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EXPERIMENTAL INVESTIGATION ON WAVE INTERACTION WITH SUBMERGED GEOTUBE BREAKWATER

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ABSTRACT

In this research work, the interaction between wave and geotube breakwater as a coastal protection structure has been investigated experimentally in a two-dimensional wave flume. Geotube breakwater is a cost-effective & adaptable measure in breaking waves as far as management of the coastal environment is concerned. Mutual interaction between monochromatic waves of different time periods (T=1.6s, 1.7s, 1.8s, and 2.0 s) and three different scenarios of geotube placements with different heights (hb=30cm, 40cm, and 50 cm) has been studied at 50 cm still water level in the laboratory flume. Results obtained from experiments inform that the minimum value of transmission coefficient (Kt=0.54) is observed for breakwater when the relative submergence hb/h=1.0 and for the shortest wave scenario (T=1.6sec). Minimum reflection coefficient (Kr=0.11) is attained for relative submergence hb/h=0.8. Notably, the effect of increasing relative breakwater width (KxB) on the reflection coefficient is very low. It is also found that the wave energy loss coefficient (KL) increases with increasing relative breakwater height. The study is also used to show that the geotube breakwater has better transmission and energy loss coefficient than single wall vertical slotted breakwater. However, double wall vertical slotted breakwater is proven to be more effective than submerged geotube breakwater.

Keywords: *geotube, submerged breakwater, shore protection, coastal management*

1. INTRODUCTION

Breakwaters are structures that are built offshore to absorb the energy of approaching waves. Due to the scarcity of construction materials such as natural rocks, construction and maintenance of traditional shore protection structures are becoming significantly expensive. As a result, many are inclined to opt for cheaper materials and systems in place of traditional rubble and concrete breakwaters (Shabankareh et al., 2017). Geotextile tubes filled with soil are an alternative and cheaper approach to normal fixed solid breakwaters. These are utilized in coastal protection due to their flexibility and resistance capacity against erosion (Lim et al., 2022). These tubes are generally long and made of polypropylene. In developing countries, these sand-filled bags have recently emerged as cost effective shore protection measures(Khajenoori et al., 2021). According to (Oberhagemann & Rahman, 2011), geotextile bags work better than concrete blocks as an underwater protective measure. In many countries, sand-filled geotextile bags are used as core elements of longshore protection(Khajenoori et al., 2021). Nowadays, these tubes are predominantly used as breakwaters, groins, and elements of various coastal management systems (Zimmermann et al., 2005).

Geotube breakwater containers can be filled with locally available soil which may be available from simultaneous dredging activities (Howard et al., 2018). Geotextiles sand filled bags are used as geotube breakwaters to protect against repeated erosion (Thompson et al., 2020). Regardless of weather conditions, current velocities, tidal movements, or water depths, containers can be positioned relatively correctly. During and after placement, contained material is not prone to erosion. Geotubes allow for a reasonably quick system setup. Geotubes are, therefore, soft and very cost competitive measures (for larger works) compared to conventional hard protections(Maurya et al., 2022). The efficiency of solid and geotube breakwaters has been the subject of several experimental and numerical research. (Sultana & Rahman, 2017) investigated the hydrodynamic performance of multiple row pile breakwater for each of submerged and emerged conditions as a coastal protective measure. (Rahman & Womera, 2013) studied the interaction of waves with a rectangular submerged impermeable breakwater both experimentally and numerically. (Rahman & Akter, 2014) assessed the hydrodynamic performance of a rectangular porous breakwater in both submerged and emerged conditions. The breakwater with the highest porosity had the lowest reflection coefficient. With increased porosity, the wave energy loss coefficient rises. It is clear from the studies that relative submergence affects these coefficients too. (Elias et al., 2021) investigated the stability parameters and damage characteristics of the geotextile sand container structure. It was revealed that increasing the sand fill ratio from 80% to 100% can increase structural stability up to 14% while increasing bag size also resulted in significantly increased stability.

