CHAPTER 169

Transmission of Random Waves Through Pile Breakwaters

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Abstract

Several previous investigators have conducted experiments leading to expressions for predicting the transformation of waves passing through closely-spaced pile breakwaters. The present study extends those earlier experiments using monochromatic waves to the case of a spectrum of random waves.

Records of incident waves and of waves after transmission through a model pile breakwater were compared to determine a coefficient of transmission. Results are presented for several cases of pile spacing and pile diameter. Good agreement is found between observed transmission coefficients and those predicted using the expression proposed by Hayashi et al. (1966).

Introduction

During the late 1960's and early 1970's considerable interest was generated in the transmission and reflection of waves from both permeable and impermeable structures such as breakwaters. Several investigators (e.g., Costello 1951; Hayashi et al. 1966; Wiegel 1964; Van Weele and Herbich 1972; Massel 1976; Khader 1978, 1981) conducted experiments which led to expressions or procedures for predicting the transformation of waves passing over or through such structures. Unfortunately, no field data of wave transmission through pile breakwaters are available to allow for quantitative evaluation of their effects on incident waves.

One of the basic problems recognized by the earlier researchers and the designers who have used their results was the character of the laboratory waves used in the experiments. The waves were monochromatic and typically small amplitude, while the prototype wave climate consisted of irregular waves forming a relatively broad spectrum. The work summarized in this paper addressed this problem by repeating the basic study of the transmission of waves through an array of closely-spaced model piles, but using spectra of random waves.

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The objectives of the investigation were twofold. First, an evaluation was made of the transmission results calculated using different characteristic parameters of the wave spectra. For example, if the transmission coefficient is defined as the ratio of the height of the transmitted wave to that of the incident wave, the question arises as to what height parameter properly characterizes the transmitted and incident spectra. Results are presented using the root-mean-square height of all waves, the arithmetic mean or average of all waves, and the significant wave height. The second objective was to compare transmission coefficients measured for the random wave case with those predicted by expressions based on earlier work with monochromatic waves (Hayashi et al. 1966).

Experimental Procedure

The Hydromechanics Laboratories at Texas A&M University have fitted their existing 120-ft long by 2-ft wide and 2-ft deep (36.6 m by 0.6 m by 0.6 m), glass-walled, wave tank with random sea-generating equipment. This configuration permits the generation of irregular waves through several "library" spectra, or through user-programmed inputs.

The three basic groups of variables in the experiment are the geometry of the pile arrays, the water depths, and the input wave spectra. No attempt was made to rigorously model the experiment based on any prototype conditions. However, a linear scale on the order of approximately 1/50 was convenient and represents typical commercially available piling used in prototype breakwaters and piers.

Two sizes of standard galvanized steel conduit pipe were used to construct the model pile arrays. Steel conduit was selected to assure rigidity in the model and uniformity from pile to pile. The sizes selected were 15/16-in. O.D. (approximately 24mm) and 1-3/16-in. O.D. (approximately 30mm). At a scale of 1/50, these models would represent piles on the order of 48 to 60 in. (122 to 152 cm.) in diameter. The spacings between the piling in the arrays were chosen to be 5, 10, and 20 percent of the pile diameters. Again, while not rigorous, it was felt that these spacings were generally representative of the practical limits which could be achieved in a prototype structure. Consistent and uniform spacings closer than 3 to 4 in. could probably not be economically realized for piles 4 to 6 ft in diameter and typically over one hundred feet in length. A definition sketch is shown in Figure 1.

The model piles were fitted into drilled templates, one at the bottom of the wave tank and one at the top, well above the water surface. Spacings represent the average of measured values and incorporate some variability, as would a prototype structure. In each test run, the array was placed in the tank, plumbed vertically, adjusted to the desired angle relative to the incident wave orthogonal (in this paper, perpendicular), and rigidly clamped in place. Only single-row arrays and circular piles were investigated.

