CHAPTER ONE HUNDRED SIXTY EIGHT

SHIP-WAVE ATTENUATION TESTS OF A PROTOTYPE FLOATING BREAKWATER

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ABSTRACT

Limited data are presented for the ship-wave attenuation of a prototype concrete pontoon floating breakwater. Results are compared with wave attenuation performance of a breakwater of identical cross-section and similar anchoring configuration as predicted by model tests using monochromatic waves. Field test procedures and limitations are described.

Introduction

Often the most severe wave climate impressed on floating breakwaters used in sheltered waters may originate not from wind-generated waves but from ship or boat waves. This paper presents limited boat wave attenuation test results for a prototype concrete pontoon breakwater. These specific tests were conducted as part of a U.S. Army Corps of Engineers prototype test program initiated to establish design criteria for floating breakwater applications in semi-protected coastal waters, lakes, and reservoirs.

The prototype testing program was established to obtain field information on, among other things, wave transmission characteristics, anchor loads, and structural forces. In particular, this paper describes the boat wave attenuation performance of a particular type of floating breakwater quite commonly used in semi-protected waters of the North Pacific coast in the United States and Canada.

Data from model tests using monochromatic waves typical to laboratory tests of such floating structures were available for a breakwater of identical cross-section and comparable anchoring scheme. Some data on wind wave performance of the prototype structure discussed in this paper also were available. This paper then takes the opportunity to compare, even if on a limited basis, laboratory, wind wave, and boat wave data for the same breakwater. Reasons why the test results are limited are indicated, and why boat wave performance tests of prototype floating structures may be limited in general is discussed.

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Description of Test Site and Breakwater

The prototype structure was installed at a test site at West Point, near Seattle, in Puget Sound, Washington. The site was in an exposed location, selected so that within the time frame of the tests the structure would be exposed to wave conditions more severe than those existing at sites currently considered as suitable for floating breakwaters. The water depths at the site varied between 40 and 50 feet (12.2 and 15.2 m) at mean lower low water (MLLW), the diurnal tide at the site is 11.3 feet (3.5 m) and the currents are variable.

The prototype breakwater consisted of two rectangular modules, each 75 feet (22.87 m) long and 16 feet (4.96 m) wide, with a draft of 3.5 feet (1.07 m) and a freeboard of 1.5 feet (0.46 m). During the boat-wave tests, the two modules were rigidly fastened together to form a single, 150-foot (45.73 m) long structure. The breakwater was anchored in place by 10 anchor lines attached to H-piles embedded in the sand and gravel bottom. Anchor lines consisted of 1-3/8-inch (35-mm) stud link chain at each end, with a one ton clump weight attached to minimize lateral displacemnt of the breakwater. The anchor lines had a minimum scope of 1 vertical to 4.5 horizontal, and were pre-tensioned to 5,000 $\pm$ 1,000 pounds (22,200 $\pm$ 4,450 N). The breakwater is shown schematically in Figure 1.

Waves were measured by resistance-wire wave staffs mounted on spar buoys equipped with damping plates and having natural periods in heave and roll of 18 and 12 seconds, respectively, both much greater than periods of either windwaves or boatwaves at the test site. For the tests discussed in detail here the wave gages were located as shown in Figure 2; they were attached to the breakwater anchor lines. The gages were connected to a microprocessor-based data acquisition system designed to handle 80 analog input channels from wave gages, and force, pressure, and motion measuring transducers used in the monitoring project. Strip-chart records were also obtained during the boatwave tests. Details of the breakwater design and the instrumentation have been provided respectively by Nelson et al. (5) and Christensen (2).

Boat-Wave Tests

Two tests are discussed here; each involved a different vessel.

The test discussed in more detail used a U.S. Coast Guard utility boat with a modified deep 'V' planing-type aluminum hull and having the following dimensions: length, 40.7 feet (12.4 m); beam, 13.4 feet (4.1 m); maximum draft, 4.9 feet (1.5 m); full load displacement, 15 tons. Nominal speeds for the constant speed, straight line courses run during the test were 12, 16, and 20 knots; at the 16-knot speed the boat is just beginning to plane and generates its largest waves.

