CHAPTER 55

LABORATORY TESTS OF LONGSHORE TRANSPORT

by

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ABSTRACT

Tests were made in CERC's Shore Processes Test Basin with wayes approaching the toe of a test beach at a 30-degree angle Beach material was quartz sand with median diameter of 0 22 millimeter which, in most tests, was molded to a 1 on 10 slope before starting a test Long crested waves generated in a constant depth of 2 33 feet traveled over the beach, shoaled and were refracted before breaking near the shoreline The breaking action caused the sand to be transported along the shore in the direction of the longshore component of the wave energy flux Transport rates of 2 to 170 cubic yards per day were measured, with the lower rate within the range of laboratory rates reported by Savage (1) and the higher rate comparable to field rates reported by Watts (2) for South Lake Worth Inlet, Florida Analysis includes correlation of the measured rates to the longshore wave energy flux, and in some tests, to the longshore current Transport rates, defined by visual fit curve of the data, are about 3 times the rates indicated by the CERC TR-4 design curve for a longshore energy range of 0 016 to 0 760 millions of foot pounds per foot of shore per day

I INTRODUCTION

General

Water waves impinging obliquely on a sandy shore scour and suspend shore materials causing them to move along the shore in the direction of the longshore component of the wave energy flux. The amount of material moving depends primarily on the wave breaker angle and the energy of the waves impinging on the shore However, the amount of material moving at a given energy flux is influenced by the wave steepness, breaker type, sand size, and the beach slope, and experience indicates that these factors may act to increase or decrease the longshore transport, where there is little or no change in the wave energy flux

The amount and direction of longshore transport is important in the planning and design of shore improvements Reliable field data on longshore transport is required in the design and economic evaluation of jetties navigation inlets, beach erosion projects, and hurrican protection projects Data, usually of questionable accuracy, is available for a few coastal areas, but present coverage is inadequate and field data is expensive and difficult to get Therefore, CERC has for some time had underway a program to obtain laboratory data which would define basic relationships and which might be used with field data to more quickly and less expensively provide the relationship between longshore wave energy flux and longshore sand transport

Laboratory Tests

This report presents results from laboratory tests of longshore transport (3,4,5,6) made in CERC's Shore Processes Test Basin (SPTB) Tests were made with waves approaching the beach at a 30 degree angle in a constant depth of 2 33 feet Figure 1 is a plan view typical of the test set-ups used, showing the wave generators and the test beach, with the sand trap at the downdrift end and the feeder beach at the updrift end

Beach material was a uniformly sized sand with a median diameter of 0 22 millimeter In most tests the beach was molded to a 1 on 10 slope before starting wave action Several tests, including some groin tests in 1957 (1) and 1958, were started on a "150 hour profile slope", which was an equilibrium slope determined from 150 hours of wave action Other tests in 1959 and earlier were started on a 1 on 20 slope



FIGURE I LONGSHORE TRANSPORT TEST LAYOUT IN THE NORTH SECTOR OF SPTB (1966)

Tests were carried out by generating long crested waves which traveled from the wave generator to the toe of the beach slope in a constant water depth As waves continued over the beach they shoaled and were refracted before breaking When the waves broke, part of their energy was dissipated in turbulence, scouring and suspending sand, part was transformed into a longshore current and part was reflected from the beach The wave action scoured the beach sand, forcing it into suspension, to be carried along the shore by the longshore current Also, the swash and backwash of the waves caused the sand to move onshore and offshore, with a resultant slantwise movement along the shore

In summary, the wave action caused the sand to move along the shore in the breaker zone, in the swash zone and in the deeper offshore zone The sand moved onshore and offshore, and with continued wave action, the bottom profile progressed toward an "equilibrium profile" characterized by a reduced transport rate and a reduced onshore-offshore exchange of material

Purpose

The purpose of the tests was to measure the longshore transport rate for a range of wave characteristics, and to establish a correlation between the measured rates and the corresponding longshore components of wave energy flux Longshore transport rates were measured in tests, wherein sand moving along the shore was deposited in a sand trap from which it was pumped and weighed under water Longshore components of wave energy flux were computed from measured wave heights and calculated wave breaker directions

From an engineering viewpoint, the purpose encompassed the obtention of laboratory data to define basic relationship for use with field data, to more quickly and economically improve and develop previous correlations between wave energy flux and longshore transport rate

OBSERVATION AND MEASUREMENT

General

The sand (0 22mm quartz), water depth (2 33 ft at toe of beach), and angle of wave generator with initial shoreline (30°) were constant in the tests

TABLE 1

TEST VARIABLES

Exp	erimental Variables	Range of Variables Tested				
1	Wave period	1 25 to 3 75 seconds				
2	Wave generator stroke	2 0 to 15 0 inches				
3	Depth at beach toe	2 30 to 2 33 feet (bottom uneven)				
4	Initial slope	1 on 10 to 1 on 20				
5	Beach material	0 22mm median diameter quartz sand				
6	Angle of waves to toe of slope	30°, constant for all tests				
7	Test time	25 to 100 hours				
8	Layout of basın	training walls or flume to open basin				

