EXPERIMENTAL INVESTIGATION ON SUBMERGED REEF

Rahul Dev Raju[1], Sakthivel S[3], Saikat De[2], Sundaravadivelu R[2], Anbazhagan K[4], Ramanamurthy M.V[5] , Panneer Selvam R[2*]

ABSTRACT

Submerged artificial reef have multipurpose benefits. They have great potential for environmental and recreational benefits in addition to shoreline protection and stabilisation. One such reef was proposed along the southern coast of Indian peninsula. As a part of studies experiments were performed to measure wave transformation and breaking over the physical model of the submerged reef with triangular steel wedge connected to shore and with a scale of 1:10. Experimental studies have been carried out to study the details of wave transformation and breaking over the submerged reef for regular wave in head sea condition and influence of water levels on breaking and wave transformation. The effect of design parameters like wave height, wave period and submergence depth of the reef were assessed from experiments. The results show that the relative water depth over the reef crest is a major factor influencing the breaking and transformation characteristics. The paper also covers the impact of submerged reefs on the waves and generation of secondary waves when the incident wave period is large and seaward slope of the reef is gentle. It is inferred from the experiment that waves break over the submerged reef dissipating most of the wave energy.

Keywords: Submerged artificial reef, Wave transformation, Wave breaking, Transmission coefficient, Steel wedge reef, Submergence depth.

1. INTRODUCTION

Coastal areas are subjected to geomorphological changes due to natural and manmade activities. Artificial reef is considered an effective way in preventing coastal erosion due to its multipurpose benefits as compared to other shore protection methods. Artificial reefs are manmade underwater structure built to promote marine life, coastal protection, shoreline stabilisation and recreational activities. Due to increased use of artificial reefs in coastal environment, it is necessary to study the various design parameters of these reefs as the behaviour of waves and beach in presence of these artificial reefs is not well established. Also there is no fixed model or design of these reefs available.

Wide crested submerged reefs dissipate the incoming wave energy by forcing waves to break on top of the reef thereby drastically reducing the wave energy reaching the shore. Wave attenuation also occurs due to turbulence and nonlinear interaction between the reef and the incoming waves. Waves in the leeward side will be shorter and smaller and help in accumulation of sediments. These types of offshore reefs are custom-designed to trap sediment for each unique zone for different application. Due to various complexities associated with wave attenuation, breaking and refraction, numerous physical and numerical model tests were performed to determine the reef configuration.

Beji et al. (1993) did experimental studies to observe the various process of refraction, diffraction, shoaling and breaking of wave propagating over an offshore bar. The generation of higher harmonics in wave propagating over a submerged obstacle has been long known but the investigation aimed at the phenomenon of de-shoaling and wave decomposition which takes place for both non-breaking and breaking waves passing over a bar. Masselink (1997) conducted a field investigation to study generation of secondary wave during wave propagation over an offshore bar. The results of the experiment showed the decomposition of breaking incident swell into smaller and shorter waves upon entering the deeper water across the bar.

[1]Department of Ocean & Mechanical Engineering, Florida Atlantic University, Florida, USA
[2]Ocean Engineering Department, IIT Madras, Chennai, India
[3]Ocean Engineering & Consultancy Private Limited, Chennai, India
[4]Hitech Civil Engineers Private Limited, Port Blair, Andaman & Nicobar Islands, India
[5]National Institute of Ocean Technology, Chennai, India
[*]Presenting author email:pselvam@iitm.ac.in

The generation of secondary wave drastically reduced the wave energy hitting the beach. Blenkinsopp et al. (2008) performed experiments to show that wave transmission and breaking is affected by the water depth over the crest of the offshore reef. There was considerable increase in wave breaking, decrease in wave transmission and reflectance observed with the reduced crest submergence. Harris (2009) elucidates two mechanisms of wave attenuation and wave refraction by which submerged breakwaters assist with shoreline stabilisation. Kamath et all (2015) stimulated wave propagation over a bar and compared numerical results with the experimental data. The wave transformation was clearly observed as the wave propagated over the upward slope of the submerged bar.