Vertical photographs were taken during the boat runs, using a conventional aerial camera. The plane elevation was about 1,000 feet (305 m), so that the nominal scale was 1:2000. Those timed, sequential photographs which included the moving boat and the breakwater provided the necessary measure of boat speed, with the breakwater providing the

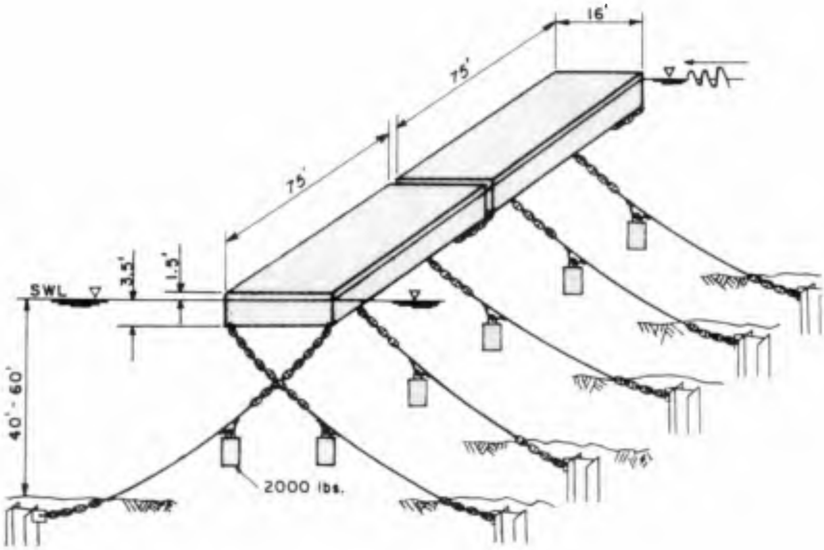

Figure 1. Schematic drawing of breakwater.

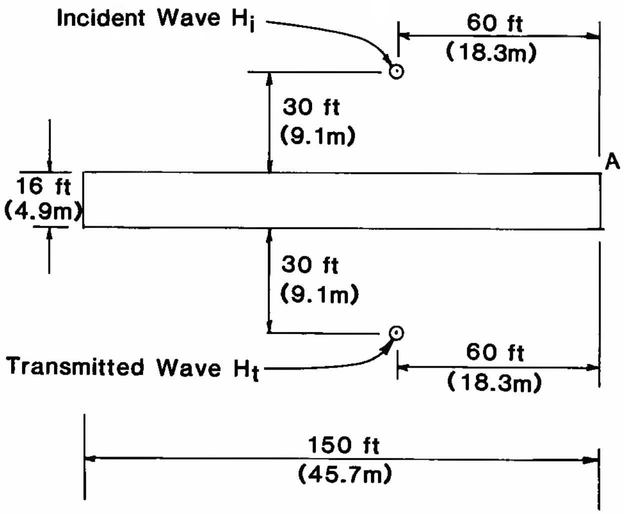

Figure 2. Wave gage locations.

horizontal scale, as well as boat direction and sailing line distance with respect to the breakwater. An example photograph is shown in Figure 3. A pipe-tire breakwater, not discussed in this paper, also appears in Figure 3. Successful photographs were not obtained for all runs. Boat speed was determined from the photographs for only one (the 16-knot) speed, so the same ratio between measured speed and that indicated by on-board instrumentation was assumed in the reduction of data. The actual speeds were thus determined to be 11.1, 14.9, and 18.6 knots. Boat wave patterns were obtained for the two higher speeds; the wave pattern angles for the "12-knot" speed had to be estimated by extrapolation. Where aerial photos were not available (when, for example, the airplane and the boat did not pass the breakwater at the same time) boat directions and distances from the breakwater were estimated on the basis of the test design and visual observations from the boat and breakwater. The breakwater corner 'A' identified in Figure 2 and in definition sketch Figure 4, was used as the reference point in distance measurements and calculations. Incident wave properties were defined at the position of the incident wave gage, as shown in Figure 4.

Wave angles β, and therefore θ (measured with respect to the sailing line direction) of the diverging waves which were the dominant waves in the boat-wave pattern were measured at various distances from the sailing line on the aerial photographs. The solid lines on Figure 5 for the 14.9 and 18.6-knot speeds are each based on over twenty individual measurements of wave crest directions on a photograph; as indicated previously, the curve for the 11.1-knot speed was obtained by extrapolation.