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TABLE 2

WAVE CONDITIONS AND TEST SET-UP CHANGES *(total hours in test)

	Wave	e Conditi	ons		
Test No	T, sec	Ecc, inches	H, ft	t*	Set-up Changes
1-58	1 50	1 00	176	60	Starting slope 1 on 20, T was sequenced in 15 minute intervals at T=1 50, 1 30, 1 50, 1 76, etc , no sand fed on feeder beach after 35 hours
2-58	1 50	1 00	176	70	Starting slope 1 on 20, T was varied as in test 1-58, feeder beach maintained throughout entire test
2a-59	3 00	2 35	192	80	Starting slope 1 on 10, T was sequenced in 15 minute intervals at T=2 50, 3 00, 3 75, 3 00, etc, upbeach training wall curved for wave refraction, beach length 90 feet
3a-59	3 00	2 35	192	50	Beach length reduced to 30 feet along SWL, other conditions same as Test 2a-59
4a-59	2 18	1 75	210	50	Starting slope 1 on 10, updrift trng wall re- curved by wave refraction for new T, sequenced in 15 minute intervals at T=1 94, 2 18, 2 50, 2 18, etc
1-59	1 50	1 00	176	25	Starting slope based on a 150 hour "equilibrium profile", segment of downbeach training wall from carriage rail to toe of slope, removed, T was varied same as in test 1-58
2-59 Phase	1 ¹⁵⁰	1 00	176	32	Same starting slope as 1-59, above, T was varied same as in test 1-59, downdrift train- ing wall completely removed
2-59 Phase	3 00 11	2 35	192	80	Starting slope was the beacn slope at end of Phase 1, T was sequenced as in test 2a-59
3–59	3 00	2 35	192	75	Starting slope 1 on 20, updrift training wall curved along wave refraction orthogonal, T was sequenced as in test 2a-59
4-59	3 00	2 35	192	50	Starting slope 1 on 20, wave period constant
5-59	3 75	2 35	140	50	Starting slope 1 on 20, wave period constant
6-59	2 50	2 35	246	50	Starting slope 1 on 20, wave period constant
1-60	2 18	1 75	210	50	Starting slope in this and all subsequent tests, 1 on 10, downdrift training wall reinstalled, and curved for wave refraction, T was sequenced as in test 4a-59
2-60	2 18	3 50	420	26	Wave Height increased as shown, T was sequenced in test 4a-59

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TABLE 2, cont'd *(total hours in test)

	Wave	Conditi	ons		
Test No	T sec	Ecc, inches	H, ft	t*	Set-up Changes
3-60	3 00	2 35	192	28	A repeat of test 3a-59 conditions to check transport of suspended sand past the sand trap
4-60	2 18	5 00	614	25	Test at maximum wave height for generators, T was sequenced as in test 4a-59
5-60	3 00	4 70	422	26	Increased wave height as shown, T was se- quenced as in test 2a-59
6-60	2 18	2 50	300	50	To test intermediate wave height value
7–60	1 36	1 50	320	50	To test maximum height at minimum period, T was sequenced in 15 minute intervals at T=1 25, 1 36, 1 50, 1 36, etc
1-61	3 00	2 35	192	50	Wave period changed every 5 instead of every 15 minutes, T was sequenced as in test 2a-59
2-61	3 00	2 35	192	50	Wave period changed at 1 minute intervals, T was sequenced as in test 2a-59
3-61	3 00	2 35	192	50	To compare results with test 4-59 (started on a 1 on 20 slope) Constant wave period
5-61	3 00	2 35	192	50	Wave period varied continuously from T=3 75 to T=2 50 through the mean, 3 00 seconds and return
6-61	2 50	2 35	246	50	Constant wave period, for comparison with re- sults of test 6-59 (1 on 20 slope)
7-61	3 75	2 35	140	50	Constant wave period, for comparison with re- sults of test 5-59 (1 on 20 slope)
1-61	3 75	2 35	140	50	Constant wave period, test of sand feeder, elevation 2 ft above SWL
2-62	3 75	2 35	140	25	Same as 1-62, elevation 0 1 ft above SWL
3-62	3 75	2 35	140	25	Same as 1-62, elevation at SWL
4-62	3 75	2 35	140	25	Constant wave period, to investigate effect of extraneous wave
6-62	1 50	094	172	48	Constant wave period, feasibility test of sand tracers
8-62	1 50	094	172	30	Same as 6-62, longer half life tracer, T was constant up to t=8 hours and wave varied as in test 1-58 after 8 hours
1-64	3 75	2 35	140	50	Constant wave period, offshore area divided into 8 flumes
1-65	3 75	2 35	140	40	Special constant wave period test, open test basin, rubble around test area

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TABLE 2, cont'd *(total hours in test)

