VOL. 12, NO. 20, OCTOBER 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

WAVE TRANSMISSION OF SUBMERGED BREAKWATERS CONSISTING MULTIPLE PIPES

Lachmi Sri Manoharan[1], Hee Min Teh[1] and Chai Heng Lim[2]
[1]Department of Civil and Environmental Engineering, Universiti Teknologi Petronas, Seri Iskandar, Perak, Malaysia
[2]Institute of Ocean and Earth Sciences, Universiti of Malaya, Kuala Lumpur, Malaysia
E-Mail: lachmi93@gmail.com

ABSTRACT

Various breakwaters have been developed to protect coastal areas from the force of waves. The majority of the breakwaters are gravity-type structures withstanding the wave energy by their effective masses. The construction of these gigantic structures is costly and the use of materials is substantial. This research study attempted to cope with the aforementioned problems by investigating wave attenuation performance of five submerged breakwaters that were made of multiple pipes in different configurations by the means of physical modelling. A series of experiments were conducted in a wave flume to study the wave transmission characteristics of the submerged breakwaters of different designs under regular waves. Wave attenuation efficiency of the breakwaters were expressed in terms of wave transmission coefficient C_t. The relationships between C_t and wave steepness H_i/L, relative breakwater width B/L and relative breakwater draft h/d were ascertained through a systematic experimental programme. The experimental results showed that the alternatively submerged breakwaters were better wave attenuator compared to the submerged ones, and the sloping front face of breakwaters helped in promoting wave breaking and energy dissipation.

Keywords: Submerged breakwater, wave transmission, wave attenuation, breakwater configurations.

INTRODUCTION

Ocean wave has powers that give incredible effects to the coastal environment. Climate change, economic growth and population development results in a range of pressures to our coastal environment. Thus, it is essential to safeguard the coastline against such powers. There are different approaches to minimize the greatness of ocean waves and one of the promising methods is by submerged breakwaters. According to Kerpen *et al*. [1], submerged breakwaters are widely preferred as a potential coastal protection structure resulting in moderate wave transmission with significant wave energy dissipation and maintain sediments in the sheltered harbour through premature wave breaking. In addition, submerged breakwaters provide more aesthetically pleasing view to the coastal environments and maintain good water quality than conventional emerged breakwaters [2].

Numerous types of submerged breakwaters have been developed in engineering practice such as, rubble mound, vertical wall and circular-front breakwaters. Different breakwaters have different hydrodynamic performances due to the variation of wave reflection, dissipation and transmission in response to the geometry of the structures [3]. A parametric study was conducted on the performance of hemi-cylindrical, rectangular and flexible breakwater models to appraise the transmission and reflection characteristics [4]. The results showed that the rectangular model performs better in dissipating wave energy compared to the hemi-cylindrical model for the case of rigid breakwaters. Whereas, the hemi-cylindrical shape performs better in diminishing waves compared to rectangular shape for the case of flexible breakwaters. Physical tests were conducted to investigate the performance of semicircular and vertical breakwaters [5]. The results stated that the semicircular breakwaters reflect less and transmit more energy than vertical breakwaters at the same water depth.

Existing studies demonstrated that coastal protection by submerged breakwaters relies upon various factors. Dattatri *et al*. [6] claimed that physical layout is an imperative factor that influencing hydrodynamics performance of a submerged breakwater. Pilarczyk [7] discussed such that submergence depth, submergence width, distance of breakwaters from shoreline, hydrodynamic characteristics of the structures, wave climate and angle of wave approach are important factors that control the wave transmission ability of a submerged breakwater. Seabrook and Hall [8], claimed that relative submergence, incident wave height and structure crest width are the most important design variables that effects the wave transmission performance. An experimental study were conducted on smooth and steeped slopes submerged breakwaters to investigate the transmission characteristics under regular waves [9]. The experimental results revealed that the submerged breakwater with steeped slope dissipate more energy compared to smooth slope. Earlier study by [10] demonstrated that an increase in relative breakwater draft h/d, results in the increase in wave transmission abilities.

Numerous ingenious designs of breakwaters have been proposed, tested, reported and even developed with blended achievement previously. The gravity-type breakwater is more preferable in many coastal and marine applications mainly due to its effective size. However, the construction of these gigantic structures is costly and the use of materials is substantial. Therefore, the present study was carried out to address the aforementioned problems by introducing a sustainable coastal engineering structure that offers potentially economic solution for coastal environments. The wave attenuation performance of the test models of various configurations were investigated

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using the physical modelling approach. The results of these experiments are presented in this paper.