The nearness of the wave staff to the breakwater posed a problem with respect to measurement of H_i, the height of the incident wave. To avoid possible effects of wave reflection from the breakwater, the following procedure was adopted. On the strip-chart records used in the present data analysis, the boat wave envelope was identified, and the vertical distance from the crest of the second wave in the boat-wave envelope to the following trough (using the gage scale factor) was defined as H_i. This is illustrated in Figure 6, traced from an expanded plot produced from the data acquisition system. The sampling rate was 4 Hz; frequencies below 0.1 Hz and above 0.8 Hz were filtered out to eliminate electronic drift and high frequency noise, respectively. Wind waves at the site were generally in the 2 to 4-second period range. The representative trace in Figure 6 was obtained from a separate piling-mounted wave gage located 150 feet (45.7 m) from the end of the breakwater opposite to the end containing point 'A', and on the longitudinal axis of the breakwater, so that there were no reflected waves. The record was obtained during tests using a 110-foot (33.5 m) tug, as described below. Figure 6 indicates that the error in the definition of H_i was small. The height H_t of the transmitted wave was the maximum wave height measured at the gage 'behind' the breakwater. Figure 6 shows the boat-wave envelope, and also indicates that at the time of the test the wind-waves were small enough so that for purposes of the present test the boat-wave heights could be measured directly from the strip-chart records.

Figure 3. Vertical aerial photograph, Coast Guard utility boat.

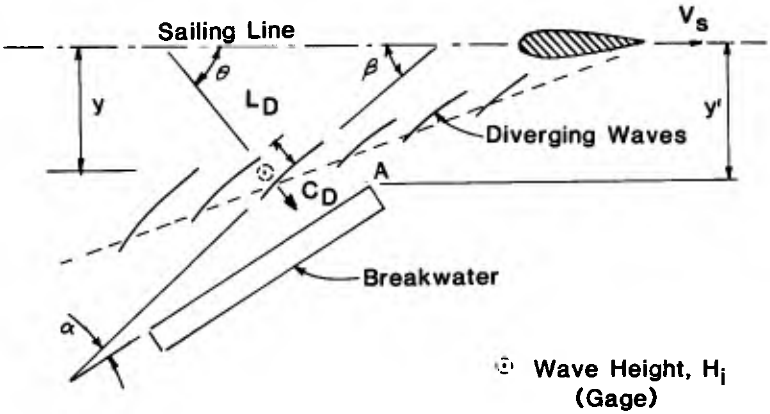

Figure 4. Definition sketch.

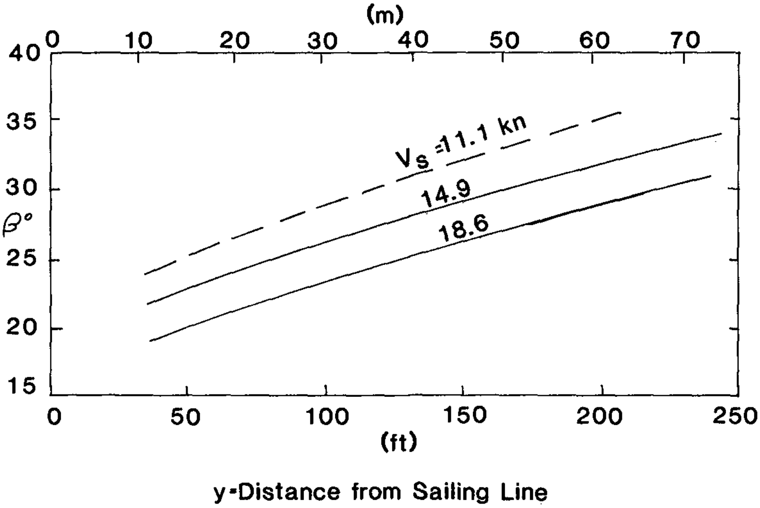

Figure 5. Wave crest direction vs. distance from sailing line, Coast Guard utility boat.

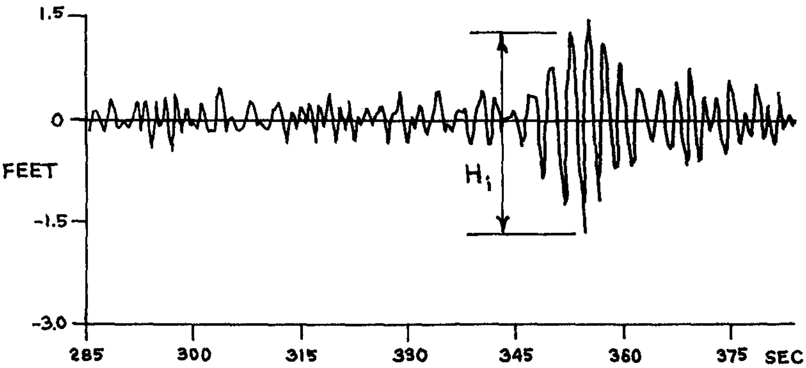

Figure 6. Representative wave trace (marine tug) and selected value of incident wave height H_i.

