LABORATORY STUDY ON PERFORMANCE OF HORIZONTAL SLOTTED SUBMERGED BREAKWATER

Md. Sadiul Alam Chyon*[1] and Md. Ataur Rahman[2]

[1] *Undergraduate Student, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology(BUET), e-mail:mdsadiulalambuetwre@gmail.com*
[2] *Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET), Bangladesh, e-mail: mataur@wre.buet.ac.bd*

ABSTRACT

In this study, laboratory experiments have been carried out on the interaction of horizontal slotted submerged breakwaters with unidirectional regular waves to assess the hydrodynamic performance of the breakwaters. The waves were generated in a two dimensional laboratory flume having dimensions of 21.3 m length, 0.76 m width and 0.74 m height. Keeping still water depth of 50 cm, waves with T=1.6 sec, 1.7 sec, 1.8 sec and 2 sec were generated from a piston type wave generator. At 800 cm from the wave generator, breakwaters of 100cm width, 75cm length and 40 cm height were constructed with varying porosities of n=0.4, 0.5 and 0.6. Water level datawere collected at six different locations for 12 run conditions. Using the measured data different hydrodynamic coefficients were calculated which include transmission co-efficient (K_t), reflection co-efficient (K_r) and wave energy loss co-efficient (K_L). These co-efficient values were then, analyzed with respect to relative breakwater width (k.B), [where, k = wave number (2π/L), B = breakwater width] and porosity of breakwater. Experimental results indicate that, for transmitting less wave energy through the breakwater, minimum transmission co-efficient, K_t = 0.526 was obtained for breakwater with the lowest porosity (n=0.4) for T = 1.6 sec. Minimum reflection co-efficient, Kr = 0.0345 was obtained for breakwater with highest porosity (n=0.6) for the longest wave, i.e. for T =2 sec. It is also seen that wave energy loss co-efficient (K_L) decreases from 0.68 to 0.47 with increasing porosity. Based on hydrodynamic performance, n=0.4 was proposed and justified as optimum porosity among the three breakwaters.

Keywords:*Submerged breakwater,porosity, transmission coefficient, wave energy loss coefficient*

1. INTRODUCTION

Coastal areas are commonly defined as the interface or transition areas between land and sea, which is diverse in function and form (Caddy et al., 1994). It is a dynamic feature and there are no exact natural boundaries that unambiguously delineate coastal areas. Coastal zone is extremely important for the social and economic welfare of current and future generations as it provides traditional resource-based activities, such as coastal fisheries, aquaculture, forestry and agriculture. Bangladesh has a difficult coastline (710 km) with many rivers and distributaries and complex ecology which is affected by natural challenges like cyclone, coastal flooding, tidal surges, shoreline erosion and salinity intrusion. Thus the exposed coastal areas of Bangladesh needs appropriate coastal protection works to prevent the intrusion of sea water into the main land and to mitigate the shoreline erosion.

Breakwaters are structures constructed parallel along the coastline used to attenuate waves and thus help prevent damage to shorelines, harbours and marine structures(Edwards et al., 2000). Many offshore breakwaters with their crest above the water have been built worldwide, known as emerged breakwater. Submerged breakwaters are distinguished from the emerged types in that here the crest of the structure is below the water level. Thus they avoid the generation of significant reflected wave that affect the nearby shoreline. Conventionally breakwaters are often solid for which porous structures can be a possible alternative. Porous structures protect the wave attack by dissipating wave energy through the viscosity induced resistance in the porous media. Submerged breakwaters may ensure the early breaking of incident waves and dissipate most of the energy. Various aspects of two and three dimensional problems of wave interaction with submerged, bottom founded, or floating surface-piercing structures have been studied both numerically and experimentally by many investigators. Liao et al. (2013) studied on the wave breaking criteria and energy loss caused by a submerged porous breakwater on a horizontal bottom. Results show that almost all tested waves can be triggered to break when the ratio of the estimated equivalent deep water wave height to the freeboard of the submerged breakwater is greater than 1. Kondo &Toma (1972) did experimental studies to find the effect of characteristics of incident waves and of the thickness of structure on wave reflection and transmission. They concluded that the relative thickness (= B/L, where B = the width of the structure and L = wave length) of the structure has appreciable effects on reflected and transmitted wave energies. Their study has shown that the reflection coefficient reaches a maximum for B/L of 0.2 – 0.25, then decreases as the B/L increases, and remains approximately uniform for B/L larger than about 0.6. (Kakuno et al., 2003) did a theoretical and experimental study on scattering of small amplitude water waves in which they have found that wall with greater height tends to scatter the flow much than wall with lower height.