(Koerner, 2000) reported that geotextile tubes can provide better protection for beach erosion. Geotextile tubes of diameters of up to 3m, made up of woven or knitted high strength fabric have been effectively used to control both inland and oceanfront erosion. (Shin et al., 2002) conducted pilot scale field tests to investigate the performance of geotubes constructed of woven geotextile and filled with dredged silty clay material by hydraulically pumping it into it. According to the findings, geotubes are a viable construction material for use in coastal engineering projects. (Tan et al., 2007) have shown the efficiency of geotextile tubes as a component in erosion control. (Yuanita et al., 2021) have shown that the effectiveness of geobag structure is widely dependent on the incoming wave height and the dimensionless wave steepness.

In this investigation, experiments are conducted in a two dimensional laboratory flume to investigate the hydrodynamic performance of geotube breakwater(s) for the submerged condition under wave actions. This is run under regular waves with various wave periods and wave heights, where the breakwater height is variable but the still water level is fixed.

2. MATERIAL & METHOD OF EXPERIMENT

2.1 Experimental Setup

The experimental runs are conducted in a rectangular flume having dimensions of 21.3 m long, 0.76 m wide, and 0.74 m deep in the Hydraulics and River Engineering Laboratory at Bangladesh University of Engineering & Technology (BUET). The breakwater was placed at 800 cm far from the wave generator. For all experimental sets, a constant water level of 50 cm is maintained in the two dimensional flume. A flap type wave generator positioned at the upstream end of the wave flume generated regular waves with four different wave periods (T=1.6 s, 1.7 s, 1.8 s, and 2.0 s). To absorb and damp the incoming waves at the onshore side of the flume, a wave absorber was placed at the dead end of the flume. Three variable heights of 30 cm, 40 cm and 50 cm are used to create three different relative structure height (relative submergence), h_b/h = 0.6 (submerged), 0.8 (submerged) and 1.0(submerged).

2.2 Geotube Material & Preparation

In most cases. geotextiles are made of polypropylene, polyethylene, and/or polyester (Zornberg et al., 2012). In this laboratory experiment, the geotube breakwater is made using a geotextile fabric bag (100% polypropylene fabric, Mass>=300 gm/m2, Unit weight: 855 kg/m3 to 946 kg/m3, thickness: 3mm) and collected from Bangladesh Water Development Board (BWDB). The bag is filled with alluvial sand collected from the river bed. The particle size of filling material is the ultimate parameter for geobag preparation. If it is not in the expected size, the soil may pass through the bag. Normally, sands that are 90% retained in the #100 sieve or sand greater than 1.50 mm are used as material. In rare scenarios, Sylhet Sand is used as the filling material. In this experiment, sand greater than 1.50 mm is used. This is done following the guideline of BWDB. As the width of the total breakwater was selected 100cm, so two bags having a width of 50 cm were used for the base of the breakwater. Depending on the relative submergence the height of the breakwaters was selected. For Relative Submergence of 0.6, two bags were kept side by side, and the height of both of them was 30 cm. For relative submergence 0f 0.8, three bags were used. 2 bottom bags were 30 cm in height and the bag kept at the top of them was 10 cm. For relative submergence of 1.0, similarly, three bags were used and the bag at the top was made 20 cm high. Figures 1(a) and 1(b) respectively demonstrate the long and lateral view of geotube breakwater placed inside the flume.

Figure 1(a): Geotextile tube filled with sand (Longitudinal View)

Figure 1(b): Geotextile tube filled with sand (Lateral View)

2.3 Experimental Run

Twelve laboratory runs were created by the interaction of regular waves of four distinct wave periods with a breakwater of three different heights. Wave heights were measured at five locations for each of the twelve experimental scenarios: two upstream of the structure, one over the structure, and the last two downstream of the structure. The water surface data is manually recorded by installing vertical glass scales on the flume side. Data of the water surface was recorded for one minute at five second intervals at each location. Figure 2 illustrates the experimental setup in further detail. Figure 3 depicts some snapshots of the equipment and data acquisition. In Figure 3(a) wave height measurement is shown. Figure 3(b) shows wave height interaction during the data collection. Figure 3(c) shows the wave height reduction downstream.