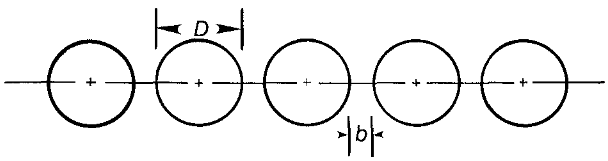
Tests were run with water depths in the tank of 16, 20, and 24 in. (41, 51, and 61 cm). Wire probes were used to measure the water level fluctuations resulting from the test waves. Each of the two probes was mounted on a movable carriage with one measuring incident wave heights and the other measuring transmitted waves on the opposite side of the model pile array. Tests were run both with the probe carriages moving and with them stationary. The probes recorded directly on standard oscillographs.

The random sea generator was capable of producing both library spectra and user input spectra. The four pre-programmed library spectra were used for these tests. No detailed discussion of the various spectra will be presented here, since results were calculated from actual wave records prior to incidence and after transmission from the arrays, rather than from the theoretical machine input. It was desired to use relatively short sequences or bursts of waves in the tests to minimize the influence of reflection in the tank. Records of a length of 25 to 30 waves were chosen for analysis. The results were examined statistically to assure that they were indeed random and of a satisfactorily significant length. Techniques are available to measure the combination of incident and reflected waves for longer records. However, the simpler approach described provided acceptable results and did not require an energy-based analysis.

It would seem that Reynolds number effects might be important and cause scale effects when comparing model results to prototype applications since a portion of the decrease in transmission in the model may be attributed to viscous damping. However, for prototype pile sizes and spacings, and for free-surface gravity waves the inertial force would likely predominate over the drag force.

Analysis Procedure

Using the described procedures, a total of 30 records were generated, each consisting of an incident wave spectrum and a transmitted wave spectrum. The waves in each record were then



D - PILE DIAMETER

b - PILE SPACING

RATIO (b/D) CHOSEN TO BE 0.05, 0.10, and 0.20

Figure 1. Definition sketch for pile geometry

characterized by actually measuring all recorded heights and calculating the following three parameters.

Root-mean-square wave height:

$$H_{rms} = \sqrt{\frac{1}{N} \sum_{j=1}^{N} H_j^2} \tag{1}$$

Mean, or average wave height:

$$\bar{H} = \frac{1}{N} \sum_{j=1}^{N} H_j \tag{2}$$

Significant wave height:

H_s = average height of the one-third highest waves. (3)

With these parameters calculated, both the incident and transmitted waves in each test could be represented by H_{rms}, $\bar{H}$, or H_s. Thompson and Vincent (1984) point out the need to distinguish between the significant wave height, H_s, as defined in equation 3 and the spectral based significant wave height, H_{m_o}, defined from the variance of the wave record. Certainly wave attenuation by a piled breakwater is an energy-based process and the spectral based H_{m_o} may be more appropriate for actual design. However, for the present laboratory case, the water depth and level bottom slope allow treating H_s and H_{m_o} as interchangable.

One concern was to assure that the relatively short sequence lengths in the wave records were indeed long enough to be significant and reasonably random. It has been shown (e.g. Shore Protection Manual 1984) that for a true Rayleigh distribution the following theoretical relationships exist:

$$\bar{H} = 0.886 \, H_{rms} \quad \text{and} \tag{4}$$

$$H_s = 1.416 \, H_{rms} \, . \tag{5}$$

Therefore, once H_{rms} had been determined for each incident record, theoretical values of $\bar{H}$, and H_s were calculated from the above relationships. These theoretical values were compared to the $\bar{H}$ and H_s determined from the records and the agreement was taken as an indicator of the significance of the wave sequence length. Figure 2 presents this comparison for H_{rms} and H_s.

In each case the theoretical and actual parameters were within a few percent of each other. While it is certainly desirable to use as long a sequence as possible, the excellent agreement obtained is an indicator that the record lengths used were acceptable and of value in characterizing any trends present.

