GEOTEXTILE TUBE AND GABION ARMOURED SEAWALL FOR COASTAL PROTECTION AN ALTERNATIVE

by

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ABSTRACT

The present study deals with a site-specific innovative solution executed in the northeast coastline of Odisha in India. The retarded embankment which had been maintained yearly by traditional means of 'bullah piling' and sandbags, proved ineffective and got washed away for a stretch of 350 meters in 2011. About the site condition, it is required to design an efficient coastal protection system prevailing to a low soil bearing capacity and continuously exposed to tides and waves. The erosion of existing embankment at Pentha (Odisha) has necessitated the construction of a retarded embankment. Conventional hard engineered materials for coastal protection are more expensive since they are not readily available near to the site. Moreover, they have not been found suitable for prevailing in in-situ marine environment and soil condition. Geosynthetics are innovative solutions for coastal erosion and protection are cheap, quickly installable when compared to other materials and methods. Therefore, a geotextile tube seawall was designed and built for a length of 505 m as soft coastal protection structure. A scaled model (1:10) study of geotextile tube configurations with and without gabion box structure is examined for the better understanding of hydrodynamic characteristics for such configurations. The scaled model in the mentioned configuration was constructed using woven geotextile fabric as geo tubes. The gabion box was made up of eco-friendly polypropylene tar-coated rope and consists of small rubble stones which increase the porosity when compared to the conventional monolithic rubble mound. In such a configuration, multi-tiered geotextile tube seawall was constructed with four layers of 10 hydraulically filled geotextile tube as the core, while stone filled polypropylene tar coated rope gabion boxes acted as armour layer for the structure. This scaled model examined for emerged water conditions of 0.5 m design water depth for different wave heights and different wave periods. The geotextile tube with gabion showed good wave energy dissipation characteristics. Furthermore, reflection characteristics of this model were also quantified. After that, the design was implemented and constructed as a pilot project on Pentha coast. This case study establishes geotextile tube seawall as an alternative to the conventional method of coastal protection.

Keywords: Seawall, Geotextile tube, Coastal Protection, Gabion, Embankment.

1 INTRODUCTION

The coastal state of Odisha is almost protected with saline embankment for a length of 475 km along the shoreline, which constructed with locally sourced soil. A particular stretch of saline embankment has been observed to regularly eroded during the storm surge, tides, waves, and flood. Pentha (20°32.5'N 86°47.5'E) is a coastal village in Kendrapara District of Odisha State at about a distance of 8.6 km from Rajnagar Town, in India. The damage to the saline embankment was posing a significant threat to the lives and livelihood of the coastal communities. In addition to this, As per the past 25 years, metrological data pertain to the coastline was also affected by two cyclones, viz. Phailin (2013) and Hud Hud (2014). Therefore, a retarded embankment built which is also likely to erode if not protected. The Government of India intends to construct a suitable geotextile tube embankment on the seaside of the retarded embankment. Hence a new geotextile tube embankment was proposed which lies between the two points of (20°32'23.10″ N – 86°47.18.01" E) and (20°32'23.10" N – 86°47'18.01" E) for 505 m length (Figure 1). The site was continuously affected by cyclones and storm surge, associated with a low pressure weather system, whereas the tidal ingression is around 500 meter into the land since 1999, that causes the water to pile up higher than the ordinary sea level and tends to increase the wave height which is a predominant reason for erosion of beach berms and dunes, since storm surge waves are non-breaking waves. The region was connected with Hexa Rivers Brahmani, Baitarani, Chinchiri, Pathsala, Maipura, Kharasrota, Barunei and Dhamara. The coastal tracts with those rivers are interconnected with fault lineament. The general topography is irregular with many drain cuts, rivers, lakes, ponds, swamps, estuaries and lagoons.

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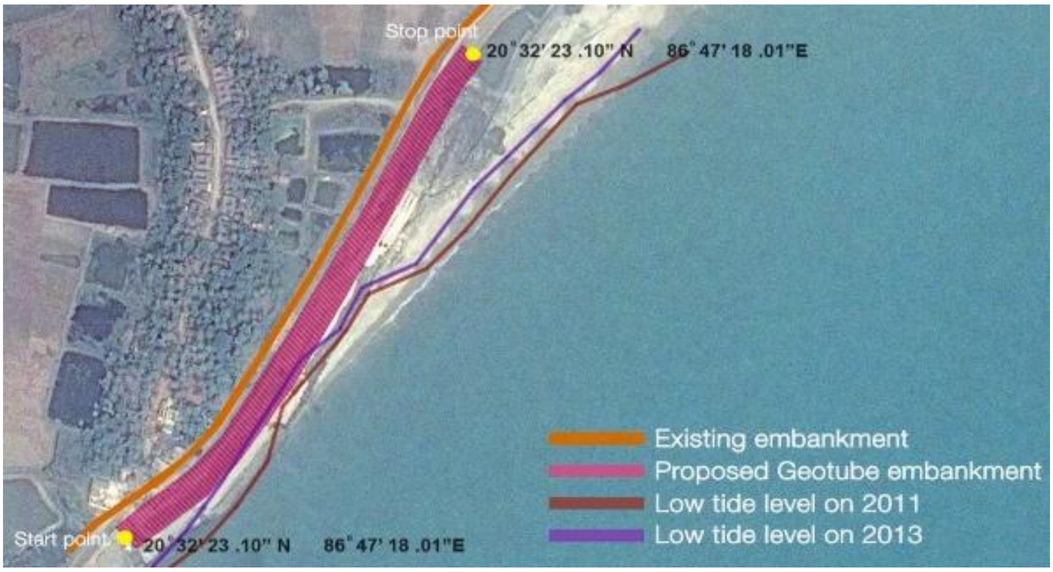

Fig. 1 Google image of geotextile seawall of 50m scale (accessed on July 2017)

