respectively. Some sediment was moved lakeward but most was retained behind the breakwaters. Plate 183 presents the results of

the 12-ft, 9-sec wave at the +6.9 ft water level indicating that the beach fill placed along the shoreline was retained behind the breakwaters.

79. 290-deg waves. Plate 184 shows the beach development for the 290-deg wave approach with the 4-ft, 4-sec wave reproduced. Nearly complete tombolos were developed for this condition. The 6-ft, 6-sec wave at the +5.0 ft water level shows some lakeward movement of sediment near the groin 10 location (Plate 185). Plate 186 indicates some lakeward movement of beach-fill sediments for the 12-ft, 9-sec wave at the +6.9 ft water level.

Discussion of Testing

Wave-generated currents

80. The wave-generated current tests may be used to help interpret the paths that sediment suspended in the water column may take. Also it is important to examine these data for currents that may create unsafe conditions for swimmers, although most likely only the smaller waves tested (2-ft and perhaps 4-ft wave height) would occur during good swimming weather.

81. In order to compare wave-generated current patterns and magnitudes for the various tests, Plates 187-194 were prepared. These plates show typical patterns and velocity magnitudes drawn from all the data for a given plan and wave condition. Plate 187 shows that the Base condition and Plan 2 had a similar range of longshore velocities at the midpoint of a groin cell for the 270-deg, 4-ft, 4-sec wave at the 0.0-ft water level, while the maximum velocity at the same location for Plan 1 was 1.1 fps slower. The velocity exiting a groin cell had smaller maximums for Plans 1 and 2 when compared with the Base condition, with Plan 1 having a higher maximum and lower minimum than Plan 2. The current exiting from the middle of a groin cell was higher for Plan 2 than Plan 1. Along the open-coast (no groin) portion of shoreline, currents of both plans were reduced significantly, as would be expected, by the offshore breakwaters. Overall, Plan 1 had lower currents than Plan 2 or the Base. Plate 188 compares results for the 270-deg, 4-ft, 4-sec wave at the +3.0 ft water level and indicates that Plan 3 velocities along the shoreline were as high or higher than Plan 1 or 2 velocities and were continuous along the entire shoreline, since there were no groins to break up the longshore current system. However, there were no significant currents exiting lakeward through the breakwaters for this initial flat beach condition (i.e., no tombolo development).

The eddy developed in the downcoast corner of a groin cell for Plan 2 was in a clockwise direction as compared with the counterclockwise eddy for Plan 1 and might aid in keeping sediment close to the shore rather than moving lakeward along the groin. Plate 189 compares Base, Plan 1, and Plan 2 for the 270-deg, 10-ft, 6-sec wave at the +3.0 ft water level. Plan 1 indicated the greatest reduction of velocities when compared with Base condition for this large wave condition, which initially broke on the lakeward side of the outer bar. Plate 190 shows the reduction in velocities along the shoreline for Plans 1, 2, and 3 when compared with the Base for the 12-ft, 9-sec wave. Among the plans, Plan 3 had the highest shoreline velocities and Plan 2 the lowest for this particular test condition.

82. For waves approaching from 290 deg, Plates 191-193 show comparisons for current patterns and magnitudes. Plate 191 compares data for the 4-ft, 4-sec wave at the +3.0 ft water level. Overall currents for the Base and Plan 1 conditions were close in magnitude, and Plan 3 currents near the shoreline were slightly higher than the Base currents for this wave approach that is about parallel to the Beach 4 and 5 shoreline. Plate 192 compares only Base and Plan 1 for the 10-ft, 6-sec wave at the +3.0 ft water level. Currents at the shoreline were locally higher for Plan 1, but on the average were lower for Plan 1, as are currents moving offshore. For the 12-ft, 9-sec wave (Plate 193), currents were reduced for Plan 1 but were similar for Plan 3 near the shoreline, when compared with the Base Test. Offshore moving currents were reduced by both plans over Base conditions.

83. Plate 194 compares the Base with Plan 1 for the 4-ft, 4-sec, 315-deg wave at the +3.0 ft water level. Current reductions for Plan 1 over the Base condition were evident both close to shore and for currents moving offshore.

84. Generally, wave-generated current measurements showed that the offshore breakwaters reduced the rip currents, producing broader outflow patterns than that of an existing groin cell. The flow along the shoreline was split up into smaller circulation cells and was reduced for most offshore breakwater test conditions except for Plan 3, where the groins were removed, and along the shoreline of Beach 6, which was outside the groin field.

85. The plans can be ranked by the amount of shoreline attacked by an angular wave approach, ignoring wave effects such as wave diffraction behind the structure, refraction, and reflection of wave energy off the groins. For a 30-deg wave angle, the percent of shoreline receiving direct attack by the

waves is 85 percent for the Base conditions (the groins protecting 15 percent of the beachline for this angle of wave approach), 66 percent for Plan 1, 58 percent for Plan 2, and 70 percent for Plan 3. As the wave angle approaches 0 deg, Plans 1, 2, and 3 would approach 70 percent of exposed shoreline and the Base would approach 100 percent. This can help explain a general trend in velocity magnitudes for the various plans for angular wave approaches.

86. From the data, including the current measurements and the dye photographs, it is possible to develop a general model of currents in the vicinity of the offshore breakwater as shown in Figure 22. This is for waves breaking between the breakwater and shore with no wave overtopping the breakwater. This pattern is similar on the upcoast side to that which exists once a tombolo has developed (Figure 22b). This current pattern was taken from testing at the Beach 10 area after tombolos had developed in the movable-bed model. Currents on the lakeward face of the breakwater tend to move parallel to the structure in either case and move shoreward once downcoast of the structure. Figure 23 shows actual current measurements made during a beach-fill test of Plan 3. The conditions modeled were for the 4-ft, 4-sec, 270-deg wave at the +3 ft water level.

Tracer tests

87. Base conditions. Base condition tracer tests indicated strong longshore movement in the groin cells, with tracer moving offshore at the downcoast end of each cell at the tips of the groins for the 270- and 315-deg angular wave approaches (e.g., Plates 98 and 110). For the larger 270- and 315-deg waves, sediment that moved offshore of the groin tips then was moved parallel to shore in the trough between the offshore bar and the groin tips (Plates 101 and 112). For 290-deg waves (normal to Beaches 4 and 5, the groin field region) there was good movement within the groin cells near the shore, but not out of the cells for the smaller waves except at groins 8 and 10 for the 4-sec, 4-ft wave at the +3.0 ft water level. There was stronger overall sediment tracer movement both nearshore and offshore for the larger waves, though only the 12-ft, 9-sec wave produced significant offshore movement of tracer from near the shoreline for the 290-deg wave approach.

88. Plan 1. For the Plan 1 breakwaters, sediment was contained behind the breakwaters for small wave conditions (Plate 137). For larger waves, there was sediment leakage around the edge of some of the breakwaters depending on the bottom contour gradient offshore of the groin cell. For the deeper

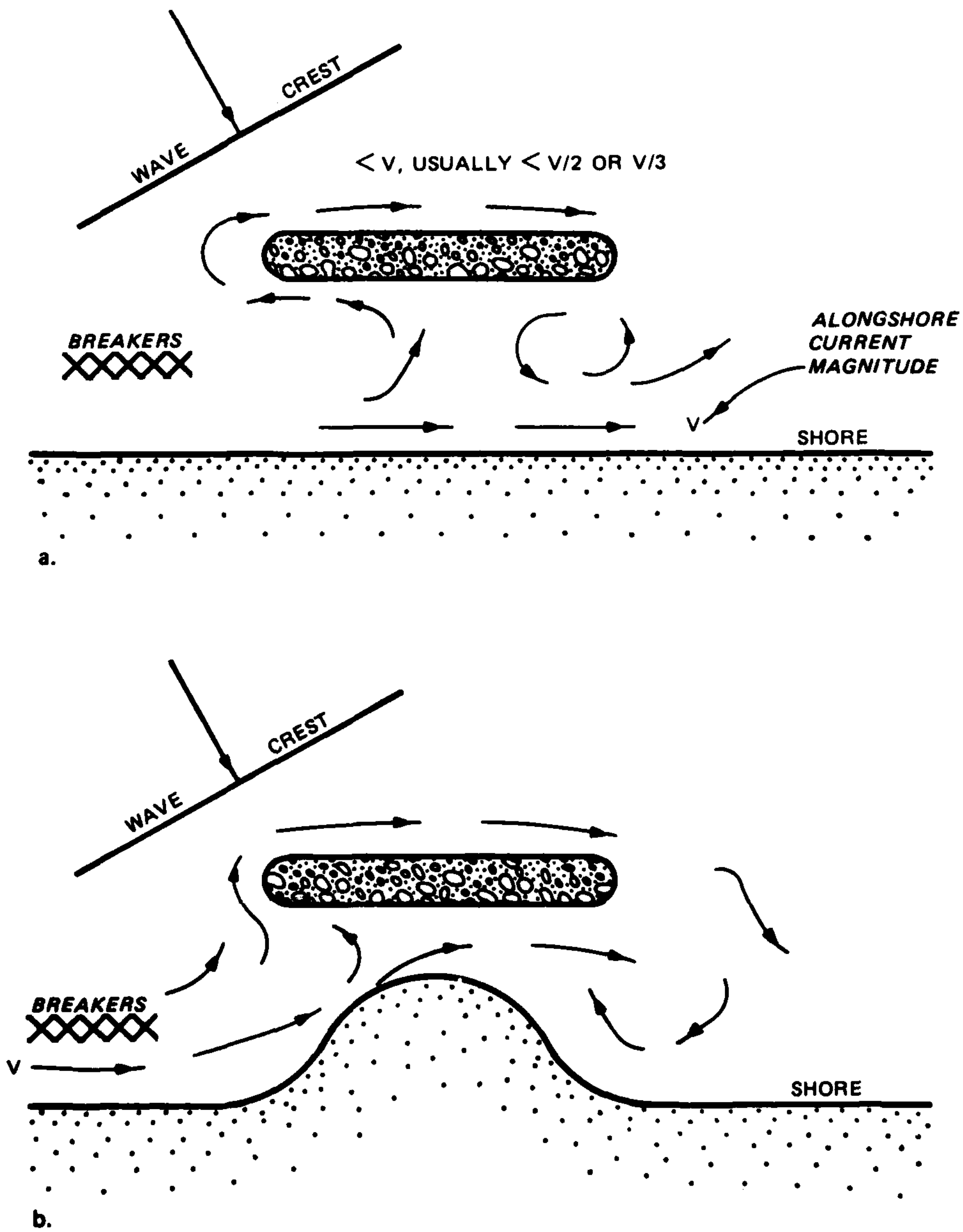


Figure 22. General model of currents in the vicinity of an offshore breakwater

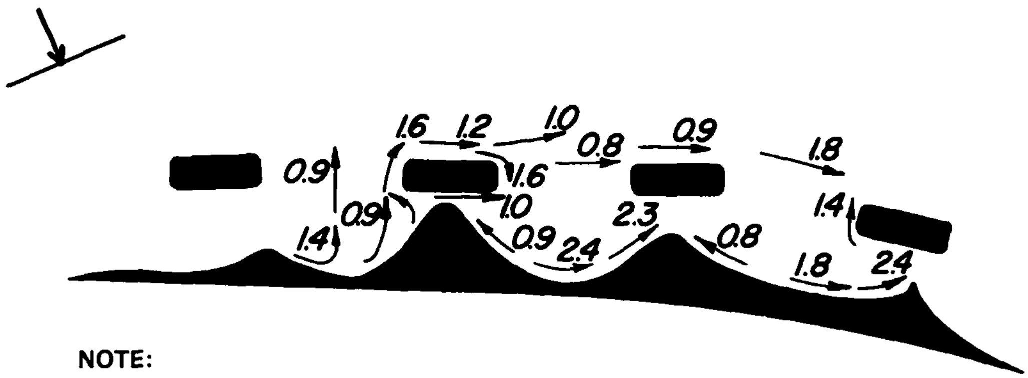


Figure 23. Currents generated by 4-ft, 4-sec, 270-deg wave at +3.0 ft water level during beach-fill test of Plan 3

contoured cells, as between groins 9 and 10, the sediment would stay close to shore; for shallower cells, e.g., between groins 10 and 11, there was some movement out of the cell around the downcoast breakwater; and for a very shallow groin cell (between groins 7 and 8), sediment would move out around both the downcoast and center breakwaters (Plate 138). If sediment tracer did move out around the upcoast breakwater tip, it would then migrate downcoast close to the breakwater and parallel to it. This was most likely due to the interaction of the incident wave and the wave reflected by the breakwater creating paths of transport in the short-crested wave field which is maintained in front of the breakwater. These paths of transport were always parallel to the reflecting structure no matter what the angle of wave approach. This effect would probably aid in promoting longshore movement lakeward of the offshore breakwaters over onshore-offshore movement. This can be noted by comparing Plates 97 and 137. This will be the case for Plans 2 and 3 also, since any wave reflecting structure will aid this effect. The permeability and wave absorbing characteristics of rubble-mound structures will limit the strength of this effect, especially when compared with the existing sheet-pile groins (highly reflective structures which aid in moving sediments perpendicular to shore and thus offshore). Also many natural wave trains do not have the initial long-crested wave necessary to create a strong incident-reflected short-crested wave field which would diminish this effect.

89. The Plan 1 system demonstrated quite well the ability of the offshore breakwater to reduce sediment transport along the shore. For example, for the smaller, more typically occurring waves, compare Plates 97 and 137 and

98 and 138. The "string" of sediment tracer along the shoreline for the Base condition was broken up as tracer accumulated behind the breakwaters of Plan 1. For larger waves, Plates 99 and 139 show a dramatic effect of the breakwaters, although the Base photograph was taken after about three times the duration of the Plan 1 test (the comparable Base photograph did not develop due to technical difficulties). Plates 100 and 140 show the reduction in movement of tracer near the shoreline between the Base and Plan 1 for the 10-ft, 6-sec wave from 270 deg. For the Base test, the sediment tracer had accumulated at the downdrift end of the groin cells and was moving offshore; while for Plan 1, sediment pockets remained behind the breakwaters and the downcoast areas adjacent to the groin had only small deposits of tracer. The cell between groins 10 and 11 shows an absence of tracer for Base conditions while retaining significant amounts of tracer for Plan 1 (compare Plates 101 and 141).

90. For the 290-deg wave approach, comparison of Plates 105 and 144 shows the breakwaters maintaining the tracer nearer shore for Plan 1 than for the Base condition, changing paths of sediment which were moving offshore at the groins to points of accumulation behind the breakwaters. Also the effect of the breakwaters at the Beach 6 region was very evident, showing the points of accumulation behind the breakwaters.

91. The Plan 1 tracer tests for the 315-deg wave approach produced results very similar to the 270-deg wave approach when compared with Base tracer tests and as discussed in paragraph 87. For example, a comparison of Plates 110 and 149 shows that the strong longshore movement of the Base Test was broken up and zones of accumulation near the shore were created by Plan 1.

92. Plan 2. The tracer tests for Plan 2 indicated that for smaller waves (4 ft or less), the tracer placed behind the breakwaters remained there (Plates 162 and 163) unlike the tracer patterns for Base conditions which moved strongly alongshore (for 270-deg waves, Plate 98). The larger 10-ft wave (Plate 164) indicated some offshore movement at groin 11 of tracer placed shoreward of the structures. The total paths of movement were reduced for Plan 2 (compare Plates 100 and 164) and tracer moved into the protected zone behind the breakwaters.

93. Plan 3. Generally, for the smaller waves, Plan 3 showed that lines of longshore tracer movement remained close to shore for tracer placed behind the breakwater since there were no interrupting groins in the Beach 4 and 5 areas.

94. The tracer tests generally illustrated the ability of the breakwater systems to break up the longshore current system developed by angled wave approaches which moved sediment out of the groin cells. Testing, of course, was for an "initial" condition, before the shoreline would begin responding and developing tombolo formations. For plan wave conditions that did move sediment out from behind the breakwaters, usually sediment transport paths turned parallel to the lakeward face of the breakwater and moved downcoast. Once past the breakwater, the sediment moved shoreward around the downcoast end of the breakwater in most cases. Sediment tracer initially placed outside the breakwaters for plan tests with smaller waves (up to 4-ft height) tended to move more in a longshore direction than the onshore-offshore movement of the Base Tests. For larger waves, which created strong alongshore movement lakeward of the groin system for Base conditions, the same strong conditions persisted for the plan tests. Plan 3, with the groins removed, indicated good alongshore movement of tracer behind the breakwaters for this initial condition (before the development of tombolos).

Beach-fill tests

95. The beach-fill tests were performed to obtain an idea of beach response behind the breakwaters that might develop over the long term due to average wave conditions. The developed beach then was subjected to larger wave conditions to look for erosion problems. Also beach-fill movement during extreme events was examined with the 12-ft, 9-sec wave at the +6.9 ft water level.

96. Examining the initial 270-deg tests with a 4-ft, 4-sec wave, Plates 113, 150, 167a, and 180 show Base Test, Plan 1, Plan 2, and Plan 3, respectively. The Base Test showed filling of each cell at the downcoast end, then movement past the tips of groins 10 and 11. Each plan produced good tombolo development behind the breakwaters. Comparing Plans 1 and 2, in which groins are still in place, Plan 2 tended to keep more sediment within the cell. For example, looking at the groin 10 location, Plan 1 showed sediment moving around the breakwater to the next cell while Plan 2 showed no movement to the next downcoast cell. A drawback with Plan 2 relates to the splitting of a swimming area by the groin. Every other "pocket" beach would be split by a groin which may not be desirable for good swimming conditions. Plan 3 indicated a slower rate of tombolo building as sediment moved through the breakwater system. All plans indicated some tendency for sediment to bypass on the

lakeside of the breakwater once the tombolos had been significantly developed, with Plans 1 and 2 showing the development sooner than Plan 3 since the groins already provided a barrier to longshore currents and deflected them lakeward around the breakwater.

97. Following the 4-ft, 4-sec wave at the +3.0 ft lwd water level, the test was continued at a higher water level (+5.0 ft lwd) with a 6-ft, 6-sec wave for 2 hr. Conditions at the end of the tests discussed in paragraph 96 were the initial conditions for this test. These results are shown in Plates 114, 151, 168, and 182 for the Base through Plan 3 tests, respectively. None of the plans indicate any serious lakeward movement of sediments, with the Base indicating the greatest susceptibility for sediment to be lost offshore.

98. The beach-fill test results for the 270-deg, +6.9 water level, 12-ft, 9-sec wave appear in Plates 115, 152, 169a, and 183 for Base through Plan 3. The Base Test showed strong sediment movement off the tips of groins 10 and 11 with leakage of sediment to the offshore bar where it then tends to move downcoast without returning shoreward. For Plan 1, there was some by-passing from one cell to the next but no strong offshore movement. Downcoast of groin 11, there was movement outside the breakwaters similar to the Base Test result. For Plan 2, there was less movement out of the cell at groin 11 to the offshore bar than for the Base on Plan 1 conditions due to the closer proximity of the breakwater downcoast from groin 11. For Plan 3, offshore movement past the breakwaters was minimal. Most sediment transport was through the system behind the breakwaters and Plan 3 provided a smoother transition between Beaches 5 and 6 (i.e., groin 11 was removed).

99. Beach-fill tests for the 290-deg wave approach were conducted in a manner similar to those for the 270-deg wave except Plan 2 was not tested. For the 4-ft, 4-sec wave at +3.0 ft, the Base Test showed sediment moving out to the groin tips (Plate 116) while Plan 1 (Plate 153) showed good tombolo development, with the beach fill closer to shore. Plan 3 (Plate 184) also had good tombolo development with a little more movement of beach fill toward the breakwaters since they were closer to shore than those of Plan 1.

100. Continuing the tests discussed in the previous paragraph, with an increased water level (+5.0 ft) and wave height and period (6 ft, 6 sec), the Base (Plate 117) showed some offshore rips transporting beach fill lakeward and erosion along Beach 6. For Plan 1, the previously developed tombolos remained protected (Plate 154) while for Plan 3 (Plate 185), there was some

offshore movement southwest of the groin 10 location but the tombolos remained intact.

101. The large 12-ft, 9-sec wave (290-deg wave direction, +6.9 ft water level) produced strong rips at groins 10 and 11 carrying beach fill lakeward for the base condition (Plate 118). Plan 1 also showed some offshore movement (Plate 155). The Beach 6 area remained better protected for Plans 1 and 3 than for the Base conditions and the Plan 3 test results (Plate 186) were similar to Plan 1 results.

Wave-Height Tests

102. Wave measurements were made for the design wave condition (12.8-ft, 9-sec, +6.9 ft water level) at gages positioned as shown in Figure 24. As noted in Figure 24, the breakwater was at the -10 ft contour, the depth of the Plan 1 breakwater. A second test condition was set up and run with the breakwater located at the -5 ft contour, the depth of the breakwater outside the groin field. Table 4 shows the wave-height measurements. Three runs were made for each breakwater location at different wave generator stroke settings to bracket the design wave height. The data then were averaged for each breakwater location. Gage 5 was located at the sea-side toe of the breakwater; gage 6 was located at the toe of the breakwater on the shoreward side. The wave height was reduced by about one-half by the breakwater for this overtopping condition. The

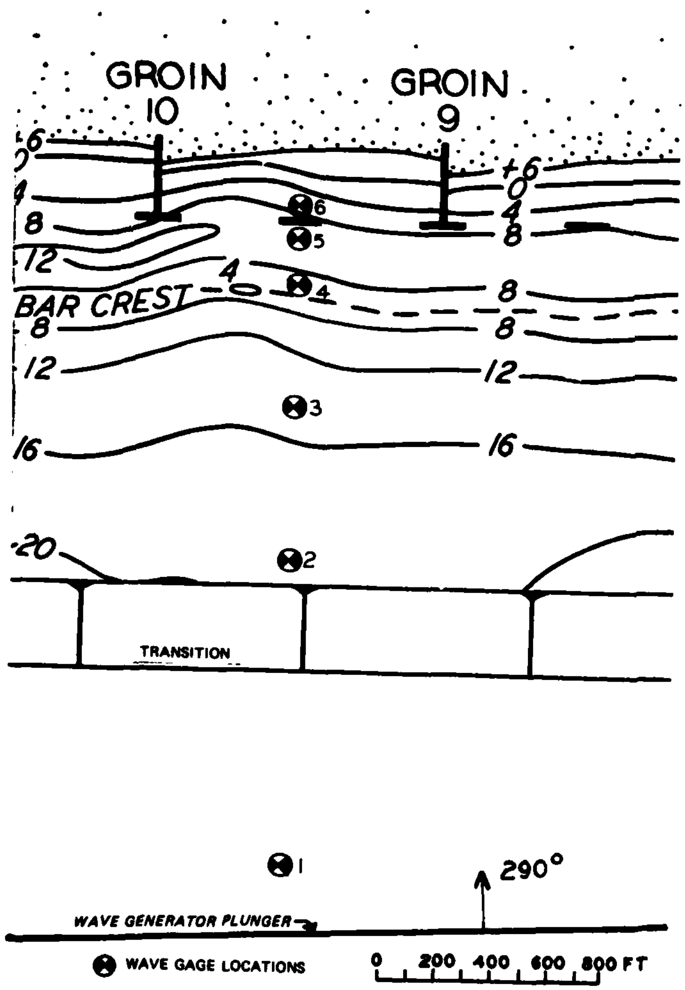


Figure 24. Wave gage locations

wave height at the lakeward toe of the breakwater (gage 5, 6.9 to 7.5 ft) was much less than the initial incident height since the wave broke at two locations before it reached the breakwater.

PART V: CONCLUSIONS

Beach 10 Testing

103. Based on testing of the movable-bed model of Beach 10, it was concluded that:

- a. The model coal sediment effectively reproduced shoreline changes in the lee of the experimental breakwaters. Tombolo development during the summer season and cutting back and rounding of tombolos in the fall-winter season were reproduced in the model for the 1979-80 spring through following spring seasons.
- b. Model testing indicated that the cutting back of tombolos was associated with higher water levels and waves overtopping the offshore breakwaters. Large wave conditions at lower water levels which did not overtop the offshore breakwaters did not cut back the tombolos to any significant degree.

Testing at Beaches 4, 5, and 6

104. Based on wave-generated current tests, sediment tracer tests, and beach-fill tests it was concluded that:

- a. Testing of existing conditions indicated strong longshore current systems existed for angled wave approaches. For smaller waves (4 ft or less) in the groin field (Beaches 4 and 5), a strong longshore current was generated within each cell and was deflected offshore by the groins. Some sediment entrained by the longshore current was deflected offshore along the downcoast groin and then moved alongshore in the trough between the tips of the groins and the large offshore bar. Once the sediment reached the trough, it was moved alongshore and was not likely to move back onshore. Larger wave conditions (greater than 4 ft) that initially break on the outer bar or farther lakeward generate strong longshore currents over the outer bar and in the trough between the outer bar and the groin tips which may carry sediment downcoast at high rates. Larger waves normal to the beach also may remove significant amounts of sediment due to strong rip currents.
- b. Generally, model testing of offshore breakwaters indicated the following:
  - (1) Tombolo development would be easily initiated.
  - (2) The extent of tombolo development (i.e., whether a tombolo will develop lakeward and reach the offshore breakwater) is a function of many variables including the existence of auxiliary structures (e.g., groin), the supply of

sediment, the water level, the crown elevation of the structure, wave energy, wave direction, and distance of the structure from the initial shoreline.

(3) The offshore breakwaters reduced wave energy attacking the shoreline and longshore currents also were reduced. Slow eddy-like currents were created and strong rips eliminated by splitting the flow into small circulation cells. Currents emanating lakeward between the breakwaters were diffuse and not as concentrated as for Base Test conditions.

(4) For offshore breakwaters paralleling the shoreline, some energy was reflected lakeward by the breakwaters, tending to change onshore-offshore movement to longshore movement lakeward of the breakwaters. This was more significant for smaller wave conditions than larger ones, which created strong longshore currents over the large offshore bar when approaching the shore at an angle for either base or plan test conditions.

(5) The placement of breakwaters at locations where the local shoreline changes orientation should be accomplished so as to have a smooth transition from one orientation to the other.

(6) The crown elevation of the breakwater relative to water level was a critical factor in determining whether a tombolo accreted or eroded.

(7) Movement of sediment from behind the breakwaters was usually limited until the tombolo was fully developed and attached to the offshore breakwater. Sediment movement then paralleled the breakwater and moved downcoast and then shoreward around the downcoast tip of the breakwater.

c. For the three plans tested:

(1) All showed good tombolo development for accretionary conditions.

(2) The beach was retained effectively during severe wave conditions.

(3) There were no indications that the spacing (350 ft) between breakwaters or the structure length (150 ft) were not satisfactory.

(4) The Plan 3 system (with groins removed) indicated that the rate of tombolo formation would be slower than Plan 1 or 2 due to the throughput of sediment behind the breakwater for this "initial condition" testing. Once tombolos had formed out to the breakwaters, Plans 1 and 3 would be very similar since the groins of Plan 1 would be covered by sand. The Plan 2 system would have a groin splitting every other swimming cell between breakwaters which might be a hazard to swimming.

REFERENCES

Ball, J. W., and Brasfeild, C. W. 1967 (Dec). "Expansion of Santa Barbara Harbor, California; Hydraulic Model Investigation," Technical Report No. 2-805, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Bottin, R. R., Jr., and Chatham, C. E., Jr. (Nov). "Design for Wave Protection, Flood Control, and Prevention of Shoaling, Cattaraugus Creek Harbor, New York; Hydraulic Model Investigation," Technical Report H-75-18, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dai, Y. B., and Jackson, R. A. 1966 (Jun). "Design for Rubble-Mound Breakwaters, Dana Point Harbor," Technical Report No. 2-725, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hunt, I. A., and Bajorunas, L. 1958 (Oct). "The Effects of Seiches at Conneaut Harbor," U. S. Army Engineer District, Lake Survey, Detroit, Mich.

Irish, S. M., and Platzman, G. W. 1962 (Feb). "Investigation of the Meteorological Conditions Associated with Extreme Wind Tides on Lake Erie," Monthly Weather Review.

Noda, E. K. 1971 (Mar). "Final Report, Coastal Movable-Bed-Scale Model Relationship," Report TC-191, Tetra Tech, Inc., Pasadena, Calif.

Platzman, G. W., and Rao, D. B. 1964 (Jun). "Spectra of Lake Erie Water Levels," Journal of Geophysical Research, Vol 69, No. 12, pp 2525-2535.

Resio, D. T., and Vincent, C. L. 1976 (Jan). "Design Wave Information for the Great Lakes; Lake Erie," Technical Report H-76-1, Report 1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Saville, Thorndike, Jr. 1953 (Mar). "Wave and Lake Level Statistics for Lake Erie," Technical Memorandum No. 37, Beach Erosion Board, Corps of Engineers.

U. S. Army Engineer District, Buffalo. 1980 (Jun, Revised Nov) "Presque Isle Peninsula, Erie, Pennsylvania, Final Phase 1, General Design Memorandum," Vols I and II.

Table 1

Lake Erie Water-Level Variations (ft lwd) for 1979

Station 3038 : Erie, Pennsylvania, on Lake Erie

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	570.70	570.59	570.47	571.07	572.08	572.18	572.32	572.10	571.98	571.81	571.52	571.57
2	571.10	570.42	570.41	571.32	571.82	572.22	572.38	572.34	572.08	571.82	571.61	/
3	571.36	570.39	570.37	571.25	571.97	572.16	572.22	572.19	572.06	572.06	571.62	571.90*
4	571.57*	570.92	570.36	571.10	571.96	572.19	572.14	572.22	571.90	571.85	571.40	571.78
5	/	570.48	570.65	571.60	571.89	572.20	572.19	572.21	571.92	572.13	571.29	571.59
6	570.75*	570.35	570.72	574.01*	571.92	572.09	572.17	572.15	572.11	572.08	571.43	571.64
7	570.57	570.40	570.65	571.44*	571.87	572.17	572.08	572.23	572.06	572.32	571.58	571.82
8	570.86	570.40	570.69	571.09	571.92	572.19	572.04	572.10	571.99	571.86	571.57	572.00
9	571.05	570.37	570.78	571.48	571.96	572.21	572.09	572.08	571.95	571.87	571.27	571.79
10	570.73	570.38	571.19	571.61	571.99	572.41	572.17	572.36	572.01	571.74	571.54	571.35
11	570.49	570.25	571.21	571.31	571.99	572.42	572.20	572.01	571.61	571.73	571.48	571.40
12	570.40	570.25	571.00	571.29	572.03	572.25	572.20	571.94	571.74	572.12	571.28*	571.42
13	570.36	570.29	570.87	571.52	572.05	572.15	572.18	572.17	571.76	572.28	571.35*	571.35
14	570.93	570.23	571.50	571.93	572.04	572.13	572.21	572.38	572.11	571.97	/	571.57
15	570.83	569.98	571.06	571.89	572.01	572.16	572.25	572.10	572.11	571.98	/	571.34
16	570.48	570.28	571.04	572.02	572.09	572.14	572.23	571.89	571.99*	571.63	571.89*	571.56
17	570.67	570.23	570.92	572.01	572.00	572.15	572.15	571.84	/	571.70*	571.60*	571.78
18	570.55	570.12	570.88	572.02	572.01	572.17	572.14	571.91	572.10*	571.51	/	571.47
19	570.25	570.28	570.76	572.01	571.96	572.05	572.09	571.86	571.98	571.64	/	571.22
20	570.38	570.22	570.87	571.99	572.01	572.03	572.07	571.78	571.94	571.64	/	571.16
21	570.48	570.48	570.92	572.00	572.05	572.09	572.05	571.79	571.92	571.67	571.25*	571.22
22	570.65	570.15	570.88	572.02	571.91	572.20	572.01	571.82	571.70*	571.59	571.34	571.31
23	570.33	570.19	570.88	572.01	571.89	572.24	571.99	571.89	/	572.15	571.36	571.35
24	570.36	570.24	570.99	571.98	571.84	572.12	572.09	571.99	571.88*	572.08	571.51	571.34
25	570.92	569.72	571.22	571.98	571.86	572.04	572.06	572.08	571.88	571.80	/	571.71
26	570.55	570.13	571.40	571.99	572.24	572.02	572.22	571.91	571.85	571.66	572.56*	571.91
27	570.44	570.43	571.16	572.10	572.17	572.06	572.05	571.94	571.78	571.44	571.71	571.91
28	570.55	570.35	570.95	572.04	572.19	572.06	572.14	571.98	571.82	571.74	572.07	572.05
29	570.65		571.11	572.02	572.20	572.05	572.09	572.04	571.82	571.50	572.03	571.97
30	570.56		571.13	572.12	572.18	572.15	572.08	572.09	571.84	571.11	572.15	571.90
31	570.50		571.25		572.13		572.14	571.97		571.34		571.80
MEAN	570.67	570.30	570.91	571.81	572.01	572.16	572.14	572.04	571.92	571.80	571.60	571.61
MAX.	572.41	571.50	571.99	575.90	572.58	573.46	572.69	573.21	572.84	573.13	573.10	573.83
	2145/02	1035/04	2012/14	0535/06	0150/01	2350/10	1415/28	0935/02	1655/14	1100/23	1622/26	0030/08
MIN.	569.99	569.33	570.16	570.36	571.41	571.52	571.74	571.48	571.42	570.75	570.81	570.86
	2000/19	2128/25	0258/04	1155/04	0745/25	0525/21	2030/28	1830/20	2105/10	2000/30	0715/02	2152/05

* Indicates Less than 90% of the Hourly Data Available.
/ Indicates No Data.

ANNUAL MEAN: 571.58

Table 2

Summary of Test Conditions

for Movable-Bed Tests at Beach 10

Test No.	Lake Level ft lwd	Wave Direction, deg	Wave Height, ft	Wave Period, sec	Test Duration, hr
1-A	+1.9	299	2.0	5.0	2.00
1-B	+1.9	299	4.0	5.0	1.00
1-C	+1.9	299	8.0	7.0	0.50
1-D	+1.9	299	13.0	9.0	0.30
2-A	+1.9	341	1.5	5.0	1.00
2-B	+1.9	341	3.0	5.0	0.10
2-C	+1.9	341	4.5	5.0	0.17
2-D	+1.9	341	6.0	5.0	0.17
2-E	+1.9	341	7.5	5.0	0.17
2-F	+1.9	341	9.0	5.0	0.17
2-G	+6.9	341	10.0	5.0	0.17
2-H	+6.9	341	7.5	5.0	0.17
2-I	+6.9	341	6.0	5.0	0.17
2-J	+6.9	341	2.0	5.0	0.17
2-K	+6.9	341	6.0	5.0	1.00
2-L	+6.9	341	7.0	7.0	0.33
2-M	+6.9	341	5.5	9.0	0.33
3	+1.9	341	1.5	5.0	1.50
4	+1.9	22	3.0	5.0	1.50
5	+1.9	313	3.0	5.0	2.00
6	+4.0	313	1.5	5.0	0.50
7-A	+4.0	313	1.3	4.0	0.50
7-B	+4.0	313	2.6	4.0	1.00
8-A	+4.0	313	2.1	4.0	2.00
8-B	+4.0	313	3.2	4.0	2.00
8-C	+4.0	313	4.2	4.0	2.00
9-A	+4.0	313	2.5	5.0	2.00
9-B	+4.0	313	4.0	5.0	0.50
9-C	+4.0	313	7.0	5.0	2.00
10-A	+4.0	313	2.1	4.0	4.00
10-B	+4.0	313	3.2	4.0	2.00
10-C	+4.0	313	4.2	4.0	2.00

(Continued)

Table 2 (Concluded)

Test No.	Lake Level ft lwd	Wave Direction, deg	Wave Height, ft	Wave Period, sec	Test Duration, hr
11-A	+4.0	313	1.3	3.5	1.00
11-B	+4.0	313	2.6	3.5	2.50
11-C	+4.0	313	3.9	3.5	0.50
11-D	+4.0	313	5.2	3.5	0.50
11-E	+4.0	313	6.4	3.5	0.50
11-F	+6.9	313	6.4	3.5	0.50
12-A	+4.0	313	1.2	4.0	1.00
12-B	+4.0	313	2.1	4.0	2.50
12-C	+4.0	313	3.2	4.0	0.50
12-D	+4.0	313	4.2	4.0	0.50
12-E	+4.0	313	2.1	4.0	0.25
12-F	+4.0	313	4.2	4.0	0.50
12-G	+4.0	313	6.2	4.0	0.66
12-H	+4.0	313	2.1	4.0	2.66
12-I	+4.0	313	6.2	4.0	0.25
12-J	+6.9	313	6.6	4.0	0.75
13-A	+4.0	313	2.1	4.0	4.00
13-B	+4.0	313	3.2	4.0	2.00
13-C	+4.0	313	4.2	4.0	2.00
14-A	+4.0	313	2.1	5.0	4.00
14-B	+4.0	313	3.2	5.0	2.00
14-C	+4.0	313	4.2	5.0	2.00
15-A	+4.0	328	2.1	5.0	4.00
15-B	+4.0	328	3.2	5.0	2.00
15-C	+4.0	328	4.2	5.0	2.00
16-A	+4.0	328	2.1	5.0	4.00
16-B	+4.0	328	3.2	5.0	2.00
16-C	+4.0	328	4.2	5.0	2.00
16-D	+6.9	328	6.4	5.0	1.00
17-A	+4.0	328	2.1	4.0	4.00
17-B	+4.0	328	3.2	4.0	2.00
17-C	+4.0	328	4.2	4.0	2.00
18-A	+4.0	328	2.1	4.0	4.00
18-B	+6.9	328	6.6	4.0	0.20

Table 3

Presque Isle Model Study Testing Program at Beaches 4, 5, and 6

Test Conditions				Type of Test											
				Wave-Generated Currents				Sediment Tracer				Beach Fill			
Wave Direction	Lake Level ft lwd	Wave Period sec	Wave Height ft	B*	1	2	3	B	1	2	3	B	1	2	3
270°	0.0	4	2	1**											
			4	2	30	30		2	30	30					
			7	3	31										
	3.0	4	2	4	32			4	32						
			4	5	33	33	33	5	33	33	33	5	33	33	33
			7	6	34			6	34						
		6	6	7											
			10	8	35	35		8	35	35					
	6.9	6.4	6	9											
		9	12	10	36	36	36	10	36	36	36	10	36	36	36
290°	0.0	4	2	11											
			4	12	37			12	37						
			7	13											
	3.0	4	2	14				14							
			4	15	38		38	15	38		38	15	38		38
			7	16	39			16	39						
		6	6	17											
			10	18	40			18	40						
	6.9	6.4	6	19											
		9	12	20	41		41	20	41		41	20	41		41
315°	0.0	4	2	21											
			4	22	42			22	42						
			7	23											
	3.0	4	2	24				24							
			4	25	43			25	43						
			7	26	44			26	44						
		6	6	27											
			10	28				28							
	6.9	6.4	8	29				29							

* B = Base; 1 = Plan 1; 2 = Plan 2; 3 = Plan 3.
** Test number is given to indicate test was run for given test condition and type of test.

Table 4

Wave Measurements

Gage No.	Wave Heights, ft: Offshore Breakwater at -10 ft Contour: Run 1	Run 2	Run 3	Average	Offshore Breakwater at -5 ft Contour: Run 1	Run 2	Run 3	Average
1	12.5	12.3	13.7	12.8	11.6	12.1	13.6	12.4
2	14.5	15.6	16.7	15.4	15.2	15.8	15.1	15.4
3	14.9	17.3	17.7	16.6	15.9	16.9	17.4	16.7
4	9.0	9.1	9.7	9.3	8.0	8.5	9.2	8.6
5	7.2	6.3	9.0	7.5	7.4	7.1	6.2	6.9
6	3.6	3.2	5.0	3.9	3.6	3.8	3.6	3.5

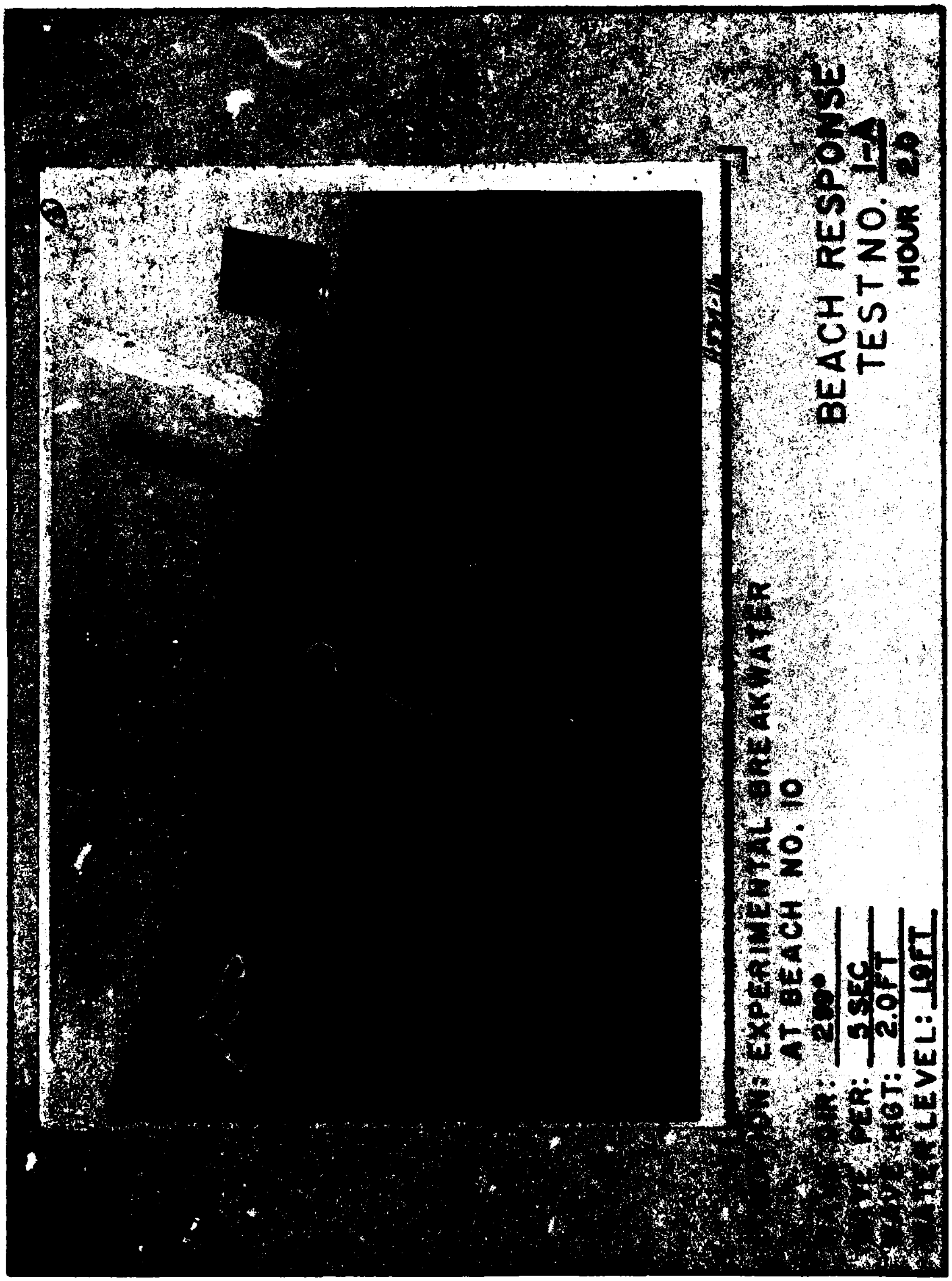

BEACH RESPONSE
TEST NO. 1-A
EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
5 SEC
2.0FT

PLATE 1

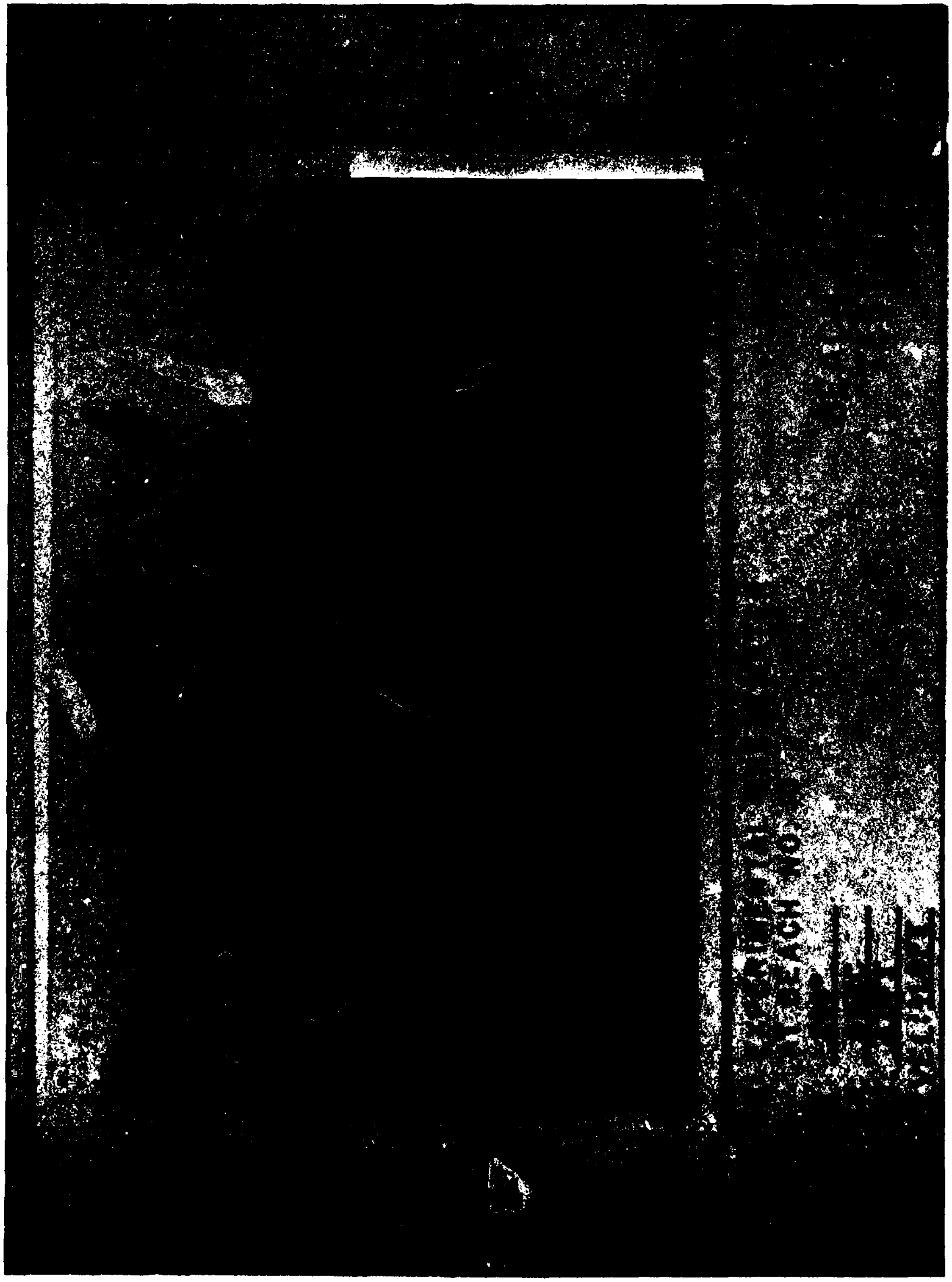


PLATE 2

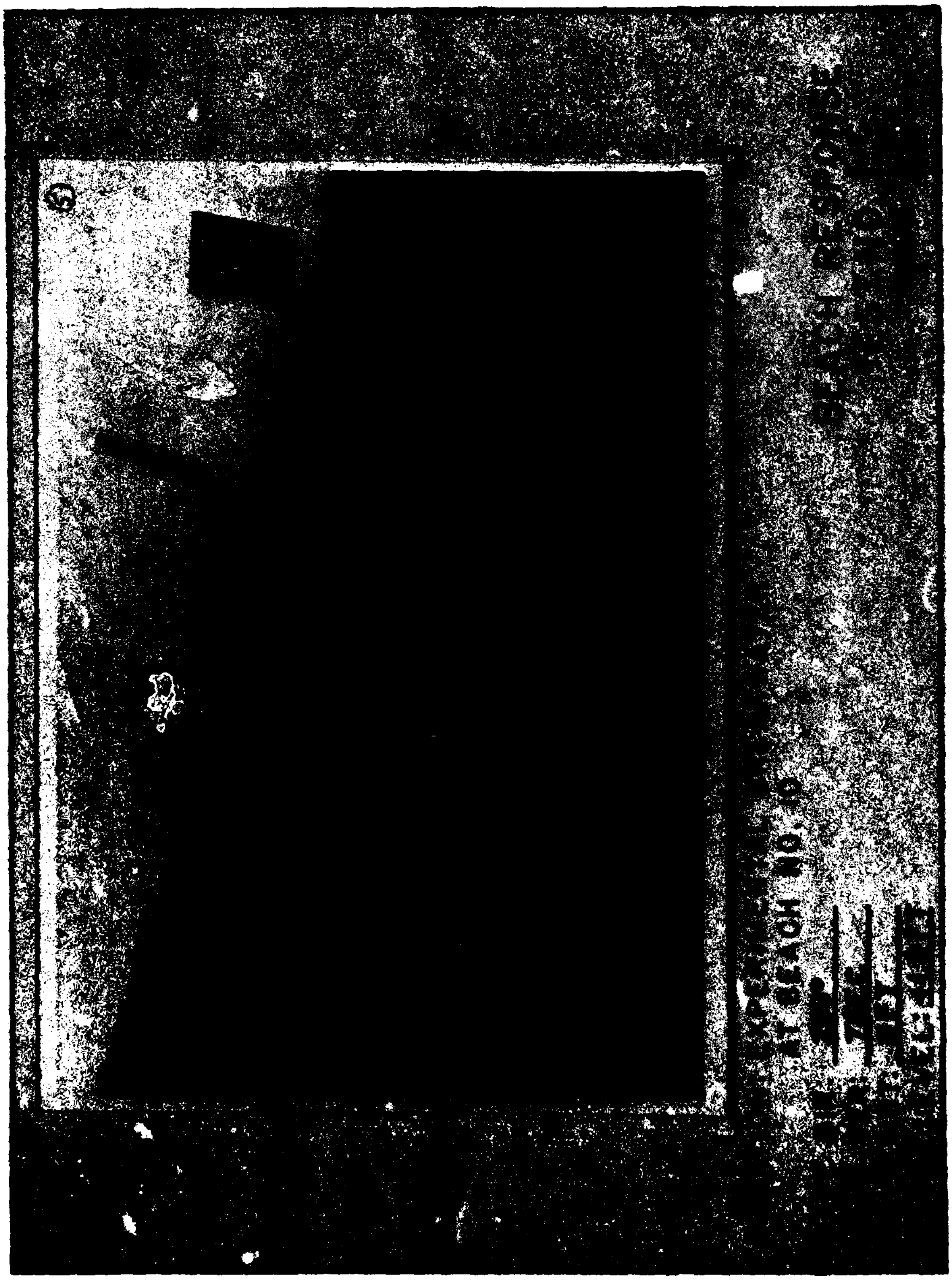


PLATE 3

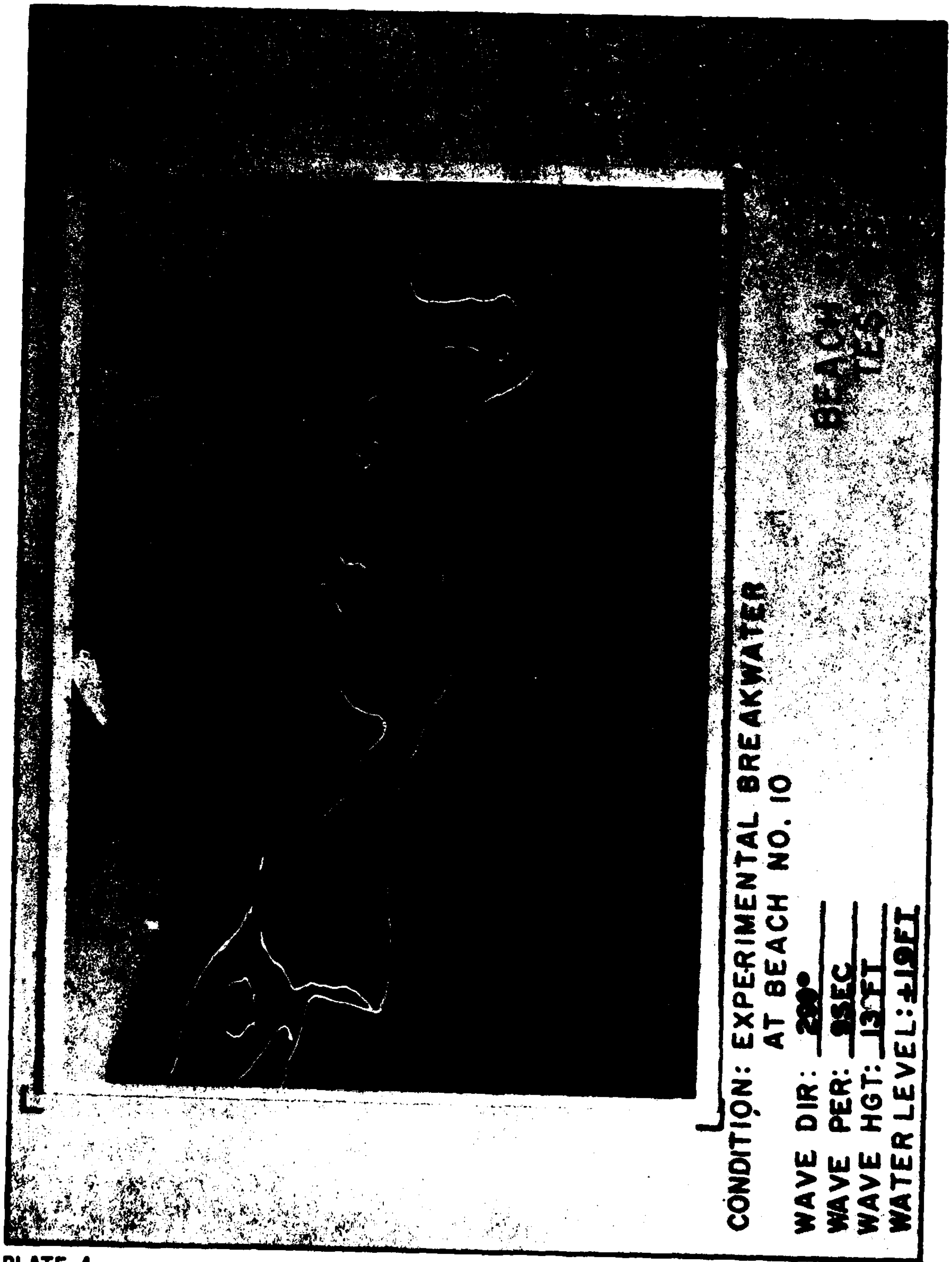

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
WAVE DIR:
WAVE PER: 9 SEC
WAVE HGT: 13 FT
WATER LEVEL: +1.9 FT

PLATE 4

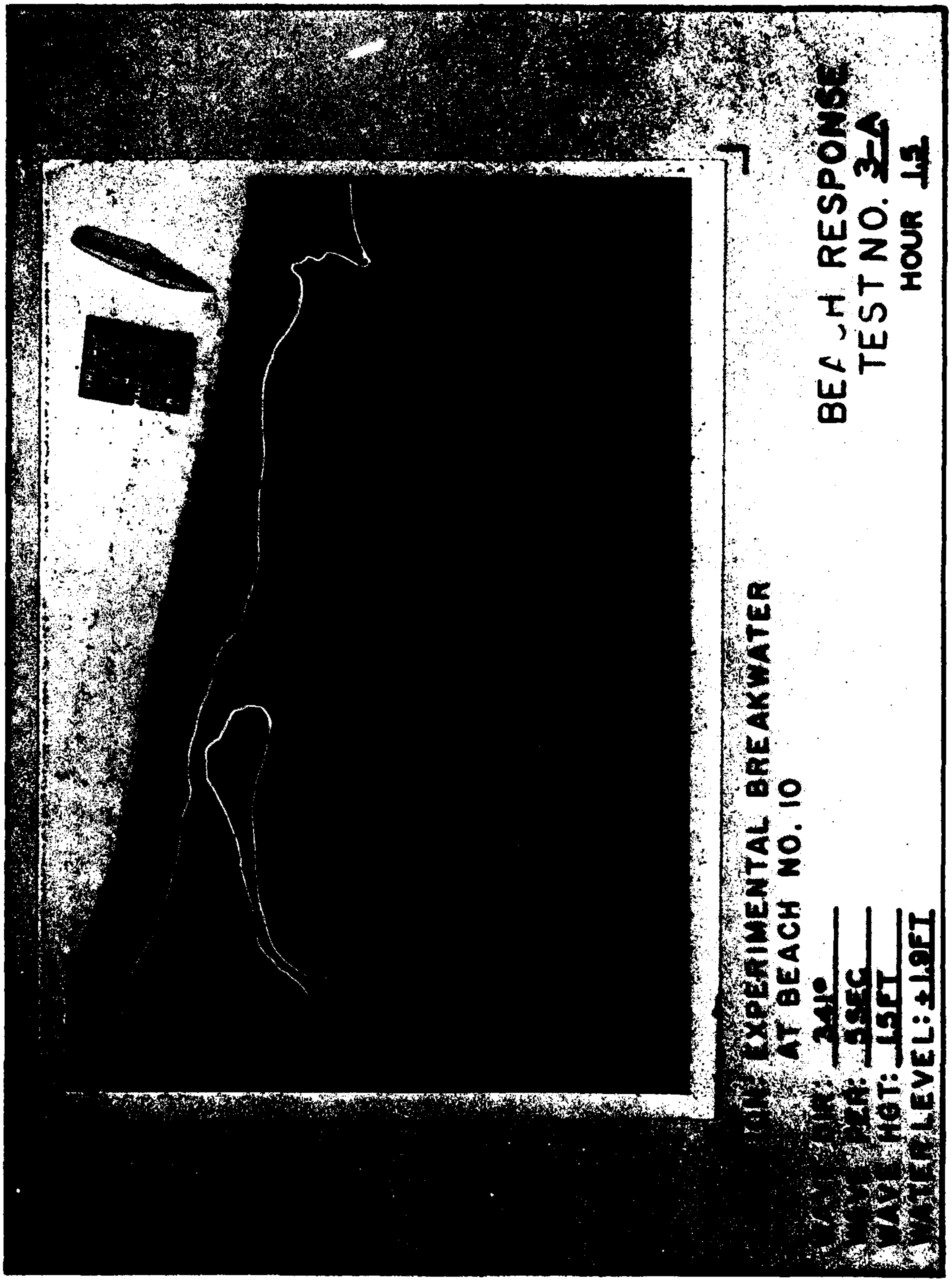

EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
RESPONSE
TEST NO. 3-A
HOUR 15

PLATE 5

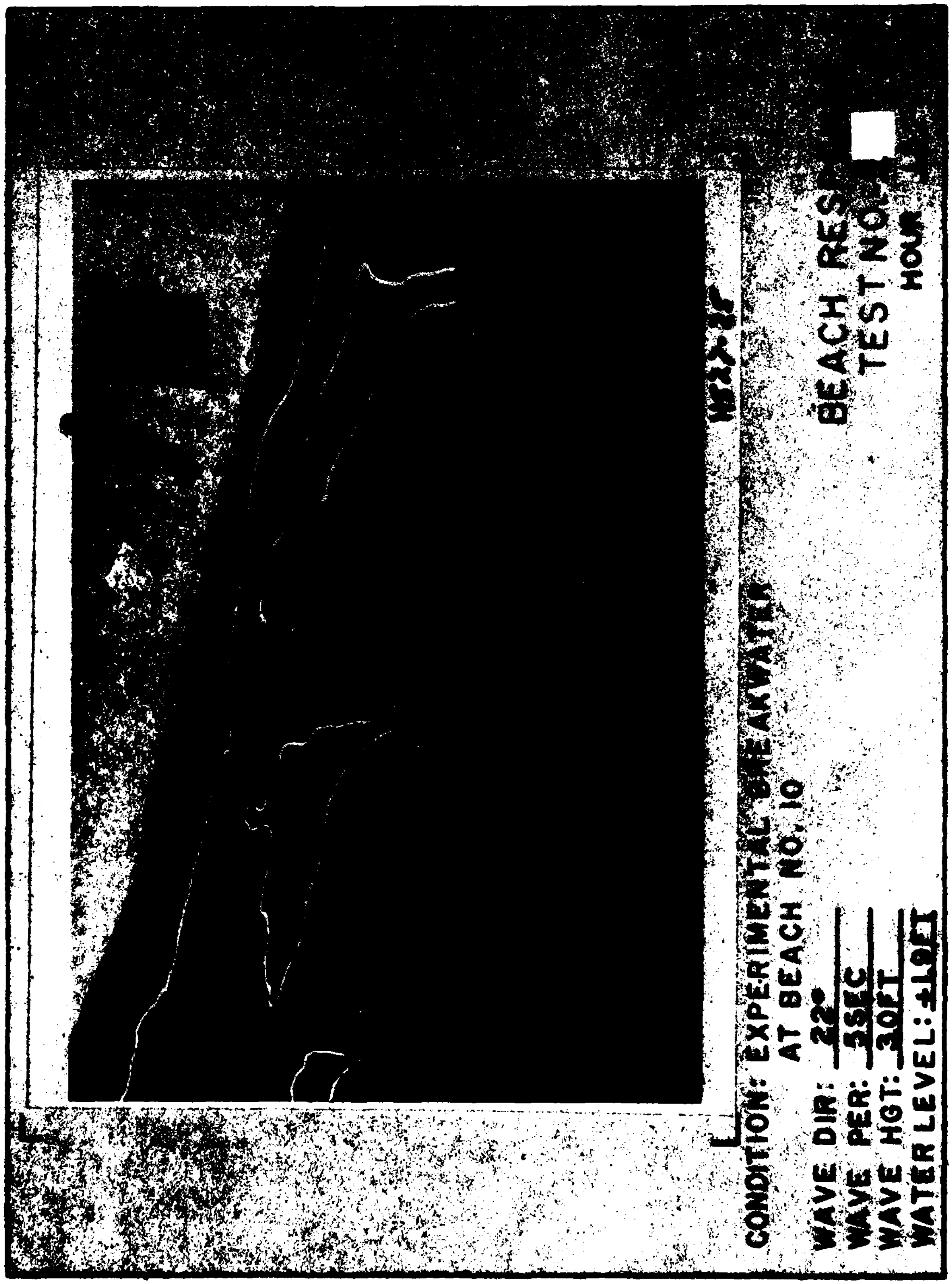

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
WAVE DIR: 22°
WAVE PER: 3SEC
WAVE HGT: 30FT
WATER LEVEL: +19FT
HOUR

PLATE 6

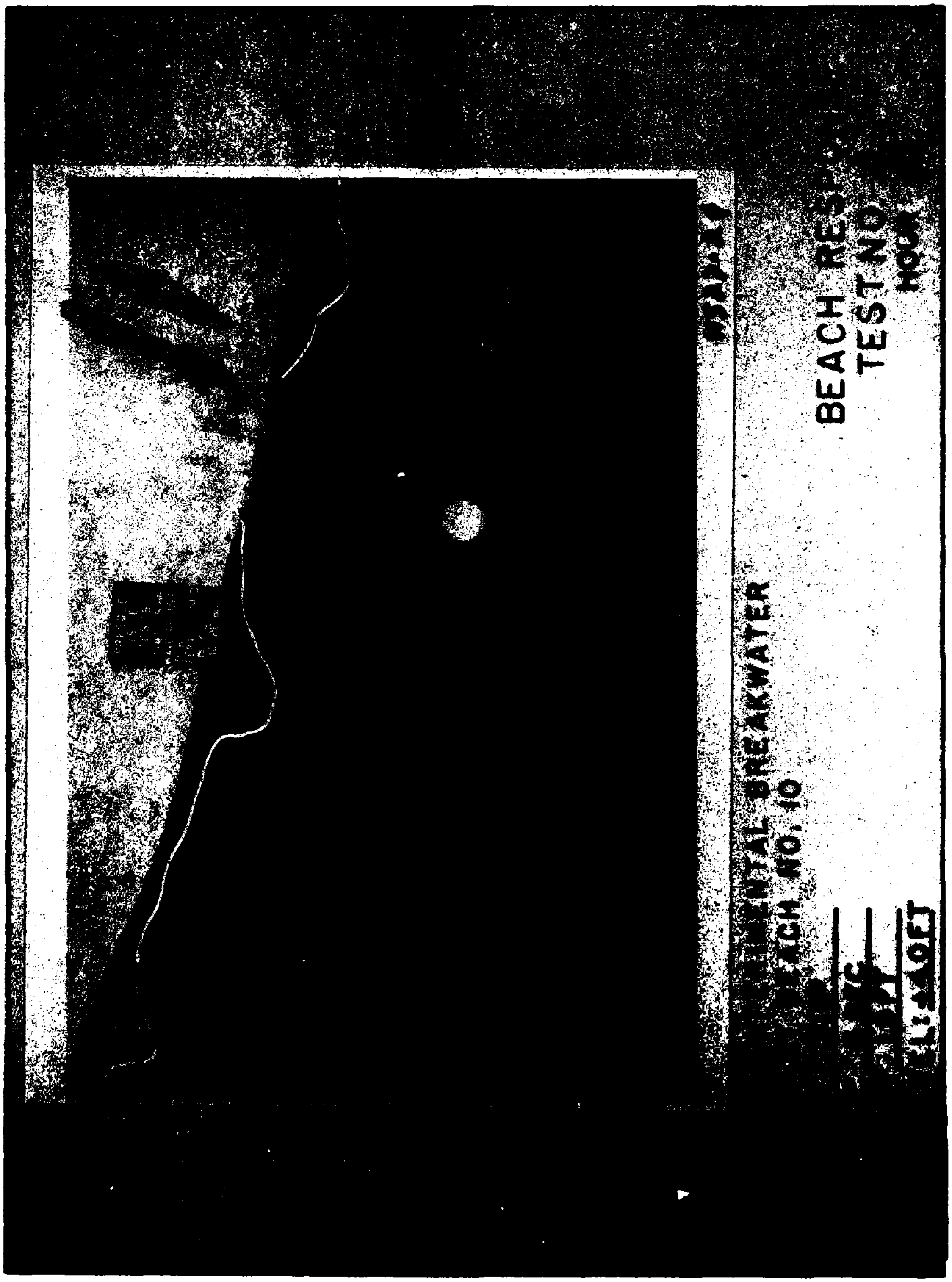


PLATE 7

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10

WAVE DIR: 313°
WAVE PER: 4SEC
WAVE HGT: 1.3FT
WATER LEVEL: +4.0FT

BEACH RESPONSE
TEST NO. 7-A
HOUR 0.0

PLATE 8

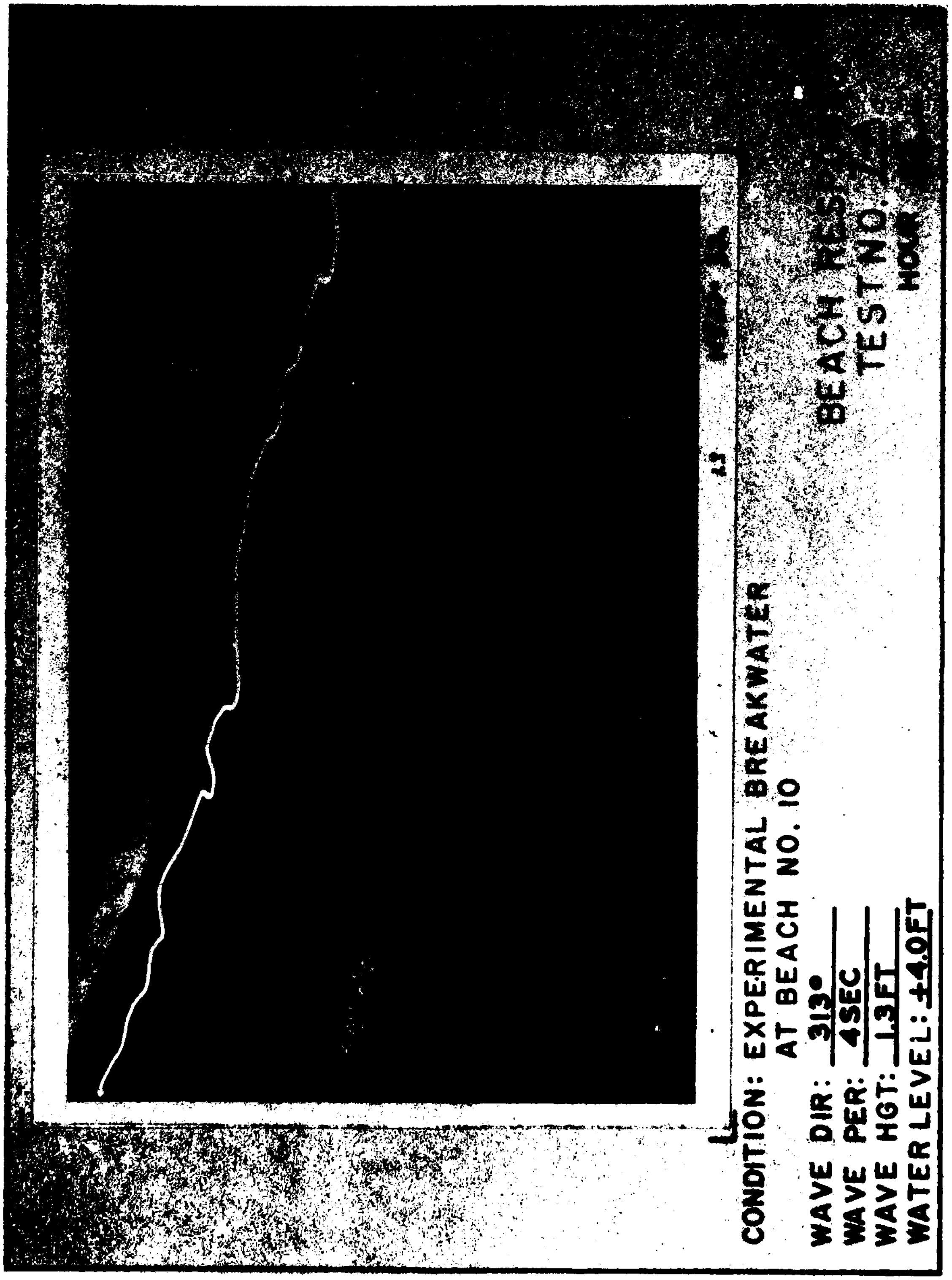

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
WAVE DIR: 313°
WAVE PER: 4 SEC
WAVE HGT: 1.3 FT
WATER LEVEL: +4.0 FT
BEACH
TEST NO.

