CHAPTER 165

WAVE TRANSMISSION THROUGH A DOUBLE-ROW PILE BREAKWATER

by

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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 or large cylinder breakwaters. The present study extends the earlier experiments which used a single row of piles instead of a double row of piles forming a breakwater. The experiments using the double-pile breakwater were performed in the same facility as the experiments conducted on a single-pile breakwater and employed the same method of analysis for a more meaningful comparison.

The experiments consisted of allowing waves to pass through a pile array and measuring the incident and transmitted wave heights. The variables were: depth, period, diameter, monochromatic and random waves. The experimental matrix was three water depths, four wave periods, two pile diameters, two gap dimensions between piles and four random wave spectra: Darbyshire, I.T.T.C., Pierson-Moskowitz and JONSWAP, two pile diameters and two gap dimensions between piles.

The two-row breakwater had less wave transmission than the single-row breakwater, as expected. For a gap to a pile diameter ratio, or b/D = 0.2 (where b = gap spacing, D = pile diameter), the wave transmission was reduced by 15 percent, as compared with a single-row breakwater; for a gap ratio of b/D = 0.1, the wave transmission was reduced by 5 to 10 percent.

Introduction

In recent decades there has been a greater use of vertical face breakwaters, and consequently a considerable development in technology of caisson-type breakwaters.

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The first large cylinder-type breakwater was in all probability constructed in Hanstholm, Denmark in 1960. The cylindrical reinforced-concrete breakwater consisting of 12.5 m (41 ft) diameter units with a 0.25 m (0.8 ft) wall thickness was installed in 12 m (39 ft) of water. The breakwater at Marsa el Brega, Libya contains cylindrical shells in caissons that are 53.8 m (177 ft) long and 16 m (52 ft) wide.

A steel pipe breakwater was constructed in the Port of Osaka, Japan in 1966. The breakwater consists of 2 m (6.6 ft) diameter pipes. The spacings between adjacent steel pipes were 5 cm (0.16 ft) on the average.

A concrete pipe breakwater was constructed to protect a marina at Pass Christian, Mississippi to replace a breakwater destroyed by a hurricane. The breakwater consists of about 1.4 m (4.6 ft) diameter piles with approximately 15.2 cm (0.5 ft) spacings.

Laboratory Studies

Several laboratory investigations have been conducted to evaluate the transmission and reflection of waves from permeable-pile breakwaters. Published data include studies by Wiegel (1969), Hayashi, et al. (1966), Allsop and Kalmus (1985) and Truitt and Herbich (1987).

Hayashi, et al. derived an expression for wave transmission based on water jets discharging through the pile gaps:

$$\frac{H_t}{H_i} = 4 \left(\frac{d}{H_i}\right) E \left[-E + \sqrt{E^2 + \frac{H_i}{2d}}\right] \qquad \ldots\ldots (1)$$

where H_t = height of transmitted wave,
H_i = height of incident wave,
d = water depth.

$$E = c \left(\frac{b}{D+b}\right) / \sqrt{1 - \left(\frac{b}{D+b}\right)^2} \qquad \ldots\ldots (2)$$

where c = constant,
b = spacing between piles,
D = pile diameter.

Wiegel derived an expression for wave transmission based solely on geometry of the piles:

$$\frac{H_t}{H_i} = \frac{b}{D+b} \qquad \ldots\ldots (3)$$

Model studies performed later showed that transmitted wave heights were larger (up to 25%) than the rate predicted by Equation 3.

Truitt and Herbich conducted experimental studies on wave transmission through a breakwater consisting of a single row of piles employing both monochromatic and random waves. Earlier experiments of other investigators had been conducted with monochromatic waves. The results of experiments with random waves indicate that the relationships developed for monochromatic waves may be applicable to random waves. Very good agreement was observed between the values of wave transmission predicted by Hayashi's equation and experimentally-obtained values with random waves, provided the coefficient employed was equal to 0.9. It was also found that two dimensionless ratios affect the transmission coefficient:

a) b/D, a ratio of breakwater spacing to pile diameter, and
b) d/H_s, a ratio of water depth to wave height.

The influence of the second ratio on the transmission coefficient is more pronounced.

