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PHYSICAL MODEL STUDY ON TANDEM BREAKWATER WITH CONCRETE CUBE ARMOUR

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Abstract: *Tandem breakwater system consists of a conventional breakwater protected by a seaward submerged reef. The reef breaks the incoming waves and causes significant dissipation of wave energy. The transmitted waves of smaller height propagate in the zone between the reef and breakwater and finally impinge on the breakwater. Such waves depleted with a large part of their energy are quite tamed and inflict less damage on the breakwater. The paper discusses physical model study on the hydraulic performance of tandem breakwater system subjected to varying wave climate and water depths. The breakwater is armoured with concrete cube and reef is made of natural stone armour. It is found that for a submerged reef of crest width 0.2m placed at a seaward spacing of 4m, coefficient of transmission (K_t) varies between 0.37 and 0.7 and inflicts 4 to 39% lower damage compare to conventional single breakwater.*

Keywords: *Conventional Breakwater; Wave breaking; Wave Transmission; Damage.*

INTRODUCTION

In the early days when breakwaters were built in relative shallow waters, the use of natural stones as armour units posed no problem since stones of required size/weight were easily obtained from quarries nearby. As the construction started moving into deeper waters, the wave load on breakwater armour increased requiring heavier armour units and it was found that natural stone no longer served the purpose of armour units since such large weights of stones were uneconomical to quarry or transport or were not available in the quarries nearby. With the development of concrete technology, the most logical solution was the use of concrete blocks instead of natural stones as breakwater armours. Several major breakwaters like Sines breakwater in Portugal (1979), Salalah, in the Sultanate of Oman, Petoskey's breakwater, Montague U.S.A (2000) etc have failed due to extreme wave loading due to cyclones. The design was based on criteria accommodating the interlocking, with a high risk of progressive failure. Hence, to avoid such failures, it was proposed to place a submerged breakwater in the front to reduce the wave load, reducing impact on main breakwater, which can then be designed with lighter armour units. Such a combined structure was called Tandem breakwater which may prove stable and economical for given wave and site conditions.

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LITERATURE REVIEW

The important parameters that influence the performance are the crest width and the depth of reef submergence. Dattatri (1978) found that the optimum crest width as B/L = 0.2 to 0.3. Gadre et al. (1985) designed a submerged bund to break higher waves and dissipate energy while protecting the revetment constructed at 100m shoreward to retain land behind it at Chennai port. Thus the required amour stone weight of 15 tons for a conventional reclamation structure in a depth of 8m was downsized to a stone weight of 2 to 3 tons. Ramamurthy and Sharma (1989) tested a submerged breakwater with B/h of 1.44 for varying wave heights, structure slope and h/d values. They concluded that for $h/d < 0.75$, the protection provided by breakwater reduces rapidly. Gadre et al. (1989) designed a submerged breakwater at 80m seaward to protect a damaged breakwater head of west breakwater at Veraval port in Gujarat, India. This submerged structure broke the storm waves protecting the damaged breakwater which was repaired later. Cornett et al. (1993) after conducting experimental investigation concluded that there could be an optimum location for submerged reef of relative height $h/d > 0.6$ which protects the inner main breakwater. Cox and Clark (1992) who coined the term tandem breakwater system, examined the effect of wave breaking, overtopping and transmission on stability of the breakwater with the slope of 1V: 1.5H. Bierawaski and Maeno (2002) found that submerged reef is the safer and efficient structure in attenuating steep waves compared to impermeable structure. Shirlal et al. (2006) conducted study of stability of a 1: 30 scaled model of breakwater defenced by a seaward submerged reef for varying characteristics of regular waves. They arrived at the optimum armour stone weight of 30gms, relative spacing between structures X/d as 6.25-8.33 and reef crest width B/d as 0.6-0.7 and B/L_o as 035-0.045 to protect the main breakwater.

OBJECTIVE OF STUDY

The objective of the present investigation was to experimentally study the stability of conventional breakwater and tandem breakwater system, wave transmission at the reef structure subjected to varying wave climate.

METHODOLOGY OF EXPERIMENTAL WORK

The 1:30 scale model of breakwater constructed with concrete cubes and protected with seaward submerged reef, is tested in a wave flume under varying wave climate. The waves of different heights and periods are generated in changing water depths. Apart from incident waves characteristics transmitted and reflected waves at the reef and damage of the breakwater were measured.