Evaluation of Characteristic Parameters

The degree to which wave heights are influenced during transmission through a structure can be described by the ratio of the height of the transmitted wave to the height of the incident wave, or:

$$\text{Coefficient of transmission} = \frac{H_T}{H_I} \tag{6}$$

When considering a spectrum of irregular waves the question arises as to how to characterize the incident and transmitted wave. If all waves in the incident spectrum are affected equally in the transmission process, then the coefficient of transmission can be based on any characteristic parameter, e.g. H_{rms} , $\bar{H}$, or H_s , as long as the same one is used for the transmitted spectrum (and no breaking occurs). However, if a structure "filters" one portion of the incident spectrum to a greater degree than other portions, the coefficient of transmission may vary depending on which parameter is used in the calculation. If we confine the present discussion to wave height parameters, then

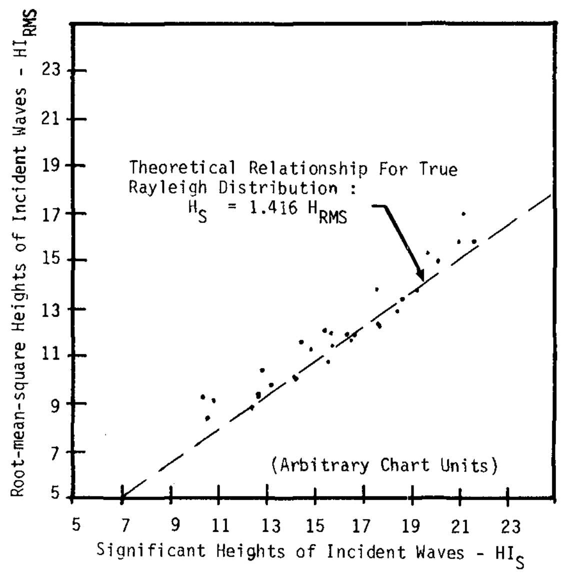


Figure 2. Comparison of observed relationships with theoretical predictors.

the relative variation of the coefficients of transmission calculated using H_{rms} , $\bar{H}$, and H_s may be an indicator of any preferential transmission effects present.

Certainly, other characteristics of the spectra involved may be equally influential and also serve as indicators. Period and wave steepness are proposed most frequently along with analysis of any changes in the relationship between energy density and frequency. All of these procedures require a representation of the wave period. While this may be done for records of actual ocean waves by use of a significant period or similar statistical or numerical methods approximation, such techniques can be difficult for laboratory wave records with all periods in the range of 1 to 2 sec.

For each of the thirty data sets a coefficient of transmission was calculated using the incident and transmitted wave heights given by H_{rms} , $\bar{H}$, and H_s . For a true Rayleigh distribution, linear relationships exist among the mean, root-mean-square, and significant parameters of a function. Therefore, if the Rayleigh distribution is assumed for the incident non-breaking wave spectra, and if the transmitted spectra are not preferentially altered, then the coefficients of transmission for a particular test should be the same whether calculated from root-mean-square, mean, or significant heights. Figure 3 is a comparison of the transmission coefficients calculated using each of the three height parameters. The agreement suggests that the transmission coefficients calculated in this experiment were

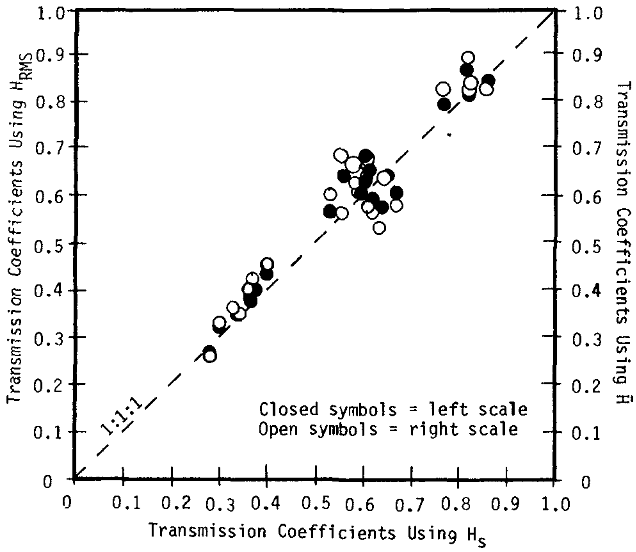


Figure 3. Comparison of transmission coefficients calculated using three different height parameters.

reasonably independent of the parameter used to characterize the wave height spectra. The values based on significant heights were selected for further comparison with predictive models since H_s is widely recognized and easily computed.

