Technical Report CERC-93-2
March 1993

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US Army Corps
of Engineers
Waterways Experiment
Station

Design for Entrance Channel Navigation Improvements, Morro Bay Harbor, Morro Bay, California

by Robert R. Bottin, Jr.
Coastal Engineering Research Center

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Prepared for U.S. Army Engineer District, Los Angeles

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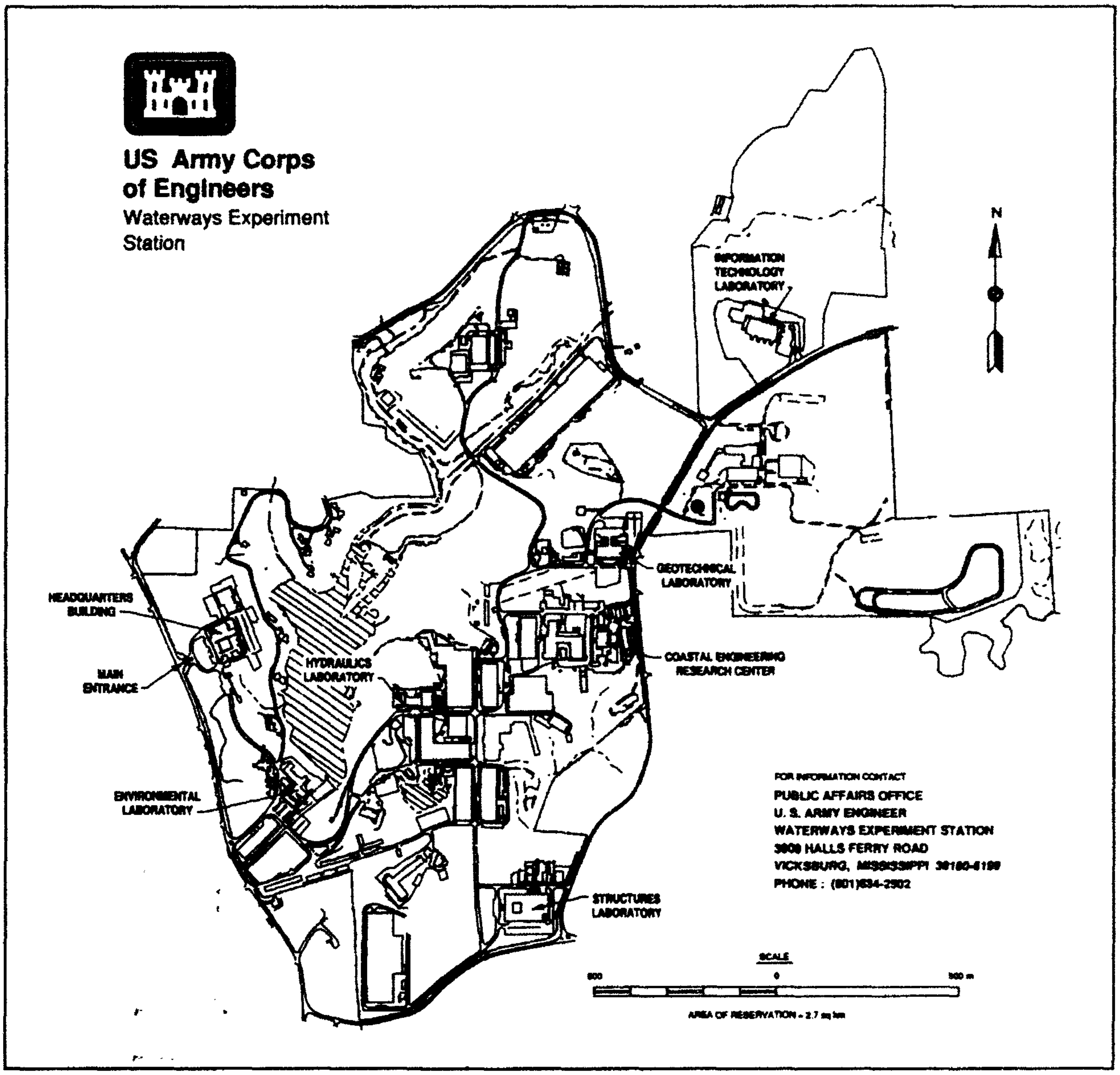

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Contents

Preface

A request for a model investigation of wave conditions at Morro Bay Harbor, California, was initiated by the U.S. Army Engineer District, Los Angeles (SPL) in a letter to the U.S. Army Engineer Division, South Pacific (SPD). Authorization for the U.S. Army Engineer Waterways Experiment Station (WES) to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers. Funds for model testing were authorized by SPL on 27 January and 20 May 1992.

Model tests were conducted at WES during the period June through September 1992 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), Coastal Engineering Research Center (CERC) under the direction of Dr. James R Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CERC, respectively; and the direct guidance of Messrs. C. E. Chatham, Jr., Chief of WDD; and Dennis G. Markle, Chief of WPB. Tests were conducted by Messrs. Marvin G. Mize, Civil Engineering Technician; William G. Henderson, Computer Assistant; and Joseph Cessna, Contract Student; under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. This report was prepared by Mr. Bottin and typed by Ms. Debbie S. Fulcher, WPB.

Prior to the model investigation, Messrs. Bottin and Mize met with representatives of SPL and visited Morro Bay Harbor to inspect the prototype site and attend an engineering review conference. During the course of the investigation, liaison was maintained by means of conferences, telephone communications, and monthly progress reports. Visitors to WES who observed model operation and/or participated in conferences during the course of the study were:

Mr. George Domurat	SPD
Mr. Art Shak	SPL
Ms. Diana Bisher	SPL
Mr. Robert Michael	SPL
Dr. Richard Kent	Consultant to City of Morro Bay, California
Mr. Dick Rodgers	Chief Harbor Patrol Officer, City of Morro Bay, California

Dr. Robert W. Whalin was Director of WES during model testing and the preparation and publication of this report. COL Leonard G. Hassell, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7646	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	25.4	millimeters
knots (international)	1.8532	kilometers per hour
miles (U.S. statute)	1.609347	kilometers
square feet	0.09290304	square meters
square miles (U.S. statute)	2.589998	square kilometers

1 Introduction

The Prototype

Morro Bay Harbor is located in a natural embayment on the central coast of California about midway between Los Angeles and San Francisco (Figure 1). It serves as the only all-weather small craft commercial/recreational harbor between Santa Barbara and Monterey. Morro Bay extends inland and parallels the shore for about 4 miles[1] south of its entrance at Morro Rock. The bay is approximately 1 mile wide and has an area of about 3.5 square miles. A sandspit, about 4 miles long by 0.5 mile wide, separates Morro Bay from the ocean. The harbor is protected from the effects of the open ocean by an existing Federal navigation project consisting of two permeable rubble-mound breakwaters, an inner harbor groin, and a stone revetment. The existing Morro Bay Federal Project also has 13,700 ft of navigation channels and is shown in Figure 2.

The north breakwater is 1,885 ft long with an average crest elevation (el)[2] of +18 ft, while the south breakwater is 1,832 ft in length with a crest elevation varying from +14 to +18 ft. These breakwaters are positioned to form a 900-ft-wide entrance. Other structural features include a 1,600-ft-long stone revetment located adjacent to Morro Rock, a 1,000-ft-long stone groin located along the northern end of the sandspit adjacent to the entrance channel, and a stone revetment extending northeasterly adjacent to Navy Channel. The Federal navigation channel commences at the gap formed by the outer breakwaters and extends to the lower bay via three channel reaches. The authorized entrance channel depth is -16 ft and the innermost channel is maintained at a depth of -12 ft. The harbor has undergone several modifications, repairs, improvements, etc. since initial construction started in 1941 (U.S. Army Engineer District (USAED), Los Angeles 1991; Bottin 1988). An aerial view of the existing harbor entrance is shown in Figure 3.

1 A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

2 All elevations (el) cited herein are in feet referred to mean lower low water (mllw).

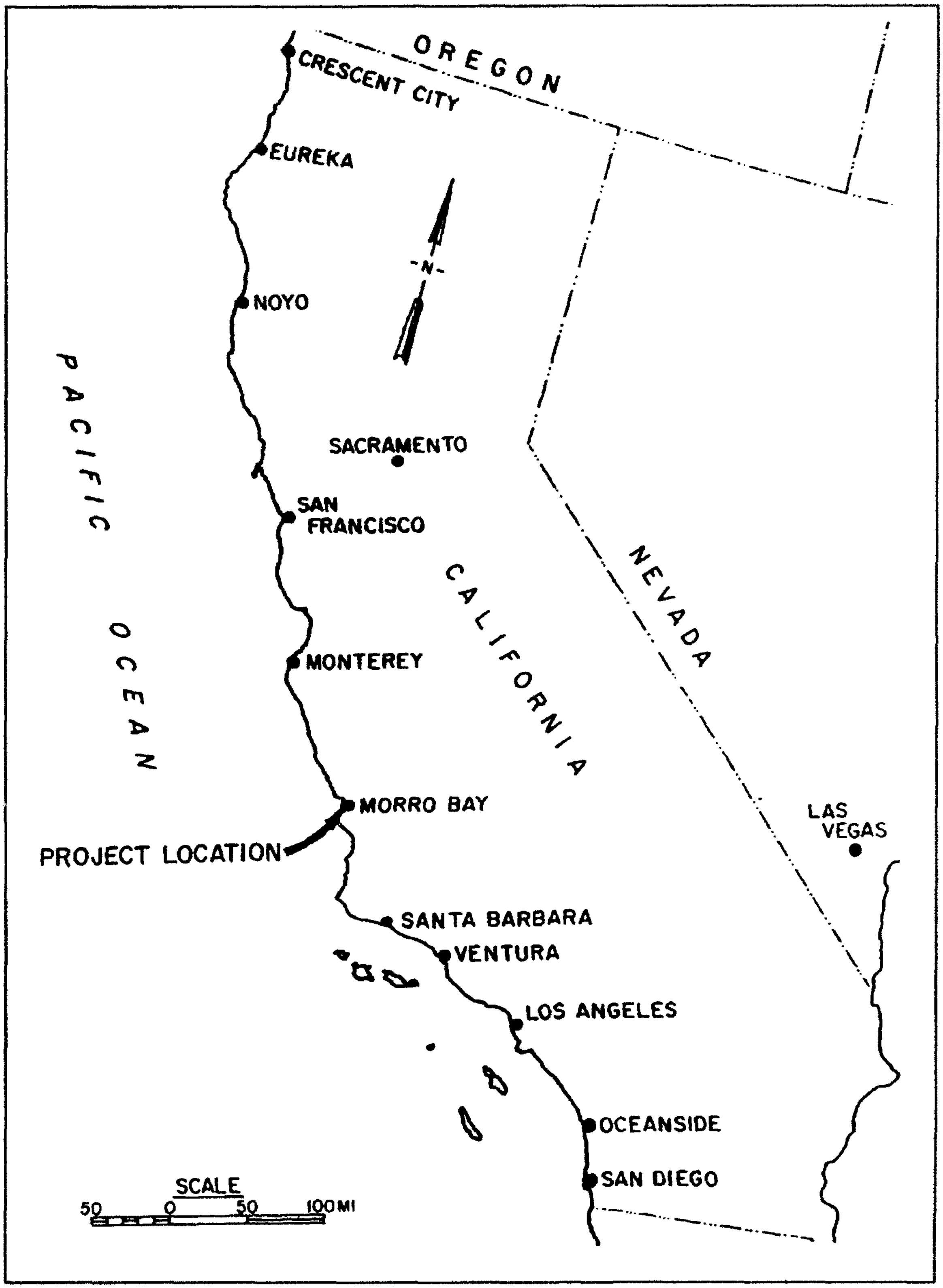

Figure 1. Project location

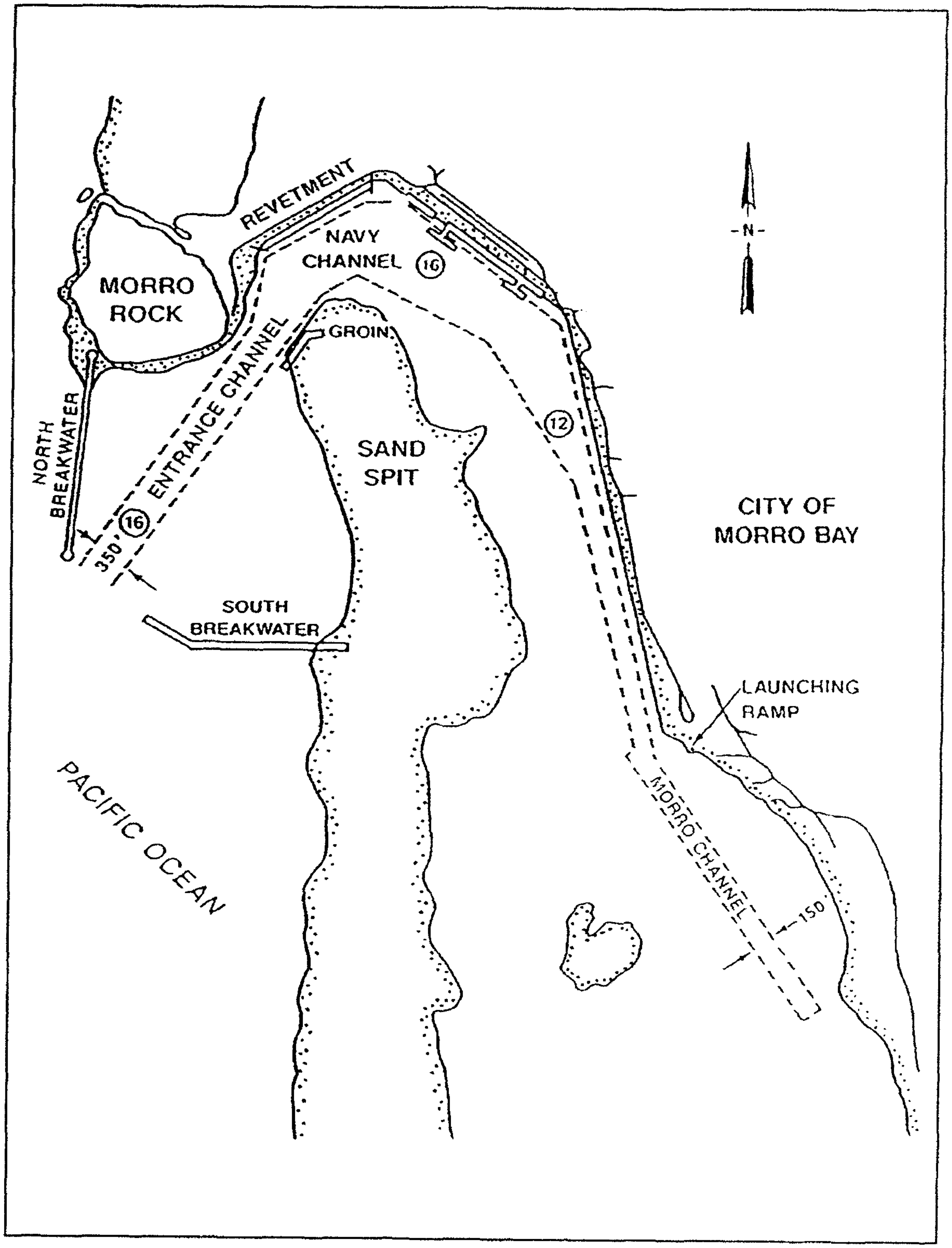

Figure 2. Existing Morro Bay Federal Project

Figure 3. Aerial view of Morro Bay entrance

Morro Bay contains an extensive complex of private and public facilities consisting of docks, piers, and moorings. The Harbor Department manages about 450 berths and moorings. There are also two small marinas in Morro Bay. The State Park Marina has facilities for over 100 recreational vessels, and the Morro Bay Marina has 17 slips and 26 off-shore mooring facilities. The Coast Guard also berths two 82-ft cutters in the Bay. The harbor contains commercial boat slips, sport fishing facilities, specialty shops, canoe/kayak and skiff rental facilities, a small trailer park, several motels, 20 restaurants, a yacht club, marine diving-construction operations, and four commercial fish buyers/processors. There are three fuel dock facilities and two boat haul-out repair facilities.

A major use of the Morro Bay waterfront is for tourism. The harbor provides a visual attraction, and the regional setting is extremely valuable for recreation with 4 million recreational days from out-of-town visitors estimated on an annual basis. The Bay is a stopping point along the central California coastline. Parks, golf courses, and a wide range of water-related tourist-oriented activities are available in the area.

The Problem

Morro Bay Harbor is known as one of the most dangerous harbors in the United States. Since 1962, 20 deaths, 67 injuries, and more than $600,000 in vessel damages have resulted from accidents caused by steep and breaking wave conditions in the Harbor entrance (USAED, Los Angeles 1991). These hazardous conditions, which occur predominantly during the winter months, close the harbor an average of 50 days a year, with a significant impact on commercial fish landings, charter boat operations, and Morro Bay's value as a landlocked harbor of refuge.

Morro Bay Harbor's entrance hazard is well-known and respected. It has a long-term reputation with a national impact. A California Department of Boating and Waterways publication entitled *Safe Boating Hints for Morro Bay*, has labeled the Harbor entrance as "one of the roughest on the West Coast," and cautions, "The boat operator should exercise caution regardless of experience," (USAED, Los Angeles 1991). In its September 1988 issue, *Yachting* magazine described Morro Bay as ". . . one of the most fearsome inlets on the West Coast." An article in the February 1981 *Motor Boating and Sailing* magazine, cited Morro Bay as being among " . . . eight of the most dangerous inlets in the United States" (USAED, Los Angeles 1991).

Morro Bay Harbor experiences entrance problems because of its exposure to storm wave conditions in the Pacific and the bathymetry in the vicinity of the harbor entrance. Breaking wave conditions occur at the entrance when ocean wave heights exceed 10 ft. Hazardous conditions also are reported for 8- to 10-ft waves, which tend to steepen sharply when they reach the shallower channel entrance, particularly during ebb tide conditions (USAED, Los Angeles 1991). Harbor officials have observed waves as low as 6 to 8 ft in height steepening sharply in the entrance, when there is a strong ebb tide current and winds from the west and northwest.

Proposed Improvements

The Morro Bay Harbor Feasibility Study (USAED, Los Angeles 1991) was conducted to provide safer navigation by mitigating the undesirable steep and breaking wave conditions in the entrance. A wide array of navigation improvements was investigated, including breakwater extensions, detached offshore breakwaters, and modifications to the existing Federal entrance channel. The breakwater alternatives lacked economic justification and were eliminated from consideration. The channel modifications were viable and economically justified. The proposed plan includes deepening the entrance to -30 ft and extending the channel seaward to the -30-ft contour. The channel would be widened to 950 ft at the seaward section and narrowed to 570 ft between the breakwater heads. The plan also provides for advanced maintenance by deepening the new channel to -40 ft and providing a triangular advanced maintenance area south of the modified channel. The advanced maintenance area would allow for shoaling over a 3-year period, consistent with current maintenance dredging operations at Morro Bay.

The proposed channel modification plan is expected to allow most large waves to pass through the entrance to Morro Bay Harbor without breaking, or steepening, and creating a hazardous condition. The safer entrance would thus allow increased passage in and out of Morro Bay. The plan is also expected to reduce the number of days each year that the entrance is impassable, from 50 to 2. This accomplishment would increase net revenues to commercial fishermen, reduce vessel damages, and provide other benefits, as well as reduce the potential for death and injury.

Purpose of the Model Study

At the request of USAED, Los Angeles (SPL), a physical coastal hydraulic model investigation was initiated by the U.S. Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) to:

a. Study wave conditions in the Morro Bay Harbor entrance for the existing channel configuration, the proposed channel modification plan, and the advanced maintenance depth of the new channel.

b. Determine if the proposed channel improvements would reduce breaking and steepening of waves in the entrance channel, and thus improve navigation conditions.

c. Determine impacts of the proposed channel improvements on existing breakwaters and on the spit between the south breakwater and the groin.

d. Develop remedial channel configurations for alleviation of undesirable conditions, if necessary.

2 The Model

Design of Model

The Morro Bay Harbor model (Figure 4) was constructed to an undistorted linear scale of 1:90, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

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

d. Efficiency of model operation.

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

f. Model construction costs.

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

Characteristic	Dimension[1]	Model-Prototype Scale Relations
Length	L	L_r = 1:90
Area	L^2	$A_r = L_r^2$ = 1:8,100
Volume	L^3	$V_r = L_r^3$ = 1:729,000
Time	T	$T_r = L_r^{1/2}$ = 1:9.49
Velocity	L/T	$V_r = L_r^{1/2}$ = 1:9.49

[1] Dimensions are in terms of length (L) and time (T).

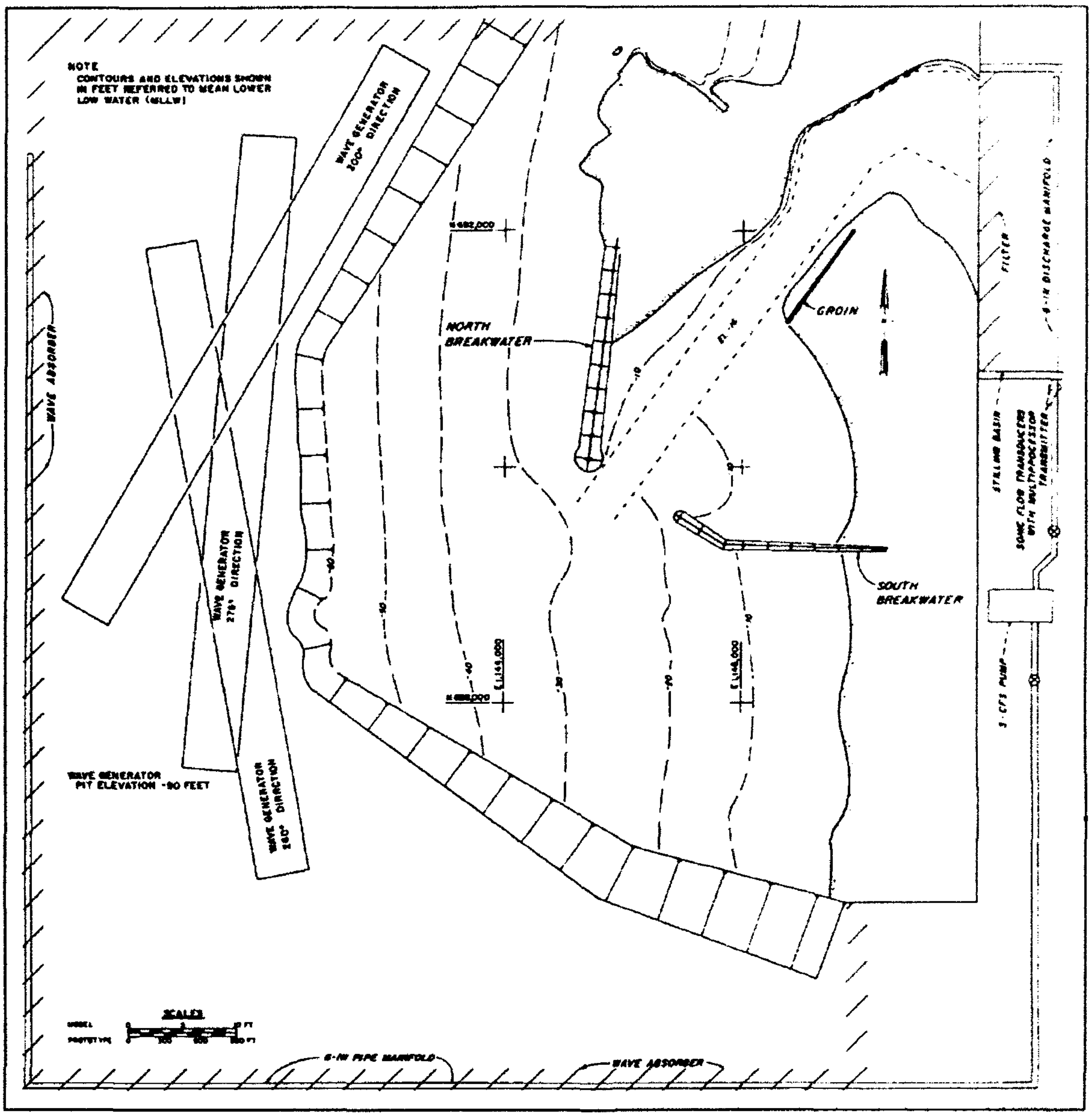

Figure 4. Model layout

The existing breakwaters, groin, and revetments at Morro Bay Harbor entrance are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission and absorption of wave energy became a matter of concern in design of the 1:90-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations at WES (Dai and Jackson 1966, Brasfeild and Ball 1967), this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Morro Bay, it was determined that a close approximation of the correct wave-energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:90-scale model to approximately two times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Morro Bay Harbor model, the rock sizes were computed linearly by scale, then multiplied by 2 to determine the actual sizes to be used in the model.

The Model and Appurtenances

The model reproduced about 7,000 ft of the California shoreline, the Morro Bay entrance, and bathymetry in the Pacific Ocean to an offshore depth of -60 ft with a sloping transition to the wave generator pit elevation of -90 ft. The total area reproduced in the model was approximately 11,640 sq ft, representing about 3.4 square miles in the prototype. A general view of the model is shown in Figure 5. Vertical control for model construction was based on mean lower low water (mllw). Horizontal control was referenced to a local prototype grid system.

Model waves were generated by a 60-ft-long, unidirectional spectral, electrohydraulic, wave generator with a trapezoidal-shaped, vertical-motion plunger. The vertical motion of the plunger was controlled by a computer-generated command signal, and the movement of the plunger caused a displacement of water which generated the required test waves. The wave generator was mounted on retractable casters, which enabled it to be positioned to generate waves from required directions.

A water circulating system (Figure 4) consisting of a 6-in. perforated-pipe water-intake and discharge manifolds, a 3-cfs pump, and sonic flow transducers with a multiprocessor transmitter, was used in the model to reproduce a steady-state tidal ebb flow. The flow corresponded to maximum ebb tidal discharges measured in the prototype. The magnitude of the current was measured by timing the progress of a weighted float over a known distance.

An Automated Data Acquisition and Control System, designed and constructed at WES (Figure 6), was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a microvax computer, the electrical output of capacitance-type wave gages, which varied

Figure 5. General view of model

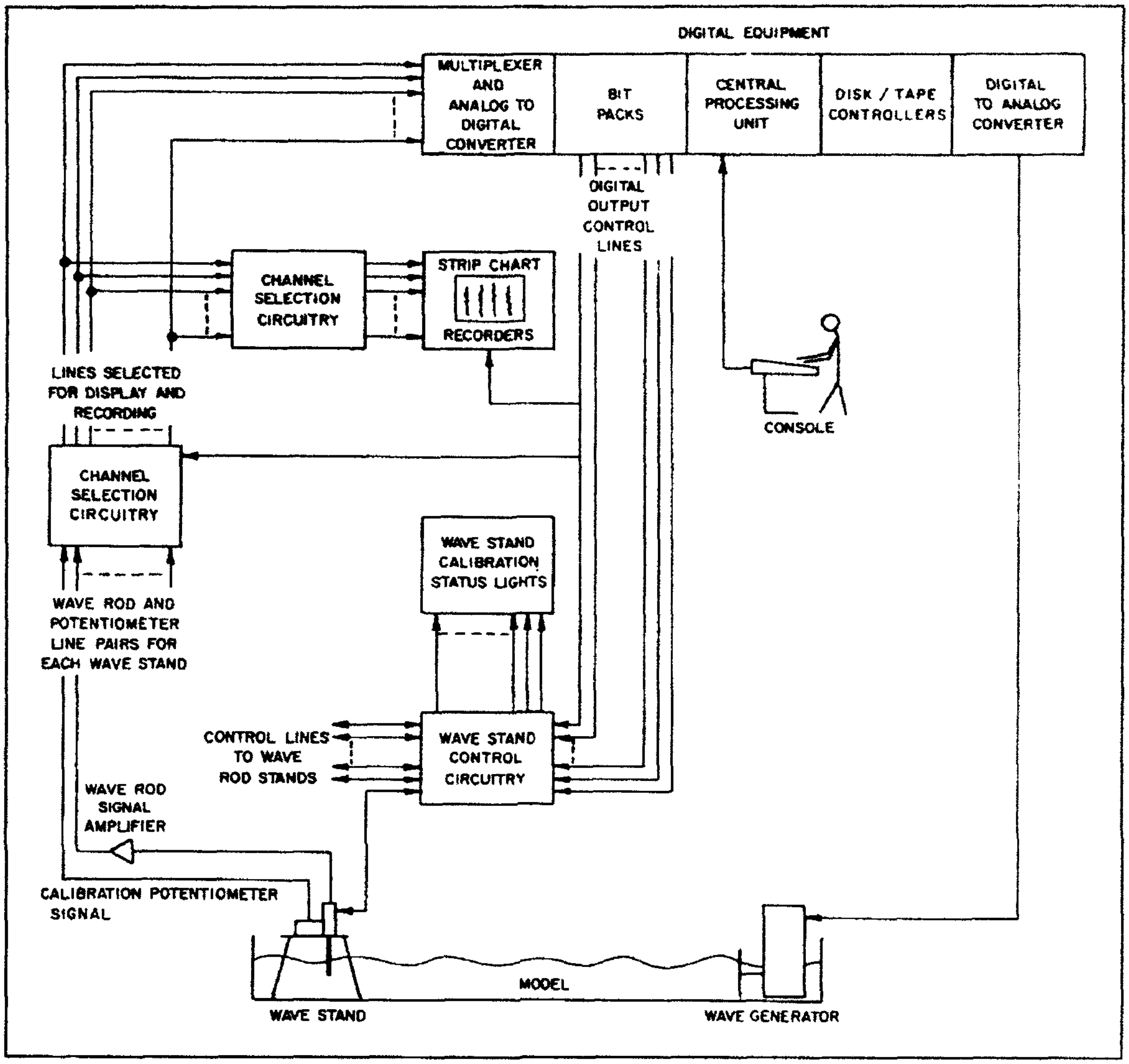

Figure 6. Automated Data Acquisition and Control System

with the change in water-surface elevation with respect to time, was recorded on magnetic disks. These data were then analyzed to obtain the parametric wave data.

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

Selection of Tracer Material

A fixed-bed model molded in cement mortar was constructed and a tracer material selected to qualitatively determine the movement and deposition of sediment in the vicinity of the harbor. The tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e. the horizontal scale λ; the vertical scale μ; the sediment size ratio n_D; and the relative specific weight ratio n_γ'. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:90 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Morro Bay Harbor was undistorted to allow accurate reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.20 mm, specific gravity = 2.65) and assuming the horizontal scale to be in similitude (i.e. 1:90), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale then was assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented the movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 0.47 mm) were selected for use as a tracer material throughout the model investigation.

3 Test Conditions and Procedures

Selection of Test Conditions

Still-water level

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

In most general cases, it is desirable to select a model swl that closely approximates the higher water stages that normally occur in the prototype; however, since the occurrences of steep and breaking waves are of primary interest at Morro Bay, lower tide stages were also selected for model tests.

Morro Bay experiences tides of the mixed semidiurnal type, with two highs and two lows occurring daily. Tidal data representative at the site are shown to the right (USAED, Los Angeles 1991). Tidal monitoring over a complete tidal cycle throughout Morro Bay reveals virtually no tidal elevation changes between the entrance channel and the central and south areas of the Bay.

	Feet
Extreme high water	+7.5
Mean higher high water	+5.3
Mean high water	+4.8
Mean sea level	+2.9
Mean low water	+1.0
Mean lower low water	0.0

Swl's of 0.0, +2.9, and +7.0 ft were selected by SPL for use in testing the Morro Bay model. The 0.0- and +2.9-ft values represent mean lower low water and mean sea level, respectively, and were used while testing operational wave conditions. The maximum ebb tidal flow was superimposed while using the +2.9-ft swl. The +7.0-ft swl (expected annual occurrence during the storm season) was used while testing extreme wave conditions.

Factors influencing selection of test wave characteristics

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

a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. The frequency of occurrence and duration of storm winds from the different directions.

c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.

d. The alignments, lengths, and locations of the various reflecting surfaces inside the harbor.

e. The refraction of waves caused by differentials in depth in the area seaward of the harbor, which may create either a concentration or a diffusion of wave energy at the harbor site.

Storms and deepwater wave data

Meteorological conditions that can result in severe waves at Morro Bay largely consist of intense extratropical cyclones that develop in the northern Pacific Ocean and move eastward. These low pressure systems are capable of generating strong winds and large waves. The size of waves arriving at Morro Bay is a function of the intensity of the low pressure center, the speed and direction of the center's movement, and its location with respect to Morro Bay, which directly influences the fetch area. Typically, these low pressure systems pass to the north of Morro Bay. Cold fronts associated with these extratropical systems usually extend from the center of the low southward. Prefrontal southerly winds are capable of generating waves of considerable height; however, waves related to prefrontal activity do not impact Morro Bay until the front is relatively close to the coast, limiting their fetch and resulting in a limited extreme wave condition for the southerly sector. The range of directions from which deepwater waves may approach the harbor entrance at Morro Bay is from

190 to 310 deg, although during most of the year, waves arrive predominantly from the west-northwest.

Measured prototype wave data covering a sufficiently long duration from which to base a comprehensive statistical analysis of deepwater wave conditions for the Morro Bay area were not available. However, statistical wave hindcast estimates representative of this area were obtained from the CERC Wave Information Studies (Corson 1985). The data had the following general statistics: a) mean significant wave height, 8 ft; b) mean peak period, 10.3 sec; c) most frequent wave direction, 292.5 deg; d) largest significant wave height, 28 ft; and e) peak period associated with the highest wave, 12.5 sec. The station from which the data were collected was located approximately 41 miles west-southwest of the harbor entrance and included historical pressure field records for the years 1956-1975.

Wave refraction

When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order to approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction may be determined by using the numerical Regional Coastal Processes Wave Transformation Model (RCPWAVE) developed by Ebersole (1985). This model predicts the transformation of monochromatic waves over arbitrary bathymetry and includes refractive and diffractive effects. Diffraction becomes increasingly important in regions with complex bathymetry. Finite difference approximations are used to solve the governing equations and the solution is obtained for a finite number of grid cells which comprise the domain of interest.

When the refraction coefficient (K_r) is determined, it is multiplied by the shoaling coefficient (K_s) and gives a conversion factor for deepwater wave heights to shallow-water values. The shoaling coefficient, a function of wave length and water depth, can be obtained from the *Shore Protection Manual* (1984). For this study, a wave refraction analysis, using RCPWAVE, was conducted by CERC (Kaihatu, Lillycrop, and Thompson 1989). A rectangular depth grid (6.1 x 13.8 miles) was utilized with grid spacing ranging from 200 to 600 ft. Depths were obtained from the latest Corps of Engineers surveys (1988) and National Oceanic and Atmospheric Administration charts.

Shallow-water wave heights and refracted wave directions were propagated to an area immediately seaward of the harbor entrance (-47-ft depth). Based on the refraction analysis, most waves approached the entrance within a window between 260-300 deg, with approximately 90 percent of all waves approaching from about 275 deg at the -47-ft contour.

Return Period (yrs)	Wave Height (ft)
10	21.0
25	26.0
50	30.0
100	33.0

An extremal analysis of the hindcast shallow-water waves (USAED, Los Angeles 1991) indicated that extreme storm waves and their frequencies are as shown in the adjacent tabulation.

Selection of test waves

Based on the hindcast data and wave refraction analysis, SPL selected the following test wave characteristics to be used in the model investigation. Operational wave conditions were generated from 275 deg with swl's of 0.0 and +2.9 ft, and extreme wave conditions were generated from 260, 275, and 300 deg with a +7.0-ft swl.

Selected Test Waves[1]	
Period, sec	**Height, ft**
Operational Waves	
12	8
15	8, 12, 14, 16
17	8, 12, 16
20	8, 12, 16
Extreme Waves	
15	21, 26, 30
17	21, 26, 30
20	21

[1] All selected test waves were defined seaward of the harbor entrance at approximately the 47-ft contour.

For sediment tracer tests, waves from 250 and 300 deg were selected to determine sediment movement patterns in the vicinity of the harbor entrance. These directions created longshore currents required to move the tracer material. Representative test waves for the 0.0- and +7.0-ft swl's were selected for use during tracer tests.

Monochromatic wave conditions were generated for all selected test waves throughout the model investigation since entrance wave time series and wave forms could be compared more easily than for spectral wave conditions. To compare significant wave heights at various locations in the model, however, unidirectional wave spectra (based on Joint North Sea Wave Project (JONSWAP) parameters) also were generated for selected test wave conditions.

Maximum ebb tidal velocities

Prototype data collected by SPL indicated that maximum ebb tidal velocities of 2 knots occur in the entrance channel (area between the groin on the south and the revetment on the north). This value occurred with a tide level of +2.9 ft. Discharges were reproduced in the model and an ebb velocity of 2 knots was simulated. This value was used during model testing for operational test waves with the +2.9-ft swl.

Analysis of Model Data

Relative merits of the various plans tested were evaluated by:

a. Comparison of wave heights and the form of the waves at selected locations in the model.

b. Comparison of sediment tracer movement and subsequent deposits (for the optimum plan).

c. Visual observations and wave pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves (H_s), recorded at each gage location, was computed. All wave heights then were adjusted, by application of Keulegan's equation,[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of wave heights in the model (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel.

[1] G. H. Keulegan. (1950). "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel," Unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Tests and Results

The Tests

Existing Conditions

Comprehensive wave-height tests were conducted for existing conditions (Plate 1) to establish a base from which to evaluate the effectiveness of various improvement plans. Wave height data were secured at various locations throughout the harbor entrance for selected test waves from 260, 275, and 300 deg. In addition, wave pattern photographs and videotape footage were obtained for representative test waves from these directions.

Improvement plans

The originally proposed improvement plan consisted of a deepened, expanded entrance channel. Wave heights, wave patterns, and videotape footage were obtained for 15 test plan configurations. Variations consisted of changes in the alignment and/or depth of the dredged entrance channel. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are shown in Plates 1-5.

a. Plan 1 (Plate 2) consisted of the originally proposed, deepened, expanded entrance channel. The channel was dredged to -40 ft and covered about 1,133,500 sq ft in the entrance. Channel side slopes were 1v:4h. The -40-ft channel included an overdredge depth of 10 ft. It was anticipated that the capacity of the channel would be great enough to allow for a 3-year maintenance dredging cycle.

b. Plan 2 (Plate 3) entailed the elements of Plan 1, but an area (22,500 sq ft) of the dredged channel west of the head of the south breakwater was filled in to existing depths.

c. Plan 3 (Plate 3) involved the elements of Plan 1, but a 100-ft-wide portion of the dredged channel west of the head of the south breakwater was filled in to the existing contours. The area in which the existing contours were placed entailed approximately 106,500 sq ft.

d. Plan 4 (Plate 3) included the elements of Plan 1, but a portion (169,300 sq ft) of the dredged channel west of the head of the south breakwater was filled in to existing depths.

e. Plan 5 (Plate 3) involved the elements of Plan 1, but a larger portion (238,300 sq ft) of the dredged channel west of the head of the south breakwater was filled in to existing depths.

f. Plan 6 (Plate 3) included the elements of Plan 1, but approximately 412,000 sq ft of the dredged channel west of the head of the south breakwater was filled in to existing contours. The southeast channel line of the dredged channel was in alignment with the existing -16-ft channel.

g. Plan 7 (Plate 3) consisted of the elements of Plan 6, but a triangular area (12,500 sq ft) of the dredged channel south of the head of the north breakwater was filled in to existing depths.

h. Plan 8 (Plate 4) entailed the elements of Plan 6, but an area (73,500 sq ft) south and west of the head of the north breakwater was filled in to existing depths.

i. Plan 9 (Plate 4) involved the channel alignment of Plan 8, but the side slopes of the southeastern portion of the channel were flattened from 1V:4H to 1V:10H.

j. Plan 10 (Plate 4) included the channel alignment of Plan 8, but an additional area (129,600 sq ft) in the southern portion of the entrance channel was filled in to existing depths.

k. Plan 11 (Plate 4) entailed the elements of Plan 8, but an area of approximately 216,500 sq ft in the southern portion of the entrance channel was filled in to existing depths.

l. Plan 12 (Plate 4) consisted of elements of Plan 11, but an area (80,000 sq ft) of the channel northwest of the head for the south breakwater was filled in to existing depths.

m. Plan 13 (Plate 4) included the channel alignment of Plan 6, but the 40-ft-deep channel was decreased to 35 ft.

n. Plan 14 (Plate 5) involved the entrance channel configuration of Plan 7. The -40-ft entrance channel covered an area of about 709,000 sq ft. The plan also included a -30-ft sand trap area (477,700 sq ft) northeast of the head of the south breakwater.

o. Plan 15 (Plate 5) entailed the elements of Plan 14, but the depth of the entrance channel was decreased from -40 to -30 ft.

Wave height tests

Wave height tests were conducted for the various improvement plans for test waves from one or more of the selected test directions. Tests involving many of the plans, however, were limited to the most critical direction (i.e., 275 deg). The optimum improvement plans (Plans 14 and 15), as determined by SPL, were tested comprehensively for waves from all test directions. Wave gage locations for each improvement plan are shown in Plates 2 through 5.

Wave patterns and videotape footage

Wave patterns and/or videotape footage were obtained for various improvement plans for test waves from the selected test directions. Wave patterns were obtained for the original plan (Plan 1) and the optimum improvement plans (Plans 14 and 15), while videotape footage was obtained for representative test waves for all the improvement plans (Plans 1-15).

Sediment tracer tests

Sediment tracer tests were conducted for improvement plan 14 only. Tracer material was introduced into the model at the root of the north breakwater for test waves from 300 deg. For test waves from 250 deg, tracer material was introduced into the model on the shoreline south of the harbor entrance.

Test Results

In evaluating test results, relative merits of the various improvement plans were based on an analysis of measured wave heights in the harbor entrance, the movement of tracer material and subsequent deposits, and visual observations. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations. In addition, wave height data were plotted depicting values through the entrance channel, and the forms of the waves in the entrance were plotted and compared for various improvement plans. The general movement of tracer material and subsequent deposits were shown in photographs. Arrows were superimposed onto the photographs to define sediment movement patterns.

Wave tests from 275 deg

Existing conditions. Results of wave height tests for existing conditions are presented in Tables 1-4 for test waves from 275 deg with the 0.0-, +2.9- and +7.0-ft swl's. For the 0.0-ft swl, maximum wave heights[1] were 19.9 ft in the entrance (gage 11) for 15-sec, 16-ft monochromatic waves; 20.7 ft at the head of the north breakwater (gage 9) for 17-sec, 16-ft monochromatic waves, 15.5 ft at the head of the south breakwater (gage 15) for 20-sec, 12-ft monochromatic waves; and 2.9 ft along the spit between the south breakwater and the groin (gage 22) for 20-sec, 16-ft monochromatic waves. With the +2.9-ft swl, maximum wave heights were 24.0 ft in the entrance (gage 10) for 20-sec, 16-ft monochromatic waves; 18.3 ft at the head of the north breakwater (gage 9) for 15-sec, 12-ft monochromatic waves; 18.9 ft at the head of the south breakwater (gage 15) for 20-sec, 12-ft monochromatic waves; and 6.1 ft along the spit between the south breakwater and the groin (gage 22) for 17-sec, 8-ft monochromatic waves. Maximum wave heights, for the +7.0-ft swl, were 32.9 ft in the entrance (gage 10) for 17-sec, 30-ft monochromatic waves; 22.5 ft at the head of the north breakwater (gage 9) for 17-sec, 26-ft monochromatic waves; 15.1 ft at the head of the south breakwater (gage 15) for 15-sec, 21-ft monochromatic waves; and 9.7 ft along the spit between the south breakwater and the groin (gage 22) for 15-sec, 30-ft monochromatic waves. Wave heights obtained for spectral wave conditions (Table 4) were generally significantly less in height than those obtained for monochromatic wave conditions. Typical wave patterns obtained for existing conditions for test waves from 275 deg are shown in Photos 1-9.

Improvement plans. Wave height test results with Plan 1 installed are presented in Tables 5-8 for test waves from 275 deg with the 0.0-, +2.9-, and +7.0-ft swl's. For the 0.0-ft swl, maximum wave heights were 18.5 ft in the entrance (gage 10) for 15-sec, 16-ft monochromatic waves; 20.5 ft at the head of the north breakwater (gage 9) for 15-sec, 16-ft monochromatic waves; 17.5 ft at the head of the south breakwater (gage 15) for 17-sec, 16-ft monochromatic waves; and 3.3 ft along the spit between the south breakwater and the groin (gage 21) for 20-sec, 12-ft monochromatic waves. With the +2.9-ft swl, maximum wave heights were 21.3 ft in the entrance (gage 10) for 20-sec, 16-ft monochromatic waves; 21.7 ft at the head of the north breakwater (gage 9) for 15-sec, 16-ft monochromatic waves; 16.4 ft at the head of the south breakwater (gage 15) for 17-sec, 16-ft monochromatic waves; and 4.5 ft along the spit between the south breakwater and the groin for 15-sec, 8-ft monochromatic waves. Maximum wave heights, for the +7.0-ft swl, were 33.1 ft in the entrance (gage 10) for 17-sec, 30-ft monochromatic waves; 27.3 ft at the head of the north breakwater (gage 9) for 15-sec, 21-ft monochromatic waves; 24.4 ft at the head of the south breakwater (gage 15) for 17-sec, 30-ft monochromatic waves; and 8.8 ft along the spit between the south breakwater and the groin (gage 21) for 15-sec, 30-ft test waves. As was the case for

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[1] Refers to maximum significant wave heights throughout report.

existing conditions, spectral wave conditions were generally significantly less than monochromatic conditions. Representative wave patterns obtained for Plan 1 for test waves from 275 deg are presented in Photos 10-18.

An evaluation of wave conditions to this point for existing conditions and Plan 1 revealed that, for operational wave conditions (0.0- and +2.9-ft swl's), wave heights in the entrance generally improved. However, for extreme wave conditions (+7.0-ft swl), wave heights significantly increased at the heads of the breakwaters, particularly the south breakwater. Plans 2-13 were installed in the model (using gravel as opposed to concrete grout) to expeditiously determine preliminary alternatives that might reduce wave heights at the head of the south breakwater.

Results of wave height tests for Plans 2-13 for 15-sec, 21-ft and 17-sec, 26-ft waves from 275 deg with the +7.0-ft swl are presented in Table 9. Maximum wave heights for Plans 2-13, respectively, were 34.0, 35.4, 34.0, 30.5, 33.7, 31.5, 32.9, 35.0, 32.5, 30.9, 32.4, and 26.4 ft in the entrance (gages 10-12); 26.5, 28.1, 26.9, 25.0, 27.2, 27.2, 28.3, 27.2, 27.9, 27.5, 27.7, and 24 ft at the head of the north breakwater (gage 9); 26.0, 22.8, 22.3, 21.2, 18.8, 18.8, 18.8, 22.1, 20.1, 21.4, 18.4, and 19.7 ft at the head of the south breakwater (gage 15); and 7.5, 7.5, 8.0, 7.6, 6.0, 6.0, 7.3, 7.8, 7.5, 6.8, 7.5, and 8.0 ft along the spit between the south breakwater and the groin (gages 21-24).

Representatives of the US Army Engineer Division, South Pacific (SPD) and SPL visited WES during the conduct of the preliminary tests (Plans 2-13). An examination of test results revealed that the channel configuration of Plan 7 appeared to be optimum. Plan 7 resulted in reduced wave heights at the head of the south breakwater with maximum capacity for sediments. Visual observations of these tests revealed that the wave rundown at the head of the north breakwater was coinciding with the incident wave at the gage 9 location. This was not considered representative of wave conditions at the breakwater head, and SPL requested that gage 9 be moved slightly to a location seaward of the head. It was also noted that the gage 7 location, although in the center of the entrance for existing conditions, was on the edge of the Plan 7 channel. SPL requested that gage 1 be moved adjacent to gage 7 and centered in the channel.

Results of wave height tests for Plan 14 are presented in Tables 10-13 for test waves from 275 deg with the 0.0-, +2.9-, and +7.0-ft swl's. For the 0.0-ft swl, maximum wave heights were 19.1 ft in the entrance (gage 10) for 20-sec, 16-ft monochromatic waves; 21.9 ft at the head of the north breakwater (gage 9A) for 17-sec, 16-ft monochromatic waves; 16.6 ft at the head of the south breakwater (gage 15) for 20-sec, 16-ft monochromatic waves; and 3.3 ft along the spit between the south breakwater and the groin (gage 22) for 20-sec, 16-ft monochromatic waves. With the +2.9-ft swl, maximum wave heights were 21.5 ft in the entrance (gage 10) for 20-sec, 16-ft monochromatic waves; 17.7 ft at the head of the north breakwater (gage 9A) for 15-sec, 16-ft monochromatic waves; 19.5 ft at the head of the south breakwater (gage 15) for 20-sec, 14-ft monochromatic waves; and 5.3 ft along the spit (gage 21) for 15-sec, 16-ft monochromatic waves. Maximum wave heights, for the +7.0-ft swl, were 31.9 ft in the entrance (gage 11) for 17-sec, 30-ft monochromatic waves; 24.0 ft at the head of the north breakwater (gage 9A) for 15-sec, 21-ft monochromatic waves; 19.5 ft at the head of the south breakwater (gage 15) for 15-sec, 26-ft and 20-sec, 21-ft monochromatic waves; and 6.7 ft along the spit between the south breakwater and the groin (gages 21, 23, and 24) for 15-sec, 26-ft and 17-sec, 30-ft monochromatic waves. Monochromatic waves generated significantly larger wave heights than spectral wave conditions. Typical wave patterns for Plan 14 are presented in Photos 19-27 for test waves from 275 deg. During testing of Plan 14, SPL requested that 15-sec, 17-sec, and 20-sec waves with a height of 14 ft be tested. This wave height (14 ft) is the threshhold (maximum) at which benefits were obtained. Visual observations indicated that waves did not break seaward of the -40-ft channel of Plan 14. Some of the 16-ft wave heights secured earlier had broken in this location.

Wave heights obtained for Plan 15 are presented in Tables 14-17 for test waves from 275 deg with the 0.0-, +2.9-, and +7.0-ft swl's. Maximum wave heights, with the 0.0-ft swl, were 18.4 ft in the entrance (gage 11) for 20-sec, 16-ft monochromatic waves; 18.8 ft at the north breakwater (gage 9A) for 17-sec, 16-ft monochromatic waves; 19.5 ft at the head of the south breakwater (gage 15) for 20-sec, 14-ft monochromatic waves; and 3.5 ft along the spit between the south breakwater and the groin (gages 21-23) for several monochromatic wave conditions. With the +2.9-ft swl, maximum wave heights were 20.6 ft in the entrance (gage 11) for 20-sec, 16-ft monochromatic waves; 20.2 ft at the head of the north breakwater (gage 9A) for 20-sec, 12-ft monochromatic waves; 19.7 ft at the head of the south breakwater (gage 15) for 20-sec, 12-ft monochromatic waves; and 6.2 ft along the spit between the south breakwater and the groin (gage 24) for 17-sec, 16-ft monochromatic waves. For the +7.0-ft swl, maximum wave heights were 31.3 ft in the entrance (gage 10) for 17-sec, 30-ft monochromatic waves; 22.2 ft at the head of the north breakwater (gage 9A) for 17-sec, 26-ft monochromatic waves; 19.7 ft at the head of the south breakwater (gage 15) for 20-sec, 21-ft monochromatic waves; and 8.7 ft along the spit between the south breakwater and the groin (gage 22) for 17-sec, 26- and 30-ft monochromatic waves. Maximum wave heights for monochromatic waves were significantly greater than those obtained for spectral wave conditions. Representative wave patterns for Plan 15 are presented in Photos 28-36.

Wave tests from 300 deg

Existing conditions. Results of wave height tests for existing conditions are presented in Table 18 for test waves from 300 deg with the +7.0-ft swl. Maximum wave heights were 31.0 ft in the entrance (gage 10) and 21.6 ft at the head of the north breakwater (gage 9A) for 17-sec, 30-ft monochromatic waves; and 15.8 ft at the head of the south breakwater (gage 15) and 7.6 ft along the spit between the south breakwater and the groin (gage 23) for 20-sec, 21-ft monochromatic waves. Representative wave patterns for existing conditions are shown in Photos 37-39 for test waves from 300 deg.

Improvement plans. Results of wave height tests with Plan 14 installed are presented in Table 19 for test waves from 300 deg with the +7.0-ft swl. Maximum wave heights obtained were 30.7 ft in the entrance (gage 10) for 17-sec, 30-ft monochromatic waves; 23.3 ft at the head of the north breakwater (gage 9A) for 17-sec, 30-ft monochromatic waves; 17.5 ft at the head of the south breakwater (gage 15) for 17-sec, 21-ft monochromatic waves; and 7.0 ft along the spit between the south breakwater and the groin (gage 24) for 15-sec, 26- and 30-ft monochromatic waves. Typical wave patterns for Plan 14 for test waves from 300 deg are presented in Photos 40-42.

