Laboratory Effects in Beach Studies

Volume IV

Movable-Bed Experiments with H_o/L_o = 0.021 (1972)

by

Charles B. Chesnutt and Robert P. Stafford

MISCELLANEOUS REPORT NO. 77-7 (IV)
DECEMBER 1977

Approved for public release;
distribution unlimited.

U.S. ARMY, CORPS OF ENGINEERS

COASTAL ENGINEERING
RESEARCH CENTER

Kingman Building
Fort Belvoir, Va. 22060

Reprint or republication of any of this material shall give appropriate credit to the U.S. Army Coastal Engineering Research Center.

Limited free distribution within the United States of single copies of this publication has been made by this Center. Additional copies are available from:

National Technical Information Service
ATTN: Operations Division
5285 Port Royal Road
Springfield, Virginia 22151

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
MR 77-7 (IV)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (*and Subtitle*)
LABORATORY EFFECTS IN BEACH STUDIES
Volume IV. MOVABLE-BED EXPERIMENTS WITH $H_o/L_o = 0.021$ (1972)

5. TYPE OF REPORT & PERIOD COVERED
Miscellaneous Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Charles B. Chesnutt
Robert P. Stafford

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of the Army
Coastal Engineering Research Center (CERRE-CP)
Kingman Building, Fort Belvoir, Virginia 22060

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
D31192

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of the Army
Coastal Engineering Research Center
Kingman Building, Fort Belvoir, Virginia 22060

12. REPORT DATE
December 77

13. NUMBER OF PAGES
60 57p

14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)

15. SECURITY CLASS. (*of this report*)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Breakers	Movable-bed experiments	Wave height variability
Coastal engineering	Wave envelopes	Wave reflection
Currents	Wave generators	Wave tanks
Model studies		

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A two-dimensional movable-bed experiment was conducted in a 6-foot-wide wave tank for 180 hours, with a wave period of 1.90 seconds and a generated wave height of 0.36 foot. The profile had an initial slope of 0.05, which was flatter than the profiles in earlier experiments (0.10 in Vols. II and III of the series), and developed a different profile shape. The profile never reached equilibrium, even though the shoreline stopped retreating and the water temperature was relatively constant for the last 80 hours.

(continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

Even with the fine-grained, well-sorted sediment used, a measurable sorting occurred as the finer material was eroded and deposited on other parts of the profile.

The reflection coefficient, K_R, varied from 0.04 to 0.27 and the variations in K_R can be related qualitatively to profile development. The reflection coefficient from the foreshore zone was between 0.06 and 0.12. The large variation in the total profile K_R appears to be the result of changes in the elevation of the offshore reflecting zone and changes in the distance between the foreshore and offshore reflecting zones.

PREFACE

Ten experiments were conducted at the Coastal Engineering Research Center (CERC) from 1970 to 1972 as part of an investigation of the Laboratory Effects in Beach Studies (LEBS) to relate wave height variability to wave reflection from a movable-bed profile in a wave tank. The investigation also identified the effects of other laboratory constraints. The LEBS project is directed toward the solution of problems facing the laboratory researcher or engineer in charge of a model study; ultimately, the results will be of use to field engineers in the analysis of model studies. The work was carried out under the CERC coastal processes program.

This report (Vol. IV), the fourth in a series of eight volumes on the LEBS experiments, analyzes a movable-bed experiment run under nearly the same conditions as one of the experiments described in Volume III except that the initial profile slope was 0.05 rather than 0.10. As in Volume III, this experiment showed a slower approach to profile equilibrium than normally anticipated in movable-bed experiments. A different profile shape developed as a result of the flatter initial slope. This experiment provided further verification of the great effect of profile change on reflection coefficient, and thus on wave height variability.

Volume I of this series describes the procedures used in the 10 LEBS experiments, and also serves as a guide for conducting realistic coastal engineering laboratory studies. Volumes II to VII are data reports covering all experiments; Volume VIII summarizes the LEBS experiments detailed in the earlier volumes.

This report was prepared by Charles B. Chesnutt, principal investigator, and Robert P. Stafford, senior technician in charge of the two experiments. Dr. C.J. Galvin, Jr., Chief, Coastal Processes Branch, provided general supervision.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

JOHN H. COUSINS
Colonel, Corps of Engineers
Commander and Director

CONTENTS

TABLES

CONTENTS

TABLES--Continued

FIGURES

CONTENTS

FIGURE--Continued

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

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

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.8532	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.1745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.

To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

LABORATORY EFFECTS IN BEACH STUDIES

Volume IV. Movable-Bed Experiments with H_o/L_o = 0.021 (1972)

by
Charles B. Chesnutt and *Robert P. Stafford*

I. INTRODUCTION

1. Background.

Profiles in movable-bed, coastal engineering laboratory experiments and models are expected to reach an equilibrium shape after a sufficiently long time. The equilibrium shape is thought to depend only on constant wave and sediment conditions. The initial slope has been assumed to have no effect on the final shape of the profile.

The Laboratory Effects in Beach Studies (LEBS) project was initiated at the Coastal Engineering Research Center (CERC) in 1966 to investigate the causes of wave height variability and other problems associated with movable-bed coastal engineering studies. Ten movable-bed laboratory experiments were conducted from 1970 to 1972 in the CERC Shore Processes Test Basin (SPTB) to measure the variation in reflection as the profile developed toward equilibrium. This report (Vol. IV) discusses the experiment with H_o/L_o = 0.021 completed in 1972; Volumes II and III (Chesnutt and Stafford, 1977a, 1977b) discussed the experiments with the same wave steepness, conducted in 1970 and 1971. The other five experiments are discussed in Volumes V to VII, part of a series of eight reports on LEBS. Volume I of the series (Stafford and Chesnutt, 1977) discusses the contents and primary purposes of these reports. The first four experiments with initial slopes of 0.10 (discussed in Vols. II and III) led directly to the experiment described in this report. The first two experiments in 1970 (Vol. II) were conducted primarily to relate the variation of wave height to changes in the movable-bed profile. The experiments were to continue until the profile reached equilibrium, at which point it was assumed that the wave height variability would be significantly reduced. However, the beach had eroded to the back of the tank before the profile reached equilibrium.

The two experiments in 1971 (Vol. III) were repeats of the first two, with more sand added so that the initial test length (distance from the wave generator to the initial stillwater level (SWL intercept) was shortened by 7 feet (2.1 meters) in both tanks. Again, neither profile reached equilibrium.

The experiment discussed in this study (72D-06) was essentially a repeat of experiment 71Y-06 in the 6-foot-wide (1.8 meters) wave tank reported in Volume III (initial test length of 93 feet or 28.3 meters) with more sand added so that the initial slope was 0.05. With the additional sand placed at an initial slope closer to the presumed final profile shape, it was thought that the profile would reach equilibrium within a shorter period of time.

The experiment covered in this study has been discussed in an earlier report (Chesnutt, 1975) which analyzed the laboratory effects observed in this experiment along with two other experiments with the same wave steepness conducted in the 6-foot tank (see Vols. II and III).

2. Experimental Procedures.

The experimental procedures used in the LEBS experiments are described in Volume I (Stafford and Chesnutt, 1977) which provides the necessary details on the equipment, quality control, data collection, and data reduction for all 10 experiments. The data collection and reduction procedures unique to the experiment in this study are documented in the Appendix.

The conditions of experiment 72D-06 (the subject of this study) and experiment 71Y-06 (discussed in Vol. III, to be compared with experiment 72D-06) are summarized in Table 1. The table shows that initial test length, water depth, wave period, wave height, and sand size were the same in both experiments.

Table 1. Summary of experimental conditions.

Experiment[1]	Initial test length (ft)	Initial slope	Wave period (s)	Generated wave height (ft)	Initial[2] median grain size (mm)
72D-06	93	0.05	1.90	0.36	0.22
71Y-06	93	0.10	1.90	0.36	0.23

[1]Refer to Volume I (Stafford and Chesnutt, 1977) for relation between these experiments and the other eight LEBS experiments.

[2]Initial d_{50} determined by dry sieve method.

NOTE.--Constants: water depth = 2.33 feet; wave energy flux = 5.8 foot-pounds per second-foot.

The experimental facility used is shown in Volume I (Fig. 3) and in the Appendix (Fig. A-1). The facility consisted of two side-by-side 6-foot-wide wave tanks, one with a 0.10 concrete slope and the other a sand slope. A generator was common to both tanks so that each had identical wave energy input. The operation of the generators is described in Section IV and Appendix B of Volume I. The concrete slope provided a control (a bench-mark value) for the varying reflection measured in the neighboring tank with the movable bed. The initial test length was 7 feet greater on the concrete side.

The initial grading of the sand slope was on 25 September 1972. The first run was on 3 October 1972, the last run was on 13 December 1972, and the data collection was completed 18 December 1972. The dates are important because the experiments were run in outdoor facilities with water temperature varying with ambient air temperature. The major events of the experiment and the cumulative time at the end of each run are summarized in Table 2.

Table 3 gives the data collection schedule within each 5-hour run. During the first 5 hours when the runs varied in length, the same data were collected, with the schedule depending on the length of the run.

3. Scope.

This report describes and analyzes the reduced data from LEBS experiment 72D-06. The original data are available in an unpublished laboratory memorandum (No. 3) filed in the CERC library (Chesnutt and Leffler, 1977).

Wave reflection, profile surveys, sediment-size distribution, breaker characteristics, water temperature, and current observations are discussed in Section II. Section III discusses (a) profile development, which examines the interrelation of changes in profile shape, sediment-size distribution, breaker characteristics, water temperature, and currents; and (b) profile reflectivity, which examines the interrelation of changes in profile shape, breaker characteristics, currents, and wave reflection. Section IV summarizes the results of wave height variability, profile equilibrium, and other laboratory effects.

The conclusions and recommendations (Sec. V) are aimed directly at the problems of the laboratory researcher or engineer in charge of a model study. Field engineers should be aware of these results when analyzing model studies for projects.

The data in this study (particularly the profiles) may have other uses. The researcher can use these data, after consideration of the laboratory effects, to analyze short- and long-term changes in profile shape. After an analysis of the scale effects, the field engineer may use these data to determine generalized shoreline recession rates.

II. RESULTS

1. Wave Height Variability.

a. Incident Wave Heights. Wave height measurements from the continuous recording of water surface elevation along the center range at station +48 during the first 10 minutes for experiment 72D-06 are shown in Table 4. The wave heights in both tanks varied from 0.32 to 0.44 foot (9.8 to 13.4 centimeters) during the first 20 seconds. Ignoring the first group of waves, the range was 0.07 foot (2.1 centimeters) in the movable-bed tank and 0.09 foot (2.7 centimeters) in the fixed-bed tank. The range of wave heights was about the same amount in the two tanks.

Table 2. Experimental schedule for experiment 72D-06.

Cumulative time[1] (hr:min)	Wave record No.	Survey No.	Special data collected
0:00		1	Sand samples
0:10	066	2	
0:40	067	3	
1:30	068	4	
3:00	069	5	
5:00	070	6	
10:00	071	7	
-----[2]	---[3]	-----[3]	
30:00	075	11	Wave reflection
-----[2]	---[3]	-----[3]	
50:00	079	15, S1	Profile survey
-----[2]	---[3]	-----[3]	
80:00	085	21	Wave reflection
-----[2]	---[3]	-----[3]	
100:00	089	25, S2	Profile survey, ripple photos, sand samples
105:00	090	26	Wave reflection
------[2]	---[3]	-----[3]	
130:00	095	31	Wave reflection
------[2]	---[3]	-----[3]	
155:00	100	36	Wave reflection
------[2]	---[3]	-----[3]	
180:00	105	41, S3	Profile survey, ripple photos, sand samples

[1] Wave records were taken *during* run ending at cumulative time shown; surveys, sand samples, and ripple photos were taken *after* the run ending at the cumulative time shown (see also Table 3).

[2] Increments of 5.

[3] Increments of 1.

Table 3. Data collection schedule within runs for experiment 72D-06.

Event	Time within runs
Photo of SWL intercept and upper slope, if damaged since last run	Before start
Current data	Throughout run
Recording of wave envelope	4:40
Preparation of visual observation form	4:55
Photos of runup and breaker	4:59
Photo of SWL intercept and upper slope, after water had calmed	5:00
Profile survey	5:00
Water temperature data collected in the morning and afternoon of each day of testing	

Table 4. Wave heights during first 10 minutes for experiment 72D-06.

Cumulative time (min:s)	Wave height (ft)					
	Movable-bed tank			Fixed-bed tank		
	(max)	(min)	(avg)	(max)	(min)	(avg)
0:00 to 0:20	0.443	0.318	0.367	0.443	0.321	0.369
0:20 to 0:40	0.384	0.354	0.373	0.387	0.360	0.372
0:50 to 1:10	0.384	0.354	0.370	0.419	0.359	0.379
1:50 to 2:10	0.386	0.360	0.373	0.383	0.354	0.368
2:50 to 3:10	0.378	0.353	0.362	0.374	0.339	0.359
3:50 to 4:10	0.363	0.347	0.357	0.378	0.348	0.357
4:50 to 5:10	0.380	0.345	0.361	0.381	0.342	0.363
5:50 to 6:10	0.383	0.353	0.366	0.374	0.327	0.351
6:50 to 7:10	0.345	0.338	0.350	0.363	0.330	0.349
7:50 to 8:10	0.369	0.359	0.359	0.369	0.345	0.355
8:50 to 9:10	0.362	0.339	0.348	0.360	0.327	0.344
9:40 to 10:00	0.362	0.321	0.350	0.378	0.344	0.360
Avg[1]			0.360			0.359

[1]Excludes averages for cumulative times 0:00 to 0:20 and 0:20 to 0:40.