Figure 7 indicates the measured decay of wave height with normal distance y from the sailing line, for each of the three boat speeds. This decay is comparable to that reported by Sorensen for a Coast Guard cutter of length and speed range close to that of the boat used in the present test (8). Wave half-periods (time from crest to trough of the boat waves, as measured at the staff gage) ranged between 1.2 and 1.4 seconds, also comparable to the values reported by Sorensen.

The second test mentioned here utilized a marine tug having the following dimensions: length, 110 feet (33.5 m); beam 34 feet (10.4 m); draft, 10 feet (3.1 m); displacement, 193 tons (gross). The nominal speed was 11 knots for all runs. Aerial photographs were taken for some runs; however, the photographs were taken at oblique angles from a small airplane by a hand-held camera. Figure 8 is an example of these oblique photos. General features of the boat-waves as they acted upon the breakwater were visible, but vessel speeds and wave angles could not be determined. Consequently, no detailed treatment of the wave height data could be made. More details of this test, and of two other short boat-wave tests of the prototype breakwater in which aerial photography was not employed have been given by Skjelbreia (7).

Model Data

Model tests had been conducted on a floating breakwater proposed for (but not eventually, so constructed) a site near East Bay, Olympia, on Puget Sound Washington. Results, here all expressed in equivalent full-scale values, were reported by Carver (1). Monochromatic waves only were used in the 1:10 scale model tests.

Two configurations were tested, as shown in Figure 9. The cross-section of Plan 2 is identical to that of the prototype breakwater used in the boat wave tests. Anchoring systems are similar but not identical and the East Bay water depths are less than at West Point, so the East bay tests did not fully model the prototype of the present tests. Trends in wave transmssion characteristics, however, would be expected to be similar. Conventional two-dimensional test results are shown in Figure 9 in the form of transmission coefficient C_t vs. L/W, where

$$C_t = H_t/H_i$$
W = breakwater width
L = length of incident wave.

To remain within the range of wave heights measured in the Coast Guard boat tests, H_i values of only 1.5 and 2 feet (0.46 and 0.61 m) from the model test data, were used in plotting Figure 9.

Plan 1 was also tested with waves having crests at an angle of obliquity & with respect to the face of the breakwater. Information concerning these tests is shown in Figure 10. Transmitted wave heights plotted in Figure 10 were maxima measured at the wave gage location shown; measurements from this gage were used because it most closely

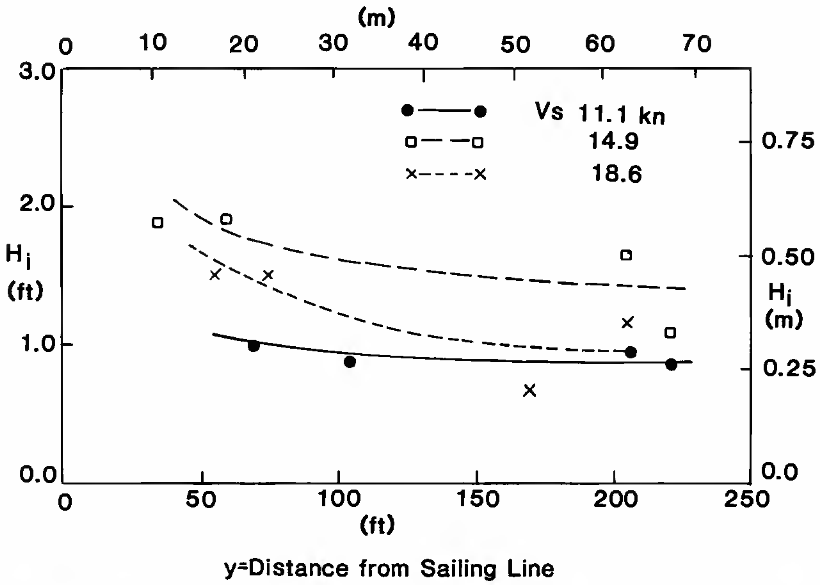

Figure 7. Decay of boat wave height with distance.

