TECHNICAL REPORT H-75-15

WAVE AND CURRENT CONDITIONS FOR VARIOUS MODIFICATIONS OF KEWALO BASIN, HONOLULU, OAHU, HAWAII

Hydraulic Model Investigation

by

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A 1:75-scale undistorted hydraulic model of Kewalo Basin, Oahu, Hawaii, and sufficient offshore area to permit generation of the required test waves was used to develop and test several plans of improvement proposed to eliminate: (a) crosscurrents in the entrance channel, (b) the presence of peaking and breaking waves in the entrance channel, and (c) undesirable wave action in the basin. Improvement plans consisted of (a) a proposed wave absorber along the channel sides, (b) various jetty plans, (c) removal of the channel (Continued)

20. ABSTRACT (Continued).

shoal, and (d) various combinations of the above. A 50-ft-long wave machine and an electrical wave height measuring and recording apparatus were used in the model. Tests were conducted with existing conditions installed and the results were compared with those for various improvement plans. It was concluded from the test results that: (a) Strong wave-induced crosscurrents entered the existing harbor channel for several hundred feet seaward of the existing jetty; and for some wave conditions, crosscurrents entered both sides of the channel and an eddy was formed. (b) Peaking and breaking waves occurred in the existing channel for incident wave heights of 8 ft or greater (at the wave generator located at a depth of -60 ft mllw) due to strong seaward-flowing currents and the channel shoal. (c) Wave heights up to 3.4 ft were measured in the existing basin, but piers in the basin generally prevented the formation of well-developed standing waves. (d) Addition of a wave absorber along the sides of the entrance channel (plan 2) was the most effective improvement plan in reducing wave heights in the basin (an average of about 13 percent and maximum wave heights were reduced from 3.4 to 1.9 ft), but this plan had little effect on current conditions. (e) A 150-ft jetty extending due south from the end of the existing jetty with a +2.0-ft crown elevation (plan 3D) was the best of the 150-ft jetty plans tested. This plan increased wave heights in the basin slightly (about 9 percent), and wave heights exceeded 2 ft four times. Channel currents in the area immediately adjacent to the jetty were significantly reduced. (f) Currents in the outer portion of the channel were relatively unaffected by a 150-ft jetty extension (in some cases, an increase in velocity was noted just seaward of this jetty). (g) Removal of the channel shoal (plan 8) tended to slightly increase basin wave heights (about 2 percent) by allowing more energy to enter the harbor, and wave heights exceeded 2 ft three times. (h) The shoal removal changed wave-breaking characteristics slightly and reduced eddy currents for some test waves. (i) Combinations of wave absorber and 150-ft jetty (plan 4), wave absorber and shoal removal (plan 7), and wave absorber, 150-ft jetty, and shoal removal (plan 5) effected slight overall reductions in wave heights (about 6, 10, and 5 percent, respectively). Wave heights in the basin did not exceed 2 ft for these plans. (j) A combination of 150-ft jetty extension and channel shoal removal (plan 6) increased overall wave heights significantly (about 18 percent), and wave heights in the basin exceeded 2 ft seven times. (k) The 500- and 900-ft jetty extensions (with channel wave absorber) tended to reduce basin wave heights, and channel eddy currents were eliminated. (l) Current magnitudes were not reduced significantly for either a 500- or 900-ft jetty extension, but currents were shifted seaward (out of the entrance channel), thus providing better navigation conditions. (m) Of all plans tested, only those involving the originally proposed wave absorber (plans 2, 4, 5, and 7) did not produce wave heights in excess of 2 ft inside the harbor basin.

PREFACE

A request for the U. S. Army Engineer Waterways Experiment Station (WES) to perform a model investigation of Kewalo Basin, Oahu, Hawaii, was made by the U. S. Army Engineer Division, Pacific Ocean (POD), in a telephone conversation on 31 January 1973. The study was subsequently authorized by the Office, Chief of Engineers (OCE), U. S. Army, and funds were authorized by POD on 17 May 1973.

The model study was conducted at WES during the period June 1973 to July 1974 in the Wave Dynamics Division of the Hydraulics Laboratory under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Dr. R. W. Whalin, Chief of the Wave Dynamics Division. The tests were conducted by Messrs. M. L. Giles, Project Engineer, and L. D. Nash, technician, under the direct supervision of Mr. C. E. Chatham, Jr., Chief of the Harbor Wave Action Branch. This report was prepared by Mr. Giles.

Liaison was maintained during the course of the investigation between POD and WES by means of conferences, telephone communications, and monthly progress reports.

Messrs. Karl Keller, Howard Kobayashi, and Ron Nishihara of POD and Mr. Neill Parker of OCE visited WES to observe model operations and participate in conferences during the model study.

Directors of WES during conduct of the investigation and preparation of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

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

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

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles	2.589988	square kilometres
tons (mass)	907.1847	kilograms
feet per second	0.3048	metres per second
degrees (angle)	0.01745329	radians

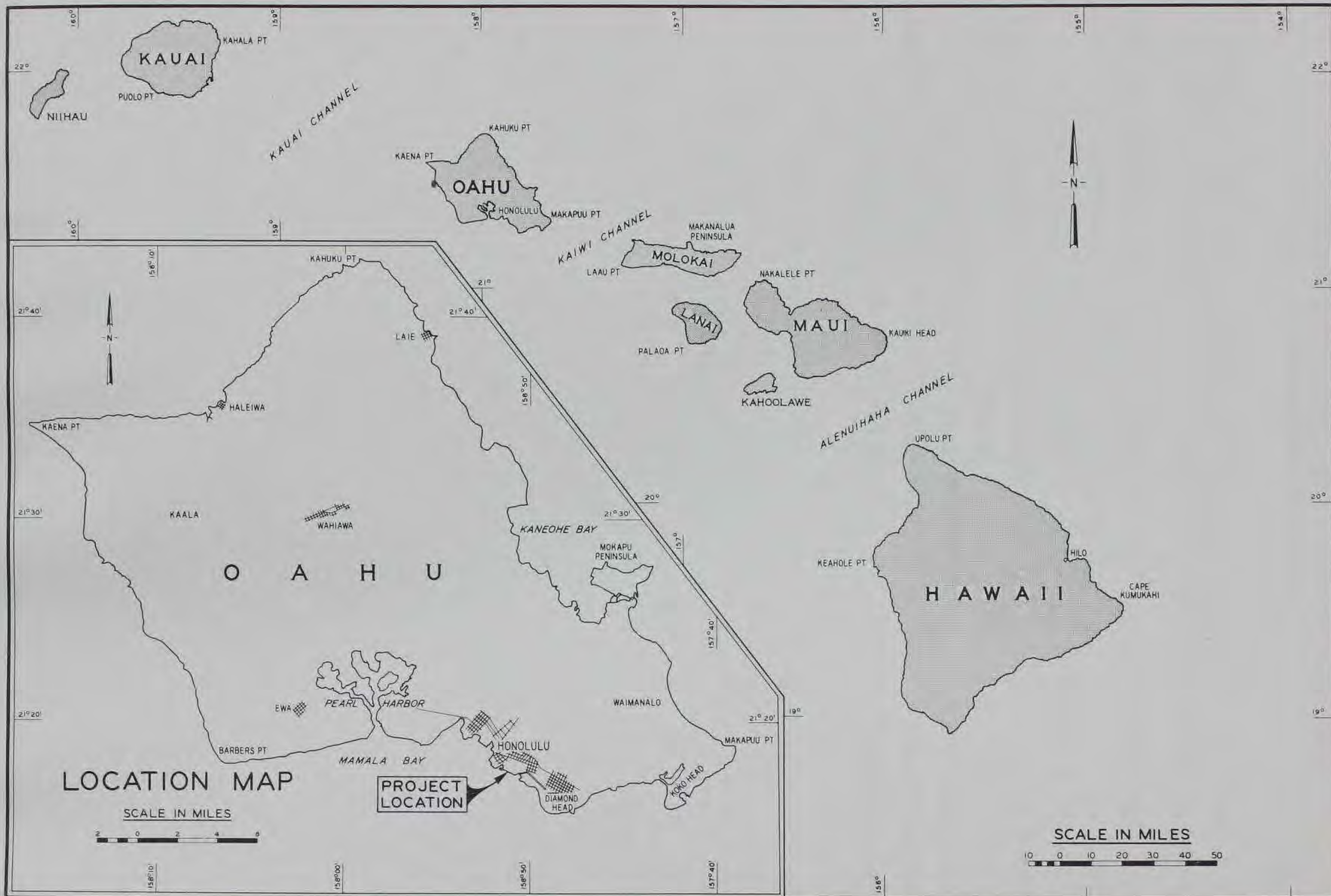

Figure 1. Vicinity map

WAVE AND CURRENT CONDITIONS FOR VARIOUS MODIFICATIONS OF KEWALO BASIN, HONOLULU, OAHU, HAWAII

Hydraulic Model Investigation

PART I: INTRODUCTION

Description of Prototype

1. Kewalo Basin is located on the south coast of Oahu, Hawaii, (Figure 1) between Honolulu Harbor and Waikiki, immediately west of Ala Moana Park (Figure 2). The man-made harbor was dredged into the coral reef, and a protecting landfill was formed on the south and east sides of the harbor basin. The harbor is approximately 800 ft* wide, 1000 ft long, and 20 ft deep. The entrance channel, located at the southwest corner of the harbor, is 200 ft wide and 20 ft deep and partially protected on the west side by additional landfill and on the east side by a 150-ft jetty. Between the channel and Ala Moana Park is an inner reef area with an average depth of 3.0 ft** below mean lower low water (mllw), extending 1500 ft east and west and about 900 ft south from the shore.

2. Kewalo Basin is the home port of a large portion of Hawaii's commercial fishing fleet and research and charter boat services. The reef on either side of the Kewalo Basin channel is a popular surfing spot for local people. "Shark Hole" on the Diamond Head side of the channel is used by board surfers, and "Point Panic" on the west side of the channel is used primarily by body surfers.

The Problem

3. The entrance channel to Kewalo Basin is exposed to storm-generated waves from all deepwater directions clockwise between east

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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.

** All elevations and depths cited herein are in feet referred to mean lower low water.

Figure 2. Project location

and west-northwest. These waves (ranging up to 18 ft in height in deep water) make navigation difficult and dangerous for small craft and boats using the harbor. Specifically, the problems are as follows:

- a. Crosscurrents generated in the channel in front of the existing jetty prove hazardous to slower and less maneuverable boats and to boats under the influence of high waves in the channel.
- b. Peaking and breaking waves in the entrance channel (worsened by the presence of a shoal) cause navigational problems.
- c. Crosscurrents in the outer portion of the channel, caused by littoral currents along the outer edge of the reef, create eddy currents which force boat operators to compensate one way and then the other as they enter the channel.
- d. Undesirable wave action in the basin causes inconvenience and occasional damage to moored boats.

Purpose of Model Study

4. The model study was conducted to investigate wave and current conditions in Kewalo Basin and its entrance channel for (a) a proposed wave absorber along the entrance channel sides, (b) various jetty extension plans, (c) removal of the channel shoal, and (d) various combinations of the above.

PART II: THE MODEL

Design of Model

5. The Kewalo Basin model (Plate 1) was constructed to a linear scale of 1:75, model to prototype. Selection of this scale was based on:

- a. Depth of water required in the model to minimize excessive bottom friction effects.
- b. Absolute size of model waves.
- c. Dimensions of the available shelter and the area required for the model.
- d. Efficiency of model operation.
- e. Characteristics of required wave-generating and wave-measuring equipment.
- f. Cost of model construction.

A geometrically undistorted model ensured accurate reproduction of wave patterns and heights in direct proportion to prototype values. After selection of the linear scale, the model was designed and operated in accordance with Froude's model law.[1] The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Scale Relation (Model:Prototype)
Length	L	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5625$
Volume	L^3	$V_r = L_r^3 = 1:421,875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$

* Dimensions are in terms of length (L) and time (T).

6. Proposed plans of improvements for Kewalo Basin included the use of rock wave absorbers along the channel sides. This type of wave absorber dissipates wave energy in the voids. Past experience and experimental research have shown that in small-scale models, rubble

structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures.[2] Consequently, some adjustment in the small-scale model wave absorber is needed to ensure satisfactory wave energy absorption characteristics. In past investigations[3,4] at WES, this adjustment was made by determining the energy dissipation properties of the structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A corresponding section was then developed for the small-scale, three-dimensional model that would provide approximately the same relative dissipation of energy. From previous findings, it was determined that a close approximation of the wave energy dissipated could be obtained by increasing the size of the rock used in the 1:75-scale model to approximately twice that required for geometric similarity. Accordingly, in constructing the wave absorbers in the Kewalo Basin model, the rock sizes were computed linearly by scale, then multiplied by 2.0 to arrive at the actual sizes used in the model.

Description of Model and Appurtenances

7. The model was molded in cement mortar and reproduced to scale the entire problem area including 2300 ft of shoreline to the west and 4000 ft of shoreline to the east of the entrance channel. Underwater contours were reproduced to -60 ft, and sufficient additional offshore area was included to permit generation of test waves from all critical directions. The total area reproduced in the model was approximately 8200 sq ft, representing about 1.7 square miles in nature. Model construction was based on the mllw datum. Horizontal control in the model was referenced to the local Punchbowl grid system. Figure 3 is a general view of the model with existing prototype conditions installed. General features of the model as originally constructed to simulate prototype conditions are shown in Plate 2.

8. Model waves were generated to scale by a 50-ft-long wave machine with a trapezoidal-shaped, vertical-motion plunger. The vertical movement of the plunger caused a periodic displacement of water incident

Figure 3. General view of model

to this motion. The length of the plunger stroke and the period of vertical motion were continuously variable over the ranges necessary to generate waves with the required characteristics. The wave machine was mounted on retractable casters that enabled it to be positioned to generate waves from the required directions.

9. Current directions and magnitudes in the model were measured by timing the progress of an injected dye which was influenced by both surface and subsurface currents. Wave height data were secured by electrical wave height gages at selected locations in the model and recorded on chart paper by an electrically operated oscillograph. The electrical output of each wave height gage was directly proportional to the submergence depth of the gage in the water.

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Still-Water Level

10. The still-water levels (swl's) for harbor wave-action models are selected so that the various wave-induced phenomena that are dependent upon water depths are accurately reproduced in the model. These phenomena include refraction of waves in the harbor area, overtopping of harbor structures by waves, reflection of wave energy from harbor structures, and transmission of wave energy through porous structures. Some of the more important factors contributing to selection of the optimum swl follow:

- a. The maximum amount of wave energy that can reach a coastal area will ordinarily do so during a severe storm that coincides with the high-water phase of the astronomical tide cycle.
- b. Severe storms are usually accompanied by some additional increase in the normal water level due to wind tide and mass transport.
- c. A relatively high swl in the model is beneficial in minimizing the scale effects due to viscous friction at the bottom.

Therefore, with consideration for the various factors contributing to and affected by the static water level in the prototype and in view of the tendency toward more conservative results from the model investigation, it was desirable that a model swl be selected that closely approximated the higher water stages that normally prevail during severe storms in the prototype.

11. At the project site, the swl varies with the stage of the astronomical tide, wind tide, and tsunamis. According to a report by Marine Advisers, Inc.,[5] the swl may be increased as much as 8 to 10 ft during a severe tsunami. However, the occurrence of such tsunamis is rare, and for this model investigation, any increase in the swl due to tsunami action was disregarded.

12. From the U. S. Coast and Geodetic Survey records,[6] the mean sea level at Honolulu Harbor, immediately west of the project site,

is +0.81 ft; the mean high water is +1.41 ft; and the mean higher high water (mhhw) is +1.88 ft. The highest tide of record, which occurred 16 January 1949, was +3.2 ft. The Coast and Geodetic Survey tide tables show a predicted astronomical high tide of +2.3 ft for that date, and it is assumed that a wind tide of 0.9 ft occurred simultaneously with the astronomical high tide.

13. Because of the low probability that an extreme wind tide and a high astronomical tide will occur simultaneously, and in the absence of more comprehensive statistical data concerning the frequency of occurrence of these phenomena, it appeared reasonable to use a swl of +2.0 ft, which is slightly higher than mhhw.

Wave Dimensions and Directions

Factors influencing selection of test-wave characteristics

14. In planning the test program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will afford a realistic test of the improvement plans proposed, thus permitting the optimum plan of improvement to be accurately determined. Surface wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the ocean surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind velocity, the duration for which wind of a given velocity continues to blow, and the water distance (fetch) over which it blows. Factors that influence the selection of test waves include:

- a. The fetch distances in the various directions from which waves can attack the harbor.
- b. The frequency of occurrence and the duration of winds blowing from the various directions.
- c. The size, alignment, and position of the harbor entrance and various harbor structures.
- d. The refraction of waves caused by differentials in depth

in the approaches to the harbor, which may create either a concentration or a divergence of wave energy at the harbor site.

Wave refraction

15. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period. The most important transformations with respect to the selection of test-wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. Changes in wave height and direction can be determined by plotting refraction diagrams and calculating refraction coefficients. These diagrams are constructed by plotting the position of wave orthogonals (lines drawn perpendicular to wave crests) from deep water into shallow water. If it is assumed that the waves do not break and that there is no lateral flow of energy along the wave crest, the ratio between the wave height in deep water (H_o) and the wave height in shallow water (H) will be inversely proportional to the square root of the ratio of the corresponding orthogonal spacings (b_o and b) or $H/H_o = K(b_o/b)^{1/2}$, where K is the shoaling coefficient and $(b_o/b)^{1/2}$ is the refraction coefficient. Thus, the product of the refraction coefficient and the shoaling coefficient results in a conversion factor for transfer of deep-water wave heights to shallow-water values. The shoaling coefficient, which is a function of wavelength and water depths, can be obtained from Reference 7.

16. An extensive refraction analysis[8] was conducted previously for the Ala Moana Reef area for representative wave periods and directions, taking into account the variability in direction of wave travel. For the present study, this analysis was extended to the -60 ft contour (depth of the model wave generators).

Prototype wave data and selection of test waves

17. Measured wave data on which a reliable statistical analysis of wave conditions could be based were unavailable for the Ala Moana Reef area. However, wave hindcast data (Reference 5) for a deepwater

station off the south coast of Oahu were obtained and are presented in Table 1 showing characteristics and estimated durations of deepwater waves approaching the Ala Moana Reef area from the southerly directions between east and west-northwest. It will be noted that the total hours duration per year exceeds 100 percent because two or more well-developed wave trains can exist simultaneously.

18. The refraction-shoaling analysis described in paragraphs 15 and 16 was used to transfer the deepwater waves into shallow water for use in the model (Table 2). The shallow-water wave directions used in the model were the average directions of the refracted waves for the significant wave periods noted from each deepwater wave direction. The characteristics of model test waves were selected from Table 2, as shown in the following tabulation:

Shallow-Water Test Direction, deg	Selected Test Wave Period sec	Selected Test Wave Height ft
180	8	6, 8
	12	6, 8, 14
210	8	6, 8
	10	14
	12	14
240	8	6, 8, 10
	12	6, 14
	18	6, 8, 10

Analysis of Model Data

19. The relative merits of the various plans tested were evaluated using (a) a comparison of wave heights at selected locations in the harbor, (b) a comparison of current directions and magnitudes at relevant locations, and (c) visual observations and photos. For the wave height data analysis, the average height of the highest one-third of the waves recorded at each gage location was selected. All wave heights thus selected were then adjusted to compensate for the greater rate of wave height attenuation (due to viscous friction scale effects) in the model by the application of Keulegan's equation.[9] From this equation, the

reduction of wave heights in the model due to bottom friction was calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel. The computed correction factors ranged from 1.03 to 1.10 in the entrance channel and from 1.13 to 1.17 in the basin.

PART IV: TESTS AND RESULTS

Description of Tests

Existing conditions

20. Prior to evaluation of various improvement plans, comprehensive tests were conducted for existing conditions (plan 1, Plate 2). Wave height and current data were secured for each selected test wave. Specific wave height gage locations for existing conditions and for each improvement plan tested are included in Plates 2-9. Various gages were shifted slightly to obtain the maximum wave height in the immediate area.

21. Analysis of the data for existing conditions indicated that significant differences in current magnitude and direction could only be discerned for larger test waves for each period and direction. Consequently, for tests of various improvement plans, current data were obtained only for the larger waves for each period and each direction.

Improvement plans

22. The alterations proposed for Kewalo Basin were: (a) addition of wave absorber along the channel sides, (b) a 150-ft-long jetty extension, (c) removal of the channel shoal to -22 ft mllw, and (d) various combinations of the above. It also was recommended that tests be conducted with jetty extensions longer than 150 ft even though the likelihood of such jetties being constructed is probably remote due to interference with surfing. These tests would provide data for evaluation of the trade-off between improved navigation conditions and interference with surfing.

23. Brief descriptions of the plan elements are given in the following subparagraphs; dimensional details are presented in the referenced plates.

a. Plan 2 (Plate 3) entailed the installation of a wave absorber (1.5- to 3.0-ton stone placed on a 1V on 3H slope) along the shelf bordering the entrance channel.

b. Plan 3A (Plate 4) consisted of a 150-ft jetty extension with a +5.5-ft crown elevation along the same alignment as the existing jetty.

c. Plan 3B (Plate 4) consisted of a 150-ft jetty extension along the same alignment as the existing jetty with a +2.0-ft crown elevation.

d. Plan 3C (Plate 5) consisted of a 150-ft jetty extension along a due south alignment with a +5.5-ft crown elevation.

e. Plan 3D (Plate 5) consisted of a 150-ft jetty extension along a due south alignment with a +2.0-ft crown elevation.

f. Plan 3E (Plate 5) consisted of a 150-ft jetty extension along a due south alignment with a 0.0-ft crown elevation.

g. Plan 4 (Plate 6) was a combination of the plan 2 wave absorber and the plan 3D jetty extension.

h. Plan 5 (Plate 7) was a combination of the plan 4 wave absorber and jetty extension with the channel shoal removed to -22 ft.

i. Plan 6 (Plate 7) was a combination of the plan 3D jetty extension with the channel shoal removed to -22 ft.

j. Plan 7 (Plate 8) was a combination of the plan 2 wave absorber and removal of the channel shoal to -22 ft.

k. Plan 8 (Plate 8) involved removal of the channel shoal to -22 ft.

l. Plan 9 (Plate 9) consisted of a 500-ft jetty extension (+5.5-ft crown) and a channel wave absorber, with the channel shoal removed to -22 ft.

m. Plan 10 (Plate 9) involved elements of plan 9 but with a 900-ft jetty extension.

24. Wave height and current data for the various improvement plans described above were secured for each selected test direction listed in paragraph 18 except for plans 3A-3E which were tested from the 180-deg test direction only to determine the best jetty plans. The two best jetty plans then were tested for all directions of wave approach.

Test Results

25. The relative efficiency of each of the improvement plans, with respect to plan 1 (existing conditions), was evaluated on the basis of their effect on crosscurrents and peaking and breaking waves in the

entrance channel and wave action in the basin.

Existing conditions

26. Results of wave height tests at various gage locations are presented in Table 3. These data reveal that a maximum wave height of 3.4 ft was recorded in the harbor basin. Peaking and breaking wave conditions were observed in the entrance channel for all test wave heights of 8 ft or greater at the wave machine. Typical current patterns and magnitudes are superimposed on wave patterns in Photos 1-8. Maximum channel currents observed are presented in Table 4 and range up to 8 fps (prototype). Generally currents flow from east to west for the 180-deg test direction with crosscurrents entering the channel for several hundred feet seaward of the existing jetty. For waves from 210 and 240 deg, crosscurrents enter both sides of the channel and an eddy is formed. Strong seaward flowing currents in the entrance channel combine with the channel shoal to cause peaking and breaking of test waves. Wave patterns in the basin indicate that there is some reflected wave energy, but the piers generally prevent the formation of well-developed standing wave patterns.

Improvement plans

27. Results of wave height tests with plan 2 installed are shown in Table 5, and maximum wave heights in the basin are compared with those for plan 1 in Table 6. A maximum wave height of 1.9 ft was recorded in the harbor basin for plan 2, and these data show a general decrease in wave heights in the basin relative to plan 1. Current and wave patterns are shown in Photos 9-14. Currents continued to flow from east to west for the 180-deg test direction, and crosscurrents entered both sides of the channel for waves from the 210- and 240-deg test directions. Maximum current velocities for plans 1 and 2 are compared in Table 7. These data show the maximum current in the channel for plan 2 to be 6.4 fps relative to 8.0 fps for existing conditions (plan 1). This decrease was probably due to reduced wave heights for the absorber plan. In general, however, neither the current patterns nor magnitudes obtained with plan 2 installed differed significantly from those for plan 1. Wave patterns (Photos 10-12) remained confused in the outer portion of the entrance

channel but became more regular in the channel between the wave absorbers.

28. Wave height test results obtained for various 150-ft jetty extensions (plans 3A-3E) are shown in Tables 8-10. Maximum wave heights obtained in the harbor basin are compared with those for plans 1 and 2 in Table 6 for the 180-deg test direction. Maximum wave heights in the harbor basin were 2.4, 2.3, 2.2, 1.7, and 1.9 ft for plans 3A-3E, respectively. Plans 3A and 3B (jetty extensions along the present jetty alignment) caused an increase in wave heights in the harbor basin. This is the consequence of the jetty extensions confining wave energy in the channel instead of allowing it to dissipate on the reef. The lower crown elevation of plan 3B did not confine as much energy as plan 3A, resulting in lower wave heights. Plan 3C produced wave conditions in the basin similar to plan 3B (i.e., slightly worse than plan 1 but better than plan 3A), and plans 3D and 3E produced results comparable to plan 1. In general, the due south jetty extensions and the lower crown elevations did not confine as much energy in the channel and resulted in lower wave heights in the basin than the other jetties.

29. Current and wave patterns for the various jetty extensions are shown in Photos 15-32. These jetty extensions had little effect on channel currents except that the maximum current was reduced from 8.0 fps for plan 1 to 6.8, 6.4, 5.2, 6.4, and 6.4 fps for plans 3A-3E, respectively. The current patterns obtained were similar to those for plan 1 except that the currents flowing from east to west were moved farther seaward for the jetty plans.

30. Based on test results from the 180-deg test direction, plans 3C and 3D were selected as being the most promising of the 150-ft jetty extensions and were tested from the 210- and 240-deg test directions. These data are presented in Tables 9 and 10, and maximum harbor wave heights are compared with those for plan 1 in Table 6. Maximum waves in the harbor basin were 2.7 and 3.3 ft for plans 3C and 3D (compared to 3.4 ft for plan 1). A comparison of all wave data for plans 1, 3C, and 3D (Table 6) reveals that both jetty plans caused a slight increase in wave heights in the basin for most conditions tested. It can be seen

in Table 6 that plan 3C resulted in four wave conditions in the basin for which maximum wave heights exceeded 2 ft, whereas plan 3D resulted in only two conditions having maximum basin wave heights over 2 ft. However, the maximum wave recorded for plan 3D was 3.3 ft while that for plan 3C was 2.7 ft. Plan 3D may be slightly better than plan 3C (relative to overall wave heights in the basin) because the lower crown elevation allowed some wave energy from the channel to spill over onto the reef.

31. Maximum channel currents and directions observed from sta 0+00 (end of existing jetty) to 5+00 (end of landfill on west side of channel) and from sta 5+00 to 11+00 (channel shoal) for plans 3C and 3D are compared with those for plan 1 in Table 7. Maximum channel currents observed for plans 1, 3C, and 3D were 4.1, 4.6, and 3.4 fps from sta 0+00 to 5+00 and 8.0, 7.2, and 7.7 fps from sta 5+00 to 11+00. In general, the magnitudes of currents from sta 0+00 to 5+00 were slightly reduced by both jetties with those from sta 5+00 to 11+00 being relatively unaffected. Current magnitudes for plan 3D were generally slightly less than those for plan 3C from sta 0+00 to 5+00. From the results of the wave height and current tests, plan 3D was selected as the best 150-ft jetty extension, and this plan was tested in combination with the other proposed improvements.

32. Wave heights obtained for various combinations of wave absorber, 150-ft jetty extension, and channel shoal removed to -22 ft (plans 4-7) and for the channel shoal removal only (plan 8) are presented in Tables 11-15. Maximum basin wave heights obtained are compared with those for plan 1 in Table 16. When wave heights for plans 4-8 are compared with those for existing conditions, it can be seen that overall wave heights were increased by the shoal removal (plan 8) and the combination of shoal removal and jetty (plan 6). All plans involving the wave absorber resulted in an overall net decrease in wave heights.

33. Wave patterns for plans 4-8 are shown in Photos 33-56. Wave patterns tended to be less confused in the channel and basin with the wave absorber installed. Addition of the jetty had little effect on wave patterns, and removal of the channel shoal had a slight effect on waves breaking in the channel.

34. Since previous tests had indicated that the wave absorber (plan 2) had little effect on current conditions, no current data were obtained for combination plans 4 and 7. It was assumed that currents obtained for plan 3D would also apply for plan 4, and those obtained for plan 8 would also apply for plan 7. Current patterns and magnitudes for plans 5, 6, and 8 are shown in Photos 36-47 and 51-56. In general, these data indicate that the patterns are similar to those obtained with existing conditions except that:

a. With plan 5 installed, no eddy current was observed for a 12-sec, 14-ft wave from 210 deg.

b. The jetty extension tends to move the east to west currents farther seaward.

c. The channel shoal removed to -22 ft tends to change the breaking location of the waves slightly.

d. The combination of shoal removal and jetty extension (plan 6) tends to increase current magnitudes slightly over existing conditions.

Maximum channel currents from sta 0+00 to 5+00 and from sta 5+00 to 11+00 are compared in Table 17 for plans 1, 2, 3D, 5, 6, and 8.

35. Results of wave height tests with plans 9 and 10 installed are shown in Tables 18 and 19, respectively. A comparison of maximum wave heights obtained in the basin for plans 1, 9, and 10 is shown in Table 20. Maximum wave heights obtained in the basin were 2.4 and 2.2 ft for plans 9 and 10, respectively. Wave and current patterns obtained with plans 9 and 10 installed are presented in Photos 57-68. For both plans 9 and 10, wave patterns in the channel were less confused (compared with those for previous plans tested); however, breaking waves still occurred in the channel for waves of 8 ft or greater at the wave machine. Channel eddy currents were eliminated by plans 9 and 10 for all test conditions, and measurable channel currents occurred only seaward of sta 5+00. The maximum currents observed for both plans are compared with those for plan 1 in Table 21. In general, current magnitudes were not reduced significantly for either plan 9 or 10. However, currents were shifted seaward of the entrance channel, thus providing better navigation conditions.

Discussion of Test Results

36. Tests of existing conditions (plan 1) indicate that peaking and breaking waves occur in the Kewalo Basin entrance channel for all wave heights of 8 ft or greater at the wave generator. Strong seaward flowing currents and possibly the channel shoal cause this condition. Wave patterns in the basin indicated some reflected wave energy, but the piers generally prevented the formation of well-developed standing waves. Some surging was noted, particularly in the southeast corner of the basin, for certain wave conditions. Current patterns indicated that wave-induced currents generally flow east to west for the 180-deg test direction with crosscurrents entering the channel for several hundred feet seaward of the existing jetty. For waves from 210- and 240-deg test directions, crosscurrents enter both sides of the channel and an eddy is formed.

37. Addition of a wave absorber along the shelf bordering the entrance channel reduced wave heights in the basin an average of about 13 percent over those obtained with existing conditions. The maximum wave height in the basin was reduced from 3.4 to 1.9 ft by addition of the wave absorber. Wave and current patterns remained relatively the same in the channel and basin except that wave patterns for plan 2 were less confused than those for existing conditions.

38. The 150-ft jetty extensions increased overall wave heights in the basin by varying degrees depending on the orientation and crown elevation of the extension. In general, jetty extensions along the present jetty alignment caused an increase in wave heights due to wave energy being confined in the channel instead of dissipating on the reef. Due south jetty extensions (especially the lower crown elevations) did not confine as much energy in the channel and resulted in lower wave heights in the basin than did the other jetties. Current patterns indicated that the east to west currents entering the channel were moved farther seaward, and currents entering the channel from the west still formed an eddy. The only benefit of a 150-ft jetty appears to be elimination (or significant reduction) of crosscurrents in that portion of the

channel adjacent to the jetty. Of the plans tested, plan 3D appears to be the best 150-ft jetty extension. Wave heights in the basin exceeded 2 ft four times (out of a total of 17 wave conditions and 6 gage locations) for plan 3D.

39. Test results for various combinations of wave absorber, 150-ft jetty extension, and channel shoal removal reveal:

- a. Overall wave heights in the basin were reduced about 6 percent by a wave absorber and 150-ft jetty combination (plan 4), and maximum wave heights did not exceed 2 ft. Current patterns remained similar to those obtained with the jetty extension alone.
- b. A combination of wave absorber, 150-ft jetty extension, and channel shoal removal (plan 5) decreased overall wave heights in the basin about 5 percent, and maximum wave heights did not exceed 2 ft. Current patterns were generally the same as those obtained for plan 1 except that the jetty moved east to west currents farther seaward, and for a 12-sec, 14-ft wave from 210-deg test direction, no eddy current was observed.
- c. A combination of the 150-ft jetty extension and shoal removal (plan 6) resulted in an overall wave height increase in the basin of about 18 percent, and wave heights exceeded 2 ft seven times. Addition of the jetty tends to move the east to west currents farther seaward, and removal of the channel shoal to -22 ft changes the wave-breaking location slightly. This combination tends to increase current magnitudes over those for plan 1.
- d. The combination of a channel wave absorber and shoal removal (plan 7) resulted in a net decrease in overall wave heights in the basin of about 10 percent, and maximum wave heights did not exceed 2 ft. Current patterns in the entrance channel were relatively unaffected, and removal of the shoal changed the wave-breaking location slightly.

40. Removing the channel shoal to -22 ft (plan 8) resulted in basin wave heights being slightly increased by an average of about 2 percent, and wave heights exceeded 2 ft three times. The wave-breaking location was changed slightly, and eddy currents occurred only for the 240-deg test direction. The observed currents were slightly greater than those obtained for existing conditions.

41. The 500- and 900-ft jetty extensions with a wave absorber along the channel sides and with the channel shoal removed (plans 9 and

10) reduced wave heights in the basin slightly, and channel eddy currents were eliminated for all test directions. Wave heights in the basin exceeded 2 ft four times for plan 9 and one time for plan 10. Current magnitudes were not reduced significantly for either the 500- or 900-ft jetty. However, currents were shifted seaward of the entrance channel, thus providing better navigation conditions. Both of these jetty plans would probably interfere with surfing in the vicinity.