1.1 Coastal erosion

High tide level at the site is about 4 m w.r.t MSL and storm surge is 1 m. Therefore, vast quantities of tidal reach pass into rivers for more than 20 km distance from the river mouth. The site lies between two rivers which discharge water into the sea and the circulation of currents between these two river clusters lead to erosion. The bathymetry is perfectly parallel to the shoreline, and the beach slope is 1:60, resulting in the formation of regular waves at equal intervals. Since beach slope is gentle wave breaks on the longshore bar, and due to higher wave celerity, it plunges over foreshore up to berm. Which results in movement of sediments from onshore and transported back to foreshore during backwashing, In addition to cross-shore transport (littoral drift). Further, the site is continuously affected by cyclones, storm surges, associated with a low-pressure weather system. A storm surge causes the water to pile up higher than the average sea level and tends to increase the wave height. It is the predominant reason for the erosion of beach berms and dunes. Since storm surge waves are of high intensity and breaks after longshore bar, the gradient in transport rate increases in the direction of net transport. The conventional materials usually used for protection against coastal erosion are rubble mounds and artificial armour units. However, these materials are costly and time-consuming to install, apart from not being readily available in large enough quantities. On the other hand, geosynthetics (geotextile-tube and gabion embankments) can serve as cost-effective soft engineering solutions for coastal protection. Moreover, when compared with conventional rubble mounds (core stone of density 2.65 t/m^3 with 20% void ratio) the load intensity due to geotextile tube (filled with sand of density 2 t/m^3 with 30% void ratio) is significantly lower. Additionally, geotextile tube acts as a single monolithic unit of high stability whereas core stones will be heterogeneous. Gabion box filled with small rocks which is more porous and hence, highly dissipative to wave energy compared to armour stones of equal weight. Thus, geotextile tube with gabion box protection is an excellent solution for coastal protection applications. The increase in wave reflection on coastal structures can lead to poor performance under the rough weather, which results in the increased possibility of scour and failure of coastal structures. One way of solving such problem is by deploy embankments with high energy dissipation characteristics, using unique geometries of geotextile tube and gabion embankments. In this study, an attempt is made to design and to understand the hydrodynamic characteristics of geotextile tube along with gabion boxes as armour layer.

1.2 Process of erosion

Coast near the Pentha is a village subjected to severe erosion for the past 25 years. Initially, the sea was 500 m away from the existing saline embankment. Since this original saline embankment eroded, a retarded embankment has been constructed 60 m behind. The shore was at 50 m from the retarded embankment on 21st Nov 2009 and on 23rd Oct 2011 and coastline was at 33 m from retarded embankment eroded at a rate of 8.5 m/annum. Hence the erosion rate is about 8.5 m per annum. Storm waves from 2009 encroached around 300 m stretch of the retarded embankment. Since the retarded embankment proven ineffective a new standalone geotextile tube embankment has designed with 30 m base width and a height of 7.4 m, aligned about 5 m to 10 m away from the retarded embankment for a length of 700 m during 2011; The standalone geotextile tube cross-section detailed in Figure 2. However, due to the subsequent erosion of coast, the base was integrated, and the width of geotextile tube embankment had altered to 24 m from 30 m.

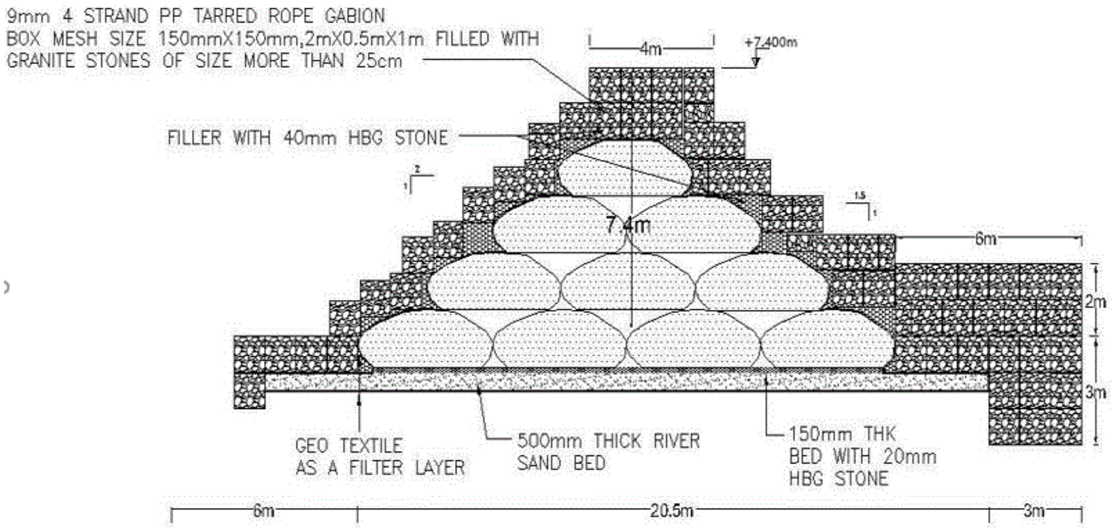

Fig. 2 Typical cross-sections of geotextile tube embankment (All dimensions are in m)

1.3 Site details

Soil samples obtained from the site was air dried, pulverised and sieved. The soil properties obtained through various laboratory tests. Soil samples collected at different locations reveal that the clay proportions in the soil content are about 87% and remaining silt and fine particles of quartz ranging 1 µm to 0.6 µm. The black coloured clayey soil in this region consists of pods and pockets; these soil samples can induce high hydrostatic pressure in the fluid within pore thus causing impounding of groundwater. The obtained soil samples are highly plastic with a liquid limit of 82%, plastic limit of 36% and the with a plasticity index of 46%, such soil is semi-impermeable, which is capable of absorbing large amounts of water due to the structural, absorption and capillary effects. The soil was classified as CH (Clay of highly plastic) with 87% of clay and 13% of silt based on unified soil classification system.