Have conditions					
Test No	T sec	Ecc, inches	H, ft	t*	Set-up Changes
2-66	2 18	2 35	290	25	Same set-up as test 1-65, reduced wave period was constant
3-66	1 25	2 00	480	50	Constant minimum period for a stable wave and 2 inch eccentric
562	3 00	7 50	750	40	A special test attempting to measure the maximum transport rate possible in the SPTB

Five other variables under the experimenter's control were wave period, wave height, initial beach slope, test duration and basin geometry Although not as simple a variable as others noted above, basin geometry changes from test to test included, the general configuration of the test layout, test beach length, arrangement of training and splitter walls, and sand feeding techniques These changes were made after continuing observation and analysis, in the hope that they would improve the quality of the data in the tests

Table 1 outlines the experimental variables and the range of these variables tested This table gives an overview of the test variables within the positive control of the project engineer Table 2 is a more detailed listing of the wave conditions and test set-up changes by test number, with the last column giving a running commentary of test-to-test changes in set-up The variables listed in Table 2 include wave height, wave period and test duration, and each of these plus five other areas of observation and measurement are discussed separately in the following paragraphs

Wave Height

Wave recordings using strip chart recorders were made regularly in the tests using parallel wire wave sensors placed along the toe of the beach slope Spot recordings were also made at other locations in the test basin Wave heights were determined from an analysis of the wave recordings, as the average height of ten successive waves

As the tests continued, wave heights were found to vary significantly, from point to point, and with time as at a fixed point Special wave measurements tests were made in 1963 and 1964 attempting to identify the cause or causes of the wave height variability. The measurement results were not conclusive Another series of tests in the SPTB are presently investigating wave reflection as a cause of wave height variability in inclosed basins such as the SPTB With continued testing and consideration of wave energy analysis in the tests, the large wave height variability (up to and exceeding a factor of 2) made it difficult to confidently specify a causative wave height in relation to a measured transport rate Specifying a causative height - say from reflectionfree waves in the SPTB was difficult because of the short distance for wave travel and the long length of the waves For the longer wave periods only two waves could be measured before wave reflection from the beach began to affect the measurements

News Conditions

Because of the length limitation in the SPTB, the measurements of wave height used in this report were made in CERC's 72-foot tank under experimental conditions equivalent to a 1/2 scale Froude model of the depth, eccentrics and periods tested in the SPTB When the SPTB wave conditions were reduced to 1/2 scale, the 72-foot tank was long enough to generate sufficient reflection-free waves from which a sound evaluation of the wave heights was possible

Considerable care was taken in measuring the wave heights in order to have heights as free from reflection effects as practicable Only those waves which reached the wave gage before reflected waves returned from the absorber beach were used For example, a wave period of 3 75 seconds and water depth of 2 33 feet in the SPTB reduces to a wave period of 2 65 seconds and 1 17 feet, respectively, at 1/2 scale At this period and depth the wave length in the 72-foot tank was 15 6 feet which would allow for measurement of 7 to 8 reflection-free waves in a 60-foot spacing between a wave sensor and an absorber beach These measurements in the 72-foot tank provided wave heights for 8 wave generator eccentrics, over a range of wave periods The range of wave periods was 1 25 to 3 75 seconds with minimum wave heights of the order of 0 1 foot and maximum wave heights up to 75 feet Figure 2 is a graph of the wave SPTB walues



Wave Period

Wave period, T, could be arbitrarily selected within a range of 1 to 4 seconds on the SPTB wave generators Dial settings, corresponding to specific wave periods in seconds, were made on a varidrive motor, which was electronically coupled by remote cable to a 7 1/2 horsepower A C drive motor for each wave generator Since there was "drift or noise" in the electronic control system, dial settings of the wave periods were calibrated at frequent intervals Also, wave period, once selected, was closely monitored to keep it constant Monitoring was done by visually timing rotations of the wave generator eccentric arm by stop watch Monitored values were checked against the varidrive dial settings and when needed, corrections were made promptly Wave period checks were made generally at 15 minute intervals for both variable and constant period tests The variable period tests were varied in sequence above and below the mean wave period and height at a fixed time interval In most of the tests this time interval was 15 minutes but in test 1-61 it was 5 minutes and in test 5-61, period and height variation was continuous The last column in Table 2 gives some detail on wave period sequencing

Longshore Transport

Longshore transport is the movement of material along the shore in the littoral zone by waves and currents⁽⁷⁾ In the laboratory tests under discussion, longshore transport rate is defined operationally as the rate of accumulation of beach material in a said trap on the downdrift end of the test beach The material accumulated without the sand trap, using eductors and hose line, into a weighing bin where it was weighed while submerged Submerged weights were converted to their equivalent dry weights (or weights in air) by multiplying them by the factor, $\rho_{\rm g}/\rho_{\rm g}-\rho_{\rm W}$), where $\rho_{\rm g}$ and $\rho_{\rm w}$ are the specific gravities of quartz and water, respectively Using this factor to convert submerged weights to dry weights assumes that the sand is 1007 quartz. These dry weights of sand, along with the time between weighings, were used to compute the longshore transport rates Generally, transport rates were computed for the first hour or a lesser time, and in 5-hour intervals to the end of the test. In a few cases, rates were computed for periods of 15 minutes