PART V: CONCLUSIONS

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

- a. Strong wave-induced crosscurrents entered the existing harbor channel for several hundred feet seaward of the existing jetty; and for some wave conditions, crosscurrents entered both sides of the channel and an eddy was formed.
- b. Peaking and breaking waves occurred in the existing channel for incident wave heights of 8 ft or greater (at the wave generator located at a depth of -60 ft mllw) due to strong seaward flowing currents and the channel shoal.
- c. Wave heights up to 3.4 ft were measured in the existing basin, but piers in the basin generally prevented the formation of well-developed standing waves.
- d. Addition of a wave absorber along the sides of the entrance channel (plan 2) was the most effective improvement plan in reducing wave heights in the basin an average of about 13 percent and maximum wave heights from 3.4 to 1.9 ft, but this plan had little effect on current directions or magnitudes.
- e. A 150-ft jetty extending due south from the end of the existing jetty with a +2.0-ft crown elevation (plan 3D) was the best of the 150-ft jetty plans tested. This plan increased wave heights in the basin (about 9 percent), and wave heights exceeded 2 ft four times (out of a total of 17 wave conditions and 6 gage locations). Channel currents in the area immediately adjacent to the jetty were significantly reduced.
- f. Currents in the outer portion of the channel were relatively unaffected by a 150-ft jetty extension (in some cases, an increase in velocity was noted just seaward of this jetty).
- g. Removal of the channel shoal (plan 8) tended to increase basin wave heights (about 2 percent) by allowing more energy to enter the harbor, and wave heights exceeded 2 ft three times.
- h. The shoal removal changed wave-breaking characteristics slightly and reduced eddy currents for some test waves.
- i. Combinations of wave absorber and 150-ft jetty (plan 4), wave absorber and shoal removal (plan 7), and wave absorber, 150-ft jetty, and shoal removal (plan 5) effected slight overall reductions in wave heights (about 6, 10,

and 5 percent, respectively). Wave heights in the basin did not exceed 2 ft for these plans.

j. A combination of 150-ft jetty extension and channel shoal removal (plan 6) increased overall wave heights significantly (about 18 percent), and wave heights in the basin exceeded 2 ft seven times.

k. The 500- and 900-ft jetty extensions (with channel wave absorber) tended to reduce basin wave heights, and channel eddy currents were eliminated.

l. Current magnitudes were not reduced significantly for either a 500- or 900-ft jetty extension, but currents were shifted seaward (out of the entrance channel), thus providing better navigation conditions.

m. Of all plans tested, only those including the originally proposed wave absorber (plans 2, 4, 5, and 7) did not produce wave heights in excess of 2 ft inside the harbor basin.

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Table 1

Estimated Duration and Magnitude of Deepwater Waves Approaching the Ala Moana Reef Area from Various Directions

Wave Height* ft	Duration, hr/yr, for Various Wave Periods,* sec							
	3-7	7-9	9-11	11-13	13-15	15-17	17-19+	Total
				East				
2-4	96	456	612	180				1344
4-6	36	696	1536	385	12			2665
6-8		60	180	84	84			408
8-10		12	72	96	36			216
10-12			24	120	24			168
12-14			36	108	36			180
14-16			12	96	72			180
16-18				12	36			48
18-20			12					12
Total	132	1224	2484	1081	300			5221
				East-Southeast				
2-4		48		36				84
4-6		24	120	12				156
6-8		36		48				84
8-10	12		24					36
Total	12	108	144	96				360
				Southeast				
2-4	12							12
4-6	12	24						36
Total	24	24						48
				South-Southeast				
2-4	142	24		56				222
4-6		54		227				281
6-8		12						12
8-10								
10-12								
12-14			6					6
14-16								
16-18				1				1
Total	142	90	6	284				522

(Continued)

* Wave height and wave period groupings include lower but not upper values.

(Sheet 1 of 3)

Table 1 (Continued)

Wave Height ft	Duration, hr/yr, for Various Wave Periods, sec 3-7	7-9	9-11	11-13	13-15	15-17	17-19+	Total
				South				
2-4	173			817	439	73		1502
4-6		42		46	109			197
6-8		8						8
8-10								
10-12								
12-14			5					5
14-16								
16-18				1				1
Total	173	50	5	864	548	73		1713
				South-Southwest				
2-4	95			1234	1435			2764
4-6		23						23
6-8		7						7
8-10								
10-12								
12-14			2					2
14-16								
16-18				1				1
Total	95	30	2	1235	1435			2797
				Southwest				
2-4	62				100	143		305
4-6		22						22
6-8		6						6
8-10								
10-12								
12-14			3					3
14-16								
16-18				1				1
Total	62	28	3	1	100	143		337
				West-Southwest				
2-4	46							46
4-6		23						23
6-8		6						6
8-10								

(Continued)

Table 1 (Concluded)

Wave Height ft	3-7	7-9	9-11	11-13	13-15	15-17	17-19+	Total
				Duration, hr/yr, for Various Wave Periods, sec				
				West-Southwest (Continued)				
10-12								
12-14			4					4
14-16								
16-18				1				1
Total	46	29	4	1				80
				West				
2-4	12	24			12			48
4-6								
6-8			12					12
Total	12	24	12		12			60
				West-Northwest				
2-4		24	168	168	216	24		600
4-6			24	60	144	96	48	372
6-8			24		12	48	48	132
8-10		12				12	24	48
10-12							36	36
12-14							24	24
Total		36	216	228	372	180	180	1212

Table 2

Estimated Duration and Magnitude of Shallow-Water Waves Approaching the Ala Moana Reef Area from Various Directions

Wave Height* ft	Duration, hr/yr, for Various Wave Periods,* sec							
	3-7	7-9	9-11	11-13	13-15	15-17	17-19+	Total
			180° (Includes 170°-190°)					
2-4	423	1368	2544	1714	571			6620
4-6	48	108	72	597	277			1102
6-8		20	12	12				44
8-10	12							12
10-12			6					6
12-14			5	1				6
14-16				1				1
Total	483	1496	2639	2325	848			7791
			210° (Includes 200°-220°)					
2-4	157			1234	1535	216		3142
4-6		45						45
6-8		13						13
8-10								
10-12								
12-14			5					5
14-16								
16-18				2				2
Total	157	58	5	1236	1535	216		3207
			240° (Includes 230°-250°)					
2-4	58	48	168	168	228	24		694
4-6		23	24	60	144	96	48	395
6-8		6	36		12	48	48	150
8-10		12				12	24	48
10-12							60	60
12-14			4					4
14-16				1				1
Total	58	89	232	229	384	180	180	1352

* Wave height and wave period groupings include lower but not upper values.

Table 3

Wave Heights at Various Gage Locations with Plan 1 (Existing Conditions) Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Location, ft (Prototype)									
180	8	6	7.2	5.4	1.8	1.0	0.6	0.5	0.8	0.7	0.9	0.7
		8	9.0	10.2	1.8	1.7	0.5	0.9	0.7	1.3	0.7	0.7
	12	6	8.7	8.6	3.0	2.6	1.0	1.1	1.2	1.9	1.0	0.8
		8	13.9	10.5	3.9	2.7	1.2	1.5	1.3	1.4	1.0	1.0
		14	15.7	9.4	5.1	3.1	1.4	1.3	1.7	1.8	1.4	1.2
210	8	6	4.2	2.6	1.3	1.0	0.9	0.4	0.6	0.7	0.6	0.6
		8	6.1	5.5	2.3	1.6	1.1	0.7	0.9	0.9	1.0	1.0
	10	14	15.2	13.4	4.0	2.7	2.4	1.7	2.1	3.4	1.4	2.3
	12	14	12.8	10.9	4.6	2.5	1.3	1.5	1.3	1.3	1.0	1.1
240	8	6	4.5	2.8	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.5
		8	6.9	3.6	0.9	0.7	0.5	0.4	0.5	0.8	0.6	0.7
		10	7.9	6.8	2.1	1.4	0.7	0.9	0.6	1.2	1.0	1.2
	12	6	5.2	2.3	0.9	0.8	0.4	0.5	0.5	0.5	0.3	0.5
		14	11.7	6.5	2.8	1.7	1.1	0.9	1.0	1.0	0.7	0.8
	18	6	4.3	4.4	1.3	0.9	0.6	0.8	0.9	0.8	0.6	1.1
		8	7.2	9.7	3.1	2.3	1.8	1.1	1.8	1.6	1.0	1.1
		10	8.2	8.5	3.1	2.1	1.4	0.9	1.5	2.0	1.4	1.6

Table 4

Maximum Channel Currents with Plan 1 (Existing Conditions) Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Observed Channel Currents, fps (Prototype) Sta 0+00 to Sta 5+00	Maximum Observed Channel Currents, fps (Prototype) Sta 5+00 to Sta 11+00
180	8	6	3.2 (W)*	3.0 (W)
		8	3.8 (W)	3.8 (W)
	12	6	1.4 (W)	3.6 (W)
		8	1.0 (W)	4.6 (W)
		14	1.9 (W)	8.0 (W)
210	8	6	2.3 (W)	2.9 (E)
		8	4.1 (W)	2.9 (E)
	10	14	3.8 (W)	5.2 (E)
	12	14	3.7 (W)	4.6 (E)
240	8	6	2.4 (W)	3.8 (E)
		8	1.9 (W)	3.8 (E)
		10	2.9 (W)	3.8 (E)
	12	6	3.3 (W)	3.8 (E)
		14	3.6 (W)	3.6 (E)
	18	6	2.2 (W)	3.8 (E)
		8	3.3 (W)	3.8 (E)
		10	3.3 (W)	3.8 (E)

* W = west direction; E = east direction.

Table 5

Wave Heights at Various Gage Locations with Plan 2 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	6.4	6.8	1.7	1.4	0.6	0.5	0.5	0.7	0.6	0.9
		8	8.5	8.1	2.8	2.6	0.6	1.0	0.9	1.0	1.0	1.1
	12	6	8.3	6.9	2.2	1.6	0.8	0.9	1.0	0.8	0.7	0.7
		8	11.8	9.3	2.1	1.4	0.9	1.4	1.4	1.0	1.1	0.9
		14	16.7	11.8	3.1	1.6	1.7	1.4	1.7	1.2	1.0	1.2
210	8	6	5.9	3.5	1.3	0.9	0.6	0.5	0.7	0.4	0.4	0.5
		8	7.9	9.0	1.7	1.7	0.7	0.5	0.8	1.0	0.7	0.8
	10	14	17.0	11.5	2.8	1.8	1.8	1.0	1.8	1.5	0.9	0.8
	12	14	22.4	9.6	1.8	1.4	0.6	0.6	0.8	0.8	0.5	0.6
240	8	6	4.3	2.8	0.8	0.6	0.4	0.2	0.4	0.4	0.3	0.3
		8	6.0	3.4	1.3	1.0	0.5	0.4	0.5	0.7	0.4	1.0
		10	8.2	4.9	2.0	1.3	0.9	0.7	0.6	0.8	0.7	1.2
	12	6	5.8	2.8	1.4	0.7	0.5	0.4	0.5	0.5	0.4	0.4
		14	12.4	7.0	2.4	1.6	0.8	1.0	1.5	1.4	0.8	0.9
	18	6	5.1	5.5	3.2	1.3	0.7	1.4	0.9	0.9	0.8	1.2
		8	7.7	9.4	3.4	2.1	1.2	1.8	1.6	1.2	1.2	1.8
		10	8.9	10.7	3.9	1.8	1.2	1.9	1.6	1.1	1.3	1.7

Table 6

Comparison of Maximum Wave Heights in the Basin (Gages 5-10)

for Plans 1, 2, 3A, 3B, 3C, 3D, and 3E

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Wave Height for Indicated Plan, ft (Prototype) Plan 1	Plan 2	Plan 3A	Plan 3B	Plan 3C	Plan 3D	Plan 3E
180	8	6	0.9	0.9	1.6	0.9	0.7	1.1	0.8
		8	1.3	1.1	2.4	1.6	1.4	1.7	1.4
	12	6	1.9	1.0	1.9	1.7	1.7	1.6	1.5
		8	1.5	1.4	2.4	1.8	2.2	1.7	1.9
		14	1.8	1.7	2.3	2.3	1.9	1.6	1.5
210	8	6	0.9	0.7			1.0	0.8	
		8	1.1	1.0			1.7	1.6	
	10	14	3.4	1.8			2.7	3.3	
	12	14	1.5	0.8			1.8	2.2	
240	8	6	0.5	0.4			0.5	0.7	
		8	0.8	1.0			0.8	0.9	
		10	1.2	1.2			1.2	1.1	
	12	6	0.5	0.5			1.0	1.1	
		14	1.1	1.5			2.2	1.9	
	18	6	1.1	1.4			1.0	1.0	
		8	1.8	1.8			1.8	1.8	
		10	2.0	1.9			2.3	1.9	

Table 7

Comparison of Maximum Channel Currents for Plans 1, 2, 3C, and 3D

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Observed Channel Currents, fps: Sta 0+00 to 5+00 Plan 1	Plan 2	Plan 3C	Plan 3D	Sta 5+00 to 11+00 Plan 1	Plan 2	Plan 3C	Plan 3D
180	8	8	3.8 (W)*	3.8 (W)	2.9 (W)	3.0 (W)	3.8 (W)	3.8 (W)	3.8 (W)	3.8 (W)
	12	8	1.0 (W)	2.9 (W)	2.9 (W)	2.4 (W)	4.6 (W)	5.8 (W)	4.5 (W)	5.8 (W)
		14	1.9 (W)	3.8 (W)	--	1.6 (W)	8.0 (W)	6.4 (W)	5.2 (W)	6.4 (W)
210	8	8	4.1 (W)	4.6 (W)	3.9 (W)	3.3 (W)	2.9 (E)	3.8 (E)	4.8 (E)	6.2 (E)
	10	14	3.8 (W)	5.0 (W)	4.6 (W)	3.4 (W)	5.2 (E)	6.4 (E)	5.5 (W)	5.0 (W)
	12	14	3.7 (W)	3.0 (E)	3.6 (W)	3.4 (W)	4.6 (E)	3.6 (W)	7.2 (W)	4.6 (W)
240	8	10	2.9 (W)	3.2 (W)	2.8 (W)	2.1 (W)	3.8 (E)	5.8 (E)	7.2 (E)	7.7 (E)
	12	14	3.6 (W)	4.6 (W)	2.4 (W)	2.4 (W)	3.6 (E)	5.8 (E)	6.4 (E)	6.4 (E)
	18	10	3.3 (W)	3.8 (W)	1.0 (W)	1.4 (W)	3.8 (E)	5.8 (E)	5.5 (E)	6.1 (E)

* W = west direction; E = east direction.

Table 8

Wave Heights at Various Gage Locations with Plans 3A, 3B, and 3E Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Location, ft (Prototype)									
					Plan 3A							
180	8	6	7.3	6.5	3.4	2.4	0.9	1.1	1.0	1.6	1.2	1.2
		8	8.7	9.4	4.3	3.0	1.1	1.3	1.5	2.4	1.7	1.2
	12	6	7.2	6.9	3.6	2.5	1.3	1.5	1.7	1.9	1.6	1.7
		8	9.6	8.4	4.4	3.7	1.5	2.1	1.9	2.4	2.1	1.8
		14	21.1	10.9	4.4	3.2	1.3	1.6	1.8	2.3	1.8	1.5
					Plan 3B							
180	8	6	7.0	6.3	2.1	1.9	0.7	0.6	0.6	0.9	0.8	0.7
		8	8.3	8.4	4.5	2.7	1.0	1.0	1.2	1.6	1.3	1.4
	12	6	6.8	7.3	3.2	2.9	1.3	1.5	1.7	1.7	1.0	1.1
		8	9.1	8.7	3.6	2.8	1.3	1.5	1.8	1.8	1.8	1.6
		14	19.6	11.7	4.4	2.8	1.7	1.7	2.3	2.1	1.5	1.3
					Plan 3E							
180	8	6	7.7	5.8	1.3	1.3	0.5	0.8	0.5	0.6	0.6	0.5
		8	11.6	9.2	3.1	2.7	0.8	1.3	1.0	1.4	1.2	1.2
	12	6	8.2	8.0	2.9	2.2	1.2	1.5	1.2	1.3	0.8	0.6
		8	9.6	8.7	2.9	2.4	1.1	1.9	1.9	1.3	1.3	1.0
		14	21.0	8.8	3.1	1.9	1.0	1.2	1.5	1.2	1.1	1.0

Table 9

Wave Heights at Various Gage Locations with Plan 3C Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
180	8	6	6.7	5.3	1.8	1.8	0.5	0.5	0.5	0.7	0.6	0.7
		8	8.0	7.4	2.8	2.6	0.9	0.8	1.0	1.4	0.8	1.1
	12	6	6.9	6.5	3.6	2.4	1.1	1.3	1.3	1.7	1.0	1.0
		8	9.1	7.8	2.9	2.1	1.4	2.2	2.0	1.9	1.5	1.3
		14	16.3	10.4	5.9	5.1	1.4	1.9	1.8	1.8	1.6	1.5
210	8	6	6.1	5.1	2.3	1.0	0.6	0.9	0.9	1.0	0.8	1.0
		8	7.5	9.9	2.6	2.1	0.8	1.3	1.0	1.7	1.4	1.2
	10	14	12.4	8.6	3.1	2.7	2.0	2.7	1.9	2.7	1.3	1.5
	12	14	19.8	8.5	2.8	1.9	1.0	1.7	1.8	1.5	1.3	1.1
240	8	6	4.8	2.8	1.0	0.8	0.3	0.5	0.3	0.4	0.4	0.4
		8	5.7	3.8	1.5	1.2	0.5	0.7	0.5	0.7	0.7	0.8
		10	7.7	4.6	1.4	1.5	0.7	0.9	0.6	1.2	1.0	0.9
	12	6	5.3	3.8	1.8	1.3	0.7	1.0	0.8	0.7	0.6	0.6
		14	13.7	6.3	3.9	2.6	1.4	2.2	1.7	1.8	1.5	1.3
	18	6	5.7	5.6	2.1	1.4	0.8	0.8	0.9	1.0	0.8	0.9
		8	7.8	8.2	3.0	2.1	1.1	1.1	1.5	1.8	1.4	1.5
		10	8.6	12.5	3.8	2.9	1.6	1.3	2.2	2.3	1.6	1.8

Note: Gage columns are Wave Heights at Indicated Gage Location, ft (Prototype).

Table 10

Wave Heights at Various Gage Locations with Plan 3D Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Wave Heights at Indicated Gage Locations, ft (Prototype) Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
180	8	6	7.5	5.4	1.8	1.4	0.5	0.6	0.6	0.9	1.1	0.9
		8	8.3	7.8	2.6	2.0	1.1	0.8	1.1	1.7	1.3	1.3
	12	6	7.4	6.7	3.0	2.1	1.1	1.6	1.2	1.5	0.9	0.8
		8	9.4	7.7	3.2	2.6	1.4	1.5	1.0	1.7	1.3	0.9
		14	21.7	8.5	2.8	2.1	1.0	1.0	1.5	1.6	1.1	0.9
210	8	6	5.2	3.2	1.4	0.9	0.5	0.8	0.4	0.5	0.7	0.5
		8	7.7	11.0	2.6	2.5	0.9	1.6	0.9	1.5	1.3	1.6
	10	14	12.4	8.8	3.4	2.4	1.3	3.3	2.1	2.1	1.2	1.3
	12	14	18.4	7.9	2.3	2.2	1.0	2.2	1.4	1.3	1.1	1.1
240	8	6	4.7	3.3	1.1	0.8	0.3	0.7	0.4	0.4	0.3	0.5
		8	5.9	4.3	1.0	1.3	0.4	0.7	0.6	0.9	0.5	0.8
		10	9.0	5.7	1.8	1.7	0.6	0.9	0.8	1.1	1.1	1.0
	12	6	5.2	3.4	1.4	1.0	0.7	1.1	0.8	0.7	0.6	0.5
		14	15.4	7.7	3.9	3.2	1.4	1.8	1.8	1.9	1.7	1.6
	18	6	5.3	5.0	1.7	1.2	0.6	0.7	0.8	1.0	0.9	0.8
		8	7.3	9.4	2.5	1.8	1.0	1.1	1.3	1.6	1.8	1.4
		10	7.9	10.9	3.1	2.2	1.3	1.3	1.7	1.9	1.3	1.6

Table 11

Wave Heights at Various Gage Locations with Plan 4 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	5.9	8.3	2.5	1.7	0.5	0.8	0.9	1.2	1.2	1.3
		8	7.6	8.3	1.9	2.6	0.8	1.3	1.4	1.2	1.1	1.3
	12	6	6.5	7.4	2.5	1.7	0.9	1.3	1.1	1.2	1.1	0.9
		8	9.3	8.2	2.9	2.2	1.1	1.5	1.9	1.3	1.5	1.4
		14	19.7	8.1	2.3	1.7	0.8	1.2	1.7	1.4	1.1	1.0
210	8	6	5.2	3.2	1.4	1.0	0.6	0.5	0.6	0.6	0.5	0.5
		8	7.2	7.9	1.4	1.4	0.6	0.7	0.9	1.1	0.7	0.5
	10	14	11.9	8.2	1.8	1.1	1.0	1.3	1.1	1.3	0.7	0.7
	12	14	19.5	6.6	2.1	1.6	0.9	1.4	1.4	1.2	1.0	0.9
240	8	6	4.3	2.8	0.9	0.6	0.4	0.5	0.4	0.4	0.3	0.3
		8	5.5	3.0	1.2	1.0	0.3	0.5	0.3	0.4	0.4	0.5
		10	6.9	5.1	1.8	1.5	0.3	0.5	0.5	0.8	0.5	0.7
	12	6	5.5	3.8	1.1	1.0	0.5	0.8	0.5	0.5	0.5	0.3
		14	15.2	7.2	3.5	2.0	0.9	1.7	1.8	1.9	1.5	1.1
	18	6	5.2	5.2	2.2	1.2	0.6	1.3	0.9	0.8	0.9	1.2
		8	7.7	9.0	2.5	1.8	0.8	1.6	1.5	1.2	1.3	1.5
		10	8.2	10.0	3.1	2.3	1.1	1.6	2.0	1.7	1.7	1.6

Table 12

Wave Heights at Various Gage Locations with Plan 5 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	6.5	5.6	1.8	1.9	0.7	0.7	0.8	0.8	0.8	1.0
		8	7.8	7.7	2.0	2.1	0.7	1.2	1.0	1.4	1.3	1.3
	12	6	7.9	6.8	2.3	1.7	1.0	0.9	1.1	0.8	0.9	1.0
		8	10.0	7.0	2.2	1.7	1.0	1.3	1.5	1.4	0.9	1.2
		14	17.8	9.3	3.6	2.2	1.2	1.7	1.9	1.3	0.9	1.3
210	8	6	5.4	3.6	1.2	1.0	0.4	0.7	0.4	0.7	0.4	0.4
		8	6.8	7.7	1.6	1.0	0.5	0.7	0.5	0.9	0.7	0.8
	10	14	12.2	7.7	2.0	1.3	1.6	1.7	1.1	1.4	0.9	0.7
	12	14	19.1	6.9	1.6	1.4	0.8	1.3	1.3	0.9	0.8	0.7
240	8	6	4.6	2.6	0.7	0.6	0.2	0.6	0.4	0.3	0.5	0.3
		8	5.4	4.0	1.4	1.3	0.3	0.7	0.5	0.7	0.6	0.9
		10	7.0	4.7	1.6	1.5	0.5	0.9	0.7	0.9	0.9	0.8
	12	6	6.0	3.2	1.2	0.8	0.5	1.1	0.7	0.6	0.7	0.5
		14	15.2	7.8	3.7	2.3	1.0	1.7	1.9	1.7	1.5	1.2
	18	6	4.4	4.8	2.2	1.2	0.5	1.3	0.9	0.8	0.9	1.0
		8	6.3	8.2	3.2	1.9	1.0	1.6	1.6	1.3	1.3	1.4
		10	7.7	10.2	3.7	2.1	1.1	1.6	1.6	1.4	1.4	1.4

Table 13

Wave Heights at Various Gage Locations with Plan 6 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	6.7	5.9	1.6	2.1	0.6	0.9	0.7	1.2	0.7	0.8
		8	8.2	8.3	2.8	2.9	0.8	0.9	1.1	1.7	1.2	1.4
	12	6	7.0	7.5	2.8	2.5	1.1	1.5	1.4	1.6	1.2	0.8
		8	10.4	8.1	3.3	3.1	1.7	2.0	2.2	2.3	1.7	1.9
		14	20.2	9.1	3.7	2.5	1.4	2.0	2.0	1.7	1.2	1.2
210	8	6	5.2	2.7	1.4	1.3	0.3	0.5	0.8	0.7	0.5	0.7
		8	5.7	6.6	1.3	1.3	0.7	0.9	0.8	0.8	0.8	0.9
	10	14	12.9	9.4	3.3	2.4	1.9	3.0	2.2	2.6	1.2	1.7
	12	14	19.2	7.7	2.6	2.0	1.1	1.6	1.5	1.8	1.6	1.4
240	8	6	4.9	2.7	0.8	1.2	0.5	0.5	0.4	0.7	0.6	0.4
		8	6.5	4.8	1.3	1.4	0.7	0.8	0.6	1.1	0.9	0.7
		10	7.9	5.7	2.1	1.9	0.8	1.0	0.6	1.4	1.3	0.8
	12	6	6.0	3.2	1.4	1.2	0.7	0.9	1.0	1.0	0.7	0.7
		14	13.1	5.8	2.5	2.0	1.0	1.3	1.3	1.4	1.1	1.1
	18	6	5.1	4.8	1.6	1.3	0.7	1.0	1.1	1.2	0.8	0.7
		8	7.2	8.5	2.9	1.8	1.1	1.2	2.0	1.8	1.7	1.3
		10	8.4	11.3	4.1	1.9	1.3	1.5	2.6	2.3	2.0	1.7

Table 14

Wave Heights at Various Gage Locations with Plan 7 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Wave Heights at Indicated Gage Locations, ft (Prototype) Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
180	8	6	6.9	5.9	2.2	1.8	0.8	0.6	0.7	1.2	0.8	1.1
		8	8.5	8.3	2.6	2.5	0.9	1.1	1.1	1.6	1.0	1.5
	12	6	7.2	6.2	2.2	1.5	0.9	1.0	0.9	0.9	0.9	0.6
		8	11.3	7.5	2.8	1.3	1.2	1.3	1.4	1.2	1.1	1.0
		14	14.5	8.0	1.7	1.1	0.8	1.0	1.0	0.8	0.9	0.8
210	8	6	4.4	3.4	1.0	1.1	0.4	0.4	0.8	0.8	0.4	0.6
		8	5.3	4.6	1.6	1.4	0.4	0.5	1.2	0.7	0.5	0.5
	10	14	11.7	9.5	2.6	1.4	1.5	1.3	1.6	1.6	1.1	0.8
	12	14	19.0	10.7	2.7	1.6	0.9	1.3	1.5	0.9	0.9	0.9
240	8	6	5.3	2.8	0.6	0.7	0.3	0.3	0.3	0.4	0.3	0.4
		8	7.1	3.9	1.3	1.4	0.3	0.5	0.6	0.7	0.6	0.7
		10	10.1	5.6	1.8	1.5	0.4	0.5	0.7	1.0	0.7	0.9
	12	6	6.4	4.6	1.6	1.0	0.6	1.3	1.0	0.9	0.7	0.5
		14	17.0	6.6	2.0	1.9	0.9	0.9	2.0	1.4	0.9	1.0
	18	6	5.1	5.0	2.4	1.1	0.5	0.9	0.7	0.8	0.7	0.9
		8	7.0	9.7	3.2	1.9	1.2	1.8	1.3	1.2	1.1	1.7
		10	7.9	7.2	2.9	2.2	0.9	1.8	1.4	1.3	1.1	1.6

Table 15

Wave Heights at Various Gage Locations with Plan 8 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Wave Heights at Indicated Gage Locations, ft (Prototype) Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
180	8	6	7.1	5.2	1.2	1.6	0.8	0.5	0.9	0.8	0.7	0.6
		8	10.1	8.1	2.5	2.6	0.8	0.8	0.8	1.5	0.7	0.6
	12	6	7.4	7.6	2.9	2.5	1.6	1.5	0.9	1.1	0.8	0.7
		8	11.7	7.9	2.9	2.7	1.6	1.7	1.6	1.8	1.5	1.2
		14	16.0	5.6	3.1	2.0	1.7	2.0	1.6	1.4	1.4	1.3
210	8	6	4.8	3.5	1.3	0.8	0.4	0.5	0.6	0.7	0.5	0.6
		8	6.1	7.7	1.5	1.6	0.5	0.7	0.9	1.0	1.0	0.8
	10	14	13.6	8.4	3.7	2.4	1.8	2.0	2.5	2.4	1.1	1.3
	12	14	19.4	9.3	2.7	2.0	1.3	1.6	2.1	1.5	1.7	1.6
240	8	6	4.7	2.0	0.9	0.7	0.2	0.3	0.3	0.4	0.3	0.3
		8	6.3	3.8	2.3	1.4	0.4	0.6	0.4	0.7	0.6	0.8
		10	8.1	4.9	1.3	1.5	0.5	0.7	0.8	0.9	0.7	1.0
	12	6	5.8	3.1	1.2	1.0	0.6	0.7	0.5	0.6	0.3	0.3
		14	13.7	5.8	1.9	1.8	1.0	1.2	1.6	1.3	1.1	0.9
	18	6	5.1	4.9	1.4	1.0	0.7	0.7	1.1	1.0	0.7	0.8
		8	7.6	9.5	3.1	2.1	1.0	1.0	1.7	1.7	1.6	1.4
		10	8.4	10.7	3.3	2.0	1.1	1.0	1.8	1.9	1.7	1.8

Table 16

Comparison of Maximum Wave Heights in the Basin for Plans 1, 4, 5, 6, 7, and 8

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Wave Height for Indicated Plan, ft (Prototype) Plan 1	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8
180	8	6	0.9	1.3	1.0	1.2	1.2	0.9
		8	1.3	1.4	1.4	1.7	1.6	1.5
	12	6	1.9	1.3	1.1	1.6	1.0	1.6
		8	1.5	1.9	1.5	2.3	1.4	1.8
		14	1.8	1.7	1.9	2.0	1.0	2.0
210	8	6	0.9	0.6	0.7	0.8	0.8	0.7
		8	1.1	1.1	0.9	0.9	1.2	1.0
	10	14	3.4	1.3	1.7	3.0	1.6	2.5
	12	14	1.5	1.4	1.3	1.8	1.5	2.1
240	8	6	0.5	0.5	0.6	0.7	0.4	0.4
		8	0.8	0.5	0.9	1.1	0.7	0.8
		10	1.2	0.8	0.9	1.4	1.0	1.0
	12	6	0.5	0.8	1.1	1.0	1.3	0.7
		14	1.1	1.9	1.9	1.4	2.0	1.6
	18	6	1.1	1.3	1.3	1.2	0.9	1.1
		8	1.8	1.6	1.6	2.0	1.8	1.7
		10	2.0	2.0	1.6	2.6	1.8	1.9

Table 17

Comparison of Maximum Channel Currents for Plans 1, 2, 3D, 5, 6, and 8

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Channel Currents for Indicated Plans, fps (Prototype) Plan 1	Plan 2	Plan 3D	Plan 5	Plan 6	Plan 8
			Sta 0+00-5+00					
180	8	8	3.8 (W)*	3.8 (W)	3.0 (W)	3.7 (W)	--	1.2 (W)
	12	8	1.0 (W)	2.9 (W)	2.4 (W)	2.2 (W)	1.3 (W)	2.5 (W)
		14	1.9 (W)	3.8 (W)	1.6 (W)	1.7 (W)	2.0 (W)	3.8 (W)
210	8	8	4.1 (W)	4.6 (W)	3.3 (W)	4.8 (W)	3.6 (W)	4.4 (W)
	10	14	3.8 (W)	5.0 (W)	3.4 (W)	3.6 (W)	4.4 (W)	4.1 (W)
	12	14	3.7 (W)	3.0 (E)	3.4 (W)	5.0 (W)	3.8 (W)	4.4 (W)
240	8	10	2.9 (W)	3.2 (W)	2.1 (W)	1.6 (W)	3.1 (W)	3.0 (W)
	12	14	3.6 (W)	4.6 (W)	2.4 (W)	2.1 (W)	0.5 (W)	3.5 (W)
	18	10	3.3 (W)	3.8 (W)	1.4 (W)	2.0 (W)	1.9 (W)	2.4 (W)
			Sta 5+00-11+00					
180	8	8	3.8 (W)*	3.8 (W)	3.8 (W)	3.6 (W)	3.0 (W)	3.5 (W)
	12	8	4.6 (W)	5.8 (W)	5.8 (W)	7.7 (W)	4.1 (W)	6.0 (W)
		14	8.0 (W)	6.4 (W)	6.4 (W)	7.7 (W)	7.7 (W)	5.5 (W)
210	8	8	2.9 (E)	3.8 (E)	6.2 (E)	3.3 (E)	4.4 (E)	3.2 (W)
	10	14	5.2 (E)	6.4 (E)	5.0 (W)	7.7 (E)	5.5 (W)	8.2 (W)
	12	14	4.6 (E)	3.6 (W)	4.6 (W)	6.1 (W)	8.2 (W)	7.2 (W)
240	8	10	3.8 (E)	5.8 (E)	7.7 (E)	6.8 (E)	6.7 (E)	6.1 (E)
	12	14	3.6 (E)	5.8 (E)	6.4 (E)	4.8 (E)	7.2 (E)	4.0 (E)
	18	10	3.8 (E)	5.8 (E)	6.1 (E)	2.6 (E)	5.7 (E)	4.8 (E)

* W = west direction; E = east direction.

Table 18

Wave Heights at Various Gage Locations with Plan 9 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	6.8	5.8	1.8	2.1	0.8	0.7	0.8	1.2	1.0	0.9
		8	8.3	7.7	3.8	2.8	0.8	0.9	1.4	1.4	1.2	1.9
	12	6	6.0	6.5	2.6	2.0	0.9	1.2	1.5	1.3	1.1	1.2
		8	9.0	7.8	3.0	2.2	0.9	0.9	1.5	1.1	0.9	0.9
		14	14.1	9.8	3.2	1.7	1.4	0.8	1.6	1.0	0.6	0.9
210	8	6	6.2	4.6	2.0	0.9	0.6	0.6	0.8	0.9	0.5	0.4
		8	7.7	6.4	2.3	1.7	0.7	0.5	0.9	0.9	0.6	0.9
	10	14	13.9	9.4	2.4	1.4	1.4	1.5	2.2	1.7	1.0	1.4
	12	14	20.2	7.0	3.1	1.0	1.2	0.8	1.7	1.2	1.0	1.2
240	8	6	4.4	2.8	0.7	0.6	0.4	0.3	0.4	0.5	0.2	0.4
		8	5.6	3.4	1.3	1.2	0.4	0.4	0.4	0.5	0.3	0.6
		10	9.0	4.4	2.7	2.3	0.8	0.6	0.7	1.3	1.0	0.8
	12	6	5.4	2.2	1.0	0.5	0.4	0.6	0.6	0.4	0.4	0.4
		14	14.1	5.0	2.1	1.8	0.7	0.8	1.8	1.1	0.8	0.8
	18	6	4.4	5.1	2.2	1.5	0.7	1.2	1.2	0.7	0.9	1.0
		8	7.4	10.6	3.7	2.3	0.9	1.9	2.2	1.4	1.4	1.6
		10	7.9	8.6	3.7	2.5	1.2	2.1	2.4	1.6	1.4	1.9

Table 19

Wave Heights at Various Gage Locations with Plan 10 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
			Wave Heights at Indicated Gage Locations, ft (Prototype)									
180	8	6	6.8	4.7	2.0	1.9	0.8	0.8	0.6	1.0	0.6	1.2
		8	8.8	5.5	3.1	2.8	0.9	0.8	1.0	1.1	0.9	1.8
	12	6	6.5	6.1	2.4	1.3	0.8	1.2	1.0	1.1	1.2	0.8
		8	9.2	6.8	3.0	1.8	0.8	1.5	1.3	1.2	1.2	1.0
		14	15.5	8.9	3.4	1.4	1.1	0.8	0.8	0.9	0.9	0.9
210	8	6	6.0	3.8	2.1	1.6	0.9	0.6	1.0	0.8	0.6	0.7
		8	7.5	3.5	1.4	1.1	0.7	0.6	0.6	0.7	0.6	1.0
	10	14	13.5	7.1	2.0	1.4	1.0	0.8	1.2	1.3	0.7	0.6
	12	14	19.6	8.3	3.5	2.4	0.9	1.0	1.9	1.7	1.1	1.0
240	8	6	3.9	1.2	1.0	0.8	0.3	0.3	0.4	0.6	0.5	0.2
		8	5.4	2.4	1.7	1.2	0.6	0.6	0.8	0.7	0.6	0.5
		10	9.7	3.4	2.0	2.2	0.8	1.0	1.1	1.0	0.8	0.8
	12	6	5.1	2.5	0.9	0.6	0.3	0.8	0.7	0.5	0.4	0.5
		14	12.3	5.0	1.9	1.8	1.0	1.0	2.2	1.6	0.9	1.1
	18	6	4.4	3.9	2.3	1.9	0.7	1.4	1.3	1.1	1.0	1.0
		8	7.5	5.3	2.5	1.7	1.0	1.9	1.1	1.1	1.2	1.2
		10	7.7	5.1	3.0	1.7	1.0	1.5	1.6	1.1	1.2	1.3

Table 20

Comparison of Maximum Wave Heights in the Basin with

Plans 1, 9, and 10 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Wave Height for Indicated Plans, ft (Prototype) Plan 1	Plan 9	Plan 10
180	8	6	0.9	1.2	1.2
		8	1.3	1.9	1.8
	12	6	1.9	1.5	1.2
		8	1.5	1.5	1.5
		14	1.8	1.6	1.1
210	8	6	0.9	0.9	1.0
		8	1.1	0.9	1.0
	10	14	3.4	2.2	1.3
	12	14	1.5	1.7	1.9
240	8	6	0.5	0.5	0.6
		8	0.8	0.6	0.8
		10	1.2	1.3	1.1
	12	6	0.5	0.6	0.8
		14	1.1	1.8	2.2
	18	6	1.1	1.2	1.4
		8	1.8	2.2	1.9
		10	2.0	2.4	1.6

Table 21

Comparison of Maximum Channel Currents with Plans 1, 9, and 10 Installed

Shallow-Water Test Direction deg	Test Wave Period sec	Test Wave Height ft	Maximum Observed Channel Currents for Indicated Plans fps (Prototype) Plan 1	Plan 9	Plan 10
180	8	8	3.8 (W)*	5.0 (W)	3.0 (W)
	12	8	4.6 (W)	7.2 (W)	4.3 (W)
		14	8.0 (W)	8.2 (W)	9.0 (W)
210	8	8	2.9 (E)	2.3 (E)	2.3 (E)
	10	14	5.2 (E)	6.8 (W)	5.0 (W)
	12	14	4.6 (E)	6.4 (W)	5.8 (W)
240	8	10	3.8 (E)	5.0 (E)	8.0 (W)
	12	14	3.6 (E)	8.0 (E)	9.0 (E)
	18	10	3.8 (E)	6.1 (E)	8.0 (W)

* W = west direction; E = east direction.