Experimental Studies

The breakwater consisted of two staggered rows of piles installed in a two-dimensional wave facility, 36.6 m (120 ft) long, 0.6 m (2 ft) wide and 0.91 m (3 ft) deep (Figures 1 and 2). The wave channel is glass-walled and is equipped with a programmable SEASIM wave generator. Either monochromatic or irregular wave spectra can be generated. Wave data were obtained using resistance-type, auto-compensating wave gauges in three water depths: 61 cm (24 in.), 51 cm (20 in.), and 41 cm (16 in.). Four wave spectra were also generated: Darbyshire, I.T.T.C., Pierson-Moskowitz, and JONSWAP.

The experiments consisted of passing waves through the pile breakwater and measuring both incident and transmitted wave heights. The models were built using steel conduit to assure rigid and uniform piles. Two sizes of conduit were used: 3.0 cm diameter (1-3/16 in.) and 2.4 cm diameter (15/16 in.). Four models were employed as shown in Table I.

TABLE I. Dimensions of Pile Breakwaters

Pile Diameter (D) (cm)	(in)	b/D	Distance Between Rows (cm)	(in)
2.4	15/16	0.1	2 (D) = 4.8	1-14/16
3.0	1-3/16	0.2	2 (D) = 6.0	2-3/8
2.4	15/16	0.1	2 (D) = 4.8	1-14/16
3.0	1-3/16	0.2	2 (D) = 6.0	2-3/8

Procedure and Analysis

Wave height measurements were made with auto-compensating wave gauges. One gauge was placed upstream of the pile array and another downstream of the breakwater. For tests with lower wave reflections, the carriage-mounted upstream gauge was moved through at least one wave length to delineate the envelope of incident and reflected waves. The incident wave height was computed from the recorded wave envelope. When high reflections occurred, the

Figure 1. Wave transmission through a pile breakwater in a glass-walled wave channel.

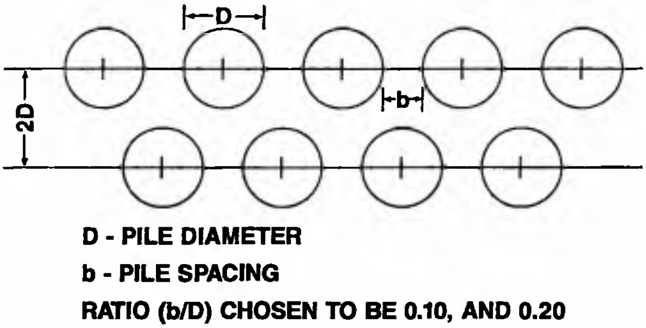

Figure 2. Definition sketch for pile geometry.

significant wave height was computed from a stationary gauge using a record of 21 waves. All of the irregular wave spectra tests were measured with a stationary gauge. Significant wave heights were computed for direct comparison with results previously obtained for a single-row breakwater.

Results

Sample plots of dimensionless wave transmission (H_t/H_i) as a function of water depth to incident wave height ratio are shown in Figures 3 and 4. The increase of wave transmission with an increase in wave period and d/H ratio (up to 25) can be seen in these figures. As anticipated, the smaller the gap ratio, the lower the wave transmission. Reducing the gap space from 20 to 10 percent resulted in transmission for a gap ratio of b/D = 0.1 being reduced to 60-80 percent of the transmission for a gap ratio of b/D = 0.2. The wave transmission was reduced even more so at lower wave periods.

Plots of dimensionless wave transmission, (H_t/H_i), as a function of d/H were also prepared for random waves (Figures 5-8). Even though scatter occurred, data for the four wave spectra tended to plot together. The curves for the two sizes of pile were similar for the same gap ratios. The reduction in gap spacing from 20 to 10 percent reduced the values of wave transmission by approximately 30 percent.

A comparison was also made between wave transmission data for one row of piles (Truitt and Herbich) and two rows of piles. Both studies were conducted in the same facilities, using the same random waves and the same pile sizes and gap ratios. Figure 9 shows a comparison for a b/D ratio of 0.2 and Figure 10 for a b/D ratio of 0.1. For these plots all data points for the same gap ratio have been plotted together regardless of pile diameter. The data for one row of piles covered a very narrow range of d/H values and the resulting curve represents linear regression of the data. For a gap ratio of b/D = 0.2, wave transmission was reduced by about 15 percent, while for a gap ratio of b/D = 0.1 it was reduced by 5 to 10 percent.