Wave heights obtained for Plan 15 are presented in Table 20 for test waves from 300 deg with the +7.0-ft swl. Maximum wave heights were 28.8 ft in the entrance (gage 10) for 17-sec, 26-ft monochromatic waves; 22.0 ft at the head of the north breakwater (gage 9A) for 17-sec, 30-ft monochromatic waves; 17.4 ft at the head of the south breakwater (gage 15) for 15-sec, 30-ft monochromatic waves; and 6.2 ft along the spit between the south breakwater and the groin (gage 24) for 15-sec, 26- and 30-ft monochromatic waves. Representative wave patterns for Plan 15 for test waves from 300 deg are shown in Photos 43-45.

Wave tests from 260 deg

Existing conditions. Results of wave height tests for existing conditions are presented in Table 21 for test waves from 260 deg with the +7.0-ft swl. Maximum wave heights were 28.6 ft in the entrance (gage 10) and 23.7 ft at the head of the north breakwater (gage 9A) for 17-sec, 26-ft monochromatic waves; 22.1 ft at the head of the south breakwater (gage 15) for 20-sec, 21-ft monochromatic waves; and 11.7 ft along the spit between the south breakwater and the groin (gage 21) for 17-sec, 30-ft monochromatic waves. Typical wave patterns for existing conditions are shown in Photos 46-48 for test waves from 260 deg.

Improvement plans. Wave height test results with Plan 14 installed for test waves from 260 deg with the +7.0-ft swl are presented in Table 22. Maximum wave heights were 30.5 ft in the entrance (gage 11) for 17-sec, 26-ft monochromatic waves; 23.2 at the head of the north breakwater (gage 9A) for 17-sec, 26-ft monochromatic waves; 21.0 ft at the head of the south breakwater (gage 15) for 20-sec, 21-ft monochromatic waves; and 9.3 ft along the spit between the south breakwater and the groin (gage 21) for 17-sec, 30-ft monochromatic waves. Typical wave patterns for Plan 14 are presented in Photos 49-51 for test waves from 260 deg.

Results of wave height tests for Plan 15 are presented in Table 23 for test waves from 260 deg with the +7.0-ft swl. Maximum wave heights were 30.7 ft in the entrance (gage 11) for 17-sec, 26-ft monochromatic waves; 22.1 ft at the head of the north breakwater (gage 9A) for 17-sec, 26-ft monochromatic waves; 21.6 ft at the head of the south breakwater (gage 15) for 20-sec, 21-ft monochromatic waves; and 11.5 ft along the spit between the south breakwater and the groin (gage 21) for 17-sec, 30-ft monochromatic waves. Representative wave patterns for Plan 15 are presented in Photos 52-54 for test waves from 260 deg.

Sediment tracer tests. The general movement of tracer material and subsequent deposits obtained for Plan 14 for test waves from 300 and 250 deg with the 0.0- and +7.0-ft swl's are shown in Photos 55-64. For test waves from 300 deg, sediment tracer moved in a southerly direction along the seaward side of the north breakwater and deposited in the entrance channel. For wave heights 16 ft or greater, some material moved across the entrance toward the head of the south breakwater and/or downcoast to the south. It was noted that extreme wave conditions for the +7.0-ft swl resulted in sediment being moved over and/or through the north breakwater with deposits on the leeward side of the structure. For test waves from 250 deg, sediment material moved northerly around the head of the south breakwater into the new -30 ft sand trap area. The most extreme waves for each swl resulted in sediment tracer material also moving and depositing into the deepened entrance channel.

Discussion of Test Results

Operational waves (8 to 16 ft) from 275 deg for existing conditions indicated hazardous wave conditions in the harbor entrance. Observations indicated that almost all the test waves for the 0.0- and +2.9-ft (maximum ebb flow) swl's began peaking up and/or breaking in the entrance creating hazardous navigation conditions. Wave height tests showed that wave heights were greater in the entrance than their respective incident heights in deeper water.

Extreme waves (21 to 30 ft) from 275 deg for existing conditions resulted in waves breaking seaward of and through the entrance. After breaking occurred, the waves reformed and broke again on the slope adjacent to the shoreline. It was noted for the +7.0-ft swl that most of the waves broke prior to impinging upon the head of the south breakwater.

Tests conducted for Plan 1 indicated that the dredged channel was effective in reducing wave heights in the entrance for operational wave conditions from the predominant 275-deg direction. Observations revealed that these 8- to 16-ft waves did not break in the entrance, and test results indicated that most conditions resulted in wave heights significantly less than those obtained for existing conditions. The results of extreme wave conditions for Plan 1, however, indicated that wave heights at the head of the south breakwater substantially increased (from 18.9 to 24.4 ft). The deepened entrance channel allowed more energy to reach the structure, as opposed to breaking and losing energy as with the existing contours. Wave heights along the spit between the south breakwater and the groin, in general, were less for Plan 1 than for existing conditions.

An examination of test results for the expedited test plans (Plans 2-13), indicated that some of the existing contours would have to remain seaward of the head of the south breakwater to prevent excessive wave heights. The channel configuration of Plan 7 appeared to be optimum (allowing the maximum dredging area with minimum wave heights at the south breakwater). Additional sand trap area, however, was required to compensate for the capacity lost due to infilling the area seaward of the south breakwater head. The selected Plan 14 configuration would allow enough capacity for a 2-yr dredging frequency cycle.

Test results for Plan 14 indicated that the improvement was effective in reducing wave conditions in the entrance for operational waves from the predominant 275-deg wave direction. The plan was particularly effective in an area starting at a projection of the north breakwater (approximate gage 12 location) shoreward to a projection of the south breakwater (approximate gage 7 location). Visual observations indicated no breaking waves in the new entrance channel. A comparison of maximum significant wave heights through the entrance (gages 10-12 and 7A-1) for existing conditions and Plan 14 is presented in Plates 6-19 for test waves with the 0.0- and +2.9-ft swl. In addition, a comparison of wave form (steepness) in the outer entrance (gages 10-12 and 7, 7A) for operational wave conditions is shown in Plates 20-47. In general, these plots reveal improved navigation conditions in the entrance. Wave heights are lower for Plan 14, and the waves are not as steep and are nonbreaking for the improvement plan.

For extreme wave conditions from 275 deg, Plan 14 resulted in no adverse wave conditions at the head of the north breakwater or along the spit between the south breakwater and the groin. Wave heights at the head of the south breakwater, however, increased slightly. The SPL stated that the south breakwater was designed for 19-ft incident waves, and Plan 14 resulted in 19.5-ft waves at the head of the structure. This was 0.6 ft greater than the 18.9-ft wave heights secured for existing conditions. Visual observations indicated that the waves were not breaking directly on the structure head, but seaward, for Plan 14. A bore (waves with air entrainment) was observed, which would have less energy than waves breaking on the structure directly. In addition, results obtained for these conditions were produced by monochromatic waves. Spectral waves (which are more near to the waves produced in nature) generally resulted in lower wave heights throughout the study area. In view of these considerations, SPL determined that wave heights between 19 and 20 ft would be acceptable at the head of the south breakwater. No test wave condition exceeded the 24-ft design wave at the north breakwater for Plan 14, and wave heights along the spit between the south breakwater and the groin were generally less for Plan 14 than for existing conditions. Maximum wave heights along the spit were 9.7 and 6.7 ft, respectively, for existing conditions and Plan 14.

The -30-ft-deep entrance channel of Plan 15 resulted in wave conditions in the entrance similar to Plan 14 for operational waves from 275 deg. In some cases wave heights were larger,and in some instances, wave heights were smaller. Maximum wave heights in the entrance occurred for Plan 14, but were less than 1 ft higher than the Plan 15 values. For extreme wave conditions from 275 deg, wave heights for Plan 15 also were lower in some cases and higher in some cases than Plan 14. In general, wave heights were lower at the north breakwater and higher in the entrance for Plan 15. Maximum wave heights at the head of the south breakwater were 0.2 ft higher (19.7 ft) for Plan 15 than for Plan 14. On the spit between the south breakwater and the groin, maximum wave heights were 2.0 ft higher for Plan 15 than Plan 14 but were still 1.0 ft less than those obtained for existing conditions.

Wave heights obtained for test waves from 300 deg for existing conditions were, in general, slightly less than those obtained in the vicinity of the entrance for existing conditions for test waves from the predominant 275-deg direction. For existing conditions, wave heights were less at the head of the north breakwater (0.9 ft) and in the entrance (1.9 ft) for waves from 300 deg, but slightly higher (0.7 ft) at the head of the south breakwater. Maximum wave heights were 1.9 ft less along the spit for test waves from 300 deg as opposed to the predominant 275-deg direction with existing conditions installed. Wave heights for Plans 14 and 15 were comparable to those for existing conditions at the head for the north breakwater and in the entrance for test waves from 300 deg. These plans, however, resulted in larger wave heights at the head of the south breakwater than existing conditions, but they were less (1.5 ft) than the 19-ft design wave height. Wave heights along the spit between the south breakwater and the groin were less for Plans 14 and 15 than for existing conditions. In summary, the installation of Plan 14 or 15 will not have adverse impacts on the structures or the spit for test waves from 300 deg.

Wave height tests revealed that waves from 260 deg resulted in the most severe conditions in the vicinity of the harbor entrance. The 260-deg direction allowed more energy in the harbor than the other wave directions, and large wave heights (greater than the structure was designed for) were obtained at the head of the south breakwater for existing conditions. Also for existing conditions, wave heights along the spit between the south breakwater and groin were 2 ft greater for waves from 260 deg as opposed to the predominant 275-deg direction. Wave heights at the head of the south breakwater for Plans 14 and 15 were 21.0 and 21.6 ft, respectively, for test waves from 260 deg. These values were greater than the 19- to 20-ft wave height range selected by SPL; however, they were less than wave heights (22.1 ft) secured for existing conditions for corresponding wave conditions. These results indicate that if 20-sec, 21-ft waves approach the harbor from 260 deg, the south breakwater head currently will be subject to damage. The installation of either Plan 14 or 15 will not increase the likelihood of damage to the structure.

An assessment of the littoral processes at Morro Bay (USAED, Los Angeles 1991) reveals, in general, that southerly sediment transport is predominant along the coast; however, northerly sediment transport toward the harbor entrance in the localized area of Morro Bay is predominant. This could be a result of the unique alignment of the coastline adjacent to the harbor entrance. The location of Morro Rock also may limit the southern transport of sediment. It is estimated that the annual transport rate toward the harbor entrance is 71,000 cu yd from the north and 400,000 cu yd from the south (USAED, Los Angeles 1991). Historic maintenance dredging records indicate that an average of 115,000 cu yd of sediment deposit in the entrance annually. The remainder of the sediment continues to move outside the entrance. Sediment tracer tests conducted for Plan 14 indicated that sediment moving in a southerly direction will deposit in the deepened entrance channel, and material moving in a northerly direction will deposit in both the entrance channel and the new sand trap area north of the south breakwater head. The SPL estimates that the capacity of the -40 ft entrance channel and the -30 ft sand trap will allow for maintenance dredging at 3-year intervals.

5 Conclusions

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

a. For the existing harbor entrance, operational waves (8 to 16 ft in height) from the predominant 275-deg direction resulted in hazardous entrance navigation conditions due to wave steepening and/or breaking.

b. For the originally proposed improvement plan (Plan 1), navigation conditions in the entrance were improved for operational waves from 275 deg; however, the plan resulted in significantly increased wave heights which may cause damage to the head of the south breakwater during extreme wave conditions (waves ranging from 21 to 30 ft in height).

c. Of the improvement plans tested, the channel and sand trap configuration of Plan 14 appeared to be optimal with respect to all wave conditions from all directions. Navigation conditions in the entrance will be improved, and the plan will have no negative impact on the existing structures or the spit between the south breakwater and the groin.

d. Sediment tracer tests indicated that sediment moving in the predominant northerly direction will deposit in the deepened entrance channel and sand trap area of Plan 14 as desired, and material moving in the southerly direction will deposit in the deepened entrance channel.

e. The -30-ft entrance channel of Plan 15 will result in similar wave conditions for operational and extreme waves as the -40-ft channel of Plan 14, which would be acceptable with regard to entrance conditions and would have no negative impact on the breakwaters and spit area.

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Table 1
Wave Heights for Existing Conditions for Monochromatic Test Waves from 275 Degrees, swl = 0.0 ft

		Test Wave									
Period (sec)		12	15	15	15	17	17	17	20	20	20
Height (ft)		8	8	12	16	8	12	16	8	12	16
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.1	0.3	0.4	0.5	0.7	0.8	0.7	0.3	0.5	0.5
	2	0.8	0.7	0.8	0.8	0.9	1.1	0.8	0.5	0.5	0.5
	3	0.9	0.7	0.7	0.8	1.1	1.2	1.0	0.7	1.0	0.8
	4	1.0	0.9	1.3	1.3	0.9	1.4	1.3	0.9	1.2	1.1
	5	1.6	1.7	2.3	2.0	1.4	2.3	2.4	1.3	1.9	1.6
	6	2.8	2.6	3.9	3.9	2.9	4.5	4.3	2.0	2.6	2.3
	7	9.1	9.5	14.1	10.6	7.5	11.8	10.2	8.2	11.5	10.3
	8	14.5	12.2	9.0	8.9	12.8	12.8	10.2	9.0	7.2	7.8
	9	10.4	12.4	18.2	15.5	8.6	14.5	20.7	12.8	16.2	10.8
	10	7.9	8.7	13.7	19.1	7.5	11.8	17.5	11.2	15.2	21.0
	11	9.5	9.7	16.0	19.9	8.5	12.2	14.8	13.5	19.0	18.3
	12	9.5	9.9	14.1	11.9	8.3	13.1	20.2	11.8	14.4	11.9
	13	10.8	9.5	14.9	11.9	9.3	16.4	20.6	14.5	13.7	12.7
	14	12.0	11.7	15.4	12.3	10.8	18.5	13.0	14.2	15.3	12.2
	15	8.0	14.2	13.2	10.7	12.1	8.9	8.2	14.4	15.5	11.9
	16	8.7	7.7	6.1	7.3	7.3	6.6	7.7	10.1	8.7	7.9
	17	13.1	11.7	14.3	14.1	10.8	15.9	12.4	9.2	11.3	11.8
	18	3.2	4.6	3.9	4.8	4.0	4.7	3.7	3.9	3.8	4.4
	19	3.5	6.1	8.3	6.9	3.3	5.6	5.7	5.1	6.3	6.4
	20	3.4	3.6	4.3	4.7	4.4	3.9	3.3	4.8	4.1	3.7
	21	1.7	1.5	2.1	2.4	1.9	1.8	1.8	1.6	2.4	1.8
	22	1.6	2.3	2.2	2.7	2.5	2.2	2.3	2.1	2.1	2.9
	23	1.5	1.8	1.6	2.0	2.5	2.2	2.1	1.9	1.8	2.1
	24	2.0	1.4	1.8	2.7	2.0	2.1	1.9	2.1	1.8	2.1

Table 2
Wave Heights for Existing Conditions for Monochromatic Test Waves from 275 Degrees, swl = +2.9 ft (ebb flow)

		Test Wave									
Period (sec)		12	15	15	15	17	17	17	20	20	20
Height (ft)		8	8	12	16	8	12	16	8	12	16
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.2	0.4	0.5	0.8	0.5	0.8	0.7	0.5	0.6	0.8
	2	0.8	0.8	0.9	1.1	1.1	1.8	1.1	0.8	1.0	1.3
	3	0.7	0.7	1.1	1.4	1.4	2.3	1.3	1.3	1.8	1.7
	4	0.5	1.2	1.6	1.5	1.2	2.2	1.5	0.9	1.8	2.1
	5	1.6	2.0	2.7	2.8	2.0	2.1	2.5	1.2	2.2	2.5
	6	2.7	3.5	4.3	5.0	2.7	3.5	4.2	2.5	2.6	3.2
	7	6.8	9.8	11.9	10.8	6.4	10.7	13.4	9.2	13.3	11.8
	8	14.0	12.2	9.5	9.2	12.8	14.4	13.1	12.4	8.6	9.0
	9	8.1	10.6	18.3	16.4	7.8	11.1	15.5	11.1	15.5	13.6
	10	9.5	8.8	15.2	19.9	10.1	14.6	18.1	10.0	16.0	24.0
	11	8.9	6.9	12.3	15.9	9.1	13.3	17.1	11.8	19.0	22.0
	12	10.9	8.9	14.2	17.1	10.0	13.6	19.1	10.9	18.9	15.7
	13	10.2	8.9	15.2	14.8	10.5	16.0	22.8	12.2	17.2	15.0
	14	10.0	9.8	16.7	12.4	12.2	18.0	17.0	13.9	19.4	17.0
	15	10.9	11.1	15.5	14.0	14.4	12.8	9.6	15.3	18.9	17.0
	16	9.2	11.8	9.0	7.9	10.3	8.5	8.0	14.3	11.3	9.8
	17	10.6	11.8	16.6	13.9	11.0	17.5	14.5	8.2	13.4	12.9
	18	4.7	6.6	5.2	5.1	6.8	5.1	5.0	8.1	5.9	6.3
	19	3.6	4.2	5.7	5.3	3.8	7.7	8.3	4.5	5.0	7.4
	20	4.7	4.1	6.6	7.2	5.5	6.6	6.0	8.8	6.7	6.9
	21	1.3	1.4	2.7	2.0	1.7	3.1	4.0	2.0	3.0	3.3
	22	3.9	5.2	2.9	4.7	6.1	4.7	3.8	5.7	3.8	5.7
	23	3.6	2.4	2.4	3.6	3.6	3.4	2.7	3.0	3.3	3.6
	24	3.9	2.6	2.9	3.2	3.4	2.9	3.3	2.5	2.3	2.5

Table 3
Wave Heights for Existing Conditions for Monochromatic Test Waves from 275 Degrees, swl = +7.0 ft

		Test Wave						
Period (sec)		15	15	15	17	17	17	20
Height (ft)		21	26	30	21	26	30	21
	Gage	Wave Height, ft, at Indicated Gage Location						
	1	1.1	1.8	1.3	1.0	1.2	1.3	1.1
	2	1.6	2.3	1.6	1.3	1.6	1.6	1.6
	3	2.2	4.0	2.4	1.8	2.0	2.2	2.1
	4	2.7	3.6	2.8	2.8	3.0	2.9	2.3
	5	3.1	6.4	6.0	3.1	3.3	3.5	3.9
	6	6.1	8.1	5.3	5.3	5.5	5.8	5.5
	7	13.4	10.4	10.0	17.6	13.9	15.3	15.[illegible]
	8	13.8	13.0	15.2	15.7	18.6	17.0	10.6
	9	17.3	18.4	16.0	21.7	22.5	21.1	15.8
	10	23.6	28.5	30.4	19.4	29.2	32.9	25.4
	11	22.5	27.7	28.6	21.0	29.8	28.3	19.5
	12	22.7	21.4	20.7	24.5	23.0	20.0	17.0
	13	20.1	20.7	20.0	24.2	17.5	17.7	15.7
	14	18.2	18.0	16.2	17.1	14.1	15.2	16.2
	15	15.1	14.0	13.3	12.1	11.6	13.2	11.2
	16	11.3	11.8	12.5	11.6	11.6	12.3	15.1
	17	16.2	16.2	17.5	18.8	22.3	22.6	16.5
	18	7.9	7.4	7.5	8.1	6.9	7.5	10.1
	19	6.4	4.8	7.1	12.0	9.8	11.4	13.6
	20	10.5	8.3	7.6	11.3	10.1	11.1	9.3
	21	3.8	7.7	7.0	7.5	9.5	7.8	4.5
	22	8.8	9.3	9.7	8.1	8.9	9.5	8.0
	23	6.7	5.8	5.9	6.8	6.4	7.2	6.6
	24	5.5	6.7	5.5	6.0	5.8	5.6	7.7

Table 4
Wave Heights for Existing Conditions for Spectral Test Waves from 275 Degrees

		Test Wave									
		swl = 0.0 ft				swl = +2.9 ft				swl = +7.0 ft	
Period (sec)		12	15	17	20	12	15	17	20	15	17
Height (ft)		8	12	16	8	8	12	16	8	21	21
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.3	0.6	0.7	0.3	0.4	0.6	0.7	0.3	1.1	1.1
	2	0.5	0.8	0.8	0.6	0.6	0.9	1.1	0.6	1.6	1.5
	3	0.4	0.7	0.8	0.5	0.6	1.1	1.3	0.8	1.9	1.9
	4	0.5	1.1	1.2	0.8	0.7	1.1	1.5	0.9	2.4	2.3
	5	0.9	1.6	1.9	1.3	1.3	2.0	2.5	1.7	3.5	3.5
	6	1.9	3.2	3.6	2.4	2.2	3.6	4.2	2.8	6.2	5.8
	7	6.7	10.4	11.4	8.2	6.3	10.7	12.3	7.7	14.2	15.1
	8	10.7	11.5	11.8	10.1	11.5	13.8	14.0	11.1	16.1	16.7
	9	7.3	12.8	14.5	9.8	7.1	13.0	15.4	9.5	18.9	18.8
	10	8.2	12.8	15.2	9.2	8.3	12.8	15.5	8.7	20.0	19.5
	11	8.4	13.0	15.2	10.2	8.6	13.0	16.6	10.0	19.2	20.1
	12	8.5	12.6	14.9	10.1	8.6	13.2	16.2	9.4	18.3	19.4
	13	8.4	12.2	14.9	10.3	8.4	12.4	15.5	9.6	18.9	19.7
	14	9.0	12.5	13.6	11.1	9.0	12.9	14.7	10.1	18.0	18.5
	15	7.9	10.6	10.1	9.9	8.7	11.4	12.5	10.4	14.5	15.0
	16	7.6	8.6	9.2	8.8	8.2	9.6	9.9	11.5	12.2	12.9
	17	9.5	12.1	12.7	10.1	9.7	13.0	14.8	10.3	16.1	16.8
	18	3.9	4.3	4.5	4.5	4.7	5.9	6.1	5.5	7.8	7.8
	19	3.1	6.2	6.6	4.9	2.8	5.8	6.7	4.3	8.3	8.6
	20	2.9	4.1	4.2	3.9	2.6	5.7	6.1	4.7	8.3	8.7
	21	1.0	2.2	2.3	1.4	0.8	2.1	2.9	1.5	4.2	4.6
	22	2.5	2.6	2.8	2.7	3.0	5.1	5.0	4.7	7.2	7.7
	23	2.0	2.3	2.6	2.5	3.0	3.6	4.2	3.4	6.0	6.5
	24	2.3	2.7	2.8	2.6	3.2	3.9	3.6	3.9	6.4	6.6

Table 5
Wave Heights for Plan 1 for Monochromatic Test Waves from 275 Degrees, swl = 0.0 ft

		Test Wave									
Period (sec)		12	15	15	15	17	17	17	20	20	20
Height (ft)		8	8	12	16	8	12	16	8	12	16
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.3	0.6	0.6	0.7	0.4	0.5	0.5	0.6	0.6	0.6
	2	0.6	0.6	1.2	1.3	0.3	0.4	0.7	0.5	0.6	0.8
	3	0.5	0.5	1.3	1.4	0.4	0.6	0.8	0.7	1.1	1.1
	4	0.9	1.3	1.6	1.8	0.7	0.8	1.0	1.1	1.3	1.3
	5	1.6	2.1	3.0	4.0	1.1	1.9	3.1	1.9	2.6	2.6
	6	2.7	2.4	4.9	7.1	1.8	3.1	4.4	2.8	4.3	4.3
	7	7.5	6.9	8.3	11.2	6.7	9.5	14.9	7.4	9.5	10.1
	8	14.9	12.4	8.4	8.1	11.9	12.2	10.6	9.6	7.8	8.2
	9	8.3	8.9	15.3	20.5	7.9	11.3	20.4	8.1	13.3	12.6
	10	6.8	8.7	13.4	18.5	6.2	9.7	13.9	8.0	12.5	16.3
	11	8.3	7.9	11.7	16.9	7.4	11.0	14.1	9.8	13.9	17.4
	12	8.2	9.0	12.5	16.8	7.5	11.2	16.6	7.7	11.9	16.3
	13	7.8	6.9	10.6	14.6	7.4	10.3	18.7	7.8	12.3	15.0
	14	7.2	7.0	10.9	15.2	6.8	10.2	15.7	7.3	11.9	12.4
	15	5.7	8.2	12.5	17.1	8.7	12.3	17.5	6.8	12.3	16.4
	16	6.1	6.0	6.8	9.3	7.4	6.6	8.4	5.3	11.9	11.2
	17	7.1	7.4	12.3	17.2	6.7	11.6	19.5	5.3	7.8	12.4
	18	3.8	3.9	3.9	4.6	3.3	3.8	4.4	3.8	4.6	4.8
	19	4.4	5.0	7.1	9.6	4.1	7.7	9.4	4.3	6.3	6.4
	20	3.8	3.3	3.7	3.6	4.2	3.5	3.7	5.4	4.4	4.8
	21	1.6	1.5	2.3	2.3	1.1	1.7	2.3	1.6	3.3	3.1
	22	2.1	2.3	2.3	2.3	2.3	1.9	2.2	2.4	2.4	2.5
	23	1.5	1.9	2.5	2.3	1.9	1.9	2.5	2.2	2.2	2.3
	24	1.8	2.6	2.3	2.2	2.6	2.4	1.8	2.3	2.4	2.4

Table 6
Wave Heights for Plan 1 for Monochromatic Test Waves from 275 Degrees, swl = +2.9 ft (ebb flow)

		Test Wave									
Period (sec)		12	15	15	15	17	17	17	20	20	20
Height (ft)		8	8	12	16	8	12	16	8	12	16
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.3	0.3	0.6	0.6	0.3	0.5	0.6	0.6	0.5	0.6
	2	1.4	0.8	1.2	1.3	0.8	1.1	1.2	0.9	0.8	0.9
	3	1.6	1.0	1.4	1.6	1.4	1.7	1.8	1.6	1.6	1.6
	4	1.6	1.5	1.9	1.8	1.0	1.8	2.3	1.9	2.5	2.3
	5	2.0	2.1	3.7	4.0	2.0	2.6	4.0	3.4	4.5	4.0
	6	3.0	3.2	4.9	6.3	1.8	2.7	4.4	4.1	4.5	4.9
	7	7.0	6.8	8.8	10.5	5.8	8.6	12.3	8.1	9.6	12.0
	8	15.3	13.7	9.4	9.2	13.1	14.6	14.5	11.7	10.0	8.9
	9	7.2	9.2	15.1	21.7	8.6	11.6	16.6	9.6	14.2	15.2
	10	8.7	10.5	16.5	21.1	9.2	12.7	16.5	8.8	14.9	21.3
	11	8.6	6.5	10.6	15.0	8.3	11.8	14.3	9.2	14.9	19.0
	12	9.1	8.2	12.5	16.3	8.5	11.1	15.5	7.9	13.1	17.3
	13	7.8	7.2	11.7	16.1	8.6	12.0	15.1	9.3	13.3	16.5
	14	6.9	6.5	10.8	14.6	7.6	10.4	15.1	7.0	11.4	12.7
	15	6.1	7.6	12.4	16.3	9.2	12.0	16.4	7.7	12.3	16.2
	16	9.4	10.9	7.6	8.6	9.3	9.6	11.3	7.2	11.4	13.4
	17	5.8	8.1	12.7	16.1	6.6	9.3	15.9	4.5	7.3	12.3
	18	6.9	5.6	5.4	6.1	6.3	5.2	5.3	8.2	6.6	6.5
	19	5.1	4.5	6.5	7.9	3.5	5.5	8.6	5.2	6.2	6.7
	20	3.6	3.5	5.1	4.7	3.4	5.0	4.7	5.7	5.7	5.3
	21	1.3	1.0	2.6	3.2	1.3	3.1	4.2	2.0	4.2	3.9
	22	4.1	4.5	3.0	3.6	3.1	2.9	2.7	3.9	3.3	3.5
	23	3.3	2.6	3.4	3.2	2.3	2.4	2.5	2.7	2.9	3.5
	24	3.7	3.8	3.5	3.7	3.5	3.7	2.9	4.2	3.0	3.2

Table 7
Wave Heights for Plan 1 for Monochromatic Test Waves from 275 Degrees, swl = +7.0 ft

	Test Wave						
Period (sec)	15	15	15	17	17	17	20
Height (ft)	21	26	30	21	26	30	21
Gage	Wave Height, ft, at Indicated Gage Location						
1	1.7	1.5	1.2	1.4	1.3	1.4	1.7
2	2.2	2.3	2.0	1.4	1.6	1.7	2.2
3	2.6	2.8	2.6	1.9	1.8	2.3	2.1
4	4.1	4.0	3.3	2.3	2.3	3.2	3.6
5	6.8	5.9	5.6	5.8	5.4	6.9	6.8
6	8.3	6.9	6.1	7.4	8.1	8.2	7.0
7	14.8	11.1	12.4	16.1	22.2	22.9	13.1
8	13.9	12.9	16.2	16.4	20.4	18.6	10.4
9	27.3	24.0	20.1	17.8	22.3	22.5	16.5
10	22.4	26.1	25.7	19.1	24.3	33.1	23.9
11	22.5	25.6	25.1	19.9	29.4	30.9	18.9
12	22.7	25.2	26.6	19.5	24.3	26.9	19.3
13	22.7	23.8	23.3	17.9	25.8	25.4	18.3
14	21.3	22.0	20.6	17.5	22.6	21.8	13.4
15	21.9	22.9	21.7	19.7	24.2	24.4	16.9
16	13.1	13.6	13.7	15.2	14.0	14.1	17.3
17	21.8	27.0	24.5	18.7	28.2	22.2	18.1
18	8.2	8.4	9.5	8.9	8.8	9.1	9.2
19	8.5	7.0	7.3	12.1	12.9	13.6	8.7
20	6.3	7.0	8.4	8.6	8.7	8.8	9.3
21	6.3	4.4	5.2	5.9	7.9	8.8	3.8
22	5.6	6.2	5.8	5.1	5.8	5.5	8.0
23	5.0	5.2	6.6	4.9	5.1	5.6	7.4
24	4.1	4.5	5.1	4.1	4.7	4.8	6.2

Table 8
Wave Heights for Plan 1 for Spectral Test Waves from 275 Degrees

		Test Wave									
		swl = 0.0 ft				swl = +2.9 ft				swl = +7.0 ft	
Period (sec)		12	15	17	20	12	15	17	20	15	17
Height (ft)		8	12	16	8	8	12	16	8	21	21
	Gage	Wave Height, ft, at Indicated Gage Location									
	1	0.4	0.7	0.8	0.5	0.3	0.7	0.8	0.4	1.5	1.6
	2	0.5	1.0	1.0	0.6	0.7	1.2	1.4	0.8	2.1	2.0
	3	0.5	1.0	1.2	0.8	0.9	1.3	1.6	1.0	2.6	2.4
	4	0.8	1.3	1.4	1.0	1.0	1.6	2.1	1.2	3.1	3.2
	5	1.4	2.5	2.9	1.9	1.5	2.4	3.9	2.1	5.7	5.6
	6	2.2	3.8	4.2	2.8	2.5	3.6	4.6	2.7	6.4	6.8
	7	5.7	8.8	11.1	6.0	5.6	8.1	11.3	5.6	14.3	15.1
	8	10.2	11.5	11.9	10.1	10.5	12.6	13.7	10.4	16.8	17.3
	9	6.5	12.3	15.0	8.4	6.6	11.3	15.7	7.9	19.9	19.3
	10	7.1	11.6	13.5	7.9	7.8	11.7	15.5	8.0	20.8	18.7
	11	7.7	11.1	14.3	8.5	7.8	10.8	14.9	8.1	19.2	19.5
	12	7.9	11.5	14.0	7.8	8.3	10.8	14.1	7.4	19.5	19.1
	13	7.8	10.4	13.8	7.9	7.8	9.8	14.4	7.5	19.2	19.3
	14	7.1	9.7	12.9	7.1	6.8	9.1	13.0	6.4	17.4	17.2
	15	7.0	11.4	14.7	8.4	6.7	10.4	14.3	8.0	17.9	18.1
	16	7.5	8.5	9.6	7.7	8.8	9.5	10.7	8.6	12.8	13.5
	17	5.9	9.5	12.3	6.2	5.9	9.2	12.7	5.8	17.8	16.8
	18	3.9	4.1	4.5	4.3	4.5	5.5	6.1	5.3	8.7	8.5
	19	3.3	6.0	7.0	4.2	3.5	5.3	6.9	3.5	8.6	9.1
	20	3.0	3.8	3.9	3.6	2.4	4.4	4.8	3.4	8.2	8.3
	21	0.8	1.9	2.4	1.0	0.8	1.9	2.8	1.3	4.4	4.3
	22	2.7	2.7	2.7	2.8	2.2	3.5	3.9	3.3	7.0	7.2
	23	1.9	2.2	2.4	2.1	2.7	3.1	3.4	3.0	5.9	6.1
	24	2.1	2.4	2.7	2.4	3.2	3.8	4.0	3.3	6.9	6.6

Table 9
Comparison of Wave Heights for Plans 2-13 for Monochromatic Test Waves from 275 Degrees, swl = +7.0 ft

	Wave Height, ft, at Indicated Gage Location Per Plan and Incident Wave Condition											
Gage	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan 9	Plan 10	Plan 11	Plan 12	Plan 13
15-sec, 21-ft Incident Wave												
1	1.2	1.3	1.5	1.3	1.5	1.6	1.4	1.4	1.5	1.7	1.6	1.5
2	2.1	2.2	2.5	2.3	2.2	2.2	1.8	2.1	2.0	2.7	2.1	1.9
3	3.0	3.2	3.0	2.7	2.8	3.0	2.6	2.7	2.8	3.4	3.1	2.5
4	4.1	4.6	5.3	4.7	4.6	4.7	4.6	4.9	4.7	5.5	5.1	4.7
5	6.2	6.6	7.1	6.5	6.1	6.1	5.7	5.8	5.2	5.9	5.3	5.2
6	8.0	7.8	7.4	7.1	7.2	6.9	6.7	6.7	7.7	7.7	7.6	6.1
7	13.0	12.6	14.9	15.9	17.3	17.0	14.9	14.2	14.9	14.5	13.9	15.1
8	11.2	13.5	14.3	14.9	13.5	14.5	13.7	14.8	14.5	14.4	14.1	15.5
9	26.5	28.1	24.9	25.0	25.6	24.1	20.0	20.7	19.7	21.1	20.8	24.0
10	20.7	20.2	22.0	20.5	21.1	21.1	21.3	21.0	21.3	21.4	21.7	22.1
11	19.4	17.6	19.1	21.5	19.5	19.7	19.5	19.2	19.4	19.7	19.5	19.0
12	19.8	19.2	17.9	20.9	19.6	21.2	20.5	20.9	20.7	19.8	20.0	19.2
13	21.5	21.7	17.2	20.0	20.1	21.2	22.2	21.4	14.0	16.9	14.4	20.2
14	22.6	21.2	18.9	20.7	19.2	18.5	18.8	19.4	16.5	17.1	16.9	19.3
15	20.0	18.6	18.2	18.1	15.8	17.2	18.2	18.4	15.9	16.9	17.7	19.7
16	11.4	12.2	11.6	12.1	10.1	10.4	11.6	9.3	9.0	10.5	9.9	11.3
17	23.5	18.0	19.5	20.6	24.5	24.8	23.8	23.8	24.0	24.4	23.6	22.3
18	7.6	7.1	7.2	7.5	6.7	7.7	9.4	8.9	8.3	7.7	8.9	8.4
19	8.1	7.2	7.4	7.1	7.0	7.3	7.2	7.9	8.4	9.5	9.3	8.5
20	5.4	5.3	5.4	5.3	5.5	5.8	6.2	7.3	8.9	8.8	9.0	6.4
21	7.5	7.5	7.4	7.6	4.6	3.7	3.5	2.9	3.2	4.0	3.4	3.5
22	5.8	5.3	5.3	5.7	6.0	6.0	7.3	7.5	6.5	6.8	7.5	8.0
23	5.3	4.8	4.9	4.8	4.3	4.5	5.7	5.7	6.8	6.3	6.6	7.0
24	4.2	4.4	4.1	3.6	4.3	3.7	4.2	3.7	5.1	5.4	5.6	4.3

(Continued)

Table 9 (Concluded)

	Wave Height, ft, at Indicated Gage Location Per Plan and Incident Wave Condition											
Gage	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan 9	Plan 10	Plan 11	Plan 12	Plan 13
	17-sec, 26-ft Incident Wave											
1	1.2	1.2	1.1	1.3	1.2	1.2	1.2	1.2	1.3	1.4	1.4	1.2
2	1.5	1.6	1.5	1.7	1.5	1.6	1.6	1.5	1.7	1.8	1.9	1.6
3	1.9	2.0	1.9	2.0	1.9	1.9	2.2	1.9	1.9	2.3	2.3	2.4
4	2.8	2.9	2.7	2.8	2.6	2.9	2.5	2.8	2.4	2.8	2.8	2.6
5	5.0	6.2	5.7	5.7	5.7	5.6	6.0	5.5	5.3	6.0	5.1	4.2
6	7.0	8.2	8.4	8.2	8.4	7.6	8.8	7.8	8.3	8.9	8.5	5.8
7	22.8	22.8	23.0	19.9	20.8	20.6	21.3	21.6	20.6	18.1	18.9	17.6
8	17.3	16.7	18.6	20.3	19.2	18.2	16.9	19.4	18.6	19.7	19.7	21.5
9	25.6	24.9	26.9	24.8	27.2	27.2	28.3	27.2	27.9	27.5	27.7	22.6
10	25.5	29.8	27.2	25.3	24.9	24.9	26.3	29.5	28.7	27.5	28.5	24.7
11	34.0	35.4	34.0	30.5	33.7	31.5	32.9	35.0	32.5	30.9	32.4	26.4
12	26.5	27.9	27.3	23.7	23.1	22.7	26.8	28.3	26.1	24.8	27.2	23.5
13	28.2	27.5	29.2	27.5	27.9	26.6	30.4	30.4	28.3	26.4	28.8	24.8
14	26.4	25.5	24.4	24.8	24.4	24.2	23.8	24.8	23.7	23.8	23.7	23.0
15	26.0	22.8	22.3	21.2	18.8	18.8	18.8	22.1	20.1	21.4	18.4	16.9
16	15.3	13.8	13.9	12.7	11.9	13.3	12.4	11.5	10.6	10.4	10.4	12.2
17	26.8	23.0	26.3	27.0	24.7	24.5	24.7	25.2	23.3	21.8	22.9	23.5
18	9.4	8.7	8.0	8.1	9.0	8.9	9.7	8.9	9.0	8.7	8.6	9.0
19	14.0	12.3	10.6	9.3	9.3	9.5	9.7	11.3	9.3	8.3	8.9	8.5
20	7.7	7.7	8.1	8.8	9.2	10.2	8.5	9.8	9.3	8.8	8.9	9.3
21	7.2	6.6	8.0	5.3	5.5	5.9	5.6	7.8	5.5	5.4	5.8	3.2
22	5.8	5.4	5.6	5.9	5.8	5.7	5.9	6.0	6.4	6.8	6.5	8.0
23	5.8	5.1	4.5	4.3	4.3	3.7	5.9	5.1	5.2	5.4	5.1	5.7
24	4.5	4.5	4.5	4.4	3.9	3.6	4.9	3.7	3.8	4.4	4.2	5.3

Table 10
Wave Heights for Plan 14 for Monochromatic Test Waves from 275 Degrees, swl = 0.0 ft

		Test Wave												
Period (sec)		12	15	15	15	15	17	17	17	17	20	20	20	20
Height (ft)		8	8	12	14	16	8	12	14	16	8	12	14	16
	Gage	Wave Height, ft, at Indicated Gage Location												
	2	1.3	1.4	1.5	1.5	1.5	1.3	1.9	2.1	2.0	1.0	1.2	1.2	1.4
	3	1.1	1.4	1.7	1.7	1.6	1.2	2.3	2.5	2.3	1.4	1.8	1.7	1.7
	4	1.9	2.0	2.5	2.5	2.8	1.5	2.5	2.6	2.9	1.7	2.6	2.7	3.0
	5	2.2	2.5	3.0	2.8	2.9	1.4	3.5	3.7	4.6	2.5	3.7	3.6	3.2
	6	3.0	2.8	3.6	3.5	4.0	2.9	4.8	5.5	5.4	3.0	3.4	3.6	3.7
	7	7.0	8.3	11.2	11.4	15.2	6.9	9.4	11.8	14.7	7.2	10.3	10.1	10.4
	7A	6.7	6.4	8.3	9.4	13.1	6.1	8.9	8.7	12.8	6.1	8.5	9.0	9.8
	8	14.1	10.8	8.1	8.3	7.4	10.5	11.5	12.5	10.5	8.4	7.8	8.2	8.0
	9A	8.4	11.7	14.8	13.6	10.6	11.2	14.2	17.8	21.9	12.7	13.1	12.1	12.3
	10	7.9	9.2	13.6	16.5	18.7	8.0	11.9	13.3	14.7	9.7	14.4	16.2	19.1
	11	7.6	8.4	11.7	13.0	14.7	8.5	11.7	13.2	14.7	10.7	16.1	17.0	17.9
	12	7.7	9.4	12.2	12.8	13.7	8.3	11.9	13.8	16.1	8.6	13.5	16.0	17.3
	13	7.2	8.4	11.4	13.3	15.6	7.4	10.1	12.8	18.9	7.9	11.6	13.8	14.4
	14	10.7	9.3	12.4	13.2	13.1	10.2	14.2	14.5	18.1	11.2	14.6	14.9	16.7
	15	7.5	9.4	9.3	9.9	10.9	12.3	8.9	9.7	12.3	12.1	14.9	14.9	16.6
	16	7.2	7.1	6.2	6.9	6.7	6.5	5.9	6.8	6.3	11.4	8.3	9.5	8.7
	17	8.9	9.1	15.0	17.9	18.8	8.4	13.6	15.9	16.5	7.2	14.0	14.9	16.5
	18	4.8	4.5	5.7	6.0	6.4	3.9	5.1	5.5	6.2	3.8	5.9	5.9	5.5
	19	3.3	3.9	5.5	5.8	6.6	3.7	4.7	5.8	5.3	2.3	3.5	3.3	3.7
	20	3.4	3.3	4.1	4.0	4.2	2.8	3.5	4.0	4.1	3.4	3.7	3.6	3.8
	21	2.9	2.5	2.8	3.1	2.8	3.0	2.8	3.1	2.9	2.6	3.1	3.0	2.7
	22	2.4	2.5	2.6	2.8	2.8	2.4	2.9	3.2	3.2	2.3	3.2	3.7	3.3
	23	1.9	2.4	2.6	2.5	2.5	2.4	2.8	3.2	3.0	2.7	2.8	2.8	2.8
	24	2.1	2.4	2.7	2.3	2.2	2.7	2.4	2.5	2.6	2.8	2.9	2.7	3.0

Table 11
Wave Heights for Plan 14 for Monochromatic Test Waves from 275 Degrees, swl = +2.9 ft (ebb flow)

		Test Wave												
Period (sec)		12	15	15	15	15	17	17	17	17	20	20	20	20
Height (ft)		8	8	12	14	16	8	12	14	16	8	12	14	16
	Gage	Wave Height, ft, at Indicated Gage Location												
	2	1.6	1.6	2.2	2.5	2.8	1.3	1.8	2.3	2.0	1.5	2.0	1.5	1.6
	3	1.6	1.8	2.3	2.1	2.5	1.7	2.8	2.8	3.3	2.0	2.5	2.0	1.8
	4	1.9	3.0	3.9	4.1	4.8	2.2	3.6	3.2	4.3	3.5	4.5	3.3	3.5
	5	2.2	2.3	3.2	3.4	4.0	2.5	3.8	4.2	5.1	4.1	4.7	4.6	4.9
	6	2.7	3.4	4.7	5.0	5.7	2.7	3.8	4.4	5.2	3.9	4.2	4.3	4.1
	7	5.4	7.2	9.1	11.3	13.3	5.9	8.7	10.9	12.0	7.7	10.0	9.8	10.2
	7A	5.6	5.2	7.6	9.3	11.0	5.8	7.9	9.9	11.3	7.1	9.7	9.5	10.0
	8	13.5	13.1	10.4	8.8	9.2	11.9	12.8	12.6	13.7	11.9	10.3	9.0	8.6
	9A	8.0	10.5	15.4	17.3	17.7	6.9	9.4	13.3	12.5	12.7	17.6	14.1	12.8
	10	9.1	9.7	15.8	18.0	21.0	9.1	13.0	11.7	16.3	8.7	14.6	18.0	21.5
	11	8.4	7.0	11.2	12.3	14.2	8.4	11.9	13.5	15.5	10.3	15.2	17.9	18.2
	12	9.4	7.6	12.2	12.9	16.3	8.9	12.1	11.9	15.0	8.3	14.2	17.7	18.6
	13	8.0	7.4	11.5	12.5	15.0	9.7	12.4	12.8	15.6	7.9	11.1	13.8	15.9
	14	8.9	7.2	11.9	13.3	15.1	9.2	12.8	13.8	18.5	9.7	13.8	19.7	21.3
	15	11.0	10.3	12.6	11.6	13.6	13.1	12.6	11.3	11.7	14.3	19.0	19.5	19.2
	16	14.6	9.7	7.2	7.1	7.7	8.1	6.9	6.4	7.1	8.6	13.0	10.1	12.0
	17	9.0	9.3	13.7	17.2	17.0	8.2	13.9	16.4	19.7	4.8	13.0	15.2	15.7
	18	5.5	4.3	5.6	5.4	6.1	3.5	5.0	4.9	5.8	4.8	6.1	7.6	7.8
	19	2.7	3.5	5.7	6.7	6.6	2.7	4.1	4.9	4.5	3.3	3.6	3.2	3.7
	20	2.8	2.2	4.2	4.1	4.7	2.0	2.5	2.9	4.2	3.2	3.4	3.1	3.2
	21	2.3	2.6	4.4	3.9	5.3	2.5	4.5	3.3	5.1	4.2	4.3	4.2	4.0
	22	2.7	1.6	3.0	3.1	3.6	1.4	2.7	3.0	4.6	2.2	4.0	4.3	4.4
	23	2.7	3.7	3.7	3.2	4.1	2.1	3.8	3.9	4.7	2.7	5.0	4.4	4.6
	24	2.8	4.5	4.4	3.7	4.4	5.0	3.9	3.3	5.2	5.1	4.5	5.2	4.5

Table 12
Wave Heights for Plan 14 for Monochromatic Test Waves from 275 Degrees, swl = +7.0 ft

		Test Wave						
Period (sec)		15	15	15	17	17	17	20
Height (ft)		21	26	30	21	26	30	21
	Gage	Wave Height, ft, at Indicated Gage Location						
	2	2.8	2.9	2.7	1.9	1.9	2.7	2.5
	3	4.0	3.4	3.6	2.2	2.1	2.8	2.8
	4	6.3	6.5	5.4	3.4	2.9	4.8	4.9
	5	4.9	5.1	5.1	5.5	5.7	6.0	5.7
	6	6.6	6.2	5.4	6.0	7.0	7.2	5.6
	7	17.5	14.4	12.0	13.8	19.6	22.7	13.8
	7A	15.7	15.8	14.2	12.6	16.0	15.1	14.0
	8	11.4	12.7	13.3	14.3	18.8	19.8	10.1
	9A	24.0	20.4	18.6	17.0	21.6	22.0	16.8
	10	21.9	26.0	27.3	16.7	22.3	31.7	24.8
	11	20.3	24.1	24.7	16.7	27.7	31.9	17.9
	12	22.1	23.3	24.9	14.0	21.3	25.3	18.0
	13	20.8	23.1	24.2	17.5	25.5	24.7	17.4
	14	20.6	22.5	22.1	19.0	22.4	21.5	16.5
	15	17.4	19.5	19.4	13.7	17.4	18.0	19.5
	16	8.7	10.0	9.8	8.2	9.7	10.1	15.1
	17	22.2	22.0	21.9	20.7	25.1	23.9	20.9
	18	7.8	7.8	6.9	7.0	7.8	10.6	8.6
	19	7.7	8.0	7.3	6.2	8.2	8.1	6.7
	20	5.2	5.7	5.9	6.9	8.0	9.3	6.2
	21	6.2	6.7	6.6	5.3	6.0	5.8	6.0
	22	4.7	4.3	4.1	6.5	6.0	6.2	4.9
	23	5.3	4.6	5.2	5.8	6.5	6.7	6.4
	24	6.4	6.7	6.6	4.9	5.2	5.7	5.7

Table 13
Wave Heights for Plan 14 for Spectral Test Waves from 275 Degrees

		Test Wave									
		swl = 0.0 ft				swl = +2.9 ft				swl = +7.0 ft	
Period (sec)		12	15	17	20	12	15	17	20	15	17
Height (ft)		8	12	16	8	8	12	16	8	21	21
	Gage	Wave Height, ft, at Indicated Gage Location									
	2	1.2	1.6	1.8	1.3	1.4	2.0	2.3	1.4	2.5	2.1
	3	1.0	1.6	1.8	1.3	1.1	2.1	2.4	1.5	2.9	2.7
	4	1.5	2.2	2.7	1.8	2.0	3.1	3.9	2.3	4.0	3.8
	5	1.7	2.5	3.0	2.3	1.9	2.9	4.0	2.7	5.2	5.3
	6	2.4	3.7	4.5	3.0	2.4	3.7	4.8	2.8	5.8	6.1
	7	5.7	8.8	11.1	6.3	5.3	8.1	11.5	6.1	14.5	14.7
	7A	5.4	8.3	9.9	5.8	5.2	7.4	10.5	5.4	13.3	13.3
	8	10.2	11.1	11.2	10.3	10.5	13.3	14.2	10.6	15.4	16.3
	9A	9.0	13.0	14.7	10.5	7.7	12.7	15.3	9.4	18.5	18.2
	10	7.9	12.5	14.5	8.9	8.3	11.4	14.8	7.9	19.0	17.7
	11	7.6	10.8	14.2	9.0	7.9	10.5	14.9	8.5	17.6	18.5
	12	7.9	11.1	13.8	7.6	8.6	10.6	13.9	7.3	17.2	17.3
	13	7.6	10.5	13.8	7.9	7.6	10.2	13.7	7.1	17.4	17.9
	14	8.3	10.8	13.3	9.0	7.8	10.9	14.6	7.5	17.6	17.9
	15	6.9	9.4	11.2	9.4	7.9	10.5	13.5	9.1	16.3	15.7
	16	7.3	8.1	8.5	7.8	8.0	9.5	10.5	9.9	11.6	11.3
	17	7.7	12.6	14.2	8.4	7.7	12.4	14.9	7.3	17.8	18.6
	18	3.6	4.9	5.5	3.6	2.9	4.5	5.7	3.2	7.9	7.9
	19	2.6	3.9	4.6	2.8	2.3	3.7	4.7	2.5	6.3	6.1
	20	2.5	3.2	3.7	2.6	1.7	2.7	3.5	1.9	5.3	5.3
	21	1.6	2.6	2.9	2.1	1.2	3.0	3.9	2.5	5.3	5.7
	22	1.9	2.5	2.9	2.1	1.6	2.4	3.6	1.8	4.7	4.7
	23	1.7	2.6	2.8	2.3	1.5	2.9	3.6	2.1	5.0	5.3
	24	1.9	2.7	3.1	2.8	1.8	3.4	4.0	3.0	5.7	5.7

Table 14
Wave Heights for Plan 15 for Monochromatic Test Waves from 275 Degrees, swl = 0.0 ft (ebb flow)