In this paper the experimental investigation of wave transformation and breaking over the submerged reef with triangular steel wedge connected to shore is carried out. The submerged reef was tested for regular and random wave at different water levels in Shallow Wave Basin at IIT Madras, India. The reef is designed for conditions of South East Coast of India. The reef makes an angle of 13° with respect to the shore line and envisaged to trap the sediments from the long shore sediment transport. The submerged reef has a triangular wedge-shaped steel structure with armour stones and concrete cubes, the first of its kind in India. The main part of the submerged reef is triangular shaped steel wedge weighing 900 t (in prototype) with dimensions 60 m × 50 m × 2.5 m with slope on either side resting on stone bed. The model studies were carried out in 1:10 model scale for head sea condition with wave heights 5 cm to 15 cm with wave period 1.9 s to 3 s. The present paper describes the experimental study details of wave transformation and breaking over the submerged reef for regular wave in head sea condition. The influence of water levels on breaking and wave transformation is also studied.

2. EXPERIMENTAL SETUP

2.1 Test Facility

The experiments were carried out in the Shallow Wave Basin of the Department of Ocean Engineering, Indian Institute of Technology Madras, India. The basin has length of 19 m, width 15 m and height 1 m. Experiments were carried out for three different water levels i.e 50 cm, 54 cm and 58 cm.

The Shallow Wave Basin is equipped with a wave maker with five piston type paddles operating at one end, through a servo actuator with a remote-control system, used to generate both regular and random waves. This is executed with a personal computer connected to the servo activator and another computer is dedicated for data acquisition of the signals from the wave probes and run-up meter through an amplifier. An artificial beach (wave absorber) on the other end is provided with the combination of parabolic perforated Fiber-Reinforced Polymer (FRP) sheet and rubble mound to absorb the waves. The top view of the shallow wave basin with the test model is shown in Figure 1.

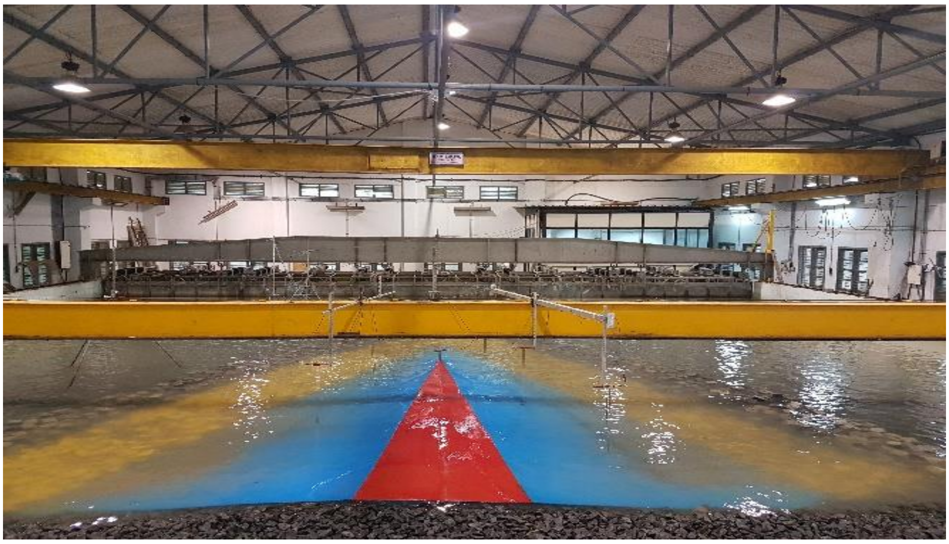


Figure 1: Top view of the experimental set-up in the shallow wave basin of IIT Madras

2.2 Test model

A submerged triangular reef is constructed using 2.5 mm thick IS 2062 grade steel sheets with base length 5 m and base height 6 m. The steel wedge consisted of top horizontal plate of base 1 m and length 4.5 m. The top horizontal plate is followed by slope of 1:0.8 on both the sides. The steel wedge has a height of 0.25 cm and installed in the basin with the toe of the wedge 7.3 m from the wavemaker. The horizontal crest of the steel wedge was at the water level for 50 cm water depth. Around the steel wedge at the opposite end of the wave generator in the basin, a beach with a 1:20 slope was made using 20 mm aggregate. The experimental setup inside the shallow wave basin is shown in Figure 2.

Armour stones of average size 5 cm was placed all around the steel wedge for a length of 1 m. Stones were placed for a depth of 10 cm(in vertical direction 2 layers) to prevent toe scour. Additional concrete cubes of size 10 cm with 2cm holes on all the six sides was place all around the armour stone for a length of 0.5 m. Concrete cubes with holes were placed in random for a depth of 20 cm to dissipate the wave energy and prevent scour erosion as shown in Figure 3.

