University of Washington
Department of Civil and Environmental Engineering

WAVE TRANSMISSION TESTS OF FLOATING BREAKWATER FOR OAK HARBOR

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Water Resources Series
Technical Report No. 32
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ACKNOWLEDGMENT

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The work was conducted at the C. W. Harris Hydraulics Laboratory, University of Washington, under the supervision of Eugene P. Richey and Ronald E. Nece, Professors of Civil Engineering. Mr. Ralf Halsan, of the laboratory staff, provided assistance in model construction and installation. Mr. Donald Miller and Mr. Alexander Coutts, students in Civil Engineering, participated in the construction, testing, and analysis phases of the program.

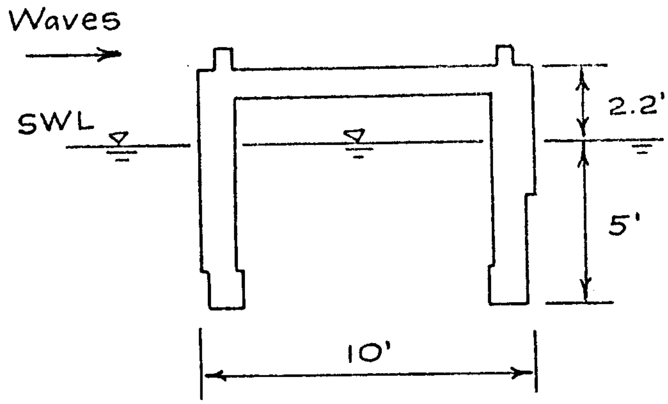
LIST OF FIGURES

I. INTRODUCTION

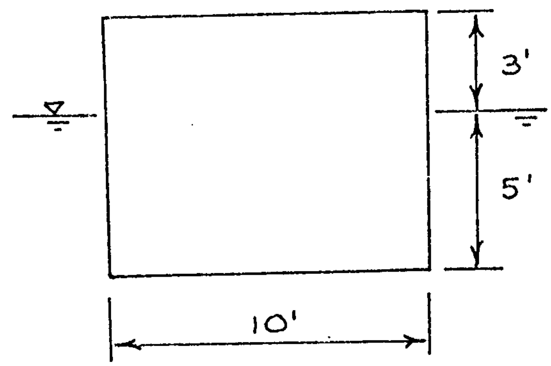
This report summarizes wave transmission results from two-dimensional regular wave tests of model floating breakwaters.

The prototype breakwaters were designed by the U. S. Army Engineer District, Seattle, for a planned installation at Oak Harbor, on Puget Sound, Washington. The range of waves for which the model breakwaters were tested was in accordance with the specifications of the Seattle District, which had determined design wave characteristics at the Oak Harbor site. More comprehensive model tests had been conducted previously of preliminary design configuration for Oak Harbor. These earlier tests, conducted at the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, have been reported in Reference 1. These earlier tests included mooring force as well as wave transmission determinations for a twin-hull floating pontoon section restrained in position by chains in one configuration and by pilings in another. The present tests were limited to wave transmission characteristics of a chain-anchored unit.

The draft and overall width of the twin-hull units tested at Vicksburg are the same as those of the rectangular unit tested at the University of Washington; these dimensions and cross-section shapes are shown in the sketch on the following page. Anchor chain lengths, attachment locations on the breakwater, and water depths used in the Vicksburg tests were reproduced in the present tests. The tests reported here then were used not only to obtain data on the rectangular unit, but to allow comparison of two configurations operating in the same wave climate. Where such comparisons are made in this report, the "twin-hull" data given are from Reference 1.



Twin-Hull Pontoon



Rectangular Pantoon

Two model scales were used in the present tests in order to cover the specified range of wave periods. The linear scale ratios were 1:10 and 1:16. The Vicksburg tests utilized a 1:10 scale. Based on Froude law similarity, the appropriate model-to-prototype relations are:

Characteristic	Model-Prototype Scales	
Length	1:10	1:16
Time	1:3.16	1: 4

All results given in this report are expressed in terms of prototype values. Anchor locations, cross-section dimensions, and notation are given on Figure 1.

II. MODEL TEST FACILITIES AND PROCEDURES

A. Description of Wave Tanks

The test program agreement specified that data were to be obtained for equivalent prototype still water depths of 10 feet and 29.5 feet, simulating low tide conditions and high tide conditions, respectively. Meeting these specifications required the use of the two wave channels available in the laboratory.

The low tide tests were conducted in a rectangular flume 54 feet in overall length, 2 feet wide and 18 inches deep, operated at a 1-foot depth in the test program so that the low tide (10-foot water depth) runs were performed at a 1:10 scale. The channel has transparent sidewalls for the 'seaward' 30 feet of its length to permit viewing of the waves. The wave generator is of the oscillating, vertical-face piston type, with variable frequency and amplitude of stroke. An adjustable sloping beach at the far end of the channel serves as an energy absorber; the beach was set at a slope of approximately 1:15 during the tests.

The high tide tests were conducted in a sub-floor concrete flume. This channel is 164 feet long, 4 feet wide, and 3.5 feet deep. Beaches are located at both ends of the channel; a 1:10 slope beach is located behind the wave generator and a 1:16 slope beach is located at the far end of the test section. The wave generator is of the hinged-flap type, with variable frequency and stroke. Water depths were maintained between 2.95 feet and 3.00 feet. The former, used with a 1:10 scale model, simulated the specified high tide still water depth of 29.5 feet. The interpretation of channel water depth for the 1:16 scale model is discussed in the following paragraph.

B. Test Ranges

The original specifications for the test program stipulated that (prototype) waves be investigated over a range of incident wave heights H_i for wave periods T ranging from 1.0 second to 5 seconds. It was not possible to generate stable waves having equivalent periods of less than 2 seconds in either laboratory channel; hence, 2-second waves were the shortest ones tested. Equivalent prototype periods of greater than 3.5 seconds could not be reached in the deeper channel when the model scale was 1:10. Accordingly, a 1:16 model was used and the periods extended to 4.5 seconds. The 1:16 scale tests, run at a 3-foot water depth, produced an equivalent prototype still water depth of d = 48 feet. Water depths in the 1:16 scale tests, with the exception of the 4.5 second wave runs, were greater than one-half of the wave length, L, and hence these data were obtained for deep-water ($d/L > 0.5$) conditions, whereas prototype conditions are not in the deep-water range for periods of 3.5 seconds or longer. Accordingly, the 1:16 scale results are not strictly an extrapolation of the 1:10 scale data, but rather give an index of breakwater performance in longer waves.

Nominal ranges covered in the three series of tests are tabulated below. The actual values are listed in data Tables 1-3.

Model Scale	d-ft	T-sec	H_i-ft
1:10	10	2.0 - 4.0	0.5 to max. stable
1:10	29.5	2.0 - 3.5	0.5 " " "
1:16	48	2.5 - 4.5	0.5 " " "

C. Description of Models

Three separate models were constructed and tested, one for each scale ratio-water depth combination. Each model was a rectangular, closed box.

The primary material was ½-inch exterior plywood. The models were ballasted with ¼-inch steel plates screwed to the insides of the sides, bottom, and top of the test section; this mass distribution was adapted in order to simulate that of the hollow concrete pontoon of the prototype. The 5-foot draft of the prototype design provided the criterion for ballasting. All construction seams except those at the top of the models were covered with impregnated marine sealing cloth, and the models were painted for water proofing. Each test section was built with a length one inch shorter than the width of channel in which it was tested, providing ½-inch end clearance.