		Test Wave												
Period (sec)		12	15	15	15	15	17	17	17	17	20	20	20	20
Height (ft)		8	8	12	14	16	8	12	14	16	8	12	14	16
	Gage	Wave Height , ft, at Indicated Gage Location												
	2	1.0	1.0	1.1	1.4	1.7	0.7	1.2	1.5	1.3	0.6	1.1	1.1	0.9
	3	0.9	1.2	1.3	1.6	1.6	0.8	1.3	1.7	1.6	1.2	1.6	1.5	1.2
	4	0.9	1.2	2.0	2.3	2.9	0.9	1.7	1.7	2.0	1.1	1.8	2.0	1.8
	5	1.0	1.8	1.7	2.2	2.5	0.7	1.9	2.4	3.4	2.1	2.9	3.2	2.3
	6	2.5	2.1	2.8	3.6	4.3	2.0	3.6	4.2	4.6	2.2	2.6	3.1	2.7
	7	6.8	8.3	12.7	12.8	13.5	5.8	8.7	9.7	12.3	8.2	10.7	11.1	10.7
	7A	6.9	6.8	10.0	12.1	13.2	4.3	7.2	9.2	12.2	6.5	9.1	8.9	8.6
	8	14.6	13.0	8.7	8.8	8.5	12.2	12.6	13.1	11.5	10.2	7.9	8.3	9.0
	9A	8.8	10.6	14.5	13.5	11.4	10.1	14.2	15.3	18.8	14.0	16.1	13.6	12.8
	10	8.3	8.0	12.6	15.2	17.1	7.0	10.6	12.4	15.0	10.0	13.2	15.8	17.9
	11	9.0	8.0	13.2	14.7	17.3	6.8	9.6	11.8	13.0	11.0	15.8	17.4	18.4
	12	8.1	8.5	13.0	15.0	15.5	7.1	10.1	11.6	15.4	9.3	13.9	16.3	17.8
	13	8.7	8.3	14.7	15.4	17.1	7.6	11.1	12.9	17.5	11.2	14.0	14.7	14.8
	14	11.5	11.3	16.5	18.0	17.2	9.9	14.3	16.8	19.6	14.1	16.8	18.6	17.1
	15	8.1	14.6	12.7	14.2	12.0	13.3	10.7	10.3	11.5	16.9	15.6	19.5	14.8
	16	6.9	6.7	7.0	6.5	7.2	6.0	6.5	6.6	6.3	8.3	9.1	9.0	7.5
	17	11.1	11.1	16.2	21.1	18.0	7.1	11.8	14.9	19.0	8.5	14.5	16.4	13.7
	18	4.0	5.2	6.2	6.3	5.8	3.3	4.8	5.7	[illegible]	4.4	6.5	6.9	6.9
	19	2.8	4.1	5.1	5.9	7.1	2.6	3.4	3.9	3.9	2.3	2.9	3.3	5.1
	20	2.4	2.9	3.5	3.9	4.3	1.7	2.9	3.9	4.0	3.1	3.7	3.9	4.5
	21	2.7	2.6	3.2	3.5	3.4	1.7	2.9	3.2	2.9	2.7	3.2	3.2	3.5
	22	2.3	2.2	2.4	2.5	2.8	1.9	2.6	2.7	3.0	2.2	3.1	3.5	3.2
	23	1.9	2.9	2.7	2.8	2.9	2.3	3.2	3.1	3.5	3.5	2.9	2.9	3.1
	24	2.0	2.6	2.4	2.3	2.5	2.5	2.7	3.2	3.2	2.6	3.2	3.4	3.1

Table 15
Wave Heights for Plan 15 for Monochromatic Test Waves from 275 Degrees, swl = +2.9 ft (ebb flow)

		Test Wave									
Period (sec)		12	15	15	15	17	17	17	20	20	20
Height (ft)		8	8	12	16	8	12	16	8	12	16
	Gage	Wave Height, ft, at Indicated Gage Location									
	2	1.3	1.5	1.9	2.2	0.8	1.1	1.4	0.8	1.2	1.1
	3	1.4	1.2	1.7	2.0	1.2	1.7	2.2	1.2	1.6	1.5
	4	2.0	2.7	3.5	3.9	1.5	2.1	2.9	2.1	2.7	2.4
	5	2.3	1.9	2.5	3.2	1.9	2.6	3.8	3.0	3.7	3.4
	6	2.2	2.8	4.1	5.1	2.0	2.5	3.6	2.8	3.5	3.3
	7	5.9	8.1	12.3	14.6	4.9	6.8	9.3	8.0	14.1	12.7
	7A	6.4	6.0	9.6	13.4	4.5	6.2	9.6	6.5	10.4	10.0
	8	14.8	13.9	9.9	8.8	13.3	16.3	14.2	12.0	9.6	8.9
	9A	8.1	9.2	15.1	16.6	8.4	11.4	13.7	13.0	20.2	15.0
	10	9.0	8.7	14.2	19.2	8.3	12.5	14.9	9.0	14.8	19.6
	11	8.6	6.0	10.7	15.1	7.2	11.1	14.3	10.5	17.6	20.6
	12	9.6	8.2	12.5	17.0	7.7	10.4	13.9	9.8	16.5	19.0
	13	8.3	7.8	13.5	20.4	9.2	12.6	16.9	10.7	14.9	17.8
	14	10.0	10.0	14.7	20.1	9.6	12.6	18.3	12.2	16.2	21.9
	15	11.3	11.8	16.4	17.9	12.5	16.9	13.3	13.5	19.7	19.5
	16	11.6	12.4	10.6	9.5	9.4	8.5	8.0	16.4	13.0	11.6
	17	10.5	11.3	17.3	17.5	7.8	12.6	19.3	6.5	12.9	17.9
	18	5.7	4.0	5.9	6.2	3.2	5.0	5.9	5.5	8.4	8.5
	19	2.5	4.2	5.9	6.4	2.3	2.9	2.8	3.2	3.4	3.8
	20	2.2	2.7	4.4	4.3	1.1	2.9	4.9	3.2	3.6	4.2
	21	3.2	3.3	4.2	4.6	2.3	3.2	3.9	4.1	5.1	5.3
	22	2.1	1.9	3.2	3.5	1.4	2.2	3.9	2.9	4.6	4.5
	23	2.2	3.7	4.0	4.9	1.5	3.7	5.1	3.7	5.3	5.9
	24	3.4	4.9	4.5	4.8	5.4	4.7	6.2	5.3	5.0	4.2

Table 16
Wave Heights for Plan 15 for Monochromatic Test Waves from 275 Degrees, swl = +7.0 ft

		Test Wave						
Period (sec)		15	15	15	17	17	17	20
Height (ft)		21	26	30	21	26	30	21
	Gage	Wave Height, ft, at Indicated Gage Location						
	2	2.5	2.9	2.4	1.3	1.7	2.1	1.6
	3	3.8	4.9	3.5	1.8	2.2	2.7	1.9
	4	6.1	8.4	4.6	2.0	3.1	3.8	2.6
	5	5.2	7.4	5.3	3.9	4.4	4.2	4.7
	6	6.8	7.9	6.2	4.8	4.9	6.2	5.2
	7	14.0	11.3	12.2	15.9	22.3	20.1	14.8
	7A	16.0	15.3	13.9	14.2	19.8	18.3	11.5
	8	12.7	13.2	16.3	15.8	19.0	16.8	11.5
	9A	15.5	13.8	12.9	15.9	22.2	20.9	15.9
	10	22.6	26.3	27.4	18.0	22.6	31.3	24.2
	11	21.1	24.5	25.8	17.7	27.2	30.3	18.9
	12	22.5	23.4	20.8	18.4	24.9	22.9	20.0
	13	22.2	22.0	19.2	22.3	26.2	21.3	18.5
	14	21.7	22.5	19.7	22.5	21.7	17.5	20.5
	15	19.6	17.5	16.1	15.9	16.2	17.9	19.7
	16	10.3	10.8	10.6	11.0	10.8	11.2	15.7
	17	26.0	20.4	18.8	24.1	19.3	23.2	18.4
	18	6.9	7.5	6.8	8.8	8.0	9.5	9.6
	19	7.9	7.7	6.7	6.6	9.8	9.3	7.4
	20	5.5	5.1	4.2	7.2	9.1	9.3	6.9
	21	6.4	7.2	5.8	3.5	5.0	5.7	5.5
	22	5.1	5.0	5.9	8.0	8.7	8.7	7.1
	23	5.1	6.2	6.4	7.0	7.1	8.2	8.2
	24	6.7	6.5	7.2	5.8	5.9	6.1	6.0

Table 17
Wave Heights for Plan 15 for Spectral Test Waves from 275 Degrees

		Test Wave									
		swl = 0.0 ft				swl = +2.9 ft				swl = +7.0 ft	
Period (sec)		12	15	17	20	12	15	17	20	15	17
Height (ft)		8	12	16	8	8	12	16	8	21	21
	Gage	Wave Height, ft, at Indicated Gage Location									
	2	0.8	1.6	1.5	0.8	0.9	1.5	1.7	1.1	2.0	1.8
	3	0.8	1.6	1.5	0.9	1.0	1.6	2.0	1.3	2.6	2.3
	4	0.9	2.2	2.2	1.2	1.4	2.3	2.9	1.8	3.4	3.1
	5	1.2	2.5	2.6	1.6	1.5	2.7	3.3	2.3	4.8	4.6
	6	2.1	3.7	3.7	2.5	1.9	3.2	4.2	2.7	6.1	6.1
	7	5.9	8.8	11.7	6.4	5.4	8.7	12.1	6.7	15.2	15.2
	7A	5.6	8.3	11.0	5.9	5.5	8.6	11.5	6.1	14.4	14.6
	8	10.6	11.1	12.2	10.0	11.0	13.1	13.8	10.7	17.1	17.7
	9A	7.9	13.0	13.8	8.9	7.2	12.3	14.7	9.4	17.1	17.9
	10	8.1	12.5	14.7	8.0	8.2	11.5	15.1	8.5	20.0	18.1
	11	7.9	10.8	14.5	8.4	8.0	11.0	15.5	8.8	18.3	19.0
	12	7.9	11.1	14.5	7.7	8.1	11.5	15.0	8.4	19.1	19.3
	13	7.5	10.5	14.6	8.1	7.6	11.0	16.0	8.6	20.2	20.1
	14	9.5	10.8	15.8	9.4	8.7	12.3	16.4	9.5	20.0	20.5
	15	7.4	9.4	11.7	10.4	8.7	12.2	14.5	10.7	17.4	17.3
	16	7.6	8.1	8.5	8.7	8.3	11.0	10.7	10.4	13.4	13.2
	17	9.3	12.6	15.2	8.8	8.9	13.5	16.3	8.5	18.7	20.1
	18	3.4	4.9	5.6	3.7	3.3	5.0	6.4	4.0	8.7	8.9
	19	2.2	3.9	4.6	2.6	2.2	3.7	4.7	2.6	6.9	7.0
	20	2.2	3.2	3.9	2.4	1.7	2.9	4.0	2.2	6.0	6.0
	21	1.2	2.6	3.3	1.8	1.6	3.2	3.9	2.7	5.6	5.8
	22	1.7	2.5	3.1	2.0	1.6	2.7	3.6	2.1	6.2	6.4
	23	1.7	2.6	3.0	2.3	1.5	3.1	4.2	2.6	6.3	6.7
	24	1.9	2.7	3.1	2.8	2.0	3.9	4.4	3.7	6.4	6.4

Table 18
Wave Heights for Existing Conditions for Test Waves from 300 Deg, swl = +7.0 ft

	Test Wave								
Period (sec)	15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)	21	26	30	21	26	30	21	21	21
Gage	Wave Height, ft, at Indicated Gage Location								
2	1.1	1.1	1.1	1.0	1.0	1.1	1.2	1.1	1.1
3	2.2	1.8	1.5	1.6	1.5	1.5	1.2	1.5	1.4
4	2.1	2.3	2.2	1.4	1.6	1.9	1.7	1.8	1.7
5	2.3	2.3	2.5	3.2	2.4	2.8	2.3	2.9	2.5
6	5.5	6.1	5.4	4.9	3.5	5.0	5.3	5.0	4.9
7	9.6	11.2	13.9	12.0	12.7	11.0	8.9	12.0	11.5
7A	11.6	12.4	13.3	12.1	11.6	12.0	10.4	11.8	10.9
8	10.2	11.9	12.1	17.0	16.7	11.7	12.6	15.6	15.5
9A	13.0	13.5	14.4	21.1	19.9	21.6	14.0	15.9	16.7
10	21.2	21.1	19.0	17.4	30.0	31.0	22.9	21.4	21.3
11	23.8	21.7	17.5	19.9	29.7	25.0	21.0	20.0	21.1
12	24.2	15.0	16.5	20.3	24.6	21.4	18.3	18.0	19.1
13	18.1	14.6	16.4	21.7	18.3	20.4	16.2	17.6	17.9
14	17.4	14.6	15.6	16.7	14.7	16.6	16.3	15.6	16.2
15	12.9	13.2	14.7	14.1	11.1	14.8	15.8	13.7	14.1
16	10.3	10.7	10.7	11.0	11.1	12.0	11.1	12.2	12.0
17	23.6	13.5	15.7	24.8	15.2	17.1	24.3	17.9	18.5
18	6.2	6.6	9.0	8.5	7.1	8.9	7.5	7.7	7.9
19	5.1	7.5	8.2	6.9	6.7	5.6	6.8	6.1	5.8
20	5.8	4.4	4.3	3.0	4.1	5.7	4.9	4.4	4.1
21	1.8	2.6	2.8	1.9	3.4	5.3	3.1	2.3	2.1
22	3.6	3.9	3.8	3.9	2.6	4.9	3.7	3.9	3.7
23	6.3	7.2	6.5	7.3	6.7	6.4	7.6	6.8	6.7
24	4 4	6.8	7.5	6.9	6.0	5.5	5.3	6.5	5.9

[1] Spectral wave conditions, others are monochromatic.

Table 19
Wave Heights for Plan 14 for Test Waves from 300 Degrees, swl = +7.0 ft

		Test Wave								
Period (sec)		15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)		21	26	30	21	26	30	21	21	21
	Gage	Wave Height, ft, at Indicated Gage Location								
	2	1.2	1.6	1.5	1.6	1.6	1.4	0.8	1.5	1.5
	3	2.2	2.5	2.6	2.1	1.9	1.8	1.1	2.0	1.8
	4	2.0	2.9	3.0	2.6	2.6	2.2	1.6	2.6	2.3
	5	2.9	2.0	2.0	2.4	2.8	2.8	3.6	3.2	3.0
	6	4.5	5.9	6.4	5.1	5.0	4.2	5.1	5.3	5.3
	7	11.4	12.0	11.9	11.4	13.6	11.8	10.1	11.2	11.4
	7A	9.5	11.5	12.9	11.8	12.8	11.1	10.3	11.7	11.0
	8	9.0	12.7	13.0	15.2	15.1	12.6	12.2	16.6	16.1
	9A	11.8	14.1	15.4	18.4	17.7	23.3	14.7	16.9	17.2
	10	18.5	22.4	20.4	18.7	30.1	30.7	24.5	20.5	21.4
	11	23.1	20.6	18.6	22.2	30.5	23.9	23.5	19.4	20.4
	12	24.5	16.9	18.5	20.7	23.9	18.1	21.9	17.2	17.7
	13	18.6	17.2	18.2	21.7	23.0	19.6	16.3	17.1	17.2
	14	16.8	15.8	17.4	18.5	19.4	18.5	15.3	15.2	15.2
	15	16.3	14.5	16.1	17.5	16.6	16.4	15.5	13.9	14.0
	16	10.5	12.5	12.7	10.0	10.5	11.8	11.9	10.8	11.4
	17	19.4	15.8	20.3	24.4	25.8	23.7	22.1	18.3	19.8
	18	5.6	5.6	5.6	7.4	7.6	5.4	6.3	6.2	5.9
	19	3.5	5.4	7.0	5.2	5.7	4.7	3.6	5.0	4.7
	20	4.3	4.7	5.5	4.1	6.0	5.0	4.9	4.9	5.0
	21	3.0	4.7	5.1	2.8	3.6	2.9	2.9	3.6	3.1
	22	3.6	4.2	5.0	4.5	5.7	5.0	4.5	4.6	4.7
	23	4.2	6.3	5.4	4.6	7.2	4.9	3.7	4.8	5.0
	24	6.3	7.0	7.0	6.9	7.6	6.1	3.7	5.3	5.4

[1] Spectral wave conditions, others are monochromatic.

Table 20
Wave Heights for Plan 15 for Test Waves from 300 Degrees, swl = +7.0 ft

		Test Wave								
Period (sec)		15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)		21	26	30	21	26	30	21	21	21
	Gage	Wave Height, ft, at Indicated Gage Location								
	2	1.5	1.4	1.4	1.4	1.1	1.4	1.1	1.4	1.3
	3	2.8	2.4	2.0	1.7	1.5	1.6	1.1	1.8	1.6
	4	2.4	2.9	3.0	2.2	2.0	2.0	1.7	2.2	2.0
	5	3.1	1.9	2.7	2.3	2.2	2.7	2.3	2.9	2.5
	6	5.7	5.8	5.7	4.7	3.9	4.9	5.6	5.0	4.9
	7	9.8	13.3	14.2	11.3	9.8	10.3	9.0	11.7	11.2
	7A	12.8	13.6	14.3	12.3	11.3	11.7	9.8	11.8	11.1
	8	13.4	11.7	12.3	17.3	15.2	12.9	13.3	17.4	15.6
	9A	12.5	13.3	14.9	21.0	21.0	22.0	14.7	16.1	16.5
	10	22.1	18.5	21.1	18.4	28.8	28.5	21.7	21.5	21.2
	11	24.1	20.1	18.9	22.5	28.5	24.4	18.9	19.8	20.9
	12	23.1	15.2	18.1	24.9	25.6	20.3	18.2	18.2	18.9
	13	15.2	15.7	17.6	21.5	20.4	19.4	14.3	17.3	17.3
	14	14.3	15.0	17.0	16.2	17.6	17.8	14.0	16.0	14.8
	15	12.7	16.8	17.4	14.6	14.8	15.8	14.0	14.2	14.3
	16	9.6	13.1	11.9	11.0	11.7	11.9	11.4	11.3	12.5
	17	24.1	14.4	17.2	25.3	19.2	19.3	22.7	19.0	18.9
	18	5.2	6.2	6.9	7.8	6.3	5.4	5.7	6.2	6.2
	19	5.1	7.1	8.3	5.8	5.3	4.1	4.7	5.2	4.9
	20	4.8	4.8	5.4	3.5	4.7	4.5	4.9	4.7	4.3
	21	4.1	4.0	4.5	2.2	2.7	3.6	2.4	2.7	2.5
	22	4.6	3.8	4.6	3.3	3.9	4.5	4.4	4.1	3.6
	23	4.0	6.3	5.4	4.6	4.3	4.7	4.0	4.5	4.2
	24	3.8	6.2	6.2	6.1	5.3	5.5	3.9	5.0	4.7

* Spectral wave conditions, others are monochromatic.

Table 21
Wave Heights for Existing Conditions for Test Waves from 260 Degrees, swl = +7.0 ft

		Test Wave								
Period (sec)		15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)		21	26	30	21	26	30	21	21	21
	Gage	Wave Height, ft, at Indicated Gage Location								
	2	4.9	2.4	2.5	2.2	1.8	3.0	1.8	2.3	2.3
	3	5.5	3.2	3.4	3.0	2.0	4.8	2.6	2.7	2.9
	4	6.3	4.4	3.8	4.1	3.1	5.7	3.0	3.2	3.4
	5	10.9	7.0	6.1	6.7	5.7	8.7	4.2	5.4	5.7
	6	14.0	8.5	7.4	8.1	8.2	11.7	6.9	6.8	7.2
	7	18.2	15.8	16.3	17.3	16.5	22.1	23.1	17.1	18.1
	7A	22.7	16.8	18.3	20.8	15.4	22.7	19.5	15.7	16.2
	8	13.8	13.8	13.4	13.7	13.3	11.4	11.2	16.2	16.6
	9A	22.5	18.8	17.9	23.4	23.7	18.3	21.3	18.2	18.6
	10	24.8	26.5	27.6	18.7	28.6	21.7	23.9	22.2	20.3
	11	23.3	20.5	22.7	20.8	28.5	20.1	21.8	20.5	19.9
	12	23.6	20.1	21.4	24.7	25.3	23.5	20.7	20.6	21.7
	13	21.0	15.3	17.5	21.7	18.0	19.1	22.9	18.8	21.5
	14	19.2	14.0	17.2	21.0	18.1	15.0	23.6	17.2	18.6
	15	14.3	12.9	17.0	20.0	15.8	11.9	22.1	14.5	15.9
	16	10.4	13.5	12.9	11.0	10.3	12.6	18.7	12.0	13.1
	17	16.0	18.5	20.4	20.2	18.5	18.7	11.4	18.9	19.2
	18	6.9	9.0	9.7	7.8	8.9	10.6	7.8	7.9	8.4
	19	11.3	9.8	10.3	9.4	10.0	14.8	12.5	9.5	11.0
	20	8.0	9.4	10.1	8.0	8.9	8.8	7.5	8.6	7.7
	21	9.6	7.8	9.6	9.8	7.3	11.7	5.9	7.2	8.1
	22	7.9	8.3	8.3	6.8	8.1	6.4	5.9	7.4	6.8
	23	7.2	6.2	6.2	5.6	6.8	6.1	5.2	6.0	5.8
	24	6.4	6.8	7.7	4.4	6.4	8.7	5.3	6.6	6.4

[1] Spectral wave conditions, others are monochromatic.

Table 22
Wave Heights for Plan 14 for Test Waves from 260 Degrees, swl = +7.0 ft

		Test wave								
Period (sec)		15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)		21	26	30	21	26	30	21	21	21
	Gage	Wave Height, ft, at Indicated Gage Location								
	2	4.9	3.5	3.5	3.0	3.5	3.6	2.4	3.1	3.1
	3	6.8	4.6	5.0	4.8	4.7	6.5	3.2	3.6	3.7
	4	10.5	6.3	8.2	6.8	6.6	8.2	4.5	5.2	5.6
	5	13.7	6.6	9.9	8.6	9.1	11.6	5.6	7.4	8.0
	6	13.1	8.2	11.6	6.7	8.5	11.7	10.5	7.3	7.6
	7	27.4	19.9	21.0	15.5	20.5	19.9	20.1	15.6	15.3
	7A	25.8	23.8	19.4	20.2	25.0	22.0	23.8	17.5	18.0
	8	15.0	13.8	13.6	13.5	12.7	13.8	11.5	16.9	17.2
	9A	19.8	17.4	15.9	15.6	23.2	19.5	22.3	18.1	18.1
	10	21.7	22.0	22.9	21.7	28.5	28.6	21.4	21.2	21.8
	11	21.3	24.3	19.9	21.6	30.5	26.4	19.4	20.9	21.9
	12	22.3	28.6	22.0	19.5	27.3	22.9	24.4	23.0	22.1
	13	19.5	30.4	21.9	22.6	27.6	24.9	25.5	24.2	22.4
	14	20.6	23.1	23.5	22.3	25.2	22.0	24.0	21.9	20.9
	15	11.9	15.6	15.8	19.1	17.1	18.6	21.0	16.6	17.5
	16	11.5	10.6	14.1	8.8	11.3	12.9	13.9	12.6	12.6
	17	17.7	18.4	15.5	26.8	26.2	21.0	15.6	19.1	21.0
	18	11.2	9.8	8.7	11.4	12.0	11.5	14.7	9.5	9.8
	19	16.6	12.3	10.8	7.5	9.9	10.6	12.6	8.0	7.9
	20	12.1	11.8	11.2	6.8	11.6	12.0	13.0	8.8	8.3
	21	8.1	8.0	8.0	9.2	8.8	9.3	7.5	7.1	6.9
	22	8.2	7.7	8.0	6.7	7.4	8.1	7.9	6.8	6.6
	23	8.4	8.3	9.0	8.0	7.3	7.9	8.2	7.2	7.0
	24	7.8	7.1	7.3	7.2	6.2	7.2	6.1	7.3	7.0

[1] Spectral wave conditions, others are monochromatic.

Table 23
Wave Heights for Plan 15 for Test Waves from 260 Degrees, swl = +7.0 ft

		Test Wave								
Period (sec)		15	15	15	17	17	17	20	15[1]	17[1]
Height (ft)		21	26	30	21	26	30	21	21	21
	Gage	Wave Height, ft, at Indicated Gage Location								
	2	4.2	3.4	3.4	2.8	2.7	3.2	2.6	2.7	2.8
	3	6.4	4.3	5.4	4.0	3.9	4.7	3.2	3.4	3.4
	4	9.4	5.5	7.3	6.4	5.7	7.3	4.4	4.6	4.6
	5	10.9	8.1	8.0	7.3	7.4	7.8	6.3	5.9	6.2
	6	14.4	9.2	9.8	7.0	7.9	9.0	9.3	6.9	7.3
	7	19.4	18.1	15.4	20.9	17.2	20.2	23.2	19.5	19.8
	7A	25.7	16.7	19.3	16.7	16.9	18.8	18.7	17.3	16.9
	8	14.7	13.4	13.6	14.9	13.8	12.5	13.2	17.0	17.1
	9A	18.1	14.4	16.0	17.5	22.1	18.3	21.9	17.3	18.3
	10	20.1	23.4	21.4	20.5	27.3	27.1	23.0	21.0	21.6
	11	21.6	19.7	15.6	23.0	30.7	25.3	20.0	20.2	22.0
	12	21.4	21.1	19.0	26.4	27.6	24.2	26.9	20.6	23.3
	13	19.8	20.4	22.8	25.7	20.0	24.8	27.9	20.7	21.7
	14	12.2	13.0	15.5	22.1	18.6	13.7	23.2	21.0	21.3
	15	16.3	15.2	19.2	19.2	16.6	18.3	21.6	16.3	17.5
	16	13.1	13.9	14.1	11.2	12.6	14.1	12.1	13.0	13.5
	17	15.0	19.8	19.8	23.2	21.1	20.1	12.7	19.5	20.3
	18	9.9	8.1	9.0	12.8	9.0	11.8	12.9	9.1	9.3
	19	14.5	10.8	7.9	8.5	7.9	9.5	11.8	9.2	9.2
	20	11.5	10.4	8.4	8.1	8.6	8.9	11.0	9.4	9.4
	21	8.8	8.2	8.7	8.8	10.2	11.5	8.5	8.2	8.6
	22	8.3	8.4	8.1	7.3	8.1	10.0	8.2	7.2	7.9
	23	9.0	7.8	9.5	7.4	6.3	11.0	8.7	7.3	7.6
	24	7.2	6.6	7.0	6.3	6.3	7.0	7.5	7.1	7.3

[1] Spectral wave conditions, others are monochromatic.

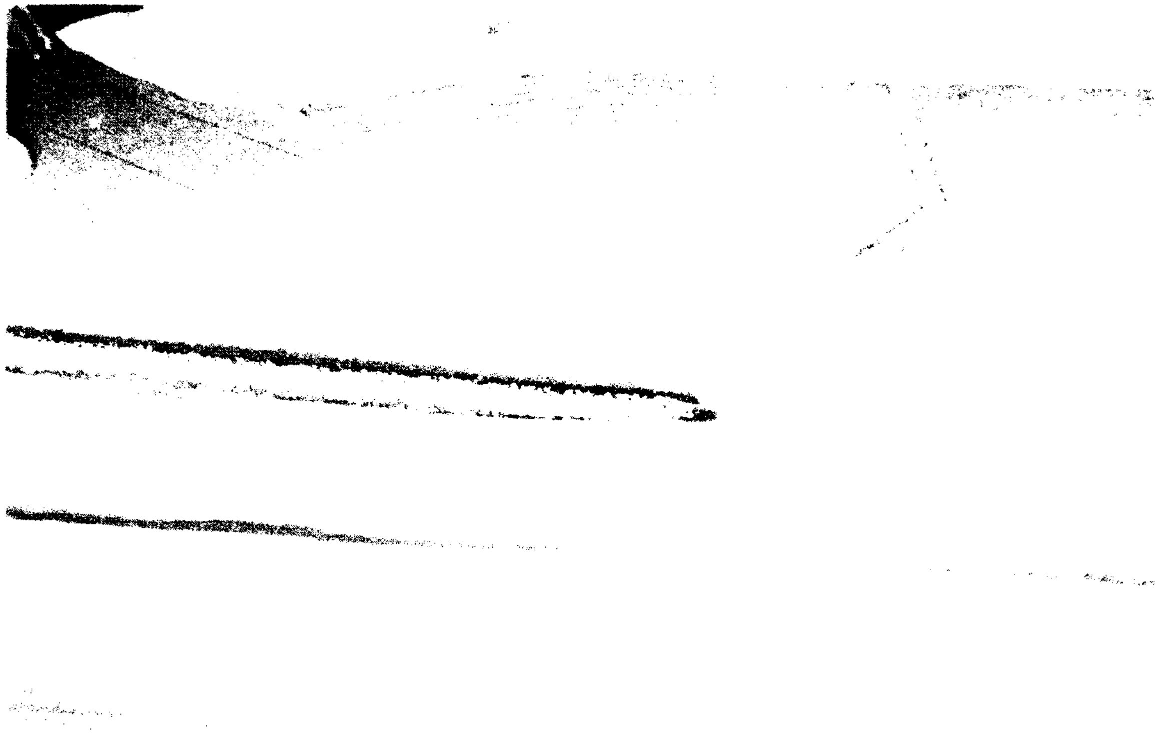


Photo 1. Typical wave patterns for existing conditions; 15-sec, 12-ft monochromatic waves from 275 deg; swl = 0.0 ft

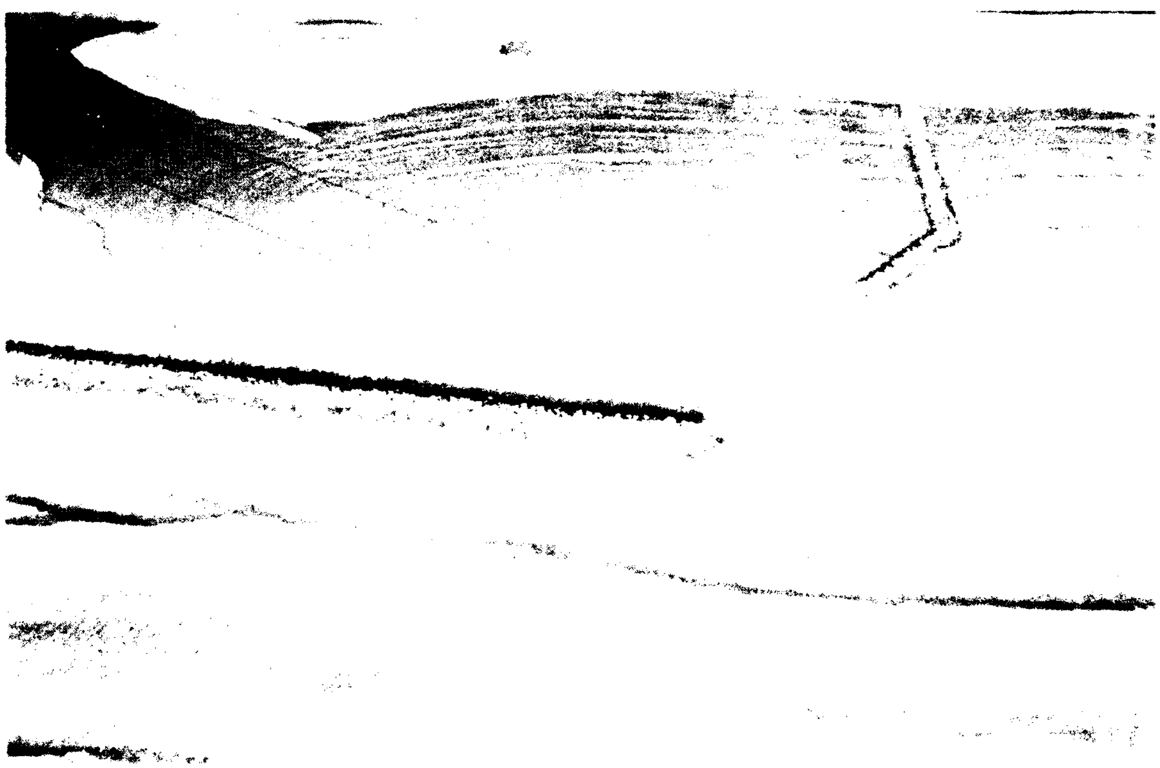


Photo 2. Typical wave patterns for existing conditions; 17-sec, 16 ft monochromatic waves from 275 deg; swl = 0.0 ft

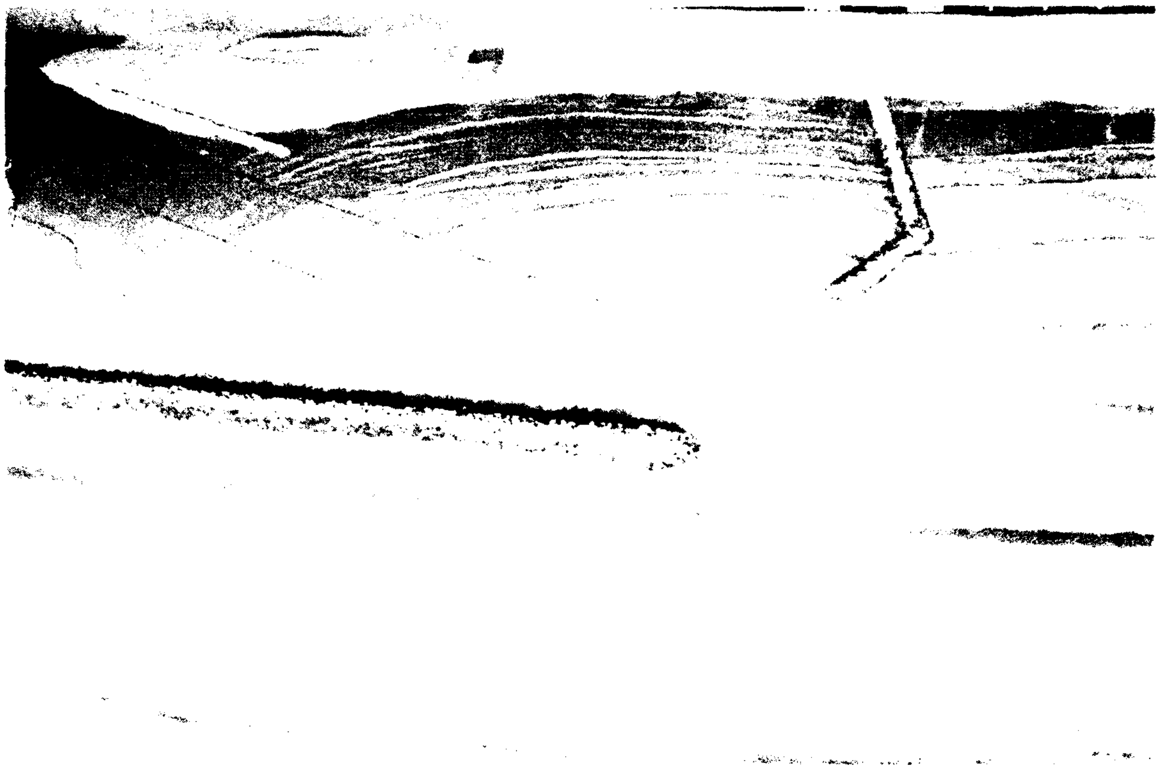


Photo 3. Typical wave patterns for existing conditions: 17-sec, 16-ft spectral waves from 275 deg; swl = 0.0 ft

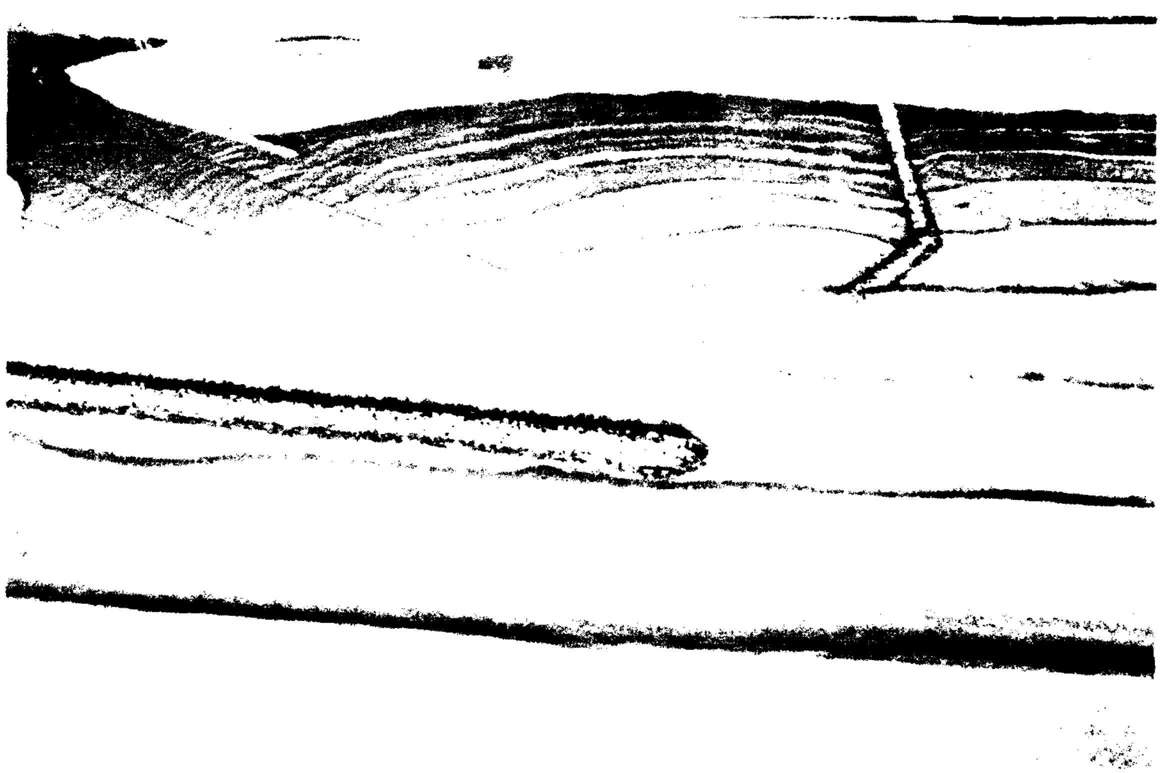


Photo 4. Typical wave patterns for existing conditions: 15-sec, 12-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

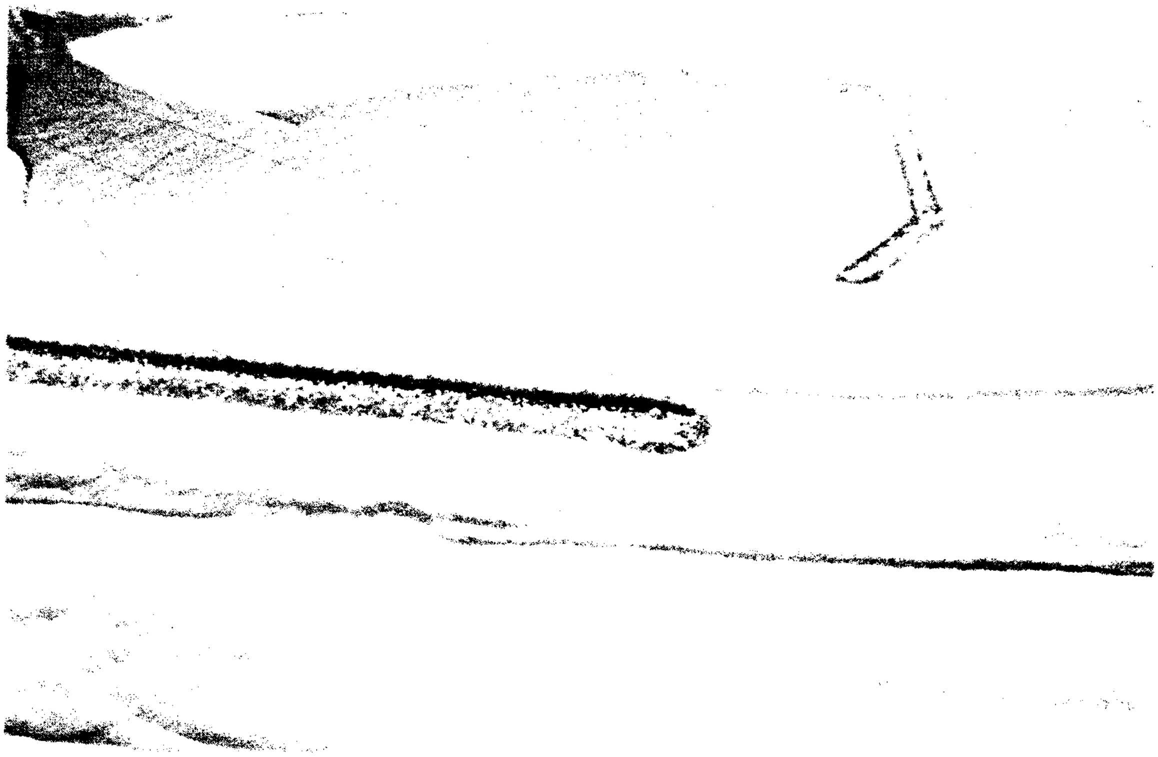


Photo 5. Typical wave patterns for existing conditions; 17-sec, 16-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

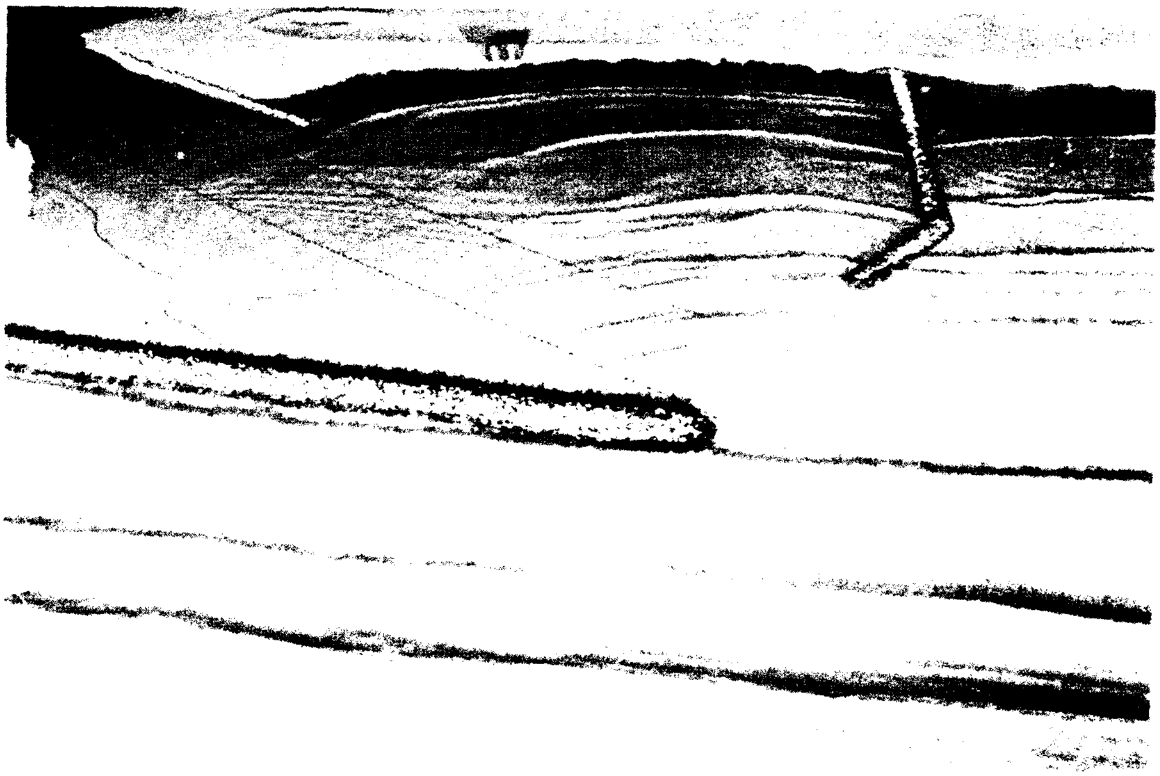


Photo 6. Typical wave patterns for existing conditions; 17-sec, 16-ft spectral waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

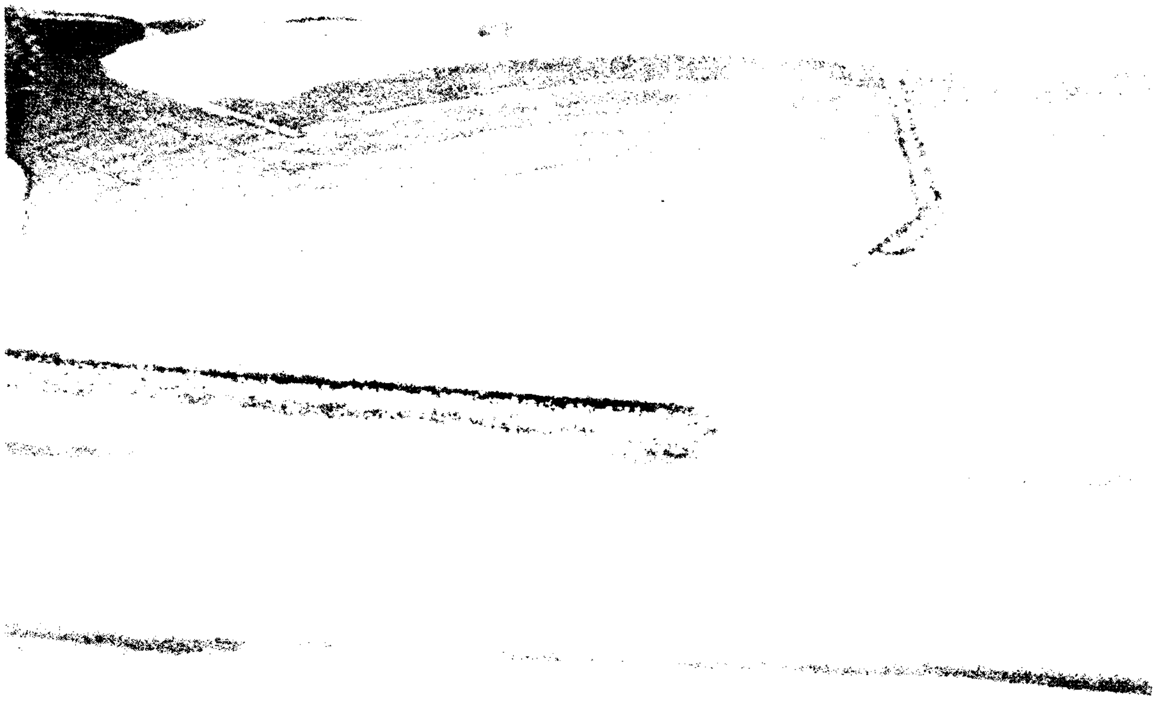


Photo 7. Typical wave patterns for existing conditions: 15 sec, 21 ft monochromatic waves from 275 deg; swl = +7.0 ft

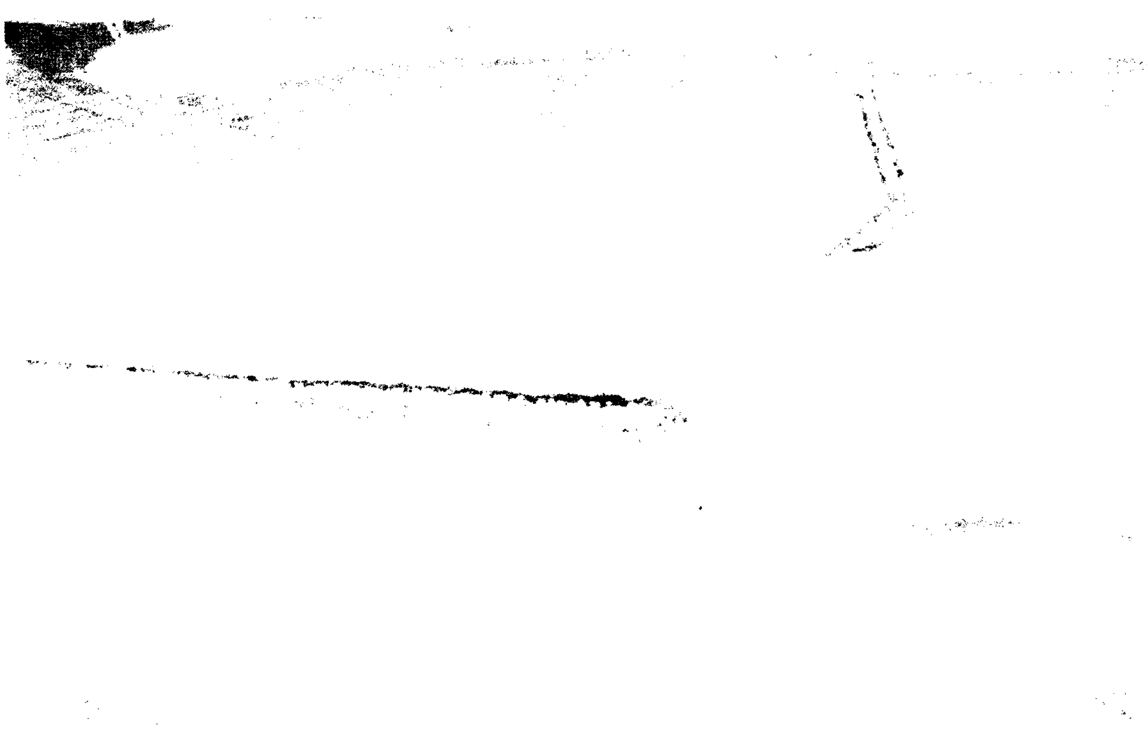


Photo 8. Typical wave patterns for existing conditions: 17 sec, 30 ft monochromatic waves from 275 deg; swl = +7.0 ft

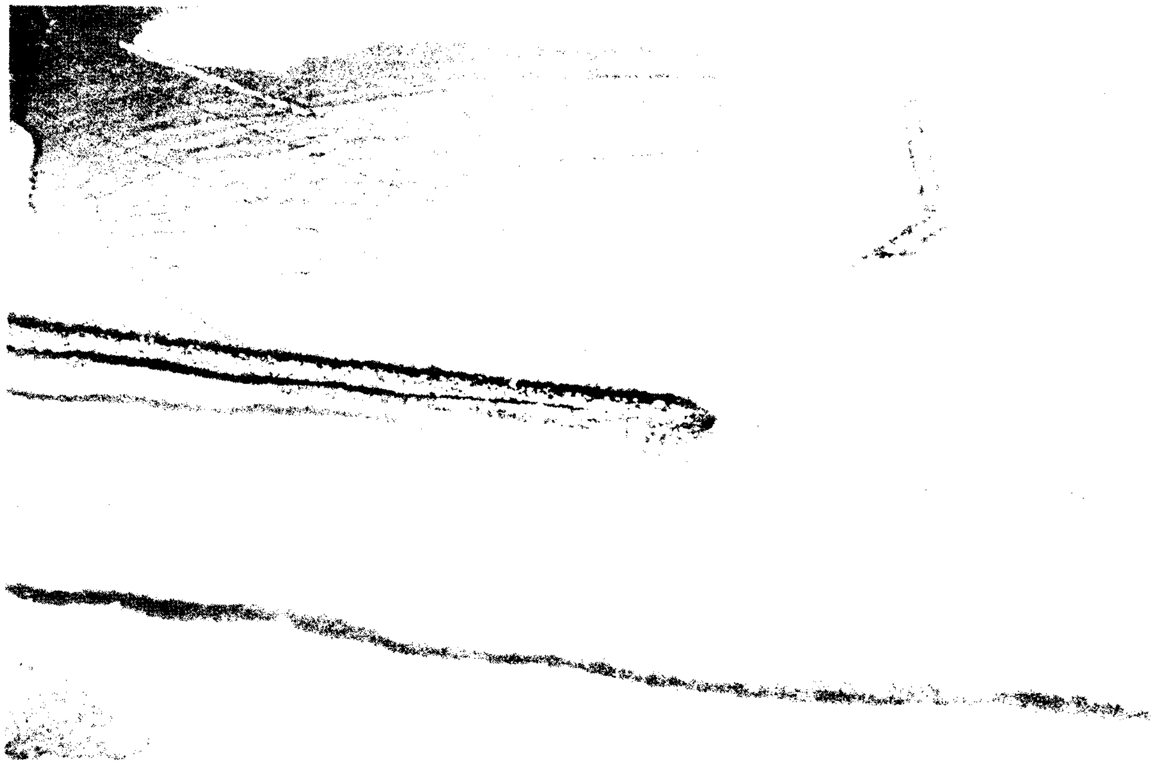


Photo 9. Typical wave patterns for existing conditions: 15-sec. 21-ft spectral waves from 275 deg; swl = +7.0 ft