METHODOLOGY

The breakwater model was made of an assembly of four units of cylindrical PVC tubes of different diameters, i.e. 4.2, 6.0, 9.2 and 11.4 cm, by the means of cable ties. The thickness of these PVC tubes is 20 mm. Several breakwater configurations were formed using these tubes of different sizes, yielding five design configurations as shown in Figure-1. Figure-2 shows the layout of Design 3 in model scale, in which the breakwater exhibits a seaward sloping face. The width and length of all test models were set at 0.308 m and 0.320 m, respectively. The maximum height of all the test models, *h* was set at 11.4 cm, which is the diameter of the largest PVC tube.

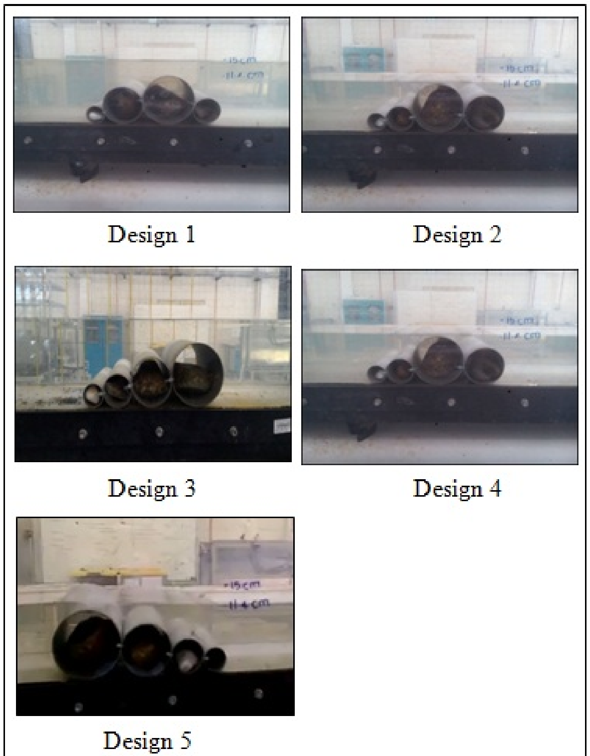

Figure-1. Breakwater configurations.

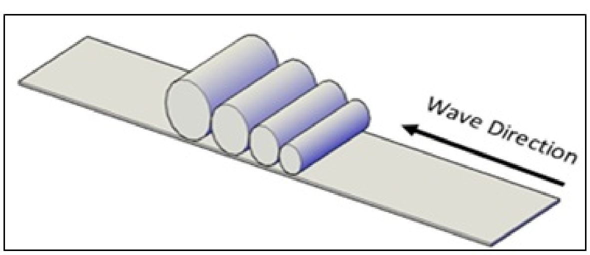

Figure-2. Conceptual view of proposed submerged breakwater.

A series of experiments were conducted at Hydraulic Laboratory of Universiti Teknologi Petronas, Malaysia. The submerged breakwater models were tested in a 10 m long, 0.32 m width and 0.48 m deep wave flume furnished with a wave generator at one end and a wave absorber at the other end, as shown in Figure-3. The test model was placed at 4 m from the wave generator. The models were positioned perpendicular to the wave motion and were anchored to the bottom by inserting the heavy weights within the horizontal pipes. Wave transmission characteristics of the test models was examined under regular waves of wave period, T = 0.8, 1.0, 1.2, 1.4 and 1.6 s at water depths, d of 11.4 cm and 15.0 cm. This yields a range of wave steepness, H_i/L varied from 0.008 to 0.065, where H_i and L are the height and length of the incident waves. At d = 11.4 cm, the breakwater crest was at the still water level, giving relative water depth h/d = 1.00. The breakwaters at h/d = 1.00 would alternatively submerged when subjected to wave action. At d = 15.0 cm, the test models were completely submerged in water, giving h/d = 0.76. In total, approximately 50 tests were conducted for this experimental study.