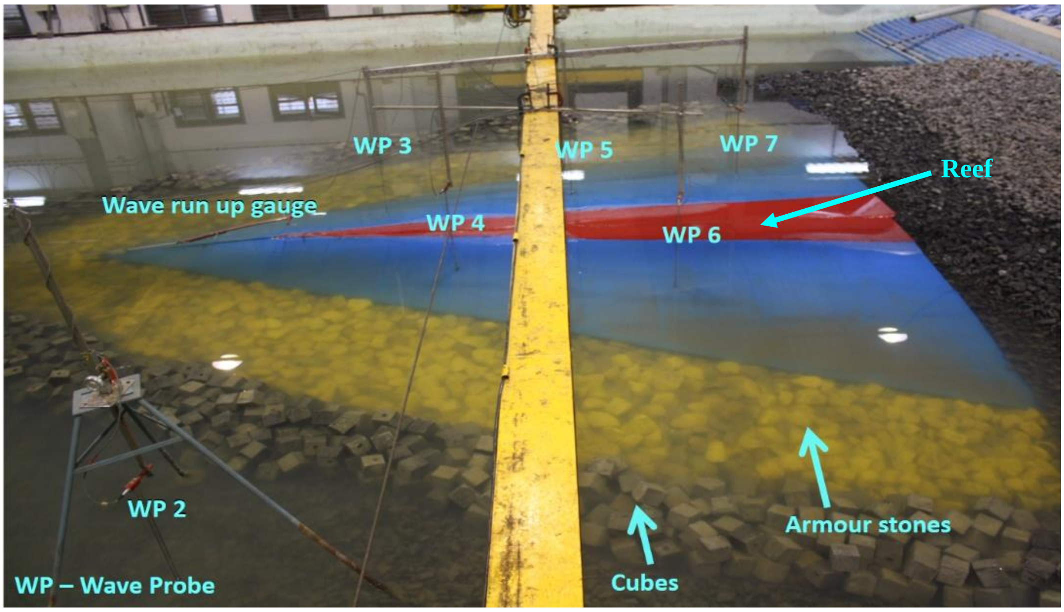


Figure 2: Experimental set up (1:10 scale) at shallow wave basin at IIT Madras

Figure 3: Armour stones and concrete cubes with holes

2.3 Instrumentation

A total of seven wave probes and a run-up meter was used during the experiment. The first wave probe (WP 1) was installed in front of the submerged reef structure at 5 m from the wavemaker to measure the incident wave. The second wave probe (WP 2) was placed over the beach at 11 m from the wave maker and 3.7 m away from the centre of the steel wedge. A further of five wave gauges (WP 3 to WP 7) were installed over the submerged reef to measure the transmitted waves in the water section near the beach end of the basin after breaking. The run-up meter (WP 8) was installed on the tip of the steel wedge to register the run-up. Location of various wave probes and runup meter is shown in the Figure 4.

The wave probes were calibrated before installation. The signatures from seven wave probes and one run-up meter, were simultaneously acquired and recorded by a personal computer loaded with data acquisition software. The signals from the measurements were recorded with a sampling interval of 0.02 s. For the present study, one personal computer connected to servo actuator was used to give the required wave height and wave period to the wave generator. Another personnel computer was used for data acquisition with application software package.