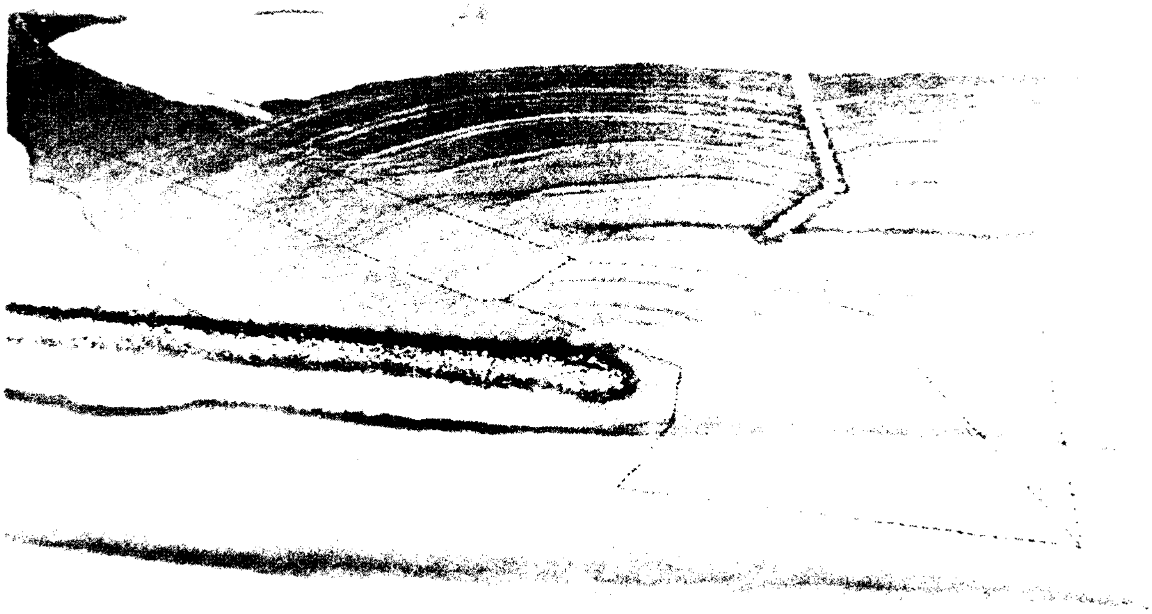


Photo 10. Typical wave patterns for Plan 1: 15-sec. 12-ft monochromatic waves from 275 deg; swl = 0.0 ft

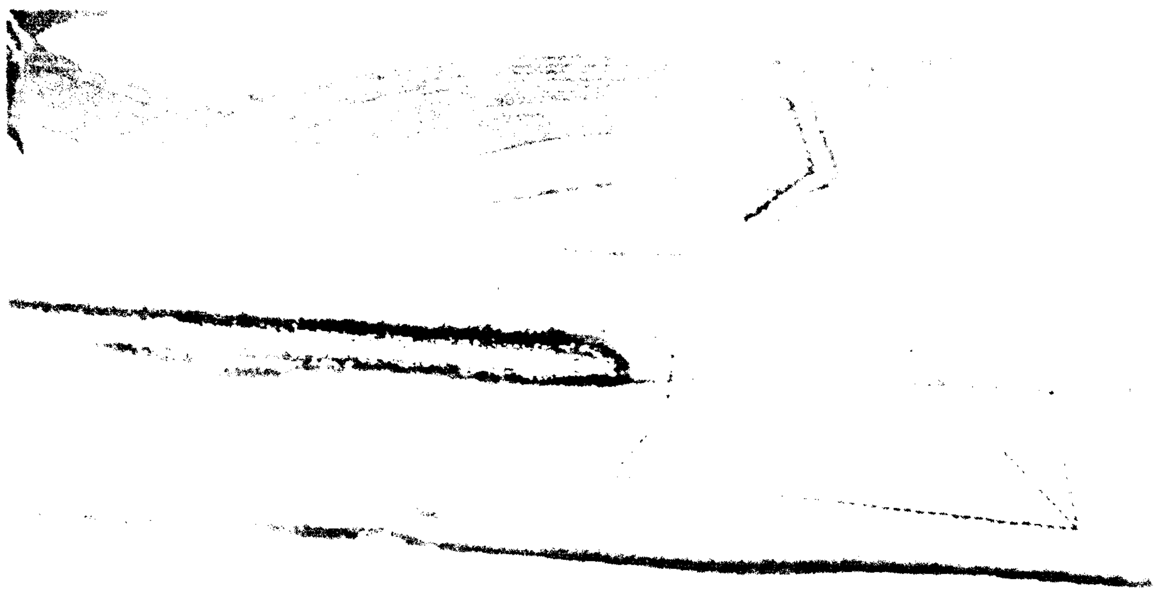


Photo 11. Typical wave patterns for Plan 1: 17-sec, 16-ft monochromatic waves from 275 deg; swl = 0.0 ft

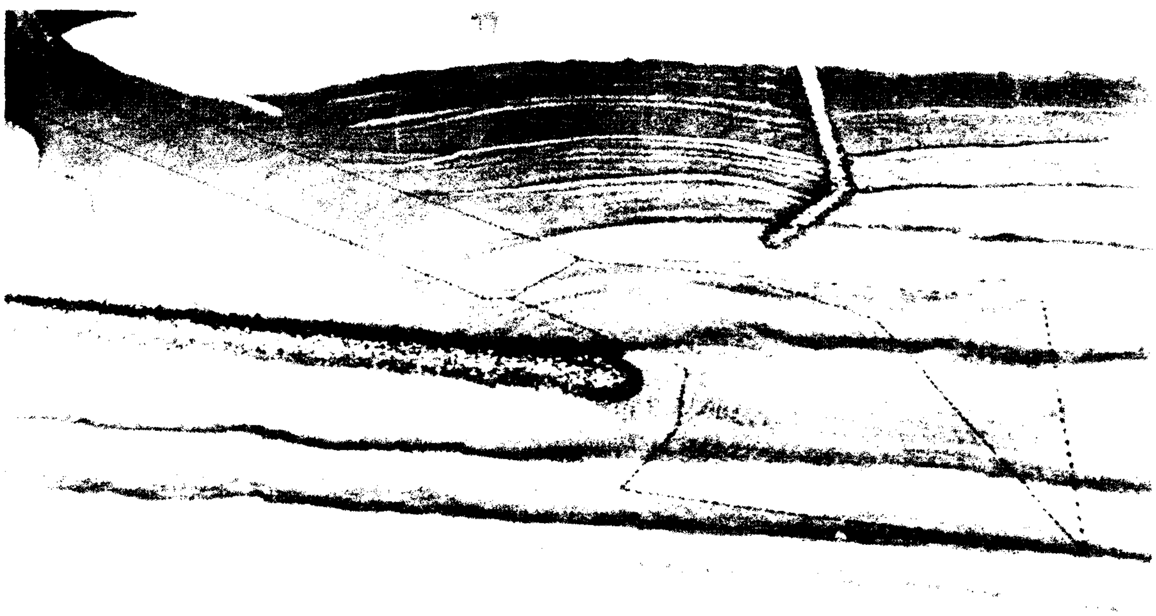


Photo 12. Typical wave patterns for Plan 1: 17-sec, 16-ft spectral waves from 275 deg; swl = 0.0 ft

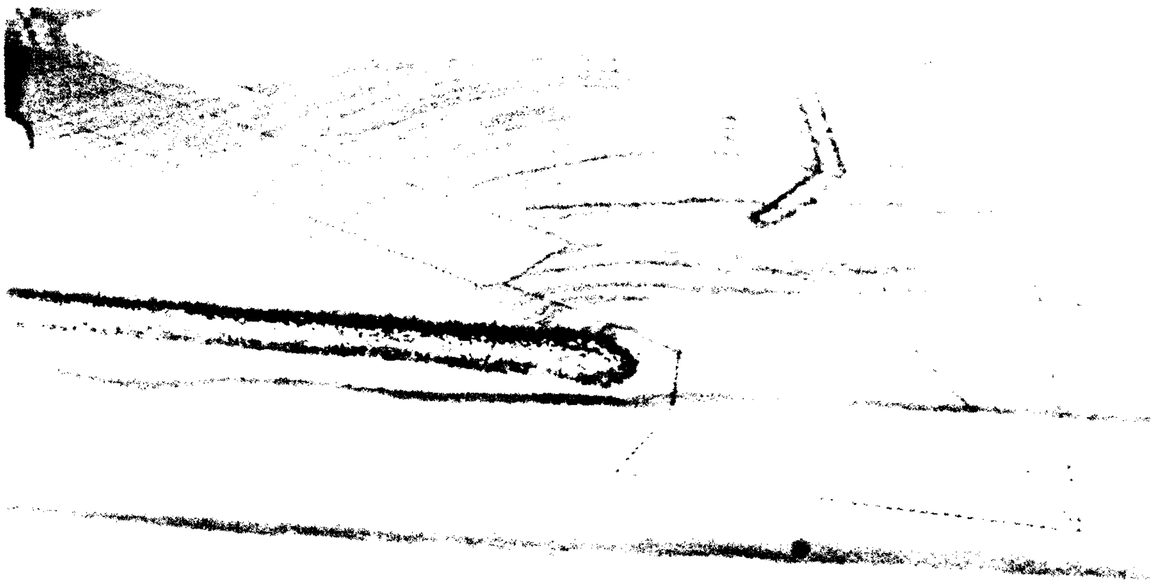


Photo 13. Typical wave patterns for Plan 1; 15-sec, 12-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

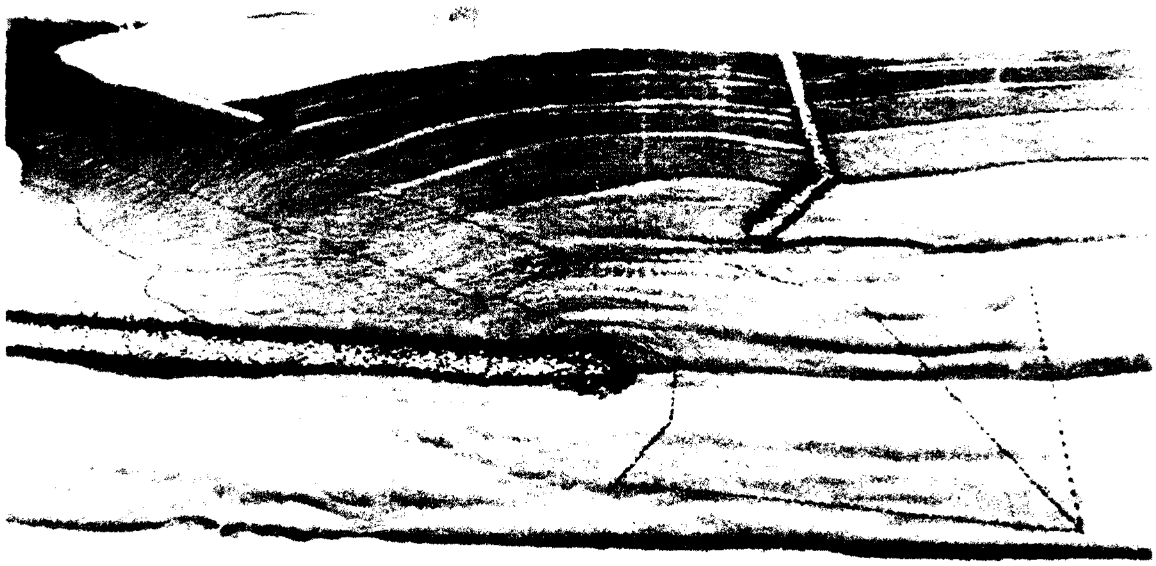


Photo 14. Typical wave patterns for Plan 1; 17-sec, 16-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

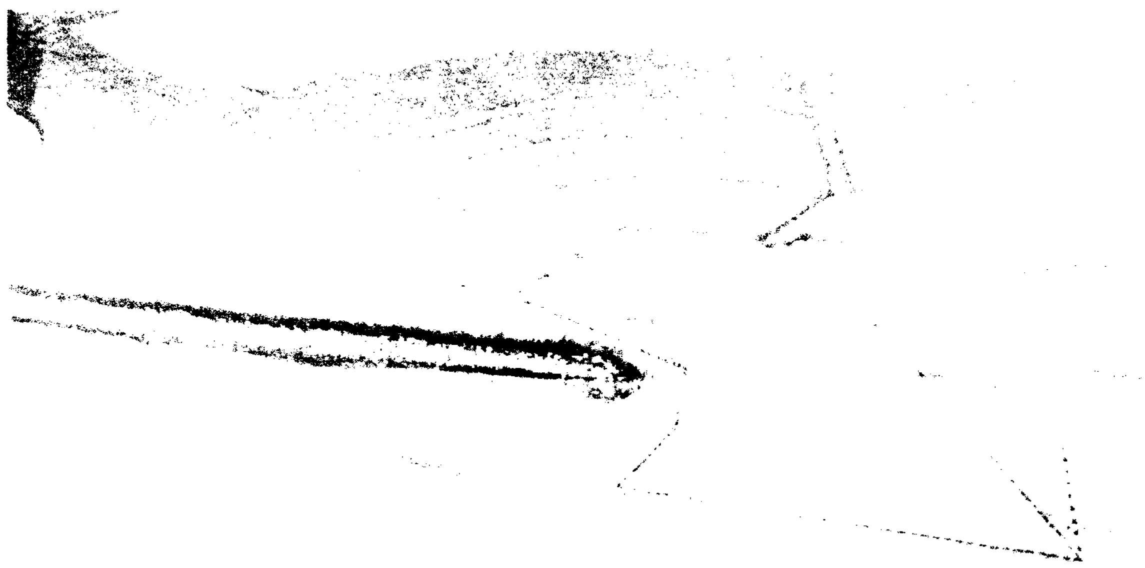


Photo 15. Typical wave patterns for Plan 1; 17-sec, 16-ft spectral waves from 275 deg, swl = +2.9 ft (maximum ebb flow conditions)

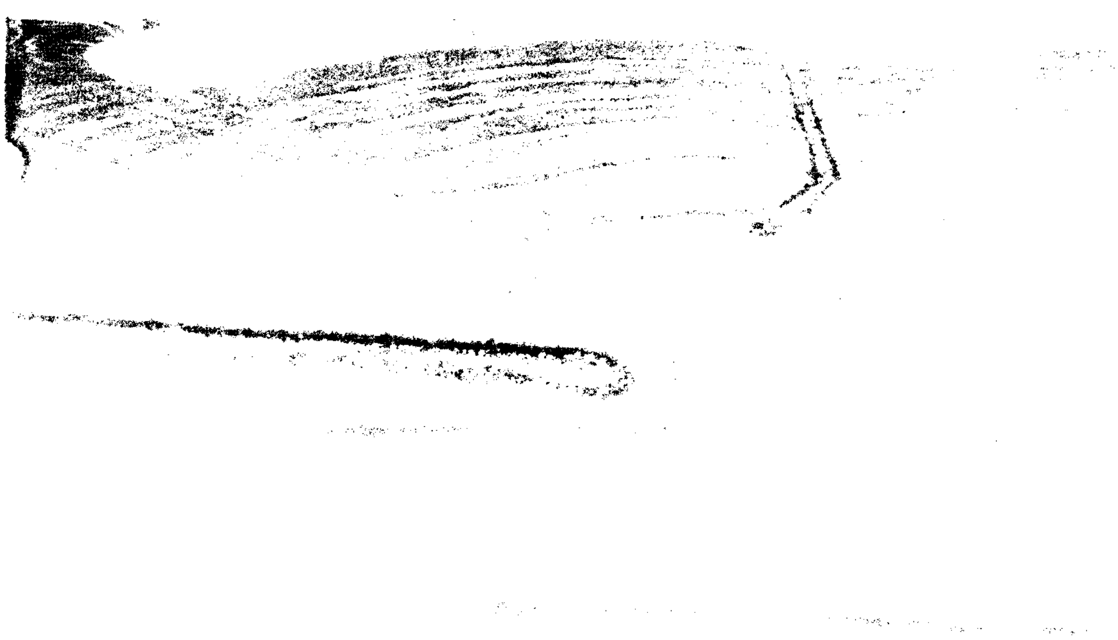


Photo 16. Typical wave patterns for Plan 1; 15-sec, [illegible] from 275 deg, swl = +7.0 ft

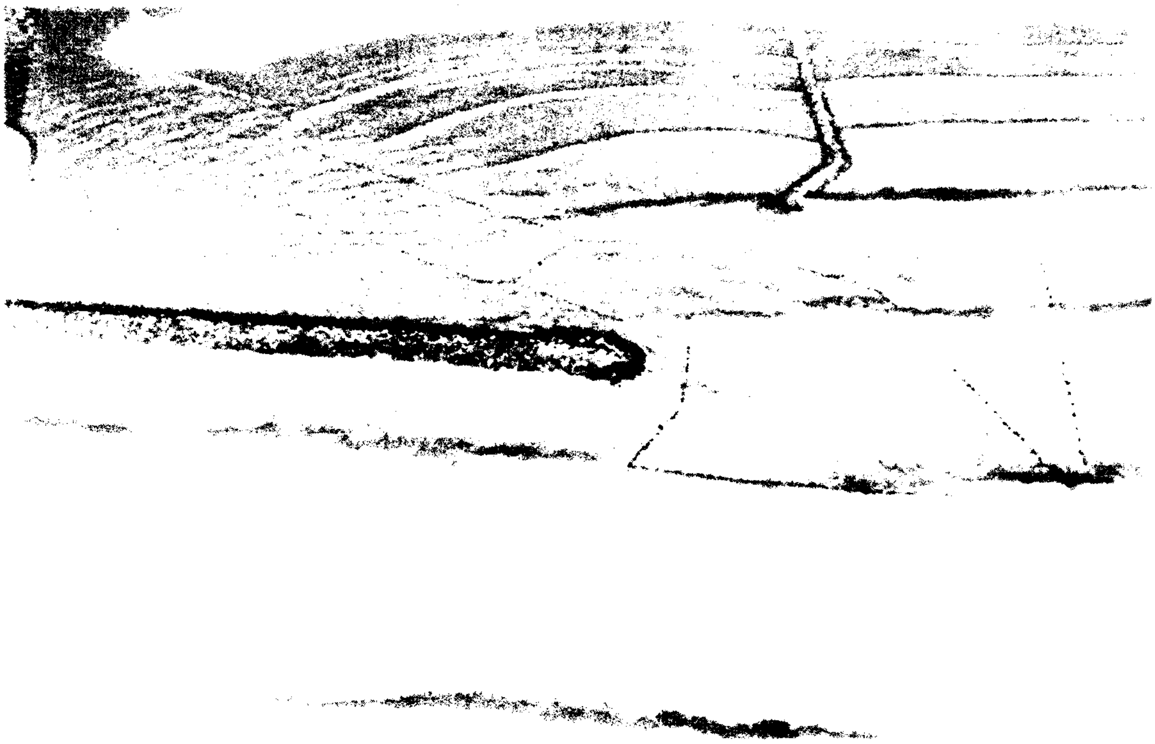


Photo 17. Typical wave patterns for Plan 1: 17-sec, 30-ft monochromatic waves from 275 deg; swl = +7.0 ft

Photo 18. Typical wave patterns for Plan 1: 15-sec, 21-ft spectral waves from 275 deg; swl = +7.0 ft

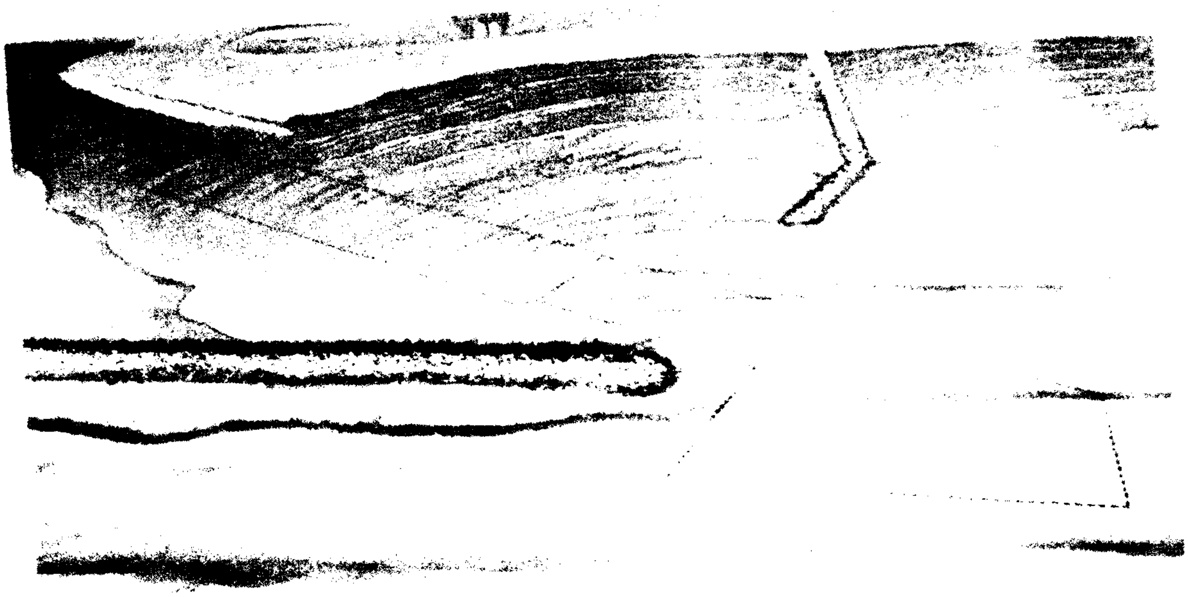


Photo 19. Typical wave patterns for Plan 14: 15-sec, 12-ft monochromatic waves from 275 deg; swl = 0.0 ft

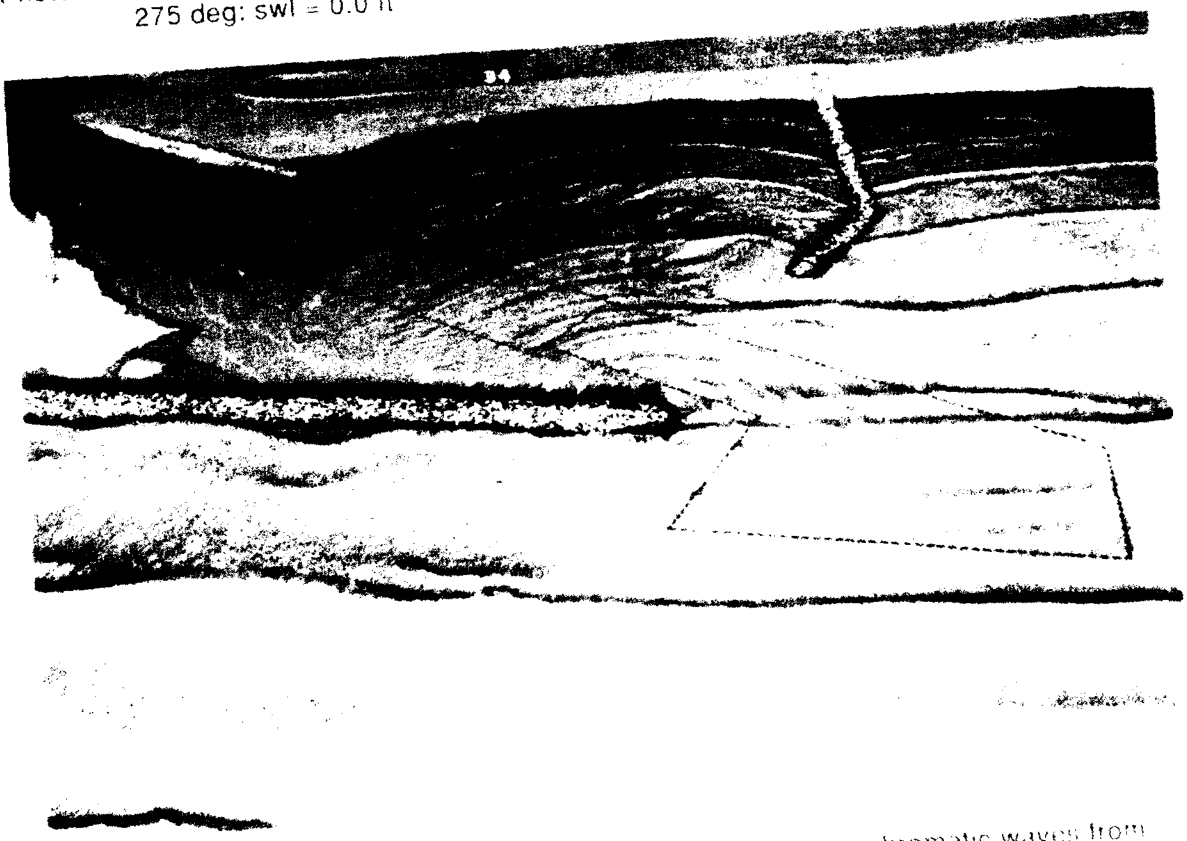


Photo 20. Typical wave patterns for Plan 14: 17-sec, 16-ft monochromatic waves from 275 deg; swl = 0.0 ft

Photo 21. Typical wave patterns for Plan 14: 17-sec, 16-ft spectral waves from 275 deg, swl = 0.0 ft

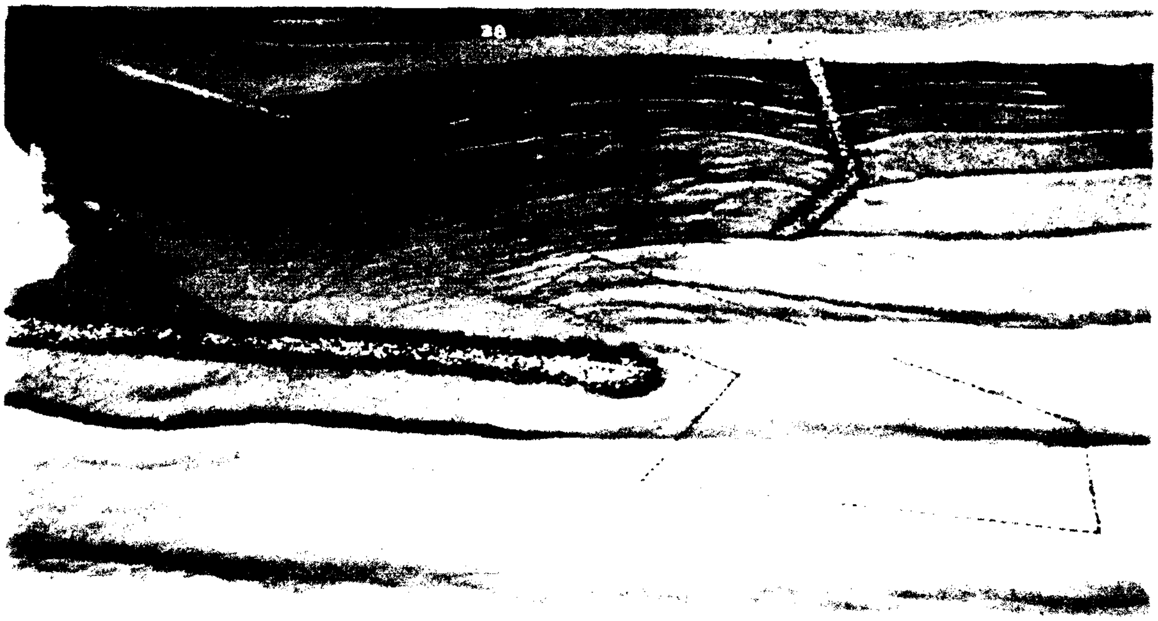


Photo 22. Typical wave patterns for Plan 14; 15-sec, 12-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

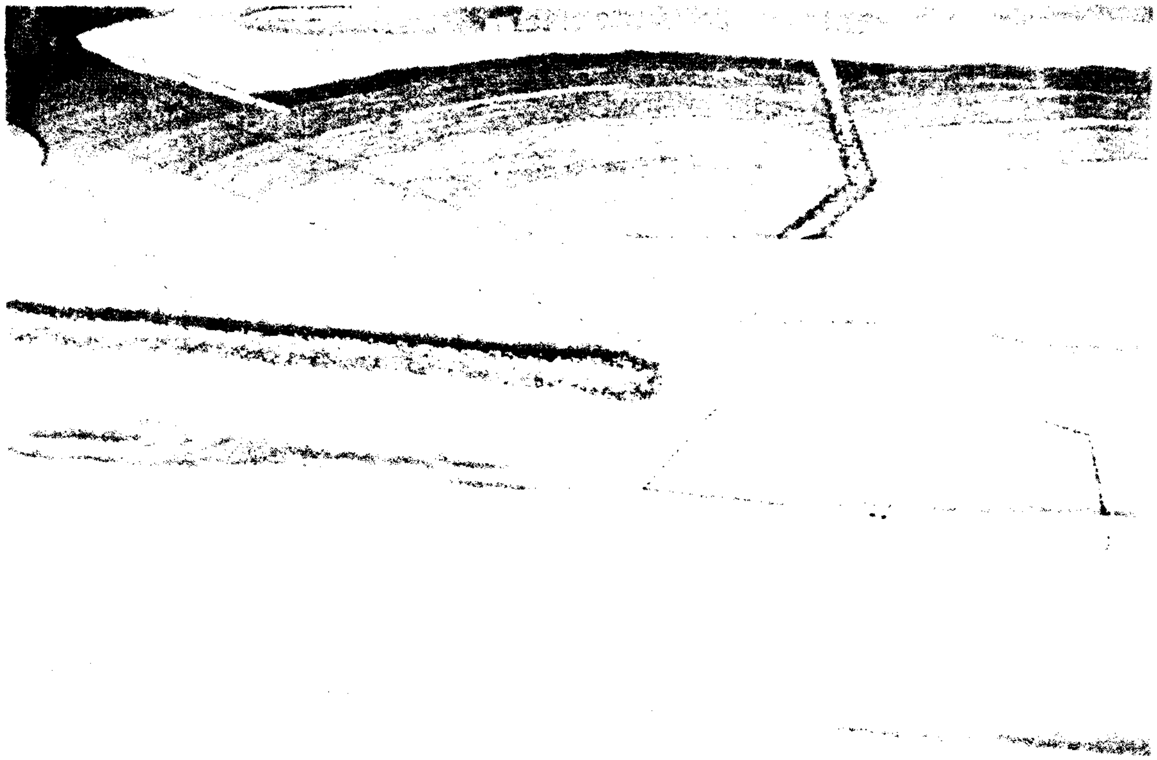


Photo 23. Typical wave patterns for Plan 14; 17 sec, 16 ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

Photo 24. Typical wave patterns for Plan 14; 17 sec, 16 ft spectral waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

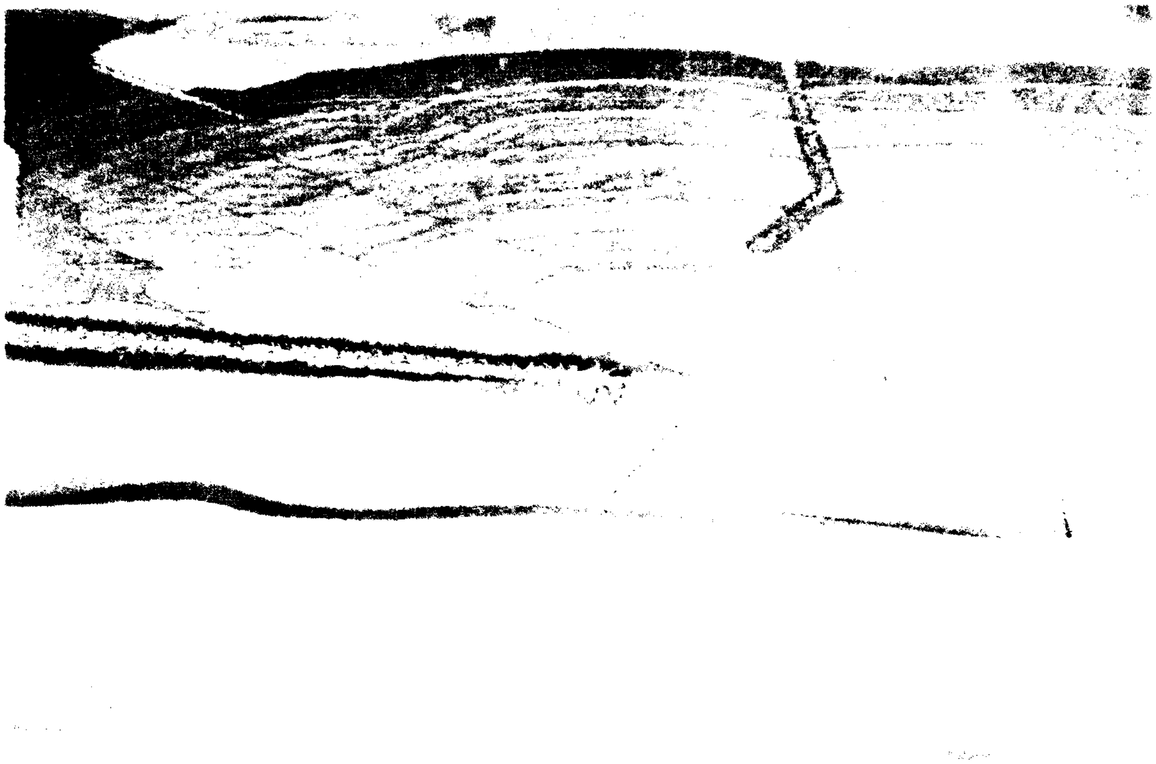


Photo 25. Typical wave patterns for Plan 14: 15-sec, 21-ft monochromatic waves from 275 deg, swl = +7.0 ft

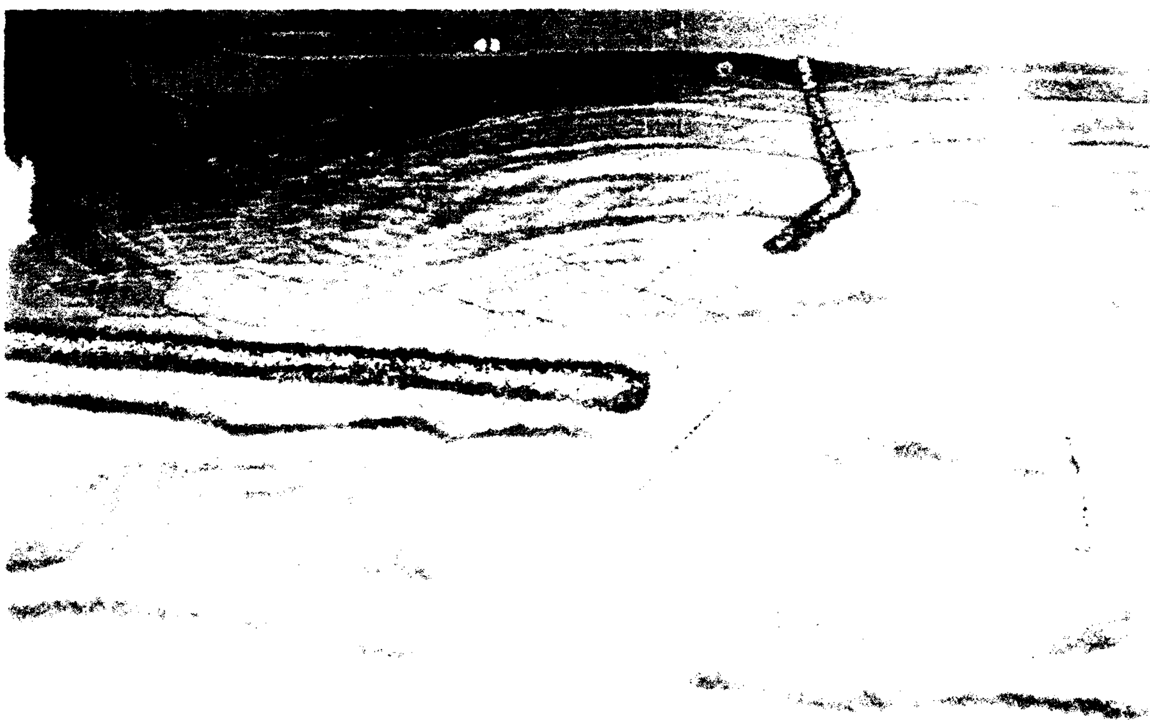


Photo 26. Typical wave patterns for Plan 14: 17-sec, 30-ft monochromatic waves from 275 deg, swl = +7.0 ft

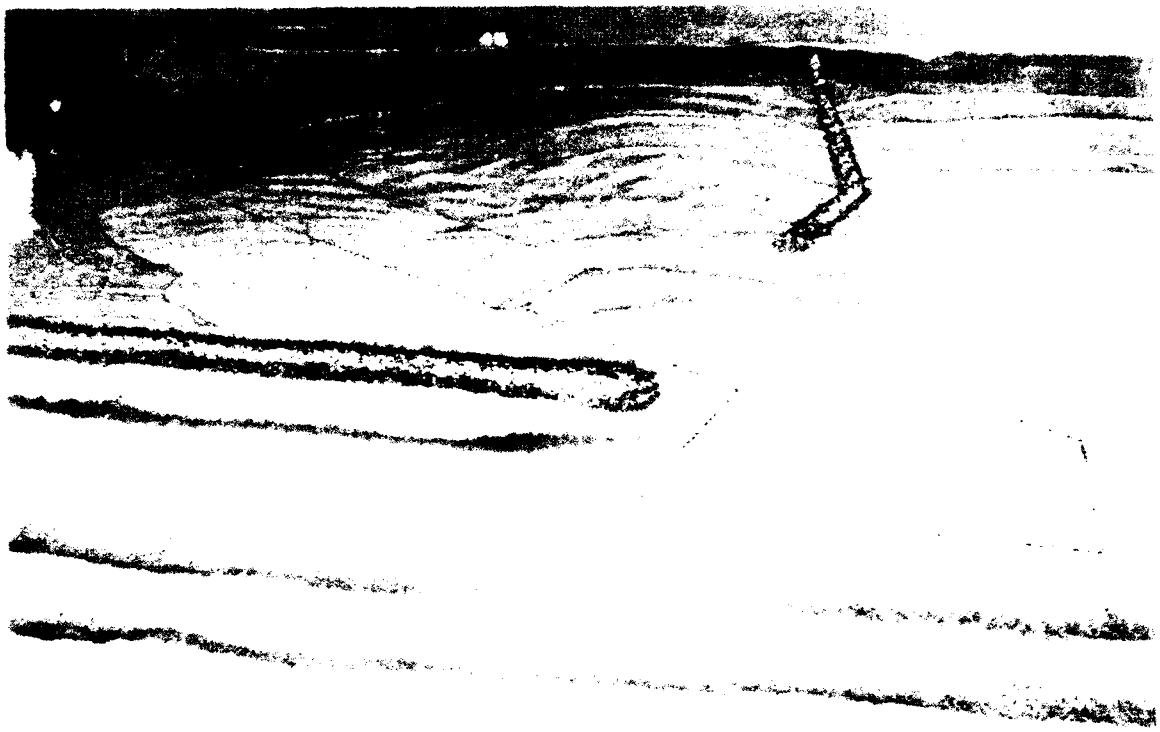


Photo 27 Typical wave patterns for Plan 14; 15 sec. 21-ft spectral waves from 275 deg. swl = +7.0 ft

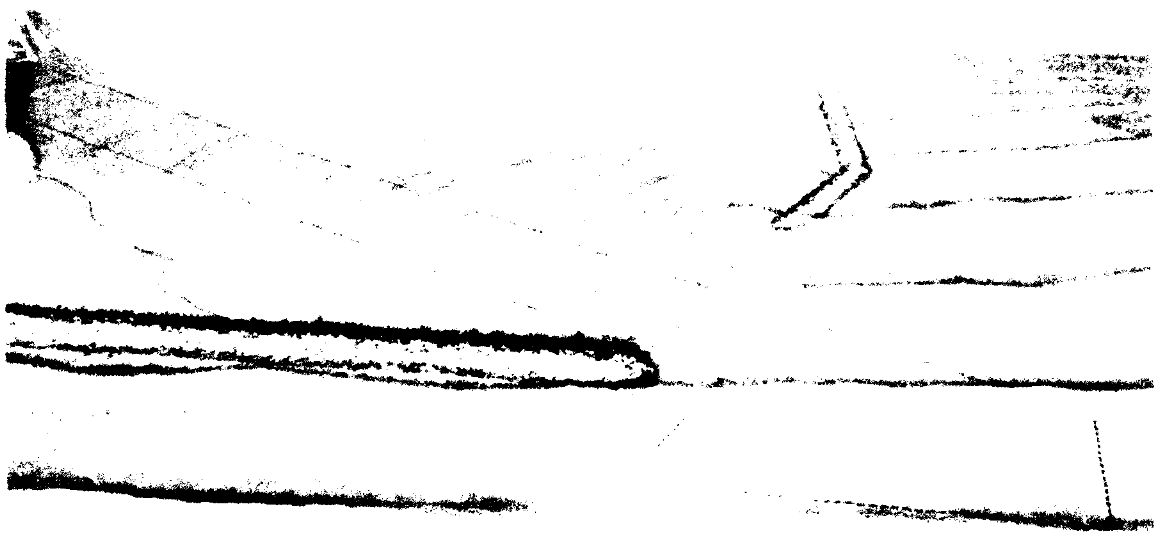


Photo 28 Typical wave patterns for Plan 15. 15 sec. 12 ft monochromatic waves from 275 deg; swl = 0.0 ft

Photo 29. Typical wave patterns for Plan 15; 17-sec, 16-ft monochromatic waves from 275 deg, swl = 0.0 ft

Photo 30. Typical wave patterns for Plan 15; 17-sec, 16-ft spectral waves from 275 deg; swl = 0.0 ft

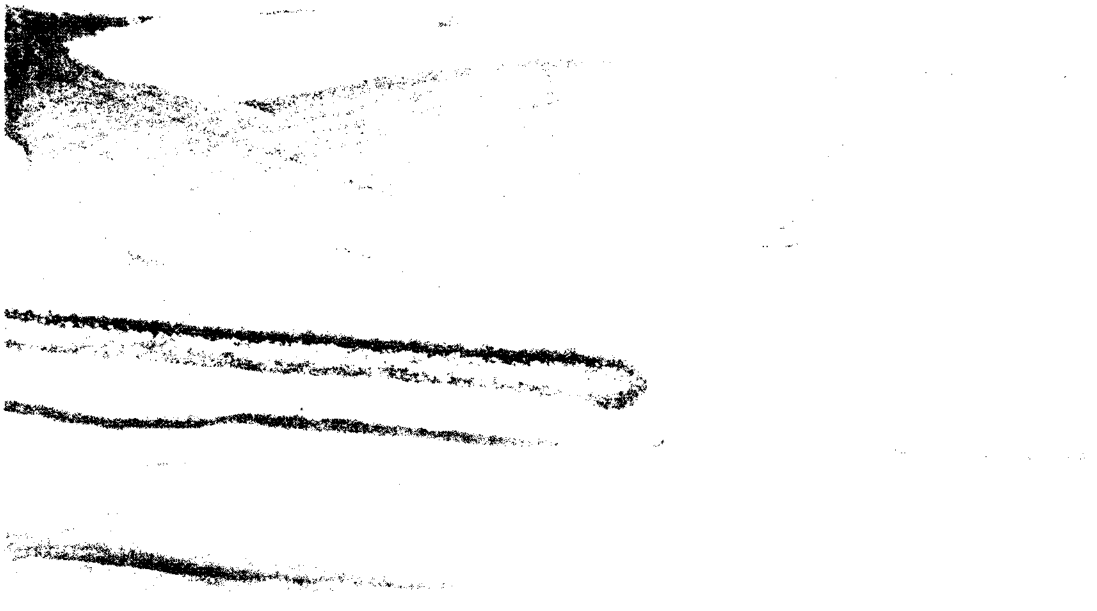


Photo 31. Typical wave patterns for Plan 15: 15 sec, 12-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

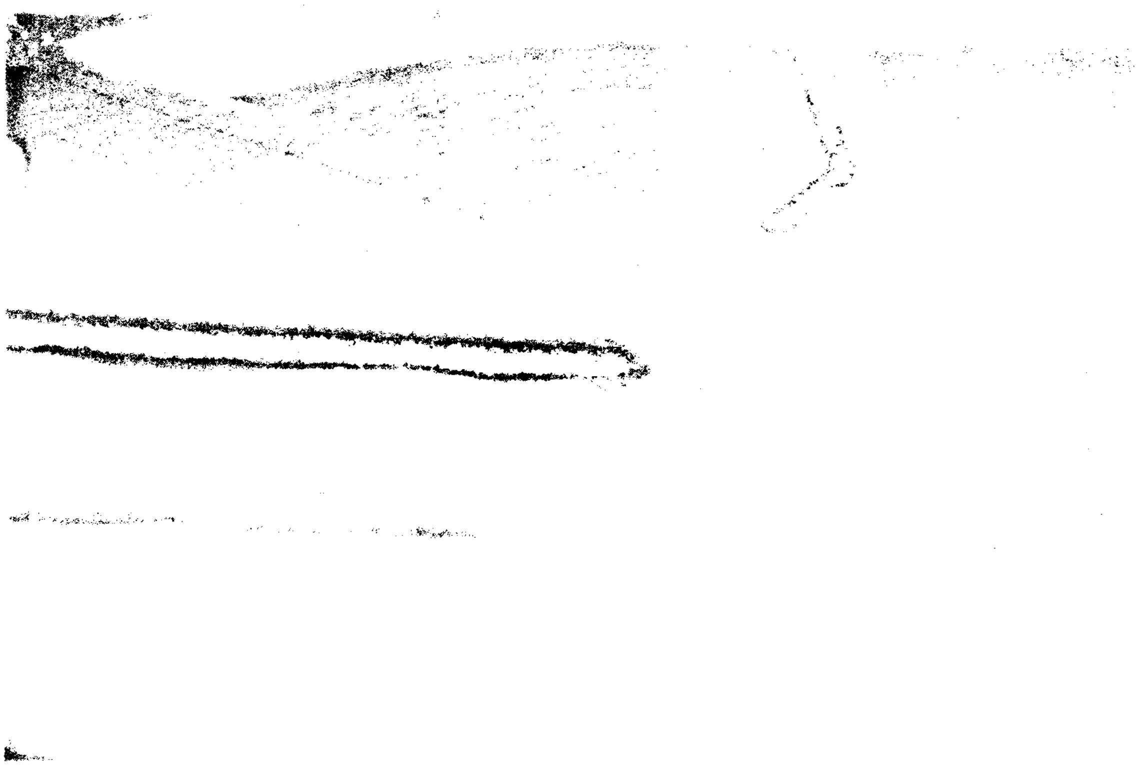


Photo 32. Typical wave patterns for Plan 15: 1[illegible] sec, 16-ft monochromatic waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

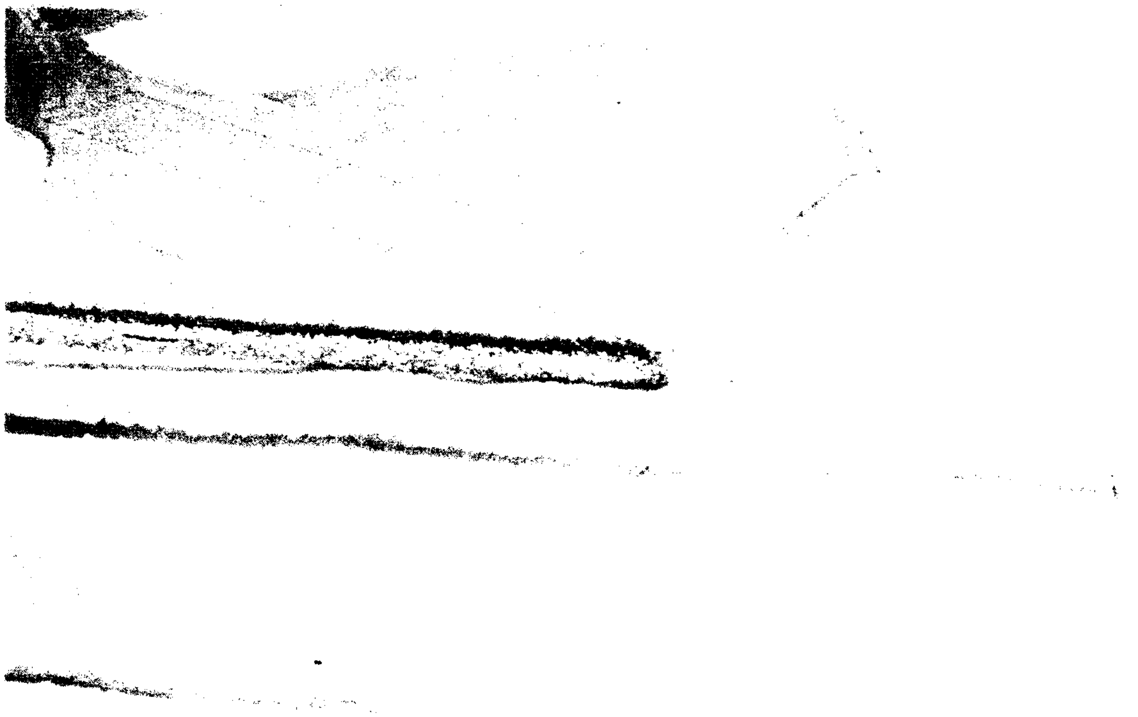


Photo 33. Typical wave patterns for Plan 15; 17-sec, 16-ft spectral waves from 275 deg; swl = +2.9 ft (maximum ebb flow conditions)

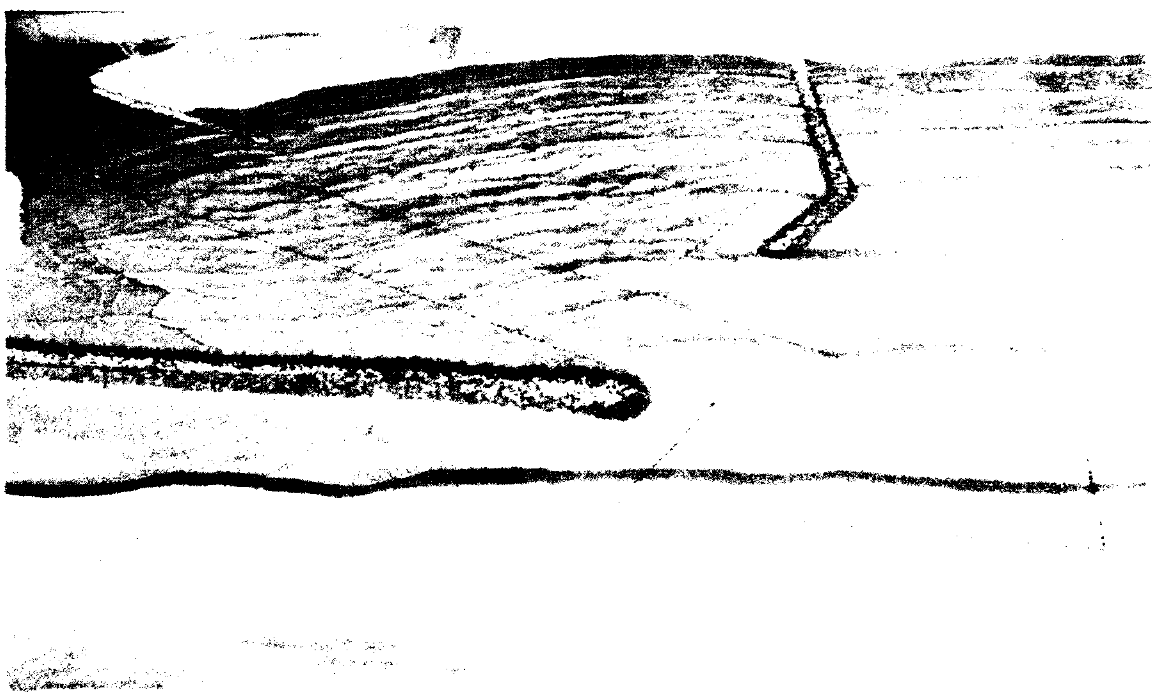


Photo 34. Typical wave patterns for Plan 15; 15-sec, 21-ft monochromatic waves from 275 deg; swl = +7.0 ft