The monochromatic wave data were also analyzed using the dimensionless parameter d/gT^2 where d is the water depth, g is the gravitational acceleration and T is the wave period. Figure 11 which is a plot of wave transmission as a function of d/gT^2 indicates that the wave transmission decreases as d/gT^2 increases. Values of wave steepness H_i/L are also shown next to the individual data points. The general trend is for the wave transmission to decrease as the wave steepness increases.

These data were also compared with a similar breakwater model consisting of one row of piles (Kilpatrick, 1984). This study was performed with slightly different pile diameters: 0.63 cm (4/16 in.) and 1.9 cm (12/16 in.) but with the same gap ratios (0.1 and 0.2). It has already been shown that pile diameter has a minimal effect on transmission and that the b/D (gap ratio) is the more important variable. Several plots of wave transmission as a function of d/gT^2 for the monochromatic waves present a comparison between the single- and double-pile breakwaters (Figures 12-15).

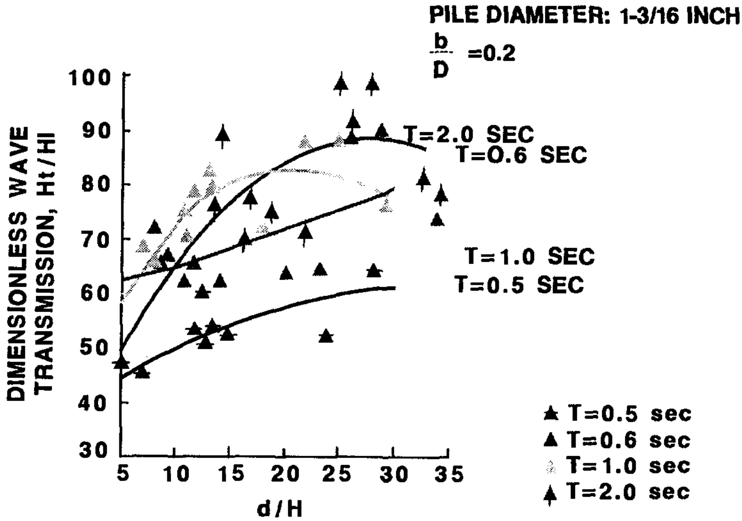

Figure 3. Dimensionless wave transmission as a function of depth to wave height ratio for four wave periods. D = 3.0 cm (1-3/16 in.), b/D = 0.2, two rows. Monochromatic waves.

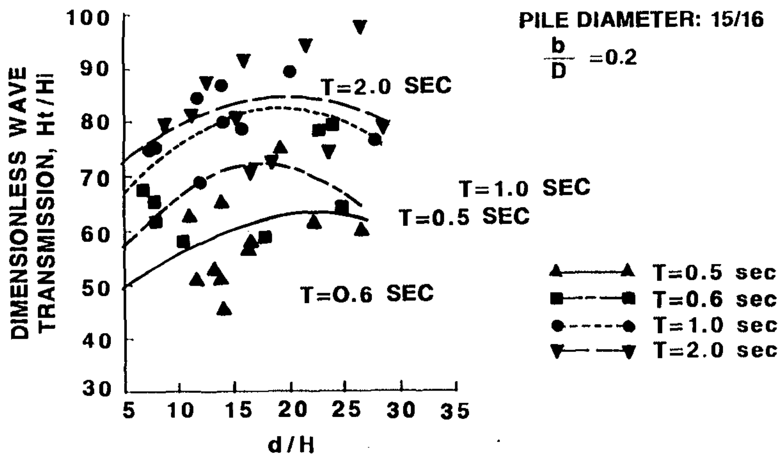

Figure 4. Wave transmission as a function of depth to wave height ratio for four wave periods. D = 2.4 cm (15/16 in.), b/D = 0.2, two rows. Monochromatic waves.