2 Background

Hydrostatic pressure occurs due to groundwater seepage and development of pore water pressure mobilises sufficient stress in the soil. The foundation soil over the site is highly plastic, and the soil characteristics are poor. Hence this low bearing and undrained material behaviour can offer less resistance to the structural loads when exposed to dynamic wave loading. Apart from foundation soil, wave characteristics must adequately assess through model study, which needed for understanding structural stability well in advance. A brief literature study of geotextile tube seawall with and without gabion protection as a coastal structure conducted along with the practical experience gained on the construction grounds.

2.1 Geotextile

Geotextile is synthetic material available in the woven and non-woven form, with various material compositions such as polyester, polyethene, and polypropylene. These materials are eco-friendly and non-reactive to the marine environment. Geotextile fabricated into various elements such as geotextile bags, geotextile mattress, geotextile tubes and geotextile containers. Each one of it will differ on its geometry used for different applications depending upon the loads, the strength of the fabric used, filling method, filling ratio, stability, and durability. In this regard, (Heerten and Wittmann 1985) discussed the physical dimensions of geotextile, the gradation of fill material and filter criteria based on the geotechnical application related to river and canal application. A complete physical and chemical laboratory test on geotextiles to assess the permeability and soil retention is provided by (Luettich et al. 1992).

2.2 Geotextile tubes

Geotextile tubes are made up of synthetic fibres which are sustainable, permeable textile fibres those can contain, filter, and reinforce soil. The integrity of the geotextile structure depends on the type of infill material and type of geosynthetics used. The permeability of the infill material and Apparent Opening Size (AOS) of geotextile has significant impacts on water outflow and rate of formation of the filter cake. Consequently, the strength of the soil infill in geotextile tubes with high moisture content will not be sufficient to support geotextile tube stacking (Shin and Oh 2007). Leshchinsky *et al.* 1996 have developed an analytical solution based on a computer program (GeoCops), to predict the design parameters such as pumping pressure, circumferential tensile force, and unit weight of the fill material along with the tube height. Various studies on the stability of stacked geotextile tubes under wave actions can be found in the works of Van Steeg et al. (2011). Experimental studies of geotextile sand-filled containers for dune erosion have been carried out by (Das Neves et al. 2009, Bezuijen et al. 2004, Pilarczyk 2008, Cho 2009). Kim *et al.* (2013) performed Finite Element Analyses (FEAs) on ground modification techniques for improved stability of geotextile tube–reinforced reclamation embankments subject to scouring. However, there are few studies on the stability of stacked geotextile tubes subjected to hydrodynamic characteristics and scouring.

2.3 Polypropylene rope gabion boxes

Gabion boxes filled with a smaller range of stones are more porous and therefore capable of dissipating sizeable kinematic wave forces. Stacking of gabion boxes with each other in various interlocking patterns is equivalent to installing the armour units for the conventional constructions (Motyka and Welsby 1987, D'Angremond et al. 1992, Takahashi 1997). U.S Army Crops, (1986) describes the use of gabions in the coastal environment subjected to wave forces and saltwater corrosion. The design of stepped gabion method of construction methods of spillways including gabion suitability and the hydraulic performances were investigated experimentally regarding the flow patterns, air-water flow properties, and energy dissipation (Wuthrich and Chanson 2014). For the present study, flexible tar coated polypropylene gabion box is used to protect stacked geotextile tube core, and gabion shield will act as armour. These gabion boxes will dissipate the wave energy because of its porous nature. It helps in scour protection and integrity of the geotextile tube core. The gabion was placed layer by layer in the form of English bond brickwork technique and correctly laced together horizontally and vertically using polypropylene tarred rope after the stacking of gabion box in position. All the gabion boxes have tied each other manually to the adjoining boxes on all sides. This arrangement will protect the gabion boxes from movement in case of large wave forces. If any differential settlement of the soil occurs, the geotextile tube will adjust with soil bed profile because of the flexibility and porous nature of geotextile tube fabric. The geotextile tube embankments also protect the inland area from erosion and stormwater inundation and provide proper coastal protection from severe in-situ erosion. Further, it facilitated by a scour apron that has been designed to protect stacked geotextile tube. Heavy-duty plastic mesh type of gabion boxes are not used in coastal protection, hence its effectiveness to tested.

2.4 Factors influencing the stability of geotextile tube and gabion boxes

There are two major factors for the failures of geotextile tube structure: the hydrodynamic factors (such as inertia and drag) and geotechnical factors. The wave-induced lateral forces must counterbalance in addition to horizontal and vertical loads by the geotechnical characteristics of soil bed profile. Inadequate handling of these loads can lead to various types of failures of the geotextile tube embankment system. The factors influencing the stability of geotextile tubes are detailed in following sub-sections.

2.4.1 Hydrodynamic failure mechanism

Hydrodynamic loads can alter the shape and geometry-related characteristics of the geotextile tube configuration, locally as well as globally. This effect set up various mechanisms of failures as reported by (Jackson *et al.* 2006) and (Lawson 2008). These studies show that sand loss or sand migration is due to the aggressive action of waves and currents which passes through the geotextile pores. This cause the failure of the geotextile tube containment system. These losses can detect a loss of sand fineness within the geotextile tube cross-section. The rate of sediment loss from the geotextile tube structure will initially influence the structure geometry, and in due time it will fail. To prevent the sand loss, the particle size of fill soil should be higher than the geotextile aperture size. Another reason for sediment loss (although not directly related to hydrodynamical loads) can be due to the damage of geotextile such as vandalism, bursting, and puncturing. The different types of hydrodynamic failure mechanism of geotextile tube due to sand loss are as follows.