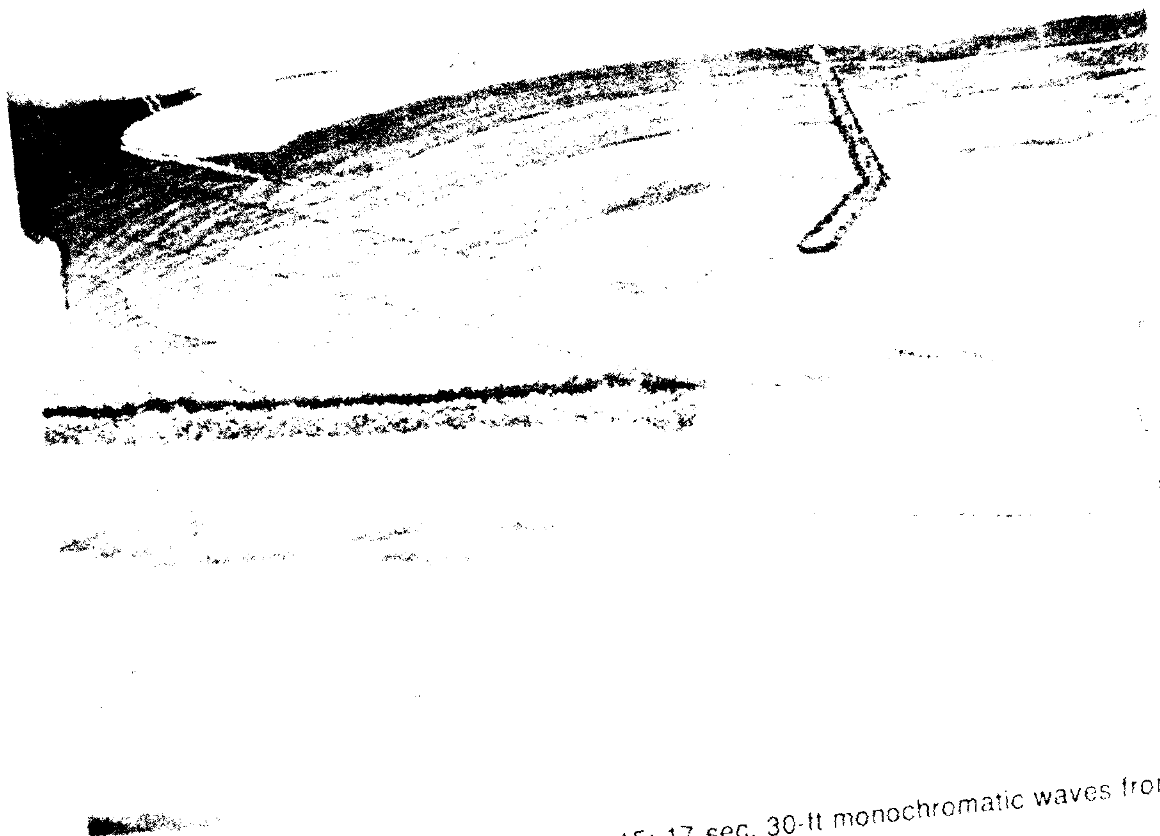


Photo 35. Typical wave patterns for Plan 15: 17-sec. 30-ft monochromatic waves from 275 deg: swl = +7.0 ft

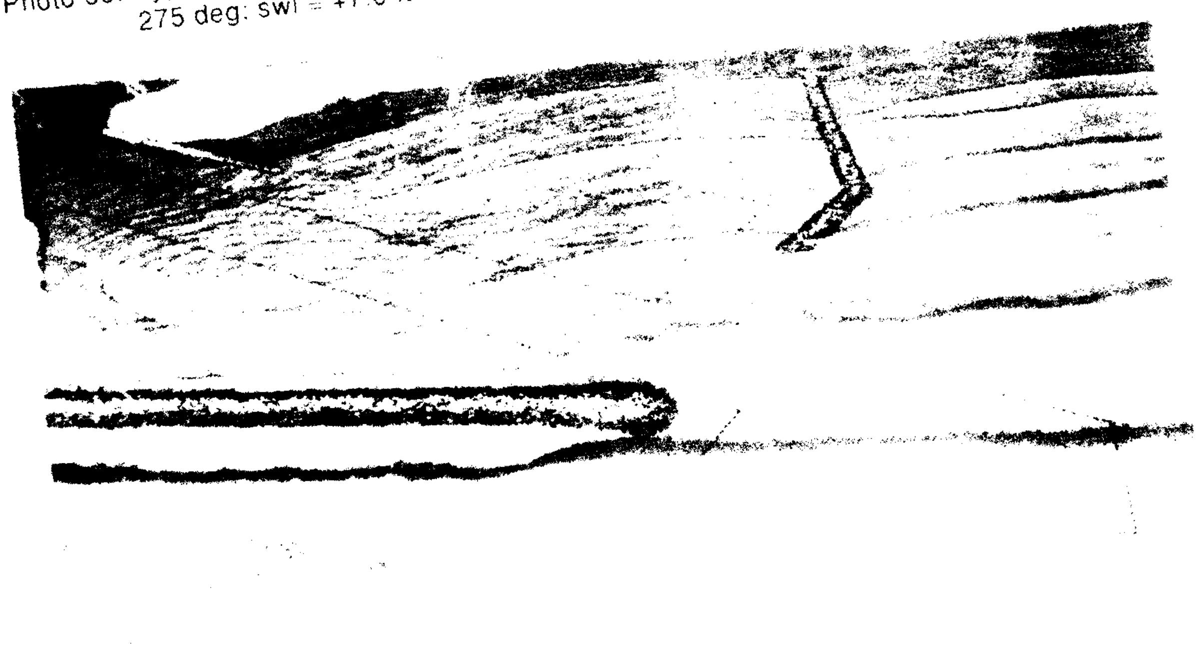


Photo 36. Typical wave patterns for Plan 15: 15-sec. 21-ft spectral waves from 275 deg: swl = +7.0 ft

Photo 37. Typical wave patterns for existing conditions; 15-sec, 21-ft monochromatic waves from 300 deg; swl = +7.0 ft

Photo 38. Typical wave patterns for existing conditions; 17-sec, 30 ft monochromatic waves from 300 deg; swl = +7.0 ft

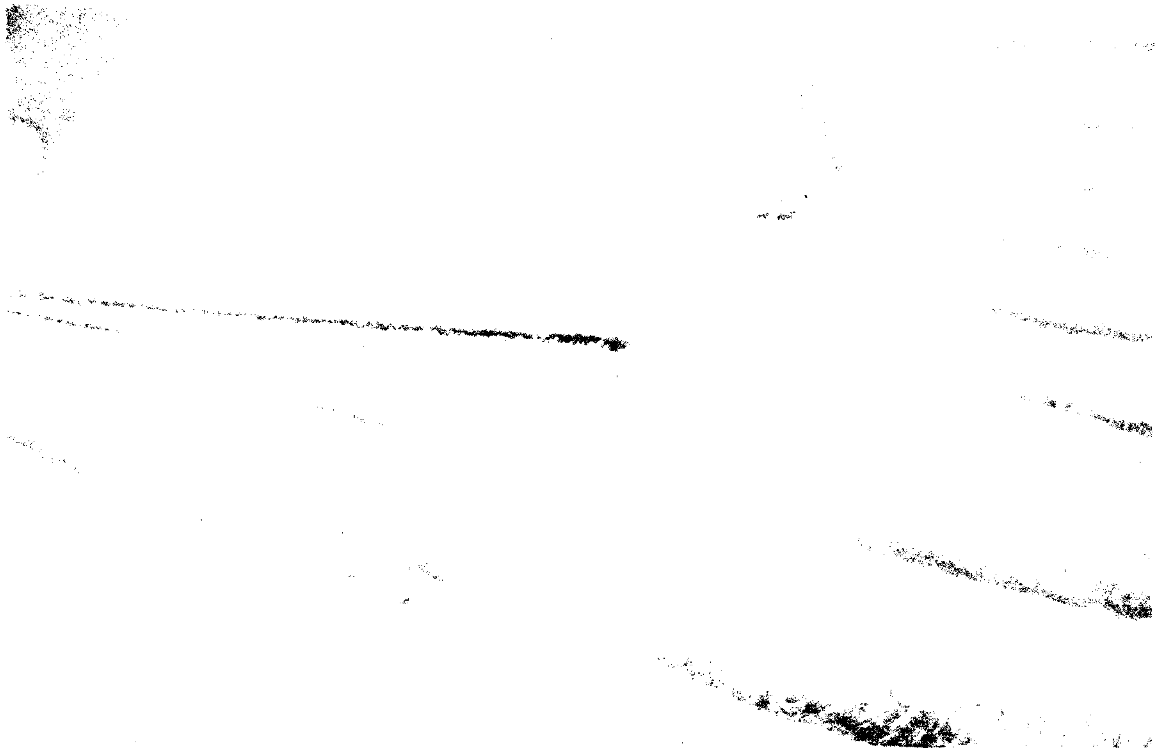


Photo 39. Typical wave patterns for existing conditions, 15-sec, 21-ft spectral waves from 300 deg; swl = +7.0 ft

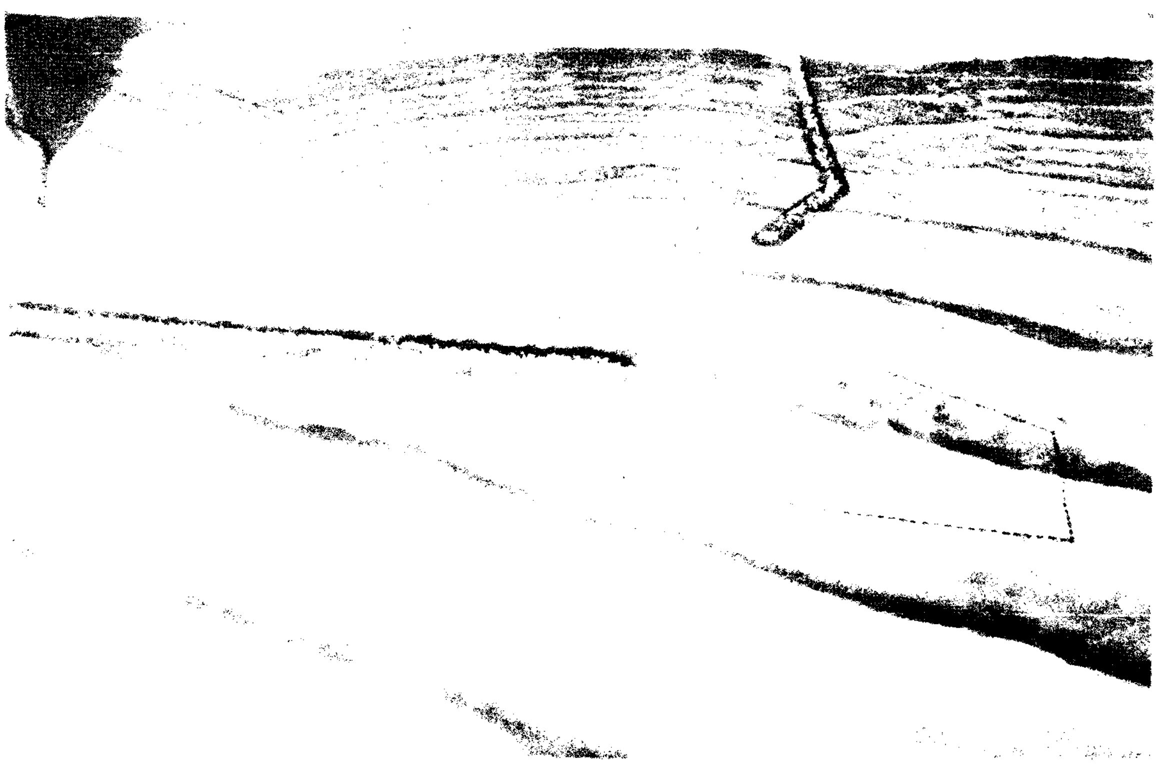


Photo 40. Typical wave patterns for Plan 14, 15-sec, 21-ft monochromatic waves from 300 deg; swl = +7.0 ft

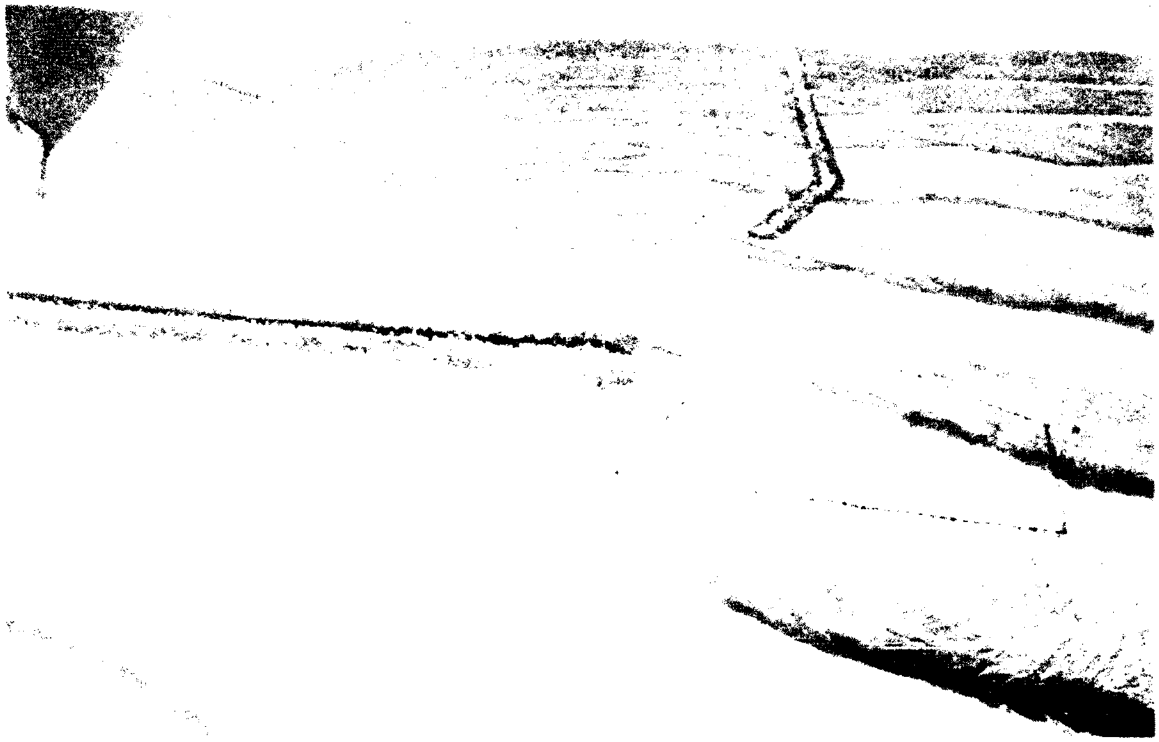


Photo 41. Typical wave patterns for Plan 14: 17-sec, 30-ft monochromatic waves from 300 deg; swl = +7.0 ft

Photo 42. Typical wave patterns for Plan 14: 15-sec, 21-ft spectral waves from 300 deg; swl = +7.0 ft

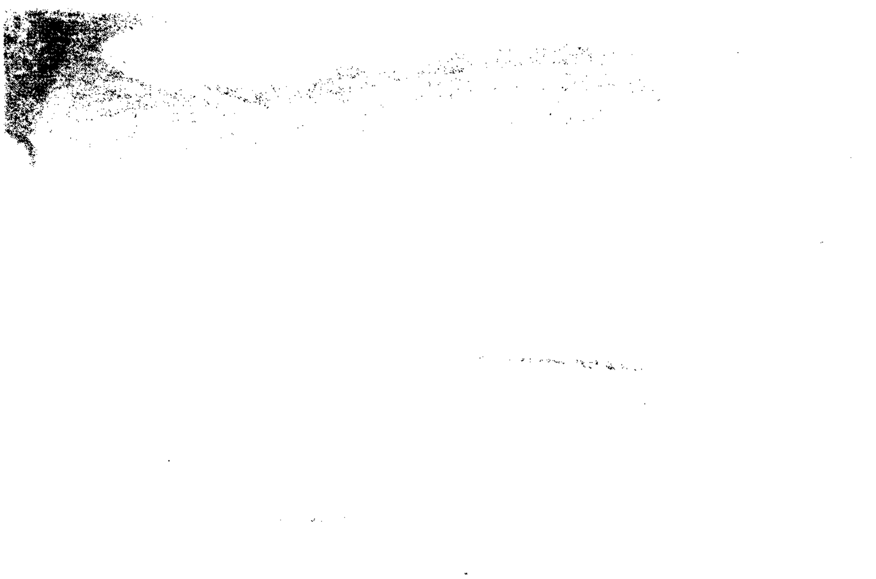


Photo 43. Typical wave patterns for Plan 15; 15-sec, 21-ft monochromatic waves from 300 deg; swl = +7.0 ft

Photo 44. Typical wave patterns for Plan 15, 17-sec, 30-ft monochromatic waves from 300 deg; swl = +7.0 ft

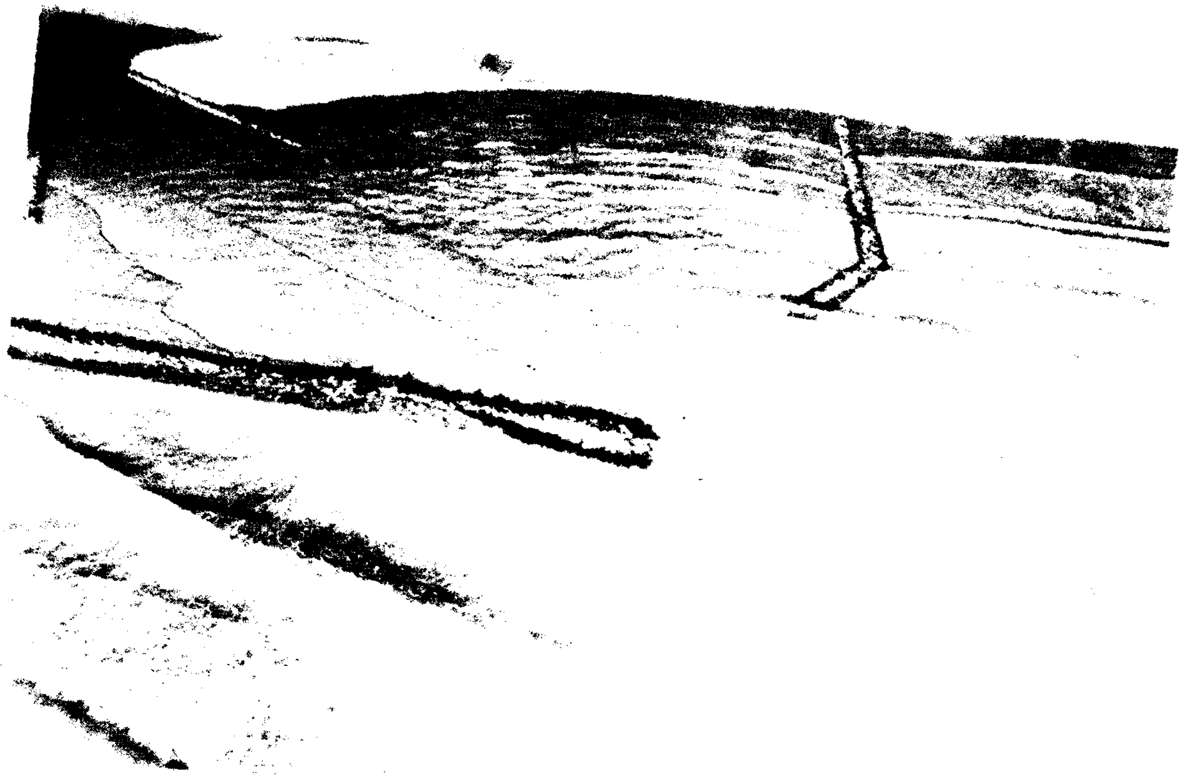


Photo 45. Typical wave patterns for Plan 15; 15-sec, 21-ft spectral waves from 300 deg; swl = +7.0 ft

Photo 46. Typical wave patterns for existing conditions; 15-sec, 21-ft monochromatic waves from 260 deg; swl = +7.0 ft

Photo 47. Typical wave patterns for existing conditions: 17 sec, 30-ft monochromatic waves from 260 deg; swl = +7.0 ft

Photo 48 Typical wave patterns for existing conditions: 15 sec, 21-ft spectral waves from 260 deg; swl = +7.0 ft

Photo 49. Typical wave patterns for Plan 14; 15-sec, 21-ft monochromatic waves from 260 deg; swl = +7.0 ft

Photo 50. Typical wave patterns for Plan 14; 17-sec, 30-ft monochromatic waves from 260 deg; swl = +7.0 ft

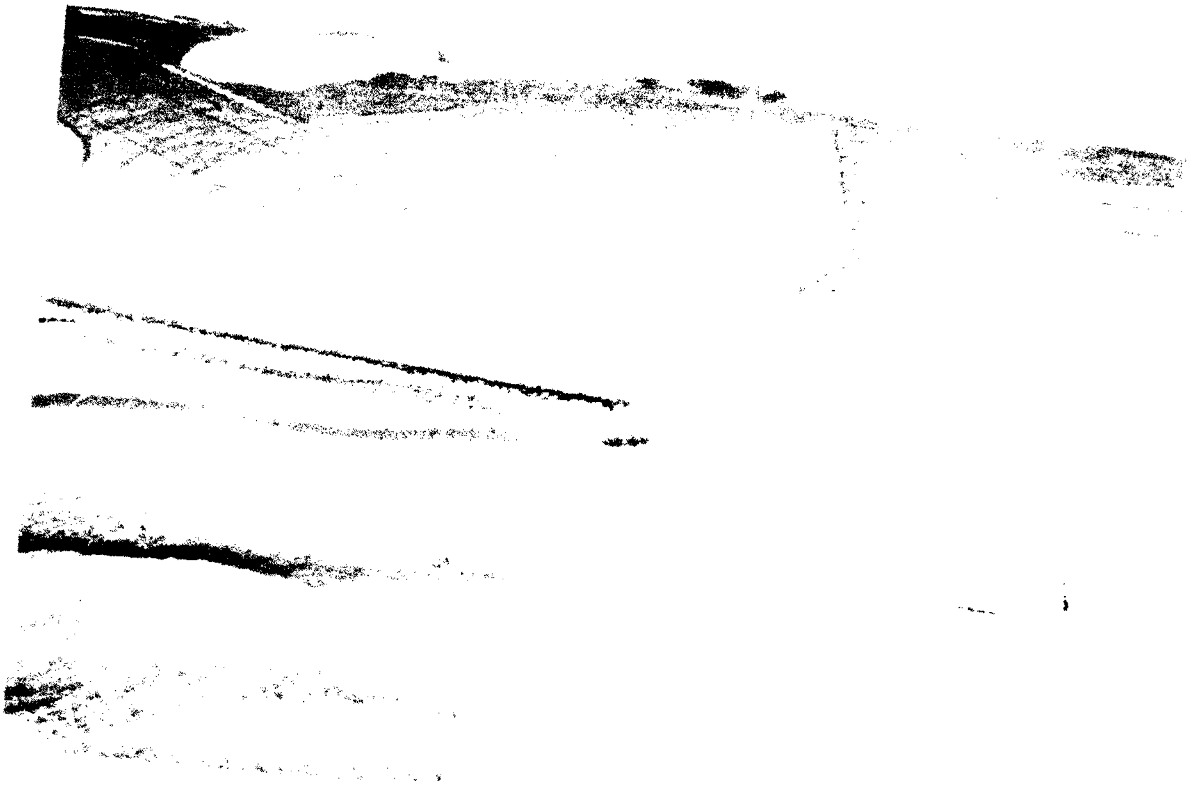


Photo 51. Typical wave patterns for Plan 14: 15-sec, 21-ft spectral waves from 260 deg; swl = +7.0 ft

Photo 52. Typical wave patterns from Plan 15: 15-sec, 21-ft monochromatic waves from 260 deg; swl = +7.0 ft

Photo 53. Typical wave patterns for Plan 15; 17-sec, 30-ft monochromatic waves from 260 deg; swl = +7.0 ft

Photo 54. Typical wave patterns for Plan 15; 15-sec, 21-ft spectral waves from 260 deg; swl = +7.0 ft

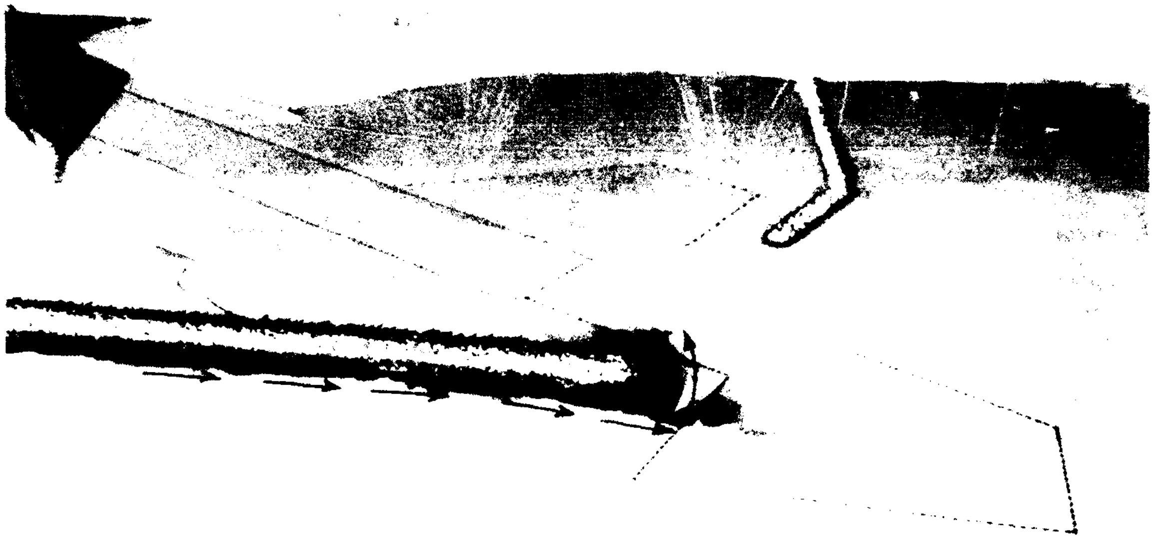


Photo 55. General movement of tracer material and subsequent deposits for Plan 14 for 12-sec, 8-ft monochromatic waves from 300 deg; swl = 0.0 ft

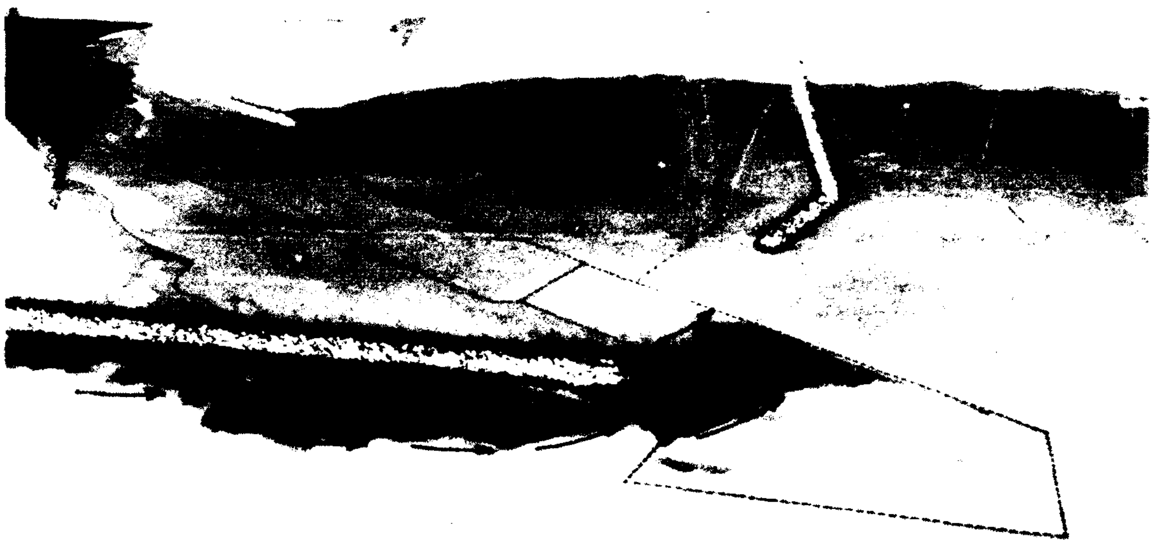


Photo 56. General movement of tracer material and subsequent deposits for Plan 14 for 15-sec, 12-ft monochromatic waves from 300 deg; swl = 0.0 ft

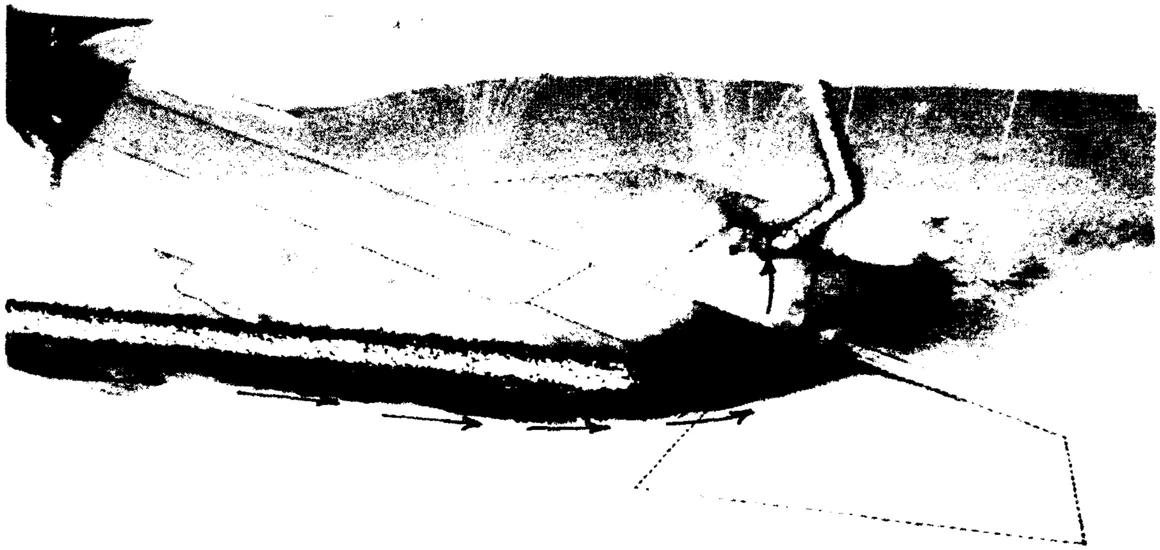


Photo 57. General movement of tracer material and subsequent deposits for Plan 14 for 17-sec, 16-ft monochromatic waves from 300 deg; swl = 0.0 ft

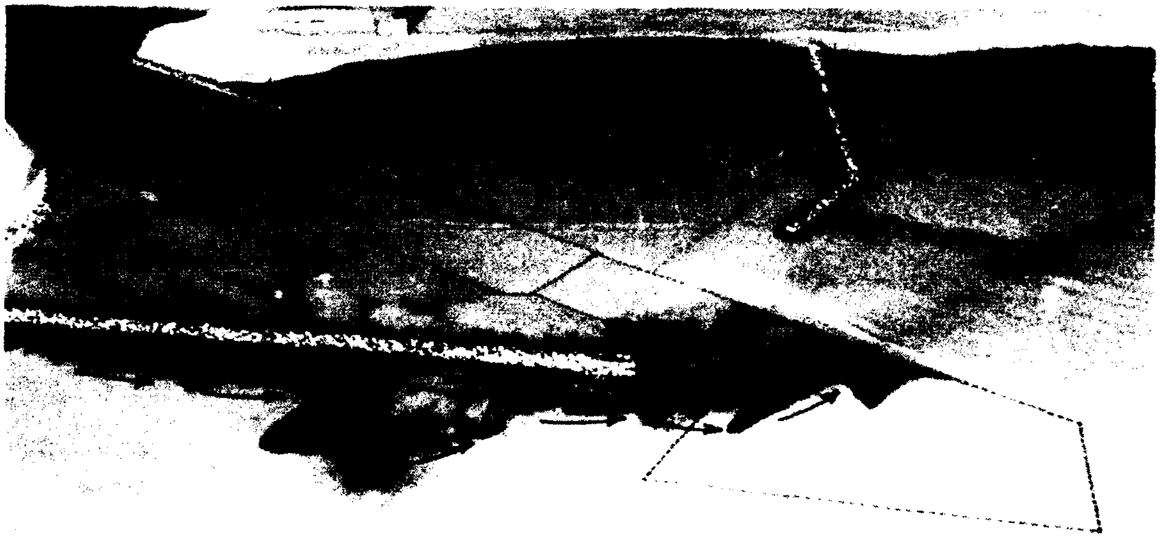


Photo 58. General movement of tracer material and subsequent deposits for Plan 14 for 15-sec, 21-ft monochromatic waves from 300 deg; swl = +7.0 ft

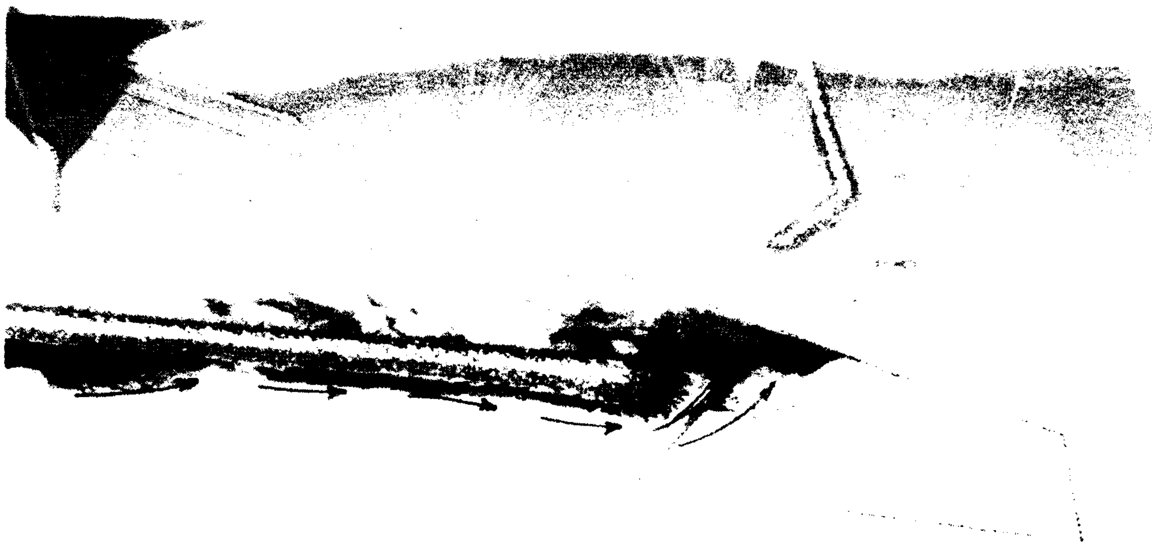


Photo 59. General movement of tracer material and subsequent deposits for Plan 14 for 17-sec, 26-ft monochromatic waves from 300 deg; swl = +7.0 ft

Photo 60. General movement of tracer material and subsequent deposits for Plan 14 for 12-sec. 8-ft monochromatic waves from 250 deg; swl = 0.0 ft

Photo 61. General movement of tracer material and subsequent deposits for Plan 14 for 15-sec, 12-ft monochromatic waves from 250 deg; swl = 0.0 ft

Photo 62. General movement of tracer material and subsequent deposits for Plan 14 for 17-sec, 16-ft monochromatic waves from 250 deg; swl = 0.0 ft

Photo 63. General movement of tracer material and subsequent deposits for Plan 14 for 15-sec, 21-ft monochromatic waves from 250 deg; swl = +7.0 ft

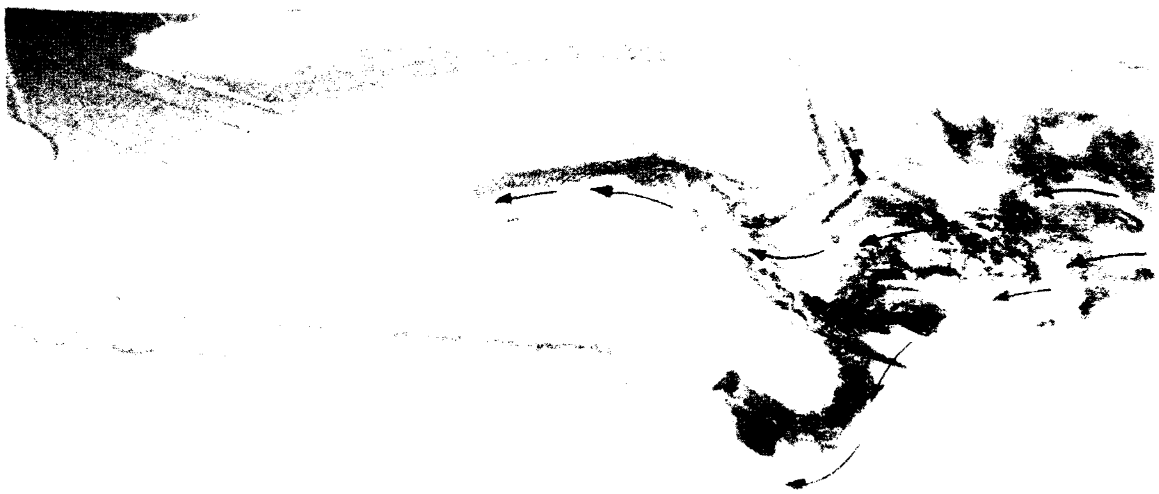
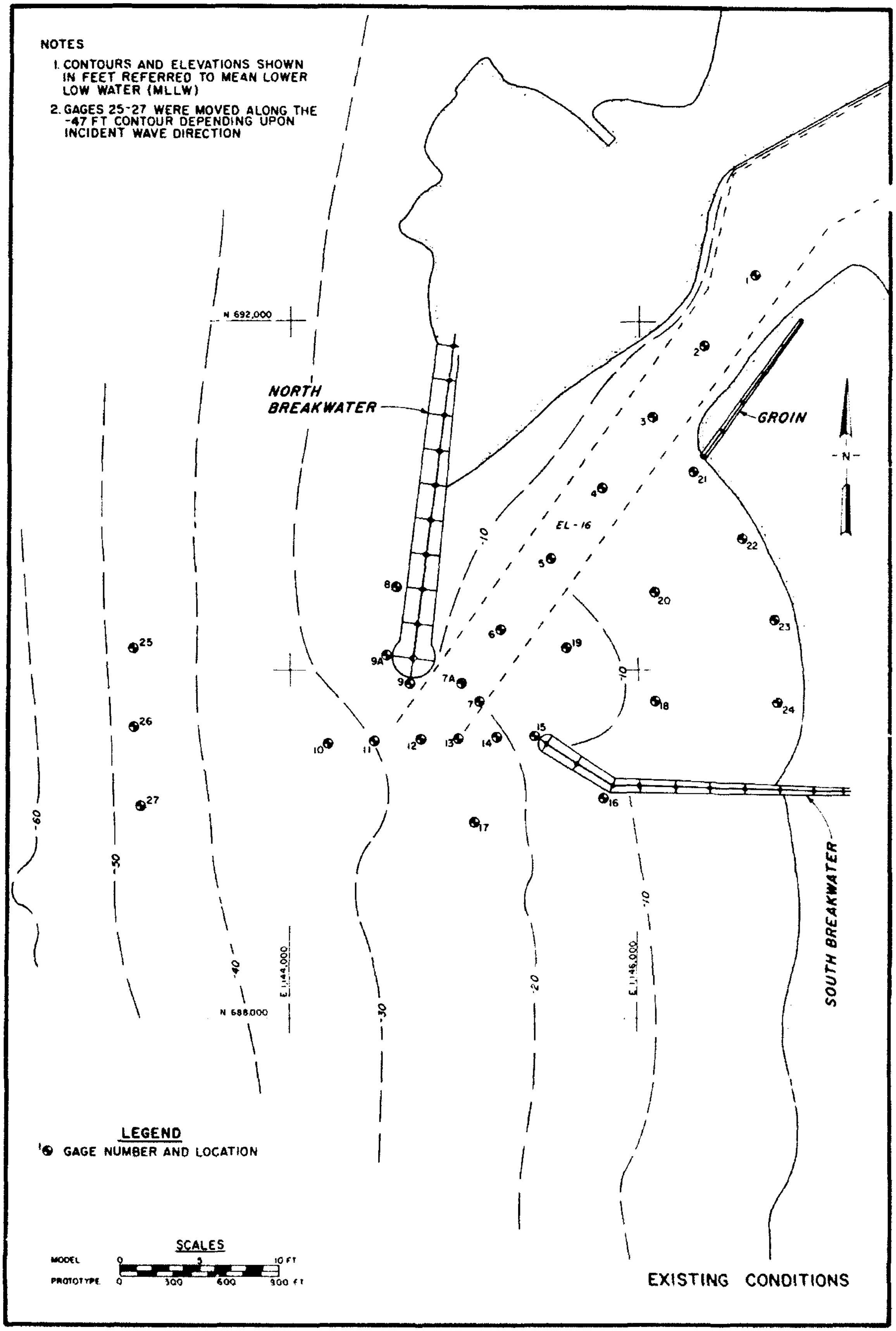


Photo 64. General movement of tracer material and subsequent deposits for Plan 14 for 17-sec, 26-ft monochromatic waves from 250 deg; swl = +7.0 ft


NOTES
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGES 25-27 WERE MOVED ALONG THE -47 FT CONTOUR DEPENDING UPON INCIDENT WAVE DIRECTION
N 692,000
NORTH BREAKWATER
GROIN
N
EL -16
-10
-20
-30
-40
-50
-60
N 688,000
E 1,144,000
E 1,146,000
SOUTH BREAKWATER
LEGEND
GAGE NUMBER AND LOCATION
SCALES
MODEL 0 5 10 FT
PROTOTYPE 0 300 600 900 FT
EXISTING CONDITIONS

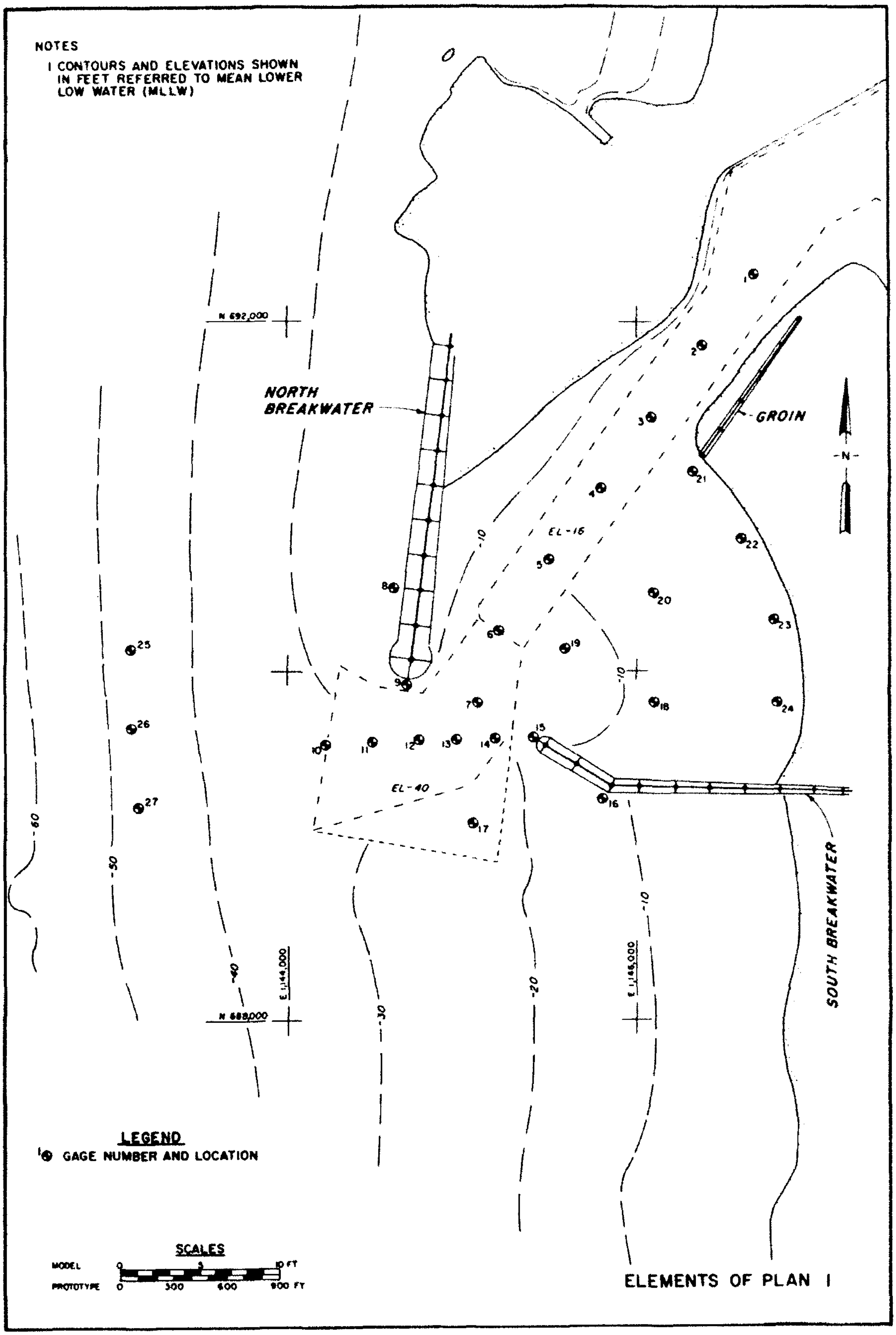
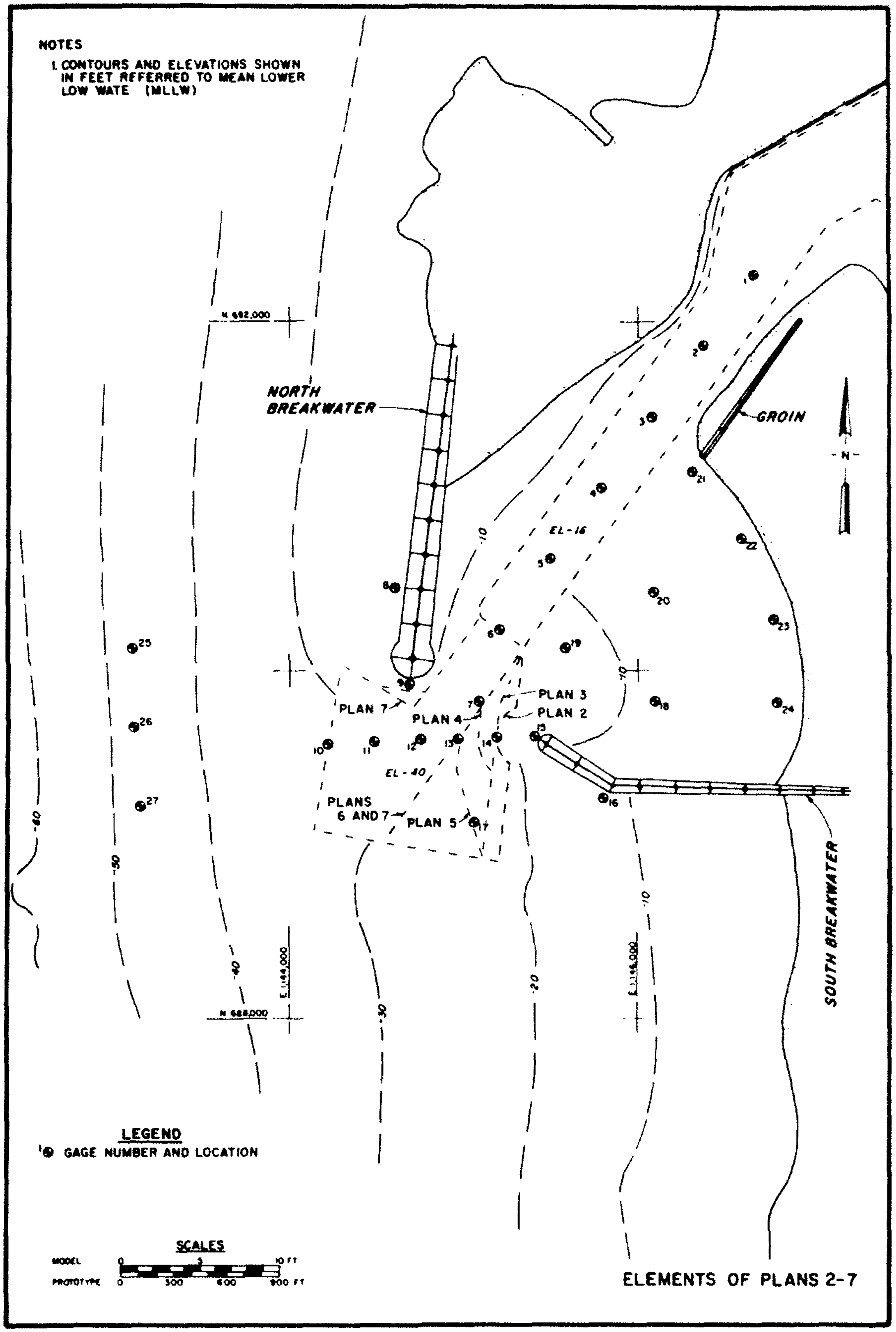
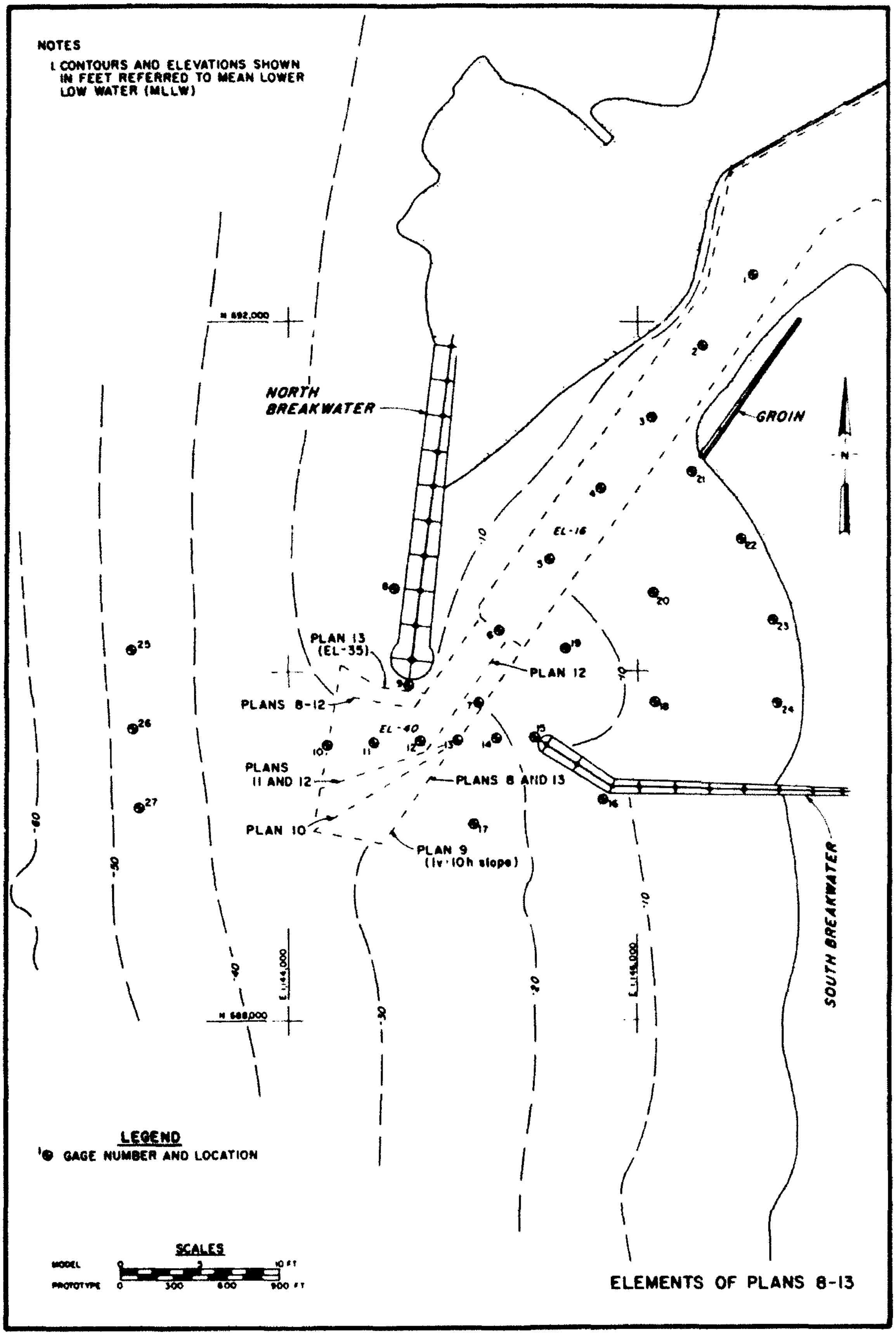
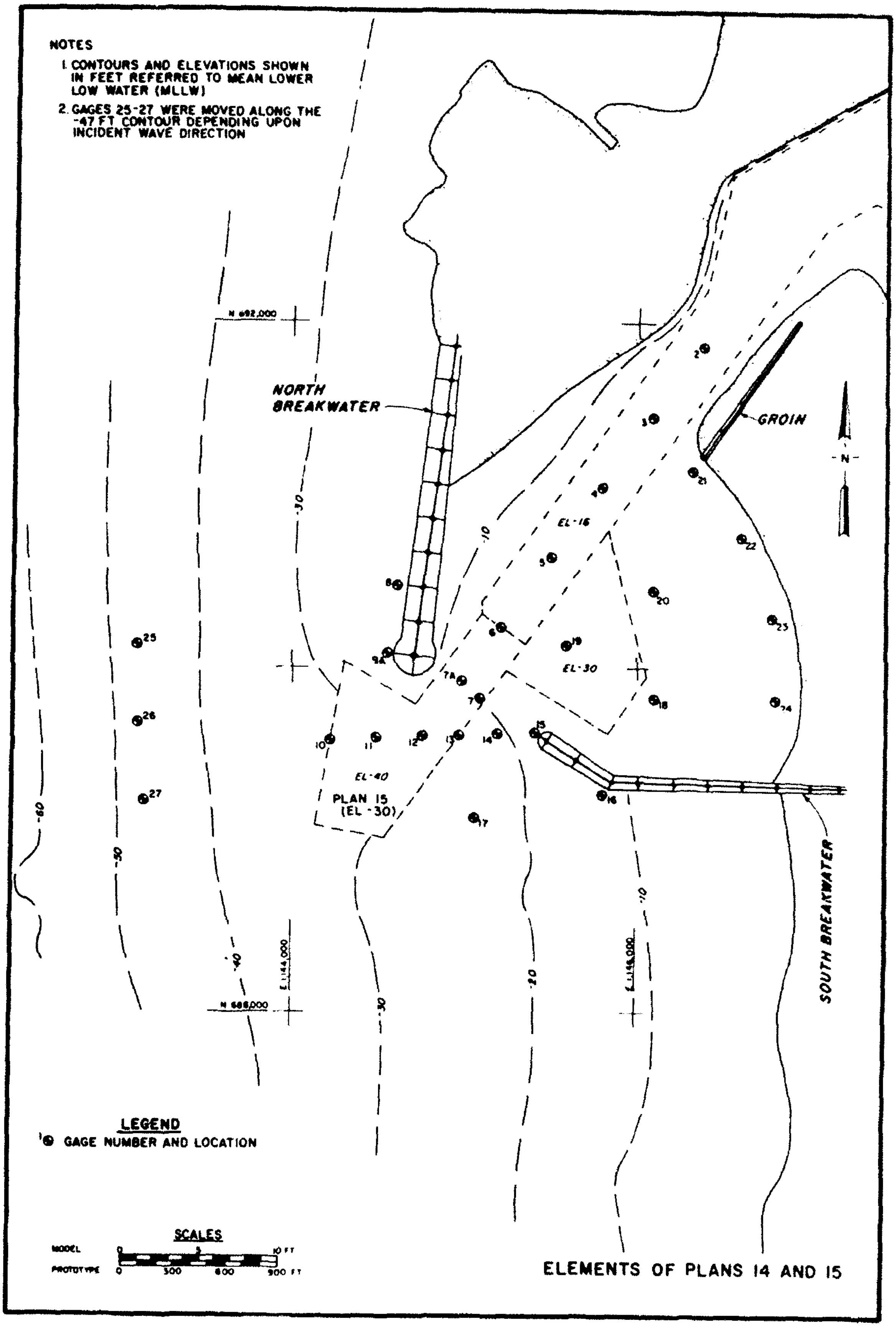