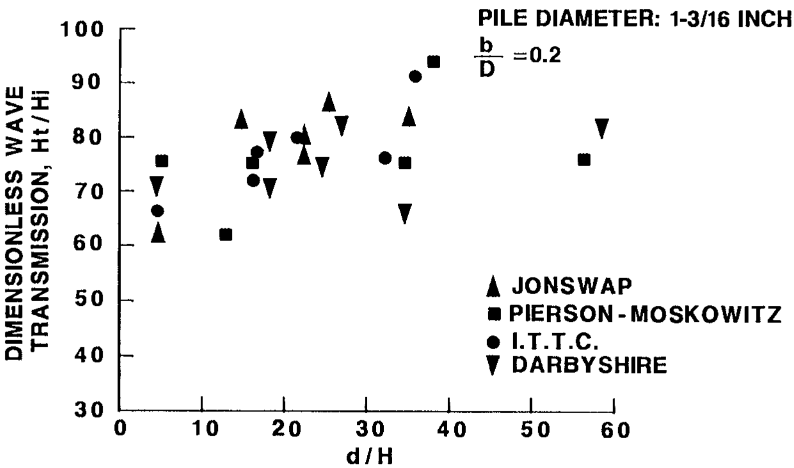

Figure 5. Wave transmission as a function of water depth to wave height ratio for random waves. D = 3.0 cm (1-3/16 in.), b/D = 0.2.

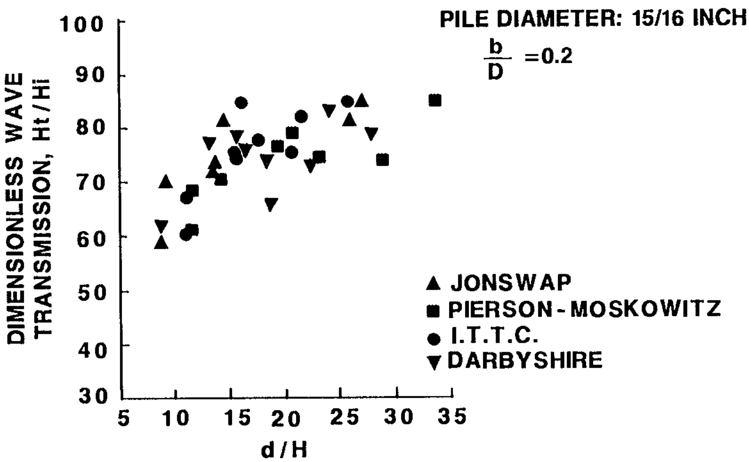

Figure 6. Wave transmission as a function of water depth to wave height ratio for random waves. D = 2.4 cm (15/16 in.), b/D = 0.2.

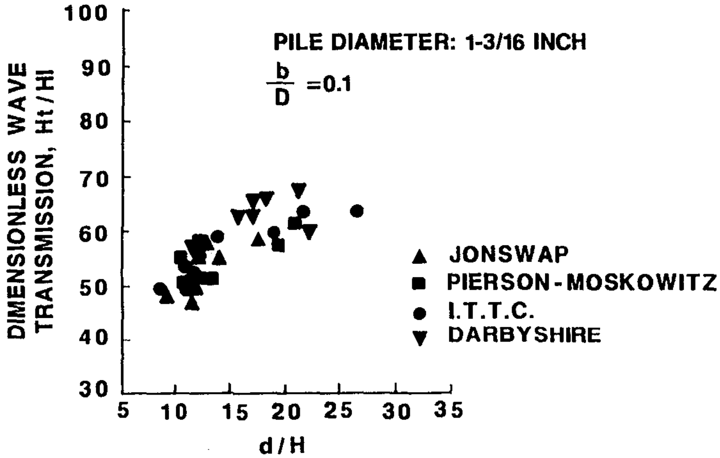

Figure 7. Wave transmission as a function of water depth to wave height ratio for random waves. D = 3.0 cm (1-3/16 in.), b/D = 0.1.

