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Experimental Study on the Stability of Concrete Block Revetment for High Waves Propagating over Submerged Geotube Breakwater

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ABSTRACT

Bangladesh has a coastline of 710 km and a long sandy beach. Moderate and high waves causes erosion along the coastline. Concrete block revetment is widely used for shore protection in Bangladesh. As per Coastal Engineering Manual, concrete block revetment stability is limited to wave height of 1.5 m. Studies reveal that the significant wave heights are greater than 1.5 m in the most parts of coastline of Bangladesh. Therefore, in some places, the concrete block revetment has failed. Revetment constructed with Tetrapod, X-bloc, Core-loc etc. are recommended to use for high waves. However, those armor units are not suitable in the context of Bangladesh considering its cost, construction and placement. Moreover, any hard protection may stop the erosion and protect the shoreline, but the sandy beach may be lost. Geotube breakwater is low cost structure for dissipating wave energy to some extent. In this study, laboratory experiments have been carried out for wave height 1.76 m to 2.40 m (as prototype) with two layer protection consisting of concrete block revetment at the shore and submerged geotube breakwater at shallow water. Concrete block size has been calculated using Pilarczyk formula for prototype wave height 1.5 m and scaled down using surf coefficient for laboratory model. Seventeen laboratory runs have been conducted and analysis of the experimental results reveal that two layer protection is effect to protect the shore from high waves. An equation has been established to design the shore protection works along the coastline experienced by high waves.

1. Introduction

The importance to the economy and ecology makes the coastal zone one of the most significant areas of any country [1]. Bangladesh's coastal zone covers 47,201 square kilometers of land [2], which is around one-third of country's total land area. This area provides shelter, sustenance, and livelihood for nearly 35 million people [3]. Bangladesh's coastline measures around 710 kilometers in length [4]. The Cox's Bazar-Teknaf Marine Drive Road along the Cox's Bazar coastline was constructed to promote tourism prospects, the fishing sector, regional connectivity, and coastal resource management [5]. The project area is in a highly susceptible and hazardous environment [6]. To protect the Marine Drive Road, the Bangladesh government took shore protection work along the seaside of the road. Bangladesh Water Development Board (BWDB) was responsible for the design, and 17 ECB, Bangladesh Army was responsible for the construction of the shore protection work. [7]. Bangladesh Water development Board considered cubical shape concrete block as an armor unit of protective work. The revetment was built in 2008. But the revetment did not sustain for a long time. The revetment failed after completion of the work in 2009. It is to be noted that graded riprap or concrete bock in the shore protection revetment is not recommended for high waves (i.e. $H_s \geq 1.5$ m) [8]. But the maximum wave height was found 2.53 m along the Cox's Bazar coastline [5]. When the significant wave height is more than 1.50 m, other types of armor unit such as Tetrapod, X-bloc, Core-loc, etc. are recommended to use in the revetment [8]. When the concrete block is staggered rather than uniformly placed, the performance is determined to be good. Tetrapod outperforms concrete block and X-block in terms of performance [9].

However, in terms of cost, construction, and placement, such armor units are unsuitable in the context of Bangladesh. Furthermore, any hard protection structure like revetment may protect the shore from wave action, but the beach in front of it will be lost by wave-breaking action at the toe and slope of the revetment.

In case of breakwater, almost all waves break when the ratio of the deep-water wave height to the freeboard of the submerged breakwater is higher than one [10]. Impermeable underwater breakwaters of trapezoidal shapes have a stronger damping action than narrow, rectangular, and triangular shapes [11]. The breakwater reflects the most, when the incident wave has the same period as a standing wave on top of the breakwater and a wavelength equal to the crest width [12]. In sediment movement, the distance between the breakwater and the shoreline is critical. The distance between the breakwater and the shoreline is proportional to the significant wave height (H_s) and negatively correlated with the amount of sediment deposited into the marsh [13]. The transmission, reflection, and wave energy loss factors all affect the efficiency of the breakwater. The transmission and the reflection coefficients are inversely proportional to the relative breakwater width, while the energy loss coefficient takes the opposite trend [14]. Submerged geotube breakwaters are a low-cost solution that allows to dissipate wave energy up to a certain limit [15]. But the remaining wave energy passing over the breakwater may cause shore erosion to some extent.