2.4.2 Geotechnical failure mechanism

Geotechnical failures refer to the failure of the base or sub-base layer underneath the geotextile tube. Hence, such failures depended upon engineering characteristics and physical composition of soil which will vary concerning location, environment and influence of load acting upon them. Usually, engineering properties which modified during soil deformation are the shear strength, stiffness, and permeability. Coastal structures exposed to wind, waves and currents; hence these environment characteristics also influence the foundation soil properties and its stability. Such scenarios explained in detail in following sections.

2.5 Need for the geotextile tube embankment

Geotextile tube made of woven geotextile sheets which are flexible and perforated, hence allows water to exit. Thus the development of pore water pressure will be avoided. If any differential settlement occurs, the geotextile tube will adjust with soil bed profile because of the flexibility and porous nature of geotextile tube. These tubes will act as a solid core in the embankment and will serve as an impervious medium. However, these geotextile tube elements continuously subjected to various static and dynamic forces such as gravity, surcharge, and wave loads. In addition to the lateral forces, they support overburden pressure. A combination of these applied forces and loading may contribute to potential problems. Therefore, to counterbalance these forces gabion boxes are used to dissipate the large kinetic wave forces. Another significant advantage of the gabion boxes is that they shield the geotextile fabric from solar Ultra-Violet (UV) radiation and hence increase their durability.

3. Experimental Investigation

To understand the hydrodynamic behaviour of geotextile tube embankment, a series of experiments have been performed for two different models. Geotextile tube standalone Structure and a second model of Geotextile tube with gabion structure were installed.

3.1 Test Facility

The experiments conducted in a wave flume at the Department of Ocean Engineering, Indian Institute of Technology Madras, India. The flume is 72.5 m long, 2 m wide and 2 m deep. A hydraulic piston wavemaker is installed at one end of the flume and has been used to generate waves with predefined characteristics for these set of experiments. A personal computer, connected to the servo actuator was used to input the time history of the signal to the wave maker as well as for the data acquisition of the signals from wave gauges through an amplifier. An artificial beach consisting of a combination of a parabolic perforated steel sheet and a rubble mound is provided at the other end of the flume to absorb the generated waves efficiently.

3.2 Details of Prototype and Scaled Model

Sand filled geo-tubes and geo-bags will be an alternative source for coastal erosion and scour protection in the case where the conventional rubble mound and another kind of artificial concrete armour units cannot use as a protective measure in various circumstances, such as low bearing capacity, severe erosion, flooding. Erosion of shoreline is a predominant phenomenon which takes place because of movement of sand mass by wave action, tidal currents, and wave-induced currents. The conventional material of coastal protection is not only expensive and time-consuming, but this material may not be readily available. Geosynthetics are innovative solutions for coastal erosion and protection which are cheap and quickly installable when compared to other conventional materials and methods. This paper discusses different approaches for construction of geo-tube embankment as a coastal protection structure using geosynthetics. Detailed scaled model studies of scale 1:10 of the geo-tube embankment with ten geo-tube of four-layer has studied without and with gabion protection. The model base width is 1.2 m and with a crest width of 0.25 m. Various tests were performed for different water depth such as maximum water depth of 0.5m and wave height of 0.1 m, 0.2 m and 0.25 m for wave period range of 0.6 sec to 2.5 sec. The prototype geo-tube embankment parameters had been scaled to model using Froude scaling. Using a chosen scaling ratio of 1:10 and model dimensions had arrived, and details had furnished in Table 1.

Type of Structure	Prototype	Model (1:10)
Geo-tube Circumference	9 m	0.9 m
Geo-tube Diameter	3 m	0.3 m
Gabion Box Dimension	2 m x1 m x 1 m	0.2 m x 0.1 m x 0.1 m
High Tide Level (HTL)	4 m	0.4 m
Strom Surge (SS)	1 m	0.1 m
Maximum Height of Water Depth (D max) = HTL + SS	5 m	0.5 m

Table 1. Details of Prototype and Scaled Model

3.3 Model Setup and Test Condition

The positions of the wave gauges and the erected model in the wave flume shown in Fig 3, and 4 show the top view and side view, respectively, of the proposed model in a wave flume. The length of an individual geotextile tube structure and geotextile tube with gabion box structure is installed across the width of the wave flume as shown in Fig.4. Moreover, the 2 m width of the flume split along the middle of the flume with a 2 mm thick galvanised iron sheet for a distance of 18 m. It separates the wave flume into two parallel channels for the models to study. The first channel of the flume has a Geotextile tube structure type installed while the other has Geotextile tube with Gabion structure. The wall clearance between the model and either side of the flume wall as 2 cm. This configuration studied for various hydrodynamic coefficients and dissipation parameters under regular waves. Further, the two different cross-section of structures is shown in Fig.5 and 6. The performance of the structure for the design water depth of 0.5 m tested for a different range of wave period ranging from 1.5 sec to 4.7 sec under regular wave condition of varying wave heights.