Experimental setup

Wave flume

The physical model were tested for regular wave attack in a two dimensional wave flume of Marine Structure laboratory of Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka, Surathkal. Fig. 1 gives a schematic diagram of experimental setup. The wave flume is 50m long, 0.71m wide and 1.1m deep. It has a 41.5m long smooth concrete bed. About 15m length of the flume is provided with glass panels on one side. It has a 6.3m long, 1.5m wide and

1.4m deep chamber at one end where the bottom hinged flap generates waves. The flap is controlled by an induction motor of 11Kw power at 1450rpm. This motor is regulated by an inventor drive (0 – 50Htz) rotating in a speed range of 0–155rpm. By changing the frequency through inverter, one can generate the desired wave period. A fly-wheel and bar-chain link the motor with flap. By changing the eccentricity of bar chain on the fly-wheel one can vary the wave height for a particular wave period.

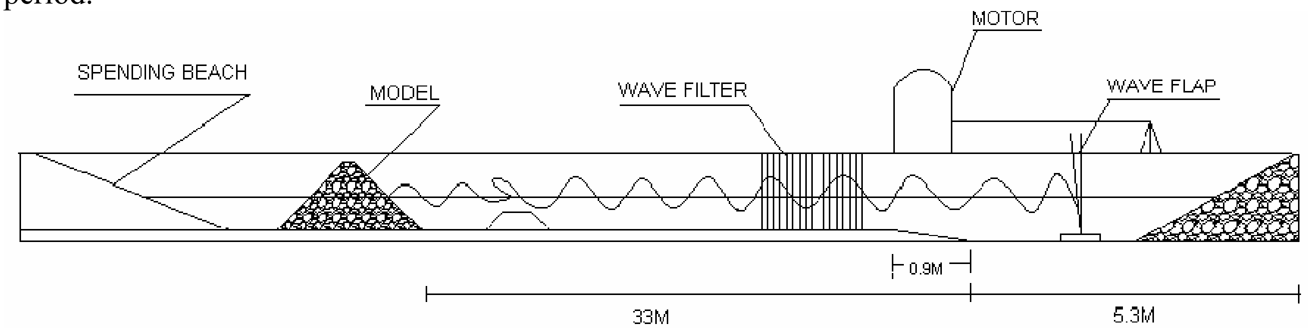

Fig. 1. Details of experimental setup.

Instrumentation

Capacitance type wave probes were used to measure incident wave height (H_i) at about 1m seaward of reef toe and measure transmitted wave height (H_t) after breaking over the reef (Refer Fig. 1). The water surface elevation on seaward and shoreward side of the reef will be converted into electrical signals then stored as digital signals by software controlled 12-bit A/D converter with 16 digital input/output. During the experiment, every time after five waves passed the reef, transmitted waveform for 10sec duration were acquired using software.

Model construction

Conventional breakwater model

The 1:30 scale breakwater model with a uniform slope of 1V:2H was constructed, at about 32m from wave generator, on the flat bed of the flume with concrete cubes of nominal diameter D_{n50} equal to 0.0325m as primary armour unit (i.e. the mean armor cube weight W_{50} of 79.51gm). Where

$$D_{n50} = \left\{\frac{W_{50}}{\gamma_r}\right\}^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

and γ_r is the mass density of the armour unit.

The primary armour cube weight (W_{50}) was determined using Hudson's formula, for a wave height of 0.1m. To attain the density of concrete (2.4gm/cc), the sand was replaced by iron ore in some proportion in cement mortar of 1:3. For this particular weight, the size of concrete cube obtained was 0.0325mx0.0325mx0.0325m. The armour units were painted with different colors and placed in bands of 0.2m to 0.3m heights to reduce their surface roughness and track their movement during damage while subjected to wave attack (Hughes 1993). The placement technique used for armour was random placement. The secondary armour and the core were also designed as for a conventional breakwater (US Army Corps of Engineers, Shore Protection manual, 1984).

Tandem breakwater

A 1:30 scale submerged reef model of natural armour stones with optimum weight of 30gms of crest width (B) 0.2m, height (h) of 0.25m and uniform slope of 1V:2H with a nominal diameter D_{n50} =0.0221m was constructed on the seaward side of the breakwater at a distance of 4m as shown in Fig. 2.