Therefore, there are both advantages and limitations of concrete block revetment and submerged breakwater as a single-layer protection. To take the advantages and to eliminate the limitations of concrete block revetment and submerged breakwater as single-layer, this research aims to study the performance of two-layer protection in the places of high waves ($H_s \geq 1.50$ m) by using concrete block revetment at the shore and geotube breakwater at the shallow water depth. In this two-layer protection, the submerged geotube breakwater has to be designed in such a way that the transmitted wave height is less than the maximum recommended wave height of concrete block revetment. Subsequently, the concrete block revetment may remain stable as the transmitted wave height is less than the maximum recommended wave height for concrete block revetment. When the incident wave pass the submerged breakwater, the wave reduces its energy. The remaining energy may not hold the suspended sediment particals and the suspended sediment particls will be deposited in the area between the shoreline and the submerged breakwater. Therefore, One of the additional advantages of this two-layer protection is the automatic nourishment of the land between the revetment and the submerged breakwater. This research also aims to develop a relationship among water depth (h_w), wave height (H), and breakwater height (h_b) to help coastal designers to design two-layer shore protection in the places of high waves.

2. Materials and methods

2.1 Experimental setup:

To investigate the performance of the revetment and submerged geotube breakwater, experimental studies had been conducted in a 2D wave flume (Length of flume = 21.3 m, width of flume = 0.76 m and depth of flume = 0.74 m) at the Hydraulics and River engineering Laboratory of Bangladesh University of Engineering and Technology. In this experiment, four different relative breakwater heights as h_b/h_w= 0.3, 0.4, 0.5 and 0.6 in 50 cm still water depth and four diffirent wave periods as T = 1.7 sec, 1.8 sec, 1.9 sec and 2.0 sec were used in this experiment to evaluate the performance of two layer protection consisting concrete block revetment at the shore and submerged geotube breakwater at shallow water depth. The wave periods were generated by adjusting the wave paddle.

The wave generator was set up 200 cm downstream of the flume's commencement. The submerged geotube breakwater was placed 800 cm downstream from the wave generator. As illustrated in Figure 1, data was collected from five different positions. The incident wave parameters were investigated at two locations in front of the geotube breakwater. Three locations at the downstream of the breakwater were chosen to assess the impact of the breakwater. Additionally, during each experimental run, still images and video records were captured. Figure 1 depicts the experimental setup in detail.

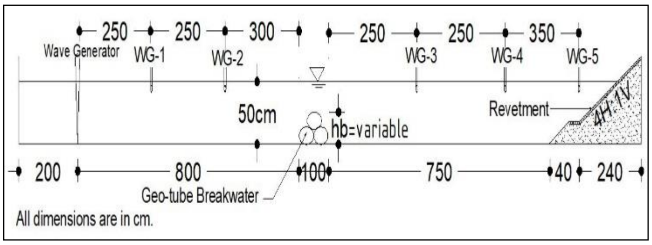


Figure 1. Detail of the experimental setup

2.2 Design of C.C. block

This experiment was carried out with a fixed bank normal slope of 1(V):4(H). All Parameters were scaled down in such a way that Surf coefficient (a dimensionless number) remain same for both prototype and laboratory data. Necessary data has been tabulated in Table 1. In the Table 1, the prototype data for significant wave height, H_s and wave period, T has been taken from previous studies [16], [17].