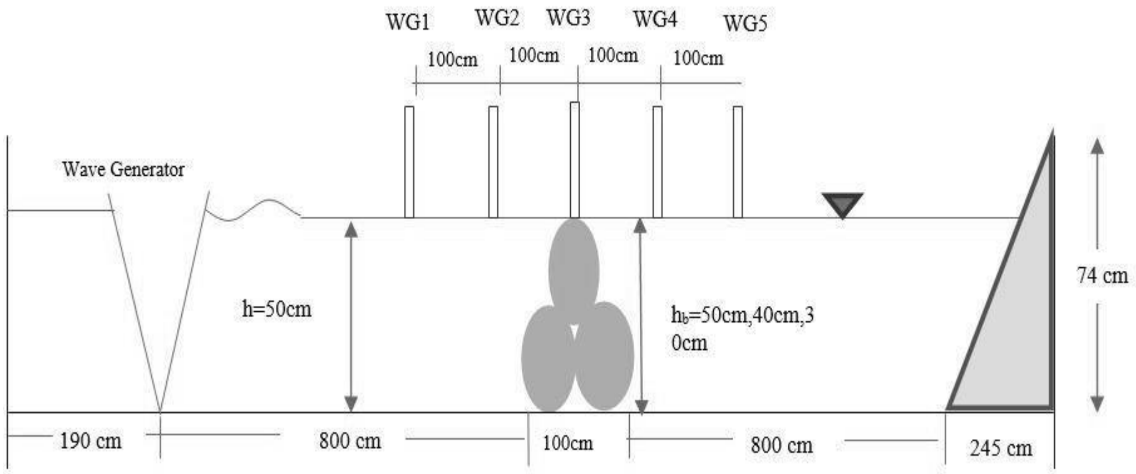

Figure 2: The experimental setup in detail

Figure 3(a): Data Collection in view (wave height measurement)

Figure 3(b): Data Collection in view (wave interaction with geotube)

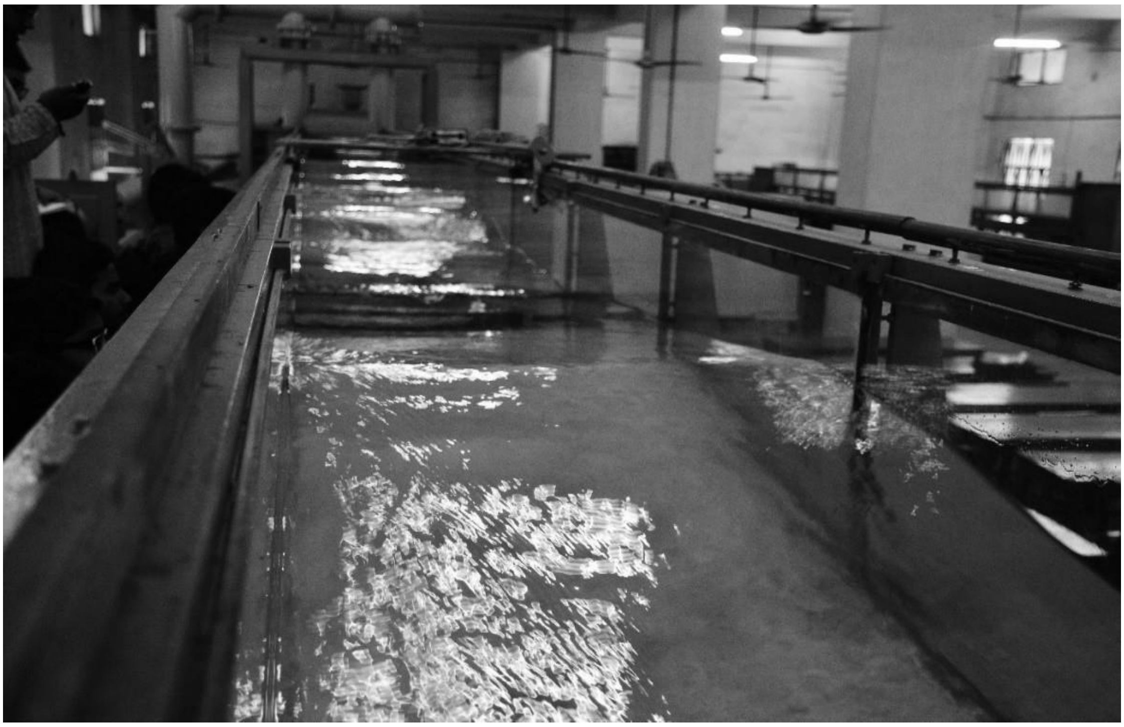

Figure 3(c): Data Collection in view (wave height reduction downstream)