Figure 8. Oblique aerial photograph, marine tug.

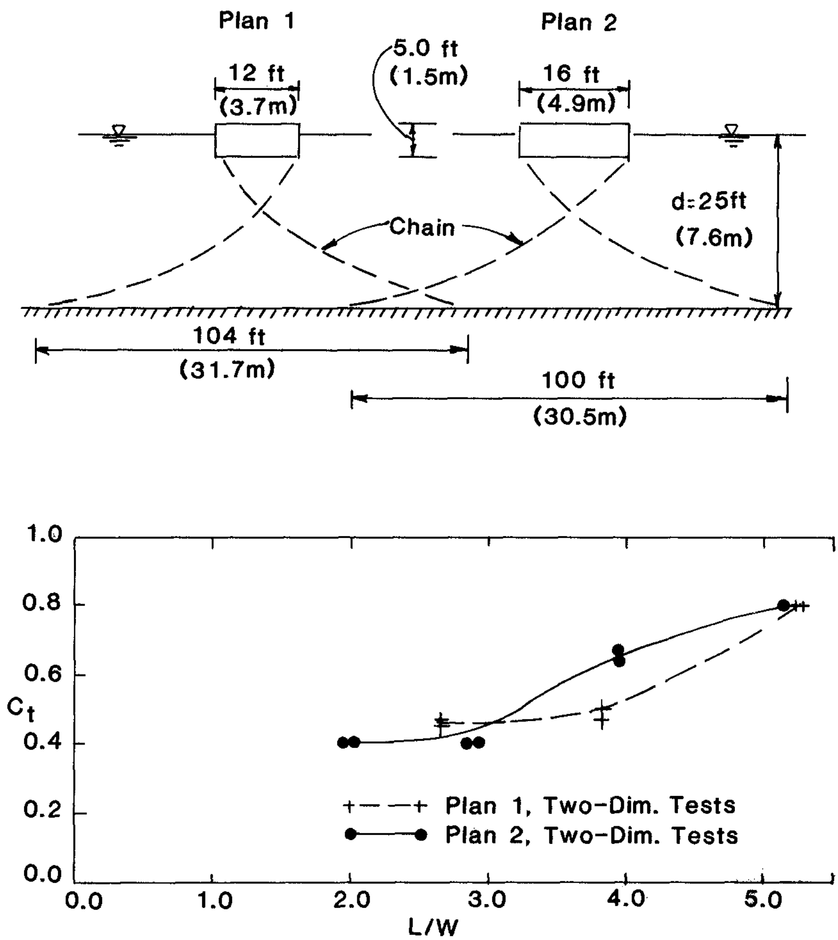

Figure 9. East Bay models, test data.