Table 1. **Preliminary Calculation of Parameters for both prototype and laboratory**

Prototype			Laboratory					
H_s (m)	T (sec)	Surf coefficient	Wave height, H_s		Wave period, T		Surf coefficient	Block Size (cm)
			Value (cm)	Scale	Value (sec)	Scale		
1.5	5.7	1.45	9.50	16	1.43	4.0	1.45	2.00
2.4	8.1	1.62	15.00	16	2.05	4.0	1.62	3.40

Here, significant wave height, H_s was 16 times scaled down. Wave period, T was calculated by 4.0 times scaled down from prototype. Finally the desired concrete block size was calculated by Pilarczyk formula [18] as shown in Eq.(1).

Characteristic size, $$D = \frac{H_s \xi^b}{\Delta m \psi_u \, \phi_{sw} \, cos\alpha} \quad (1)$$

2.3 Design of submerged geotube breakwater

When the width of the breakwater (B) is equal to the wave length (L), the reduction of wave height becomes optimum [19]. Because this is unlikely to be cost-effective, a narrower breakwater with a higher height was investigated subsequently, and it was found that the optimum reduction occurs when the relative breakwater width (B/L) is in the range of 0.2 to 0.4. [20].

In this research, breakwater heights of 15 cm, 20 cm, 25 cm, and 30 cm were established in a 50 cm still water depth for four different wave periods, T= 1.7 sec, 1.8 sec, 1.9 sec and 2.0 sec and corresponding wavelengths are 332 cm, 357 cm, 381 cm and 406 cm. For optimum reduction of wave height, the breakwater width was chosen as 100 cm. In this experiment, the relative breakwater width was ranged from 0.25 to 0.30 which is within the range of 0.2 to 0.4. The length of the breakwater is normally chosen to the equal length of the coastline that needs protection. The width of the 2D flume that used in this experiment is 76 cm. Therefore, in this experiment, the width of the breakwater has been selected as 76 cm.

2.4 Laboratory experimental run conditions

In this experiment, four different relative breakwater heights as h_b/h_w= 0.3, 0.4, 0.5 and 0.6 were used in still water depth of 50 cm. Therefore, the heights of the breakwater are 15 cm, 20 cm, 25 cm and 30 cm. Four wave periods were used in this experiment to evaluate the performance of submerged geotube breakwater and concrete block revetment. The wave periods that are used in this research are 1.7sec, 1.8sec, 1.9 sec and 2.0 sec. The wave periods were generated by adjusting the wave paddle. Table 2 represents the conditions of the experimental run in detail.

Table 2. Test Scenario of the experiment

Run No	Relative breakwater height ($\frac{h_b}{h_w}$)	Wave period, T (sec)	Incident Wave Height, H_i (cm)	Incident Wave Length, L_i (cm)
1	No breakwater	2.0	15	406
2	0.3	1.7	11	332
3		1.8	12	357
4		1.9	14	381
5		2.0	15	406
6	0.4	1.7	11	332
7		1.8	12	357
8		1.9	14	381
9		2.0	15	406
10	0.5	1.7	11	332
11		1.8	12	357
12		1.9	14	381
13		2.0	15	406
14	0.6	1.7	11	332
15		1.8	12	357
16		1.9	14	381
17		2.0	15	406

3. Results and Discussion

3.1 Effect of relative breakwater height on reducing wave height

The Figure 2 the demonstrate the effect of relative breakwater height (h_b/h_w, where h_b is the breakwater height and h_w is the still water depth) on wave transmission coefficient, K_t ($K_t = H_t/H_i$ (where, H_t is the wave height of transmitted wave and H_i is the wave height of incident wave) for four specific wave periods. The analysis result prevails that increases of the relative breakwater height, h_b/h_w, decreases the transmission coefficient, K_t for any specific wave period. It is also found that transmission coefficient, K_t falls as the wave period, T decreases for any particular relative breakwater height, h_b/h_w.

For relative breakwater height, h_b/h_w= 0.6 and wave period, T=2 sec, wave height drops by 40% due to breaking. For relative breakwater height, h_b/h_w= 0.5, 0.4 and 0.3 the reduction of wave height due to breaking of wave over the submerged geotube breakwater are 37%, 27% and 20% respectively for the same wave period, T= 2.0 sec. The variation in wave height decrease follows the similar pattern for other experimental runs.

