CHAPTER 55

LAB PROFILE AND REFLECTION CHANGES FOR H_o/L_o=0.02

by

Charles B. Chesnutt[1] and Cyril J. Galvin, Jr.[2]

ABSTRACT

Reflection coefficients and profile changes were measured during four lengthy experiments in two relatively long, narrow wave tanks. Each tank had a periodic wave generator at one end and a 0.2 mm movable sand bed at the other end. Generator period (1.90 sec), water depth (2.33 ft), nominal wave height before reflection (0.36 ft), and initial sand slope (1:10) were constant in the four experiments. Measured reflection coefficients (K_r = H_r/H_i) ranged from 0.05 to 0.30, with the typical time variation of K_r related to profile changes as follows: K_r increased by a factor of 3 to 4 within the first minutes while a steep foreshore was built on the undeformed profile; K_r fluctuated and dropped to a lower value as the inshore widened; K_r increased as the offshore steepened. Large variations in K_r near the end of the experiments appeared to result from minor profile changes. The apparently similar experiments showed very different rates of profile development, implying control by other variables such as water temperature or tank geometry. "Equilibrium" in these experiments was never reached, even after as many as 375 hours of wave action.

I. INTRODUCTION

Wave heights in movable bed, coastal engineering laboratory experiments vary both in space and in time in a manner illustrated by Figure 1. Such variability is common over the constant depth section of wave tanks with movable beds (Savage, 1962; Fairchild, 1970a, 1970b; Galvin and Stafford, 1970).

The preliminary study (Galvin and Stafford, 1970) from which Figure 1 is taken has shown that wave height variability in simple wave tanks is caused largely by wave reflection from the tank boundaries, especially from the movable boundary. Spatial wave height variability results from the envelope of superposed incident, reflected, and re-reflected waves. Temporal wave height variability, indicated by the range of wave heights

[1]Hydraulic Engineer, Coastal Processes Branch, U.S. Army Coastal Engineering Research Center, Ft. Belvoir, Virginia

[2]Chief, Coastal Processes Branch, U.S. Army Coastal Engineering Research Center, Ft. Belvoir, Virginia

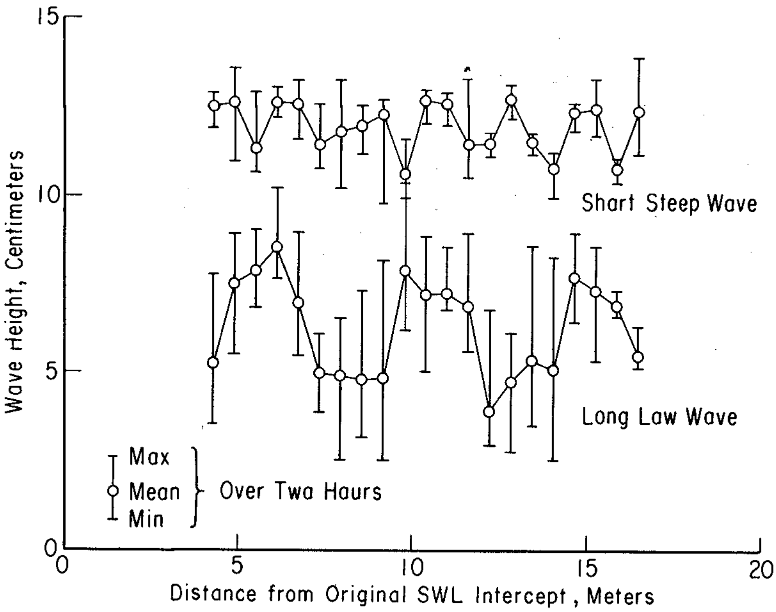


Figure 1. Examples of Wave Height Variability in Long Narrow Tank (Wave Heights are Averages of Ten Consecutive Waves)

at each distance on Figure 1, results from the changing reflectivity and position of the developing movable bed profile.

In order to study the interaction between wave height variability and profile development, ten experiments were conducted at the U.S. Army Coastal Engineering Research Center. This paper reports major results from four of the ten experiments, all four of which were run under the same wave conditions. The results affect the planning and interpretation of coastal engineering movable bed experiments, including both research and model experiments.

II. DATA COLLECTION AND REDUCTION

Experimental Conditions. Two wave tanks were constructed of aluminum panels within a large, 3-ft (0.9-m) deep, outdoor, fresh water, concrete test basin. Piston-type wave generators produced the waves.

Wave generator stroke (0.39 ft, 0.12 m), wave period (1.90 sec), and water depth (2.33 ft, 0.71 m) were held constant. In the constant-depth section these conditions produced a nominal wave height of 0.36 ft (0.11 m), wave length (computed from linear theory) of 14.3 ft (4.4 m) and relative depth of 0.163. The equivalent deepwater wave steepness was 0.021. Water temperature in the outdoor test basin varied from 30°C to 7°C during the testing seasons, which lasted from late spring through late autumn. The movable beds (consisting of 0.2 mm sand smoothed to an initial slope of 1:10) were graded in the same manner for each experiment to insure that initial conditions were the same. Each of the two tanks had a control tank next to it, situated so that the same generator simultaneously produced the waves in both the test tank and the control tank. The control tank had a 1:10 smooth concrete slab instead of a movable bed.

Because wave conditions were held constant, the four experiments in this paper are identified in Table 1 by a combination of tank width and initial test length. Each experiment had a different initial test length (the distance from the wave generator to the still water line on the initial sand slope).

TABLE I. Defining Variables of the Four Experiments

	Tank Width		Initial Test Length	
Experiment No.	ft	m	ft	m
0-06	6	1.8	100	30.5
1-06	6	1.8	93	28.4
0-10	10	3.0	61.7	18.8
1-10	10	3.0	54.7	16.7

Data Collection. Each experiment was performed in a series of runs. During each run, data on water temperature, wave breaking, and wave reflection were collected. After each run, profile surveys were made according to the schedule shown on Figure 2. The special surveys marked in Figure 2 were more detailed and included surface sand sampling.