Sand Feeding

The feeder beach area was a small area at the updrift end of the test beach where sand was fed into the wave swash in order to maintain the test beach The sand feeder at the updrift end of the sand beach, shown in Figure 1, is in the feeder beach area In earlier tests, a variety of methods were used to feed sand into the feeder beach, and to maintain a hydrography in the feeder beach area similar to that which develops downdrift of it The initial method was to stockpile sand on the beach, and to shovel sand from the stockpile directly into the wave swash Later methods included dumping from an overhead boom-supported bin, wheelbarrow dumping and the discharge of a water-sand slurry into the wave swash Also, wheelbarrow lots were dumped at the shoreline and then shoveled directly into the wave swash, similar to shoveling from a stockpile Except for the discharge of sand slurry by hose line, which scoured the beach, sand feeding methods were adequate to keep the tests going What appeared to be needed was a method of continuous sand feeding, with a minimal influence on the natural action-reaction between wave and beach

In 1962 a method for sand feeding ⁽⁸⁾ was introduced which enabled an automatic and continuous feeding of wet sand into the wave swash. The method made use of a vertical cylindrical sand feeder which deposited wet sand continuously and automatically into the wave swash. The sand feeder, shown in Figure 3 with functional parts indicated, is basically a vertical cylinder filled with sand and water. It had been modified by welding a cone section at the bottom to retard the flow of wet sand through it. Another modification was a supply line at the top for keeping the sand feeder supplied with sand

In the absence of waves, the sand in the sand feeder mouth rested directly on the sand beach tending to stabilize the column of sand in it but with some noticeable oozing of sand about the mouth In the presence of wave action, and so long as the sand was maintained at a constant level, the sand feeder was observed to feed at a fairly consistent rate. The two main factors



affecting the rate of sand fed through the feeder and onto the beach were the weight of sand and water in the feeder and the scouring action at the mouth of the feeder due to the wave swash and backwash. The weight of the sand and water in the feeder acted to force sand out at the mouth and onto the beach, while the wave swash and backwash scoured the beach under the feeder mouth making it easier for sand to be forced out and onto the beach. The amounts of sand fed into the sand feeder or onto the feeder beach were obtained by weighing the sand while submerged- the same method used to obtain the weight of sand deposited in the sand trap.

FIGURE 3 AUTOMATIC SAND FEEDER

Beach Soundings

Soundings of the test beach were made regularly. The first sounding was made on a smooth molded beach before any waves acted on it. This initial sounding was made after submerging the beach for one or two days, to allow time for settling of the material before the start of wave action. Subsequent soundings were made after one hour and five hours of wave action and thence at 5-hour intervals to the end of a test. Soundings were made from a level railing using a telescoping sounding rod with a hinged aluminum foot. Readings were made with respect to a still water level datum to one thousandth of a foot; and recorded areally on a survey sheet, analogous to the method of recording elevations in plane table surveys. Figure 4 is a contour chart of the beach obtained by contouring along points of equal depth as recorded in sounding surveys in test 4-60 after 25 hours or wave action.

Test Duration

In the earlier tests, there were no hard and fast rules for determining the length of a longshore transport test. However, there were general principles, and the philosophy of these was, that during longshore transport measurement there be a meaningful similarity between the test beach profiles and typical profiles found on natural beaches. Based on this philosophy, tests were run until the beach profiles had reached a condition defined as "equilibrium profile". "Equilibrium profile" is defined as the near constant or minimum change stage of a beach profile under the sustained action of constant condition waves⁽⁹⁾ When tests neared an equilibrium profile stage, longshore transport rate decreased, becoming fairly constant in some tests



FIGURE 4 BEACH CONTOURS AFTER 25 HOURS IN TEST 4-60

Wave action time required for a test beach to reach an equilibrium profile stage generally ranged from 15 to 30 hours depending on the wave period, wave height and the starting beach slope Tests started on a 1 on 10 slope generally reached equilibrium in less time than tests started on a 1 on 20 slope While an equilibrium profile stage was observed to occur as early as 15 hours, and as late as 30 hours, typical tests were run for 50 hours and while a large number of the tests were run 50 hours, a few tests exceeded 100 hours and several repeat tests were run only 25 hours Fifty hours was usually enough time for a smooth beach to reach an equilibrium profile stage, with 20 hours or more remaining for observation and measurement under a fairly "steady state" condition, of continuing but reduced, profile adjustment and longshore transport rate