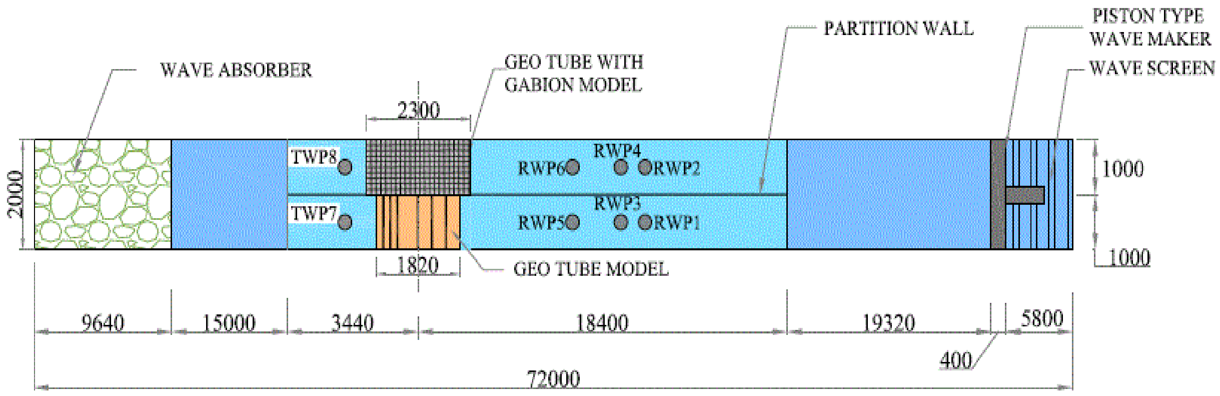

Fig. 3. Plan View of Wave flume with Models arrangement

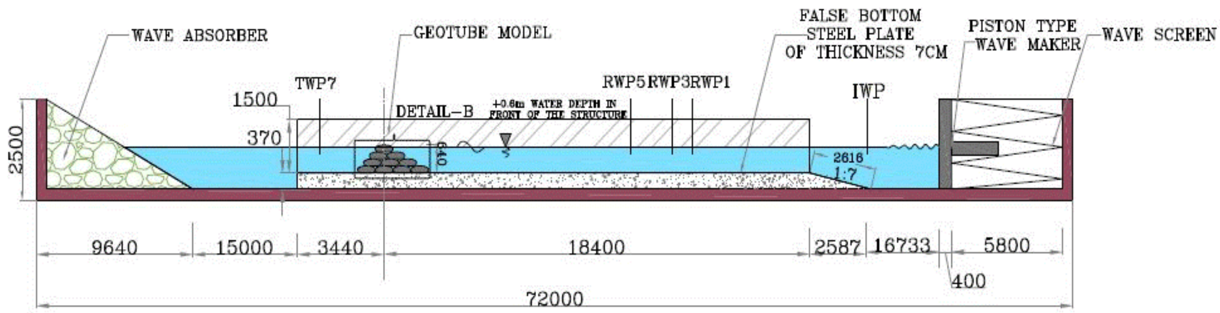

Fig. 4. Typical Cross Section of Wave flume with Models

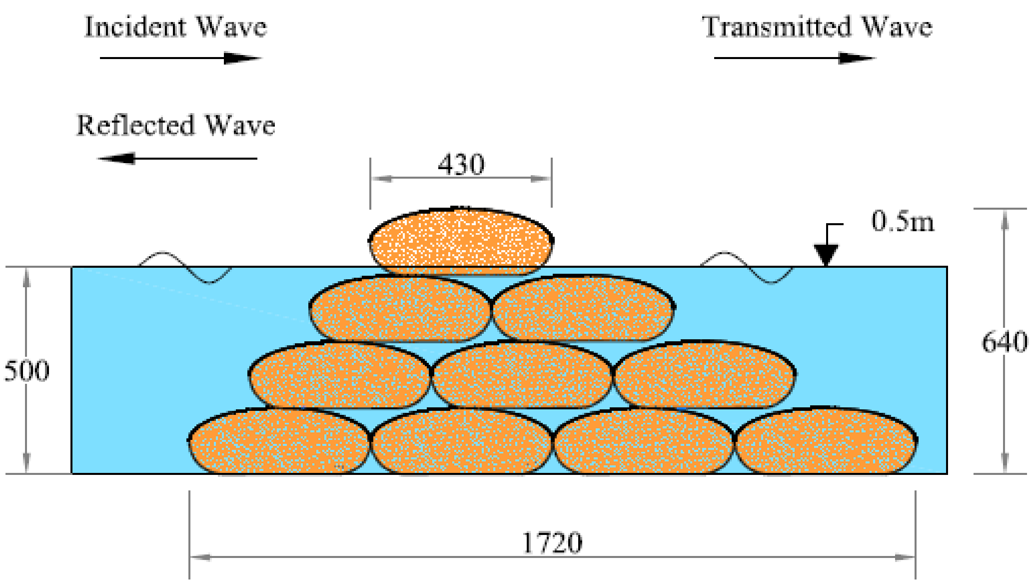

Fig. 5. Typical Cross Section of Geotextile tube Section (GTS)

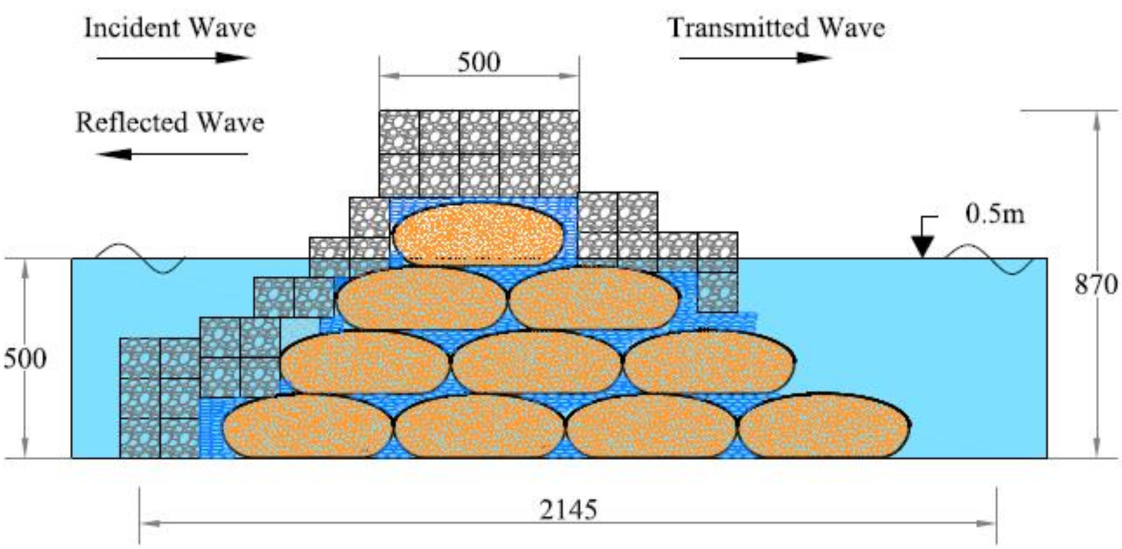

Fig. 6. Typical Cross Section of Geotextile tube with Gabion Section (GGTS)

