SUBMERGED GEOTEXTILE SAND CONTAINERS FOR COASTAL DEFENCE

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Abstract

Geotextile Sand Containers (GSCs) used as submerged reefs are increasingly being incorporated into coastal defence solutions because of they are and eco-friendly and cost effective. These cause wave breaking and reduce the wave action on the lee side. In the present experimental study, trapezoidal submerged reefs of 0.25 m height are constructed with GSCs weighing about 485 gm placed in different alignments, like Perpendicular, Parallel, and Flemish, at a uniform slope of 1V:2H. These models are tested in water depth of 0.3 m with wave heights of 0.1 m and 0.12 m and different wave periods varying from 1.5 s to 2.5 s. During the investigation, damage of the submerged breakwater and wave transmission are measured. After the tests, it is found that though the structure is damaged, it is still effective in inducing wave breaking and energy dissipation resulting in effective damping of waves. The wave transmission coefficient K_t varied between 0.65 and 0.9.

Introduction

A breakwater, with its crest at or below SWL, is a submerged breakwater and is used for creation of a protected area of water or for protection of coastal structures and beaches from damage of erosion caused by wave action.

Since the crest of the structure is at lower elevation, wave overtopping and/or breaking takes place due to which armour units are subjected to relatively smaller wave force thus the structure can be economically constructed with relatively smaller sized armour. Johnson et al. (1951) studied the wave damping action of submerged breakwater and recognized that wave steepness (H/L), crest width (B), structure height (h) and water depth (d) are important parameters. They concluded that for a given height of the structure, steeper waves are effectively damped than flat waves due to breaking of waves. Submerged breakwater induces wave breaking causing great turbulence on lee side. Current and turbulence together on lee side of submerged breakwater have a strong power of erosion on a sandy bottom and can thus prevent siltation. They also offer resistance through friction and turbulence created by breakwater interference in wave field causing maximum wave damping and energy dissipation, minimum wave reflection and bottom scour, and maximum sand trapping efficiency and are used for coastal protection. (Baba, 1985 and Pilarczyk and Zeidler, 1996).

Apart from conventional breakwaters other types of obstructions such as vertical/inclined barriers have also been investigated for managing steep waves and reduce their influence on the leeside (Subba Rao et al., 2009). The authors conducted 1:30 scale model studies on submerged thin plate barriers inclined at various angles for regular wave heights ranging from 0.05 m to 0.15 m of periods 1 s to 2.2 s and water depths varying from 0.3 m to 0.5 m. It was concluded that inclined plates at 600 angle were effective enough to provide the value of $K_t < 0.6$ for an entire range of wave parameters studied.

Fridman et al. (2010) authors discuss an experimental study on the impact of single and double submerged barriers on the propagation of a solitary wave package with the characteristic horizontal scale exceeding the water layer depth by a factor of 10-30. The study was undertaken in a 5 m long and 0.105 m deep basin with single and double vertical barriers. The height of the barriers and the distance between them were varied during the experiments, while keeping the position of the first barrier fixed with respect to the wave generator (1.02 m). The ratio of the barrier height (h) to the water depth (d) was varied from 0.3 to 1.2. It was concluded that showed that double barriers were more efficient than single barriers of the same size in reducing the tsunami runup, a minimum runup existed for a particular distance between two submerged barriers and as the barrier height increased, the relative amplitude of the minimum runup decreased.

Kriebek and Bollmann (1996) describe the small scale experiments on wave transmission at vertical wave barriers with varying wall penetration w/d of 0.4-0.7 where, w is the depth of vertical wall penetration in a water depth d. The results were compared with three theories. The theories for predicting regular wave transmission past vertical wave barriers are power transmission theory, modified power transmission theory that includes effects of wave reflection and the Eigen function expansion theory. The tests were conducted in a wave tank 36.6 m long, 2.43 m and 1.52 m deep. A thin rigid wall 0.05 m thick was placed about 18.3 m from the wave maker. The wave periods varied from 0.9 sec to 2.5 sec and wave heights ranged from 0.025 m to 0.23 m. The wave steepness, H/L, varied between 0.01 and 0.06 with most tests being in the range of 0.02 to 0.04. It was observed that transmission coefficient K_t decreased with increase in wall penetration w/d. None of the theories considered accurately predict K_t.

