Transactions on the Built Environment vol 8, © 1995 WIT Press, www.witpress.com, ISSN 1743-3509

Improving the efficiency of rectangular caisson floating breakwaters

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Abstract

This paper examines concrete caisson floating breakwaters designed by Bourgon Lafleur Inc., St. Polycarpe, Québec. The performance of a traditional rectangular caisson floating breakwater with a horizontal top has been improved by using a design with a sloping top and two rows of energy-dissipating porous sheets installed underneath the caisson.

1 Introduction

In recent years, there has been a resurgence of interest in floating breakwaters, because of their advantages over rubblemound breakwaters with respect to their relatively low impact on the environment. For example, floating breakwaters are much less likely to interrupt natural circulation currents; thus, they do not hinder or interfere with the dispersion of pollutants that might be in the nearshore zone. Floating breakwaters are often favoured for the protection of small craft harbours and marinas in lakes and rivers where fetches are limited and wave heights are small.

The major problem with floating breakwaters has always been their efficiency. At short wave periods, they can be reasonably efficient, transmitting less than approximately 35% of the incident wave height into the marina. However, at longer wave periods, a breakwater that is not carefully designed will transmit most of the wave energy. Over the years, there have been many different designs proposed for floating breakwaters, and numerous model studies to measure their efficiencies. Two excellent state-of-the-art reviews are by Hales [1] and Western Canada Hydraulic Laboratories Ltd. [4].

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This paper describes hydraulic model studies conducted on a number of different configurations of Bourgon Lafleur breakwaters. The basic design was the same for all configurations; that is, the flotation units were concrete caissons that were internally partitioned to allow sinking of the units below the water surface to avoid ice loading during the winter months. A description of the construction and operation of the Bourgon Lafleur floating breakwaters is in Jamieson & Mogridge [2].

Breakwater modules with two widths (or beams) of 3 m and 6 m (full-scale units) were tested in a laboratory wave flume. All modules were 12 m long. Each breakwater that was tested consisted of three modules, connected by flexible joints that were hinged to allow movement about the horizontal axis, but not the vertical axis. Figure 1 provides a brief description, a coded notation, and an icon of a cross-sectional view, of each breakwater configuration tested and discussed in this paper.

The 3 m wide breakwaters were constructed with a sloping top of 11.5°. However, for the V configuration the waves were incident on a vertical front face, and in effect the caisson had a rectangular cross-section. When the waves were incident on the sloping top, the configuration was S. A further configuration with two rows of porous sheets attached to the underside of each caisson was tested and the results are given in Jamieson & Mogridge [2].

The basic 6 m wide breakwater caisson is rectangular (configuration R). The investigation to improve the performance of the basic rectangular caisson breakwater involved ballasting to a trim angle of 4.5° and 13.5°. Also, the breakwater was tested floating level and at a trim of 4.5°, with vertical porous sheets installed underneath each caisson at the front and rear (configurations REM and 4SEM respectively). The performance of all these breakwater configurations are given in Jamieson & Mogridge [2]. The only 6 m wide breakwater test results described in this paper are for the configurations R and REM to show the effect of energy-dissipating porous sheets on breakwater performance.

2 The floating breakwater models and test set-up

The hydraulic model tests of the breakwaters were conducted at a scale of 1:3 in a wave flume which was 14.2 m wide, 62.8 m long and 1.5 m deep. All breakwater configurations were tested in a water depth of 3.66 m (full scale). The 36 m long (full scale) breakwaters were not constructed to fit tightly between the walls of the wave flume, and so wave energy that propagated past the ends of the breakwaters was confined to channels by wave-guides so as to prevent interference with waves transmitted underneath the breakwaters. Four upwave and four downwave mooring lines were used to moor the breakwaters. The upwave mooring lines extended a distance of approximately 18 m (full scale) to an anchor bolt in the flume floor. Clump weights were attached to the upwave mooring lines. A mini-beam load cell was used to measure the mooring force in one of the upwave mooring lines.

A single wave probe near the wave machine and two arrays of eight wave probes either side of the breakwater models were used to measure the wave heights upwave and downwave of the breakwater models.

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3 Data acquisition and test procedures

The data acquisition system for the breakwater study consisted of a VAX workstation, Neff Instrumentation Corporation data acquisition and control hardware, and the GEDAP data acquisition, wave generation and data analysis software package. Data acquisition commenced 10 s after the wave generator was started. The analog signals were sampled at a rate of 20 Hz (model scale). Data acquisition continued for a record length of 80 s (model scale) for each model test.

For a water depth of 3.66 m (full scale), the breakwater models were tested in regular waves with periods of 1.5 s, 2.0 s, 2.5 s, 3.0 s, 3.5 s and 4.0 s (full scale), and a minimum of three wave heights for each wave period. The 3 m wide breakwater models were not tested for wave periods of 3.5 s and 4.0 s.