There was no attempt to reproduce exactly the anchor chains used in the Vicksburg test, although the chains used in the two tests appear quite comparable. A $^{5}/64$-inch double loop galvanized wire chain was used in the present tests. Attachment to the models was accomplished by a simple hook-eye arrangement; turnbuckles provided an adjustment to insure that the models were properly aligned in the channel. Simple lead weights resting on the channel bottom served as the anchors; these anchors were sufficiently far removed from the model location, and provided minimal obstruction in the test channels, so that they did not affect the incident waves arriving at the breakwater. Small differences in chain configuration are considered to have negligible effect on breakwater performance.

D. <u>Test Procedures</u>

All wave data were obtained by use of a nichrome wire resistance wave gage. The gage is installed in one arm of a Wheatstone bridge circuit. Both excitation and output signal amplification of the gage are provided by a Brush pre-amplifier unit. The continuous analog output is obtained on a Brush recording oscillograph which provides a record of water surface elevation vs.

time at the gage location. A static calibration of the wave gage was performed prior to each test series.

All test data were obtained with a single wave gage. The gage location was kept constant for all tests in each channel. This location was between 6 and 7 feet to the leaward side of the model in all tests. The gage was thus at least one wave length behind the breakwater in each case, providing adequate distance for the wave forms to become reestablished and provide an accurate measurement of the transmitted wave height, H_t.

Each individual test run was made in the following sequence. First, the model was removed from the channel, and the wave generator adjusted to the desired T-H_i combination. With the model still removed from the channel, characteristics of the incident wave were measured with the wave gage in its fixed location. The model was then inserted in the channel, and the transmitted wave characteristics were measured for the same wave generator setting.

To expedite the testing, each sequence of runs was made with a constant stroke setting for the wave generator, with periods being set for each individual run. Wave heights H_i and H_t were determined from the oscillograph record; periods T were likewise found using the known chart speed of the oscillograph record, and were checked by direct timing.

The model was located 22 feet from the wave generator in the 10-foot depth (low tide) tests. The duration of H_t data acquisition was limited to the period between initial arrival of the incident waves at the breakwater and the time when the first reflections originating at the model had made the return trip between the breakwater and the wave generator. In the lower tank the model was 70 feet from the generator, and data acquisition times for H_t were correspondingly longer.

If there was little or no variation in recorded wave height during the period of measurement of the transmitted waves, a simple average from the oscillograph record was listed for H_t. If there was significant variation, due to particular interactions between breakwater and waves, the values recorded in Tables 1 - 3 indicate the range of H_t values recorded.

III. RESULTS AND ANALYSIS

Data are summarized in Tables 1-3, and results are shown on Figures 2-8. The results shown on the figures are discussed sequentially in the following text.

Average values of H_t for varying H_i for different wave periods T for the 1:10 models are given on Figure 2. If the transmission coefficient $C_t = H_t/H_i$ were truly a constant for all H_i for a given period T, all of the curves plotted on Figure 2 would be straight lines passing through the origin. The data show no significant variation in C_t with H_i -- i.e., wave steepness H_i/L has little effect. For the particular discrete values of T at which tests were made, the wave transmission past the breakwater was smallest at T = 3.0 seconds for both the d = 10 feet and d = 29.5 feet runs; this point is discussed in more detail later. There is relatively little difference in wave transmission characteristics of the shorter period waves for the two water depths, even though in the d = 10 feet case the breakwater with its 5-foot draft has a relative penetration y/d = 0.5, compared with the much smaller 0.17 for the 29.5-foot depth; the greater penetration becomes significant at the longer wave lengths (periods).

Comparable data for the 29.5 and 48-foot depths are plotted on Figure 3. There is greater transmission for the shallower depth case (1:10 model) than for the deeper water (1:16 model), except for steeper waves. Again, wave transmission is lowest at the 3.0 second prototype wave for both models. Transmission coefficient values approach unity for the long waves, d = 48 feet; these waves produce a repetitive orbital motion of the breakwater, with no overtopping of the breakwater, and regular transmitted waves which show very little attenuation due to the breakwater presence. Comparable behavior might be assumed for the longer period waves (T = 4, 4.5 seconds) which were not obtainable with the 1:10 scale model.

Figures 4-6 give ranges of $C_t = H_t/H_i$ for each of the three model configurations. The parameter λ/L is selected as the single geometrical ratio which perhaps can best be used as an index for predicting the performance of floating breakwaters. Auxiliary scales showing wave periods are also given. There has been no attempt to plot data curves for various wave steepness ranges because the results show no pronounced effect of steepness.

In all three models the minimum wave transmission occurs at an equivalent T = 3.0 seconds. Simple laboratory observations with each of the three models indicated an equivalent prototype heave period for the breakwater of very nearly 3.0 seconds. The breakwater motion when the wave period and the structure's heave period were essentially equal was considerably different than at other wave periods. The primary mode of motion was heave, with very little roll of the structure. The outstanding feature of the motion is that the vertical displacement of the breakwater is out of phase with the water surface displacement under the incident waves. When the wave crest arrives at the breakwater the latter is at its lowest elevation; when the wave trough arrives the breakwater is at its highest elevation. These conditions are shown in Figures 9 and 10, respectively, taken for the following conditions: T = 3.0 seconds, d = 10 feet, H_i = 1.5 feet. Scaling from the photographs yields the following approximate motion distances: vertical heave, 2 feet; horizontal sidesway, 1 foot. Although structure displacements were not measured during the tests it was observed that heave magnitudes did, as anticipated, increase with increasing wave height H_i.

Utilizing approximate added mass coefficients from Reference 2, the natural period of heave of the structure was calculated to be nearly 3.5 seconds, slightly depth dependent, versus 2.5 seconds if the added mass term is neglected. The observed period falls within this range. No attempt was made to calculate a natural period of roll for the prototype. Simple laboratory observations yielded an equivalent roll period of just over 9 seconds, with the breakwater chains attached and also with the chains removed. This period is far longer than that of the longest waves tested, and so unforced roll motion and frequency of the breakwater were viewed as having little effect on the test results.

The significant natural period for the structure is that of heave, and the out-of-phase, almost translatory motion of the breakwater when the wave period is the same as the heave period produces significant wave damping characteristic at this T. Comparable phenomena have been reported for other tests of floating breakwaters. For example, in Reference 3, tests on a unit having an inverse-trapezoid cross-section, and with mooring arrangements comparable to those of the present tests, showed that there was a marked increase in wave attenuation when T of the waves was equal to the roll period; the particular shape reported was very sensitive to roll.

The behavior of the present rectangular breakwater is different for wave periods which are longer than 3.0 seconds than for periods shorter than 3.0 seconds. For the shorter periods the breakwater assumes a greater angle of tilt, has less heave, develops an erratic motion rather quickly, and jerking action of the anchor lines occurs. As the wave period would become much shorter, and λ/L increase beyond the values of the test, the wave transmission coefficient would be expected to drop to about 0.2 as an approximate lower limit. For the longer waves the breakwater itself follows an orbital path, there is very little roll, and likewise minimum wave attenuation.

Figures 7 and 8 provide a comparison of the performances of the twin-hull and rectangular breakwaters for the 10-foot and 29.5 foot water depths; the summary curves drawn are for H_i values of 1.0 foot and 2.5 feet, to cover a range of prototype conditions. In general, although the two breakwaters have quite different cross-sections all of the curves plotted on the two figures fall within a general envelope of curves which could be drawn for an even wider variation of floating breakwater configurations (Reference 4). For the short waves, C_t appears to trend toward a common value for all cases; motions of the water between the two pontoons of the twin-hull unit appear to have little effect, and the equal gross displacement shapes of the two forms of breakwater appear to over-ride differences in cross-section details.