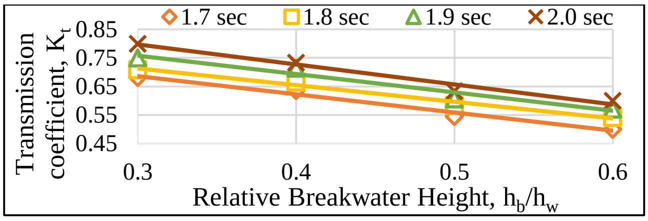


Figure 2. Effect of relative breakwater height on the reduction of wave height for different wave periods

3.2 Effect of relative breakwater width on wave height reduction

Figure 3 represents the effect of relative breakwater width, B/L (where, B = breakwater width, and L = wave length) on wave transmission coefficient, K_t for four different relative breakwater heights (h_b/h_w=0.3, 0.4, 0.5 and 0.6). For a specific relative breakwater height (h_b/h_w), with the increases of relative breakwater width (B/L), the wave height reduction increases due to wave breaking on the breakwater.

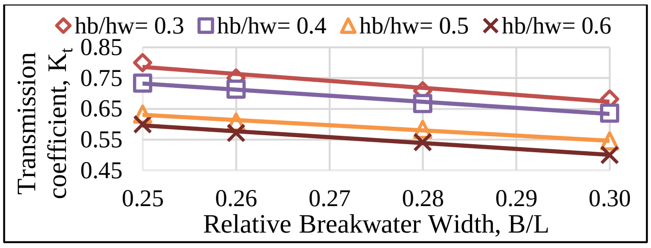


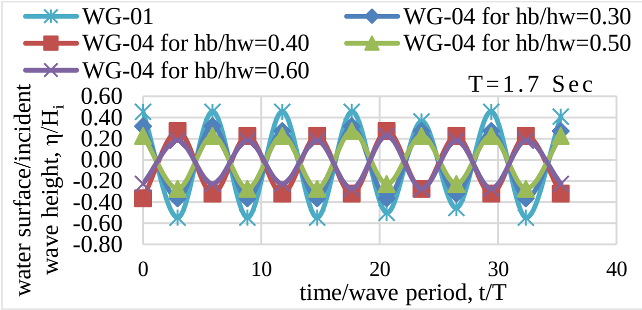
Figure 3. Effect of relative breakwater width on the reduction of wave height for different relative breakwater heights

For example, for relative breakwater height, h_b/h_w= 0.5 and relative breakwater width, B/L= 0.25, the height of wave reduces by 37% due to breaking. For relative breakwater width, B/L= 0.26, 0.28, and 0.30 the height of wave reduced by 39%, 42% and 45% respectively for relative breakwater height h_b/h_w= 0.5. The reduction of wave height follows this pattern for any specific ratio of B/L.

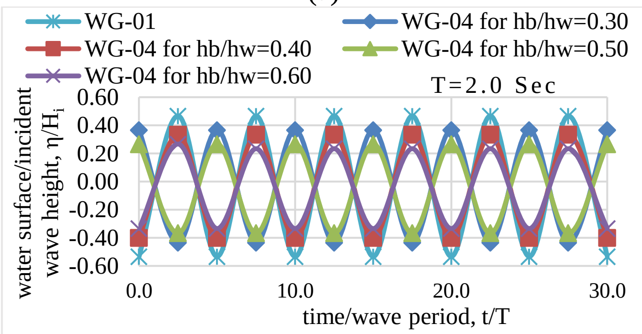
3.3 Dimensionless water surface profile with time

The changes of water surface profile (η) with time (t) (measured at location WG-1 and WG-4 in front and behind the breakwater respectively) is illustrated in dimensionless form (η/H_i with t/T) in the Figure 4. The location of the WG-1 and WG-4 in the laboratory flume has been shown in the Figure 1.