In this study work, the functional performance of horizontal slotted submerged (porous) breakwater will be evaluated in terms of wave height reduction, reflection, transmission and wave energy dissipation caused by this breakwater. To assess the performance of horizontal slotted submerged breakwater in reducing wave action a laboratory experiment has been conducted. The reflected waves and the dissipated wave energy are strongly affected water depth, wave properties such as period and height and structure properties.

2. METHODOLOGY

2.1 Experimental Set-up

To investigate the performance of the proposed horizontal slotted submerged breakwater, experimental studies are carried out in a two-dimensional wave flume at the Hydraulics &River Engineering Laboratory of Bangladesh University of engineering and Technology. The flume is 21.3 m long, 0.76 m wide and 0.74 m deep where a breakwater is placed at 800 cm far from wave generator. The transmitted waves through the permeable breakwaters are absorbed by a wave absorber placed at the end of the wave flume. Six measuring tapes are used to measure the water level in six different locations and twelve experimental runs are conducted. The experimental setup is shown below in Figure 1. The laboratory flume and wave generator are shown in Figure 2.

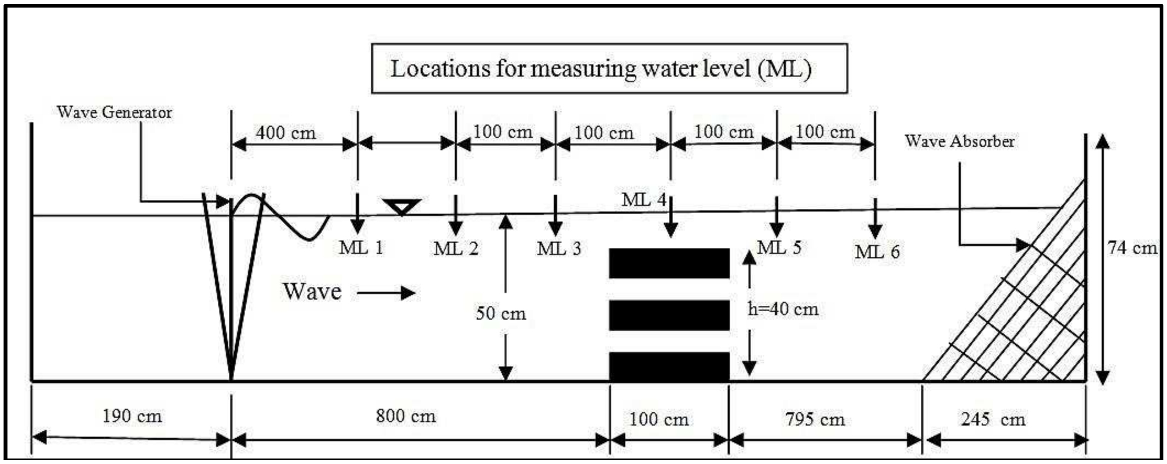


Figure 1: Detail of the Experimental Set-up

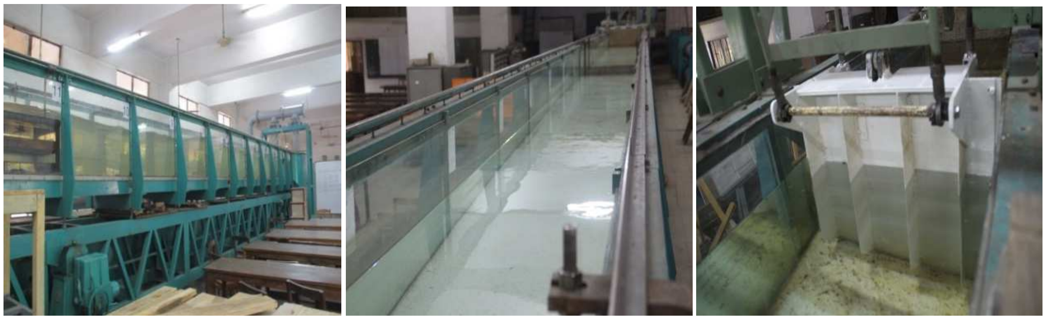


Figure 2: Laboratory Wave flume (1stand 2ndfrom the left); Wave Generator (3rdone)

2.2 Wire Screensand Wave Absorber

Screens made of coarse wire mesh kept at 6 inch from each other were placed in front of the wave generator to reduce wave reflections. In total 15 screens were used. To dampen the transmitted wave that passes through and over the breakwater, a wave absorber is installed at the end of the wave flume. The wave absorber is 245 cm in length with a sloped surface of 3.3H: 1V. The function of the wave absorber is to reduce the generation of reflecting or 'bounced back' wave by dissipating the energy of the transmitted wave. Figure 3 shows the photo views of the wire screen and wave absorber.