Longshore Current

Estimates of the longshore current velocity were made from timings of fluorescein dye travel in the surf zone Generally, two estimates were made, one for the updrift and one for the downdrift part of the test beach The dye was squirted into the wave uprush by a plastic "squeeze" bottle Actual clockings observed the travel time of the leading or downdrift edge of a dye trace, and not the travel time of the dye-patch center Since the leading edge of the dye trace was timed, the rates estimated are probably maximum rates for the wave conditions tested

Water Temperature

Water temperature was taken hourly and in some tests more frequently Dial type thermometers were used, mounted on a rod, where the dial was visually accessible and the sensing element remained submerged Water temperature data, although taken regularly, did not seem to be of any direct usefulness in the analyses of the tests However, considerable data on wave induced suspended sediment (10) and also on suspended sediment in rivers (11) have shown that water temperature does effect the quantity of sediment in suspension, and since these tests were made in an outdoor facility, subject to a significant range of water temperature change, it was felt that the temperature measurements, though not of immediate usefulness in the analysis, were justified in terms of their anticipated value in some future analysis. The water temperature data observed ir the tests is available at CERC

TABLE	3
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WAVE PARAMETERS

Ref* No	Т, Sec	H ft	Hb ft	d _b ft	е <mark>**</mark> b	₫ _b °	к _R	E *** a	
3-66	1 25	0 48	363	459	4 17	16	95	1 08	
7-60	1 36	0 32	310	399	3 17	14	94	0 66	
(6)	1 50	0 18	227	294	1 65	12	93	0 29	
(3)	2 18	0 21	325	410	5 86	10	94	0 86	
6-60	2 18	0 30	410	522	10 45	10	94	1 58	
2-60	2 18	0 42	507	660	17 94	12	94	3 22	
4-60	2 18	0 62	642	854	32 48	13	94	6 29	
(2)	2 50	0 25	386	495	10 46	9	94	1 43	
(11)	3 00	0 19	355	452	10 24	7	93	1 07	
5-60	3 00	0 42	596	760	37 00	9	94	5 05	
(8)	3 75	0 14	309	388	8 99	5	93	0 68	

*Inducates a specific test, or the number of tests as (6) in row 3 ** E_b is in ft lbs/ft crest/wave *** E_a is in ft lbs/ft of shore/wave

ANALYSIS OF TESTS

A single longshore transport test included the specification of a wave and test set-up condition, test operation, measurements, observations and analysis The first part of Table 2 lists the test number, eccentricity, height, period, and duration The second part of Table 2 contains comments on special aspects of the test set-up

Table 3 lists measured and computed parameters associated with the waves, and Table 4 lists the longshore wave energy flux and the measured transport rates The wave height, H, as listed in both Tables 2 and 3, is the wave height appropriate to the offshore part of the test area, where the water depth was 2 33 feet This height can be read from Figure 2 by taking a wave period and a wave generator eccentric from those listed in Table 2 for a given test number

Thus far this report has considered the tests in general The following paragraphs present a test by test description of four representative tests

Representative Tests

Tests selected for discussion are representative of the entire series of 36 tests The representative tests are tests numbered 4-60, 4-62, 1-64, and 3-66 The longshore transport in each representative test was measured over 25 or more hours at a specified wave height and period in the general setup illustrated in Figure 1 Wave conditions span the full range of the wave conditions tested, test layouts are typical of the different aetups tested, the range of transport rates approximate the total range of all rates tested, and, testing problems are felt to be typical. Tests selected for discussion are also special in that each test usually represents a specific type of set-up For example, some of the types of set-up in representative tests were a maximum wave height condition in test 4-60, dividing the offshore basin area into wave flumes in tests 4-62 and 1-64, and eliminating training and splitter walls entirely in test 3-66

Test 4-60

Test 4-60, made in the North Section of the SPTB, had the highest height and largest transport rate of the five tests run at a 2 18 second period The period, T, was changed at 15-minute intervals through a sequence of wave periods as indicated in Table 2 for test 4a-59 Initial wave action began on a molded, 1 on 10 beach slope at a wave period of 1 94 seconds See Tables 2 and 3 and Figure 2 for details of wave conditions

The emphasis in test 4-60 was in measuring the transport rate at a mean period of 2 18 seconds for the maximum wave height obtainable at this period This test resulted in an average longshore transport rate of 9,880 pounds of sand per hour, 45% higher than the immediately preceding test, and nearly 4 times higher than the previous maximums. As a result of the higher rate, the test apparatus and personnel were hard-pressed just to keep the test going and to make the observations and measurements. One of these tasks was simply feeding enough sand, properly, to keep the test beach from eroding seriously Another task was keeping the wave generators operating as smoothly and as continuously as possible, since at a higher rate, smoothness of operation was difficult to maintain and wave machine stops due to breakdown or run-away were frequent

Longshore transport sand feeding and longshore current results for test 4-60 are summarized in Figure 5 Note the correlations in Figure 5 between longshore transport and downdrift longshore current, and between sand feeding rate and updrift longshore current Compilations of the data from all the tests, including that used to plot Figure 5, are available at CERC