Geotextile Sand Container (GSC) structures, have a clear advantages compared to other breakwater structures that environmentally damaging quarrying and transporting of rock are not required and this structure can be easily dismantled in the case of adverse and unforeseen situations. With the expected worsening of coastal erosion, a soft, and inexpensive solution like GSC structures will be a strong contender to replace a more conventional hard engineering solution as coastal communities which are highly developed will be severely affected. Several types of materials and container systems have been developed specifically for the designing of coastal erosion protection systems (Pilarczyk, 1996) and for beneficial uses of dredged material (Harris 1994). Such applications have made engineering construction eco-friendly, highly durable and economical while allowing the speedier construction. The ability to use local material and labour, makes construction easier and faster and possible in isolated areas. The use of GSC structures allows for a more flexible and adaptive approach that can be more easily modified if the desired outcome is not satisfactory or if the design conditions change. GSC structures can even be easily removed in the event that the GSC structure does not perform.

Geotextiles have been widely used in coastal applications (Oh and Shin 2006). The concept of employing sand filled containers of various sizes and shapes for erosion control has been in existence for centuries. The initial evolution of sand filled containers for coastal erosion control has occurred over the past four hundred years, since the Dutch first employed small sand-filled containers to shore up their dike and dam structures in the 17th century. The myriad of enormous dikes surrounding Holland provide continuous protection to a nation which is sited largely below sea level (Harris and Sample 2009).

Sand-filled containers have been utilized to construct a variety of traditional coastal erosion control structures, including both shore-perpendicular and shore-parallel structures. These systems have included jetties, groins, vertical seawalls, sloped revetments, breakwaters and sill structures with varying degrees of success. Due to the lower costs and less need for heavy equipment, sand-filled containers have been used in developing countries (Harris and Zadikoff,, 1999). Geotextiles have several applications those could be especially important for coastal management programs. They are environmental restoration, flood prevention, and erosion control (CPRA, 2012). Extensive studies have been undertaken on the hydraulic stability of single geotextile tubes (Pilarczyk, 2000; Recio and Oumeraci, 2009; and Dassanayake and Oumeraci, 2013), and these have been used in coastal protection works (Kudale, 2013 and 2015; Sundar, 2013; and Sundar and Sannasiraj, 2013). However, current understanding of hydraulic stability and wave transmission of stacked GSC structures is limited and calls for further investigations. The performance study of such a GSC structure like a submerged reef could be both an innovative and low-cost solution for various coastal projects is the real motivator for the present study.

Objectives

The objectives of the present physical model study are to examine GSC armour stability and wave transmission of submerged reef constructed with GSC armour arranged in different alignments like Parallel, Perpendicular and Flemish.

Experimental details

Wave Flume

The wave flume of Marine Structures Laboratory of the Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal which generates monochromatic waves is used to test the physical models of the GSC reefs. Fig. 1 gives a schematic diagram of the experimental setup.