Photo 1. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 1 installed

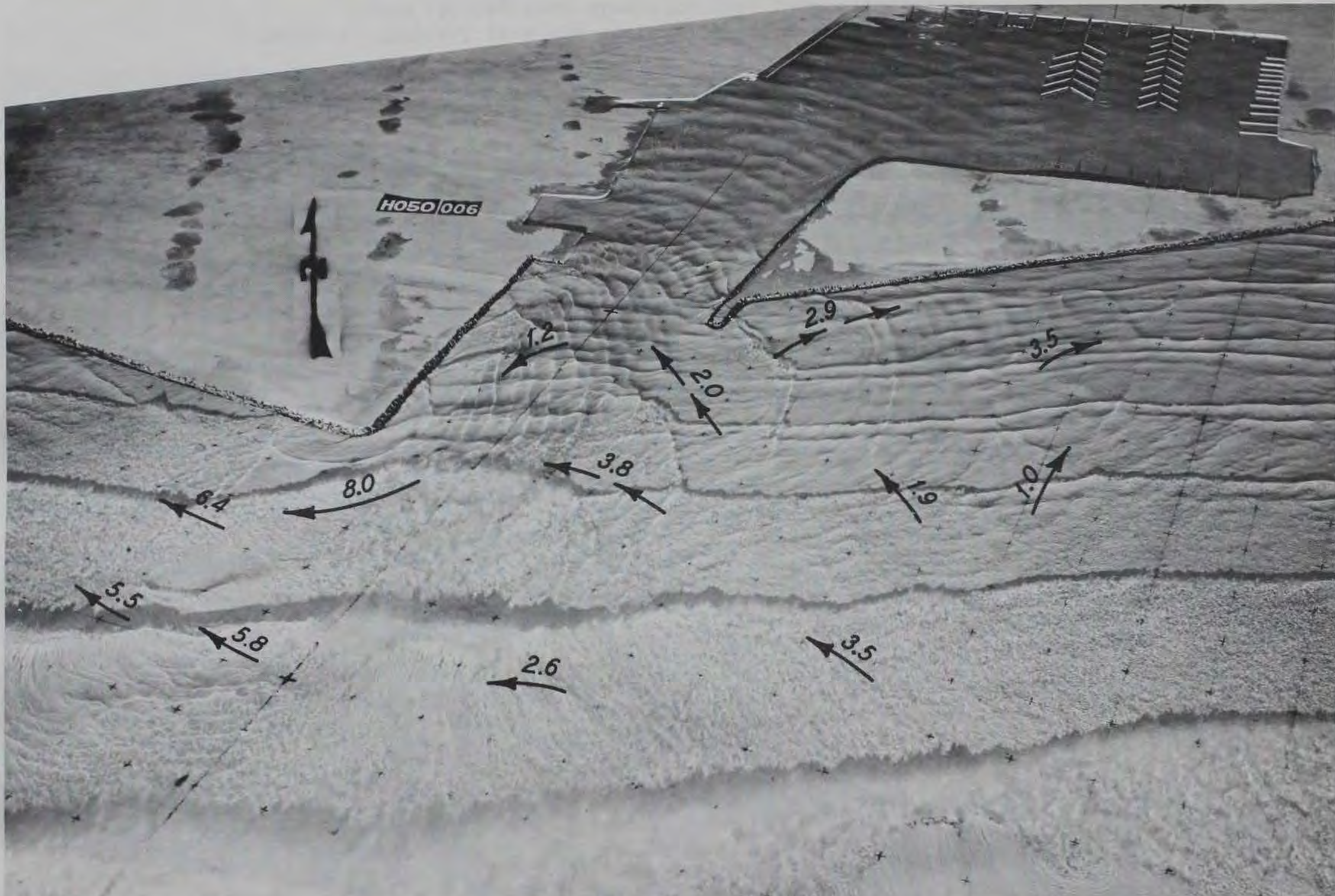


Photo 2. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 1 installed

Photo 3. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 1 installed

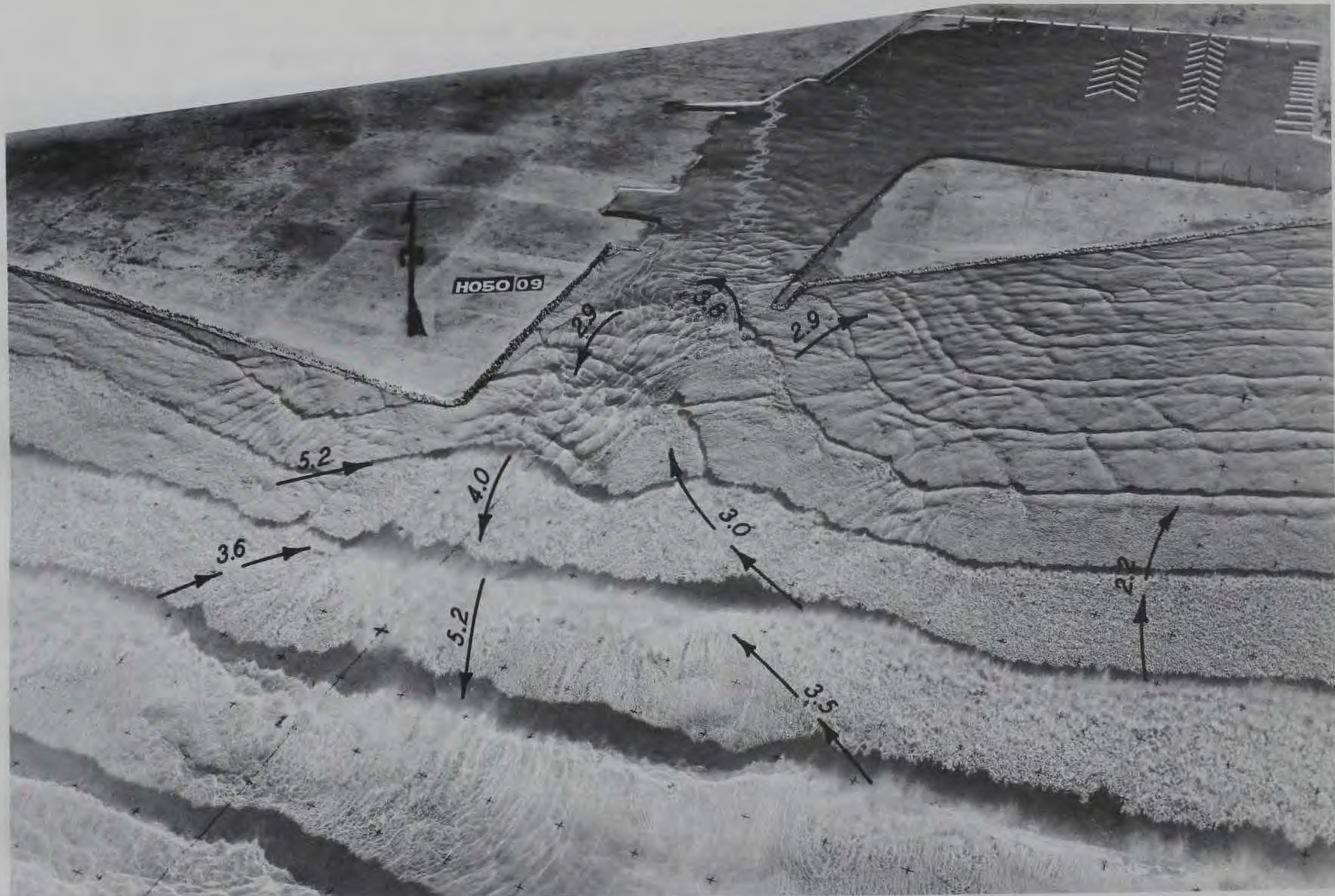


Photo 4. Typical wave and current patterns for 10-sec, 14-ft waves from 210-deg test direction with plan 1 installed

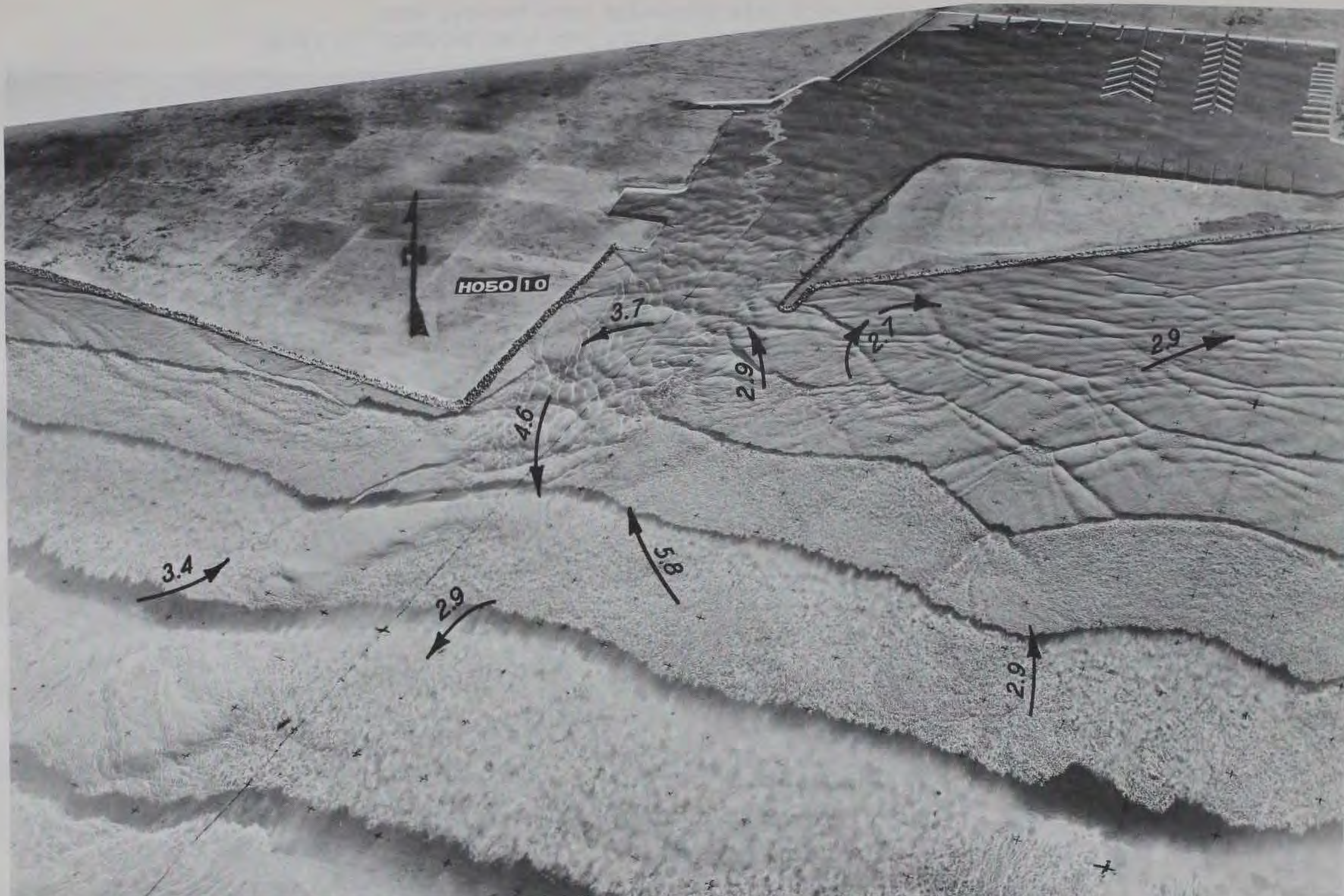


Photo 5. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 1 installed

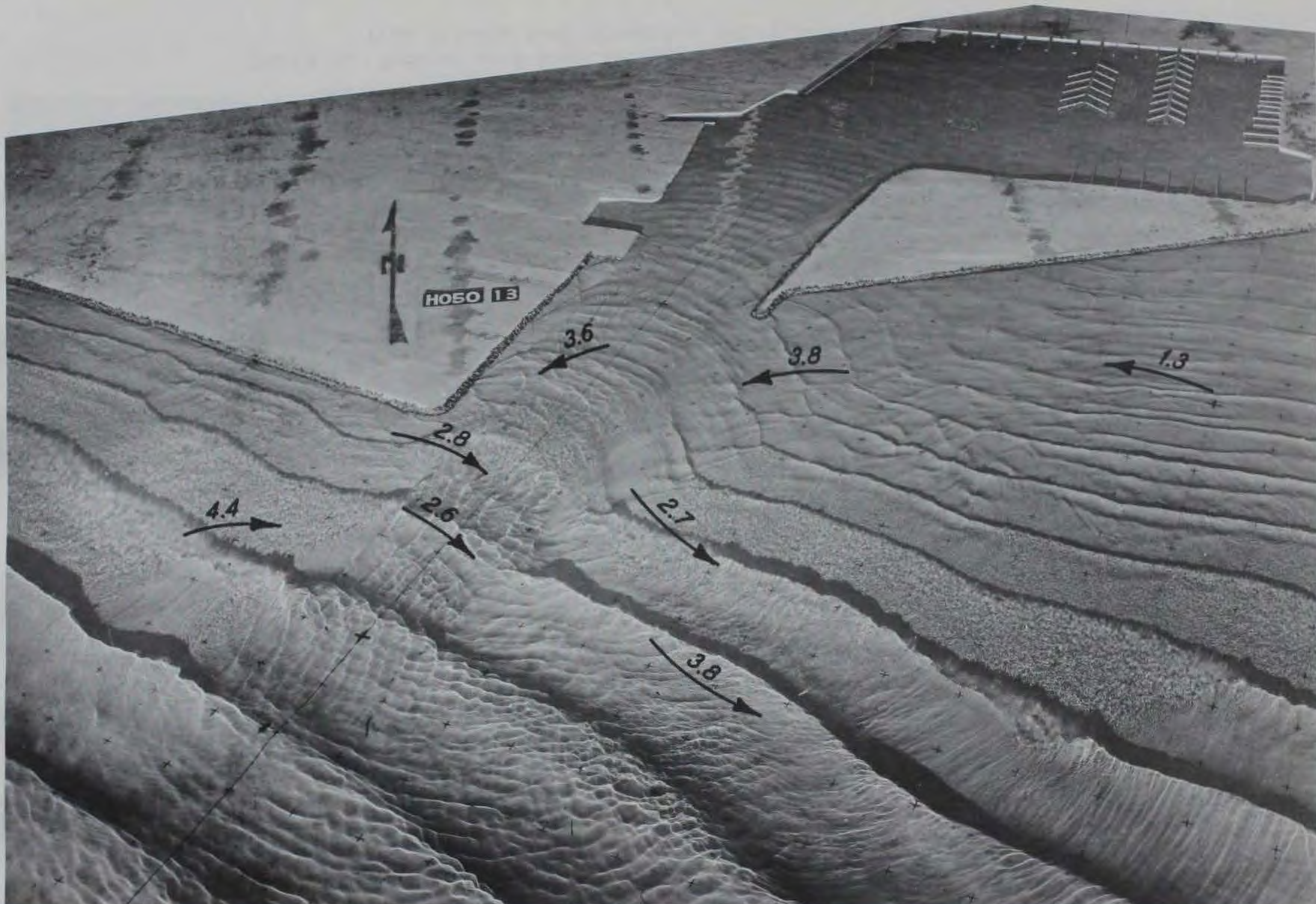


Photo 6. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 1 installed

Photo 7. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 1 installed

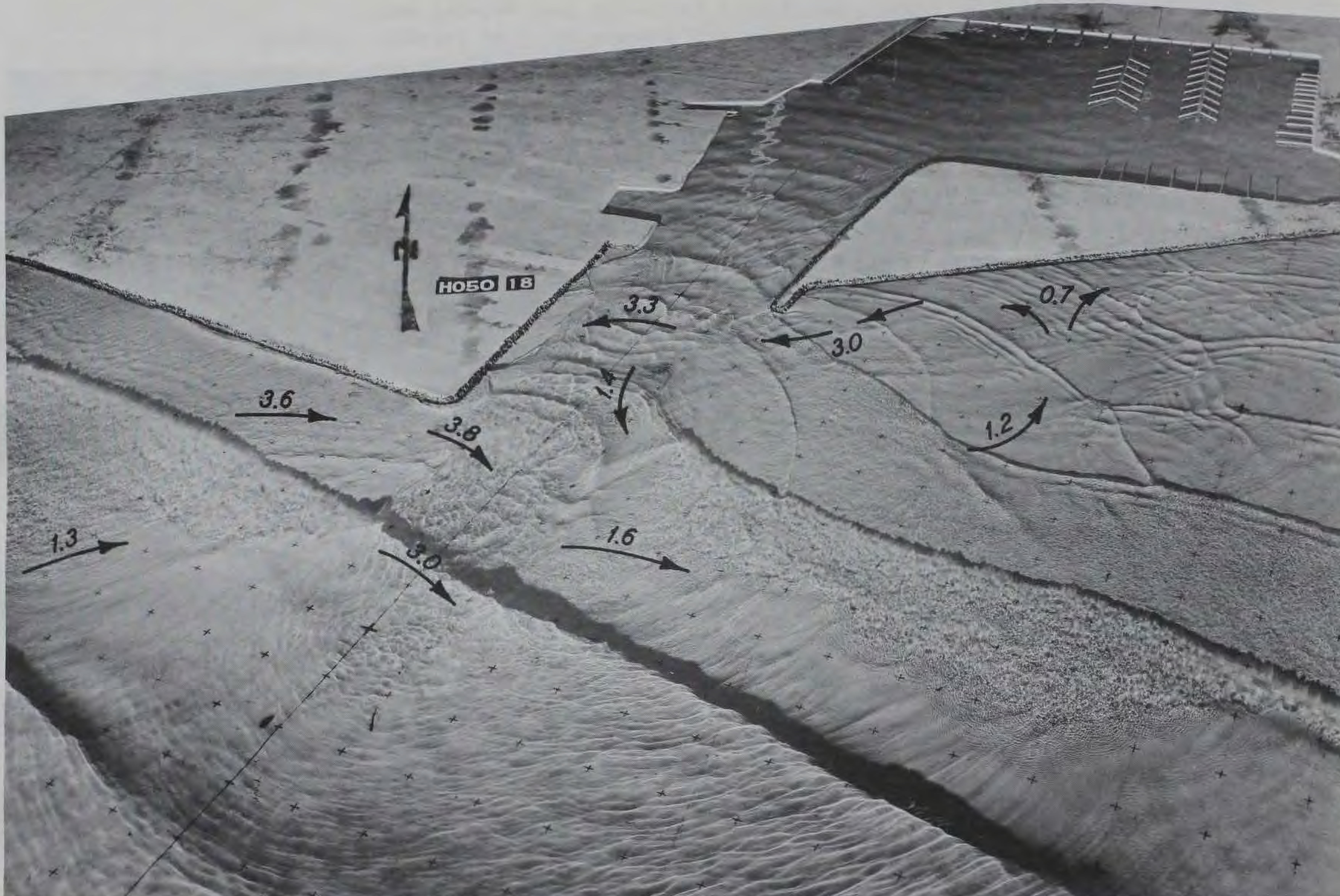


Photo 8. Typical wave and current patterns for 18-sec, 10-ft waves from 240-deg test direction with plan 1 installed

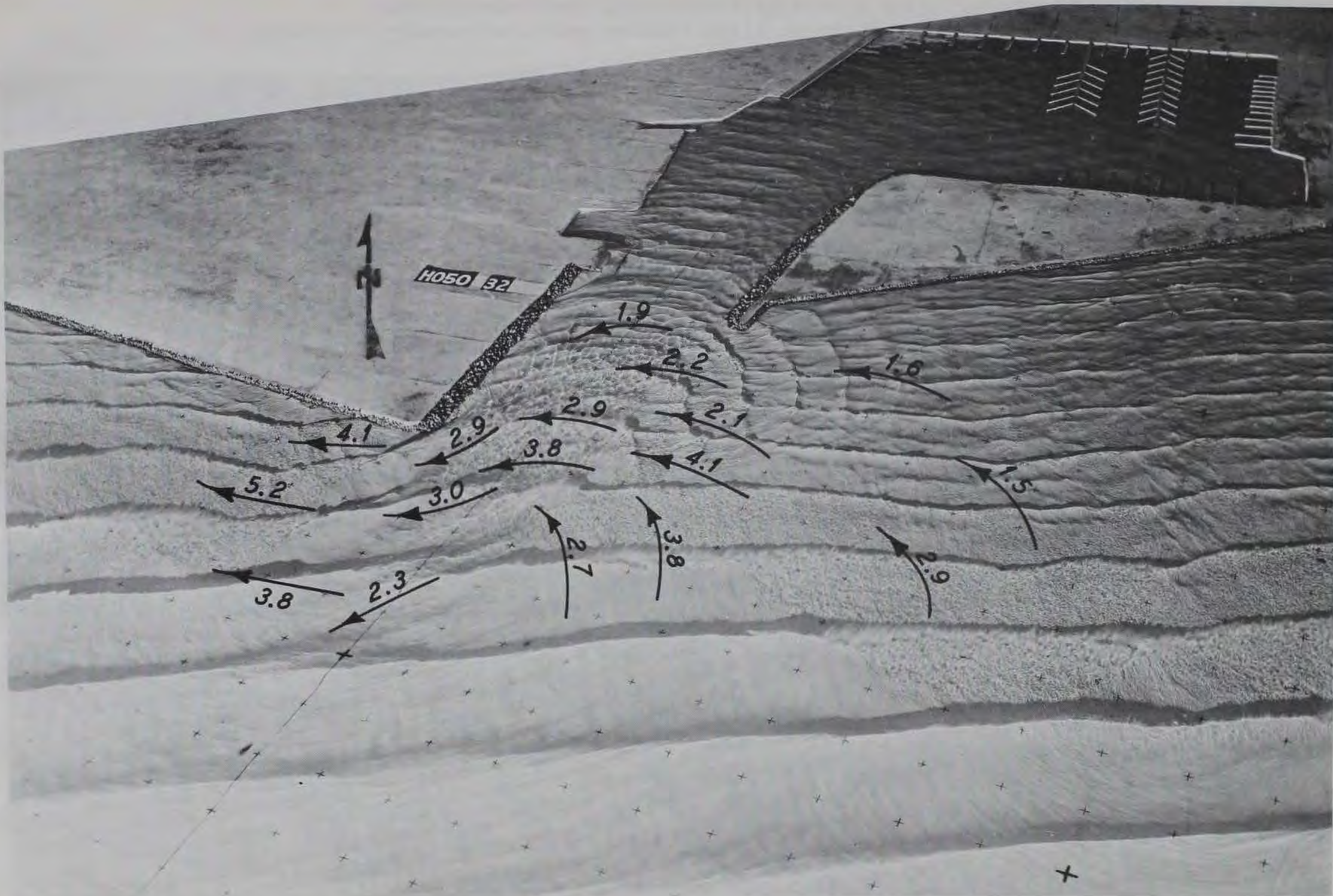


Photo 9. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 2 installed

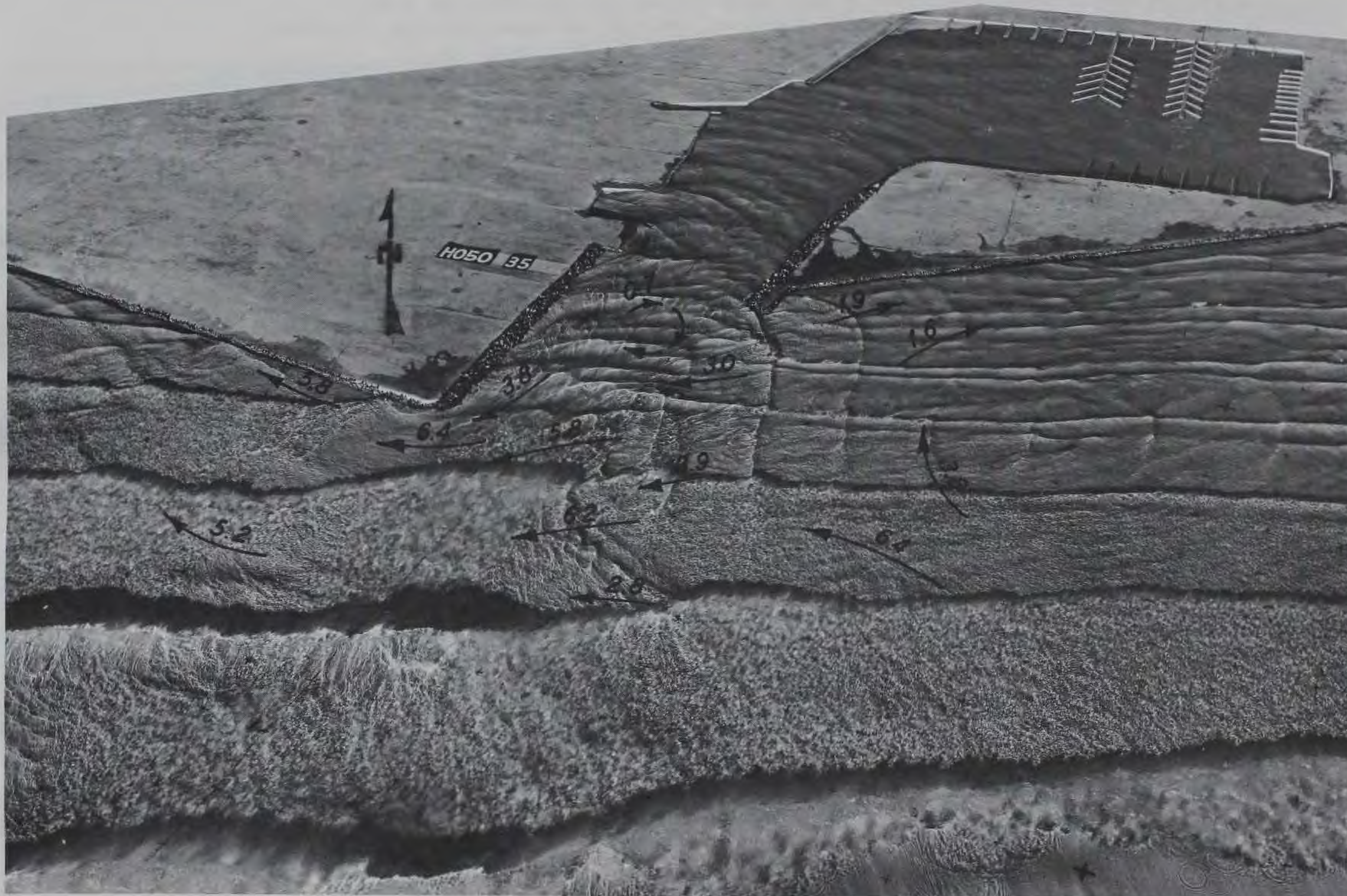


Photo 10. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 2 installed

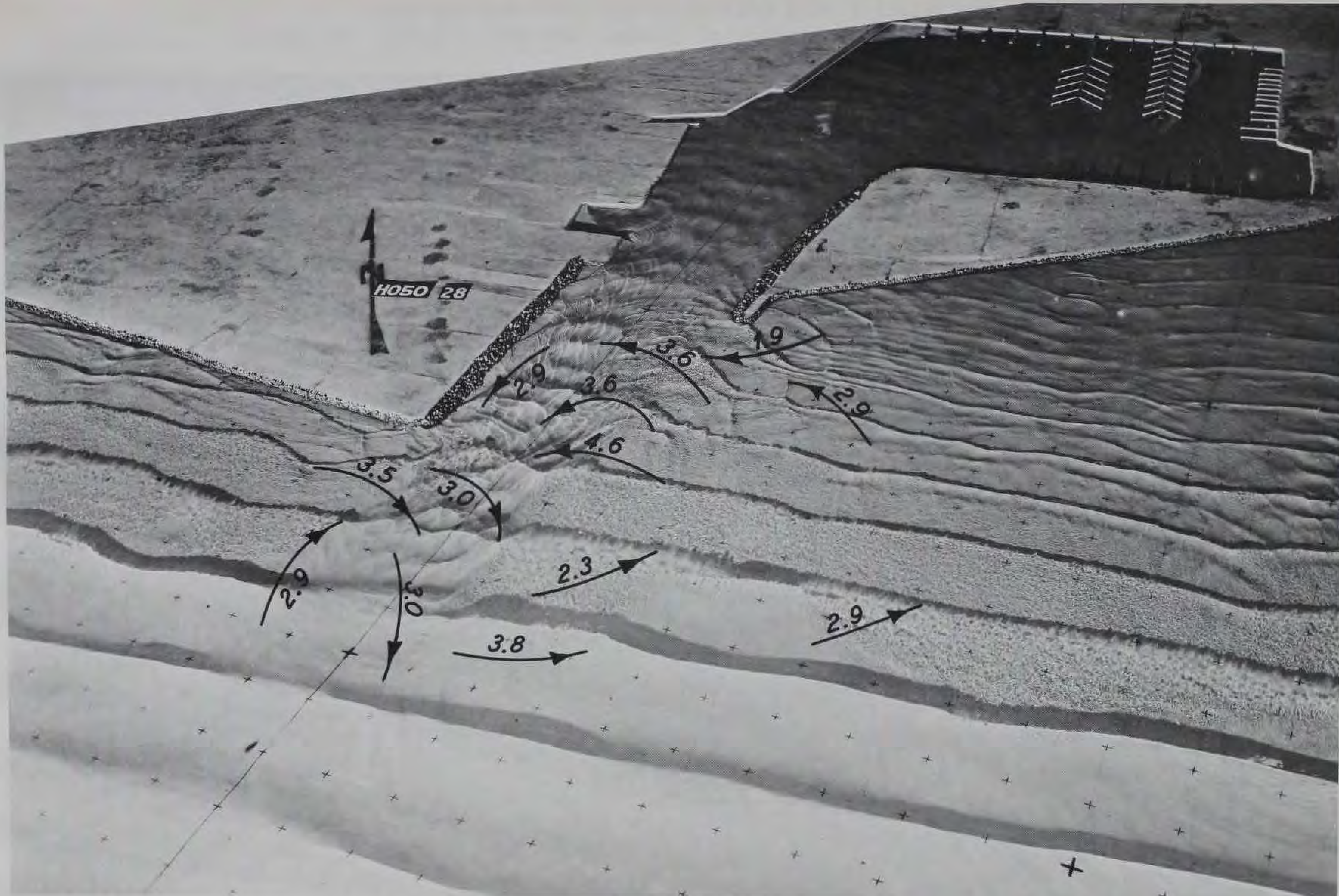


Photo 11. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 2 installed

Photo 12. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 2 installed

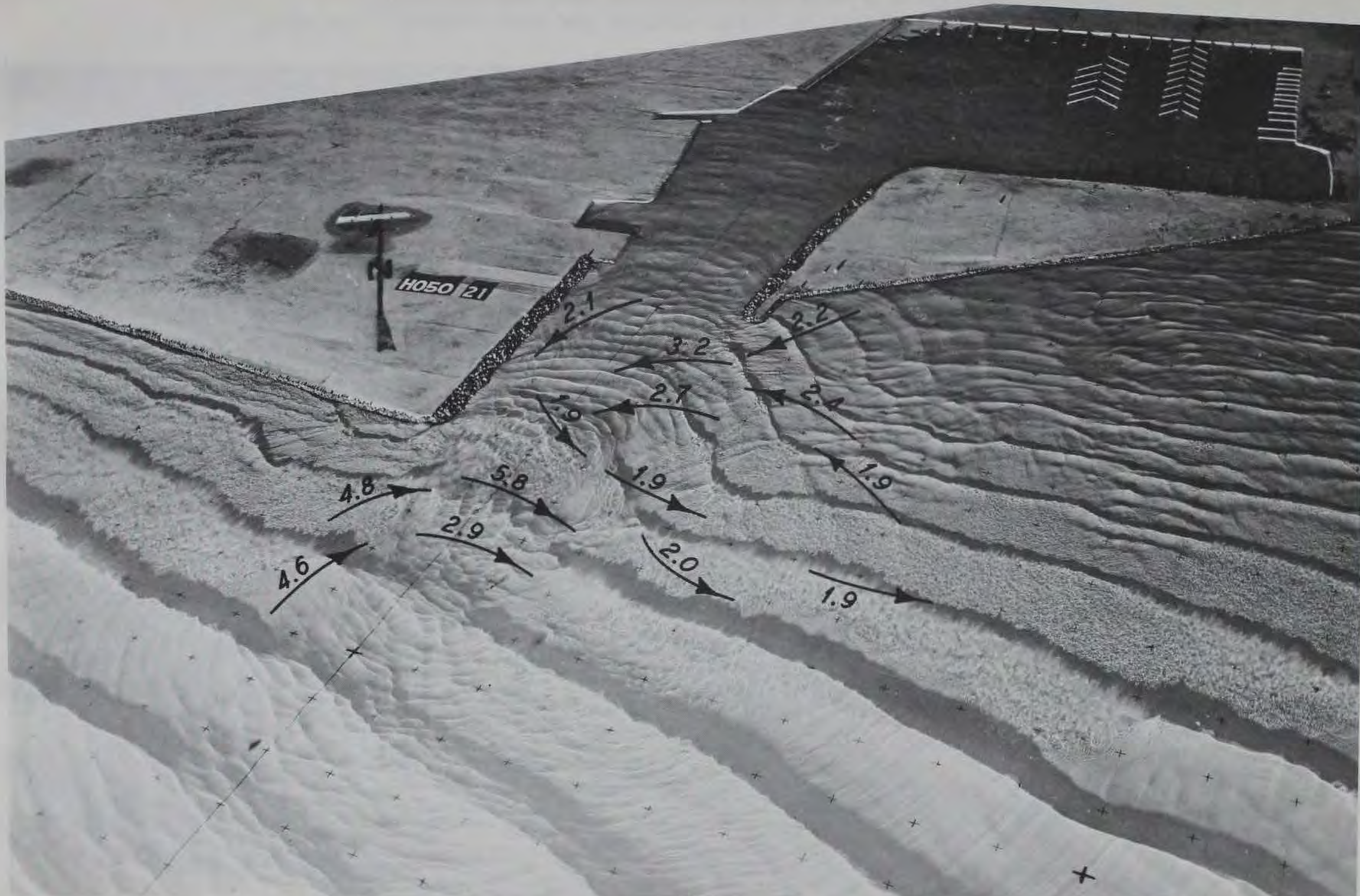


Photo 13. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 2 installed

Photo 14. Typical wave and current patterns for 12-sec, 14-ft waves
from 240-deg test direction with plan 2 installed