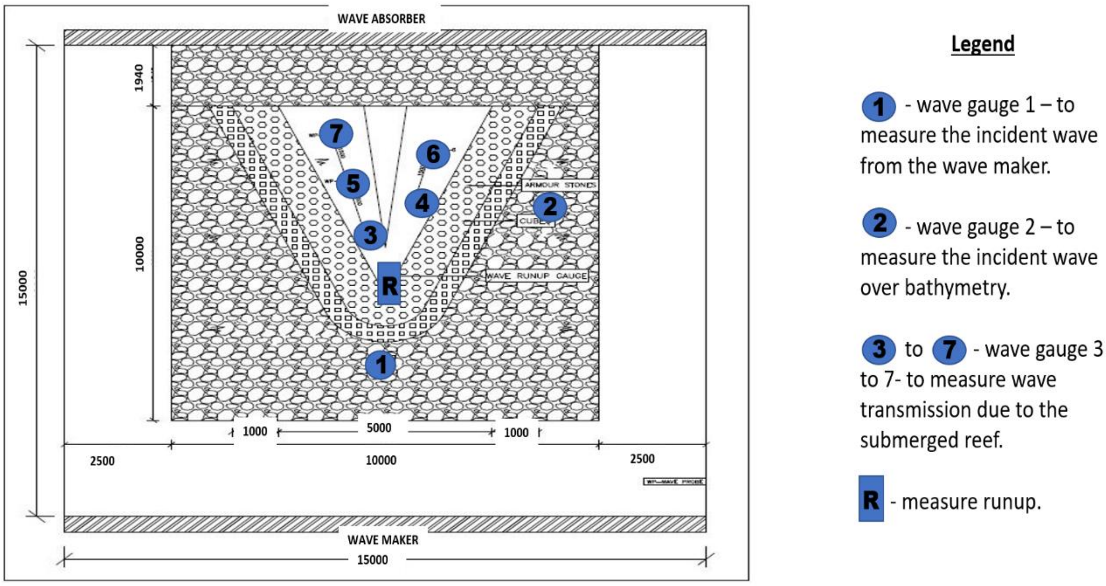


Figure 4: Location of various wave probes and runup meter at shallow wave basin

2.4 Experimental program

During the experiment the test were conducted for three different water levels i.e 50 cm, 54 cm and 58 cm considering both the situation with and without storm surge. Regular waves with different wave heights of 5 cm, 8 cm, 10 cm, 12 cm and 15 cm were generated with various wave period of 1.9 s, 2.2 s, 2.5 s, 2.8 s and 3 s. A total of twenty-five different combinations were realised for the regular wave: five different wave heights and five different wave periods. The tests were conducted for all three different water levels. Thus, a total of seventy-five runs were performed for regular wave.

3. RESULTS AND DISCUSSION

During the experiment typical wave elevation were measured over the submerged reef subjected to regular wave field characterised by input wave height H= 5 cm, and 15 cm; wave period T=1.9 s, 2.5 s, 3 s at various water depth of 50 cm, 54 cm and 58 cm. Visual observation during the experiments and from inspection of chart elevation we concluded that submergence depth, wave height and wave period greatly influence the breaking and transformation of the wave over the submerged reef.

3.1 Submergence depth

Figure 5 and 6 depicts the wave elevation over the reef at various points for H=5 cm, T=1.9 s and H=15 cm, T=3 s for various water depth respectively. The transformation of the wave as it propagates over the submerged reef is computed using the wave probes fixed at various places over the reef. The incident wave on the submerged reef is measured by wave probe(WP1) as shown in Figure 5. The wave is deformed as it moves up the slope of the submerged reef due to shoaling as seen in wave probe 3 (WP3) in Figure 5 (a). The wave reaches the crest of the reef and propagates. The decomposition of wave begins at wave probe 5 (WP5) in Figure 5 (a). The formation of secondary crest after the primary crest is observed. As the wave propagates further over the reef towards wave probe 7 (WP7), the amplitude of wave reduces drastically and secondary and tertiary crests are seen. It is clearly seen that the intensity of wave breaking increases as the water depth and submergence depth of reef crest is reduced. Shallower depth of submergence of the reef, results in greater portion of water column becoming turbulent due to higher air entrapment and energy dissipation. Hence the breaker type of the wave is strongly influenced by the water level over the reef crest.