4 Data analysis

Waves generated by the wave machine are referred to as incident waves with heights designated by H_i. When the waves impinge on the model, part of the incident wave height is reflected from the breakwater back towards the wave machine (reflected wave height, H_r); part of the wave height is transmitted past the breakwater (transmitted wave height, H_t); and part of the wave height is absorbed by the breakwater.

The transmission coefficient is used to describe the performance of a floating breakwater. It is defined as $C_T = H_t/H_i$ expressed as a percentage. The incident wave height is estimated by averaging the height of the waves measured by the wave probe located 5 m in front of the wave machine, before any waves reflect back from the model. The transmitted wave height is estimated by averaging the wave heights measured by the wave probes in the array downwave of the model, before any waves reflect back from the wave absorber at the end of the wave flume.

The performance of the breakwater was also reported (in Jamieson & Mogridge [2]) in terms of the reflection coefficient defined as $C_R = H_r/H_i$ expressed as a percentage. The reflected wave height is always superimposed on the incident wave height. The least-squares method which was used for separating the incident and the reflected components is described by Mansard & Funke [3].

5 Effect of breakwater size on performance

In Figure 2, transmission coefficients are compared for the 3 m wide breakwater configuration V, and the 6 m wide breakwater configuration R. These two configurations simulate basic rectangular caisson breakwaters. The results are not a direct comparison of breakwater width, because the draft of the V configuration is 0.61 m and the draft of the R configuration is 0.81 m. As expected, the wider breakwater is the most efficient for each of the wave periods tested. The coefficients of transmission are lowest ($C_T \approx 12\%$) for the 6 m breakwater at a wave period of T = 1.5 s. The highest values of C_T are for the 3 m breakwater at T = 3.0 s, where $C_T \approx 95\%$. The trend in the data can be more easily observed by plotting C_T against breakwater width relative to wave length, B/L, for a constant value of H_i/L as in Figure 3. The decreasing trend of C_T with increasing B/L is obvious, with some scatter of data caused by the different drafts and masses of the two configurations, and experimental errors.

6 Effect of a sloping top on breakwater performance

Test data for the 3 m wide breakwater configurations V and S are plotted in Figure 4. The V configuration simulates a standard rectangular caisson. The S configuration has a sloping top of 11.5° towards the incident waves. At wave periods of T = 1.5 s and 2.0 s, the configuration S with the sloping top has significantly lower coefficients of transmission. For example, at T = 2.0 s and for large wave heights, C_T for the standard breakwater is approximately 27% while for the S configuration C_T is approximately 9%. The same improvement is not observed at higher wave periods.

Apparently, if the draft of the breakwater is relatively large compared to the wavelength, a significant proportion of the incident wave energy is incident on the caisson and shoals onto the top slope where the energy dissipates. However, where the draft on wavelength (D/L) is small, only a small part of the wave energy is incident on the caisson draft whether it is the V or S configuration, and most of the energy is transmitted underneath. Thus, for constant B/L, when the relative drafts (D/L) are small, changing the draft or top slope of the caisson will have little effect on the performance of the breakwater.

7 Effect of porous sheets on breakwater performance

Transmission coefficients measured for the 6 m wide breakwater configurations R and REM are compared in Figure 5. Both of these breakwaters floated level, and the configuration REM had porous sheets extending 1 m below the bottom of each caisson at the front and rear. The data in Figure 5 shows that the addition of the porous sheets makes a major improvement to the performance of the 6 m breakwater. Although at short wave periods the transmission coefficients are similar for configurations R and REM, the value of the porous sheets becomes clearly evident at wave periods of T = 2.5 s to 4.0 s. For example, at T = 3.5 s, configuration R is not a good breakwater (C_T = 82% to 93%), but configuration REM is an excellent breakwater with coefficients of transmission between 21% and 29%. Even at a wave period of T = 4.0 s, configuration REM is still reasonably efficient with C_T = 55% to 63%. A similar configuration but ballasted forward to a trim angle of 4.5° resulted in coefficients of transmission between 14% and 27% at T = 3.5 s, and between 41% and 45% at T = 4.0 s (Jamieson & Mogridge [2]).

Data from the load cell in the mooring line showed that contrary to what might be expected, mooring forces were not increased by the addition of porous sheets to the underside of the breakwaters.

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8 Concluding remarks

i) The most efficient breakwater configuration tested was a 6 m wide breakwater ballasted to an angle of 4.5°, and with the addition of two rows of porous sheets. The coefficients of transmission ranged from approximately 5% at T = 1.5 s to 27% at T = 3.5 s, and 45% at T = 4.0 s.

ii) For relative breakwater widths (B/L) of greater than approximately 0.5, the transmission coefficients for rectangular caisson breakwaters were generally less than approximately 35%.

iii) Vertical porous sheets are very effective in improving the performance of rectangular caisson floating breakwaters. For example, for a wave period of T = 3.5 s the addition of two rows of porous sheets reduced the transmission coefficients from approximately 82% to 25%.