Figure 3: wire screen (1stfrom the left); wave absorber (2nd and 3rd)

2.3 Horizontal Slotted Submerged Porous Breakwater

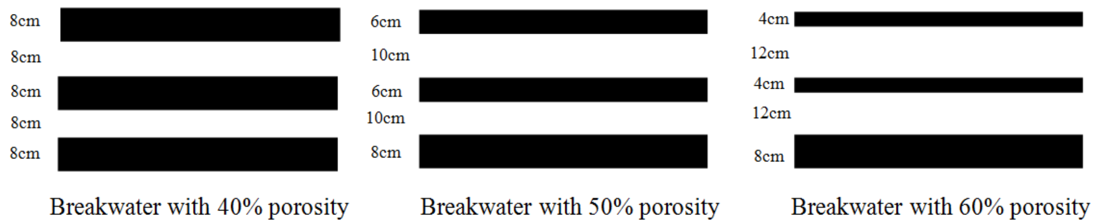
A steel frame was used to encapsulate wooden planks to construct the breakwater. Along the wave direction the width of the breakwater was 100 cm, length of the breakwater was 76 cm, equal to the width of the flume. Figure 4 shows the front view and longitudinal view of the breakwater.

Figure 4: Front View-along of breakwater (left); Longitudinal view (right)

Three different breakwaters were having different porosities (n=0.4, 0.5, 0.6) were constructed. To make the porous breakwater, initially a rectangular framework was constructed by steel angles. Then wooden planks of different thicknesses- 8 cm, 6 cm and 4 cm were placed inside the steel frame to have the desired varying porosities.

2.4 Construction of breakwater

Breakwater with 40% porosity has been constructed by using three wooden planks of 8 cm thickness and leaving gaps of 8 cm in between the planks. Using an 8 cm wooden plank at bottom and two 6 cm wooden planks at middle and top leaving two gaps of 10 cm the breakwater with 40% porosity has been constructed. Construction of breakwater with 60% porosity is done by using an 8 cm wooden plank at the bottom and two 4 cm planks at middle leaving two spaces of 12 cm in between. Figure 5 shows the configuration of the breakwater with 40%, 50% and 60% porosity respectively from the left.



Breakwater with 40% porosity Breakwater with 50% porosity Breakwater with 60% porosity

Figure 5: The configuration of the breakwater with 40%, 50% and 60% porosity (left to right)

2.5 Basis of Breakwater Size Selection

Dick and Brebner (1968) proved in their study on solid and permeable submerged breakwaters that form optimum reduction in transmitted wave height, breakwater width B should be as large as possible up to 2 wavelengths. For being an uneconomical proposition, narrower breakwater with greater height was investigated later. Kawasaki and Iwata(2001) investigated the breaking limit and the breaker type due to submerged trapezoidal breakwaters and found that for relative structure height $h_s/h=0.8$, usually the waves break when the relative breakwater width B/L is in the range of 0.2 to 0.4. In this study, laboratory experiments are conducted for four different wave periods ranging from T=1.6 sec to 2 sec and corresponding wavelengths of 250 cm to 400 cm. For optimum reduction in transmitted wave height, the breakwater width along the wave direction was selected as 100 cm so that the relative structure width B/L ranges from 0.25 to 0.4. Breakwater lengths are usually selected to cover the protection required length of the coastline. In this study the breakwater length is selected as 76 cm.

2.6 Experimental Run

Regular waves of different wave periods ranging from T=1.6 sec, 1.7 sec, 1.8 sec and 2 sec were generated in the wave flume. The still water depth was kept constant at 50 cm for all the runs. The run was carried out after adjusting the wave generator and setting the frequency of the wave paddle of the wave generator results in a deviation of the wave period (maximum 0.1%) from the required wave period. When the actual wave period was seen quite close to the designated wave period by some minor adjustment in the wave generator, then the experiment was carried out and measurements of water level at six different locations were taken for different run conditions. Table 1 presents the test scenarios.

Table 1: Test Scenarios of the Experiment

Run No	**Wave Properties**			**Breakwater Properties**			**StillWater Depth h (cm)**
	Wave Period T(sec)	**Wave Length L(cm)**	**Incident wave height H_i(cm)**	**Porosity (n)**	**Width (cm)**	**Height (cm)**	
1	1.6	307	14	0.4	100	40	50
2	1.7	332	14.5				
3	1.8	357	16				
4	2.0	406	17				
5	1.6	307	12.5	0.5			
6	1.7	332	13				
7	1.8	357	13.75				
8	2.0	406	14.5				
9	1.6	307	9.5	0.6			
10	1.7	332	11.5				
11	1.8	357	13				
12	2.0	406	14				

3. DATA ANALYSIS AND RESULTS

3.1 Analysis of Water surface Profile

Figure 6 shows the temporal variation of water surface. Installation of the submerged porous breakwater has caused the reduction of incident wave energy. Among the three different porosities, wave height reduction is greater for n=0.4 than the other porosities at the same wave period.