IV. CONCLUSIONS

The performance characteristics of the rectangular pontoon are typical of the behavior of floating breakwaters under laboratory tests over the same general range of variables. The minimum values of $H_t/H_i \approx 0.20$-0.25 are typical of the best wave attenuation characteristics of many types of breakwaters as reported in Reference 5.

According to data supplied by the Seattle District and incorporated in Reference 1, the maximum waves from the exposed direction at Oak Harbor range up to 3.5 seconds in period and 2.0 feet in height, and it is desired that wave heights within the proposed basin not exceed 0.5 foot. The laboratory tests covered a range exceeding the quoted incident wave values. For H_i = 2.0 feet, the laboratory tests produced equivalent H_t values in excess of the desired 6-inch height for all wave periods.

Values given in the general literature also are based on two-dimensional laboratory wave channel tests such as described in this report. It may well be that the reported results are conservative. In an actual field installation there will be a spectrum of waves present instead of simply one regular wave of constant frequency; wave crests may strike the breakwater in an oblique fashion and thus not present identical loadings over the entire pontoon or pontoon-assembly length, as is the case simulated in the laboratory where wave crests are parallel to the breakwater axis; wave crest lengths in a natural wave climate are finite and not infinite as is the simulated condition in the laboratory. All of these factors could lead to statistically smaller values of H_t/H_i. Although they were not investigated in the present test, anchor forces may exhibit a comparable field-laboratory discrepancy. Field data from installed prototype units must be obtained to help bridge the gap between field and laboratory behavior; this is the major need in the engineering design process.

Laboratory data still provide an index of performance. Observations made during the present tests prompt the following precautions:

1. Structural motions for equal incident wave heights are more violent at the shorter period waves, at equivalent periods of 3.0 seconds and shorter. The waves at the Oak Harbor site are mostly within this period range, a factor of importance in considering design against fatigue failure of anchor and structural connections.
2. These structure motions may limit the size of boat which could be moored at the breakwater if such a dual use of the unit is contemplated. Special multi-point moorings may be required. Also, motions in rough weather may pose questions of safety to personnel.
3. The decision to utilize floating breakwaters at the Oak Harbor site was reached because of the poor bottom conditions. At low tides especially the breakwaters will tend to concentrate flows and to cause increased water velocities below the pontoons for both wave-induced motions and tidal currents. A potential exists for increased sediment motion and/or scour within the harbor. Among other things, such increased sediment motions could have some effect on the breakwater anchors, silting over of anchor chains, etc. Bottom conditions should be watched carefully after the breakwater is installed.

4. The two-dimensional single-period wave conditions under which the usual laboratory tests are performed leave out the structure motion components of surge, pitch, and yaw; these are very important to the connections between modules. No data are available on the magnitudes of the forces to be expected, but the general recommendation is to make the assembled breakwater in the longest continuous length possible so that the forces causing these motions will be of random nature in time and distribution, rather than of periodic nature and uniformly applied as could be approached in shorter units.

V. REFERENCES

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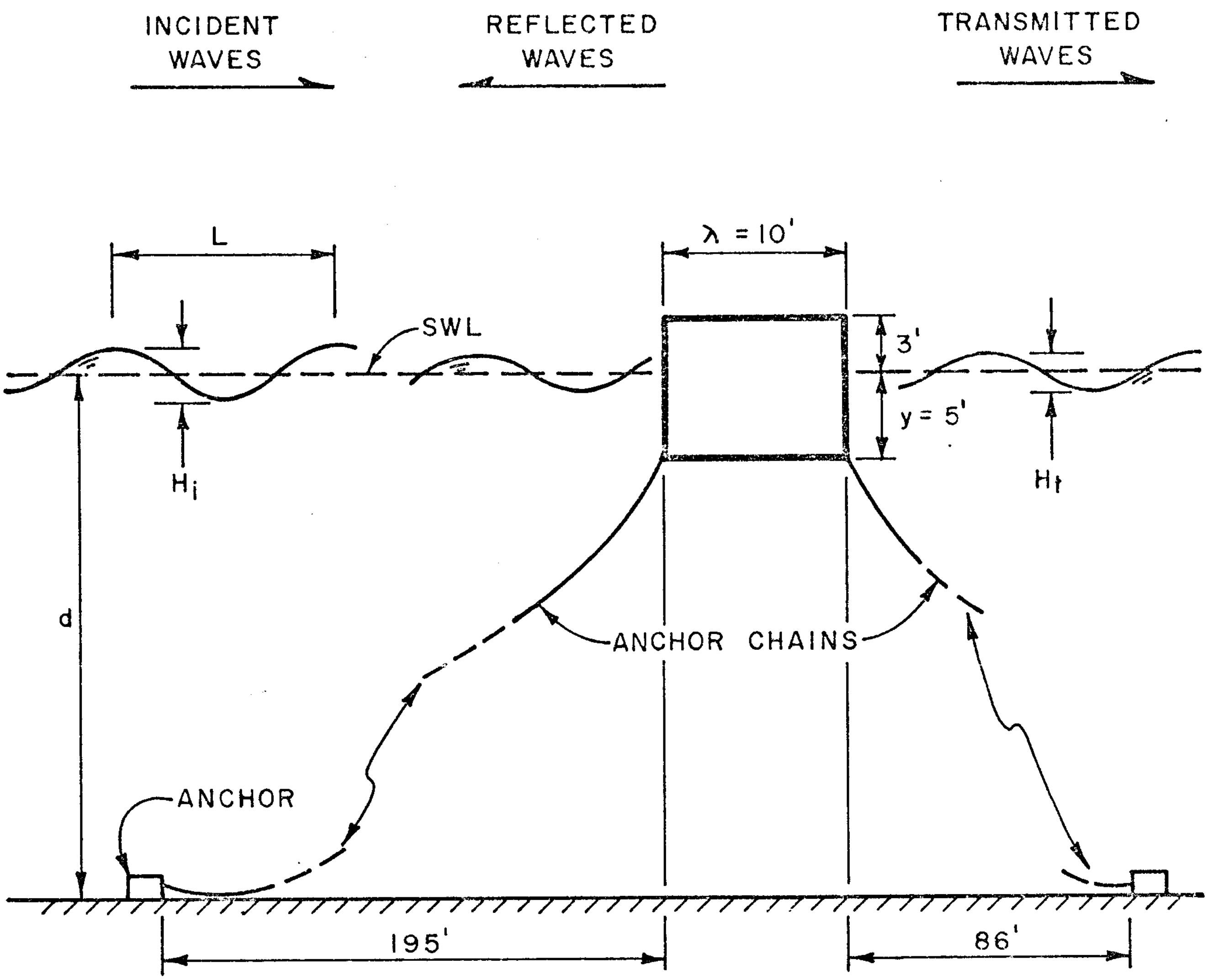