3.4 Estimation of hydrodynamic coefficients

The effectiveness of the design in dissipating the incident wave energy is highly dependent upon the relationship between the wave characteristics, structural characteristics, and water depth. The hydrodynamic characteristics such as the reflection coefficient (K_R) and transmission coefficient (K_T) are obtained from the wave gauge measurements using three probe method (Mansard and Funke 1980). This approach provides the spectral energy of the incident, reflected and transmitted waves. To obtained the reflection and transmission coefficient, the losses (K_L) are calculated using Eq (1), by the conservation principle, i.e.

$$\boldsymbol{K_R^2 + K_T^2 + K_L^2 = 1} \quad (1)$$

An attempt was made to examine the effect of reduction on the depth of submergence of the structure in attenuating the incident waves. The reduced depth of submergence is expected to reduce the cost of installation of the proposed structure while increasing the water exchange beneath the structure. Further such a measure can provide an insight into the hydrodynamic efficiency of the structure under extreme scenarios.

3.4.1 Reflection coefficient

Incident waves may be reflected (partially or wholly) from a beach and coastal or harbour structures, depending on the wave characteristics and the structure geometry. The magnitude of the reflection can represent by a reflection coefficient (K_R) as shown in Eq (2), which is nothing but the ratio of the reflected wave height (H_R) to the incident wave height (H_I). It can also obtain using wave energy as the square root, the ratio of the reflected wave energy (E_R) to the incident wave energy (E_I).

$$\boldsymbol{K_R = \frac{H_R}{H_I} = \sqrt{\frac{E_R}{E_I}}} \quad (2)$$

Impermeable vertical walls fully reflect and so that majority of the non-overtopping incident waves (i.e., $K_R \approx 1.0$). Beaches and sloped structures, however, reflect only a portion of incident wave energy. Several studies have been employed to estimate the amount of reflected energy regarding reflection coefficient (Harris and Sample 2009). Presently, the three-probe method used for determining reflection coefficient. It helps in the resolution of the incident and reflected amplitudes using least square technique and two-phase difference of the waves at three locations (Mansard and Funke 1980).

3.4.2 Transmission coefficient

The primary purpose of a breakwater or a coastal structure is to reduce the wave energy on its lee-side as well as to lessen the attenuation of approaching waves. The wave transmission is the wave energy which travels through a breakwater, either by passing through or by overtopping the structure. Wave energy attenuation in the lee-side of the breakwater is either dissipated by the structure (e.g., by friction, wave breaking, armour unit movement,) or reflected back as reflected wave energy (Yuliastuti and Hashim 2011). The effectiveness of a breakwater in attenuating wave energy measured by the amount of wave energy is transmitted or pass through the structure. Wave transmission is quantified by the using wave transmission coefficient by Eq (3).

$$\boldsymbol{K_T = \frac{H_T}{H_I} = \sqrt{\frac{E_T}{E_I}}} \quad (3)$$

Where, K_T is the wave transmission coefficient where, H_T is the height of the transmitted waves on the leeward side of the structure, and H_I is the height of the incident waves on the seaward of the structure. Alternatively, else regarding wave energy, one can rewrite as the square root the ratio of the transmitted wave energy (E_T) to the incident wave energy (E_I).

3.4.3 Loss Coefficient or Dissipation Coefficient

The portion of the energy judges the effectiveness of a coastal structure dissipated through friction, turbulence and wave breaking. Loss coefficient determined by the following relation given in Eq (4), loss Coefficient (K_L) is also called as Dissipation coefficient.

$$\boldsymbol{K_L = \sqrt{(1 - K_R^2 - K_T^2)}} \quad (4)$$

4 Results and discussions

The variation of K_R, K_T, $K_{L,}$ are studied for design water depth of 0.5 m. The former water-depth used for assessing the effect of high tides, whereas the latter one includes the high tide and storm surge. Results of the various hydrodynamic coefficients compared with non-dimensional parameter (D/L) for different wave steepness ranges H_{m0}/L, where, H_{m0} is the significant wave height obtained from the wave spectrum and D/L denotes the relative water depth. D is usually the water depth it crosses the structure from toe and L is the respective wavelength of the corresponding period of the regular wave were tested. In general, the present study confirms that the geotextile tube configurations structures have better hydrodynamic performance than the conventional rubble mound structures concerning reflection and dissipation coefficients. These results are discussed separately and compared for geotextile tube structure (GTS) and geotextile tube with gabion structure (GGTS). The variation of K_R, K_T, K_L with D/L for various wave steepness ratios are filtered and separated on three different wave steepness range, The results for K_R, K_T, and K_L are discussed for three different wave steepness range (H_{m0}/L) viz. Lowest wave steepness (0.001 to 0.01), Moderate wave steepness (0.01 to 0.02), and Highest wave steepness (0.02 to 0.038). Comparisons are discussed in the in the following sections.

4.1 Water depth (0.5m) to study high tide effects and storm surge

For the 0.5m water depth, the chosen water depth represents a scenario where the combined effects of high tide level and storm surge are studied. Herein, the water level is below 0.14 m for geotextile tube structure (GTS) beneath the crest of the structure height while the water level is 0.37 m beneath for geotextile tube with gabion structure (GGTS). The K_R and K_T are studied for the D/L range. Nevertheless, the K_L is in the range between 0.65 and 0.95 (Figure 6 (d-f)), meaning that the energy lost from the interactions of the waves due to the structure geometry, roughness, porosity effect of gabion boxes, wave breaking and run-up over the structure.