2.4 Theory & Data Acquisition

The reflection, transmission coefficients (K_r & K_t) and the wave energy loss coefficient (K_L) are among some of the important parameters studied in this research. To calculate these, incident wave height (H_i) and reflected wave height (H_r) are required as $K_r = H_r/H_i$ and $K_t = H_t/H_i$ [H_t = transmitted wave height]. Again, the maximum height (H_{max}) & the minimum height (H_{min}) at both the upstream (wave generator side) and downstream (wave absorber side) were measured to estimate incident wave height (H_i) from $H_i = (Hmax + H\text{min})/2$ and reflected wave height(H_r) from $Hr = (Hmax - Hmin)/2$ formulas respectively. To accomplish this calculation, two wave gauges are placed at distances of L/4 and L/2 from the breakwater, where L is the wavelength. Surface water data is manually recorded for one minute at five second intervals at each position (antinode, L/4, and node, L/2). The difference between the maximum and minimum water surface readings at antinode and node, respectively, was used to compute the maximum or minimum wave heights ($Hmax + H\text{min}$) in cm.

The formula for the calculation of the energy loss coefficient was as proposed by (Thornton & Calhoun,1972) : $K_r^2 + K_t^2 + K_L^2 = 1$. To separate the incident and reflected wave components of the measured wave train, the traditional method of (Dean & Dalrymple,1991) is used.

3. RESULTS & DISCUSSIONS

3.1. Influence of relative submergence (h_b/h) and relative breakwater width ($k \times B$) on Transmission coefficient (K_t)

The relationship between the transmission coefficient (K_t) and relative breakwater width (k x B=2B/L) is shown in Figure 4, where k is the wavenumber. Relationships for Three breakwater ratios(h_b/h) are illustrated in three different lines in the same figure. It is shown that the transmission coefficient (K_t) decreases with the increase of relative breakwater width. The phenomenon means that when the breakwater width (B) or wavelength (L) grows, the breakwater lessens the transmitted waves. This particular wave characteristic can be explained by two major phenomena. One of them is that increasing the breadth of the breakwater increases the friction between the breakwater's surface and the transmitted waves, resulting in more wave energy being dissipated. Second, when the waves become shorter, the velocity and acceleration of water particles change abruptly. The turbulence that results from this occurrence causes the wave energy to dissipate. Furthermore, as hb/h increases, the transmission coefficient decreases. This could be due to a reduction in transmitted wave energy as the area through which water flows shrinks. Figure 4 indicates that as kxB climbs from 1.48 to 1.93, the transmission coefficient drops from 0.71 to 0.54 for hb/h =1.0. When hb/h = 0.8, it drops from 0.78 to 0.72, and when hb/h=0.6, it drops from 0.88 to 0.84.