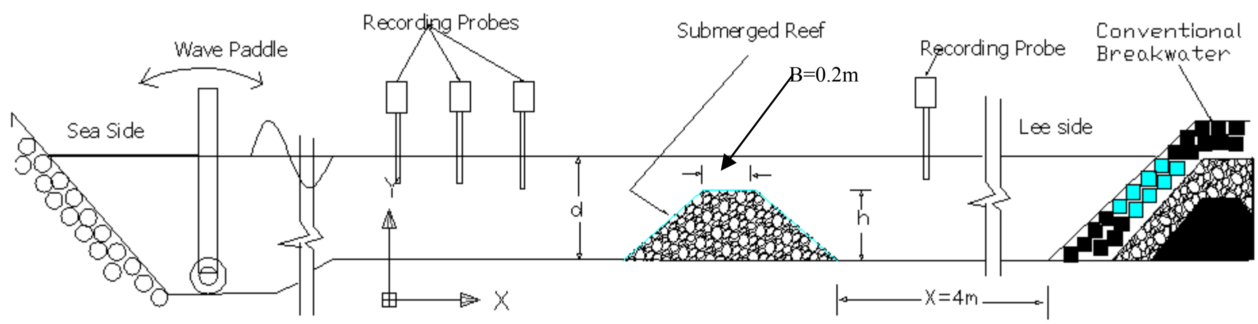

Fig. 2. Tandem breakwater model set-up.

Model testing

In the first phase, conventional breakwater model was tested for its armour stability in a varying wave climate and in the second phase tandem breakwater is tested for similar wave climate.

Test procedure

Initially the newly constructed breakwater slope was surveyed with the profiler, which was, the reference survey for comparison with subsequent surveys. The waves were sent in short burst of five waves during the test and the generator was shut off just before the wave energy reflected from slope could reach the wave flap.

The model was subjected to a series of smaller wave heights (H_i) starting from 0.1m and then gradually wave height is increased by 20% each time till it reached the highest value of 0.16m for different periods (T) of 1.5, 2.0 and 2.5secs and water depths (d) of 0.3, 0.35 and 0.4m. Waves were run in bursts in the model until it appeared that no armour cubes moved further by waves of this height or 3000 waves which is equivalent to a actual storm for 6 to 11hours, for each trial or the failure of the structure whichever occurred earlier. This was because more than 90% of the total damage would have already inflicted by that time and equilibrium would have established (Hegde and Samaga, 1996, Van der Meer and Pilarczyk, 1984). Damage level (S) was calculated as the ratio of area of erosion (A_e) to square of nominal diameter D_{n50} of breakwater armour (Van der Meer, 1988). According to him the damage criteria for breakwater with armour slope of 1V: 2H is as follows.

S = 2 to 3 (No damage)
S = 5 to 6 (Intermediate damage)
S ≥ 8 (Failure)

The failure for these tests was defined as the displacement of primary armour cubes to expose the filter layer due to wave action.

RESULTS AND DISCUSSIONS

During the test, the experimental data like the incident wave characteristics, wave breaking, wave transmission and reflection at reef, wave run up and run down over the breakwater slope and armour stone movements were recorded / measured.

The data collected in the present experimental work was converted into various non-dimensional terms to study their interdependence. Run up, run down, damage level, wave transmission etc., are plotted against deepwater wave steepness to analyse their behaviour.

Response of conventional breakwater

Wave run up and run down

The influence of deep water wave steepness parameter (H_o/gT^2), on relative run up (R_u/H_o) and run down (R_d/H_o) for varying wave climate in different depths of water or increasing d/gT^2 is shown in Fig. 3 and 4. Both the run up and the run down, decrease with an increase in wave steepness. The extreme values are 1.25 and 2.14 for run-up, 0.7 and 1.14 for rundown, for the complete range of H_o/gT^2 between 1.45×10^{-3} and 7.85×10^{-3}. The influence of d/gT^2 on run up and run down is minimal. On an average the run up and run down in the present case are almost same those for breakwater of stone armour as given by SPM. The present study shows a trend comparable with that for natural stones armour given by SPM (1984).