4.2.1 Influence of geotextile tube structure (GTS)

The GTS model (of 0.64 m height) is 0.14 m above the water depth. The effects of D/L range were 0.0483 to 0.165 on the hydrodynamic coefficients are studied in Figures 6 (a-c). For the H_{m0}/L range of 0.001 to 0.038 and maintaining D/L in the range of 0.0483 to 0.165, the K_R is decreasing from 80% to 30% as D/L increases and K_T is also reducing from 25% to 2%. K_L is increasing from 62% to 95%. For lower H_{m0}/L range of 0.001 to 0.01, the K_R is increasing rapidly from 50% to 80% due to long wavelength. Further, the K_T is found to be within a range of 2% to 27%. One must note that for lower H_{m0}/L values, $K_L$is increasing from 65% to 95%.

4.2.2 Influence of geotextile tube with gabion structure (GGTS)

For the GGTS D/L range is within 0.0483 to 0.165, were the freeboard height is 0.42 m above the water surface with a total height of structure as 0.92 m, since gabion boxes protect the geotextile tubes on the top. For the lower H_{m0}/L range i.e., 0.001 to 0.01, the hydrodynamic coefficients have a uniform change (Figures 6 (d-f)). In the given scenario, the K_R decreases from 75% to 50%, K_T increases from 2.5% to 30% and K_L increases from 67.5% to 99% as D/L increases. The physical reason for the increase in hydrodynamic coefficients in the lower wave steepness range is due to the influence of longer wavelength. The K_R is decreasing from 70% to 20%; the $K_T$is reducing from 15% to 2%, and K_L is increasing from 70% to 99%. For the smaller wave steepness (H_{m0}/L) range of 0.02 to 0.038, the K_R and K_T resemble lower values with a noticeable higher K_L value. It means that most of the energy is lost due to the interactions of the waves with the geotextile tube with gabion structure through wave breaking mechanism over the structure.

4.2.3 Comparison of geotextile tube structure (GTS) and geotextile tube with gabion structure (GGTS)

Comparing the different model cases (Figures 7 (a-c)) for estimating the efficiency of the geotextile tube with gabions, i.e., GTS and GGTS, the D/L is varied from 0.0483 to 0.165 for GTS while the D/L varies within 0.0483 to 0.165, In GTS, the K_R shows a large variation, *i.e.*, 0.37 to 0.8 for the lower H_{m0}/L range of 0.001 to 0.01; this is mainly due to the long period waves. Similar significant change is found for the transmission rate K_T, which implies loss coefficient, *i.e.*, the wave energy dissipation (due to porosity. Geometry, friction, *etc*.) has increased from 0.65 to 0.9. For GGTS, the K_R decreases while K_T increases along with wave steepness. Also, the K_L increases simultaneously which is due to the gabion boxes which are dissipating the wave energy. For both the cases, higher reflection and transmission coefficients are reported for longer wavelengths. Owing to the wave breaking from reflections, again the small, medium and high wave steepness cases are chosen based on visual observations. One can easily observe that; the hydrodynamic characteristics are better for the geotextile tube with gabion structure. As both the reflection and transmission coefficient for the GGTS with a freeboard of 0.37 m, may be the optimum height of the relatively submerged depth to dissipate the incident waves.