NOTE.--Average of 3d through 10th wave; 6th wave was omitted due to recording omission on sand channel.

The average wave height in each tank was determined by averaging the average of the last 10 waves in the last 20-second interval for each of the 10 minutes. The average wave height was 0.36 foot (11.0 centimeters) in both the fixed- and movable-bed tanks. The equal values are coincidental, since the gages were different distances from the profile.

Table 5 shows the average incident wave heights in the two tanks. These heights were determined by the automated method for determining the reflection coefficient, K_R (see Vol. I). The range of values for the fixed-bed tank was 0.03 foot (0.9 centimeter). This variation is probably caused by generator operation variation, measurement errors, and all errors not caused by a changing profile. The range of values in the movable-bed tank was 0.08 foot (2.4 centimeters). The difference between the two amounts of variation indicates that 0.05-foot (1.5 centimeters) variation in the movable-bed tank was due to the changing shape and position of the profile, causing a varying profile reflection and thus a varying re-reflection from the wave generator. The re-reflected wave superposing with the generated wave created an incident wave height which varied in time.

Table 5. Incident wave heights, movable- and fixed-bed tanks.

Time (hr)	Incident wave height (ft)	
	Movable bed	Fixed bed
0.66	0.39	0.38
1.50	0.40	0.38
3.00	0.36	0.38
5.00	0.36	0.39
10.00	0.38	0.40
20.00	0.37	0.38
25.00	0.38	0.39
30.00	0.37	0.37
35.00	0.34	0.39
45.00	0.36	0.40
80.00	0.41	0.40
105.00	0.40	0.38
110.00	0.39	0.37
120.00	0.40	0.38
125.00	0.36	0.38
130.00	0.36	0.39
140.00	0.41	0.37
150.00	0.39	0.37
155.00	0.41	0.38
160.00	0.40	0.39
165.00	0.41	0.38
170.00	0.39	0.38
180.00	0.42	0.39
Avg	0.39	0.38

b. Wave Reflection. The reflection coefficient, K_R, data determined by the manual and automated methods are given in Table 6. The two methods are described in Volume I. A plot of K_R versus time (Fig. 1) comparing the two methods, indicates that both methods show the same time variation in K_R. A scatter plot (Fig. 2) of K_R values for the manual method versus the automated method, for those wave records reduced by both methods, shows that the manual values were higher than the automated values by an average of 0.05, and that the variation did not increase with increased reflection.

All K_R data versus time are plotted in Figure 3, with the manual values reduced by 0.05 to give a single curve. For the first 25 hours the K_R was 0.10 or below. After 25 hours the K_R increased in mean value and in variability, reaching as high as 0.18 at 35 hours and 0.27 at 115 hours, and as low as 0.07 at 135, 140, and 150 hours.

Values of K_R in the fixed-bed tank as determined by the automated method (Table 6) varied from 0.04 to 0.07. At times of high K_R in the movable-bed tank (at 30, 35, 40, 105, 110, and 120 hours) the K_R in the fixed-bed tank varied within the range of 0.05 to 0.07, indicating that the high K_R in the movable-bed tank was not caused by a change in generator operation. The 0.03 variation of K_R in the fixed-bed tank indicates that variation in K_R greater than ±0.015 in the movable-bed tank can be attributed to changes in the movable-bed profile.

The K_R values determined in the inshore zone, which represent the reflection from the foreshore zone, are shown in Table 7. The average K_R varied from 0.06 to 0.12.

Table 7. Reflection coefficients in the inshore zone of the movable-bed tank.

Time (hr)	K_R[1] Range 1	K_R[1] Range 3	K_R[1] Range 5	Avg
101	0.11	0.10	0.10	0.10
105	0.10	0.09	0.17	0.12
126	0.09	0.06	0.04	0.06
130	0.09	0.09	0.11	0.10
152	0.08	0.13	0.13	0.11
155	0.10	0.07	0.08	0.08

[1]Data reduced by the manual method; values reduced by 0.05 using Figure 2 to calibrate the manual method against the automated method.

2. Profile Surveys.

a. Interpretation of Contour Movement Plots. The profile surveys (discussed in Vol. I) measured the three space variables of onshore-

Table 6. Reflection coefficients, manual and automated methods.

	Manual method	Automated method	
Cumulative time (hr)	Movable bed (K_R)	Movable bed (K_R)	Fixed bed (K_R)
0.16	-----[1]	-----	-----
0.66	-----	0.047	0.062
1.50	-----	0.039	0.061
3.00	-----	0.058	0.065
5.00	-----	0.082	0.048
10.00	-----	0.069	0.050
15.00	0.114	-----	-----
20.00	-----	0.092	0.062
25.00	-----	0.099	0.062
30.00	0.191	0.149	0.053
35.00	-----	0.183	0.049
40.00	0.196	-----	-----
45.00	-----	0.123	0.049
50.00	0.183	-----	-----
55.00	0.191	-----	-----
60.00	0.203	-----	-----
65.00	0.128	-----	-----
70.00	0.135	-----	-----
75.00	0.142	-----	-----
80.00	0.129	0.084	0.067
85.00	-----	-----	-----
90.00	0.199	-----	-----
95.00	0.181	-----	-----
100.00	0.200	-----	-----
105.00	0.252	0.208	0.066
110.00	-----	0.217	0.058
115.00	0.323	-----	-----
120.00	-----	0.195	0.045
125.00	-----	0.129	0.052
130.00	0.163	0.107	0.052
135.00	0.119	-----	-----
140.00	-----	0.072	0.038
145.00	0.145	-----	-----
150.00	-----	0.069	0.043
155.00	0.155	0.099	0.049
160.00	-----	0.098	0.060
165.00	-----	0.101	0.042
170.00	-----	0.097	0.050
175.00	0.150	-----	-----
180.00	-----	0.076	0.049

[1]Not analyzed by this method.

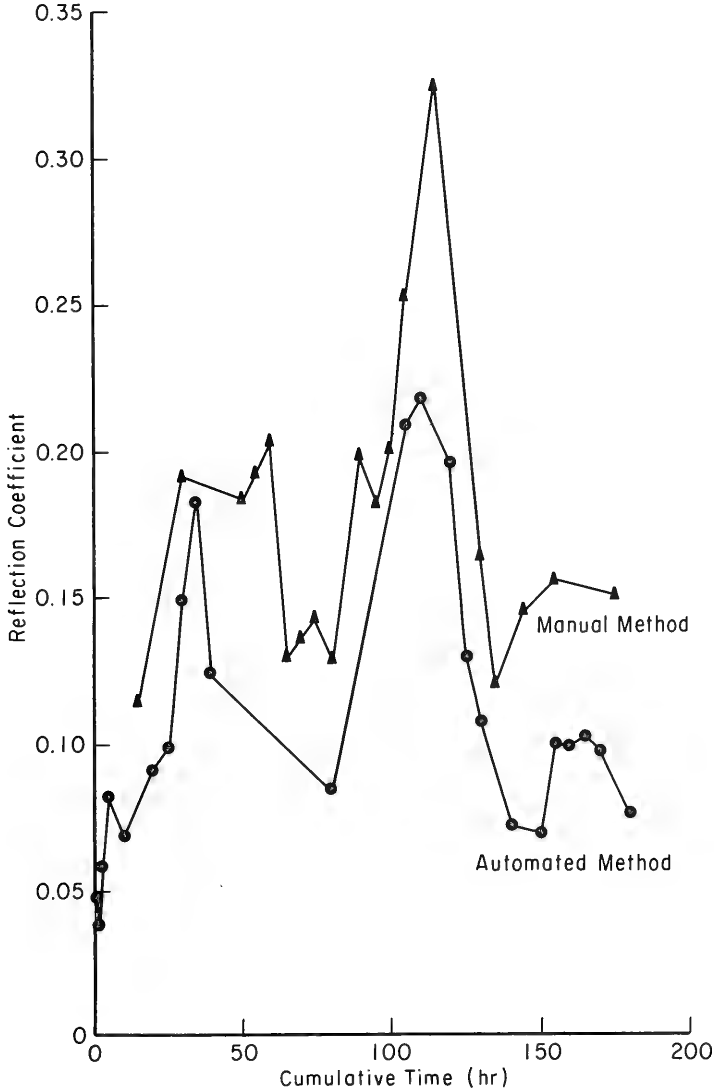

Figure 1. Comparison of manual and automated reflection coefficients along range 3 seaward of the profile.

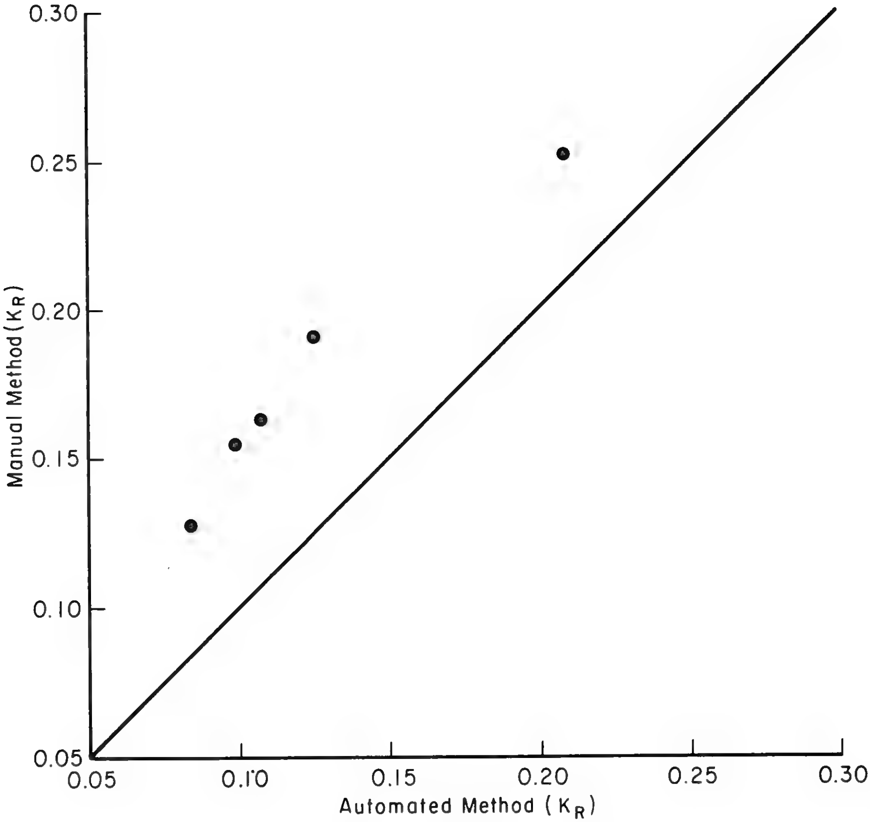

Figure 2. Correlation of manual and automated reflection coefficients.

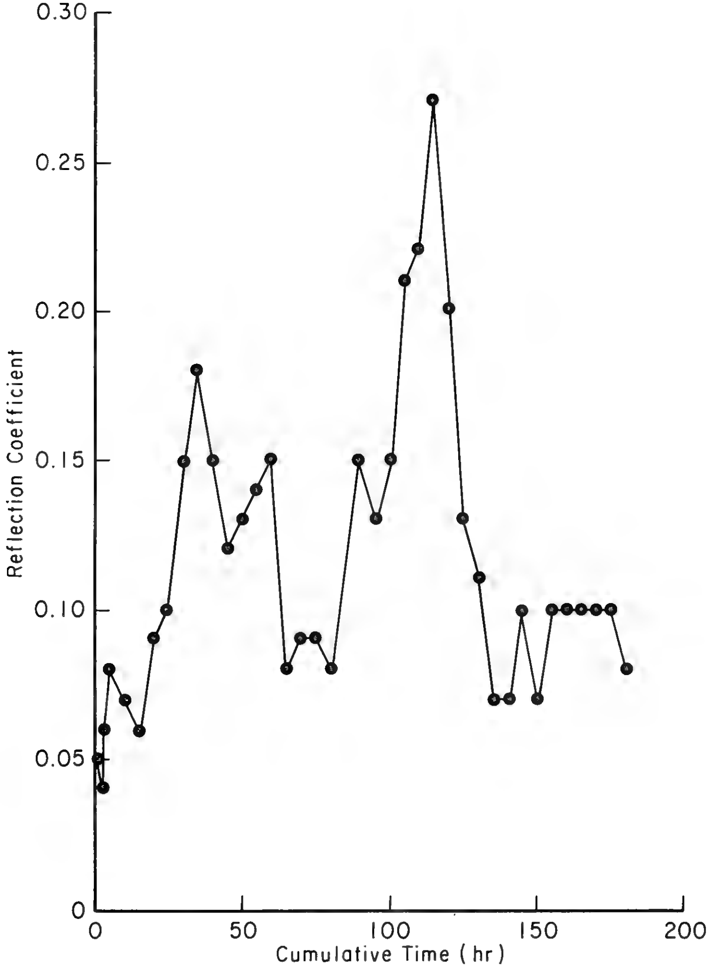

Figure 3. Reflection coefficient variation for experiment 72D-06 along range 3 seaward of the profile.

offshore distance (station), alongshore distance (range), and elevation at fixed times (Table 2) during the experiment. The CONPLT method (see Vol. I) for presenting the data involves fixing the alongshore distance by selecting data from 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; i.e., -0.1, -0.2, and -0.3 on the hypothetical profile in Figure 4(a). These contour positions from each survey are then plotted against time (Fig. 4,b).