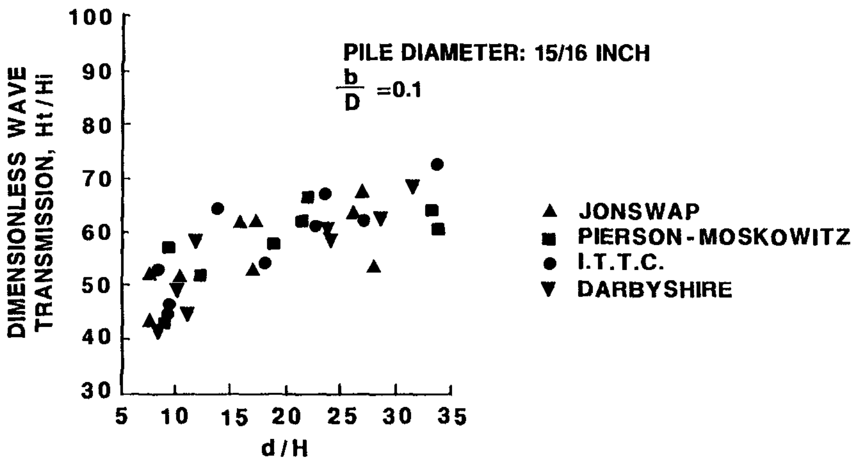

Figure 8. Wave transmission as a function of water depth to wave height ratio for random waves. D = 2.4 cm (15/16 in.), b/D = 0.1.

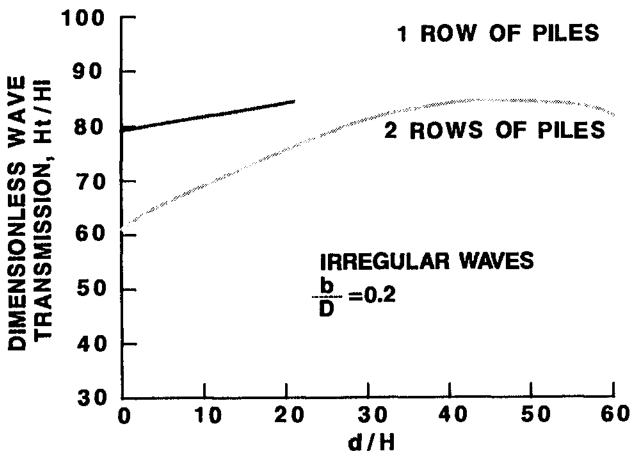

Figure 9. Wave transmission for one and two rows of piles. Random waves, b/D = 0.2.

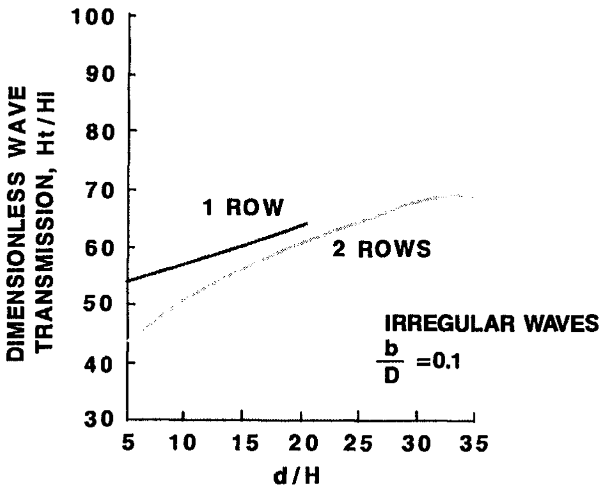

Figure 10. Wave transmission for one and two rows of piles. Random waves, b/D = 0.1.

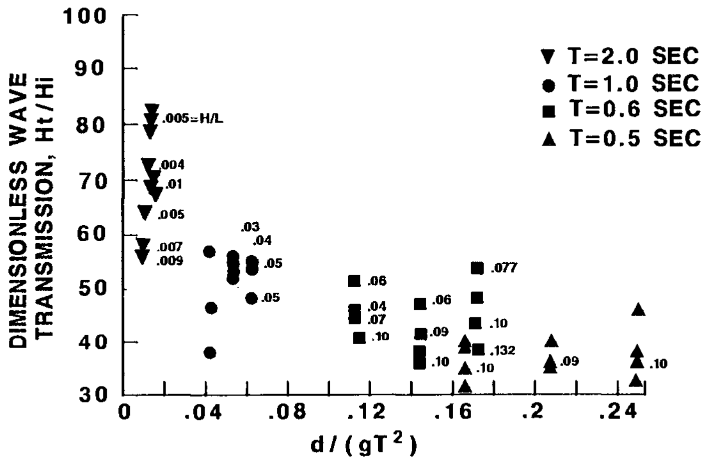

Figure 11. Wave transmission as a function of relative depth ratio for four wave periods. Monochromatic waves. D = 3.0 cm (1-3/16 in.), b/D = 0.1.

