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Experimental Investigations on Wave Transmission at Submerged Breakwater with Smooth and Stepped Slopes

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Abstract

Submerged breakwaters are gaining more popularity as a potential coastal protection structure resulting in moderate wave transmission with significant wave energy dissipation. Submerged breakwaters are mainly adopted to prevent erosion and to dissipate the incident wave energy. In addition, the premature wave breaking facilitates the wave surfing activities by proper designing of submerged breakwater. In the present study, the experiments are conducted on submerged breakwaters in a two dimensional wave flume to investigate the influence of stepped and smooth front slope of the submerged breakwater, its height and width in reducing wave energy. A total number of eighteen sets of experiments has been conducted for three different breakwater heights (31cm, 28cm and 26cm) and three different breakwater widths (10cm, 20cm and 30cm) with stepped and smooth front slope of breakwater. The submerged breakwater models are subjected to regular waves of four different wave heights and five different wave periods in a constant water depth of 31cm, to determine wave transmissions characteristics. The influence of relative breakwater width, relative depth of submergence of the breakwater and roughness of breakwater front slope on wave transmission are analyzed and discussed in this paper.

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Keywords: Submerged breakwaters; transmission; wave energy dissipation; relative breakwater width; relative depth of submergence of breakwater.

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1. Submerged Breakwaters

Submerged breakwaters are effectively used to maintain tranquility inside the harbor basin, to reduce the siltation at the harbor entrances and along the approach channel, against coastal erosion, as a shelter for marine habitats, as an eco-friendly structure. Submerged breakwaters allow the exchange of water masses between offshore and onshore region reducing the pollution on the beaches. The level of coastal protection provided by the submerged breakwater depends on the various factors such as width and depth of submergence of breakwater; distance of breakwater from the shore, hydrodynamic characteristics of the structure, wave climate and angle of wave attack (Pilarczyk et al., 2003). A comprehensive experimental investigation is conducted on submerged breakwater to study the performance characteristics (Dattatri et al., 1978). The results on this experimental study conclude that submerged breakwaters can be effectively used for wave attenuations. Also, the author states that the crest width and depth of crest submergence have greater influence on the performance of submerged breakwater; the shape of breakwater has significant effect on the reflection characteristics of the structure. A parametric study is conducted on the hemi-cylindrical, rectangular and flexible breakwater models to evaluate the transmission and reflection characteristics (Dimitrios et al., 2003). The experimental results declare that the rectangular model performs better in dissipating wave energy in comparison with the hemi-cylindrical model for the case of rigid breakwaters. Whereas, the hemi-cylindrical model performs better in reducing wave energy compared to rectangular shapes for the case of flexible breakwaters. The physical model tests are conducted to evaluate the performance of culvert pipe blocks against conventional blocks (Jian-Wui Lai et al., 2008). They stated that the culvert pipe blocks with constrictive sections dissipate more wave energy compared to the conventional blocks. Also, the authors declare that the wave energy dissipation is almost the same for culvert pipe with constrictive compared to permeable rubble mound breakwaters. The experimental studies are conducted on stepped slope floating type breakwater (single, double and triple rows) to investigate the transmission and reflection characteristics under various wave conditions (Teh.H.M et al., 2013). The experimental results conclude that the wave attenuation for the triple-row breakwater is 35% more compared to the single row breakwater. Also, the energy loss coefficient of triple-row breakwater is 20% higher compared to single row-breakwaters. The reflection has less effect for all the cases such as single, double and triple-row floating breakwater. The experiments are conducted to evaluate transmission and reflection characteristics of the submerged rectangular stepped breakwater (El Sai Yasser Moh., 2014). He declares that maximum and minimum wave energy dissipation occurs in case of three rectangular vertical submerged breakwaters (71.25%) and single rectangular vertical submerged breakwater (11.26%) respectively. The hydraulic model tests are conducted on two stepped embankments with slope 1:2 and 1:3 to evaluate the mean overtopping rate under various wave conditions (Kerpen et al., 2014). He states that for the relative free board height, the mean overtopping rate for 1:2 sloped stepped embankments is 2.5 to 5 times greater than 1:3 sloped stepped embankments. Also, the authors state that