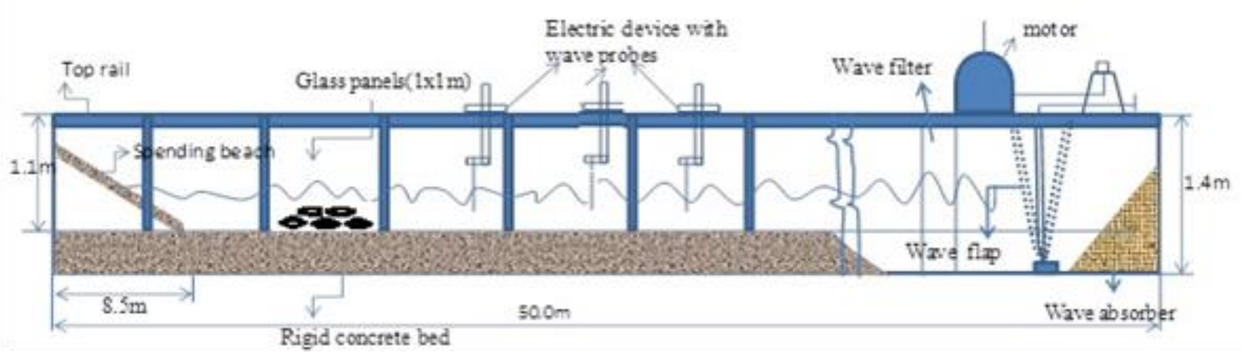


Figure 1. Schematic diagram of experimental set up with GSC reef model

The wave flume is 50 m long, 0.71 m wide and 1.1 m deep. About 15 m length of the flume is provided with a smooth bed and side walls and also glass panels on one side to facilitate photography of test models. This reduces wave reflection significantly. It has a 41.5 m long smooth concrete bed. Gradual transition is provided between normal bed level of the channel and that of wave generating chamber by a ramp. The flume has a 6.3 m long, 1.5 m wide and 1.4 m deep chamber with a the bottom hinged flap at one end which generates waves. The wave filter consists of a series of vertical asbestos cement sheets spaced at about 0.1 m centre to centre and parallel to length of the flume. A fly-wheel and bar-chain link the motor with the flap. By changing the eccentricity of bar chain on the fly-wheel, the wave height can be varied for a particular wave period. The changing of frequency through inverter, waves of desired wave period can be generated. The flap is controlled by an induction motor of 11 Kw power at 1450 rpm. This motor is regulated by an inventor drive (0 – 50 Hz), rotating in a speed range of 0–155 rpm. In this flume, monochromatic waves of 0.08 m to 0.24 m heights and periods of 0.8 s to 4.0 s in a maximum water depth of 0.5 m can be generated. Wave reflection from the structure does not interfere with freshly generated incident waves. In all tests, a series of 5 waves of uniform height were generated and measurements were limited to exclude any effects of wave reflection from the structure, beach or from the wave maker. Therefore, any kind of wave reflection was not considered in this study.

Instrumentation

The capacitance type wave probes along with amplification units are used for data acquisition. Three such probes are used during the experimental work for acquiring incident wave heights (H) as shown in Fig. 1. The spacing between probes is adjusted approximately to one third of the wave length to ensure accuracy (Isaacson, 1991). During experimentation, signals from wave probes are verified online through a software using the earlier calibration data stored and recorded by the computer through the data acquisition system. These are then processed to extract the incident waves using another software.

Test models

The GSCs were made with a non-woven polypropylene polymer material. The properties of this material are conforming to PIANC (2011), and are not mentioned here according to the supplier's request. The sand used as fill material in the GSCs is beach sand from NITK beach at Surathkal with a median grain size of 0.45mm. Each GSC unit was 0.16 m long, 0.08 m wide and 0.035 m high and weighed about 485 gm when completely filled with sand. 1:30 scale models of the submerged reef were constructed manually with GSCs at a distance of 3 m from the spending beach on the flume bed. See Fig. 1. The GSCs were arranged in trapezoidal manner, layer wise with a slope of 1V to 2H to a height (h) 0.25 m and varying crest widths (B). In the models, GSCs were aligned in four different alignments with respect to direction of wave propagation namely Parallel (single layer), Parallel with two layers, Flemish, and Perpendicular as shown in Fig. 2.