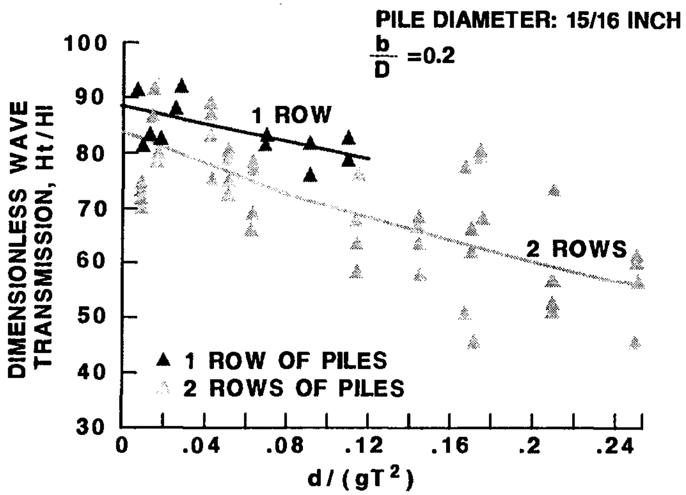

Figure 12. Wave transmission as a function of relative depth ratio for one and two rows of piles. Monochromatic waves. D = 2.4 cm (15/16 in.), b/D = 0.2.

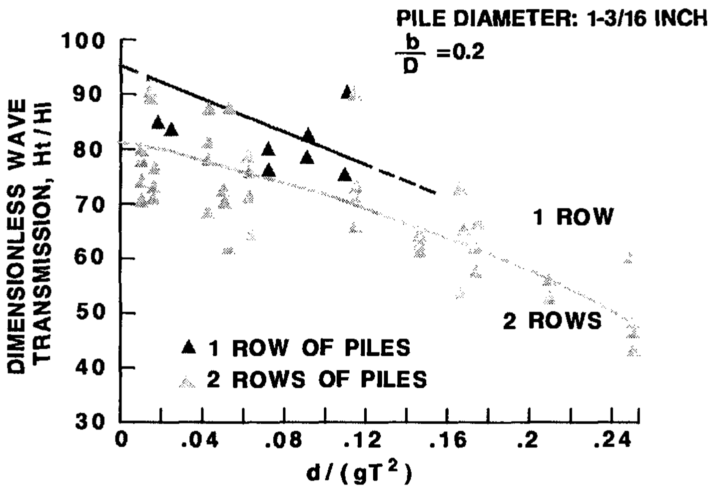

Figure 13. Wave transmission as a function of relative depth ratio for one and two rows of piles. Monochromatic waves. D = 3.0 cm (1-3/16 in.), b/D = 0.2.

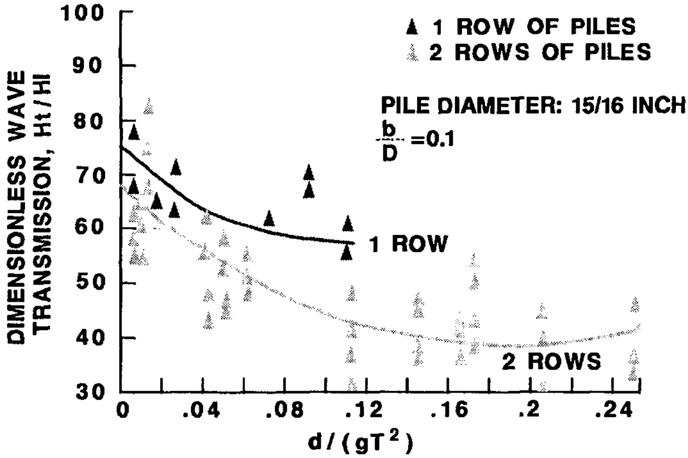

Figure 14. Wave transmission as a function of relative depth ratio for one and two rows of piles. Monochromatic waves. D = 2.4 cm (15/16 in.), b/D = 0.1.