PLATE 9

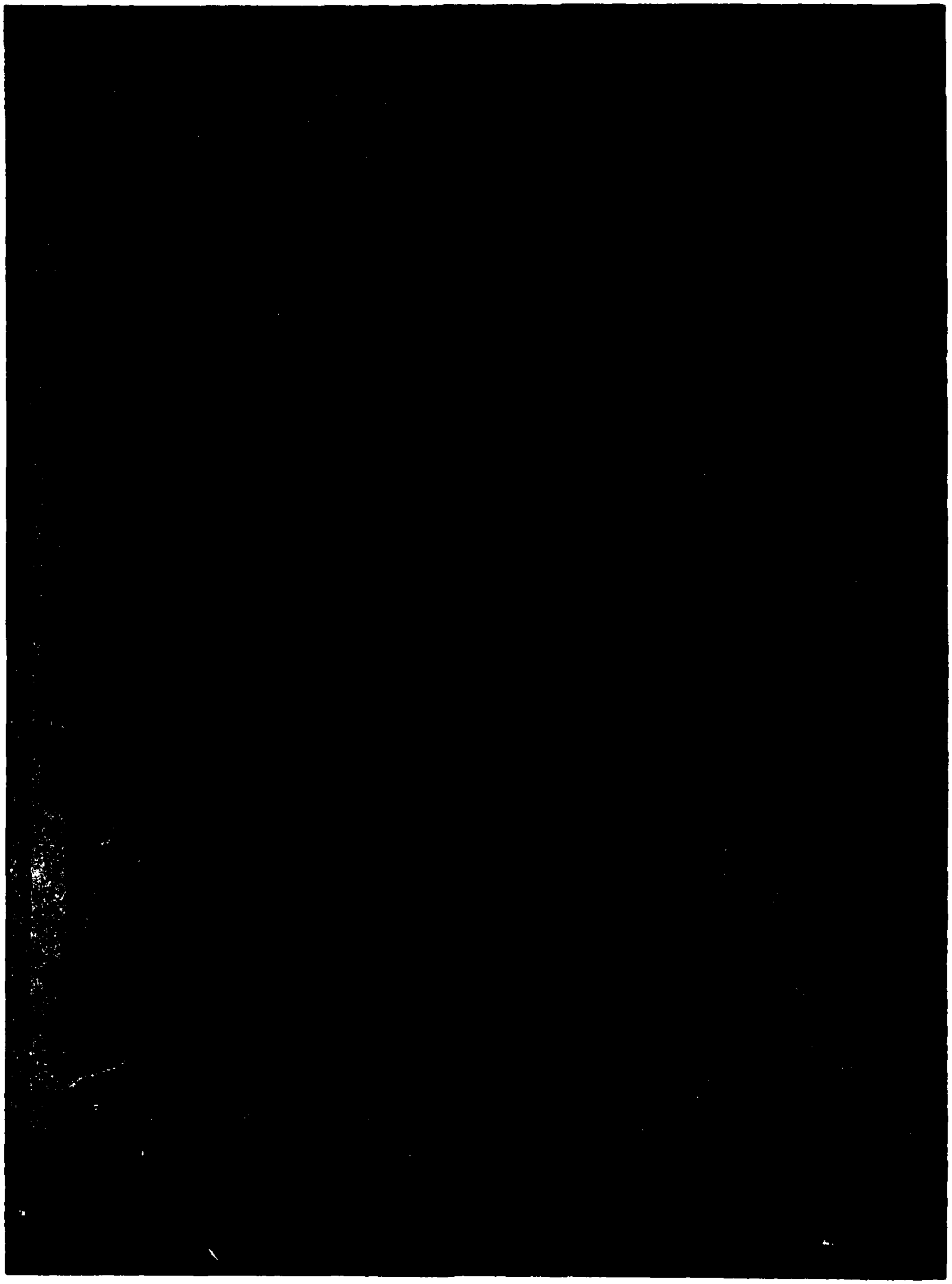


PLATE 10

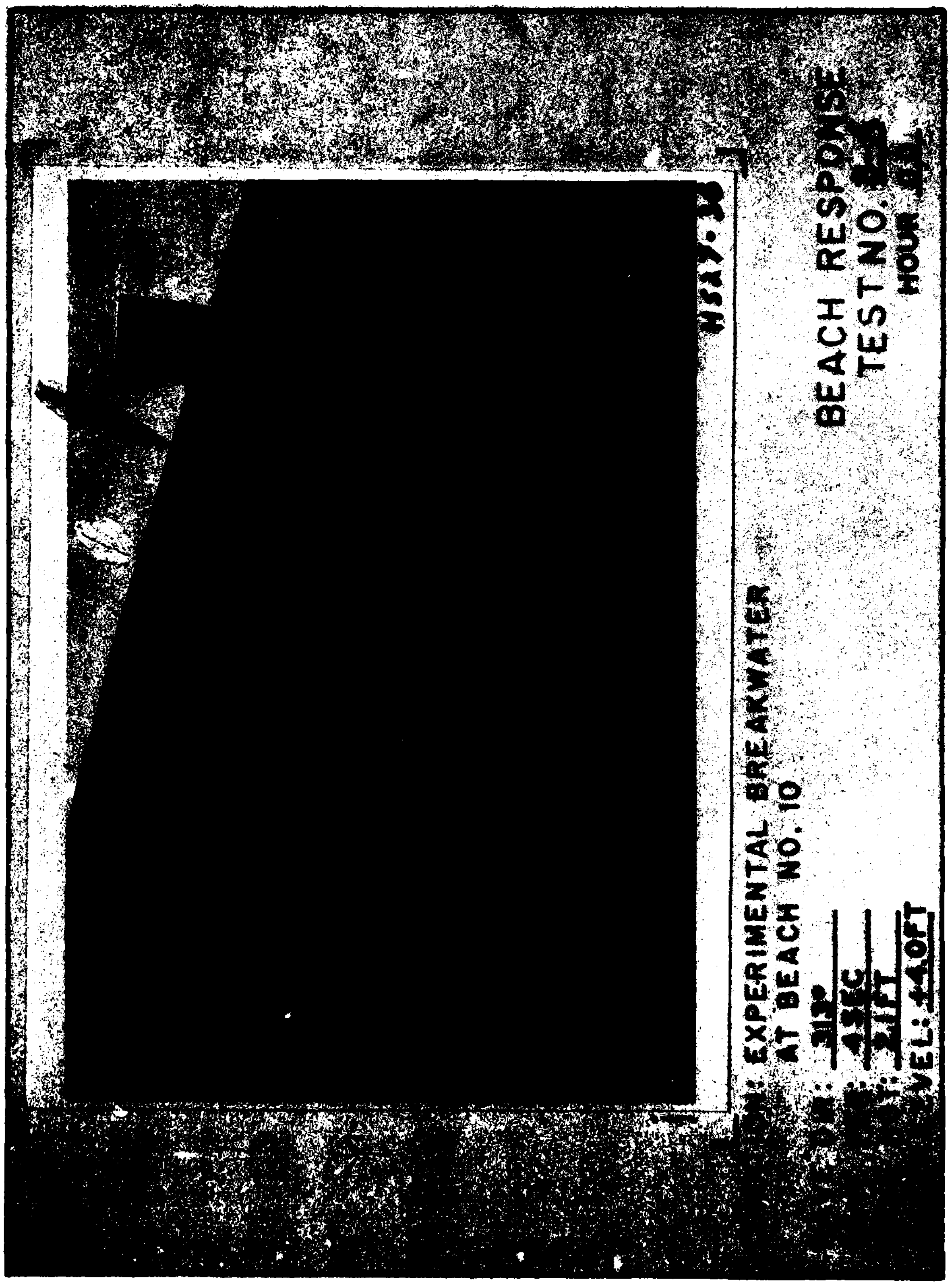

EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
BEACH RESPONSE
TEST NO.
HOUR

PLATE 11

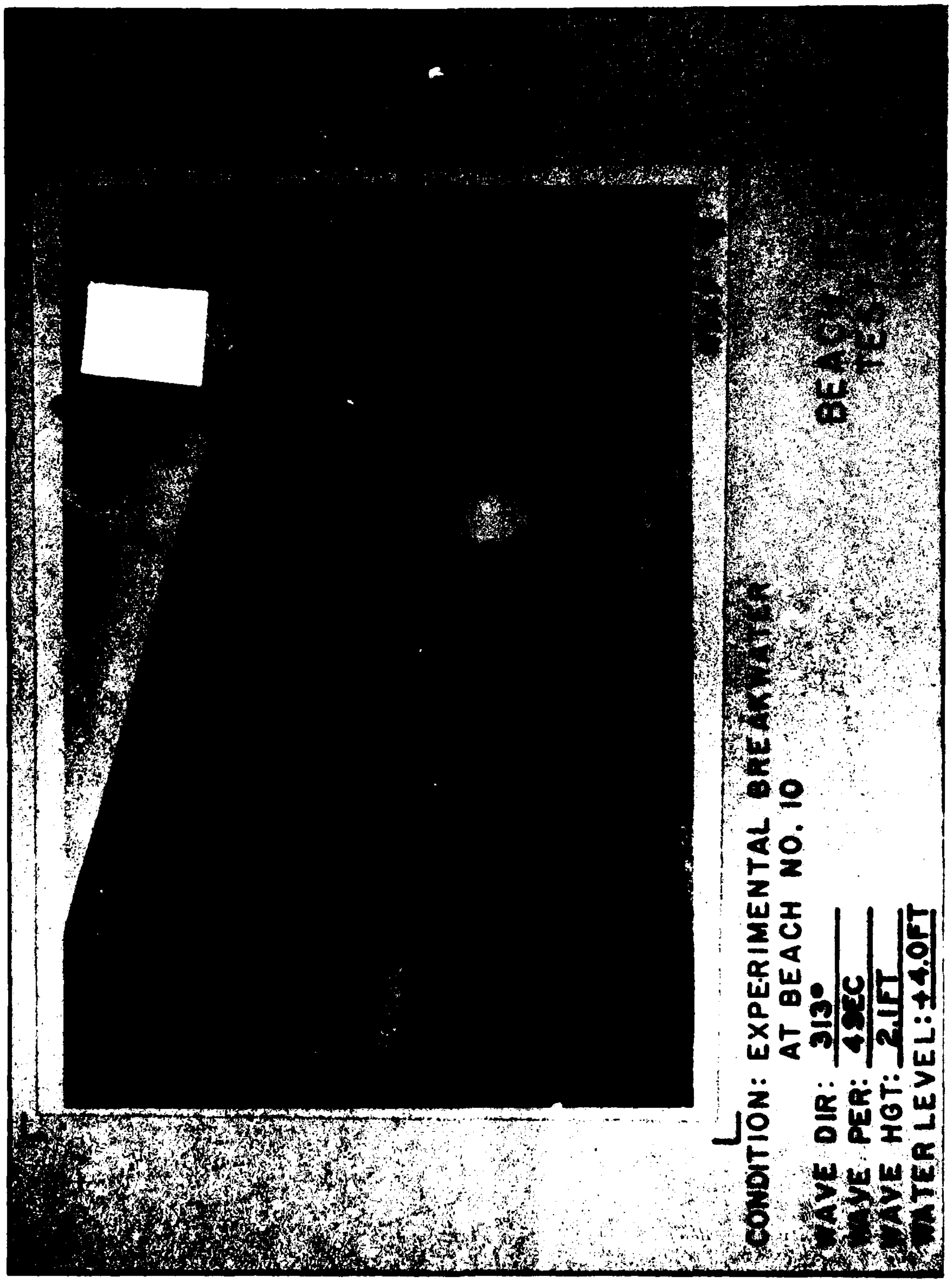

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
WAVE DIR: 313°
WAVE PER: 4 SEC
WAVE HGT: 2.1 FT
WATER LEVEL: +4.0 FT

PLATE 12

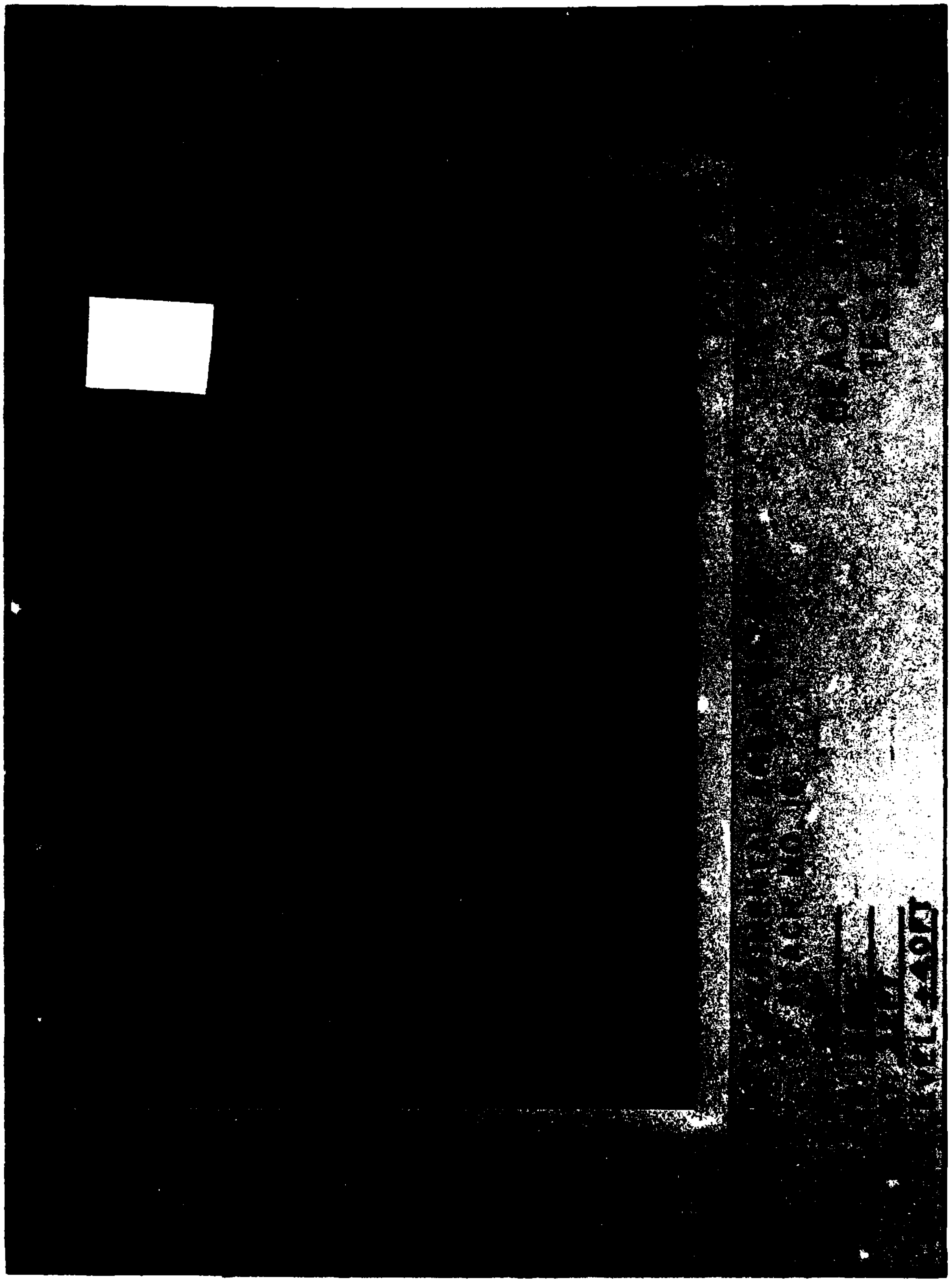


PLATE 13

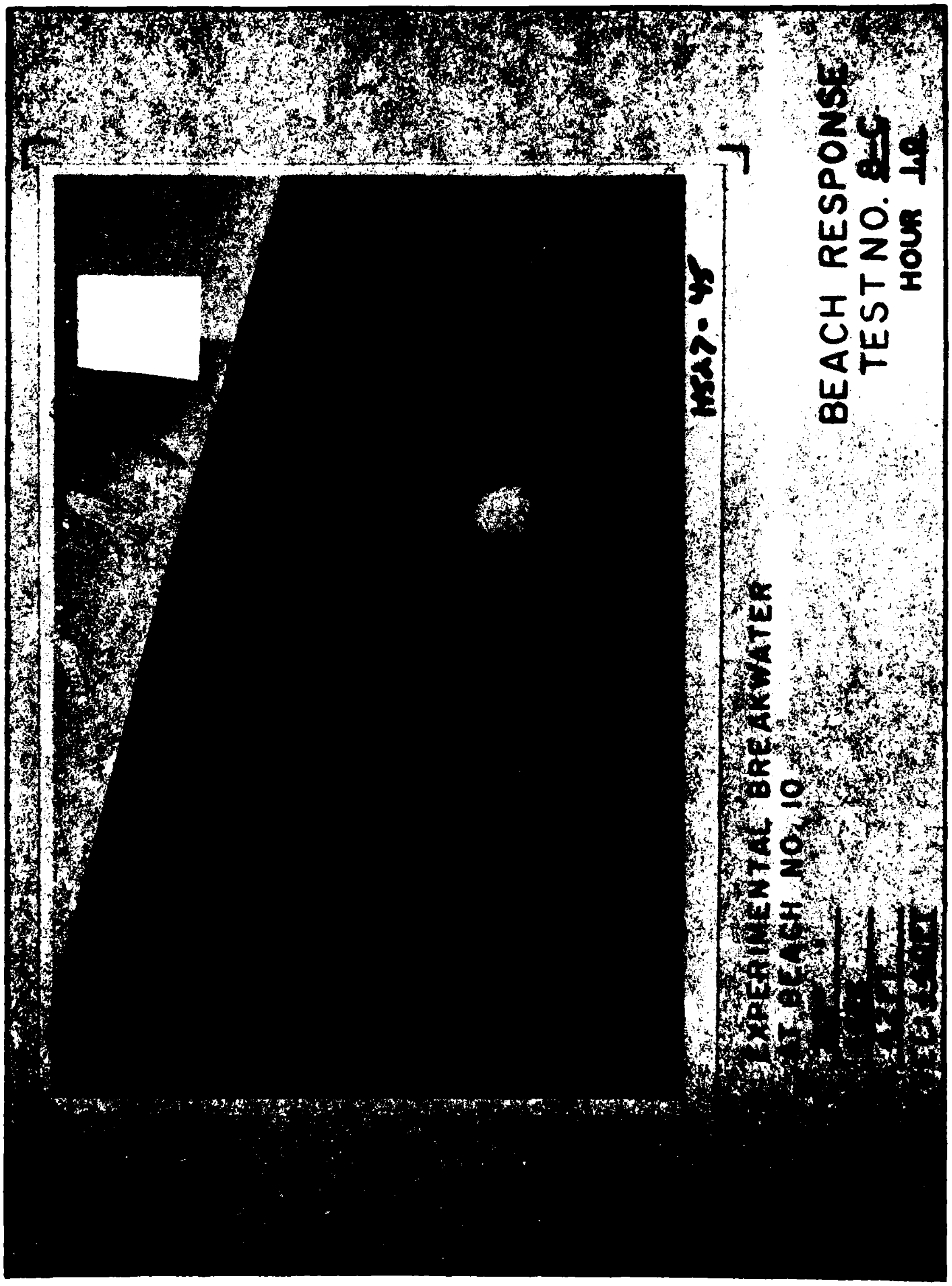

BEACH RESPONSE
TEST NO.
HOUR
EXPERIMENTAL BREAKWATER
AT BEACH NO. 10

PLATE 14

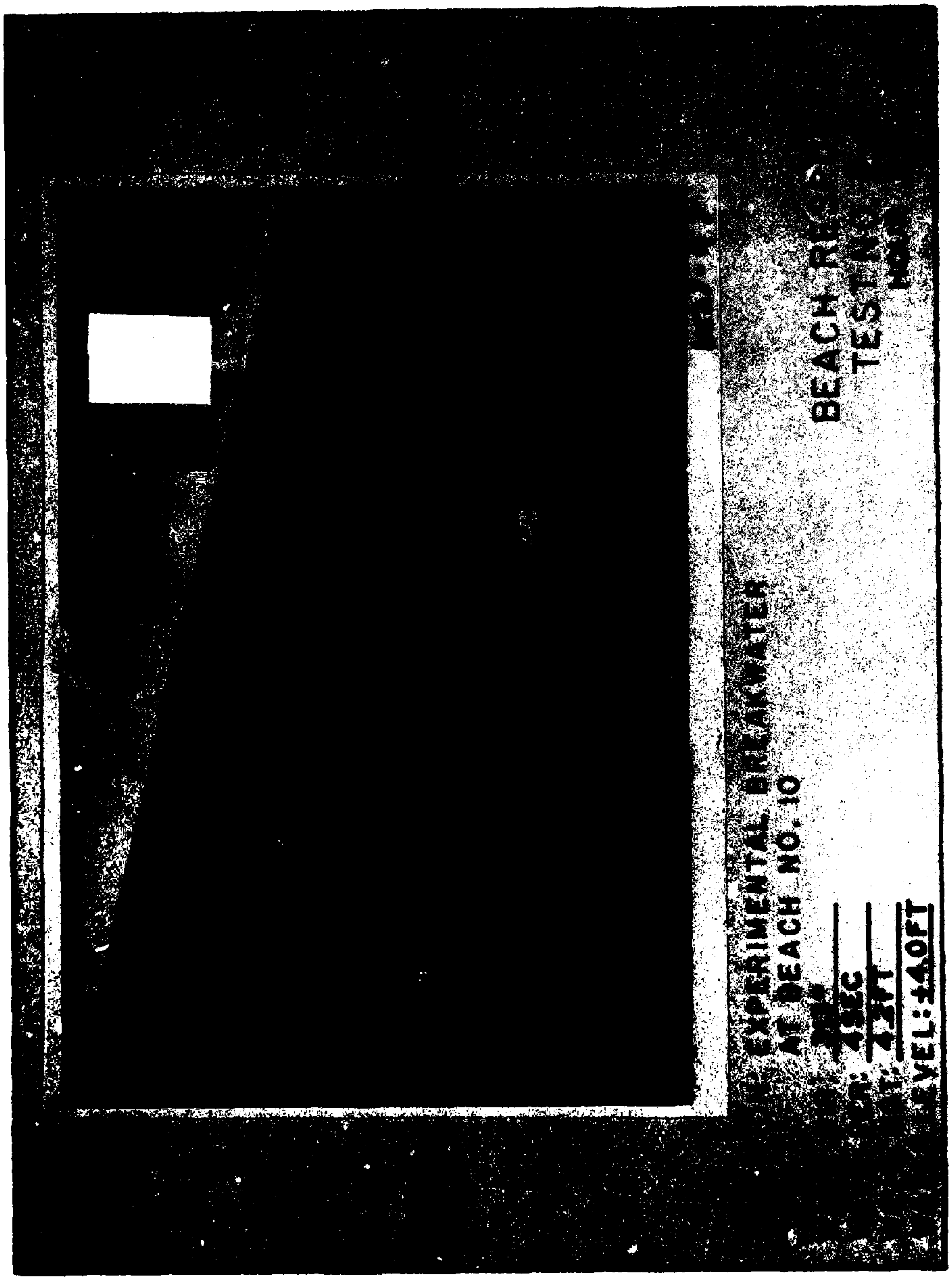


PLATE 15

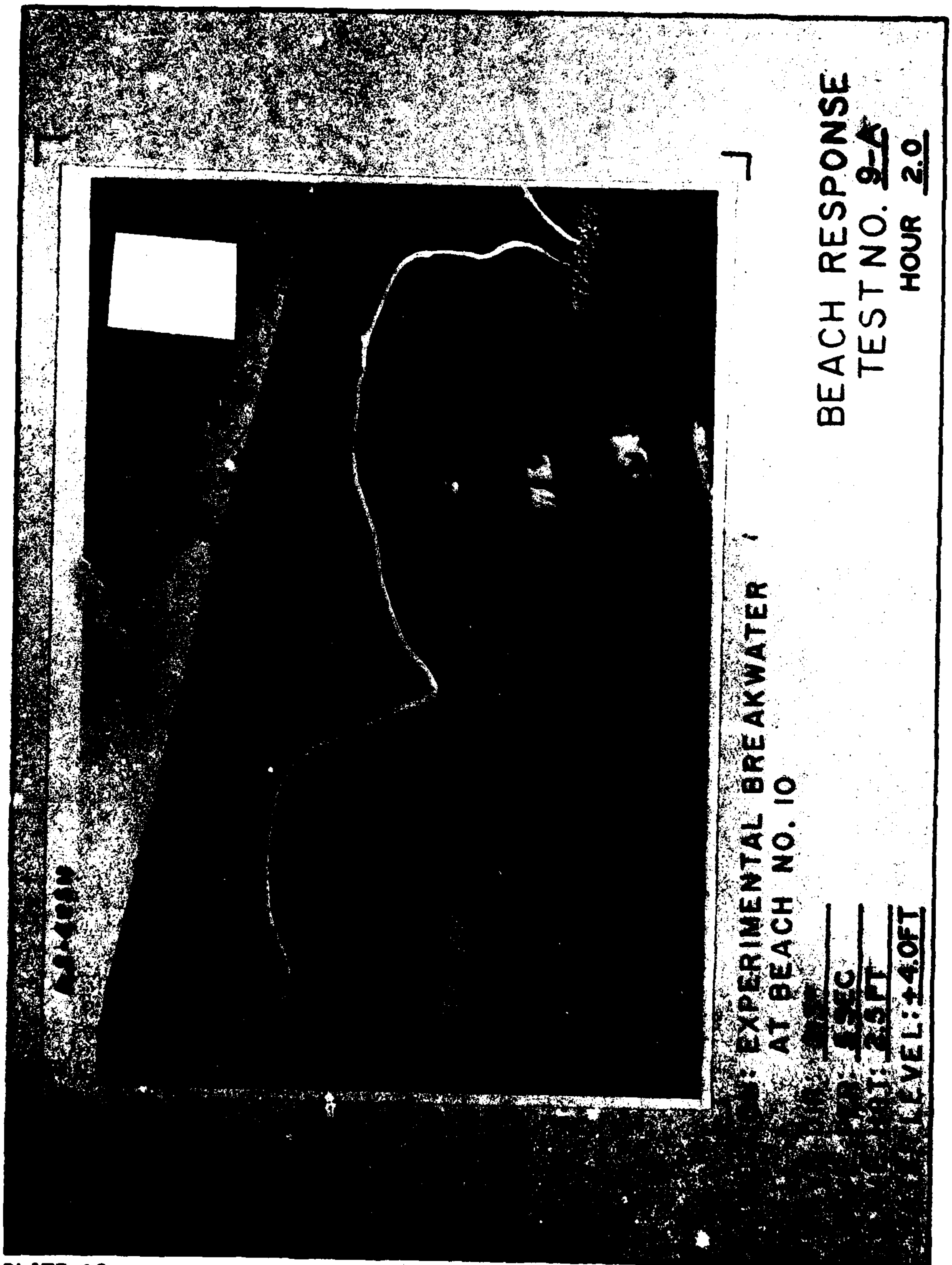

EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
5 SEC
2.5 FT
LEVEL: +4.0FT
BEACH RESPONSE
TEST NO. 9-A
HOUR 2.0

PLATE 16

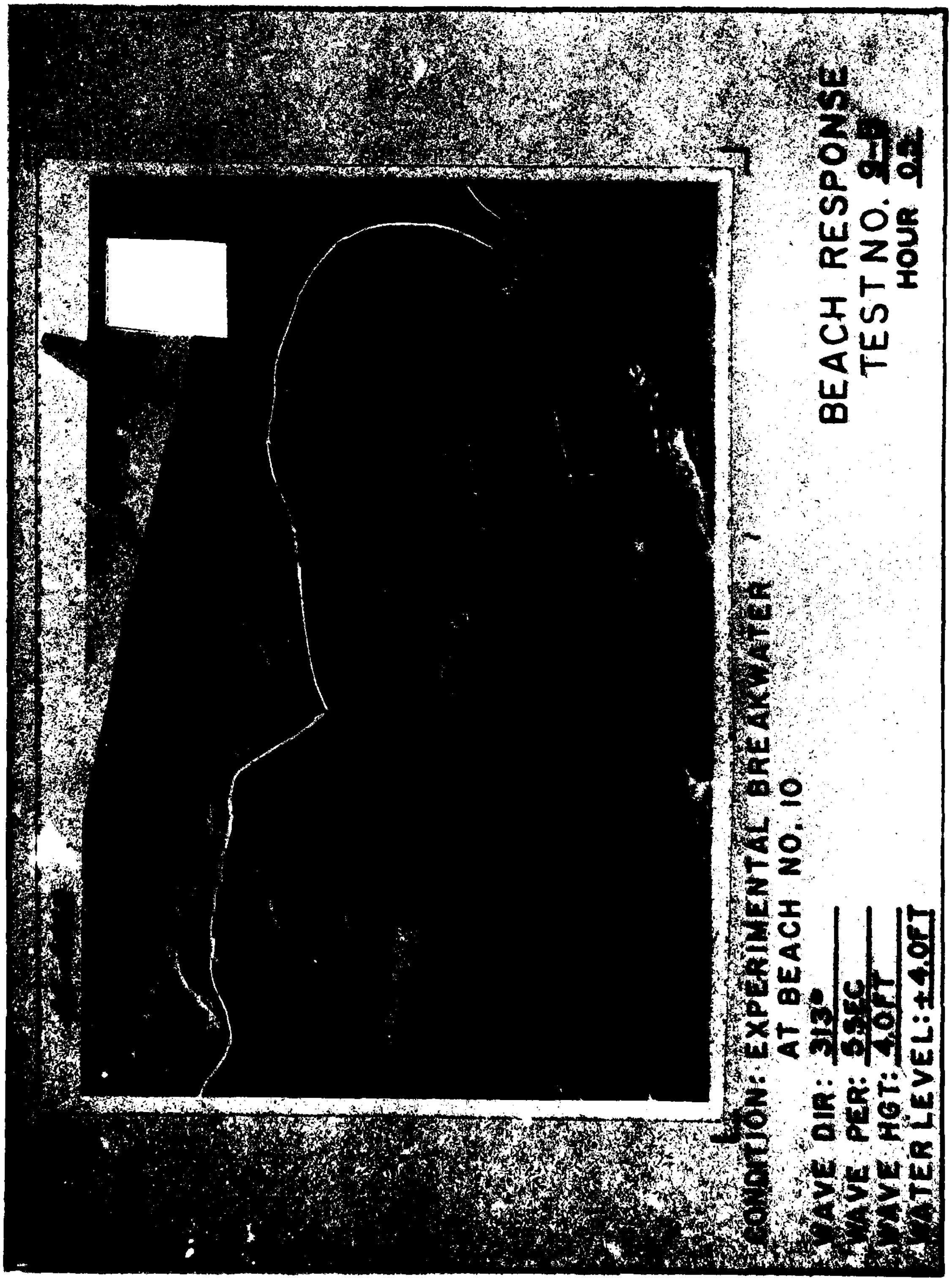

CONDITION: EXPERIMENTAL BREAKWATER
AT BEACH NO. 10
WAVE DIR: 313°
WAVE PER: 5 SEC
WAVE HGT: 4.0 FT
WATER LEVEL: +4.0 FT
BEACH RESPONSE
TEST NO.
HOUR

PLATE 17

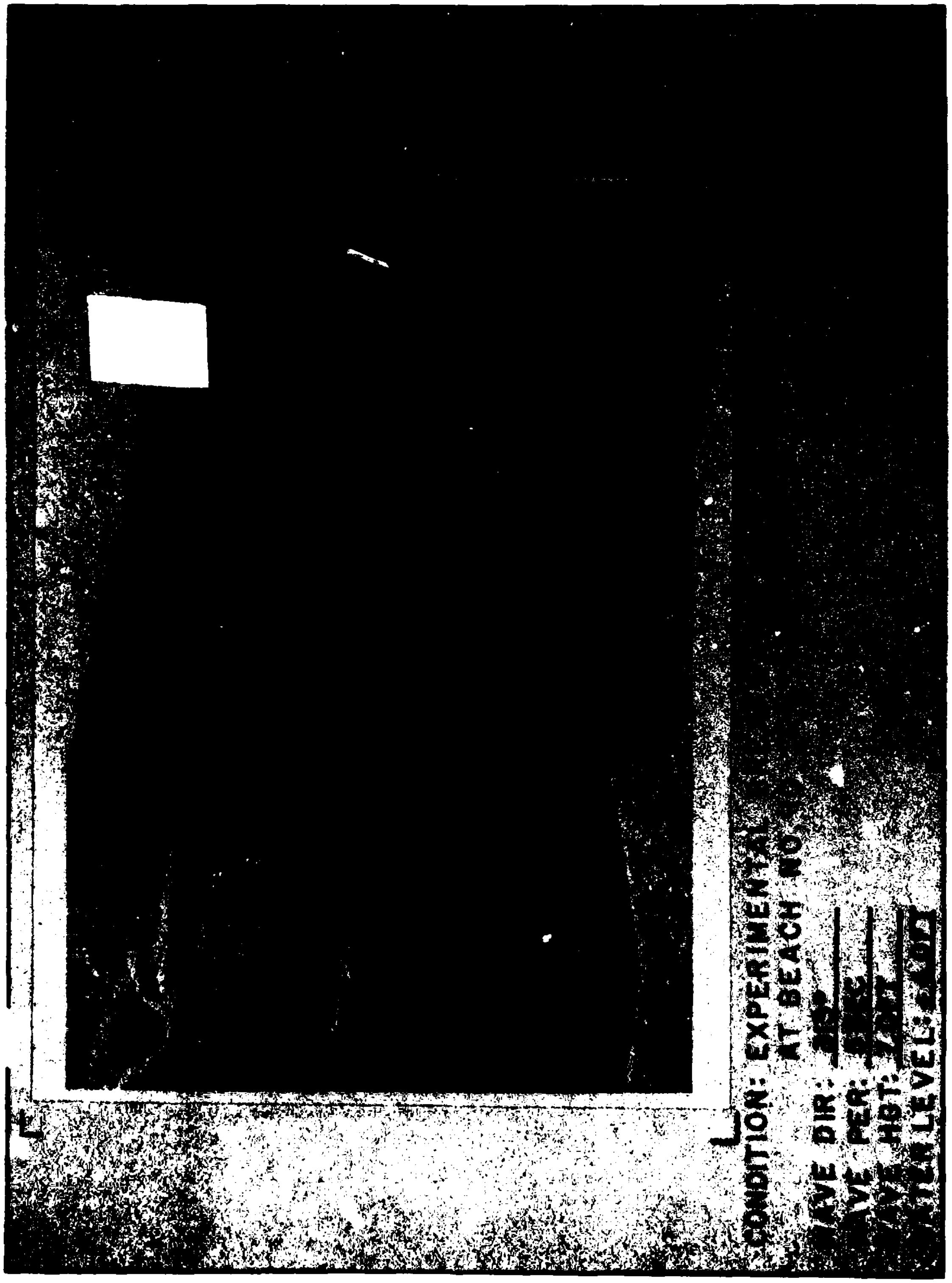


PLATE 18

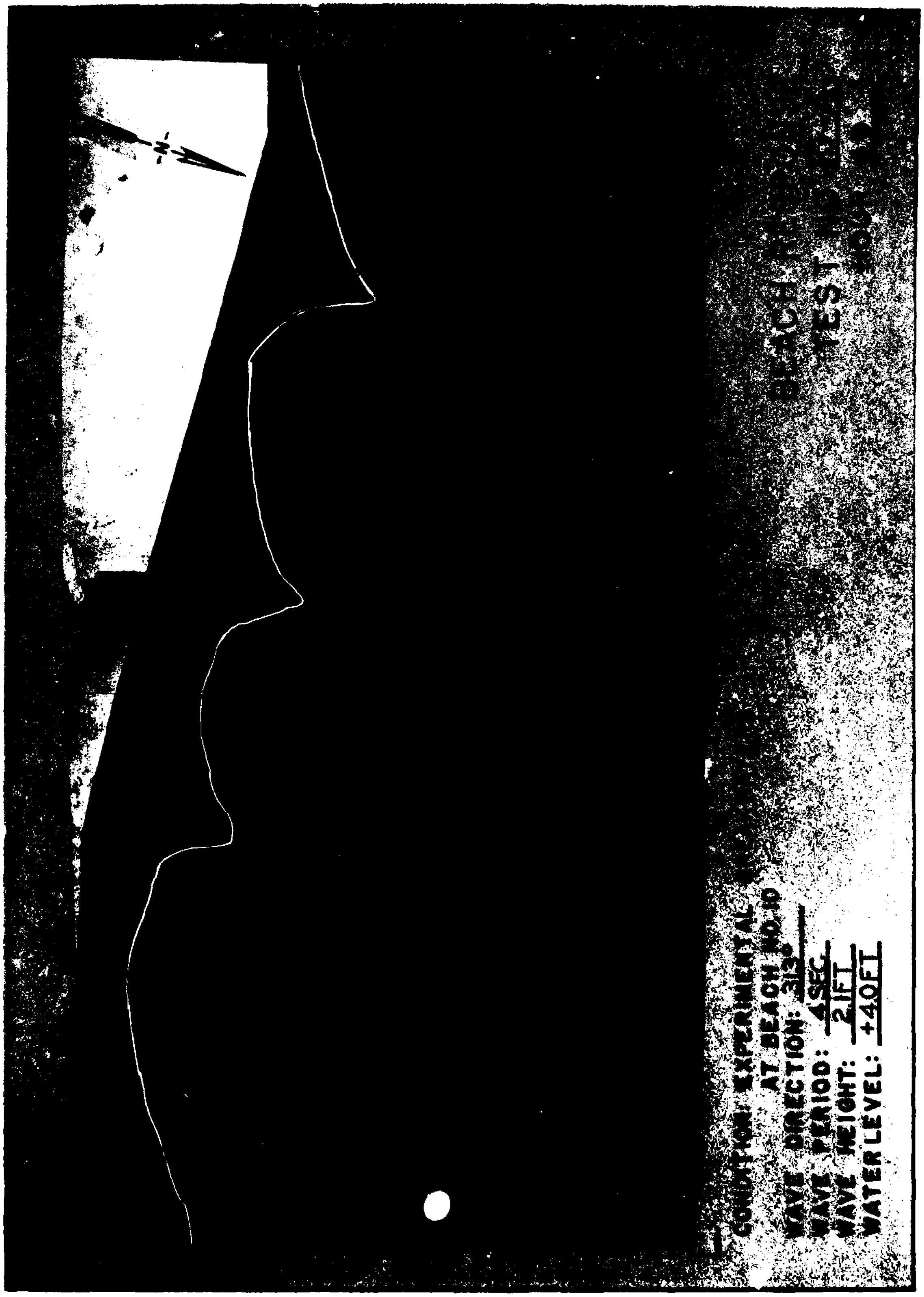

CONDITION: EXPERIMENTAL
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 2.1 FT
WATER LEVEL: +4.0 FT

PLATE 19

CONDITION: EXPERIMENTAL BREAKWATERS AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 3.2 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 10-B
HOUR 2.0

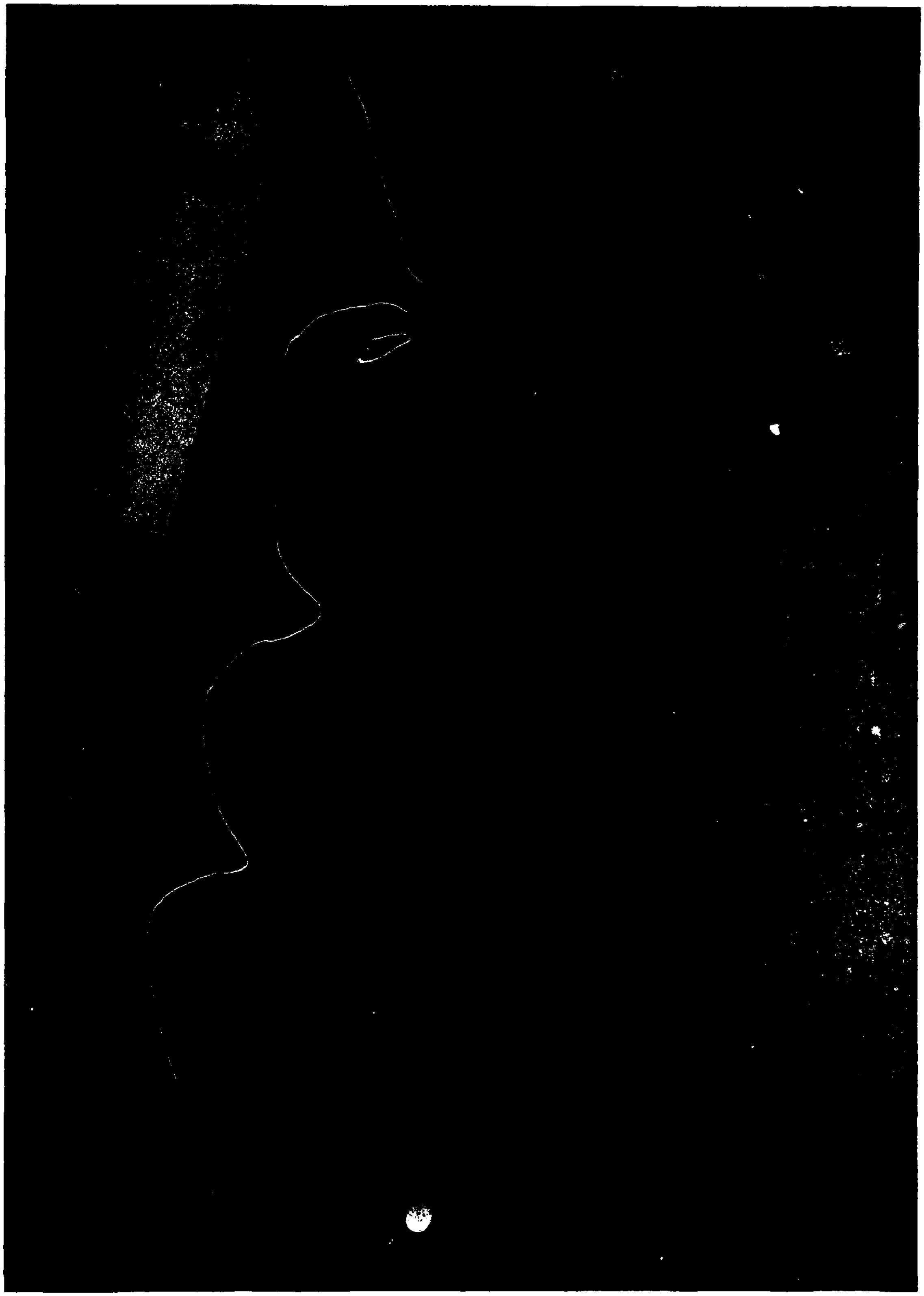
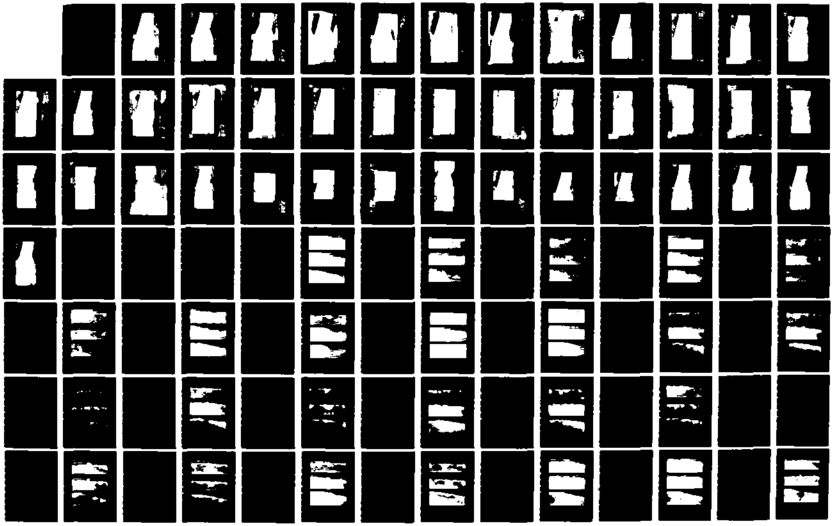
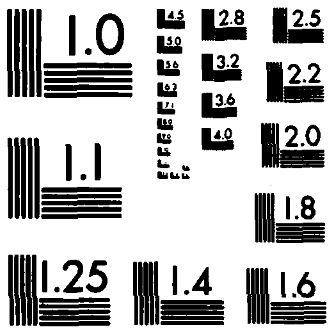


PLATE 21

AD-A135 394 DESIGN FOR PREVENTION OF BEACH EROSION AT PRESQUE ISLE 2/4
BEACHES ERIE PENNS..(U) ARMY ENGINEER WATERWAYS
EXPERIMENT STATION VICKSBURG MS HYDRA.. W C SEABERGH
UNCLASSIFIED JUN 83 WES/TR/HL-83-15 F/G 8/8 NL





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

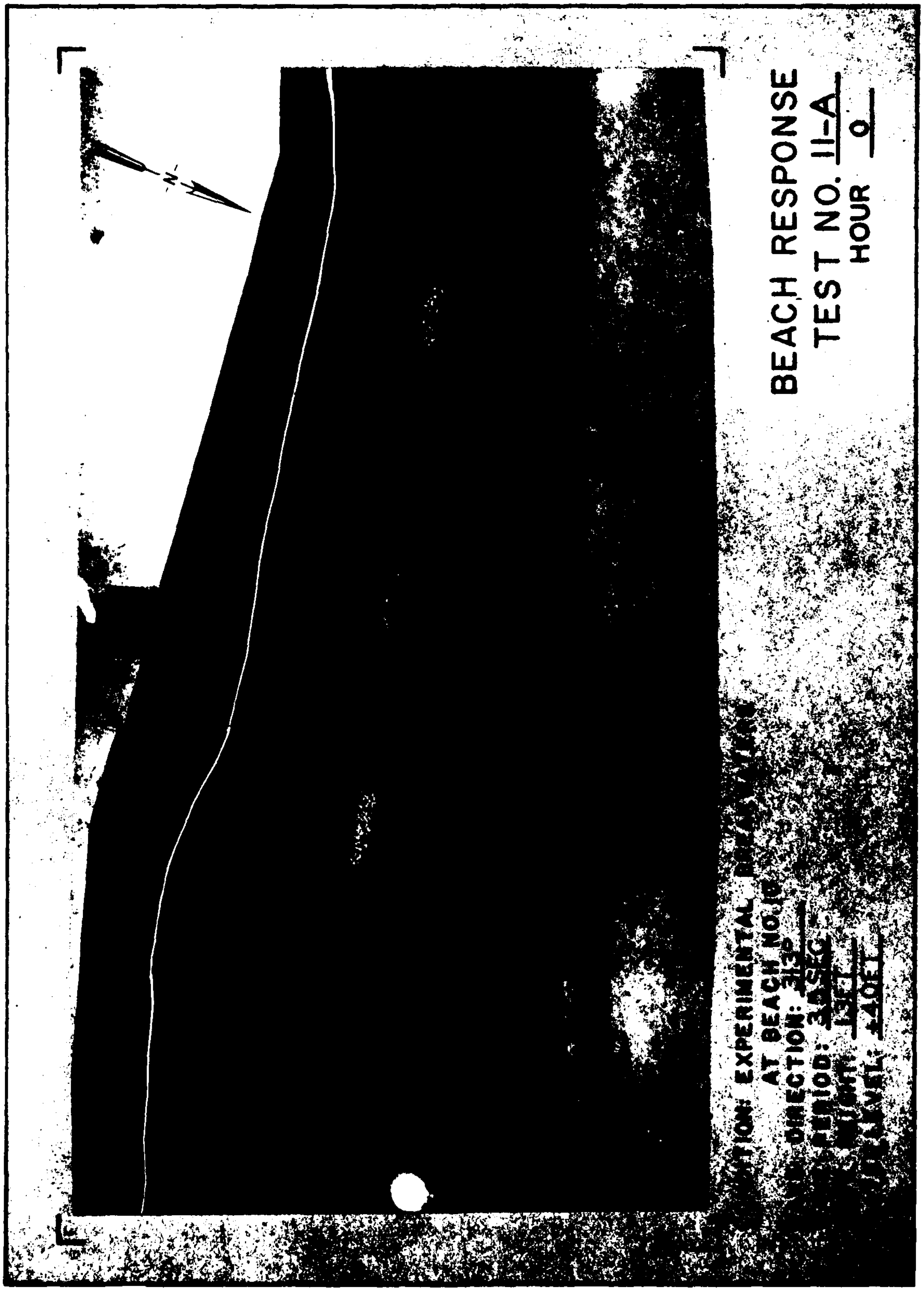


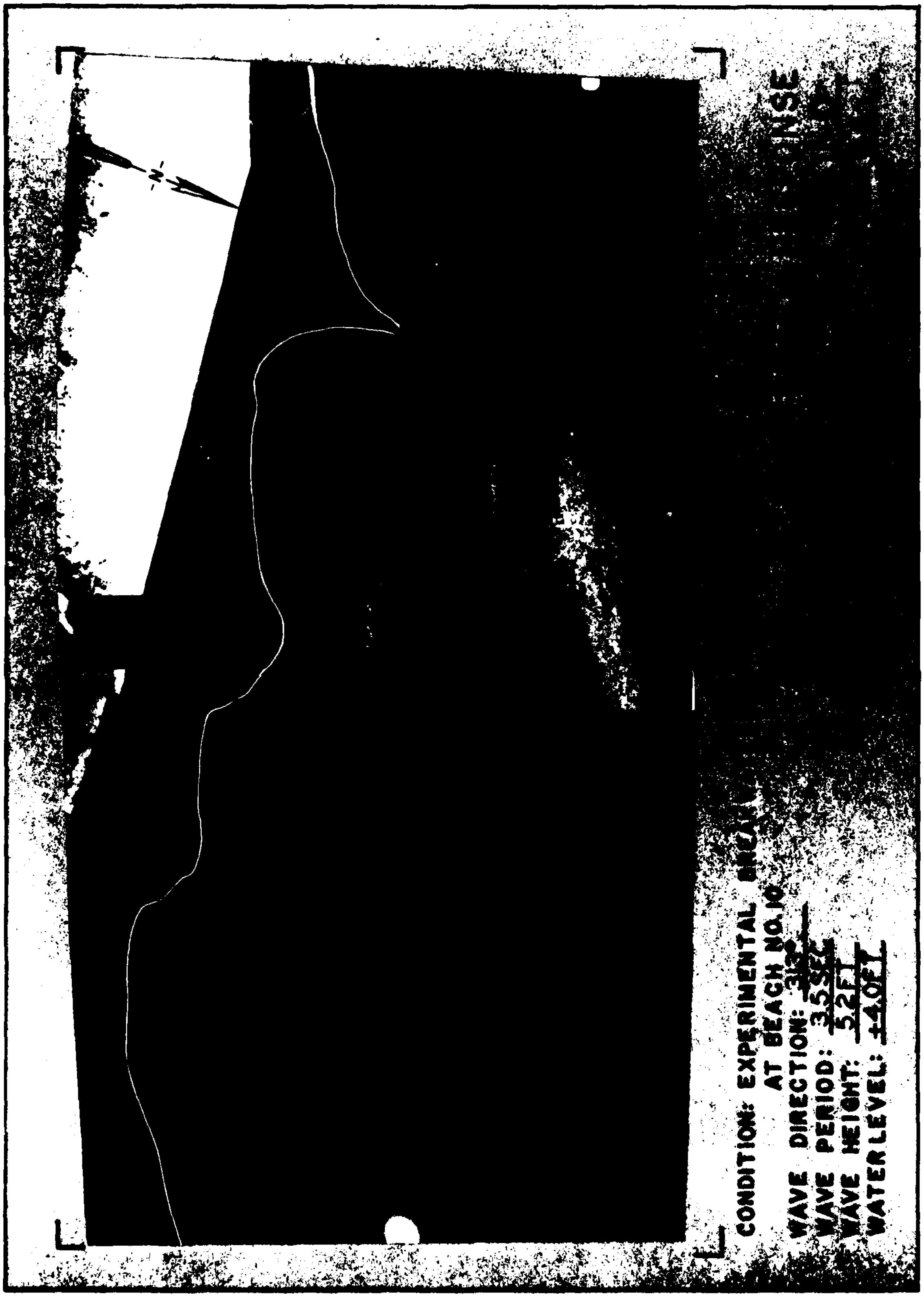
PLATE 22

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 3.5 SEC
WAVE HEIGHT: 1.3 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 11-A
HOUR 1.0

PLATE 24

PLATE 25



CONDITION: EXPERIMENTAL
AT BEACH NO. 10
WAVE DIRECTION:
WAVE PERIOD: 3.5 SEC
WAVE HEIGHT: 5.2 FT
WATER LEVEL: +4.0 FT

PLATE 26

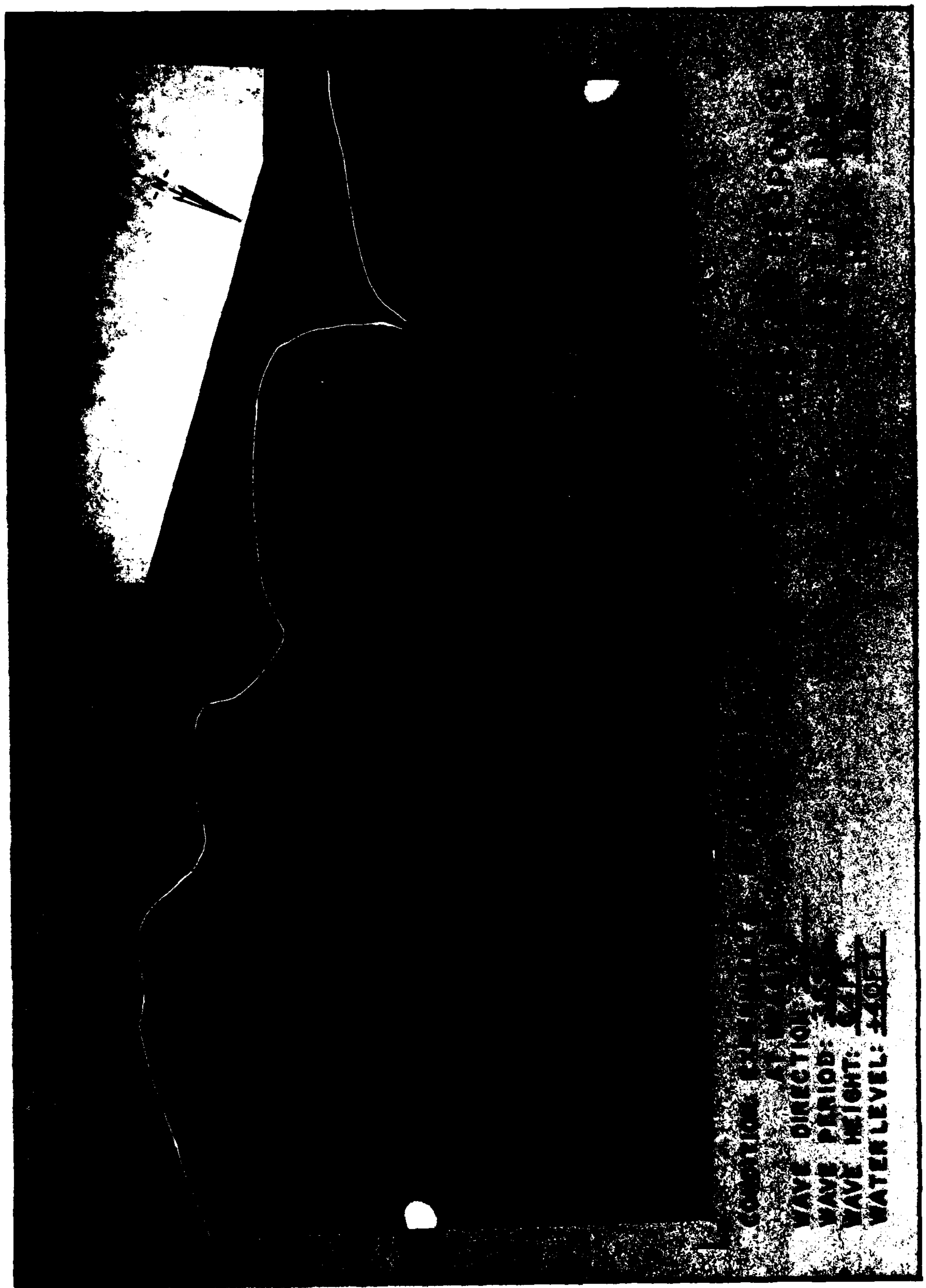


PLATE 27


CONDITION: EXPERIMENTAL
AT BEACH
WAVE DIRECTION:
WAVE PERIOD: 3.5 SEC
WAVE HEIGHT: 6.4 FT
WATER LEVEL: +6.9 FT

PLATE 28

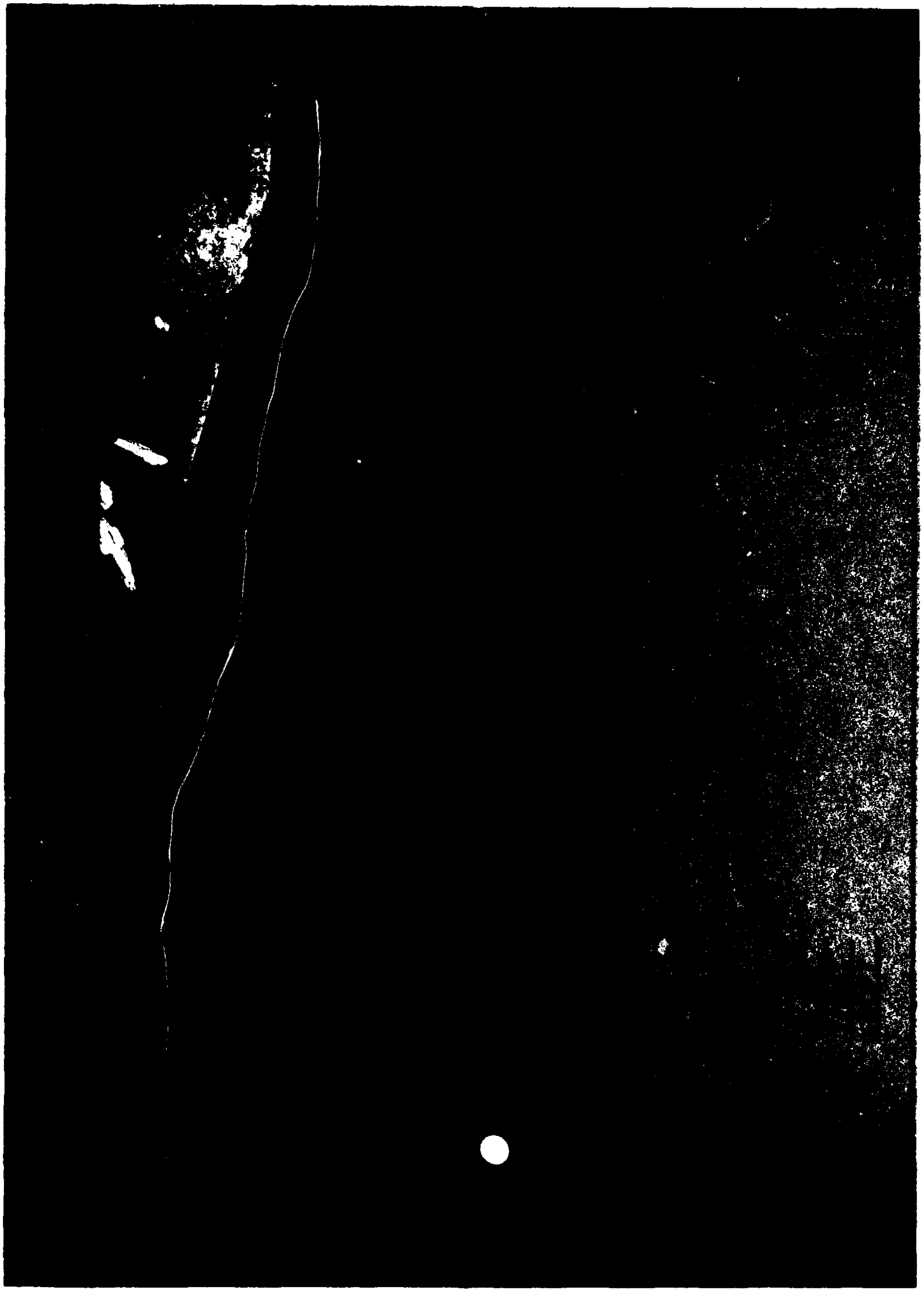
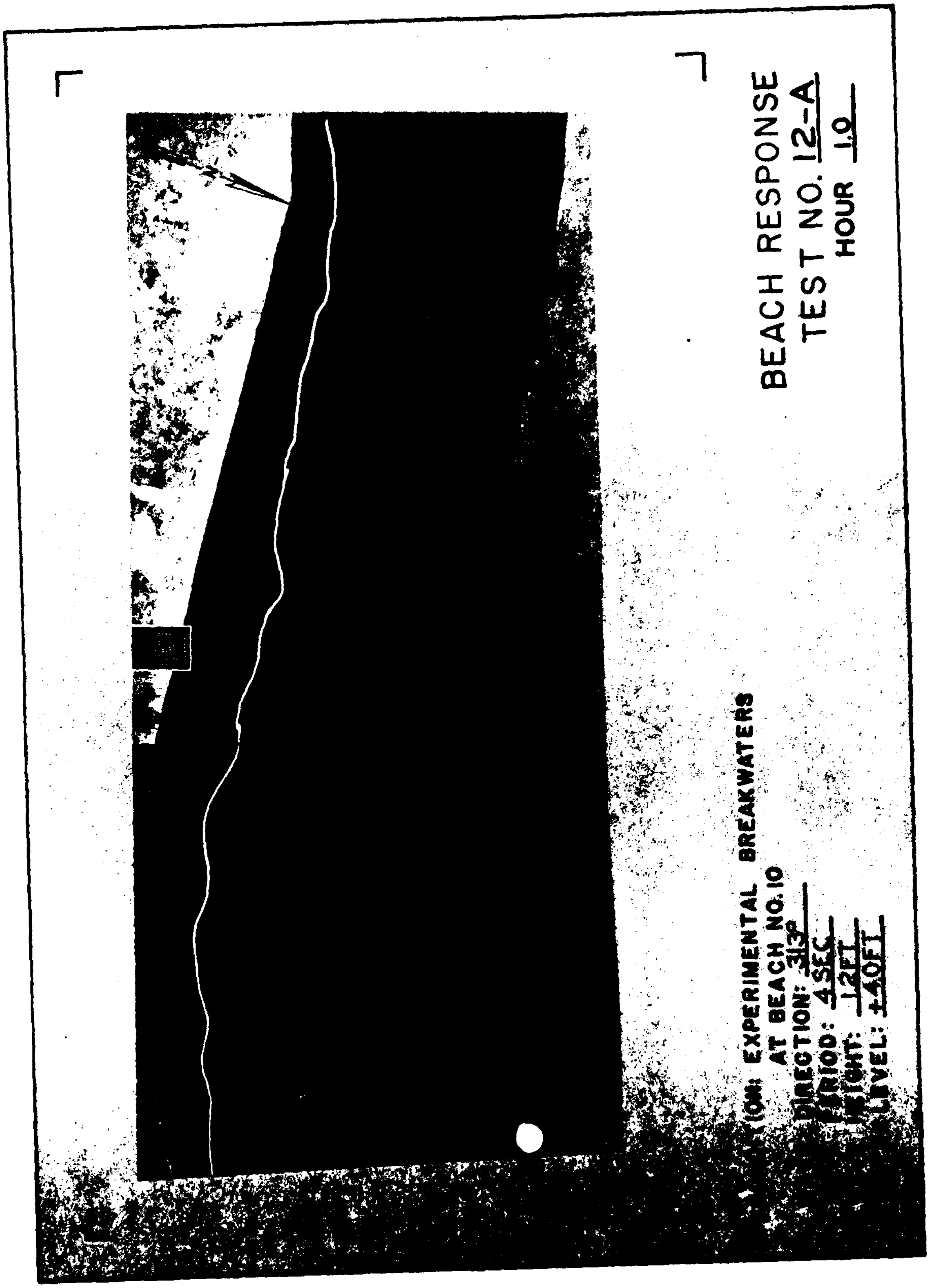