Figure 1. Definition and Notation Sketch

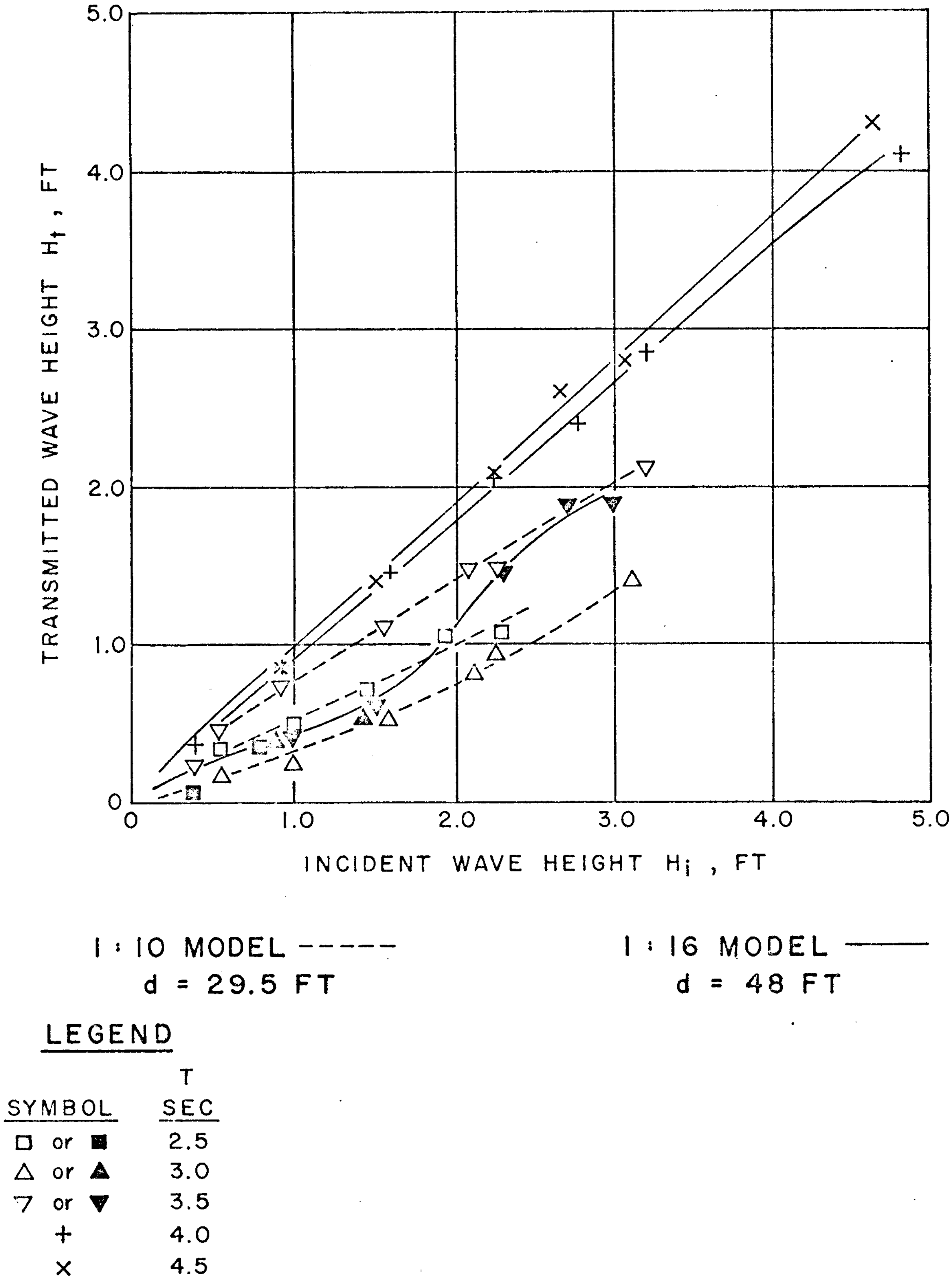

Figure 2. H_t vs H_i, d = 10 Feet and d = 29.5 Feet

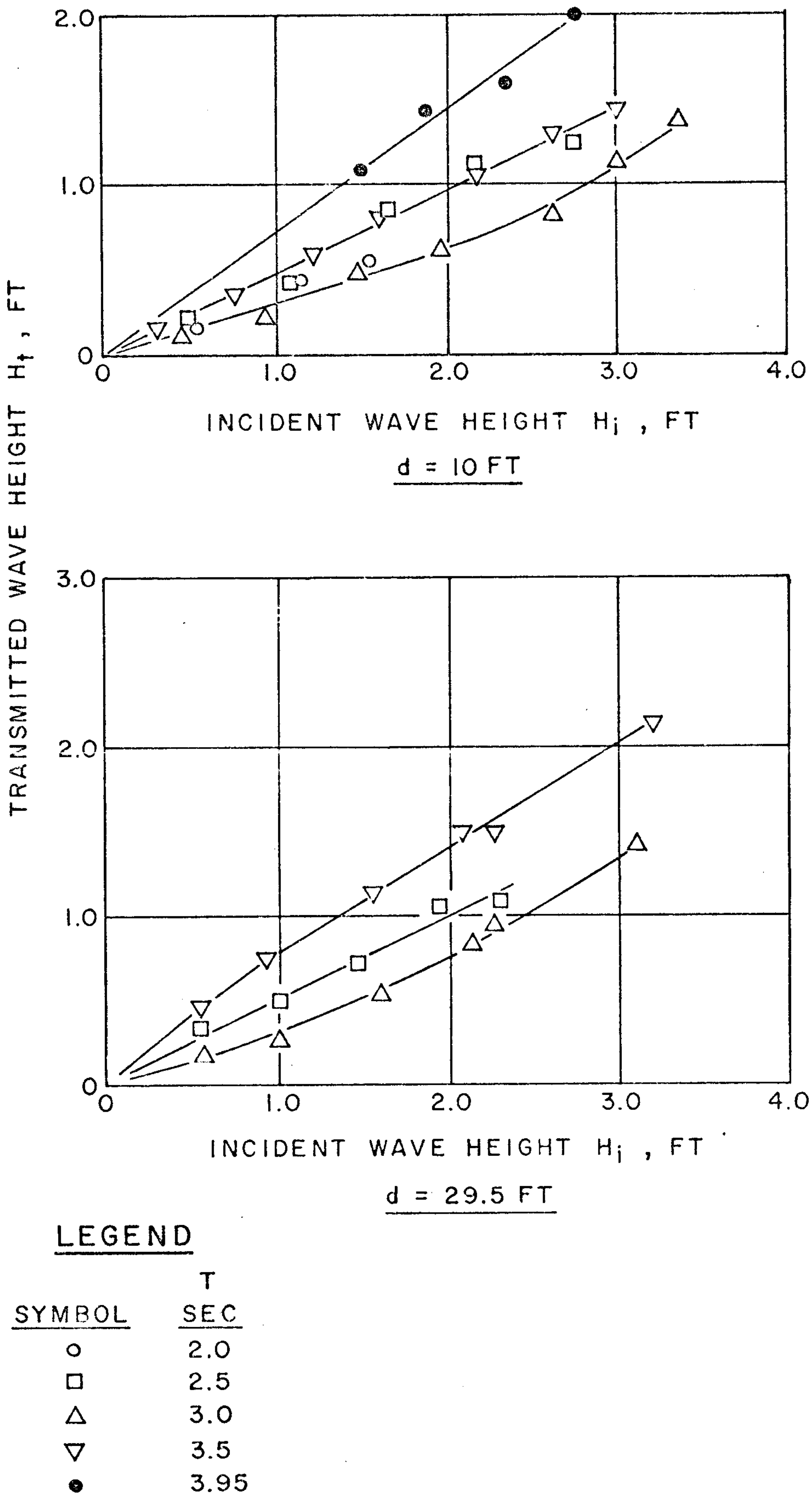