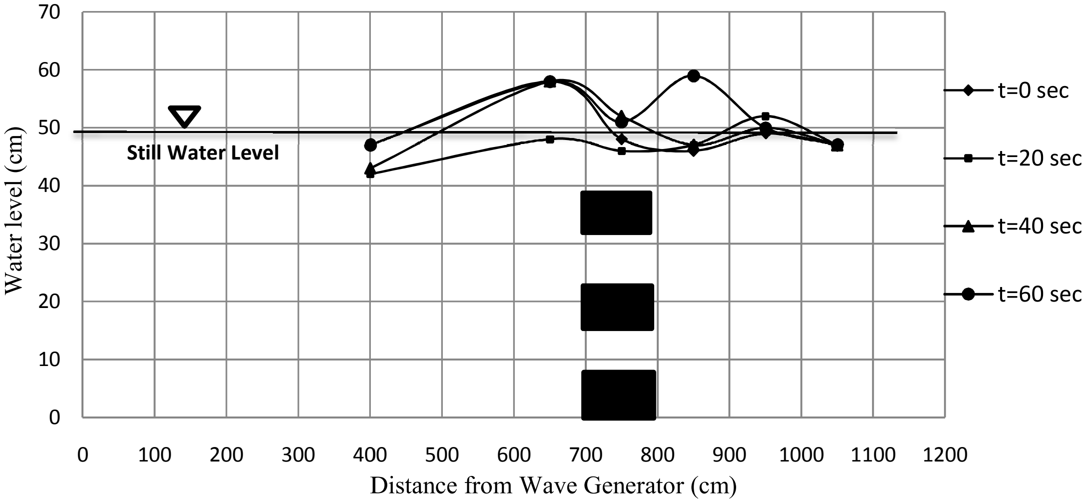


Figure 6(a): Water surface profile for wave period, T=1.6 sec; porosity, n=0.4

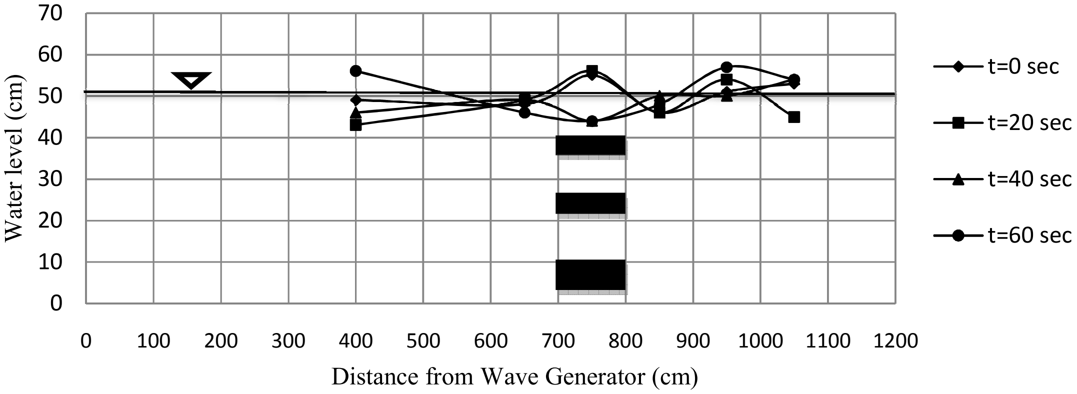


Figure 6(b): Water surface profile for wave period, T=1.6 sec; porosity, n=0.5

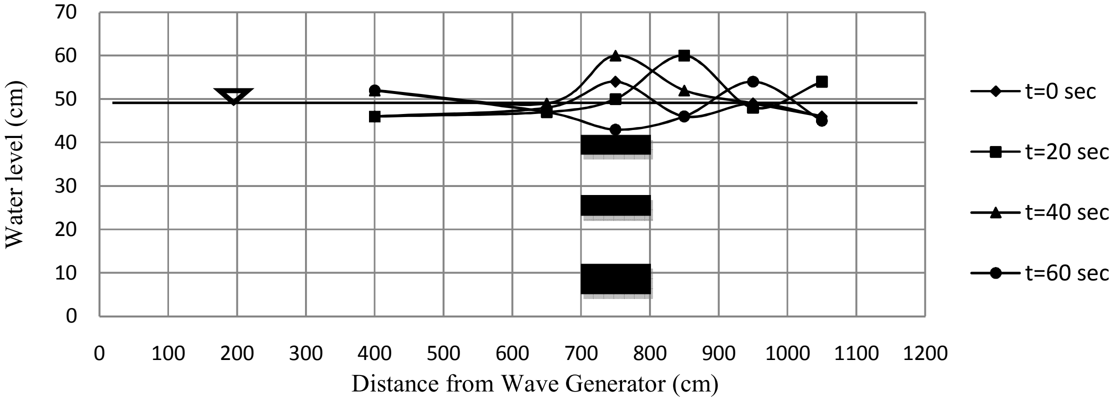


Figure 6(c): Water surface profile for wave period, T=1.6 sec; porosity, n=0.6

From Figure 6(a) to 6(c), it is observed that for the interaction of the wave period T=1.6 sec with less porous breakwater of n=0.4, the incident wave height of 9.5 cm reduces to 5 cm at the onshore side of the structure. For n=0.5, reduction was from 12.5 cm to 7 cm and for n=0.6 incident wave height reduced from 14 cm to 9 cm. Thus for T=1.6 sec breakwater having n=0.4 reduces 47.4% of incident wave height whereas breakwater having n=0.5 and n=0.6 reduced incident wave height up to 44% and 35.71% respectively. For T=1.7 sec and breakwater having porosity n=0.6 reduces 34.5% incident wave height whereas n=0.5 reduced the height up to 34.6% and maximum wave height reduction of 39.1% was attained by the breakwater having least porosity (n=0.4) for the same wave period. Observing the wave height reductions for T=1.8 sec for different porosities of 0.4, 0.5, 0.6 the reduced wave heights were found to be 38.5%, 34.5% and 31.25% respectively. Evidently, the most effective breakwater for T=1.8 sec is also the one with the least porosity of n=0.4. For T=2 sec, the breakwater having porosity of 40 % has caused the