PLATE 29



BEACH RESPONSE
TEST NO. 12-A
HOUR 1.0
EXPERIMENTAL BREAKWATERS
AT BEACH NO.10
4 SEC
1.2FT
+4.0FT

PLATE 30

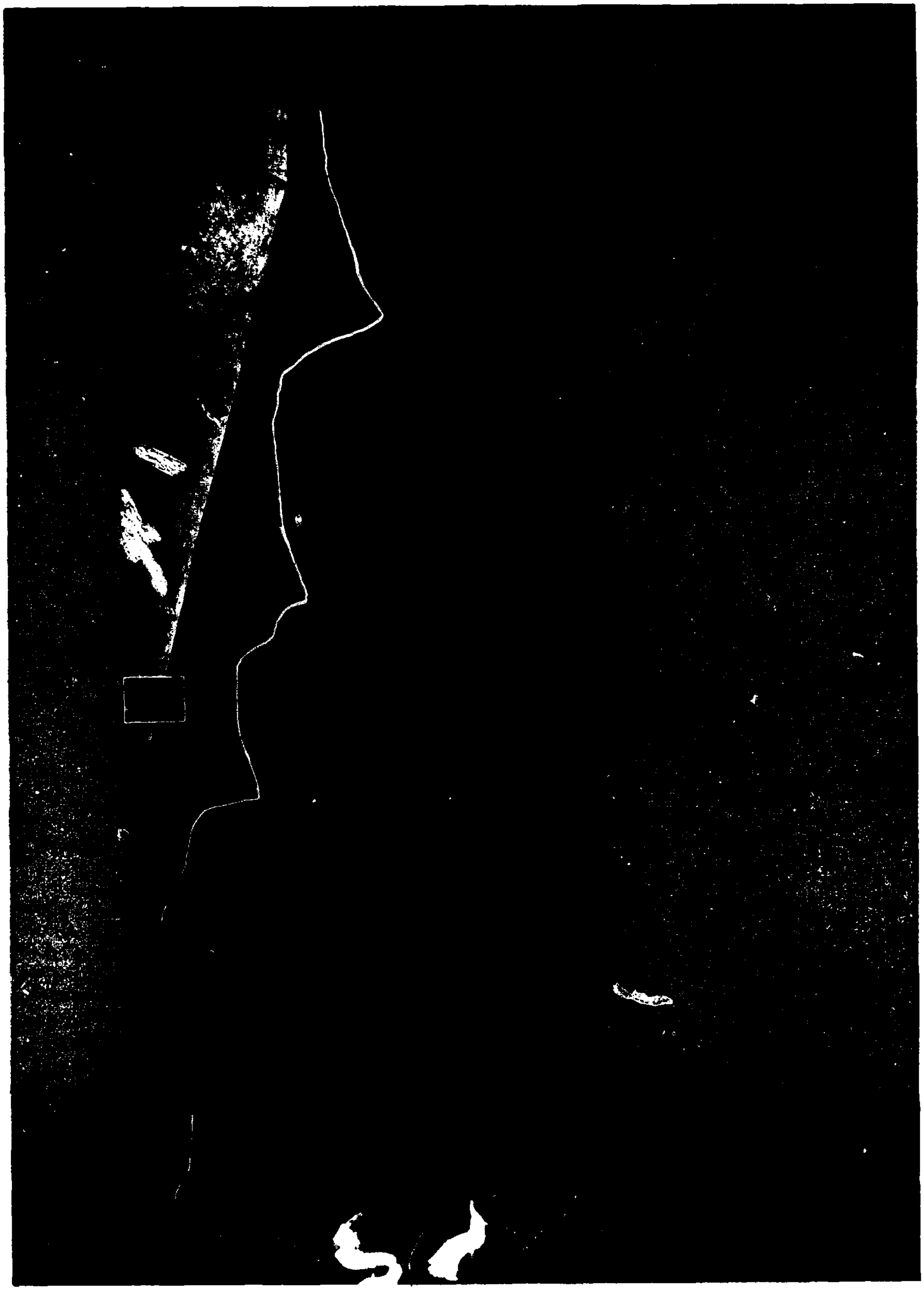


PLATE 31

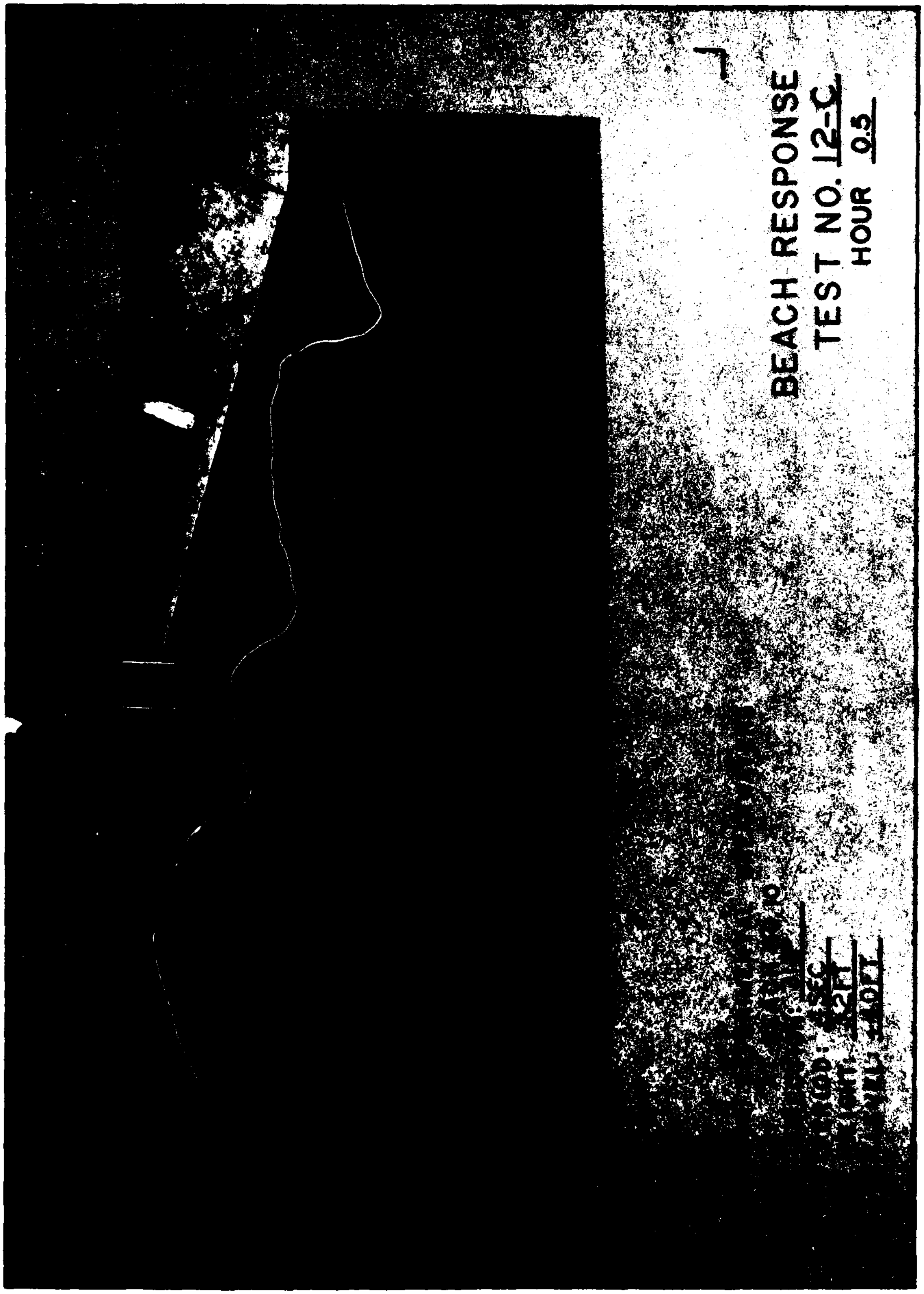


PLATE 32

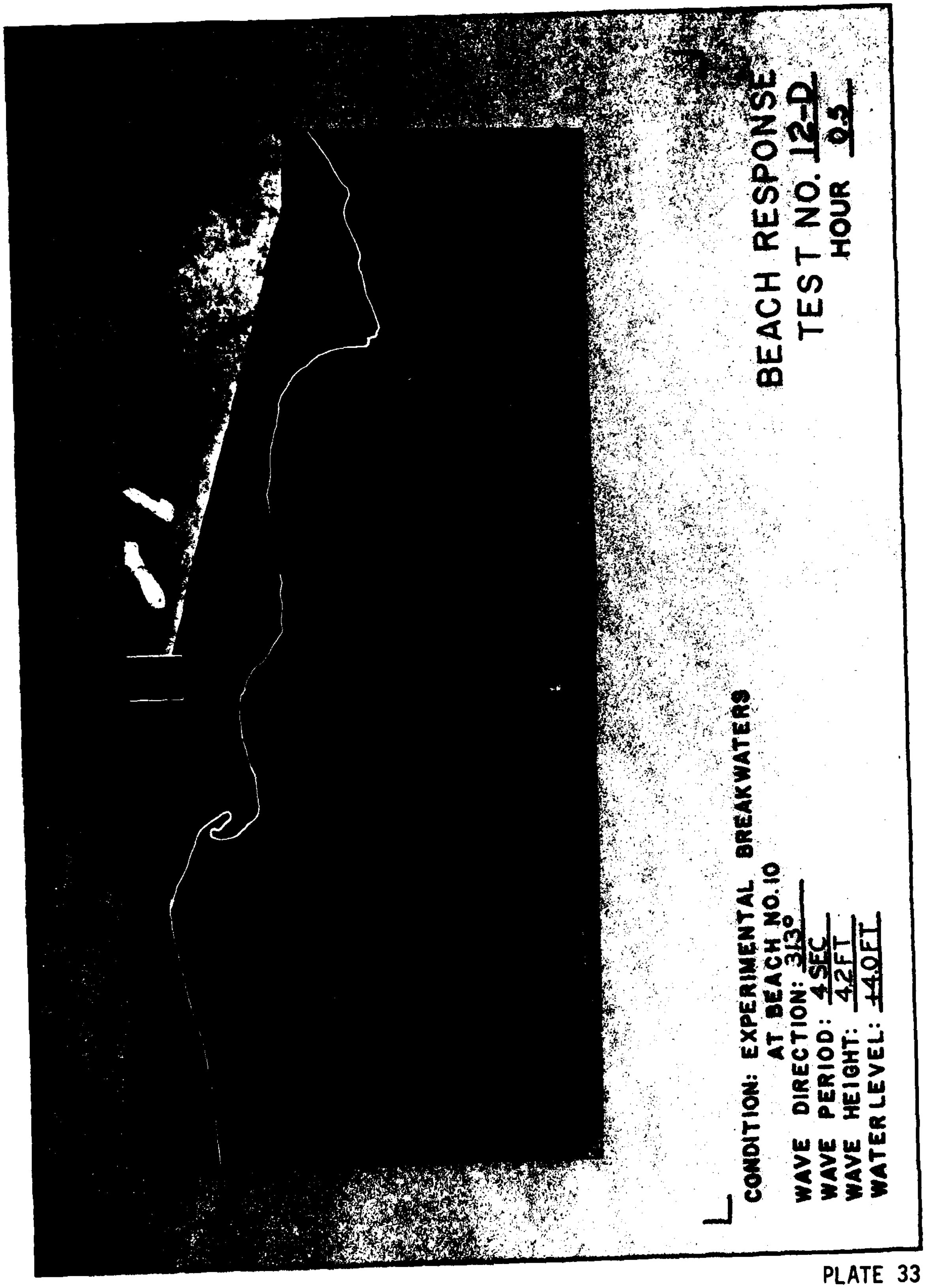

BEACH RESPONSE
TEST NO. 12-D
HOUR 0.5
CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO.10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 4.2 FT
WATER LEVEL: +4.0 FT

PLATE 34

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 4.2 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 12-F
HOUR 0.5

PLATE 36

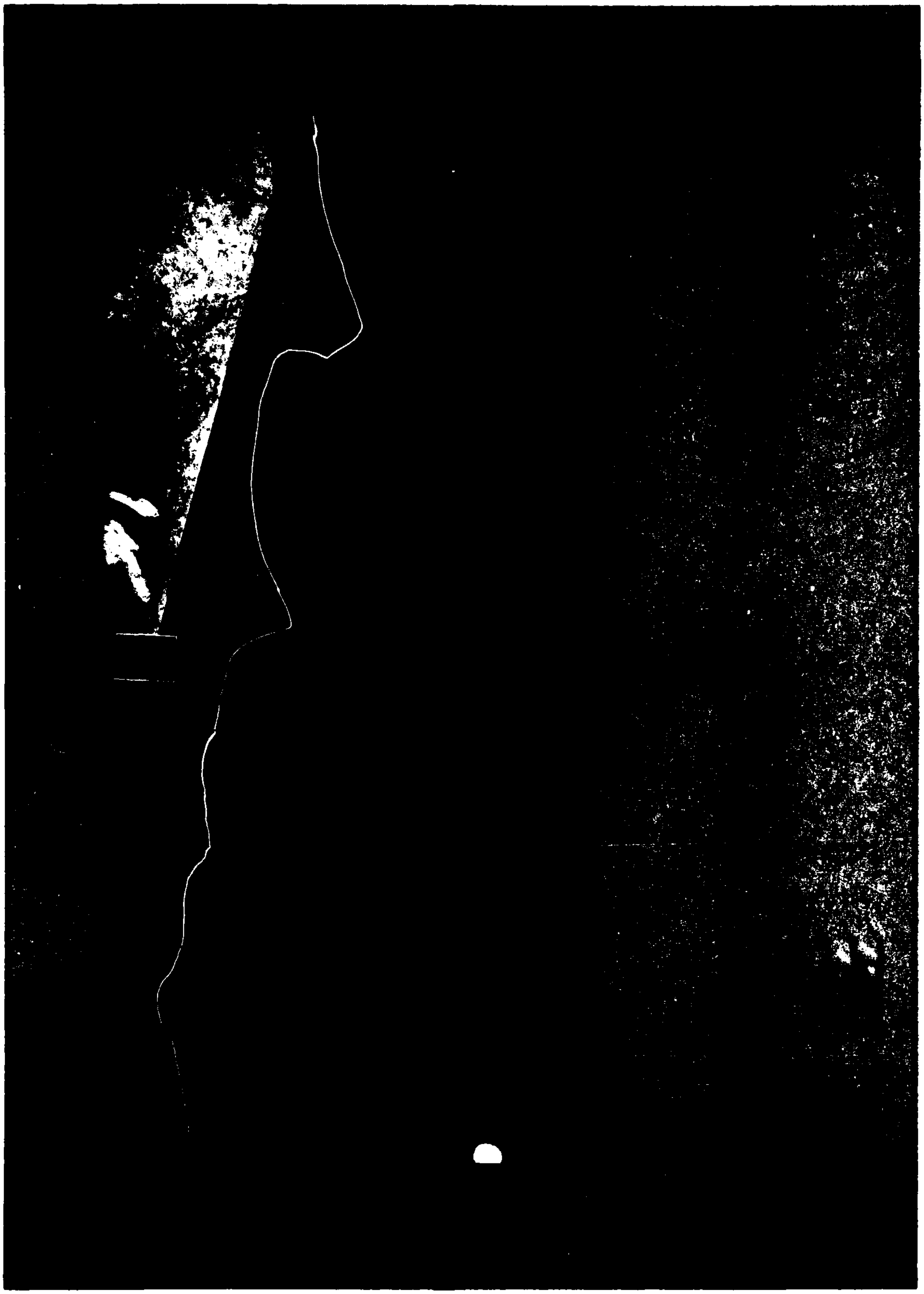


PLATE 37

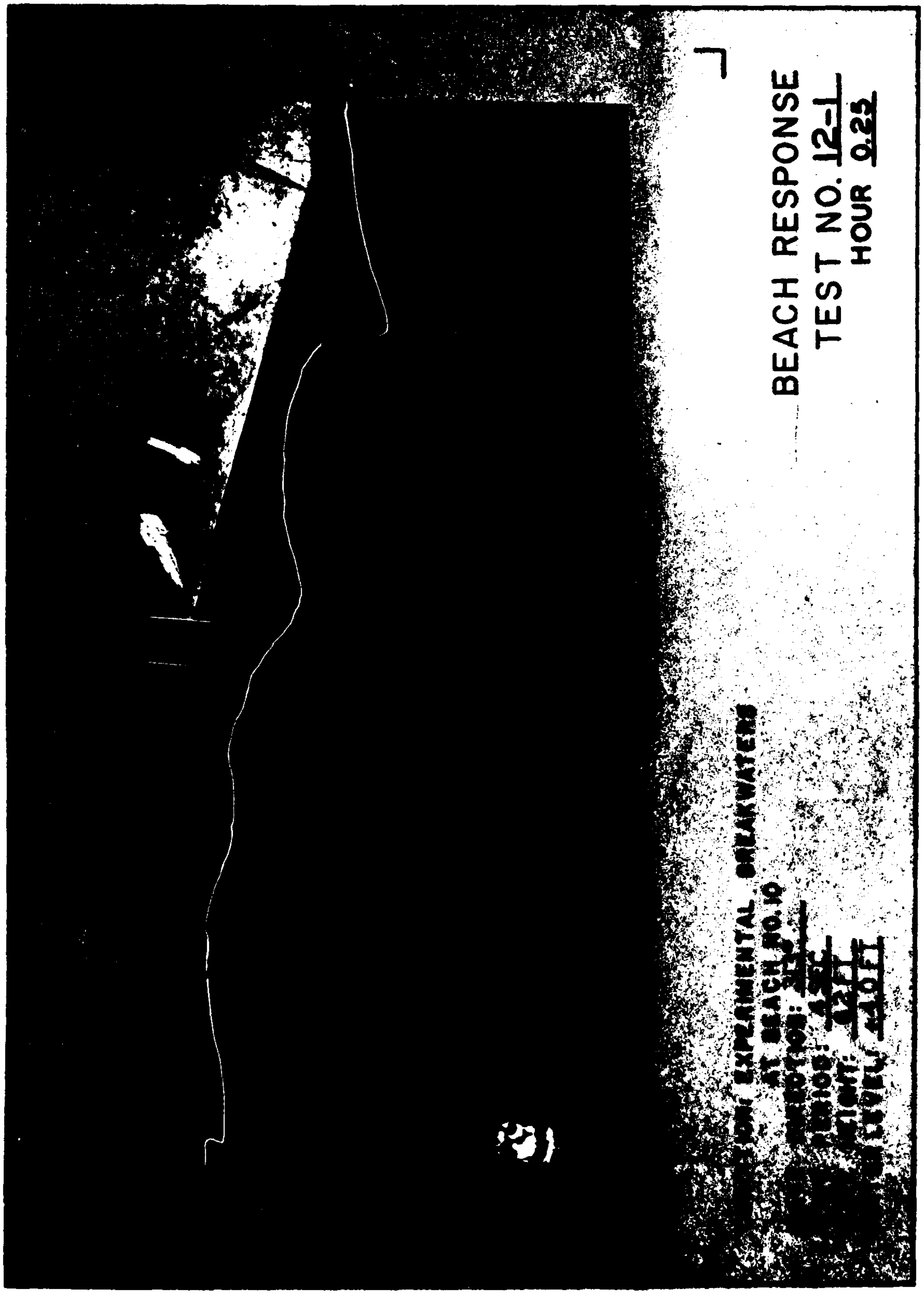
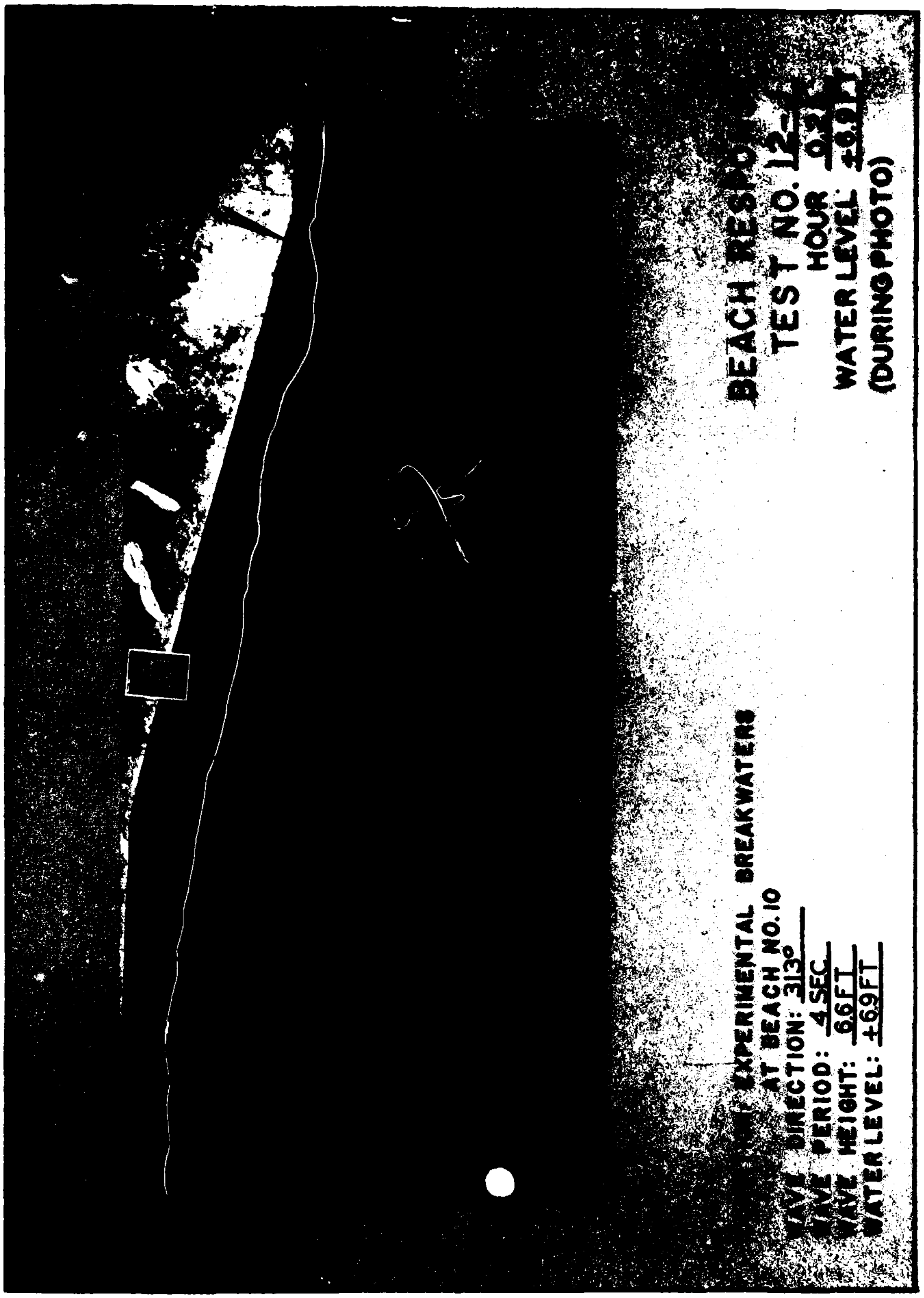


PLATE 38


EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
DIRECTION: 313°
PERIOD: 4 SEC
HEIGHT: 6.6 FT
LEVEL: +6.9 FT
TEST NO.
HOUR
WATER LEVEL
(DURING PHOTO)

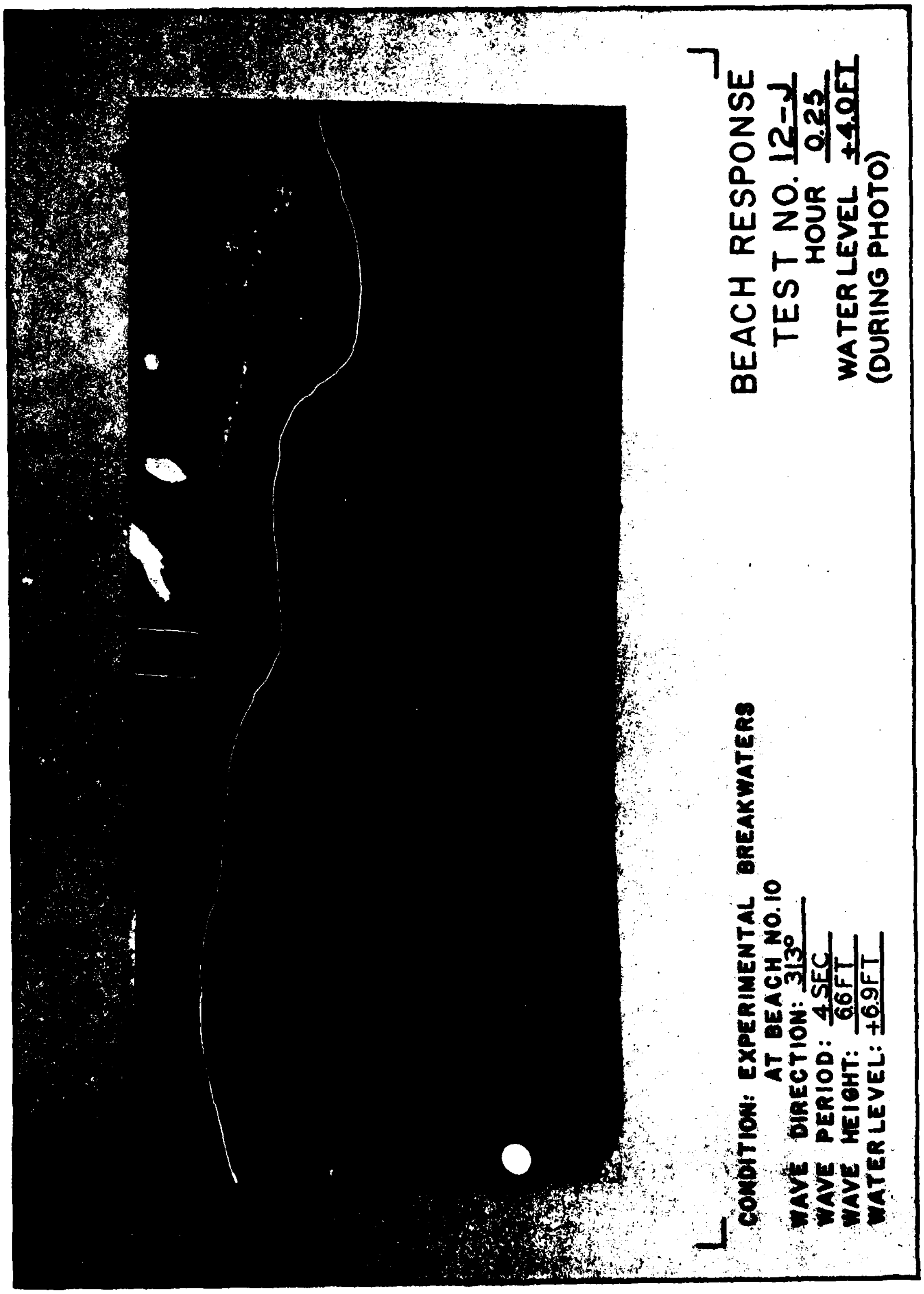

BEACH RESPONSE
TEST NO. 12-J
HOUR 0.25
WATER LEVEL +4.0FT
(DURING PHOTO)
CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 6.6FT
WATER LEVEL: +6.9FT

PLATE 40

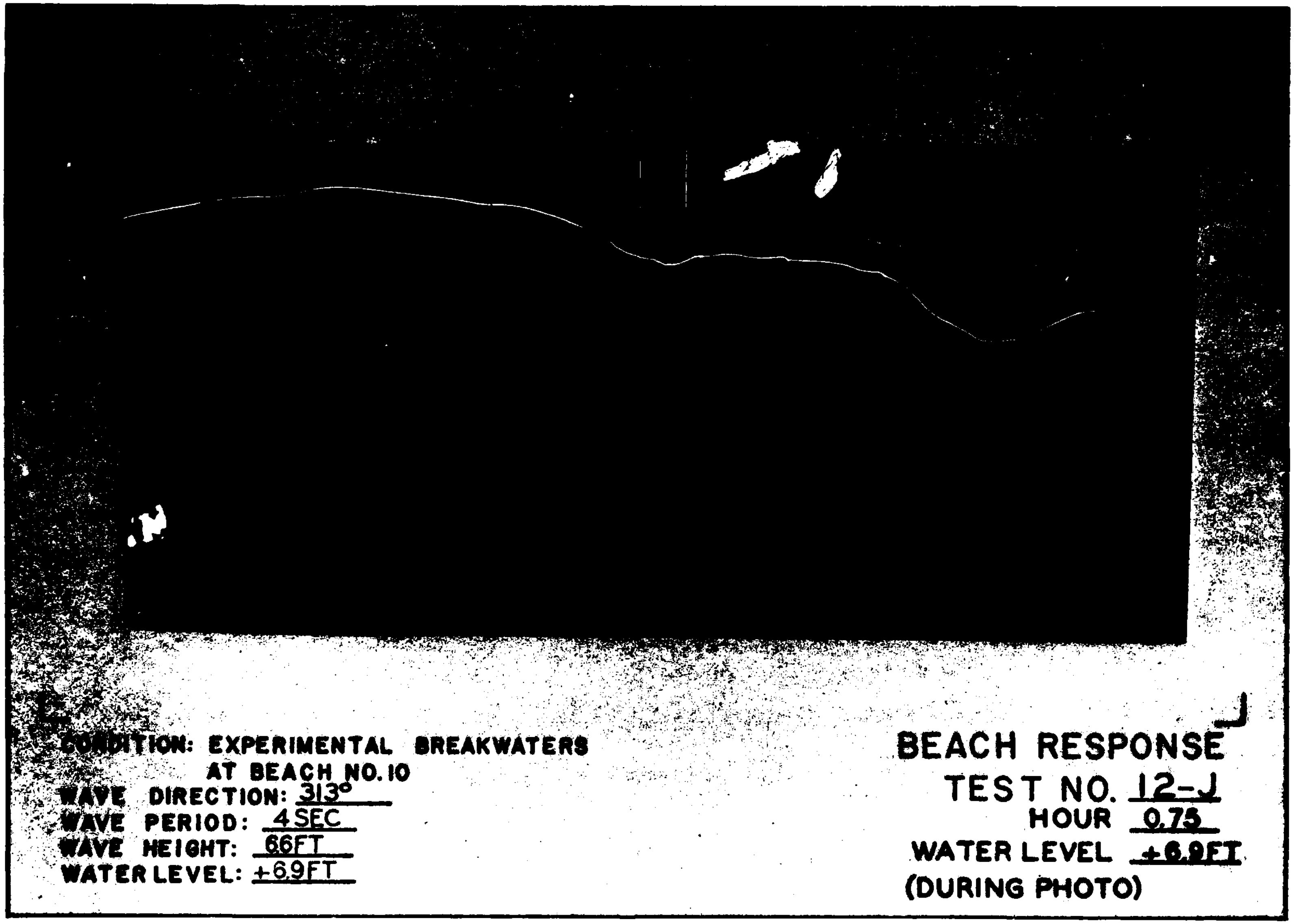

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 66FT
WATER LEVEL: +6.9FT
BEACH RESPONSE
TEST NO. 12-J
HOUR 0.75
WATER LEVEL +6.9FT
(DURING PHOTO)

PLATE 41

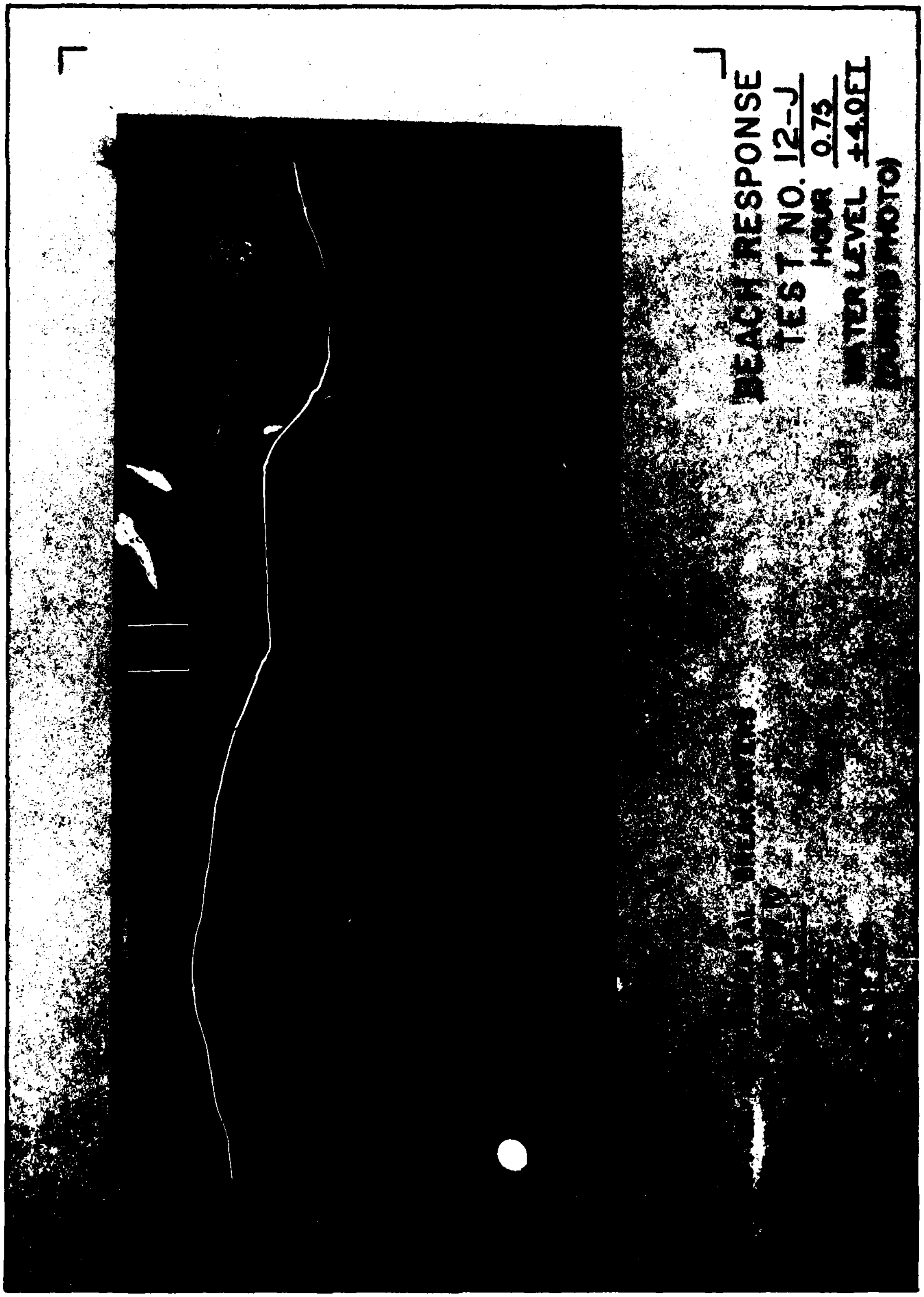


PLATE 42

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 313°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 2.1 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 13-A
HOUR 1.0

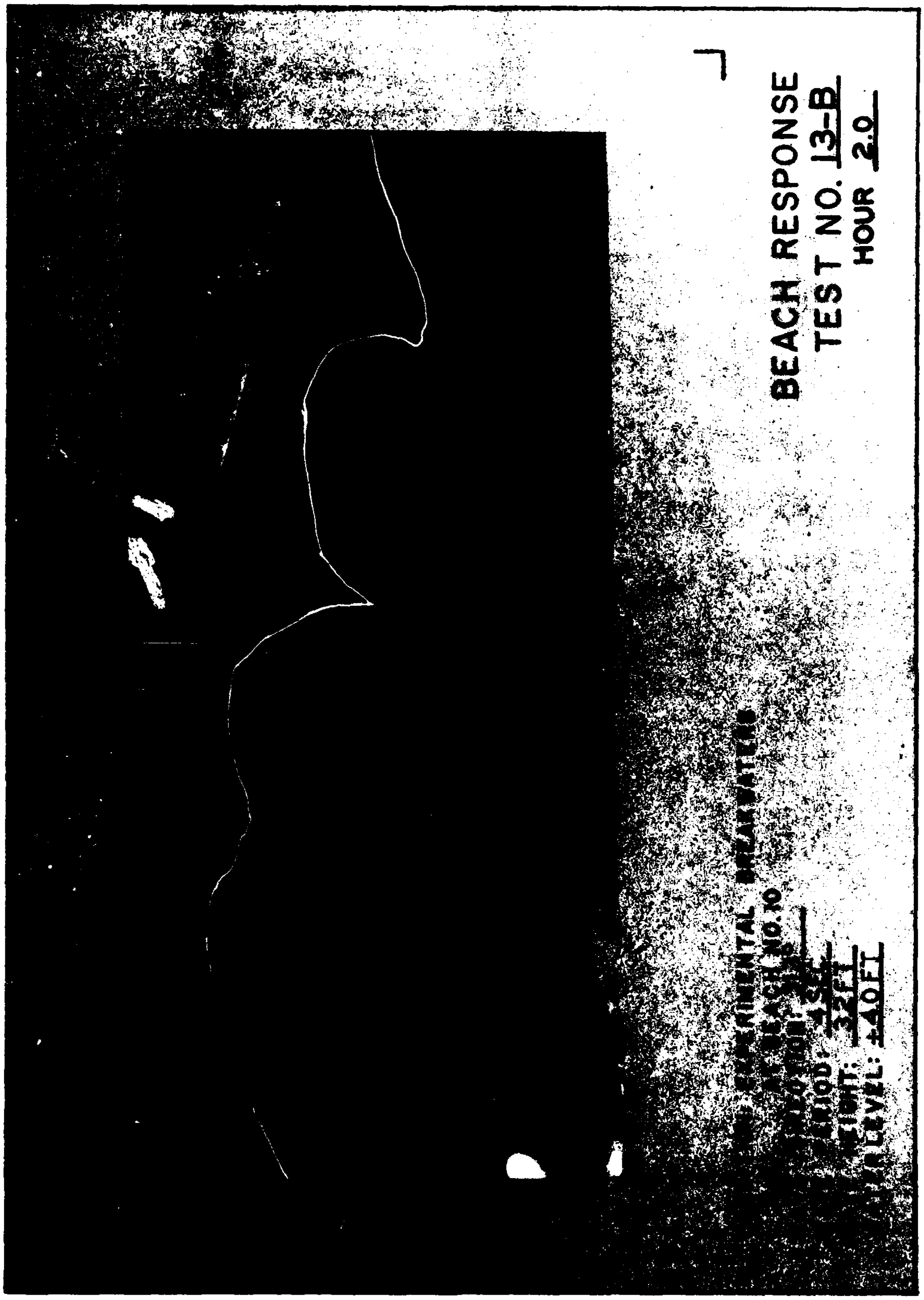


PLATE 44

PLATE 45

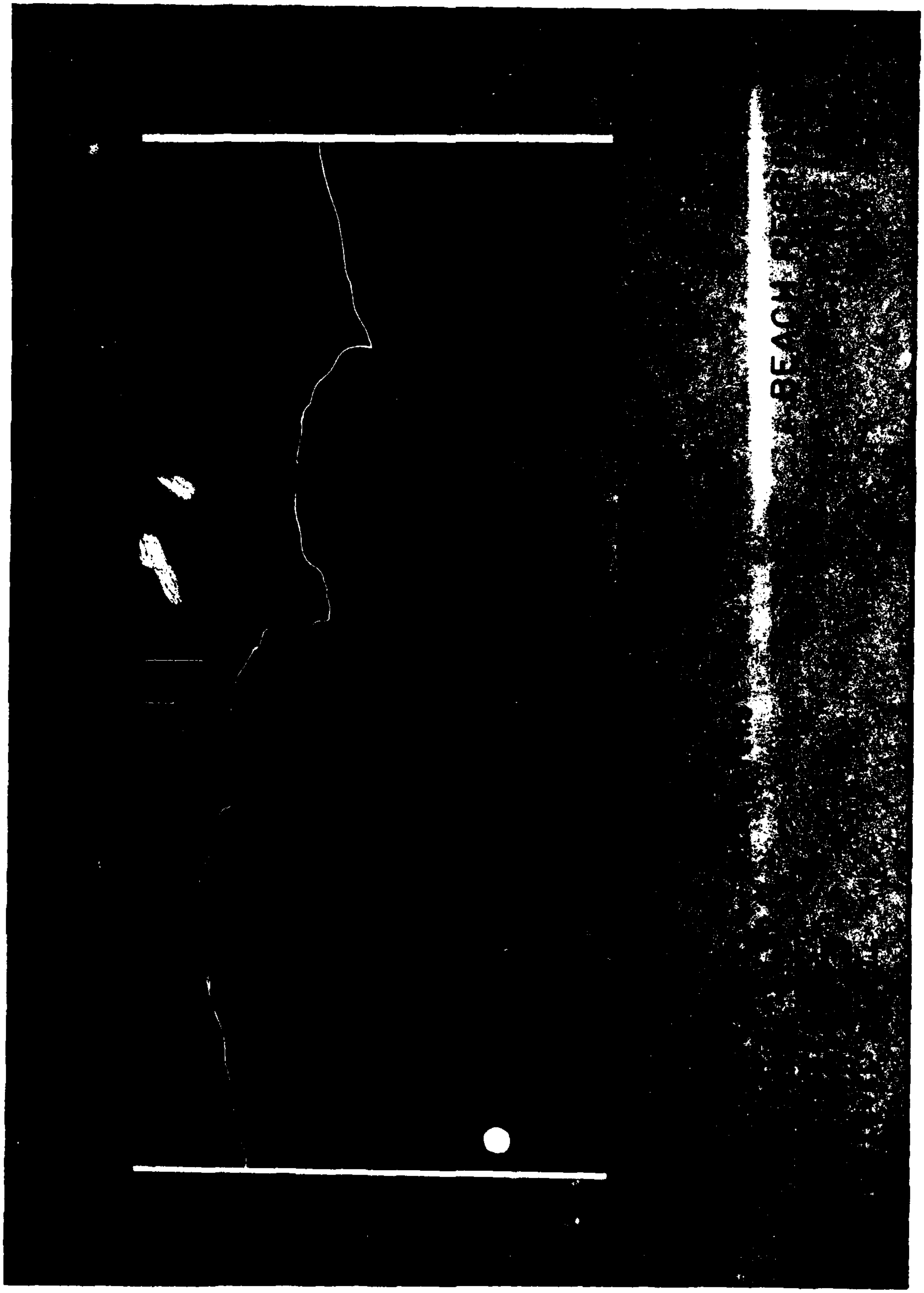


PLATE 46

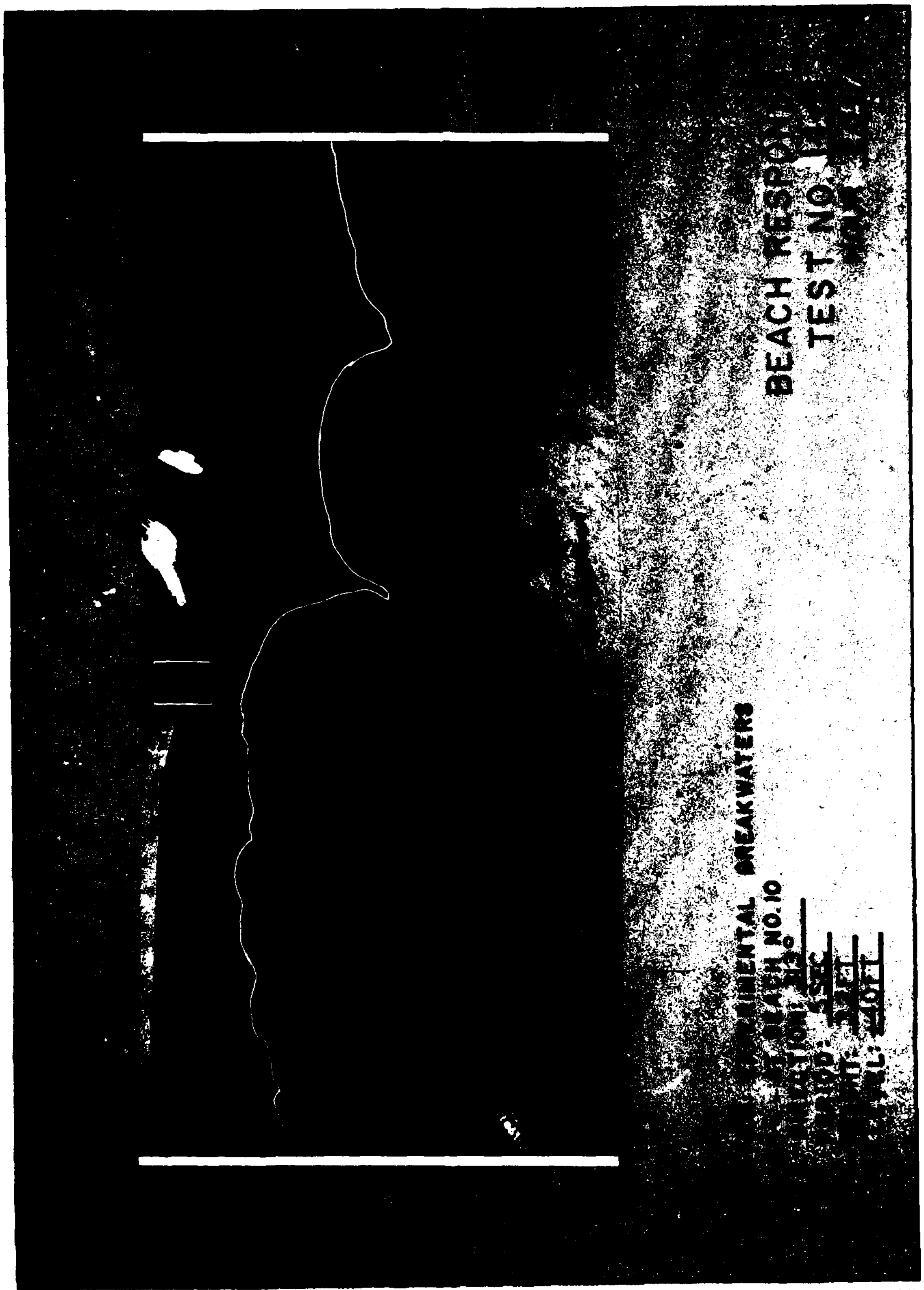


PLATE 47

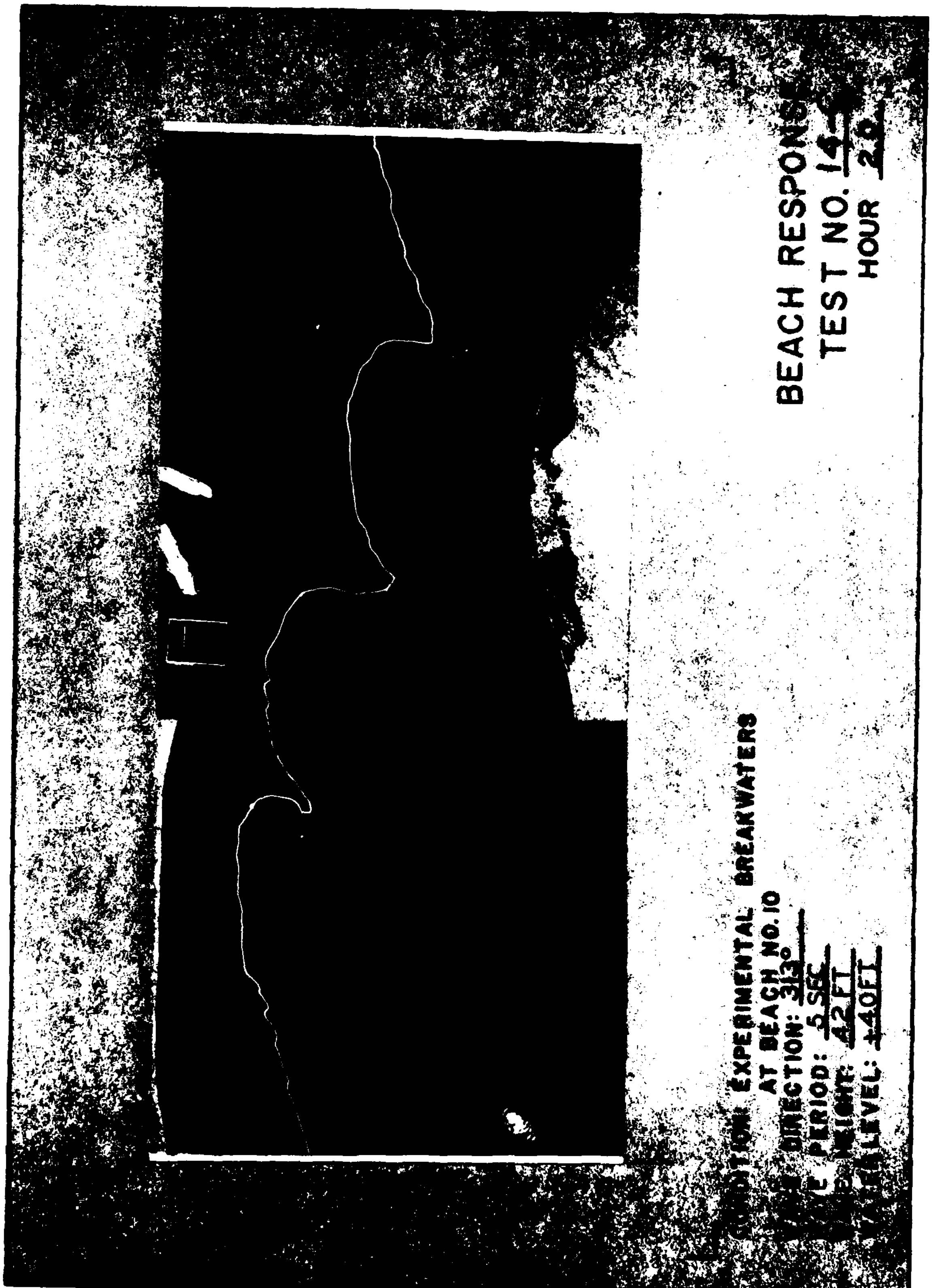

BEACH RESPONSE
TEST NO. 14
HOUR 20
EXPERIMENTAL BREAKWATERS
AT BEACH NO.10
DIRECTION: 313°
PERIOD: 5 SEC
4.2 FT
+4.0FT

PLATE 48

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 5 SEC
WAVE HEIGHT: 2.1 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 15-A
HOUR 4.0

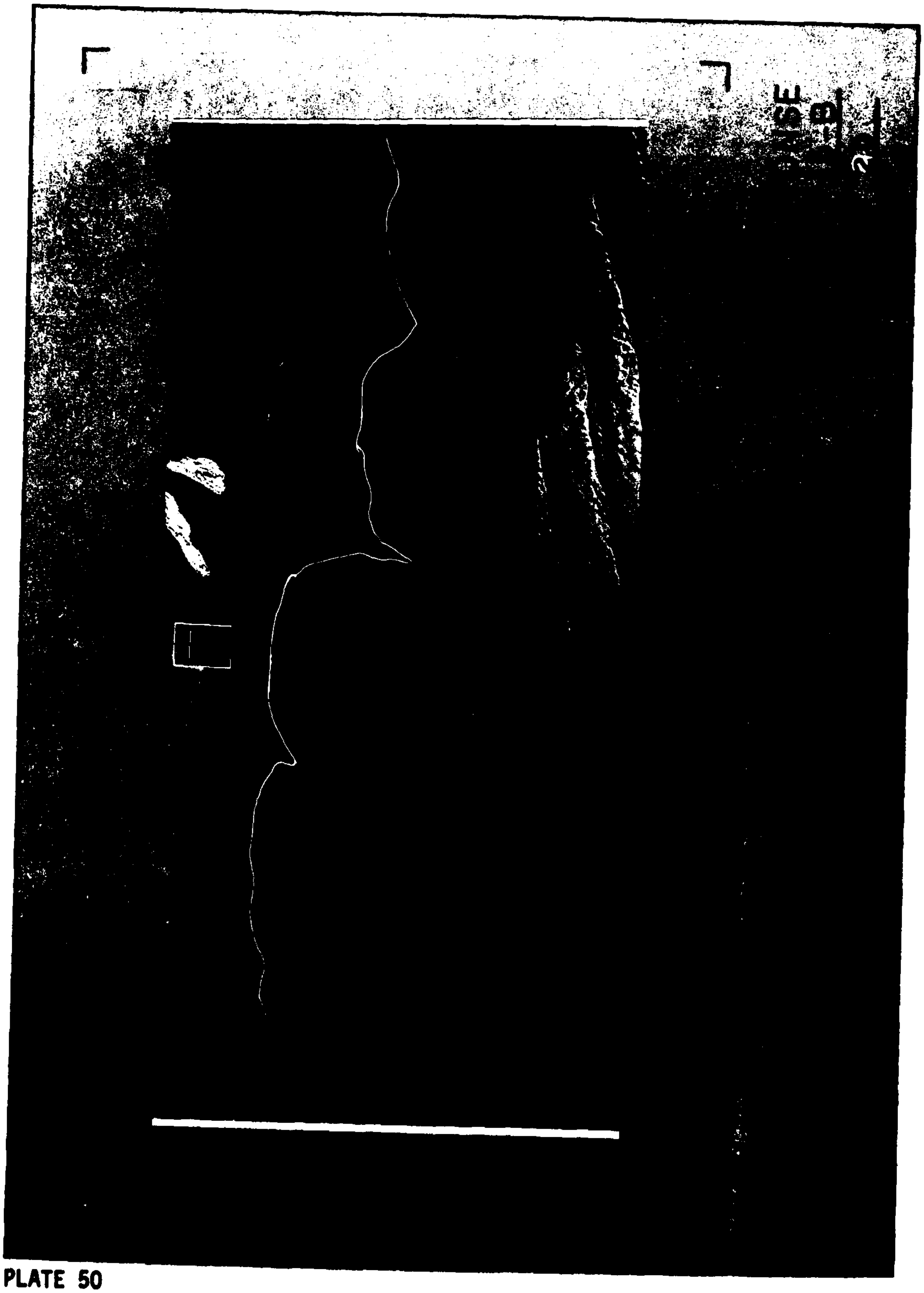


PLATE 50

CONDITION: EXPERIMENTAL BREAKWATERS AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 5.0 SEC
WAVE HEIGHT: 4.2 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 15-C
HOUR 2.0

PLATE 52

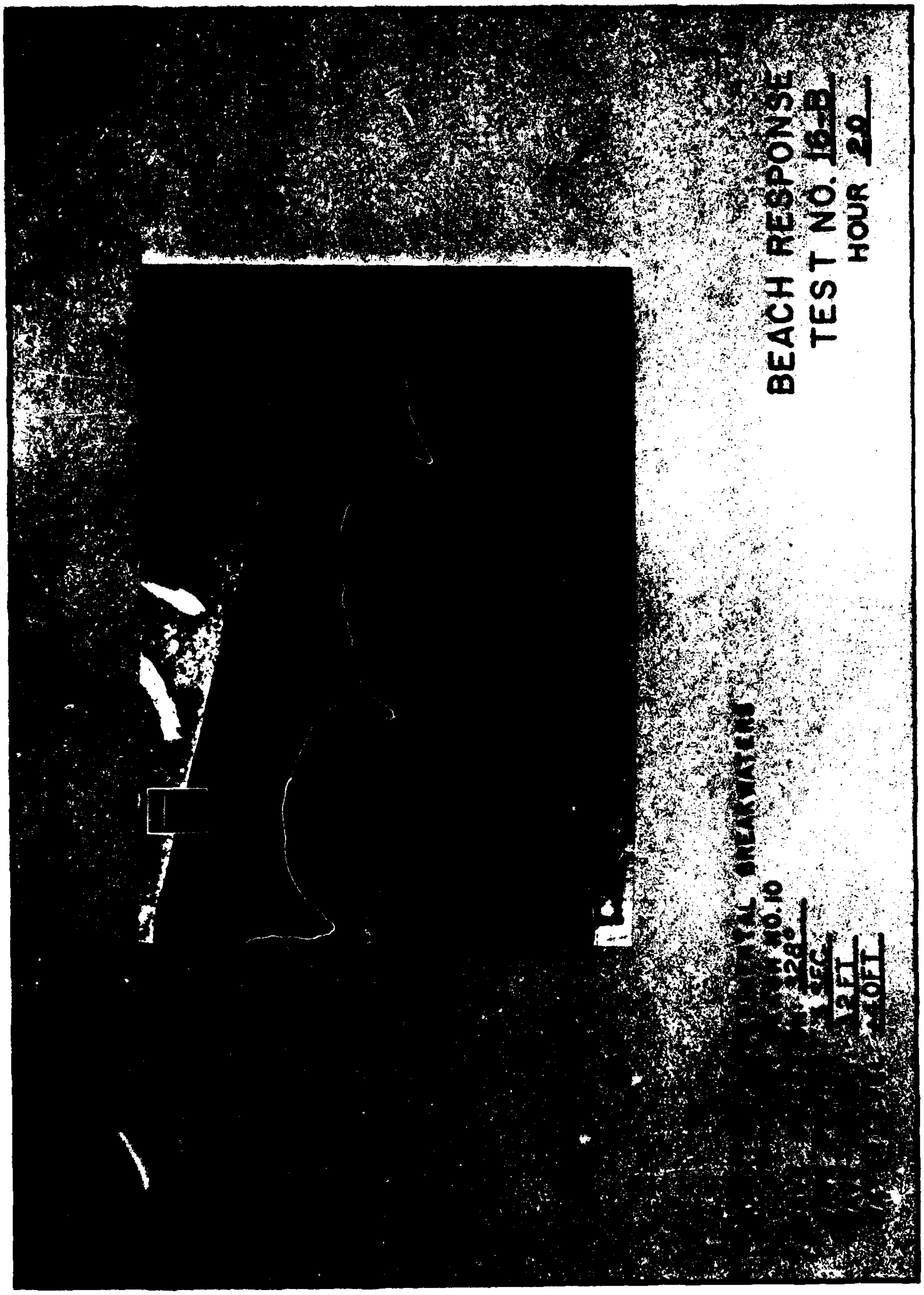


PLATE 53

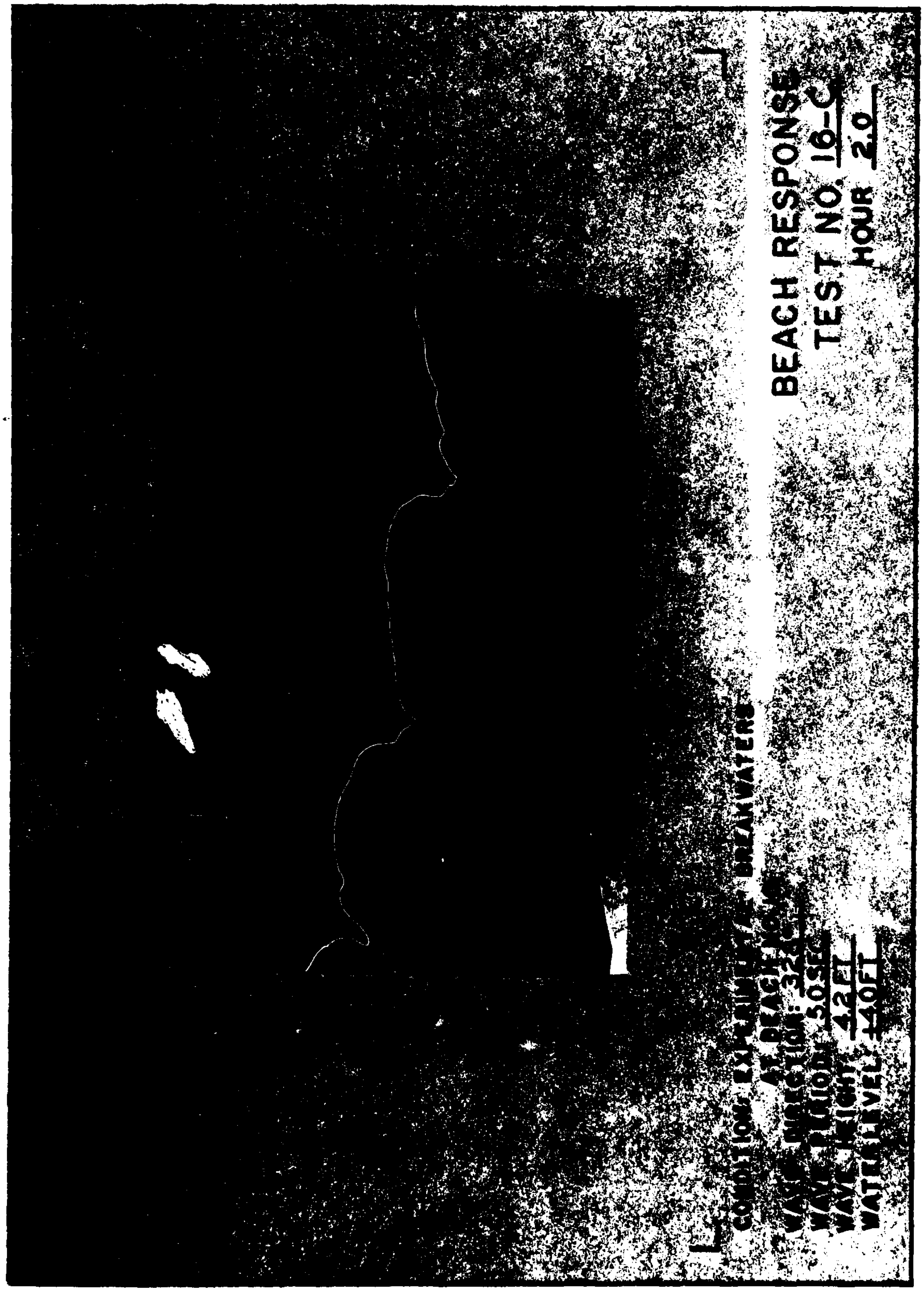


PLATE 54

HOUR 0

HOUR 1

CONDITION: EXPERIMENTAL BREAKWATERS AT BEACH NO. 10

WAVE DIRECTION: 328°

WAVE PERIOD: 5 SEC

WAVE HEIGHT: 6.4 FT

WATER LEVEL: +6.9 FT

BEACH RESPONSE

TEST NO. 16-D

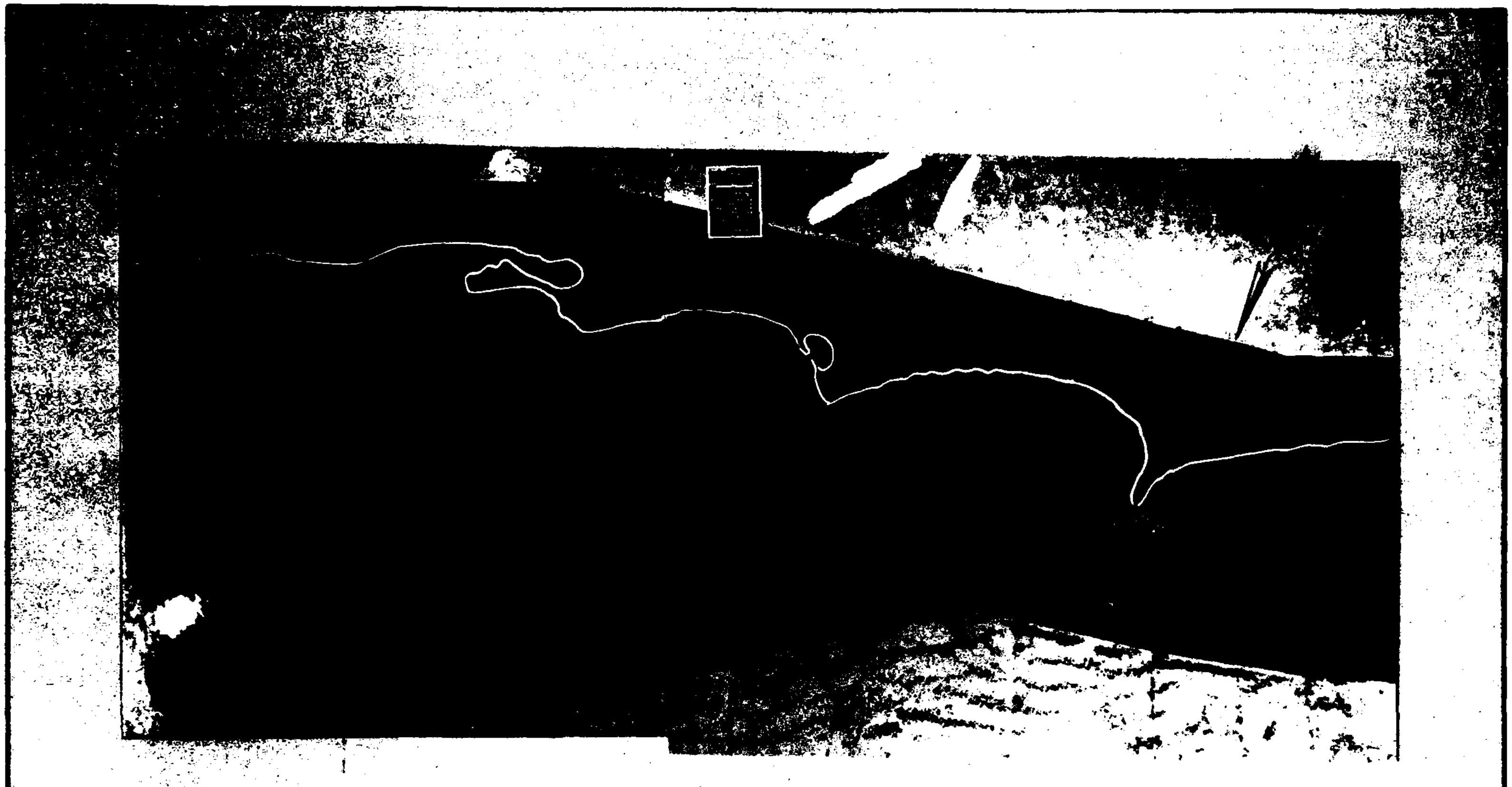
PLATE 56

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 3.2 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 17-B
HOUR 2.0

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 4.2 FT
WATER LEVEL: ±4.0 FT

BEACH RESPONSE
TEST NO. 17-C
HOUR 2.0



CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 4 SEC
WAVE HEIGHT: 2.1 FT
WATER LEVEL: +4.0 FT

BEACH RESPONSE
TEST NO. 18-A
HOUR 4.0

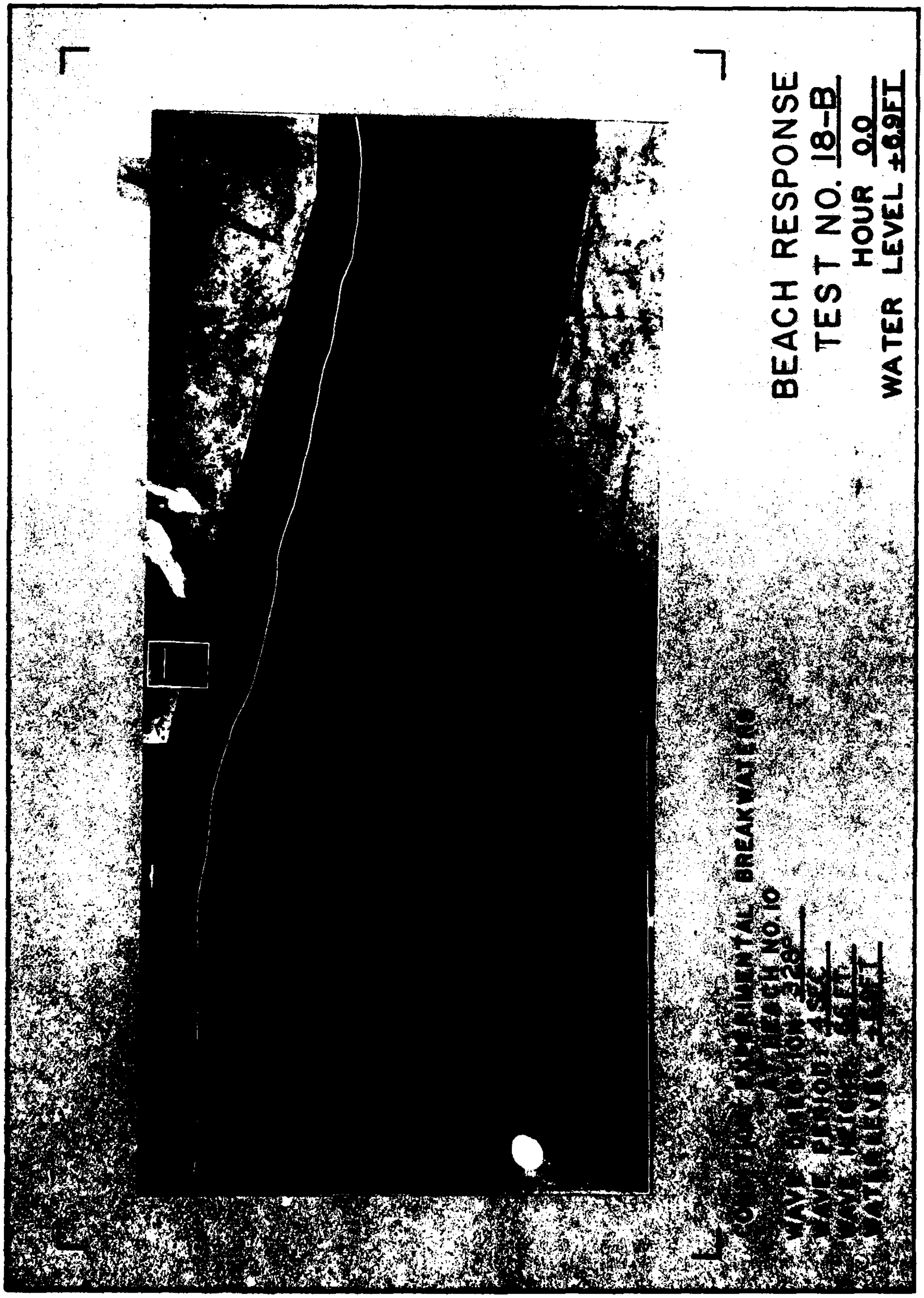


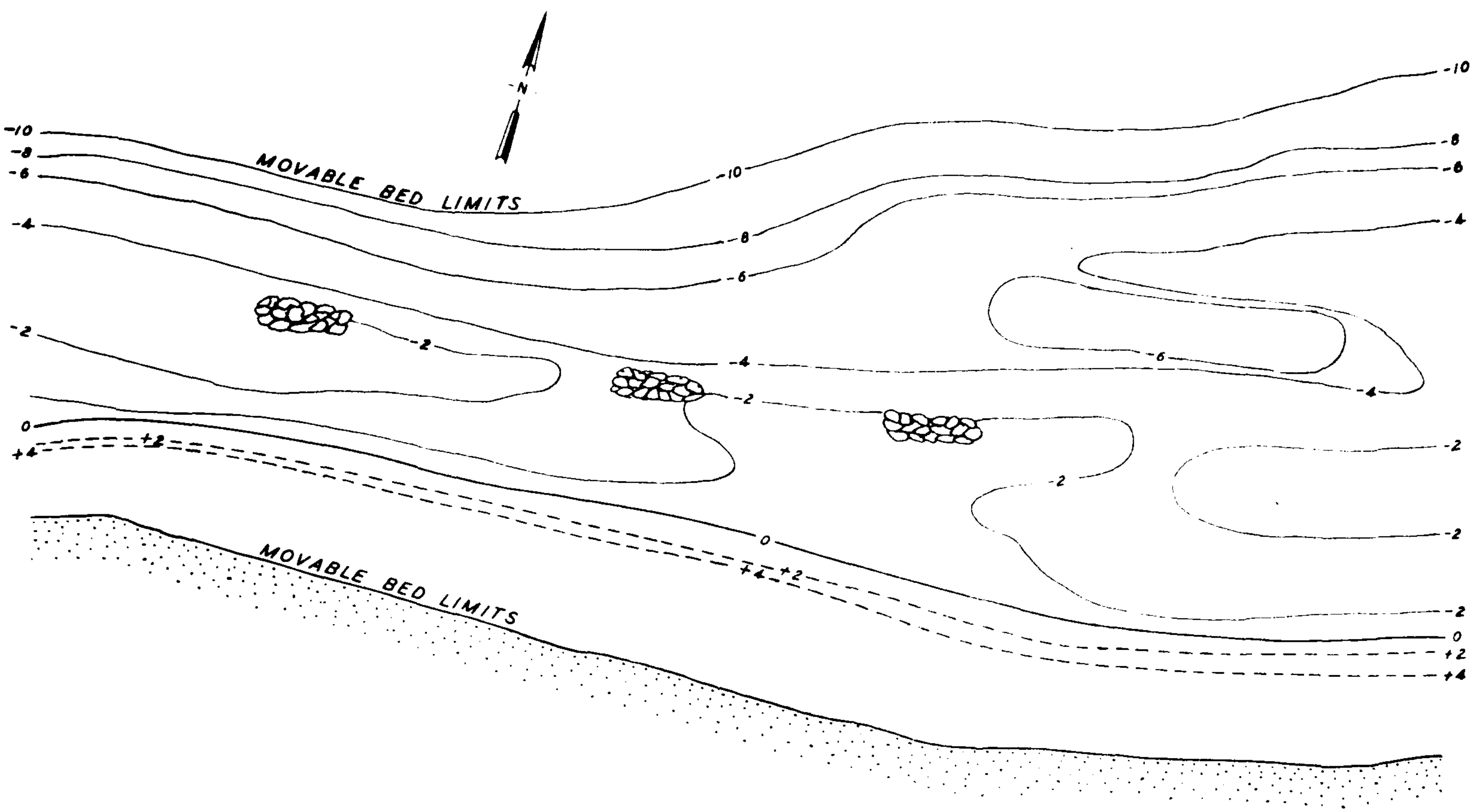
PLATE 60

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO.10
WAVE DIRECTION: 328°
WAVE PERIOD: 4SEC
WAVE HEIGHT: 6.6FT
WATER LEVEL: +6.9FT

BEACH RESPONSE
TEST NO. 18-B
HOUR 0.2
WATER LEVEL +6.9FT

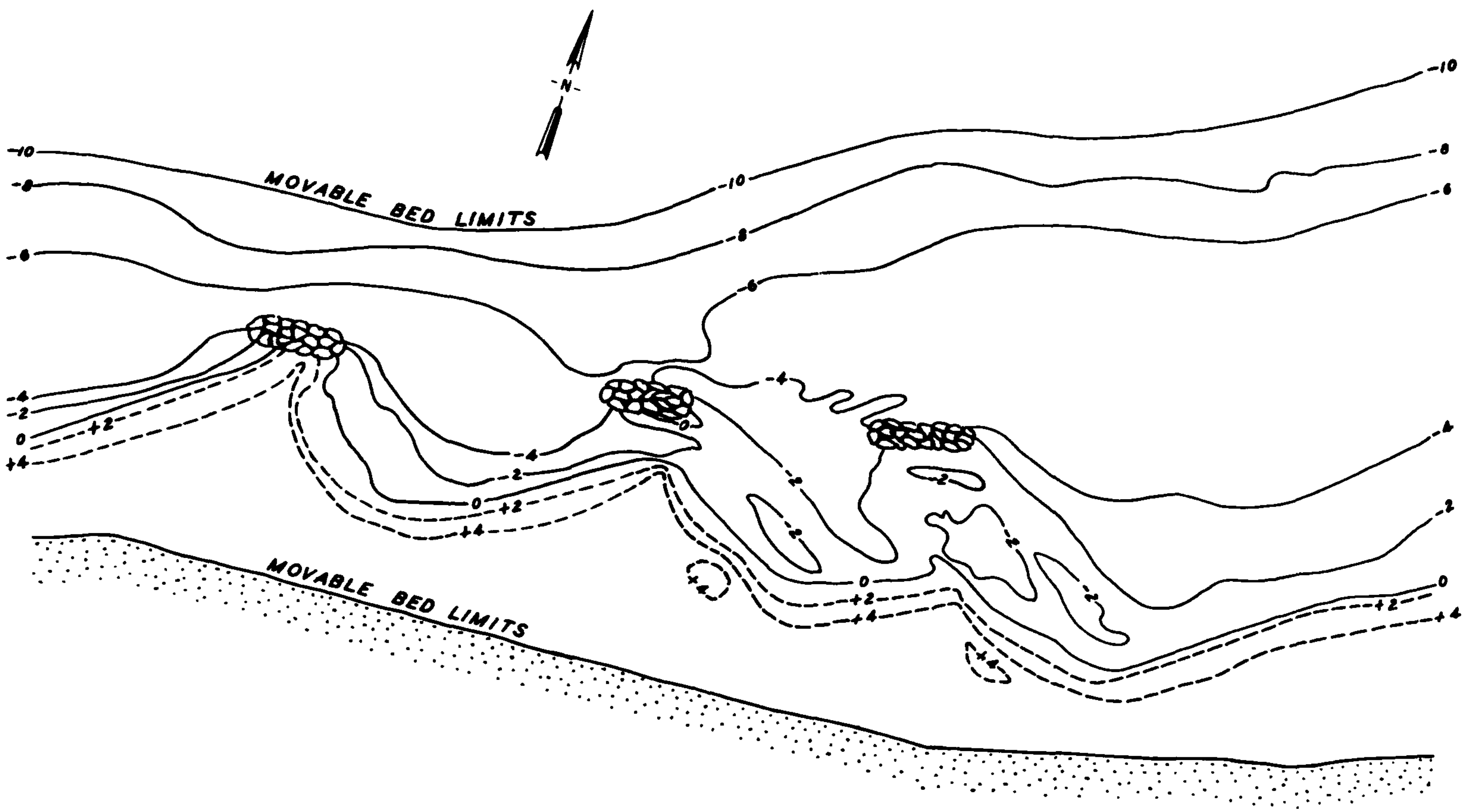
BEACH RESPONSE
TEST NO. 18-B
HOUR 0.2
WATER LEVEL +4.0FT

CONDITION: EXPERIMENTAL BREAKWATERS
AT BEACH NO. 10
WAVE DIRECTION: 328°
WAVE PERIOD: 4SEC
WAVE HEIGHT: 6.6FT
WATER LEVEL: +6.9 FT



NOTE: ELEVATIONS ARE REFERRED TO LWD OF LAKE ERIE.