Figure 3. H_t vs H_i, d = 29.5 Feet and d = 48 Feet

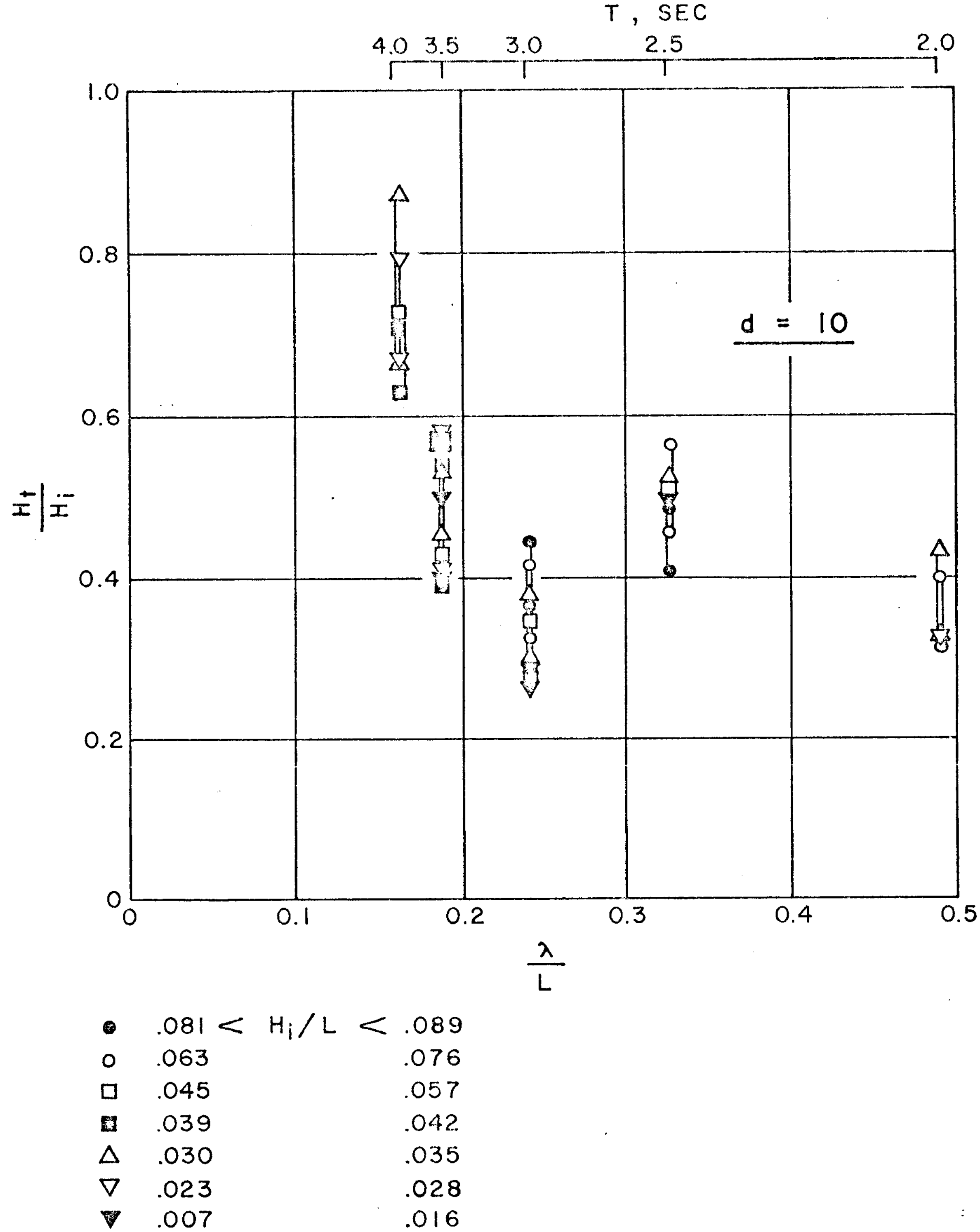

Figure 4. H_t/H_i vs. λ/L, d = 10 Feet

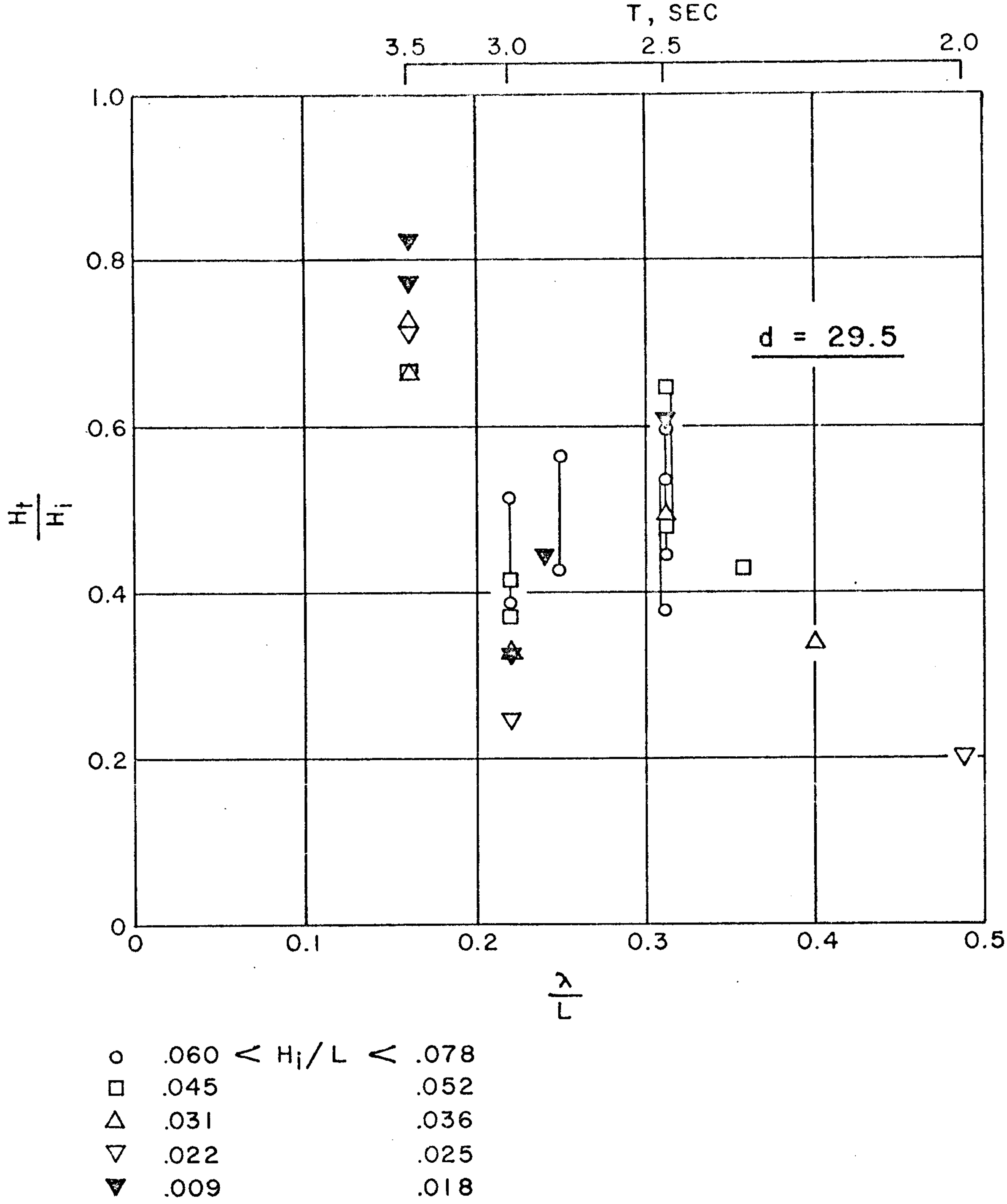

Figure 5. H_t/H_i vs. λ/L, d = 29.5 Feet