A horizontal line in Figure 4(b) represents no change in contour position. An upward-sloping line indicates landward movement of contour position (i.e., erosion); a downward-sloping line indicates deposition. The slope of a line indicates the horizontal rate of erosion or deposition at that elevation. The three x's at time t_2 (Fig. 4,b) indicate multiple contour positions at elevation -0.2 which is shown by the intersection of the dashline with profile t_2 in Figure 4(a).

Three types of contour movement plots included in this study are:

(a) The seawardmost intercepts along one range for selected depths;

(b) the seawardmost intercepts for one selected depth along all ranges; and

(c) all contour intercepts including multiple intercepts along one range, for up to 12 selected depths.

The coordinate system used for the contour movement plots is shown in Figure 5. The following elevations are referred to in the discussion that follows: 0.1 foot (3.0 centimeters), 0.2 foot (6.1 centimeters), 0.3 foot (9.1 centimeters), 0.4 foot (12.2 centimeters), 0.5 foot (15.2 centimeters), 0.6 foot (18.3 centimeters), 0.7 foot (21.3 centimeters), 0.8 foot (24.4 centimeters), 0.9 foot (27.4 centimeters), 1.0 foot (30.5 centimeters), 1.1 feet (33.5 centimeters), 1.2 feet (36.6 centimeters), 1.3 feet (39.6 centimeters), 1.4 feet (42.7 centimeters), 2.1 feet (64.0 centimeters).

b. Profile Zones. Definitions of coastal engineering terms used in LEBS reports conform to Allen (1972) and the Shore Protection Manual (SPM) (U.S. Army, Corps of Engineers, Coastal Engineering Research Center, 1975). For the profiles zones in this study, the boundary between the foreshore and inshore zones is defined at elevation -0.2 foot.

The seaward edge of the inshore zone is defined as extending through the breaker zone. The boundary between the inshore and offshore zones for this experiment is at elevation -0.8 foot.

A definition sketch of the profile zones is shown in Figure 6. Early profiles (solid line in Fig. 6) had a steep foreshore, a long flat inshore, and a slightly steeper (than 0.05) offshore. Later profiles (broken line

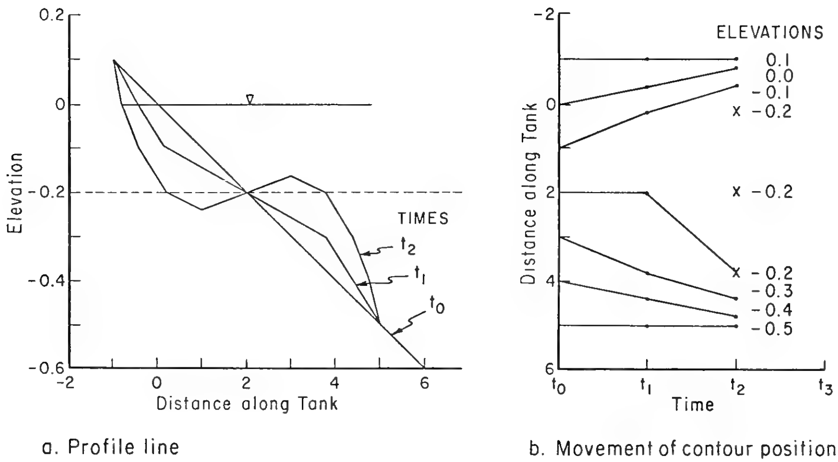

Figure 4. Interpretation of contour movement plots.

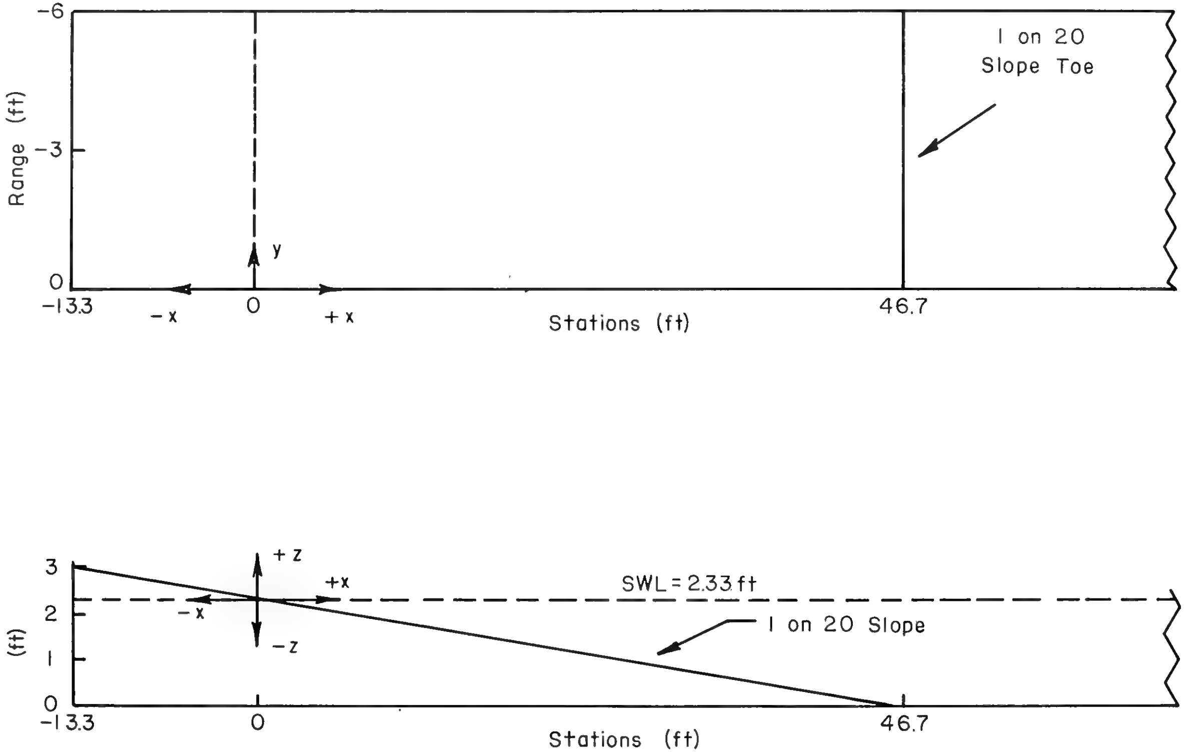

Figure 5. Definition of coordinate system.

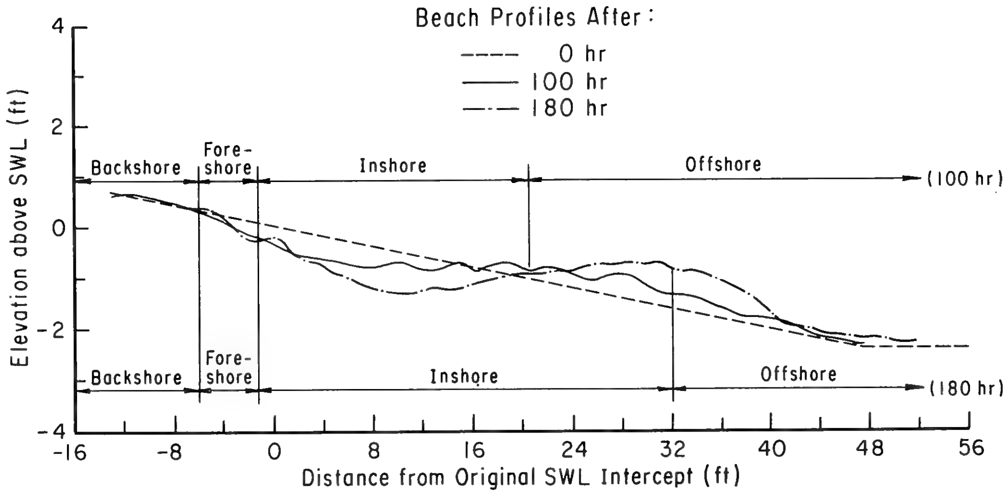

Figure 6. Definition sketch of profile zones.

in Fig. 6) also had a steep foreshore, a longer inshore with a significant depression between stations 2 and 20, and a relatively steep offshore. This development is shown by contour movement plots (Figs. 7, 8, and 9) of the seawardmost contour intercepts for elevations at 0.1-foot-depth increments from +0.2 to -2.1 feet. The heavier lines for -0.2- and -0.8-foot contours distinguish the three profile zones in the figures. In the foreshore and offshore zones the contour lines are close together indicating steeper slopes; in the inshore zone the lines are spaced farther apart indicating flatter slopes.

(1) Foreshore Zone. Within the first 10 hours the foreshore developed the shape which it maintained throughout the remainder of the experiment (Fig. 10). Between 5 and 125 hours the foreshore retreated as material eroded from the backshore and the foreshore (upward-sloping lines in Fig. 10); between 125 and 135 hours, the foreshore prograded seaward (downward-sloping lines in Fig. 10). After 135 hours the shoreline position was stable.

Although the contour lines of the foreshore moved together, the lines were not always parallel, indicating a variation in foreshore slope with time at each range (Figs. 7, 8, and 9). Slope values at the SWL intercept (Table 8) were determined by measuring the slope between the survey points on either side of the shoreline. The steepest slope was 0.5 and the flattest slope was 0.02; the average slope of the foreshore (after 3 hours) was about 0.19.

The lateral variation in the slope of the foreshore developed as a result of concentrations of backwash, which created gullies or flatter slopes. The flow of the wave uprush and backrush for the same wave conditions that shaped the foreshore is discussed in Volume II (Chesnutt and Stafford, 1977a). Figure 11 shows the foreshore at 45 hours, with a typical foreshore shape.

The shoreline (0 contour) movement along the three ranges is compared in Figure 12. The slope of the 0 contour indicates the shoreline recession rate. Because the slope of the backshore was 0.05 (and not flat), the volume rate of erosion was not constant and increased at a rate proportional to the square of the shoreline recession rate. No significant lateral variations occurred in the shoreline recession (Fig. 12). The average rate of shoreline recession between 5 and 125 hours was 0.05 foot per hour. Between 125 and 135 hours the foreshore prograded seaward and then remained stationary.

(2) Inshore Zone. The movement of all contour intercepts in the inshore zone along the three ranges is shown in Figures 13, 14 and 15; the movement of selected individual contours along the three ranges is compared in Figure 16.

Within the first 10 minutes of testing, a longshore bar formed near station +8, between the -0.5- and -0.3-foot contours. By 5 hours

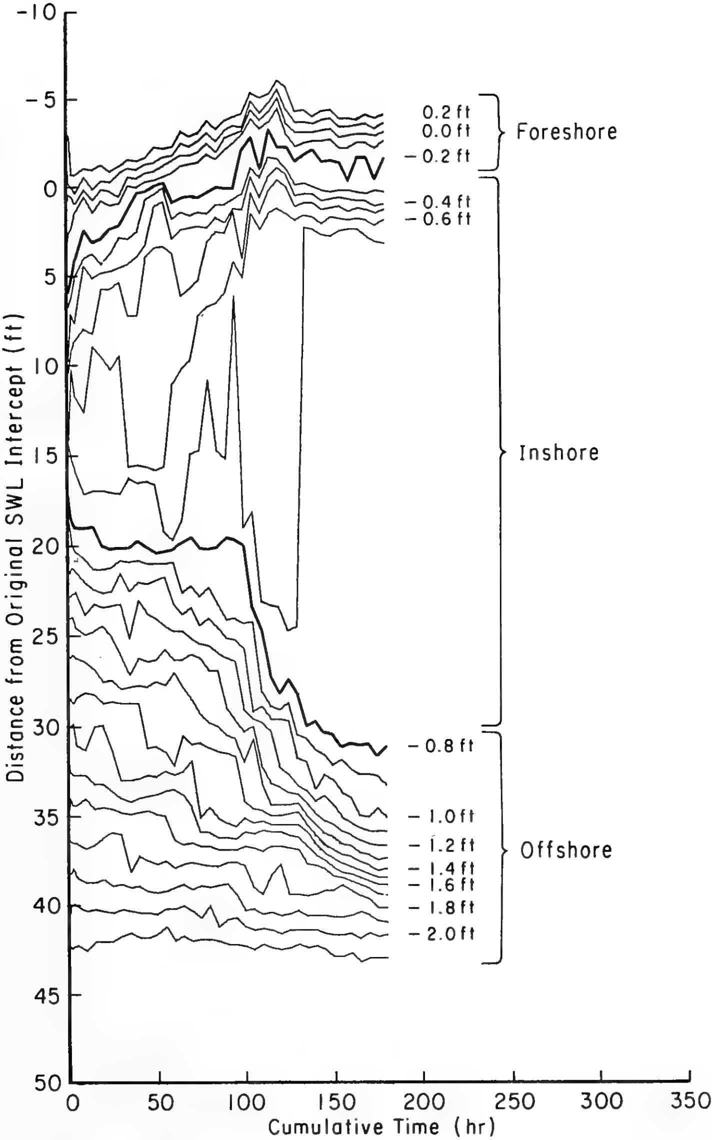

Figure 7. Profile changes along range 1.