The experimental procedure for the four experiments varied only in the timing of some special surveys, the duration of the experiments, and a beach replenishment procedure used in Experiment Nos. 0-06 and 0-10. In these two experiments, the beach face had eroded to the back of the tank after 54 hours and 62 hours, respectively. After this happened, the dimensions of the backshore zone (from limit of uprush to the back of the tank) were artificially stabilized by periodically rebuilding a scarp whose crest was approximately

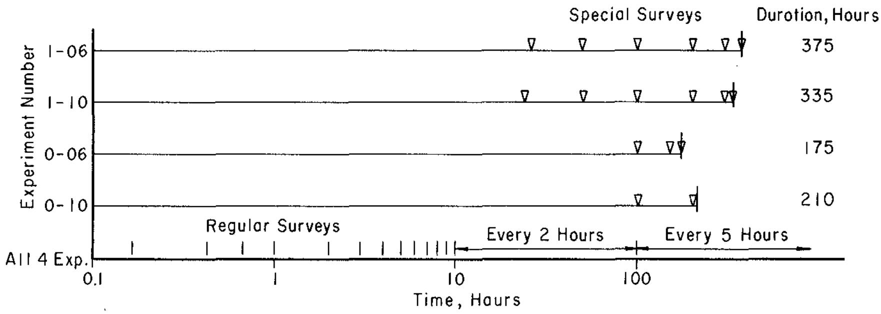


Figure 2. Frequency of Data Collection

0.5 ft from the back of the tank and 0.7 ft above the upper limit of the beach face.

The principal measurements were the wave envelopes and the profile surveys, both measured by instruments mounted on a carriage which traveled along the tank walls. Wave heights were measured using the FWK Model-1 CERC Laboratory Wave Gage (Stafford, 1972) and a paper chart recorder. The envelopes of wave heights were recorded along the centerline of each tank from near the toe of the movable bed to near the wave generator, and except for runs during the first ten hours, they were recorded starting one hour before the end of the run. A typical wave envelope is shown in Figure 3.

Profile surveys were made with point gages modified by replacing the point with a gimballed foot which provided a flat, 1-in. diameter surface to rest on the sand. The gages were read to the nearest 0.01 ft. Regular surveys were made along ranges 2 ft (0.61 m) apart starting 1 ft (0.30 m) from the walls (Figure 4). Along a given range, elevations were surveyed at distance intervals of 0.5 ft (0.15 m) from the station at the back of the tank to station +10; at intervals of 1 ft (.30 m) from +10 to +23; and at intervals of 0.5 ft from +23 to the toe of the slope. The origin (Station 0.0) of the coordinate system is the intersection of the still water level and the initial sand surface, which is called "original SWL intercept" on figure axes. The distance and elevation pairs were recorded on sets of computer scanning sheets for each tank, range and survey number.

Photographs of the breaking wave were taken at the start and end of each run, as well as at the time of the wave envelope recording. In Experiment Nos. 1-06 and 1-10, the position and type of breaker were determined and recorded at the time of the envelope measurement. Water temperature was measured in °C at the bottom of the tank and at the water surface at the beginning and end of each day. This procedure gave an approximate average temperature for each run.

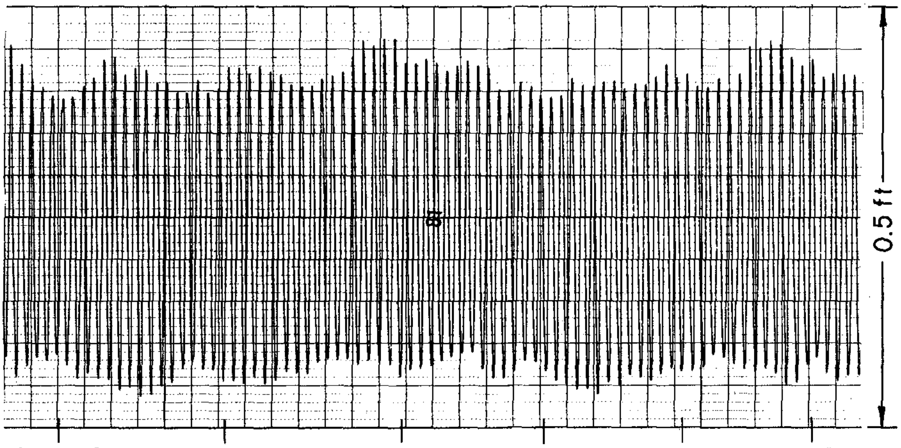


Figure 3. Example Wave Envelope

Data Reduction. The reflection coefficient was determined from the wave records by measuring the wave height at the nodes and antinodes of the wave envelope (Figure 3) and using the formula

$$K_r = \frac{H_r}{H_i} = \frac{H_a - H_n}{H_a + H_n}$$

where K_r = reflection coefficient, H_r = reflected wave height, H_i = incident wave height, H_a = wave height at the antinode, and H_n = wave height at the node. As illustrated by the envelope on Figure 3, locations of nodes and antinodes are not always clear. Independent checks of the reflection coefficients indicate that the values obtained are reproducible and correctly indicate at least relative magnitudes of K_r.