2. Experimental Setup

The laboratory experiments are conducted at Hydraulic laboratory of Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering, Leibniz University, Hannover, Germany. The submerged breakwater models are tested in a 700cm long, 30cm wide and 54cm deep unidirectional wave flume equipped with wave a flap type wave generator and wave absorber on the either ends. A total number of eighteen sets of experiments are conducted for three different breakwater heights (31cm, 28cm and 26cm) and three different breakwater widths (10cm, 20cm and 30cm) with stepped and smooth front slope of breakwater. The front (smooth, stepped) and rear (smooth) slopes considered for the submerged breakwater model are 1:2 and 1:1 respectively. The submerged breakwater models are subjected to regular waves of four different wave heights (3cm, 5cm, 7cm, 9cm) and five different wave periods (0.55s, 0.65s,0.75s, 0.85s, 0.95s) in a constant water depth of 31cm, to determine wave transmission characteristics. The photographic view of wave flume and experimental setup is presented in Fig. 1. The submerged breakwater model is placed at a distance of 231cm from the wave maker. Three wave gauges are used to measure the surface elevation with a resolution of 0.5mm. For each test run, wave heights are measures at two locations in front of the submerged breakwater and at one location behind the submerged breakwater. The first and second wave probes are located in front of the submerged breakwater model at a distance of 77cm and 60cm respectively. The third wave probe is located at a distance of 45cm from the submerged breakwater model. The submerged breakwater models are made up of wood material with smooth and stepped front slope are presented in Fig. 2.

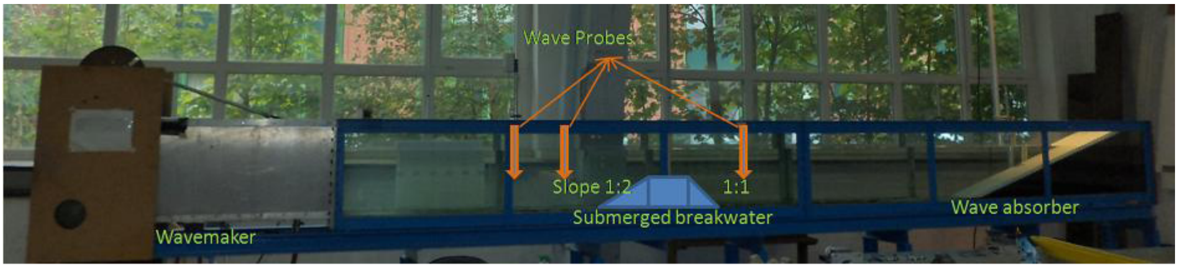

Fig. 1. A photographic view of wave flume and experimental setup

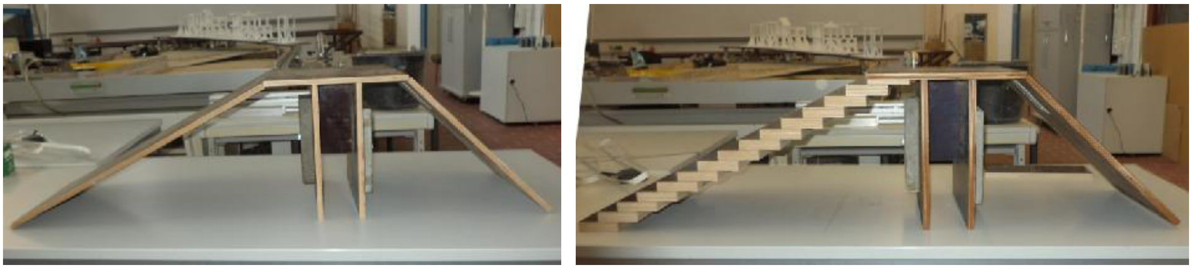

Fig. 2. A view of the submerged breakwater model set-up with smooth and stepped front slope

3. Results and Discussion

The hydrodynamic performance of the submerged breakwater is measured in terms of transmission coefficient, reflection coefficient and energy loss coefficient. The transmission coefficient is the ratio of transmitted wave height (H_t) to the incident wave height (H_i), for instance a lower transmission coefficient indicates effective wave attenuation.