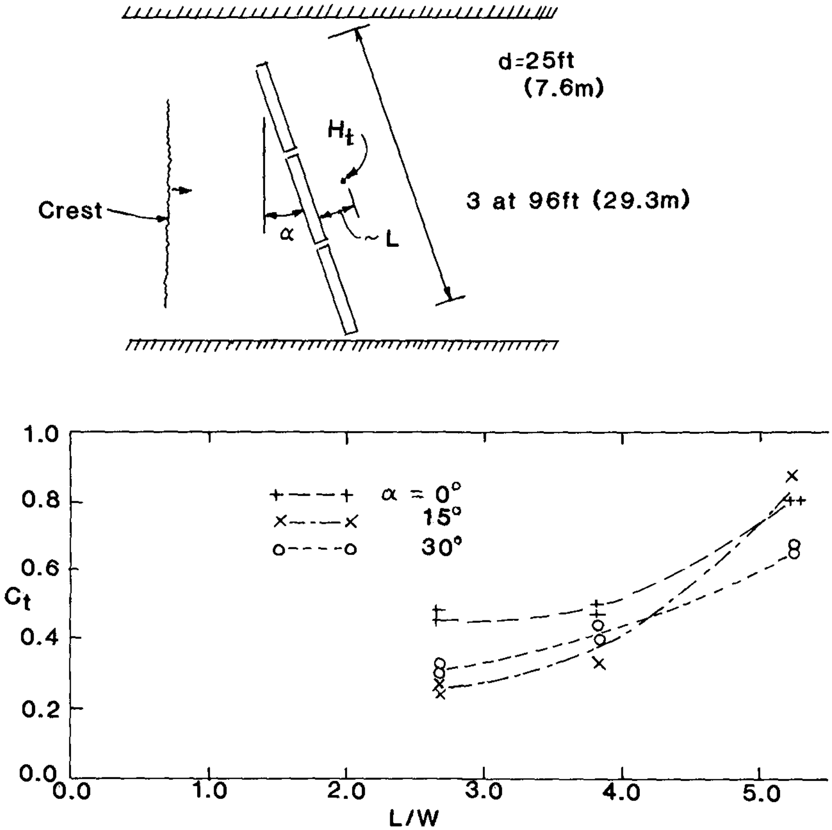

Figure 10. East Bay model data, Plan 1.

simulated the location of the transmitted wave staff in the boat wave tests.

Results of Prototype Tests

In order that the boat wave data be compared with laboratory data such as shown in Figure 10, it is necessary that & and L be determined for the divergent waves of the boat wake which were the incident waves at the breakwater. Since it has long been established, e.g. (4) that boat wave patterns depend upon vessel speed and hull form (3), the aerial phototgraphs were nesessary. Wave periods and water depths at the test site allowed deep-water equations for linear wave theory to be employed in the analysis.

Since the Kelvin-type wave pattern as a whole moves with the vessel, the wave crest (phase velocity) of the divergent wave is

$$C_D = V_s \cos \theta$$

in the direction normal to the wave crest as shown in Figure 4. Using the deep-water relations, the other wave properties are obtained:

$$T_D = \frac{2\pi C_D}{g} = \frac{2\pi V_s \cos\theta}{g}$$

$$L_D = \frac{g T_D^{\ 2}}{2\pi} = \frac{2\pi V_s^{\ 2} \cos^2\theta}{g}$$

The period T_D is not that recorded by a stationary wave gage as the diverging waves pass it. Wave lengths so calculated for the boat wave tests did agree well with wave lengths measured directly from the aerial photographs. The quality of the photographs was such, however, that wave crest angles could be measured more accurately than lengths; hence, the procedure followed.

Results of twelve passes of the boat past the breakwater are recorded in Table I. As noted, boat directions and distances from the breakwater could be obtained from only four photographs; other values are best estimates. To conserve space, only the foot units originally used are tabulated. Calculated incidence angles α are listed, and compared with values estimated by an observer on the breakwater and with those few which could be measured from the photographs. Disparities in results indicate the need for a complete set of good quality photographs if a good, full set of data is to be obtained.

Wave transmission results are plotted as a function of wave length in Figure 11, and in conventional dimensionless form in Figure 12. The L and T in both figures apply to the diverging waves as they reached the incident wave gage. For the shorter boat waves, the transmission coefficient agrees with the results from the monochromatic wave model tests. For longer wave lengths L_D, however, C_t values for the boat

Table I

Run No.	Vessel Speed knots	Angle[a] degrees	Dist. y' feet	Dist. y feet	β degrees	Calc. α degrees	Estimated α (Field Notes)[b] degrees
12-1	11.1	0	250	220	36	36	-
12-2	11.1	30	200	205	35	-5	-
12-3	11.1	0	100	70	27	27	20
12-4	11.1	50	75	105	29	20	15
16-1	14.9	0	250	220	33	33	15
16-2	14.9	45	200	205	32	13	5-10
16-3	14.9	1[c]	65[c]	35	22	22	20+(30)[c]
16-4	14.9	51[c]	54[c]	85	25	26	15-20(18)[c]
20-1	18.6	0	200	170	27	27	5
20-2	18.6	45	200	205	29	16	20
20-3	18.6	0[c]	85[c]	55	20	20	20(24)[c]
20-4	18.6	55[c]	44[c]	75	21	24	25-30(35)[c]