Test 4-62 and 1-64

Changes in Tests 4-62 and 1-64 included the installation of splitter walls in the offshore portion of the test layout to study wave height variability The splitter wall in Test 4-62 was installed parallel to, and 10 feet updrift of the downdrift training wall The splitter wasl was conceived because repeated visual observations of wave profiles and the results of wave height



measurements suggested that a significant variation in wave height with distance across the basin was caused by resonance between training walls The visual observations were views of the water surface profile along a wave crest as outlined against the wave generator blade at the instant of generating the wave crest Figure 6 is a schematic drawing of the modes of profiles observed Mode 1 was observed only for the longer period waves - say 3 75 seconds or longer Modes 2 and 3 were also observed, with mode 3 generally associated with shorter wave periods

The function of the splitter wall was to change the mode of the cross basin wave It was further hypothesized that placing the splitter wall 10 feet (L/4) updrift of the training wall, placed it at an antinode of a cross basin wave A splitter wall placed at the antinode would impede the cross basin flow and thus force the wave mode to change with a possible lessening of wave height variability across the basin The two curves in Figure 7 for a 3 75 second period show that the total range of the wave height variability was reduced, and that the initial bimodal distribution of wave height was changed

The test set-up for Test 1-64 was a further application of splitter walls in which 7 splitter walls divided the offshore test area into 8 flumes, each 5 feet wide The reasoning, as in Test No 4-62, was that the splitter walls should change the mode of a cross-basin wave hypothesized to be a cause of wave height variability across the basin Wave height measurements showed that the 7 splitter walls in Test 1-64 did change the distribution of wave heights, as a single wall did in Test 4-62, but had little effect in reducing the wave height variation In summary, measurement results in Test 1-64, Test 4-62 and a similar four-flume test suggest that the wave height variability is independent of the spacing between training or splitter walls



FIGURE 6 SCHEMATIC DRAWING, ILLUSTRATING VISUALLY OBSERVED WAVE MODES IN THE SPTB



Longshore transport, sand feeding and longshore current results for Tests 4-62 and 1-64 are summarized in Figure 8 Note the correlations in Figure 8 between downdrift longshore current and longshore transport rate Also note similar correlations between the sand feeding rate and the updrift longshore current



Test 3~66

Test 3-66, completed in October 1966, was the last test completed With two important differences, the test set-up was similar to the set-up for Test 1-64 described in the previous section The first difference was the deletion of all training and splitter walls and the use of a longer beach necessitating the generation of a longer crested wave (80 feet in contrast to 40 feet in Test 1-64 and other prior tests) The second difference was the installation of a concrete slope, 20 feet wide, immediately updrift of the feeder beach as shown in Figure 1 The first difference, an open basin set-up, was designed to reduce variability in wave height, by eliminating some reflective surfaces (the training walls) and the second, an updrift concrete slope, was designed to provide a more natural longshore current It was reasoned that wave reflection could be a significant contributor to the wave height variability problem and that the small distance between the training wall and the feeder beach area in previous tests may have hindered the development of a natural longshore current

Test 3-66 was a constant wave period test with a high wave steepness It had a high wave energy relative to the wave energies in many other tests Wave breaker type in the test was spilling to plunging and yet the transport rate seems relatively low for its relative wave energy level among the tests

TABLE 4

LONGSHORE WAVE ENERGY FLUX AND LONGSHORE TRANSPORT RATES (E, 15 1n millions of ft lbs/ft of shore/day)*

Test No	E _a *	0-5 hrs	Q in yds ³ /day 20-30 hrs	at test times 40-50 hrs	Average	
1-58	017	2 36	2 65	2 77	2 49	
2-58	017	1 94	2 09	2 19	2 42	
2a-59	031	15 62	13 20	13 28	14 23	
3a-59	031	10 56	13 54	13 88	13 77	
4a-59	034	19 72	18 38	16 53	18 17	
1-59	017	183	1 93	-	1 97	
2-59						
Ph 1	017	273	2 45	-	2 46	
Ph 2	031	1 23	3 59	1 77	4 57	
3-59	031	683	13 30	12 30	11 44	
4-59	031	7 19	9 52	11 64	973	
5-59	016	5 65	6 15	4 58	578	
6-59	049	8 32	7 62	6 69	7 19	
1-60	034	17 30	19 92	21 71	19 48	
2-60	128	61 06	56 20	-	61 03	
3-60	031	14 24	17 20	-	16 05	
4-60	250	92 98	80 03	-	83 64	
5-60	145	96 42	132 80	-	121 32	
6-60	063	40 06	39 83	38 04	40 62	
7-60	042	13 70	8 11	7 20	8 91	
1-61	031	20 16	18 63	15 76	17 88	
2-61	031	23 04	19 56	20 00	20 41	
3-61	031	12 88	8 03	8 18	9 20	
5-61	031	19 64	19 70	18 01	19 18	
6-61	049	30 16	27 94	31 29	29 59	
7-61	016	6 22	2 26	3 64	3 37	
1-62	016	3 01	5 99	4 92	5 63	
2-62	016	2 31	5 12	-	5 13	
3-61	016	3 14	4 77	-	4 77	
4-62	016	4 53	2 88	-	2 88	
6-62	015	9 21	7 23	6 80	744	
8-62	015	5 98	6 08	-	6 11	
1-64	016	3 50	5 43	4 97	5 05	
1-65	016	15 70	5 49	-	8 90	
2-66	063	26 18	34 95	-	33 12	
3-66	095	19 76	9 65	777	10 55	
5-62	763	special	test, Q=171 32	2 yd ³ /day		