3.1. Effect of relative crest width (B/L) on wave transmission coefficient (K_t)

A sufficient crest width is required to trigger the wave breaking resulting in a higher amount of wave energy dissipation, which in turn reduces the transmission characteristics of the structure. The transmission coefficient at smooth sloped and stepped submerged breakwater is plotted against the relative crest width (crest width/wave length) for crest width B=10cm, 20cm and 30cm are shown in Fig. 3 and 4 respectively. For crest width B=10cm, 20cm and 30cm, from the Fig. 3 and 4, it is observed that transmission coefficient K_t decreases with an increase in B/L. It is also observed that when crest width is less than the one fourth of the wave length, a lot of oscillations are seen in the variation of transmission coefficient for all ranges of relative submergence of crest width (R_c/H_i=depth of Submergence/wave height) considered in the present study. Whereas, for the crest width greater than one fourth wave length, the transmission coefficient decreases with the increase in B/L for all ranges of relative submergence of crest width considered. The average reduction in the transmission coefficient for submerged breakwater with smooth front slope, relative submergence of crest width R_c/H_i=0 and crest width of B= 20cm and 30cm are 8.67% and 22.75% respectively compared to crest width B=10cm. Whereas, for R_c/H_i= -3.10 ~ -1.40, the average reduction in the transmission coefficient for the crest width of B= 20cm and B=30cm are 11.16% and 38.15% %

respectively compared to crest width B=10cm. Also, for R_c/H_i= -4.64 ~ -2.39, the average reduction in the transmission coefficient for submerged breakwater with smooth front slope and crest width of B= 20cm and 30cm are 20.83% and 31.82% respectively compared to crest width B=10cm.

Similarly, the average reduction in the transmission coefficient for submerged breakwater with stepped front slope, relative submergence of crest width R_c/H_i=0 and crest width of B= 20cm and 30cm are 4.98% and 16.30% respectively compared to crest width B=10cm. Whereas, for R_c/H_i= -3.10 ~ -1.40, the average reduction in the transmission coefficient for the crest width of B= 20cm and B=30cm are 12.7% and 30.21% respectively compared to crest width B=10cm. Also, for R_c/H_i= -4.64 ~ -2.39, the average reduction in the transmission coefficient for submerged breakwater with smooth front slope and crest width of B= 20cm and 30cm are 17.55% and 28.69% respectively compared to crest width B=10cm.

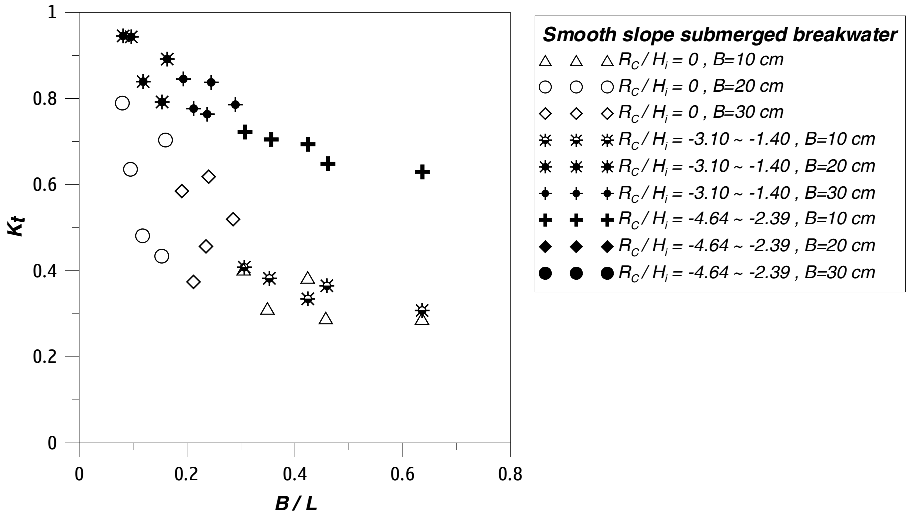

Fig. 3. Transmission coefficients at smooth slope submerged breakwater with respect to the relative submergence of crest width for B= 10cm, 20cm and 30cm