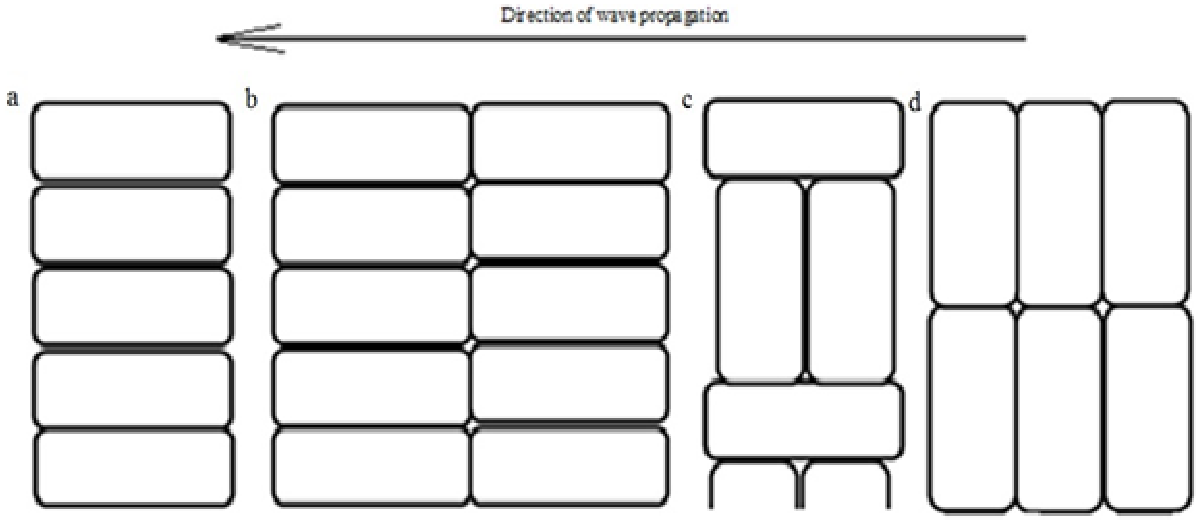


Figure 2. GSC alignments (a) Parallel (single layer), (b) Parallel double layer, (c) Flemish (d) Perpendicular

Test procedure

The models designed as submerged GSC reefs are tested for the stability of their armour (GSC) units and wave transmission while subjected to varying wave height and wave period in a water depth of 0.3m in a two dimensional wave flume. The incident wave height, wave transmission and movement of GSC units, i.e. damage of the reef, of constant reef crest height are recorded along with number waves passing during physical model investigation. The test methodology is shown in Fig. 3.

The wave flume is filled with potable water to the required depth. Before starting the experiment, the flume (with all its constituents) was calibrated to produce the incident waves of different combinations of wave height and wave periods. Combinations that produced the secondary waves in the flume were not considered for the experiments. The wave probes were calibrated at the beginning and at the end of the test runs. These models were tested for stability in a water depth (d) of 0.3 m (then the freeboard F = d – h = 0.05 m) with varying waves of heights (H) of 0.1 m and 0.12 m, and wave periods (T) of 1.5 s to 2.5 s. The wave data acquired by the probes were recorded by a computer and analysed using software. Occasionally, the wave heights were measured manually to crosscheck the instrumental data.