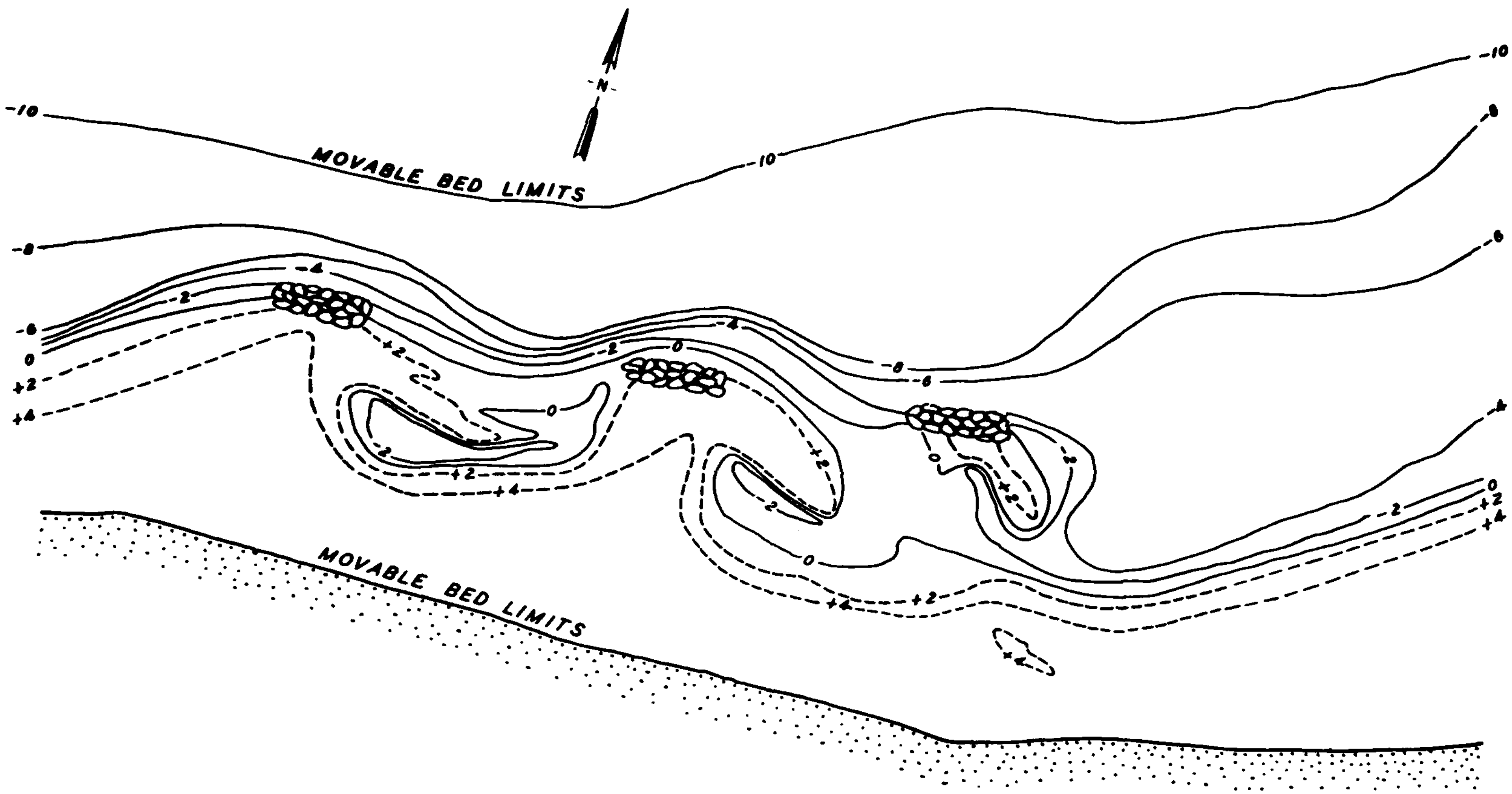
INITIAL BATHYMETRY



NOTE: CONDITION AFTER 4 HOURS:
4 HOURS OF 2.1 FT WAVES, 4 SECOND PERIOD, +4.0 FT WATER LEVEL, 313° WAVE ANGLE
ELEVATIONS ARE REFERRED TO LWD OF LAKE ERIE

BATHYMETRY AFTER
4 HOURS OF OPERATION

PLATE 64

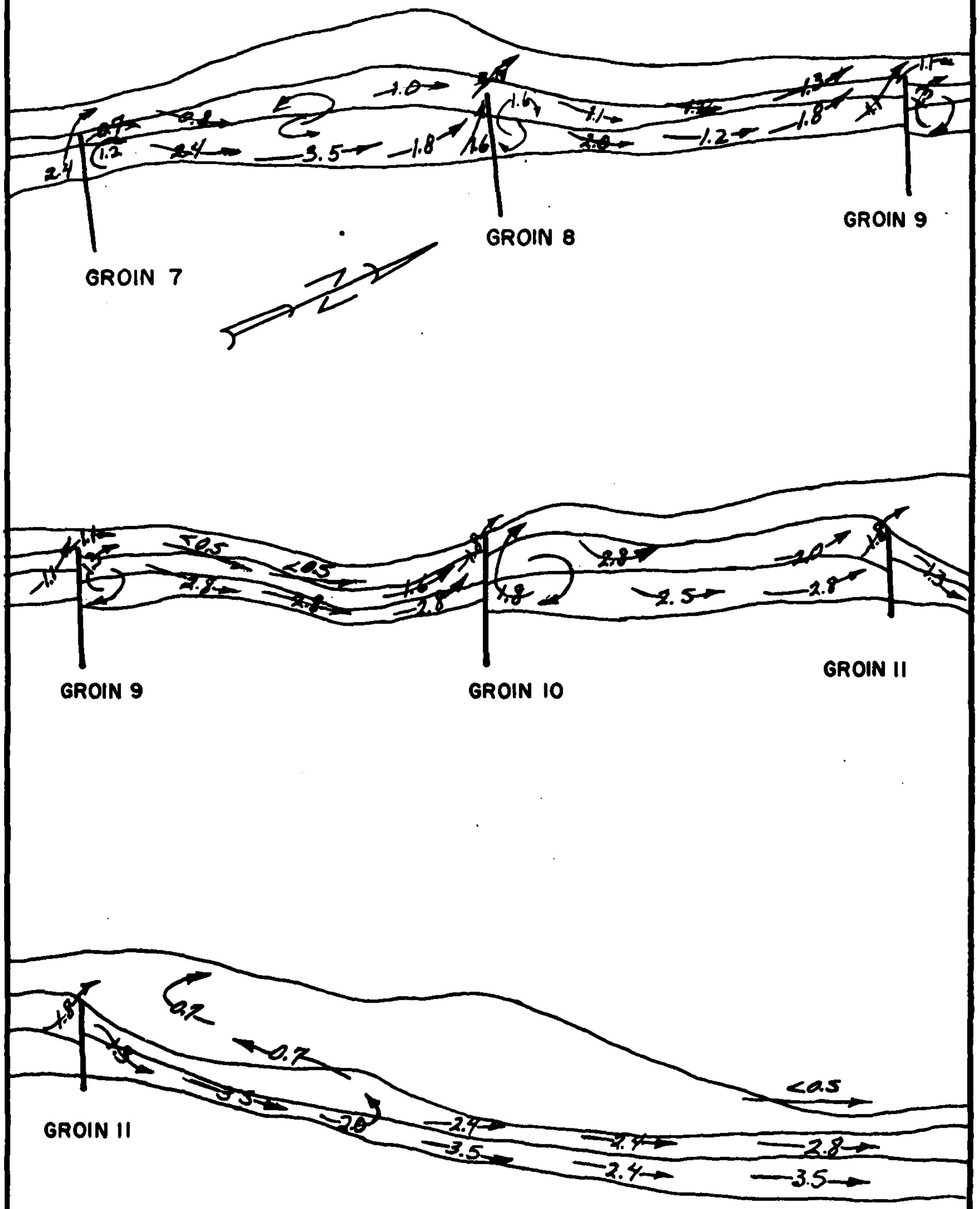


NOTE: FINAL CONDITION:
4 HOURS OF 2.1 FT WAVES, 4 SECOND PERIOD, +4.0 FT WATER LEVEL, 313 WAVE ANGLE
2 HOURS OF 3.2 FT WAVES, 4 SECOND PERIOD, +4.0 FT WATER LEVEL 313 WAVE ANGLE
2 HOURS OF 4.2 FT WAVES, 4 SECOND PERIOD, +4.0 FT WATER LEVEL, 313 WAVE ANGLE

TOTAL 8 HOURS OF WAVES

ELEVATIONS ARE REFERRED TO LWD OF LAKE ERIE

FINAL BATHYMETRY



TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE: 0 100 200 300 400 500 FT

MODEL: 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 1

BEACH 4

BEACH 5

BEACH 6

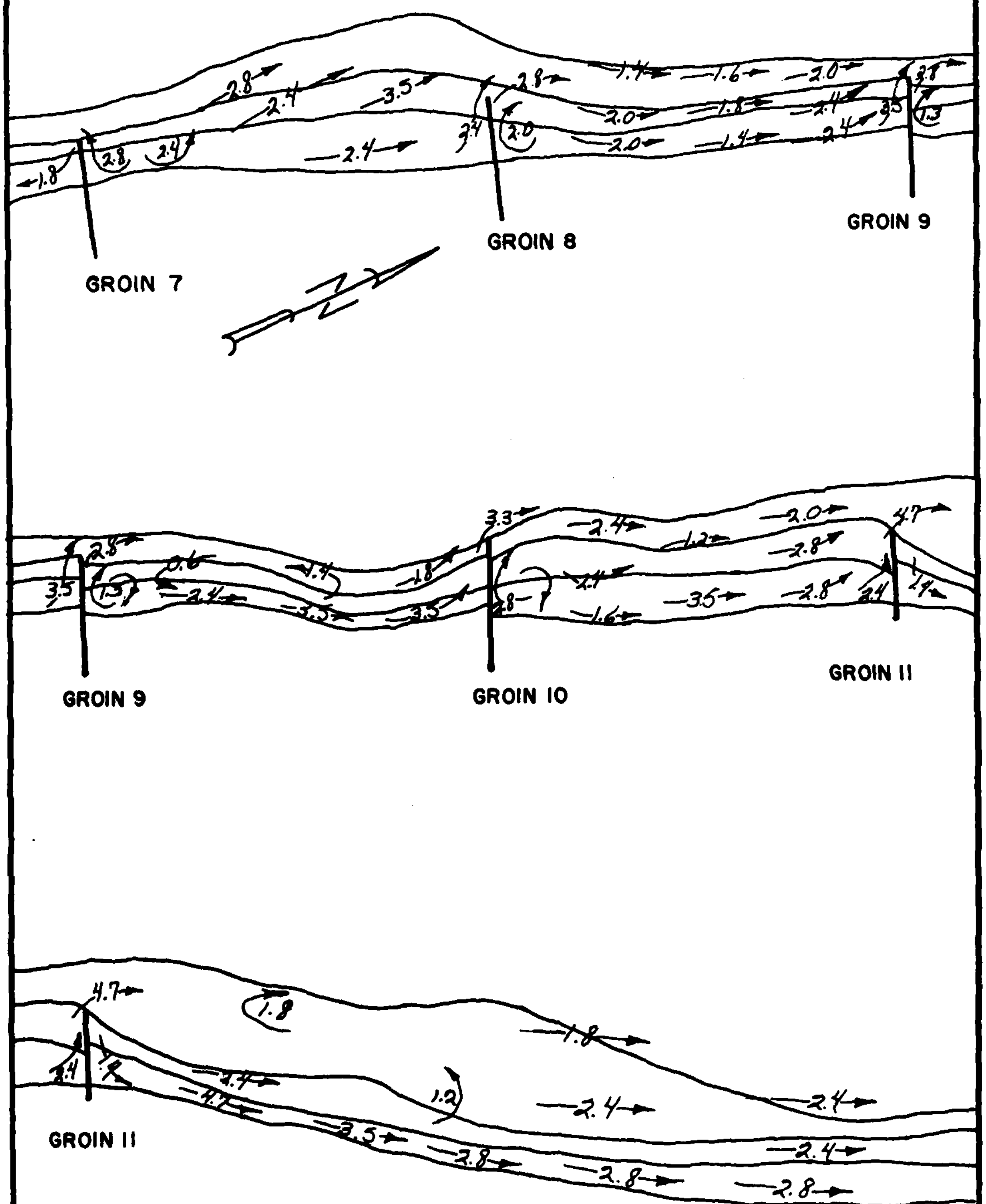
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 1



TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 2

PLATE 67a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 2

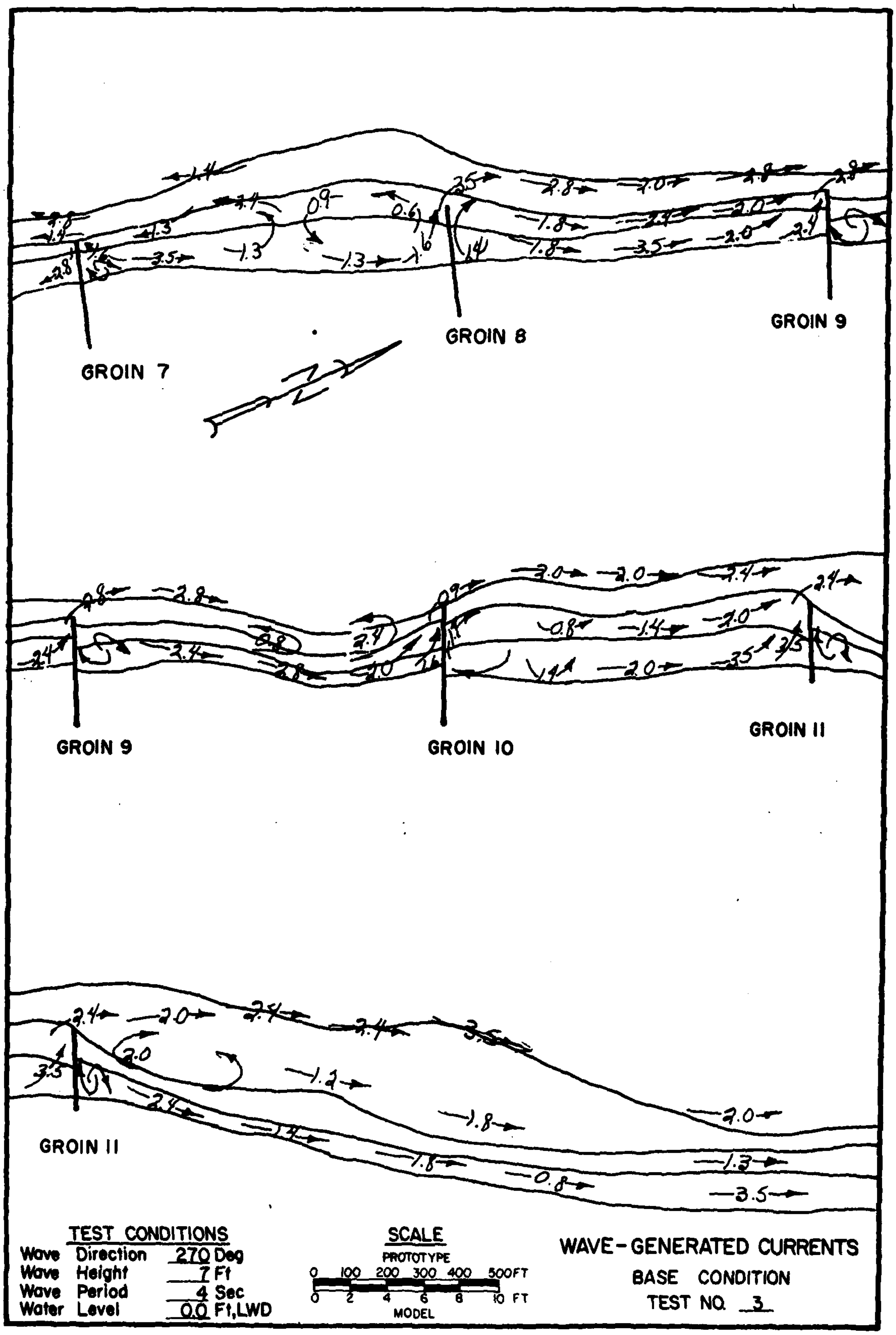
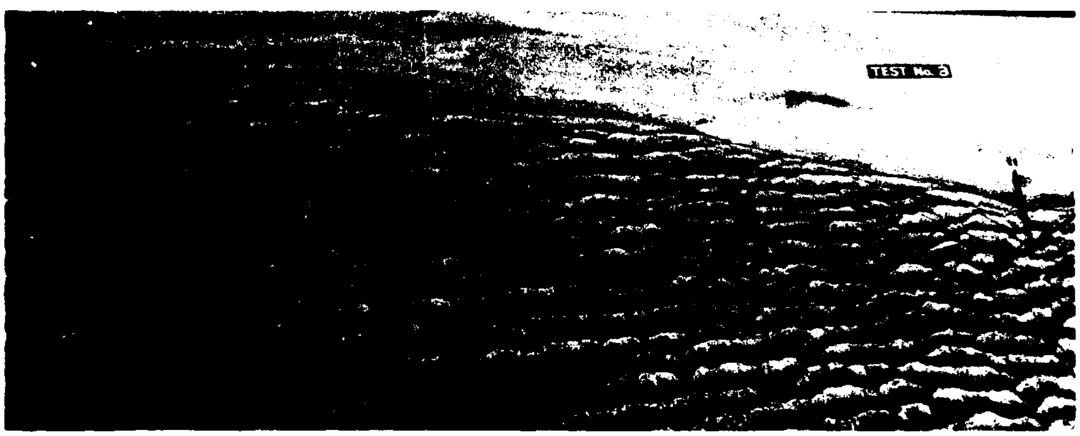

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 3

PLATE 68a

BEACH 4

BEACH 5



BEACH 6

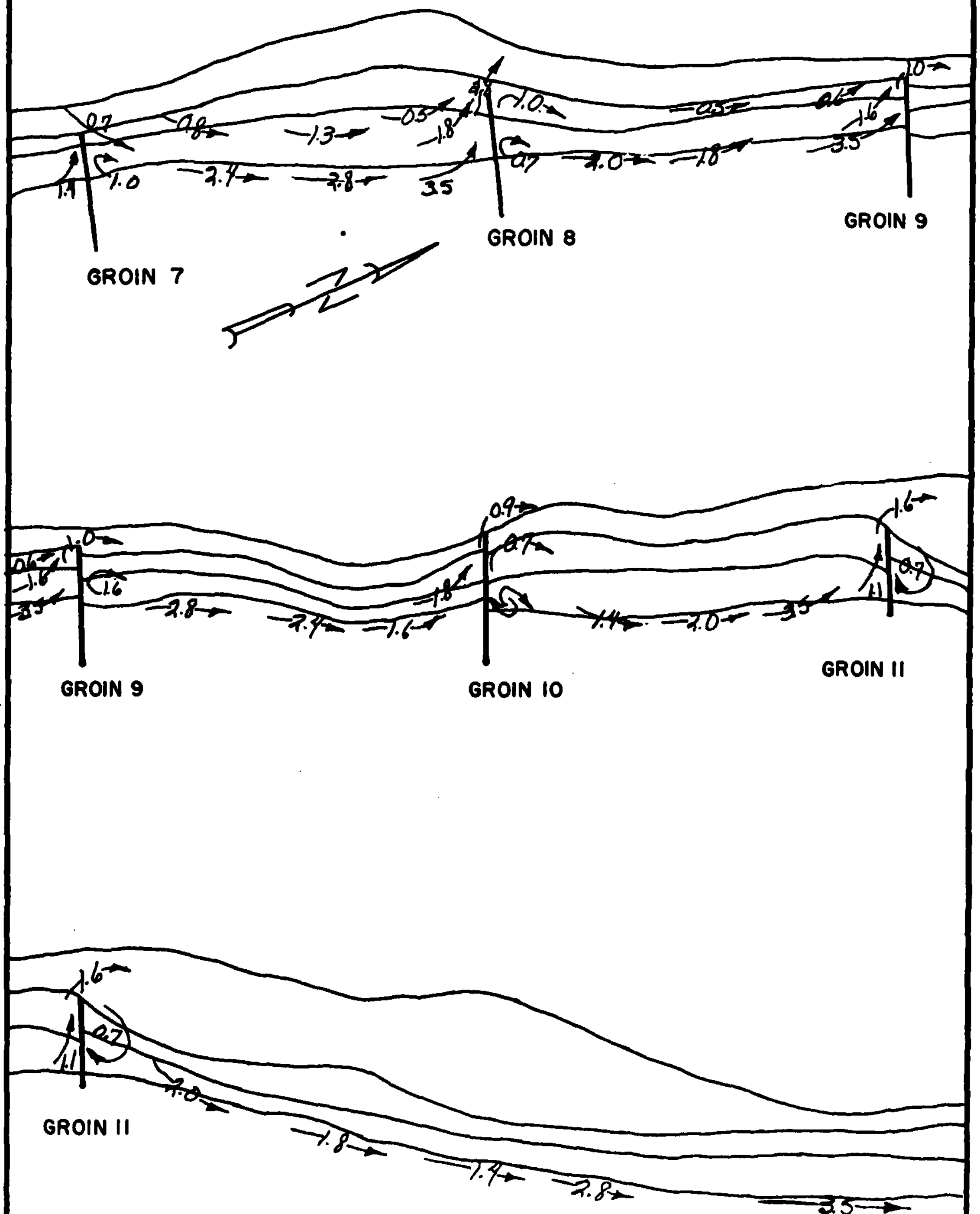
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 3



TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	2 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

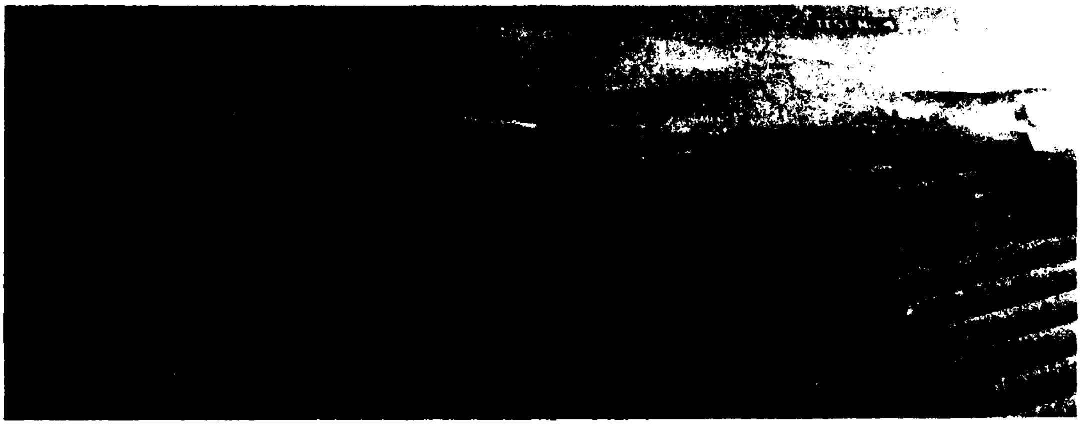
WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 4

PLATE 69a

BEACH 4



BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 2 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION
TEST NO. 4

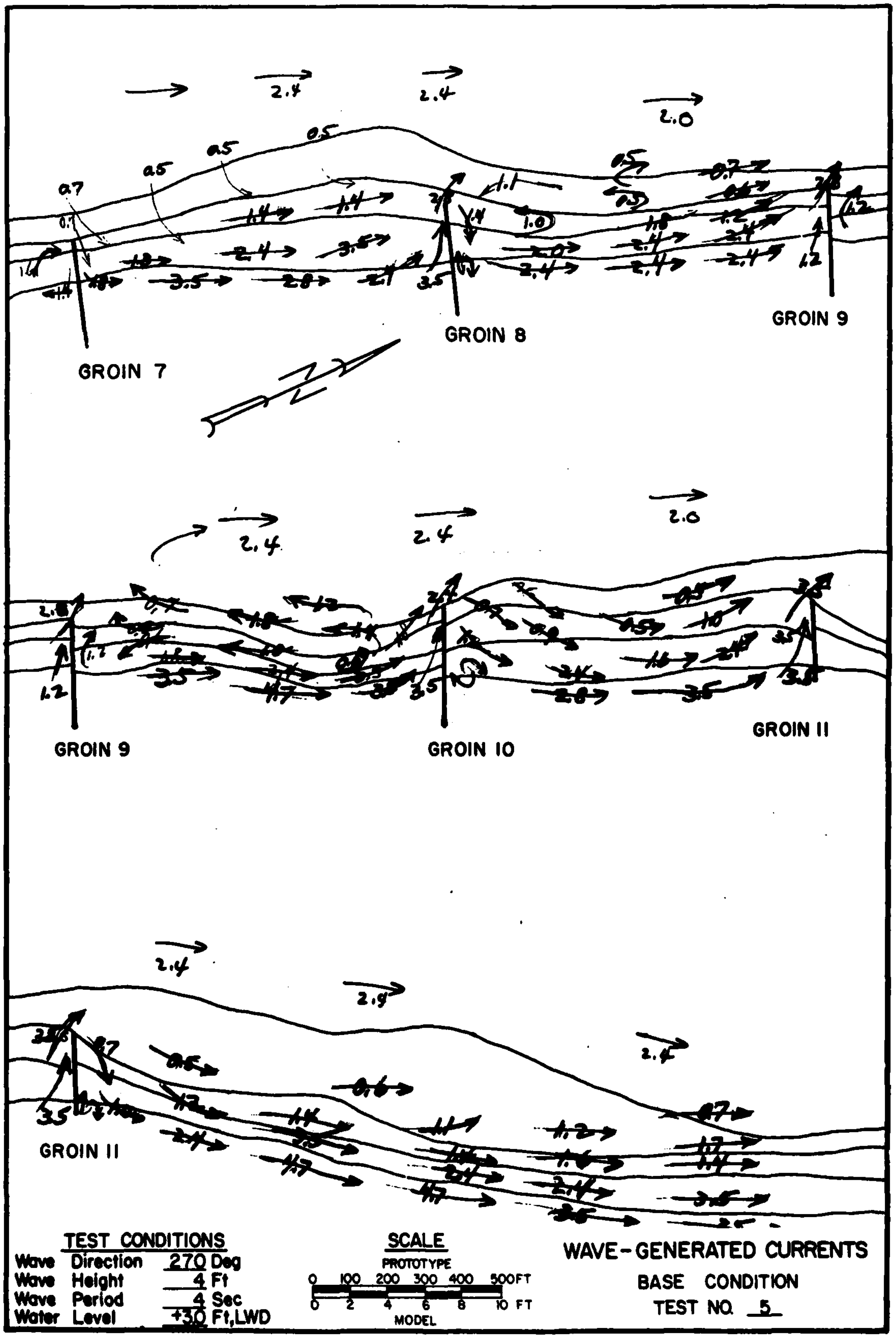
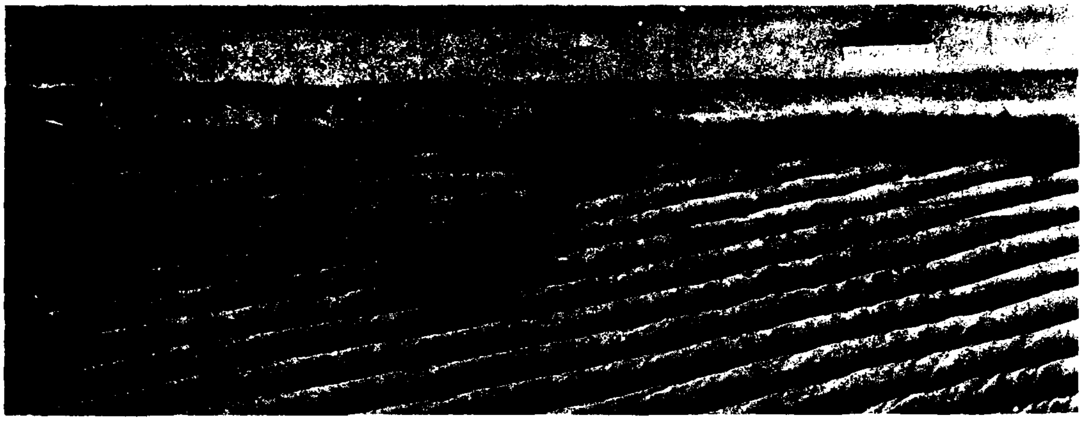

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 5

PLATE 70a



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 5

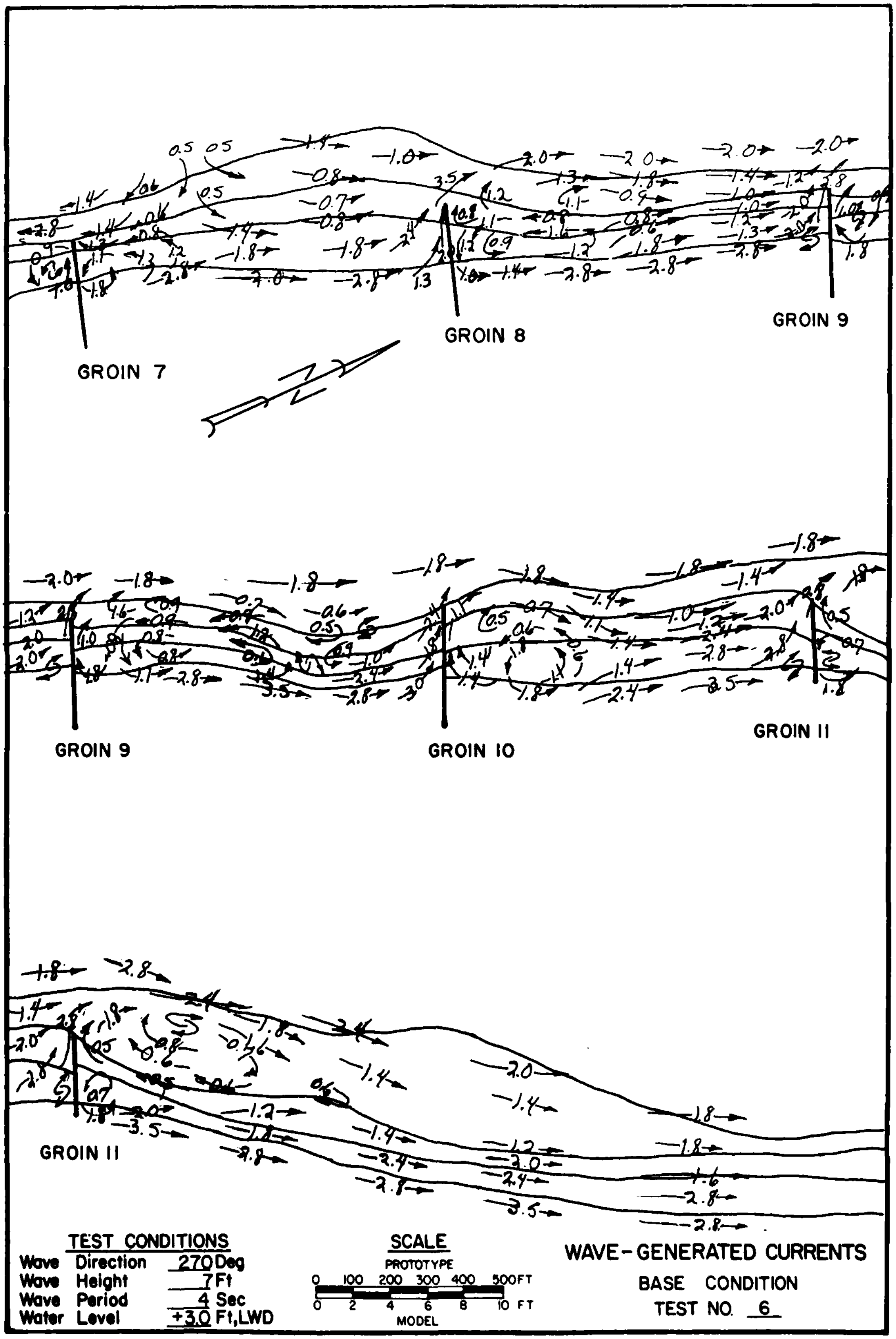
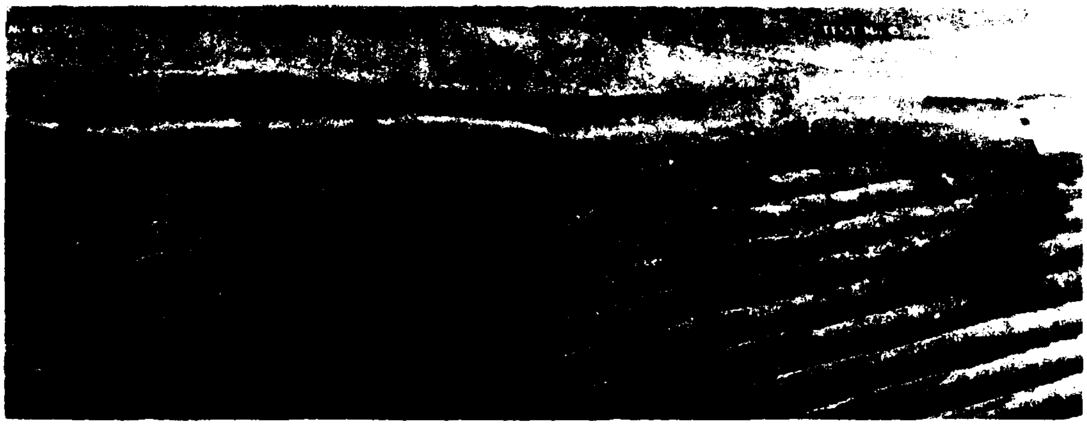
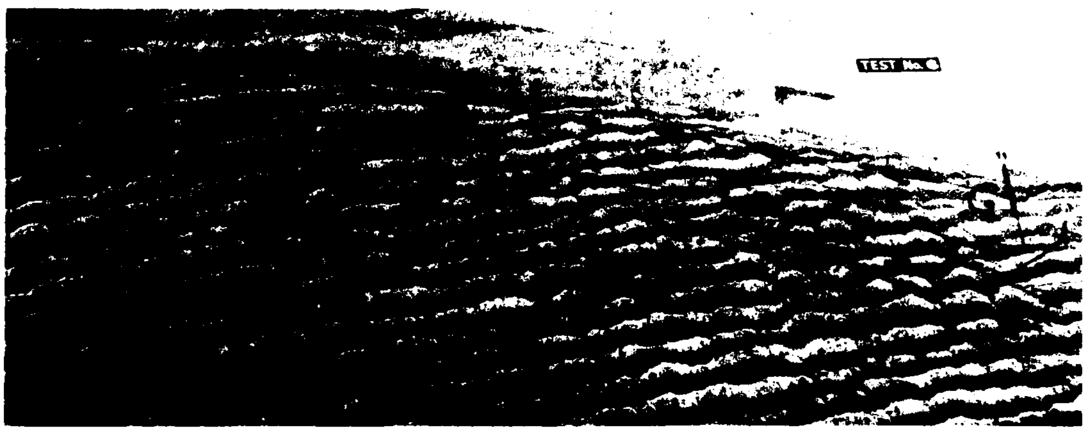

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 6

PLATE 71a

BEACH 4



BEACH 5



BEACH 6

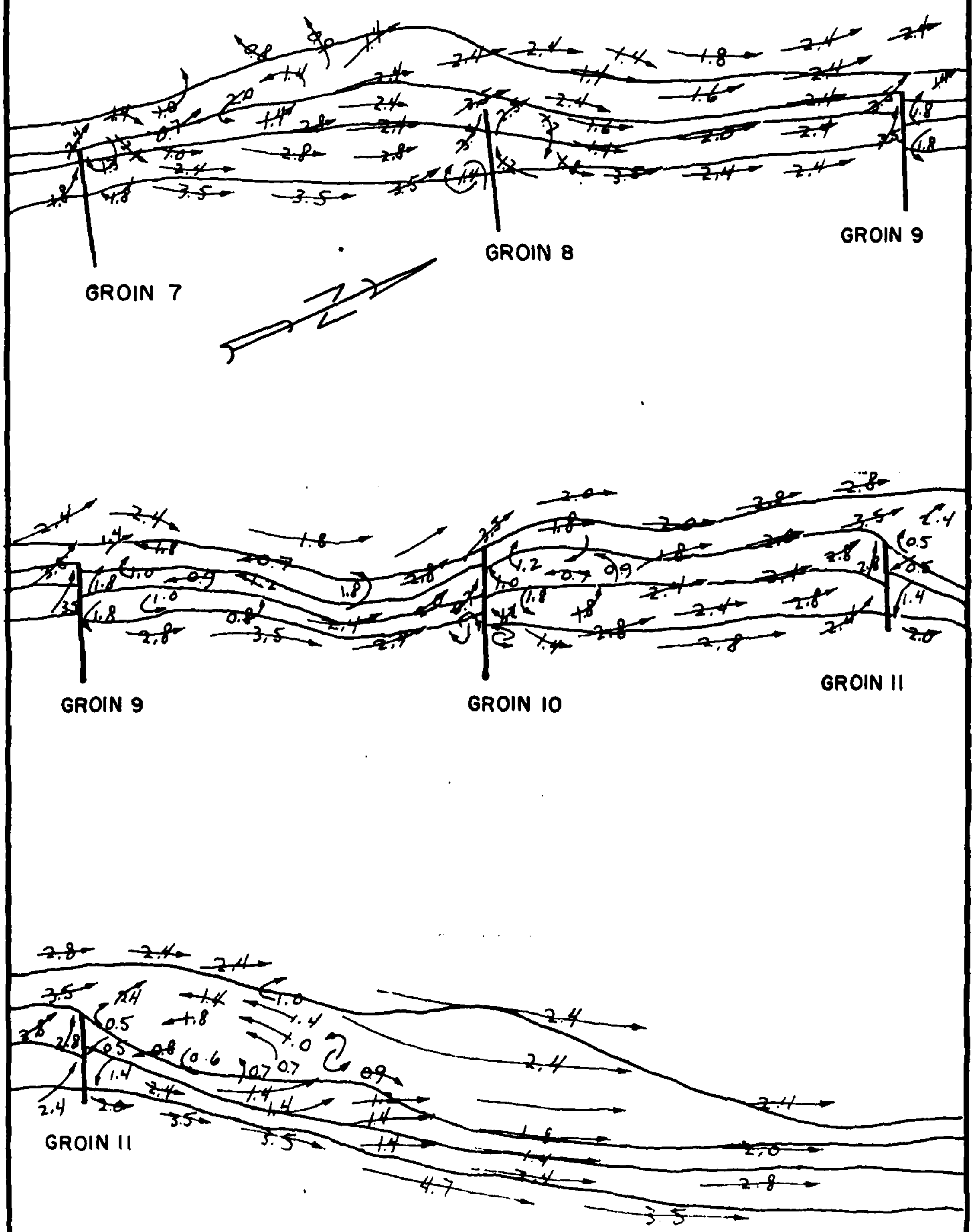
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 6



TEST CONDITIONS		
Wave	Direction	270 Deg
Wave	Height	6 Ft
Wave	Period	6 Sec
Water	Level	+3.0 Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 7

PLATE 72a

BEACH 4

BEACH 5

BEACH 6

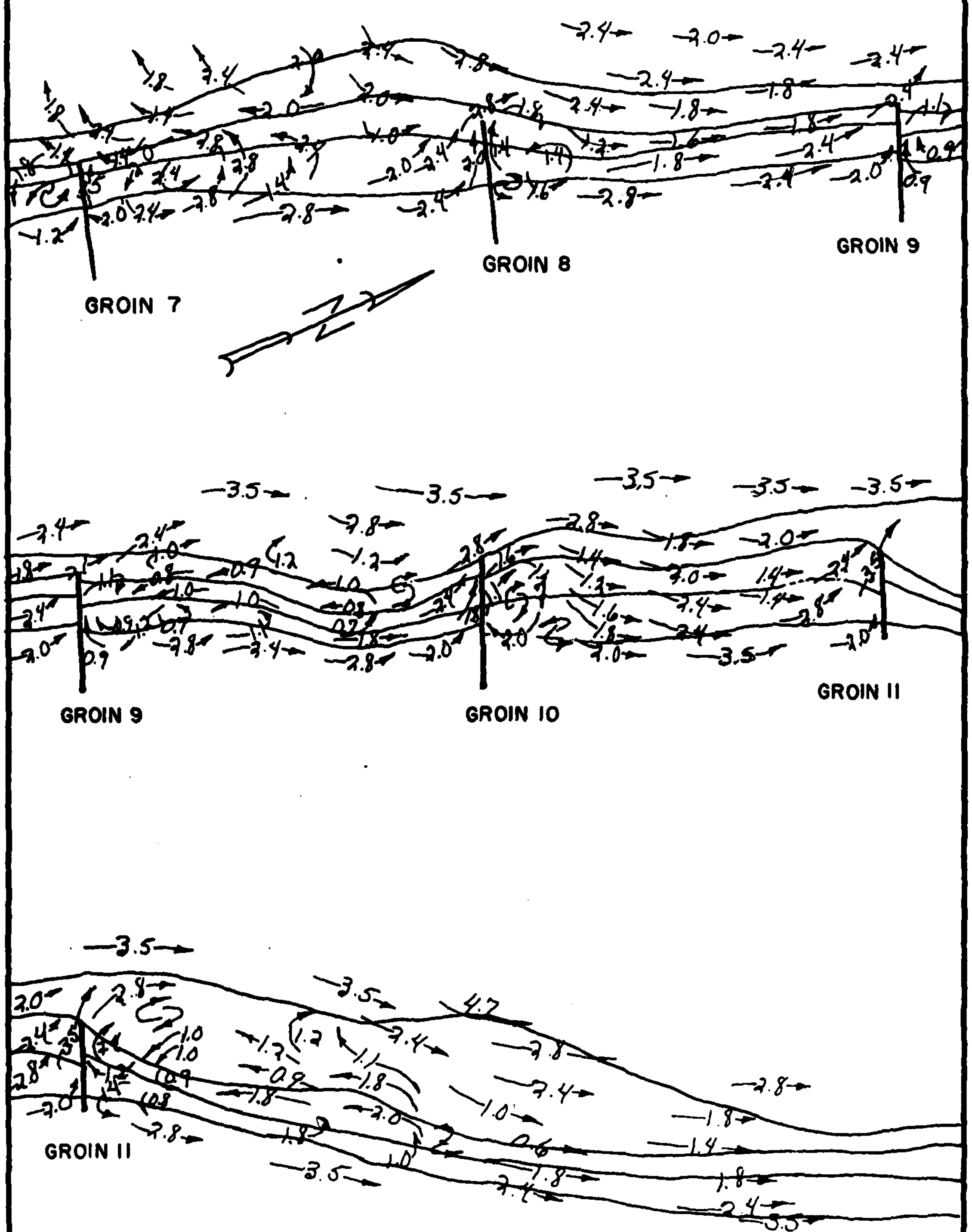
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 7



TEST CONDITIONS		
Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 8

PLATE 73a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 8

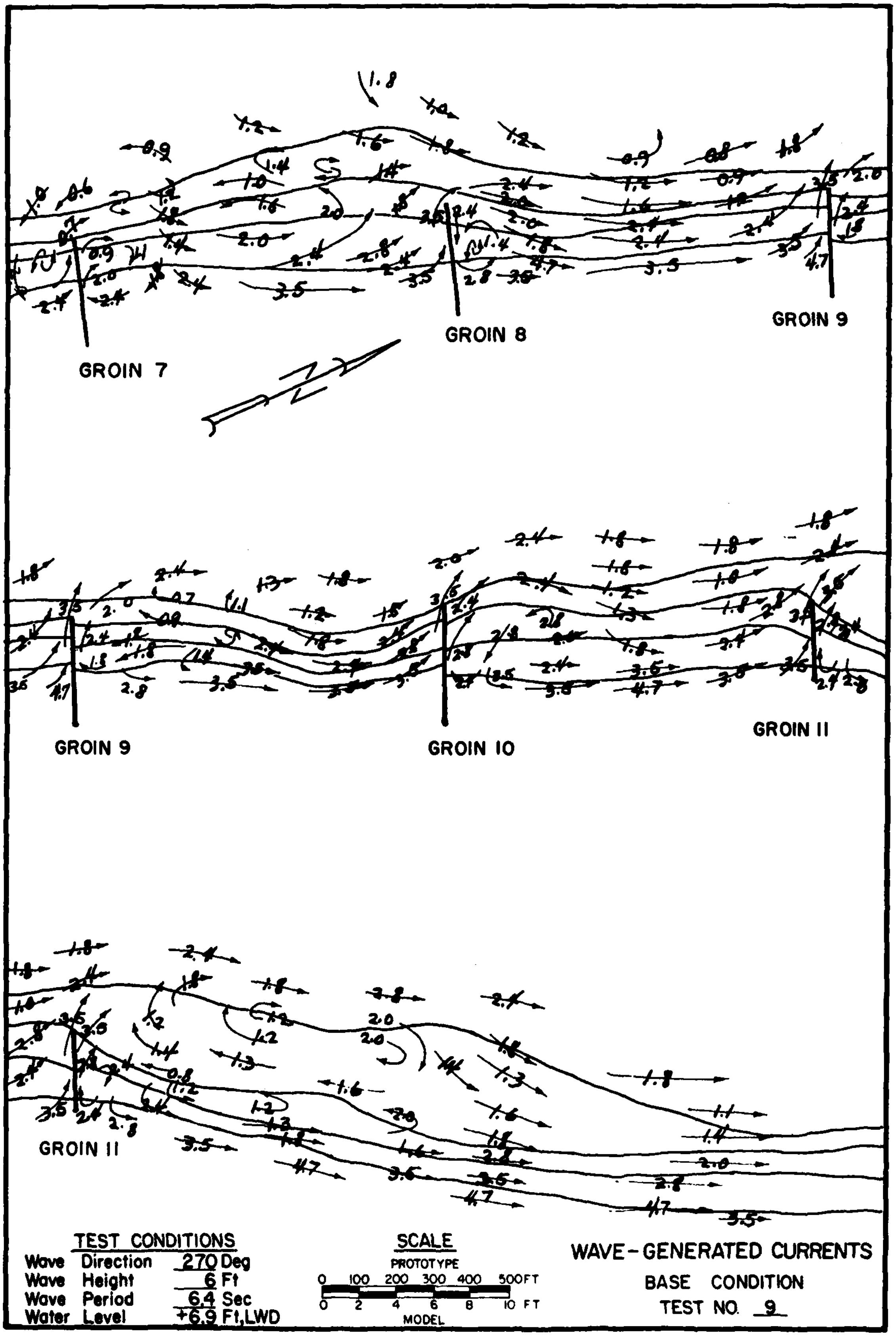
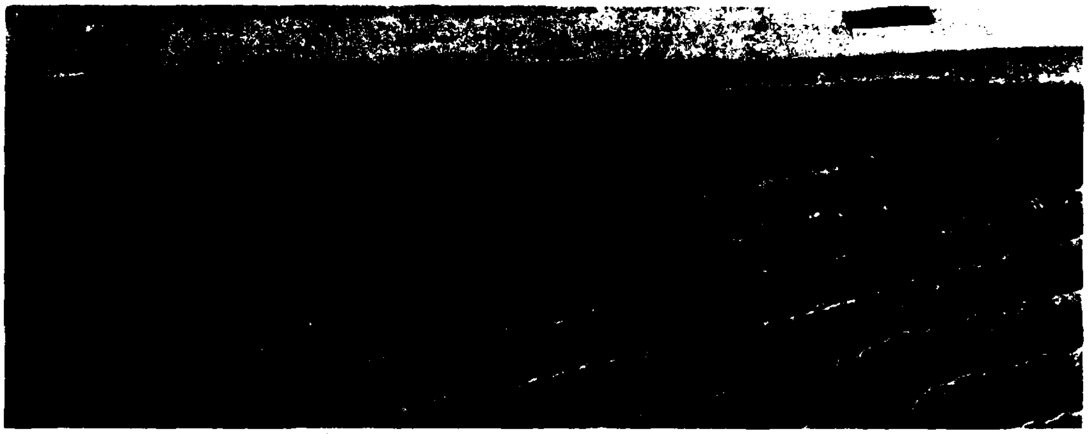

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 6 Ft
Wave Period 6.4 Sec
Water Level +6.9 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 9

PLATE 74a



BEACH 4

BEACH 5

BEACH 6

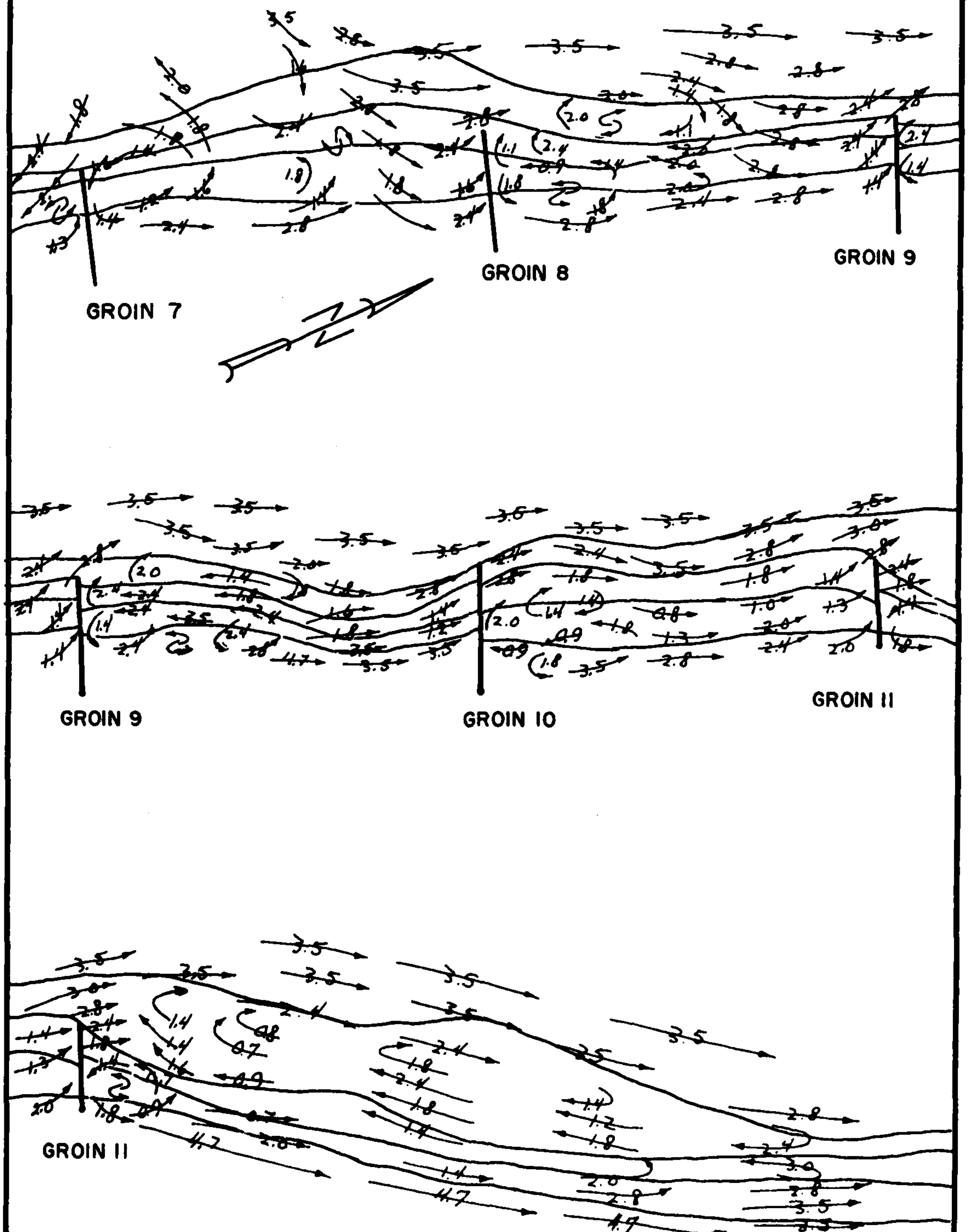
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	6	Ft
Wave Period	6.4	Sec
Water Level	+6.9	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 9



TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

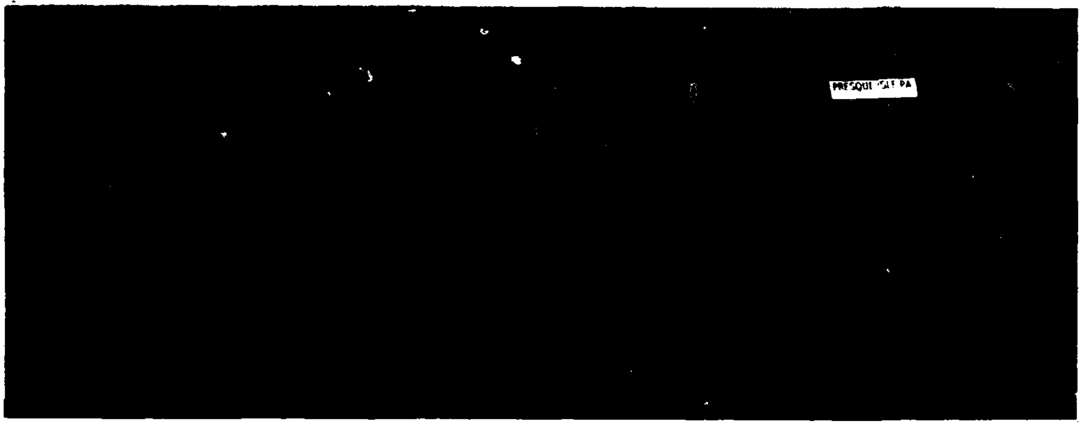
MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 10

PLATE 75a



BEACH 4

BEACH 5

BEACH 6

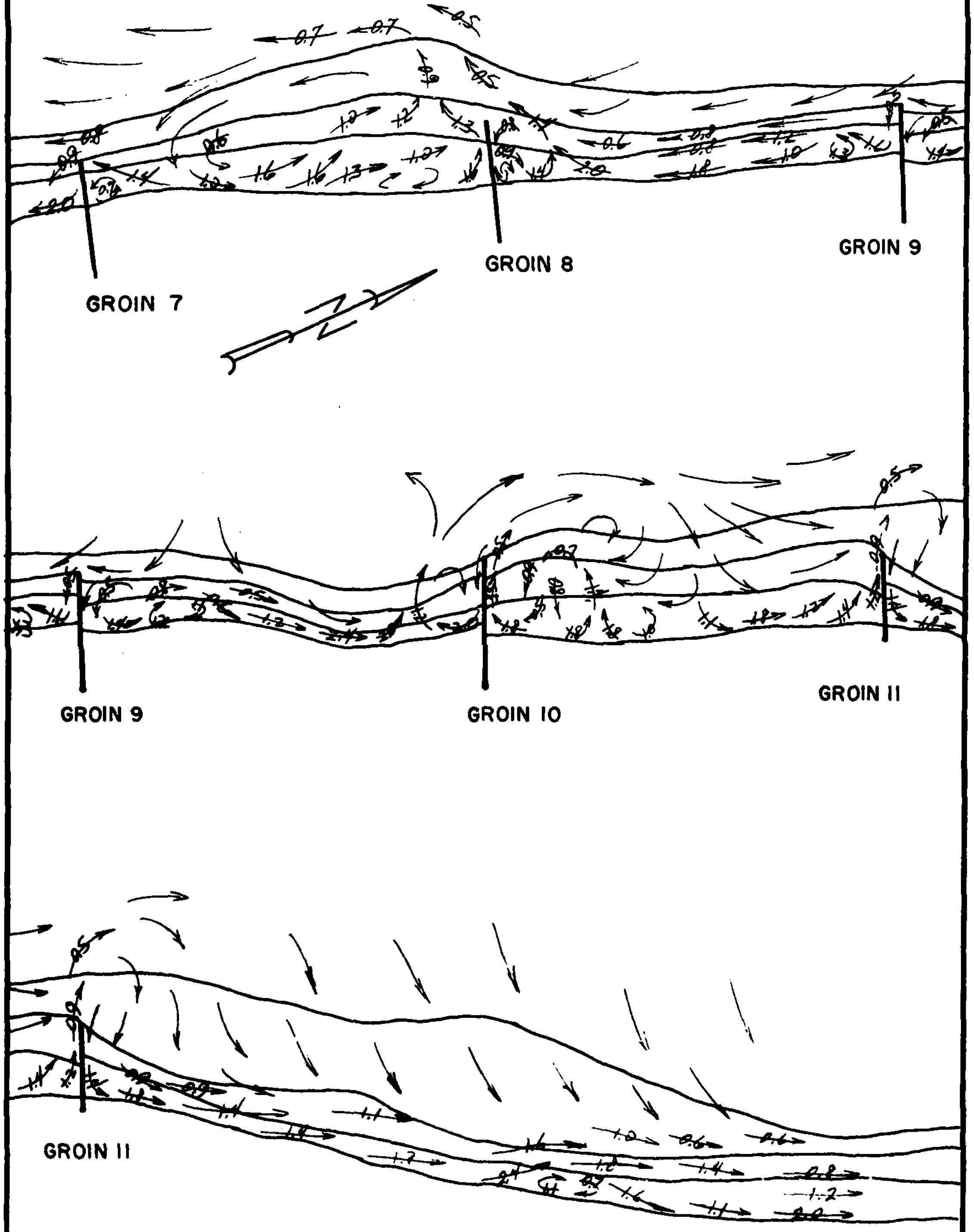
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 10



TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	2 Ft
Wave	Period	4 Sec
Water	Level	0.0 Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

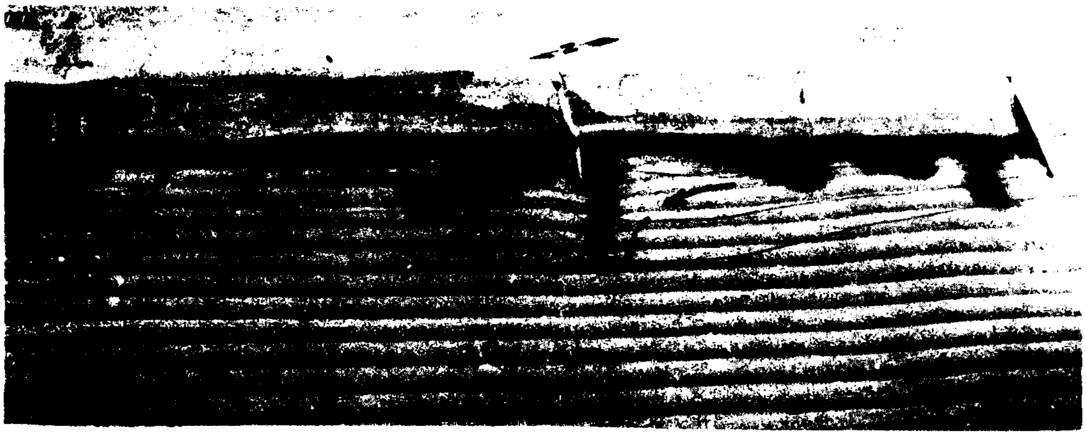
MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 11

PLATE 76a



BEACH 4

BEACH 5

BEACH 6

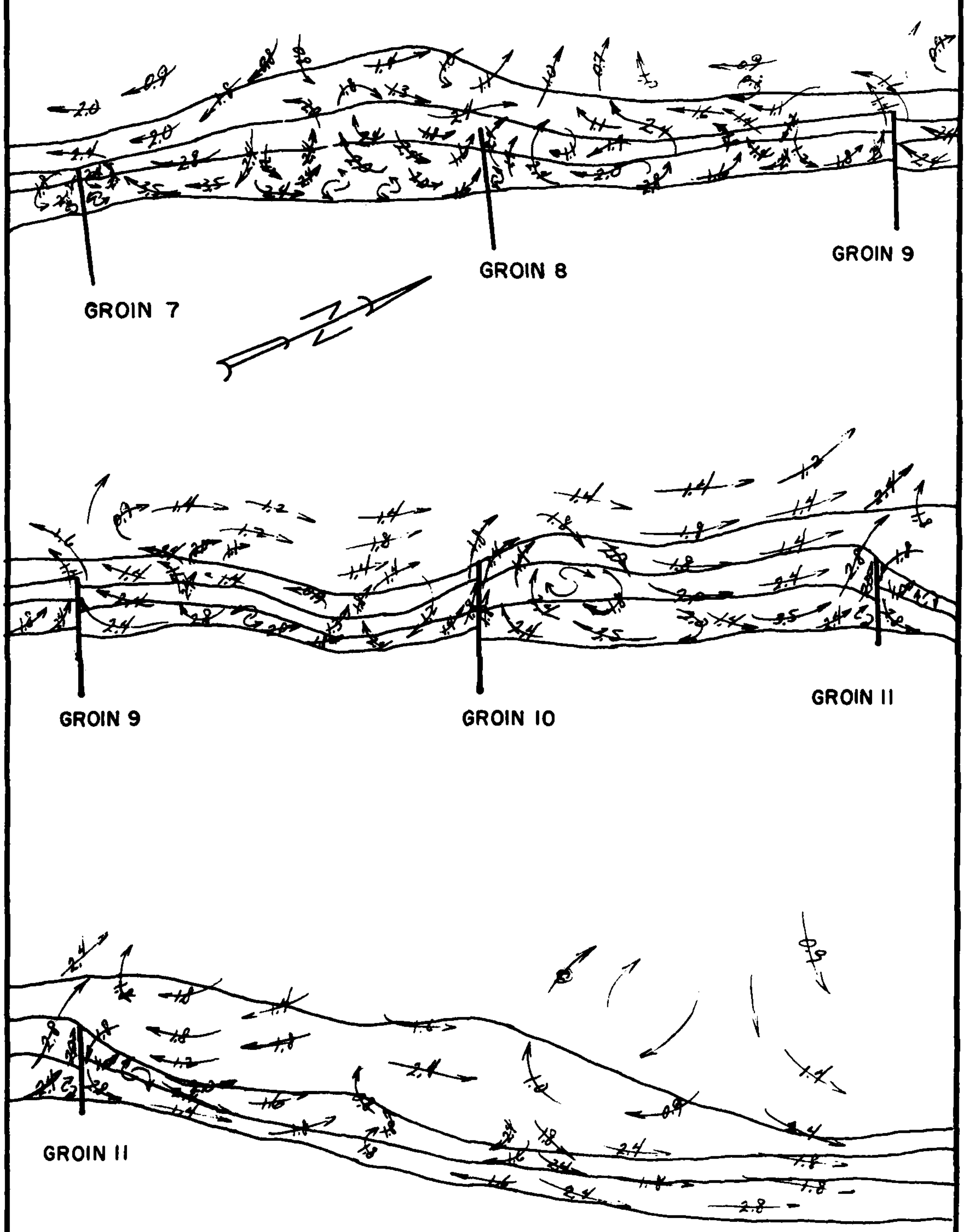
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	0.0	Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 11



TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

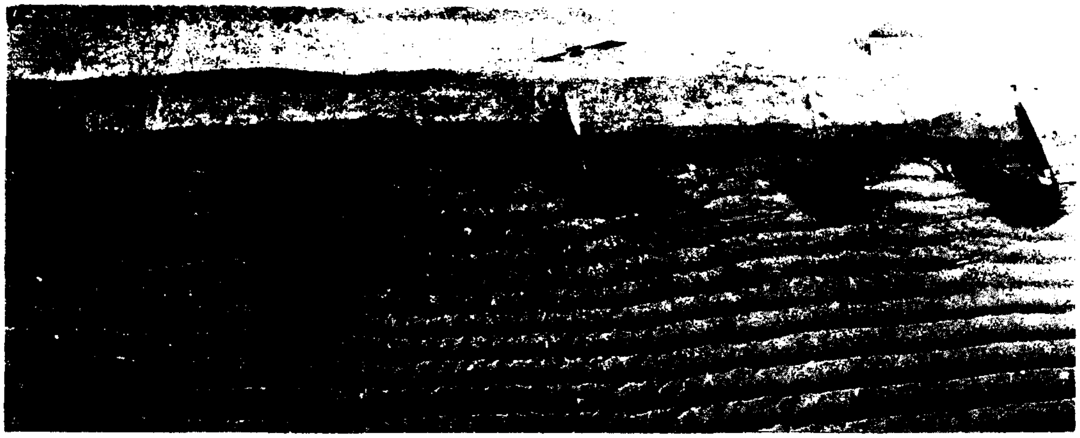
MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 12