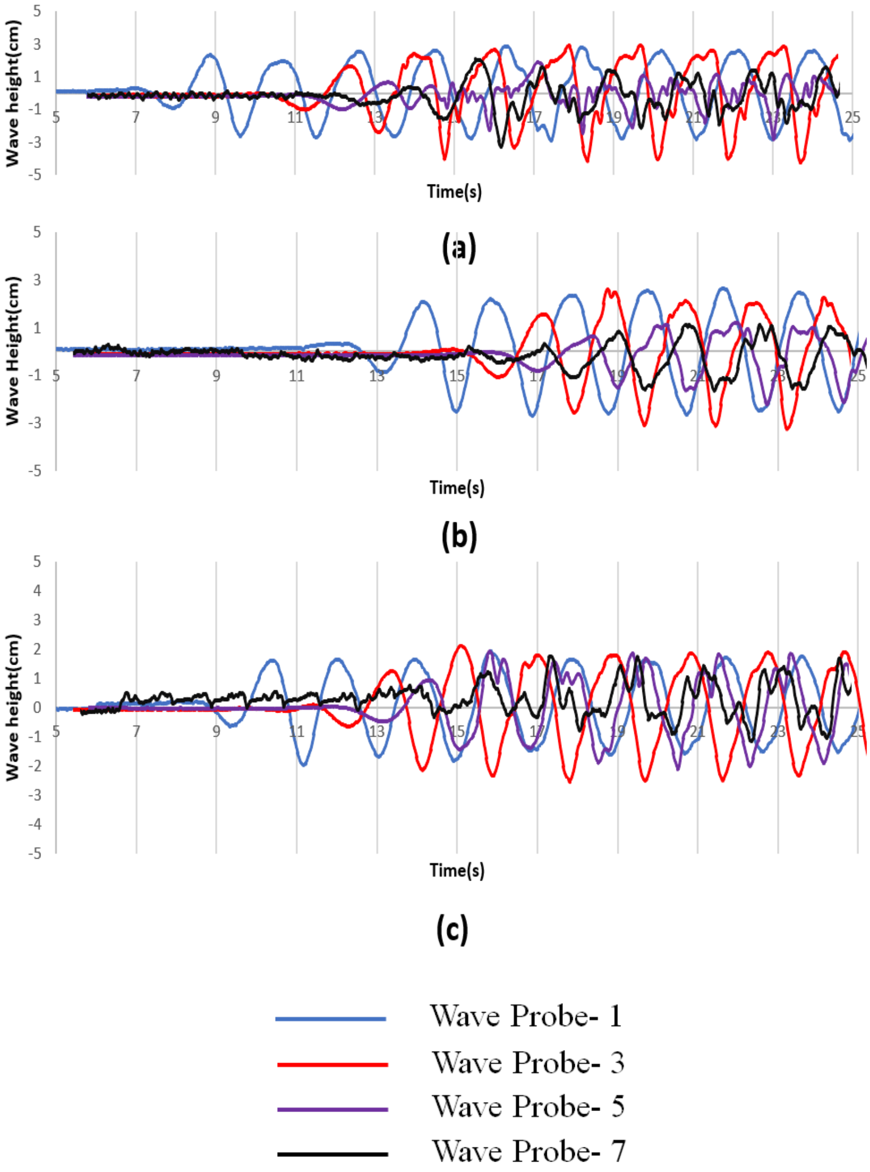


Figure 5: Surface elevation records for wave height 5 cm and wave period 1.9 s for water depth (a)50 cm (b)54 cm (c)58 cm.

3.2 Wave height and wave period

In Figure 5 and 6 it is seen that at wave probes 5 and 7, waves propagating across the reef is predominantly breaking as indicated by observation and suggested by their asymmetric shape. But the wave breaking does not alter the characteristics of the wave form completely; hence it is comparable with its unbroken counterpart.

The pattern of wave transformation in Figure 5 for H=5 cm and in Figure 6 for H=15 cm are similar but with few differences in the transformed wave. There is formation of sharp secondary peaks at WP 5 in Figure 5 as compared to Figure 6. Also the secondary peak is much lower than the primary peak in Figure 6.

Long waves (T=3 s), as they travel upslope of the reef, lose their vertical symmetry and assume saw toothed shape due to generation of primary secondary harmonics. In these waves a very rapid flow of energy begins from the primary wave to higher harmonics which generates dispersive tail waves travelling at nearly the same celerity as the primary waves as mentioned in study reported by Beji et all (1993). Short waves (T=1.9 s) do not develop tail wave as they grow in amplitude but keep their vertical symmetry and appear as higher order Stokes waves.