Figure 4(a) shows that incident wave height for wave period 1.7 sec (measured at WG-01) reduces at significant amount after passing the submerged geotube breakwater. The transmitted wave height was measured at WG-04. The figure also shows that as the relative breakwater height increases the transmitted wave height decreases for a particular wave period. For wave period, T=1.7 sec and relative breakwater height 0.6, 50% of the incident wave height is reduced. Whereas when relative breakwater heights are 0.5, 0.4 and 0.3, the incident wave height is reduced up to 45%, 36% and 32% respectively.



(a)



(b)

Figure 4. Variation of dimensionless water surface (η/Hi) with time (t/T)

Figure 4(b) shows that incident wave height for wave period 2.0 sec (measured at WG-01) reduces at significant amount after passing the submerged geotube breakwater. For T= 2.0 sec, when the submergence of geotube breakwater is 60%, 40% of incident wave height is reduced. 37% wave reduction occurs when relative breakwater, h_b/h_w is 0.5, whereas breakwater having relative breakwater height, h_b/h_w =0.4 reduces 27% of incident wave height. The minimum reduction (20%) occurs for 30% submergence of the geotube breakwater.

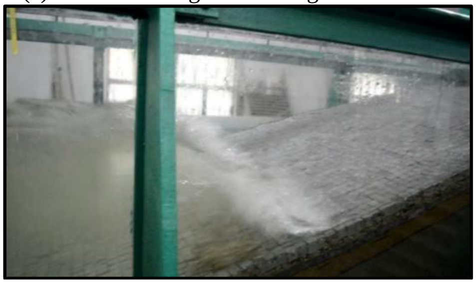
For wave period, T= 1.8 sec, When the geotube breakwater height is 30 cm, it reduces 46% of incident wave height. 42% incident wave height is reduced by geotube breakwater height of 25 cm. 20 cm geotube breakwater height, decreases incident wave height by 33%. The minimum reduction (29%) is occurred by 15 cm geotube breakwater for the same wave period of 1.8 sec.

For wave period, T= 1.9 sec, maximum reduction (43%) occurred by installing 30 cm geotube breakwater. For the same wave period, geotube breakwater having height of 25 cm reduces 39% of incident wave height, whereas geotube breakwater having height of 20 cm reduces 29% of incident wave height. The minimum wave height reduction (25%) is occurred by 15 cm geotube breakwater having relative breakwater height, h_b/h_w =0.3 for the same wave period.

3.4 Wave breaking

The main function of any breakwater is decreasing the wave energy by breaking the wave. As the breakwater height increases the breaking of the incident wave also increases. In this experiment, the incident wave height breaks on submerged geotube breakwater. Therefore, though the prototype incident wave height is higher than the maximum recommended wave height (1.5 m) for concrete block revetment, transmitted wave which breaks and reflects at the revetment is less the 1.5 m. Consequently, the concrete block revetment becomes stable as the wave height striking the revetment is less than the maximum recommended wave height. Figure 5 shows the breaking of the wave on the submerged geotube breakwater and on the revetment.

(a) Wave breaking on submerged breakwater



(b)Wave breaking on revetment

Figure 5. Wave breaking

3.5 Revetment stability

Total 17 experimental runs were performed to investigate the performance of cement concrete block revetment and submerged geotube breakwater. In the first experimental run, the prototype wave height was taken as 2.4 m [17], which is much higher than the maximum permissible limit of concrete block revetment of 1.5 m. The size of the cubical shaped concrete block has been calculated as 3.4cm x 3.4cm x 3.4cm. The size of the concrete block was calculated using Pilarczyk equation [18]. Without having any breakwater in front of the concrete block revetment (Run no. 1), the revetment failed as expected. To make the revetment stable, geotube breakwater was placed in the nearshore zone. The height of the submerged geotube breakwater had to select in such a way that the transmitted wave height become less than the maximum permissible wave height for concrete block revetment. To do this, another sixteen experimental run was performed and analyzed.