PLATE 77a



BEACH 4

BEACH 5

BEACH 6

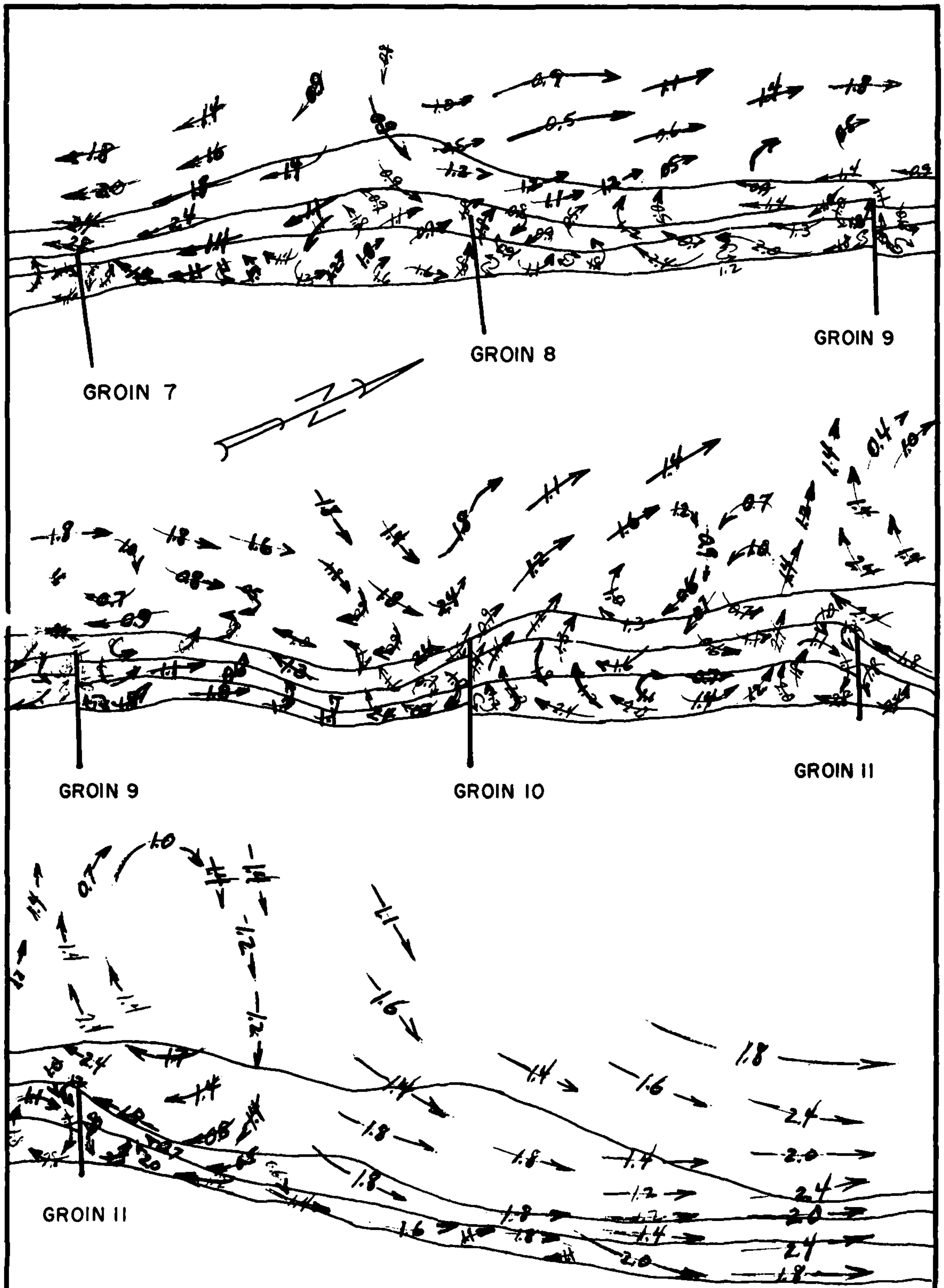
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 12



TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	7 Ft
Wave	Period	4 Sec
Water	Level	+0.0 Ft, LWD

SCALE

PROTOTYPE: 0 100 200 300 400 500 FT

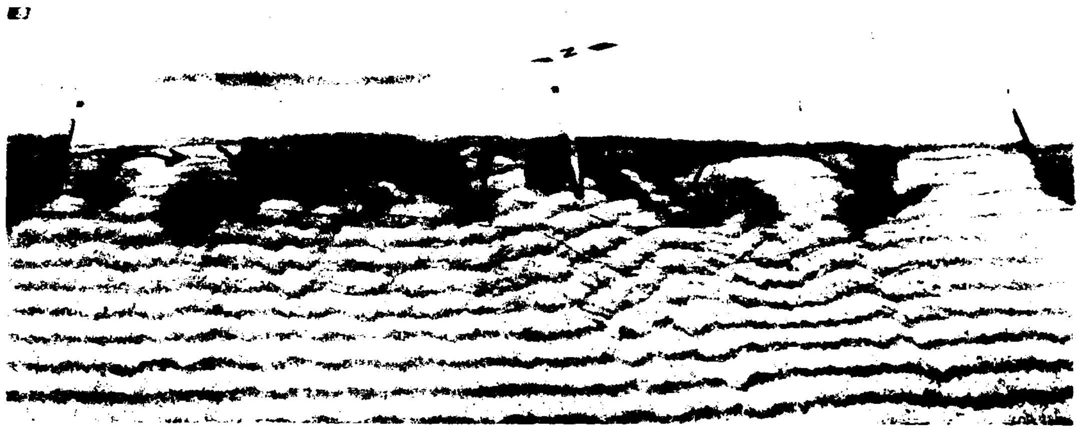
MODEL: 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

BASE CONDITION

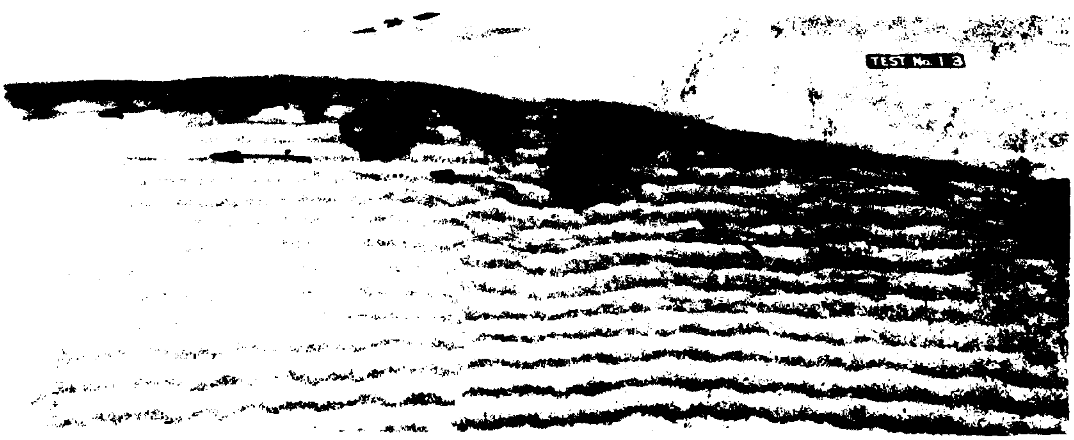
TEST NO. 13

PLATE 78a



BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 13

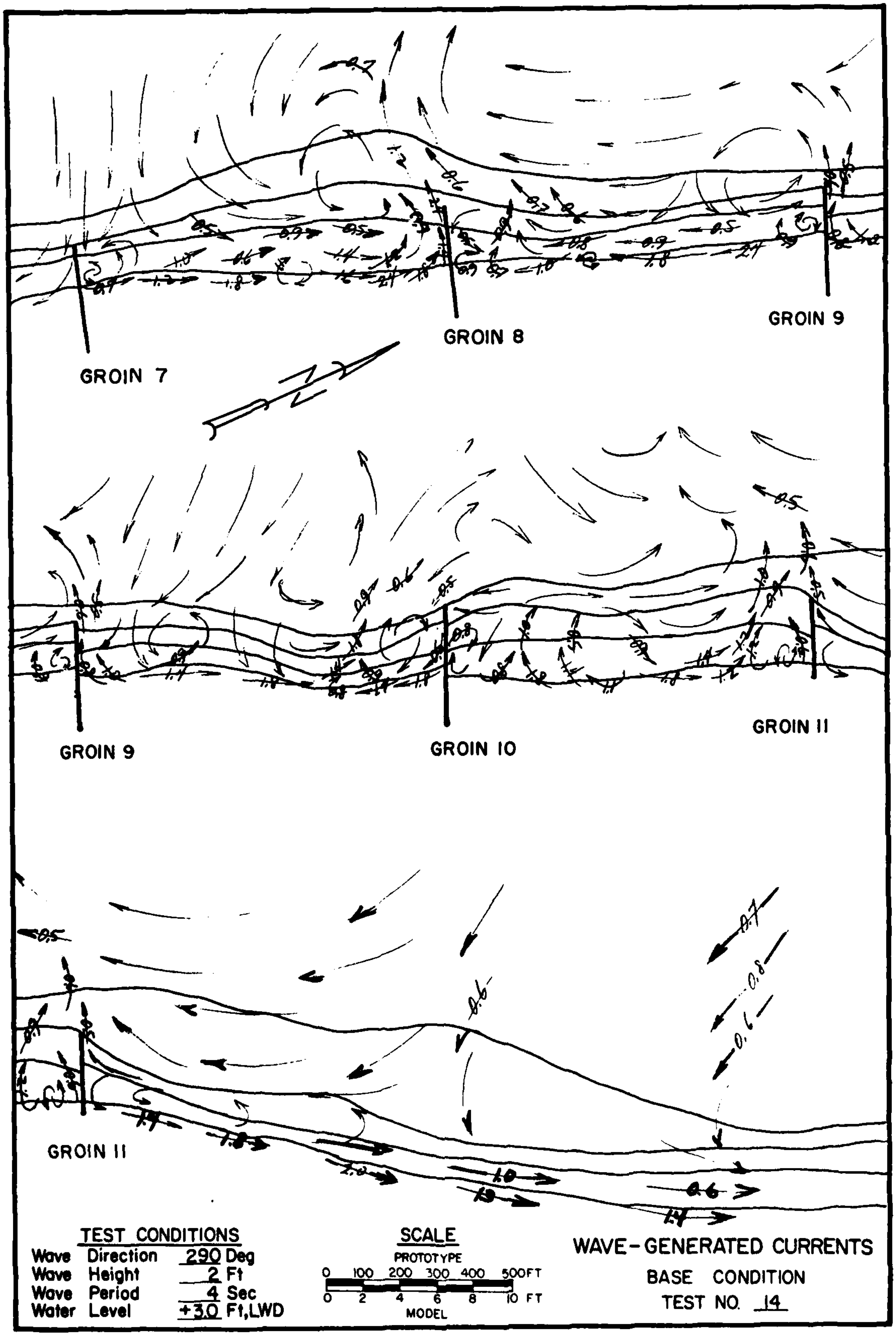
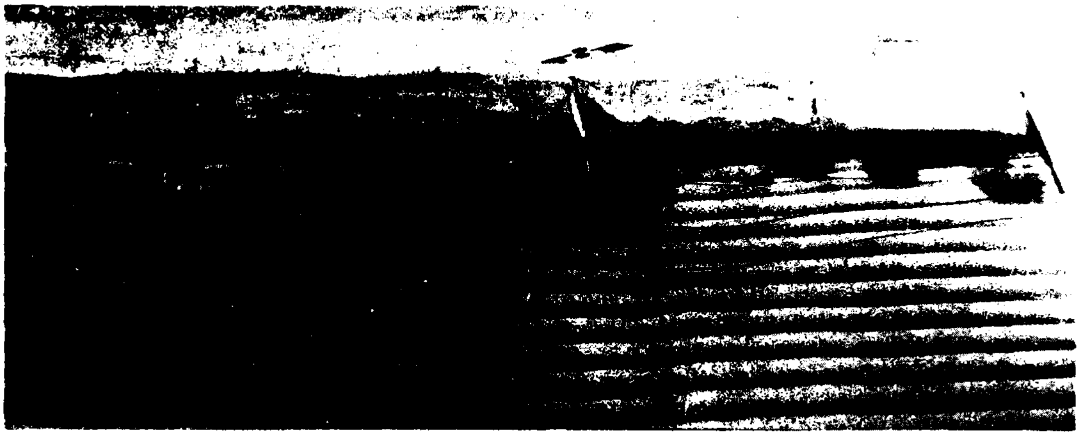
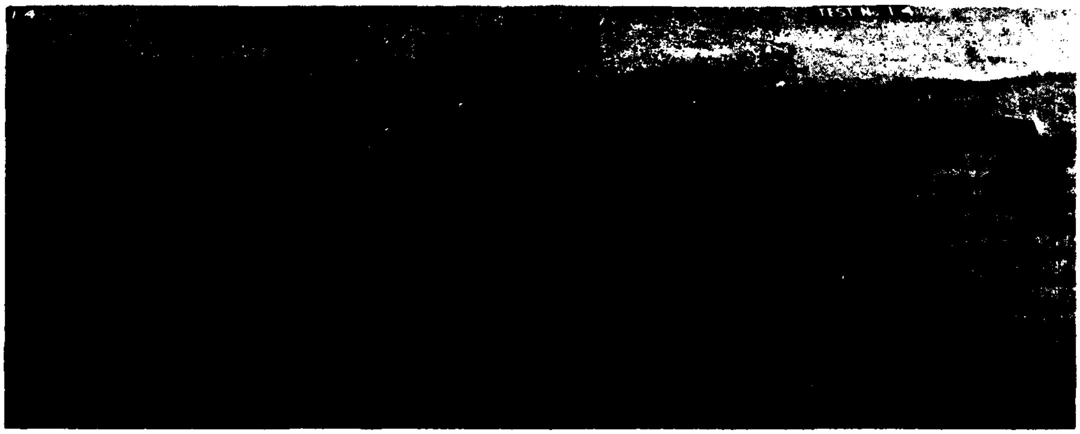

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 2 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 14

PLATE 79a



BEACH 4



BEACH 5

BEACH 6

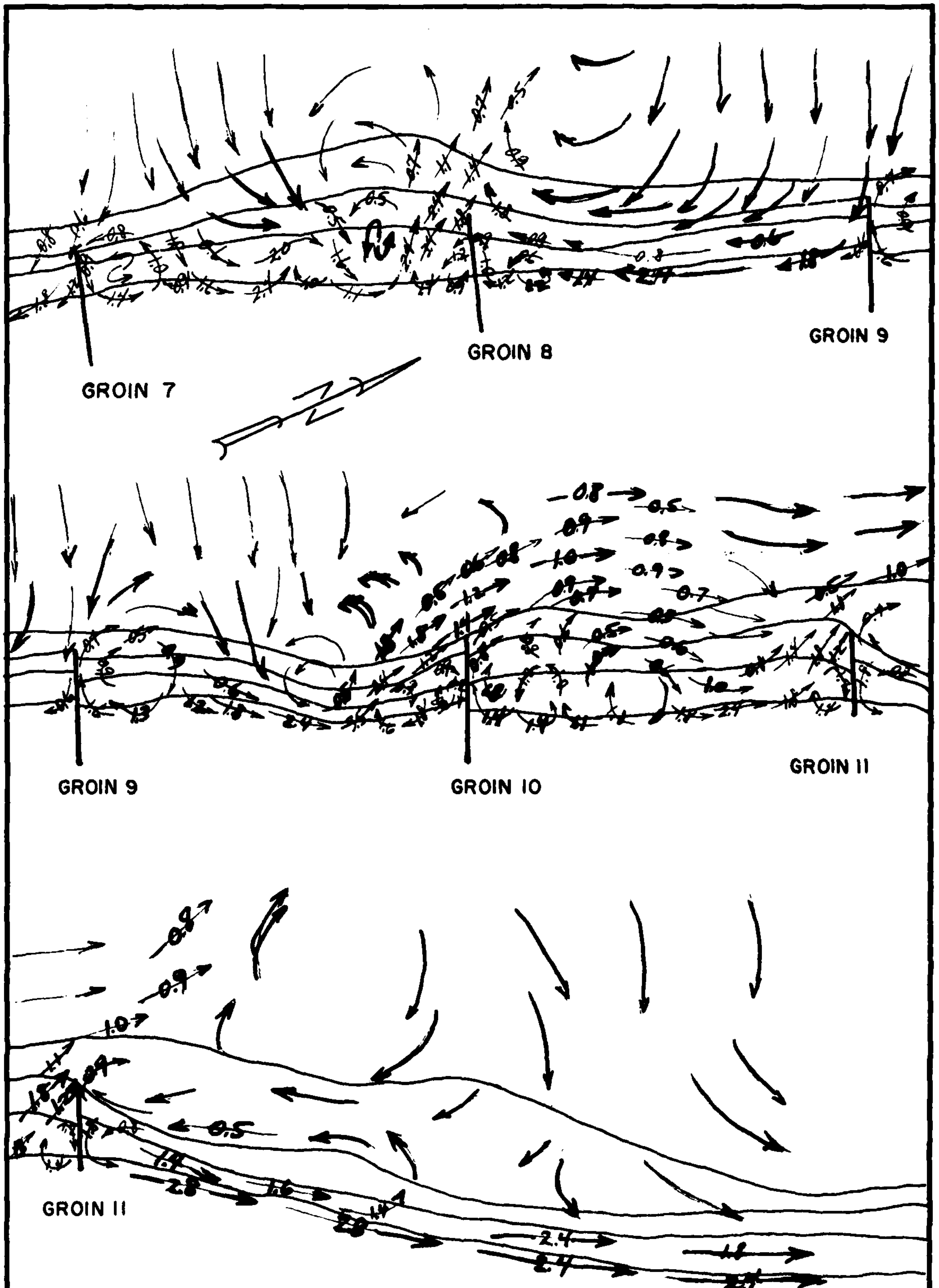
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	3.0	Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 14



TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	4 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

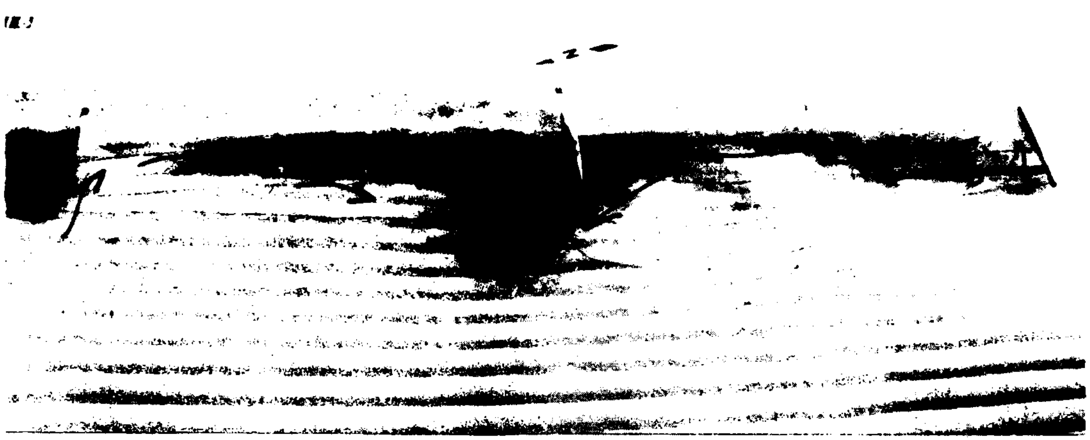
MODEL

WAVE-GENERATED CURRENTS

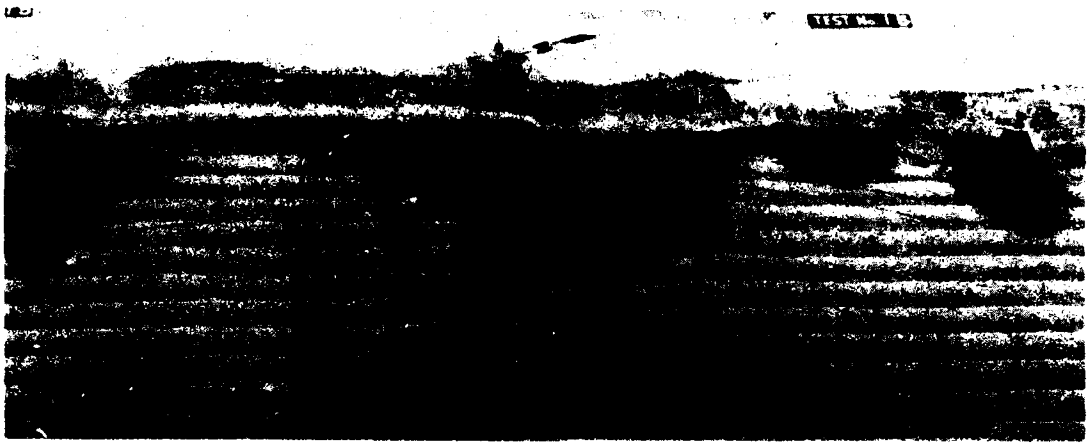
BASE CONDITION

TEST NO. 15

PLATE 80a



BEACH 4



BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 15

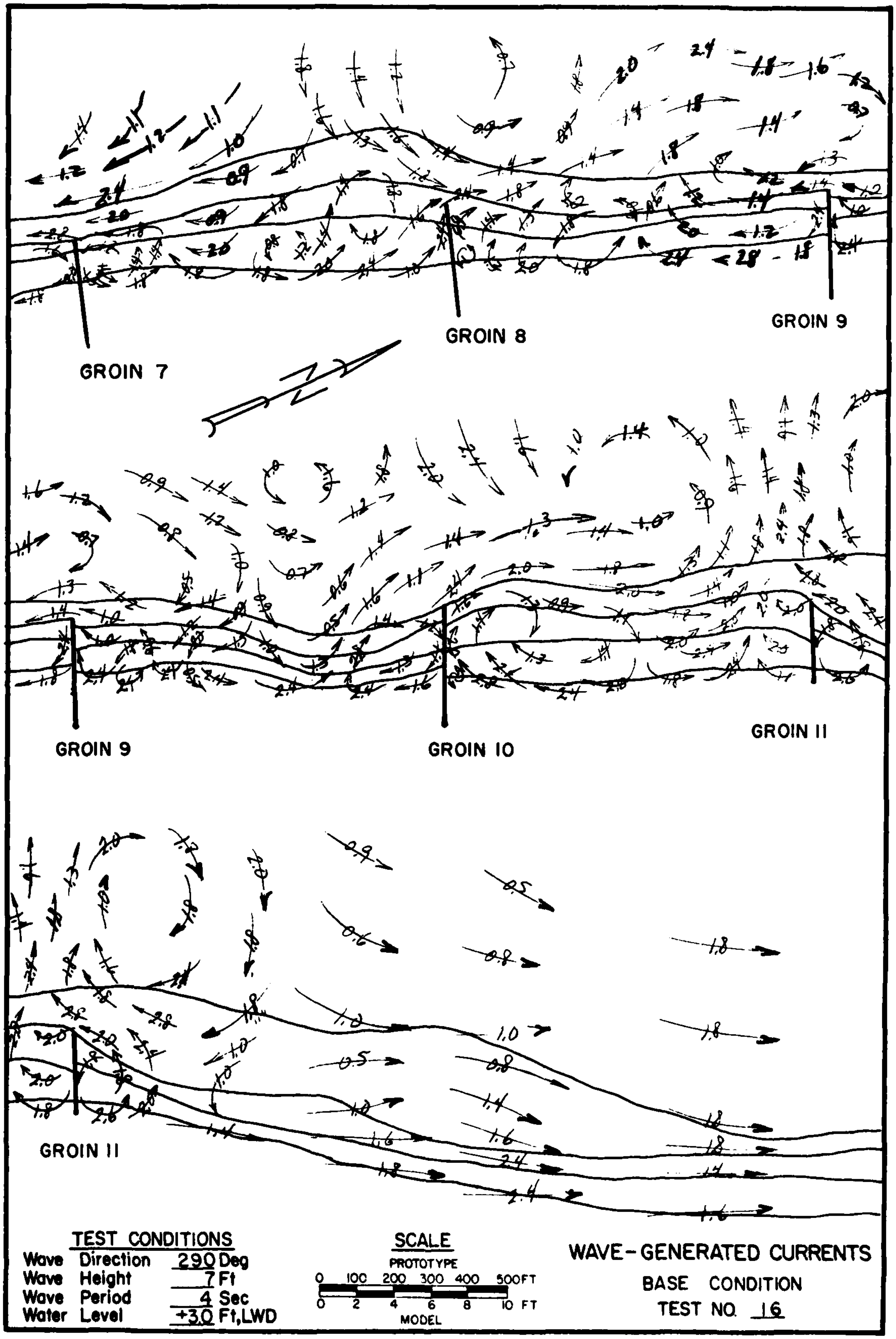
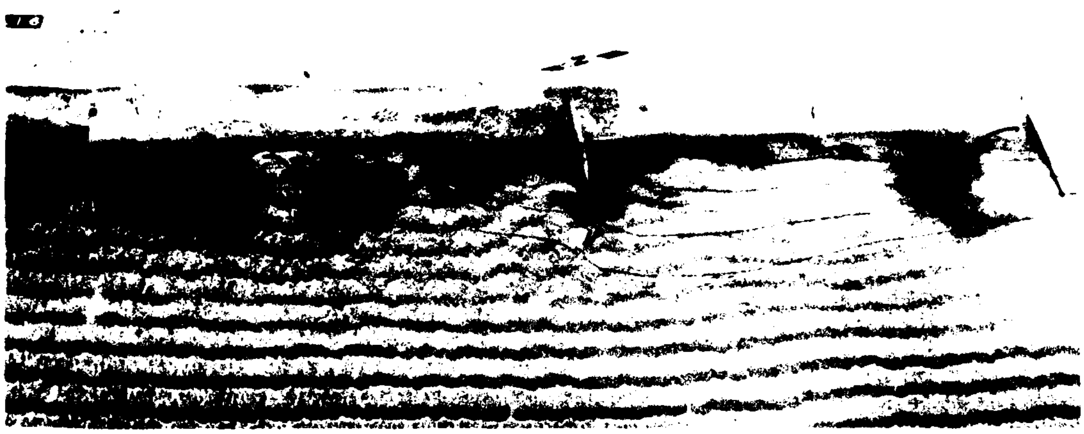

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 16

PLATE 81a



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 16

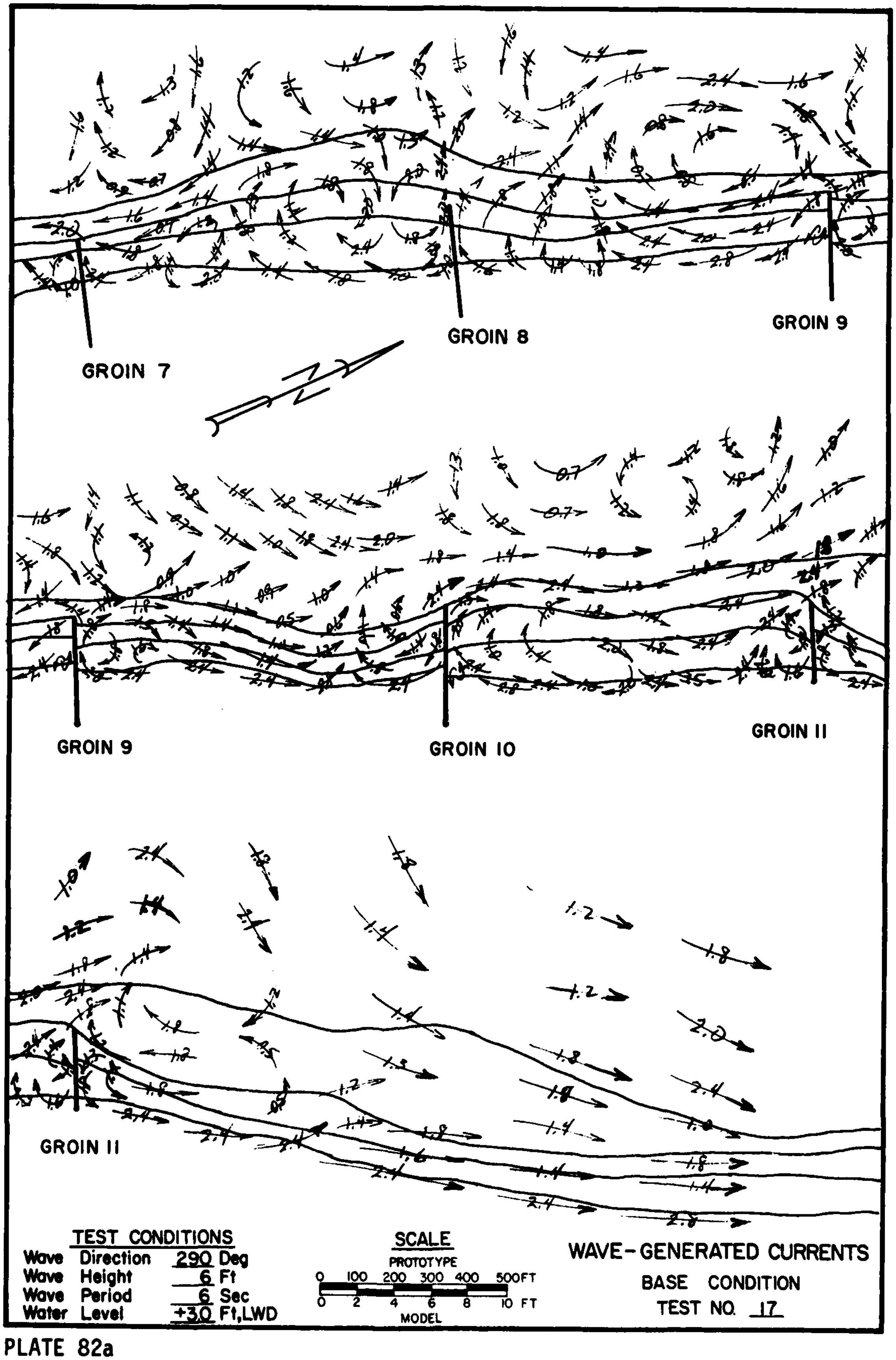
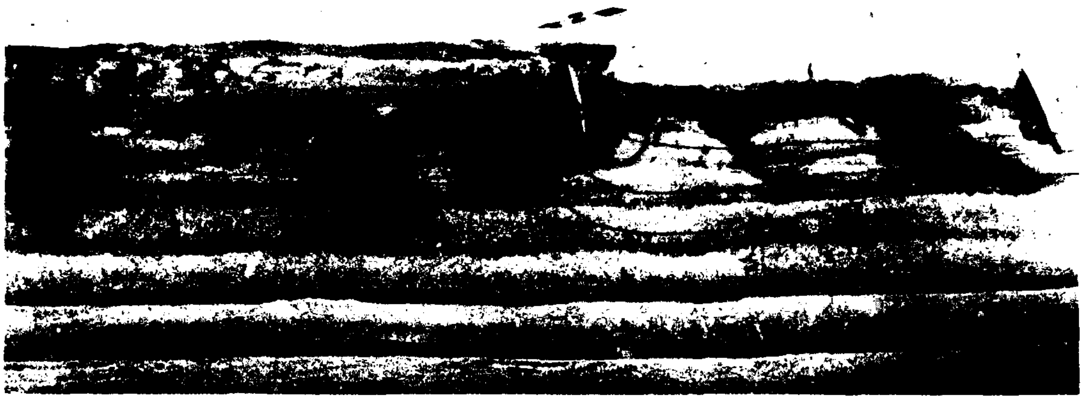

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 6 Ft
Wave Period 6 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 17

PLATE 82a



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 17

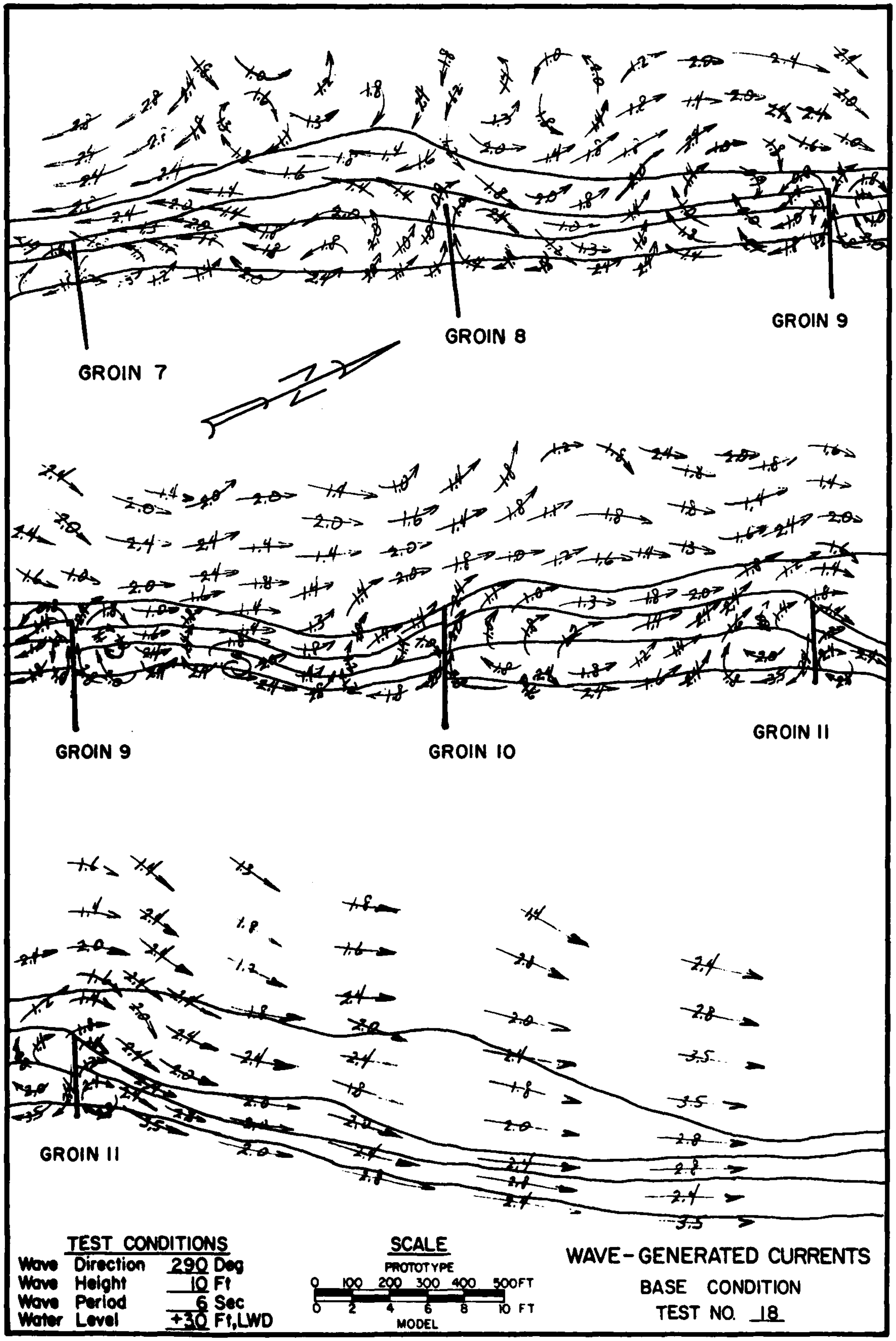

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 10 Ft
Wave Period 6 Sec
Water Level +30 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 18

PLATE 83a

BEACH 4

BEACH 5

BEACH 6

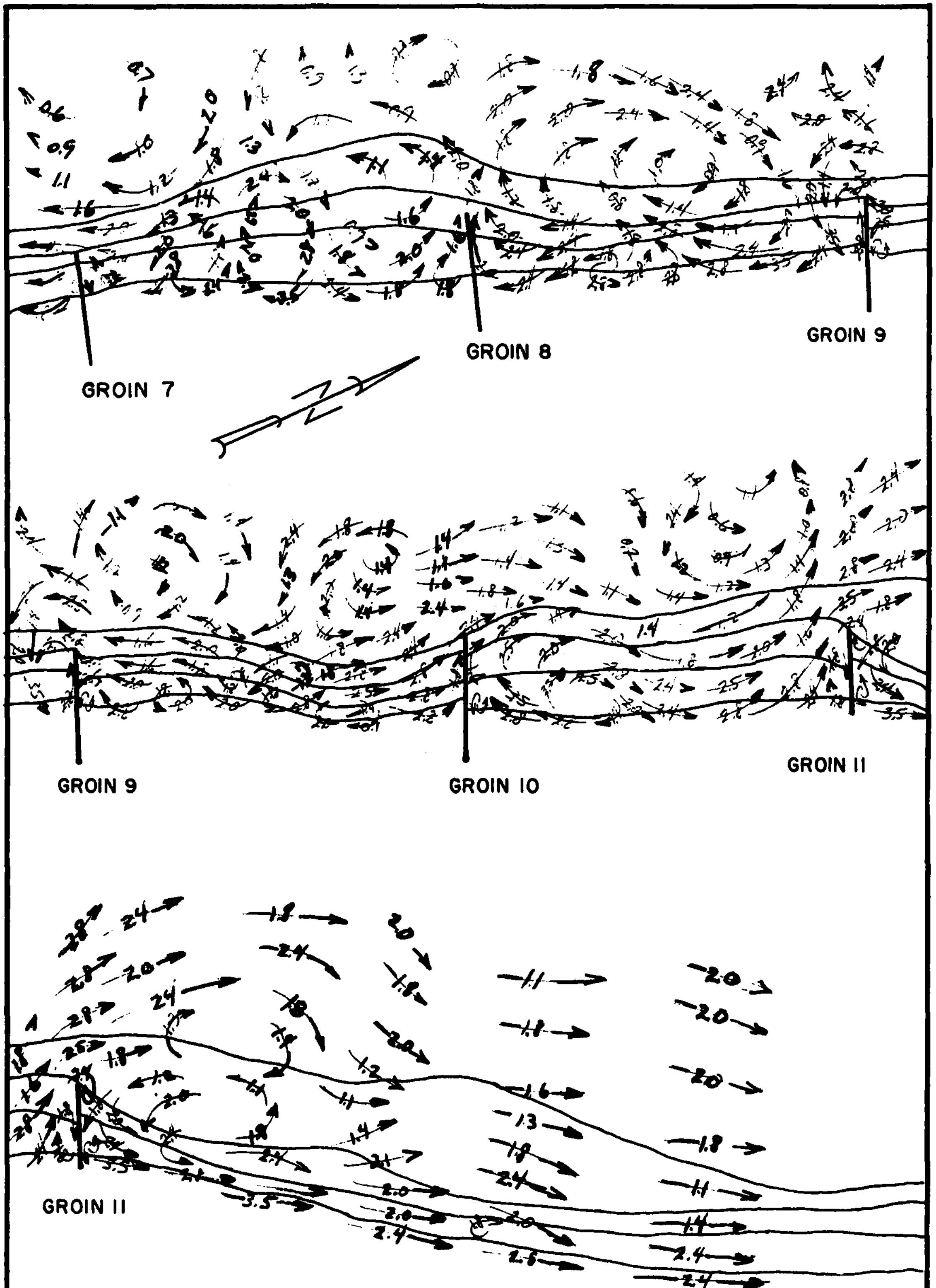
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 18



TEST CONDITIONS

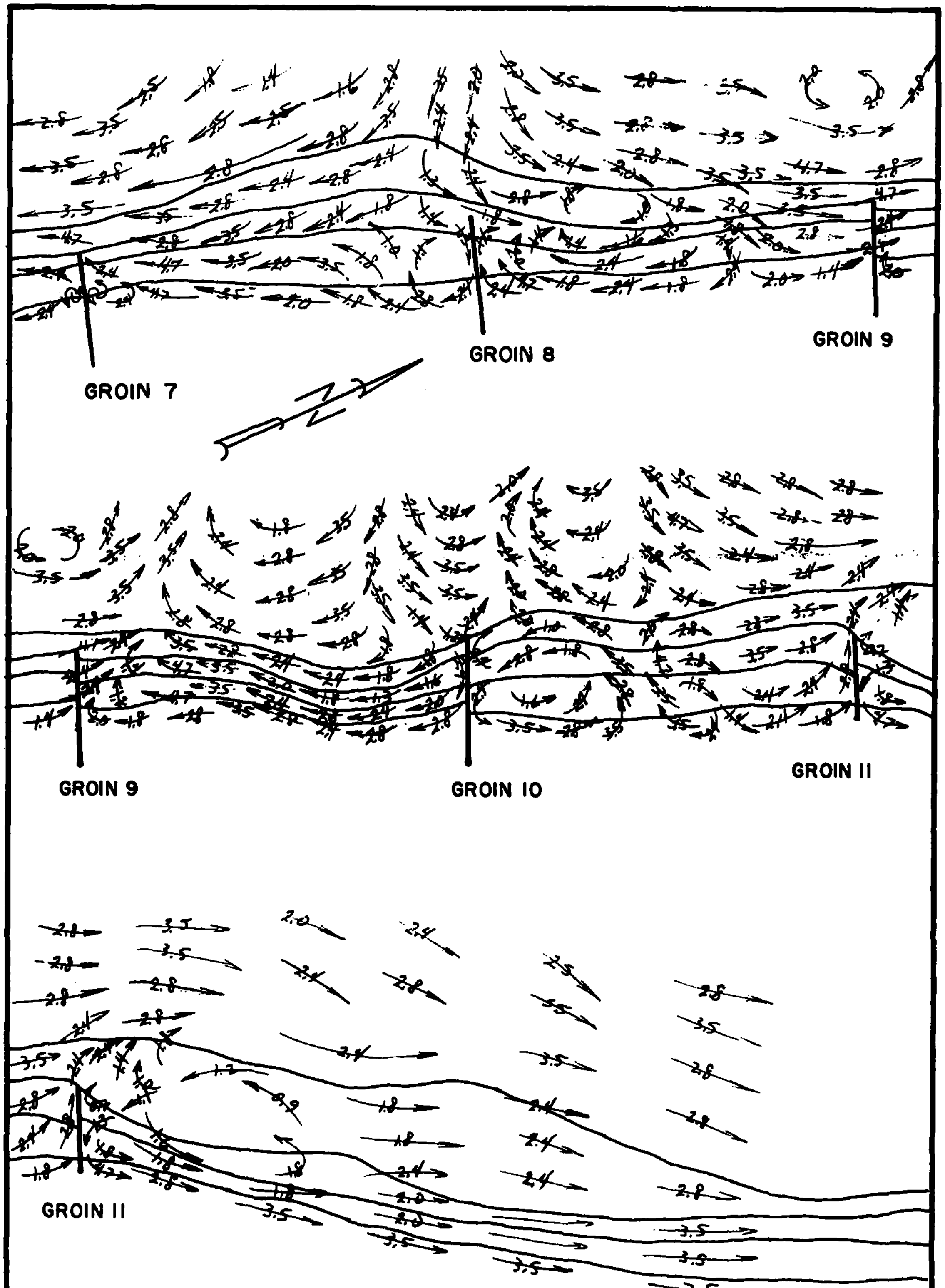
Wave	Direction	290 Deg
Wave	Height	6 Ft
Wave	Period	6.4 Sec
Water	Level	+6.9 Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 19

PLATE 84



TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	12 Ft
Wave	Period	9 Sec
Water	Level	+6.9 Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 20

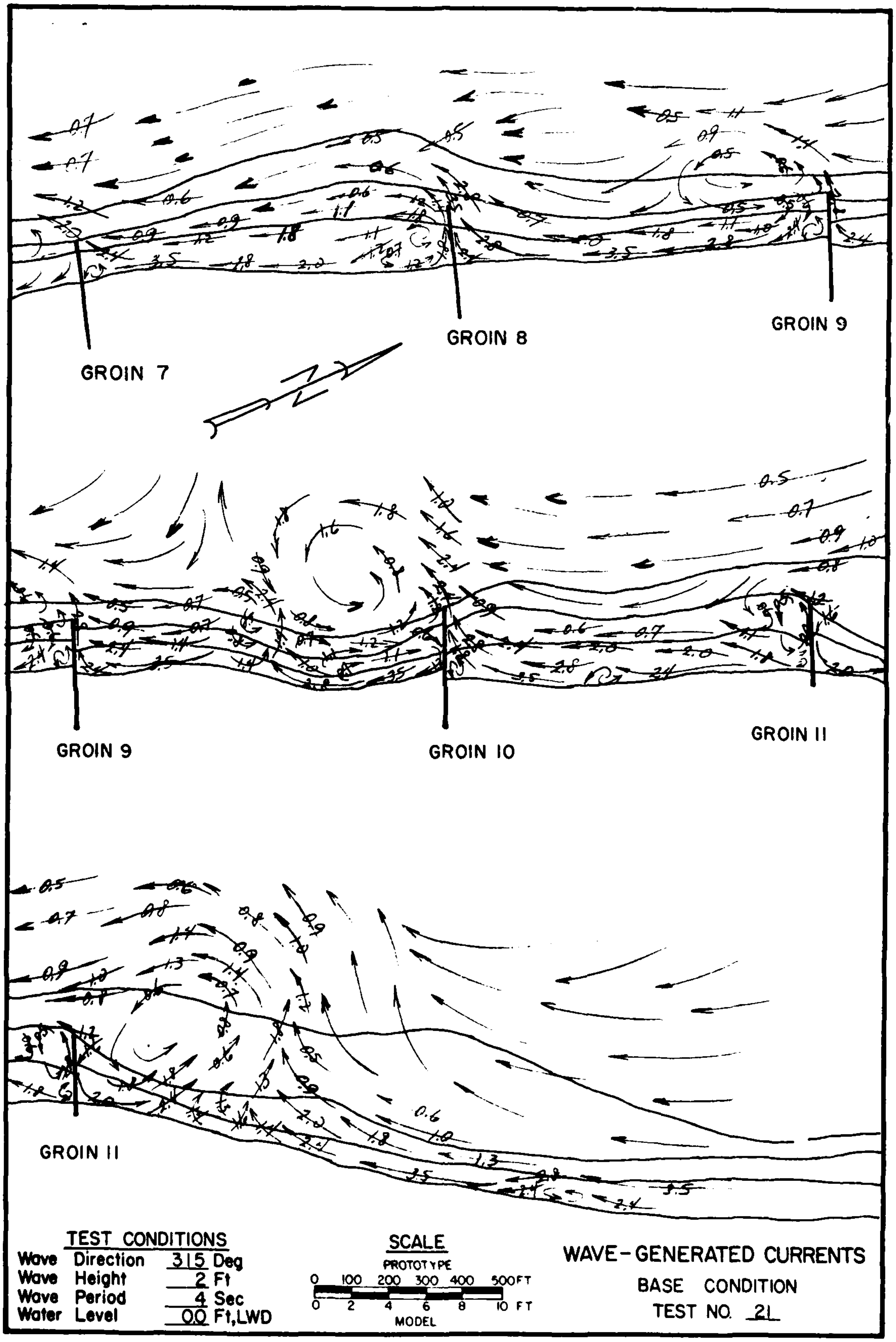
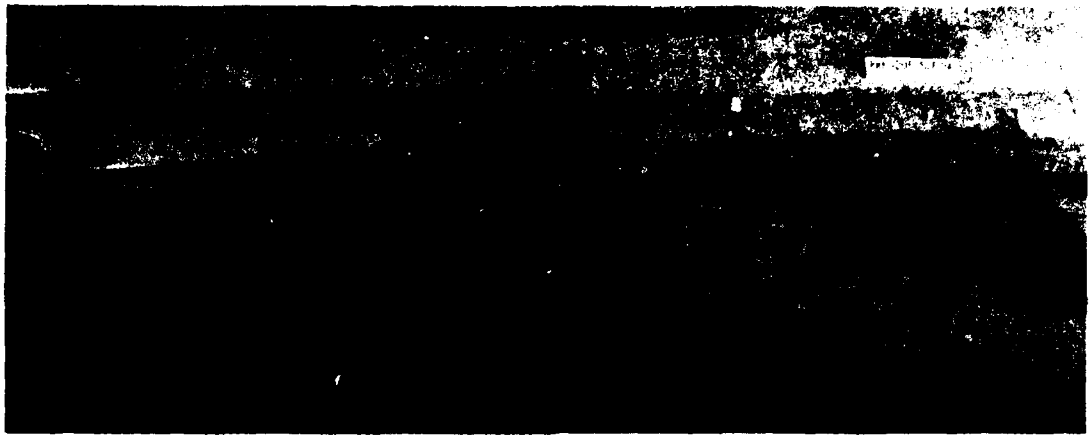
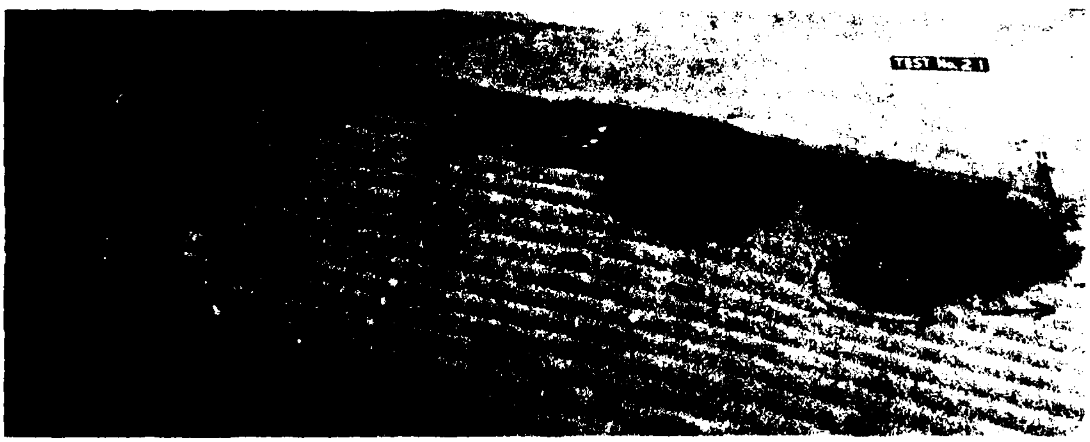

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 315 Deg
Wave Height 2 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 21

PLATE 86a



BEACH 4

BEACH 5



BEACH 6

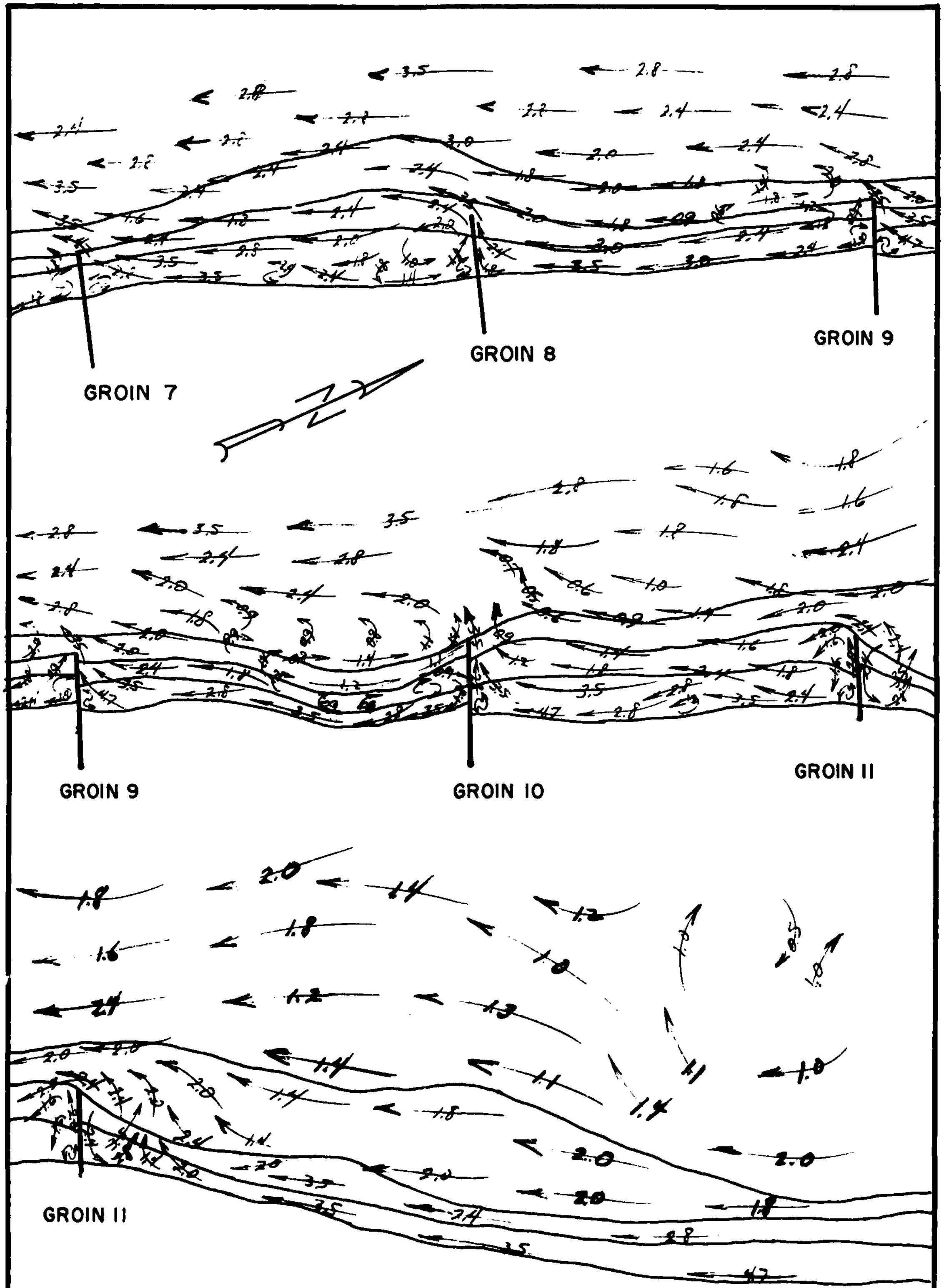
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 21



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 22

PLATE 87a

BEACH 4

BEACH 5

BEACH 6

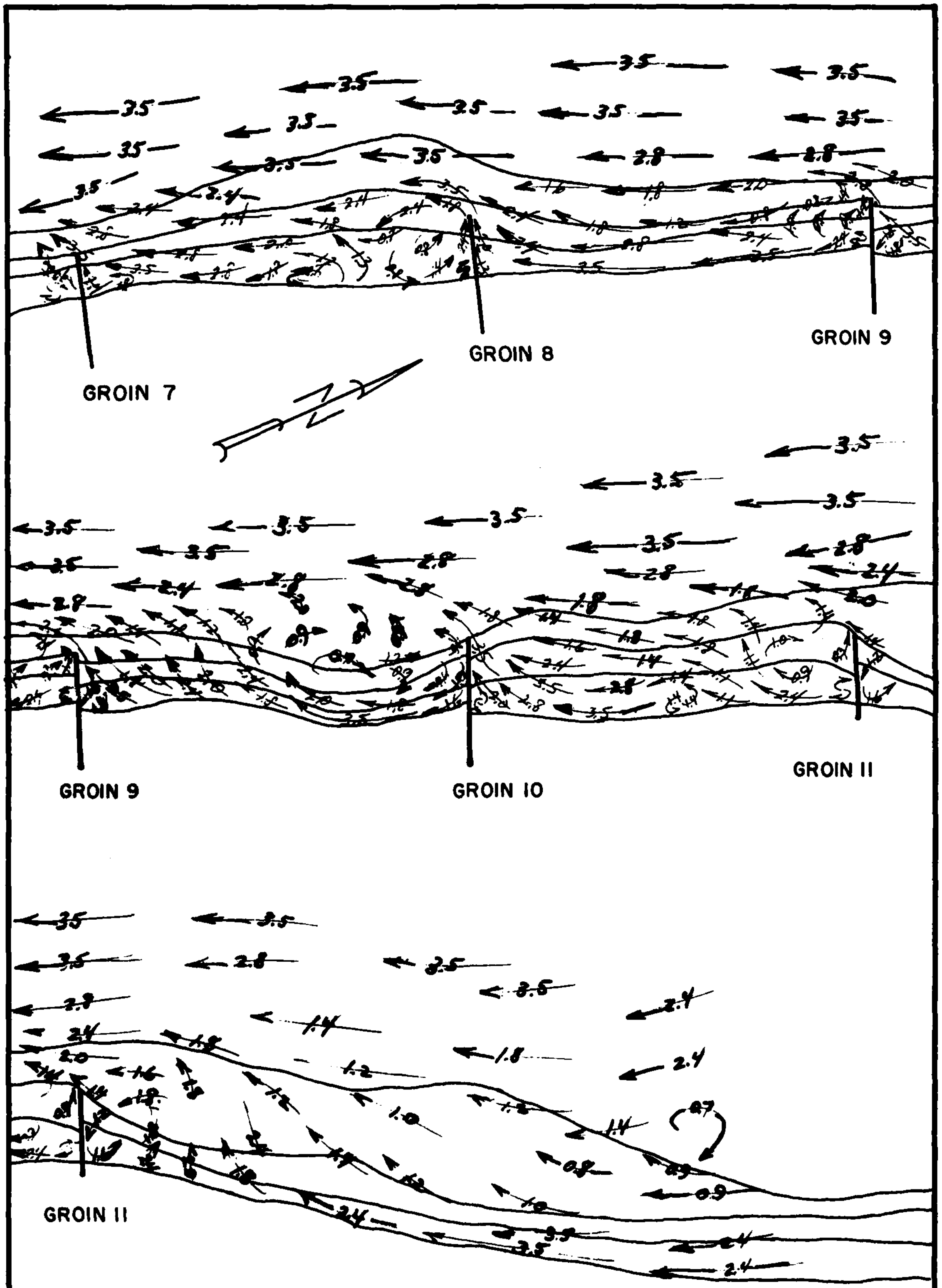
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 22



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

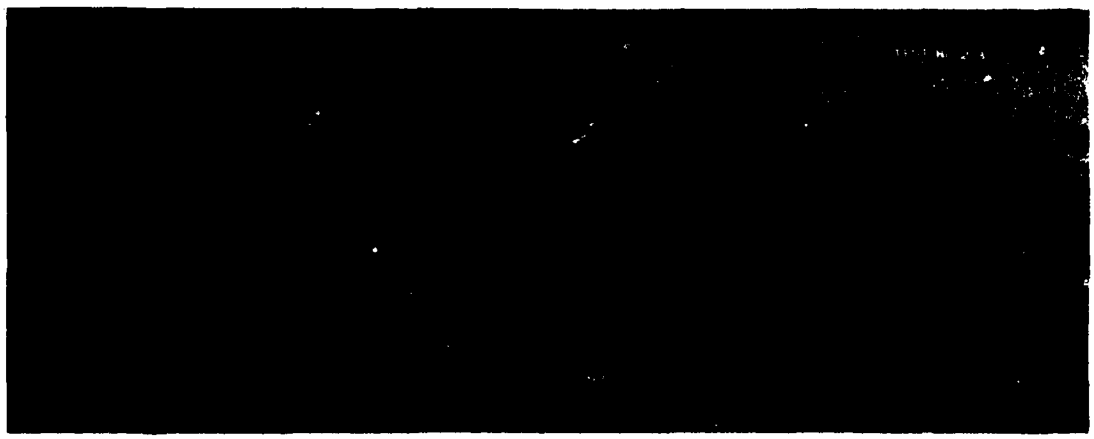
BASE CONDITION

TEST NO. 23

PLATE 88a

BEACH 4

BEACH 5



BEACH 6

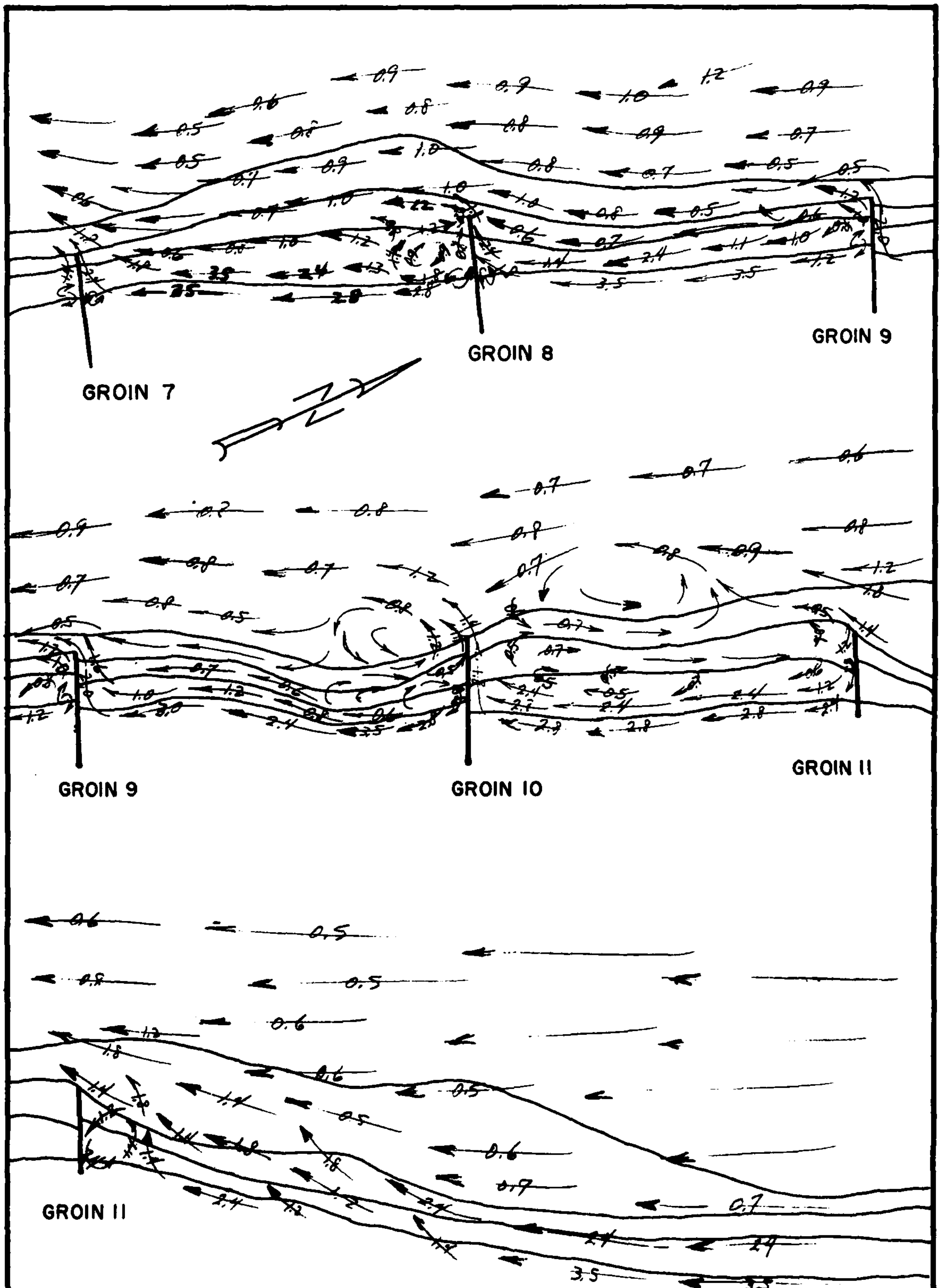
TEST CONDITIONS

Wave Direction 315 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level 0.0 Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 23



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

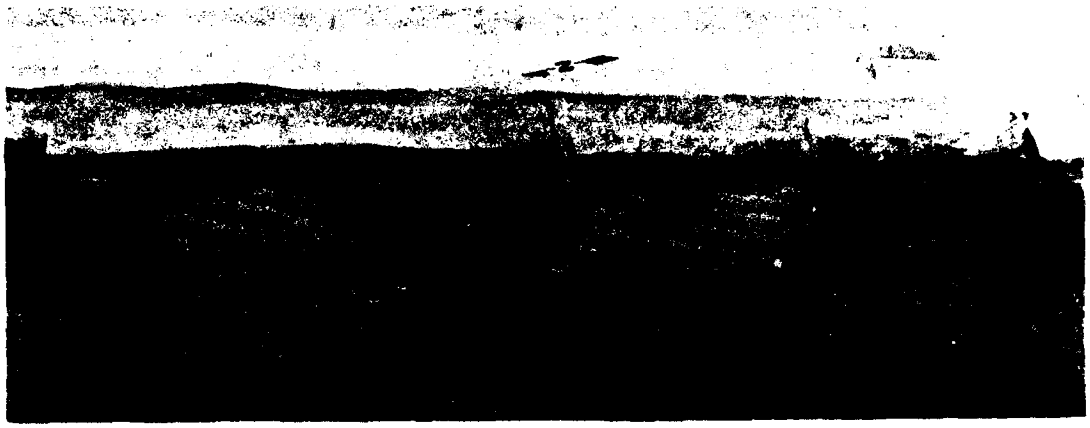
MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 24

PLATE 89a



BEACH 4

BEACH 5

BEACH 6

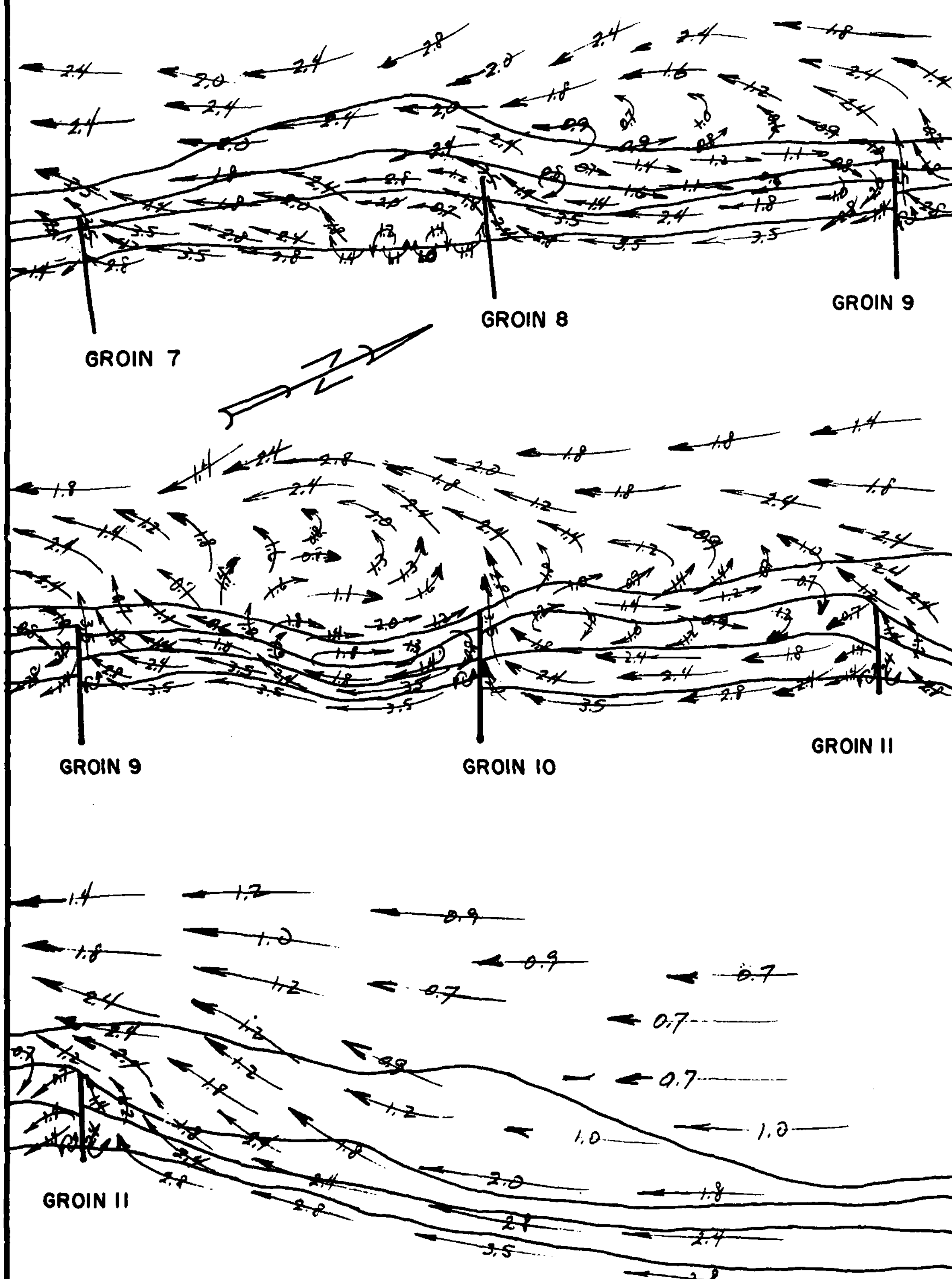
TEST CONDITIONS

Wave Direction 315 Deg
Wave Height 2 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 24



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 25

PLATE 90a

BEACH 4

BEACH 5

BEACH 6

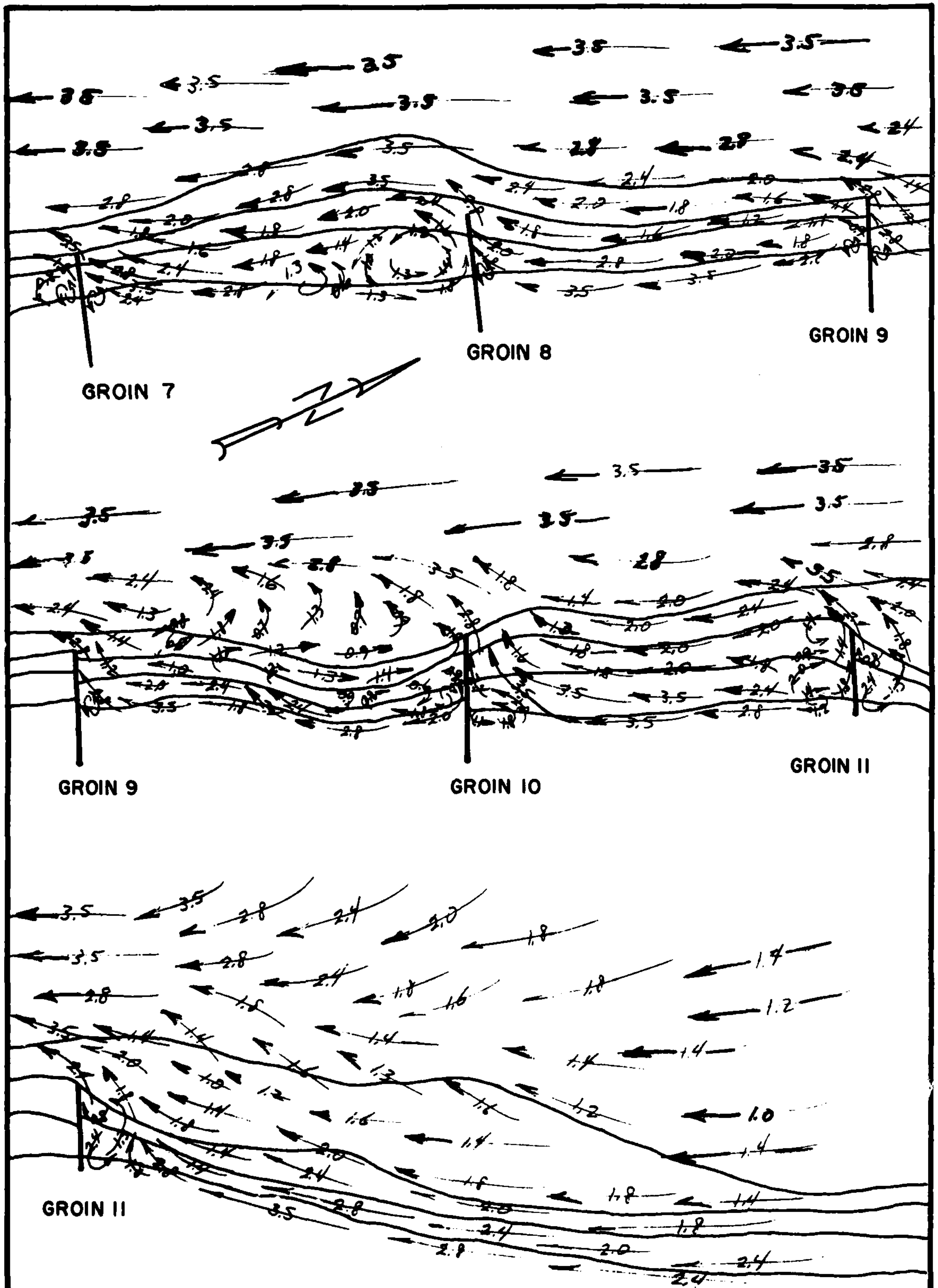
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 25