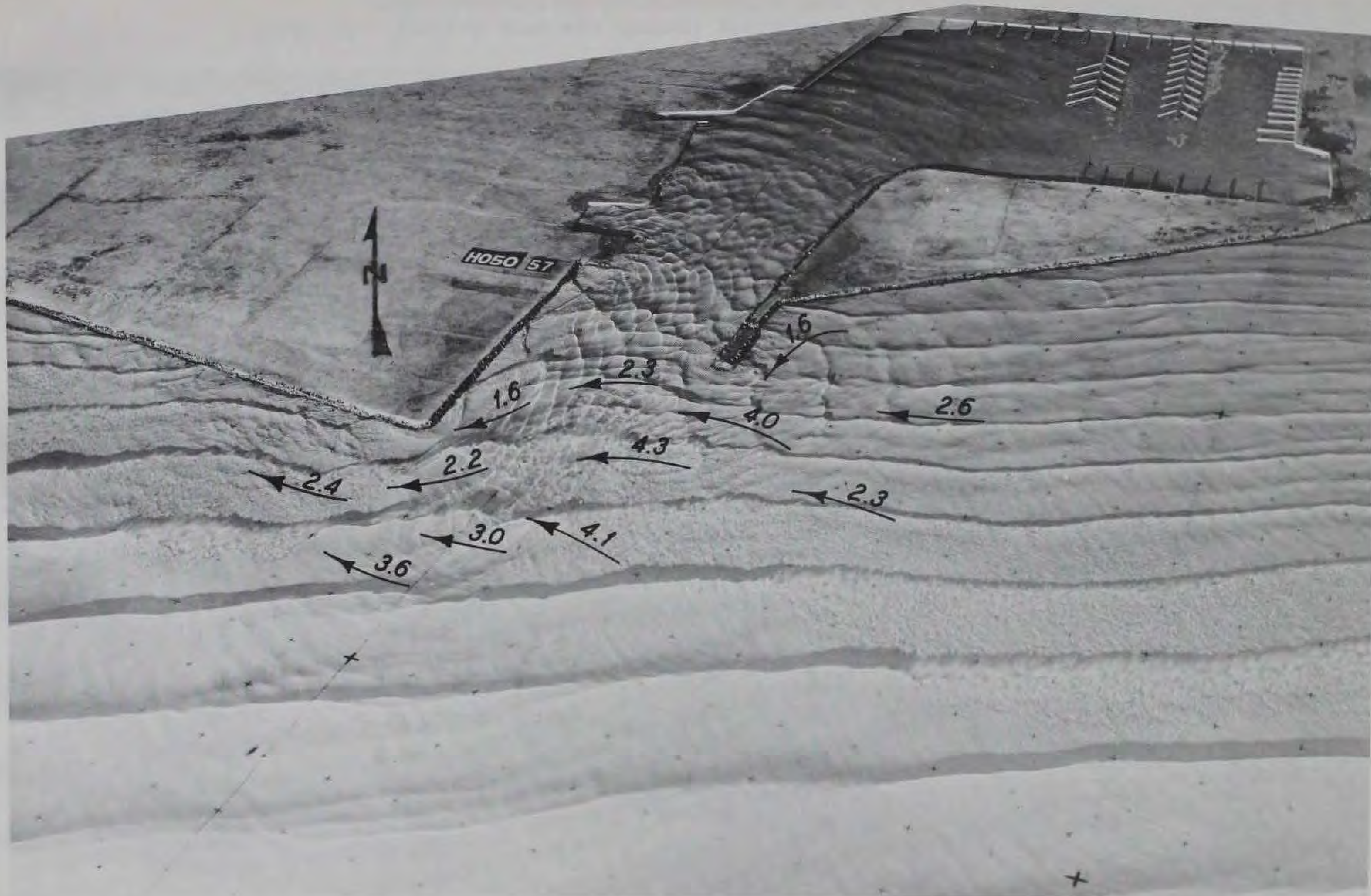


Photo 15. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 3A installed

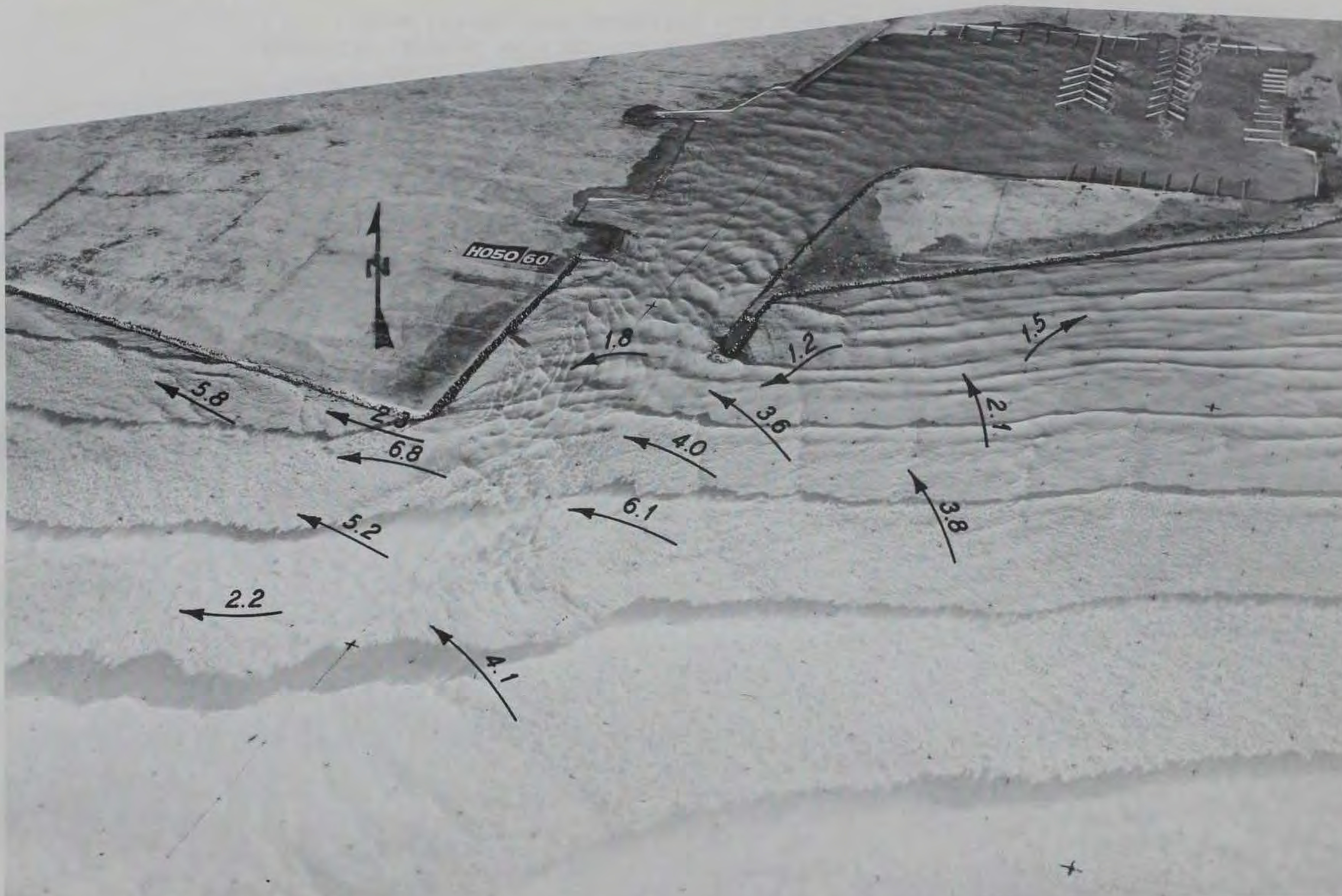


Photo 16. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 3A installed

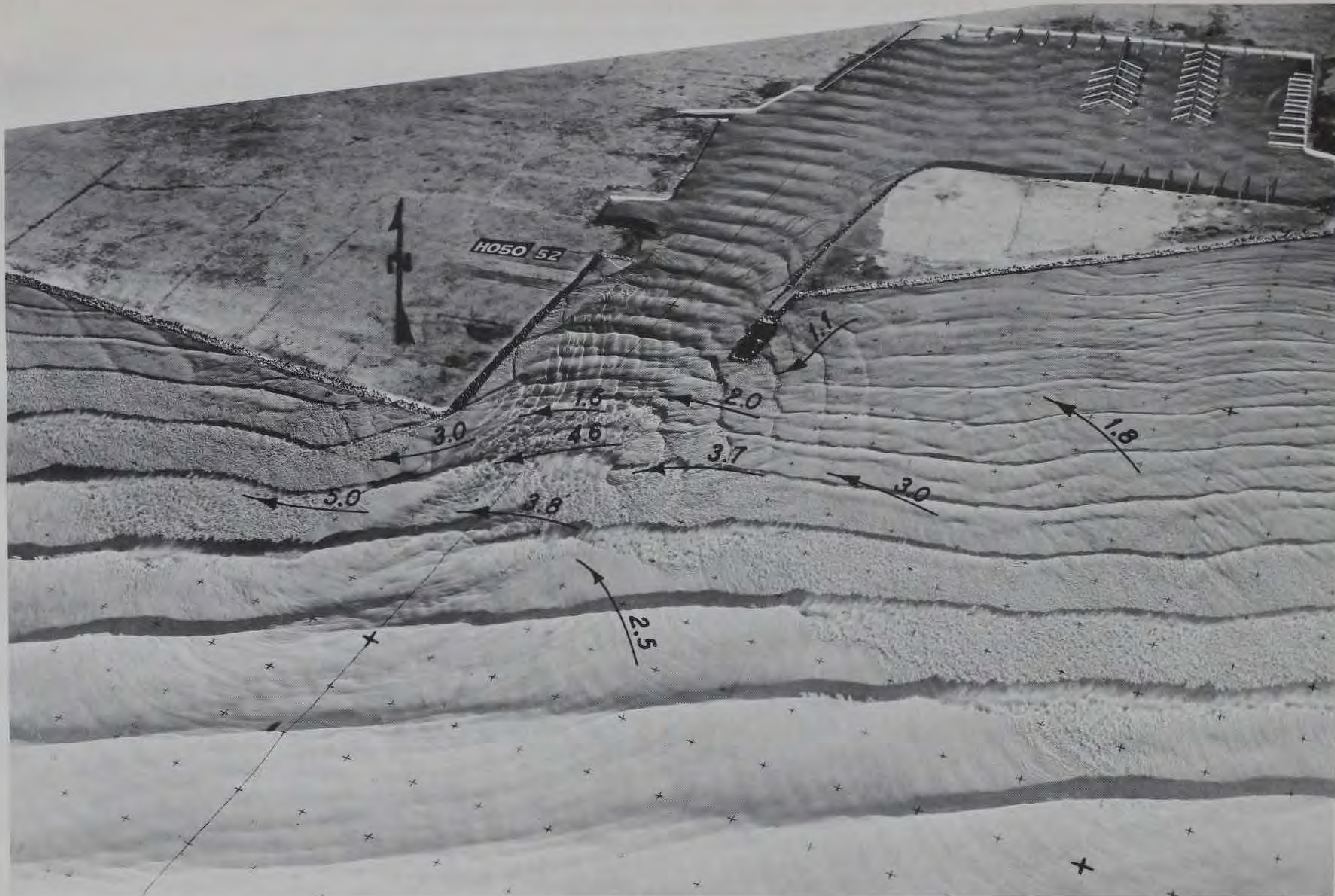


Photo 17. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 3B installed

Photo 18. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 3B installed

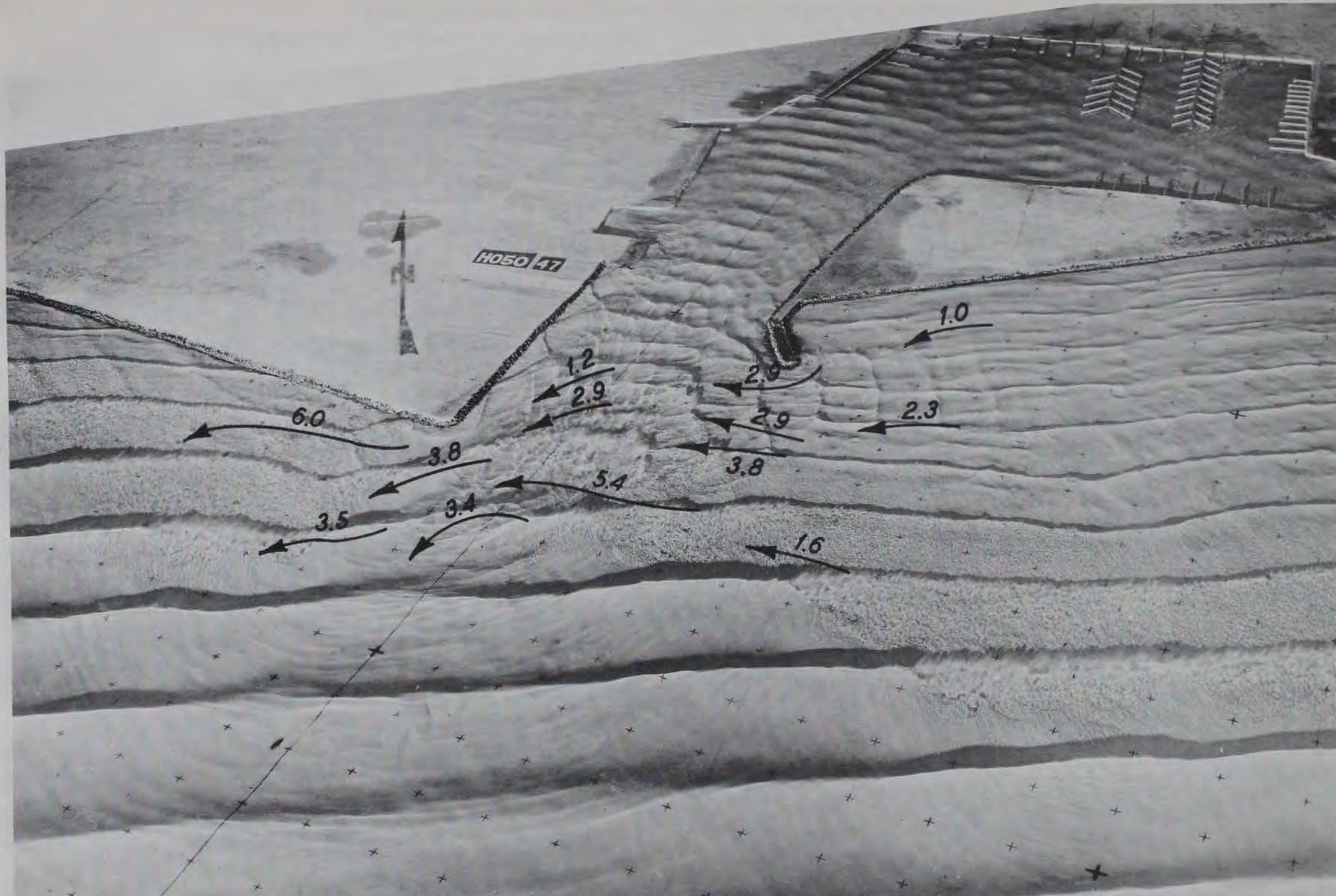


Photo 19. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 3C installed

Photo 20. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 3C installed

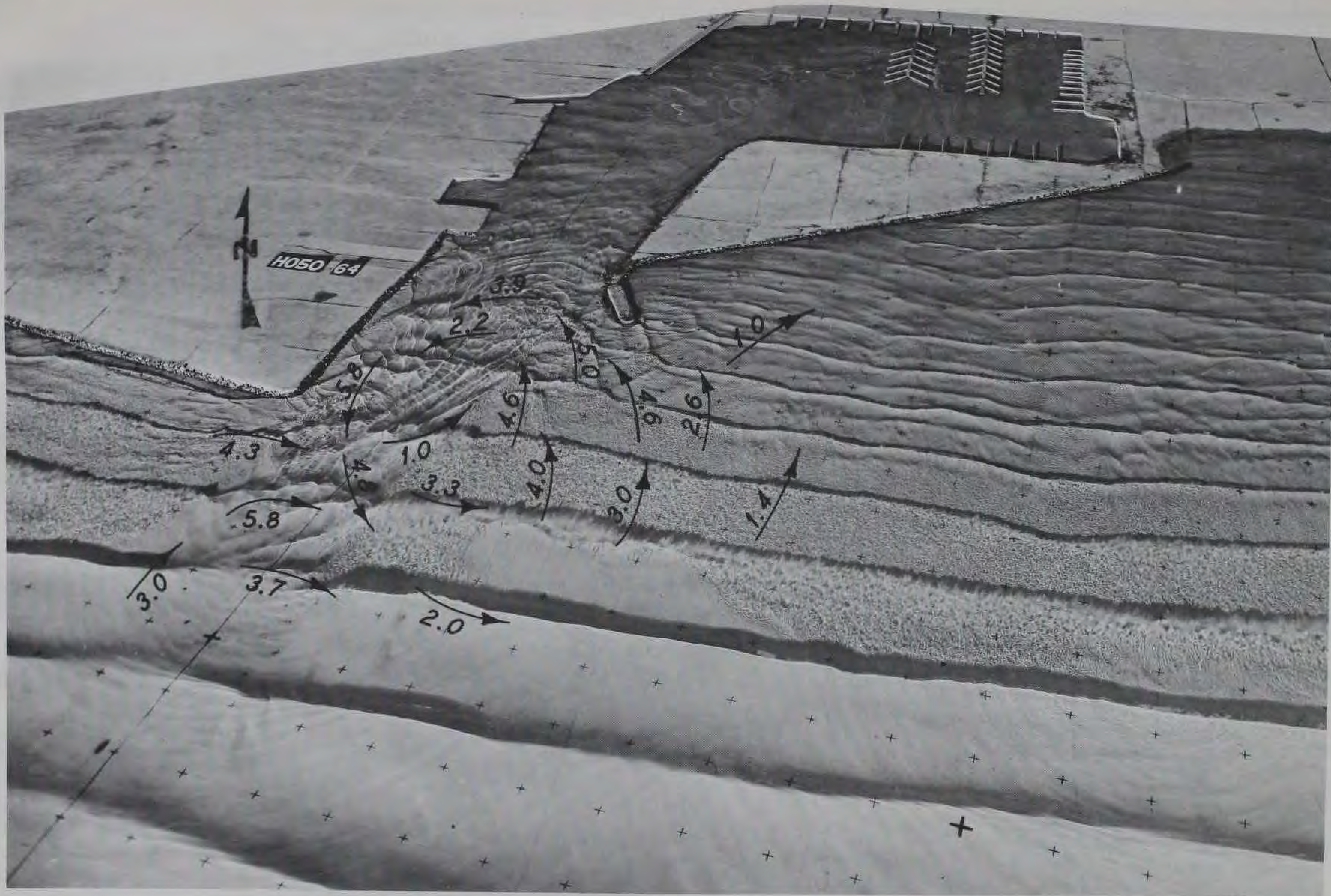


Photo 21. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 3C installed

Photo 22. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 3C installed

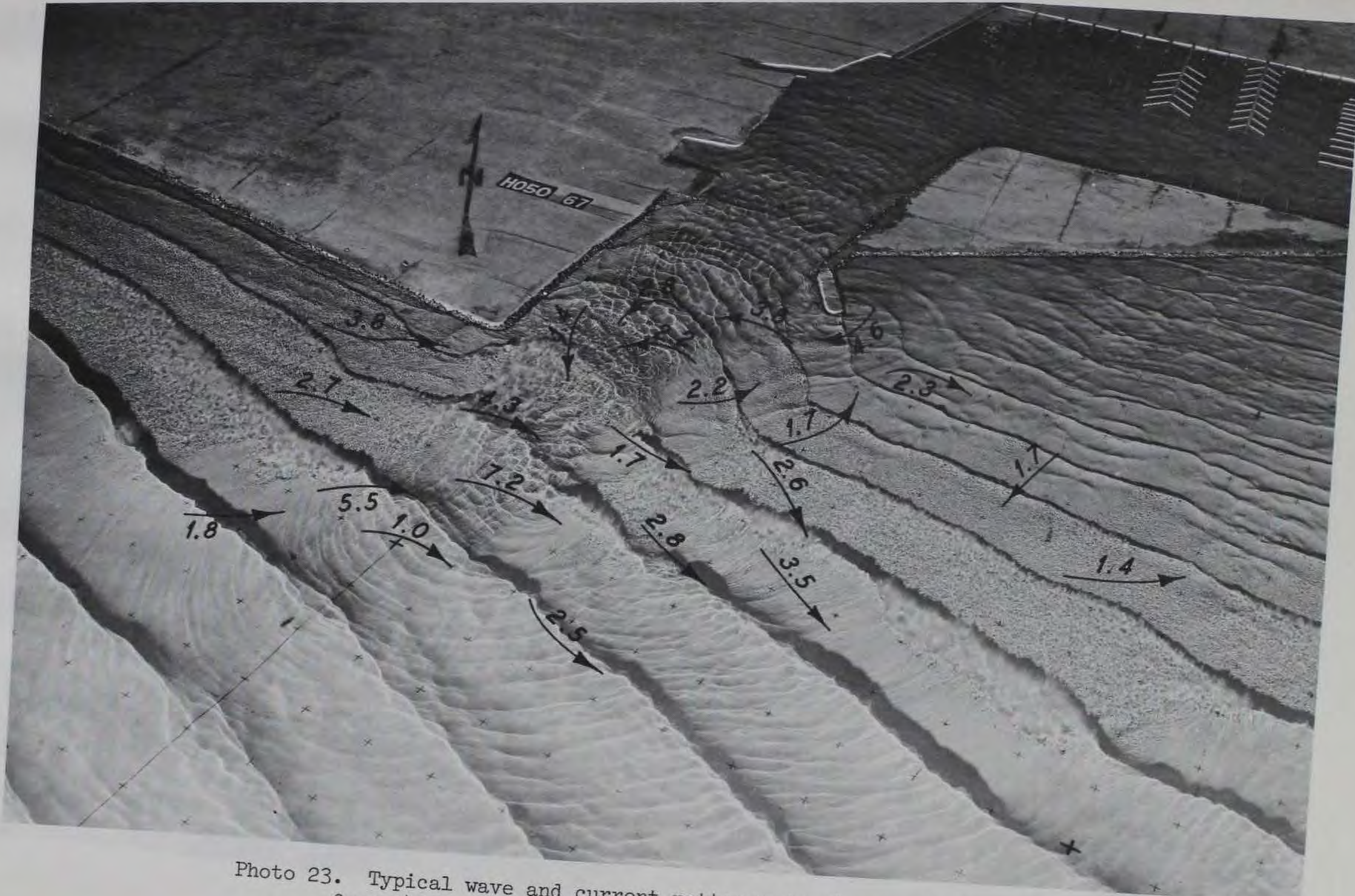


Photo 23. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 3C installed

Photo 24. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 3C installed

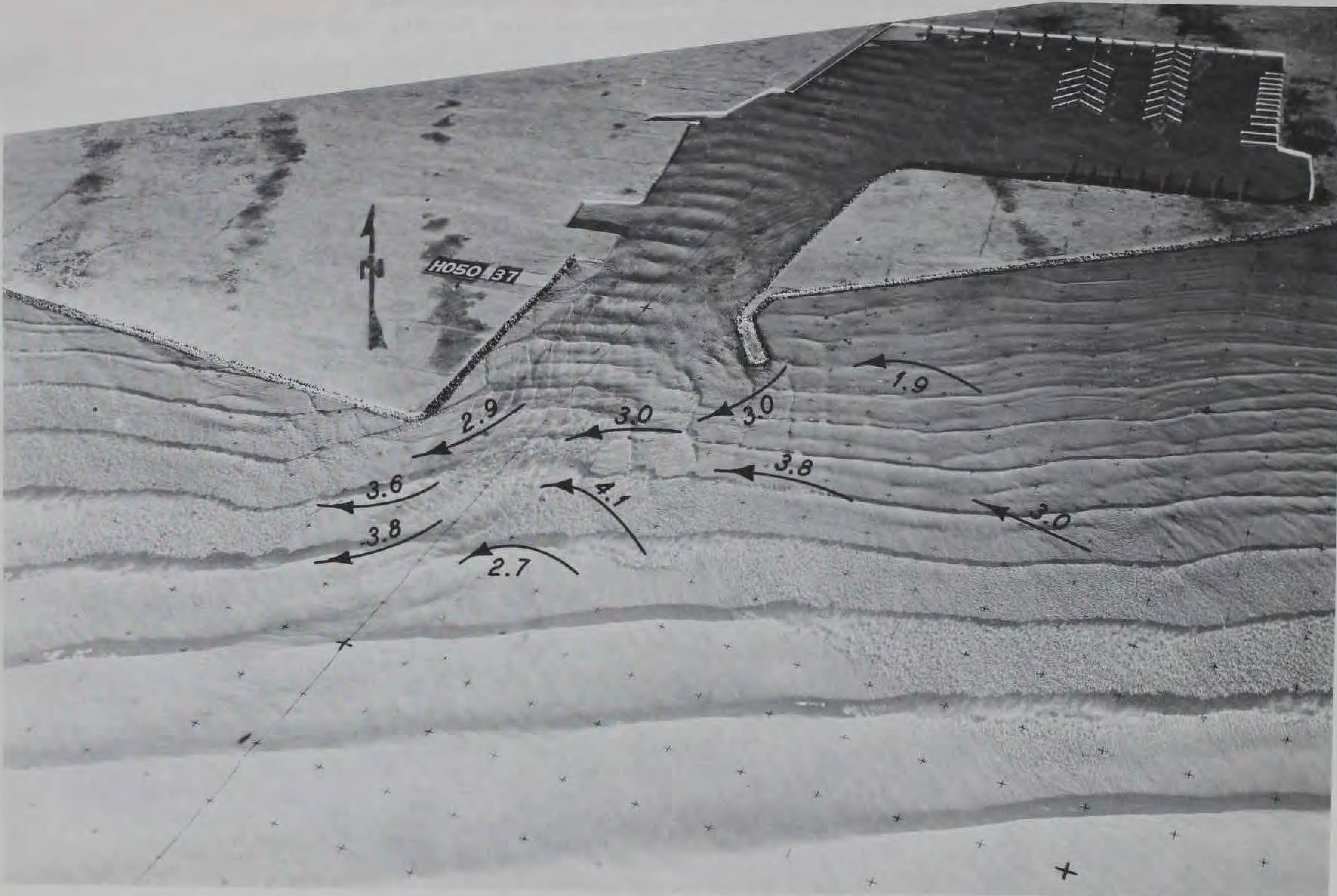


Photo 25. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 3D installed