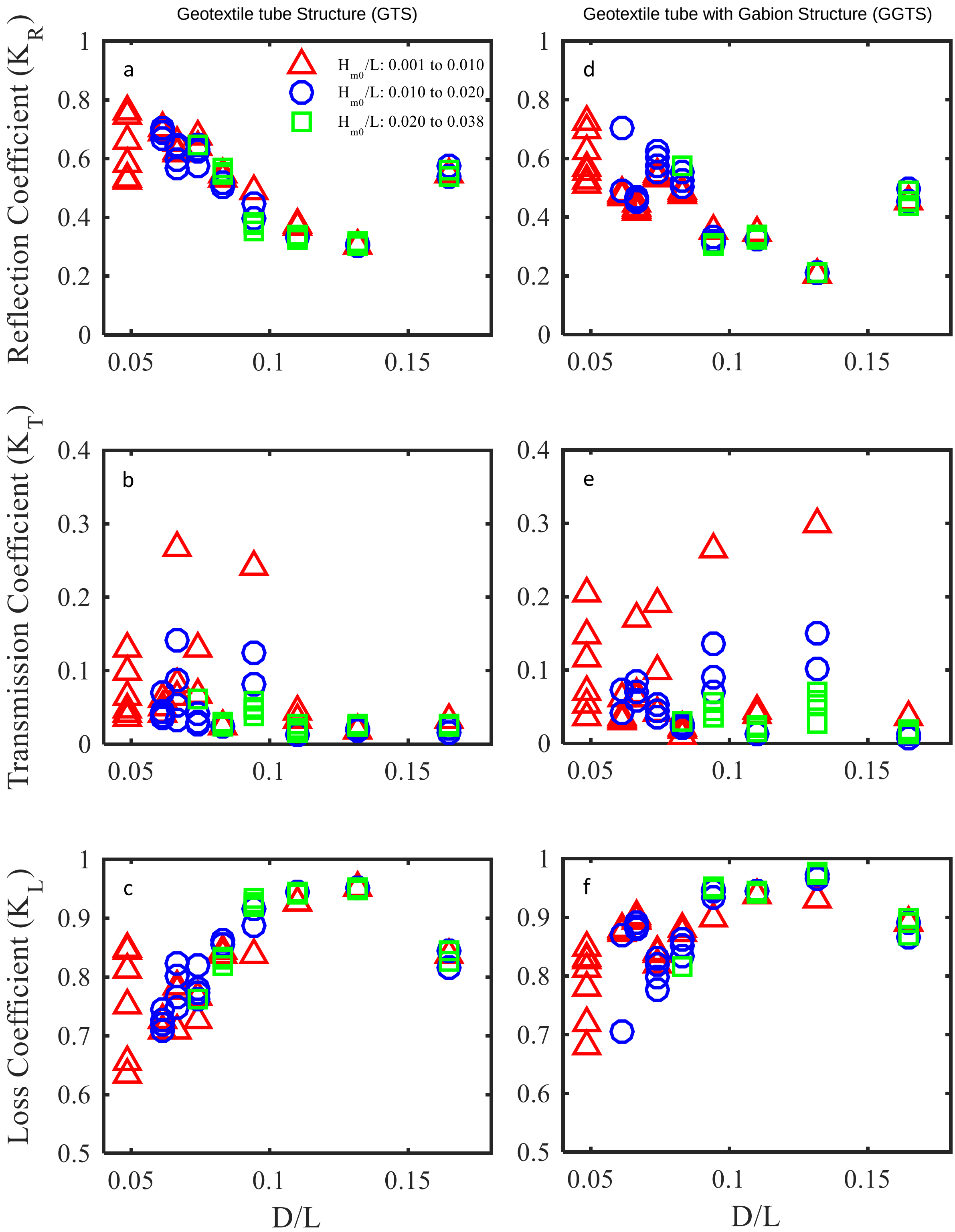

Fig.6 (a-c) Scatter plots of 0.5 m water depth showing a variation of *D/L* range over GTS. (d-f) Corresponding scatter plots for GGTS

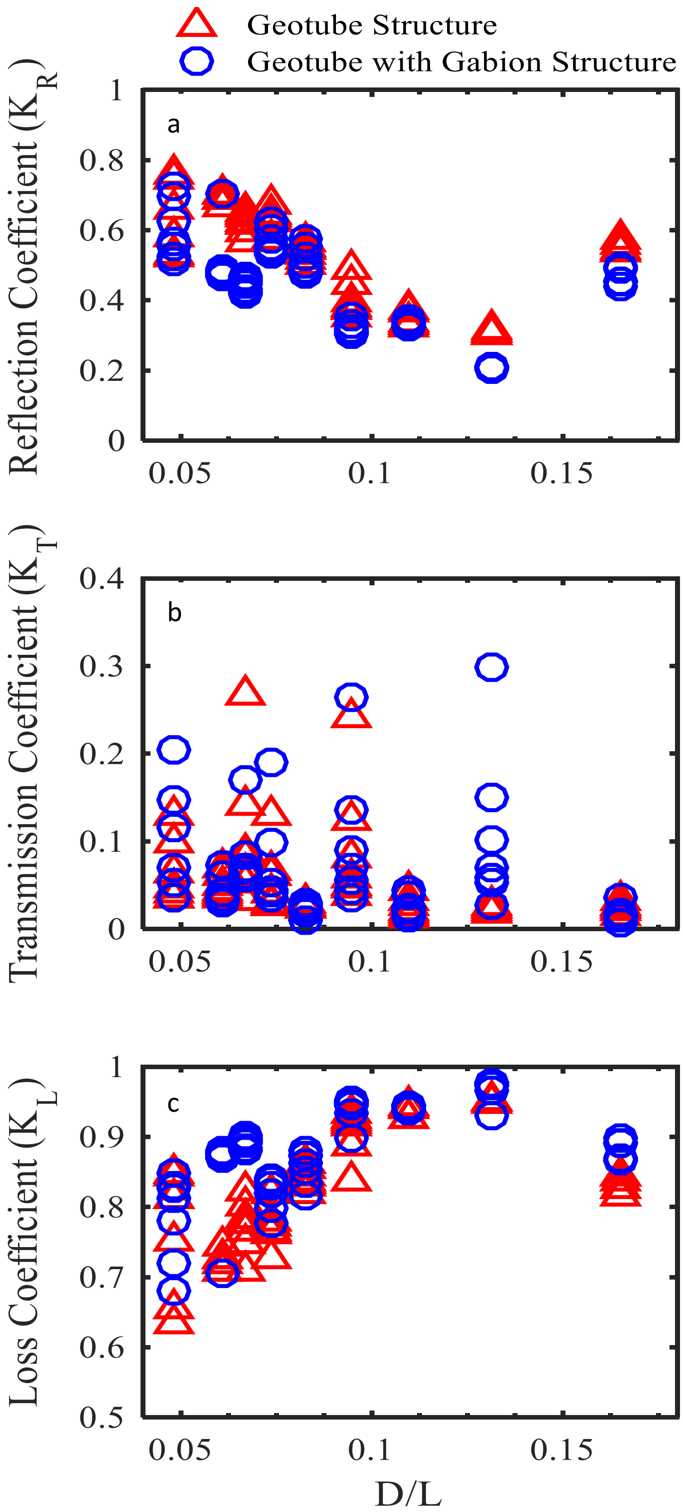

Fig.7 (a-c) Scatter plots of 0.5 m water depth showing *D/L vs K_R, K_T, K_L* for GTS & GGTS

5 Conclusions

The hydrodynamic performance of two different structure types has been examined and quantified. The wave reflection, transmission, and energy dissipation characteristics checked for regular waves of different wave heights and wave periods for design water depth. Both the models have higher energy dissipation characteristics. Usually, the reflection coefficient will be higher for long period waves.

However, Geotextile Tube with Gabion (GGTS) model provides a better reduction in reflection coefficients than the Geotextile Tube, section (GTS) model.

Considering the limitations of geotextile in coastal protection applications, a major problem with geotextile tube is that they have ultraviolet (U.V) stability even though it is eco-friendly to the marine environment. Geotextiles, when exposed to high UV radiation, will fail. Hence it is suggested to provide a model of Geotextile Tube with Gabion protection. It will preserve the integrity of the Geotextile tube core. Moreover, Gabion boxes are polypropylene tar coated mesh boxes filled with a smaller range of stones which increases that porosity. Such Gabion boxes are capable of dissipating large kinematic wave forces than the conventional monolithic coastal structures. In addition to these measures, Gabion boxes protect the Geotextile Tubes from various hydrodynamic and geotechnical failure.

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