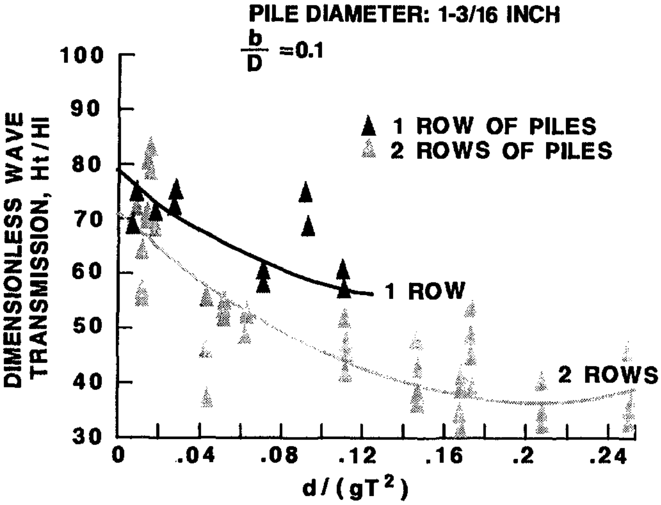

Figure 15. Wave transmission as a function of relative depth ratio for one and two rows of piles. Monochromatic waves. D = 3.0 cm (1-3/16 in.), b/D = 0.1.

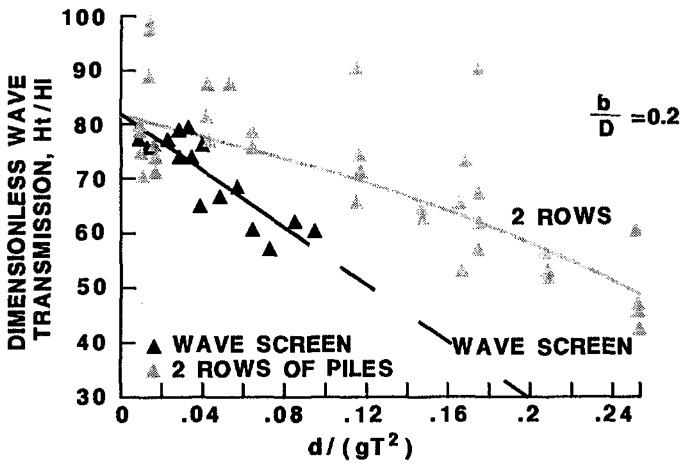

Figure 16. Wave transmission as a function of relative depth ratio. A comparison between two rows of piles and a wave screen.

The results were also compared with wave transmission data presented by Allsop and Kalmus (1985) for wooden wave screens. An arrangement of wooden wave screens was proposed to provide the wave protection for a new marina at Plymouth, United Kingdom. The wave screen breakwater consisted of vertical, rectangular slats with a gap ratio of 0.2. Experiments were performed with irregular wave spectra. The results were published for wave transmission as a function of wave frequency. These results could not be directly compared with the random wave pile experiments because the wave period was not measured for the random wave tests. However, the wave screen results were compared with the monochromatic wave pile experiments. Caution should be used when comparing these two sets of data. The wave screen experiments were conducted using irregular waves, a 8.6 meter water depth, 12 meter long slats and 3 to 12 second wave periods. The wave screen allowed less transmission than the pile breakwater. The results of both experiments agree better at smaller values of d/gT^2 and diverge as the value of d/gT^2 increases (Figure 16).

Conclusions

1. Wave transmission increases as d/H (water depth/wave height ratio) increases
2. Wave transmission for monochromatic waves increases as the wave period increases.
3. Wave transmission decreases as H/L (wave steepness) increases.
4. Wave transmission for monochromatic waves decreases as d/gT^2 (water depth/gravitational acceleration (wave period)^2) values increase.
5. For a 10 percent gap ratio, the addition of a second row of piles reduced the wave transmission by 5 to 10 percent.

References

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