Photo 26. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 3D installed

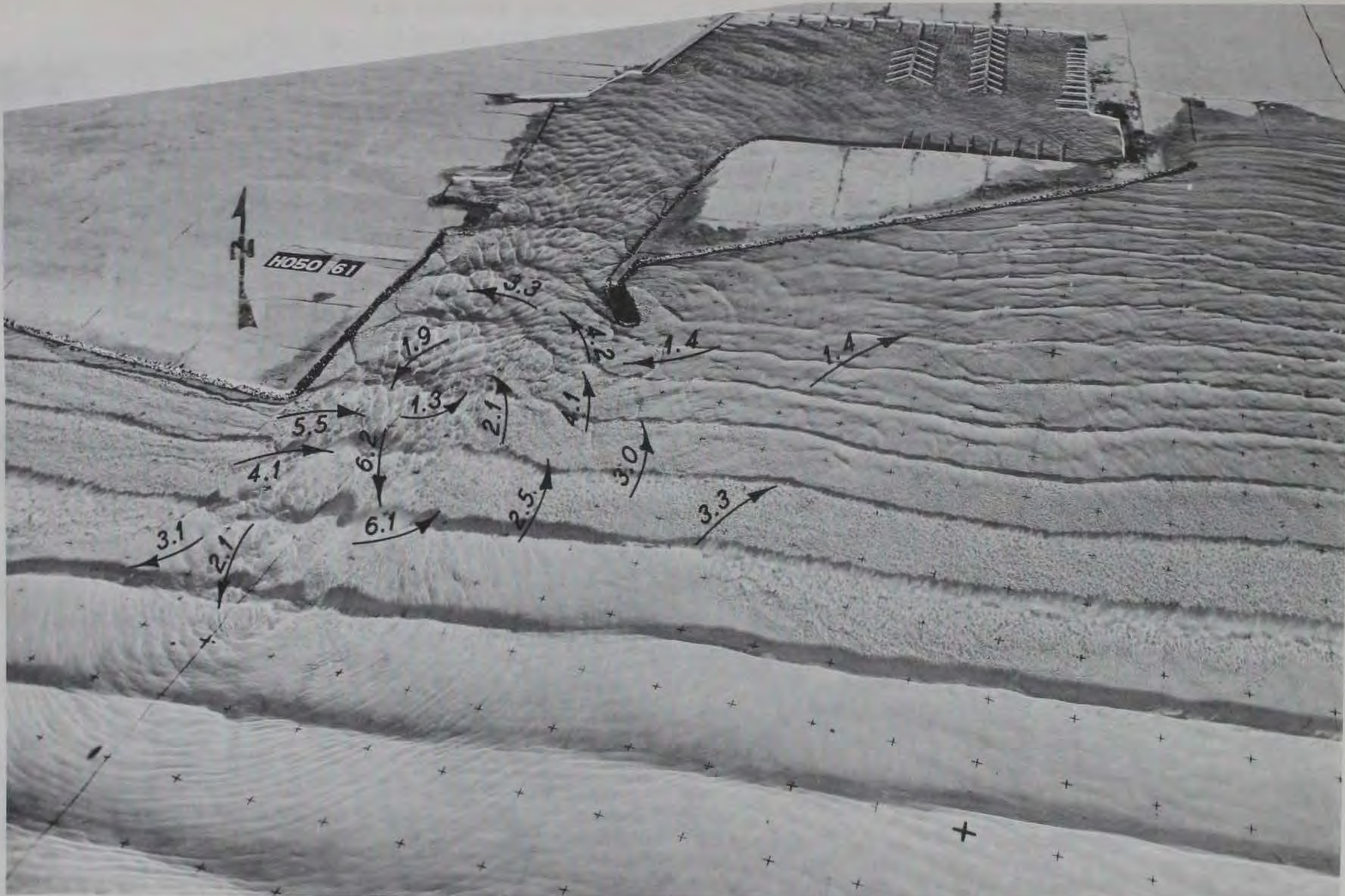


Photo 27. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 3D installed

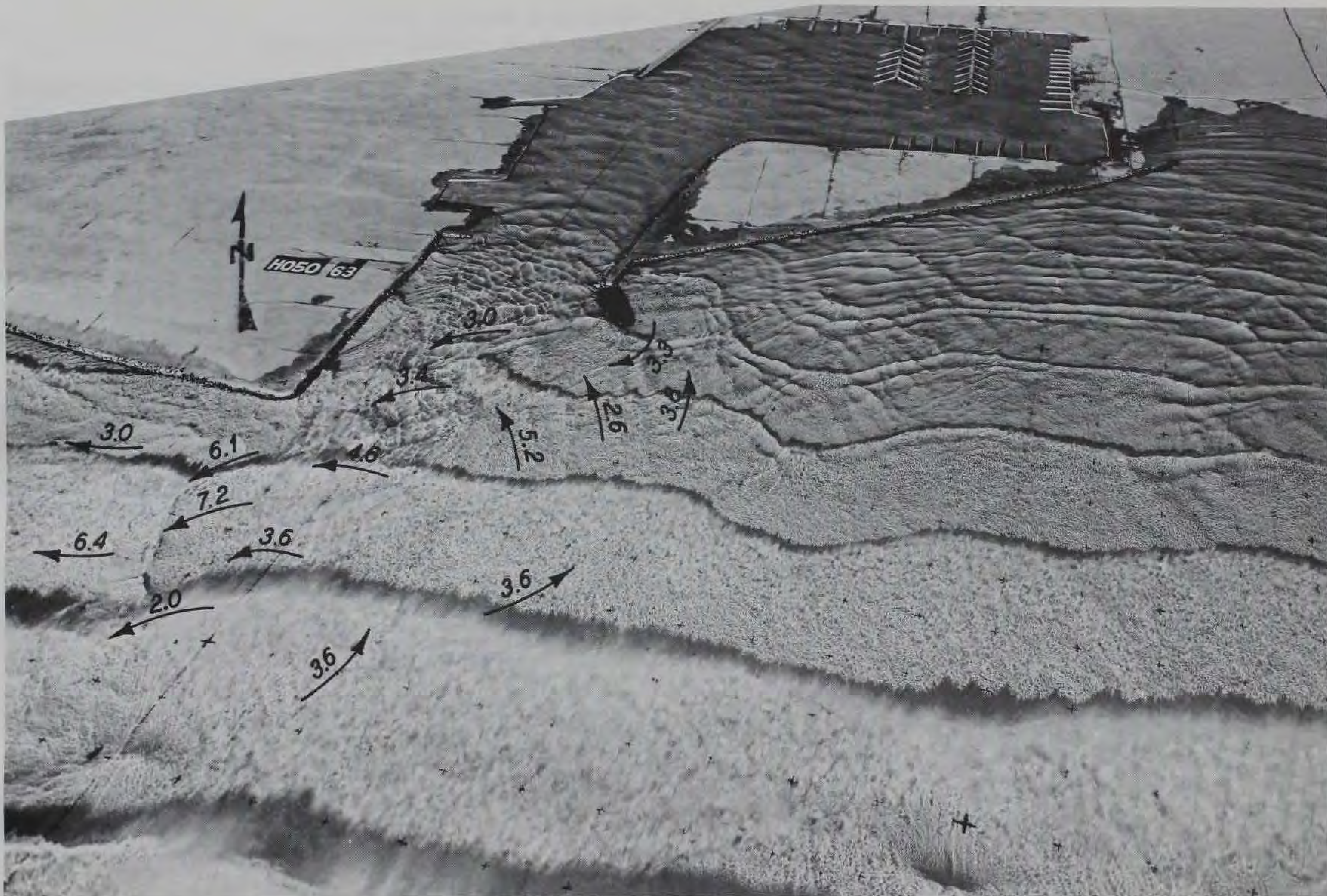


Photo 28. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 3D installed

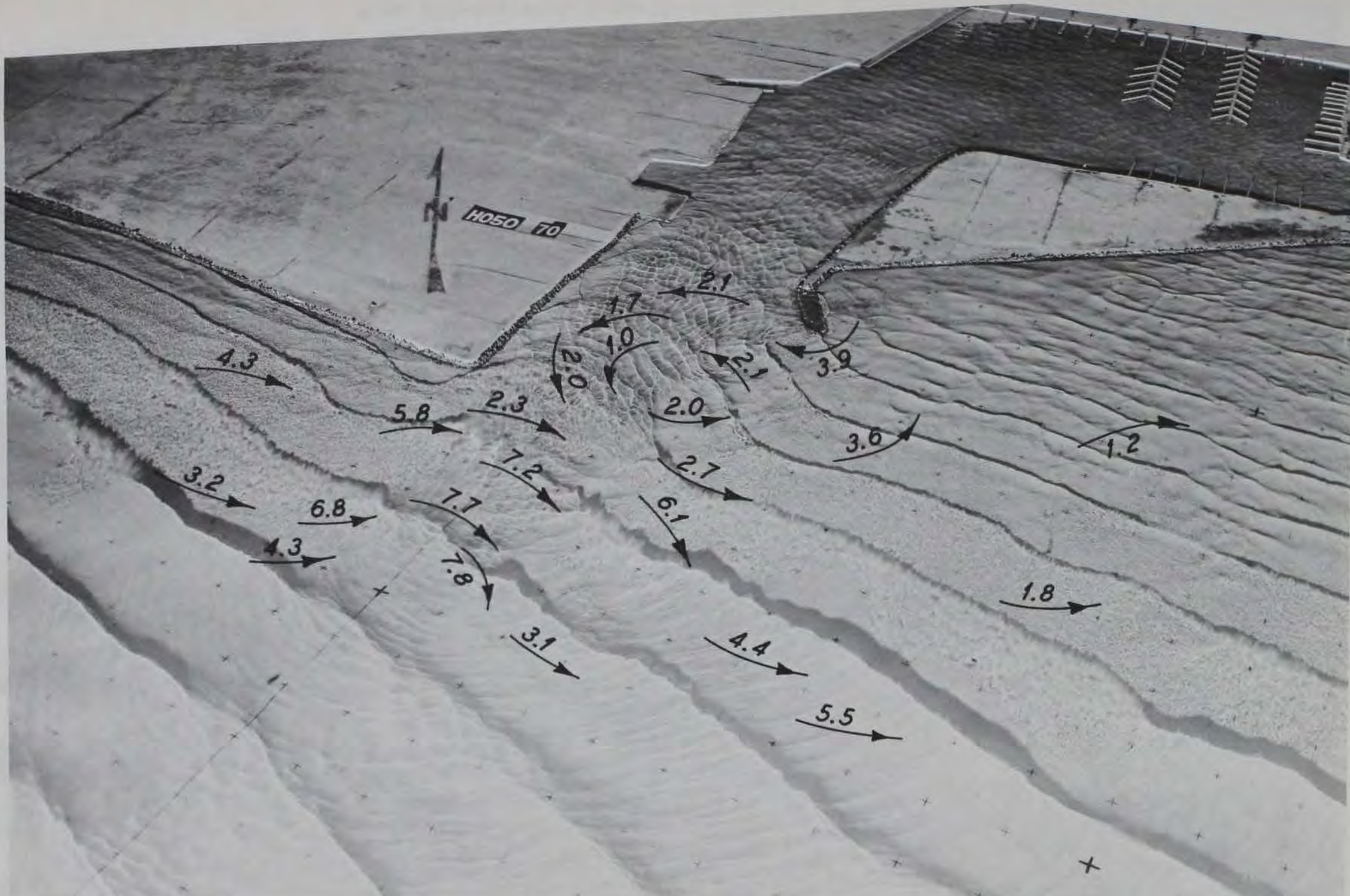


Photo 29. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 3D installed

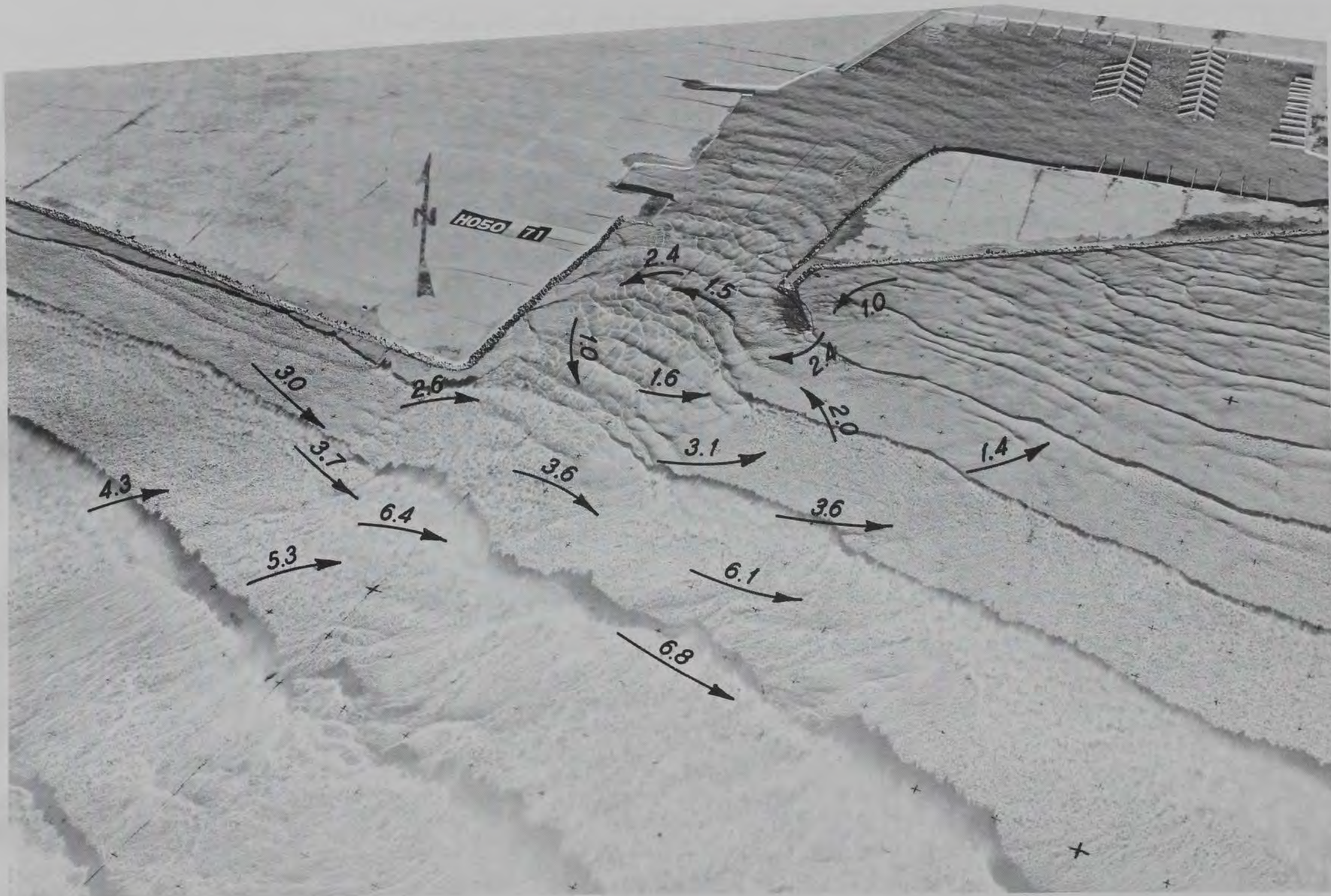


Photo 30. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 3D installed

Photo 31. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 3E installed

Photo 32. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 3E installed

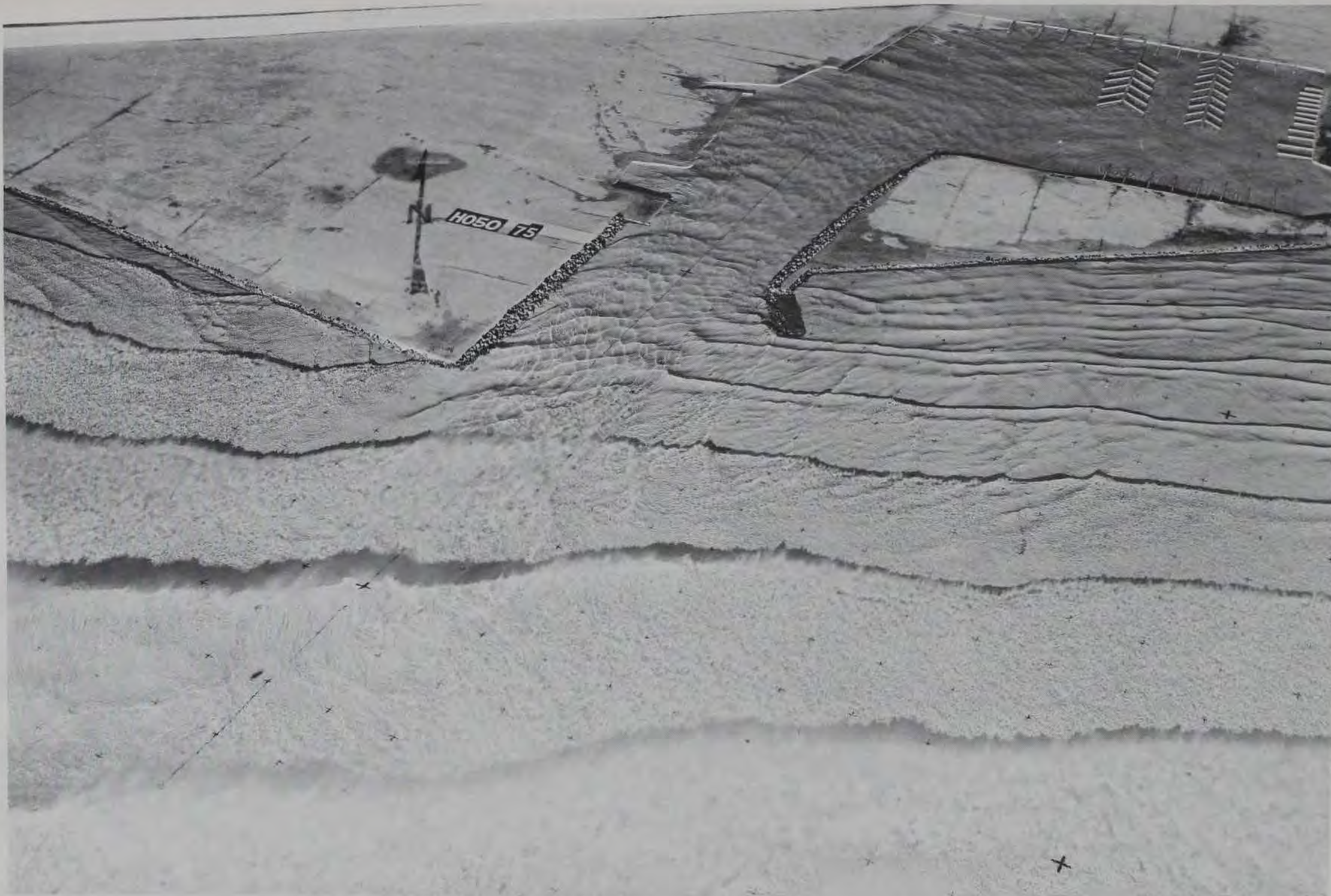


Photo 33. Typical wave patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 4 installed

Photo 34. Typical wave patterns for 12-sec, 14-ft waves
from 210-deg test direction with plan 4 installed

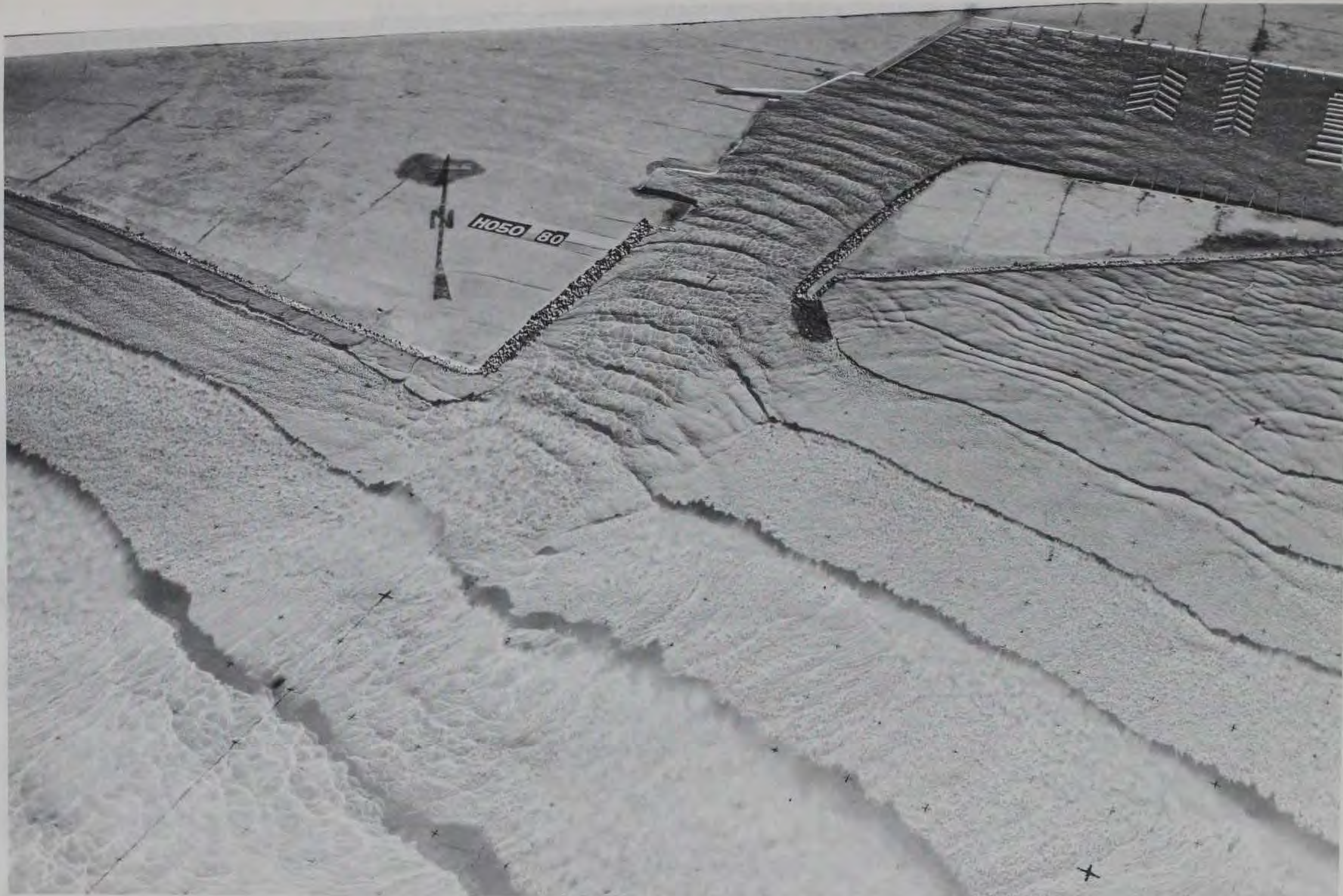


Photo 35. Typical wave patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 4 installed