Run No.	Calculated Values, Diverging Waves θ degrees	T_D sec	L_D feet	Measured Wave Heights H_i feet	H_t feet	C_t	$\frac{L_D}{W}$
12-1	54	2.19	24.5	0.87	0.33	0.38	1.53
12-2	55	2.11	22.8	0.95	0.42	0.44	1.43
12-3	63	1.73	15.4	1.00	0.33	0.33	0.96
12-4	61	1.79	16.5	0.87	0.2	0.23	1.03
16-1	57	2.68	36.7	1.09	0.6	0.55	2.29
16-2	58	2.60	34.5	1.67	0.7	0.42	2.16
16-3	68	1.83	17.2	1.92	0.9	0.47	1.08
16-4	65	2.07	22.0	1.92	0.8	0.42	1.37
20-1	63	2.78	39.4	0.67	0.4	0.60	2.46
20-2	61	2.98	45.3	1.17	0.8	0.68	2.83
20-3	70	2.19	24.6	1.50	0.7	0.47	1.53
20-4	69	2.19	24.6	1.50	0.7	0.47	1.53

[a]: Angle between sailing line and breakwater longitudinal axis
[b]: Visual estimates by observer on the breakwater
[c]: Measured from aerial photographs

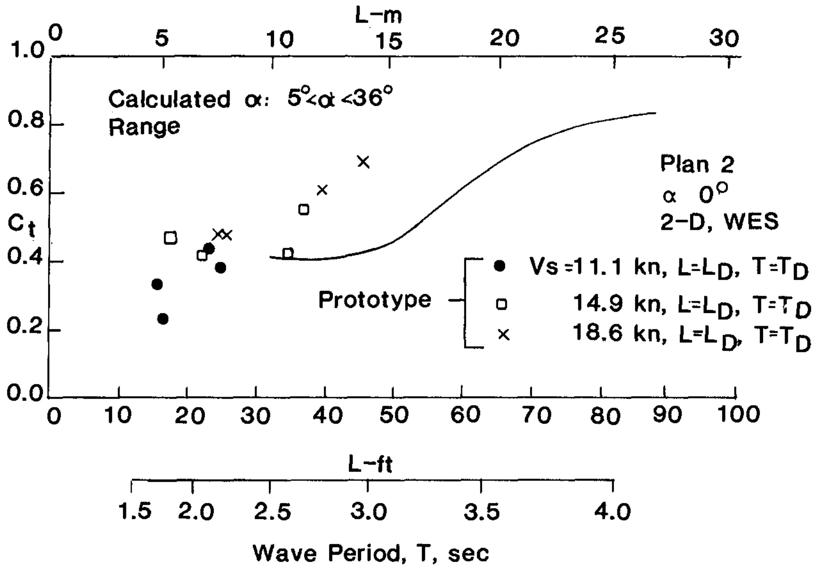

Figure 11. Boat wave data, Coast Guard utility boat.

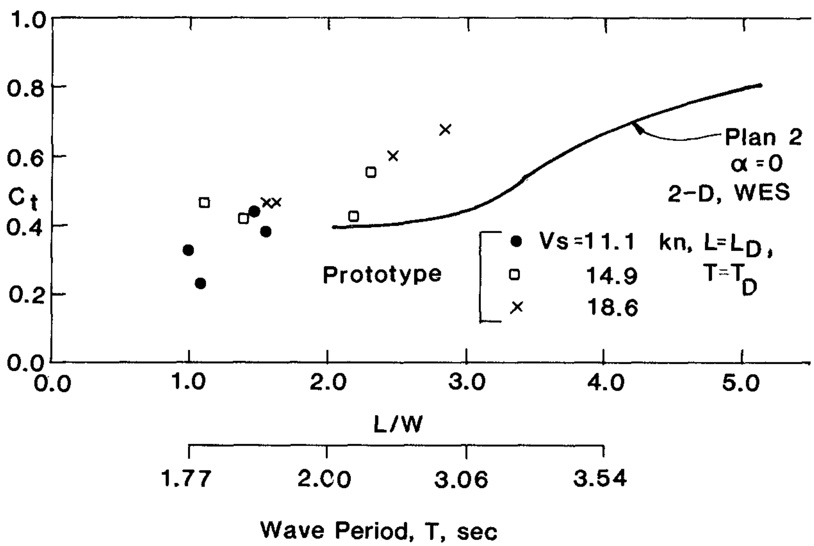

Figure 12. Boat wave data, Coast Guard utility boat.

waves appear to be larger than those for the model tests. There is no discernible relationship of C_t to the obliquity angle α, within the α range indicated. The data are too limited for conclusive statements. One possible reason for the differences in C_t at the longer wave lenghts could be the differences in the anchor line tensions.