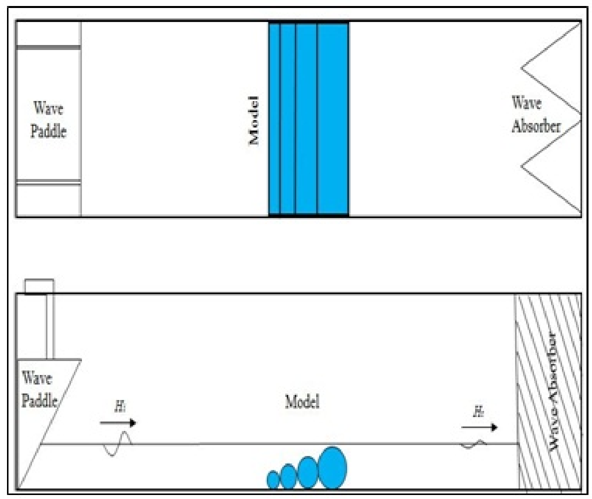

Figure-3. Test models.

RESULTS AND DISCUSSIONS

Hydraulic characteristics of the test models were evaluated in terms of the wave transmission coefficient, C_t. Wave transmission coefficient is the ratio of the transmitted wave height, H_t to the incident wave height, H_i. The lower the C_t values, the better will be the wave dampening performance of the breakwater. In the following section, the C_t of the test models subjected to relative breakwater draft, h/d = 0.76 and 1.00 are plotted with respect to wave steepness, H_i/L and relative breakwater width, B/L where h and B are the height and width of the structure, respectively.

a) Effect of H_i/L

Figure-4 presents the C_t variation of all breakwater design configurations corresponding to H_i/L and h/d when subjected to regular waves. At h/d = 0.76,

 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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the C_t of the test models are mostly scattered between 0.3 and 0.6 with an undefined trend with the increasing H_i/L. It can be seen that the C_t of Design 1 and 5 display a mild increasing trend as H_i/L increases; whereas, the C_t of the remaining breakwater designs show no appreciable variation with H_i/L. Overall, the influence of wave steepness on C_t of the submerged breakwater of various designs is less evident,.

As the still water level is at the crest of the breakwater (h/d = 1), the breakwaters are alternatively emerged under wave action. The breakwaters are exposed to intensive wave-structure interactions resulting in wave breaking, frictional dissipation and energy loss. Consequently, the C_t of the breakwaters are further suppressed to the lower range ($0.1 < C_t < 0.3$) within the test range of H_i/L. Hence, immersion depth of the breakwater is one of the key factors affecting wave attenuation effectiveness of the proposed breakwater. Similar to the case of h/d = 0.76, the C_t variations of all the test models with respect to H_i/L are small with standard deviation of less than 0.05.

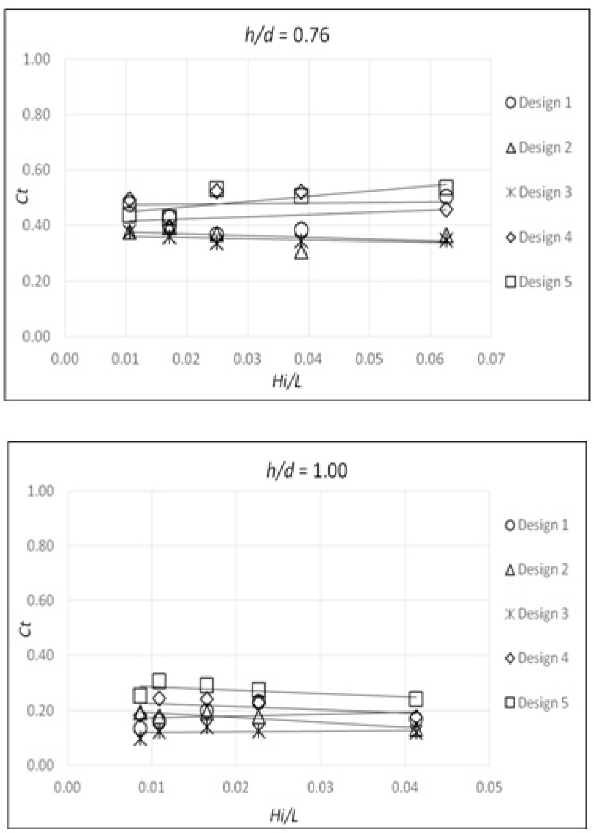

Figure-4. Transmission coefficient with respect to wave steepness.

b) Effect of B/L

The effect of relative breakwater width on C_t of the test models is demonstrated in Figure-5. It is apparent that the trends of the data points for h/d = 0.76 and 1.00 resemble those shown in Figure-4. Since the breakwater width is fixed at 0.308 m for the present study, the length of the incident waves, which is derived from the linear wave theory, is the only controlling factor in this respect. The C_t of the respective breakwater designs are mildly affected by the change of B/L or the change of wavelength. This indicates that the wave attenuation of the test models are not much affected by the change of wavelength or wave period in both totally submerged (h/d = 0.76) and alternatively submerged (h/d = 1.00) cases. Nonetheless, the variation of C_t with respect to h/d is significant. The finding is in agreement with that presented in Section 3.1.