As the maximum permissible wave height for single layer revetment is 1.5m, the size of concrete block was calculated taking prototype wave height 1.5 m for other sixteen experimental runs (Run no. 2-17) [8]. The laboratory wave height was 9.5cm and the block size was 2cm x 2cm x 2cm which had been determined from Pilarczyk equation [18]. Revetment was stable for twelve experimental runs (experimental Run no: 2, 3, 6, 7, 10, 11, 12, 13, 14, 15, 16 and 17) among the sixteen experimental runs.

(a) Stable revetment (Run No: 3)

(b) Partially failed revetment (Run No: 4)

Figure 6. Revetment condition after experimental Run

The reason for the stability of those experimental runs is that the transmitted wave height of those experimental runs was equal to or less than the design wave height (9.5 cm).

Table 3. Summary of results of experimental runs

Run No	Relative break w-ater height ($\frac{h_s}{h_w}$)	Wave peri-od (T) sec	Incid-ent Wave Height, H_i (cm)	Trans-mitted Wave Height, H_t (cm)	% of reduct-ion of wave height ($\frac{Hi-Ht}{Hi}$)	Revetm-ent Conditi-on after 10 minutes experim-ental run
1	No bre-akwater	2.0	15	-	-	Failed
2	0.3	1.7	11	7.5	32	Stable
3		1.8	12	8.5	29	Stable
4		1.9	14	10.5	25	Partially Failed
5		2.0	15	12	20	Partially Failed
6	0.4	1.7	11	7	36	Stable
7		1.8	12	8	33	Stable
8		1.9	14	10	29	Stable
9		2.0	15	11	27	Partially Failed
10	0.5	1.7	11	6	45	Stable
11		1.8	12	7	42	Stable
12		1.9	14	8.5	39	Stable
13		2.0	15	9.5	37	Stable
14	0.6	1.7	11	5.5	50	Stable
15		1.8	12	6.5	46	Stable
16		1.9	14	8	43	Stable
17		2.0	15	9	40	Stable

Revetment was partially failed for three experimental runs (experimental Run no: 4, 5, and 9). The transmitted wave height of those experimental runs was higher than the design wave height (9.5 cm). Figure 6 represents the revetment condition after experimental run.

For experimental Run no.8, though the transmitted wave height (10 cm) was higher than the design wave height (9.50 cm), the revetment was stable after the experimental run. One of the reasons is that the wave height used to determine the size of concrete block by Pilarczyk equation is significant wave height. The significant wave height (H_s) is defined as the mean wave height of the highest third of the waves. Therefore, there will be higher waves than significant wave height in a wave spectrum. Another reason is the experimental run time. In this experiment, the experimental run time was 10 minutes. The revetment may fail if the experimental run time is increased. Table 3 shows the summary of results of the experimental runs.

3.6 Relationship among transmission coefficient (K_t), relative breakwater height (h_b/h_w), wave period (T) and significant wave height (H_s)

A relation among significant wave height (H_s), wave period (T), relative breakwater height (h_b/h_w) and transmission co-efficient (K_t) is required to select the economic section of geotube breakwater. Following parameters are the governing parameters associated with the performance of breakwaters considering the transmission of waves [21].

$$K_t = f\,(H_s, T, h_w, h_b, B, D_{50}, \tan\alpha, g) \qquad (2)$$

Where, H_s = significant wave height, T = wave period, h_w = depth of water, h_b = breakwater height, B = breakwater width, D_{50} = medium size of the material, $\tan\alpha$ = seaward slope, g = acceleration due to gravity.

To develop a relationship it is necessary to make dimensionless parameters. 'Buckingham Pi Theorem' is an established method for dimensionless analysis. In this research, the independent dimensions H_s and T were used as repeating variables. The following dimensionless groups were formed after the dimensionless analysis.

$$K_t = f\left(\frac{H_s}{h_w}, \frac{H_s}{h_b}, \frac{H_s}{B}, \frac{H_s}{D_{50}}, \frac{gT^2}{H_s}, \tan\alpha\right) \qquad (3)$$