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE: 0 100 200 300 400 500 FT

MODEL: 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 26

PLATE 91a

BEACH 4

BEACH 5

BEACH 6

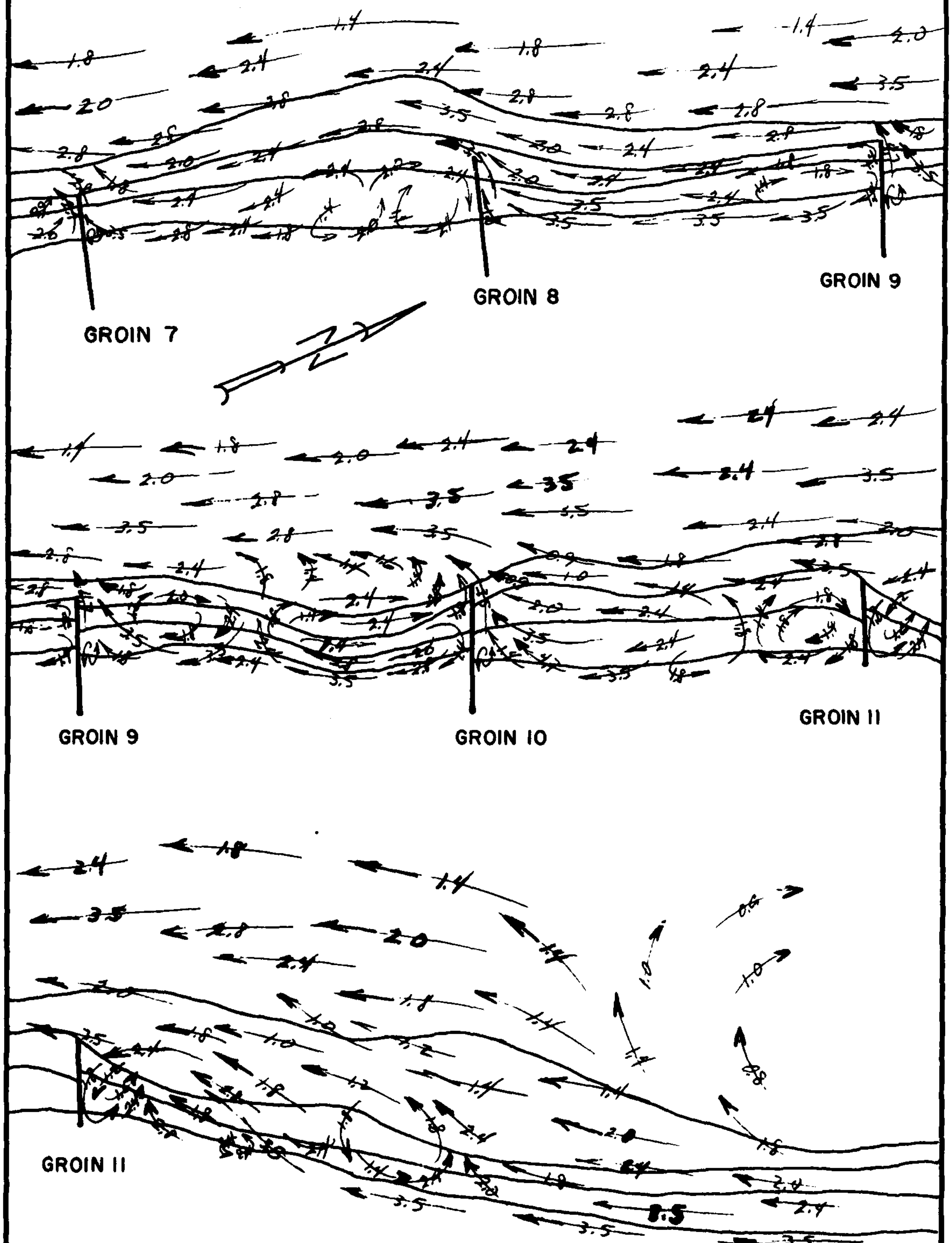
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 26



TEST CONDITIONS		
Wave Direction	315	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE 0 100 200 300 400 500 FT

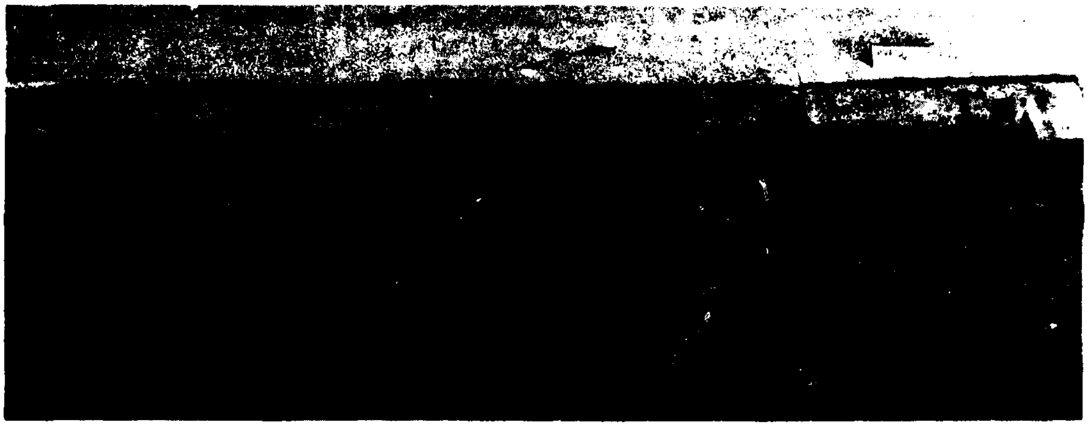
MODEL 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 27

PLATE 92a



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

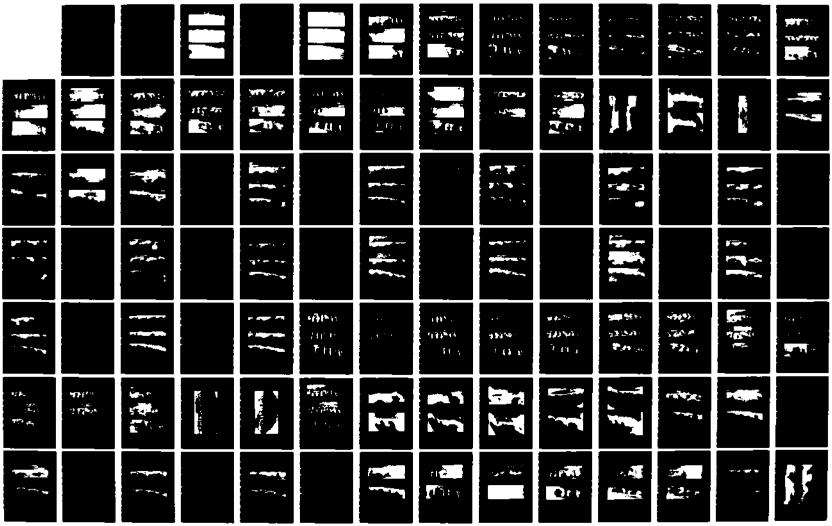
WAVE-GENERATED CURRENTS

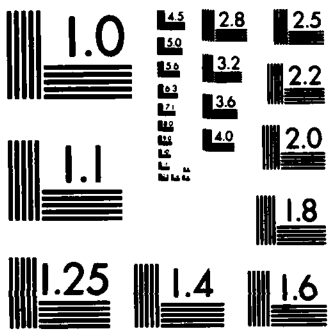
BASE CONDITION

TEST NO. 27

AD-A135 394 DESIGN FOR PREVENTION OF BEACH EROSION AT PRESQUE ISLE BEACHES ERIE PENNS..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS HYDRA.. W C SEABERGH 3/4

UNCLASSIFIED JUN 83 WES/TR/HL-83-15 F/G 8/8 NL





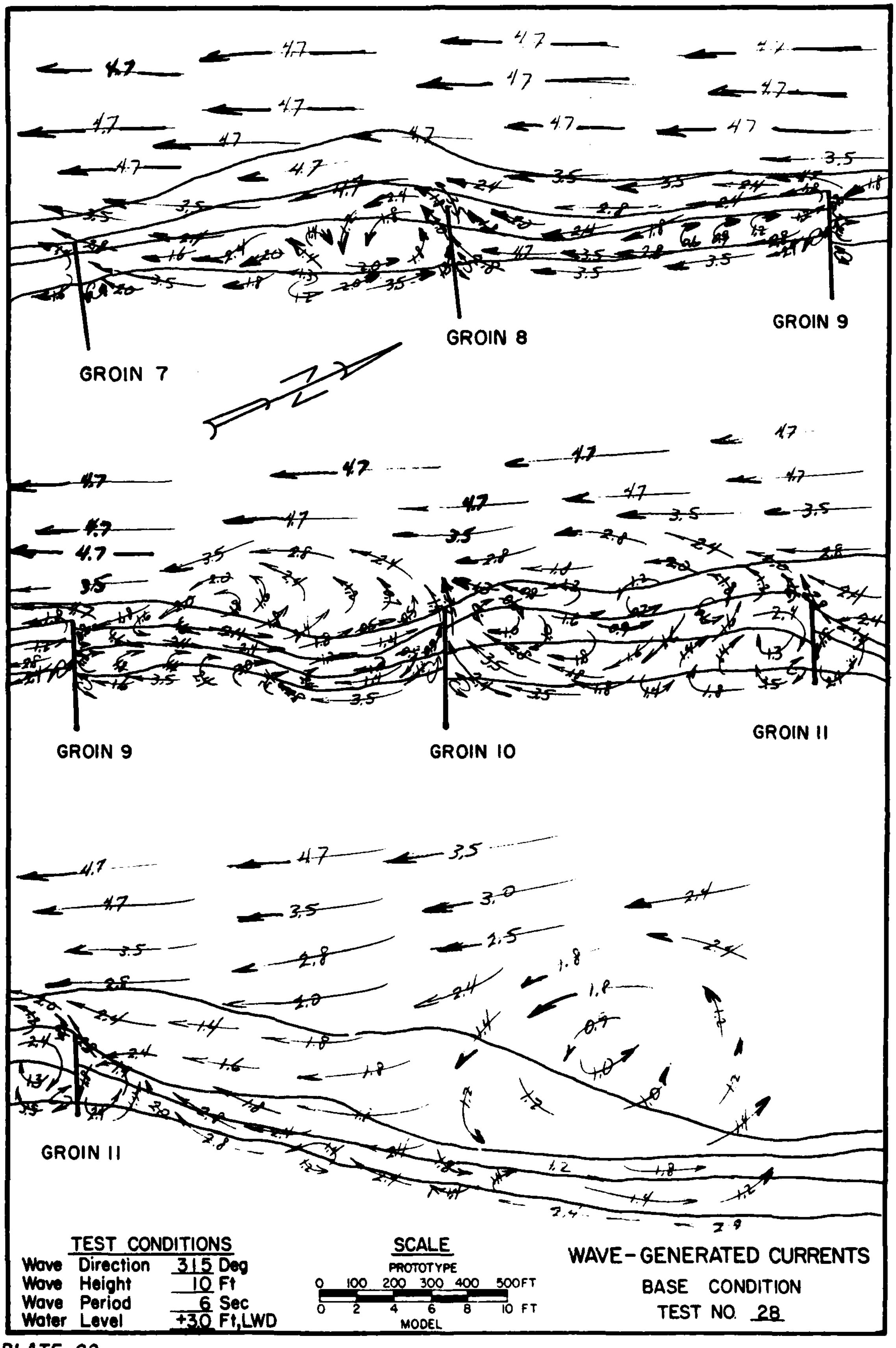

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 315 Deg
Wave Height 10 Ft
Wave Period 6 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 28

PLATE 93a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 28

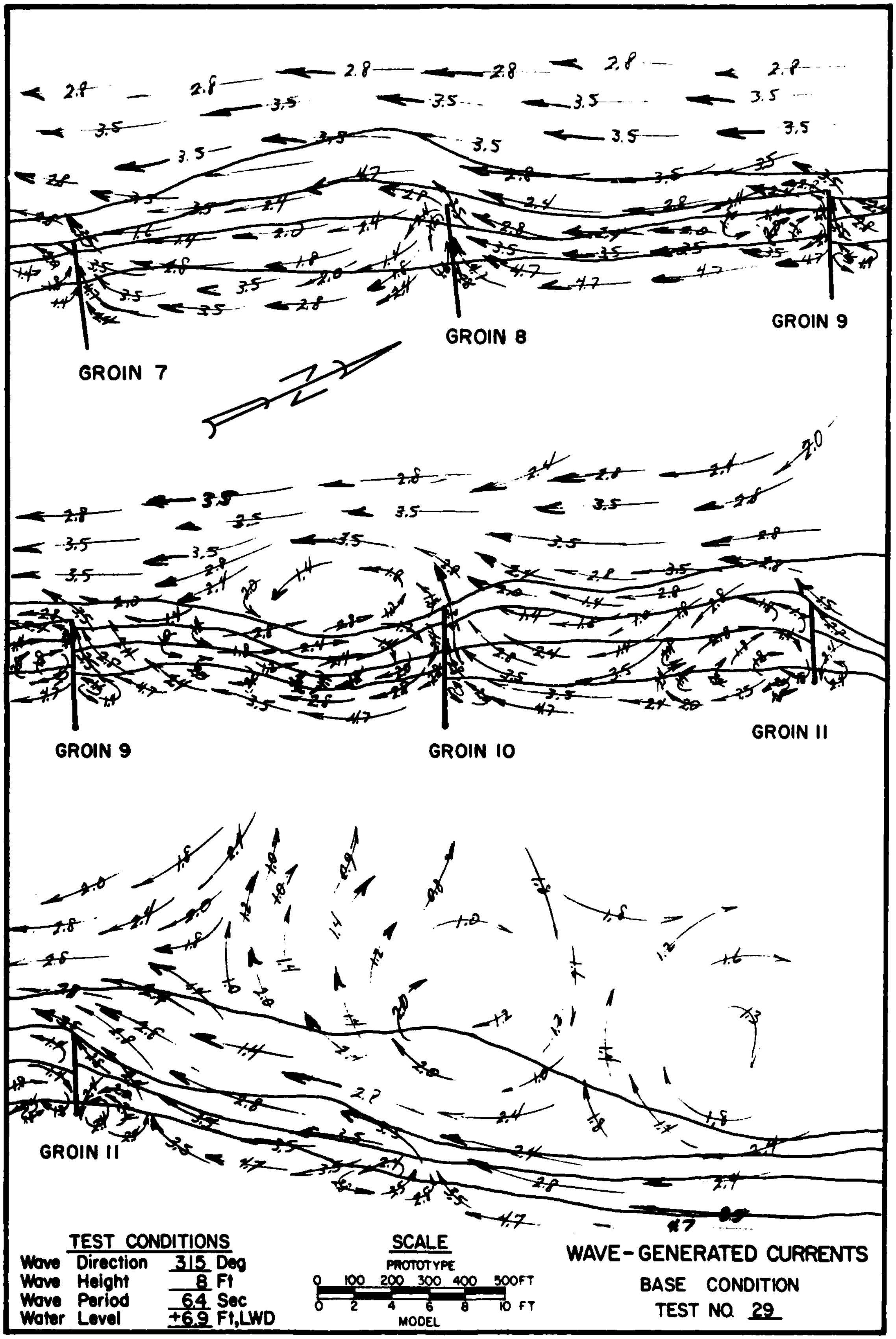
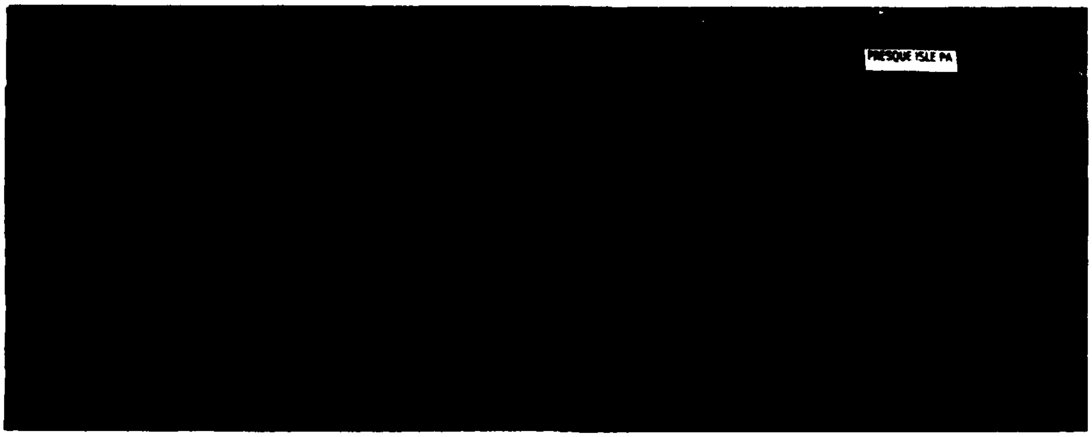
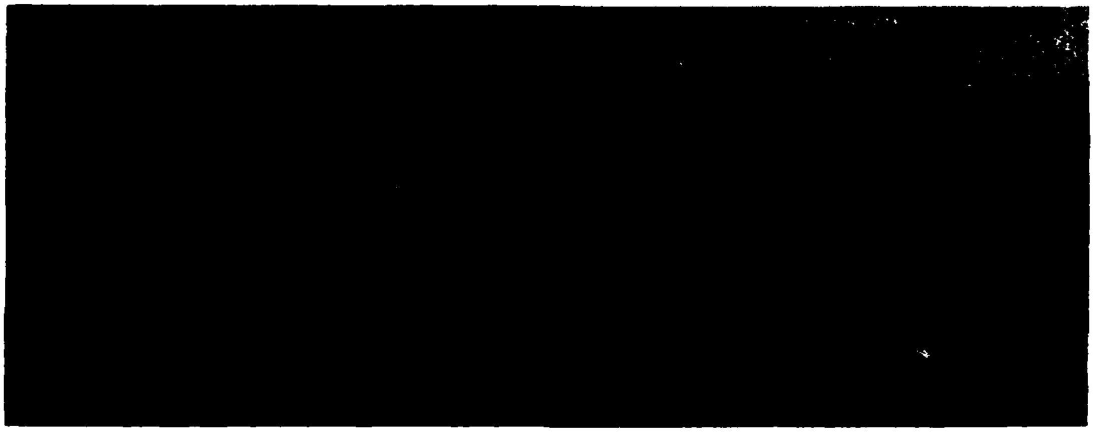

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 315 Deg
Wave Height 8 Ft
Wave Period 6.4 Sec
Water Level +6.9 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
BASE CONDITION
TEST NO. 29

PLATE 94a



BEACH 4



BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	8	Ft
Wave Period	6.4	Sec
Water Level	+6.9	Ft, LWD

WAVE-GENERATED CURRENTS

BASE CONDITION

TEST NO. 29

BEACH 4

BEACH 5

BEACH 6

SEDIMENT TRACER TEST
LAYOUT FOR
BASE CONDITION

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft,LWD

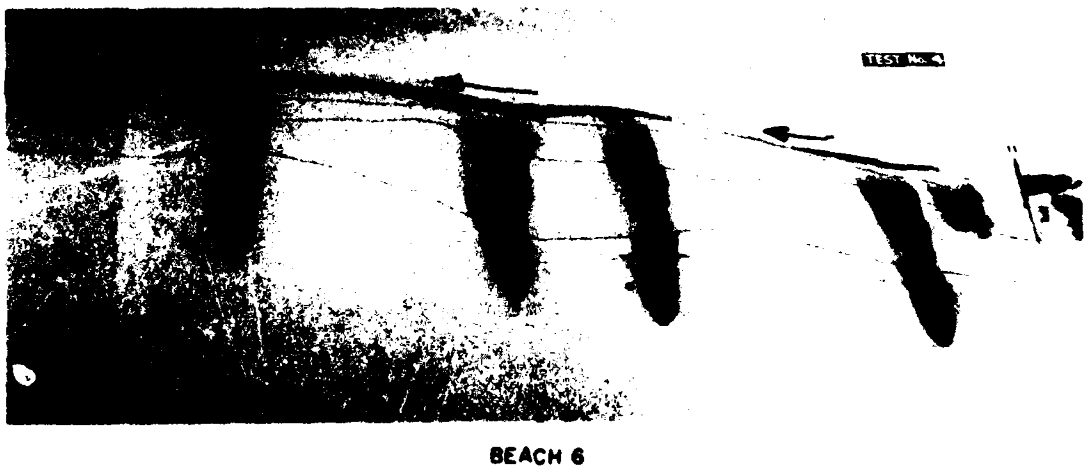
SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 2

BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 4

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	4 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 5

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 6

BEACH 4

BEACH 5

BEACH 6

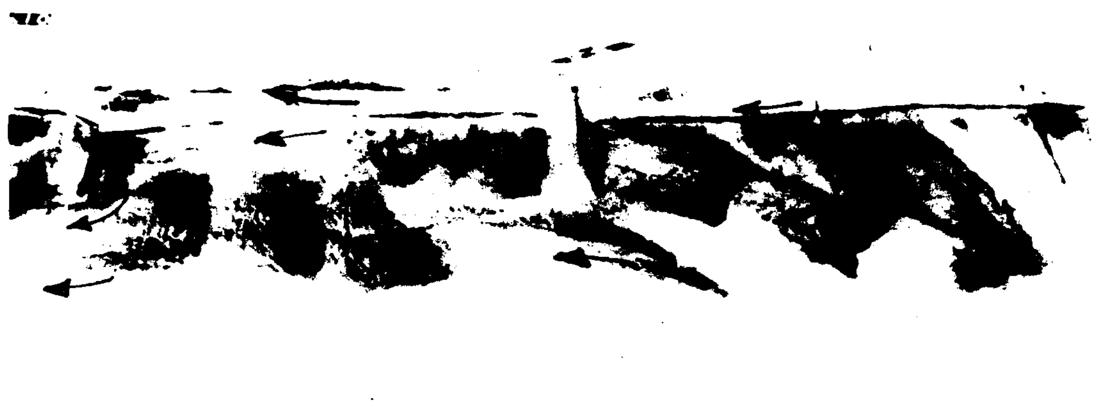
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 8



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 10

BEACH 4

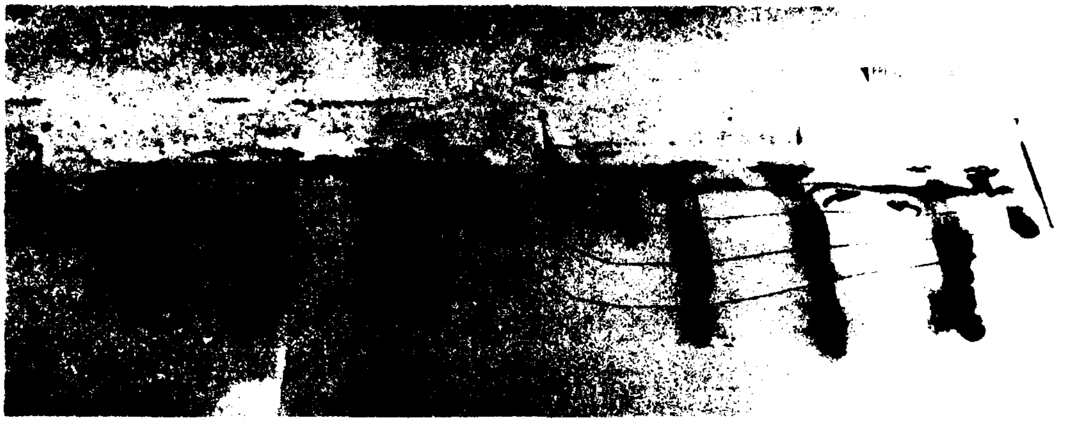
BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft,LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 12



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 14

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

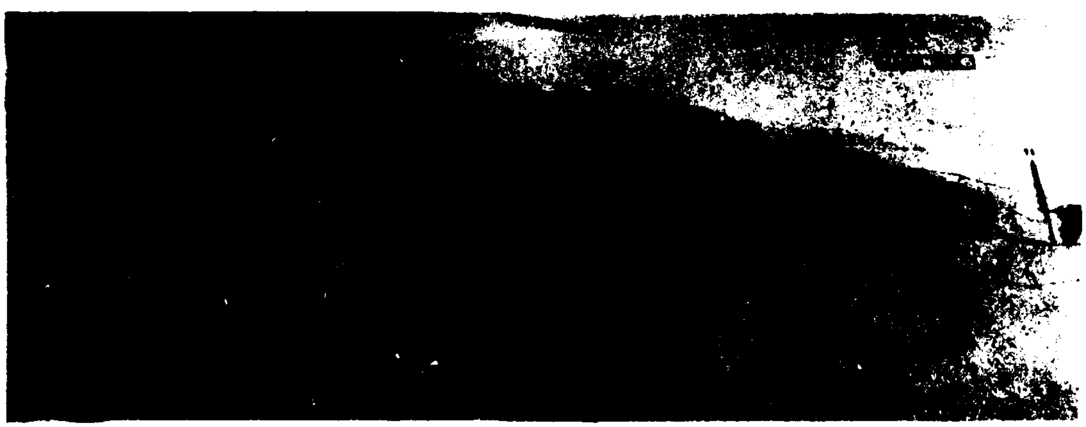
SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 15

BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	7 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 16

PLATE 105

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 18

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 20

PLATE 107

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 315 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 22

BEACH 4

BEACH 5

BEACH 6

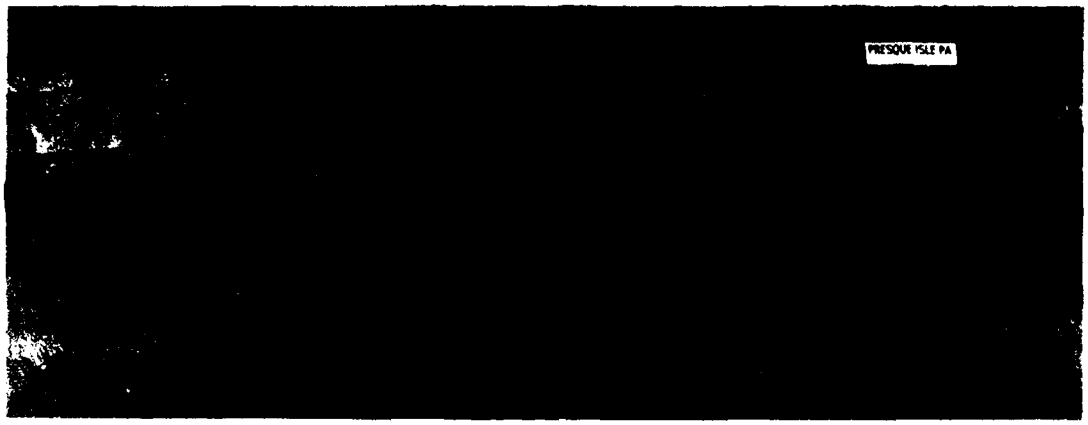
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 24



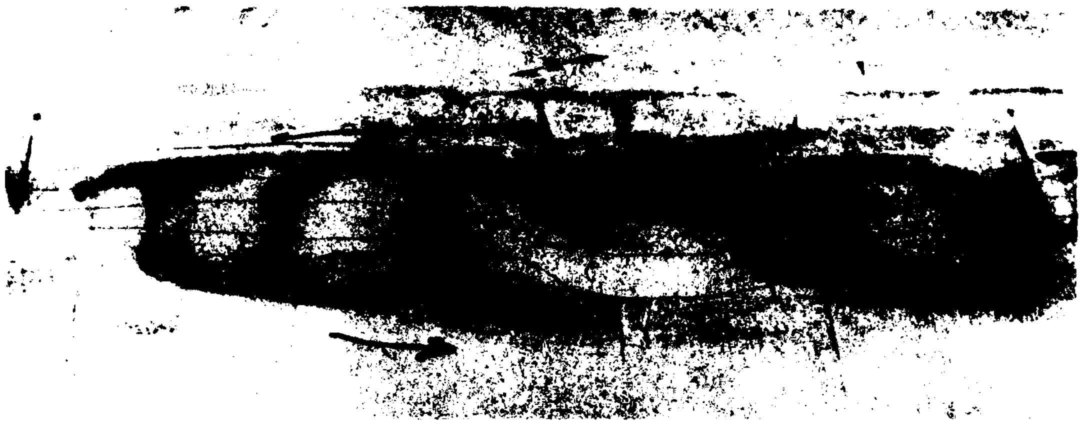
BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS		
Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 26



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST
BASE CONDITION
TEST NO. 28

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS		
Wave Direction	315	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

SEDIMENT TRACER TEST

BASE CONDITION

TEST NO. 29

TEST CONDITIONS

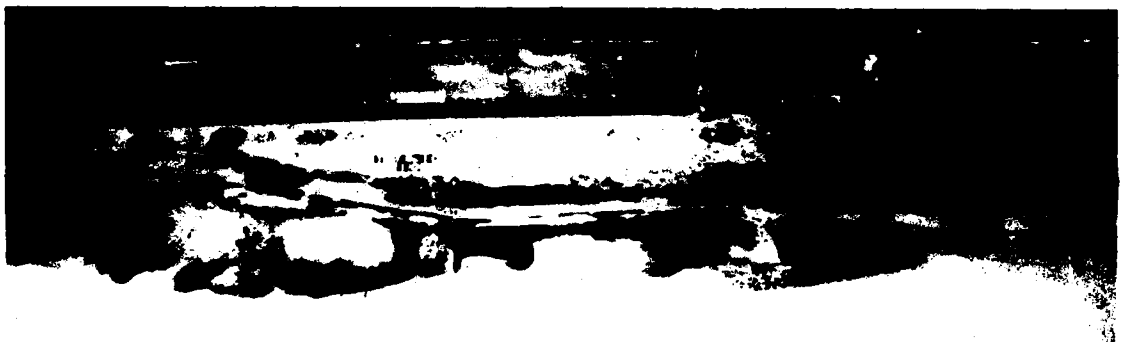
Wave	Direction	270 Deg
Wave	Height	4 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 5
HOUR 5.0

TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	6	Ft
Wave	Period	6	Sec
Water	Level	+5.0	Ft, LWD

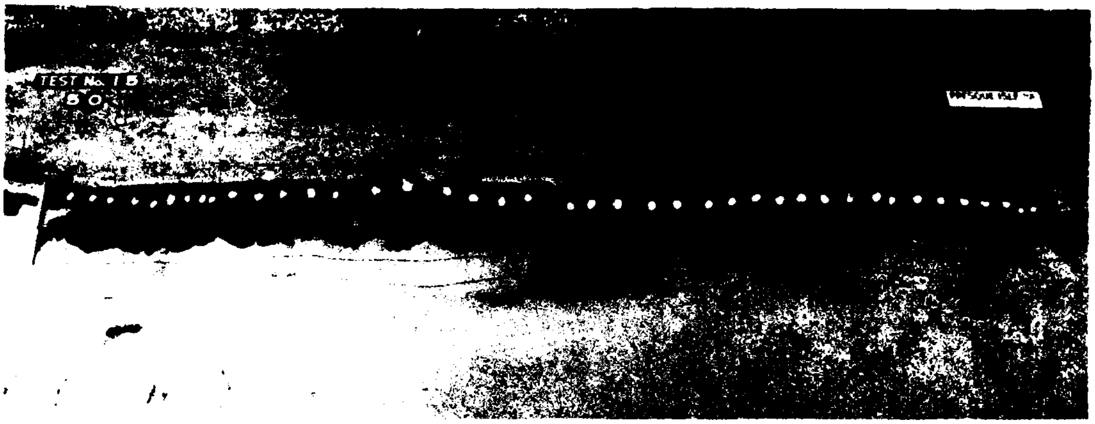
BEACH FILL TEST
BASE CONDITION
TEST NO. 5-1
HOUR 20



TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	12 Ft
Wave	Period	9 Sec
Water	Level	+6.9 Ft,LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 10
HOUR 10



BEACH 5

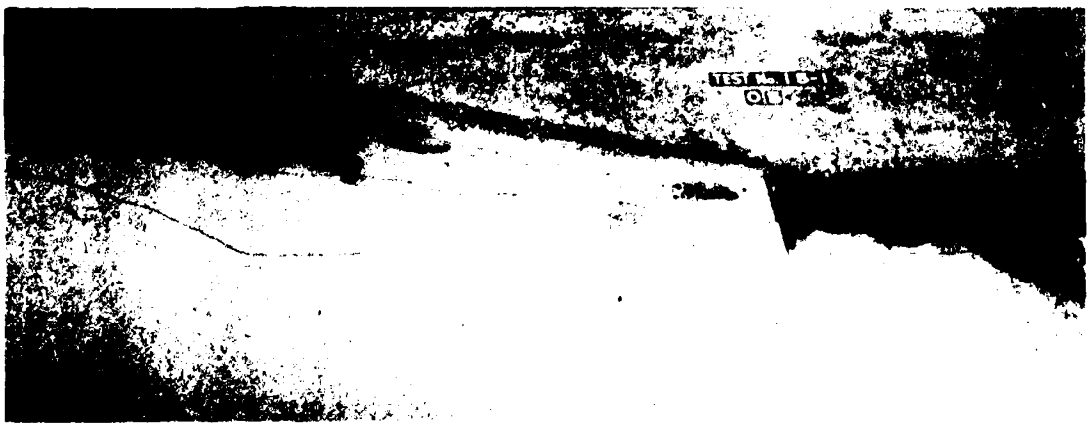
BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 15
HOUR 50

BEACH 5



BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+5.0	Ft,LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 15-1
HOUR 0.5

BEACH 5

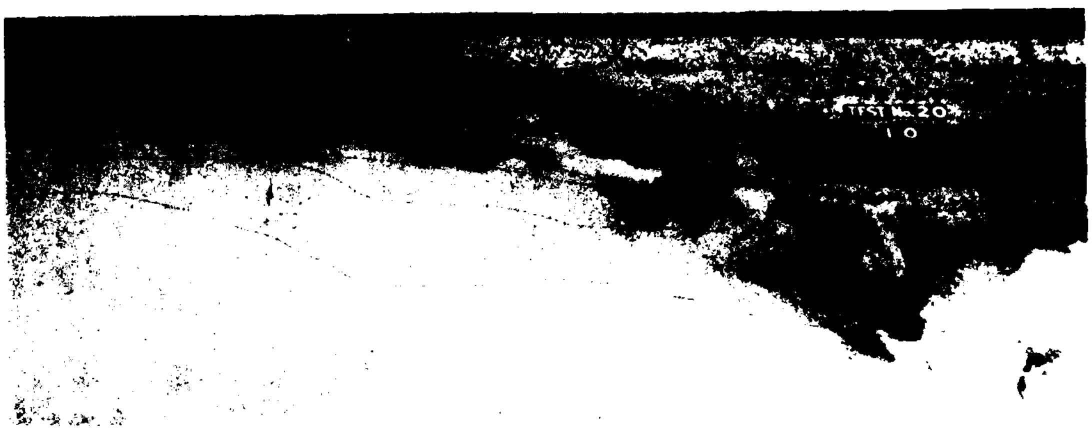
BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+5.0	Ft,LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 15-1
HOUR 2.0

BEACH 5

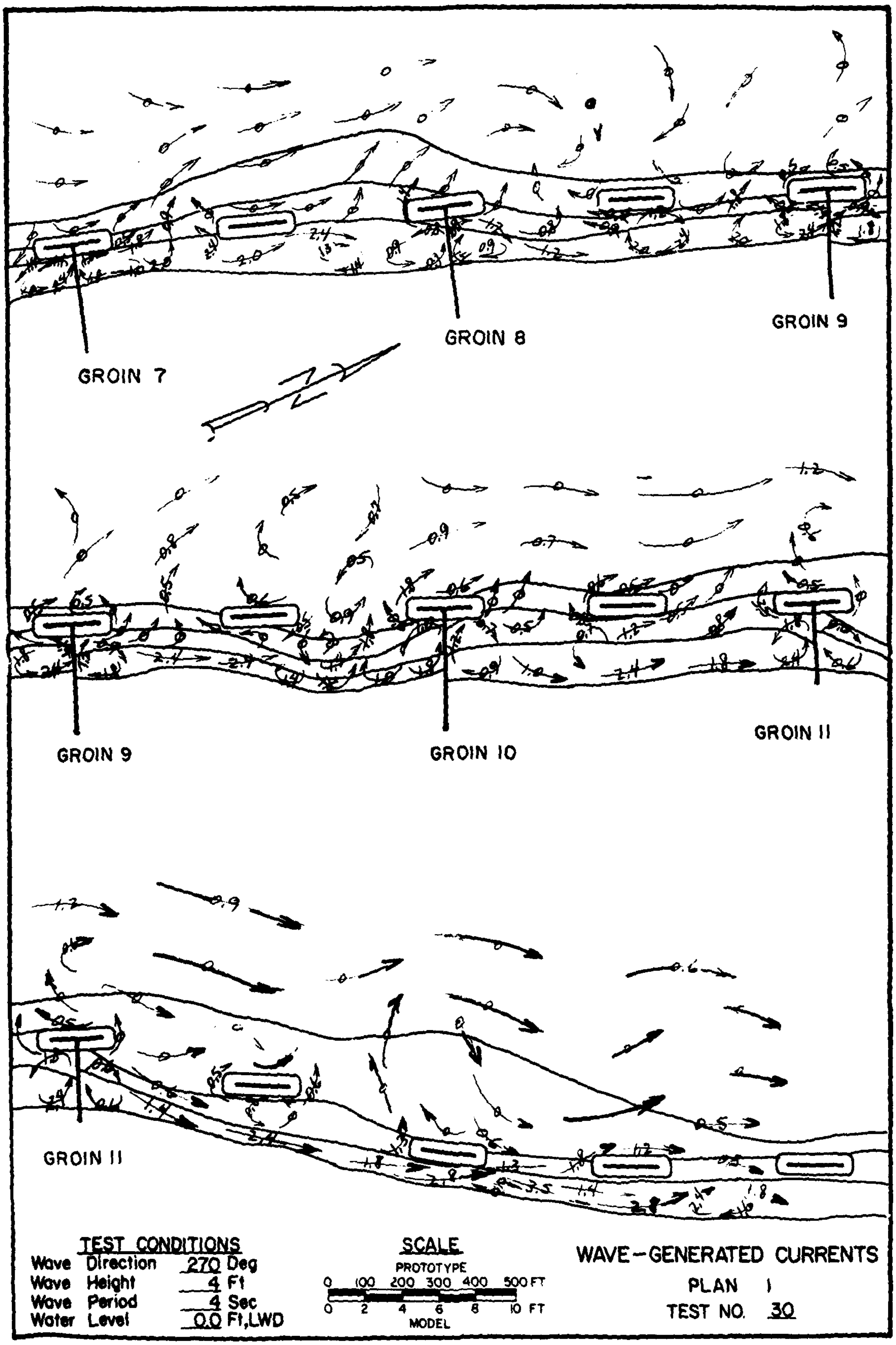


BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST
BASE CONDITION
TEST NO. 20
HOUR 10


GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level 0.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 1
TEST NO. 30

BEACH 4

BEACH 5

BEACH 6

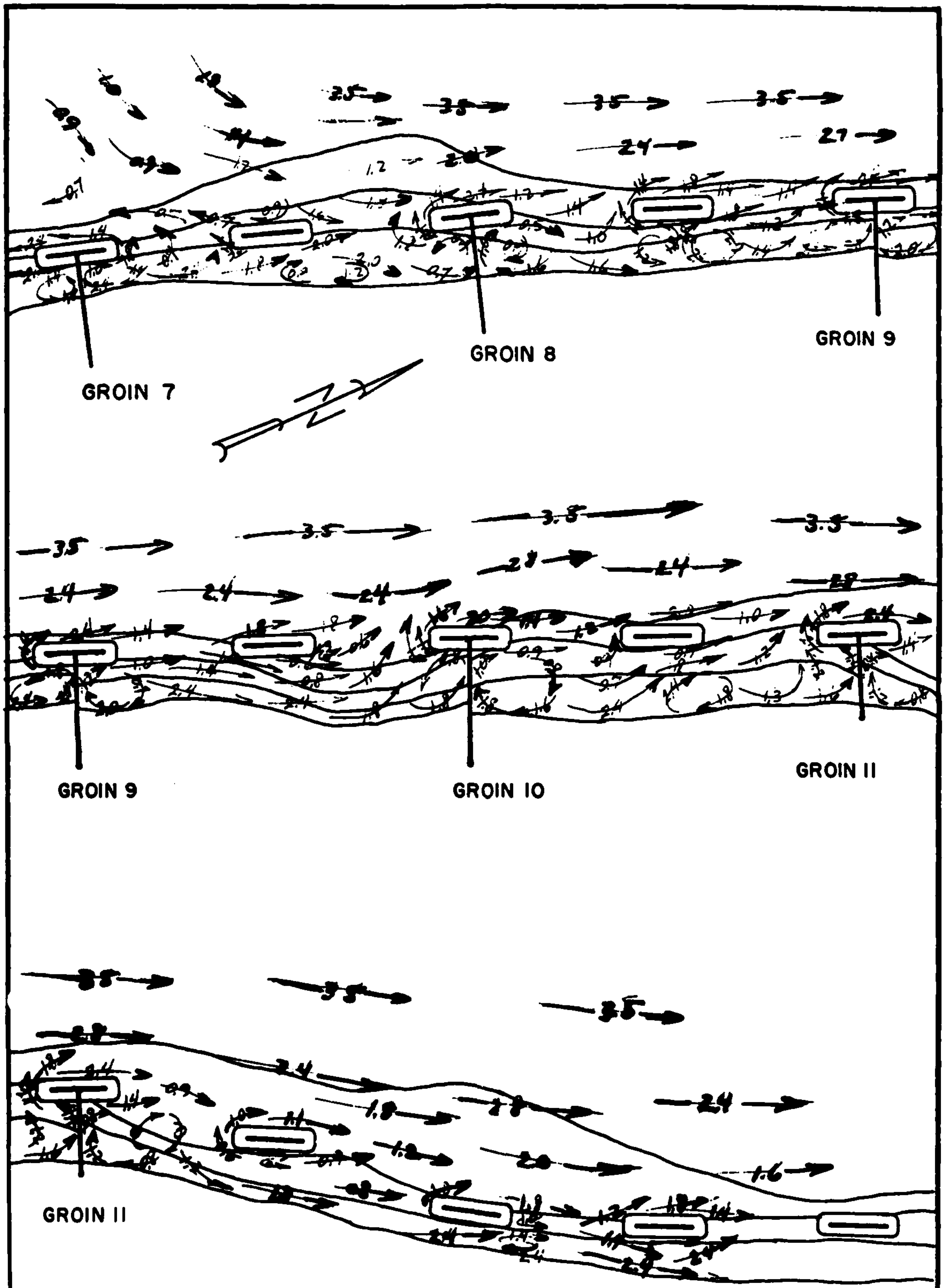
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 30



TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD

SCALE

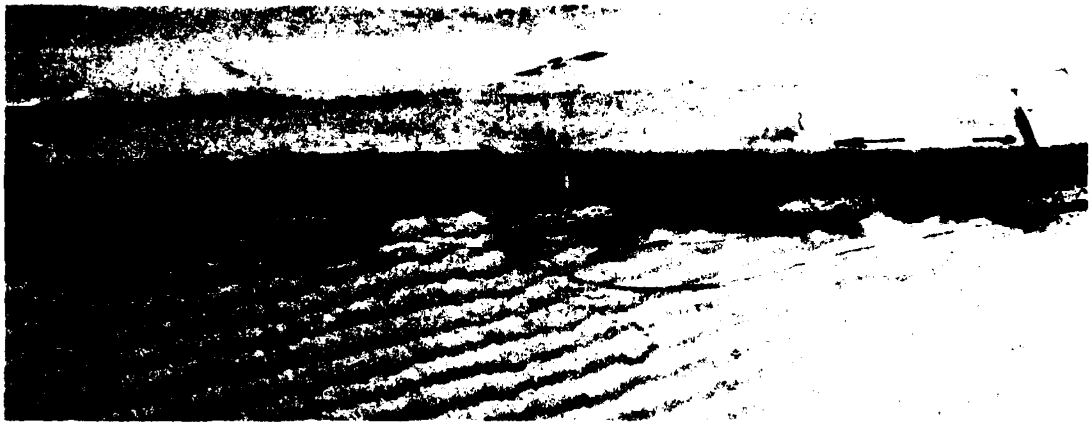
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

WAVE-GENERATED CURRENTS

PLAN I

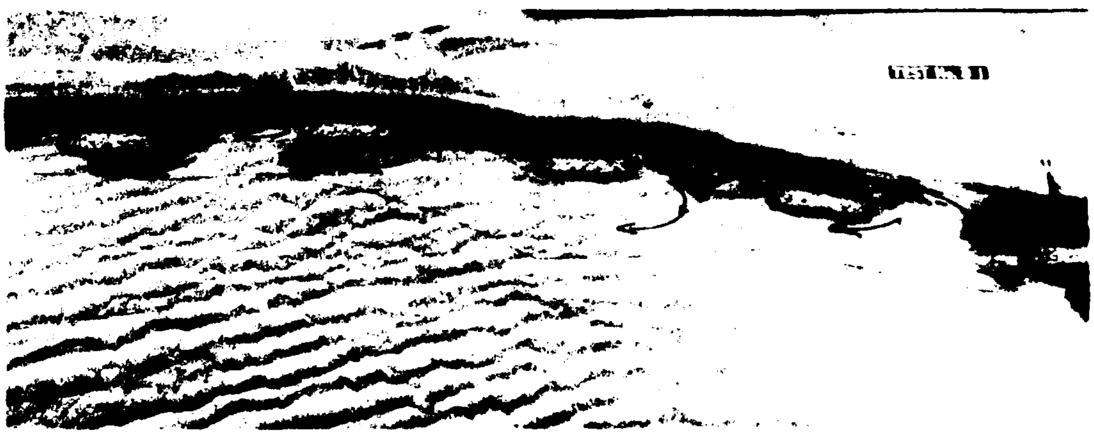
TEST NO. 31

PLATE 121a



BEACH 4

BEACH 5



BEACH 6

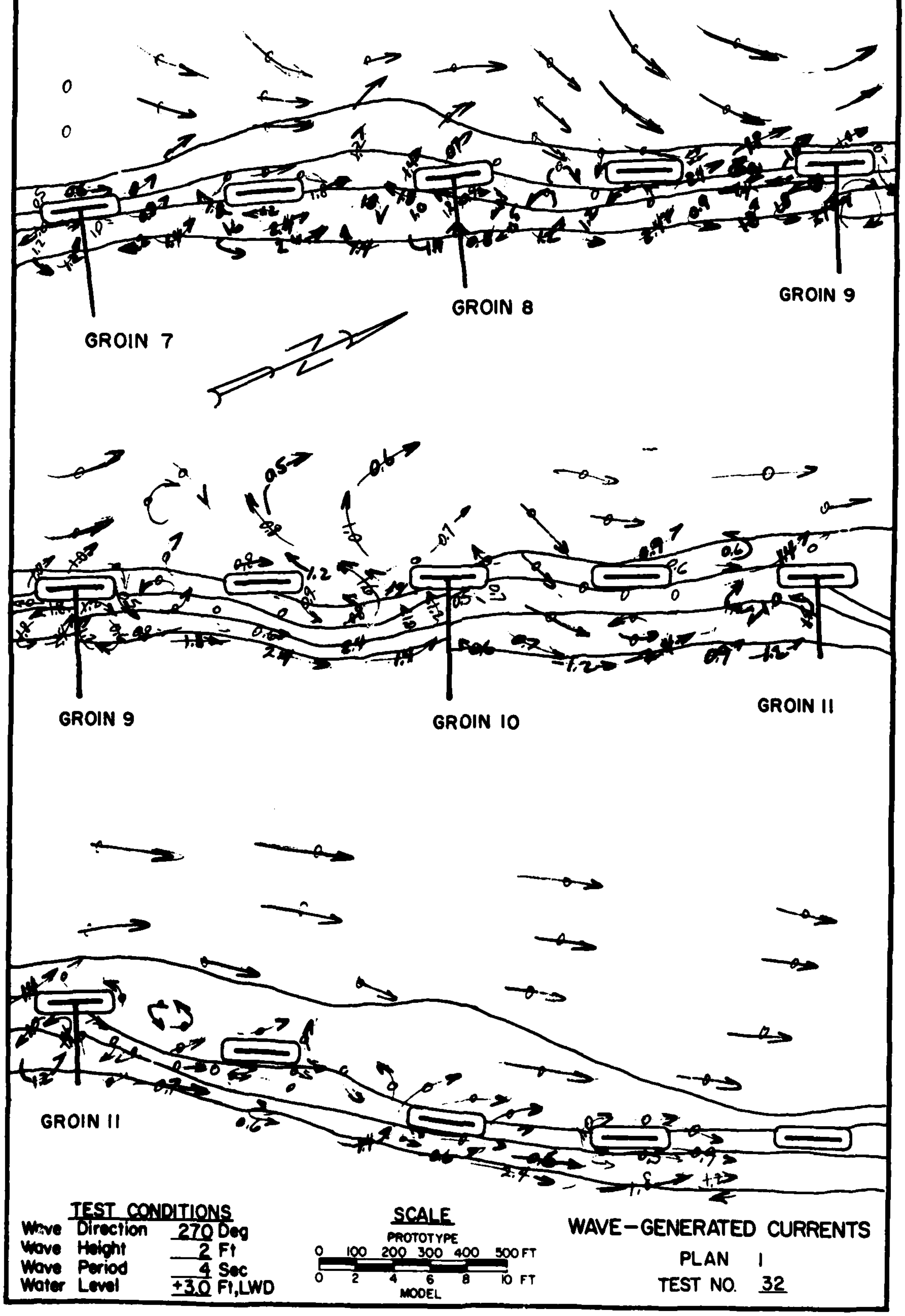
TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	7	Ft
Wave	Period	4	Sec
Water	Level	0.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 31



TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	2 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 32

PLATE 122a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 32

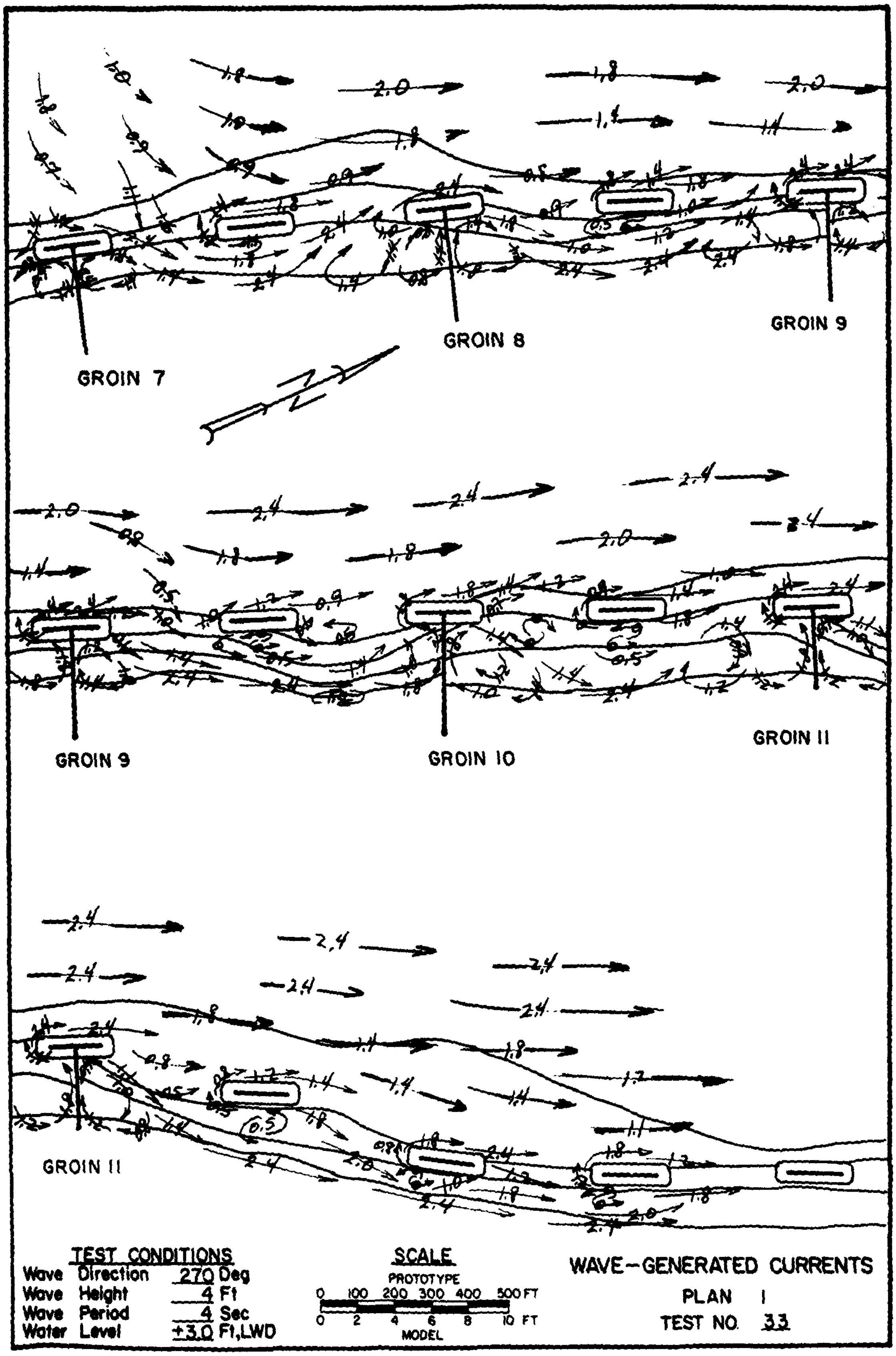

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN I
TEST NO. 33

PLATE 123a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 33

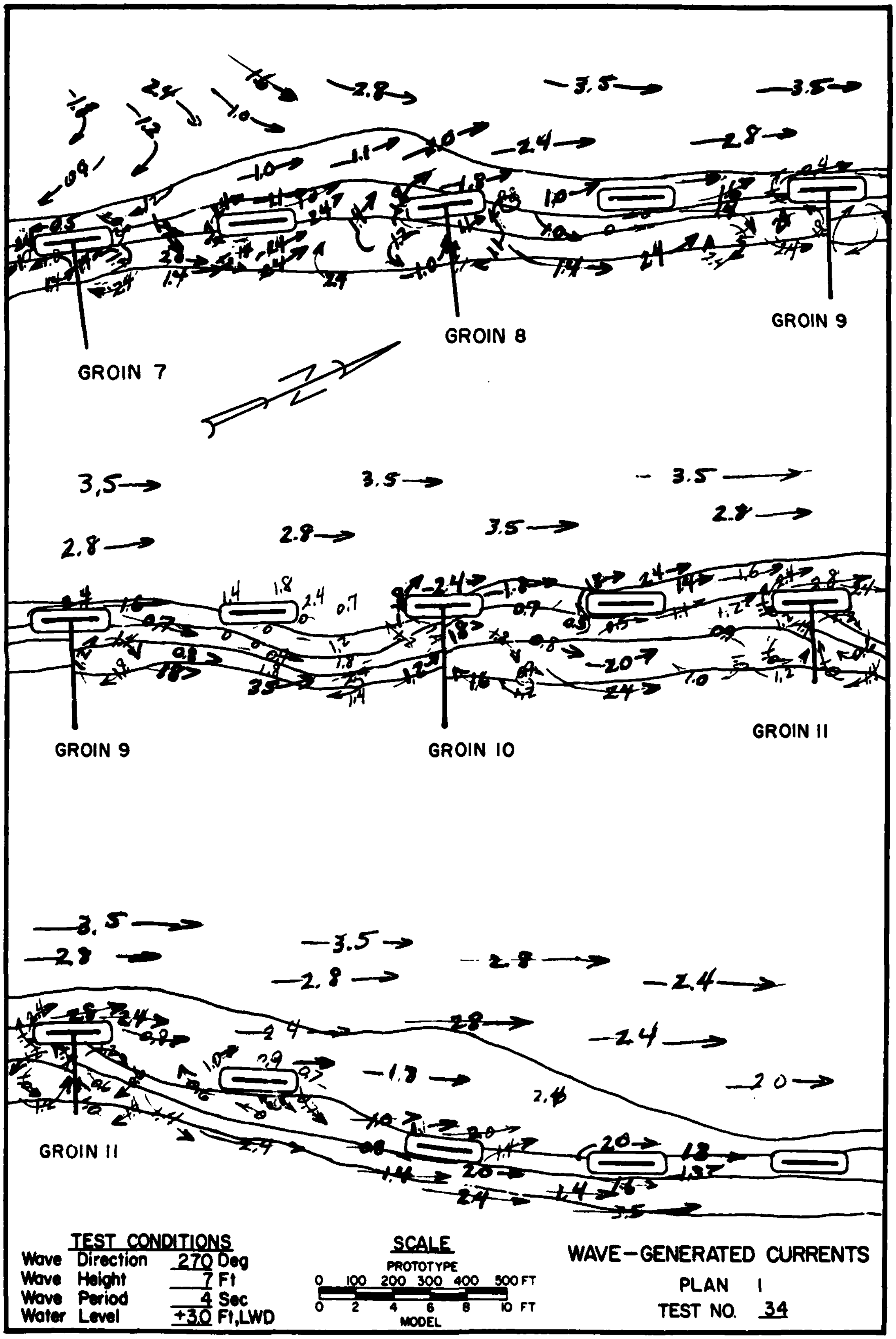

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 1
TEST NO. 34

PLATE 124a

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 34

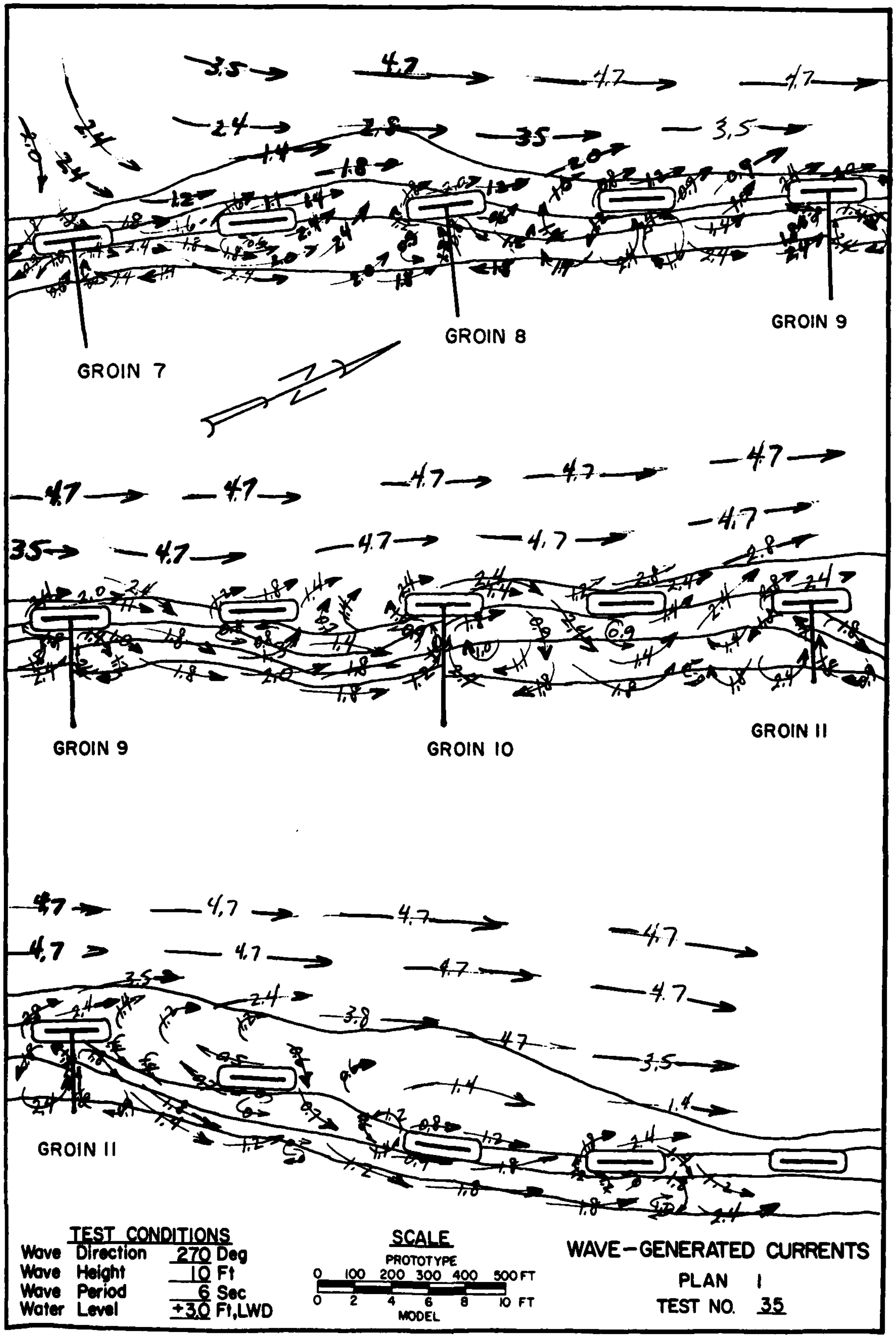
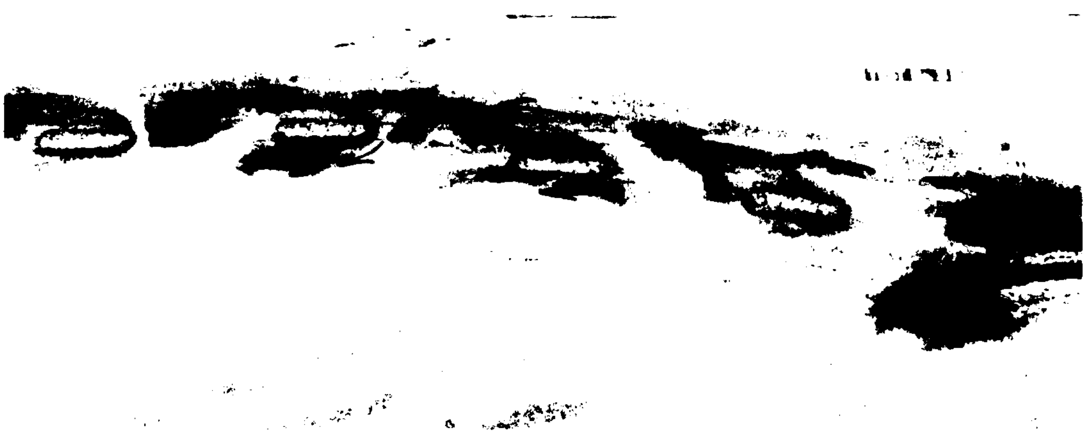

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 10 Ft
Wave Period 6 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 1
TEST NO. 35

PLATE 125a

BEACH 4

BEACH 5



BEACH 6

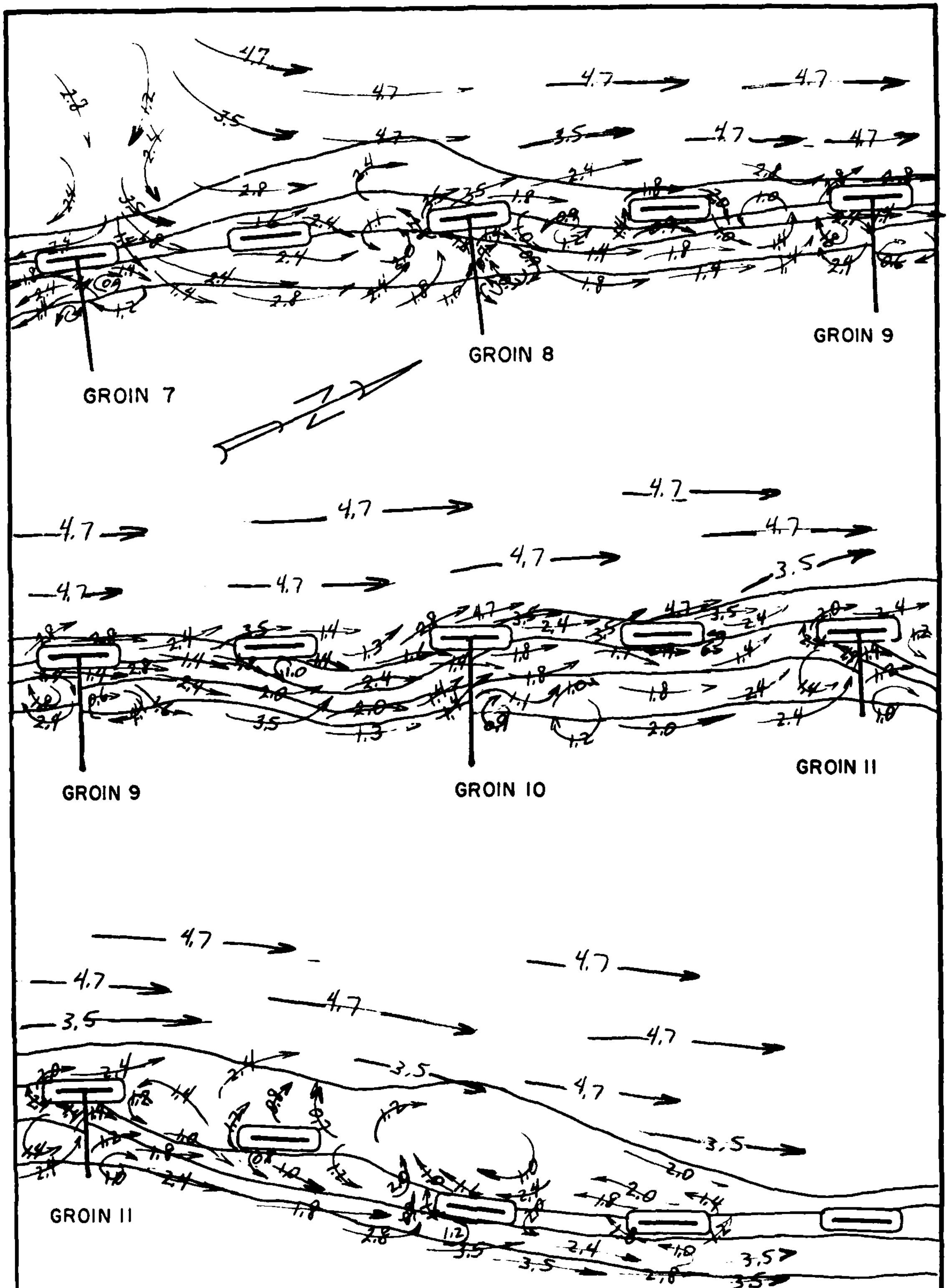
TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	10 Ft
Wave	Period	6 Sec
Water	Level	+3.0 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN I

TEST NO 35



TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

SCALE

PROTOTYPE: 0 100 200 300 400 500 FT

MODEL: 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 36

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

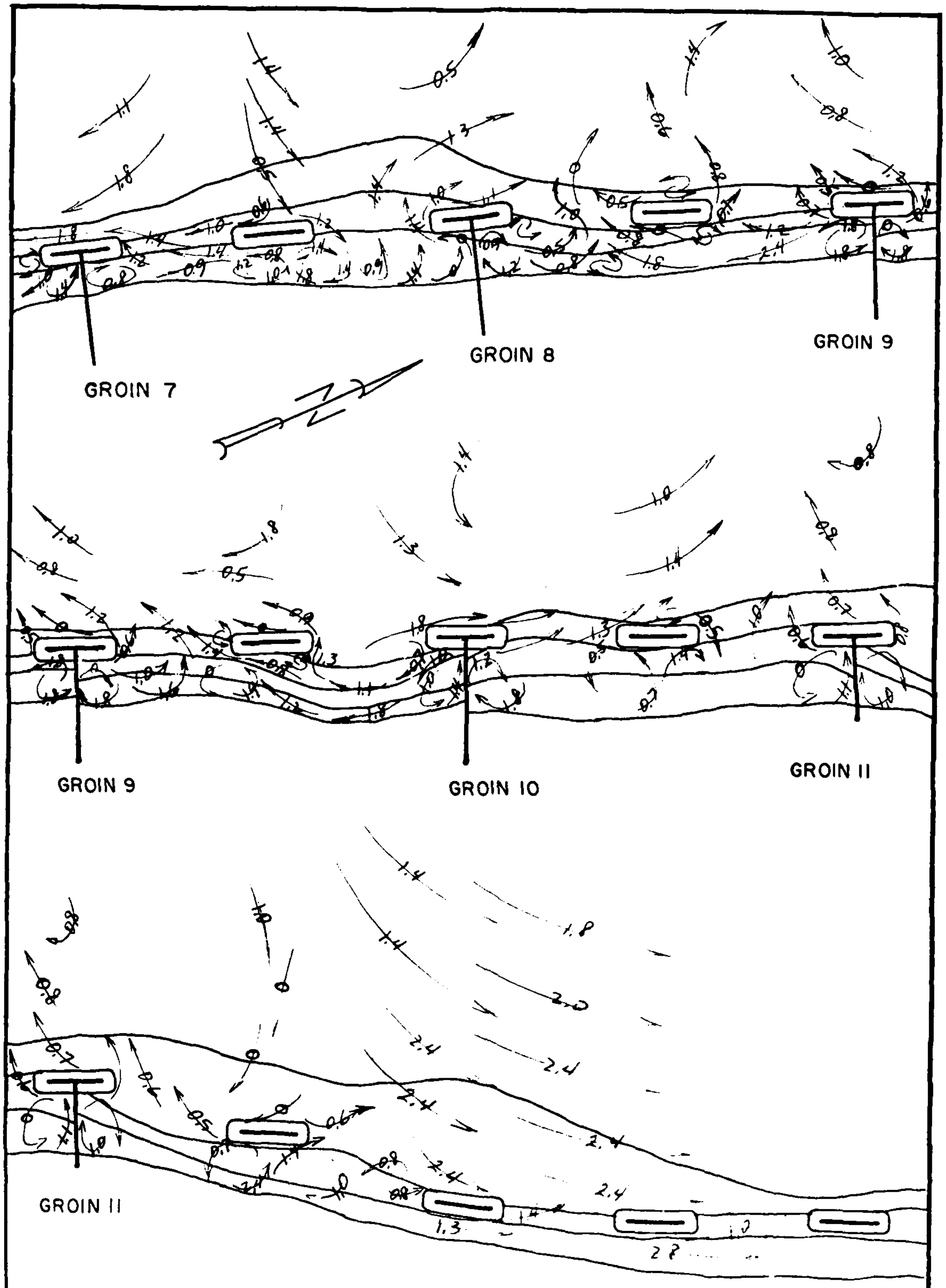
Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