The point gage survey after each run produces a three-dimensional picture of the sand surface at that time. Since as many as 125 such surveys were made in a given experiment, the analysis and presentation of these data

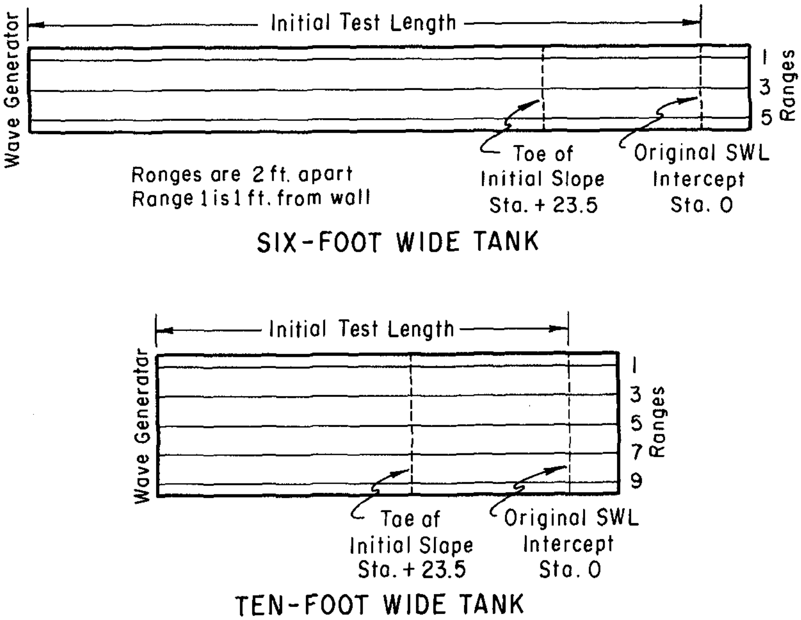
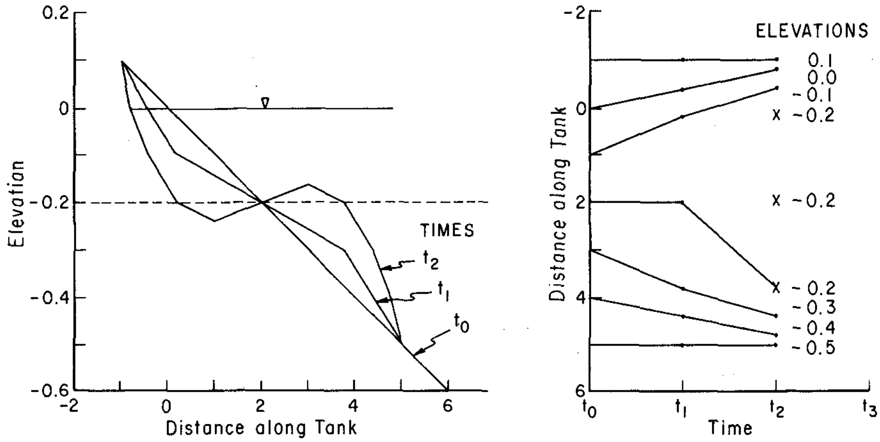


Figure 4. Survey Ranges in the Two Test Tanks

require special procedures. These surveys measured the three space variables (onshore-offshore distance, alongshore distance or range, and depth) at each time during the experiment. The method selected for presenting the data involves fixing the alongshore distance by selecting data from a given range and analyzing the surveys along that range. The surveyed distance/elevation pairs along that range are used to obtain the interpolated position of equally spaced depths, for example, -0.1, -0.2, -0.3, etc. on the hypothetical profile in Figure 5a. These contour positions from each survey are then plotted against time as shown in Figure 5b.

On Figure 5b, a horizontal line represents no change in contour position. An upward-sloping line indicates landward movement of contour position, that is, erosion; likewise, a downward sloping line indicates deposition. The slope of a line indicates the rate of erosion or deposition (horizontally) at that elevation. The x's at time t_2 on Figure 5b indicate multiple contour positions at elevation -0.2 which is shown by the dashed line on Figure 5a. Only the most seaward contour position is used in this paper.



a. Profile Line b. Movement of Contour Position

Figure 5. Interpretation of Contour Position Plots (Figures 8, 11, 13, and 14)

To supplement the profile changes, breaker type and breaker position were determined from the slides and by visual observations, and the breaker depth was then determined from the profile surveys.

III. GENERAL RESULTS

Reflection Coefficients. Figure 6 presents the values of the reflection coefficient versus time for the four experiments. All tests show the same general pattern of variation, although the inferred initial condition was too transient to show on the time axis of Figure 6.

a. In the first few minutes of all experiments, it is inferred that the reflection coefficient rose sharply because of the following facts. Waves breaking on the concrete slab gave measured K_r ranging from 0.03 to 0.07. Since the permanent slope of the concrete slab was identical to the initial slope of the movable bed, there is no reason to doubt that these low K_r values also occurred during the first moment of testing on the movable bed. However, the first K_r measurements from the movable bed, which occurred after 12 to 20 minutes of wave action, gave measured K_r ranging from 0.14 to 0.19 in the four experiments.

b. After the initial high values of reflection and for the next few hours the reflection coefficient varied from 0.08 to 0.17. The

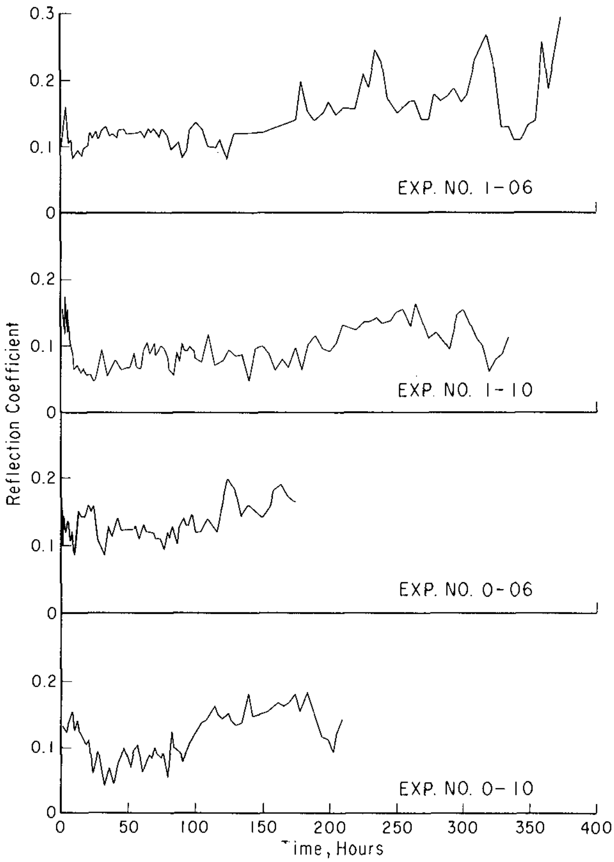


Figure 6. Time Variation of Reflection Coefficient for Four Experiments with Identical Generated Wave Conditions

period of high values and high variability was followed by a drop in the reflection coefficient. The time at which the drop occurred varied from 4 to 20 hours. Experiment No. 0-06 varied slightly from this pattern (Figure 6).

c. For an extended period of time (duration varying from 60 to 160 hrs), the reflection coefficient was relatively small ($K_r \leq 0.13$ in the six-ft tank and ≤ 0.11 in the ten-ft tank).

d. For the remainder of each experiment, the reflection coefficient increased in mean value and in variability (for example, varying from 0.10 to 0.30 in Experiment No. 1-06).