NOTES
1 CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
NORTH BREAKWATER
GROIN
SOUTH BREAKWATER
N
EL-16
EL-40
N 692,000
N 688,000
E 1,144,000
E 1,148,000
LEGEND
GAGE NUMBER AND LOCATION
SCALES
MODEL 0 5 10 FT
PROTOTYPE 0 300 600 900 FT
ELEMENTS OF PLAN 1

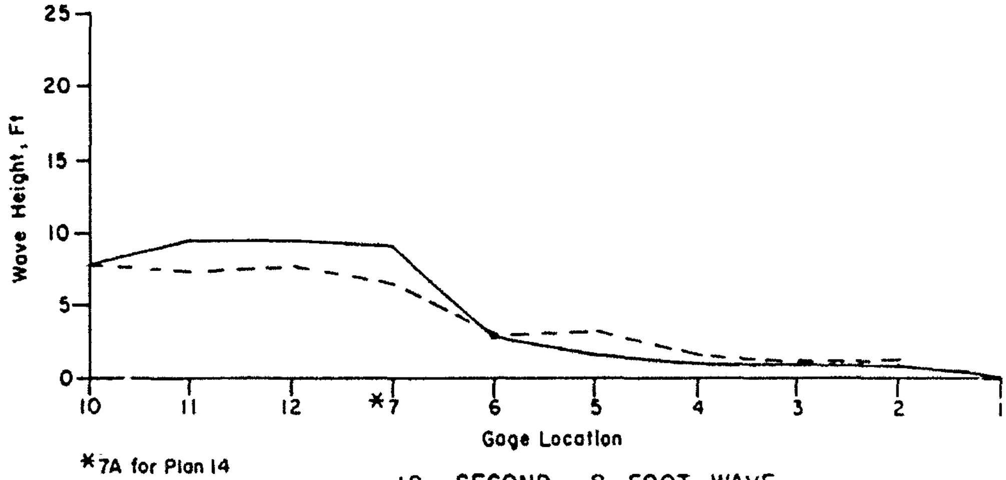
Plate 2



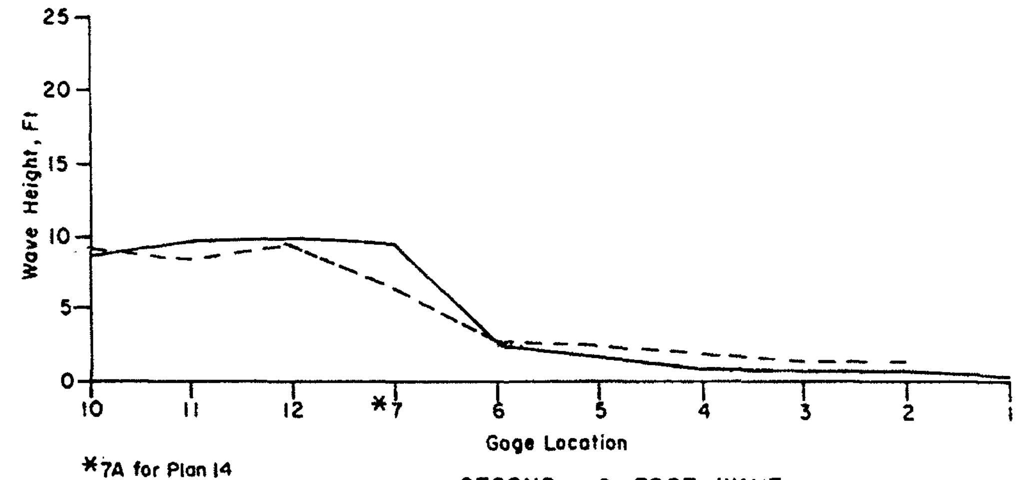
ELEMENTS OF PLANS 2-7


NOTES
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
NORTH BREAKWATER
GROIN
N
EL-16
PLAN 13 (EL-35)
PLAN 12
PLANS 8-12
EL-40
PLANS 11 AND 12
PLANS 8 AND 13
PLAN 10
PLAN 9 (1v:10h slope)
SOUTH BREAKWATER
N 692,000
N 688,000
E 1,144,000
E 1,148,000
-10
-20
-30
-40
-50
-60
LEGEND
GAGE NUMBER AND LOCATION
SCALES
MODEL
PROTOTYPE
0 300 600 900 FT
ELEMENTS OF PLANS 8-13


NOTES
1. CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
2. GAGES 25-27 WERE MOVED ALONG THE -47 FT CONTOUR DEPENDING UPON INCIDENT WAVE DIRECTION
NORTH BREAKWATER
GROIN
SOUTH BREAKWATER
N
EL -16
EL -30
EL -40
PLAN 15 (EL -30)
LEGEND
GAGE NUMBER AND LOCATION
SCALES
MODEL
PROTOTYPE
ELEMENTS OF PLANS 14 AND 15



12 - SECOND, 8 - FOOT WAVE

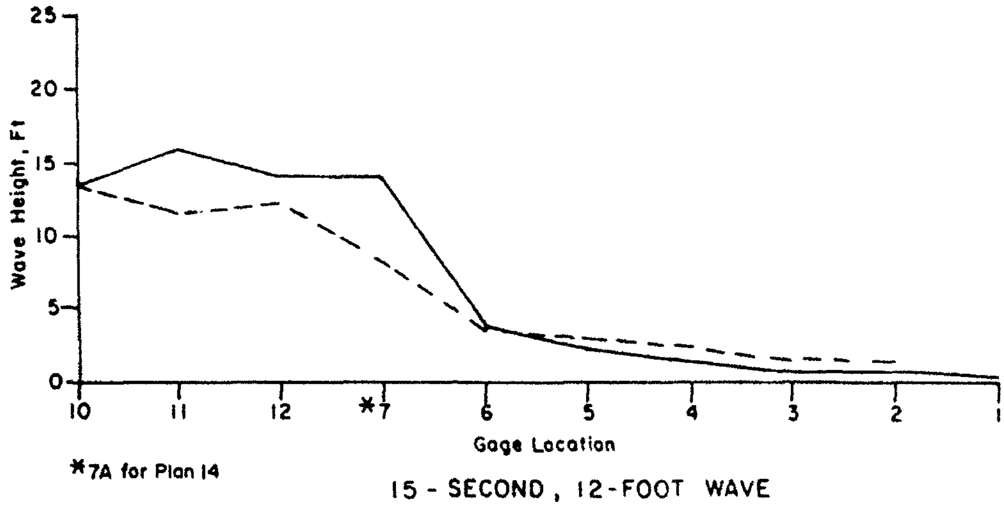


15 - SECOND, 8 - FOOT WAVE

LEGEND

——— Existing Conditions
– – – Plan 14

COMPARISON OF WAVE HEIGHT IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
12 AND 15-SEC, 8-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = 0.0 FT



15 - SECOND, 12-FOOT WAVE

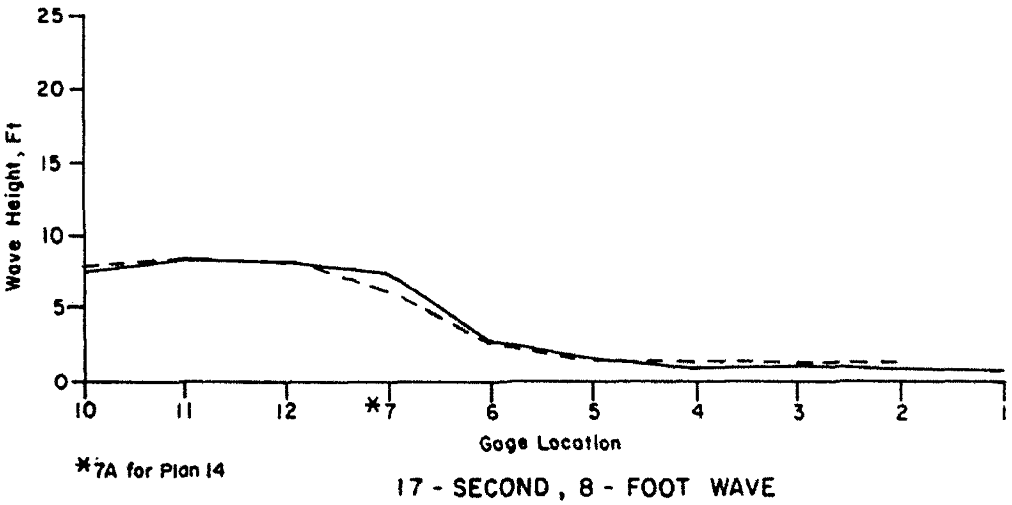
15 - SECOND, 16-FOOT WAVE

LEGEND

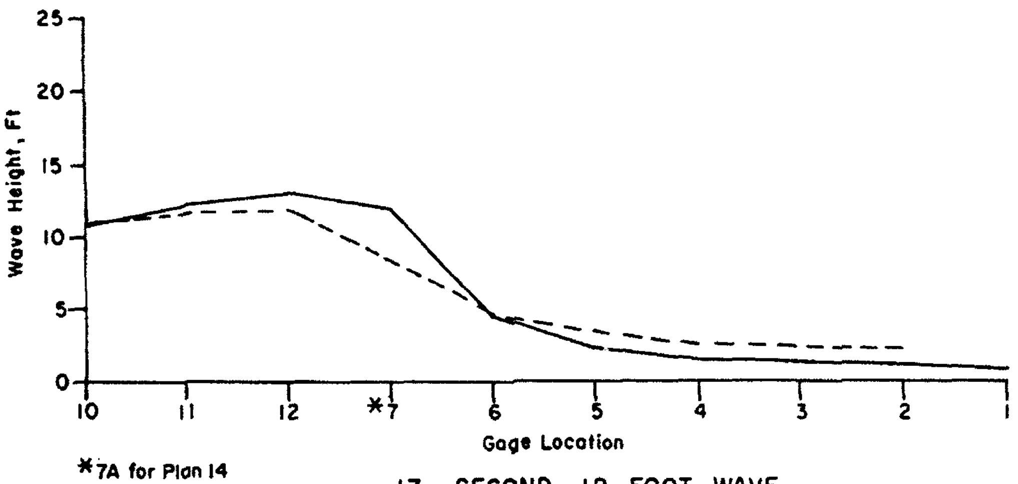
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHT IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 15-SEC, 12 AND 16-FT MONOCHROMATIC WAVES FROM 275 DEGREES, SWL = 0.0 FT



17 - SECOND, 8 - FOOT WAVE

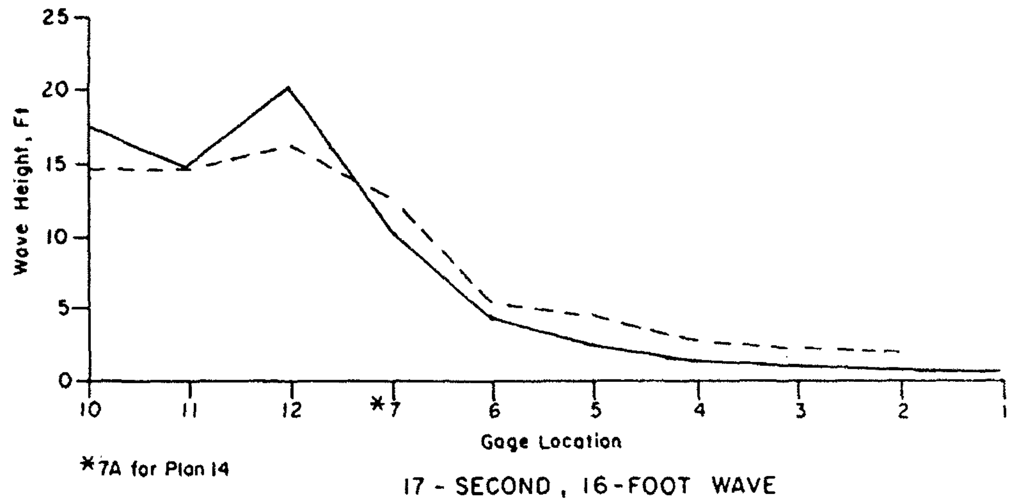


17 - SECOND, 12 - FOOT WAVE

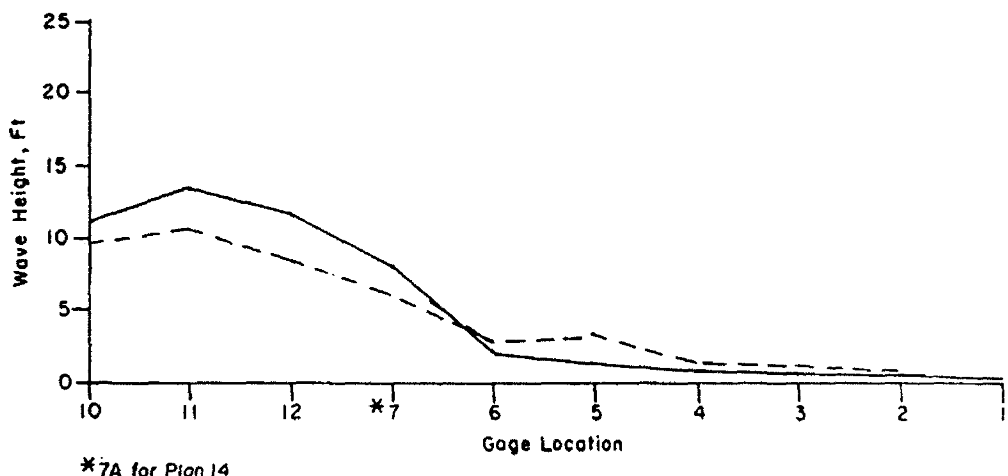
LEGEND

——— Existing Conditions
– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
17-SEC, 8 AND 12-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = 0.0 FT



17 - SECOND, 16-FOOT WAVE



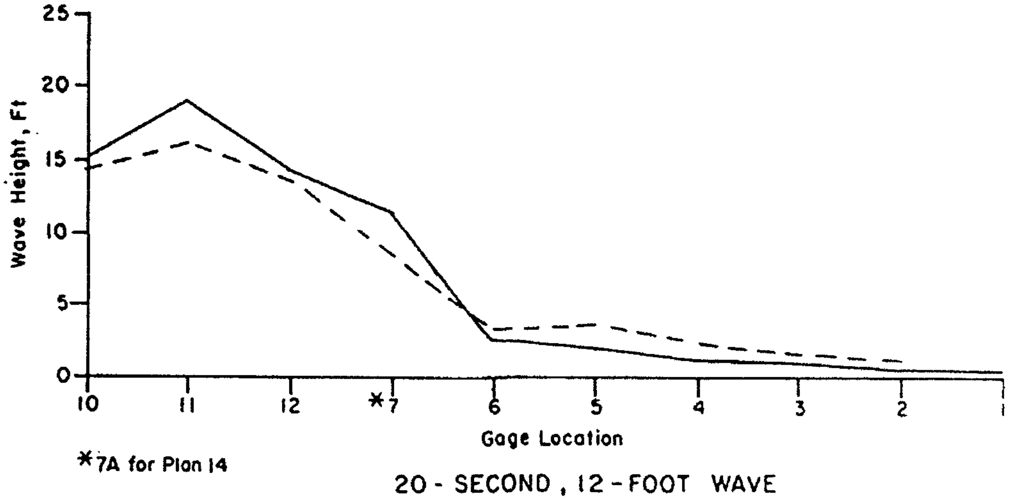
20 - SECOND, 8 - FOOT WAVE

LEGEND

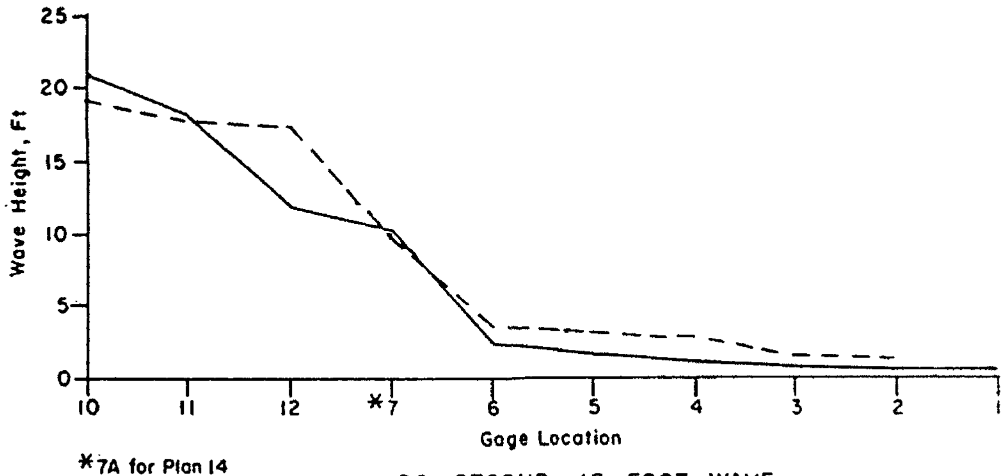
——— Existing Conditions

– — — Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
17-SEC, 16-FT AND 20-SEC, 8-FT MONOCHROMATIC
WAVES FROM 275 DEGREES, SWL = 0.0 FT



20 - SECOND, 12 - FOOT WAVE



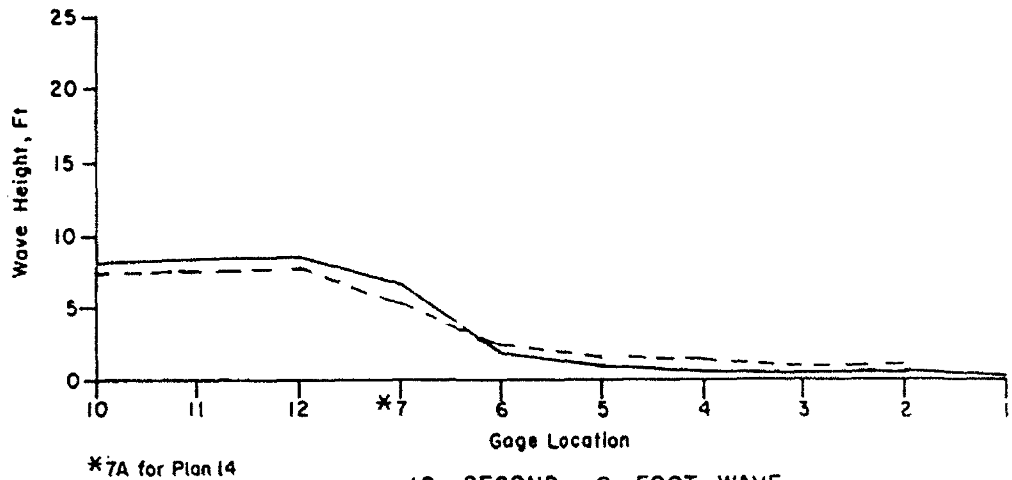
20 - SECOND, 16 - FOOT WAVE

LEGEND

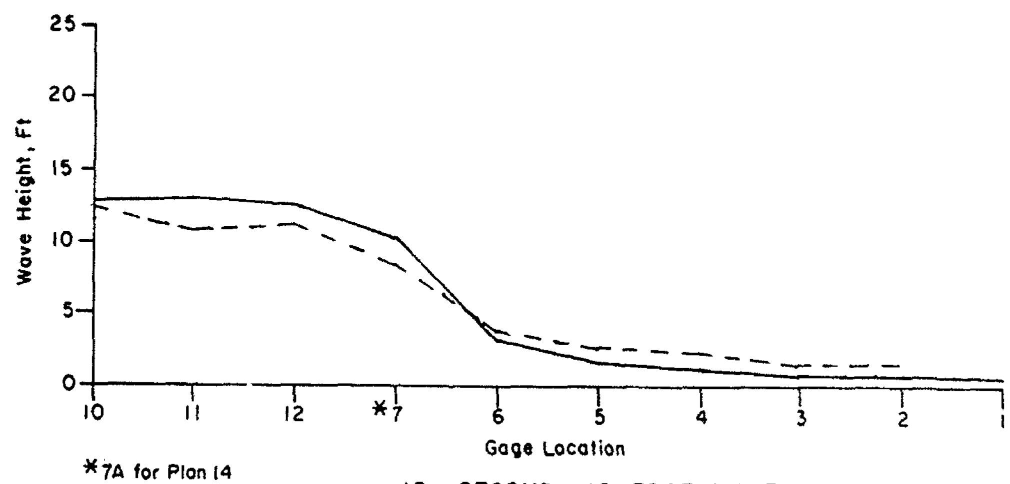
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
20-SEC, 12 AND 16-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = 0.0 FT



12 - SECOND, 8 - FOOT WAVE



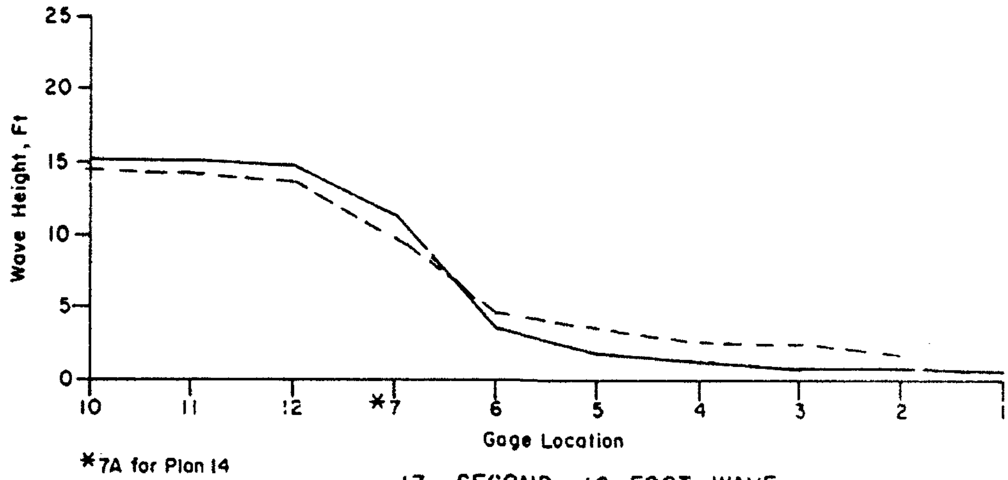
15 - SECOND, 12-FOOT WAVE

LEGEND

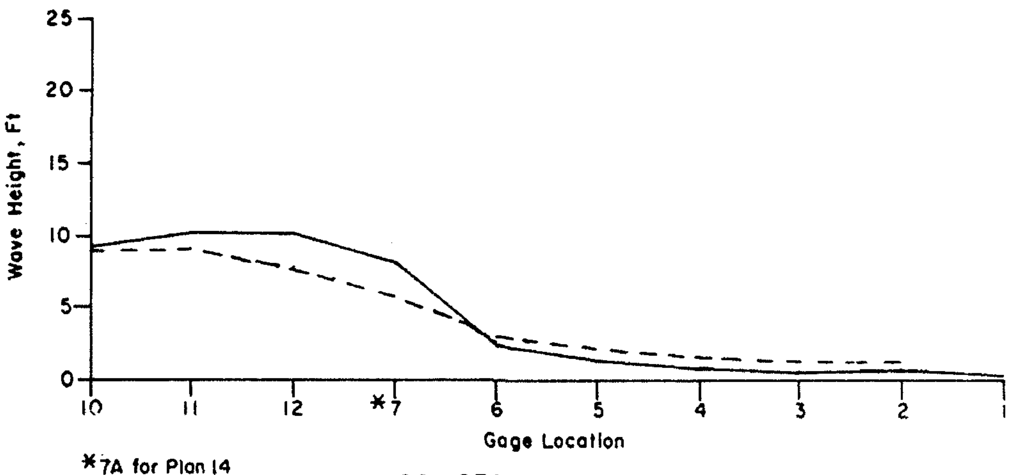
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
12-SEC, 8-FT AND 15-SEC, 12-FT SPECTRAL WAVES
FROM 275 DEGREES, SWL = 0.0 FT



17 - SECOND, 16-FOOT WAVE

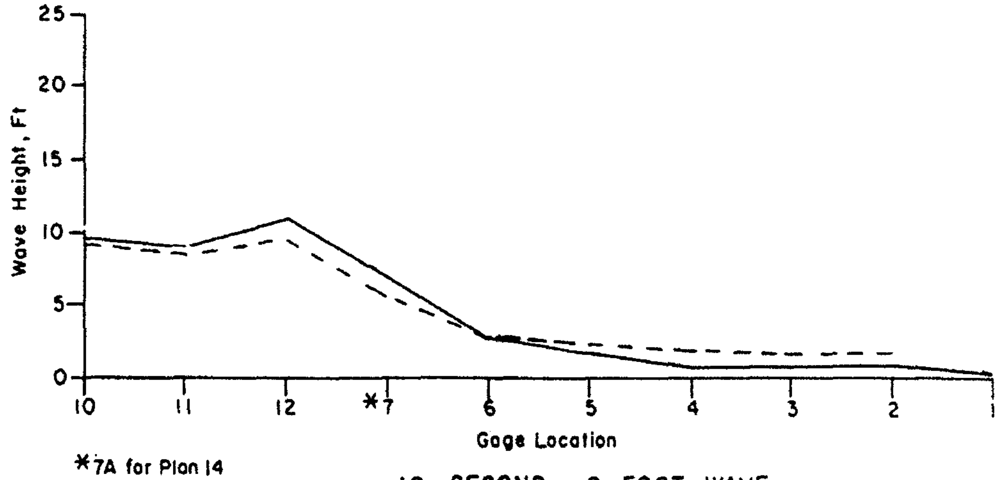


20 - SECOND, 8 - FOOT WAVE

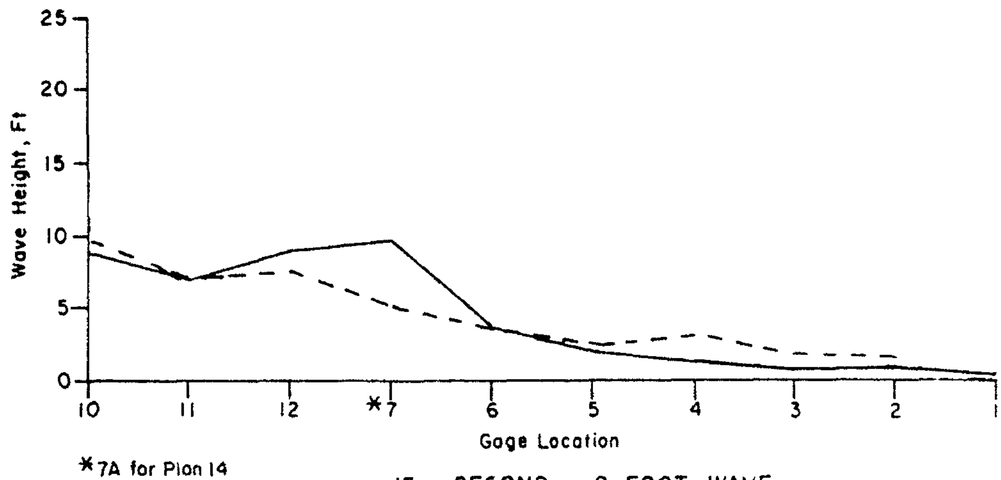
LEGEND

——— Existing Conditions
– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 17-SEC, 16-FT AND 20-SEC, 8-FT SPECTRAL WAVES FROM 275 DEGREES, SWL = 0.0 FT



12 - SECOND , 8-FOOT WAVE



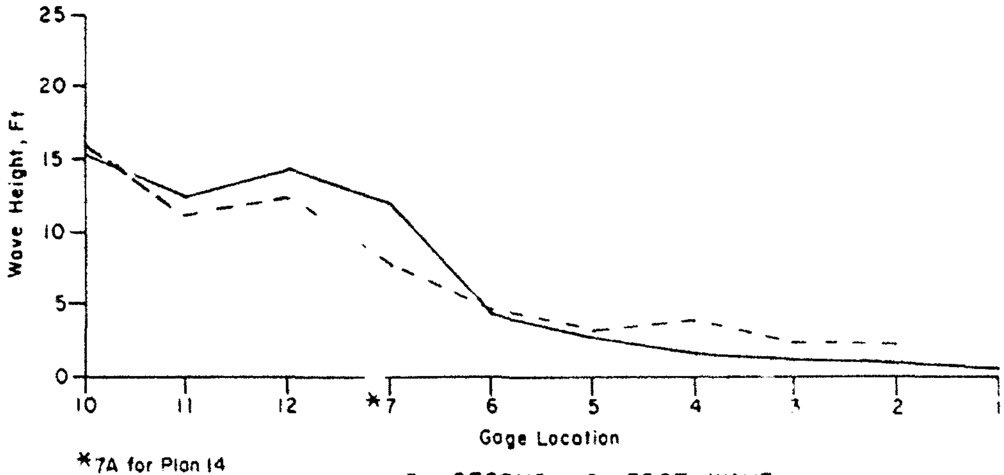
15 - SECOND , 8-FOOT WAVE

LEGEND

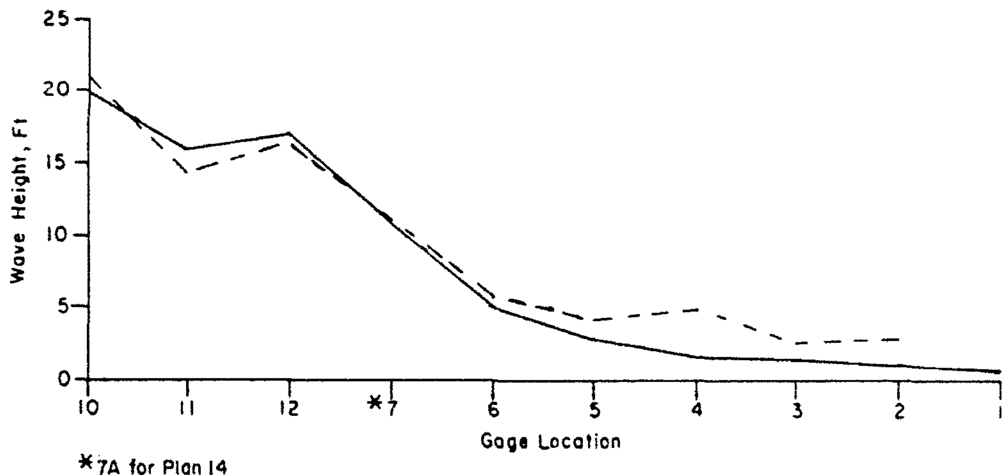
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
12 AND 15-SEC, 8-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = +2.9 FT



15 - SECOND, 12 - FOOT WAVE



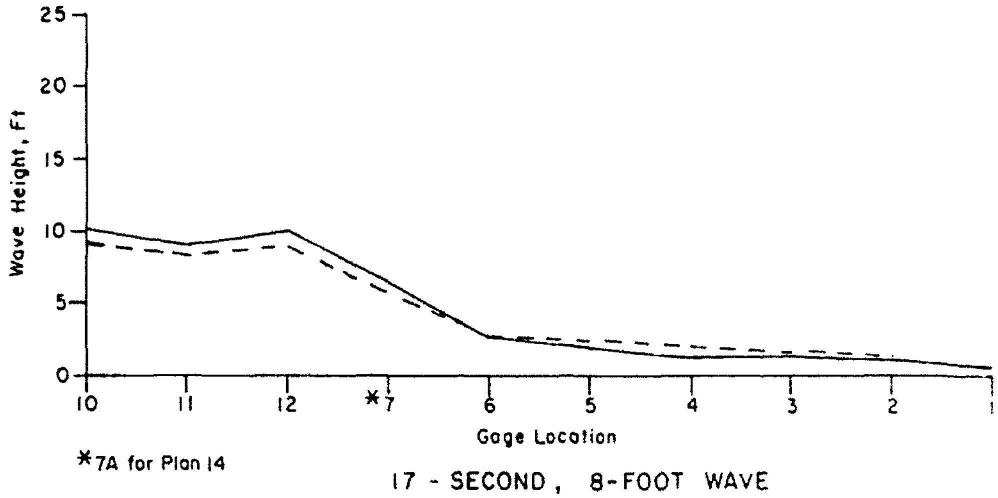
15 - SECOND, 16 - FOOT WAVE

LEGEND

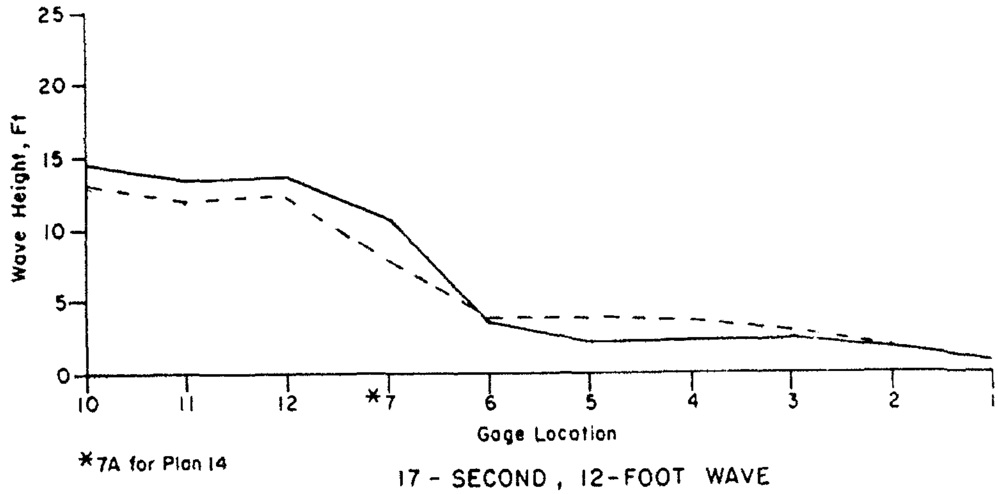
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
15-SEC, 12 AND 16-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = +2.9 FT



17 - SECOND, 8-FOOT WAVE

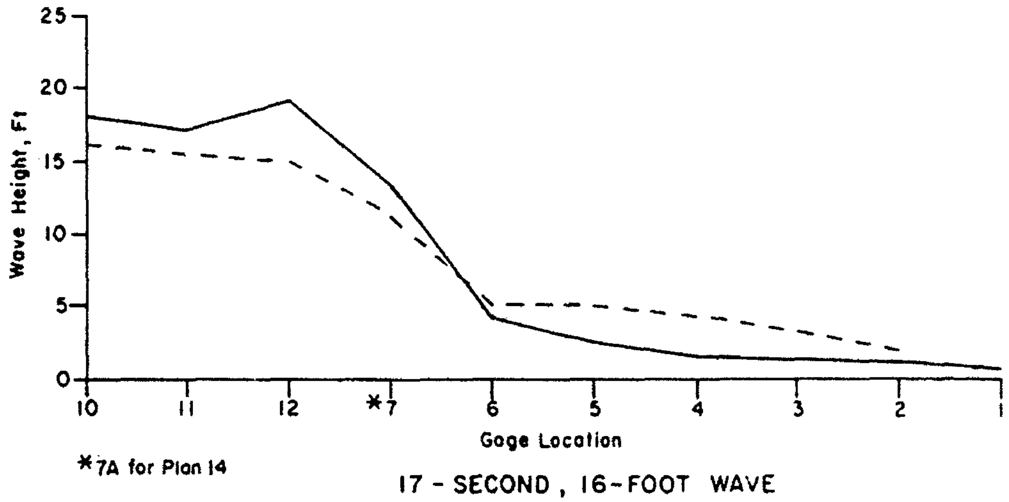


17 - SECOND, 12-FOOT WAVE

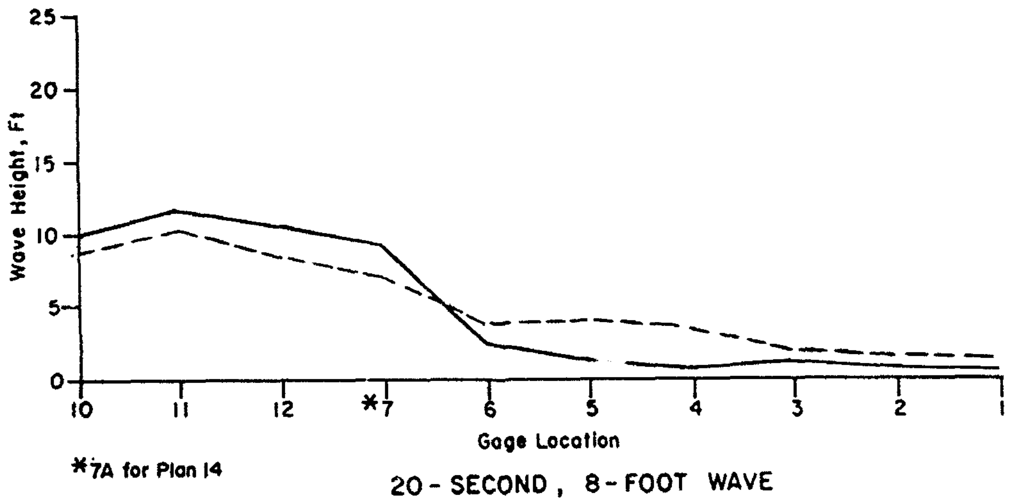
LEGEND

——— Existing Conditions
– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
17-SEC, 8 AND 12-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = +2.9 FT



17 - SECOND, 16-FOOT WAVE

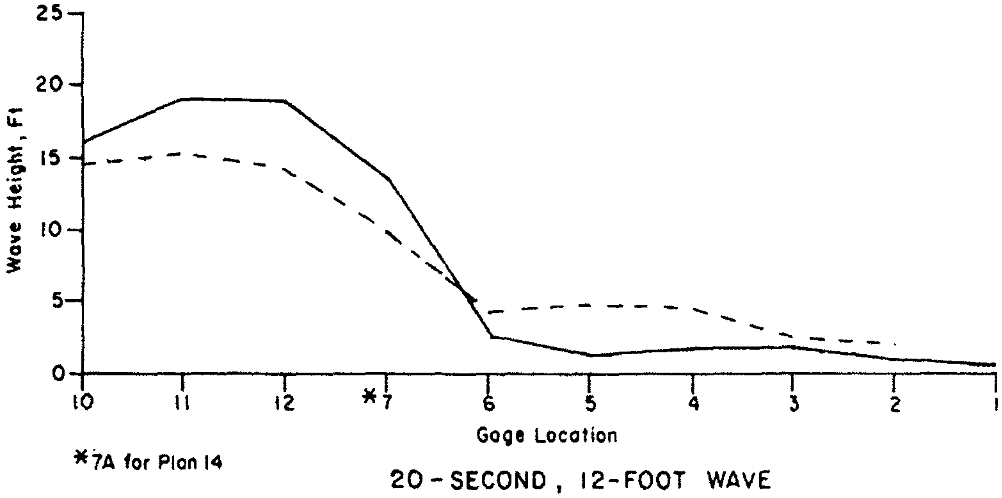


20 - SECOND, 8 - FOOT WAVE

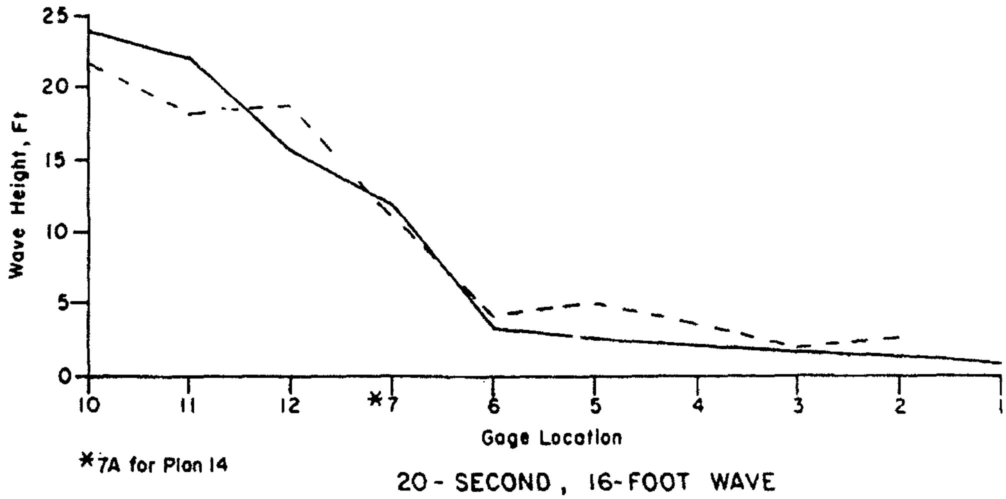
LEGEND

——— Existing Conditions
– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
17-SEC, 16-FT AND 20-SEC, 8-FT MONOCHROMATIC
WAVES FROM 275 DEGREES, SWL = +2.9 FT



20-SECOND, 12-FOOT WAVE



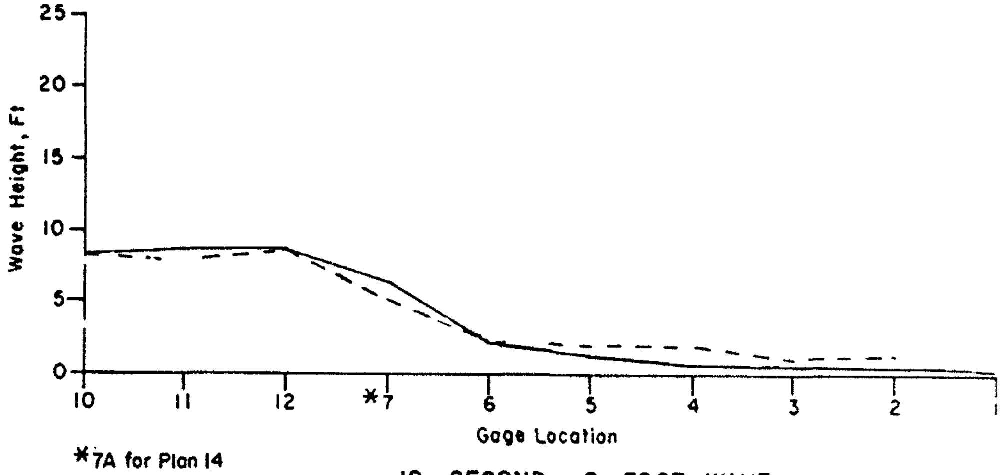
20-SECOND, 16-FOOT WAVE

LEGEND

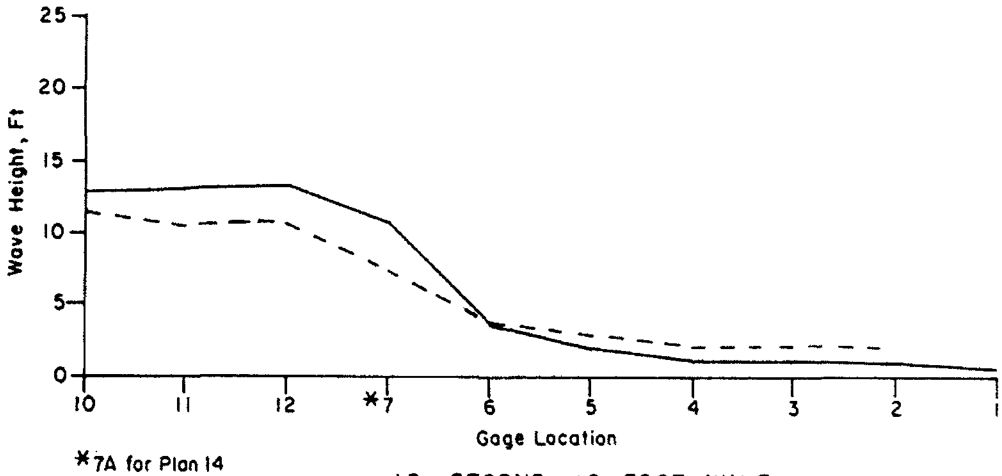
——— Existing Conditions

– – – Plan 14

COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
20-SEC, 12 AND 16-FT MONOCHROMATIC WAVES
FROM 275 DEGREES, SWL = +2.9 FT



12 - SECOND, 8 - FOOT WAVE



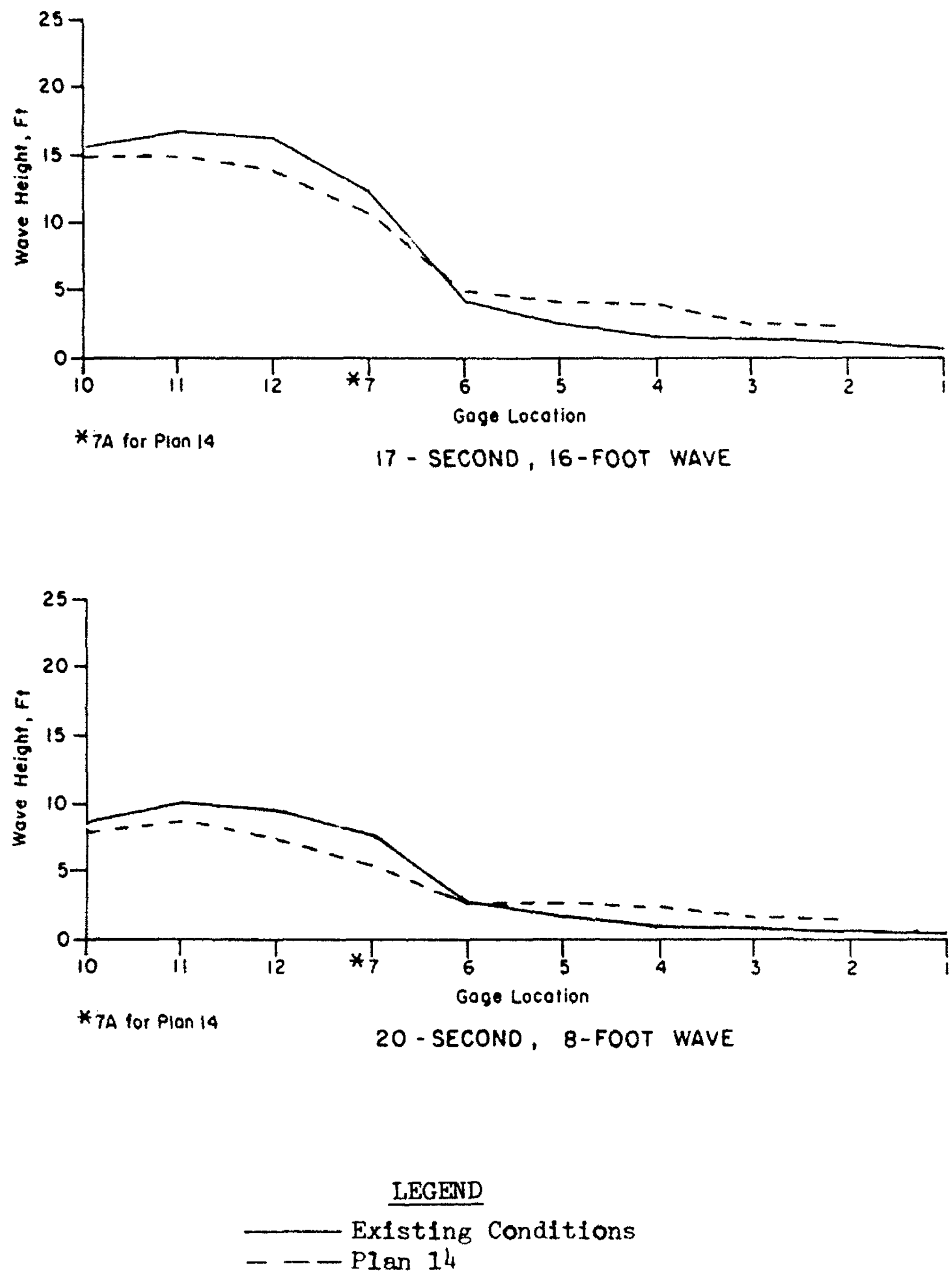
15 - SECOND, 12 - FOOT WAVE

LEGEND

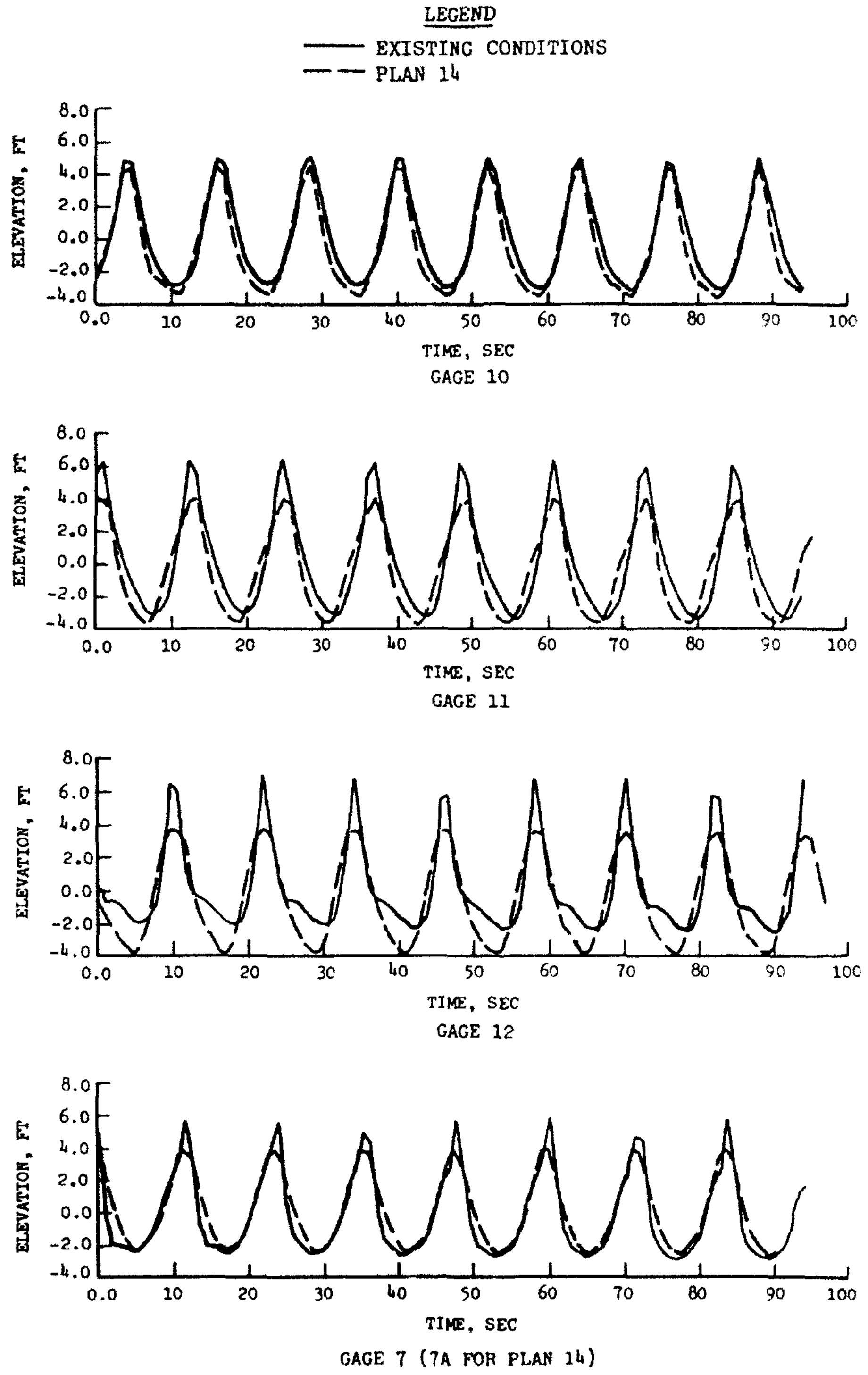
——— Existing Conditions

– – – Plan 14

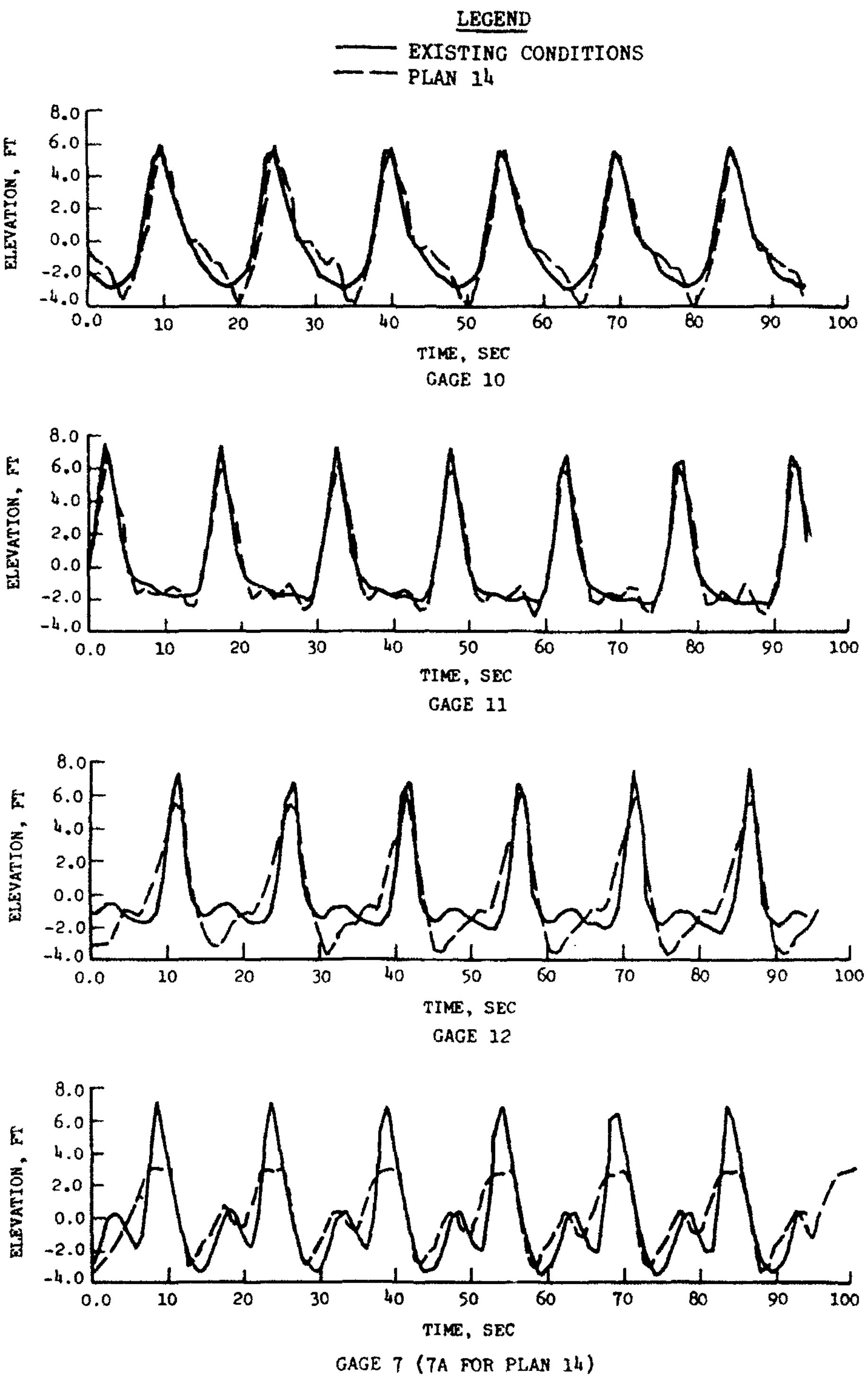
COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
12-SEC, 8-FT AND 15-SEC, 12-FT SPECTRAL
WAVES FROM 275 DEGREES, SWL = +2.9 FT