maximum reduction of wave height of 35.7%,whereas n=0.5 porous breakwater can reduce the wave height up to 24.1% and n=0.6 reduced the wave height up to 17.64%. Thus it is evident that even for the wave period of T=2 sec, maximum wave attenuation was made possible by the breakwater having the least porosity. Thus from Figure 6 it is substantiated that for all the wave periods 1.6 sec, 1.7 sec, 1.8 sec and 2 sec maximum wave height reduction was caused by breakwater having the least porosity.

3.2 Variation of Water Surface/Incident wave Height, η/Hi with t/T

Variation of water surface (η) of transmitted wave (measured at location ML6 behind the breakwater) with time (t) is shown in the non-dimensional form as variation of η/Hi with t/T in Figure 7.

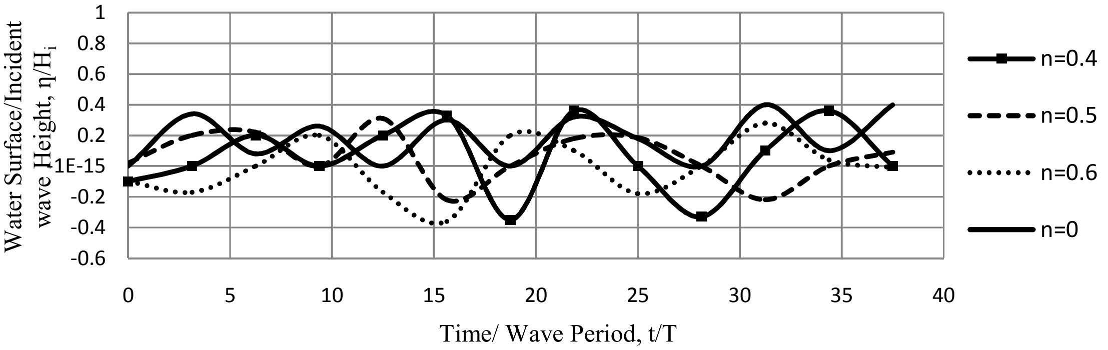


Figure 7(a): Variation of η/Hi with t/T for T=1.6 sec at ML6

In Figure 7(a), for wave period T=1.6 sec, the incident wave height Hi = 9.5 cm is reduced after breaking due to breakwater installation. When the breakwater porosity is 0.4 the incident wave height is 47.4% reduced. For installation of breakwater of n=0.5, the wave height is reduced by 44% of the incident wave height. When the breakwater porosity is n=0.6, 35.71% wave height is reduced due to wave breaking. For the same wave period, previous studies done by Rahman and Womera (2013) in the same wave flume in case of solid breakwater (n=0) of 40 cm height, wave height reduces up to 59% which is shown in Figure 7(a).