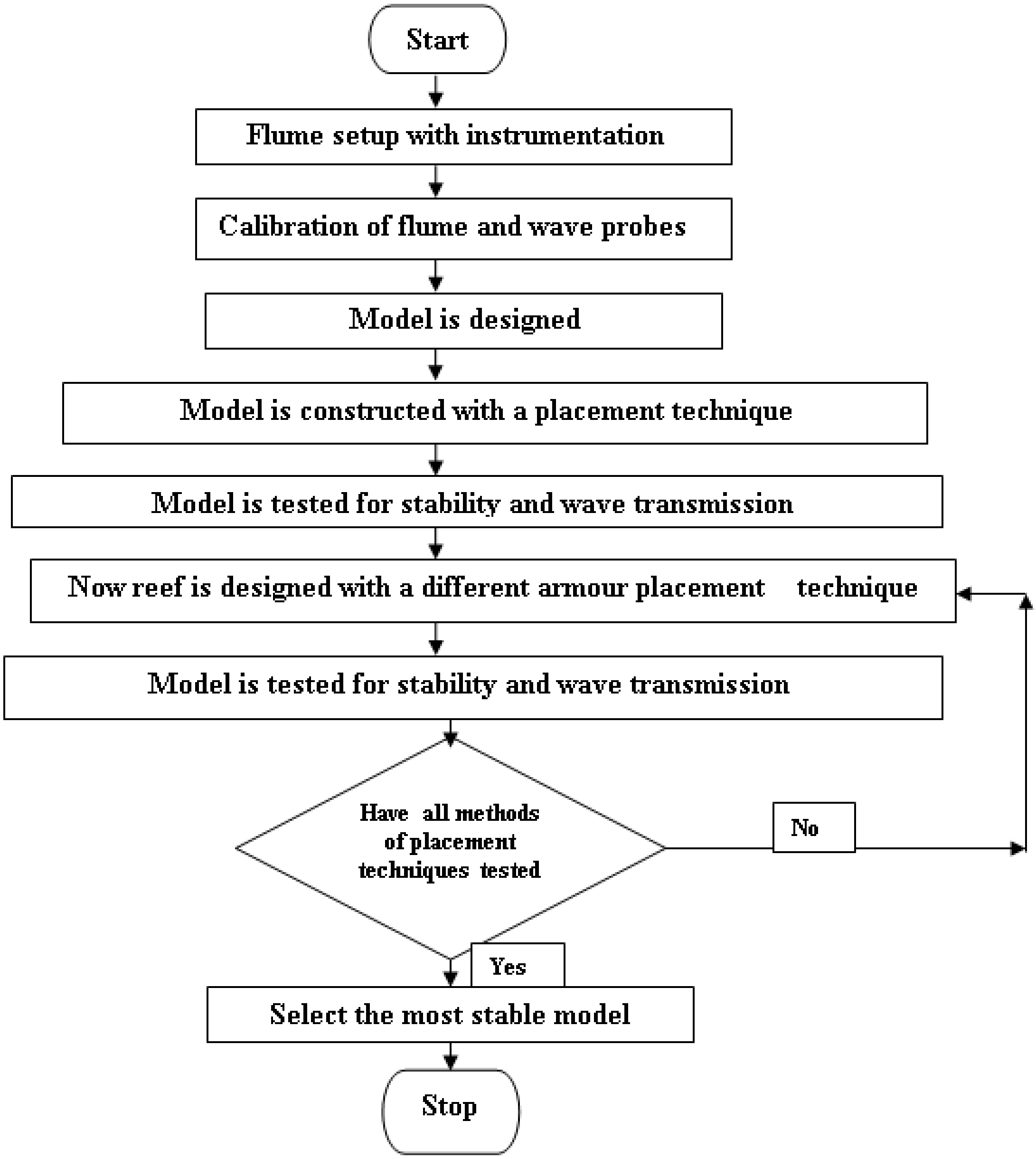


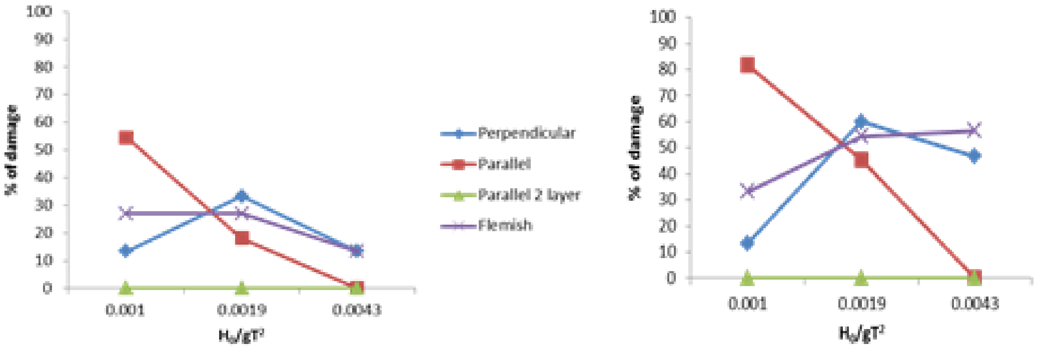
Figure 3. Flow chart of the methodology

Results

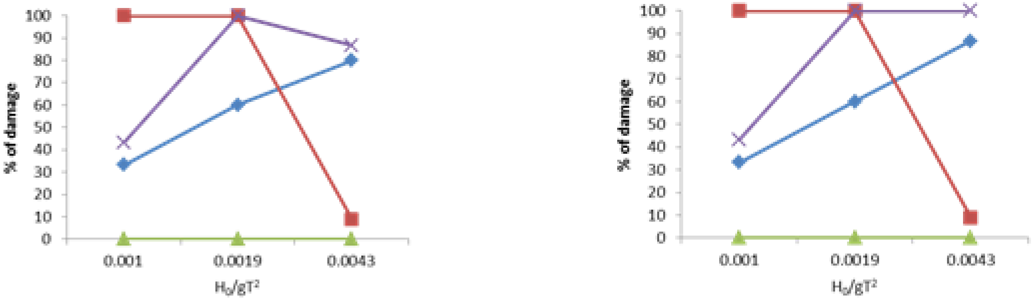
In this section, the influence of wave steepness parameter and wave activity (as number of waves) on reef damage and wave transmission is analyzed for a constant relative reef height (h/d) of 0.83 (i.e. h/F = 5).

Damage

All the GSCs present in the crest layer of different reef models are considered to be critical. Percentage damage is computed as number of GSCs detached against those in the critical layer and plotted against deep water wave steepness parameter (H_0/gT^2) for wave activity of 100, 500, 1000, and 1500 waves (where H_0 is the deep water wave height and actually the damage was measured up to 1800 waves) as shown in Fig. 4 for a constant relative reef height (h/d) of 0.83 (Shirlal and Mallidi, 2013 and 2015). The GSCs with parallel double layer alignment suffered no damage throughout the test regardless of wave steepness parameter and storm duration.