The longshore current rate is quite high and seemed by direct observation to be out of step with the transport rate in the test The wave breaking turbulence appeared to remain very much near the water surface and seemed too weak to really stir up the bottom boundary layer

Longshore transport, sand feeding and longshore current rates for Test 3-66 are summarized in Figure 9 These tests results also show a correlation between longshore transport and downdrift longshore current rate and between sand feeding rate and the updrift longshore current rate

Discussion of Longshore Transport Data

As described earlier, rates of longshore transport, sand feeding and longshore current have been compiled for each of the tests Reduced and compiled rates and associated littoral drift data are available at CERC Some



of this data has been summarized and is shown in Table 4 The data in Table 4 gives the test number, longshore wave energy, E_a , and the longshore transport rate, Q, at test times of 0-5, 20-30 and 40-50 hours The rates listed are volumetric rates based on a conversion factor of 105 pounds per cubic foot (satisfactorily checked by volumetric measurements of the sand) to obtain rates for the dry weight, or weight in air of the sand, as described in the section on "Longshore Transport"

The transport rates vary considerably, as the values in Table 4 show The greatest variation appears to be in the long period - low energy tests run at a constant wave period Eight of these tests are listed in Table 4, each with a longshore energy flux, E_a, of 016 millions of foot pounds per foot of beach per day Figures 10 and 11, respectively, give a graphical comparison of transport rate and longshore current rate variation with test time for ten selected tests. The ten tests include the four representative tests described in the previous section. The data on Figures 10 and 11 indicate, that tests with higher transport rates generally have higher longshore current rates and vice versa. Several tests corroborate this similarity, but there are two notable exceptions. One is Test 3-66 having a very high steepness and another is Test 1-64 with a very low steepness. Another similarity is the increases and decreases of longshore transport and longshore current rates which appear to be fairly well correlated. In most tests, the variations in longshore current are



noticeably greater than the variations in longshore transport Actually, the transport rates appear steady when compared with the quite variable longshore current rates

Energy Flux - Longshore Transport Correlation

The total wave energy per unit crest width in one wave length of an oscillatory wave⁽⁷⁾ is given by $E_t = \frac{1}{8} pgH^2L[1-M-\frac{H^2}{L^2}]$ where $\rho=w/g$ is the mass density of water (fresh water = 1 94 slugs/ft³) and M is an energy coefficient defined as $\frac{\pi^2}{2 \tanh^2(2\pi d/L)}$ When considering a single wave at the breaking depth the above formula may be re-written as

 $E_b/wave = 1/8 \rho g H_b^2 L_b \left[1 - M_b - \frac{H_b^2}{L_b} \right]$, where the subscript, b, refers to wave break-

ing conditions This formula was used in these tests to compute the wave breaker energy per wave Calculations were carried out on a desk calculator using the Modified Solitary Wave Theory - wave breaker indices curves and Weigels Tables in CERC TR-4 Wave breaker height, H_b, breaker depth, d_b , and wave breaker energy, E_b, are tabulated in Figure 3 for discrete combinations of wave height and period

Wave breaker angle, α_b , and wave refraction coefficient, K_R , were obtained empirically using the analytic expression, $K_R = \sqrt{\frac{\cos \alpha}{\cos \alpha}}^{\circ}$, of Snell's law in a nomograph of d/L_0 , α_0 , and $K_R^{(12)}$ In using the nomograph, it was assumed that α_0 was 30° which was the wave approach angle in a constant depth of 2 33 feet in the test set-up. The breaker depth, d_b , was used in the expression d_b/L_0 , to enter the nomograph and the angle, read from the graph was considered as α_b , even though it was not based on the theoretical deep water for the respective wave periods. When the wave breaker energy, E_b , per wave was multiplied by $\cos \alpha_b$ sin α_b and K_R^2 the product was the longshore component of the wave energy flux, E_a , in foot pounds per foot of shore per wave. These last three parameters, α_b , K_R and E_a are tabulated in Table 3. E_a is also tabulated in Table 4, in millions of foot pounds per foot of beach per day.