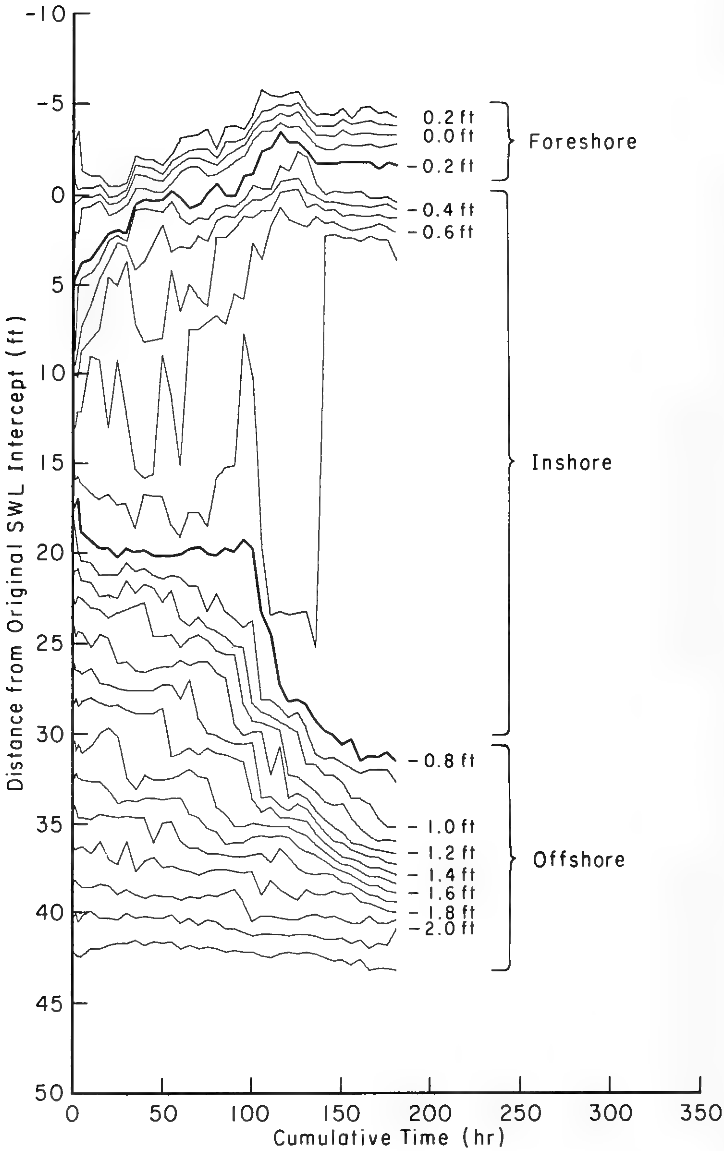

Figure 8. Profile changes along range 3.

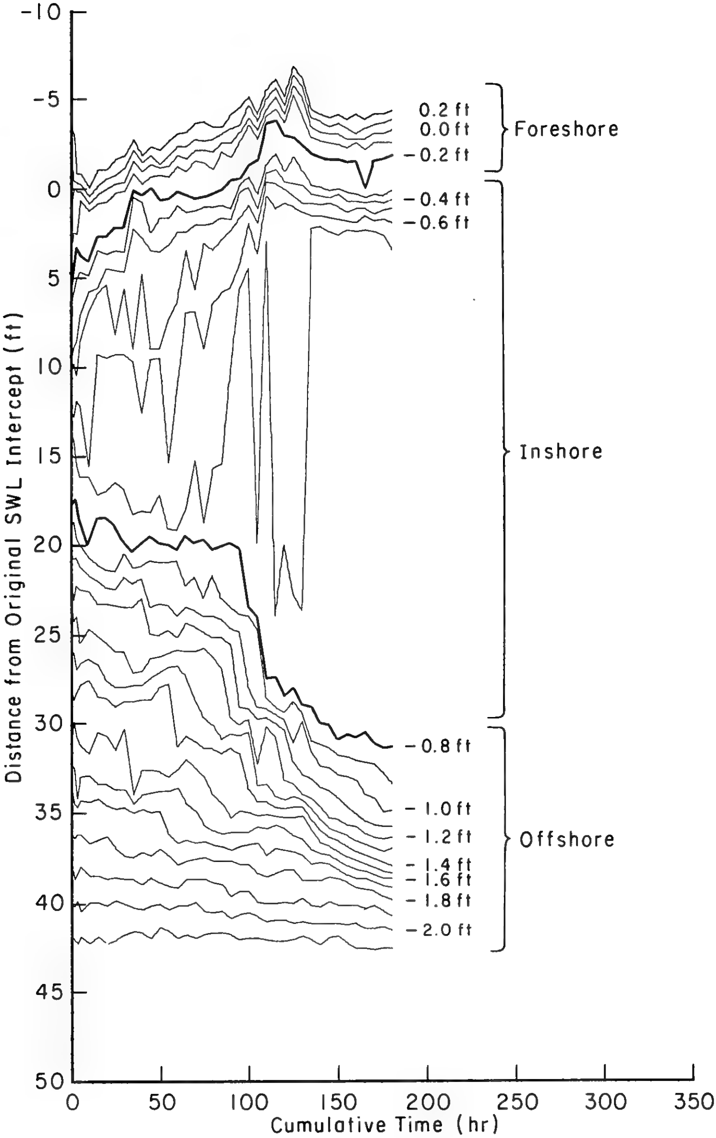

Figure 9. Profile changes along range 5.

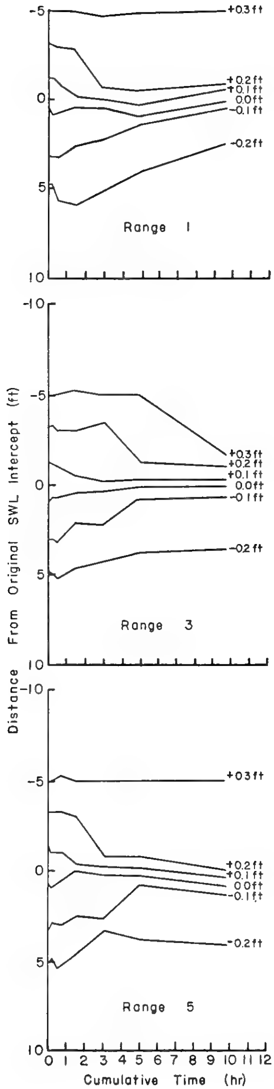

Figure 10. Comparison of initial contour movement on the foreshore zone.

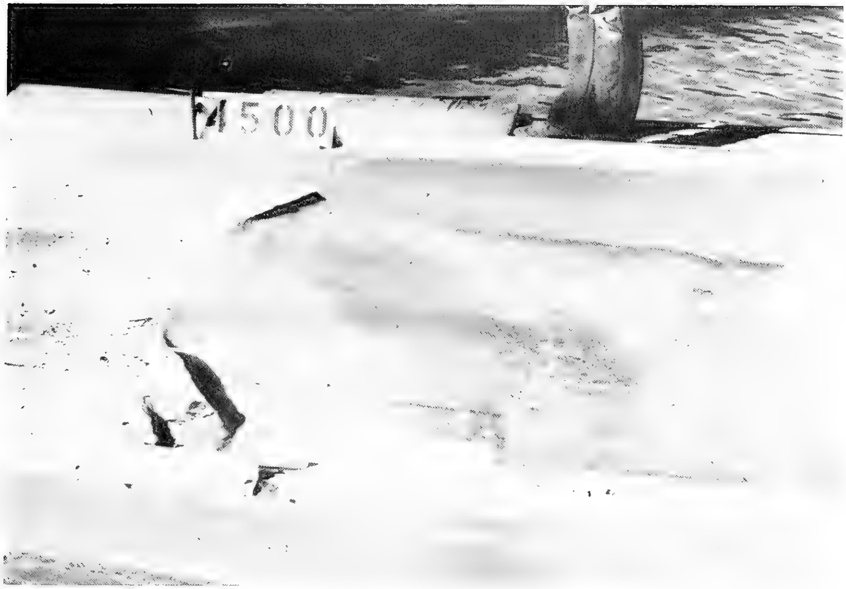

Figure 11. Shape of the foreshore zone.

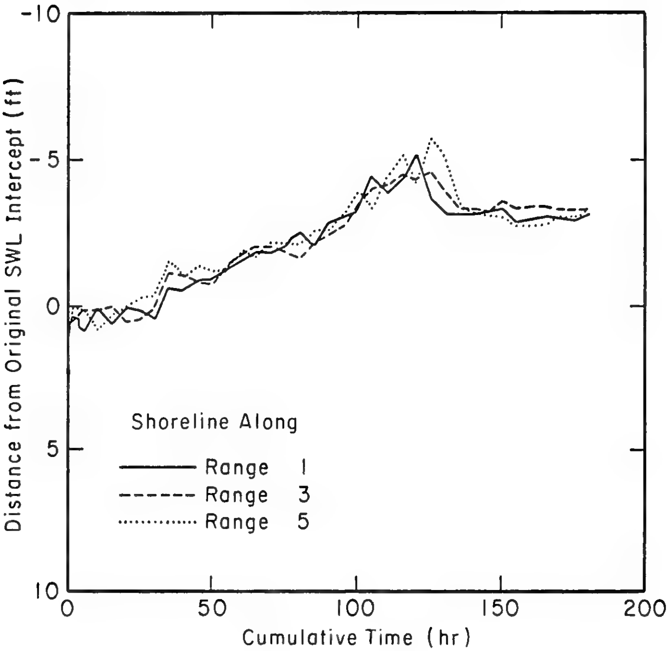

Figure 12. Comparison of the shoreline (0 contour) movement.

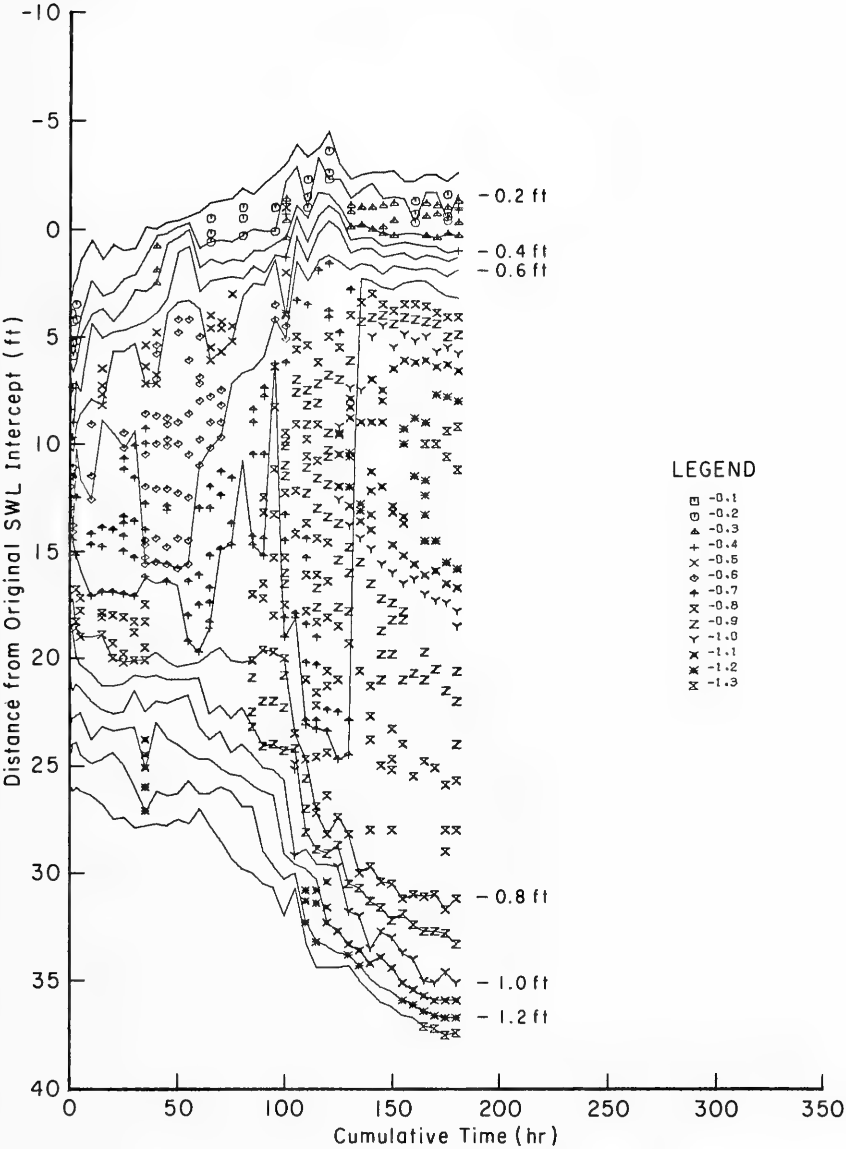

Figure 13. Changes in the inshore zone along range 1.

