Hydraulic Characteristics of a Stepped-slope Floating Breakwater

IOP Conf. Series: Earth and Environmental Science **16** (2013) 012060 doi:10.1088/1755-1315/16/1/012060

Hydraulic Characteristics of a Stepped-slope Floating Breakwater

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Abstract. A stepped-slope floating breakwater is developed to provide wave protection to small ports and harbours. The width of the structure can be enhanced by increasing the number of breakwater units that are placed side-by-side to each other. This produces three types of test model, *i.e.* single-row, double-row and triple-row breakwaters. The test models have been tested in monochromatic waves in a wave flume to determine their hydraulic performance in various wave conditions. The incident and reflected wave profiles in the vicinity of the test models are recorded and analysed by using moving-probe method. The hydraulic performance of the test models are quantified by the coefficients of transmission, reflection and energy loss. The experimental results showed that the stepped-slope floating breakwater is an effective anti-reflection structure and a reasonably good wave attenuator.

1. Introduction

In recent years, the use of floating breakwaters for providing protection from wave disturbance has become prevalent in recreational harbours, marinas and fishing ports that do not require a high level of wave attenuation. For recreational harbours, coastal swimmers and surfers prefer to have acceptable wave condition to suit their sporting activities; and for marinas and fishing harbours, creation of complete still water conditions in the shelter regions may not be a necessity. Due to extensive application potentials in various sectors, floating breakwaters are still being one of the most studied structures in coastal engineering.

Floating breakwaters of various ingenious designs have been developed to cope with a broad range of applications. Breakwaters of different configurations are classified into four types: box, pontoon, mat, and tethered float [1]. Some other floating breakwaters with exclusive features are the Y-frame floating breakwater [2], floating plate breakwater [3], and floating pipe breakwater [4]. The majority of these floating breakwaters suppress the wave energy mainly by reflection, which may, in turn, result in standing waves in front of the structures. The confusing sea states may pose navigation hazard to the small floating vessels in the vicinity of the breakwaters.

Various efforts have been made by different researchers to identify the most optimum floating breakwater design that is capable of providing the desired hydraulic performance, *i.e.* adequate wave attenuation with minimal reflection effect [2,3,4,5].With respect to the geometrical effect of the breakwater, McCartney provided a comprehensive survey on each floating breakwater type [1]. Koftis and Prinos studied the hydraulic performance of box-type, circular-type and trapezoidal-type floating barriers using Reynolds Average Navier-Stokes Equation solver [5]. They concluded that the trapezoidal-type barrier is geometrically more advanced than the other forms of barrier in attenuating wave energy. This is because the trapezoidal barrier provides increased surface area for wave interaction and energy dissipation. This finding was in consensus with the numerical finding by Duclos et al. who simulated vorticity around the trapezoidal barrier with a concave front face [6]. The vortices generated in front of the trapezoidal barrier were found to be more developed than those generated at the rear face. The geometry of the barrier also generated multiple higher harmonic components in the reflected waves resulting in energy dispersion over a large range of angular frequency.

In this research, a trapezoidal barrier with a stepped-slope feature at both front and rear faces of the structure is developed. Figure 1 shows a single row of the stepped-slope floating breakwater model used in the experiment. The stepped slope at the front face of the breakwater is designed to facilitate wave breaking and to minimize the overtopping discharge. The test model has dimensions of 0.80 m length, 0.25 m bottom width and 0.13 m height. The density of the model is 784 kg/m^3 and it generates a draft of 0.08 m in static water. The size of the breakwater model can be enlarged by introducing additional test unit(s) to the primary one with side-by-side connection mode. This produces three types of test model for the stepped-slope floating breakwater, *i.e.* single-row, double-row and triple-row models. The total widths of the respective models, *B*, are 0.25 m, 0.50 m and 0.75 m. Further details of the model set-up are described in the subsequent section.

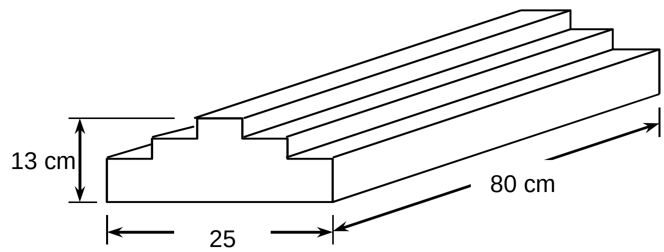

Figure 1. A single-row stepped-slope floating breakwater model.