(a) After 100 waves (b) After 500 waves



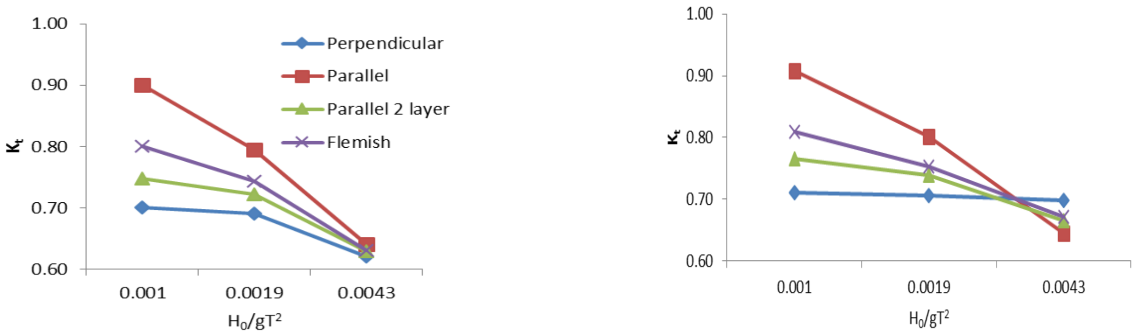
(c) After 1000 waves (d) After 1500 waves

Figure 4. Plot of percentage damage against H_o/gT^2 for various GSC alignments and storm durations

The maximum detachment of GSCs for the parallel alignment (single layer) was 55 % to 100 % for H_0/gT^2 up to 0.0019 (i.e. gentle to moderately steep waves), while the reef was stable and the damage was least i.e. about 0 to 5 %, for the steepest waves (i.e. H_0/gT^2 of 0.0043) for a wave activity up to 1500 waves. The other GSC alignments suffered increased detachment with the wave activity with maximum being about 90 % to 100 %. The damage was almost constant after 1500 waves and the reef profile stabilized. However, it was observed that damage of a submerged GSC reef exhibited inconsistent behaviour with H_0/gT^2.