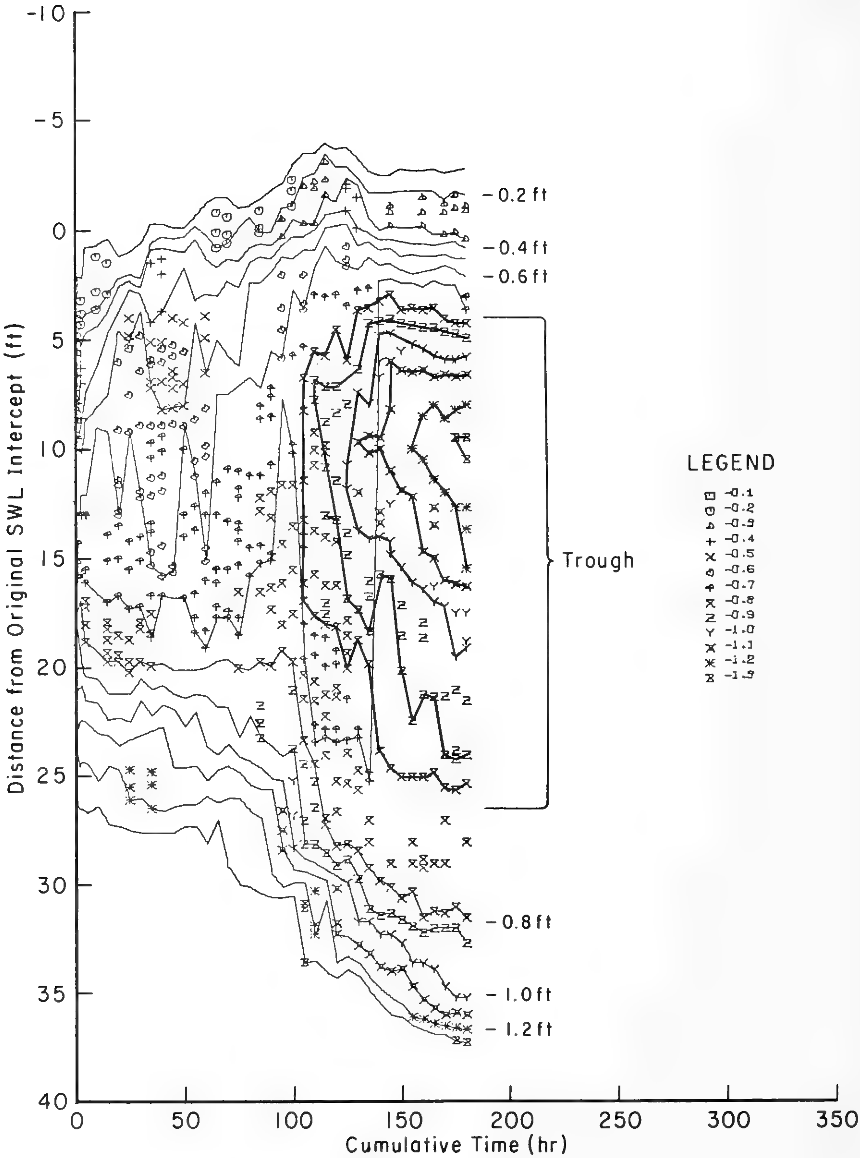

Figure 14. Changes in the inshore zone along range 3.

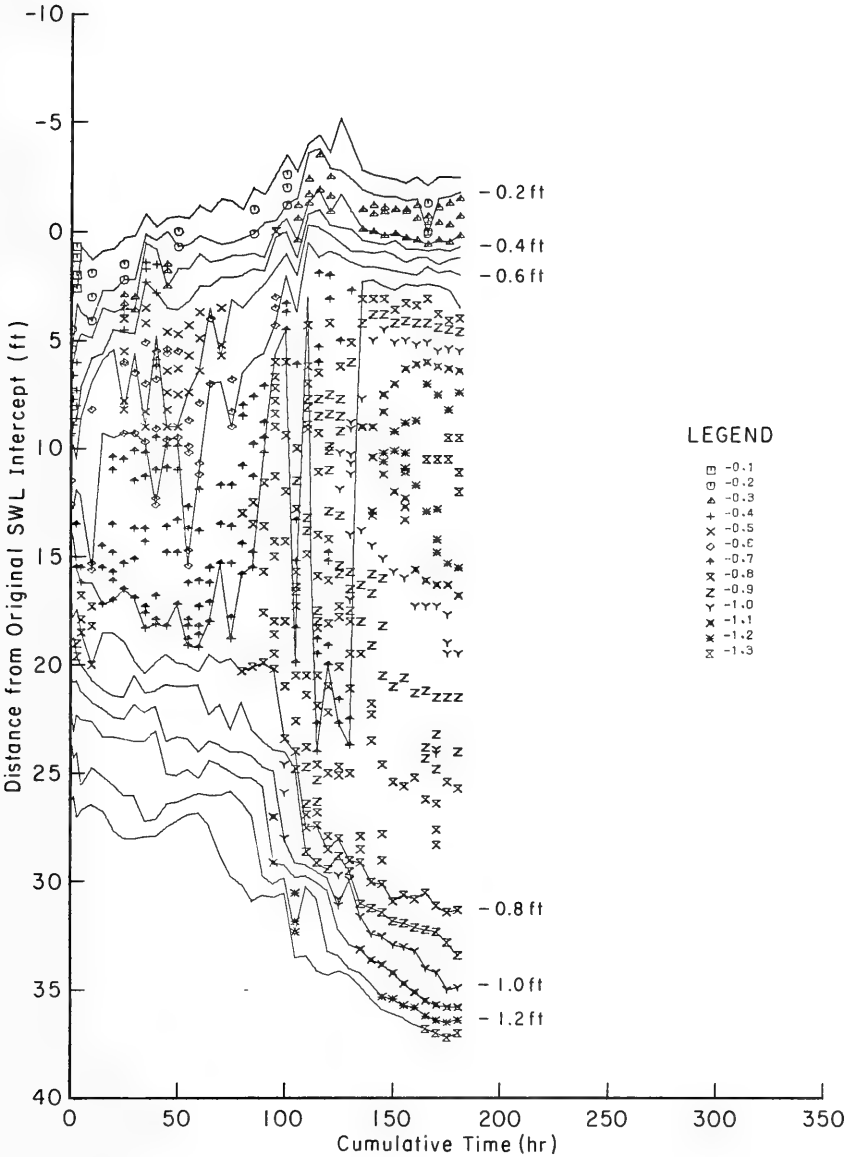

Figure 15. Changes in the inshore zone along range 5.

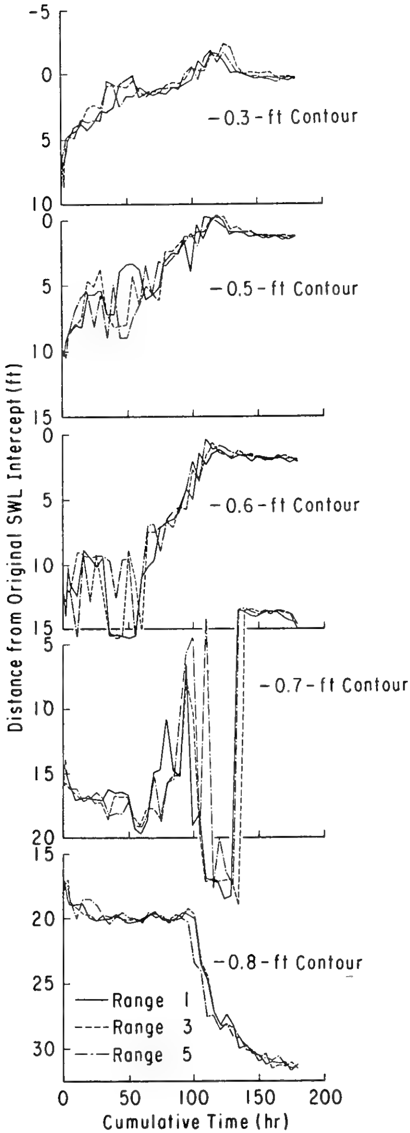

Figure 16. Comparison of the -0.3-, -0.5-, -0.6-, -0.7-, and -0.8-foot contour movements.

Table 8. Slope of the beach face at the SWL intercept in experiment 72D-06.

Cumulative time (hr)	Range 1	Range 3	Range 5
0:00	0.08	0.02	0.04
0:10	0.06	0.06	0.08
0:40	0.06	0.08	0.12
1:30	0.18	0.02	0.26
3:00	0.20	0.18	0.26
5:00	0.16	0.26	0.24
10:00	0.28	0.18	0.22
15:00	0.16	0.18	0.20
20:00	0.18	0.20	0.12
25:00	0.18	0.24	0.16
30:00	0.10	0.22	0.26
35:00	0.18	0.16	0.18
40:00	0.22	0.20	0.14
45:00	0.16	0.18	0.16
50:00	0.20	0.20	0.40
55:00	0.16	0.16	0.18
60:00	0.34	0.26	0.16
65:00	0.16	0.20	0.14
70:00	0.22	0.22	0.16
75:00	0.18	0.18	0.18
80:00	0.16	0.22	0.12
85:00	0.16	0.10	0.24
90:00	0.20	0.16	0.14
95:00	0.20	0.26	0.24
100:00	0.50	0.26	0.12
105:00	0.22	0.18	0.16
110:00	0.22	0.18	0.24
115:00	0.18	0.22	0.18
120:00	0.16	0.18	0.18
125:00	0.18	0.18	0.16
130:00	0.18	0.18	0.18
135:00	0.14	0.18	0.16
140:00	0.18	0.16	0.16
145:00	0.16	0.16	0.22
150:00	0.16	0.16	0.20
155:00	0.16	0.18	0.14
160:00	0.22	0.18	0.44
165:00	0.24	0.16	0.18
170:00	0.24	0.12	0.24
175:00	0.20	0.16	0.18
180:00	0.18	0.20	0.18
Avg	0.19	0.18	0.19

the bar completely eroded and thereafter the inner inshore (between -0.2- and -0.5-foot elevations) remained fairly steep, as indicated by the shoreward movement of the -0.2- to -0.5-foot contours. This material was deposited at elevations -0.7, -0.8, and -0.9 foot. During the first 5 hours, the shoreward movement of the -0.5-foot contour and the seaward movement of the -0.8-foot contour indicate fairly rapid development of a long, flat shelf in the outer part of the inshore zone.

Between 5 and 100 hours the seaward edge of the shelf (and inner inshore zone) remained stationary and the shelf grew as the shoreward edge (-0.5-foot contour) moved shoreward. During this period some lateral variations occurred in the positions of the -0.5- and -0.6-foot contours; however, these variations were not significant.

Between 75 and 95 hours the -0.7-foot contour retreated about 10 feet (3 meters) along range 3 (Fig. 14), indicating significant erosion at that depth. The same erosion occurred along the other ranges (Figs. 13 and 15).

After 100 hours, material deposited at the seaward edge of the shelf (inshore zone) at depths of 0.7 and 0.8 foot advanced the inshore zone 8.5 feet (2.6 meters) in 20 hours. The shelf (-0.8-foot contour) continued to advance seaward for the remainder of the experiment. No significant lateral variations occurred at the -0.8-foot elevation. After 135 hours the -0.7-foot contour retreated 23.0 feet (7.0 meters) as the seaward part of the shelf flattened. The erosion of the -0.7-foot contour along ranges 1 and 5 occurred 5 hours sooner.

At 105 hours the area between stations 8 and 10 began eroding, which eventually became a large trough with a bottom elevation of -1.3 feet at station 10 at 175 hours (shown by heavy lines in Fig. 14).

(3) Offshore Zone. The movement of contours in the offshore zone is shown in Figures 7, 8 and 9 for ranges 1, 3, and 5. The offshore zone developed from the initial 0.05 slope to a relatively steep slope as a result of the deposition of material seaward of the breaker.

During the first 5 hours, most of the material was deposited at elevations -0.9 and -1.0 foot. Between 5 and 85 hours there was slight deposition at various depths. After 85 hours significant amounts of material were deposited in the offshore zone, beginning first at a depth of 1.2 feet, then at a depth of 1.1 feet at 90 hours, 1.0 foot at 95 hours, and 0.9 foot at 100 hours. This deposition created a relatively steep offshore slope, which subsequently became steeper as more material was deposited offshore.

Movements of the -1.0-, -1.4-, and -2.1-foot contours along the three ranges are compared in Figure 17. The only lateral variation in contour movement occurred at the -1.4-foot elevation near 50 hours, when the deposition started first along range 1 and last along range 5.

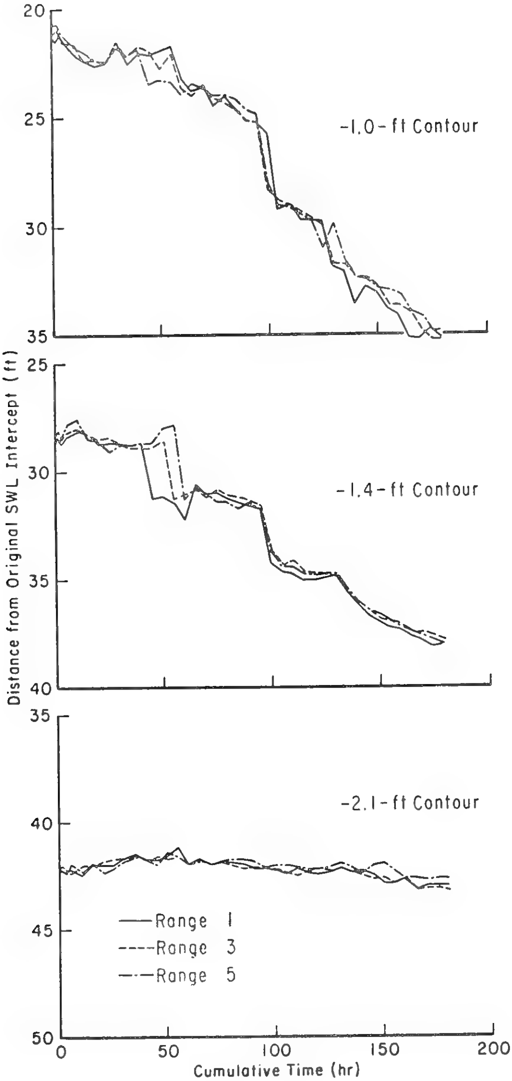

Figure 17. Comparison of the -1.0-, -1.4-, and -2.1-foot contour movements.

3. Sediment-Size Distribution.

The sand for these experiments was the same sand used by Savage (1959, 1962) and Fairchild (1970). In Volumes II and III, the median grain size (sieve method) for the material was reported to be 0.23 millimeter. The material added to the profile in this experiment for a 0.05 initial slope was evidently slightly finer. The six surface samples collected from the profile before the start of the experiment and analyzed by the sieve method had a d_{50} of 0.22 millimeter.