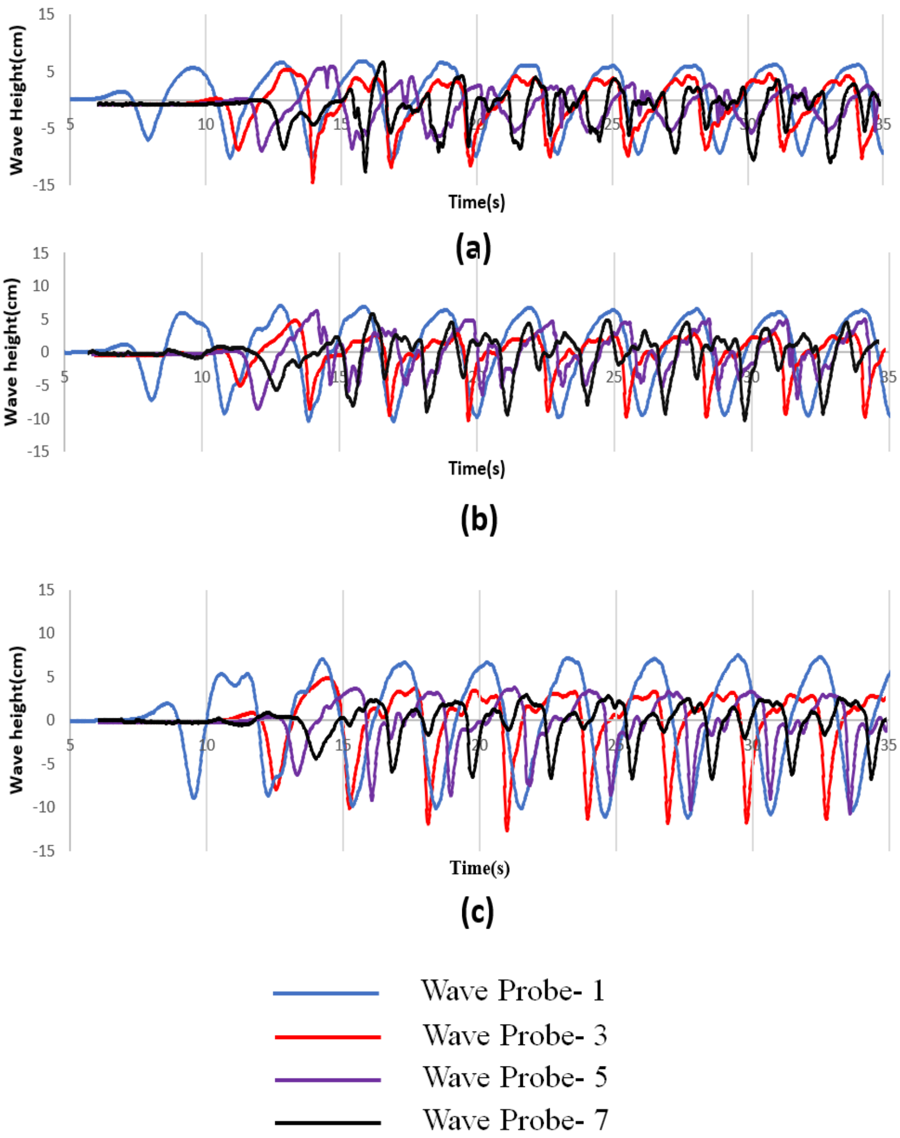


Figure 6: Surface elevation records for wave height 15 cm and wave period 3 s for water depth (a) 50 cm (b)54 cm (c)58 cm.

3.3 Transformation coefficient

Study of wave transformation characteristics of submerged reef is important for calculation of near shore currents, beach evolution and effect of wave forces on the shoreline structures. The transformation coefficient (the wave height(Ht) at different locations (WP3 to WP7) on the reef divided by the incident wave height (Hi), WP1) was found to be influenced by the incident wave conditions (wave height and wave period) and the submergence depth of the reef.

The different locations of the probe from tip of wedge on the reef (D_P) is normalized with the ratio of water depth to height of reef (d/h_r) and the transformation coefficient, H_T/H_i plotted Vs D_P/L_r in Fig7 to Fig10. The transformation coefficient increases from 1 to more than 1.5 as the wave propagates from WP1 to WP3 and then decreases. The non-dimensional parameter submergence depth, d/h_R (h_R is 50 cm and is equal to the total height of reef) and relative wave steepness H/L (L is wave length) are used to study the effect of submergence depth of reef and wave period. The submergence depth of 1,1.08 and 1.16 corresponds to 50 cm, 54 cm and 58 cm water depth respectively. The relative wave steepness varies in the range of 0.056 to 0.038 and the non-dimensional wave height, Hi/d varies in the range of 0.086 to 0.1 for lower wave height and 0.25 to 0.3 for higher wave height. The influence of each wave height and each wave period with all three water depth in the same plot have been evaluated.

Figure 7 and Figure 8 shows the result for lower input wave height (Hi/d), wave period of 1.9 s, 2.5 s and 3 s subsequently for all three submergence depth. Similarly, Figure 9 and Figure 10 shows the result for higher input wave height (Hi/d), wave period of 1.9 s, 2.5 s and 3 s subsequently for all three submergence depth. From Figure 7 to Figure 10, it is concluded that transformation coefficient reduces from as the wave propagates over the reef.