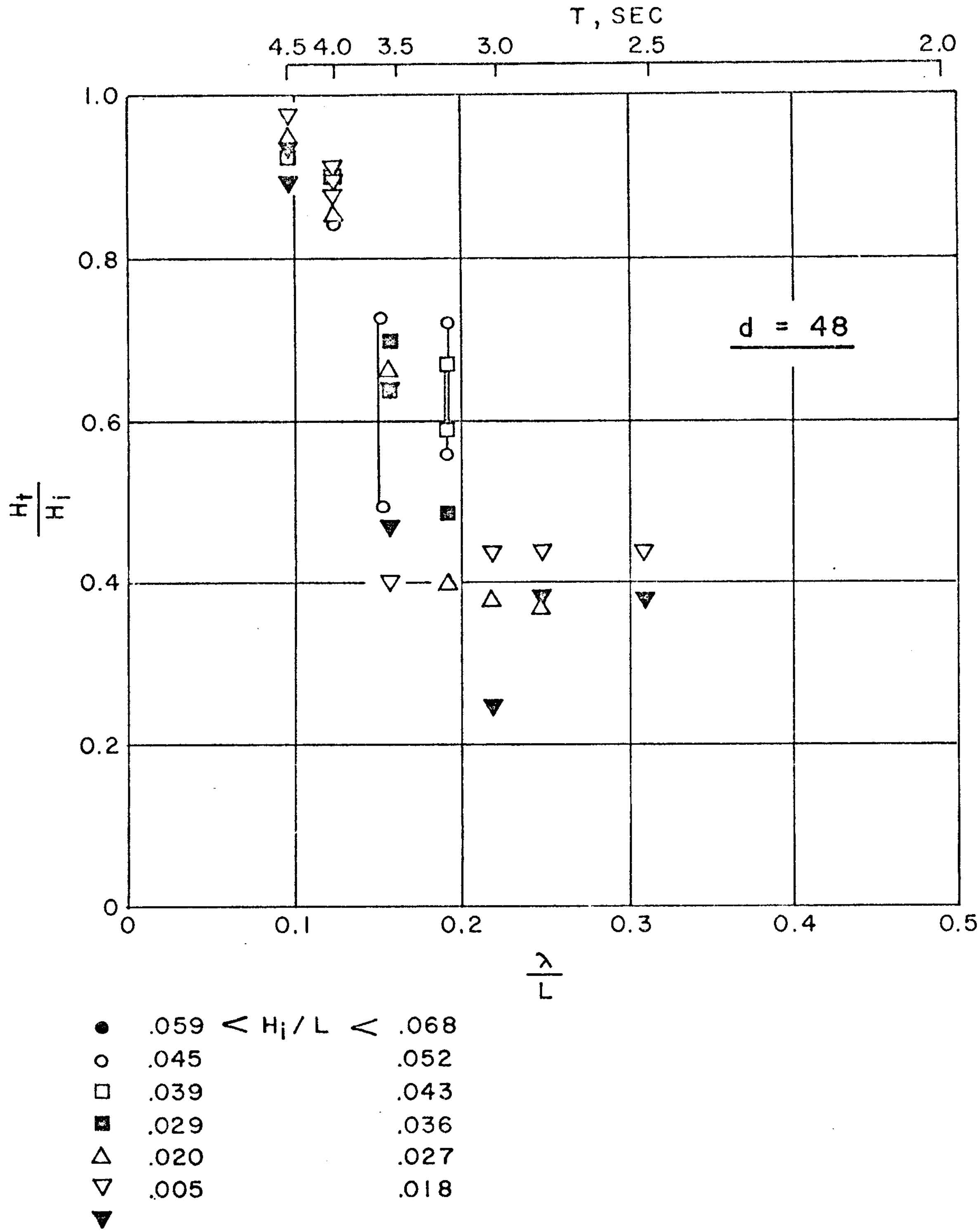

Figure 6. H_t/H_i vs. λ/L, d = 48 Feet

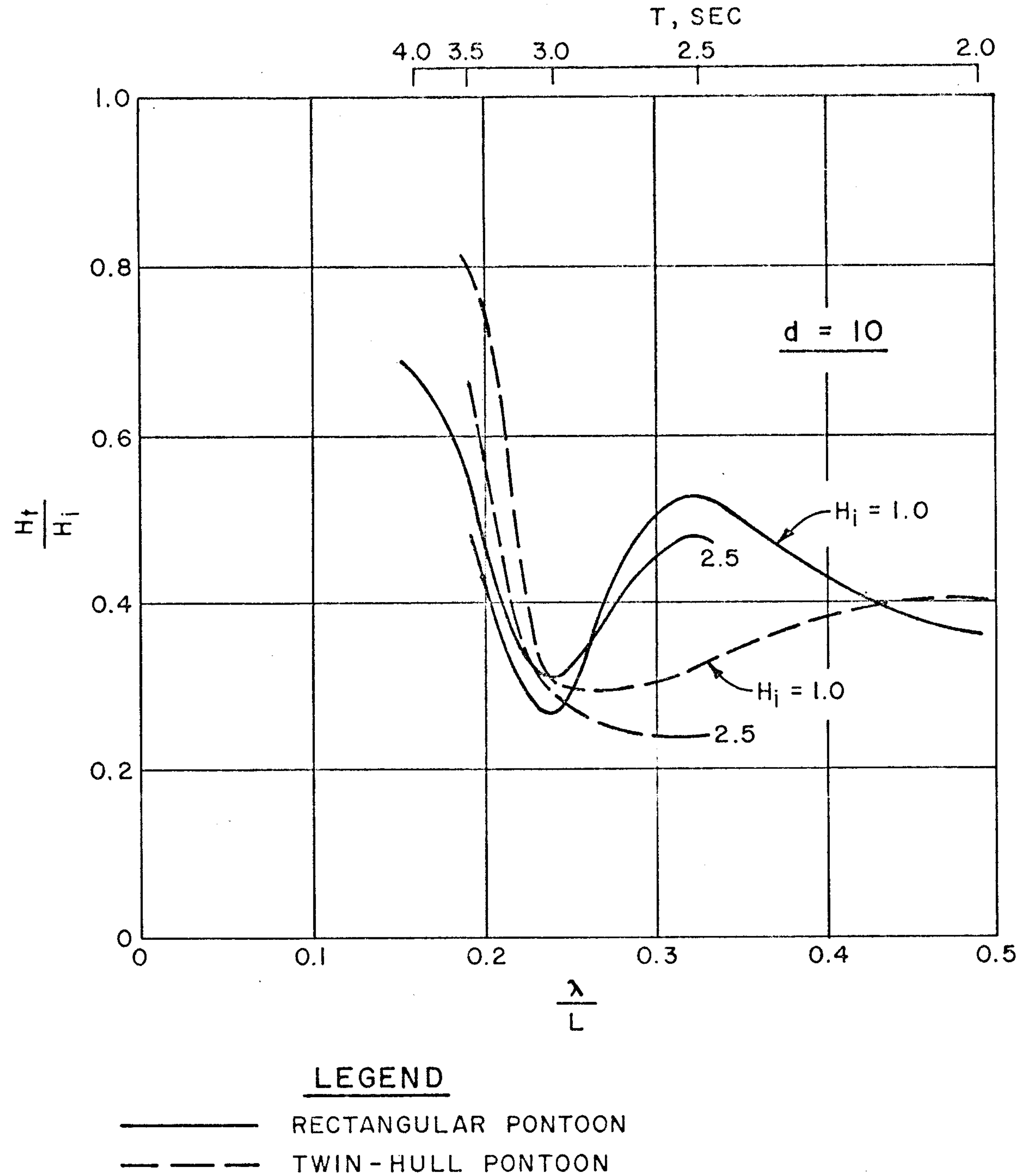

Figure 7. Wave Transmission Comparison, Twin-Hull and Rectangular Breakwaters, d = 10 Feet