The reflection coefficient varied from 0.05 to 0.30 in the four experiments, which is a large variation considering the generated wave conditions were held constant. The time at which the reflection coefficient began to increase (paragraph d, above) varied in each experiment.

Profile Development. The profile in each experiment developed in a similar sequence as the sediment adjusted to the imposed wave conditions (Figure 7). Early profiles (solid line on Figure 7) had a steep foreshore zone (from the limit of uprush to the seaward limit of backwash), a short inshore zone (from the toe of the foreshore to just seaward of the breaker) with a longshore

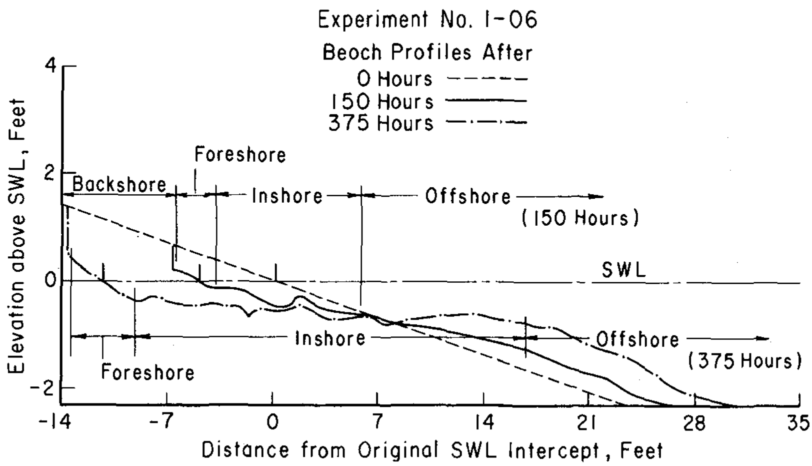


Figure 7. Typical Features of Profile Development

bar formed at the breaker position, and a gently-sloping offshore zone (from the seaward edge of the inshore zone to the seaward edge of sand). Later profiles (broken line in Figure 7) also had a steep foreshore zone, but the inshore zone widened to a long flat shelf which terminated in a relatively steep offshore zone. It is evident that the eroding foreshore and accreting offshore were complementary processes because the depth over the inshore remained relatively constant.

Breaker Evolution. The wave broke as a plunging breaker on the early profiles and, as the inshore zone slope became flatter, the breaker type changed to spilling, and the depth at breaking increased.

IV. SUMMARY OF THE FOUR EXPERIMENTS

The results of Experiment No. 1-06 are representative of the four experiments and are described in detail below. Highlights of the other experiments, especially where they deviate from Experiment No. 1-06, are then presented in following sections.

Experiment No. 1-06. Figure 8 is a plot of the movement of the contour positions at 0.1 ft contour intervals for Experiment No. 1-06. Superimposed on the plot is the movement of the breaker position. During part

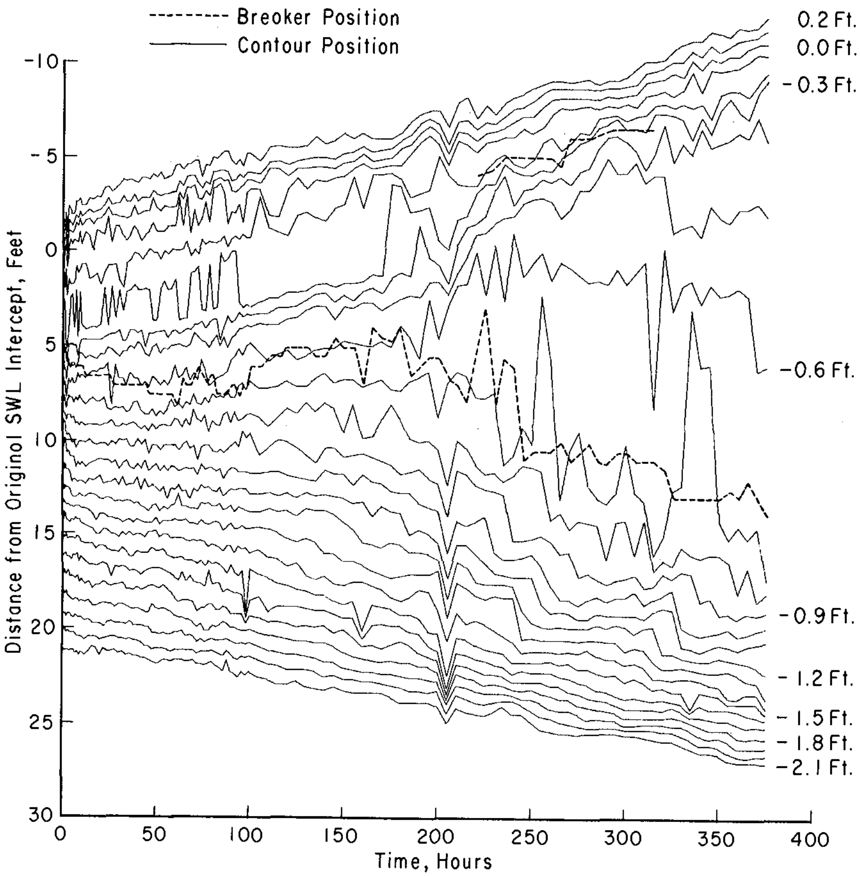


Figure 8. Movement of Contour Positions at Range 3 During Experiment No. 1-06

of the experiment each wave broke twice.