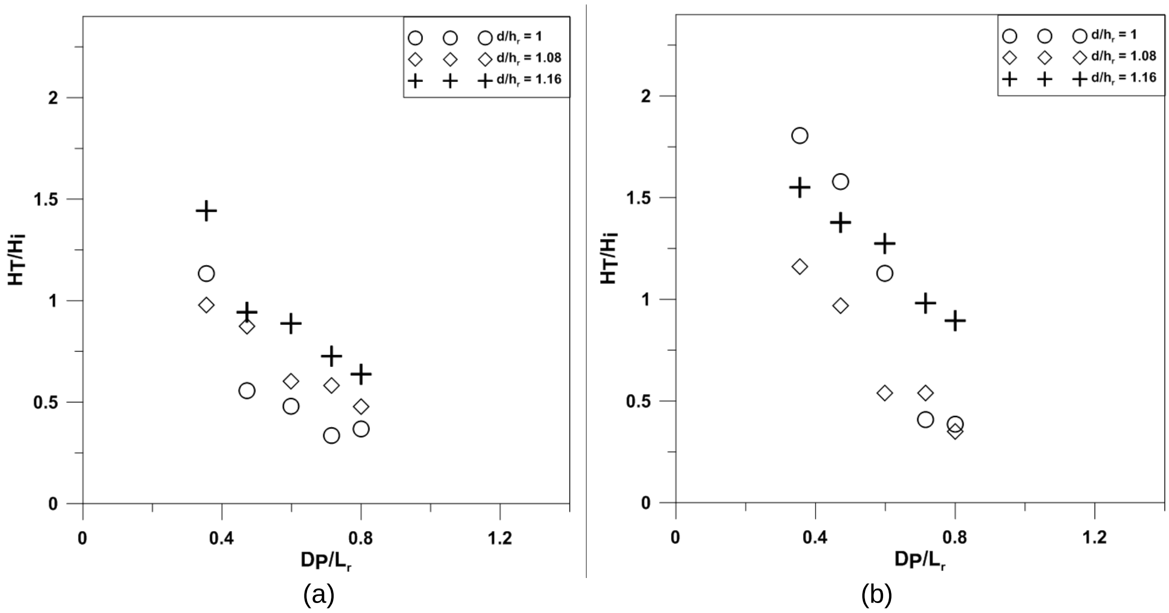


Figure 7: Wave Transformation for L_r/L = 1.48 to 1.56 & H/d = 0.086 to 0.1 (a) and Wave Transformation for L_r/L = 1.4 to 1.48 & H/d = 0.086 to 0.1 (b)