Although the addition of porous sheets significantly improved breakwater performance, mooring forces were not increased.

If marine growth is expected to be a problem at some sites, alternatives to porous sheets should be investigated; that is, sheets with very large holes, slatted construction, or even vertical solid sheets.

9 References

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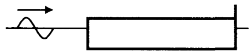
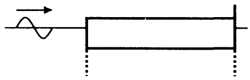
Description	Notation	Icon
3 m wide caisson	V	
3 m wide caisson with 11.5° sloping top	S	
6 m wide caisson	R	
6 m wide caisson with two rows of porous sheets	REM	

Figure 1: Configurations of concrete caisson floating breakwaters.

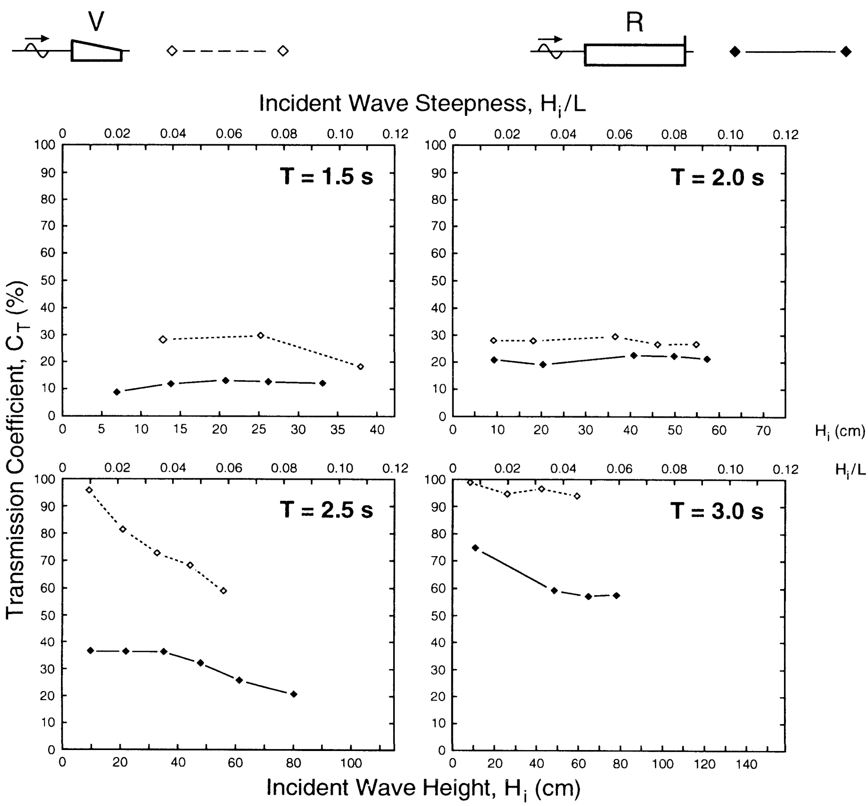


Figure 2: Effect of breakwater size on performance.

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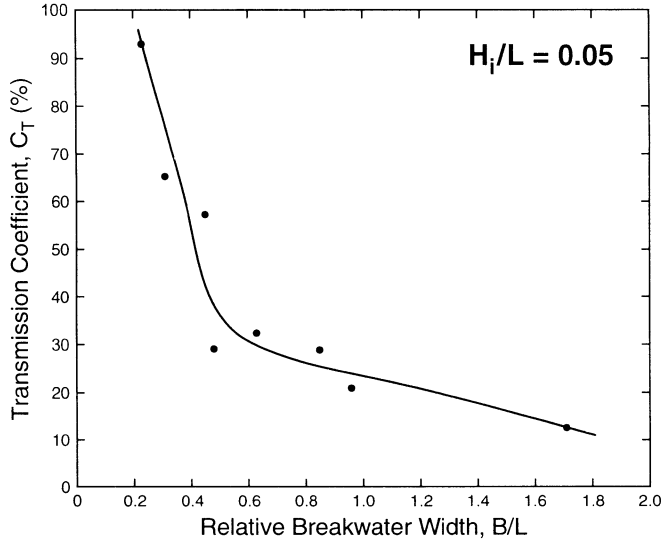

Figure 3: Transmission coefficient plotted against relative breakwater width for rectangular caisson configurations V and R.