Within the first hour, the foreshore evolved to an equilibrium slope that did not change significantly throughout the 375 hours of the test. The constancy of the foreshore slope is indicated by the approximately equal spacing between the +0.2, +0.1, 0.0, and -0.1 ft contour positions in Figure 8. The slope of the 0.0 ft contour position line indicates that the average rate of shoreline retreat was 0.03 ft/hr.

Within the first hour the plunging breaker formed a longshore bar, and for the first 180 hours the wave broke mostly at a depth of 0.6 ft. As more material was eroded from the foreshore and deposited offshore, the length of the inshore zone increased and its slope decreased. As a result of the flatter slope, the breaker type after 105 hours began fluctuating between plunging and spilling. After 180 hours, the breaker position coincided with the general seaward movement of the -0.7 ft contour and the breaker type was primarily spilling. As the breaker moved in the seaward direction, the longshore bar eroded (the shoreward movement of the -0.3, -0.4, and -0.5 ft contours after 210 hours in Figure 8). The material deposited seaward of the breaker eventually reached an elevation of -0.8 ft and formed the long, flat shelf in the inshore zone and the relatively steep slope in the offshore zone. Between 220 and 315 hours the wave broke twice: by spilling at a depth of 0.7 ft, and by plunging at the toe of the foreshore.

The largest fluctuations in contour position in Figure 8 are two temporary shifts of about 10 and 12 feet in the position of the -0.7 ft contour. The same shifts occurred simultaneously at all three surveyed ranges (Figure 9), showing that the movable bed had a largely two-dimensional profile, and suggesting that significant net sand transport occurred across the inshore zone. Only the most seaward contour is plotted on Figure 8, but the large shifts in the -0.7 ft contour represent the removal of a bar projecting slightly above the -0.7 ft contour on the seaward portion of the inshore (Figure 7). The removal of this bar shifted the most seaward contour across the relatively flat inshore, as would occur on Figure 5a for the most seaward contour position at the elevation of the dashed line, if the bar on profile t_2 were removed.

The temporal variation of the reflection coefficient in Experiment No. 1-06 is shown in the top curve in Figure 6. Between 4 and 175 hours, the reflection coefficient was 0.12 or less. After 125 hours, the reflection coefficient showed a general upward trend, but with two large fluctuations. The overall upward trend in K_r occurred at a time when the width of the offshore zone decreased, that is, the average slope of the offshore steepened. For example, in Figure 8 the distance between the prograding -1.0 and -2.0 ft contours at 175 hours was about 10 ft (the same slope as the initial 1:10), but between 180 and 300 hours, this distance decreased to 7 feet. Therefore, a nominal average slope of the offshore zone steepened by about 43% at the same time that the reflection coefficient (exclusive of fluctuations) increased by approximately 33% (Figure 6).

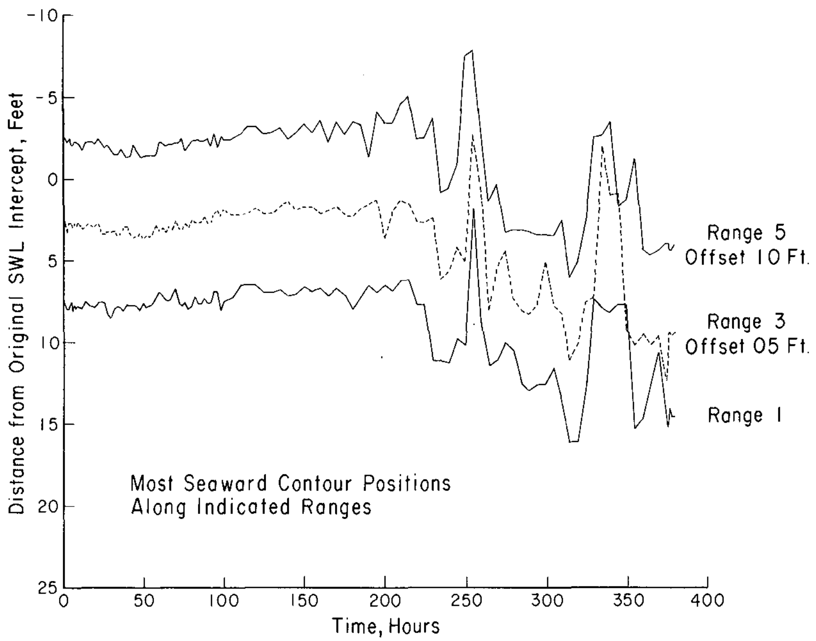


Figure 9. Movement of -0.7 ft Contour Position Indicating Two-Dimensionality During Experiment No. 1-06

The large fluctuations in K_r after 175 hours coincided with fluctuations in the position of the -0.7 ft contour (Figure 10). Peak values of K_r occurred when the -0.7 ft contour was in its more seaward position. Since a more seaward position of a fluctuating contour on an otherwise stable slope necessarily steepens the average slope seaward of that contour, the K_r peaks also correlate with a steepening of the seaward portion of the profile. However, the magnitude of the K_r fluctuations appears to be out of proportion to the magnitude of the changes of the whole profile. If the correlation shown on Figure 10 is substantiated by other data, then there appears to be a very sensitive adjustment of total profile reflectivity to minor profile changes.

Experiment No. 1-10. Figure 11 presents profile development along the center range during Experiment No. 1-10. In this experiment the tank was 4 ft wider and the initial test length was 38.3 ft shorter than in Experiment No. 1-06. The same sequence of profile development occurred, but at a slower rate. In Experiment No. 1-10 (Figure 11), the shoreline retreated an average of 0.01 ft/hr, or approximately one-third the rate of Experiment No. 1-06 (Figure 8).