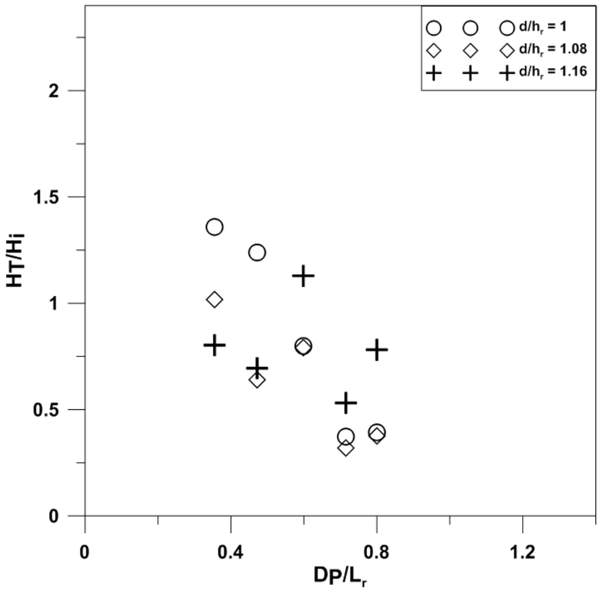
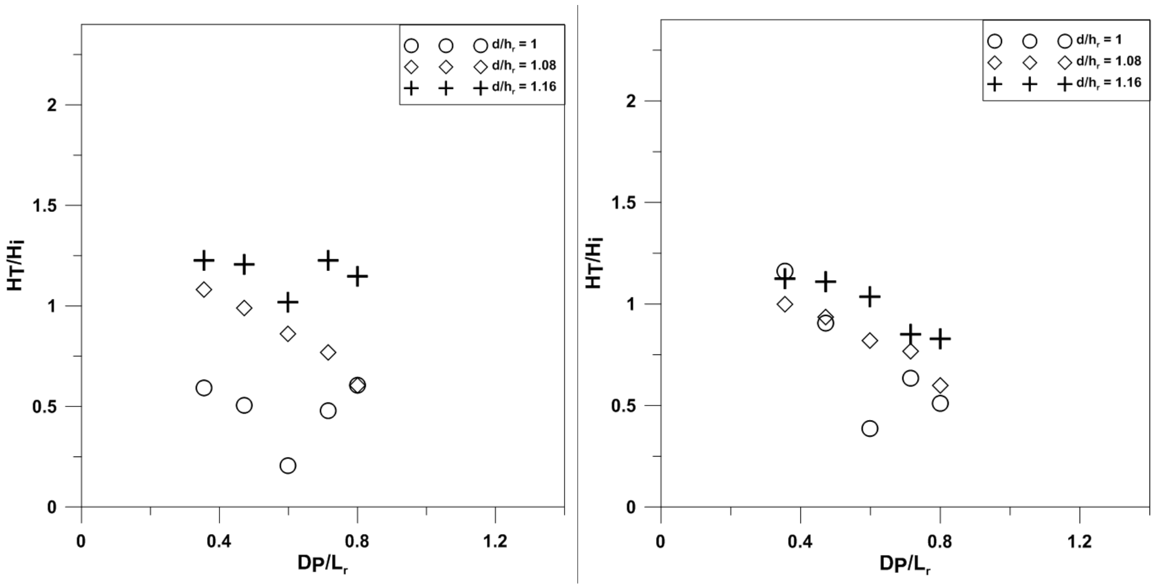


Figure 8: Wave Transformation for L_r/L = 0.88 to 0.93 & H/d = 0.086 to 0.1



(a) (b)

Figure 9: Wave Transformation for L_r/L = 1.48 to 1.56 & H/d = 0.25 to 0.3 (a) and Wave Transformation for L_r/L = 1.4 to 1.48 & H/d = 0.25 to 0.3 (b)

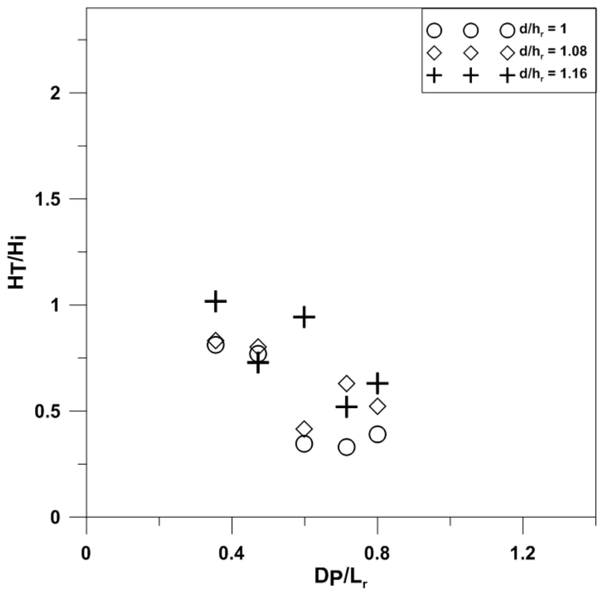


Figure 10: Wave Transformation for L_r/L = 0.88 to 0.93 & H/d = 0.25 to 0.3

Where,

H_T = Transformed wave height
Hi = Measured incident wave height
L_r = Length of the submerged Reef
D_P = Position of wave probe from tip of the wedge
h_R = Total height of reef
d = water depth
L = Wave length

4. CONCLUSIONS

The main findings for regular wave in head sea condition on the reef being installed in India are given below.

1. Intensity of the wave breaking increases as the submergence depth of the reef crest is reduced.
2. When crest of reef is submerged long period waves get attenuated and generate dispersive tail wave.
3. The wave with higher incident height shows more shoaling on the upward slope of the submerged reef as compared to the lower incident wave height. Hence wave transformation depends on the incident wave height.
4. Transmission coefficient increases with increase in submergence depth and wave period and decreases with increase in wave height.
5. Wave breaking is enhanced by the submerged reef.

5. REFERENCES

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