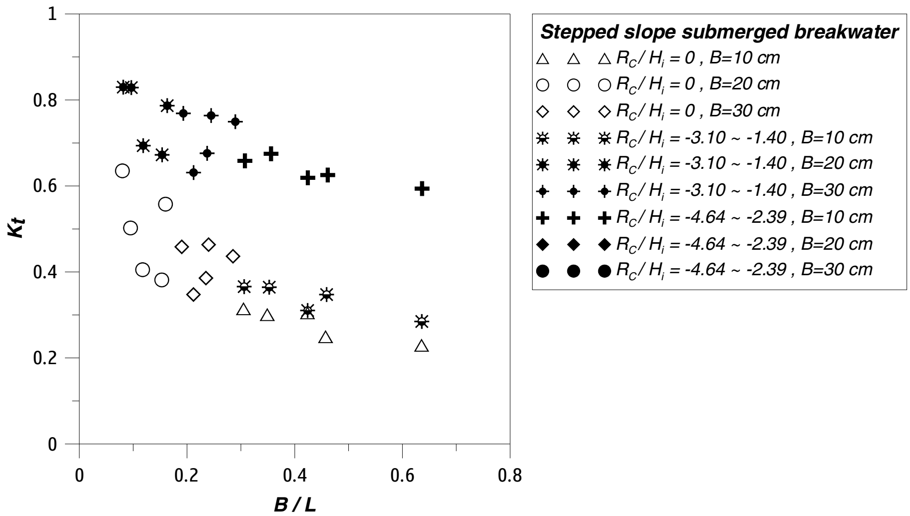

Fig. 4. Transmission coefficients at stepped slope submerged breakwater with respect to the relative submergence of crest width for B= 10cm, 20cm and 30cm

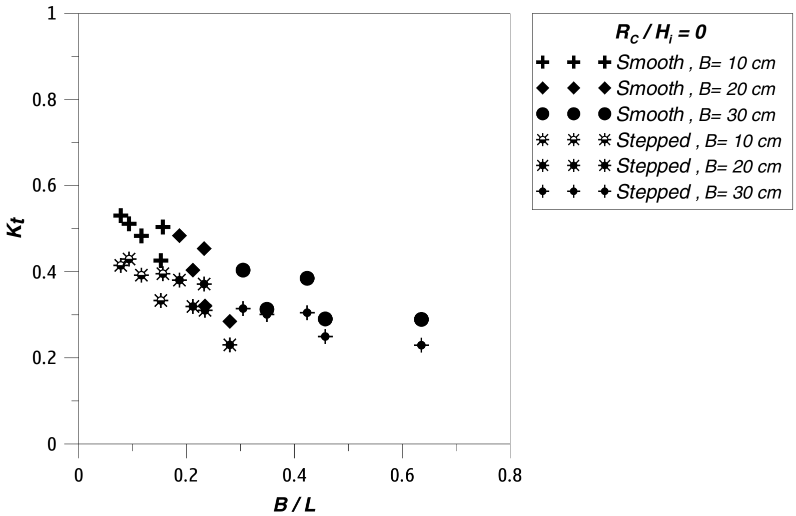

Fig. 5. Transmission coefficients at smooth and stepped slope submerged breakwater for R_c/H_i=0 with respect to the relative submergence of crest width for *B*= 10cm, 20cm and 30cm

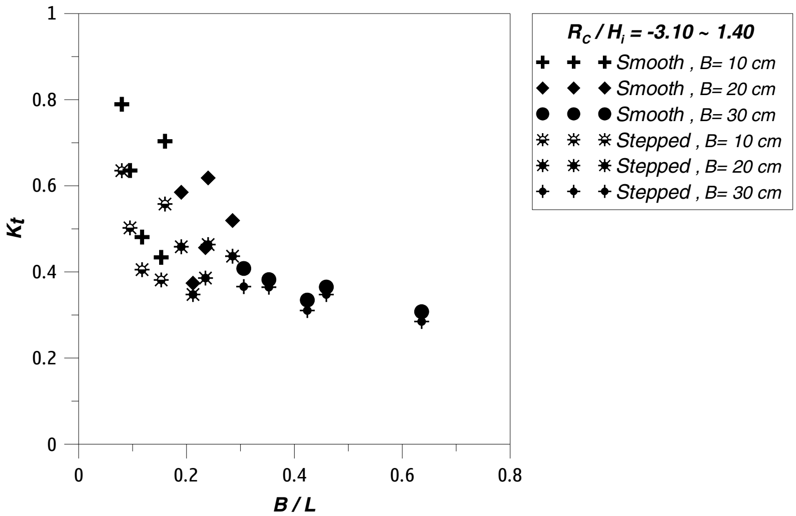

Fig. 6. Transmission coefficients at smooth and stepped slope submerged breakwater for R_c/H_i = -3.10 ~ -1.40 with respect to the relative submergence of crest width for *B*= 10cm, 20cm and 30cm