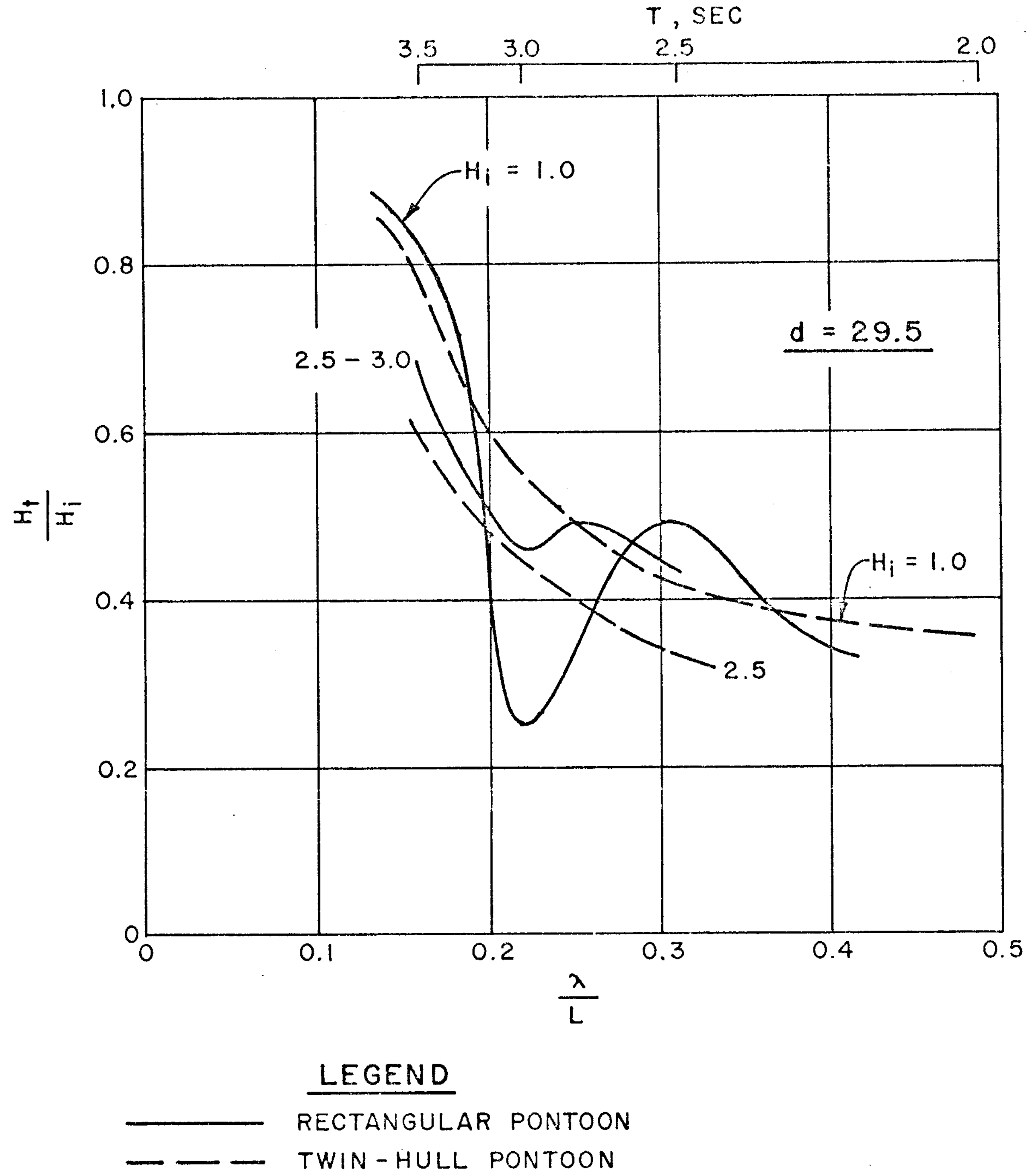

Figure 8. Wave Transmission Comparison, Twin-Hull and Rectangular Breakwaters, d = 29.5 Feet

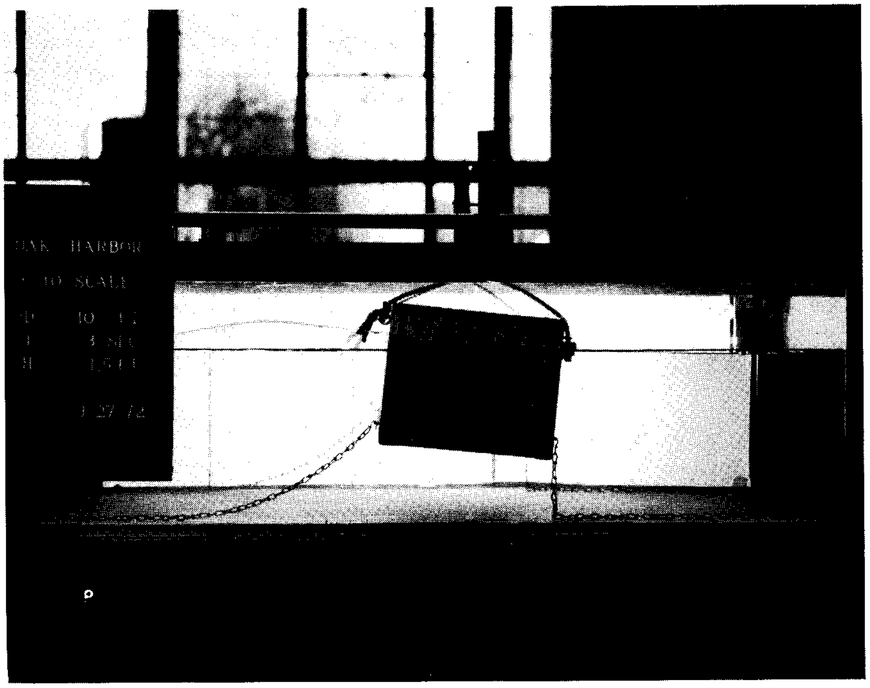

Figure 9. Heave Displacement of Breakwater, Wave Crest at Breakwater; T = 3.0 Sec, d = 10 Feet

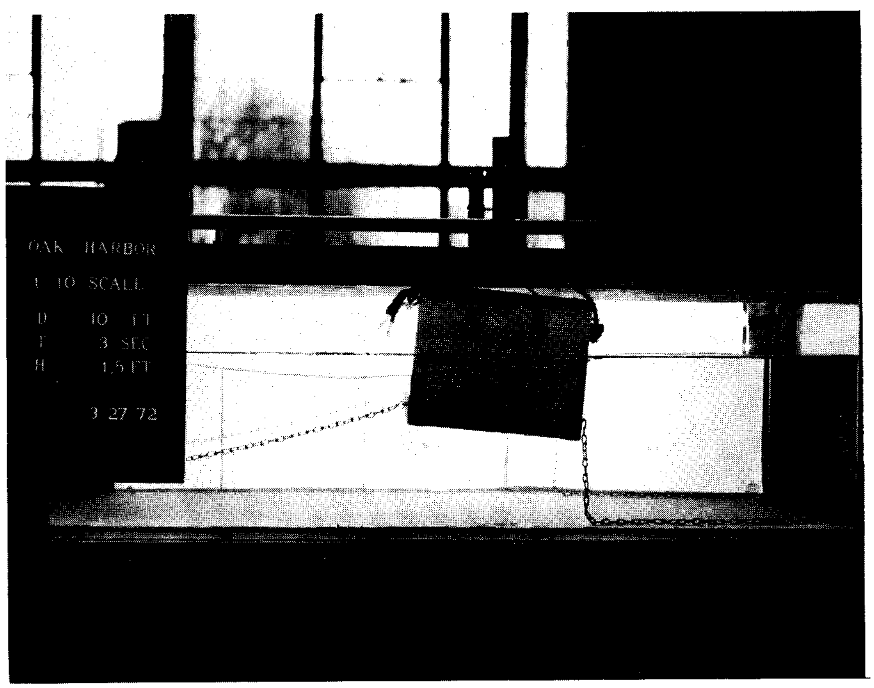

Figure 10. Heave Displacement of Breakwater, Wave Trough at Breakwater; T = 3.0 Sec, d = 10 Feet