Comparison With Predictive Expressions

Wiegel (1961) proposed the following relationship to predict the coefficient of transmission for a single-row pile array:

$$\frac{H_T}{H_I} = \frac{b}{D + b} \tag{7}$$

In this expression b is the spacing and D is the pile diameter as shown on Figure 1. This is a variation on the porosity parameter used in earlier studies of permeable wave absorbers. Wiegel later measured transmitted wave heights typically 25 percent greater than predicted.

Hayashi et al. (1966) proposed the following relationship arising from consideration of the velocity of the water jets discharging through the pile spaces:

$$\frac{H_T}{H_I} = 4\left(\frac{d}{H_I}\right) E \left[- E + \sqrt{E^2 + \frac{H_I}{2d}}\right] \tag{8}$$

$$\text{with } E = C\left(\frac{b}{D + b}\right) \Big/ \sqrt{1 - \left(\frac{b}{D + b}\right)^2} \tag{9}$$

The use of b , D , and H are as above, and d is the water depth (still water). The parameter C is a representation of the effects of jet contraction and velocity in Bernoulli's theorem and is recommended as equal to 0.9 to 1.0. It is analogous to a coefficient of discharge, defined as the product of a velocity coefficient, C_v, and a contraction coefficient, C_c. The recommended values of 0.9 to 1.0 suggest that the spacing and well-rounded character of the openings between round piles are such that little decrease in discharge occurs from friction or flow contraction effects. Pile arrays that use other shapes or geometries suggestive of a sharp-edged outlet would require a lower value of C.

For each of the thirty data sets, coefficients of transmission were calculated using the above expression with $C = 0.9$ and again with $C = 1.0$.

The predicted coefficients were then compared to those actually calculated from the observed wave height data. Figures 4 and 5 summarize that comparison. The equation with $C = 1$ tends to predict a somewhat higher transmission coefficient than observed, especially at the closer pile spacings. The use of $C = 0.9$ provided a better general prediction of these tests.

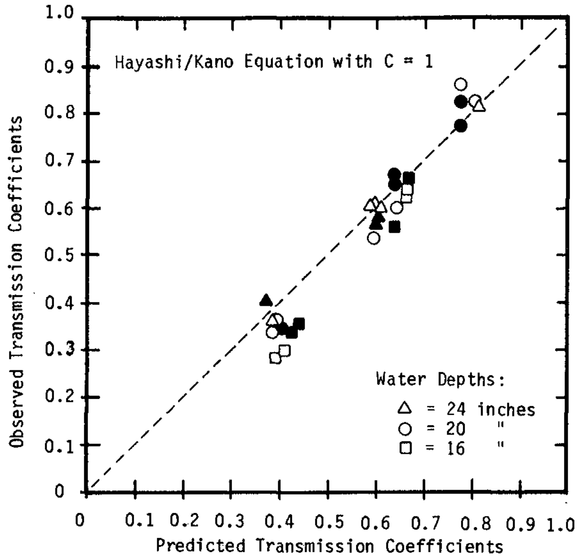


Figure 4. Comparison of observed transmission coefficients with those predicted using equation proposed by Hayashi et al. (1966) (C = 1)

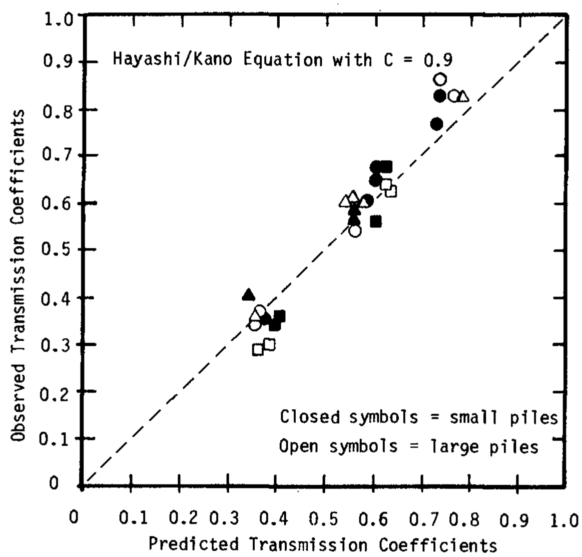


Figure 5. Comparison of observed transmission coefficients with those predicted using equation proposed by Hayashi et al. (1966) (C = 0.9)