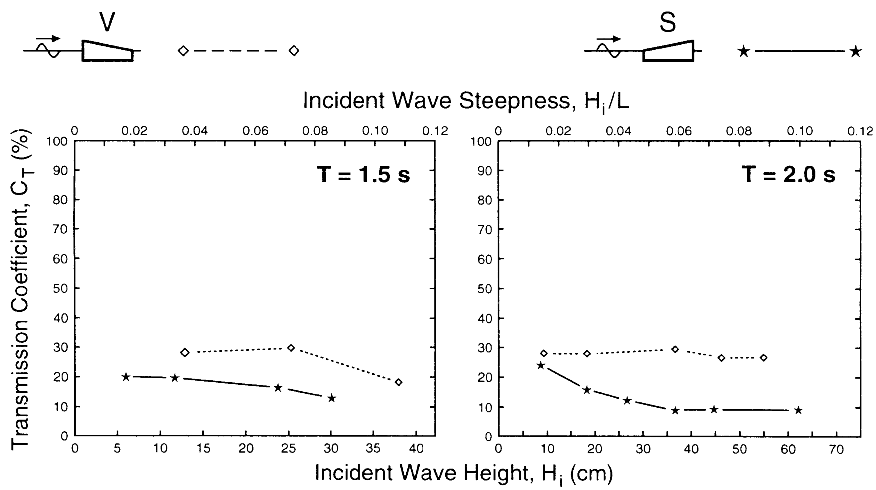

Figure 4: Effect of a sloping top on breakwater performance.

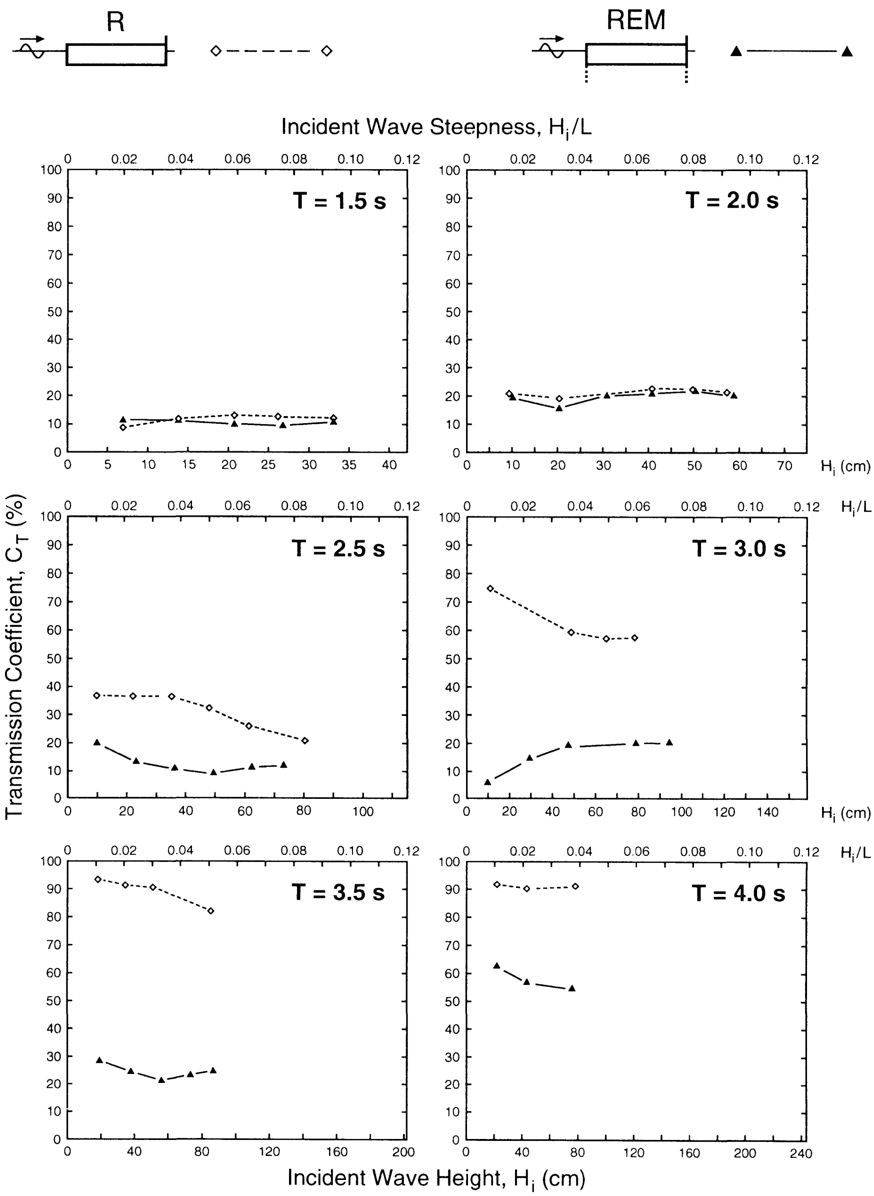

Figure 5: Effect of porous sheets on breakwater performance.