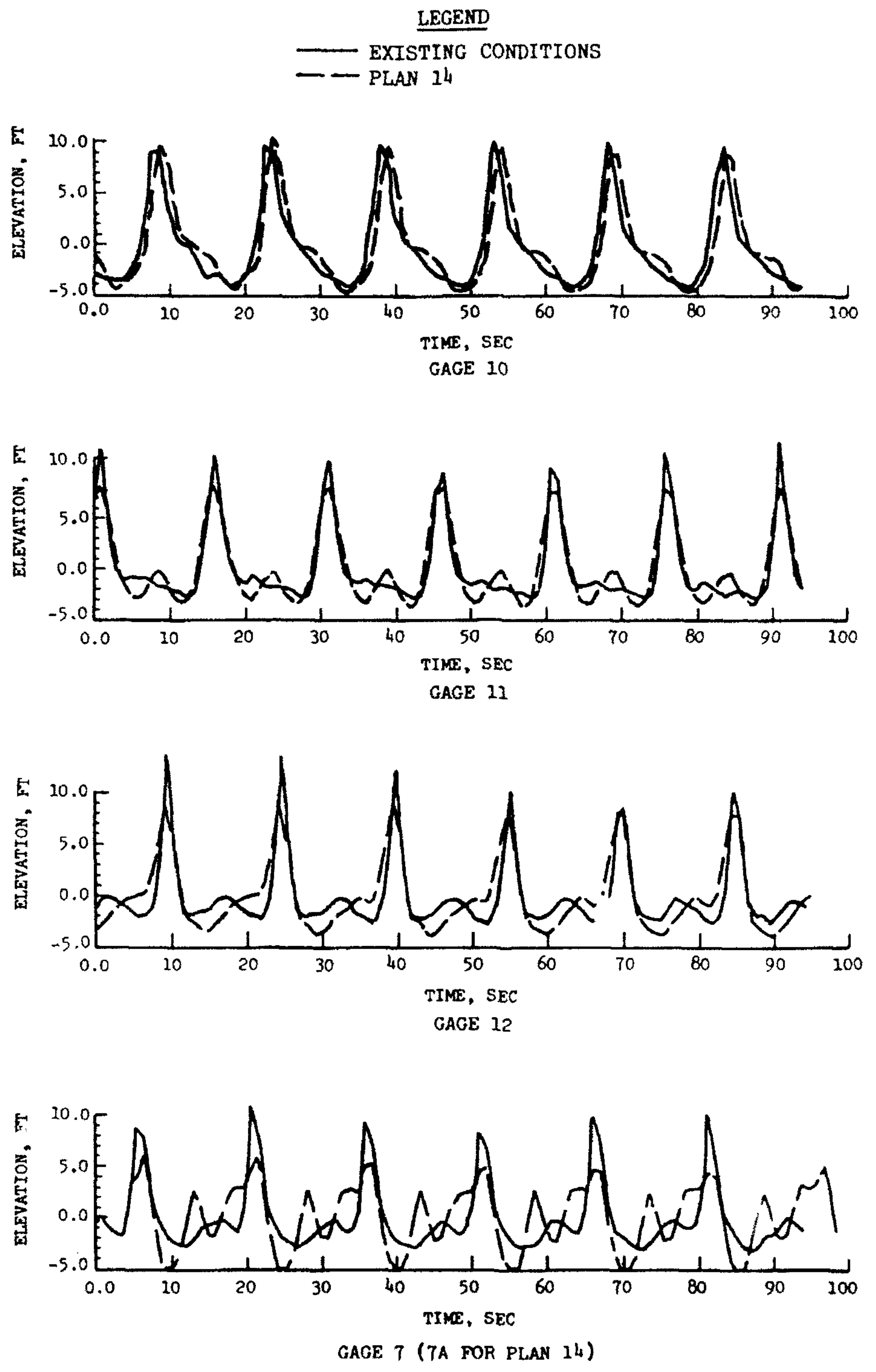
COMPARISON OF WAVE HEIGHTS IN ENTRANCE CHANNEL
FOR EXISTING CONDITIONS AND PLAN 14;
17-SEC, 16-FT AND 20-SEC, 8-FT SPECTRAL
WAVES FROM 275 DEGREES, SWL = +2.9 FT



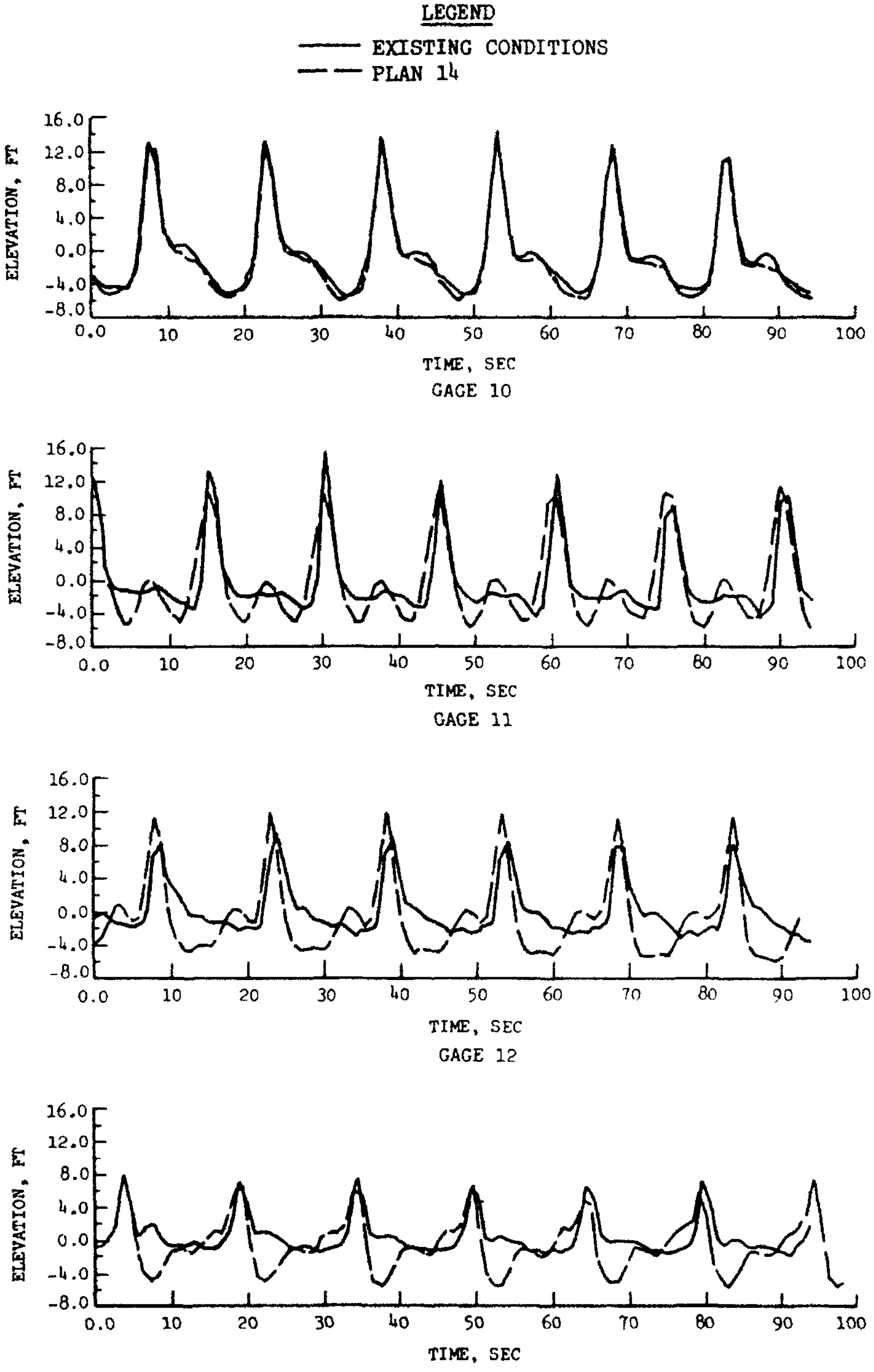
COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 12-SEC, 8-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



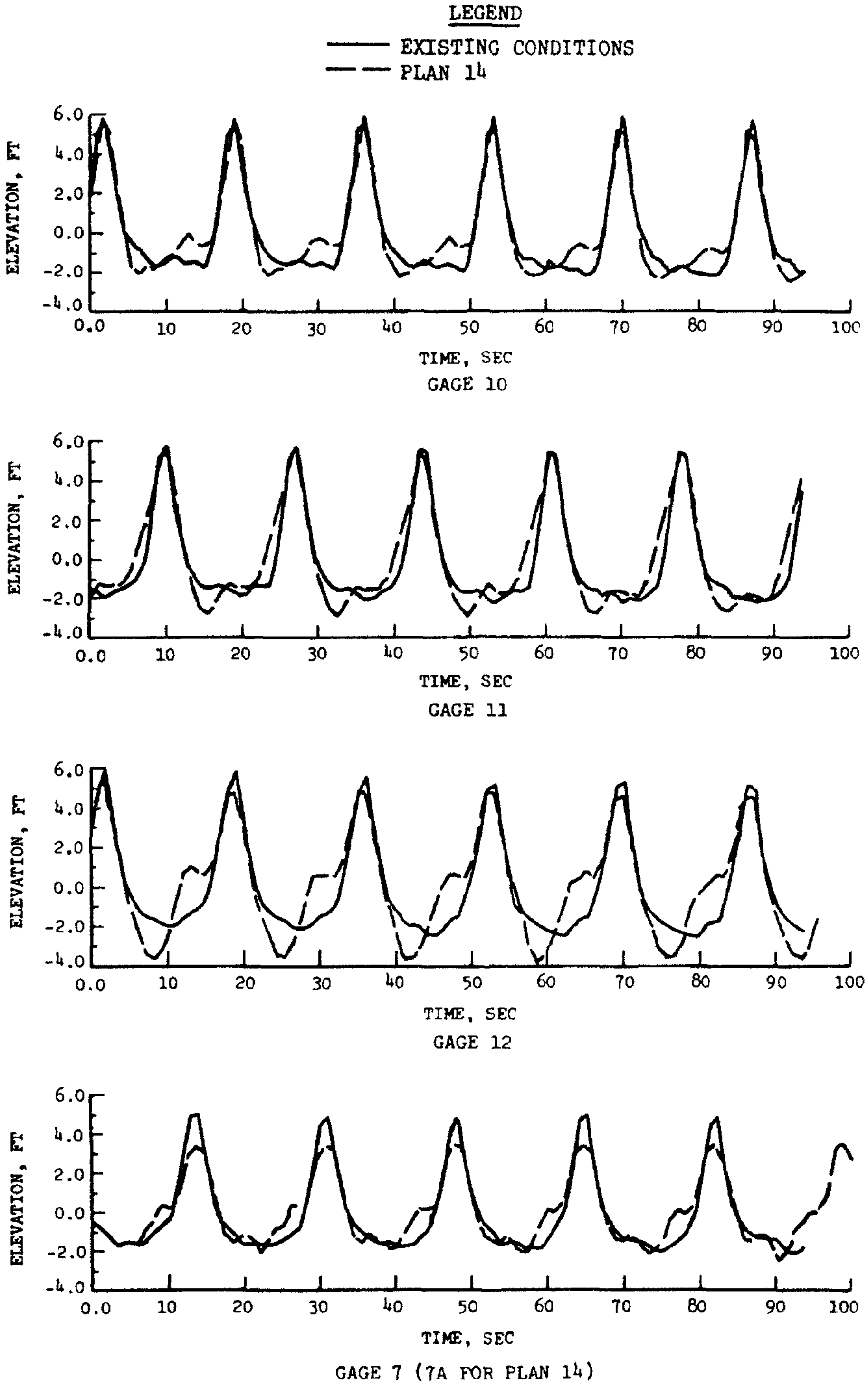
COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 15-SEC, 8-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



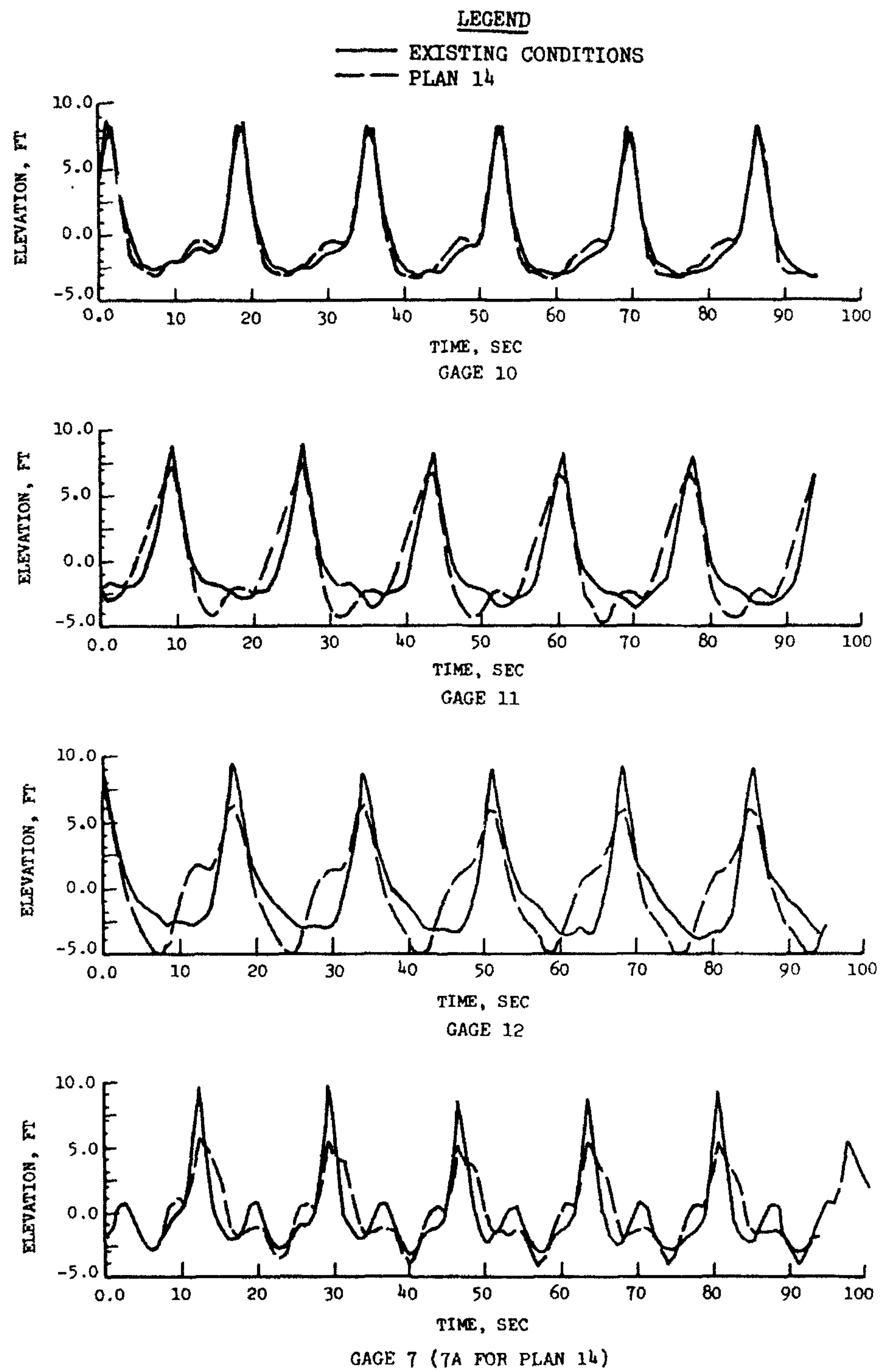
COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 15-SEC, 12-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



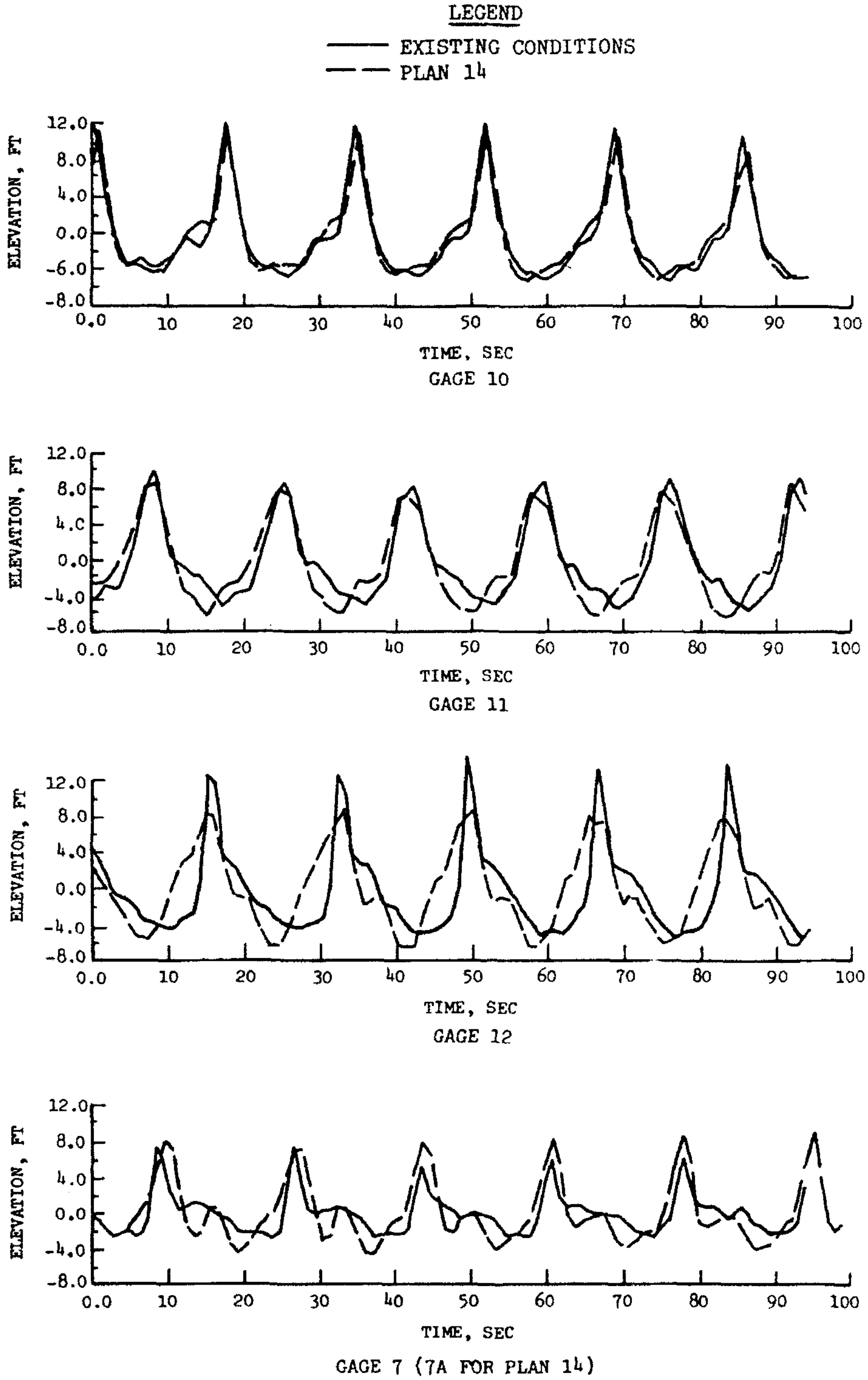
COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 15-SEC, 16-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 17-SEC, 8-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



COMPARISON OF WAVE FORM (STEEPNESS) IN ENTRANCE CHANNEL FOR EXISTING CONDITIONS AND PLAN 14; 17-SEC, 12-FT MONOCHROMATIC WAVES FROM 275 DEGREES; SWL = 0.0 FT



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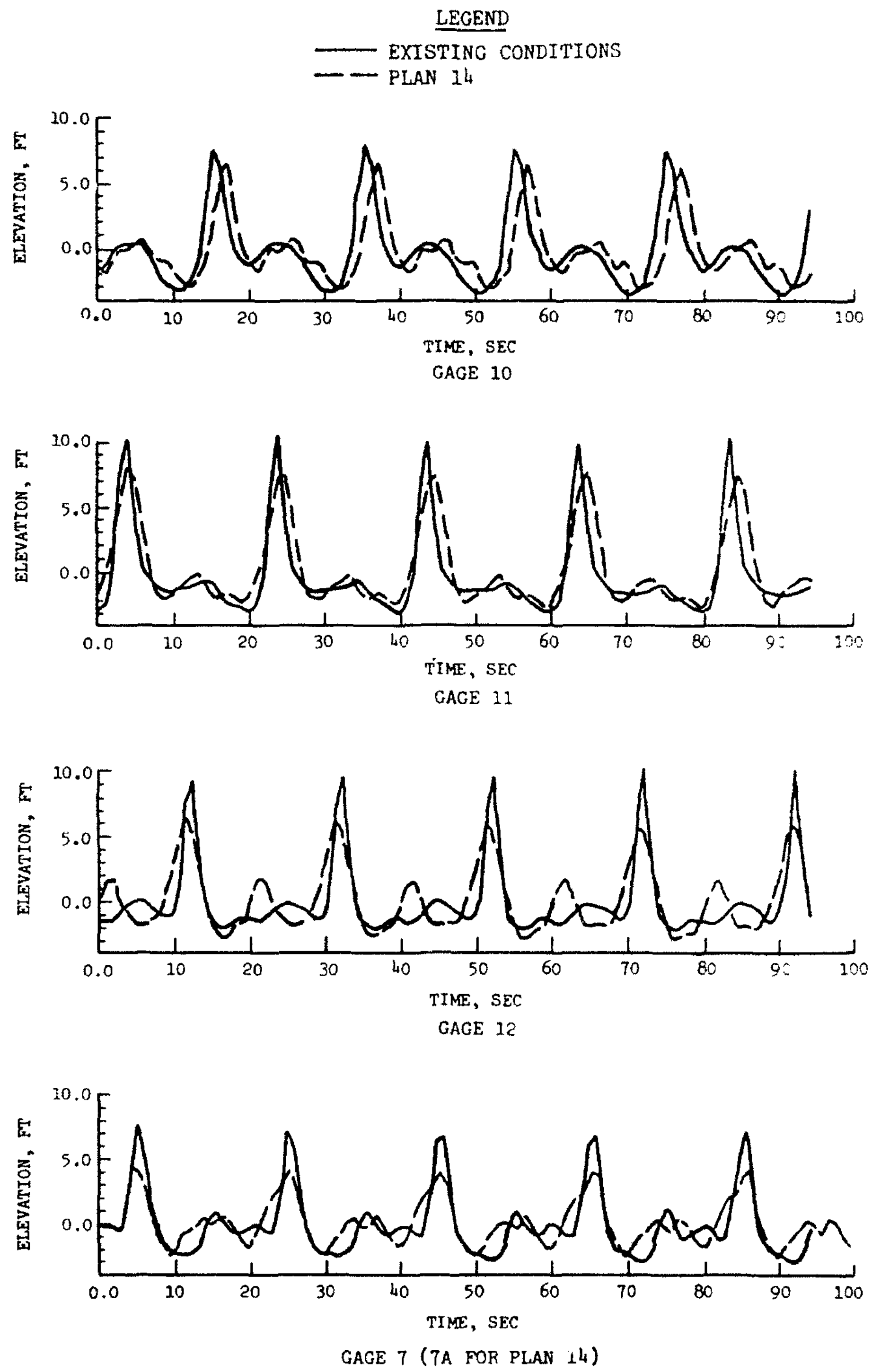

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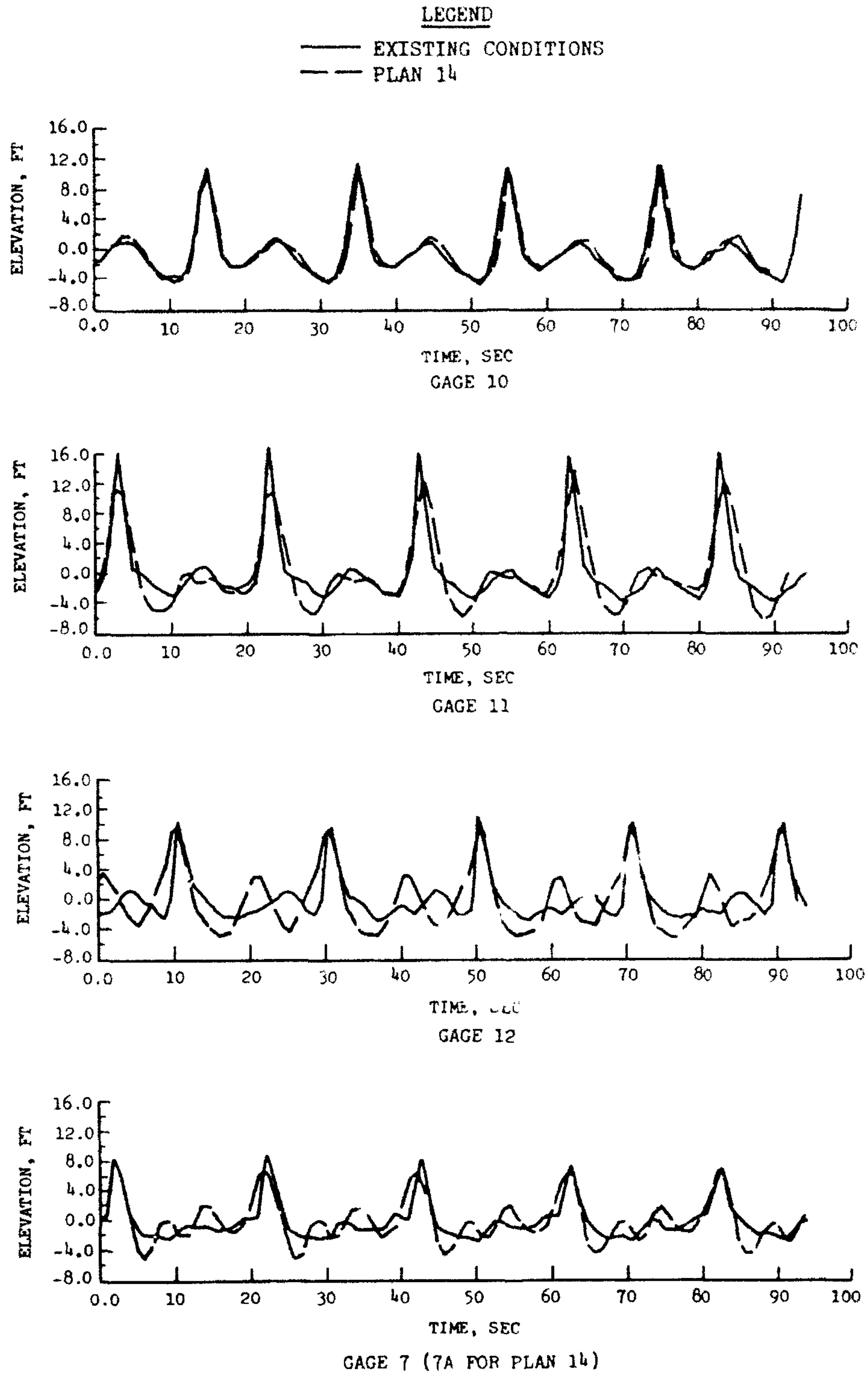

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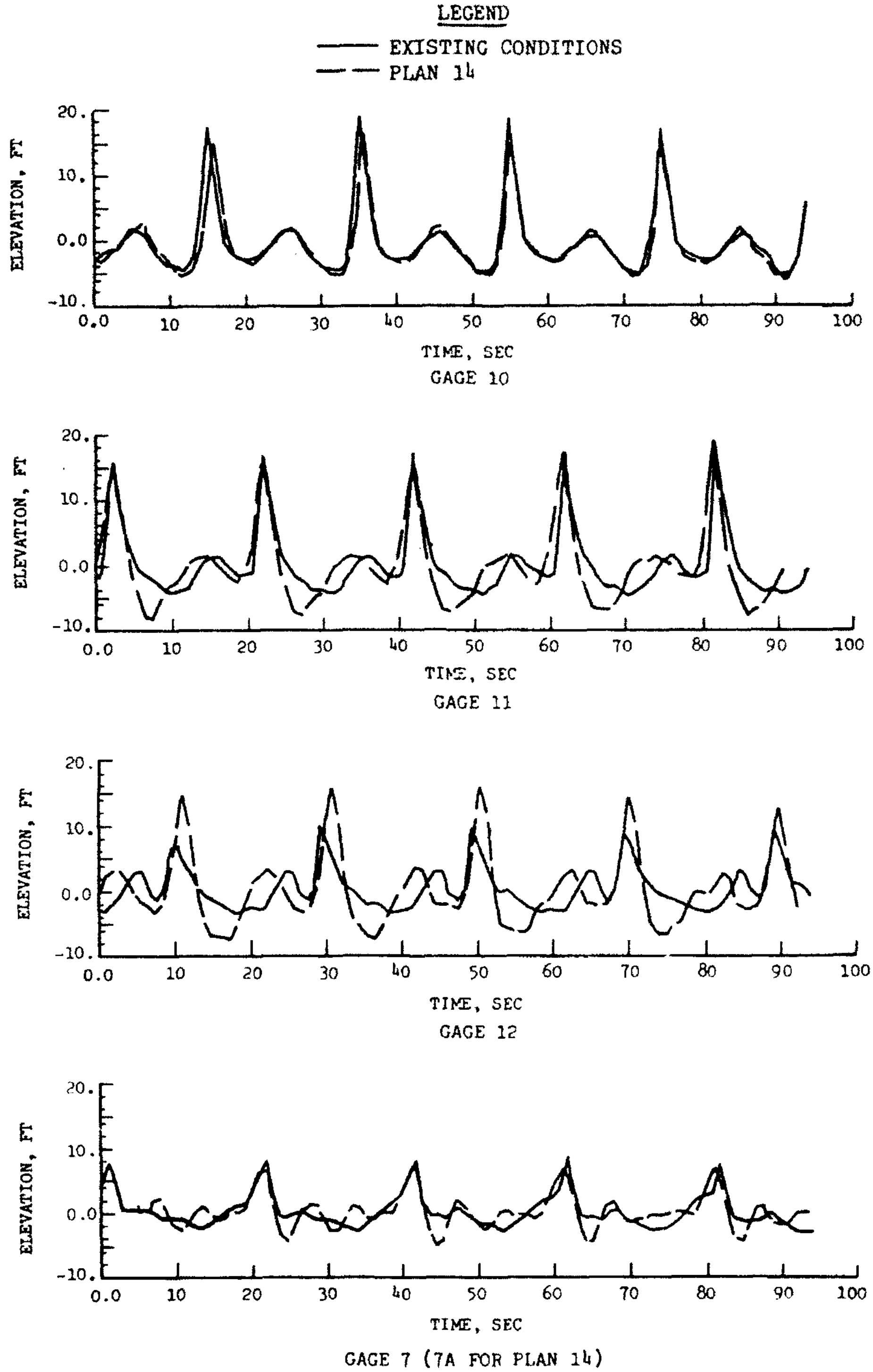

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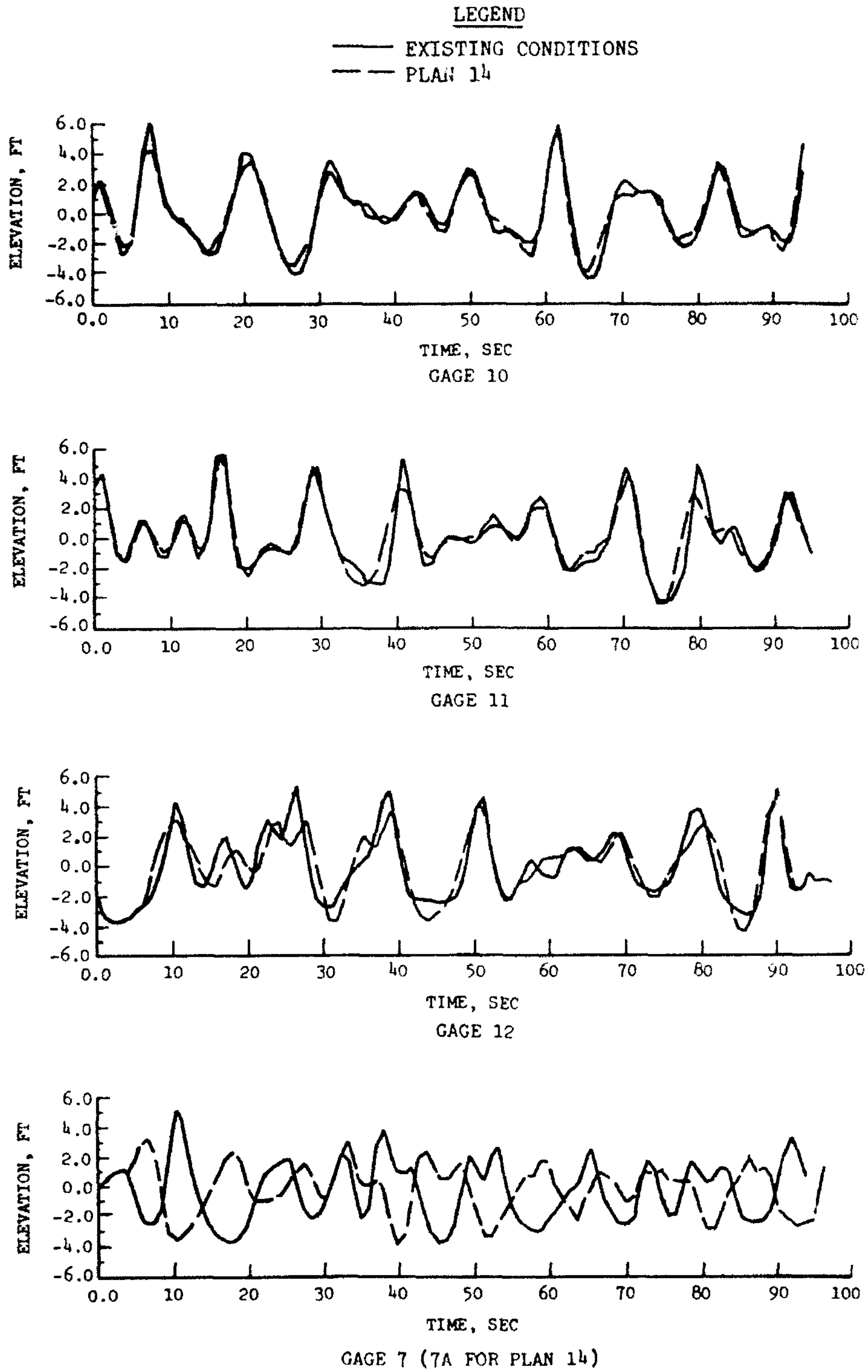

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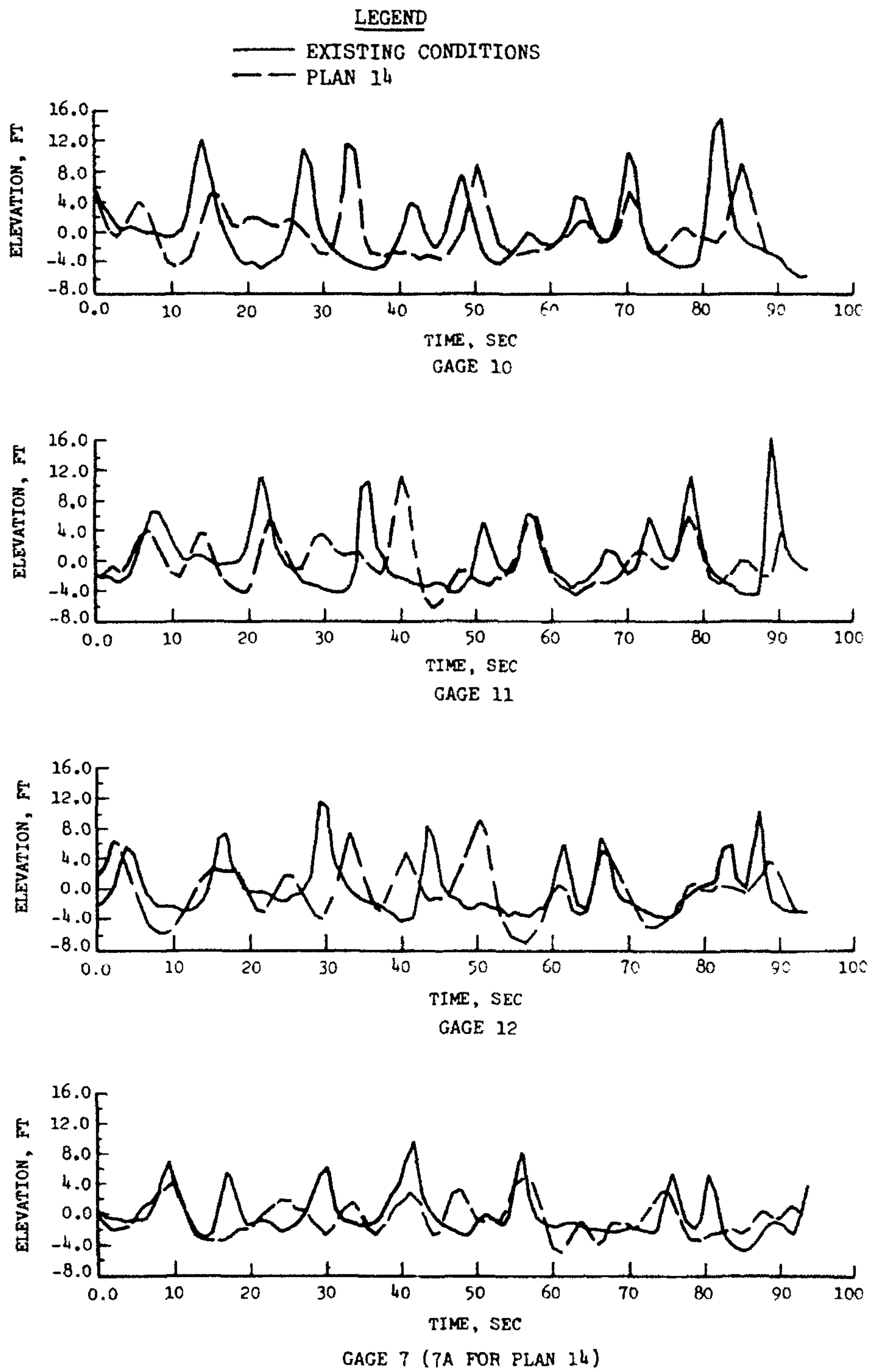

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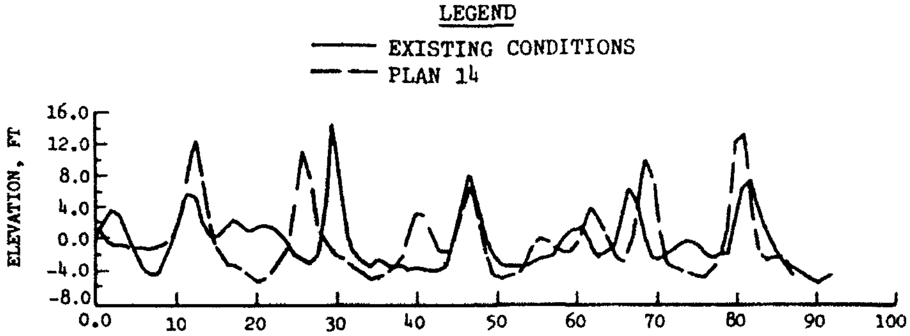

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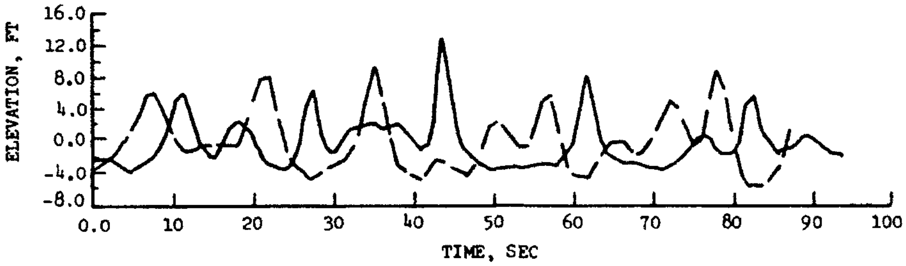

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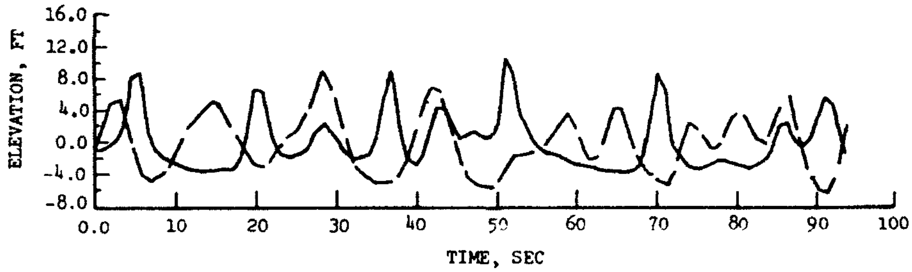

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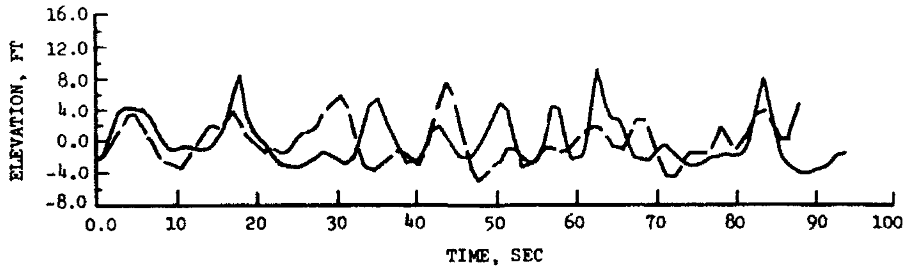

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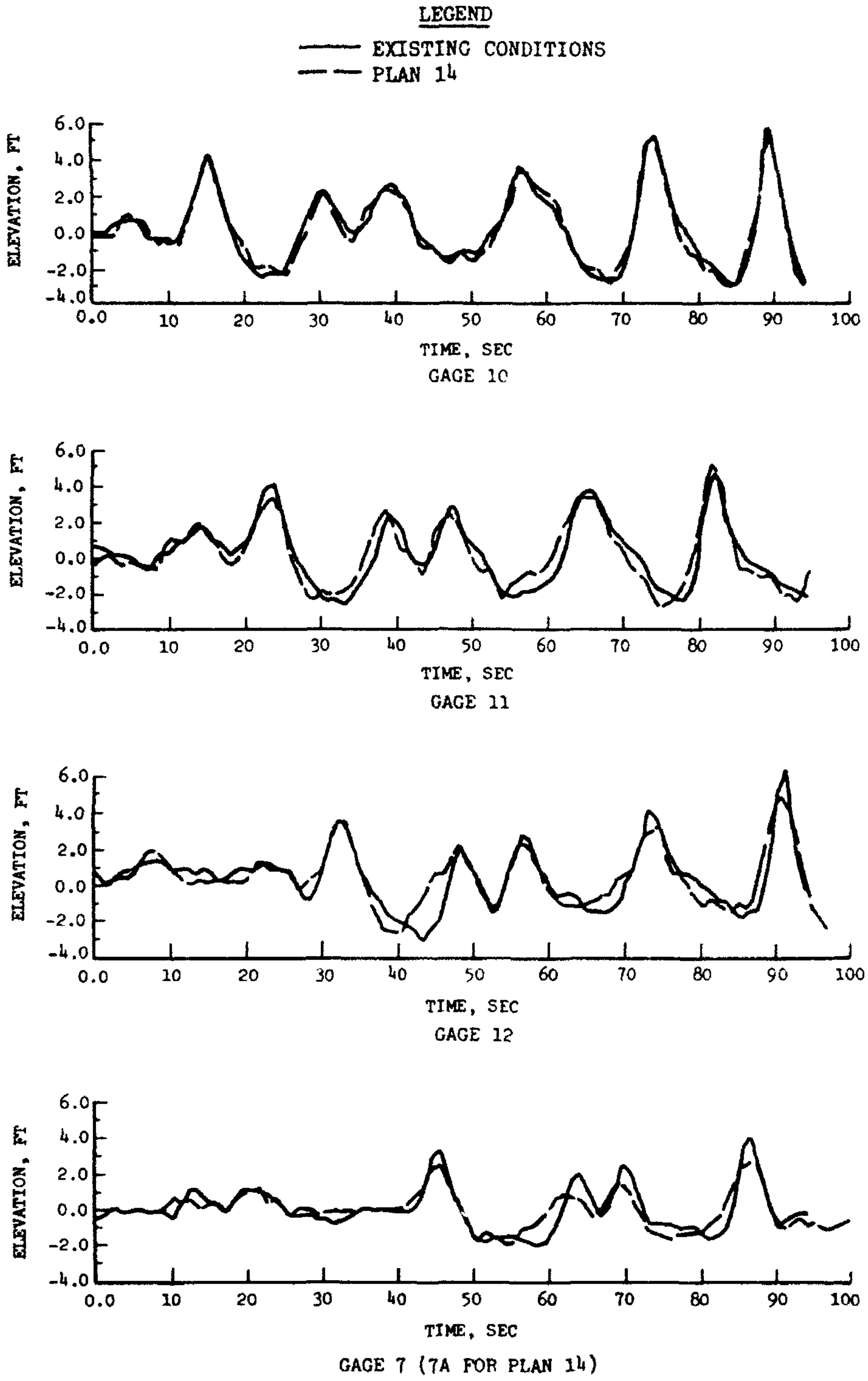

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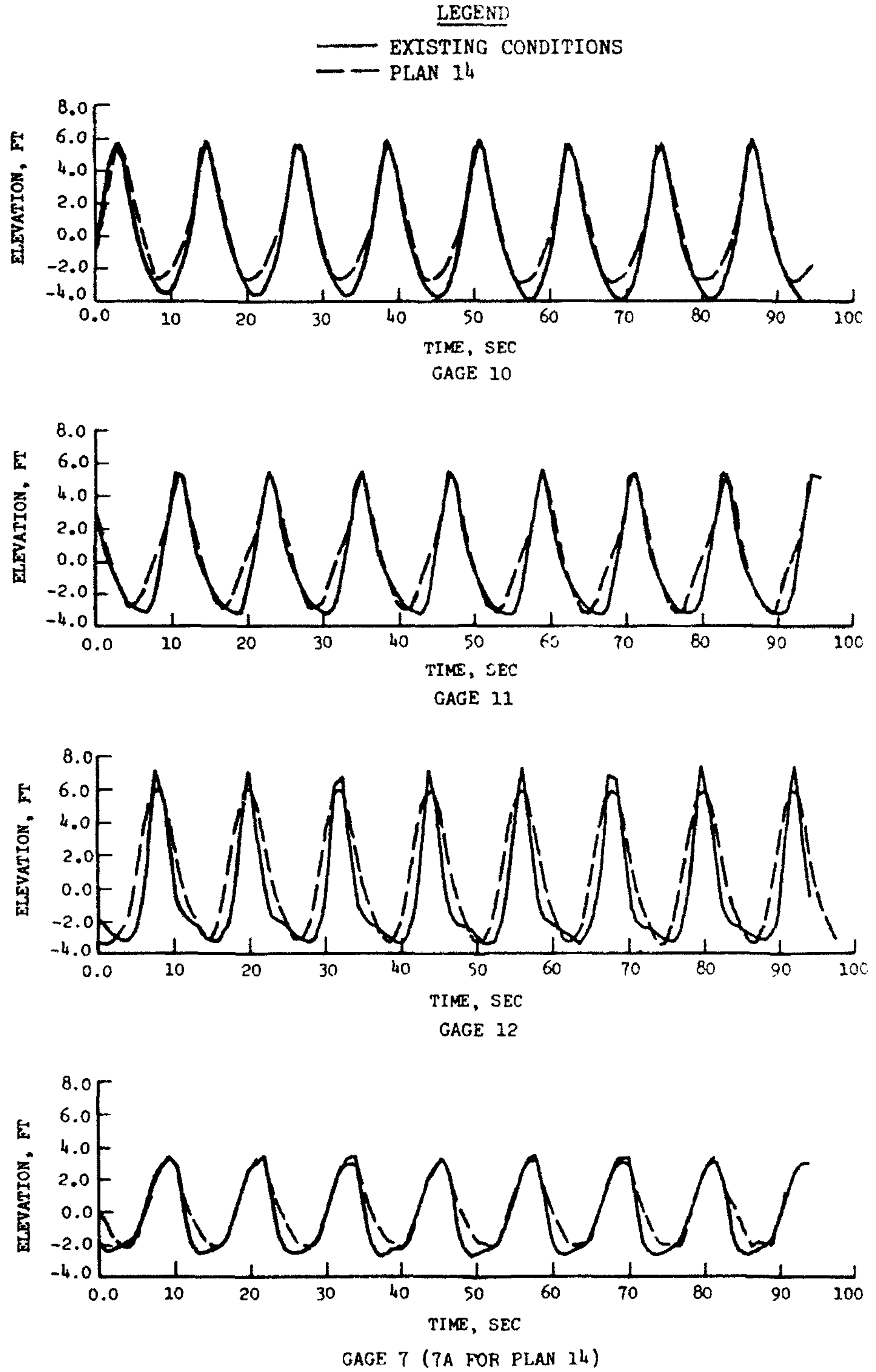