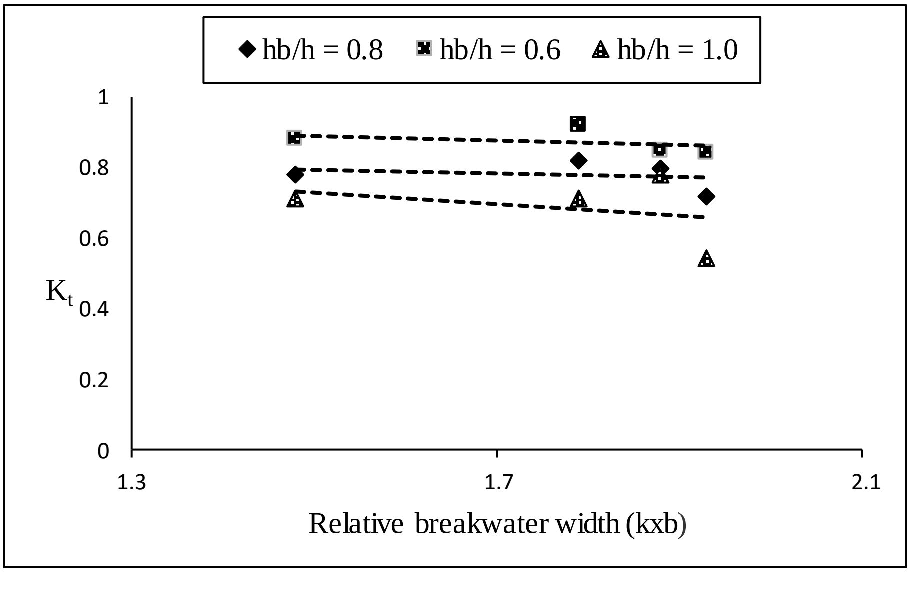

Figure 4: Influence of relative breakwater width on transmission coefficient (K_t)

3.2 Influence of relative submergence (h_b/h) and relative breakwater width ($k \times B$) on reflection coefficient (K_r)

Figure 5 shows that the wave reflection coefficient (Kr) and relative breakwater width (k x B = 2B/L), where k is the wavenumber, have a significant relationship. This statement holds for the breakwater ratios (hb/h) of 0.6, 0.8, and 1.0. The reflection coefficient (Kt) drops as (k x B) rises, as shown in the graph. This means that as the breakwater width (B) or wavelength (L) decreases, the breakwater reduces the transmitted waves.

Figure 5 shows how increasing kxB from 1.48 to 1.93 lowers the reflection coefficient from 0.14 to 0.13 for hb/h=1.0. Similar characteristics are observed for relative submergence of 0.8 and 0.6. Kr reduces from 0.14 to 0.13 when hb/h = 0.8, and from 0.13 to 0.12 when hb/h = 0.6.

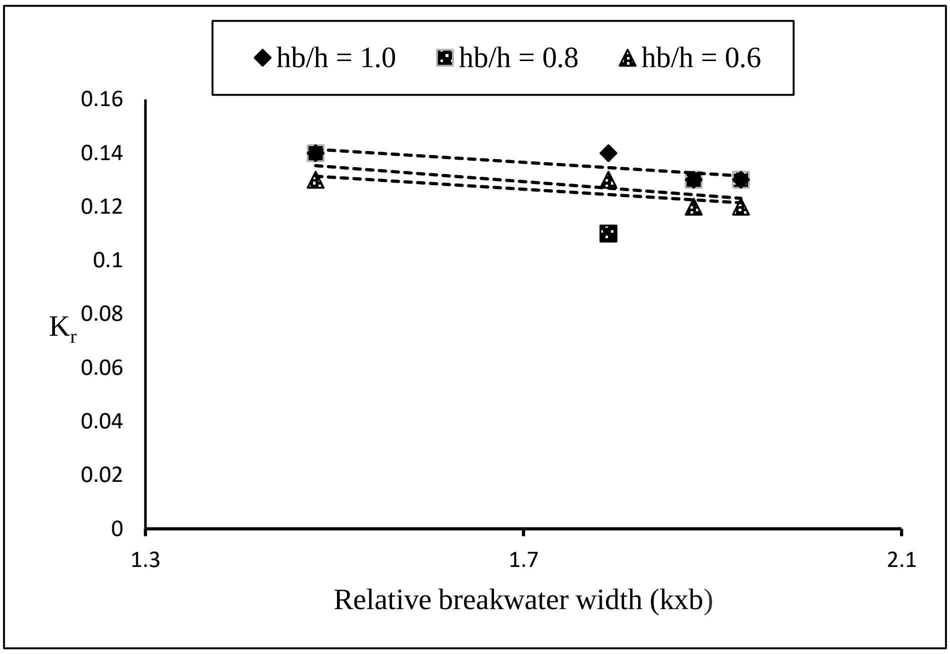

Figure 5: Effect of relative breakwater width on reflection co-efficient (K_r)

3.3 Influence of relative submergence (h_b/h) and relative breakwater width (k x B) on Wave energy loss coefficient (K_L)

Figure 6 presents the relationship between relative breakwater width and Energy Loss coefficient (K_L) for relative submergence of 1.0, 0.8, and 0.6 respectively when T=1.6, 1.7, 1.8, 2.0 sec. For every case, it has been found that with the increment of KxB, the Energy loss coefficient increases. For hb/h = 1.0, K_L increases from 0.68 to 0.82; For h_b/h=0.8, it increases from 0.60 to 0.67; For h_b/h 0.6, it increases from 0.45 to 0.49.