In Figure 7(b), for wave period T=1.7 sec, When the breakwater porosity is 0.4 the incident wave height is 39.1% reduced. For installation of breakwater of n=0.5, the wave height is reduced by 34.6% of the incident wave height. When the breakwater porosity is n=0.6, 34.5% wave height is reduced due to wave breaking. For the same wave period, previous studies done by Rahman and Womera (2013) in the same wave flume in case of solid breakwater (n=0) of 40 cm height, wave height reduces up to 60% which is shown in Figure 7(b).

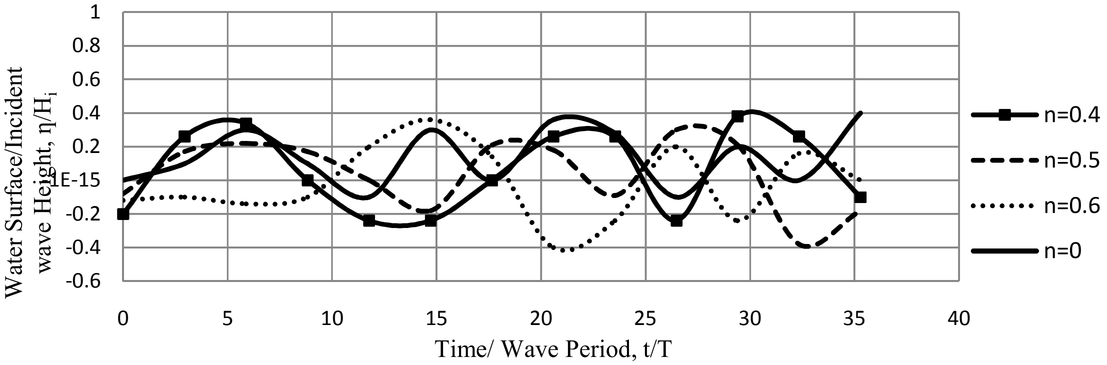


Figure 7(b): Variation of η/Hi with t/T for T=1.7 sec at ML6

For wave period T=1.8 sec, When the breakwater porosity is 0.4 the incident wave height is 38.5% reduced. For installation of breakwater of n=0.5, the wave height is reduced by 34.5% of the incident wave height. When the breakwater porosity is n=0.6, 31.5% wave height is reduced due to wave breaking. For the same wave period in case of solid breakwater (n=0) of 40 cm height, wave height reduces up to 58%.For wave period T=1.8 sec, When the breakwater porosity is 0.4 the incident wave height is 35.6% reduced. For installation of breakwater of n=0.5, the wave height is reduced by 24.1% of the incident wave height. When the breakwater porosity is n=0.6, 17.7% wave height is reduced due to wave breaking. For the same wave period in case of solid breakwater (n=0) of 40 cm height, wave height reduces up to 55% (Rahman and Womera, 2013)

3.3 Determination of hydrodynamic co-efficient

The usual practice of assessing the functional efficiency is performed by the measure of wave reflection, transmission and wave energy loss coefficient. In practical design of the porous breakwaters these coefficients are obtained either by conducting physical model tests or by using appropriate theoretical, empirical or numerical models.The maximum and minimum wave heights (H_{max} and H_{min}) at the wave generator side, upstream the breakwater and the transmitted wave heights (H_t) at the wave absorber side, downstream the breakwater were measured to estimate the reflection and the transmission coefficients (K_r and K_t) as follows:

$$H_i = \frac{(H_{max} + \mathrm{Hmin})}{2} \text{and } H_t = \frac{(H_{max} - H_{min})}{2} \qquad (1)$$

Where,H_{max}= maximum wave height measured at antinode and H_{min}= minimum wave height measured at nodes. Then we have$K_r = \frac{H_r}{\mathrm{Hi}}andK_t$=$\frac{H_t}{H_i}$ (2)

Where, H_i= Incident wave height, H_r=Reflected wave height, H_t= Transmitted wave height

Based on energy conservation, the energy loss coefficient K_L can be calculated from the following relation (Thornton and Calhoun 1972):K_r^2+K_t^2+K_l^2 =1. (3)

3.2.1 Effect of Porosity on the wave reflection coefficient (Kr)

Figure 8 represent the relationship between the wave reflection coefficient (Kr) and the relative breakwater width (k.B= 2Bπ/L), for n=0.4, 0.5 and 0.6, where k is the wave number 2π/L, B is the breakwater width and L is the wavelength.

K_r=H_r/H_i where H_r is reflected and Hi is incident wave height; H_i= (H_{max} + H_{min})/2 and H_r= (H_{max} - H_{min})/2. H_{max} is maximum wave height measured at anti-nodes and H_{min} is the minimum wave height measured at nodes.