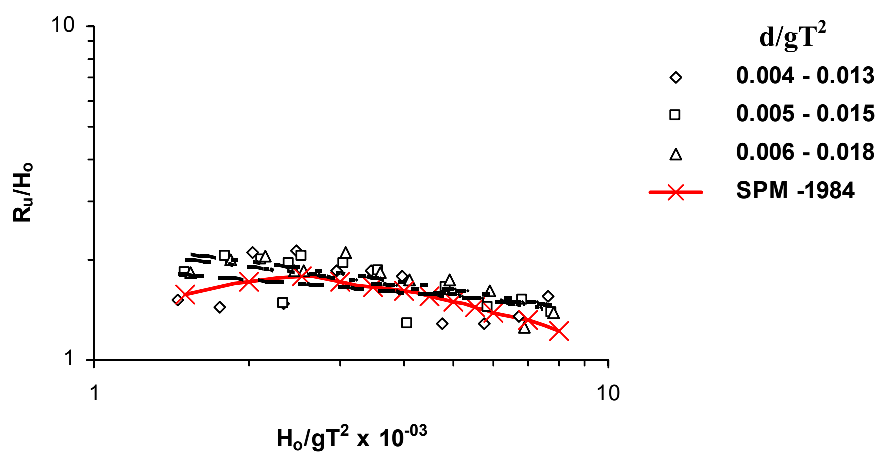

Fig. 3. Variation of R_u/H_o with H_o/gT^2.

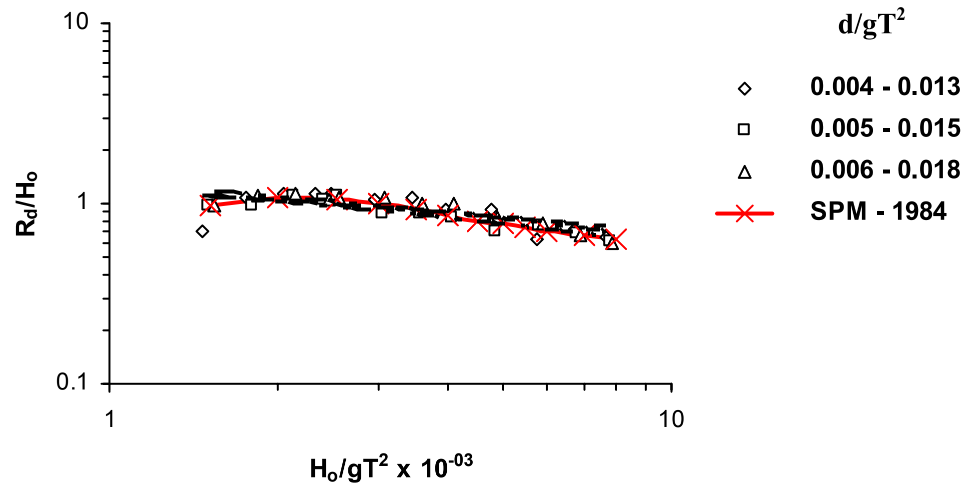

Fig. 4. Variation of R_d/H_o with H_o/gT^2.

Damage level (S)

The trends of damage level (S) with varying wave steepness parameter (H_o/gT^2) for increasing d/gT^2 are shown in Fig. 5. Most of waves of periods of 1.5sec and 2sec caused failure of breakwater while breakwater was safe and no damage were caused by waves of period of 2.5sec.

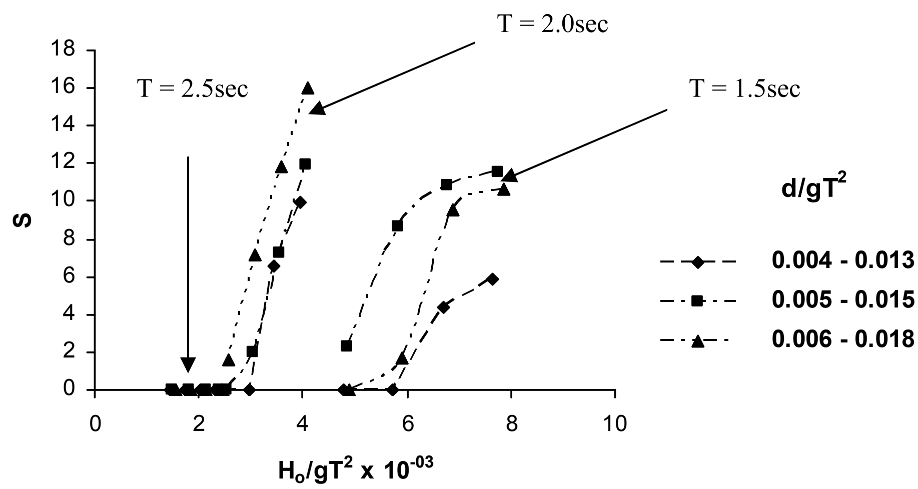

Fig. 5. Variation of S with H_o/gT^2.