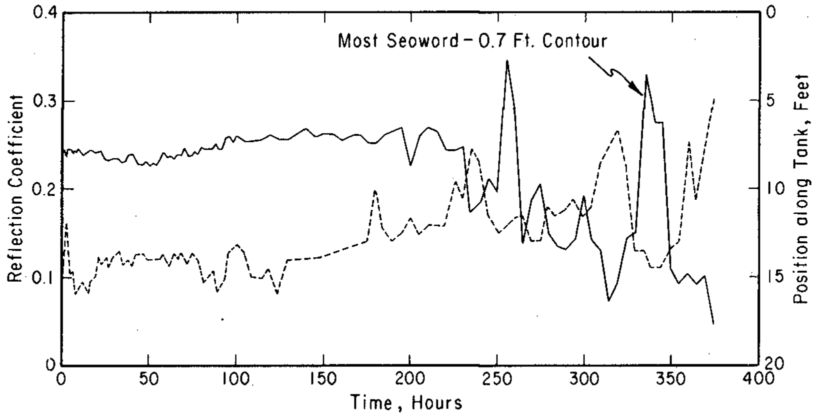


Figure 10. Fluctuations in Reflection Coefficient and -0.7 ft Contour Position During Experiment No. 1-06

Profile shape in Experiment No. 1-10 exhibited significantly greater lateral variations than in Experiment No. 1-06, as illustrated by the comparison of the movement of the -0.6 ft contour position along five ranges in Experiment No. 1-10 (Figure 12). The flat shelf in the inshore zone developed (over a 100-hour period) first along range 9 and last along range 1, although the shoreline retreat rates along all profiles were equal. Although there was greater variation in the shape and position of the offshore zone in Experiment No. 1-10, there was less variation in the value of the measured reflection coefficient (Figure 6), perhaps because lateral variation in profile development smoothed out the sharp K_r fluctuations found in the narrow tank of Experiment No. 1-06.

Experiment No. 0-06. The only difference in initial conditions between Experiment No. 0-06 and Experiment No. 1-06 was the initial test length which was 7 ft greater in No. 0-06. The contour positions at the center range are shown in Figure 13. The approximately horizontal lines marking the foreshore contour positions after 54 hours indicate the stabilized shoreline position produced by the repeated backshore replenishment. During the first 50 hours, the shoreline retreated at a rate which varied from 0.06 ft/hr to 0.14 ft/hr, or an average rate of 0.10 ft/hr.

Experiment No. 0-10. Figure 14 presents profile development along the center range of Experiment No. 0-10. The inshore in this experiment developed over a 45-hour period first along range 1 and last along range 9, that is, opposite to results from Experiment No. 1-10 shown in Figure 12 (data available at CERC). The shoreline retreat rate averaged 0.08 ft/hr during the first 50 hours.

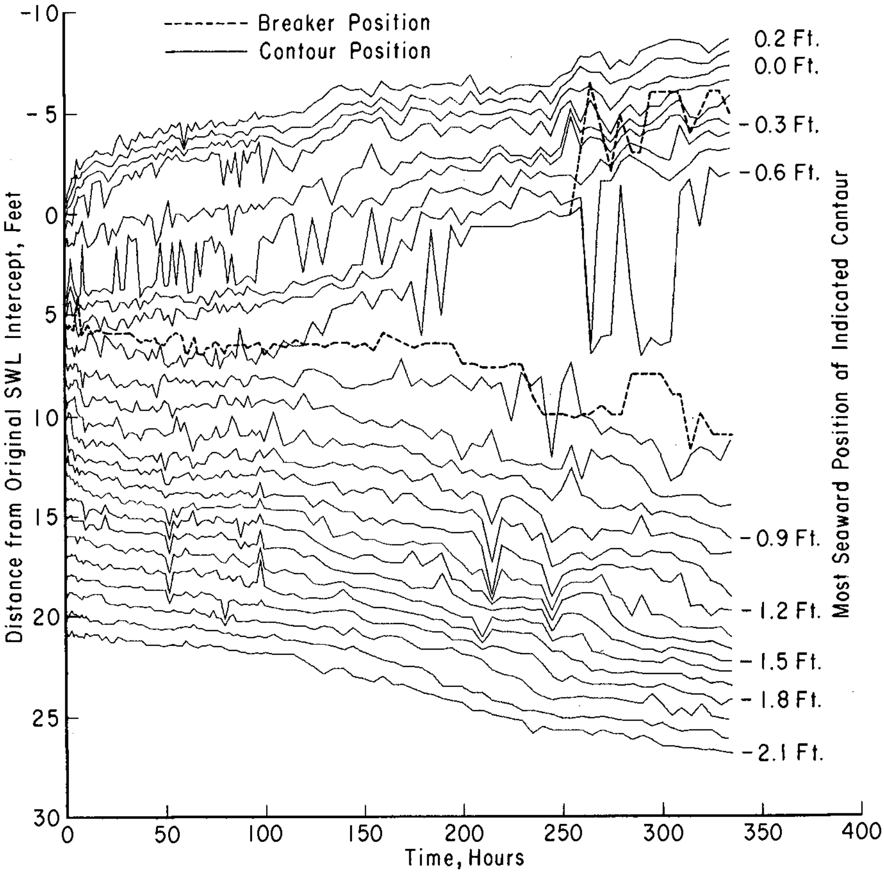


Figure 11. Movement of Contour Positions at Range 5 During Experiment No. 1-10

V. PROFILE REFLECTIVITY

At least three processes reflect wave energy from the movable bed in typical coastal engineering laboratory experiments. These include the conversion of potential energy stored in runup on the foreshore into a seaward traveling wave, the seaward radiation of energy from a plunging breaker, and reflection of the incident wave from the movable bed, particularly where the depth over the movable bed changes significantly. Depth changes are significant if the depth difference is an appreciable fraction of the average depth over a horizontal distance less than a wavelength. For conditions of these experiments, the wavelength is 14.3 ft seaward of the movable bed and approximately 9 ft in the inshore zone.