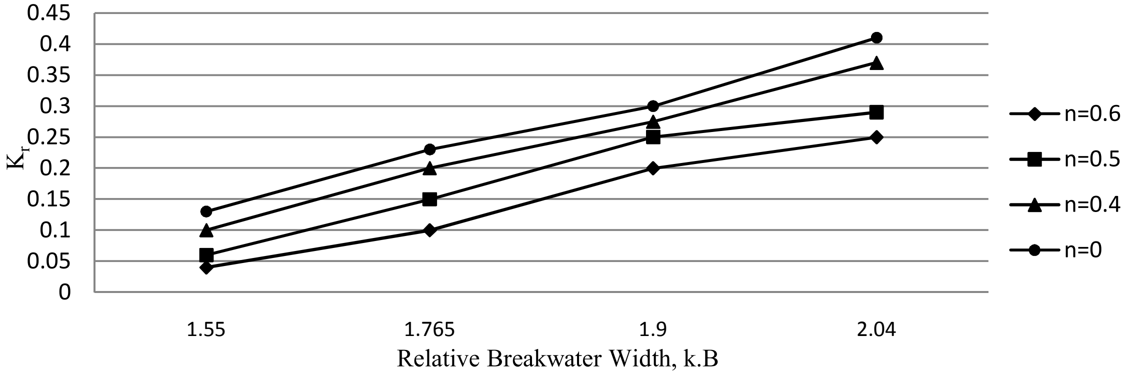


Figure 8: Effect of breakwater porosity on reflection coefficient

The Figure 8 shows that K_r increases as relative breakwater width increases. This may be attributed to the increase of the wave energy loss as the width of the porous media increases. Again the reflection coefficient decreases as porosity increases.Reflection coefficient decreased from 0.368 to 0.107 as k*B increases from 1.55 to 2.50 when structure porosity was n=0.4, decreased from 0.286 to 0.059 when structure porosity was 0.5 and decreased from 0.24 to 0.034 when porosity was n=0.6. For n=0, a study previously done by Rahman and Womera (2013) in the same flume with a breakwater height of 40 cm and still water depth at 50 cm shows that reflection coefficient has a higher value in case of solid structure. So it is evident from the Figure 8 that when n=0.6 porosity of the breakwater was used, the reflection coefficient shows very less value as most of the wave energy passes through the breakwater and less reflectance occurs.

3.2.2 Effect of porosity on the wave transmission coefficient (K_t)

Figure 9 represents the relationship between the transmission co-efficient (K_t) and the relative breakwater width k*B. The figure shows that the transmission co-efficient decreases as k*B increases which implies that the wide breakwater reduces the transmitted waves more as compared to narrow breakwater.

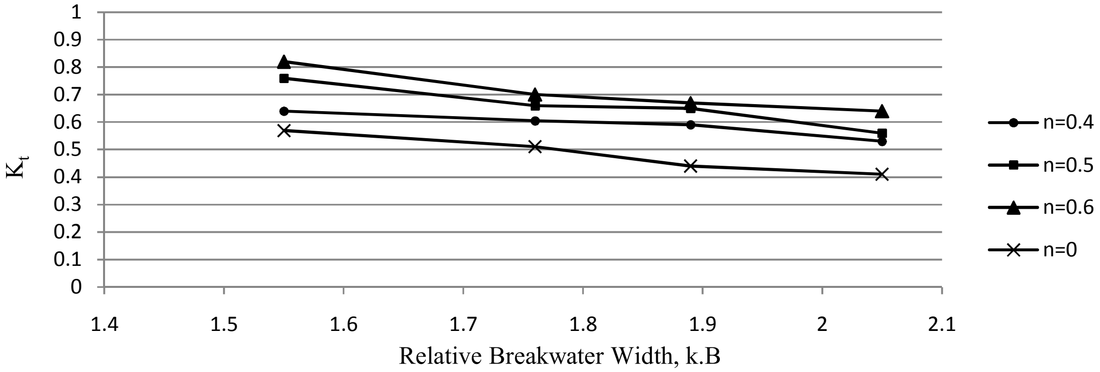


Figure 9: Effect of breakwater porosity on the transmission coefficient

There can be two plausible reasons which can be attributed to above mentioned behaviour. First, the increase of the breakwater width causes the increase of the friction between the breakwater surface and the transmitted waves, causing more loss of wave energy. Second, as the wave becomes short the water particle velocityand acceleration face changes and the turbulence caused due to these changes cause dissipation in the wave energy.
In Figure 9, when porosity n=0.4, the transmission coefficient (K_t) decreased from 0.64 to 0.53 for k*B increasing from 1.55 to 2.50. When porosity increased to n=0.5, transmission co-efficient (K_t) decreased from 0.76 to 0.56, and when the porosity is n=0.6, Kt decreased from 0.82 to 0.64 with increasing k*B from 1.55 to 2.50. For n=0, a study previously done by Rahman and Womera (2013) in the same flume with a breakwater height of 40 cm and still water depth at 50 cm shows that transmission coefficient has the least value which is desirable.