Table 1: 10-Foot Water Depth, 1:10 Model

T sec	L ft	H_i ft	H_t ft	H_t/H_i	H_t/H_i (avg)	H_i/L	λ/L
2.00	20.4	0.56	0.19	0.33	0.33	0.028	0.49
"	"	1.12	0.37 0.50	0.33 0.44	0.38	0.055	"
"	"	1.56	0.50 0.63	0.32 0.40	0.36	0.076	"
2.50	30.9	0.50	0.25	0.50	0.50	0.016	0.32
"	"	1.06	0.56	0.53	0.53	0.034	"
"	"	1.69	0.88	0.52	0.52	0.055	"
"	"	2.18	1.00 1.25	0.46 0.57	0.52	0.071	0.32
"	"	2.75*	1.13 1.38	0.41 0.50	0.46	0.089	"
3.00	41.6	0.44	0.12	0.29	0.29	0.011	0.24
"	"	0.94	0.25	0.27	0.27	0.023	"
"	"	1.47	0.44 0.56	0.30 0.38	0.34	0.035	"
"	"	1.97	0.56 0.69	0.29 0.35	0.32	0.047	"
"	"	2.62	0.75 0.88	0.28 0.33	0.31	0.063	"
"	"	3.00*	1.00 1.25	0.33 0.42	0.38	0.072	"
"	"	3.38*	1.25 1.50	0.37 0.45	0.41	0.081	"
3.50	52.4	0.38	0.19	0.50	0.50	0.007	0.19
"	"	0.78	0.31 0.44	0.40 0.56	0.48	0.015	"
"	"	1.22	0.50 0.69	0.41 0.58	0.49	0.023	"
"	"	1.62	0.75 0.88	0.46 0.54	0.50	0.031	"
"	"	2.19	0.88 1.25	0.40 0.57	0.49	0.042	"
"	"	2.62	1.12 1.50	0.43 0.57	0.50	0.050	"
"	"	3.00	1.25 1.62	0.42 0.54	0.48	0.057	"
3.95	61.6	1.50	1.00 1.19	0.67 0.79	0.73	0.024	0.16
"	"	1.88	1.25 1.63	0.67 0.87	0.77	0.030	"
"	"	2.38	1.50 1.69	0.63 0.71	0.67	0.039	"
"	"	2.75	2.00	0.73	0.73	0.045	"

*Some splashing, waves began to overtop breakwater.

Table 2: 29.5-Foot Water Depth, 1:10 Model

T sec	L ft	H_i ft	H_t ft	H_t/H_i	H_t/H_i (avg)	H_i/L	λ/L
2.00	20.5	0.50	0.10	0.20	0.20	0.025	0.49
2.21	25.0	0.91	0.31	0.34	0.34	0.036	0.40
2.34	28.0	1.44	0.62	0.43	0.43	0.052	0.36
2.50	32.0	0.56	0.34	0.61	0.61	0.018	0.31
"	"	1.00	0.50	0.50	0.50	0.031	"
"	"	1.44	0.69	0.48	0.57	0.045	"
			0.94	0.65			
"	"	1.94	0.88	0.45	0.53	0.061	"
			1.18	0.61			
"	"	2.30	0.88	0.38	0.46	0.072	"
			1.25	0.54			
2.78	39.5	3.10*	1.30	0.43	0.50	0.078	0.25
			1.70	0.57			
2.84	41.2	0.56	0.25	0.45	0.45	0.014	0.24
3.00	46.0	0.56	0.19	0.33	0.33	0.012	0.22
"	"	1.00	0.25	0.25	0.25	0.022	"
"	"	1.60	0.53	0.33	0.33	0.035	"
"	"	2.12	0.81	0.38	0.38	0.046	"
"	"	2.25	0.94	0.42	0.42	0.049	"
"	"	3.10*	1.20	0.39	0.46	0.067	"
			1.60	0.52			
3.50	62.5	0.56	0.44	0.78	0.78	0.009	0.16
"	"	0.91	0.75	0.83	0.83	0.015	"
"	"	1.56	1.13	0.72	0.72	0.025	"
"	"	2.06	1.50	0.73	0.73	0.033	"
"	"	2.25	1.50	0.67	0.67	0.036	"
"	"	3.20*	2.14	0.67	0.67	0.051	"

* Some splashing, waves began to overtop breakwater.

Table 3: 48-Foot Water Depth, 1:16 Model

T sec	L ft	H_i ft	H_t ft	H_t/H_i	H_t/H_i (avg)	H_i/L	λ/L
2.52	32.5	0.40	0.14	0.38	0.38	0.012	0.31
"	"	0.80	0.35	0.44	0.44	0.025	"
2.80	40.3	0.40	0.14	0.38	0.38	0.010	0.25
"	"	0.90	0.40	0.44	0.44	0.022	"
"	"	1.34	0.50	0.37	0.37	0.033	"
3.00	46.0	0.40	0.10	0.25	0.25	0.009	0.22
"	"	0.90	0.40	0.44	0.44	0.020	"
"	"	1.44	0.54	0.38	0.38	0.031	"
3.20	52.2	1.50	0.61	0.40	0.40	0.029	0.19
"	"	2.14*	1.06	0.49	0.49	0.041	"
"	"	2.70*	1.60 }	0.59 }	0.63	0.052	"
			1.81	0.67			
"	"	3.20*	1.81 }	0.56 }	0.64	0.061	"
			2.30	0.72			
3.52	63.2	0.40	0.26	0.64	0.64	0.006	0.16
"	"	0.94	0.45	0.47	0.47	0.015	"
"	"	1.50	0.61	0.40	0.40	0.024	"
"	"	2.29	1.50	0.66	0.66	0.036	"
"	"	2.70*	1.90	0.70	0.70	0.043	"
"	"	2.99*	1.90	0.64	0.64	0.047	"
3.56	65.0	4.39*	2.19 }	0.50 }	0.62	0.068	0.15
			3.20	0.73			
4.00	82.0	0.40	0.35	0.88	0.88	0.005	0.12
"	"	0.94	0.85	0.90	0.90	0.011	"
"	"	1.60	1.46	0.91	0.91	0.020	"
"	"	2.24	2.05	0.91	0.91	0.027	"
"	"	2.78	2.40	0.86	0.86	0.034	"
"	"	3.20	2.86	0.90	0.90	0.039	"
"	"	4.80	4.10	0.85	0.85	0.059	"
4.48	102.4	0.94	0.85	0.90	0.90	0.009	0.10
"	"	1.50	1.41	0.94	0.94	0.015	"
"	"	2.14	2.10	0.98	0.98	0.021	"
"	"	2.66	2.61	0.98	0.98	0.026	"
"	"	3.06	2.90	0.95	0.95	0.030	"
"	"	4.61	4.30	0.93	0.93	0.045	"

*Some splashing, waves began to overtop breakwater.