WAVE - GENERATED CURRENTS

PLAN I

TEST NO. 36

PLATE 126b



TEST CONDITIONS		
Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

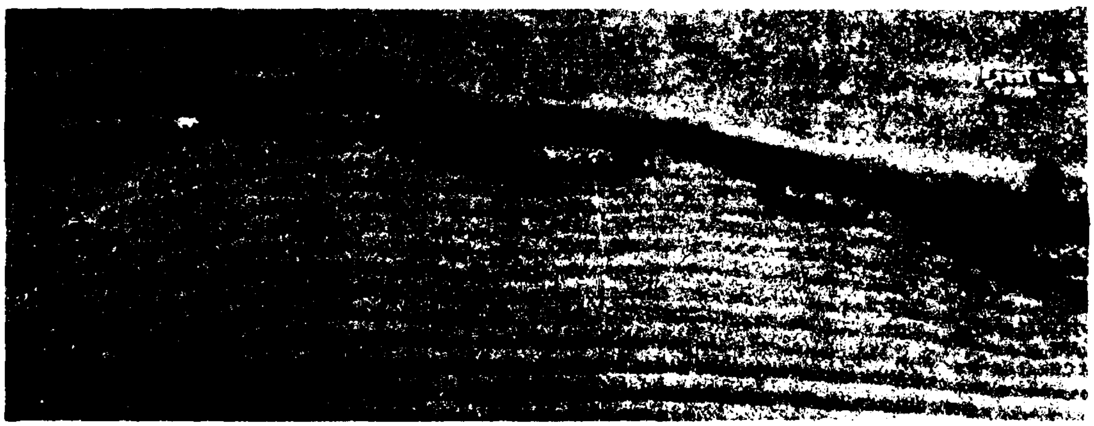
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

WAVE-GENERATED CURRENTS
PLAN I
TEST NO. 37

PLATE 127a

BEACH 4

BEACH 5



BEACH 6

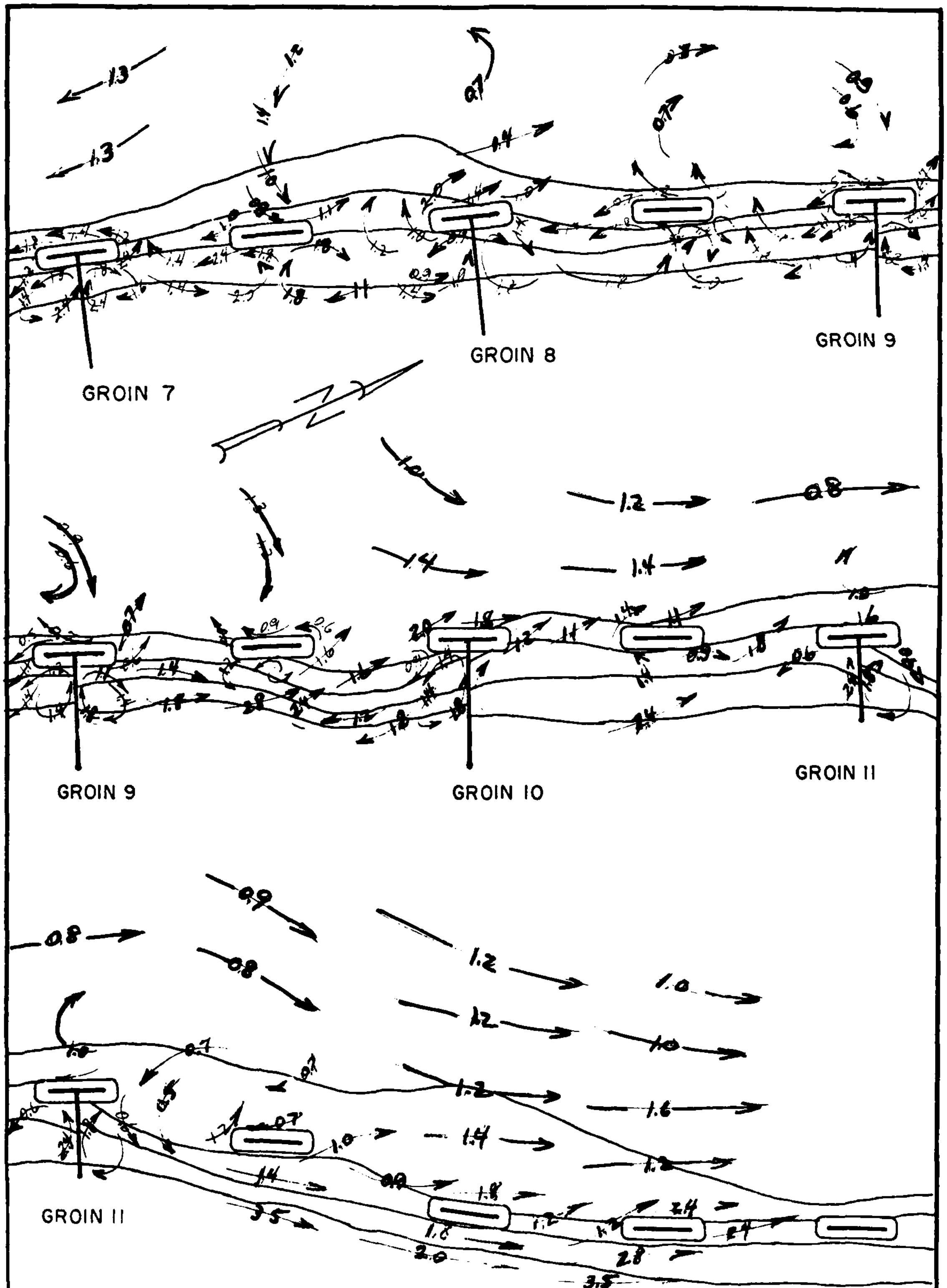
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft,LWD

WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 37



TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

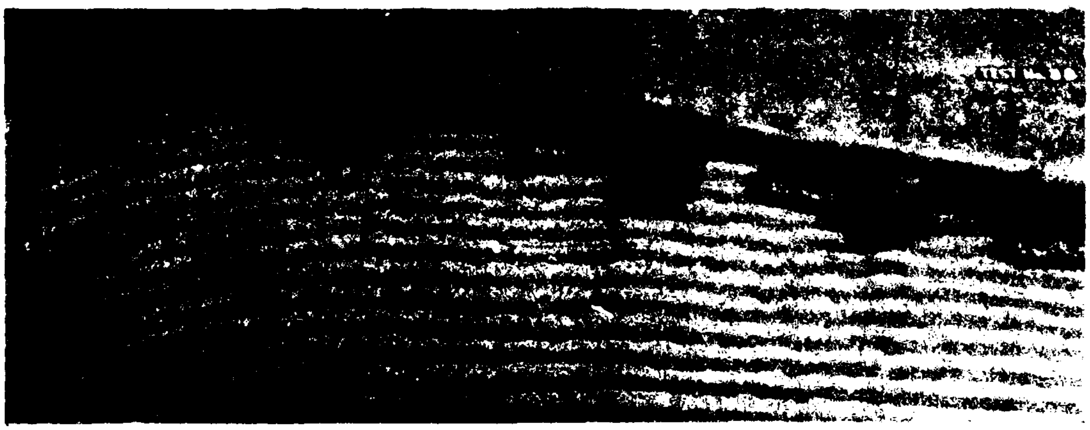
WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 38

BEACH 4

BEACH 5



BEACH 6

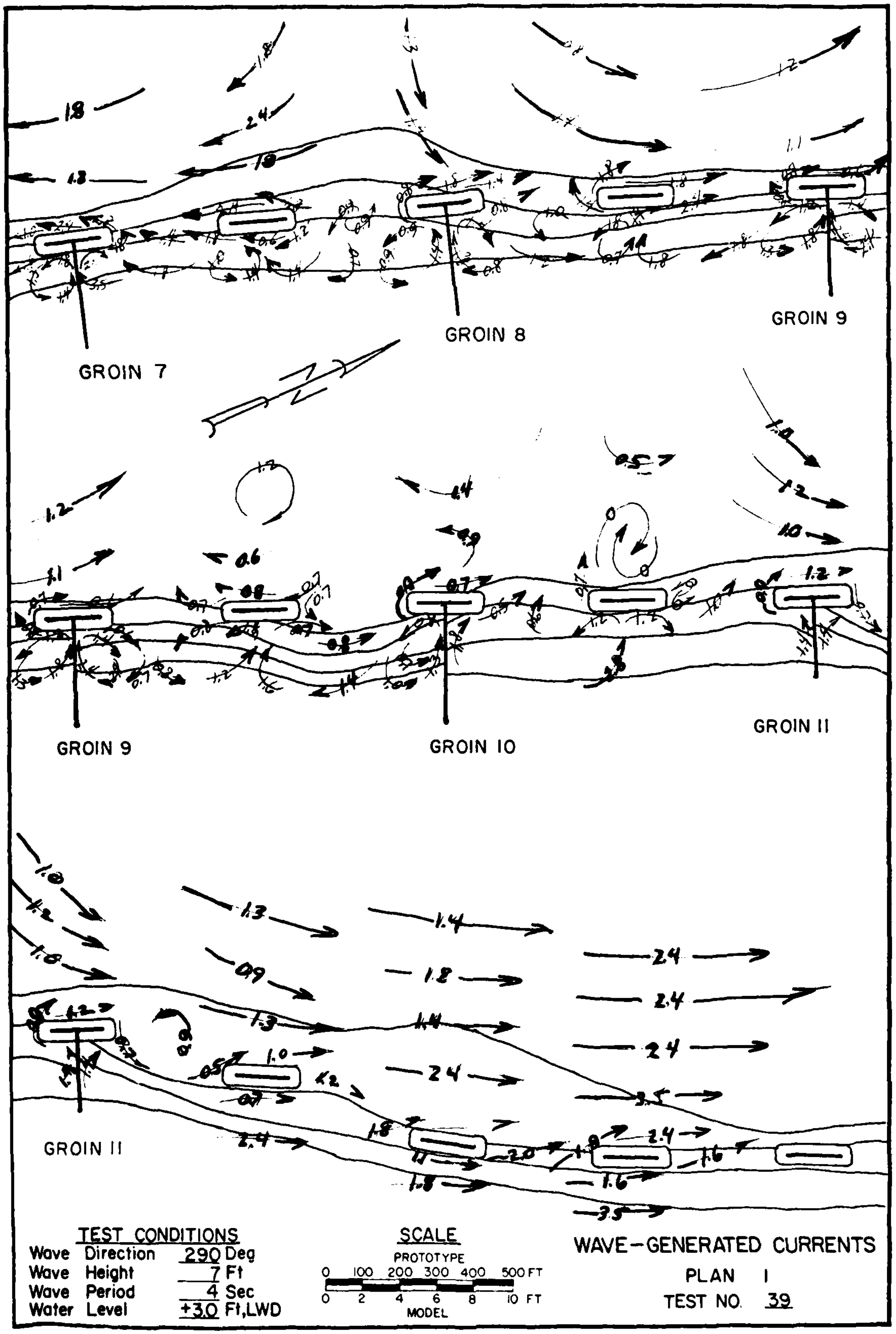
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 38

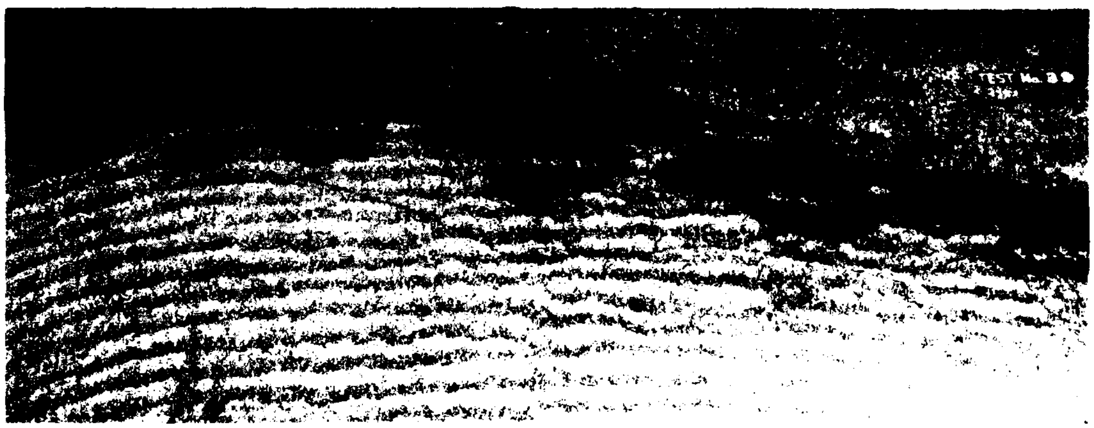


GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN I
TEST NO. 39

PLATE 129a

BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 39

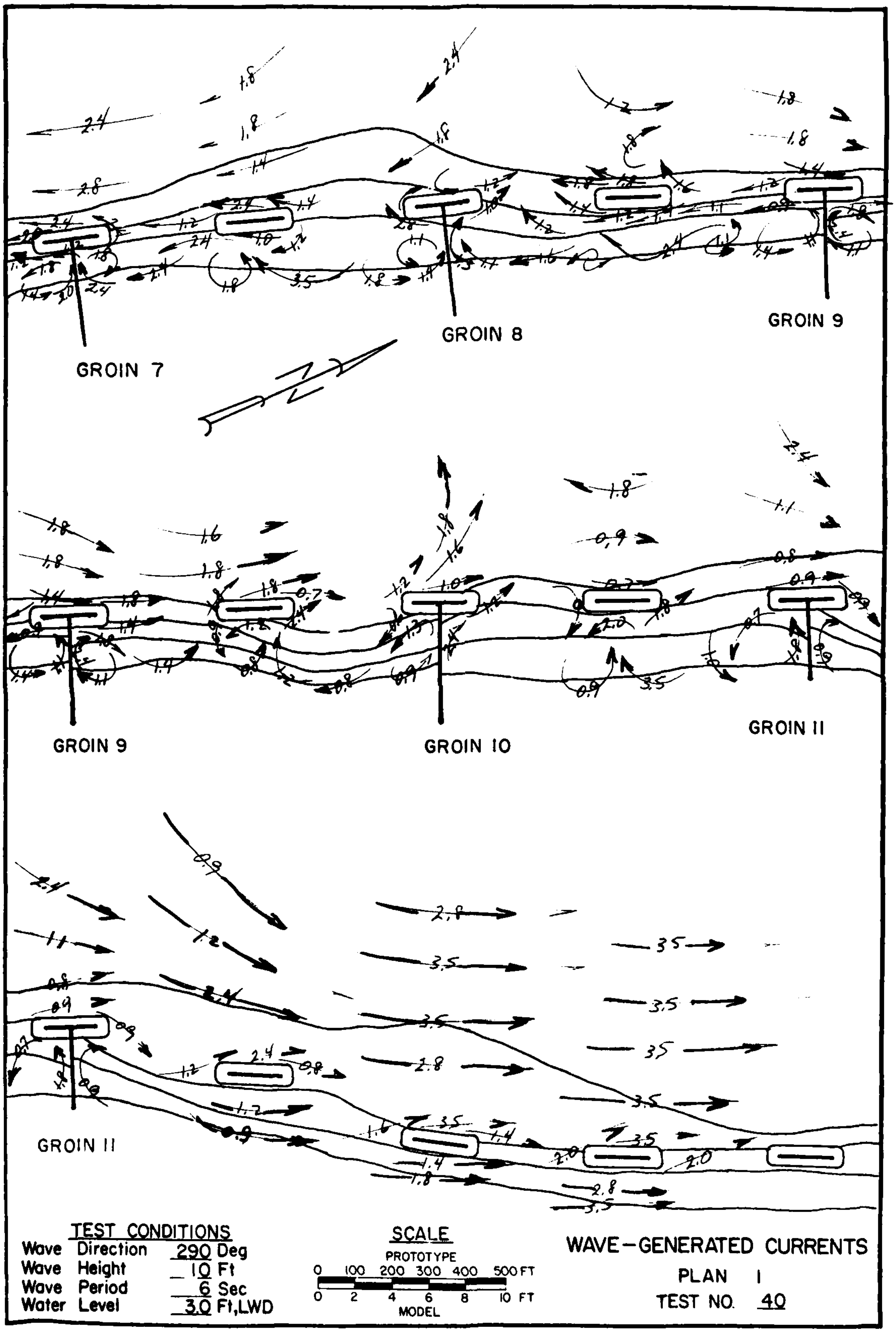

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 10 Ft
Wave Period 6 Sec
Water Level 3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN I
TEST NO. 40

PLATE 130a

BEACH 4

BEACH 5

BEACH 6

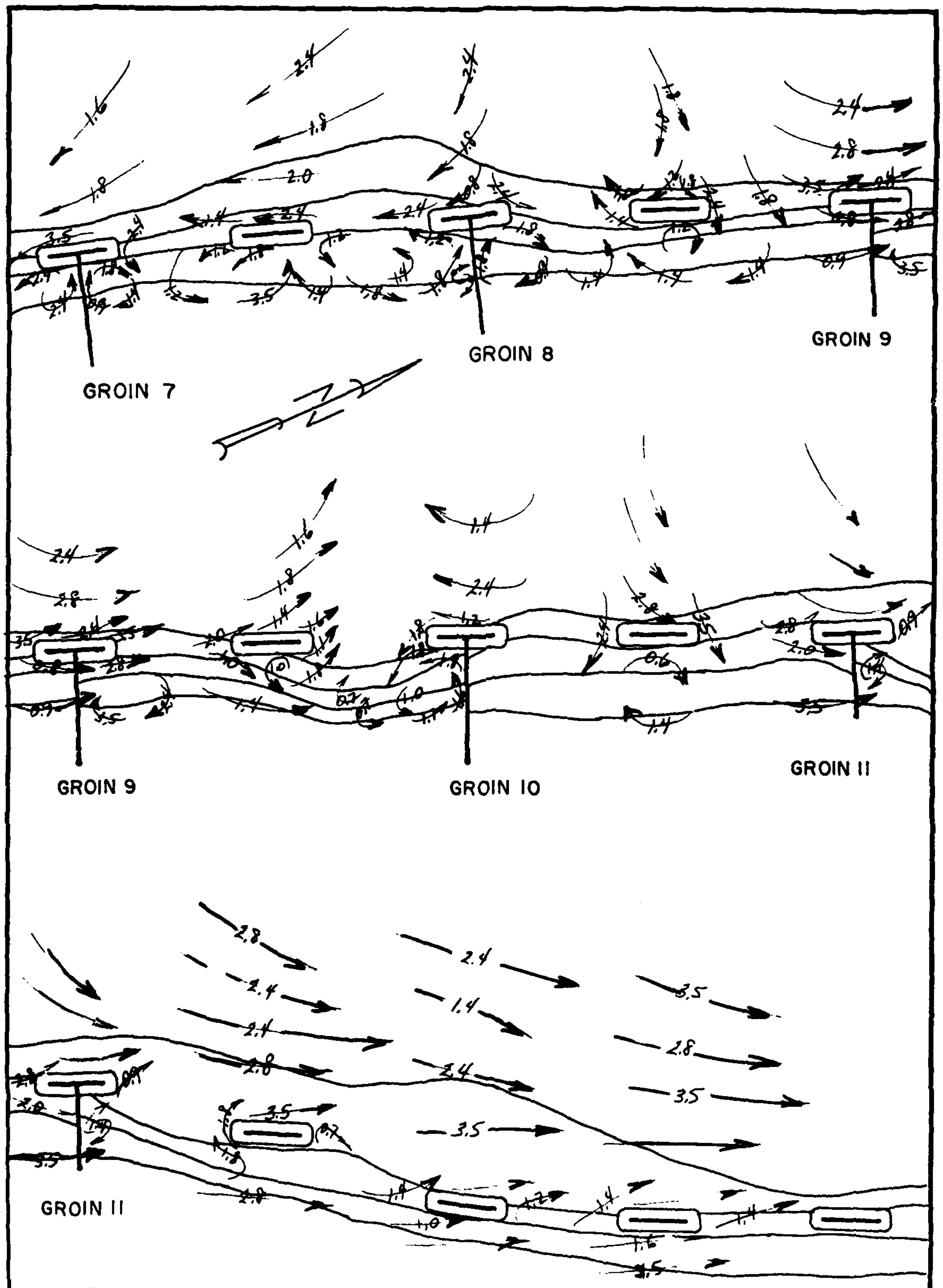
TEST CONDITIONS		
Wave Direction	290	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 40

PLATE 130b



TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 41

BEACH 4

BEACH 5

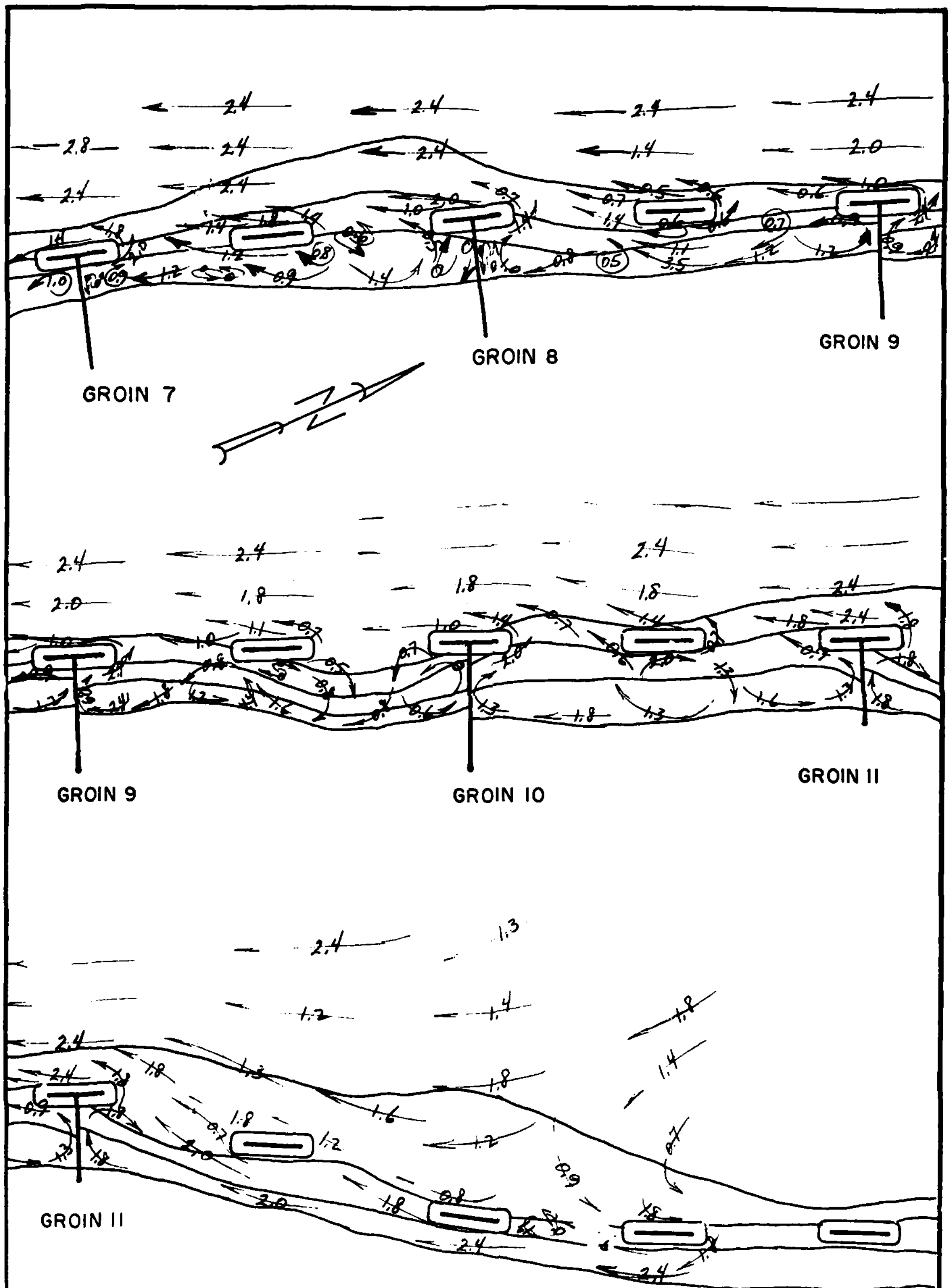
BEACH 6

TEST CONDITIONS		
Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN I

TEST NO. 41



TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SCALE

PROTOTYPE

0 100 200 300 400 500 FT

0 2 4 6 8 10 FT

MODEL

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 42

BEACH 4

BEACH 5

BEACH 6

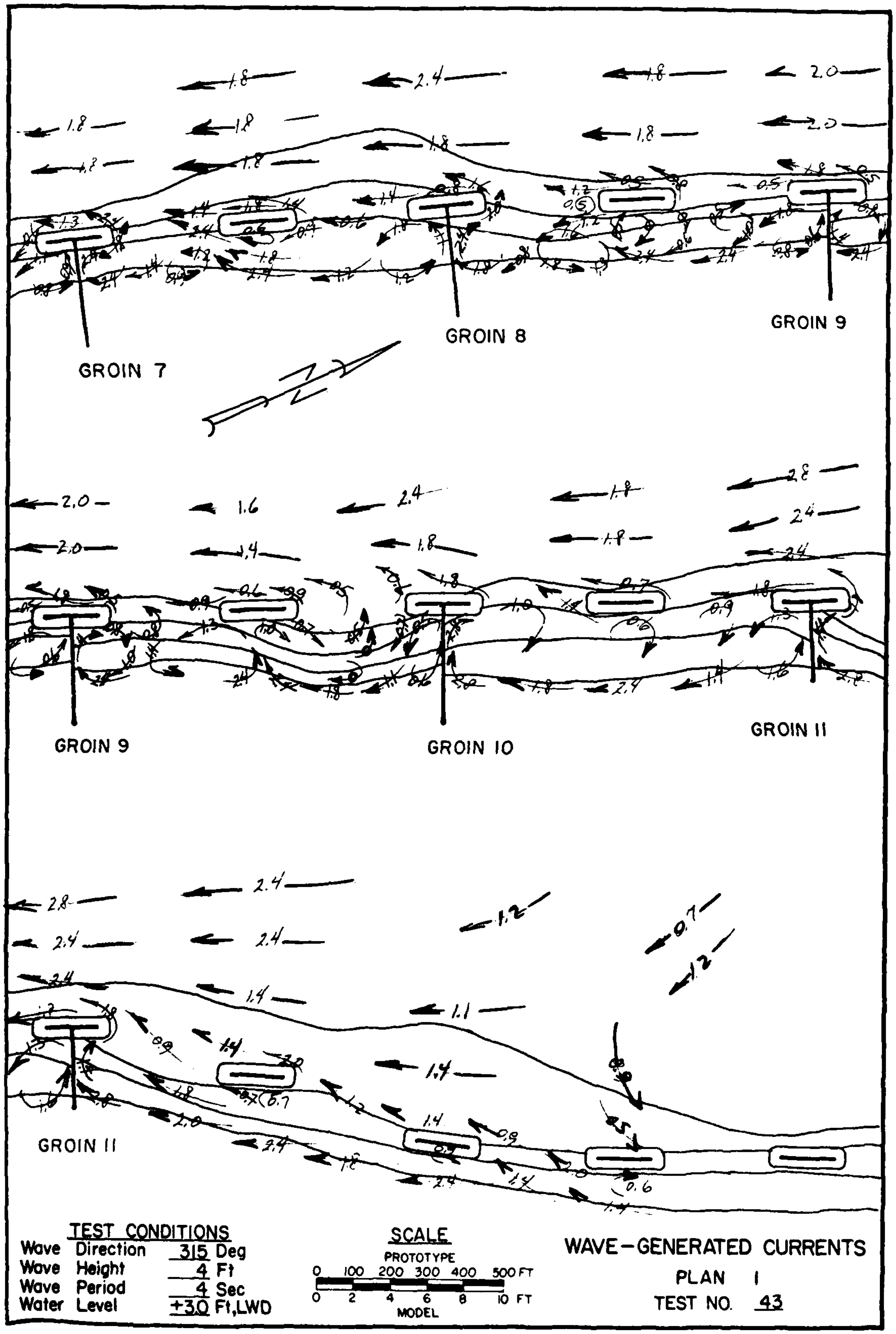
TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

WAVE - GENERATED CURRENTS

PLAN I

TEST NO. 42


GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 315 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN I
TEST NO. 43

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

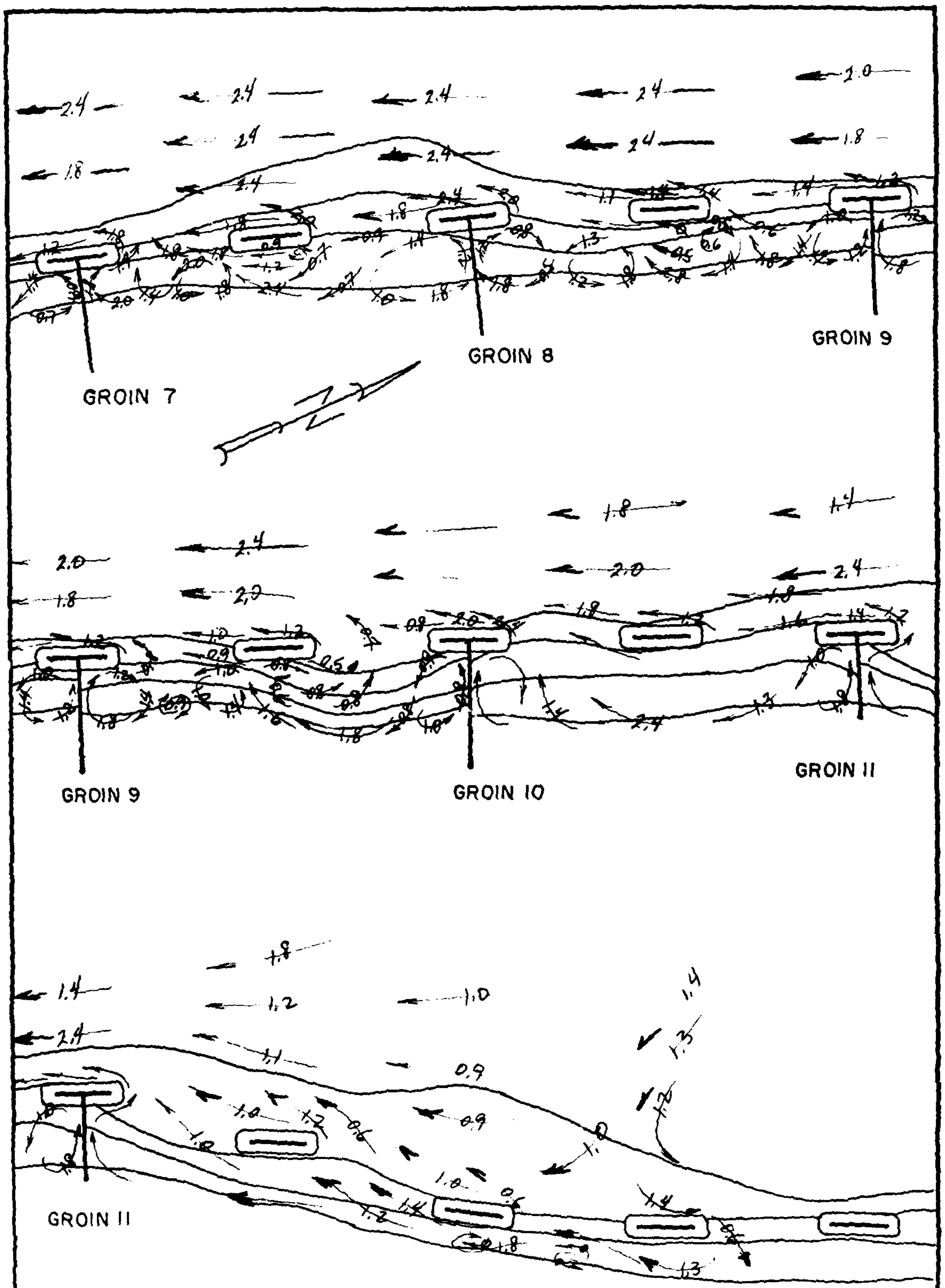
Wave Direction	315	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 43

PLATE 133b

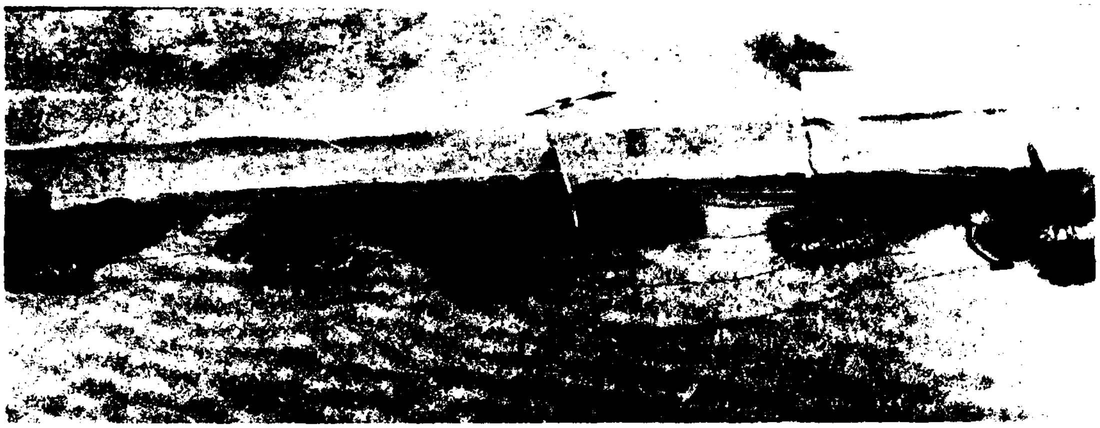


TEST CONDITIONS		
Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE
PROTOTYPE 0 100 200 300 400 500 FT
0 2 4 6 8 10 FT MODEL

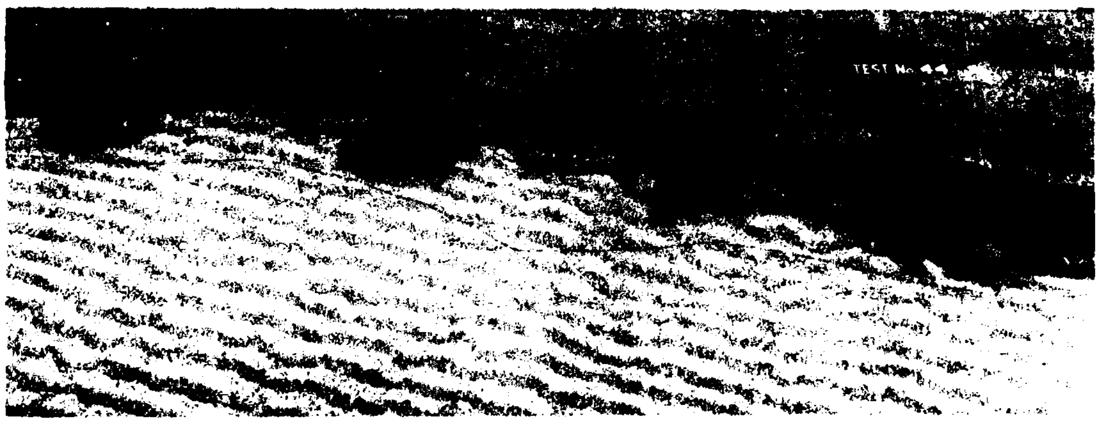
WAVE-GENERATED CURRENTS
PLAN 1
TEST NO. 44

PLATE 134a



BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

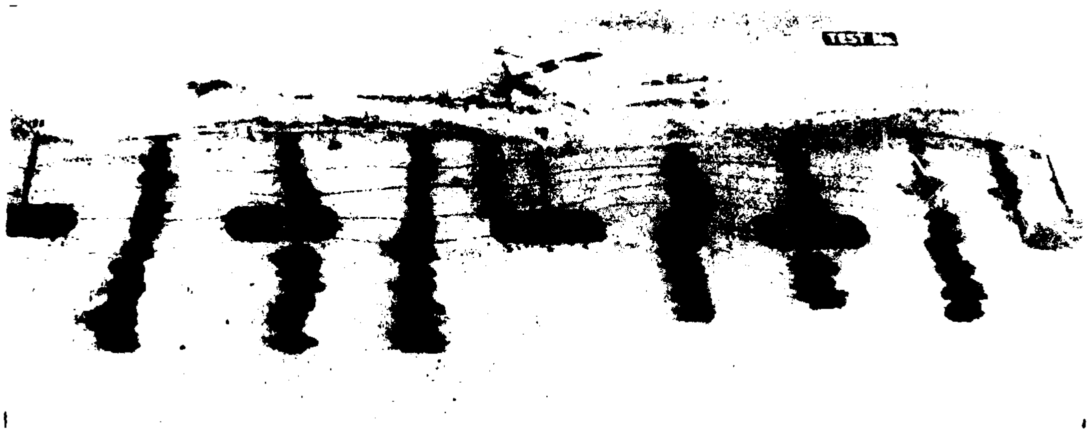
Wave Direction 315 Deg
Wave Height 7 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 1

TEST NO. 44

BEACH 4

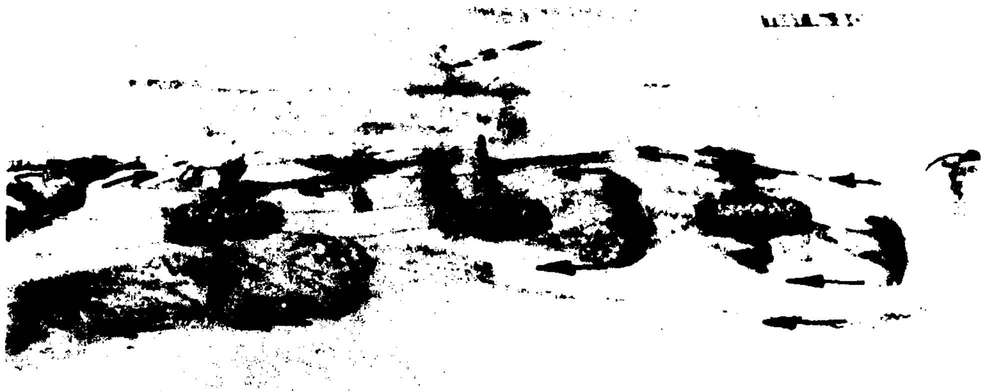


BEACH 5

BEACH 6

SEDIMENT TRACER TEST
LAYOUT FOR
PLAN 1

BEACH 4



BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270 Deg
Wave Height	4 Ft
Wave Period	4 Sec
Water Level	0.0 Ft, LWD

SEDIMENT TRACER TEST
PLAN I
TEST NO. 30

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	2	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 32

BEACH 4

BEACH 5

BEACH 6

<u>TEST CONDITIONS</u>

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST
PLAN I
TEST NO. 33

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

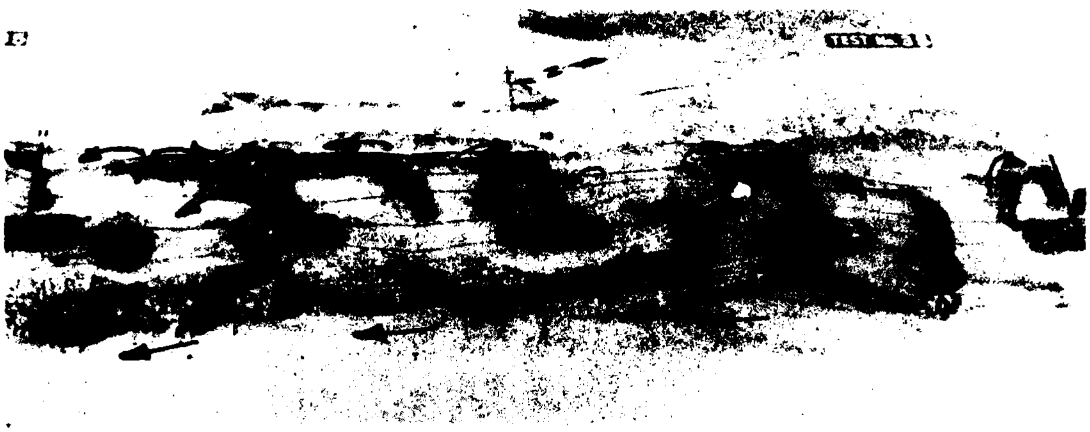
Wave	Direction	270 Deg
Wave	Height	7 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 34

BEACH 4



BEACH 5

BEACH 6

TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	10	Ft
Wave	Period	6	Sec
Water	Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST

PLAN 1

TEST NO. 35

BEACH 4

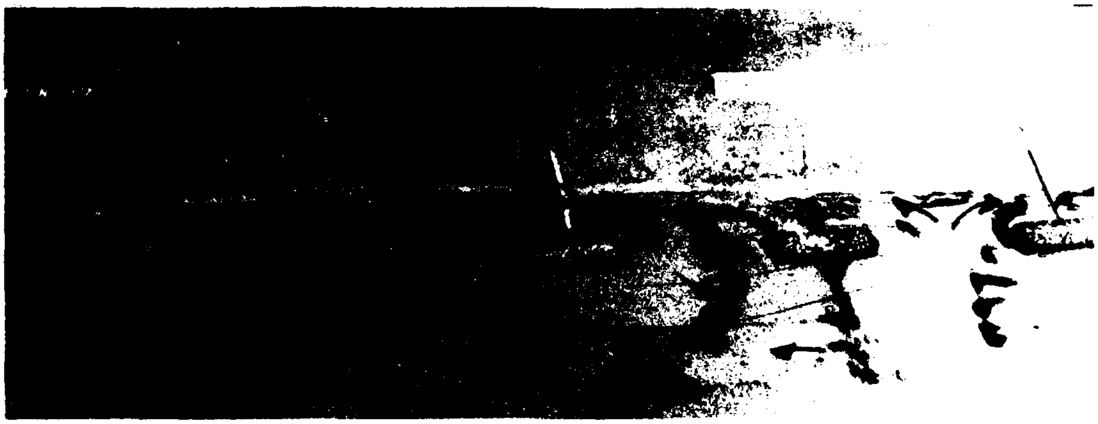
BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 12 Ft
Wave Period 9 Sec
Water Level +6.9 Ft,LWD

SEDIMENT TRACER TEST
PLAN I
TEST NO. 36



BEACH 4

BEACH 5

BEACH 6

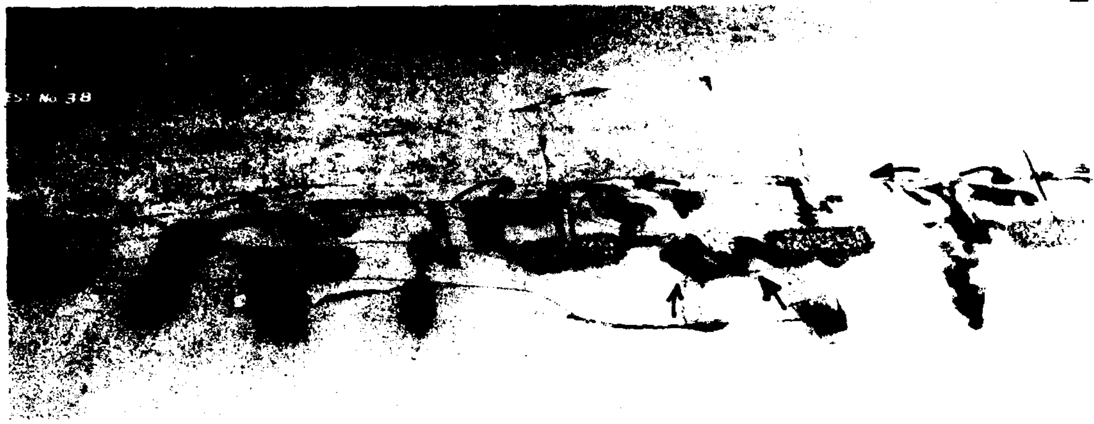
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	0.0	Ft, LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 37



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 38

BEACH 4

BEACH 5

BEACH 6

<u>TEST CONDITIONS</u>

Wave Direction	290	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST

PLAN 1

TEST NO. 39

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave	Direction	290 Deg
Wave	Height	10 Ft
Wave	Period	6 Sec
Water	Level	+3.0 Ft,LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 40

BEACH 4

BEACH 5

BEACH 6

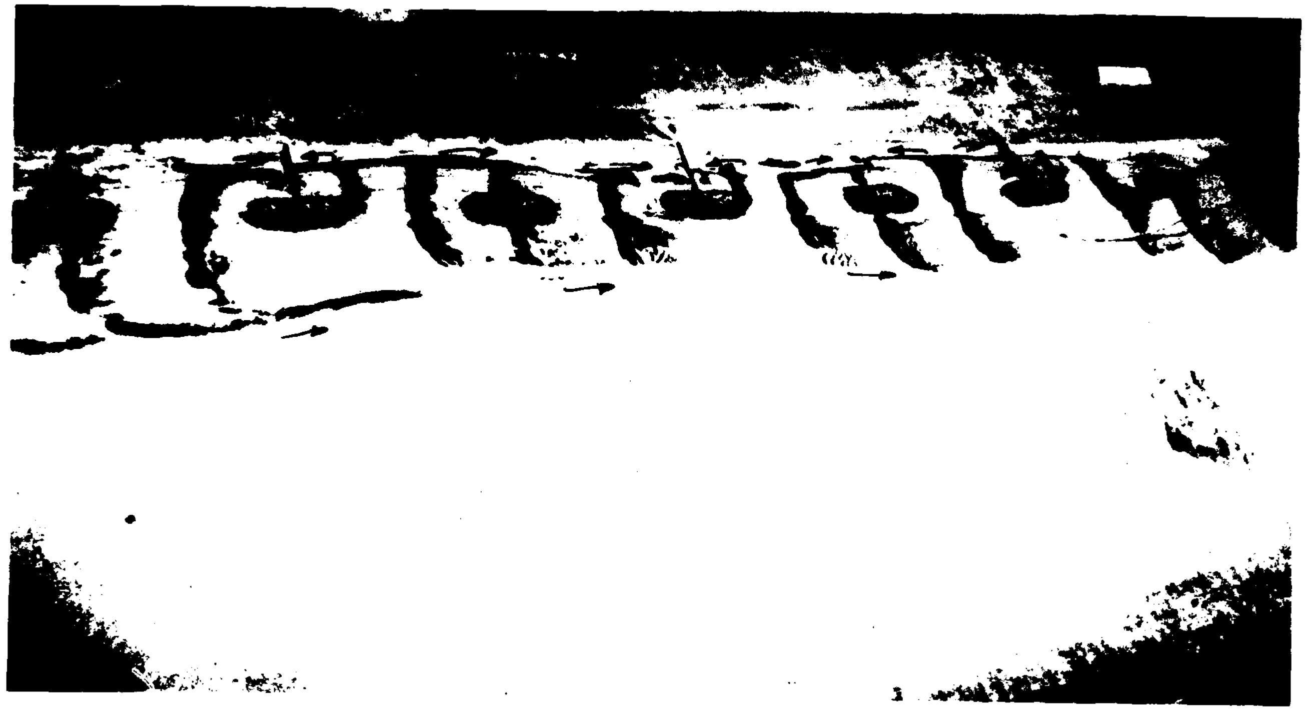
TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

SEDIMENT TRACER TEST

PLAN I

TEST NO. 41



TEST CONDITIONS

Wave	Direction	315	Deg
Wave	Height	4	Ft
Wave	Period	4	Sec
Water	Level	0.0	Ft,LWD

SEDIMENT TRACER TEST
PLAN I
TEST NO. 42

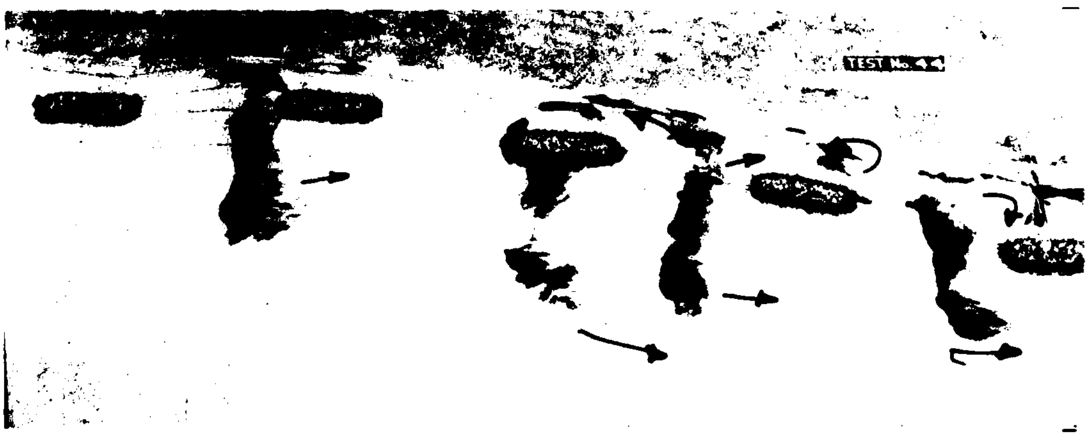
Wave	Direction	315	Deg
Wave	Height	4	Ft
Wave	Period	4	Sec
Water	Level	+3.0	Ft, LWD

TEST CONDITIONS

SEDIMENT TRACER TEST
PLAN 1
TEST NO. 43

BEACH 4

BEACH 5



BEACH 6

TEST CONDITIONS

Wave Direction	315	Deg
Wave Height	7	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST
PLAN I
TEST NO. 44

TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	4 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

BEACH FILL TEST
PLAN 1
TEST NO. 33
HOUR 5.0

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 6 Ft
Wave Period 6 Sec
Water Level +5.0 Ft,LWD

BEACH FILL TEST
PLAN I
TEST NO. 33-1
HOUR 2.0

TEST CONDITIONS

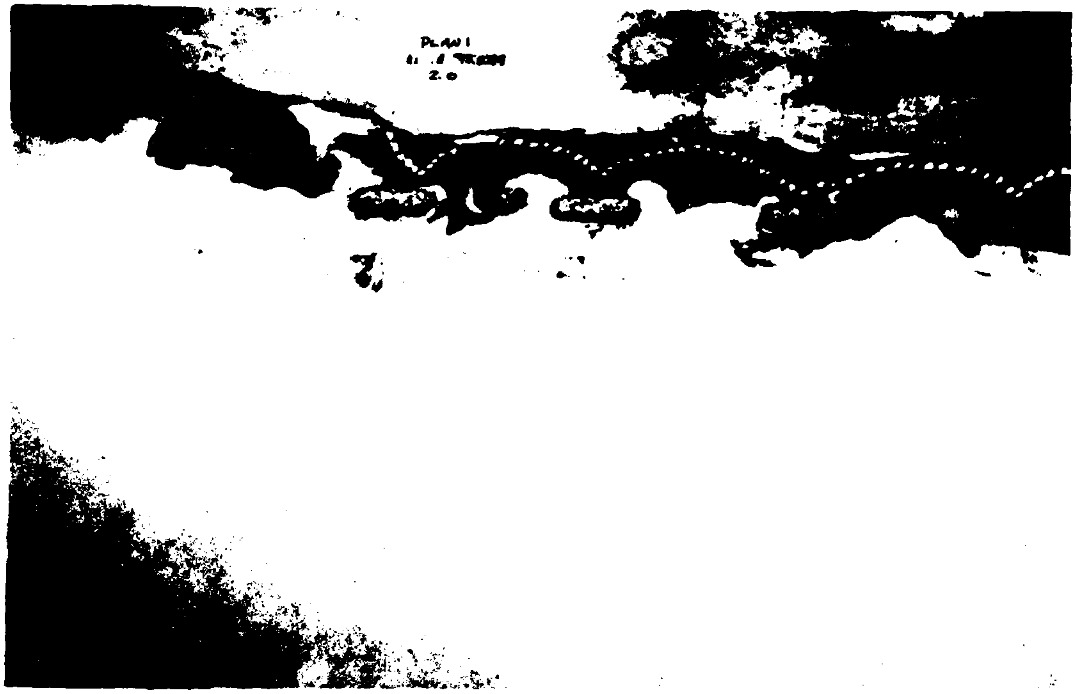
Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST
PLAN I
TEST NO. 36
HOUR 10

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

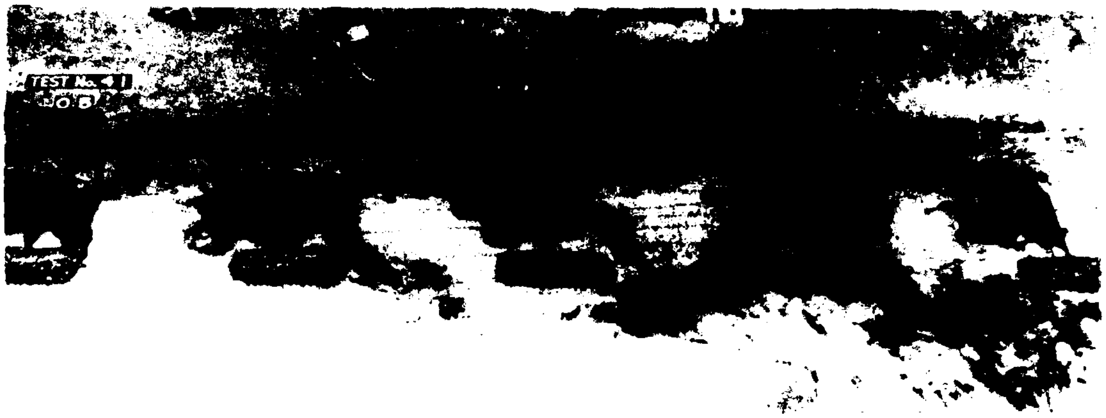
BEACH FILL TEST
PLAN I
TEST NO. 38
HOUR 50



TEST CONDITIONS

Wave Direction	290 Deg
Wave Height	6 Ft
Wave Period	6 Sec
Water Level	+5.0 Ft,LWD

BEACH FILL TEST
PLAN 1
TEST NO. 38-1
HOUR 2.0



BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST
PLAN I
TEST NO. 41
HOUR 0.5

BEACH 5

BEACH 6

TEST CONDITIONS		
Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST
PLAN I
TEST NO. 41
HOUR 1.0

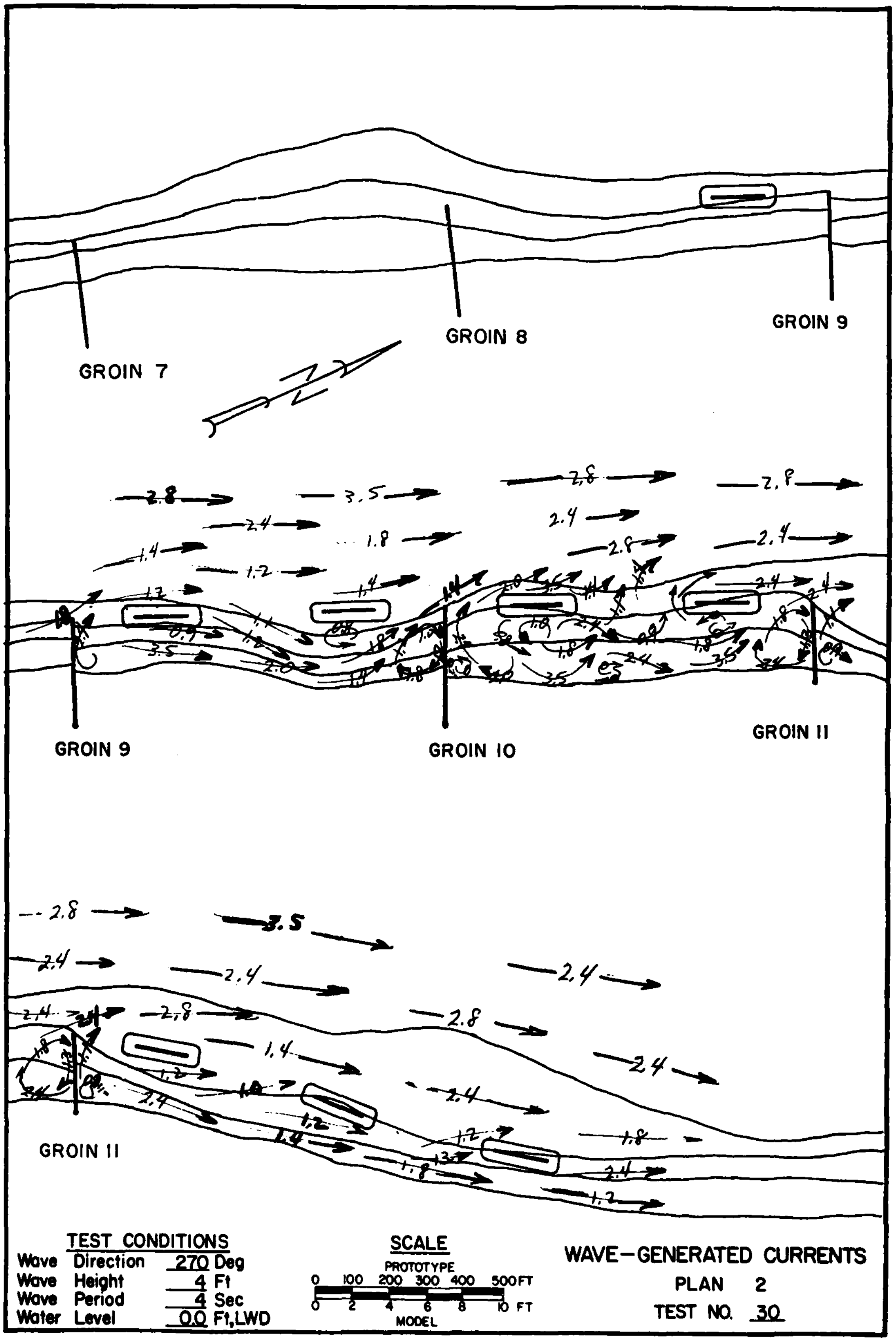

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level 0.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 2
TEST NO. 30

PLATE 157a

BEACH 5

BEACH 6

TEST CONDITIONS

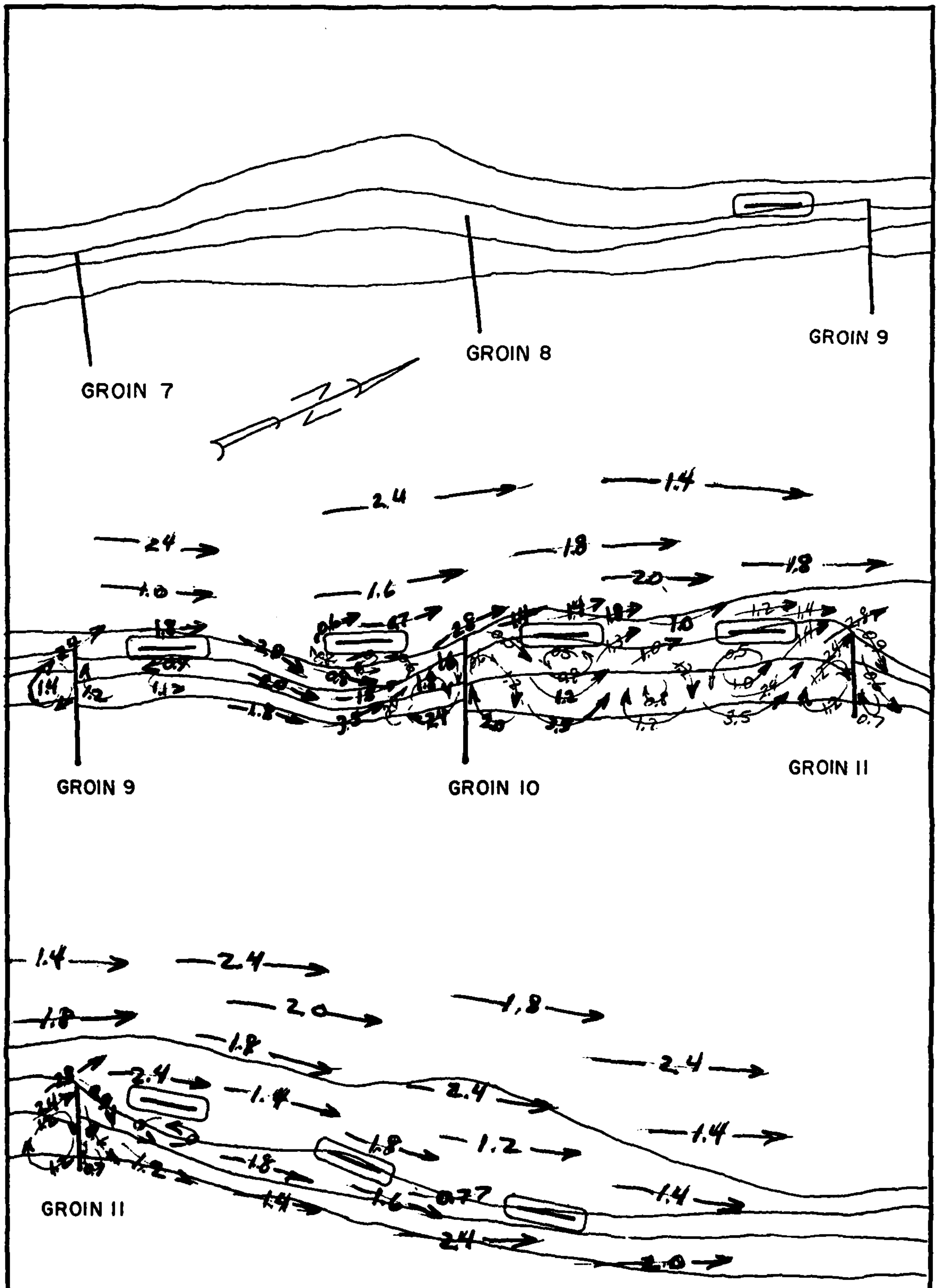
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level 0.0 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 2

TEST NO. 30

PLATE 157b



TEST CONDITIONS		
Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL

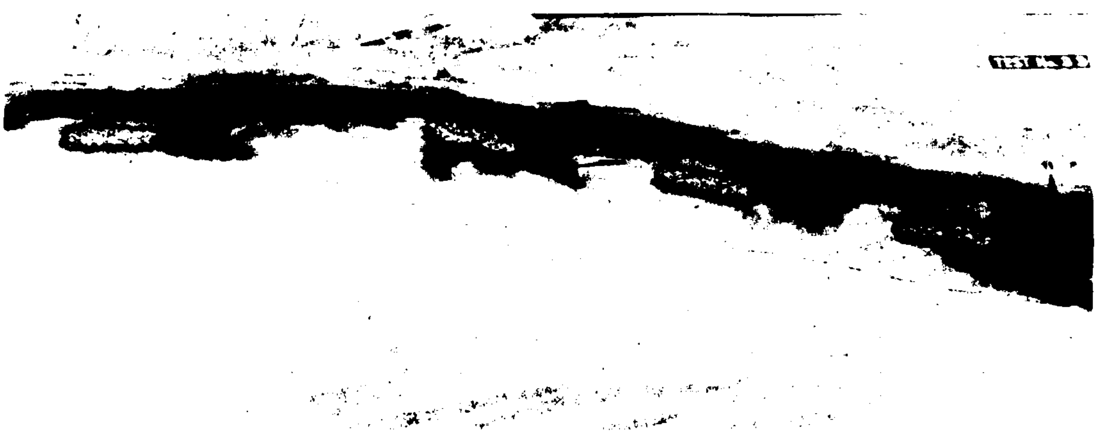
WAVE-GENERATED CURRENTS

PLAN 2

TEST NO. 33

PLATE 158a

BEACH 5



BEACH 6

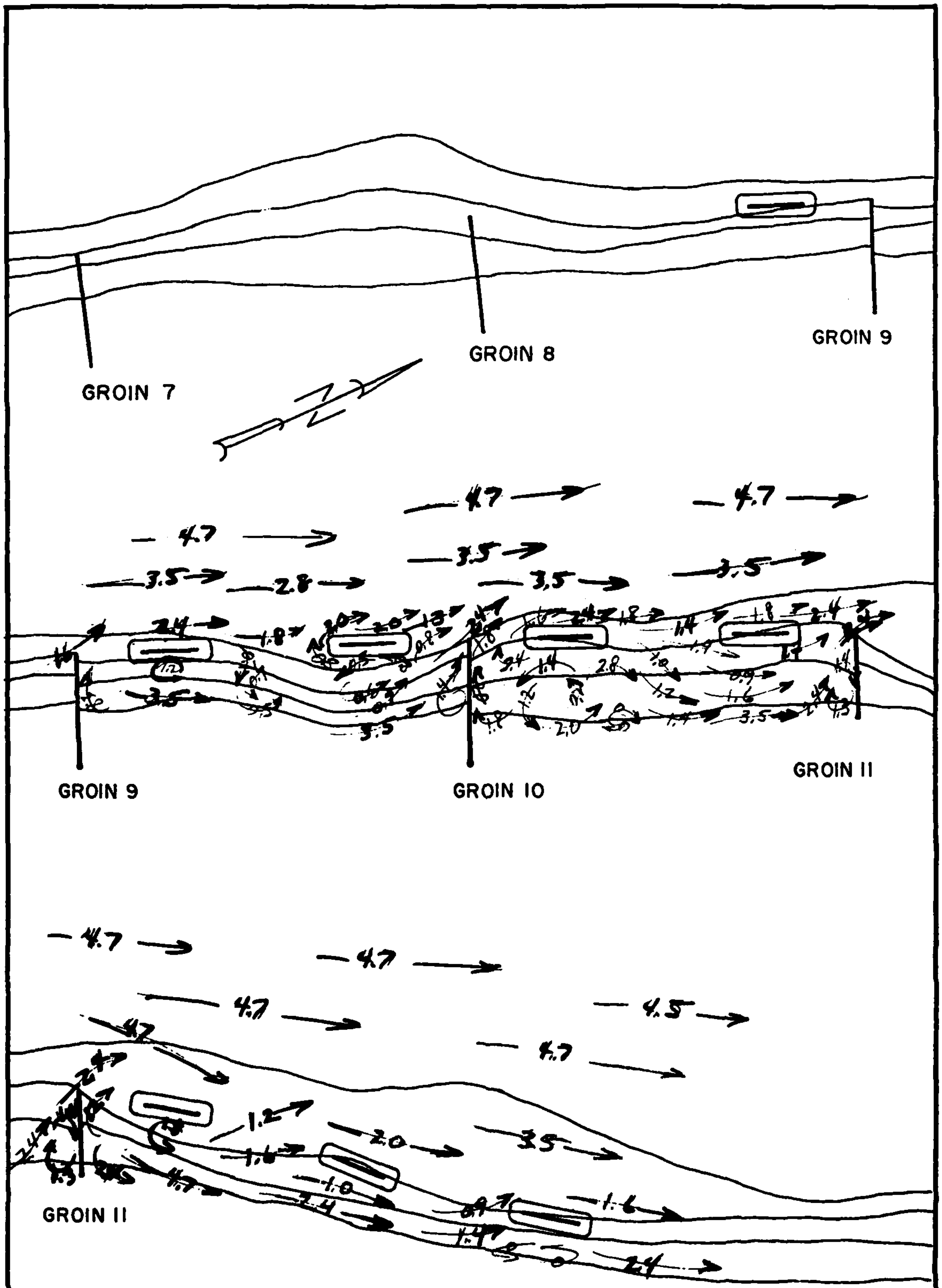
TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 2