2. Experimental Programs

The laboratory experiments were conducted at the hydraulic laboratory of Coastal and Offshore Engineering Institute, *Universiti Teknologi Malaysia*, Kuala Lumpur, Malaysia. The models were tested in an 18 m long, 0.95 m wide and 0.9 m high unidirectional wave flume equipped with a piston-type wave generator. At the other end of the flume was a wave absorber so as to reduce the reflected waves in the flume. The test models were made of a composite material (*i.e.* cement, sand and polystyrene) to provide adequate structural durability and buoyancy. Two capacitance-type wave probes were used for the measurement of wave profiles at the seaward and the leeward side of the test models. The seaward probe, which was located at the mid-section of a movable carriage that travelled along the steel rails at the top of the side walls of the flume, was used for measurement of the incident and reflected waves in the flume using the moving-probe method. The transmitted waves were measured by the leeward probe that was placed away from the test models by 3 times the tested water depth. These probes were plugged into a data acquisition system (DAS-800) for data recording. The wave probes adopted in the experiments were well calibrated prior to experiments, on a regular basis.

The three types of model, namely the single-row, double-row and triple-row stepped-slope floating breakwaters were tested in regular waves. Each test model was cross-moored to the bottom of the flume by four nylon ropes such that no initial pre-tension was present in the mooring lines. These breakwater models were subjected to 9 wave periods ranging from 0.9 s to 1.7 s in two water depths, *i.e.* 0.20 m and 0.33 m. For each test, the models were respectively exposed to waves of two different amplitudes. In total, 108 series of tests were conducted to study the hydraulic behavior of the stepped-slope floating breakwater models.

3. Results and Discussion

The hydraulic performance of the breakwater can be expressed in terms of the coefficients of transmission, reflection and energy loss. The transmission coefficient, C_T is the ratio of the transmitted wave height-to-the incident wave height, *e.g.* a lower C_T value indicates the breakwater is an effective wave attenuator. The reflection coefficient, C_R is represented by the ratio of the reflected wave height-to-the incident wave height, *e.g.* a lower C_R value implies the breakwater is an effective anti-reflection structure. Since the energy dissipated at the breakwater involves complicated processes and is difficult to measure experimentally, it is therefore mathematically estimated based on the principle of conservation of energy, giving the energy dissipation coefficient, $C_L = 1 - C_T^{\ 2} - C_R^{\ 2}$. The C_L value indicates the percentage of the energy dissipated at the breakwater by the incident waves. Hence, a good energy dissipater always yields a high C_L value.

3.1. Wave transmission

In this study, the energy coefficients (*i.e.* C_T, C_R and C_L) are plotted with respect to the relative breakwater width, B/L, where B and L are the breakwater width and wavelength, respectively, as shown in Figure 2. For Figure 2(a), with a relative breakwater draft D/d = 0.24 (where D = breakwater draft and d = water depth), it was observed that the C_T of the single-row, double-row and triple-row models decreased with the increase in B/L. This implies that the stepped-slope floating breakwaters exhibit higher wave attenuation performance when exposed to shorter period waves. This is sensible as the shorter waves tend to have more intense interactions with the floating structure. On the other hand, wave attenuation efficiency of the breakwater in longer period waves is not much affected by the number of models used. It is interesting to note that the double-row model performed more efficiently than the triple-row model for the tested wave conditions. For instance, the double-row model is capable of reducing the incident wave height by nearly 90% at $B/L \approx 0.4$ whereas the triple-row would require a $B/L \approx 0.7$ for the similar degree of wave attenuation. It is also seen from Figures 2(a) and 2(b) that the wave suppression ability of the breakwater models improves in deeper waters (*i.e.* as D/d increases). This is due to the fact that wave energy of the deeper waters, which is well distributed at the upper column of the water, was efficiently dissipated by the stepped-slope feature of the breakwaters. Overall, it can be deduced that the double-row stepped-slope floating breakwater is superior to the single-row and triple-row breakwaters, particularly in deeper waters.

3.2 Wave reflection

The reflectivity of the stepped-slope floating breakwaters is demonstrated in Figures 2(c) and 2(d). It is learnt from the figures that the C_R values of the test models are barely beyond 0.4 (equivalent to a reflection of 16% of the incident wave energy) which is relatively small compared to the amount of waves reflected by the conventional breakwaters. The C_R of the test models do not exhibit a strong correlation with B/L, indicating that the reflectivity of the breakwaters is less influenced by the wave period. The variation of C_R grows gradually as D/d increases from 0.24 to 0.40. This is attributed to the fact that the C_R values are governed by the effect of wave height more in deeper waters. In addition, it is also noticed that the C_R values are not subjected to the number of breakwater unit used, *i.e.* increasing the number of test models (*i.e.* double- and triple- row models) will not further amplify wave reflection in front of the breakwaters.