3.5 Relationship between K_t, K_r, and K_L in terms of relative submergence (h_b/h)

By observing the relationship between the increment of relative submergence and the change of behavior on the transmission coefficient (Kt), reflection coefficient (Kr), and the wave energy loss coefficient (KL), it is seen that the reflection coefficient and the wave energy loss coefficient both rise with increasing submergence. On the other hand, the transmission coefficient decreases. This is shown in Figure 7. The transmission coefficient reduces 19.32 % with rising submergence from 0.6 to 1.0 in the figure, whereas the reflection coefficient grows 7.69 % and the energy loss coefficient jumps 51.11 % for the same increment in relative submergence.

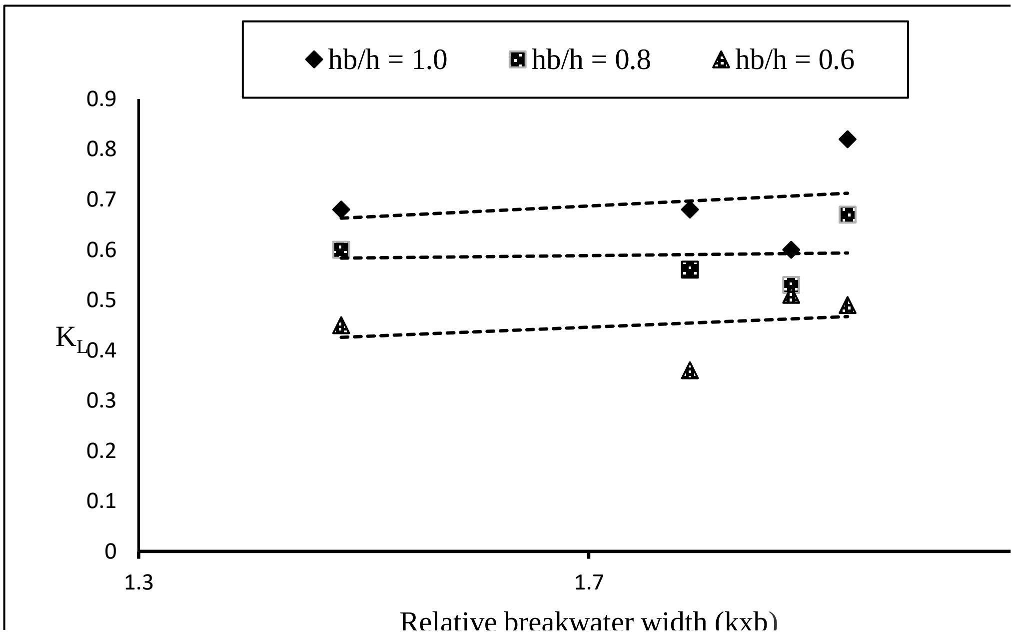

Figure 6: Influence of relative breakwater width on wave energy loss co-efficient