TEST NO. 33



TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

SCALE

PROTOTYPE: 0 100 200 300 400 500 FT

MODEL: 0 2 4 6 8 10 FT

WAVE-GENERATED CURRENTS

PLAN 2

TEST NO. 35

PLATE 159a

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 2

TEST NO. 35

PLATE 159b

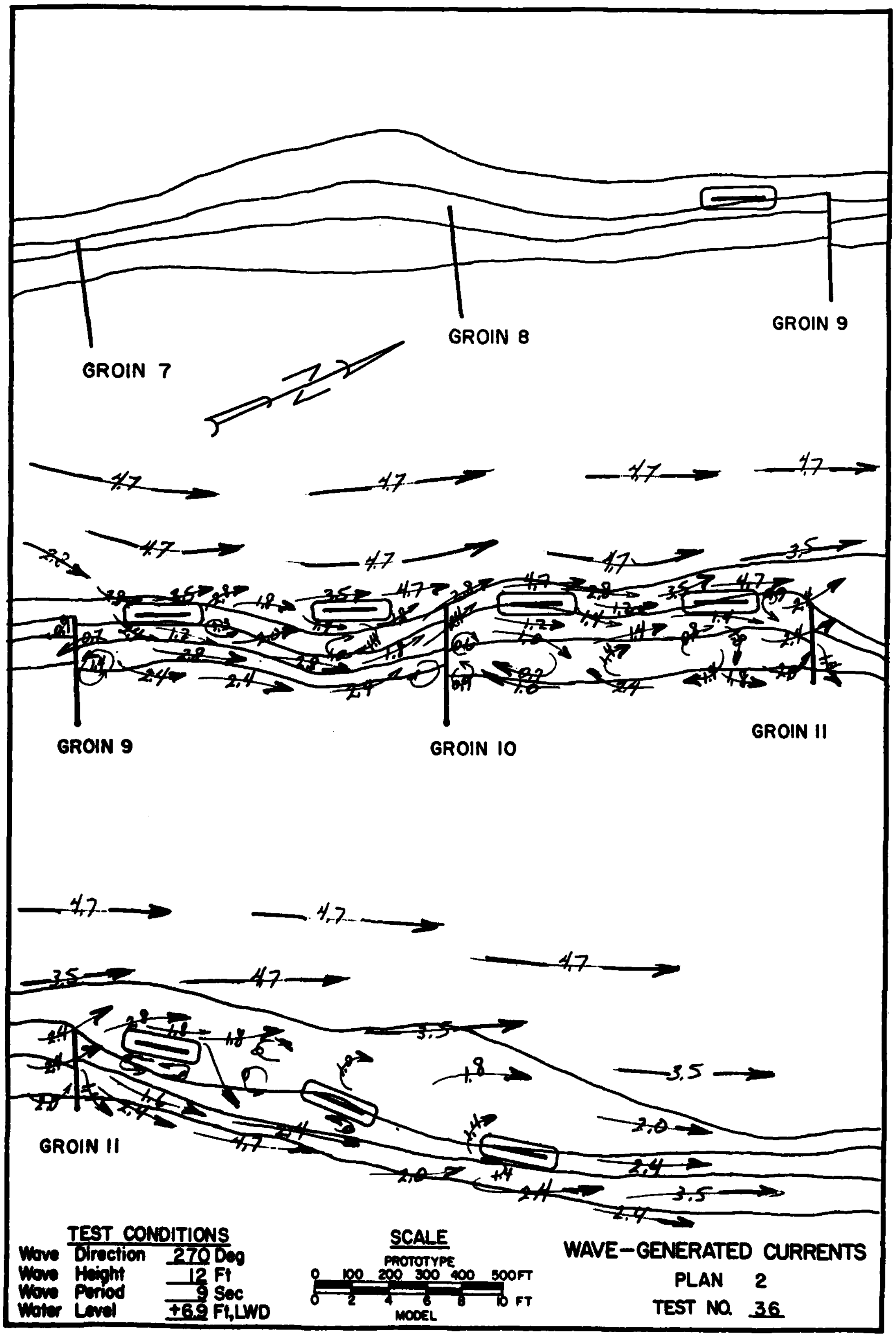

GROIN 7
GROIN 8
GROIN 9
GROIN 9
GROIN 10
GROIN 11
GROIN 11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 12 Ft
Wave Period 9 Sec
Water Level +6.9 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 2
TEST NO. 36

PLATE 160a

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 12 Ft
Wave Period 9 Sec
Water Level +6.9 Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 2

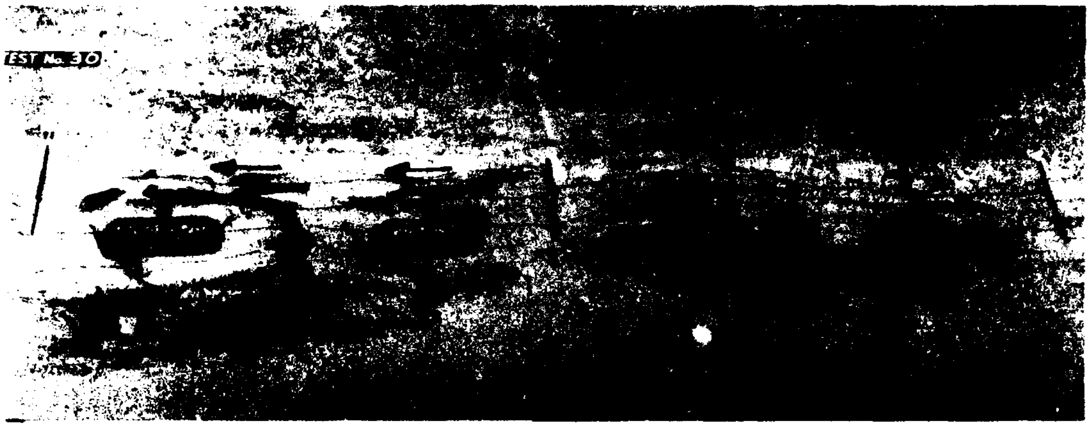
TEST NO. 36

PLATE 160b

BEACH 5

BEACH 6

SEDIMENT TRACER TEST
LAYOUT FOR
PLAN 2



BEACH 5

BEACH 6

TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	4	Ft
Wave	Period	4	Sec
Water	Level	0.0	Ft,LWD

SEDIMENT TRACER TEST

PLAN 2

TEST NO. 30

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST
PLAN 2
TEST NO. 33

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	10	Ft
Wave Period	6	Sec
Water Level	+3.0	Ft,LWD

SEDIMENT TRACER TEST
PLAN 2
TEST NO. 35

BEACH 5

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

SEDIMENT TRACER TEST
PLAN 2
TEST NO. 36

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

BEACH FILL TEST

PLAN 2

TEST NO. 33

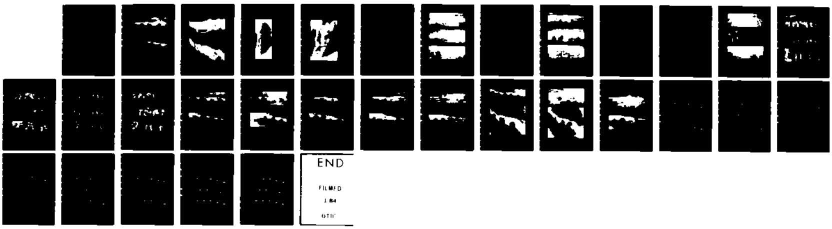
HOUR 2.5

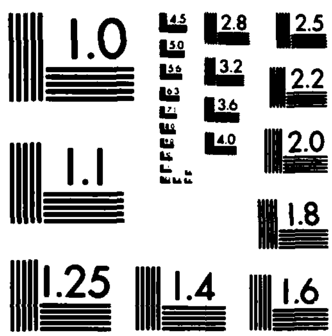
TEST CONDITIONS		
Wave	Direction	270 Deg
Wave	Height	4 Ft
Wave	Period	4 Sec
Water	Level	+3.0 Ft,LWD

BEACH FILL TEST
PLAN 2
TEST NO. 33
HOUR 5.0

AD-A135 394 DESIGN FOR PREVENTION OF BEACH EROSION AT PRESQUE ISLE BEACHES ERIE PENNS..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS HYDRA.. W C SEABERGH 4/4

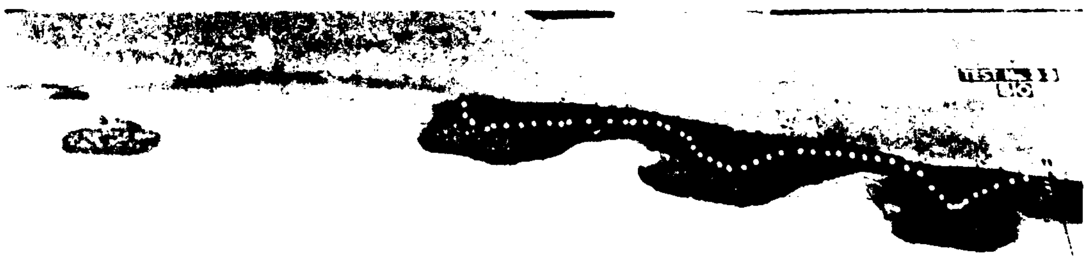
UNCLASSIFIED JUN 83 WES/TR/HL-83-15 F/G 8/8 NL





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

BEACH 5



BEACH 6

TEST CONDITIONS		
Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

BEACH FILL TEST
PLAN 2
TEST NO. 33
HOUR 5.0

PLATE 167b

<u>TEST CONDITIONS</u>

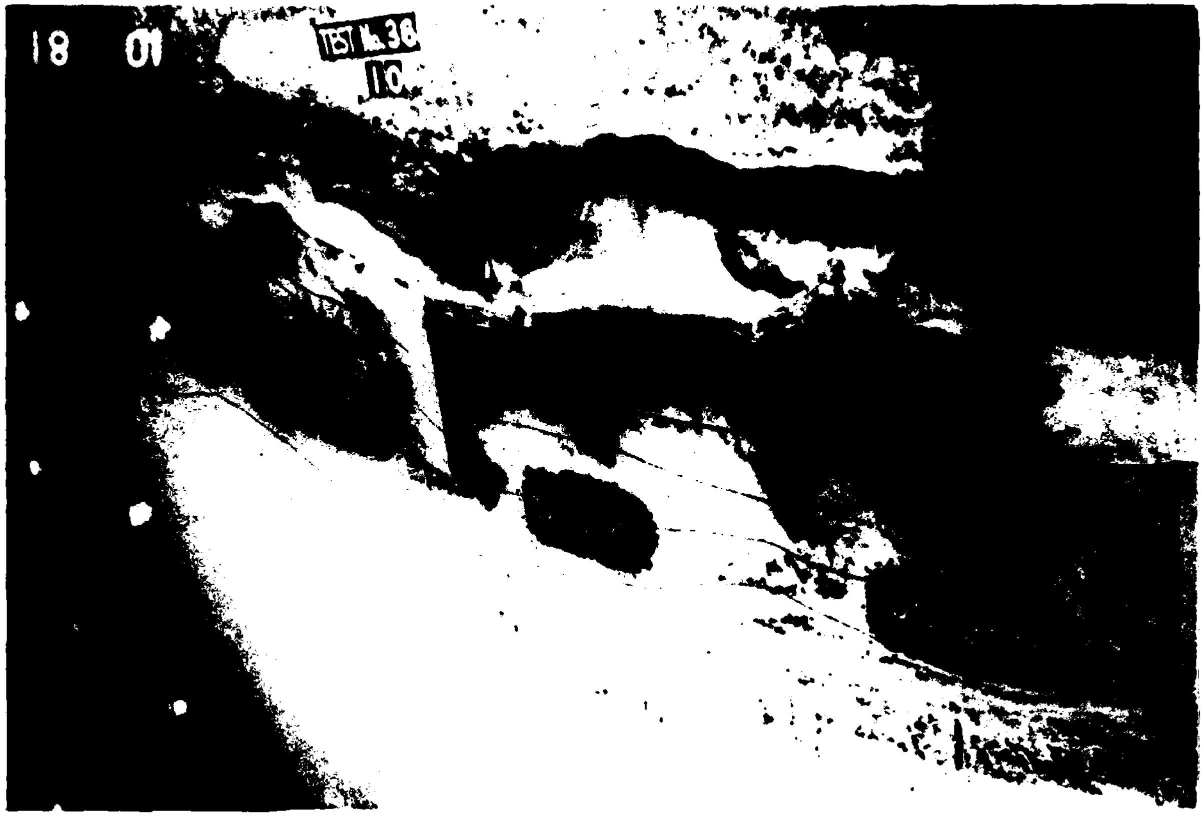
Wave Direction 270 Deg
Wave Height 6 Ft
Wave Period 6 Sec
Water Level +5.0 Ft,LWD

BEACH FILL TEST
PLAN 2
TEST NO. 33-1
HOUR 2.0

TEST CONDITIONS

Wave	Direction	270 Deg
Wave	Height	12 Ft
Wave	Period	9 Sec
Water	Level	+6.9 Ft,LWD

BEACH FILL TEST
PLAN 2
TEST NO. 36
HOUR 10



TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	12	Ft
Wave	Period	9	Sec
Water	Level	+6.9	Ft,LWD

BEACH FILL TEST
PLAN 2
TEST NO. 36
HOUR 1.0

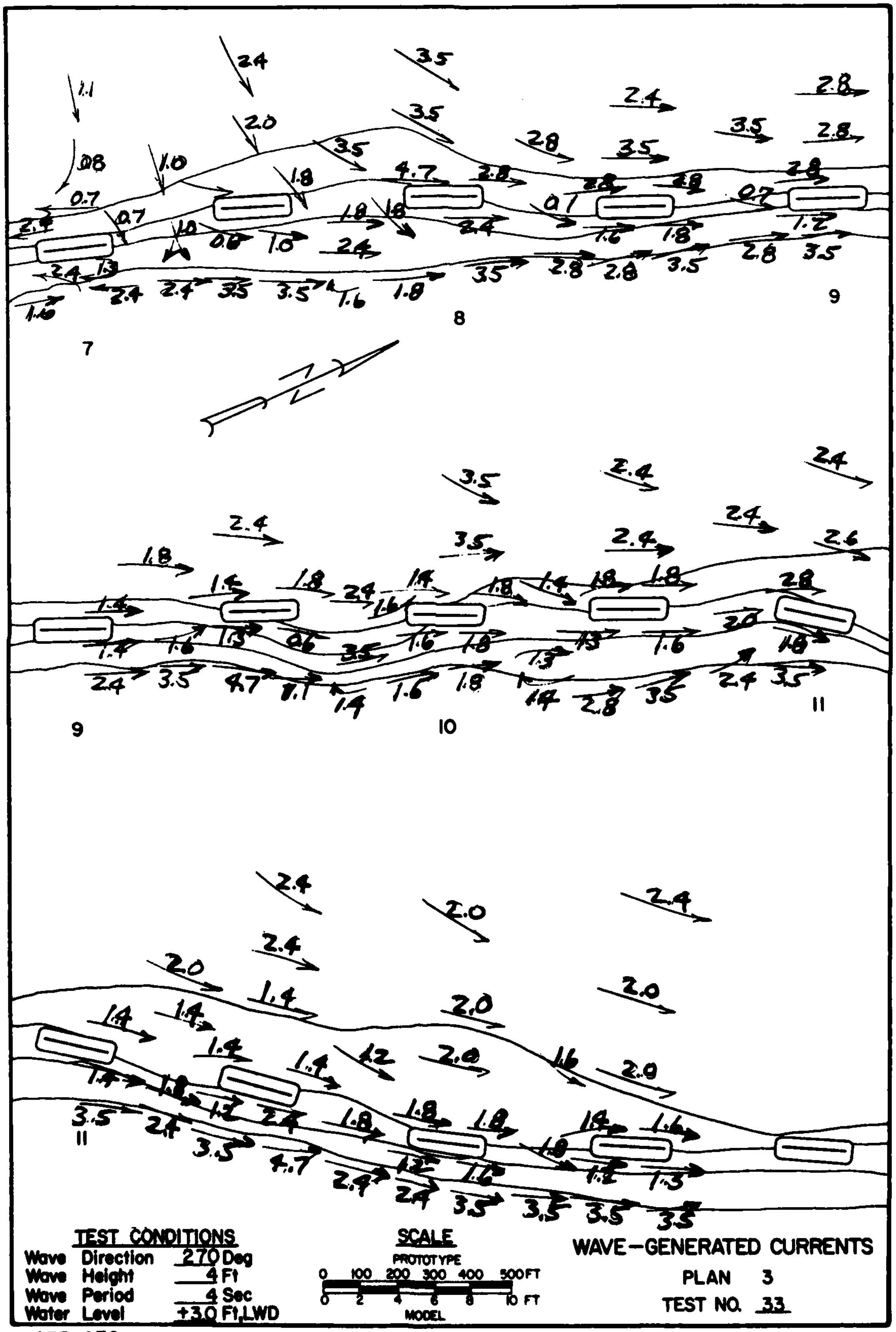

7
8
9
10
11
TEST CONDITIONS
Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 3
TEST NO. 33

PLATE 170a

BEACH 4

BEACH 5

BEACH 6

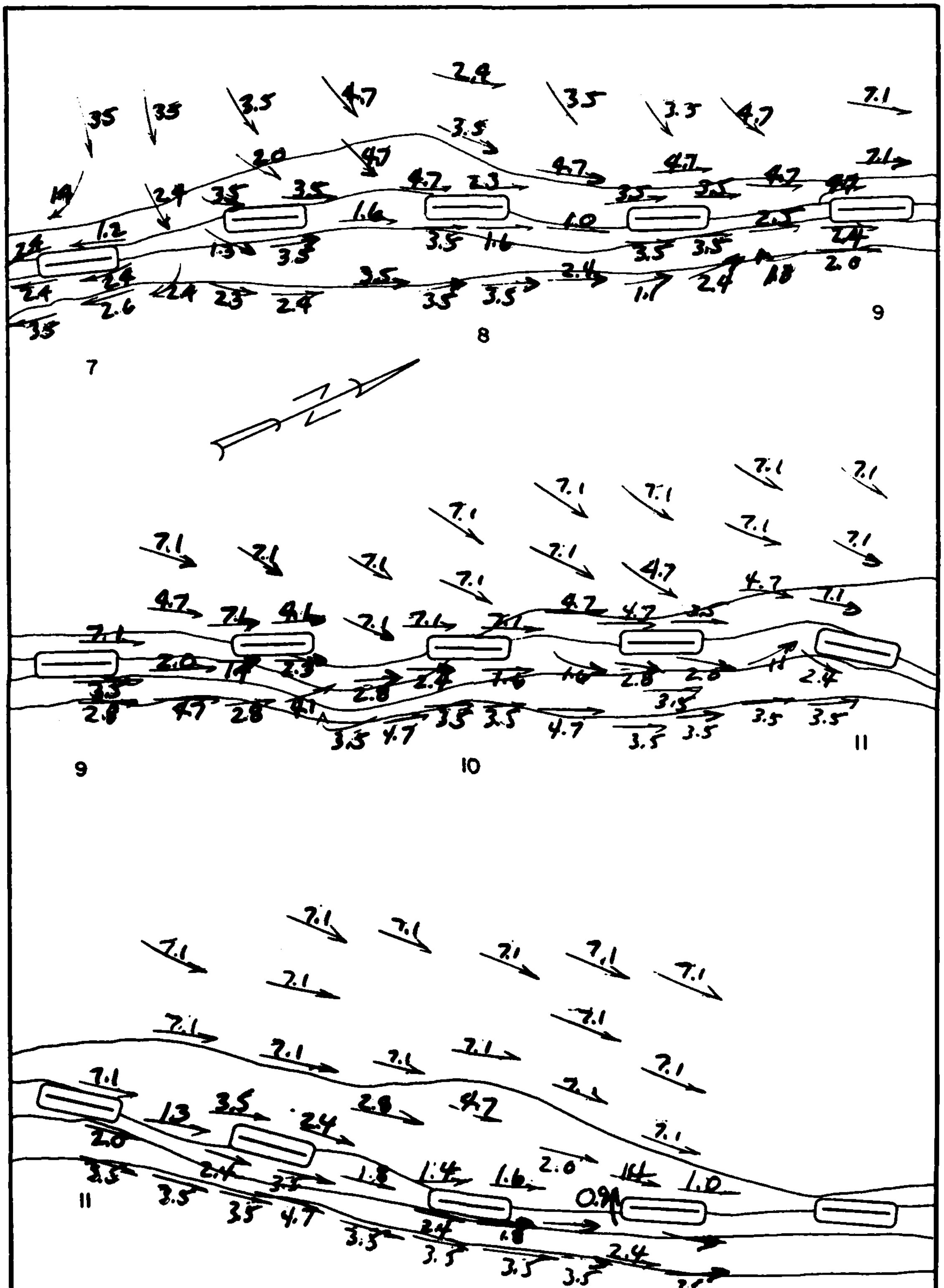
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

WAVE-GENERATED CURRENTS

PLAN 3

TEST NO. 33



TEST CONDITIONS

Wave Direction	270 Deg
Wave Height	12 Ft
Wave Period	9 Sec
Water Level	+6.9 Ft, LWD

SCALE

PROTOTYPE 0 100 200 300 400 500 FT

MODEL 0 2 4 6 8 10 FT

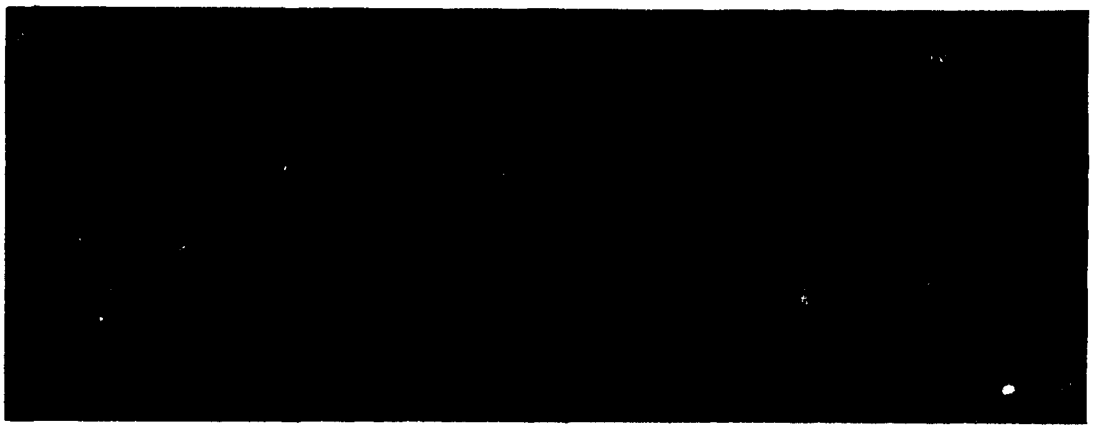
WAVE-GENERATED CURRENTS

PLAN 3

TEST NO. 36

BEACH 4

BEACH 5



BEACH 6

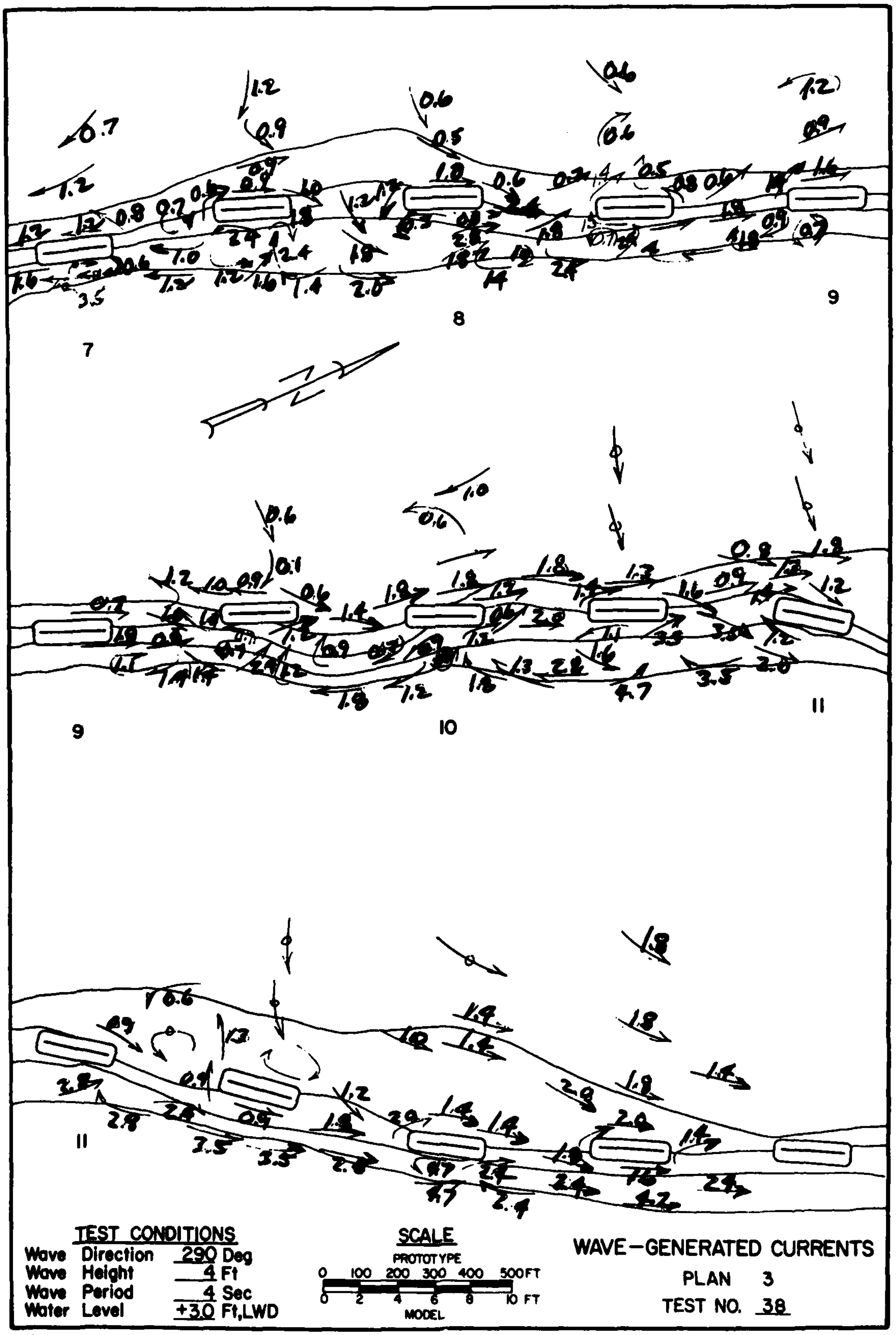
TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft, LWD

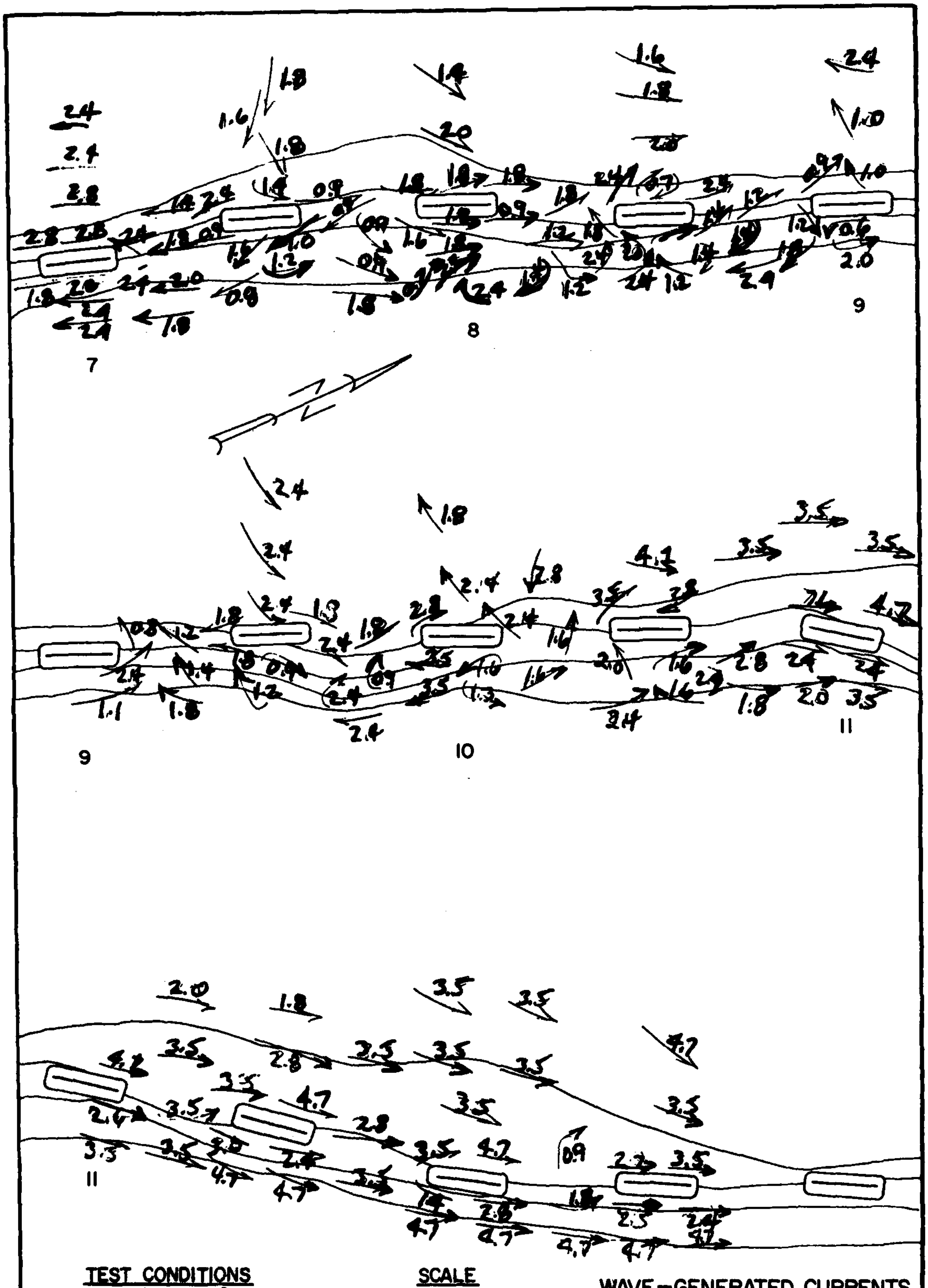
WAVE-GENERATED CURRENTS

PLAN 3

TEST NO. 36



7
8
9
9
10
11
11
TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD
SCALE
PROTOTYPE
0 100 200 300 400 500 FT
0 2 4 6 8 10 FT
MODEL
WAVE-GENERATED CURRENTS
PLAN 3
TEST NO. 38



TEST CONDITIONS

Wave Direction 290 Deg
Wave Height 12 Ft
Wave Period 9 Sec
Water Level +6.9 Ft, LWD

SCALE

PROTOTYPE
0 100 200 300 400 500 FT
0 4 6 10 FT
MODEL

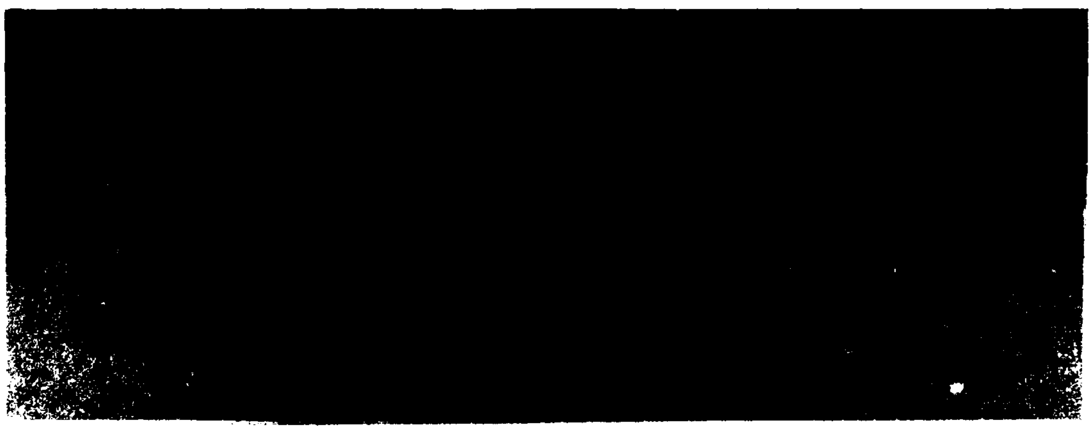
WAVE-GENERATED CURRENTS

PLAN 3

TEST NO. 41

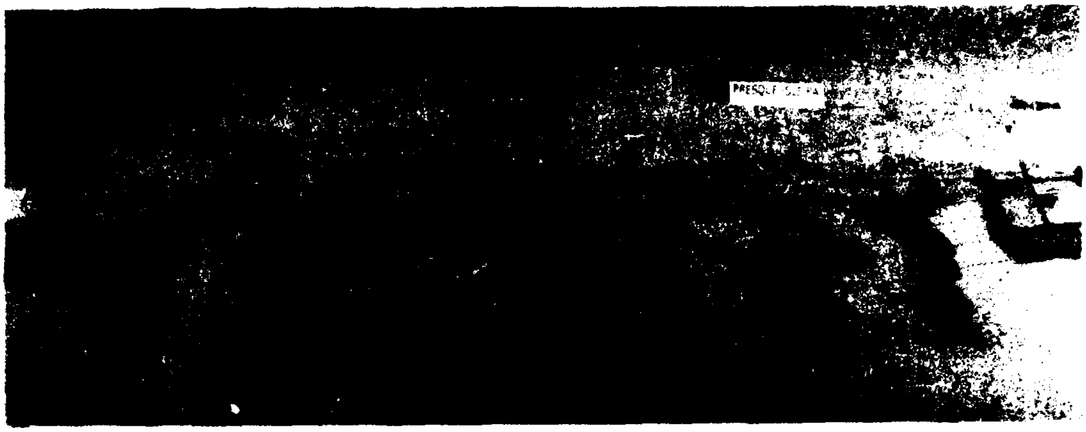
BEACH 4

BEACH 5



BEACH 6

SEDIMENT TRACER TEST
LAYOUT FOR
PLAN 3



BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction 270 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD

SEDIMENT TRACER TEST
PLAN 3
TEST NO. 33

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave	Direction	270	Deg
Wave	Height	12	Ft
Wave	Period	9	Sec
Water	Level	+6.9	Ft, LWD

SEDIMENT TRACER TEST

PLAN 3

TEST NO. 36

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft, LWD

SEDIMENT TRACER TEST
PLAN 3
TEST NO. 38

BEACH 4

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

SEDIMENT TRACER TEST

PLAN 3

TEST NO. 41

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

BEACH FILL TEST

PLAN 3

TEST NO. 33

HOUR 2.5

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	4	Ft
Wave Period	4	Sec
Water Level	+3.0	Ft,LWD

BEACH FILL TEST

PLAN 3

TEST NO. 33

HOUR 50

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+5.0	Ft,LWD

BEACH FILL TEST
PLAN 3
TEST NO. 33-1
HOUR 0.5

BEACH 5

BEACH 6

TEST CONDITIONS

Wave Direction	270	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+5.0	Ft,LWD

BEACH FILL TEST

PLAN 3

TEST NO. 33-1

HOUR 20

BEACH 5

BEACH 6

TEST CONDITIONS		
Wave Direction	270	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST

PLAN 3

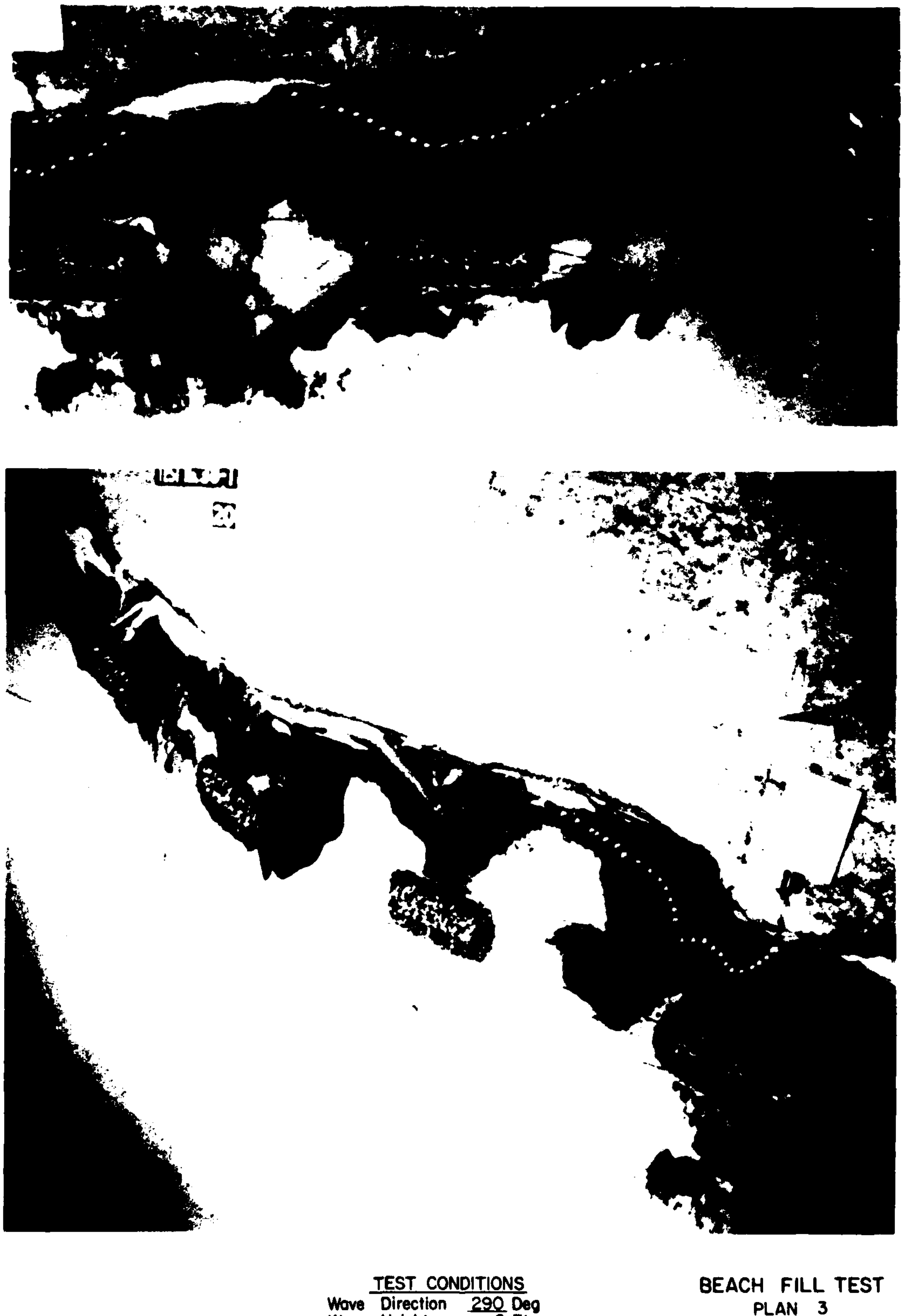
TEST NO. 36

HOUR 10

TEST CONDITIONS
Wave Direction 290 Deg
Wave Height 4 Ft
Wave Period 4 Sec
Water Level +3.0 Ft,LWD

BEACH FILL TEST
PLAN 3
TEST NO. 38
HOUR 5.0

PLATE 184



TEST CONDITIONS

Wave Direction	290	Deg
Wave Height	6	Ft
Wave Period	6	Sec
Water Level	+5.0	Ft,LWD

BEACH FILL TEST

PLAN 3

TEST NO. 38-1

HOUR 2.0

BEACH 5

BEACH 6

TEST CONDITIONS

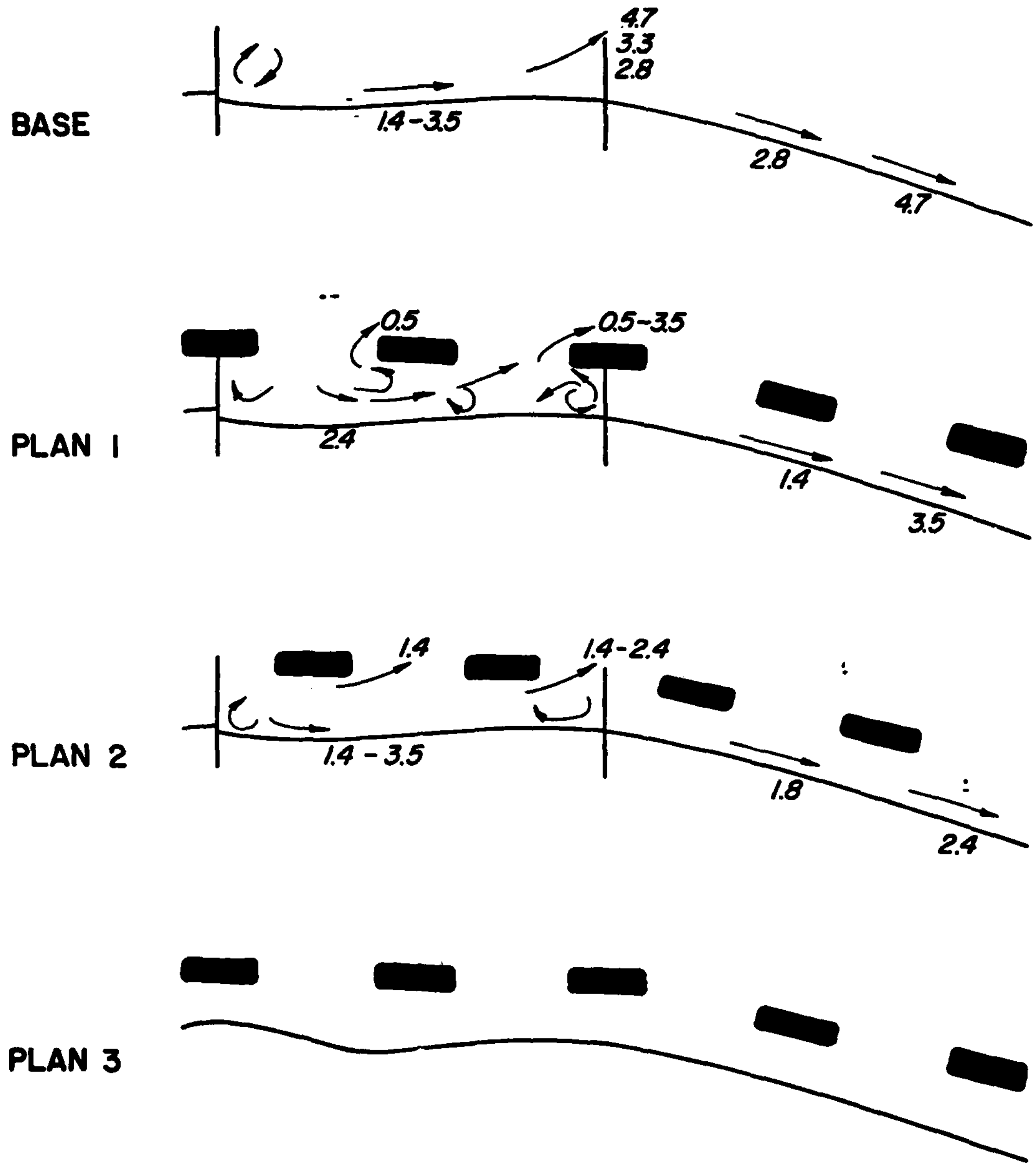
Wave Direction	290	Deg
Wave Height	12	Ft
Wave Period	9	Sec
Water Level	+6.9	Ft,LWD

BEACH FILL TEST

PLAN 3

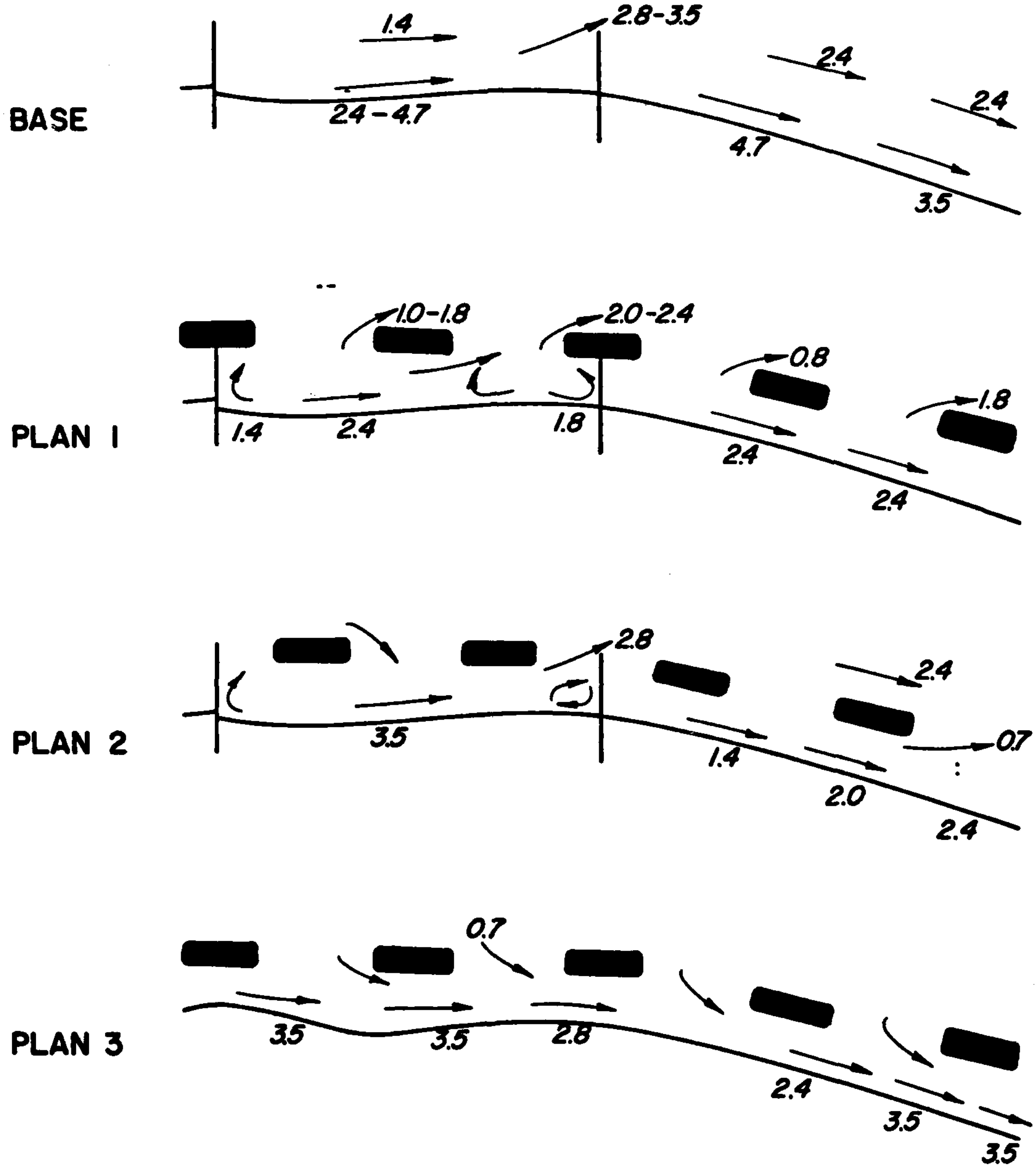
TEST NO. 41

HOUR 1.0



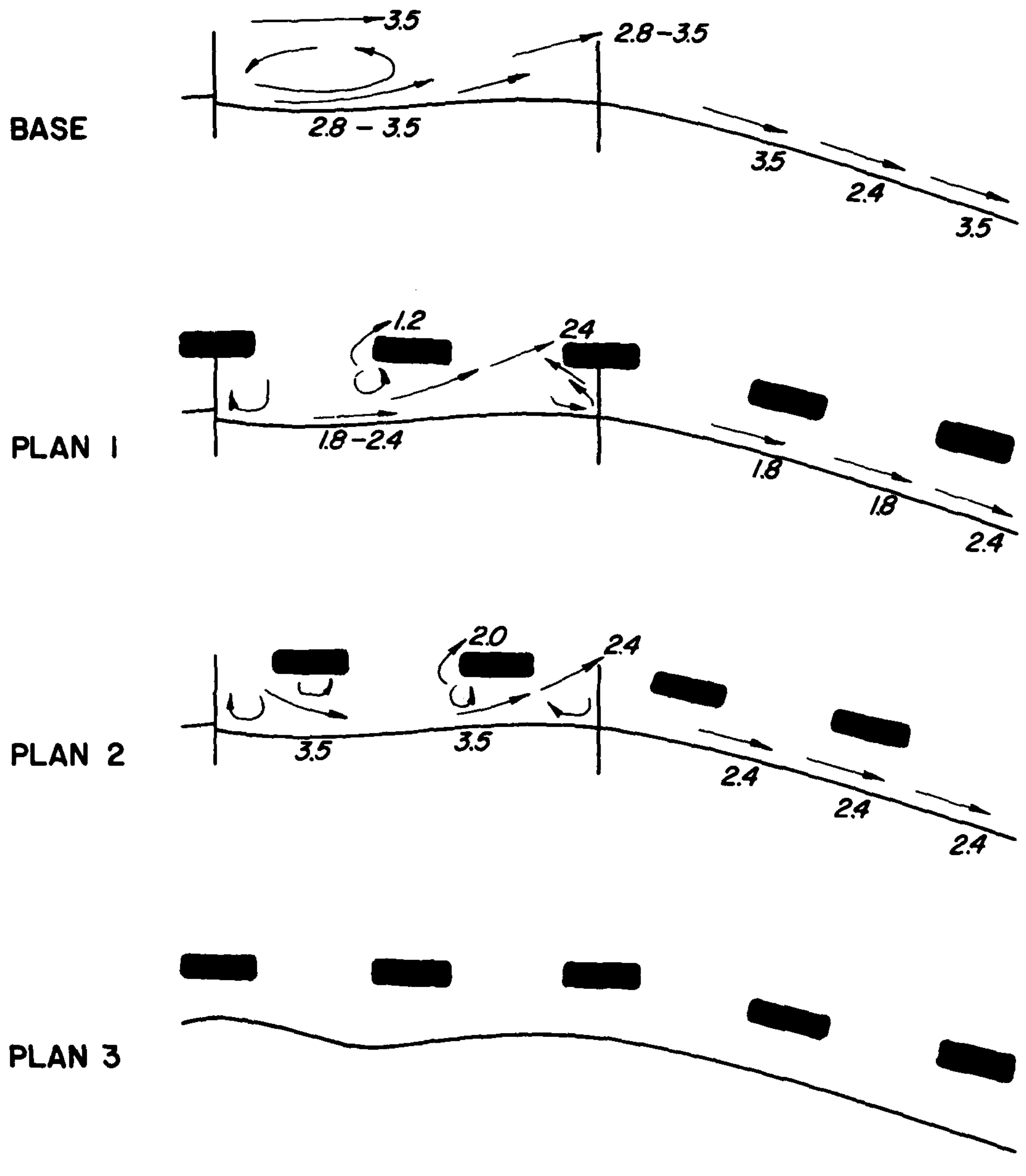
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 270°, 4 Ft-4 Sec Waves
at 0.0 Ft, LWD



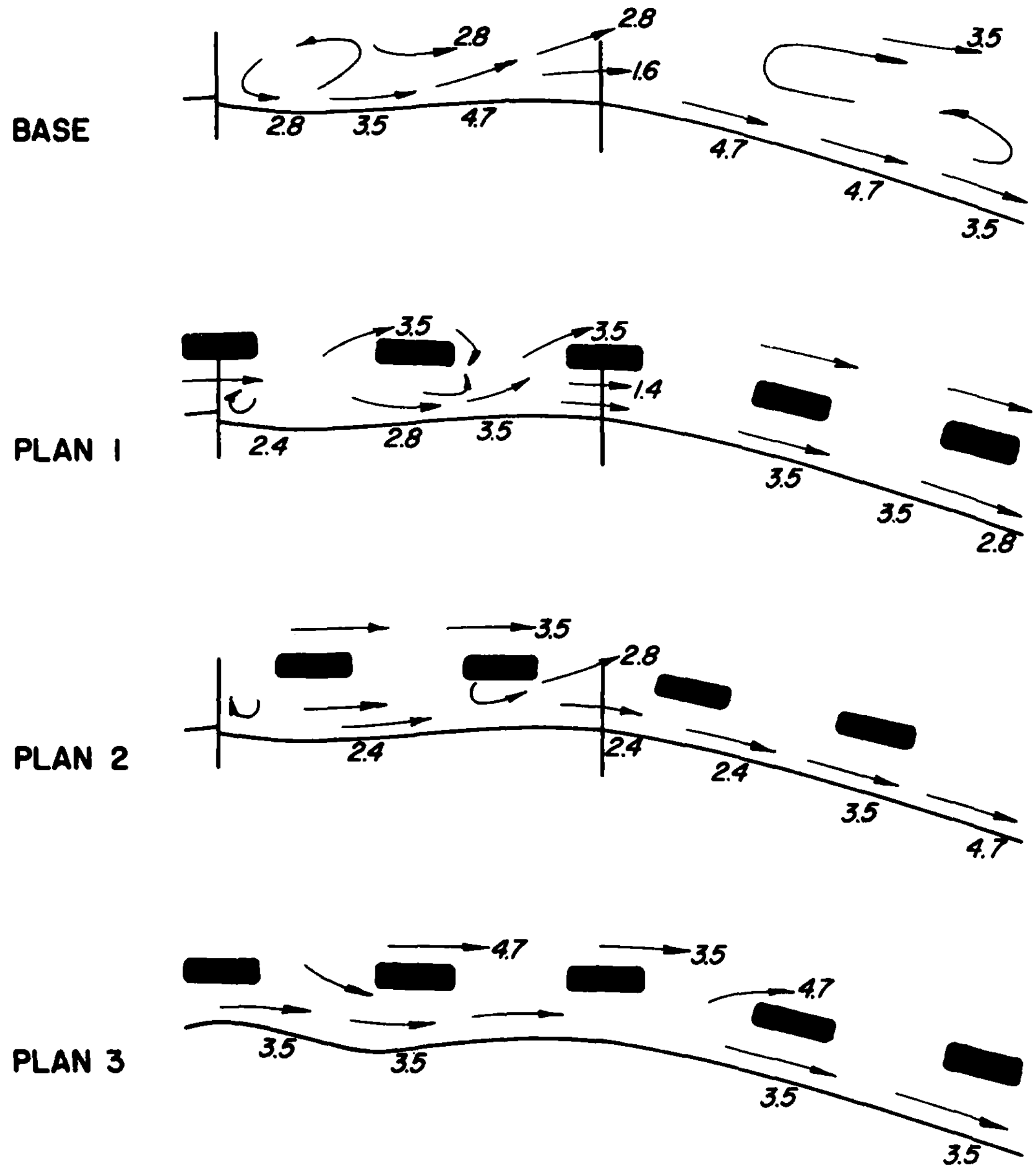
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 270°, 4 Ft-4 Sec Waves
at +3.0 Ft, LWD



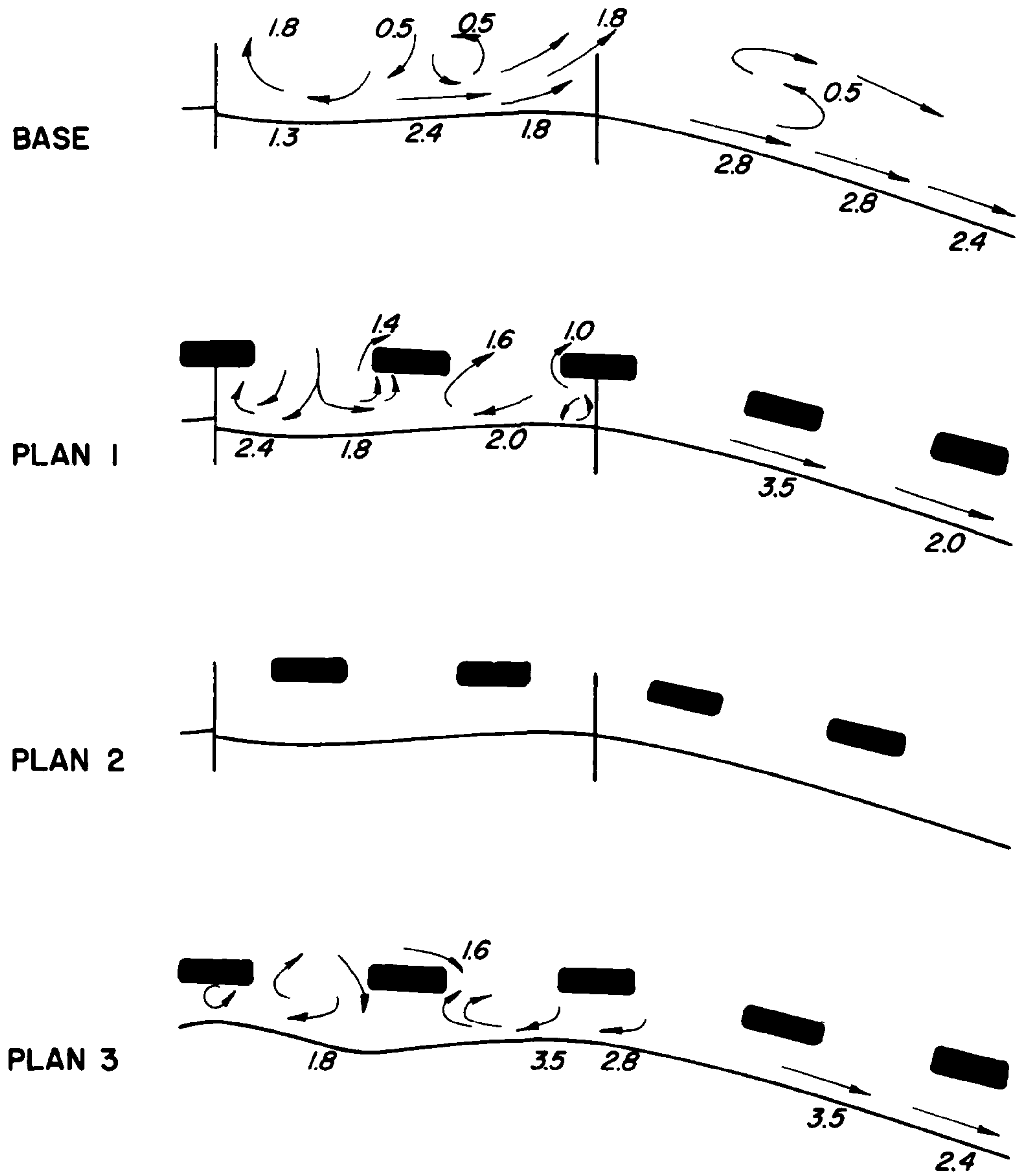
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 270°, 10 Ft-6 Sec Waves
at +3.0 Ft, LWD



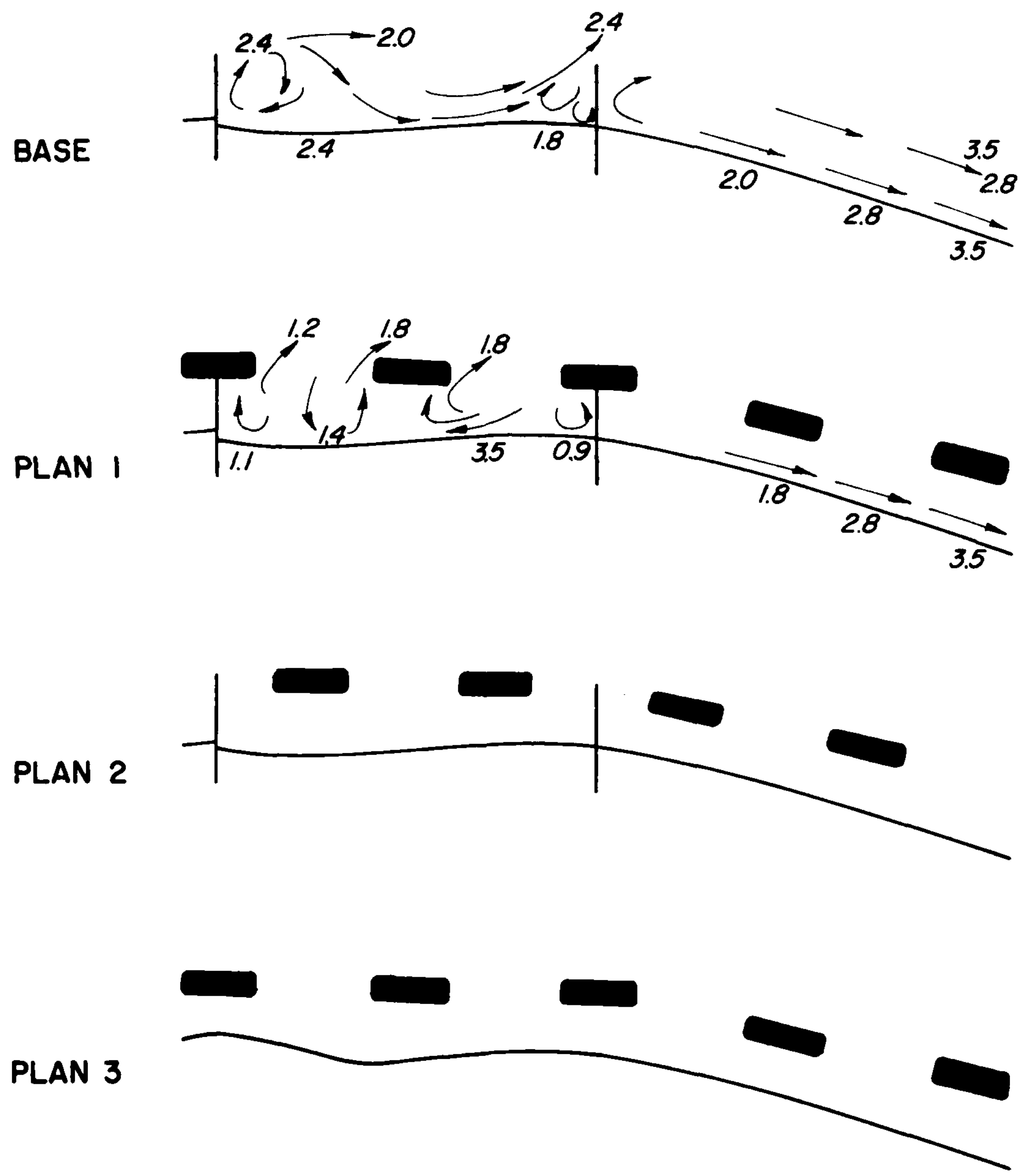
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 270°, 12 Ft-9 Sec Waves
at +6.9 Ft, LWD



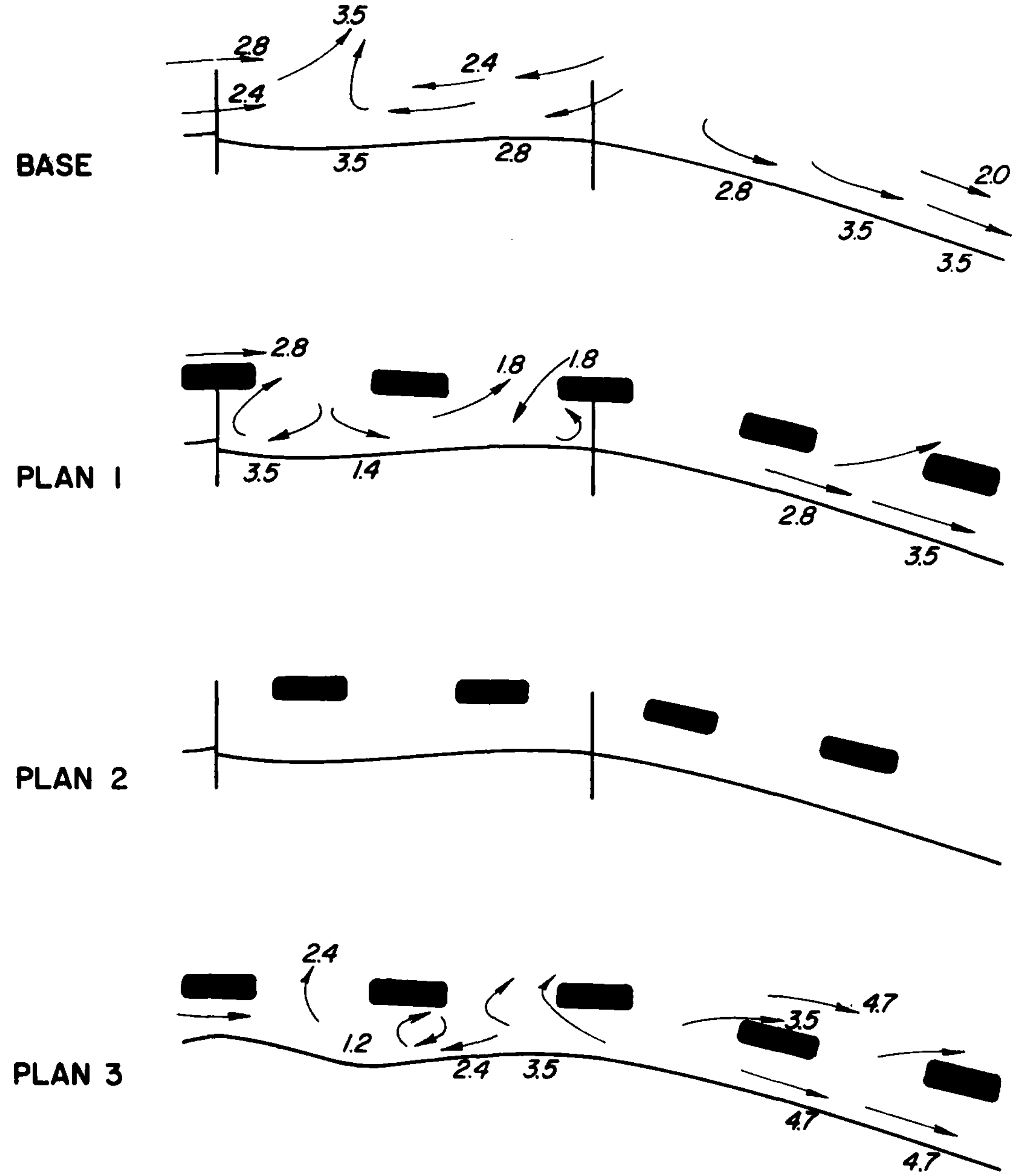
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 290°, 4 Ft-4 Sec Waves
at +3.0 Ft, LWD



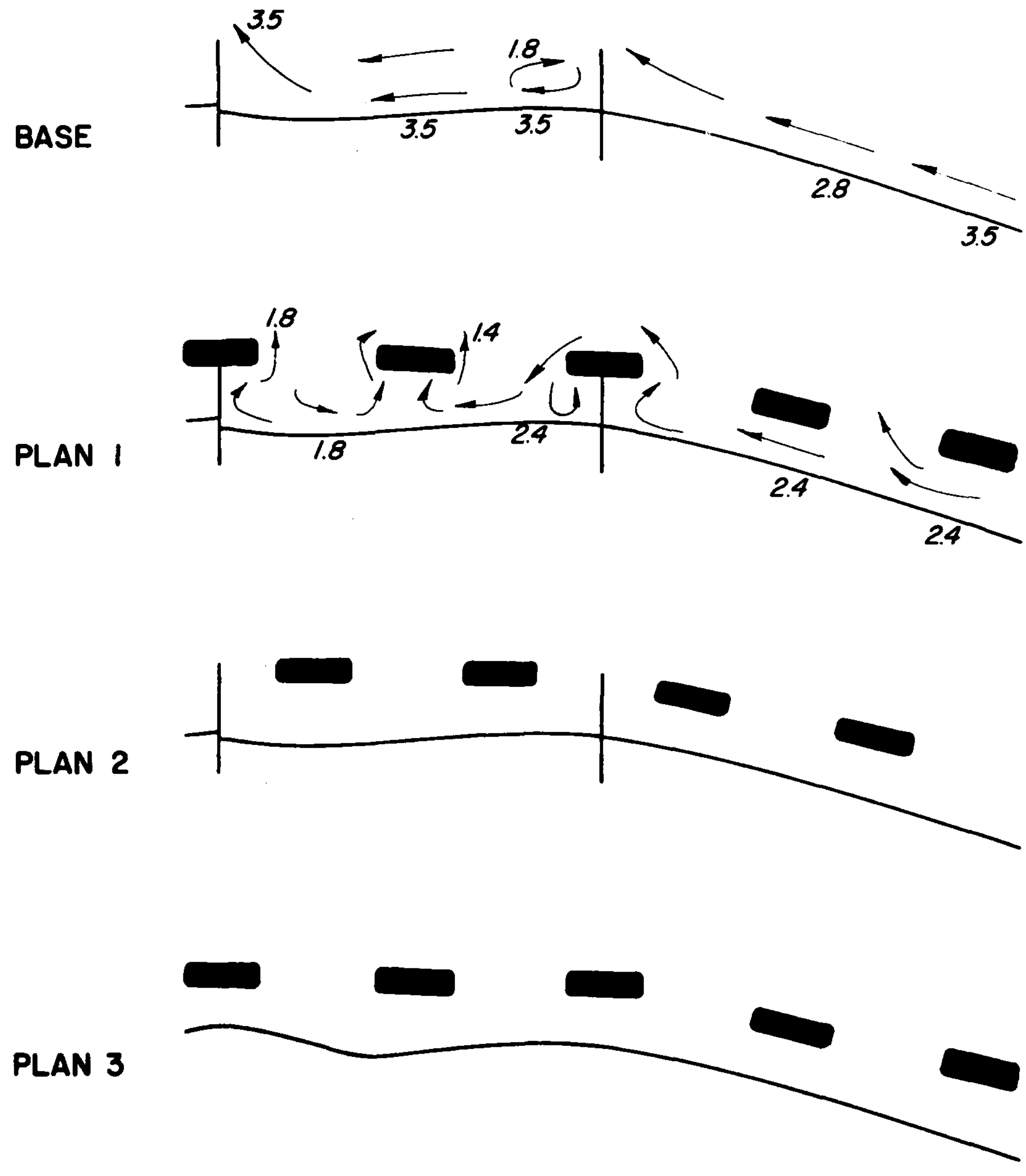
NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 290°, 10 Ft-6 Sec Waves
at +3.0 Ft, LWD



NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 290°, 12 Ft-9 Sec Waves
at +6.9 Ft, LWD



NOTE:
Velocities are in ft/sec

VELOCITY SUMMARY
For 315°, 4 Ft-4 Sec Waves
at +3.0 Ft, LWD

PLATE 101

END

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