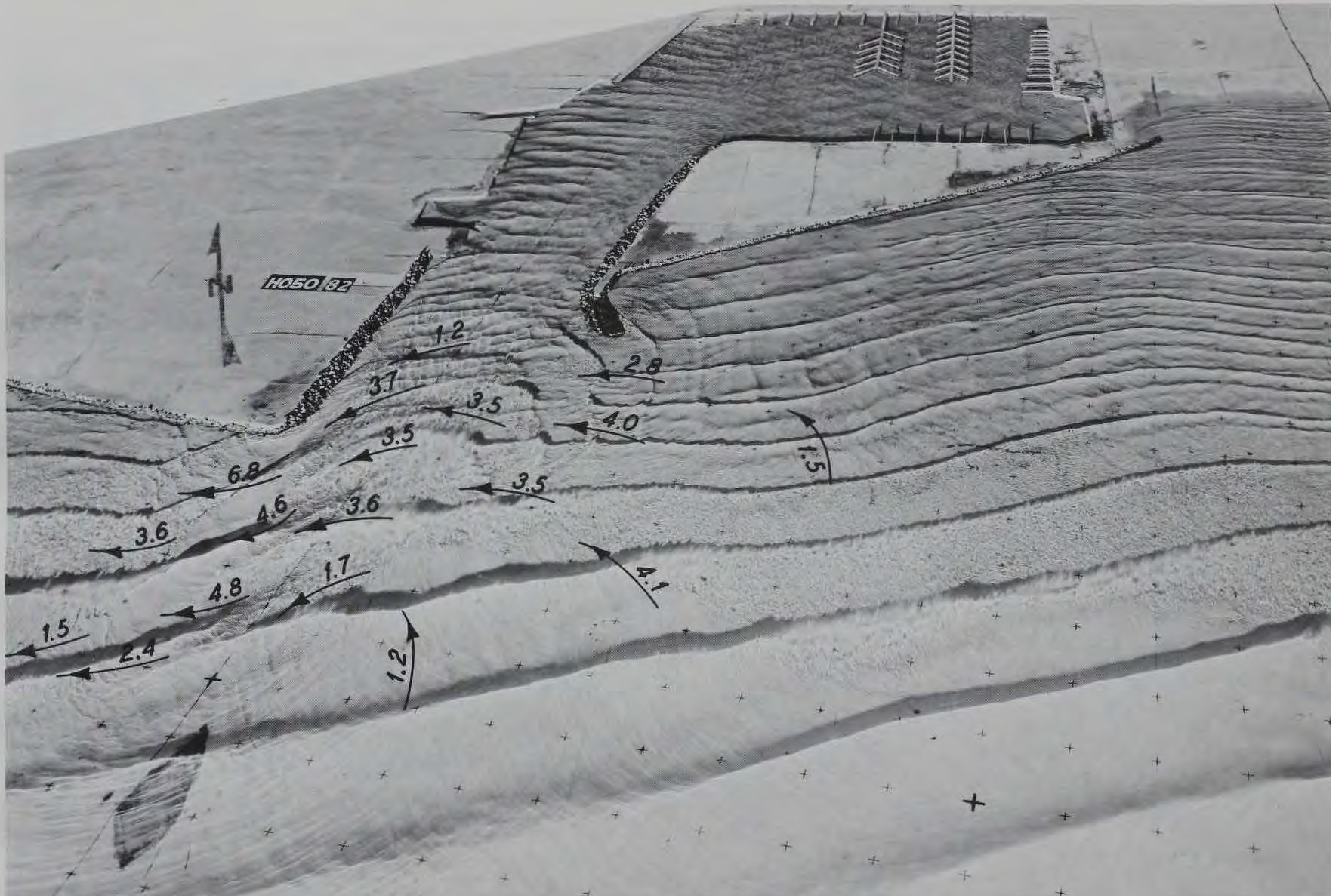


Photo 36. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 5 installed

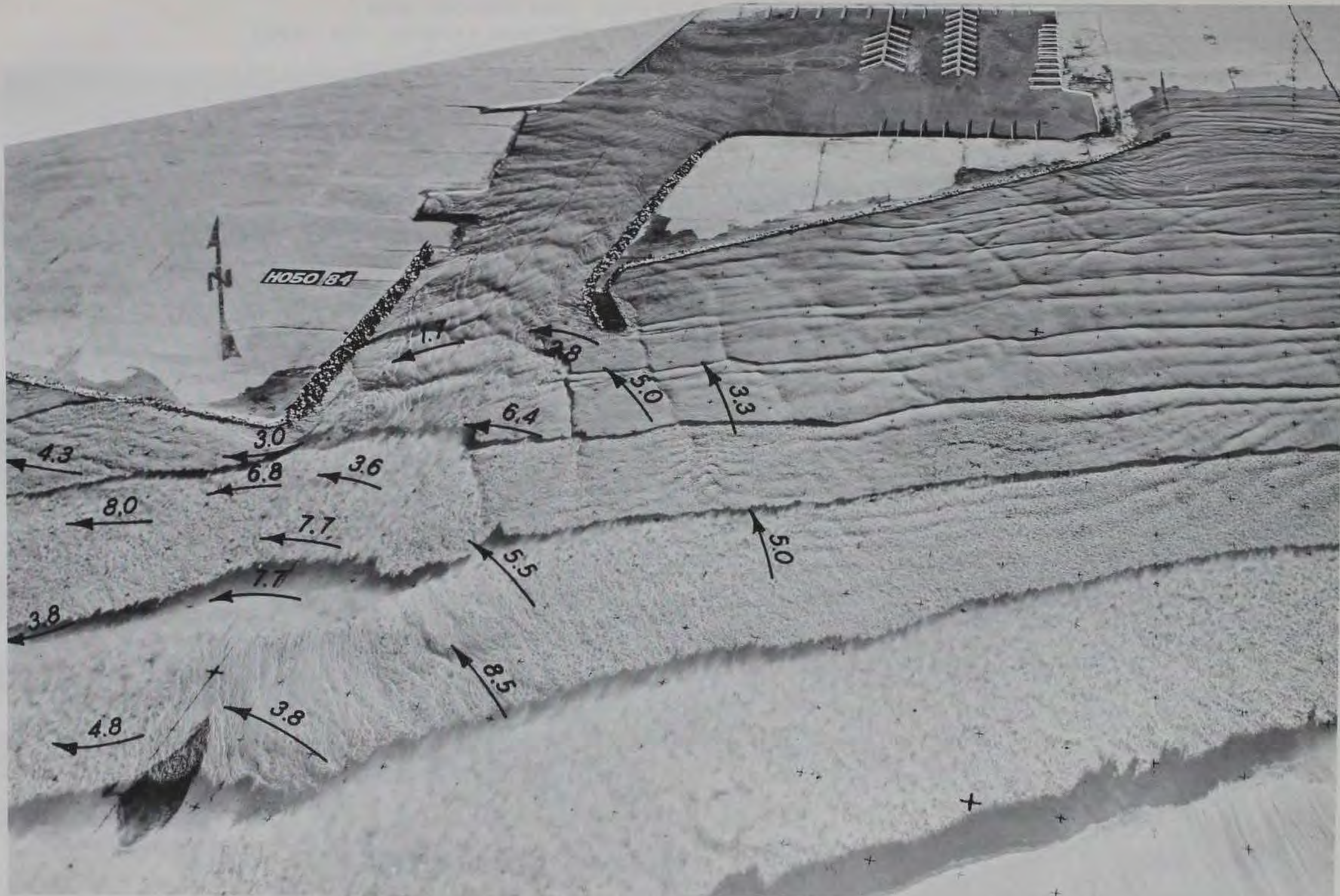


Photo 37. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 5 installed

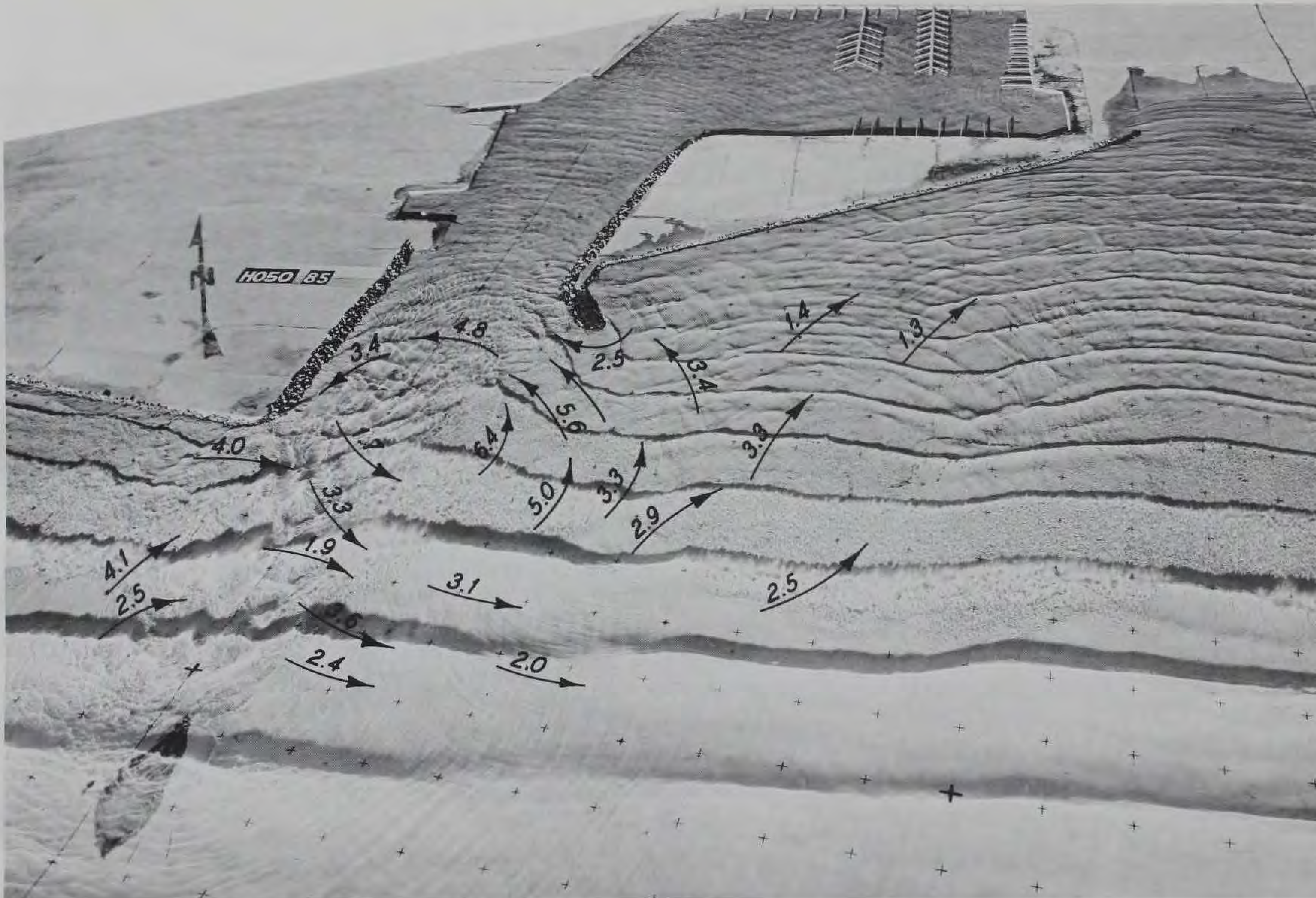


Photo 38. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 5 installed

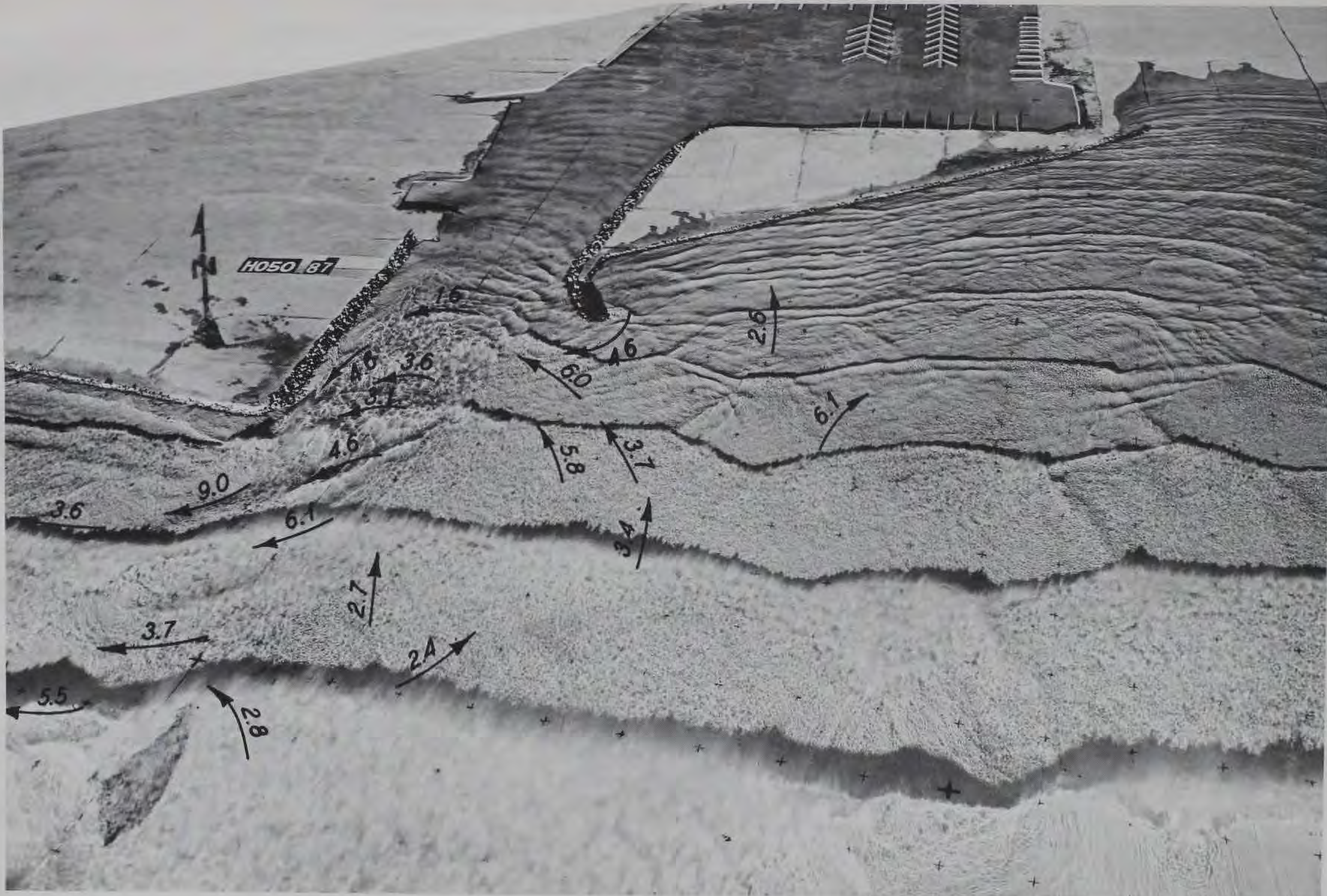


Photo 39. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 5 installed

Photo 40. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 5 installed

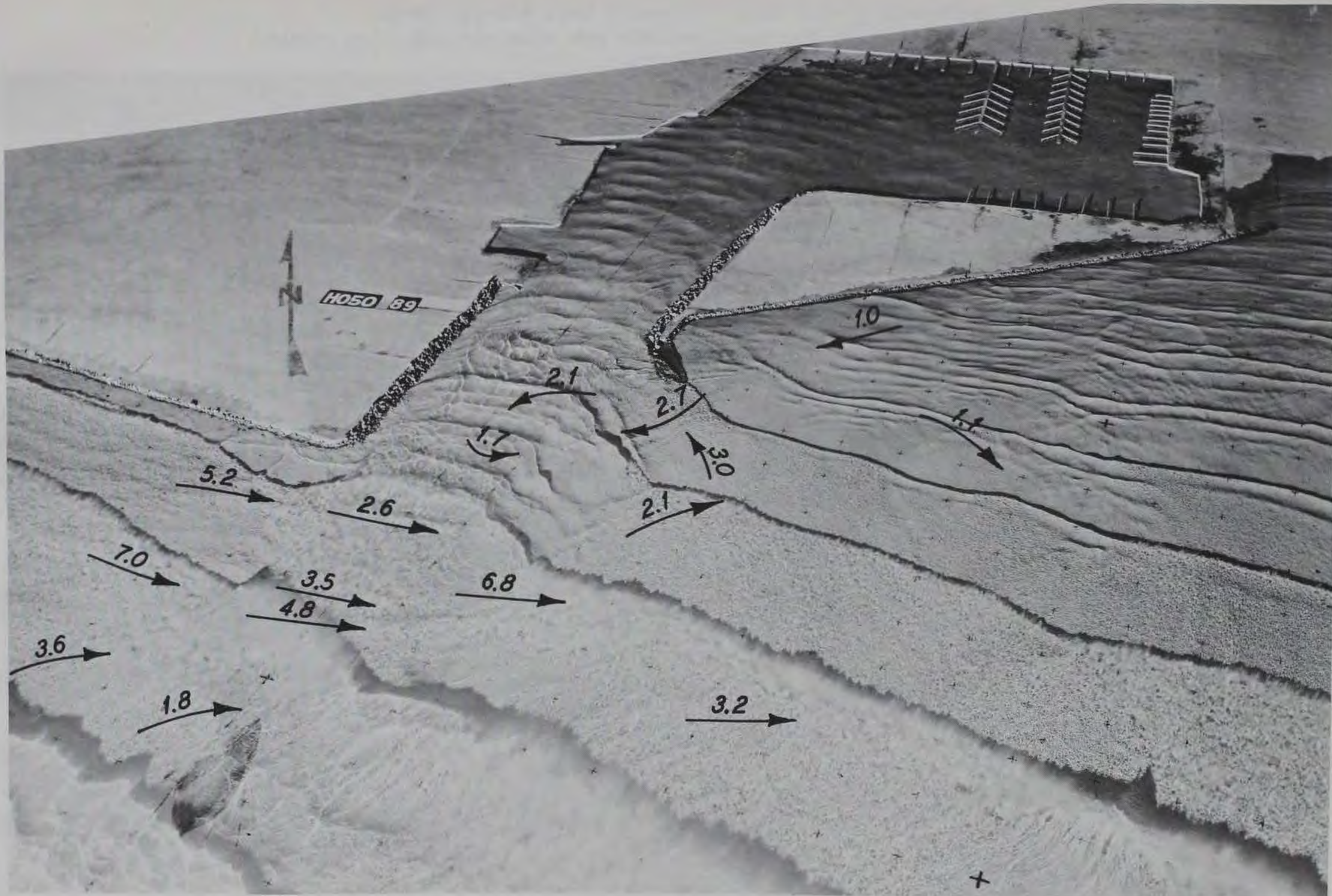


Photo 41. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 5 installed

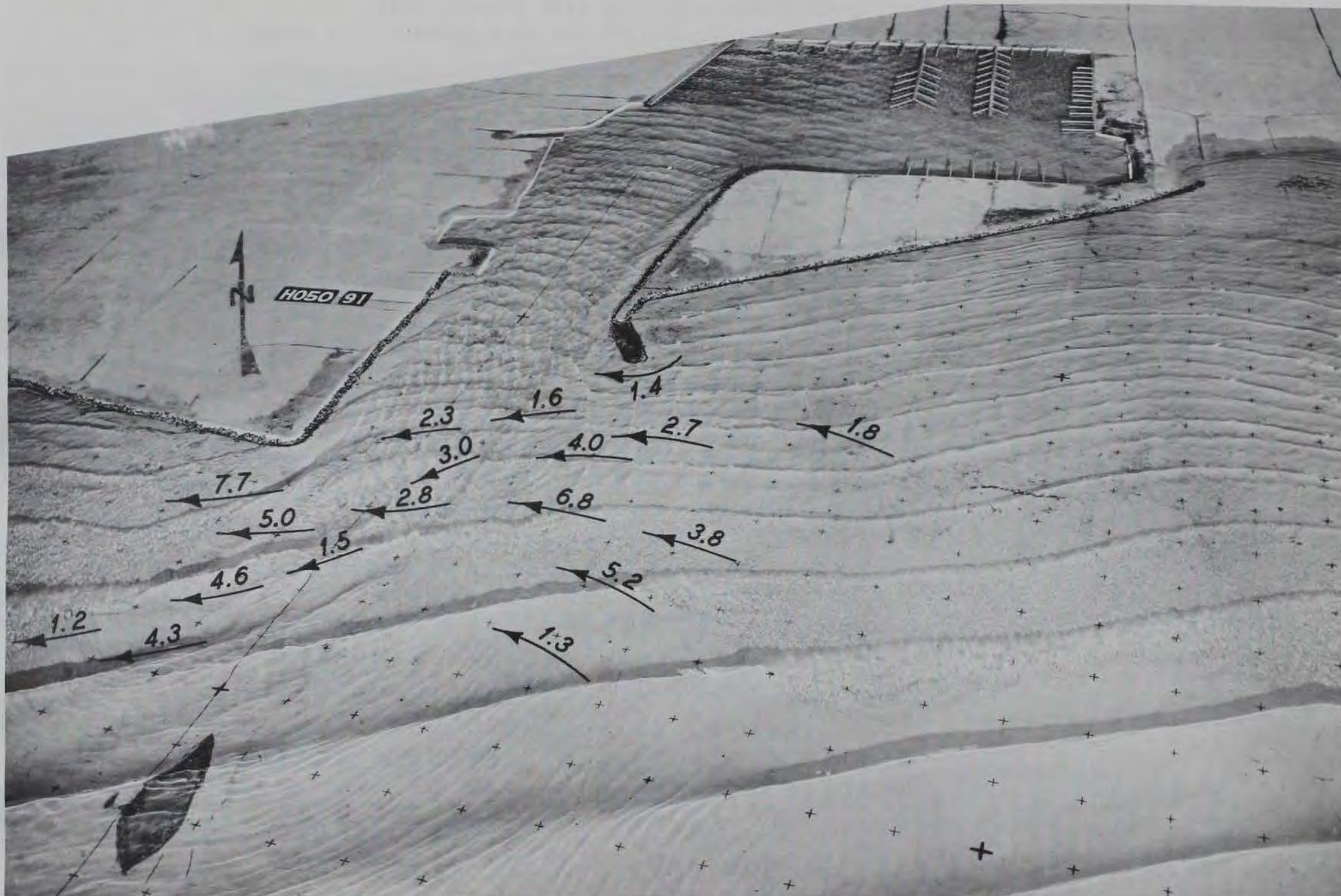


Photo 42. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 6 installed

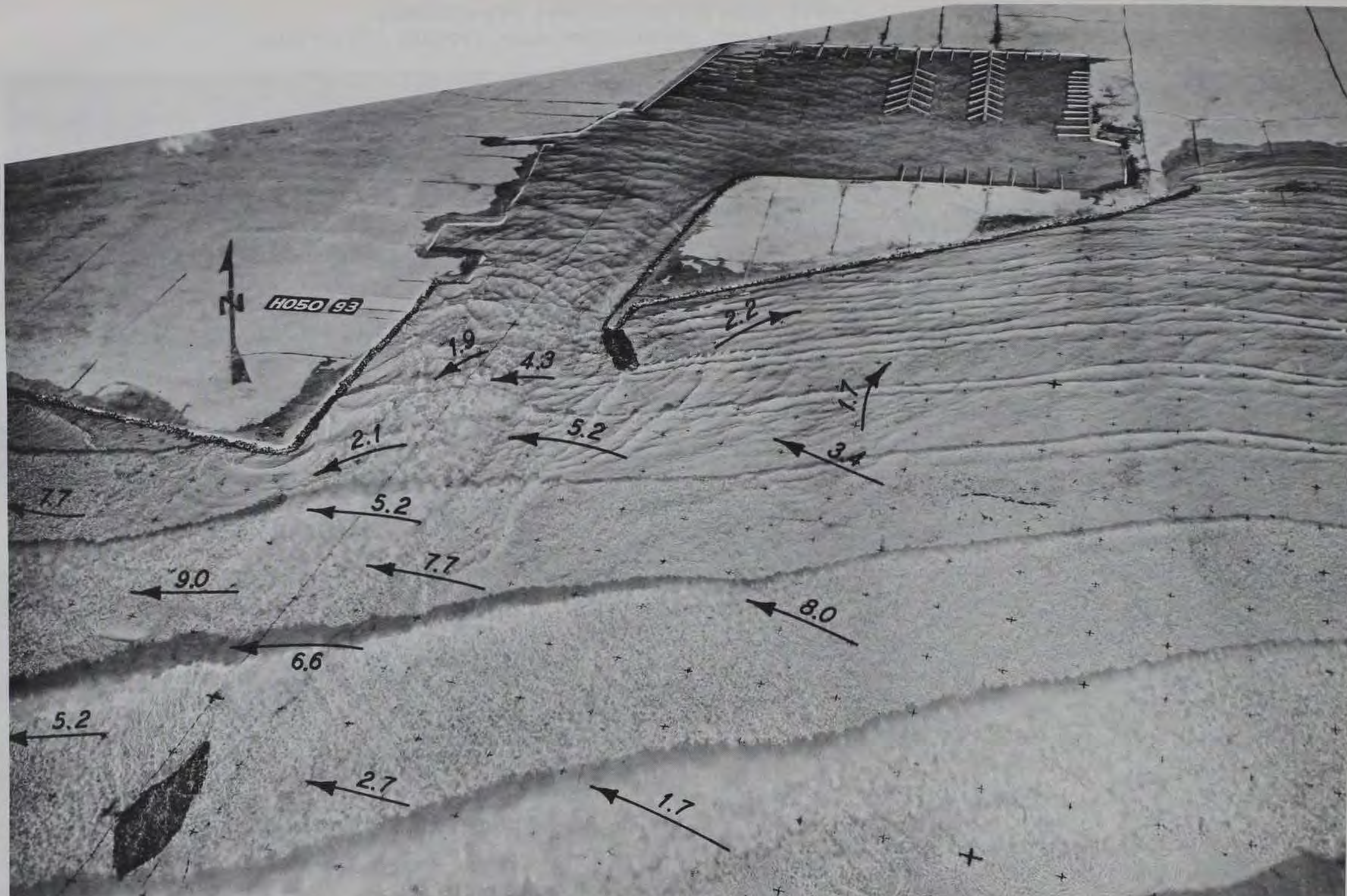


Photo 43. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 6 installed

Photo 44. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 6 installed

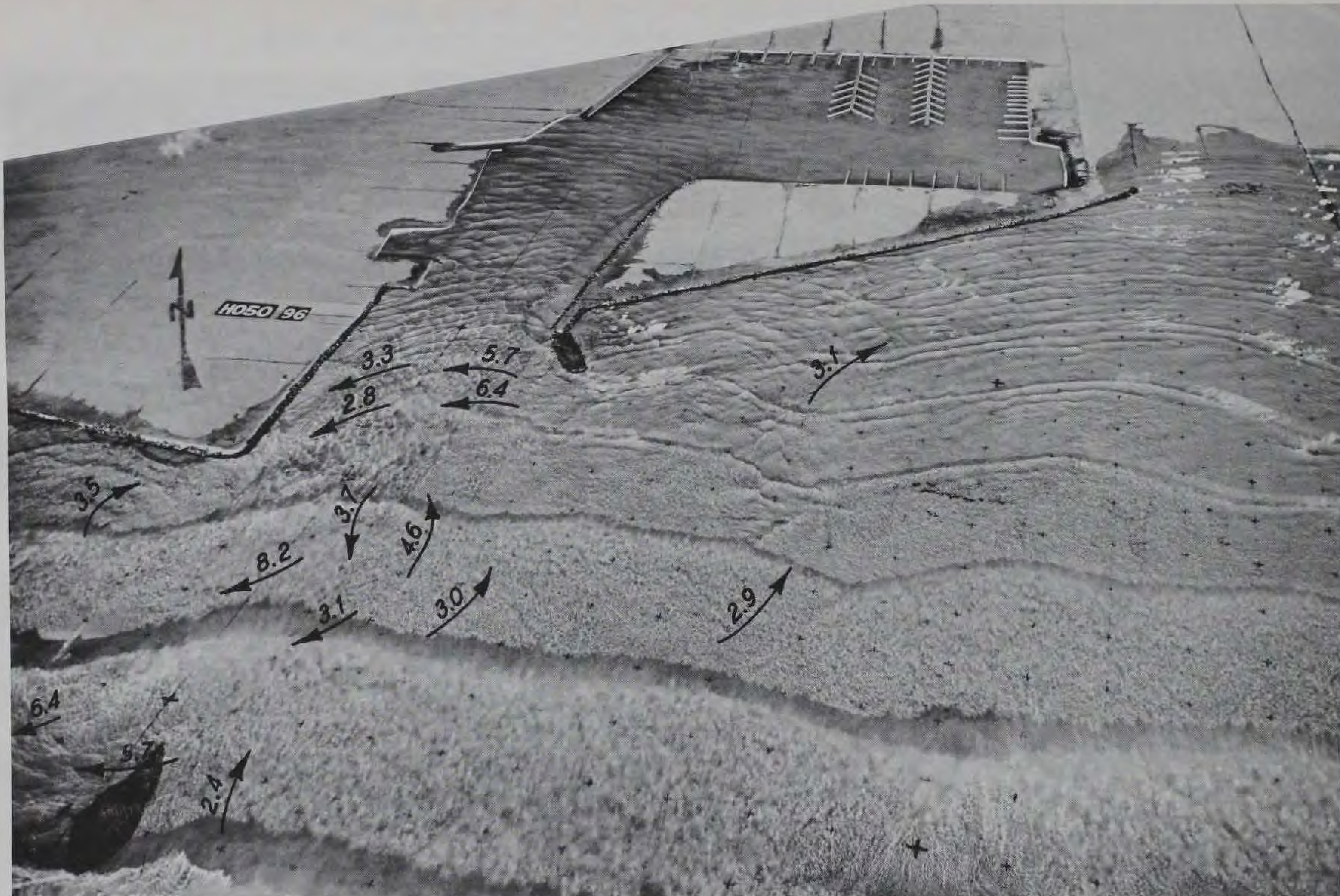


Photo 45. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 6 installed

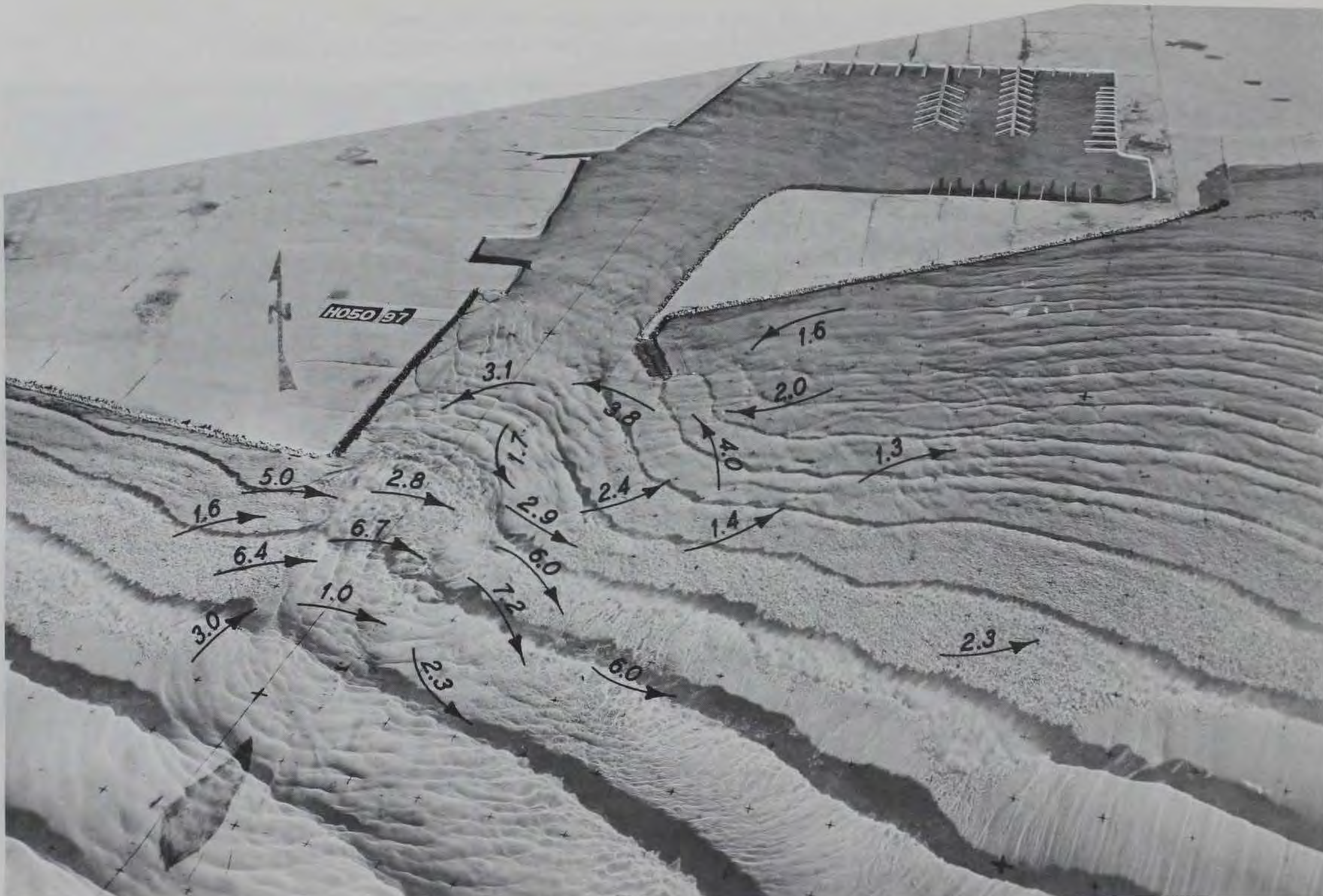


Photo 46. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 6 installed

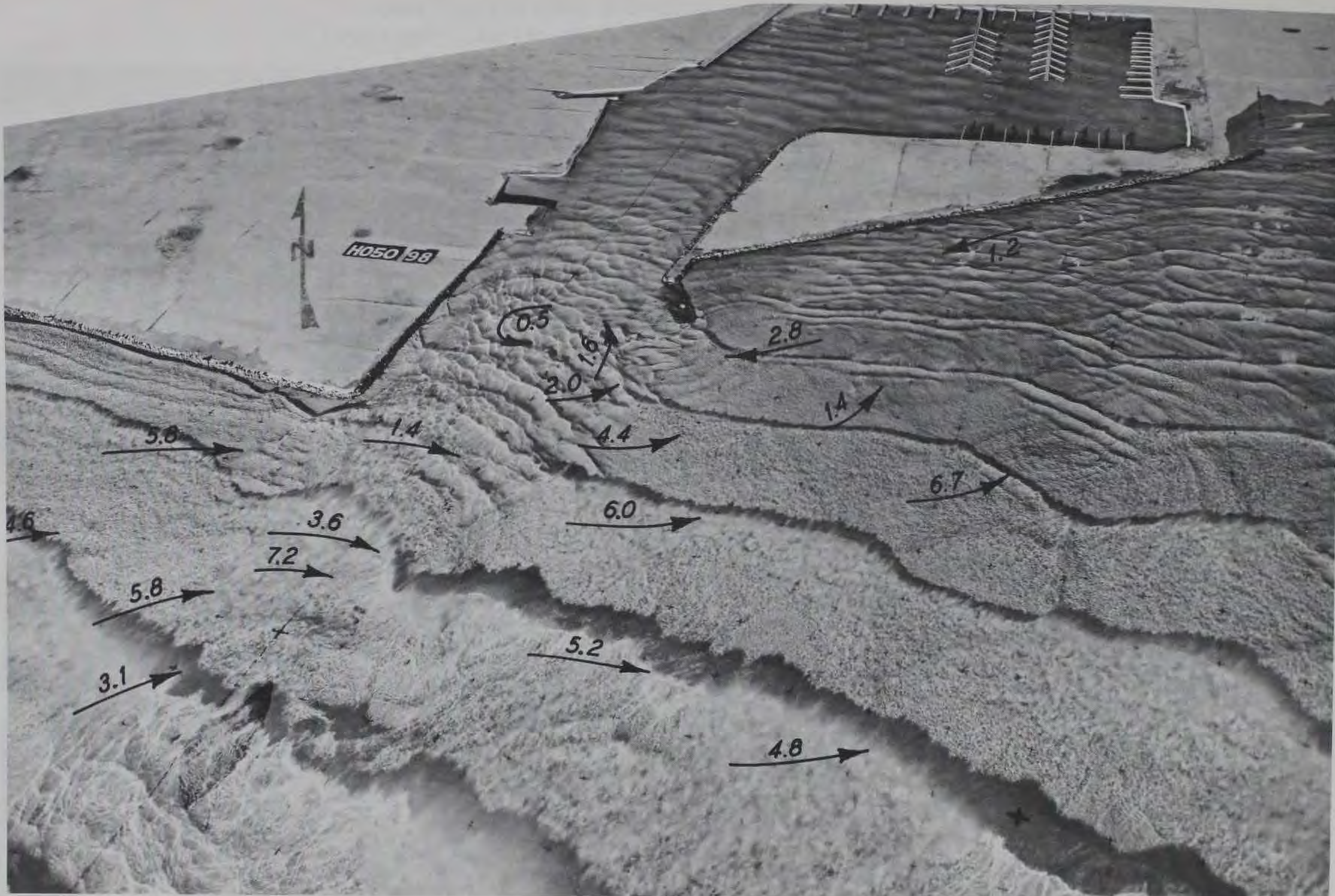


Photo 47. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 6 installed

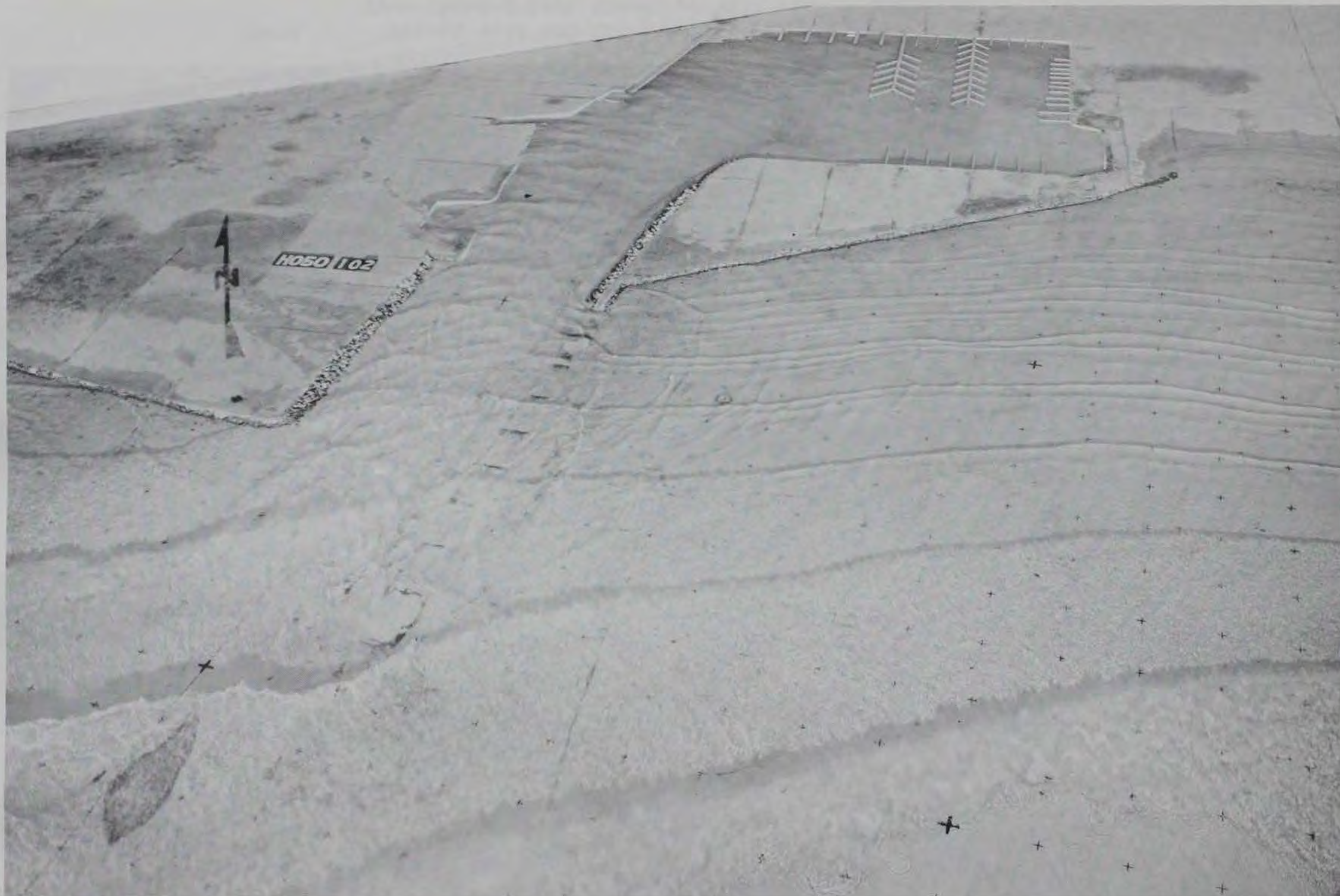


Photo 48. Typical wave patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 7 installed

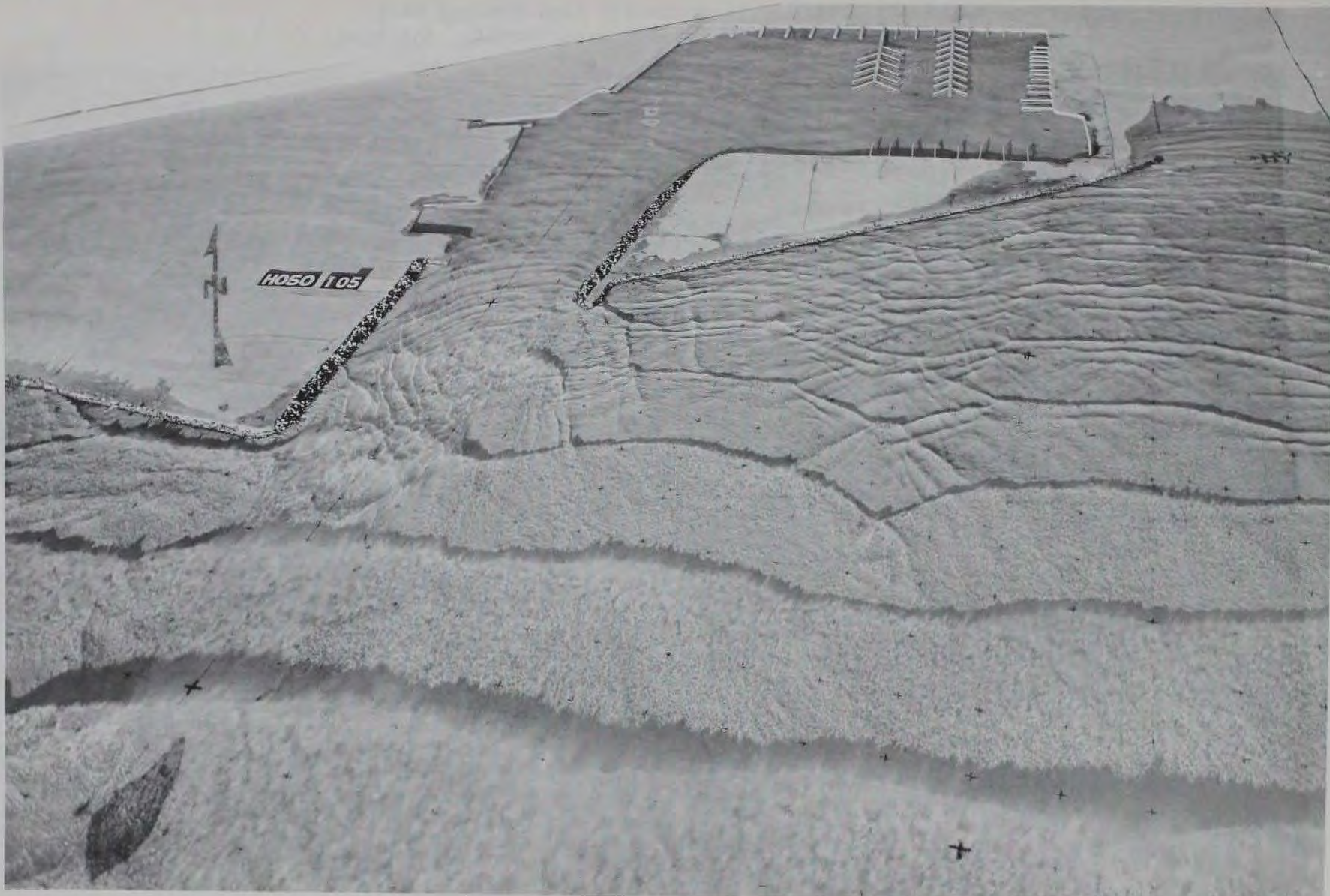


Photo 49. Typical wave patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 7 installed

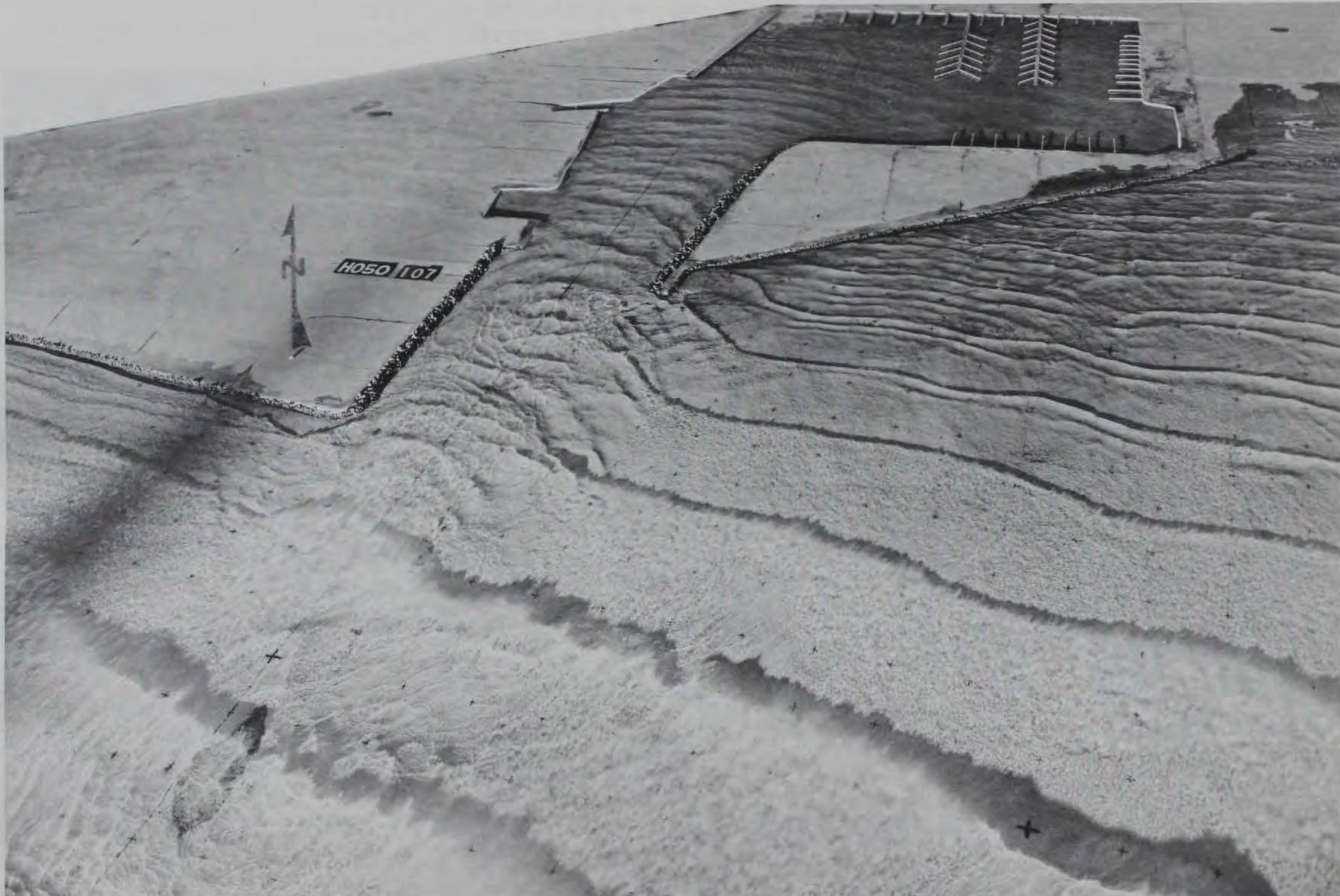


Photo 50. Typical wave patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 7 installed