The final results are given in Figure 12 as a scatter plot of longshore wave energy flux versus longshore transport rate at test times of 20-30 hours The visual best fit curve drawn through the points is based only on the 1 on 10 starting-slope tests Figure 12 also includes the suggested design curve of the wave energy-longshore transport relationship excerpted from CERC's TR-4 Results plotted in Figure 12 include a total of 36 points which includes eight points for the relatively low energy - low transport, constant period tests Most of the points falling on or near the CERC TR-4 curve have a 1 on 20 starting slope The maximum point on the curve is from a special test of four hours duration In this test, sand moving past the downdrift end of the beach dropped over a vertical ledge and formed a mound of sand, which was measured volumetrically by a method of successive surveys

Most of the data point scatter in the longshore transport rates is not felt to be just simple data scatter per se, but is more likely meaningful scatter For example, the legend in Figure 12, which categorizes the results into only four discrete classes, cannot adequately account for significant influences on the longshore transport rate caused by wave height yariability, wave breaker type, model effects at the sand trap and at the feeder beach, or wave diffraction All of these causes, admittedly influence longshore transport rates in model basins, and the influence of one, wave diffraction, was tested and demonstrated in the SPTB at CERC (13)

Summary

A total of 36 tests were completed for the following experimental conditions, wave periods of 1 25 to 3 75 seconds, and wave heights of 0 14 to 0 75 feet in a constant water depth of 2 33 feet between a wave generator and the beach Waves were generated at a 30° angle to the beach with portable wave generators, which when used singly, generated a wave crest 20 feet long, or when used - say in groups of five - generated a continuous wave crest 100 feet long Waves, so generated, traveled in the constant depth to a molded sand slope, where they impinged along a variable length shoreline from 30 to 95 feet, depending on the length of wave crest generated and the test set-up conditions. In addition to variable period, height, length of wave crest generated and shoreline length, specific tests were either variable about some mean period and height or they were constant, with starting slopes of 1 on 10, 1 on 20, or a 1 on 30 equi-librium slope

As waves shoaled and broke along the 0 22 mm median-diameter sand beach, they caused the sand to move downdrift where it was deposited in a sand trap Amounts of sand deposited in a given time were reduced and compiled as longsnore transport rates Longshore wave energy flux, computed from measured wave heights and calculated wave breaker angles is plotted against measured longshore transport rates in Figure 12 The results in the plot are compared with the suggested



design curve of the longshore wave energy flux - longshore transport relation from CERC TR-4 Transport rates along the best fit curve of the laboratory data range from a low of about 6 yd^3 per day to a high of 170 yd^3 per day, and exceed the CERC TR-4 design curve rates by an average factor of 3

Conclusions

It is concluded that the laboratory rates, noted above as exceeding the CERC design rates by a factor of 3, are at least as large as indicated in Figure 12, and except for some test difficulties noted above, would be larger than indicated Moreover, transport rates would be expected to be higher if, (1) tests were run continuously, not intermittently, and (2) at a changing water level, simulating a tide, instead of a constant water level

A localized and deep wave scour immediately updrift of the sand trap, restricted the transport to that in suspension in some tests, and thus reduced the transport rate In several tests, bars, cuts and cusps developed along the shoreline, and it is felt that these features reduced the transport rate In addition, accumulation of pebbles armored the beach locally against the waves in some tests, which was judged to have reduced the transport rate

It is also concluded that the actual wave height, defined as the effective wave height impinging along the test beach, was significantly higher than the scaled-up Froude model height used to compute the wave energy Figure 13 is presented in support of this conclusion, as a typical result from the wave height variability measurements It shows that the average sustained height of the SPTB waves exceeded the Froude model height by 46 percent in a wall compartmented basin and by 71 percent in an open basin It is important to note here, that if these percentages were applied in Figure 12, the plotted points



FIGURE 13 COMPARISON OF WAVE HEIGHT VARIABILITY AT A CONSTANT WAVE CONDITION IN A WALL COMPARTMENTED BASIN AND AN OPEN BASIN

would move to the right by a factor of about 2 to 3 and then fall much nearer, or even cluster about the CERC TR-4 curve While such good agreement would indeed be gratifying, it must be recognized that some part of the increase in height (energy) illustrated in Figure 13 was caused by reflected waves, either from the beach, the wave generator or both

Recommendations

It is recommended that in future tests, consideration be given to running some tests continuously to completion, with a tide range superposed on the mean water levels. It is further recommended that wave height variability, wave breaker type, model effects at trap and feeder beach and wave diffraction effects be monitored and documented in future tests and so become part of the test results

It is also recommended that in future tests, consideration be given to short period tests of the order of 10 minutes to be made - say in the middle of a test beach length - somewhat removed from the influences of trap, feeder beach and wave diffraction Such tests might be made by interfacing sheet plastic along a profile line vertically, and laterally along the bottom for collecting sand drifting past the interface At the same time measurements could be made of the wave height at the toe of the beach profile and at the peak height before wave breaking Wave measurements and analysis should account for the percent of a wave height which is due to wave reflection

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