All samples collected for this experiment were analyzed by the Visual Accumulation (VA) tube method and 10 percent of the samples were analyzed by the dry sieve method for quality control (described in Vol. I). The values given here are the VA tube results. In Volume I, results showed that the VA tube median is 0.015 millimeter less than the sieve median for the 10 percent of the samples analyzed by both methods.

Table 9 gives the median grain-size results, including values at the beginning of the experiment. The average 0 hour median grain size was 0.21 millimeter.

A summary of the median grain sizes, the mean of the medians, range of values, and the number of samples within each profile zone are given in Table 10. At 100 hours the foreshore was an eroding foreshore and the median grain sizes of the two samples were high. Median grain sizes varied the most in the inshore zone. The values in the offshore zone were all low, as would be expected in an area of deposition. However, the mean of the medians was 0.21 millimeter in both the inshore and offshore zones.

At 180 hours (when twice as many samples were collected), the foreshore no longer eroded but had built up with the deposition of finer material, ranging from 0.20 to 0.22 millimeter. The inshore zone still had the widest range of median sizes, but included more finer samples. The offshore zone had a wider range of median values, including some finer and some coarser than the values at 100 hours. The mean of the medians was 0.21 millimeter in all three zones.

4. Breaker Characteristics.

A plot of breaker position superimposed on a plot of contour movement along range 3 is shown in Figure 18. During the first 20 hours the wave broke by plunging at depths between 0.6 and 0.7 foot. From 20 to 100 hours the breaker type varied between plunging and spilling and the wave broke at depths varying from 0.6 to 0.7 foot. After 100 hours, the breaker conditions were more complex. At the seaward end of the inshore zone the wave broke (except at 105, 120, and 125 hours) by spilling at depths between 0.7 and 0.8 foot. At the shoreward end of the inshore zone, the wave broke by plunging at depths between 0.2 and 0.4 foot, except at 115 hours when it broke at a depth of 0.6 foot.

Table 9. Sediment-size analysis at 0, 100, and 180 hours for experiment 72D-06.

Station	Range 2			Range 4		
	Elevation (ft)	Median (mm)	Median (phi)	Elevation (ft)	Median (mm)	Median (phi)
			0 hr			
-12	0.60	0.25	2.00	0.60	0.20	2.33
-8	0.50	0.21	2.27	0.50	0.21	2.32
-4	0.25	0.21	2.22	0.25	0.21	2.32
0	0.05	0.22	2.20	0.05	0.20	2.31
4	-0.20	0.21	2.25	-0.20	0.20	2.31
8	-0.40	0.22	2.20	-0.40	0.21	2.26
12	-0.70	0.21	2.28	-0.70	0.21	2.28
16	-0.75	0.21	2.26	-0.75	0.20	2.29
20	-0.95	0.21	2.29	-0.95	0.20	2.31
24	-1.20	0.21	2.28	-1.20	0.21	2.25
28	-1.40	0.21	2.29	-1.40	0.20	2.32
32	-1.60	0.20	2.32	-1.60	0.20	2.31
36	-1.76	0.21	2.28	-1.76	0.21	2.25
40	-1.98	0.20	2.33	-1.98	0.20	2.33
44	-2.20	0.21	2.29	-2.20	0.20	2.32
47	-2.33	0.21	2.26	-2.33	0.20	2.31
			100 hr			
-8	0.50	0.20	2.31	0.50	0.20	2.32
-4	0.15	0.27	1.90	0.20	0.26	1.94
0	-0.30	0.27	1.91	-0.40	0.22	2.21
4	-0.50	0.21	2.22	-0.70	0.20	2.34
8	-0.90	0.20	2.30	-0.80	0.20	2.34
12	-0.90	0.20	2.32	-0.80	0.20	2.31
16	-0.90	0.20	2.36	-0.80	0.20	2.36
20	-0.80	0.21	2.23	-0.80	0.21	2.26
24	-0.90	0.21	2.23	-1.00	0.21	2.28
28	-1.10	0.21	2.27	-1.00	0.21	2.29
32	-1.30	0.20	2.32	-1.35	0.21	2.22
36	-1.70	0.21	2.24	-1.60	0.20	2.33
40	-1.89	0.20	2.31	-1.95	0.21	2.29
44	-2.20	0.20	2.34	-2.20	0.20	2.31

Table 9. Sediment-Size analysis at 0, 100, and 180 hours for experiment 72D-06.--Continued

Station	Range 2			Range 4		
	Elevation (ft)	Median (mm)	Median (phi)	Elevation (ft)	Median (mm)	Median (phi)
180 hr						
-12	0.60	0.20	2.29	0.60	0.21	2.20
-10	0.55	0.20	2.29	0.55	0.20	2.34
-8	0.50	0.20	2.31	0.50	0.24	2.05
-6	0.30	0.22	2.17	0.40	0.22	2.22
-4	0.14	0.20	2.34	0.10	0.20	2.34
-2	-0.20	0.20	2.32	-0.20	0.20	2.30
0	-0.30	0.20	2.32	-0.30	0.21	2.29
2	-0.60	0.18	2.51	-0.62	0.20	2.35
4	-0.80	0.18	2.44	-0.80	0.18	2.44
6	-0.90	0.17	2.54	-1.10	0.18	2.50
8	-0.90	0.19	2.40	-1.25	0.20	2.36
10	-0.90	0.19	2.40	-1.30	0.19	2.39
12	-0.90	0.20	2.31	-1.30	0.20	2.31
14	-0.90	0.20	2.31	-1.25	0.21	2.27
16	-0.90	0.20	2.29	-1.15	0.20	2.31
18	-0.90	0.20	2.32	-1.05	0.20	2.29
20	-0.90	0.21	2.24	-0.95	0.26	1.97
22	-0.90	0.21	2.29	-0.90	0.22	2.19
24	-0.90	0.21	2.23	-0.90	0.21	2.29
26	-0.80	0.25	1.98	-1.30	0.25	1.99
28	-0.80	0.23	2.12	-1.30	0.23	2.13
30	-0.85	0.25	1.99	-1.30	0.25	1.99
32	-0.86	0.22	2.18	-0.80	0.23	2.10
34	-0.98	0.22	2.22	-0.95	0.22	2.21
36	-1.14	0.21	2.26	-1.20	0.21	2.25
38	-1.60	0.20	2.32	-1.50	0.19	2.38
40	-1.80	0.21	2.26	-1.82	0.20	2.32
42	-2.05	0.20	2.29	-2.03	0.20	2.30
44	-2.20	0.20	2.29	-2.25	0.21	2.25
46	-2.33	0.20	2.32	-2.33	0.20	2.34
48	-2.33	0.20	2.29	-2.33	0.21	2.28
50	-2.33	0.21	2.22	-2.33	0.23	2.15

Table 10. Summary of median grain-size values within profile zones.

Cumulative time (hr)	Profile zones								
	Foreshore[1]			Inshore			Offshore		
	mean (mm)	range (mm)	No.	mean (mm)	range (mm)	No.	mean (mm)	range (mm)	No.
100	0.26	0.26 to 0.27	2	0.21	0.20 to 0.27	12	0.21	0.20 to 0.21	12
180	0.21	0.20 to 0.22	4	0.21	0.17 to 0.26	34	0.21	0.19 to 0.23	20

[1]Samples collected from the backshore not included.

NOTE:--The mean of the median sizes at 0 hours was 0.21 millimeter.

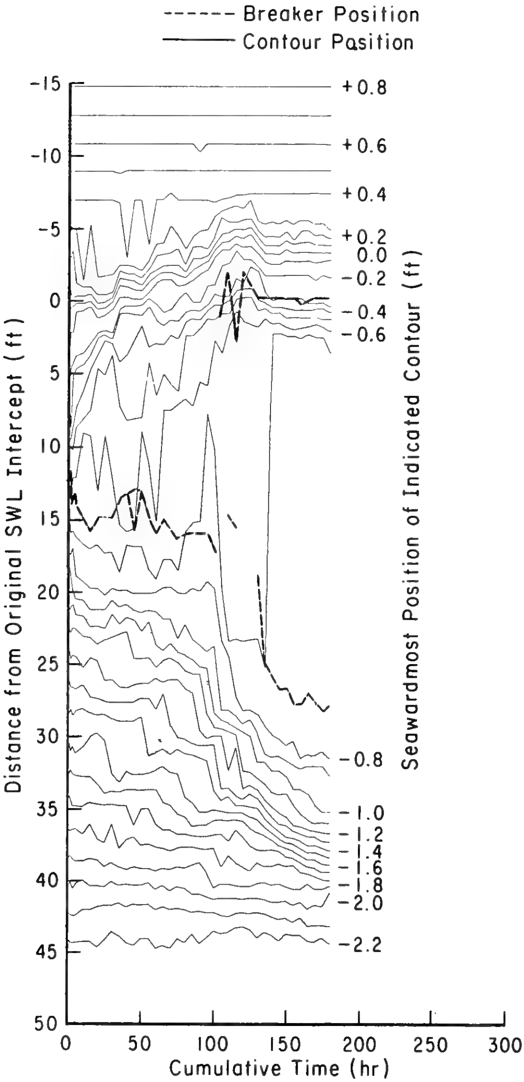

Figure 18. Movement of the breaker position.

Breaker height was determined twice during the experiment. At 30 hours the breaker height was 0.49 foot (14.9 centimeters) and the breaker depth was 0.65 foot (19.8 centimeters); at 80 hours the breaker height was 0.58 foot (17.7 centimeters) and the breaker depth was 0.70 foot.

5. Wave-Generated Currents.

The procedures for collecting current velocity data are described in Volume I. During the first 50 hours of this experiment, observations of the wave-generated currents were made using small bobs. Regular observations of the bottom currents were not possible, but on three occasions the heavy bobs were recovered several feet seaward of their initial placement, indicating a seaward current near the bottom.

The surface currents in the inshore zone were all in the shoreward direction, and at times the currents tended to move from the center of the tank toward the range 1 side of the tank before 40 hours and toward the range 9 side after 40 hours. On three occasions, surface bobs near the toe of the foreshore moved in a circular pattern.

6. Water Temperature.

Figure 19 gives data on the daily average water temperature versus cumulative test time and real time. The water temperature generally decreased during the experiment.

III. PROFILE DEVELOPMENT AND REFLECTIVITY

Results are analyzed by (a) Profile development, in which the interdependence of the changes in profile shape, sediment-size distribution, breaker characteristics, and water temperature is analyzed; and (b) profile reflectivity, in which changes in profile shape and breaker characteristics are related to the variability of the reflection coefficient. Profile development is discussed first to provide an introduction to profile reflectivity.

1. Profile Development.

The important changes in the foreshore, inshore, and offshore zones, the breaker conditions, median grain size, and water temperature during this experiment are summarized and tabulated as a function of time in Table 11.

Almost immediately the plunging breaker formed a longshore bar on the inner inshore, which eroded between 3 and 5 hours. During the first 5 hours the foreshore developed and material was deposited at depths of 0.6 to 0.9 foot.

Between 5 and 125 hours the shoreline retreated at a fairly constant rate of 0.05 foot per hour. The inner inshore eroded to a fairly steep

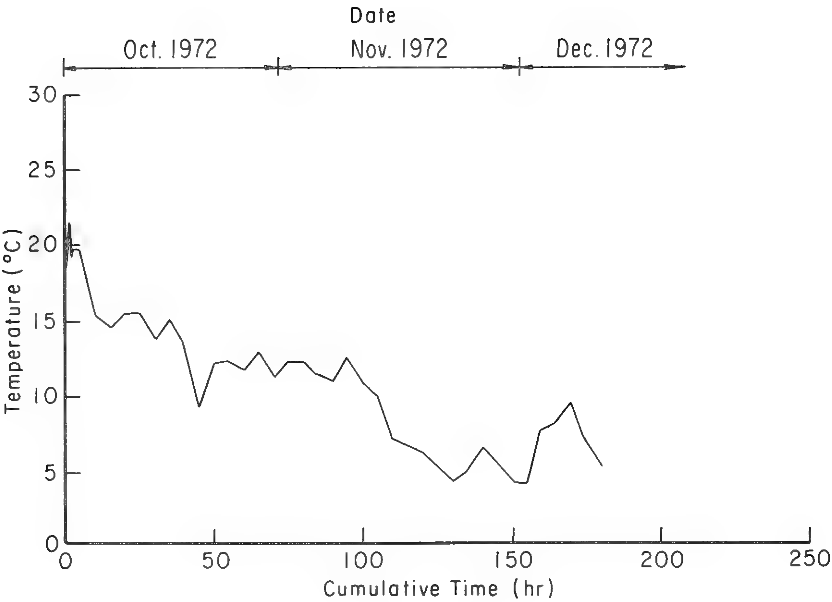

Figure 19. Water temperature data.

Table 11. Summary of profile development for experiment 72D-06.