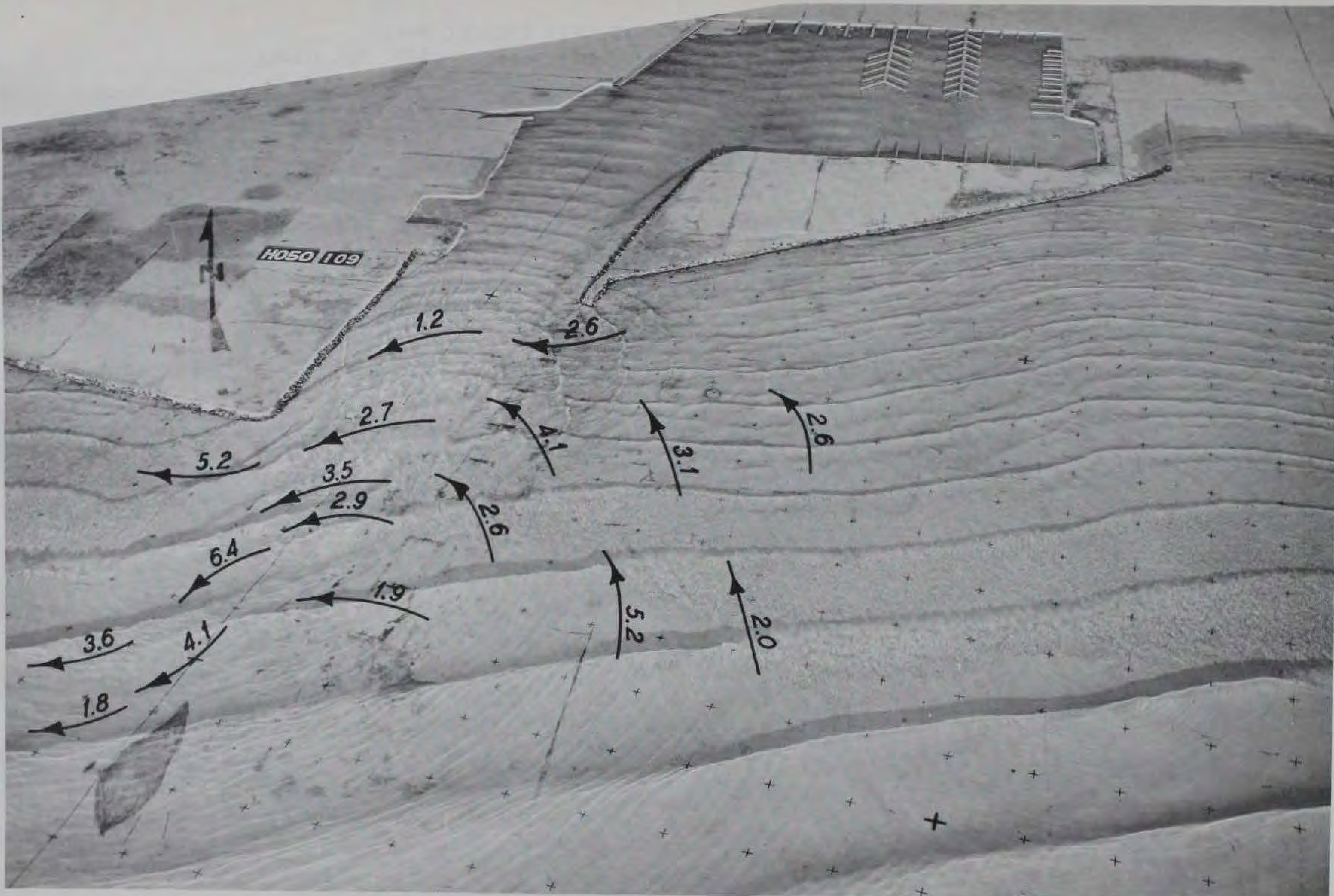


Photo 51. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 8 installed

Photo 52. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 8 installed

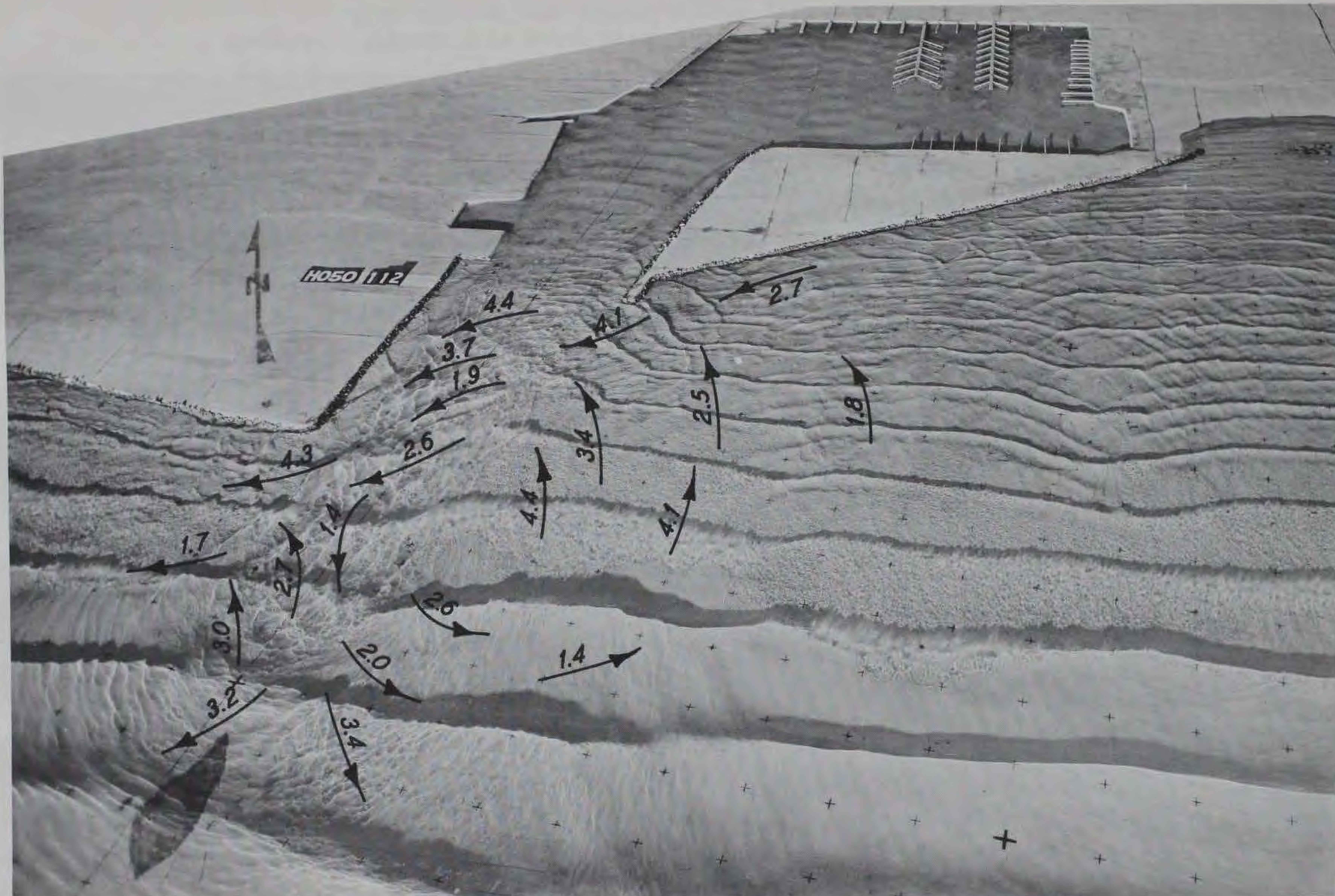


Photo 53. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 8 installed

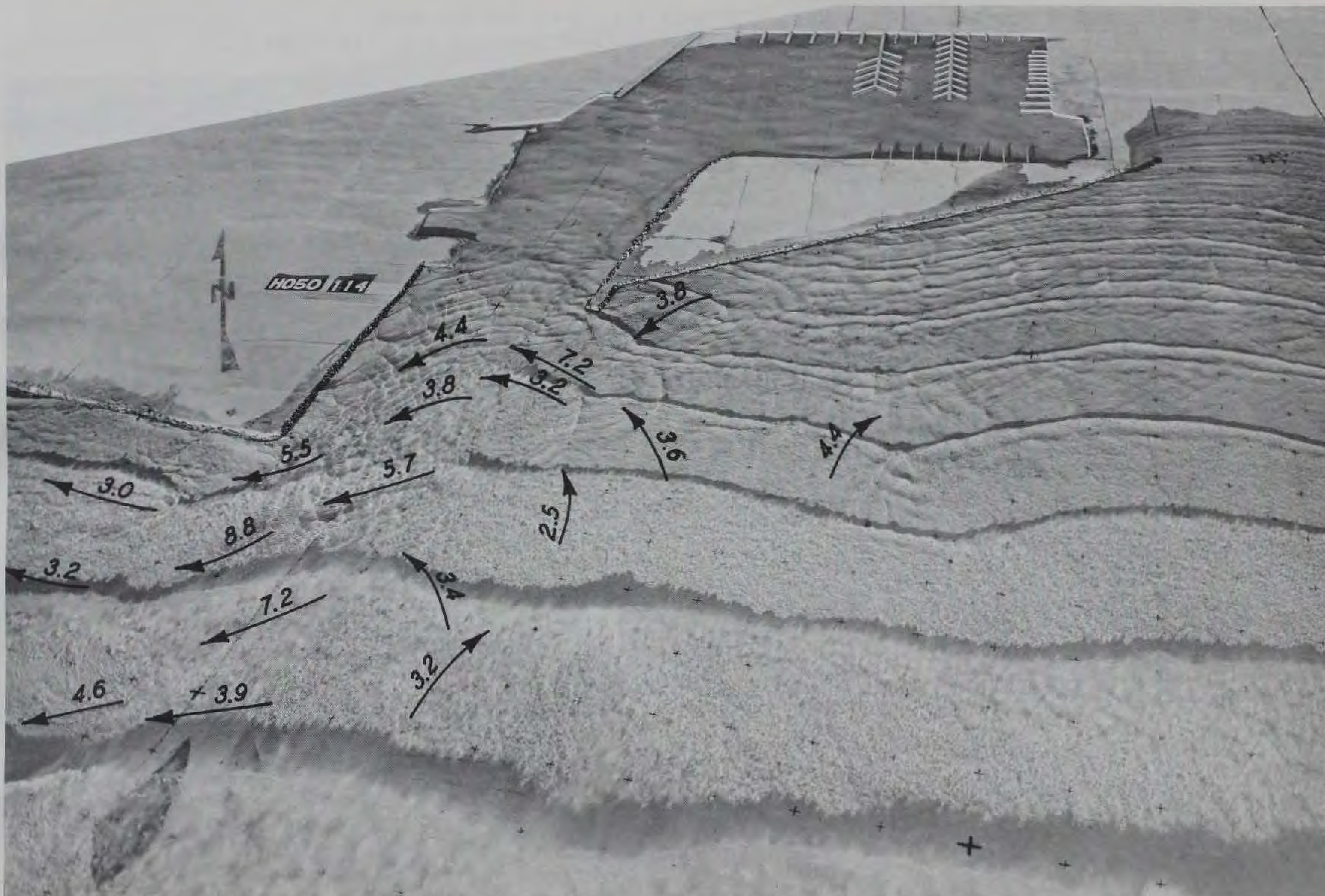


Photo 54. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 8 installed

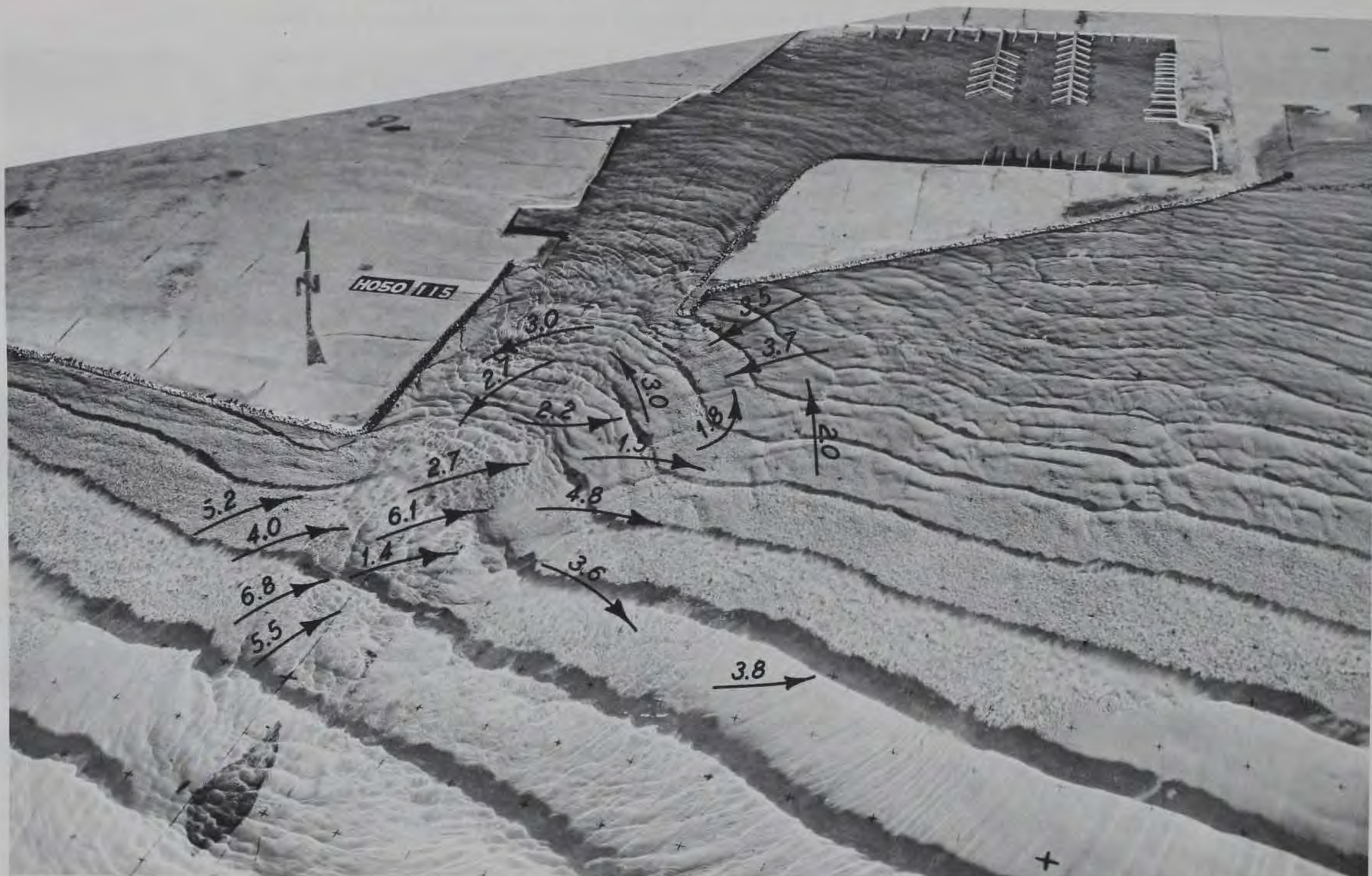


Photo 55. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 8 installed

Photo 56. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 8 installed

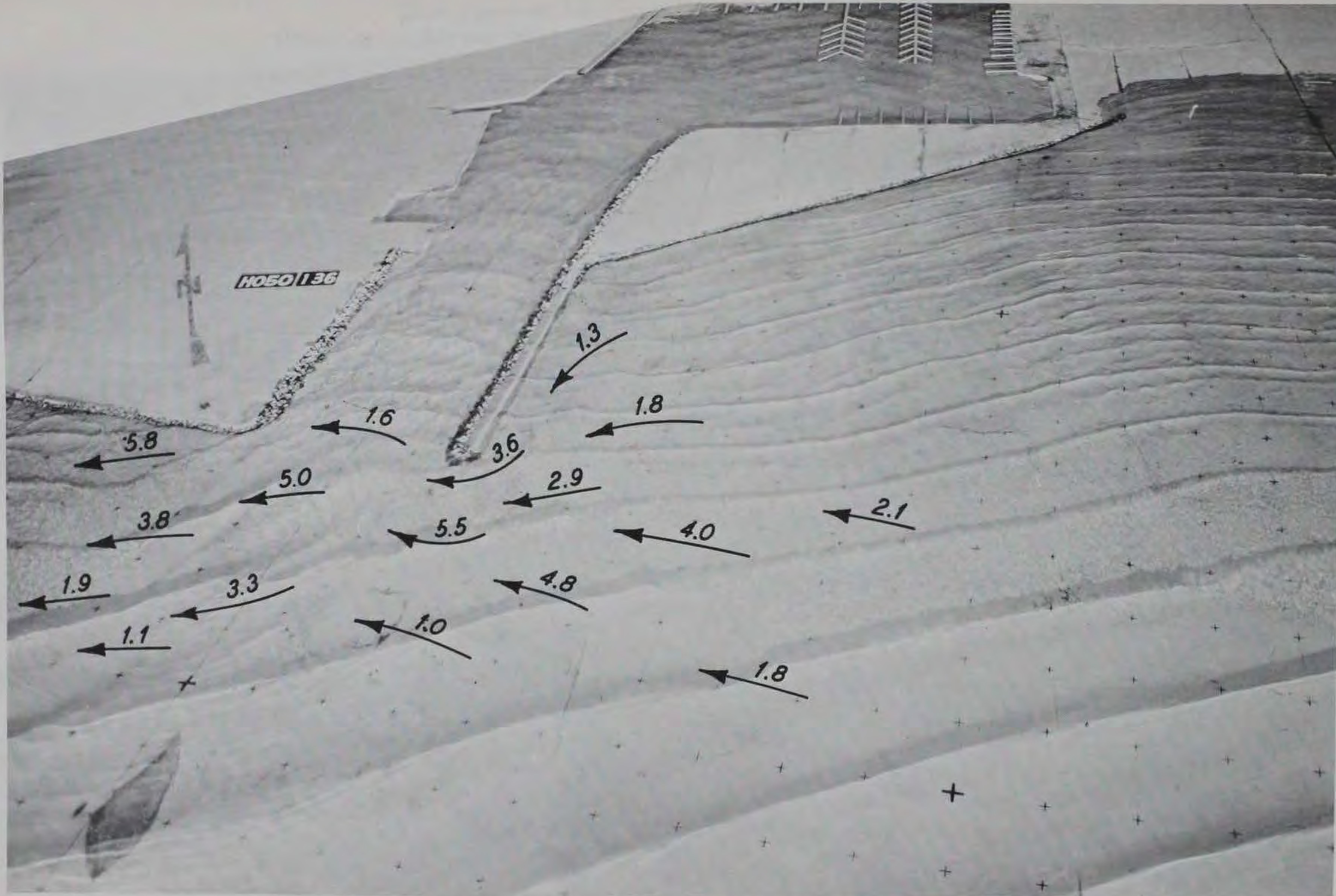


Photo 57. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 9 installed

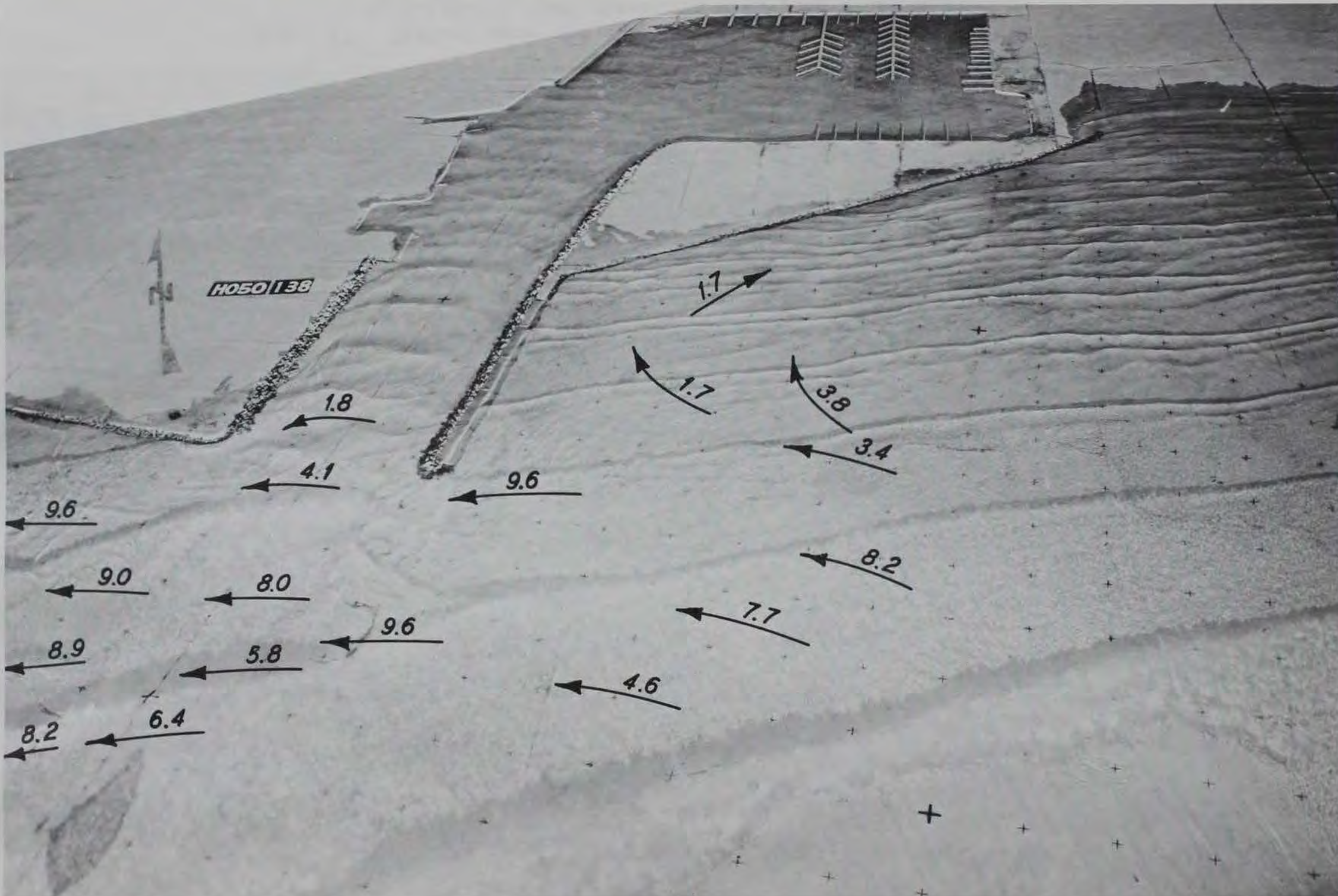


Photo 58. Typical wave and current patterns for 12-sec, 14-ft waves from 180-deg test direction with plan 9 installed

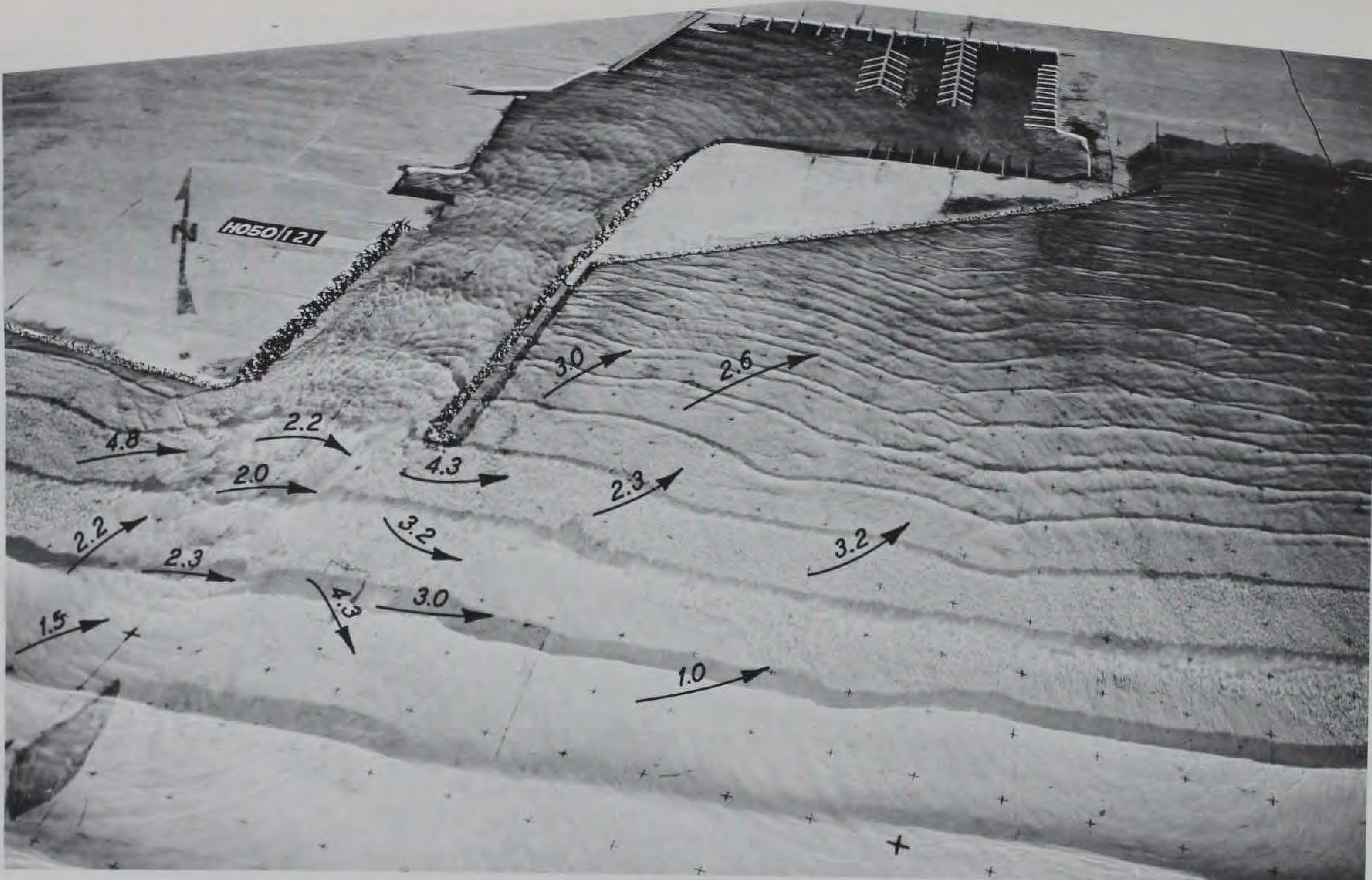


Photo 59. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 9 installed

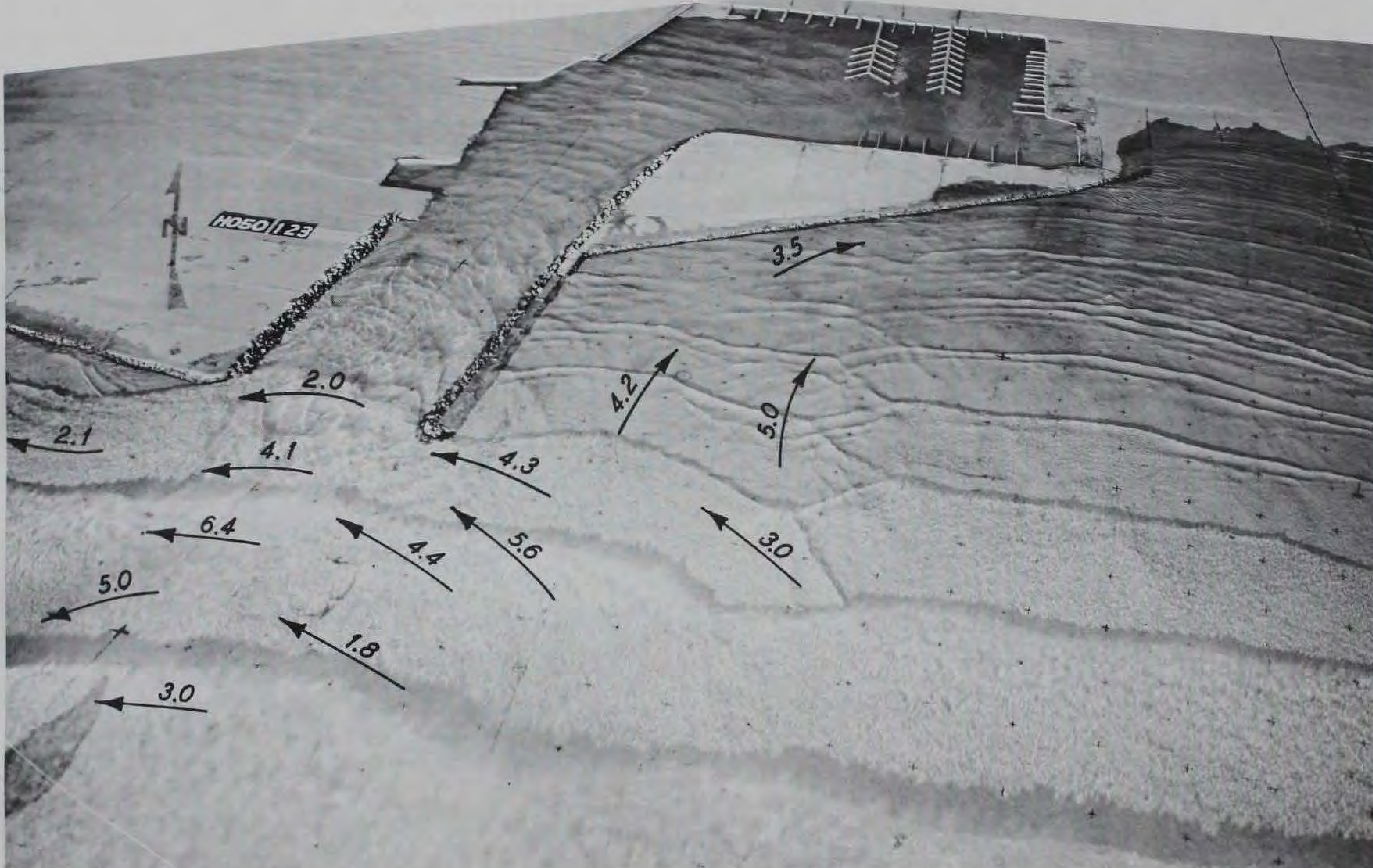


Photo 60. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 9 installed

Photo 61. Typical wave and current patterns for 8-sec, 10-ft waves from 240-deg test direction with plan 9 installed

Photo 62. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 9 installed

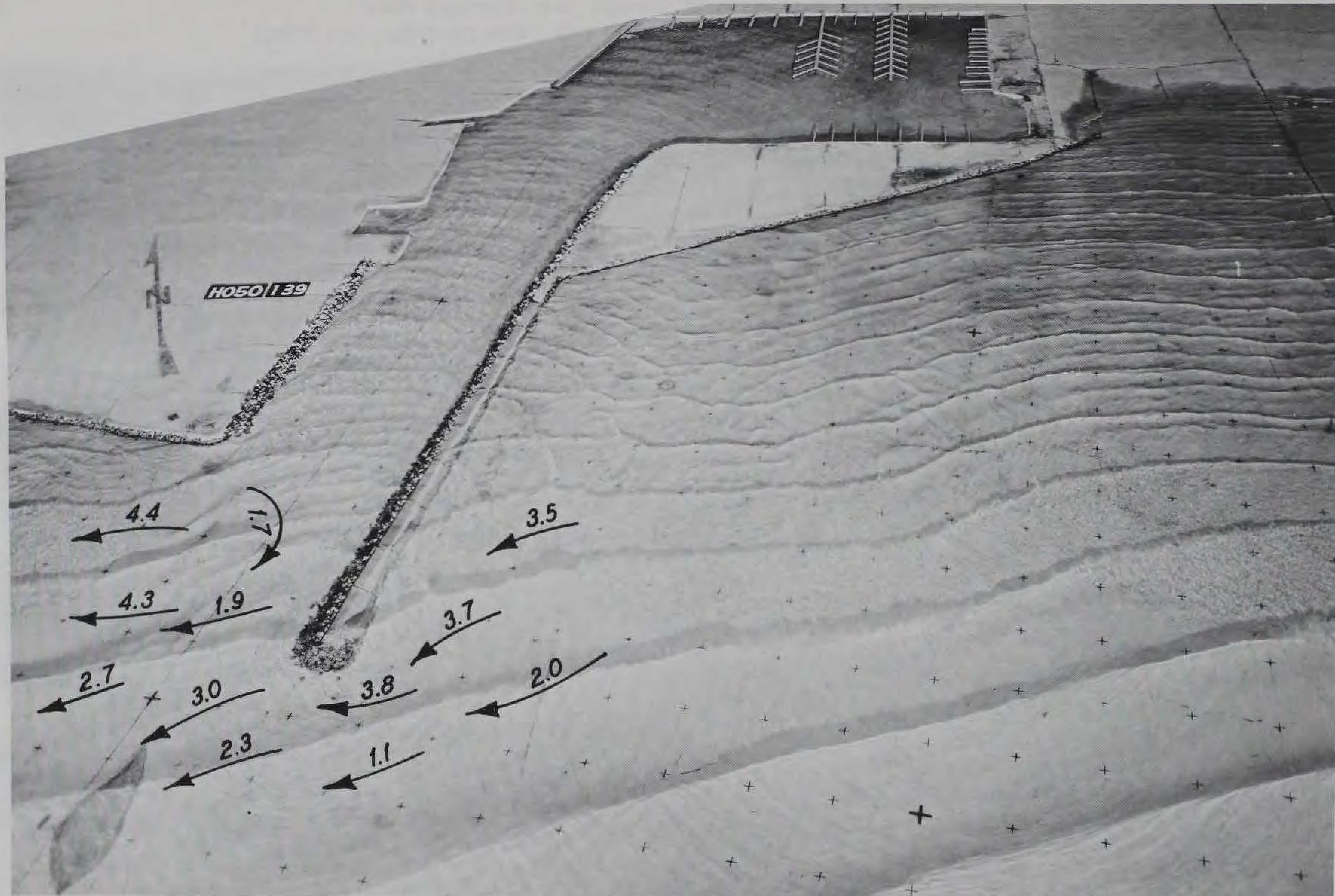


Photo 63. Typical wave and current patterns for 8-sec, 8-ft waves from 180-deg test direction with plan 10 installed

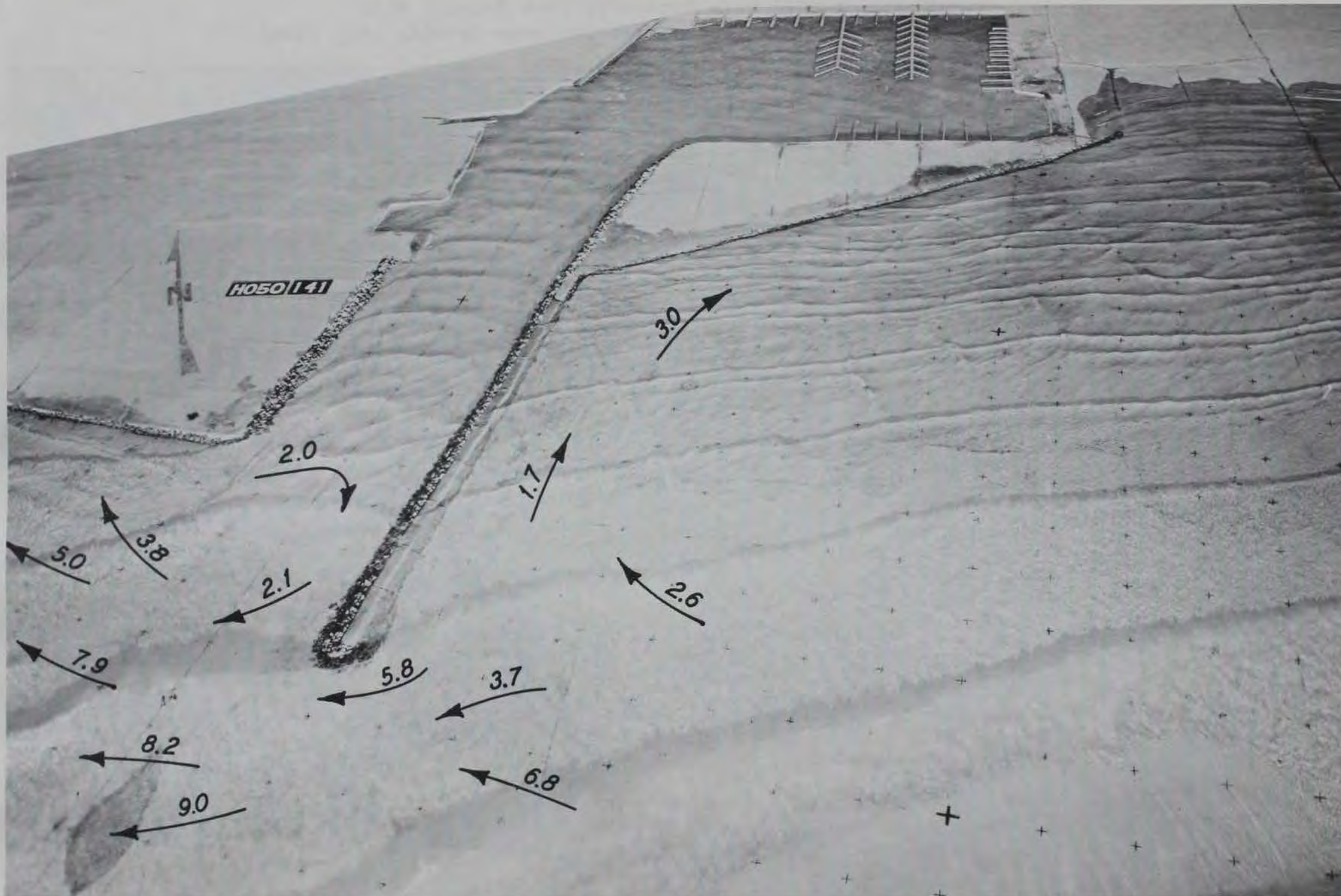


Photo 64. Typical wave and current patterns for 12-sec, 14-ft waves
from 180-deg test direction with plan 10 installed

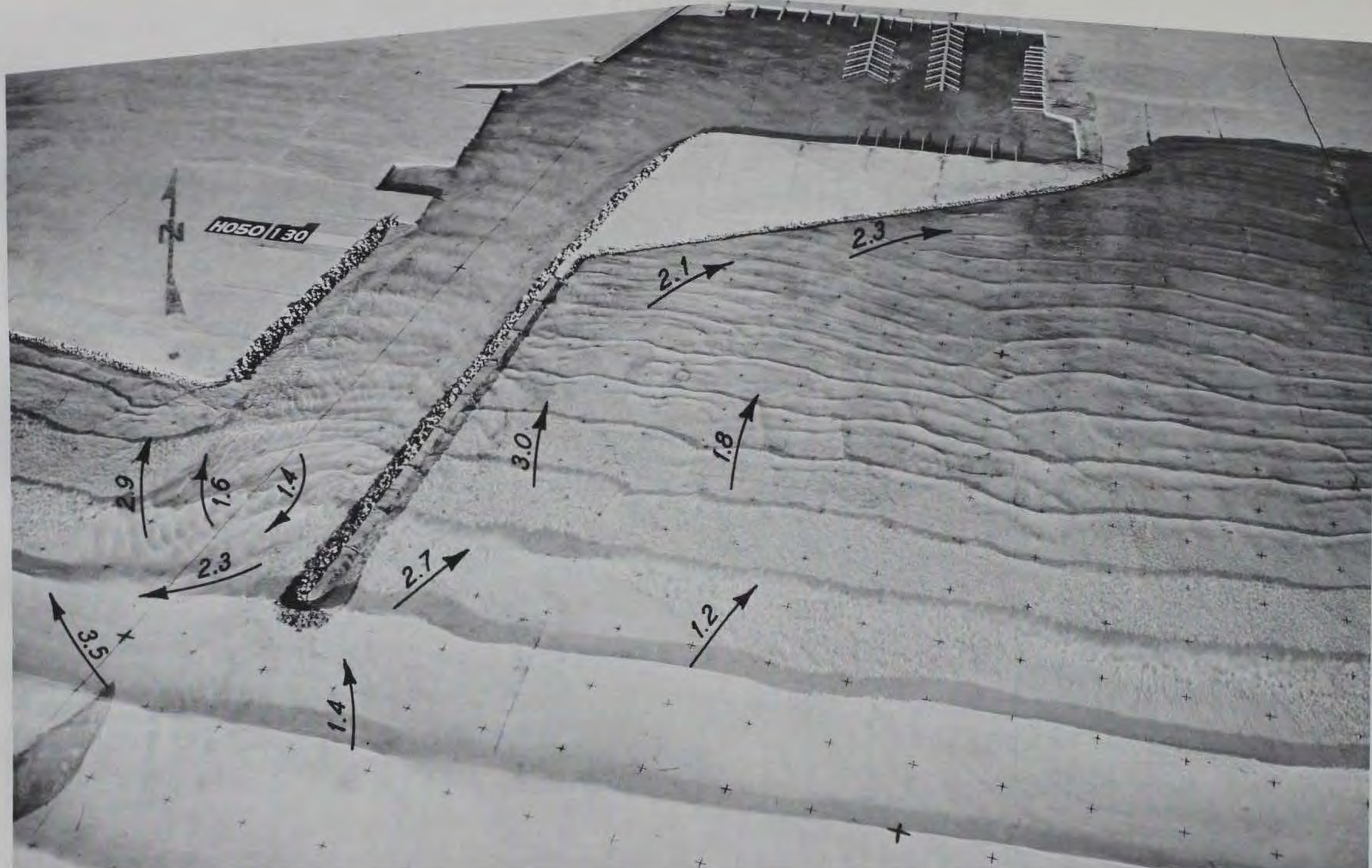


Photo 65. Typical wave and current patterns for 8-sec, 8-ft waves from 210-deg test direction with plan 10 installed