3.2.3 Effect of porosity on the wave energy loss coefficient (K_L)

Figure 10 depicts the relationship between the wave energy loss coefficient (K_L) and the relative breakwater width k*B for varying porosities of n=0.4, n=0.5 and n=0.6. The straight line with increasing slope shows that wave energy loss coefficient increases as the porosity increases.In Figure 10 when porosity n=0.4, the wave energy loss coefficient increased from 0.78 to 0.81 for k.B increasing from 1.55 to 2.5. For porosity n=0.5, KL increased from 0.66 to 0.78 and for n=0.6 porosity, KL increased from 0.58 to 0.73 for an increase of k.B from 1.55 to 2.5.

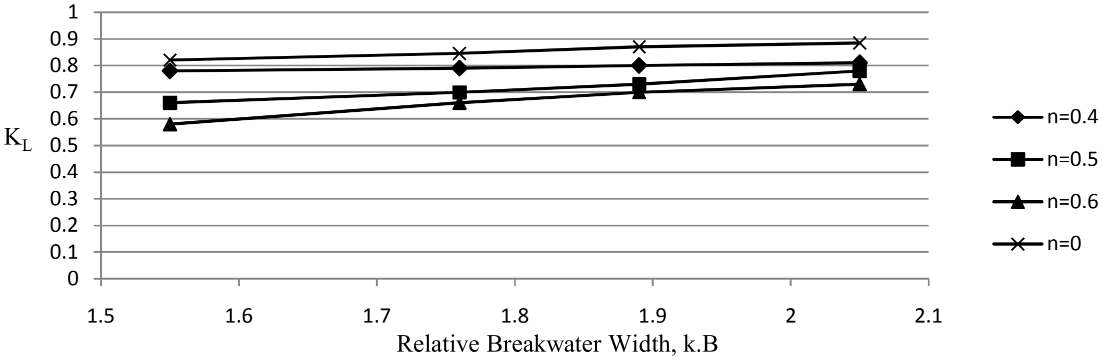


Figure 10: Effect of breakwater porosity on the wave energy loss coefficient

Thus from the above Figure 10 and discussion it can be concluded that wave energy loss coefficient is higher for less porous structure. Maximum value is attained for solid structure (porosity, n=0) For n=0 from a study previously done by Rahman and Womera (2013) in the same flume with a breakwater height of 40 cm and still water depth at 50 cm. This is due to the fact that most of the wave energy can be transmitted through the highly porous structure.

4. CONCLUSION

In this study the interaction between wave and horizontal slotted submerged breakwater has been investigated experimentally to find out the effective size and porosity of this protection structure for the reduction of wave height. In a two dimensional wave flume twelve experimental runs have been conducted with the horizontal slotted submerged body of three different porosities (n=0.4, 0.5, 0.6) in still water depth h= 50 cm for regular waves of four different periods of T=1.6 sec, 1.7 sec, 1.8 sec and 2.0 sec respectively. The functional efficiency of horizontal slotted submerged porous breakwater is measured by wave reflection, transmission and wave energy loss co-efficient. Wave reflection coefficient increases as relative breakwater width (k.B) increases (k.B= 2Bπ/L, where k is the wave number). Also the reflection coefficient decreases as porosity (n) increases. Reflection coefficient decreased from 0.368 to 0.107 with decreasing k.B from 2.05 to 1.55 when structure porosity was n=0.4, decreased from 0.286 to 0.059 when structure porosity was n=0.5 and decreased from 0.24 to 0.034 when structure porosity was n=0.6.The transmission coefficient decreases as relative breakwater width k.B increases. This implies that the breakwater reduces the transmitted waves as the breakwater width (B) increases or the wave length (L) increases. Wave energy loss coefficient increases as relative breakwater width increases. Also the wave energy loss coefficient increases as the porosity decreases. When porosity is n=0.4, the wave energy loss coefficient increased from 0.61 to 0.68 with increasing k.B from 1.55 to 2.05. For porosity n=0.5, K_L increased from 0.56 to 0.63 and for n=0.6, K_L increased from 0.47 to 0.55 with increasing k.B from 1.55 to 2.05.The transmission coefficient is found minimum for minimum porosity of n=0.4 which is 0.52 and increased to 0.64 with the increasing porosity of n=0.6. Also the wave energy loss coefficient is found maximum for minimum porosity of n=0.4 which is 0.83and decreased to 0.71 with the increasing porosity of n=0.6.

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