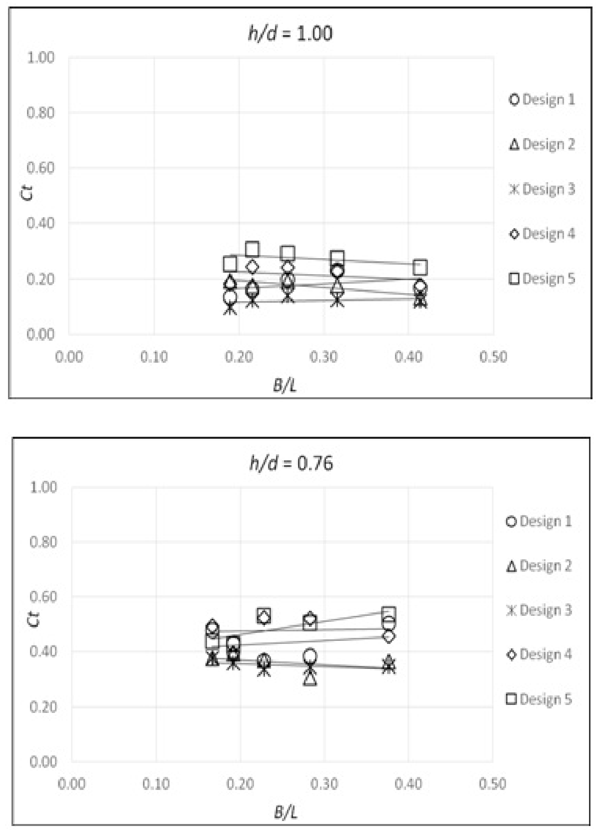

Figure-5. Transmission coefficient with respect to relative breakwater width.

c) Effect of breakwater configuration

With respect to the effectiveness of various breakwater designs, it is obvious from the Figure-4 and Figure-5 that Design 3 attained the lowest C_t values (C_t = 0.35 for h/d = 0.76 and C_t = 0.10 for h/d = 1.0) within the test range of H_i/L and B/L. This also means that Design 3 exhibits a superior configuration in attenuating the incident wave height. This can be explained by the fact that the seaward sloping face of Design 3 has been fully optimized to enhance wave breaking and energy dissipation at the slope. It is also anticipated that wave reflection in front of the structure is less severe due to the slope front face. In contrary, Design 5 which has the sloping shoreward slope performs the least in wave attenuation. It seems that waves have intensive interaction with the first unit of pipe; however, the remaining waves that pass over the first pipe experience less reduction in size. The broken waves have less interference with the remaining of the pipes due to increased water depth as the waves travel further from the first pipe. The configurations of Designs 1 and 2 are quite similar to that of Design 3, in which they have gradual sloping seaward faces that promote wave breaking and energy dissipation. Wave transmission characteristics of Designs 1, 2 and 3 are quite alike regardless of their submergence condition.

CONCLUSIONS

A series of experiments were conducted in a wave flume to study the wave transmission characteristics of submerged breakwaters consisting of multiple pipes subjected to regular waves. The following conclusions are reached within the limitations of the test program:

- Wave transmission of the breakwater models was largely influenced by the relative water depth h/d but less affected by wave steepness H_i/L and B/L regardless of their configurations.
- The alternatively submerged breakwaters were better wave attenuator compared to the submerged ones.
- The alternatively submerged breakwaters was capable in suppressing waves as much as $0.1 < C_t < 0.3$ at $h/d = 1$.
- The sloping front face breakwaters outperformed other breakwater designs in attenuating wave energy due to increased wave breaking and energy dissipation at the seaward slopes.
- Breakwater Design 3 is the best wave attenuator among all breakwater designs tested in this study.

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