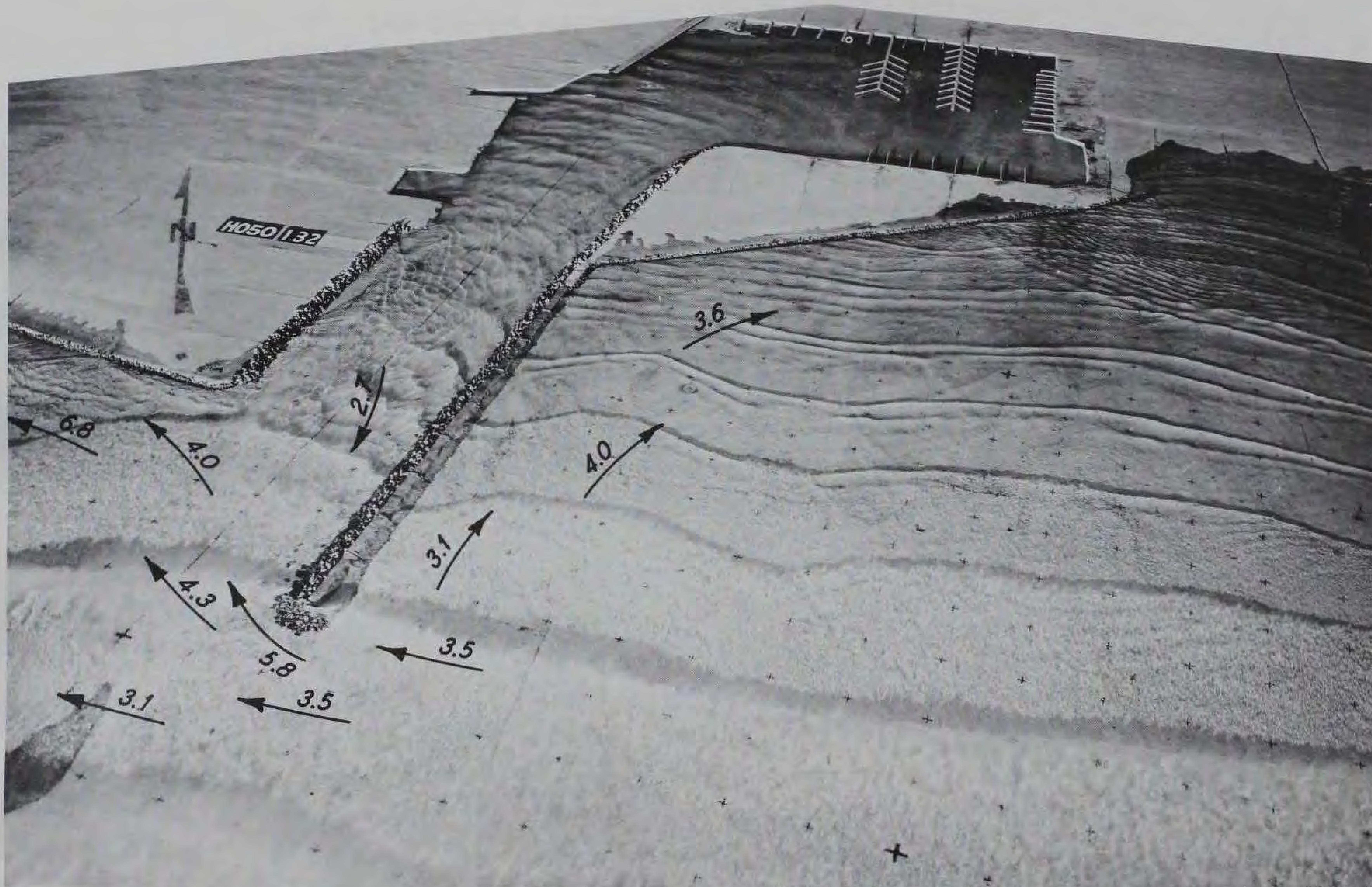


Photo 66. Typical wave and current patterns for 12-sec, 14-ft waves from 210-deg test direction with plan 10 installed

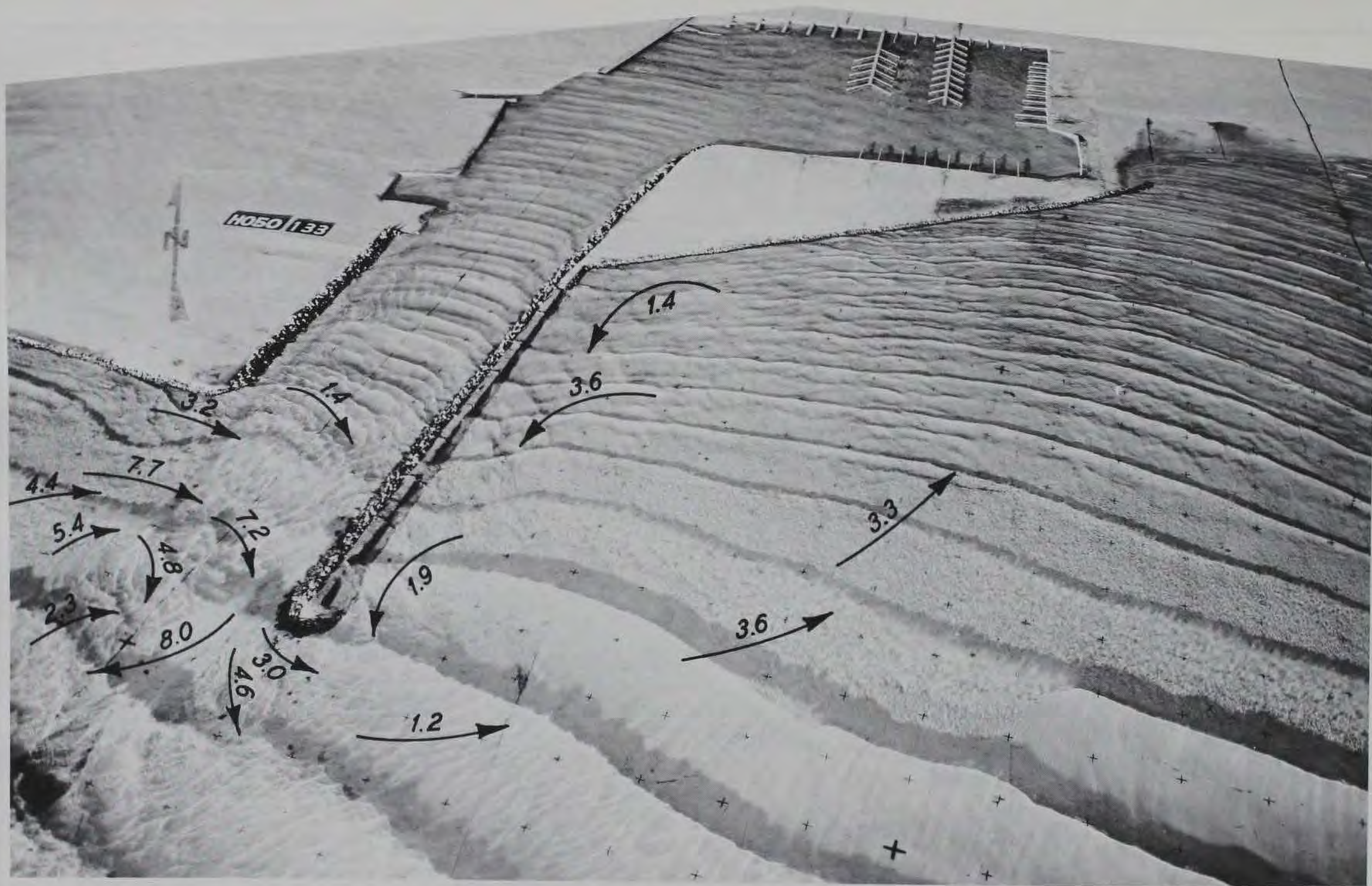
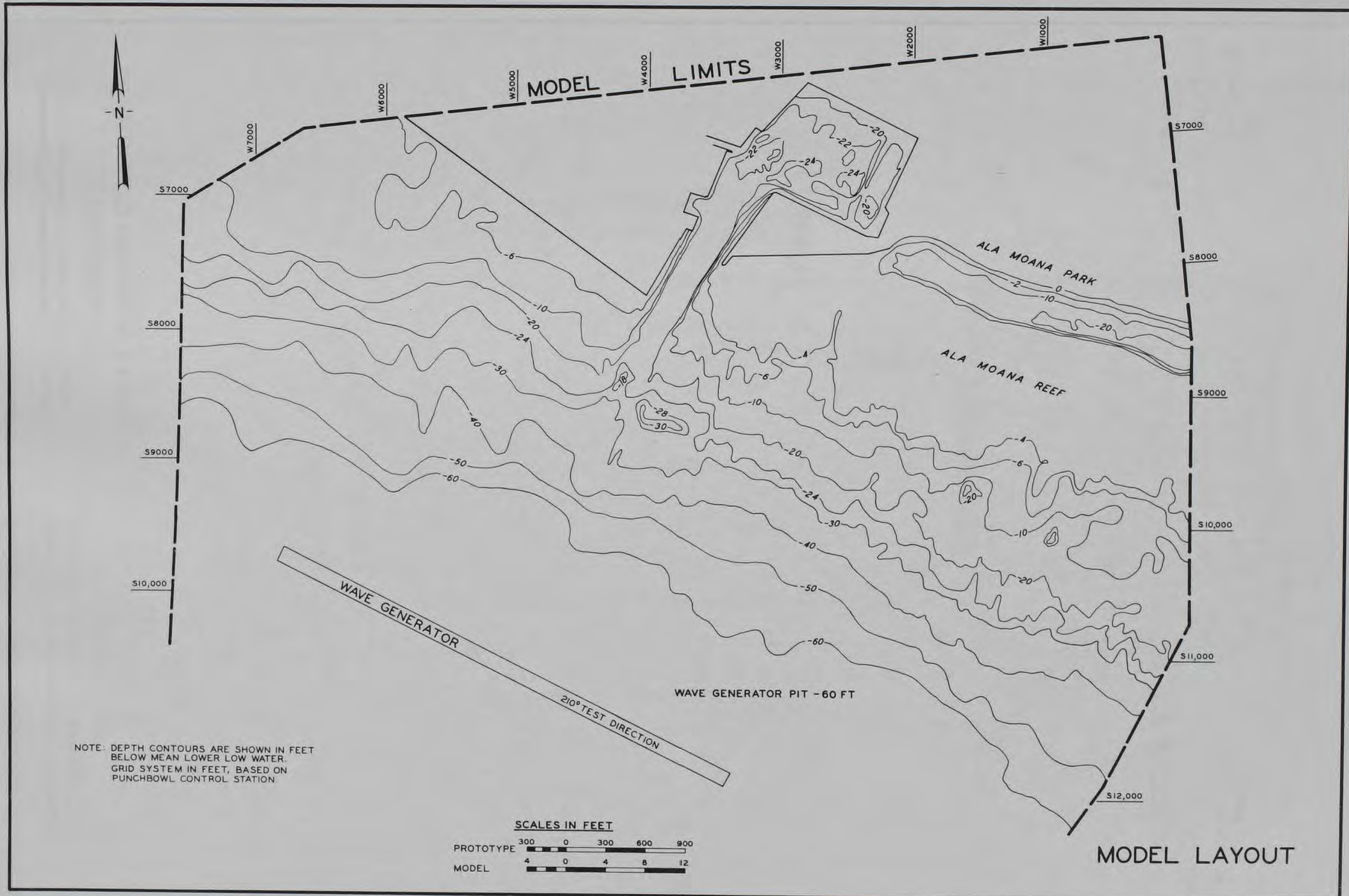


Photo 67. Typical wave and current patterns for 8-sec, 10-ft waves
from 240-deg test direction with plan 10 installed

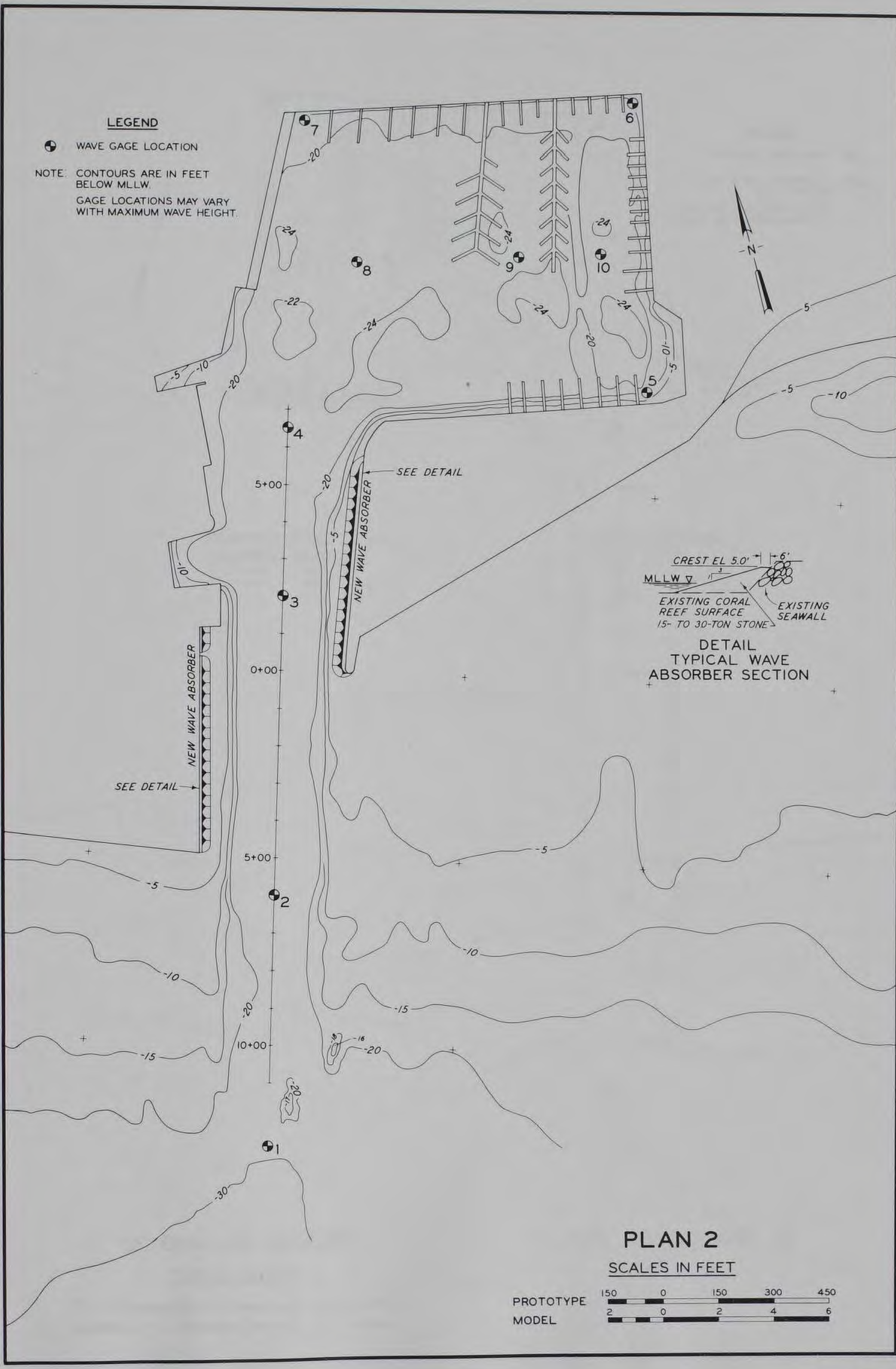
Photo 68. Typical wave and current patterns for 12-sec, 14-ft waves from 240-deg test direction with plan 10 installed



MODEL LAYOUT

PLATE 1

PLAN 1 (EXISTING CONDITIONS)


LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT.
SEE DETAIL
NEW WAVE ABSORBER
NEW WAVE ABSORBER
SEE DETAIL
CREST EL 5.0'
6'
MLLW
EXISTING CORAL REEF SURFACE
EXISTING SEAWALL
15- TO 30-TON STONE
DETAIL
TYPICAL WAVE ABSORBER SECTION
N
5+00
0+00
5+00
10+00
PLAN 2
SCALES IN FEET
PROTOTYPE
MODEL
150 0 150 300 450
2 0 2 4 6

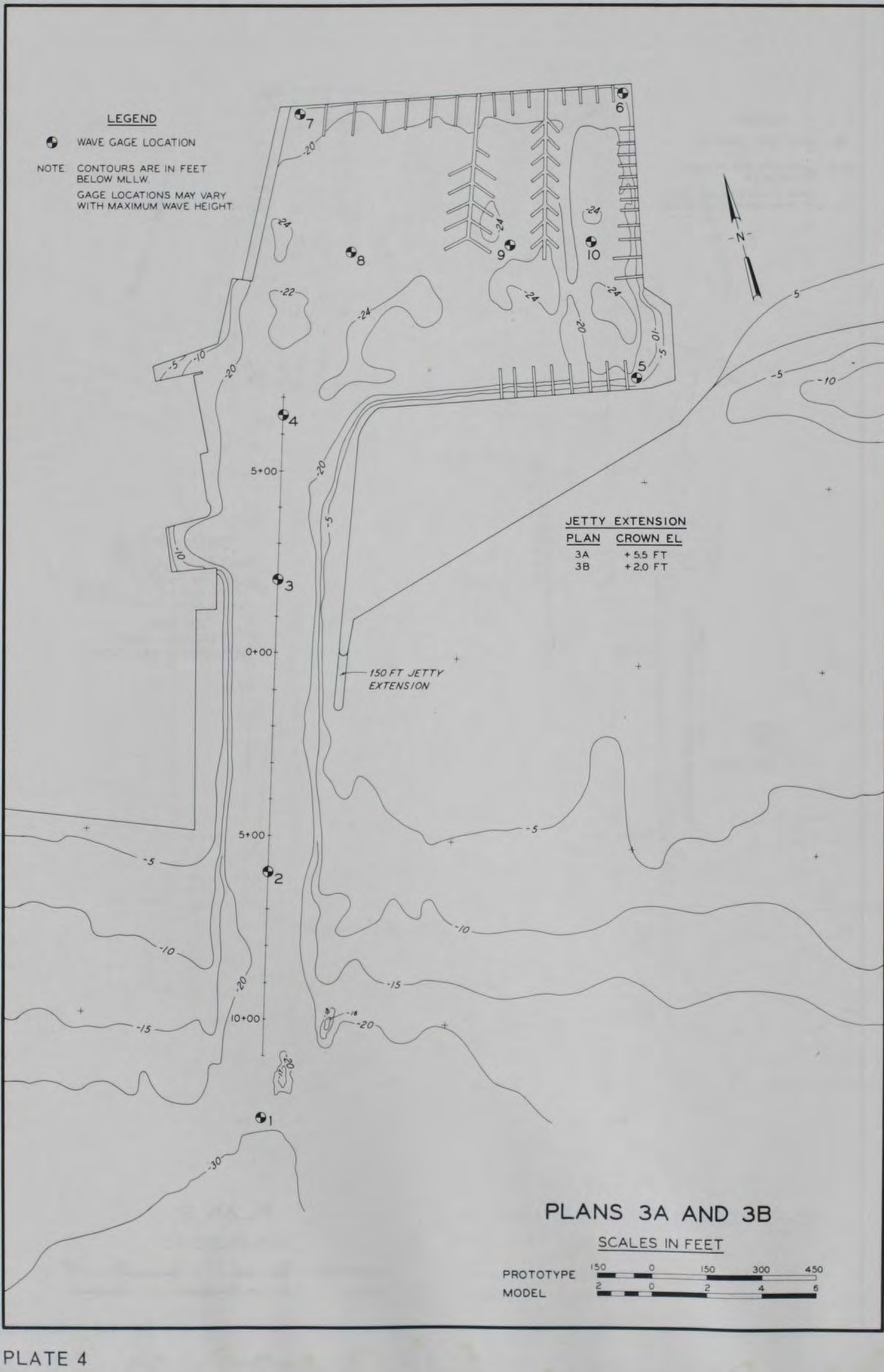
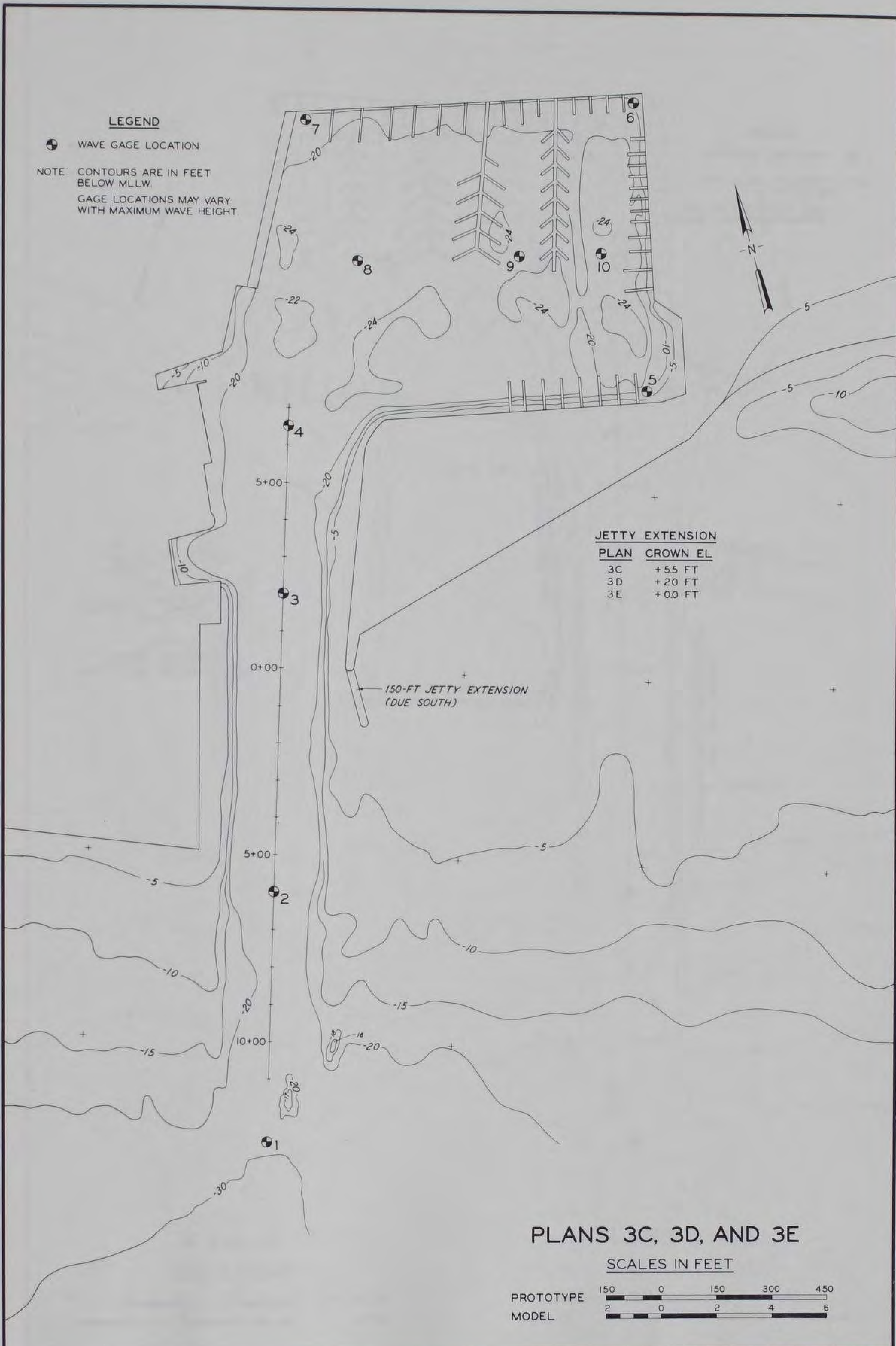
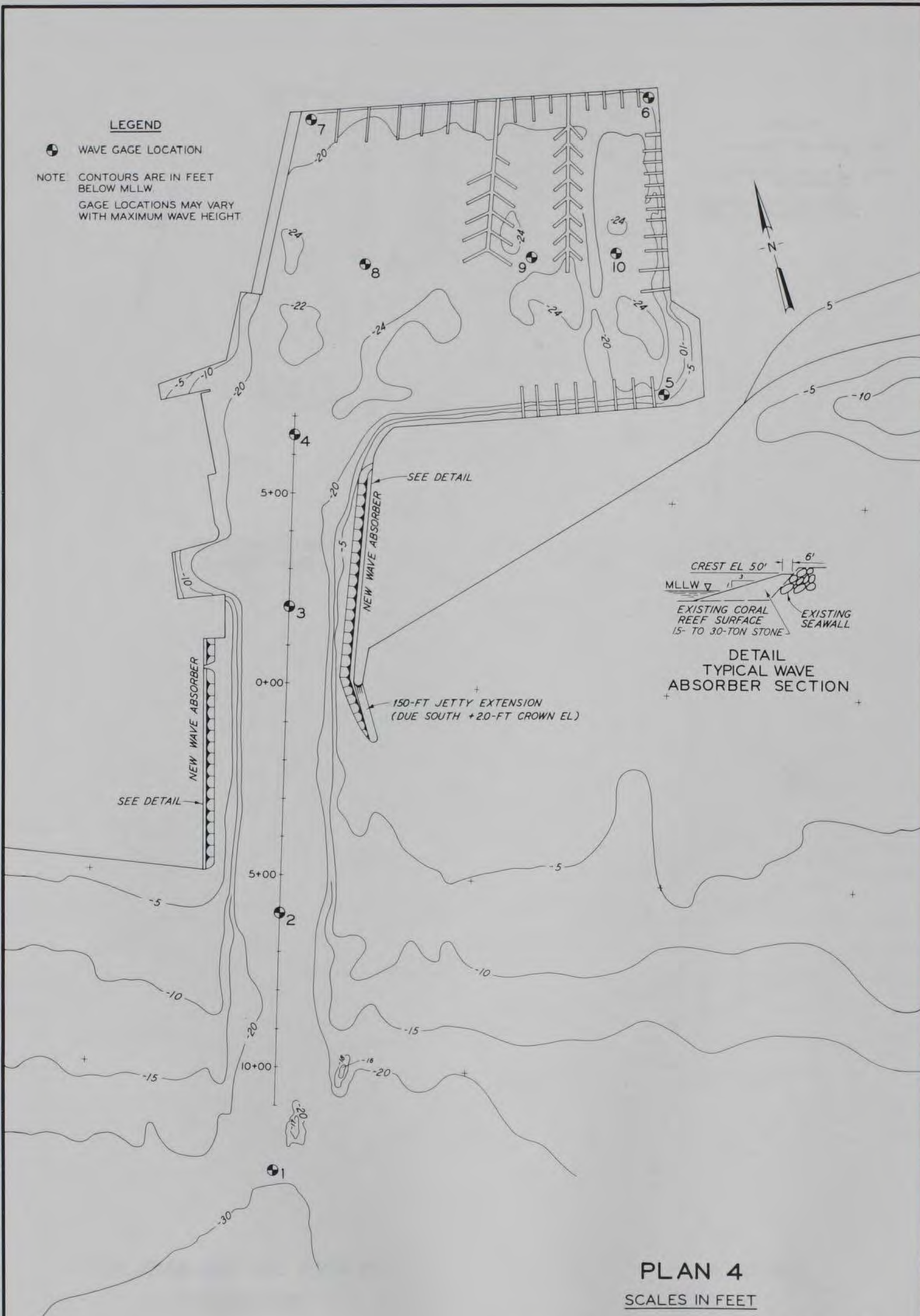
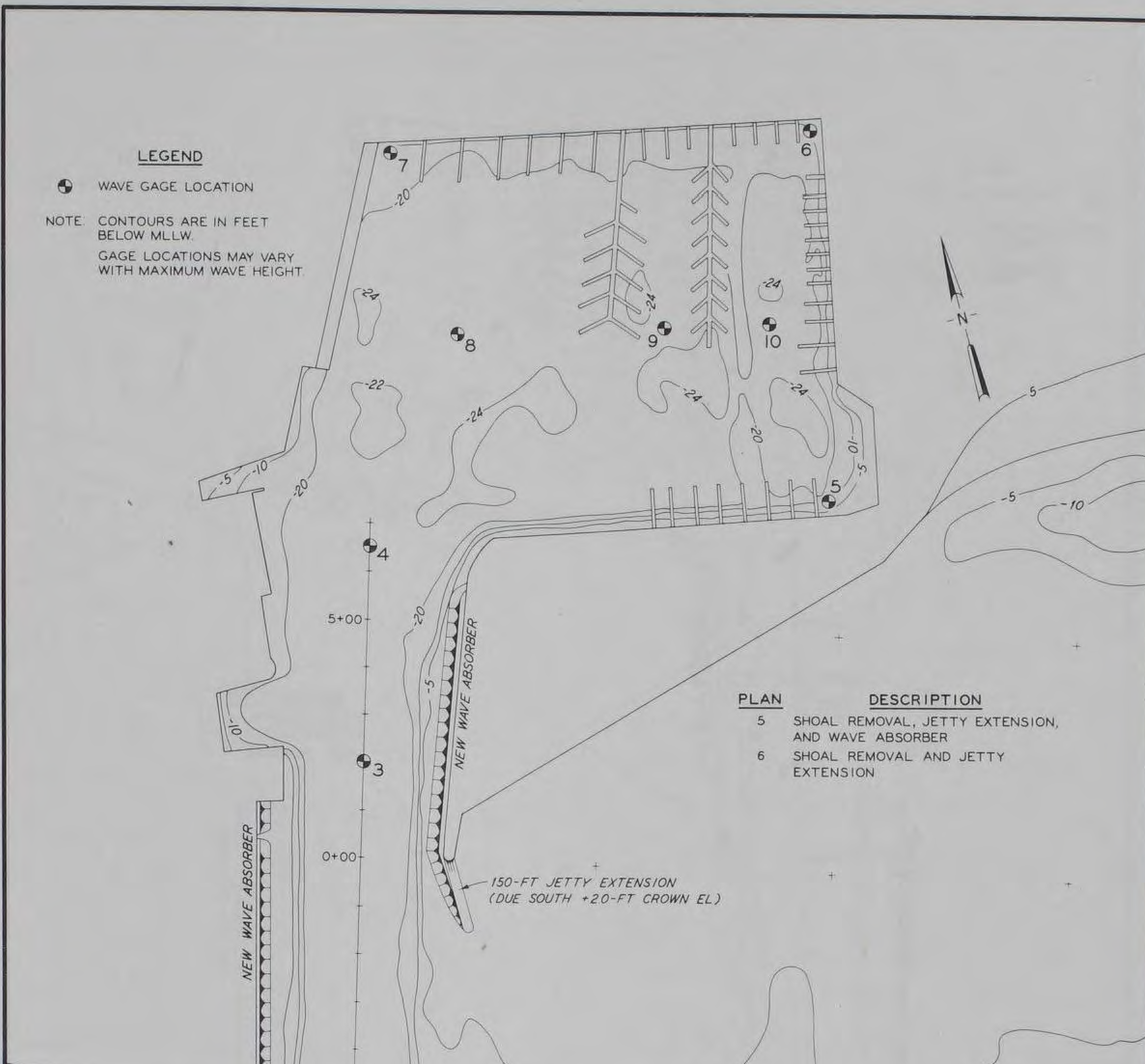

LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT.
JETTY EXTENSION
PLAN CROWN EL
3A +5.5 FT
3B +2.0 FT
150 FT JETTY EXTENSION
N
PLANS 3A AND 3B
SCALES IN FEET
PROTOTYPE 150 0 150 300 450
MODEL 2 0 2 4 6

PLATE 4

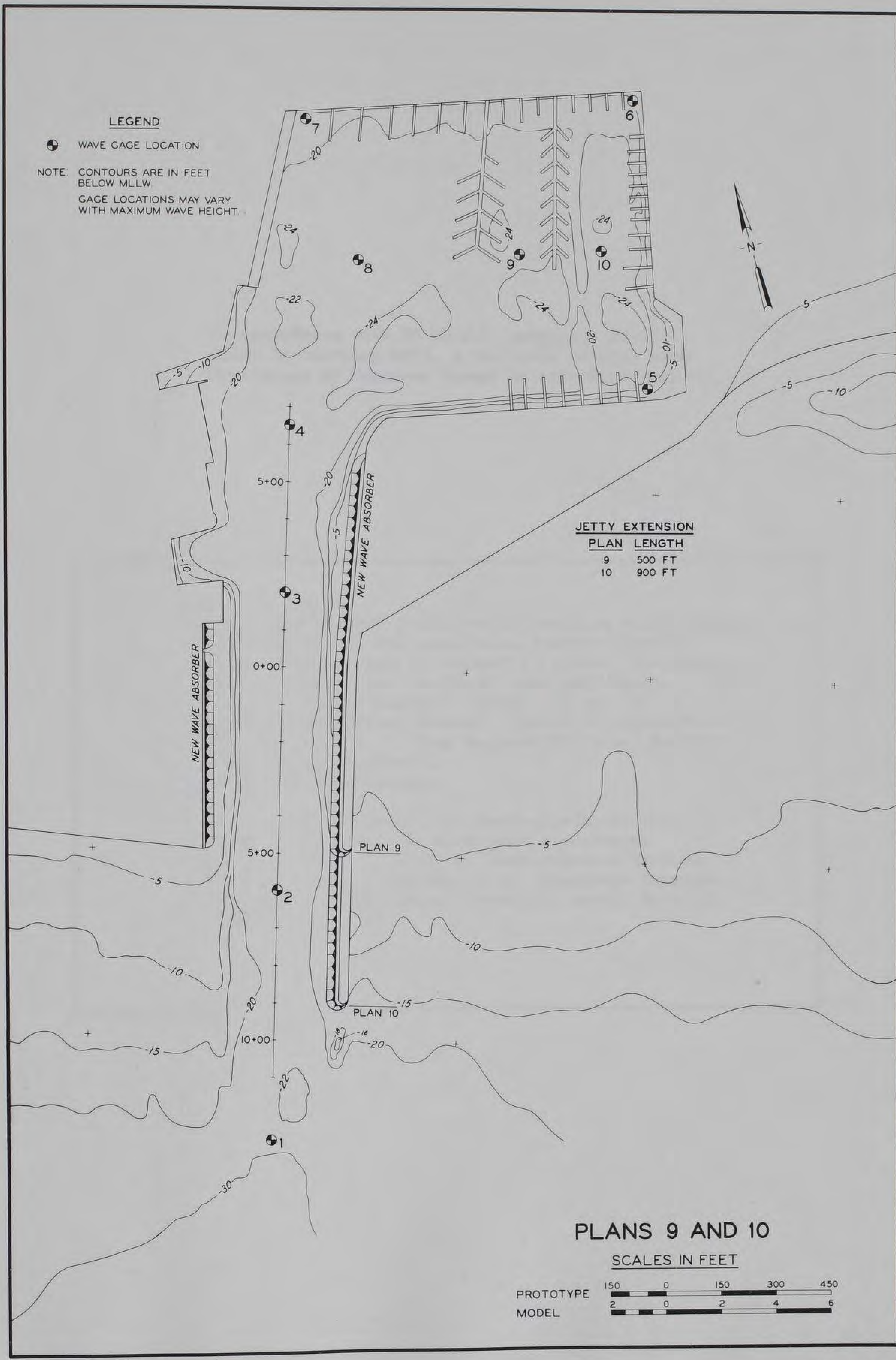


PLANS 3C, 3D, AND 3E


LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT
NEW WAVE ABSORBER
SEE DETAIL
150-FT JETTY EXTENSION (DUE SOUTH +20-FT CROWN EL)
CREST EL 5.0'
6'
MLLW
EXISTING CORAL REEF SURFACE
15- TO 30-TON STONE
EXISTING SEAWALL
DETAIL
TYPICAL WAVE ABSORBER SECTION
N
5+00
0+00
10+00
PLAN 4
SCALES IN FEET
PROTOTYPE
MODEL


LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT.
PLAN DESCRIPTION
5 SHOAL REMOVAL, JETTY EXTENSION, AND WAVE ABSORBER
6 SHOAL REMOVAL AND JETTY EXTENSION
NEW WAVE ABSORBER
NEW WAVE ABSORBER
150-FT JETTY EXTENSION (DUE SOUTH +2.0-FT CROWN EL.)
N
5+00
0+00
5+00
10+00
PLANS 5 AND 6
SCALES IN FEET
PROTOTYPE 150 0 150 300 450
MODEL 2 0 2 4 6

LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT.
NEW WAVE ABSORBER
NEW WAVE ABSORBER
PLAN DESCRIPTION
7 SHOAL REMOVAL AND WAVE ABSORBER
8 SHOAL REMOVAL
N
PLANS 7 AND 8
SCALES IN FEET
PROTOTYPE 150 0 150 300 450
MODEL 2 0 2 4 6


LEGEND
WAVE GAGE LOCATION
NOTE: CONTOURS ARE IN FEET BELOW MLLW.
GAGE LOCATIONS MAY VARY WITH MAXIMUM WAVE HEIGHT.
NEW WAVE ABSORBER
NEW WAVE ABSORBER
JETTY EXTENSION
PLAN LENGTH
9 500 FT
10 900 FT
PLAN 9
PLAN 10
5+00
0+00
5+00
10+00
N
PLANS 9 AND 10
SCALES IN FEET
PROTOTYPE 150 0 150 300 450
MODEL 2 0 2 4 6