Figure 13 shows some results reported by Nelson and Broderick (6) for wind waves at the prototype structure. The wave crests were essentially parallel to the breakwater axis for waves generated by southerly winds. The incident wave gage used was the pile-mounted gage referred to earlier, so that wave reflections from the breakwater posed no problem. The period shown is that at the spectral energy peak, obtained from spectral analysis of 2,048-point, approximately 8-1/2 minute records. The significant wave height was taken as four times the variance (standard deviation squared) of the wave rcord, an approximate result for calculations based on the Rayleigh distribution function (9).

No correlation of boat wave data from the test using the marine tug are given in this paper. Incident waves were of the order of magnitude 2-3 feet (0.6-0.9 m) as typified by the trace in Figure 6, and transmitted wave heights were approximately 0.5 foot (0.15 m). It was difficult to separate the transmitted boat-waves from the surface chop on the "transmitted" side of the breakwater on the day of the tests, just as it was difficult to identify th transmitted boat waves by visual observation. There was water on the deck of the breakwater when it was impacted by the waves generated by the tug. This breaking of waves on the breakwater provided an additional wave attenuation mechanism which may not have been relatively so significant in the laboratory studies; hence, wave attenuation by the prototype was greater than would be predicted by the laboratory model tests. Again, differences in anchor line restraint could be a major cause for the differences in performance of the laboratory model under monochromatic waves and the prototype breakwater subjected to boat waves.

Conclusions

The limited data did not allow identification or separation of effects of the many variables involved in correlating wave transmission performances of a floating breakwter for continuous, monochromatic waves typical of model studies and for the finite envelope of waves experienced in boat wakes.

It appears that for shorter wave lengths (say $L/W = 2$ or less) boat wave transmission of a breakwater can be predicted reasonably well from monochromatic wave model tests. At many sites where floating breakwaters may be feasible, this range of L/W might cover the anticipated range of boat waves that might be generated by smaller vessels such as pleasure craft.

For $L/W > 2$, results reported here are not conclusive. For the Coast Guard boat waves, transmitted waves were greater than predicted using the model test results, while the opposite was true for the tug-generated waves. This difference is perhaps due mostly to nonsimilitude in the anchoring systems. The pre-tensioned anchor lines

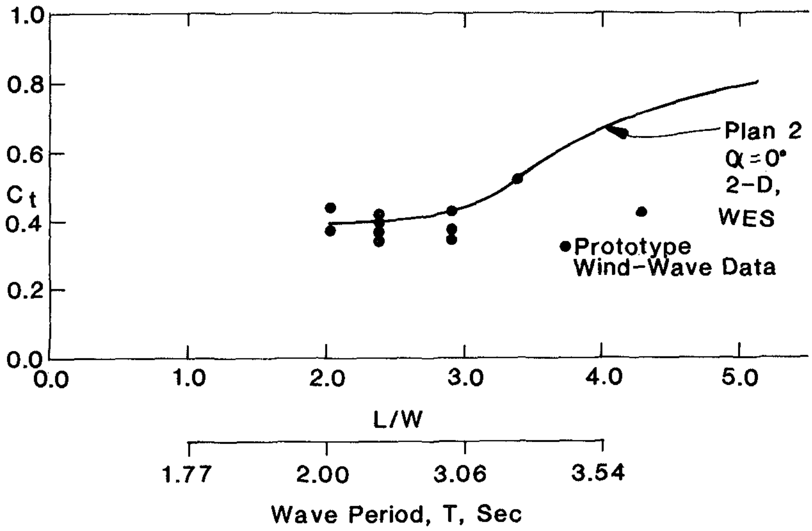

Figure 13. Wind wave data.

in the prototype may have kept the breakwater, while responding to the boat wave envelope, from achieving the motions obtained under continuous waves in the laboratory. For waves of moderate height the model data were not conservative, while they were for higher steeper waves which broke over the prototype.

In almost all cases for both model and prototype wave crests were inclined at angles of 30 degrees or less from the breakwater longitudinal axis. No significant effect of wave incidence angle on wave transmission was detected in the field test data.

Aerial photography is an important, and almost necessary, component of a comprehensive field test of the behavior of a floating structure to ship-generated waves. Tests involving aerial phototgraphy require careful planning and coordination, and must be responsive to such constraints as visibility conditions, sea state, and perhaps, elevations at which the aircraft used are allowed to fly if other air traffic is a conerned. These requirements indicate why availability of such data may, in general, be limited.

Acknowledgements

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