Wave transmission

The submerged breakwater successfully trips the steeper waves and dissipates a major portion of wave energy. The submerged breakwater has two main energy dissipation mechanisms that attenuate wave height. First, energy is dissipated when the wave breaks due to abrupt change in water depth at the submerged breakwater; secondly, some energy dissipation may occur due to surface friction offered by GSC layer of the submerged reef (but no value for surface friction has been assumed in this study). The effectiveness of reef in damping of waves increases with an increase in wave steepness for all the alignments of GSC armour. This is clearly illustrated in Fig. 5 for initial condition and storm durations of 100, 500, and 1000 waves for a constant relative reef height (h/d) of 0.83. The K_t was found reducing in the order of parallel (single row), flemish, parallel with two layers and perpendicular alignments up to about 100 waves changed the pattern later.



a) Initial b) After 100 waves

c) After 500 waves d) After 1000 waves

Figure 5. Plot of K_t against H_o/gT^2 for various GSC alignments and storm durations

The wave transmission coefficients K_t at the initial condition i.e. immediately after construction and after passing 100 waves are comparable except for the case of perpendicular alignment as shown in Fig. 5a and 5b. It can be said that the damage caused by a longer wave duration has not changed the reef's wave transmission character even after the reef suffering damages up to 55%. The wave transmission coefficient K_t continues to follow more or less the same pattern after suffering damage due to passing 500 waves. The K_t varied between 0.65 and 0.9 for various GSC alignments. After passing 500 waves while the damages to the reef increased up to 80%, K_t increased by about 5% to 12% compared to the previous case for all the GSC alignments. K_t for parallel (single row) remained almost constant throughout the experiment. While parallel alignment with two layers of GSCs exhibited constant trend after the passage of 100 waves. Though the damage of the reef increased up to 100% after passing 1000 waves, the K_t for all GSC alignments remained almost constant after about 500 waves. Parallel alignment with two layers of GSCs in the crest, though was stable with zero damage, and exhibited 6.6% increase in K_t. It is found that though the structure is damaged, it is still effective in inducing wave breaking and energy dissipation resulting in effective damping of waves. This is because, though the damage displaced the armour units from their initial position still these units interfered with the wave field and offered the resistance and created turbulence to the passing wave thus inducing wave breaking and damping the waves.

Conclusions

From the present study following conclusions are drawn:

Reef damage

Damage of a submerged GSC reef exhibits inconsistent behavior with Ho/gT2, but increases with increase in storm duration. A reef model should be tested for minimum storm duration of 1000 to 1500 waves to define its damage status completely. Parallel alignment with two layers of GSCs in the crest is the only alignment that is stable and the reef damage is zero for the complete range of test conditions.

Wave transmission

The wave transmission is influenced by GSC alignment and reef damage. The effectiveness of reef in damping of waves increases with an increase in wave steepness for all the alignments of GSC units. The K_t varied between 0.65 and 0.9. The wave transmission coefficients K_t at the initial condition i.e. immediately after construction and after passing 100 waves (i.e. even after the reef suffering damages up to 55%.) are almost similar except for the case of perpendicular GSC alignment. After passing 500 waves while the damages to the reef increased up to 80%, K_t increased by about 5% to 12% compared to the previous case (i.e. after passing 100 waves). Though the damage increased with the number of waves passed, K_t almost stabilized after passing 500 waves. Parallel alignment with two layers of GSCs in the crest, though was stable with zero damage and exhibited 6.6% increase in K_t. It is found that though the structure is damaged, it is still effective in inducing wave breaking and energy dissipation resulting in effective damping of waves.

The above conclusions are derived from a small scale physical model study conducted within a limited wave conditions. However, a large flume with large waves may give a different number of waves to test stability. Also different wave steepness would give different results.

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