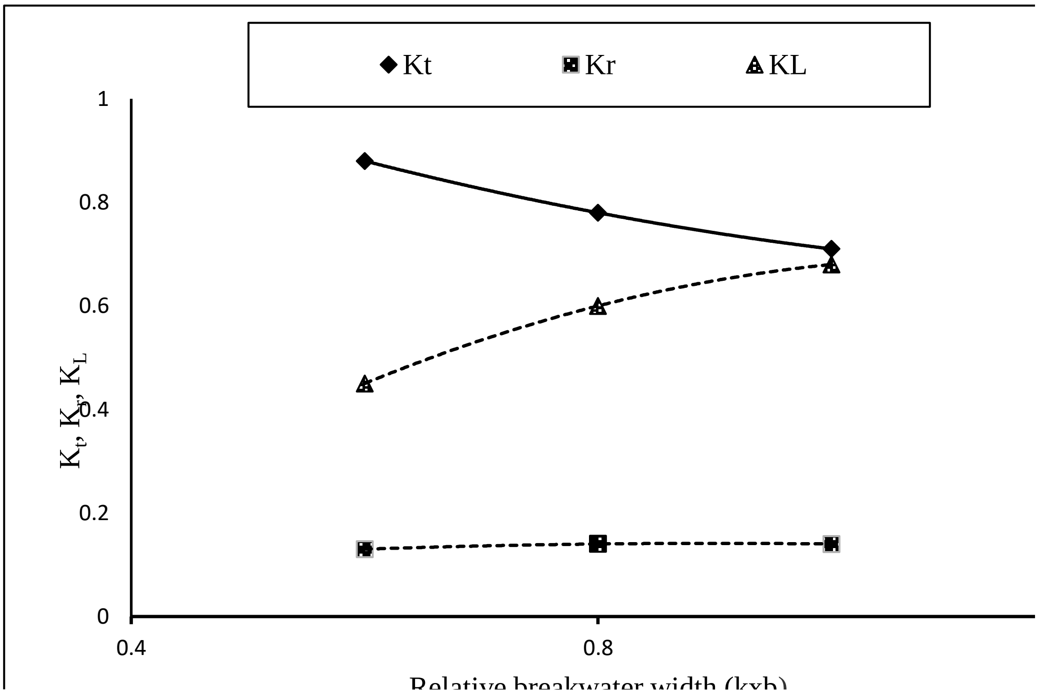

Figure 7: Influence of relative submergence on three coefficients (K_t, K_r, K_L) for T=1.6s

3.6 Comparison between Submerged Geo-tube Breakwater and Vertical Slotted Breakwater

(Shuvro & Rahman, 2018) investigated hydrodynamic performance of Vertical Slotted Breakwater(s) as a shore protection structure. Comparison between wave transmission coefficient (K_t) and energy loss co-efficient (K_L) of geo-tube breakwater with vertical wall breakwater is show in figure 8,9 for time period T = 1.6 sec for different submergence. From the figure we found that geo-tube breakwater has better transmission and energy loss co-efficient form than single wall vertical slotted breakwater, but not as effective as double wall vertical slotted breakwater.

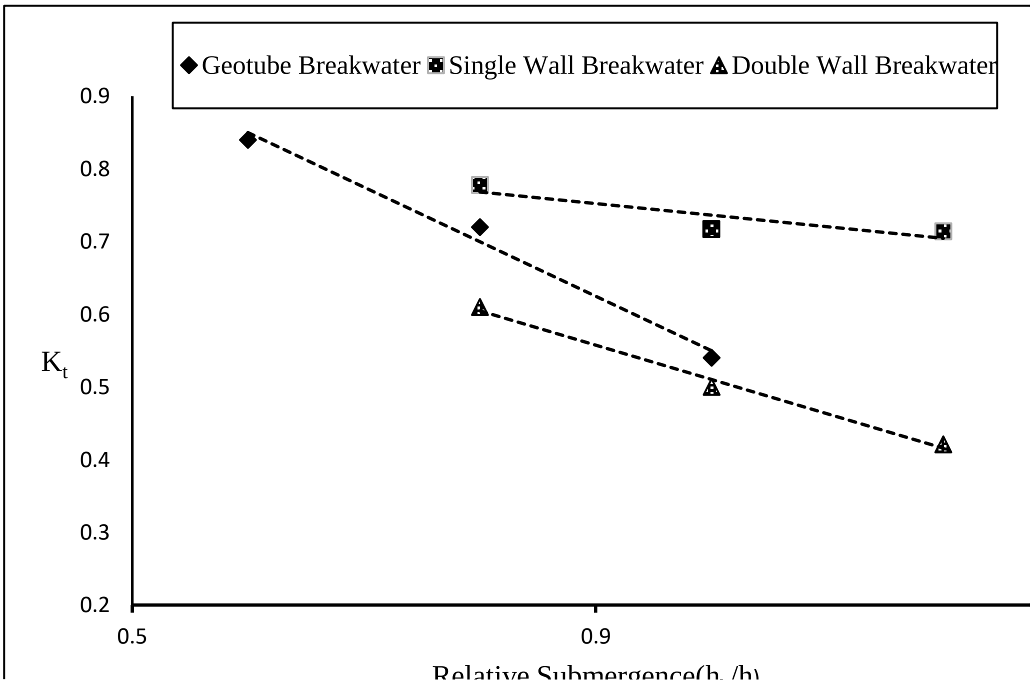

Figure 8: Comparison of Transmission coefficients (K_t) Between Vertical Wall Breakwater and Geotube Breakwater for T=1.6s