Since breakwater width (B), medium size (D_{50}), seaward angle (α) has not been changed in this experiments, $\frac{H_s}{B}, \frac{H_s}{D_{50}}, \tan\alpha$ these three dimensionless parameters have not been analyzed. Remaining two dimensionless parameters $\left(\frac{H_s}{h_w}, \frac{H_s}{h_b}\right)$ have been simplified, and a new dimensionless parameter (relative breakwater height, $\frac{h_b}{h_w}$) has been analyzed. Therefore, for this research, the transmission coefficient is a function of the following parameters.

$$K_t = f\left(\frac{h_b}{h_w}, \frac{gT^2}{H_s}\right) \qquad (4)$$

Experimental results have been analyzed using Microsoft excel solver tool and the following equation has been found.

$$K_t = 1.05 - 0.67\left(\frac{h_b}{h_w}\right)^{0.83} - 2.4\times10^{-4}\left(\frac{gT^2}{H_s}\right) \qquad (5)$$

Where,
K_t = transmission coefficient
H_s = significant wave height
T = wave period
h_w = the depth of water
h_b = the breakwater height
g = the acceleration due to gravity

The intercept of the Eq.(5) is positive (1.05) and the slope of relative breakwater height is negative (-0.67). Thus means the transmission coefficient will decrease with increase of relative breakwater height for any particular wave. In the developed relation (Eq.5) breakwater width is not considered. The relative breakwater width shall be in the range of 0.2 to 0.4 for optimal reduction of incident wave height [20].

The sum of squired residuals (SSR) of the Eq.(5) is 0.026. The sum of squired residuals is the sum of squired residuals, and residuals is the deviation of the calculated transmission coefficient by the Eq.(5) from the laboratory transmission coefficient. The mathematical expression of SSR is states below.

$$SSR = \sum_{i=1}^{n}(y_i - f(x_i))^2 \qquad (6)$$

Where, y_i is the i^{th} value from laboratory experiment and f (x_i) is the i^{th} value calculated from the new developed relation.

3.7 Shore protection design along the Cox's Bazar shoreline using developed relation

The highest wave height was found 2.53 m along the Cox's Bazar shoreline [5]. The maximum permissible wave height recommended by he U.S. Army of Crops Engineers for one layer revetment is 1.50 m [8].

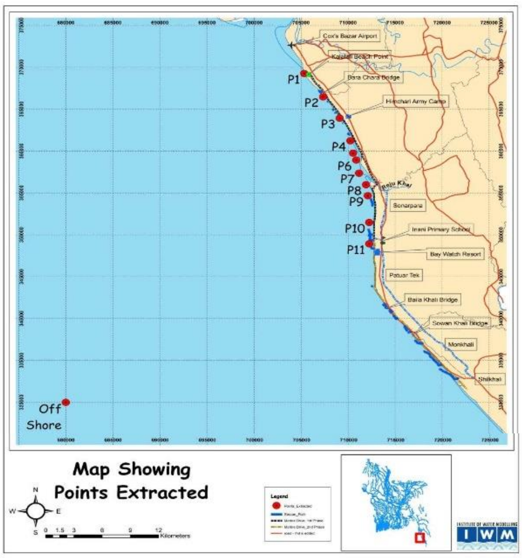


Figure 7. Nearshore locations of along Marine drive road Cox's Bazar, Bangladesh

Therefore, the breakwater height has to be selected in such a way that the transmitted wave height becomes

<= 1.50 m. Eq.(5) has been used to select the relative breakwater height. The relative breakwater height of 11 locations near the Himchari, Cox's Bazar (Figure 7) has been shown in the Table 4 in the last column. The relative breakwater width (B/L) has been taken within the range of 0.2 to 0.4 for maximum reduction of wave height [20].