The transmission coefficient at smooth sloped and stepped submerged breakwater is plotted against the relative crest width for R_c/H_i = 0, R_c/H_i = -3.10 ~ -1.40 and R_c/H_i = -4.64 ~ -2.39 are shown in Fig. 5, 6 and 7 respectively. The average reduction in the transmission coefficient for submerged breakwater with stepped front slope, relative submergence of crest width R_c/H_i=0 and crest width of *B*= 10cm, 20cm and 30cm are 20%, 16.54% and 16.28% respectively compared to submerged breakwater with smooth front slope. Whereas, for R_c/H_i= -3.10 ~ -1.40 and submerged breakwater with stepped slope, the average reduction in the transmission coefficient for the crest width of *B*= 10cm, 20cm and 30cm are 17.81%, 17.02% and 6.86% respectively compared to submerged breakwater with smooth slope. Also, for R_c/H_i= -4.64 ~ -2.39 and submerged breakwater with stepped slope, the average reduction in the transmission coefficient for crest width of *B*= 10cm, 20cm and 30cm are 13.7%, 10.54% and 6.61% respectively compared to submerged breakwater with smooth slope.

The total average reduction in the transmission coefficient for submerged breakwater with stepped front slope, relative submergence of crest width R_c/H_i=0, R_c/H_i= -3.10 ~ -1.40, R_c/H_i= -4.64 ~ -2.39 are 17.61%, 13.9% and 10.29% respectively compared to submerged breakwater with smooth front slope. Analyzing the results of present study, it is recommended that the values of R_c/H_i should be in the range of -3.10 ~ -1.40 and crest width should be greater than one fourth of the wave length in order to achieve the wave transmission coefficient less than 50%.

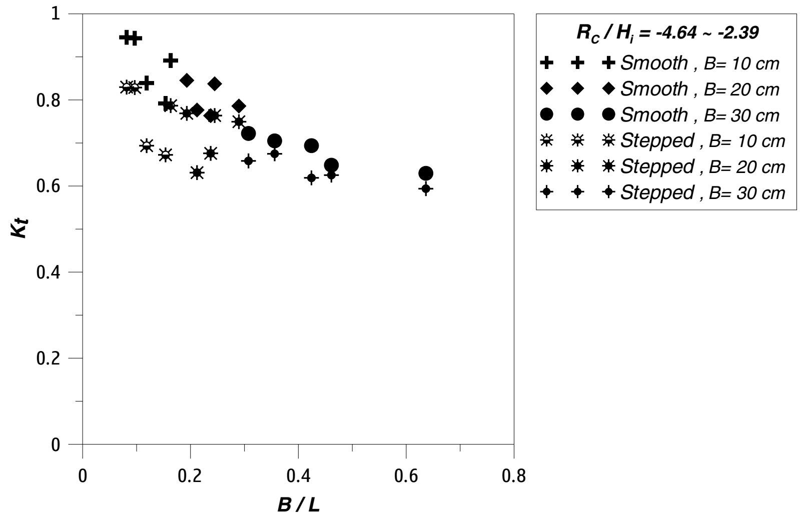

Fig. 7. Transmission coefficients at smooth and stepped slope submerged breakwater for R_c/H_i = -4.64 ~ -2.39 with respect to the relative submergence of crest width for *B*= 10cm, 20cm and 30cm

4. Conclusion

The experimental study is carried out to investigate the transmission characteristics of submerged breakwaters with smooth and stepped front slope. The crest width, breakwater submergence and slope roughness are the important geometry factors influencing the wave transmission coefficient in evaluating the performance of submerged breakwater. The result on the present study indicates that submerged breakwaters with stepped front slope dissipate more energy compared to smooth front slope. The total average reduction in the transmission coefficient for submerged breakwater with stepped front slope, relative submergence of crest width R_c/H_i=0, R_c/H_i= -3.10 ~ -1.40, R_c/H_i= -4.64 ~ -2.39 are 17.61%, 13.9% and 10.29% respectively compared to submerged breakwater with smooth front slope. In order to achieve the wave transmission coefficient less than 50%, it is recommended that the values of R_c/H_i should be in the range of -3.10 ~ -1.40 and crest width should be greater than one fourth of the wave length. The results of this investigation can be used in design of submerged breakwater for medium wave transmission in dissipating wave energy.

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