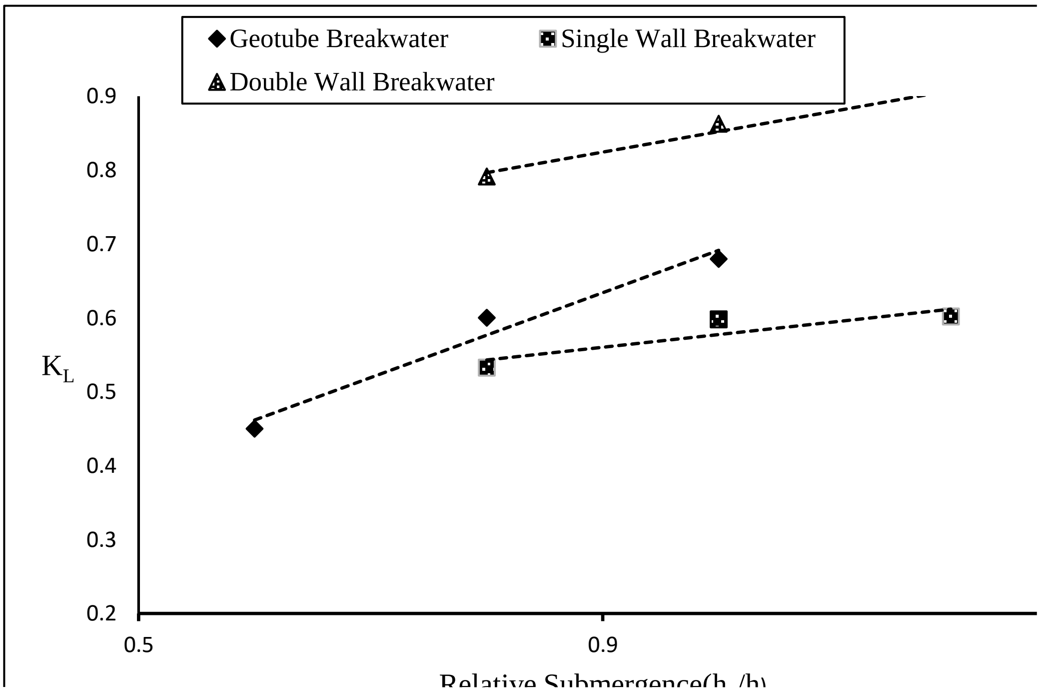

Figure 9: Comparison of Energy Loss Coefficients (K_L) Between Vertical Wall Breakwater and Geotube Breakwater for T=1.6s

4. CONCLUSIONS

It is clear from detailed and thorough experimental research and data analysis from twelve experimental runs that a higher breakwater can reduce incident wave height more than a smaller breakwater for the same wave period. As the relative breakwater width kxB grows, the transmission coefficient falls. This means that as the breakwater width (B) or wavelength (L) grows, the breakwater lessens the transmitted waves. The experimental analysis also shows that, for the short wave (T=1.6 s), the lowest transmission coefficient is obtained for relative submergence of 1.0. As the relative breakwater width kxB rises, the reflection coefficient drops as well. Again, results from experiments show that a minimum reflection coefficient is observed for the relative submergence of 0.6. Then, wave energy loss coefficient K_L increases with increasing kxB. In this case, like the reflection coefficient, the wave energy loss coefficient is lowest in the relative submergence 0.6.

It is also revealed that geo-tube breakwater has better transmission and energy loss co-efficient form than single wall vertical slotted breakwater, but not as effective as double wall vertical slotted breakwater. The performance of geotube breakwater is also affected by breakwater features such as relative submergence and breakwater width, according to the study. The values of these coefficients can be useful to coastal engineers for shoreline protection using geotubes and also understand coastal dynamics.

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