Table 4. Relative breakwater height calculation

Point No. (Figure 7)	Measured data at Cox's Bazar		Max. permissible wave height for revetment	$K_t = H_t/H_s$	Relative breakwater height, h_b/h_w (using Eq. 5)
	H_s (m)	T (sec)	H_t (m)		
1	2.32	8.65	1.5	0.65	0.42
2	2.37	8.62	1.5	0.63	0.45
3	2.38	8.70	1.5	0.63	0.45
4	2.28	8.74	1.5	0.66	0.40
5	2.31	8.70	1.5	0.65	0.42
6	2.25	8.79	1.5	0.67	0.38
7	2.43	8.70	1.5	0.62	0.47
8	2.35	8.57	1.5	0.64	0.44
9	2.5	9.09	1.5	0.60	0.49
10	2.42	8.76	1.5	0.62	0.47
11	2.53	8.51	1.5	0.59	0.52

As the transmitted wave height which is the maximum permissible limit (1.5 m) for concrete block revetment has been taken as the significant wave height to calculate the concrete block size. Table 5 represents the calculated concrete block size for marine drive road having different slope. The slope of the concrete block revetment shall be finalized from geotechnical investigation.

Table 5. Concrete block size calculation for revetment

H_s (m)	T (sec)	slope	Surf coefficient	Block size (cm)
1.5	5.7	1(V):2(H)	2.90	55
1.5	5.7	1(V):3(H)	1.94	39
1.5	5.7	1(V):4(H)	1.45	32
1.5	5.7	1(V):5(H)	1.16	27

These parameters will help the coastal engineer to design two-layer shore protection at the marine drive road, Cox's Bazar considering the maximum wave height limitation of concrete block revetment.

4. Conclusions

In this study, the stability of cubical shaped concrete block shore protection revetment for high waves (wave height > 1.5 m) propagating over submerged geotube breakwater has been investigated experimentally. Results show that when the concrete block revetment is exposed to the high waves, it fails for the wave height greater than the maximum recommended wave height (1.5 m). Submerged geotube breakwater has been placed in front of the revetment to reduce the incident wave height The effectiveness of a submerged geotube breakwater in lowering wave energy is evidenced by the results of this experiment. The relative breakwater height (h_b/h_w) and relative breakwater width (B/L) are crucial characteristics for reducing incident wave height for any given wave period, according to the findings. Because of the breaking induced by the submerged breakwater, as the relative breakwater height (h_b/h_w) increases, the incident wave decreases. In addition, the reduction in wave height also increases as the relative breakwater width (B/L) increases. The incident wave breaks over the submerged geotube breakwater and its energy gets reduced. The remaining energy is transmitted to the concrete block revetment. Experimental results show that if the transmitted wave height is less than the maximum permissible wave height (1.5 m) for concrete block revetment, the revetment become stable. If the transmitted wave is greater than 1.5 m, the revetment become unstable. The relative breakwater height has to be selected in such a way that the prototype transmitted wave height becomes ≤ 1.5 m. To select sustainable and economic relative breakwater height, a relationship has been developed among transmission coefficient (K_t), relative breakwater height (h_b/h_w), wave period (T) and significant wave height (H_s), which is is $K_t = 1.05 - 0.67(\frac{h_b}{h_w})^{0.83} - 2.4 \times 10^{-4}(\frac{gT^2}{H_s})$ considering the relative breakwater width (B/L) within 0.2 to 0.4. This relationship will help the coastal designer to design two-layer protection in the places of high waves.

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6. List of Symbols

B	Breakwater width (m)
b	Exponent related to the interaction process between waves and revetment
D	Thickness of the cover layer (m)
g	Acceleration due to gravity
H_i	Incident wave height (m)
H_s	Significant wave height (m)
H_t	Transmitted wave height (m)
h_b	Breakwater height (m)
h_w	Water depth (m)
K_t	Transmission coefficient

T_m Average wave period (sec)
W Weight of revetment material (kg)
ρ_s Density of protection material (kg/m^3)
ρ_w Density of water (kg/m^3)
Δm Relative density of submerged material = $(\rho_s-\rho_w)/\rho_w$
α Bank normal slope, (°)
ψ_u System determines stability upgrading factor
φ_{sw} Stability factor for incipient motion
ξ_z Wave breaker similarity parameter

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