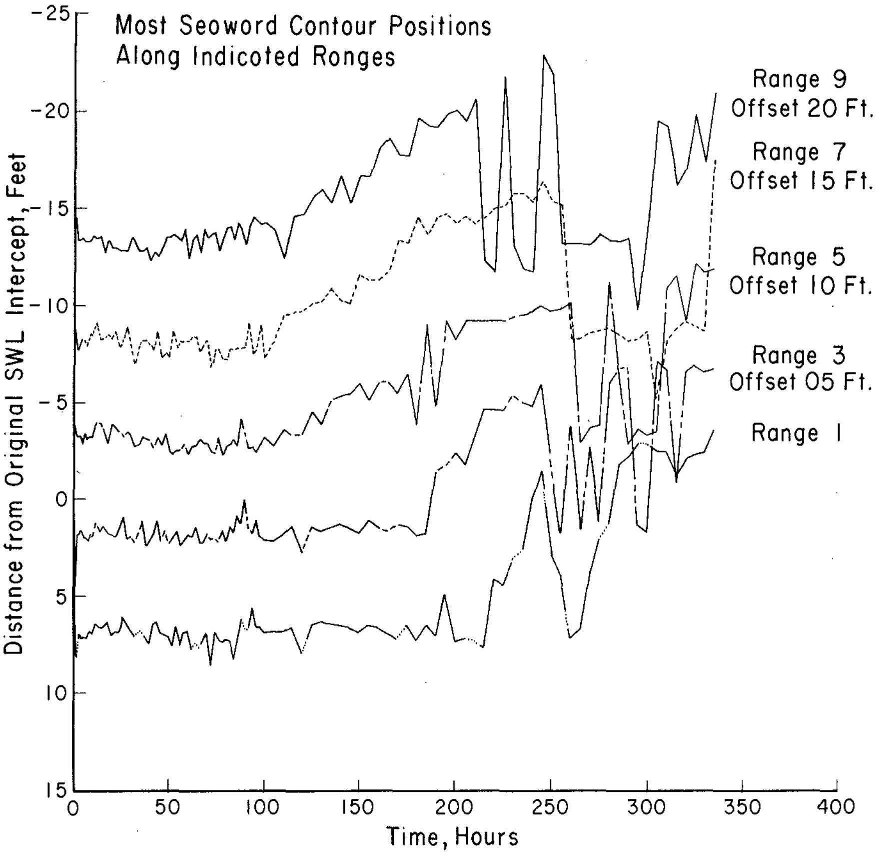


Figure 12. Movement of -0.6 ft Contour Position Indicating Lack of Two-Dimensionality During Experiment No. 1-10

Reflection from the Foreshore. The foreshore zone developed a relatively stable slope within the first hour of testing, well before the other elements of the movable bed profile had become prominent. The developed foreshore had a slope of about 1:6.5, which is considerably steeper than the initial 1:10 slope of the movable bed. The initial high values of K_r are probably the result of reflection from the foreshore of waves which dissipated relatively little energy until almost at the foreshore. Reflection from the foreshore is a function of the height of the wave reaching the foreshore, and this height would diminish as the inshore and offshore segments of the profile (Figure 7) became prominent.

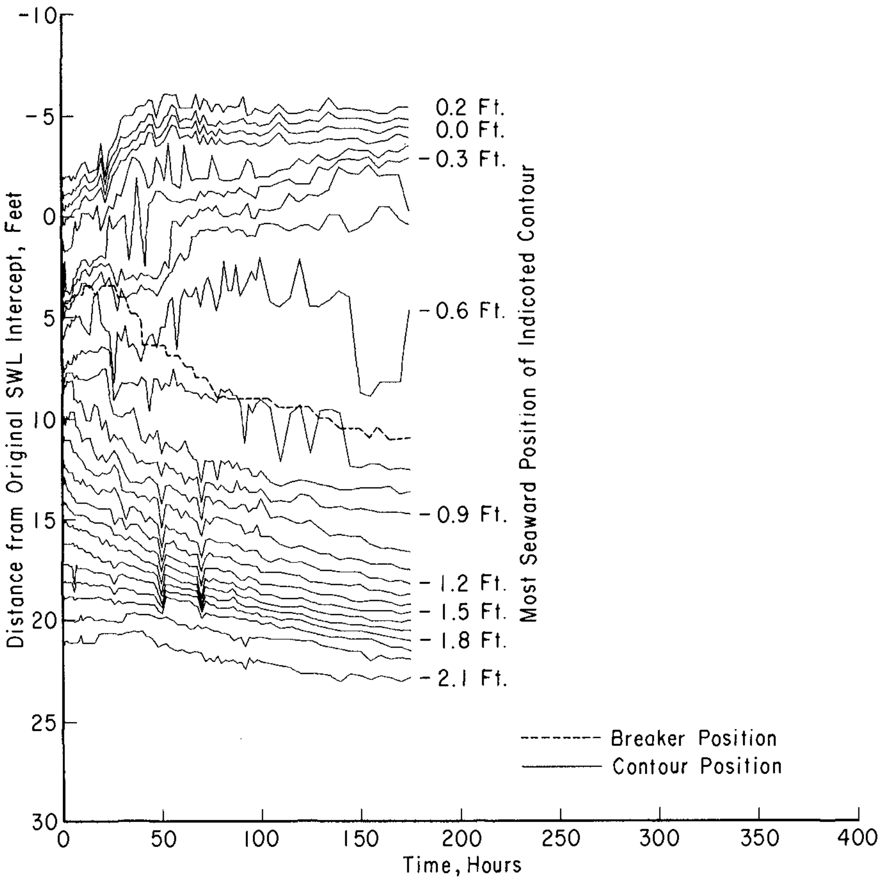


Figure 13. Movement of Contour Position at Range 3 During Experiment No. 0-06

<u>Reflection as Result of Wave Breaking</u>. On the concrete slab the wave broke as a plunging breaker and on the movable bed profile the breaker was initially a less well-developed plunger and evolved to a spilling breaker. The concrete slab had the same slope (1:10) as the initial slope of the movable bed. Because the total reflection was significantly less on the concrete slab ($K_r \approx 0.05$), where the plunger is assumed to contribute relatively more to the total reflection, it is likely that reflection from the movable bed by breaking was never very important, and became less important as the breaker type changed to spilling.