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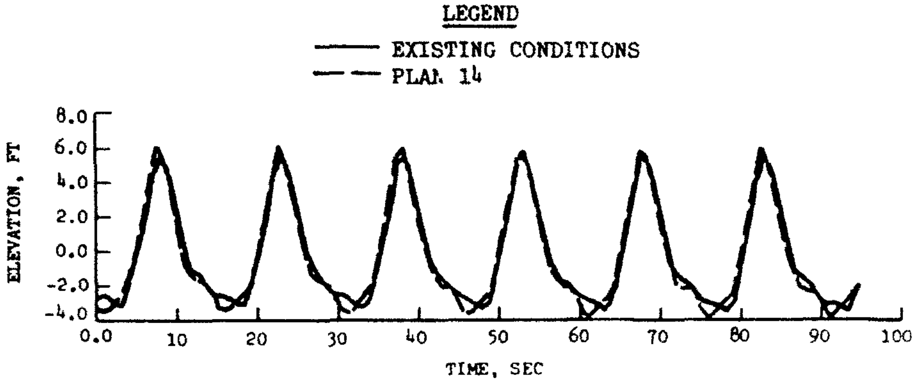

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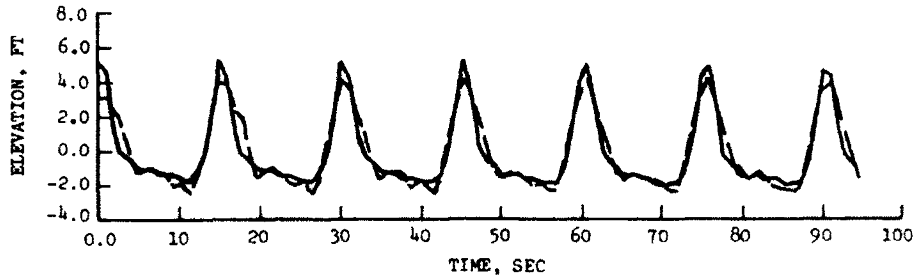

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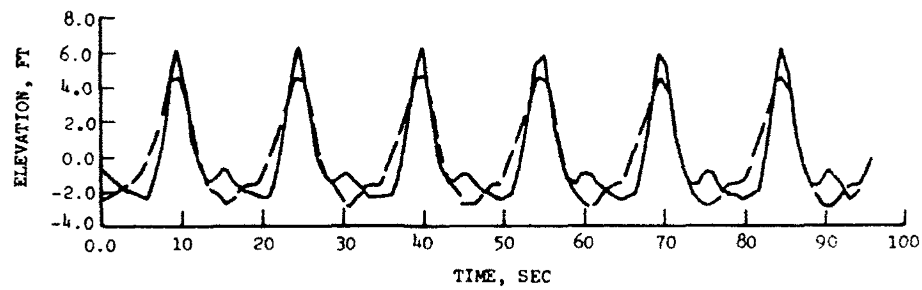

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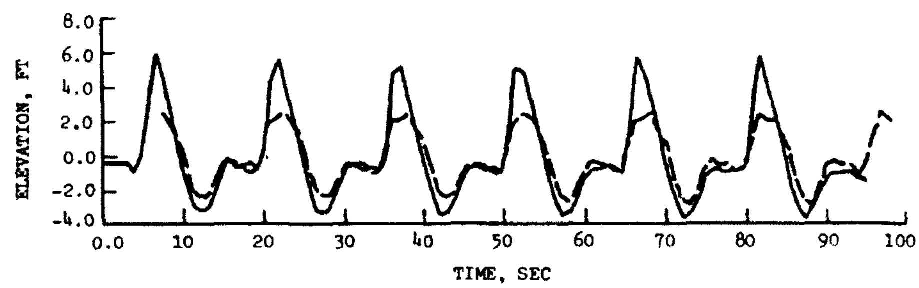

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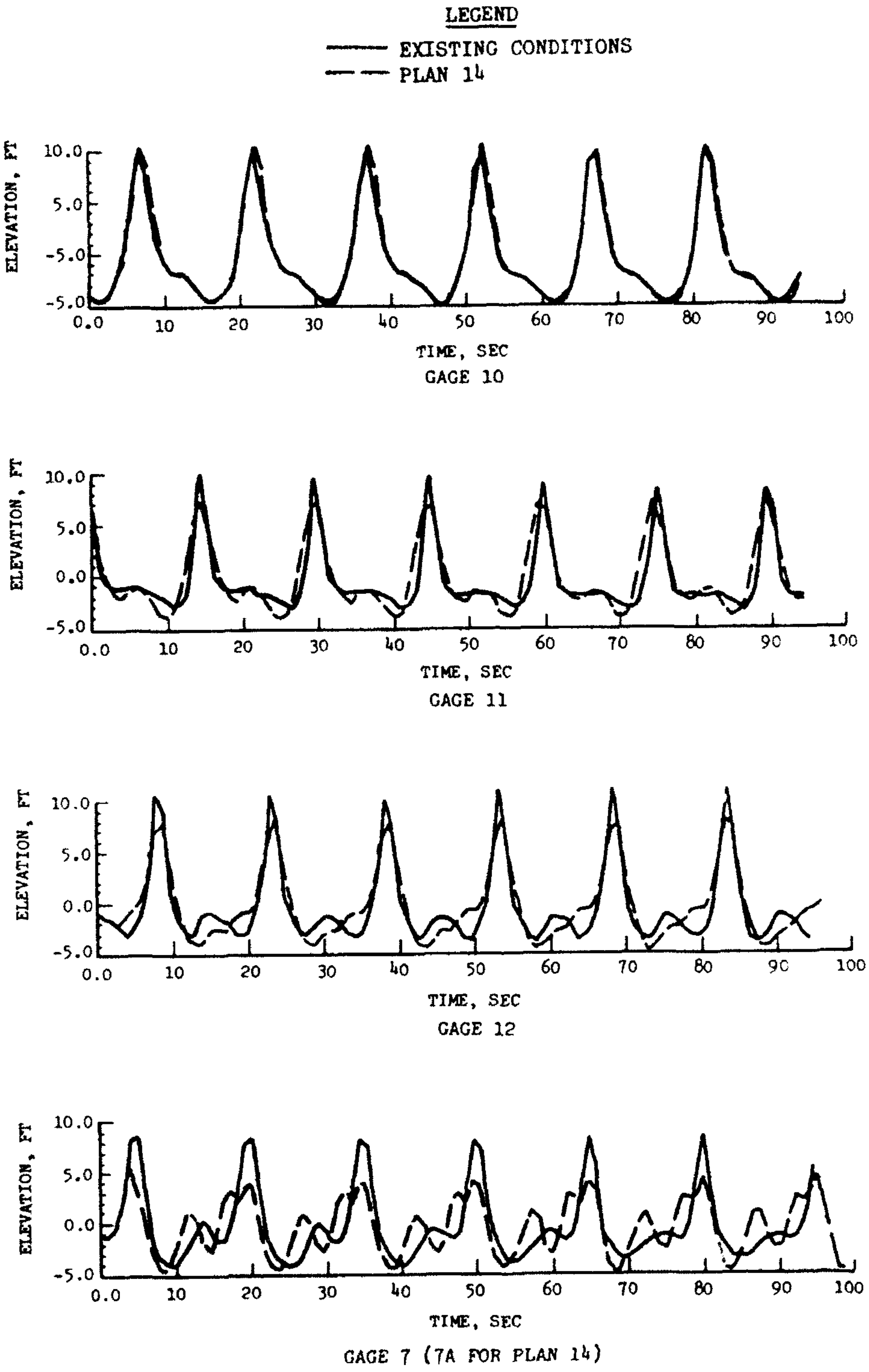

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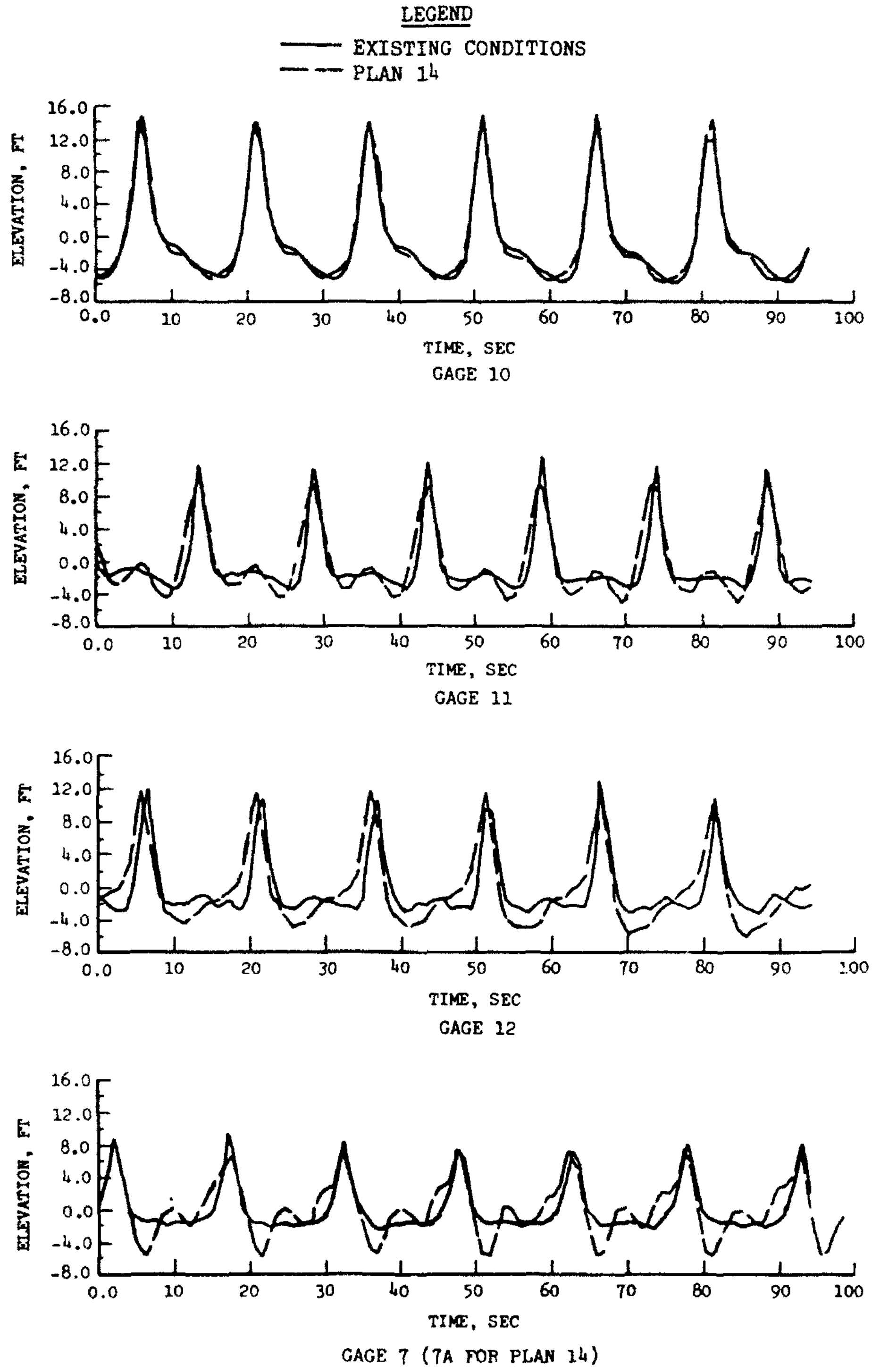

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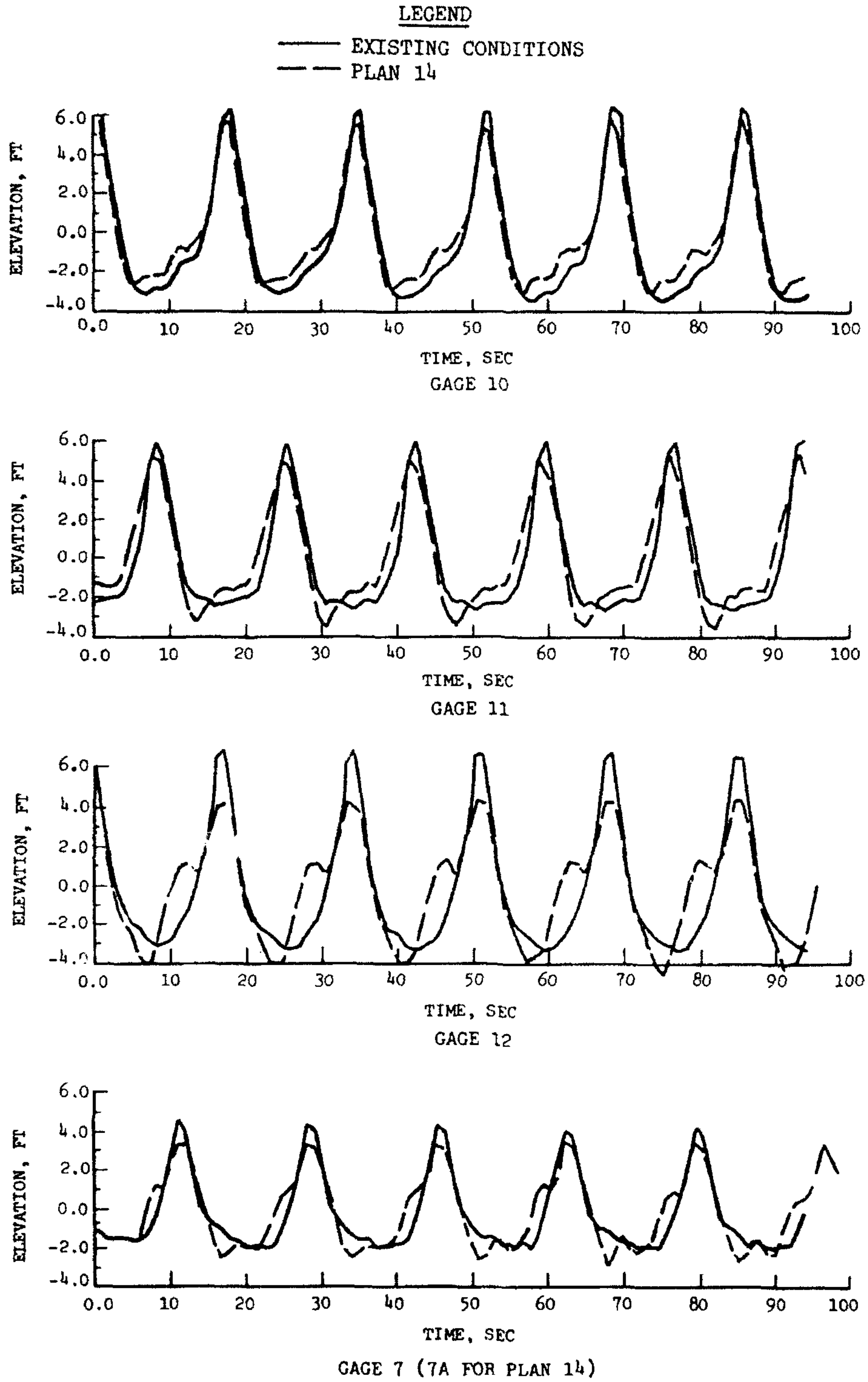

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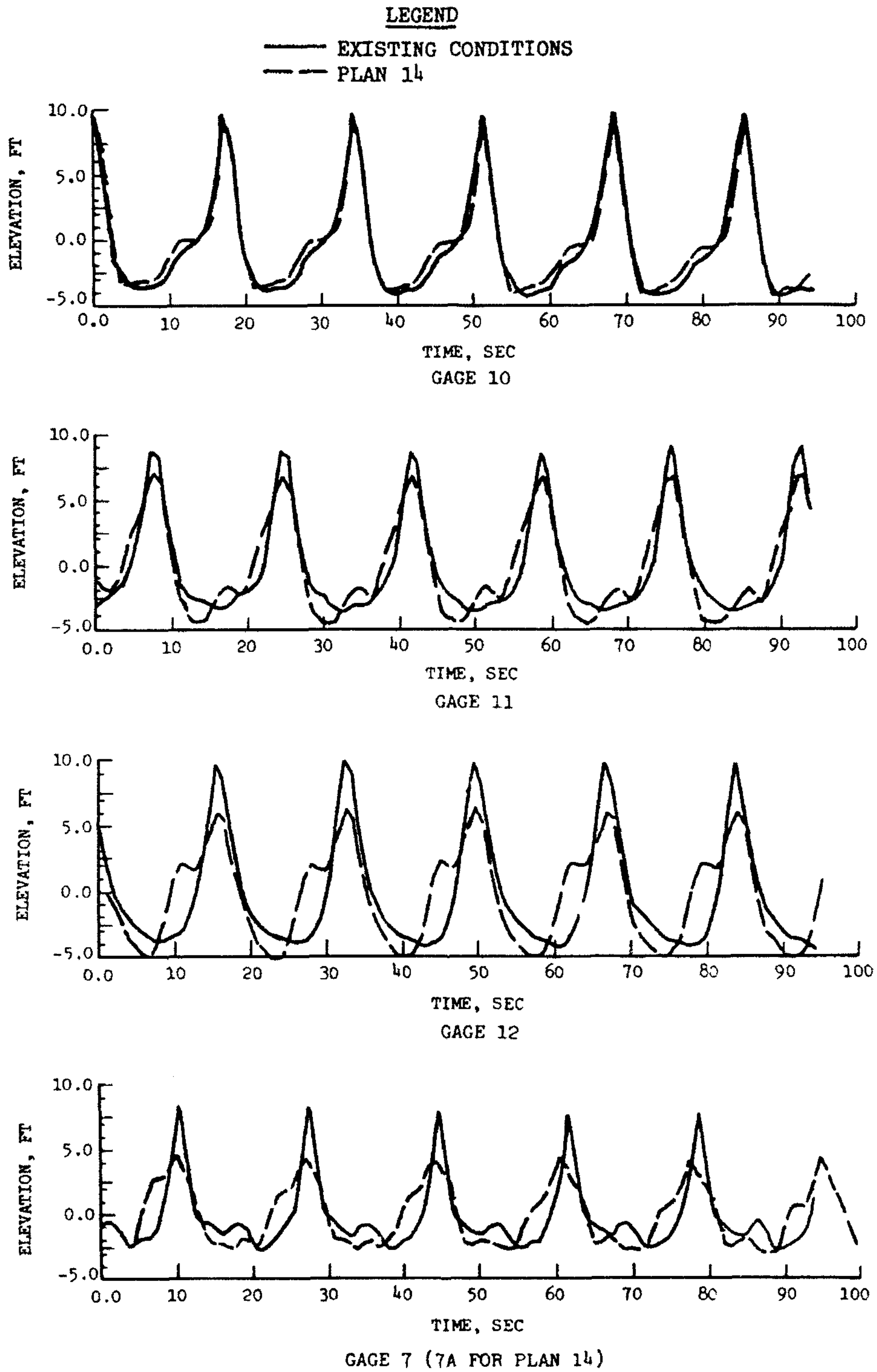

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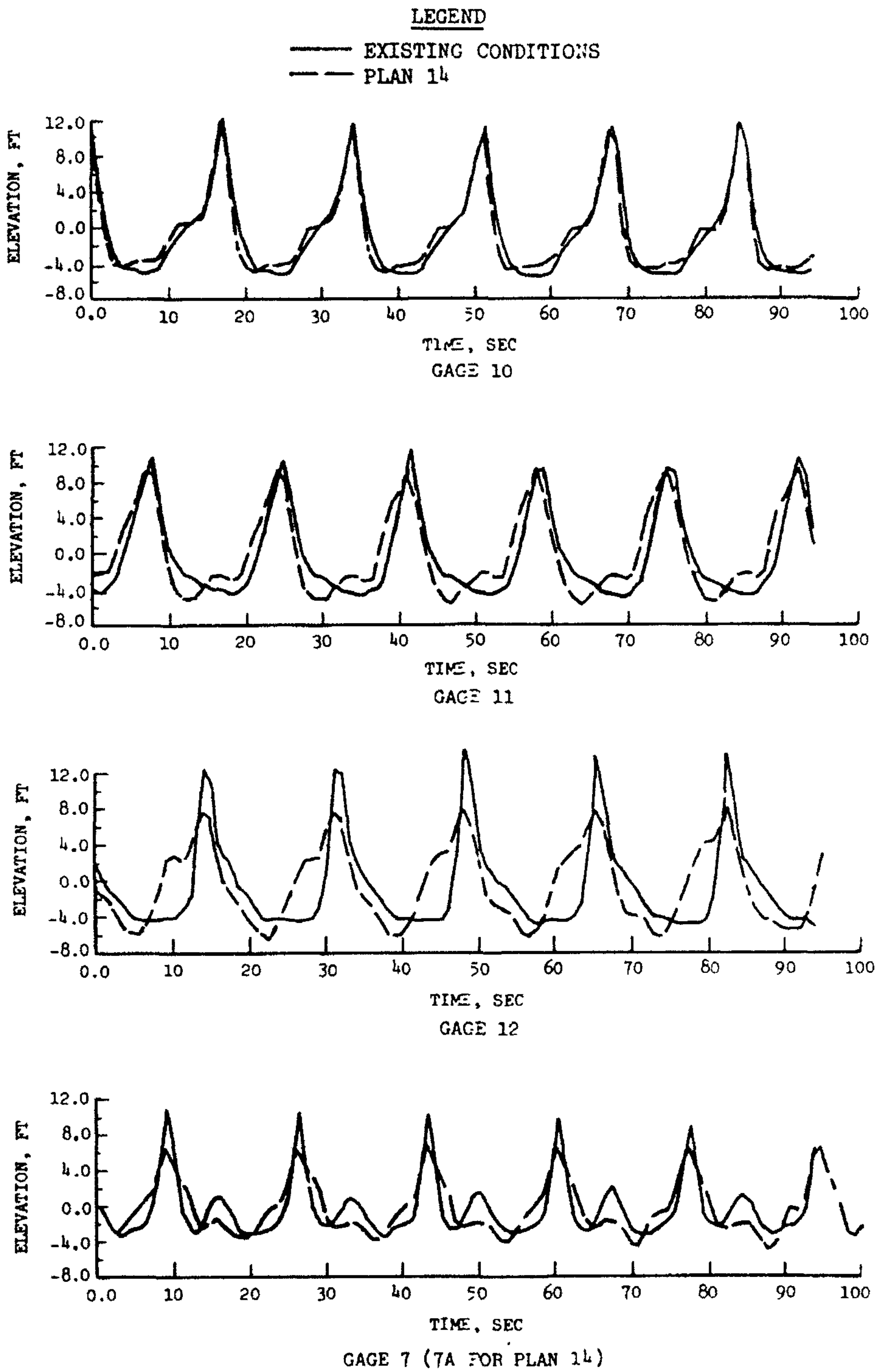

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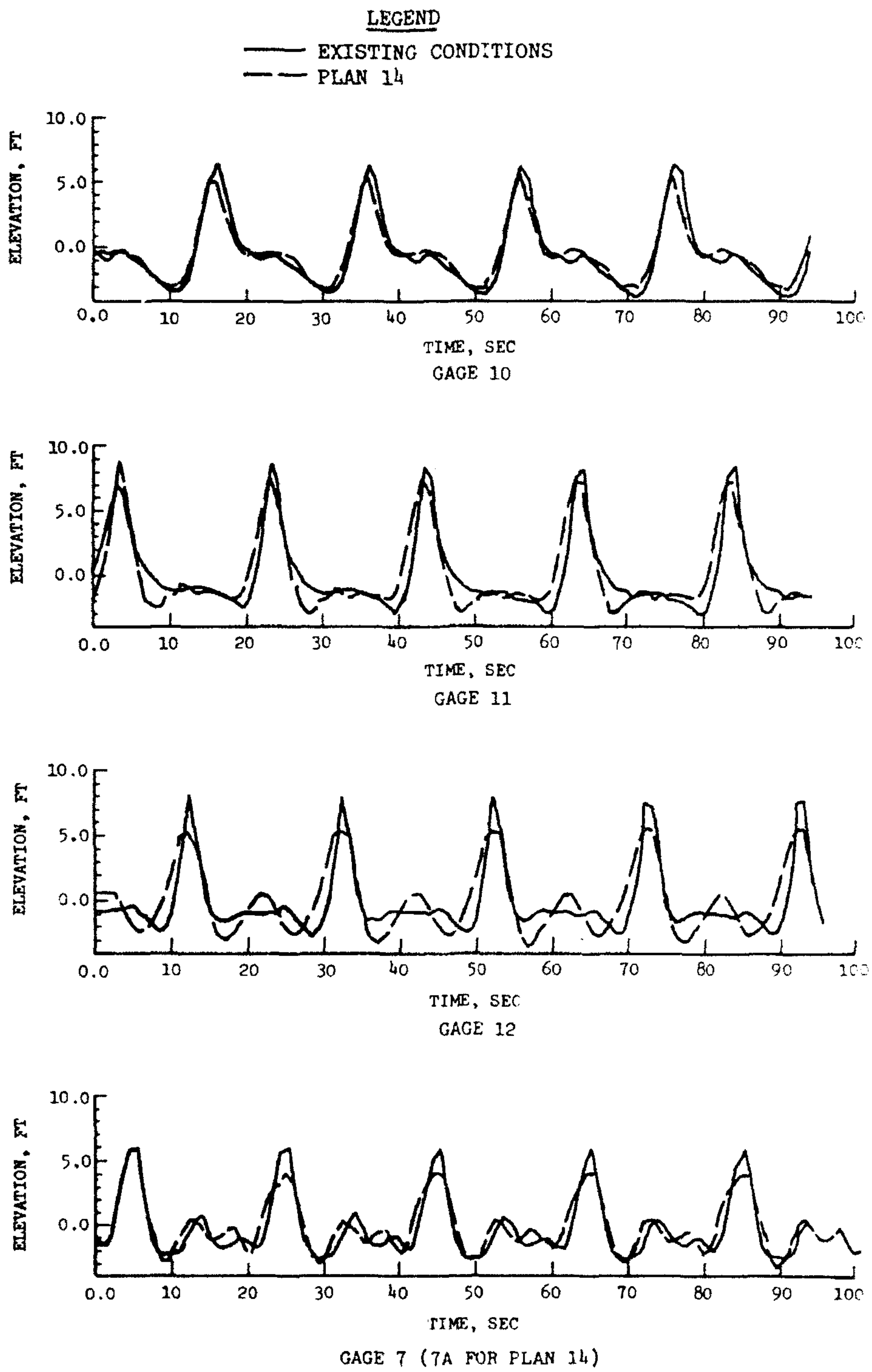

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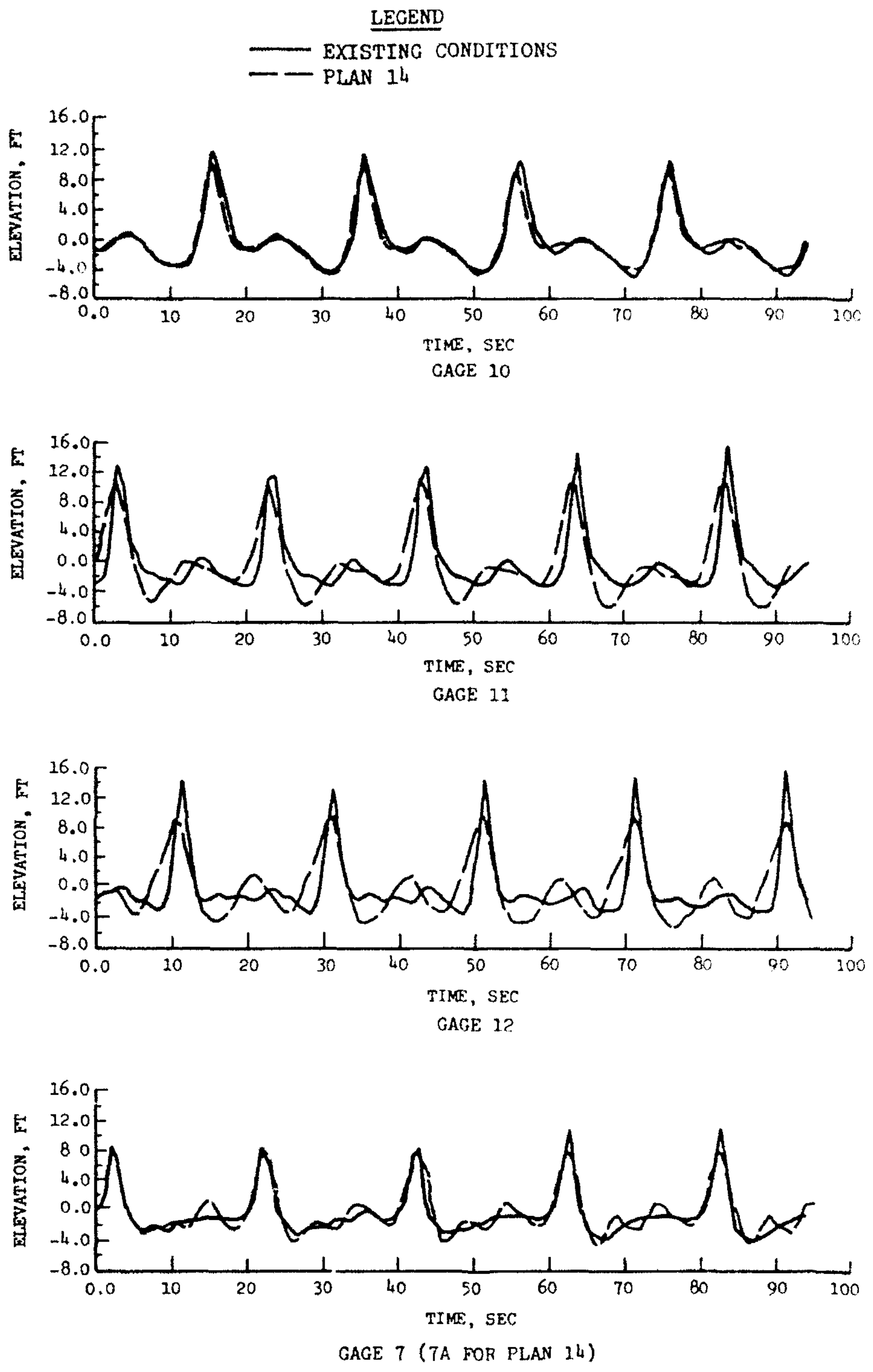

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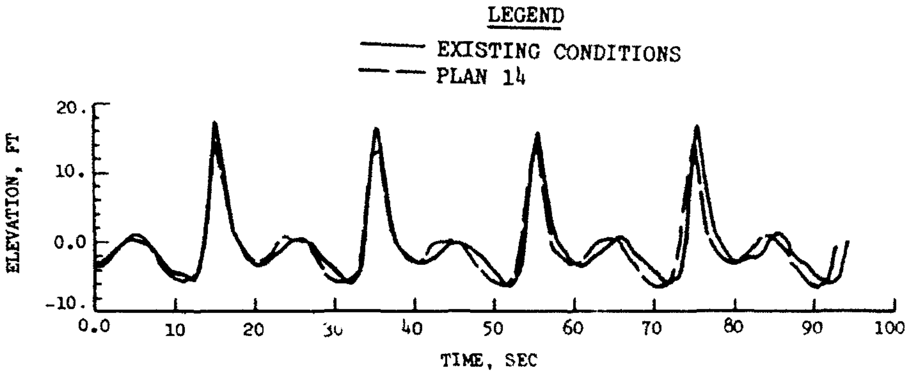

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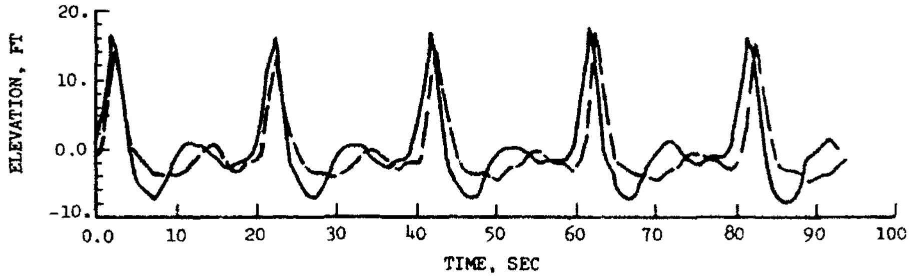

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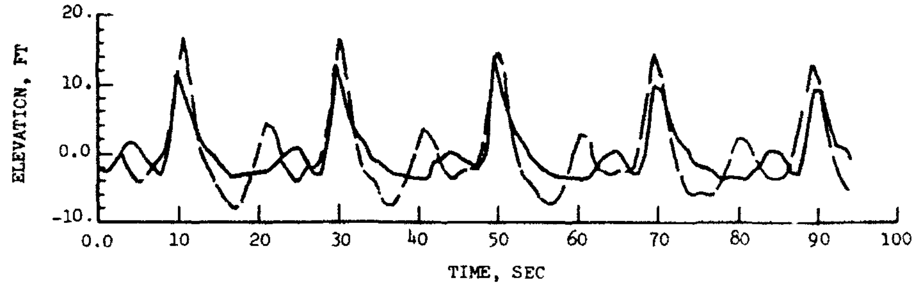

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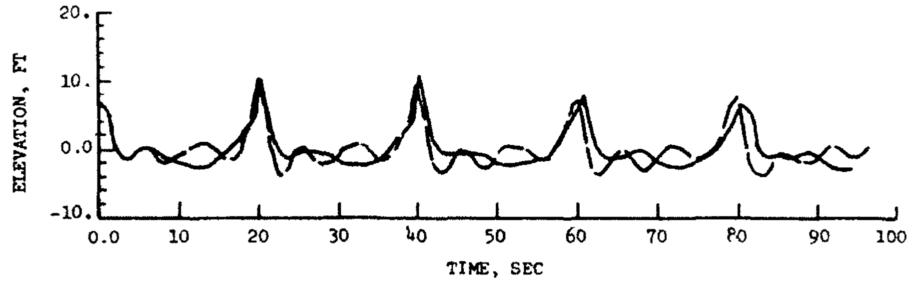

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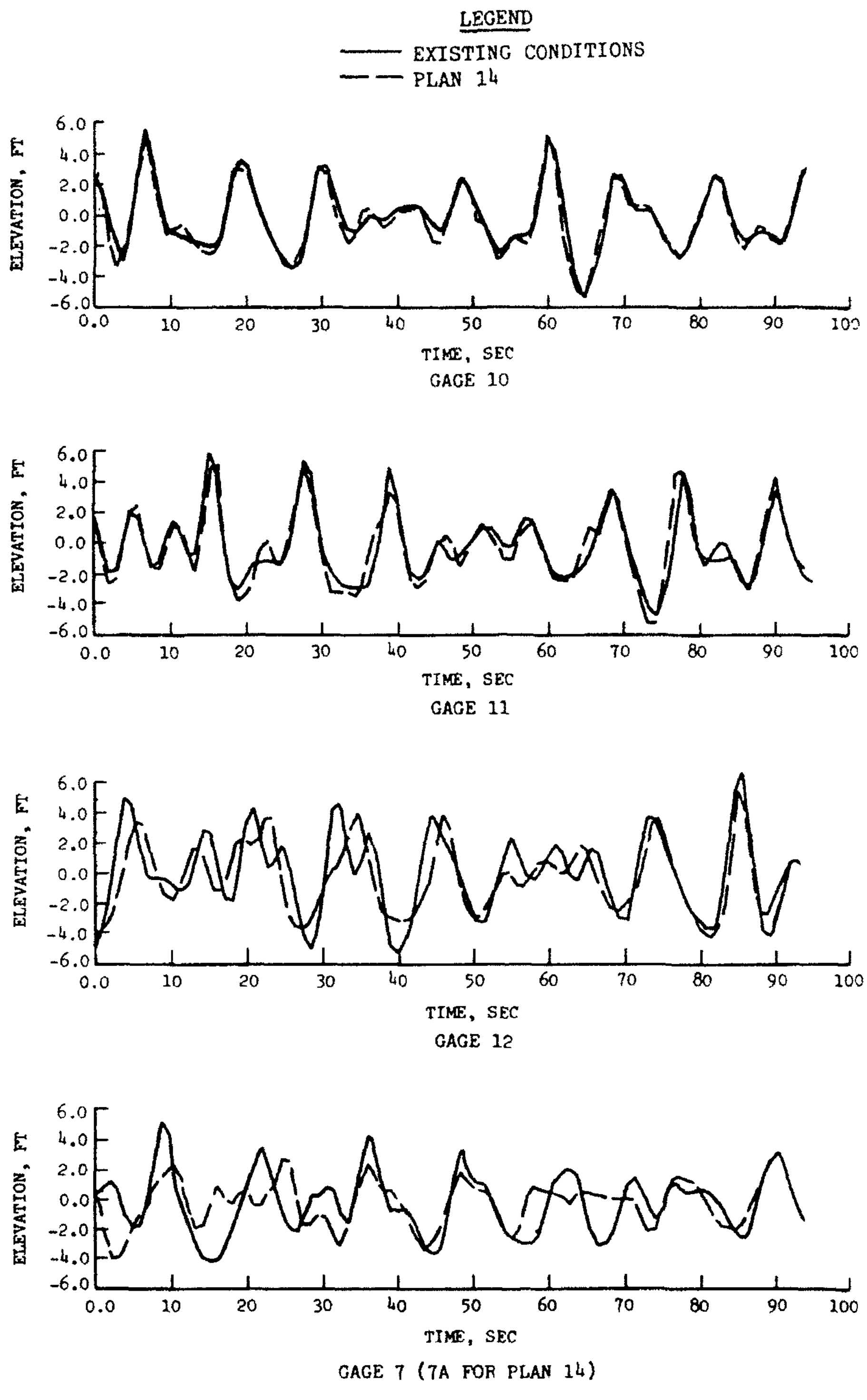

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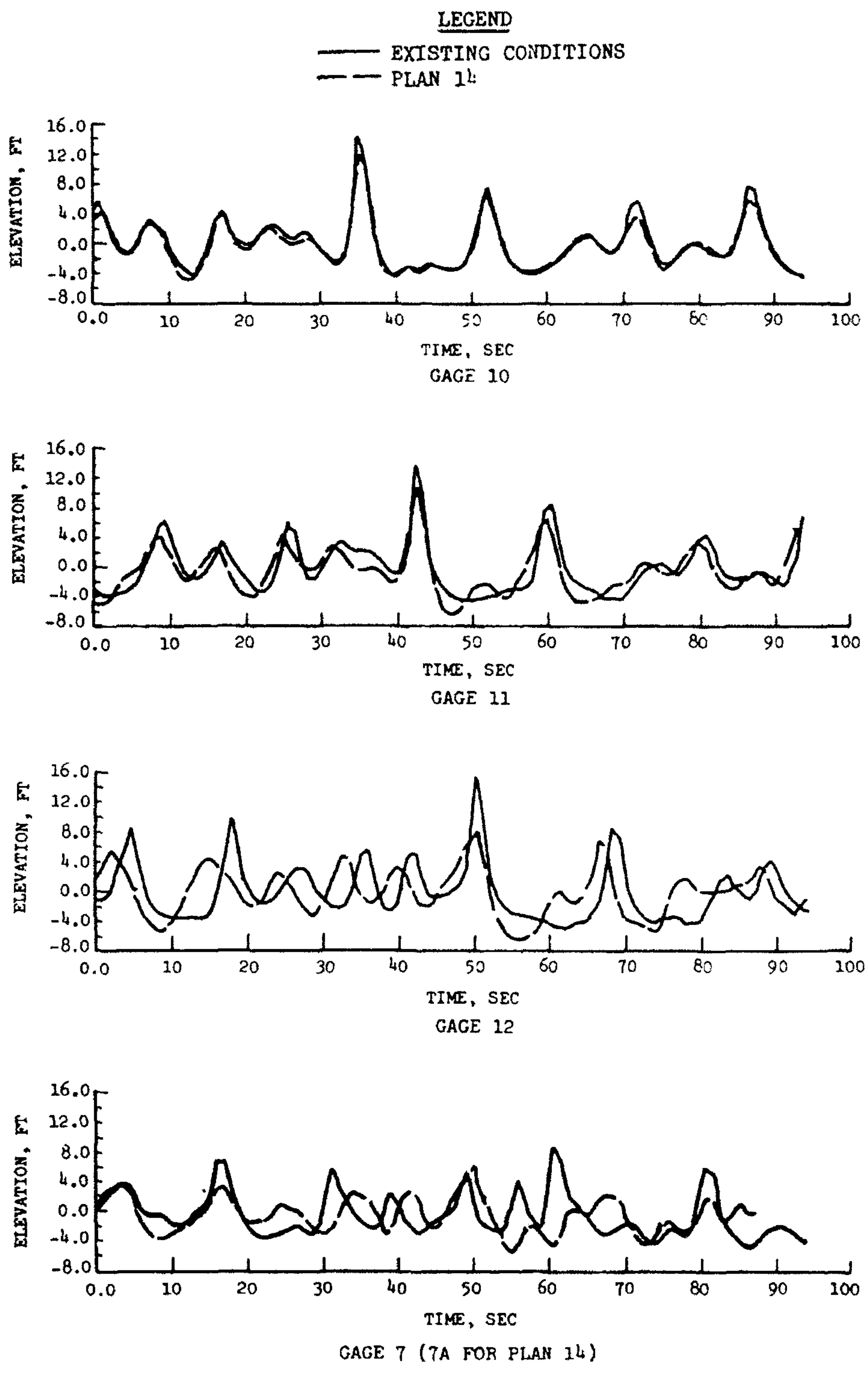

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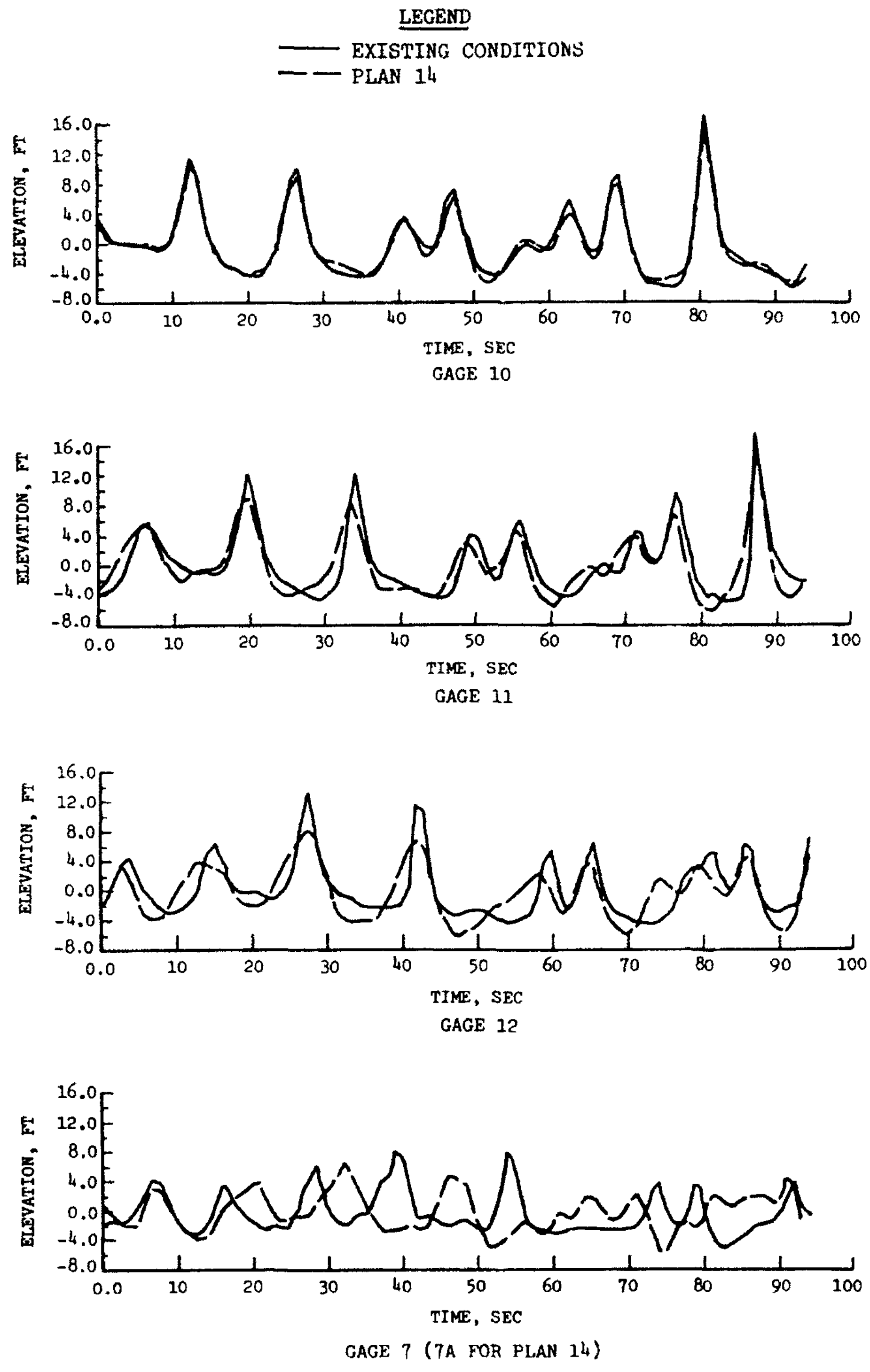

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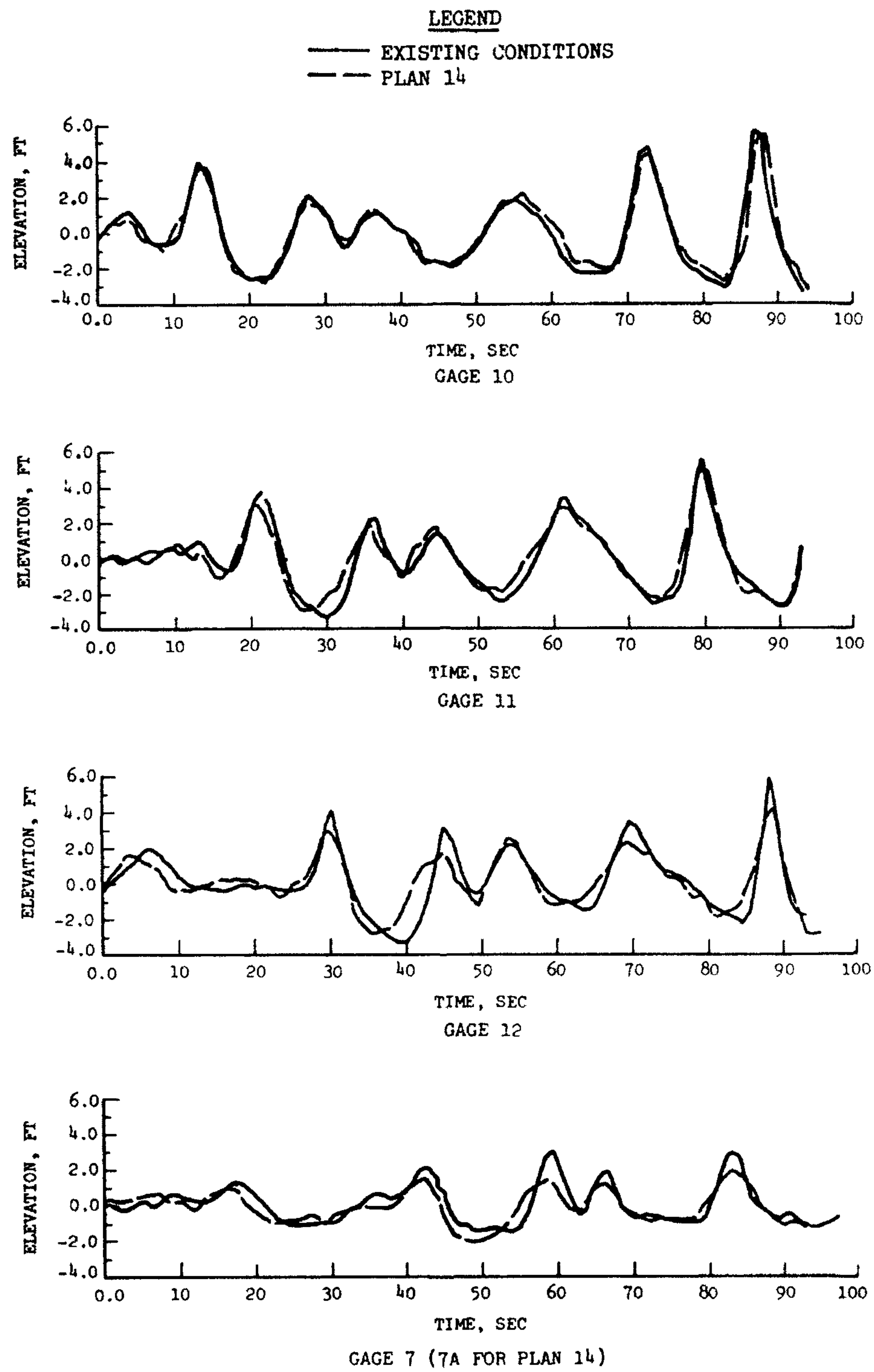

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Robert R. Bottin, Jr.

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U.S. Army Engineer Waterways Experiment Station
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13. ABSTRACT *(Maximum 200 words)*

A 1:90 scale, three-dimensional hydraulic model was used to investigate the design of proposed entrance channel depth modifications at Morro Bay Harbor, California, with respect to navigation conditions. The impact that the proposed depth changes may have on wave conditions at the existing structures and the spit between the south structures also was addressed, and sediment tracer patterns were obtained in the entrance. The model reproduced the harbor entrance, approximately 7,000 ft of the California shoreline, and offshore bathymetry in the Pacific Ocean to a depth of 60 ft mean lower low water (mllw). A 60-ft-long unidirectional, spectral wave generator, an automated data acquisition system, and crushed coal tracer material were utilized in model operation. It was concluded from test results that:

a. For the existing harbor entrance, operational waves (8 to 16 ft in height) from the predominant 275 deg direction resulted in hazardous entrance navigation conditions due to wave steepening and/or breaking.

b. For the originally proposed improvement plan (Plan 1), navigation conditions in the entrance were improved for operational waves from 275 deg; however, the plan resulted in significantly increased wave heights which may cause damage to the head of the south breakwater during extreme wave conditions (waves ranging from 21 to 30 ft in height).

(Continued)

14. SUBJECT TERMS

Breakwaters	Hydraulic models
Harbors, California	Morro Bay Harbor, California
Harbor shoaling	Navigation

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13. (Concluded).

c. Of the improvement plans tested, the channel and sand trap configuration of Plan 14 appeared to be optimal with respect to all wave conditions from all directions. Navigation conditions in the entrance will be improved, and the plan will have no negative impact on the existing structures or the spit between the south breakwater and the groin.

d. Sediment tracer tests indicated that sediment moving in the predominant northerly direction will deposit in the deepened entrance channel and sand trap area of Plan 14 as desired, and material moving in the southerly direction will deposit in the deepened entrance channel.

e. The -30-ft entrance channel of Plan 15 will result in similar wave conditions for operational and extreme waves as the -40-ft channel of Plan 14, which would be acceptable with regard to entrance conditions and would have no negative impact on the breakwaters and spit area.