Time (hr)	Foreshore	Inner inshore	Outer Inshore	Offshore	Breaker conditions Depth (ft)	Breaker conditions Type[1]	Water temperature (°C)
0 to 0.16	Development of equilibrium slope and length	Development of bar	Deposition at -0.6, -0.7, and -0.8 ft	Deposition at -0.9 ft	0.6 to 0.7	P	19 to 20
0.16 to 3		Bar stable					
3 to 5		Bar eroded					
5 to 20	Erosion, shoreline recession rate of 0.05 ft/hr	Erosion; fairly steep slope, retreating with foreshore	Deposition at -0.7 and -0.8 ft	Some deposition, mainly at -1.3, -1.4, and -1.5 ft at various times			14 to 16
20 to 35					0.6 to 0.7	P,S	
35 to 60			Not much change; elevation over shelf varying between -0.6 and -0.7 ft				9 to 13
60 to 65			Erosion at -0.6 ft				
65 to 75			No change				11 to 12
75 to 85			Large erosion at -0.7 ft				
85 to 95				Large depositions from -0.9 to -1.5 ft			
95 to 100			Large deposition at -0.7 ft				
	d_{50} = 0.26 to 0.27 mm		d_{50} = 0.20 to 0.27 mm	d_{50} = 0.20 to 0.21 mm			
100 to 110			Large Deposition at -0.7 and -0.8 ft		0.7 to 0.8	S	7 to 10
110 to 120			Continued deposition mainly at -0.8 ft; erosion near station 8				6 to 7
120 to 125				Significant deposition at all elevations above -1.9 ft	0.2 to 0.4	P	4 to 5
125 to 135	Deposition; shoreline advance	Deposition					
135 to 140	Foreshore stable	No change	Significant erosion at -0.7 ft; deposition at -0.8 ft				6
140 to 180			Erosion near station 10 reached -1.3 ft; deposition at -0.8 ft				4 to 9
	d_{50} = 0.20 to 0.22 mm		d_{50} = 0.17 to 0.26 mm	d_{50} = 0.19 to 0.23 mm			

[1]P = plunging; S = spilling.

slope, which continued to erode as the foreshore retreated. The eroded material was deposited mostly at depths of 0.7 and 0.8 foot up to 35 hours, which at 20 hours caused the breaker type to become mixed between plunging and spilling. From 35 to 85 hours, the foreshore and inner inshore continued to erode and the material was deposited in the offshore zone at various depths. Between 60 and 65 hours the outer inshore eroded at the 0.6-foot depth and thereafter the elevation remained below -0.6 foot. Between 75 and 95 hours significant erosion occurred at -0.7 foot across the entire outer inshore.

From 85 to 125 hours the foreshore and inner inshore continued to retreat as sand was eroded and deposited in large amounts in the outer inshore and offshore zones. Deposition occurred first (85 to 95 hours) in the higher elevations of the offshore zone, then in the outer edge of the outer inshore (95 to 120 hours), and finally, throughout the offshore zone after 120 hours. With the inshore zone much longer and flatter at 100 hours, the breaker at the seaward edge of the inshore zone became consistently spilling and a secondary plunging-type breaker developed at the shoreward edge of the inshore zone.

At 125 hours the erosion of the foreshore and inner inshore ceased and for the next 10 hours material was deposited in this region, with some of this sand from erosion near station 8 (shoreward end of the outer inshore). After 135 hours the foreshore and inner inshore stabilized, but the trough near station 8 continued to deepen as material eroded from this region. Between 135 and 140 hours the shelf in the outer inshore eroded to below -0.7 foot and thereafter the elevation remained below -0.7 foot. Material continued to be deposited at depths of -0.8 foot and lower.

The daily mean water temperature with shoreline position is compared in Figure 20. The figure shows no obvious correlation between erosion rates and water temperature. The development of the trough near station 8 beginning at 110 hours coincided with the permanent temperature drop below 10° Celsius at 110 hours, but that may have been coincidental.

2. Profile Reflectivity.

The basic profile shapes which evolved during the profile development are shown in Figure 6. Early profiles (solid line in Fig. 6) had a steep foreshore, a long flat shelf within the inshore, and a slightly steeper offshore zone. Later profiles (broken line in Fig. 6) had a steep foreshore, a wider inshore with a large trough at the shoreward end, and a relatively steep offshore zone.

Chesnutt and Galvin (1974) discussed the processes which reflect wave energy from movable beds for four experiments with the same wave conditions as used in this experiment. The processes 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 the reflection of the incident wave from the movable bed, particularly where the depth over the movable bed changes significantly. Depth changes are significant

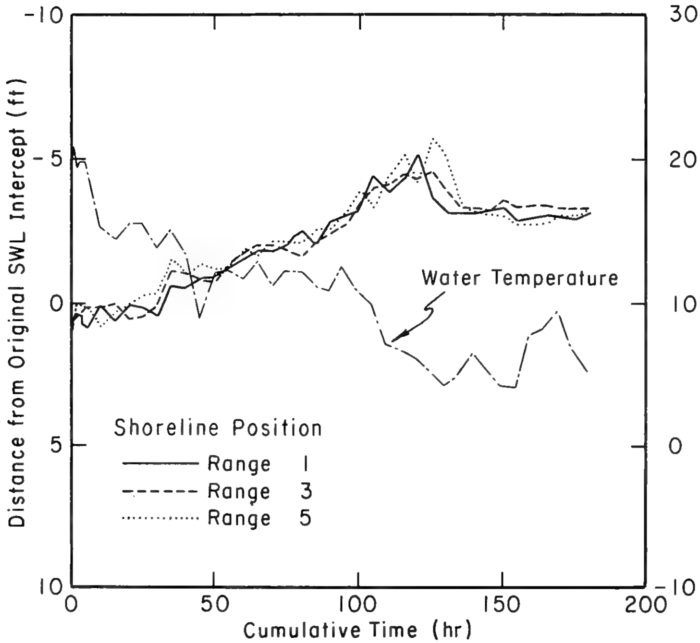

Figure 20. Comparison of water temperature and shoreline position.

if the depth difference is an appreciable fraction of the average depth over a horizontal distance less than a wavelength. For the conditions of this experiment, the wavelength is 14.3 feet (4.36 meters) in the section seaward of the movable bed and approximately 9 feet (2.74 meters) over the inshore zone. The depth change over the inshore zone is about 1 foot at the deepest section, and occurs over about 8 feet in the horizontal (Fig. 7).

a. Reflection from the Foreshore. The foreshore zone did not develop until 5 hours (Fig. 10). The developed foreshore had a slope of about 0.19, considerably steeper than the original 0.05 slope. The rise of K_R above 0.06 after 1.5 hours (minimum point in Fig. 3) may be the result of the formation of the foreshore.

K_R measurements over the inshore shelf after 100 hours (Table 7) indicated that reflection from the foreshore varied from 0.06 to 0.12 and was not as variable as the total K_R values.

b. Reflection as a Result of Wave Breaking. The plunging breaker and the longshore bar developed almost immediately and were probably the largest reflectors during the first 3 hours when no other features were prominent on the profile (Figs. 3 and 8). The K_R during the first 3 hours was only 0.06 or less, so the breaker could only have contributed that much or less. By 20 hours the breaker type was already mixed between plunging and spilling. Reflection from a spilling breaker is assumed to be negligible, so that after 20 hours the reflection from the breaker would have become small and after 100 hours the reflection from the primary breaker would have been negligible. Reflection from the secondary breaker, after 100 hours, would also have been small, because the wave height at that point was much smaller. Thus, reflection from the breaker was probably never very important, and became less important as the breaker type changed.

c. Effect of Inshore and Offshore. As the shelf in the inshore zone developed after 5 hours, the offshore slope became slightly steeper and the K_R increased significantly. As the shelf widened, the K_R decreased for a time and then increased to a maximum value during the period of greatest deposition at the outer edge of the inshore shelf and the upper offshore slope. Subsequently, as the shelf widened more, the K_R decreased (Figs. 3 and 8).

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 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.

Chesnutt and Galvin (1974) examined the results from experiment 71Y-06 and pointed out an apparent correlation between the movement of the -0.7-foot contour and the variability of the reflection coefficient, and suggested that the reflection is very sensitive to small changes in depth near the seaward edge of the inshore zone. These depth changes 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.

The position of the -0.7-foot contour and the reflection coefficient versus time for experiment 72D-06 are compared in Figure 21. The initial seaward (downward) movement of the -0.7-foot contour is an indication of the development of the flat inshore shelf and steeper offshore slope. The K_R increased as the shelf developed. The decrease in K_R between 60 and 85 hours is possibly due to a phase difference change. The increase of K_R to a maximum coincided with the large seaward movement of the -0.7-foot contour, and the steepest offshore slope at 100 hours. The decrease in K_R at 135 hours coincided with the shoreward movement of the -0.7-foot contour and the decrease in the offshore slope steepness.

IV. SUMMARY OF RESULTS

1. Wave Height Variability.

Three possible causes of wave height variability in experiment 72D-06 are: (a) Wave reflection from the changing profile, (b) re-reflection from the wave generator, and (c) secondary waves. This experiment was designed primarily to quantify the amount of variability due to reflection.

a. Wave Reflection from the Profile. The K_R varied from 0.04 to 0.27 in this experiment. K_R values were low initially and increased as the foreshore slope and inshore shelf developed. Later, as the offshore reflecting surface became much steeper, the K_R increased in mean value and variability. The large variations appear to have been caused by the small changes in depth near the seaward edge of the inshore zone (the top of the offshore reflecting surface) and by the gradual separation of the two reflecting surfaces as the offshore slope prograded seaward (Chesnutt and Galvin, 1974).

b. Re-Reflection from the Generator. The reflected wave advanced to the generator and was again reflected. As the height of the reflected wave varied, the height of the re-reflected wave varied; as the phase difference between the reflected wave and the generator motion varied with changes in the profile, the height and phase of the re-reflected wave varied. The height of the wave incident to the profile, which was the average of wave heights along the full tank length and was composed of the generated wave and the re-reflected wave, varied from 0.34 to 0.42 foot (10.4 to 12.8 centimeters) in the movable-bed tank. Part of that variation (0.03 foot) can be attributed to measurement errors or to variations in the generated wave. The remainder of the variation (0.05 foot) is likely due to re-reflection.

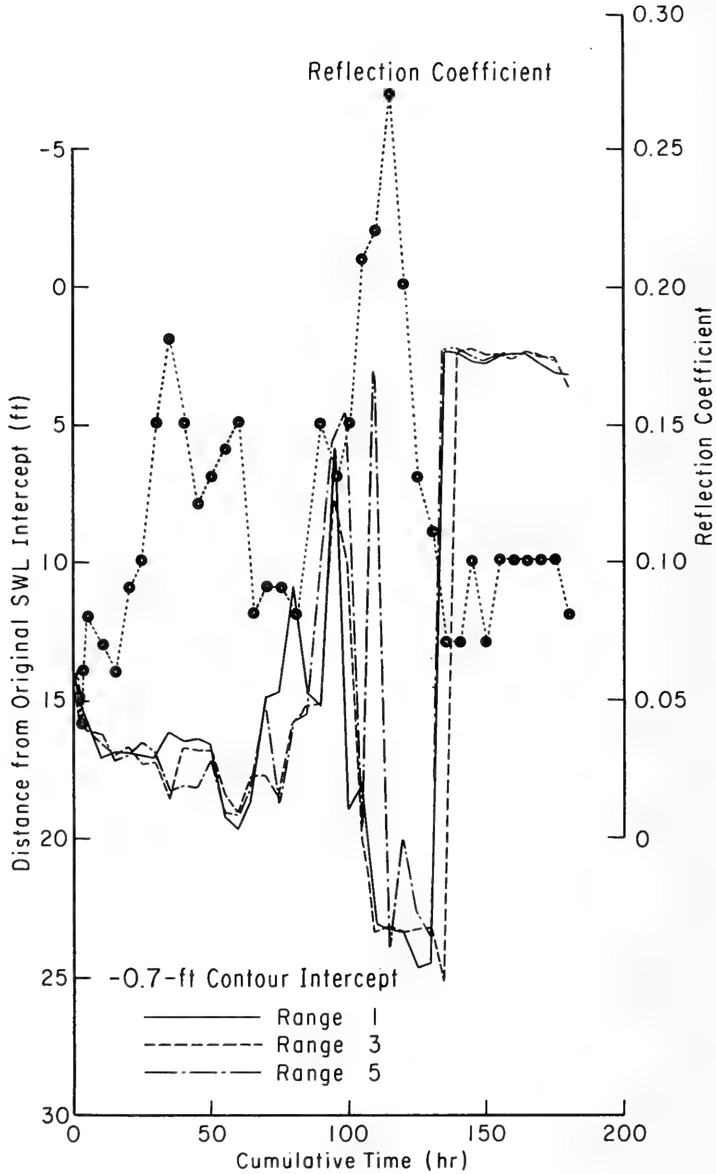

Figure 21. Comparison of the -0.7-foot contour position and K_R.

c. Secondary Waves. Along the length of the tank, between the generator and the toe of the profile, wave heights on any given recording varied as a result of secondary waves. Galvin (1972) and Hulsbergen (1974) described secondary waves (called solitons by Galvin) and their effects; secondary waves can be observed on the wave records. The wave height variability due to secondary waves does not affect the incident and reflected wave heights reported here since the incident and reflected wave heights are spatial averages.

2. Profile Equilibrium.

Experiment 72D-06 was the third effort in an attempt to define the equilibrium profile shape for this set of wave and sediment conditions. Based on experience gained from experiments 70X-06 and 71Y-06 (see Vols. II and III), the initial slope of 0.05 selected for this experiment was thought to be much closer to the equilibrium profile, and was certainly close to the final profile in experiment 71Y-06; e.g., erosion of the longshore bar and development of the long, flat shelf in the inshore zone that occurred after 200 hours in experiment 71Y-06 occurred after only 3 hours in this experiment. Also, at 100 hours in this experiment the inshore zone had the same length as at 375 hours in experiment 71Y-06, but the offshore zone was not nearly as steep and extended farther toward the wave generator.

After 125 hours in this experiment the shoreline stopped retreating, and after 135 hours the shoreline stabilized, which never occurred in experiment 71Y-06. Even though the shoreline stabilized, the profile continued to change. A large trough was scoured near the shoreward edge of the inshore zone and the material was deposited in the offshore zone. The offshore slope was never as steep in experiment 72D-06 as it was in experiment 71Y-06.