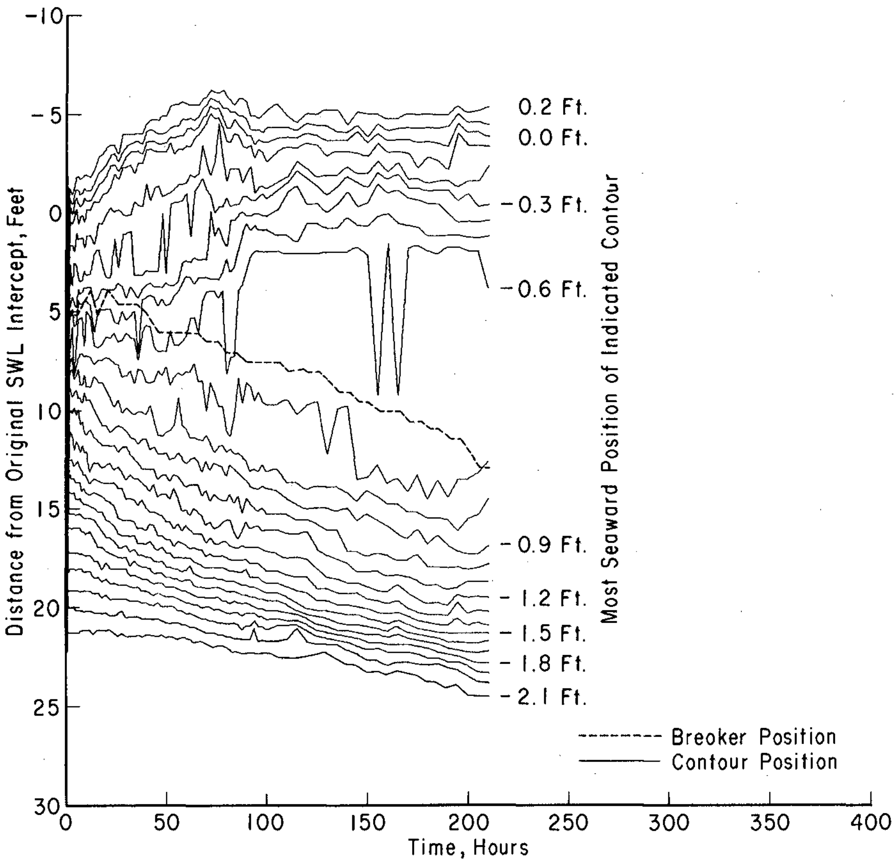


Figure 14. Movement of Contour Positions at Range 5 During Experiment No. 0-10

Effect of Inshore and Offshore. As the experiment proceeded, the inshore widened and the offshore steepened. At first the widening of the inshore dominated and the lowering of the reflection after the high initial values (Figure 6) is attributed to the greater energy dissipation in the inshore. The later steepening of the offshore correlates well with the trend toward higher K_r later in all the experiments, as can be seen by comparing the offshore contour positions on Figures 8, 11, 13, and 14 with the appropriate reflection curve on Figure 6. The earlier onset of higher reflection in Experiment Nos. 0-06 and 0-10 (Figure 6) is explained by the quicker development of the offshore reflector in those experiments (Figure 13 and 14).

With the development of the two reflecting zones (foreshore and offshore) separated by a relatively flat inshore zone, the measured reflected wave was composed of two reflected waves. A change in phase or amplitude of either reflected wave would change the phase and amplitude of the measured wave. Part of the long-term K_r variability can be attributed to the change in phase difference between these two reflected waves as the foreshore retreated landward and the offshore built seaward.

The apparent correlation between the movement of the -0.7 ft contour in Experiment No. 1-06 and the variability of the reflection coefficient (Figure 10) suggests that the reflection is very sensitive to small changes in the depth near the seaward edge of the inshore zone. (In a less pronounced way, the -0.6 ft contour position also varies with the changing values of K_r in Experiment No. 1-10 (Figure 6 and 11).) This variability in the depth would cause variability in the reflection of the incident wave from the offshore slope and variability in the amount of energy trapped on the inshore shelf.

VI. CONCLUSIONS

Reflection Results

a. For constant incident wave conditions in four experiments with a movable sand bed, the reflection coefficient (K_r) varied from 0.05 to 0.30. This indicates a possible range of measured wave heights from 0.25 to 0.47 ft for the nominally constant 0.36-ft height used in these four experiments. Under the same wave conditions, K_r from a 1:10 concrete slab varied only from 0.03 to 0.07.

b. K_r correlates with profile changes. K_r more than doubled in the first few minutes of wave action on the movable bed due to development of the steeper foreshore. The reflection decreased as the inshore widened. Later increases in K_r occurred when the offshore began to steepen. Large fluctuations in K_r occurred at times of large shifts in contour position on the relatively flat inshore zone.

c. Because of the variable profile reflectivity, incident wave measurements to characterize a coastal engineering experiment should be based on calibration of the wave generator rather than spot wave measurements during the experiment.

d. Further work needs to be done in quantifying the different processes causing reflection from a profile and in determining the importance of phase difference on profile reflectivity.

Profile Results.

a. Profiles in all four experiments developed in the same sequence.

b. The foreshore attained its equilibrium slope within the first hour of testing and maintained this slope throughout the experiments. The position of the foreshore retreated at average rates which varied from 0.04 to 0.10 ft/hr, averaged over the first 50 hours of each experiment.

c. "Equilibrium" profiles were not attained after as many as 375 testing hours (as many as 470,000 waves).

d. Initial slopes for two-dimensional coastal engineering experiments with a movable bed should be chosen according to the purpose of the experiments. For experiments which presume an "equilibrium" profile, an approximation of that "equilibrium" profile should be used to start the test, as done by Savage (1959) and Fairchild (1970a). However, data in this paper suggest caution in the determination of "equilbrium" conditions.

e. Further work needs to be done on the effect of water temperature, tank width, and initial test length on profile development.

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