3.3 Energy dissipation

The mechanisms of energy dissipation observed in the experiments were (i) wave breaking at the seaward slope of the model, (ii) wave run-up on the seaward slope of the model, (iii) wave overtopping, (iv) wave run-down at the shoreward slope of the model, and (v) vortices formed at the bottom edges of the floating model. The energy loss posed by these hydraulic phenomena is estimated by the coefficient of energy dissipation, C_L. Figures 2(e) and 2(f) demonstrate the energy dissipation by the breakwater models tested in D/d = 0.24 and 0.40, respectively. It is evident that the test models are highly dissipative when exposed to shorter period waves, particularly in deeper waters, among which, the double-row model is the most efficient and viable energy dissipater, resulting in energy loss of almost 95% at *D/d* = 0.24 and almost 82% at *D/d* = 0.40, with both occurring at *B/L* ≈ 0.4. Increasing the number of breakwater units does not seem to boost the dissipative performance of the breakwater considerably. Therefore, it is suggested that the double-row stepped-slope floating breakwater be designed at *B/L* = 0.4 so as to achieve the optimal hydraulic performance.

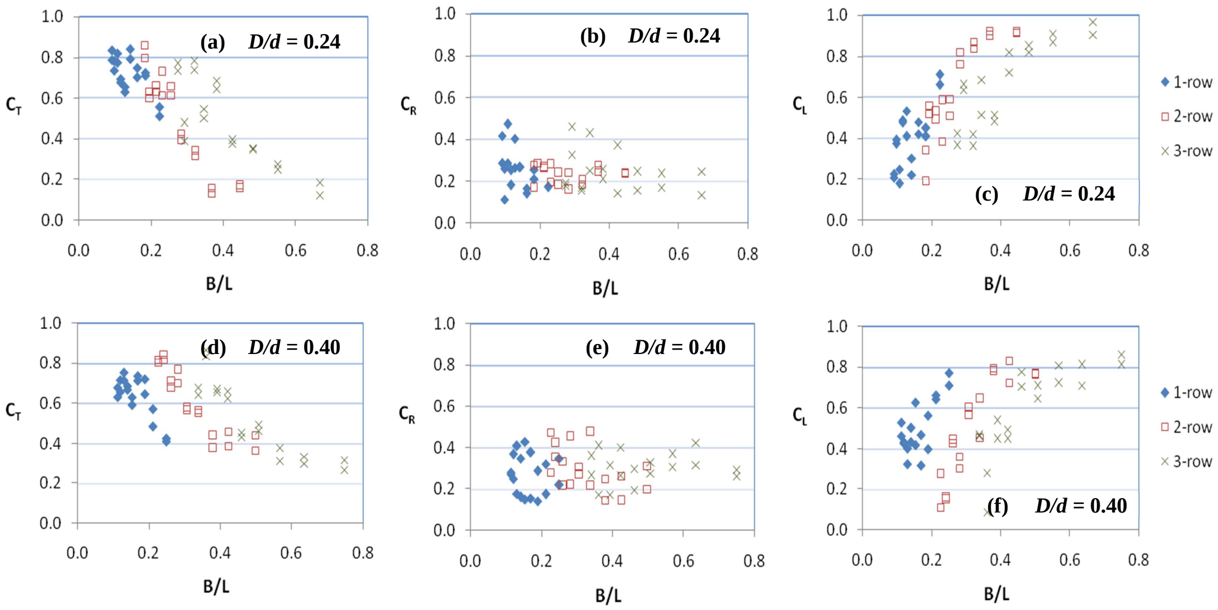

Figure 2. Energy coefficients with respect to the relative breakwater width, *B/L*.

4. Conclusion

Laboratory experiments were conducted to study the hydraulic characteristics of a stepped-slope floating breakwater system in various wave conditions. The experimental results revealed that the hydraulic performance of the breakwater models was strongly influenced by the effects of relative breakwater width. The breakwaters were effective anti-reflection structures with high dissipative ability, particularly when subjected to shorter period waves in deeper waters. Due to the highly energy dissipative ability, the double-row stepped-slope floating breakwater was claimed to be the most hydraulically viable structure compared to the single-row and the triple-row breakwaters. It achieved the optimum hydraulic performance at *B/L* = 0.4, whereby it attained wave attenuation and energy dissipation as high as 95%, and the maximum wave reflection anticipated at this range was about 40%.

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