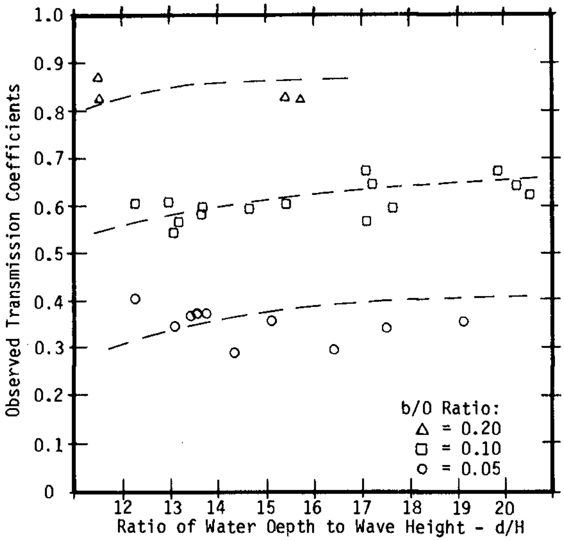


Figure 6. Observed transmission coefficients versus water depth to wave height ratio

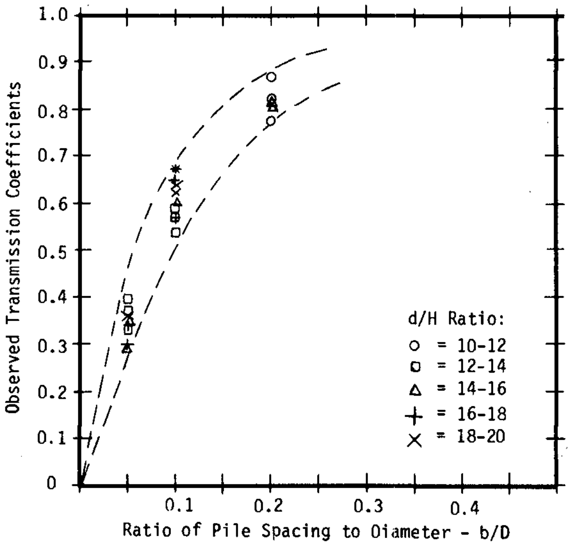


Figure 7. Observed transmission coefficients versus pile spacing to diameter ratio

The additional influences of water depth and of relative spacing were considered. Figures 6 and 7 show the observed transmission coefficients plotted against the ratios of water depth to wave height (d/H_s), and pile spacing to pile diameter (b/D), respectively. Figure 6 clearly shows the influence of the b/D ratio over a range of water depth/wave height values. The influence of d/H_s is not readily apparent in Figure 7. Note that the ratios of water depths to wave heights, d/H_s , in these tests were typically 3 to 5 times larger than those reported by Hayashi et al. (1966). At the lower d/H_s ratios, Hayashi et al. (1966), depicted a strong sorting of the data based on this influence. It appears that as the wave height becomes a smaller precentage of the water depth (larger d/H_s), and/or for random wave spectra consisting of many wave heights, the transmission coefficient is influenced more by the breakwater geometry, b/D , than by the water depth.

Conclusions

As long as the same parameter was used for both incident and transmitted spectra, little difference was noted in transmission coefficients calculated from H_{rms} , $\bar{H}$, or H_s for these laboratory experiments.

The results of these tests indicate that some of the analysis techniques developed earlier for predicting the transmission of monochromatic waves through pile breakwaters can be extended to random waves. Very good agreement was obtained using the equation presented by Hayashi et al., 1966.

The ratio of water depth to wave height (d/H_s) influences the transmission coefficient in the general sense, but the influence of the breakwater geometry, i.e. ratio spacing to diameter (b/D) is more pronounced. Further work should investigate the influences of wave steepness and/or period on transmissions. An energy analysis may be necessary for such an investigation.

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