Although the flatter initial slope hastened the profile development and during the last 80 hours the water temperature was fairly constant (below 10° Celsius), the profile never reached equilibrium.

3. Other Laboratory Effects.

Chesnutt (1975) compared the profile development in this experiment with that in experiment 71Y-06 and discussed the effect of initial slope.

As discussed in Section IV, 2, the flatter initial slope hastened the development of the typical foreshore and inshore shapes for this set of wave and sediment conditions (Fig. 8 in this report; Fig. 9 in Vol. III). However, three striking differences between the final profile in experiment 72D-06 and the final profile in experiment 71Y-06 were: (a) A stable foreshore and shoreline, (b) a large trough at the shoreward edge of the inshore zone, and (c) a longer and less steep offshore zone. The longer offshore zone, resulting directly from the flatter initial slope, may be the cause for the other differences. First, the wave traveling over the 0.05 slope was subject to greater energy losses due to bottom friction, particularly after the inshore zone became wider, and as a result the wave no longer had sufficient energy to erode the foreshore. Second, because of secondary waves, the velocity distribution at the toe of the profile may have been different in the two experiments since the toe in this experiment was 23 feet closer to the generator than in experiment 71Y-06. The effect of secondary waves on profile development was discussed by Hulsbergen (1974). The difference in velocity distribution at the toe of the profile would have caused a different velocity distribution over the shelf and may be the cause of the trough in the inshore zone.

V. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions.

(a) In experiment 72D-06 with a water depth of 2.33 feet (0.71 meter), a wave period of 1.90 seconds, and a generator stroke of 0.39 foot (11.9 centimeters), the average incident wave height was 0.39 foot. Reflection measurements in the control tanks with a fixed-bed profile varied from 0.04 to 0.07, indicating that the wave generators were operating uniformly and that the measurement error in determining K_R was ±0.015 (Tables 5 and 6).

(b) K_R varied from 0.04 to 0.27, and the variation correlated with profile changes. K_R was quite low during the first few hours when the profile had not developed many features on the 0.05 slope. The K_R increased first as the foreshore developed, and later as the inshore zone became a long, flat shelf with a slightly steeper offshore. The mean value of the K_R increased as the offshore steepened. Large fluctuations in K_R occurred at times of large shifts in contour position on the inshore shelf, further verifying observations in Volume III that reflection is sensitive to small changes in depth at the shoreward edge of the submerged reflecting surface (Figs. 3 and 21).

(c) The profile never reached an equilibrium shape, even though the water temperature was relatively constant for the last 80 hours of the experiment (Figs. 7, 8, 9, and 20).

(d) A comparison of experiment 72D-06 (initial profile slope of 0.05) with experiment 71Y-06 of Volume III (initial slope of 0.10) indicates three primary differences in profile shape: stable foreshore, large trough in inshore, and longer offshore. These differences may have been caused by the different initial slopes (Figs. 7, 8, 9, 13, 14, and 15 and Vol. III).

(e) These two experiments also differed in that experiment 72D-06 developed typical (for these wave conditions) foreshore and inshore shapes more quickly. This difference is due primarily to the difference in initial slope (Figs. 7, 8, and 9).

2. Recommendations.

(a) Experimenters should be cautious in defining equilibrium profile conditions.

(b) Additional research is recommended to prove the effect of initial slope on equilibrium profile shape; however, experimenters should not assume that initial slope has no effect on profile development.

LITERATURE CITED

ALLEN, R.H., "A Glossary of Coastal Engineering Terms," MP 2-72, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Washington, D.C., Apr. 1972.

CHESNUTT, C.B., "Laboratory Effects in Coastal Movable-Bed Models," *Proceedings of the Symposium on Modeling Techniques*, 1975, pp. 945-961.

CHESNUTT, C.B., and GALVIN, C.J., Jr., "Lab Profile and Reflection Changes for H_o/L_o = 0.02." *Proceedings of the 14th Conference on Coastal Engineering*, 1974, pp. 958-977.

CHESNUTT, C.B., and LEFFLER, M.W., "Reduced Data from Laboratory Effects in Beach Studies (LEBS) Experiment 72D-06," Laboratory Memorandum No. 3, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., unpublished, 21 Dec. 1977.

CHESNUTT, C.B., and STAFFORD, R.P., "Movable-Bed Experiments with H_o/L_o = 0.021 (1970)," Vol. II, MR 77-7, *Laboratory Effects in Beach Studies*, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Aug. 1977a.

CHESNUTT, C.B., and STAFFORD, R.P., "Movable-Bed Experiments with H_o/L_o = 0.021 (1970)," Vol. III, MR 77-7, *Laboratory Effects in Beach Studies*, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., Nov. 1977b.

FAIRCHILD, J.C., "Laboratory Tests of Longshore Transport," *Proceedings of the 12th Conference on Coastal Engineering*, 1970, pp. 867-889.

GALVIN, C.J., Jr., "Finite-Amplitude, Shallow Water-Waves of Periodically Recurring Form," *Proceedings of the Symposium on Long Waves*, 1972, pp. 1-32.

HULSBERGEN, C.H., "Origin, Effect, and Suppression of Secondary Waves," *Proceedings of the 14th Conference on Coastal Engineering*, 1974, pp. 392-411.

SAVAGE, R.P., "Laboratory Study of the Effect of Groins on the Rate of Littoral Transport: Experiment Development and Initial Tests," TM-114, U.S. Army, Corps of Engineers, Beach Erosion Board, Washington, D.C., June 1959, p. 56.

SAVAGE, R.P., "Laboratory Determination of Littoral-Transport Rates," *Journal of the Waterways and Harbors Division*, Vol. 88, No. WW2, May 1962, pp. 69-92.

STAFFORD, R.P., and CHESNUTT, C.B., "Procedures Used in 10 Movable-Bed Experiments," Vol. I, MR 77-7, *Laboratory Effects in Beach Studies*, U.S. Army, Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Va., June 1977.

U.S. ARMY CORPS OF ENGINEERS, COASTAL ENGINEERING RESEARCH CENTER, *Shore Protection Manual*, Vols. I, II, and III, 2d ed., Stock No. 008-022-00077-1, U.S. Government Printing Office, Washington, D.C., 1975, 1,160 pp.

APPENDIX

EXPERIMENTAL PROCEDURES FOR 72D-06

This appendix documents those aspects of the experimental procedures unique to experiment 72D-06. The procedures common to all experiments are documented in Volume I (Stafford and Chesnutt, 1977).

1. Experimental Layout.

At the beginning of experiment 72D-06, the movable-bed profile was constructed with sufficient sand to form a 0.05 initial slope, with the initial SWL intercept the same distance from the generator as in experiment 71Y-06. The SWL intercept on the fixed-bed slope was 7 feet farther from the generator as in experiment 71Y-06. Figure A-1 shows the position of the initial profiles with respect to the coordinate system.

In the process of moving the needed sediment from the stockpile to the experimental facility, the sediment was screened through 0.5-inch wire mesh to remove any large material. No attempt was made to remove the fine material which had contaminated the stockpile and significantly increased the turbidity of the water.

2. Data Collection.

a. Regular Data.

(1) Wave Height Variability. During the first run (to 0:10), a continuous water surface elevation recording was made at station 48 near the toe of the movable-bed profile and 25 feet (7.6 centimeters) from the toe of the fixed-bed slope. During all subsequent runs, wave envelopes were recorded with wave gages moving along the center of each tank from station +15 to +85 and return up to 10 hours and from station +20 to +85 and return after 10 hours, with the instrument carriage moving at a near-constant speed of 10 feet per minute. From 100 to 180 hours, envelopes were also recorded from station +20 to +5 and return.

(2) Wave-Generated Current Data. Observations of wave-generated surface currents were limited to the first 50 hours of the experiment. Attempts to observe bottom currents were hampered by the turbidity problem.

b. Special Data. Four types of special data were collected at less frequent intervals, and Table A-1 indicates the times when each type of data was collected.

3. Data Reduction.

a. Wave Height Variability. The wave reflection envelope recordings were divided into two grades for data reduction. The automated method for determining K_R was used with the grade I data, which had no data

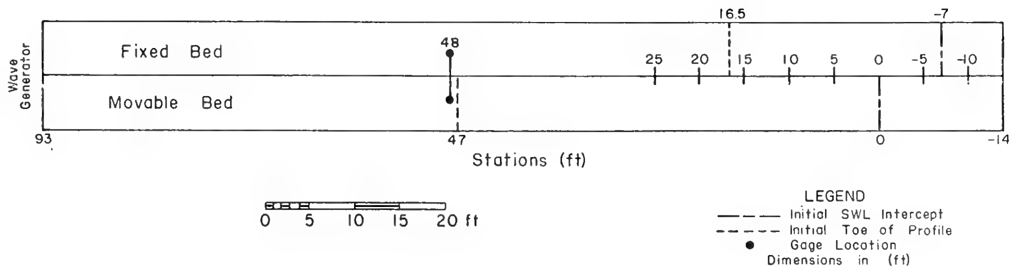

Figure A-1. Experimental setup.

Table A-1. Summary of special data collection.

Time (hr)	Profile survey limits[1] (ft)	Photo survey limits (ft)	Sand sample limits[2] (ft)	Wave envelope limits[3] (ft)
0	Not taken	Not taken	-12 to +47	Not taken
30	Not taken	Not taken	Not taken	Envelope: +20 to +85 Stands: +85 to +9
50	-5.5 to +5.0	Not taken	Not taken	Not taken
80	Not taken	Not taken	Not taken	Envelope: +20 to +85 Stands: +85 to +6.5
100	-7.0 to 5.0	-13 to +49	-8 to +44	Not taken
105	Not taken	Not taken	Not taken	Envelopes: +20 to +85 +85 to +20 +20 to +5 +5 to +20
130	Not taken	Not taken	Not taken	Envelopes: +20 to +85 +85 to +20 +20 to +5 +5 to +20
155	Not taken	Not taken	Not taken	Envelopes: +20 to +85 +85 to +20 +20 to +5 +5 to +20
180	-13.0 to +52.0	-13 to +51	-12 to +50	Not taken

[1]Elevations measured at 0.5-foot intervals between the given stations along ranges 0.5 foot apart.

[2]Samples collected at 4-foot intervals at 0 and 100 hours, and at 2-foot intervals at 180 hours between the given limits along ranges 1 foot either side of centerline.

[3]One-minute stands recorded at all nodes and antinodes between +85 and +20 at both 30 and 80 hours, at 1-foot intervals between +20 and +9 at 30 hours, and at 0.5-foot intervals between +20 and +6.5 at 80 hours. Special wave envelopes were recorded along range 3 in the fixed-bed tank and along ranges 1, 3, and 5 in the movable-bed tank.

quality problems. The manual method for determining K_R was used with the grade II data, which had problems of (a) pen skips, (b) highly variable instrument carriage velocity, or (c) off-scale values. Twenty percent of the grade I envelopes were also reduced manually to provide a comparison of the two methods. The water surface elevation data collected with the gage stationary during the first 10 minutes, and the two runs indicated in Table A-1 were analyzed manually to determine average wave heights.

b. Sand-Size Distribution. All samples were analyzed using the VA tube method by the U.S. Army Engineer Division, Missouri River, Laboratory. Approximately 10 percent of the samples were analyzed by project personnel using the dry sieve method as a quality control measure. Table A-2 gives the results from the dry sieve method.

c. Breaker Characteristics. Breaker type and position data were determined from the visual observation form. Breaker height data were determined from the stationary recordings of water surface elevations in the inshore zone at 30 and 80 hours.

Table A-2. Sediment-size analysis (dry sieve method), at 0, 100, and 180 hours for experiment 72D-06.

Station	Range 2			Range 4		
	Elevation (ft)	Median (mm)	Median (phi)	Elevation (ft)	Median (mm)	Median (phi)
			0 hr			
-4	0.25	0.22	2.20	0.25	0.22	2.18
8	-0.40	0.22	2.17	-0.40	0.22	2.18
20	-0.95	0.22	2.17	-0.95	0.22	2.19
			100 hr			
-8	0.50	0.22	2.21	0.50	----	----
4	-0.50	0.23	2.11	-0.70	0.21	2.24
16	-0.90	0.21	2.24	-0.80	0.22	2.16
28	-1.10	0.23	2.11	-1.00	0.23	2.13
40	-1.89	0.23	2.13	-1.95	0.22	2.16
			180 hr			
-10	0.55	0.21	2.24	0.55	0.22	2.20
10	-0.90	0.20	2.32	-1.30	0.20	2.31
30	-0.85	0.26	1.93	-1.30	0.28	1.83

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627

Chesnutt, Charles B.
Laboratory effects in beach studies, Volume IV. Movable-bed experiments with H_o/L_o = 0.021 (1972) / by Charles B. Chesnutt and Robert P. Stafford.—Fort Belvoir, Va. : U.S. Coastal Engineering Research Center ; Springfield, Va. : available from National Technical information Service, 1977.
60 p. : ill. (Miscellaneous report – U.S. Coastal Engineering Research Center ; no. 77-7, v.4)
Bibliography: p. 54.
A movable-bed experiment with an initial slope of 0.05 and wave period of 1.90 seconds developed a different final profile shape than earlier experiments with initial slopes of 0.10 and the same wave. Reflection coefficient variations correlated well with profile changes.
1. Coastal engineering. 2. Breakers. 3. Currents. 4. Movable beds. 5. Wave generators. 6. Wave reflection. 7. Wave tanks. I. Title. II. Stafford, Robert P., joint author. III. Series: U.S. Coastal Engineering Research Center. Miscellaneous report 77-7, v.4.

TC203 .U581mr no. 77-7, v.4 627