Response of tandem breakwater system

Wave run up and run down

Fig. 6 and 7 reveal the influence of deep water wave steepness parameter (H_o/gT^2) on relative run up (R_u/H_o) and run down (R_d/H_o) respectively for varying wave climate in depths of water of 0.3m, 0.35m and 0.4m i.e. increasing ranges of depth parameter (d/gT^2).Both the relative run up and run down decrease with the increase in H_o/gT^2.

The maximum relative run up and run down are respectively 1.8 times and 0.92 times the deep water wave height for the range of variables considered in the present study. Considering all the ranges H_o/gT^2 , relative run up for depths of water of 0.3m (i.e. $0.004 < d/gT^2 < 0.013$) , 0.35m (i.e.$0.005 < d/gT^2 < 0.015$) and 0.4m (i.e.$0.006 < d/gT^2 < 0.018$) are 32%- 46%, 22%-31% and 11%- 21% lower than that for conventional breakwater. Similarly, for the same range of parameters, relative run down are 25% to 32%, 15% to 18% and 5% to 7% lower than that for conventional single breakwater.

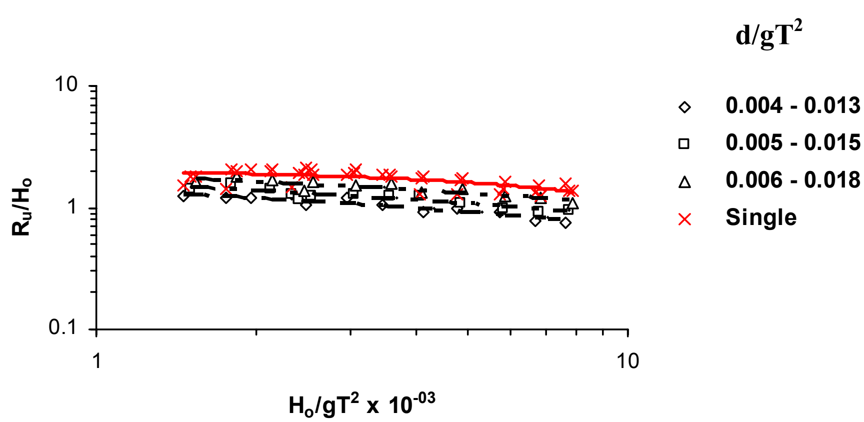

Fig. 6. Variation of relative wave run-up (R_u/H_o) with deep water wave steepness (H_o/gT^2).

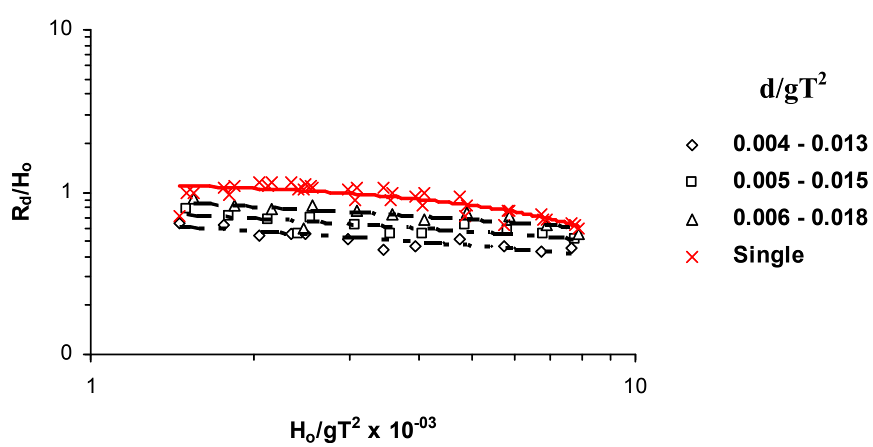

Fig. 7. Variation of relative wave run-down (R_d/H_o) with deep water wave steepness (H_o/gT^2).

Transmission coefficient (K_t)

Fig. 8 shows decrease of transmission coefficient K_t with the increase in deep water wave steepness parameter (H_o/gT^2) and relative reef height (h/d). The figure shows the best fit lines for K_t. For $1.45 \times 10^{-3} < H_o/gT^2 < 7.851.45 \times 10^{-3}$, K_t decreases from 0.53 to 0.37 (30.2%), 0.62 to 0.4 (35.5%) and 0.7 to 0.55 (21.4%) for h/d of 0.833, 0.714 and 0.625 i.e. for water depth of 0.3m, 0.35m and 0.4m respectively. The wave height attenuation achieved is 30% to 63%.

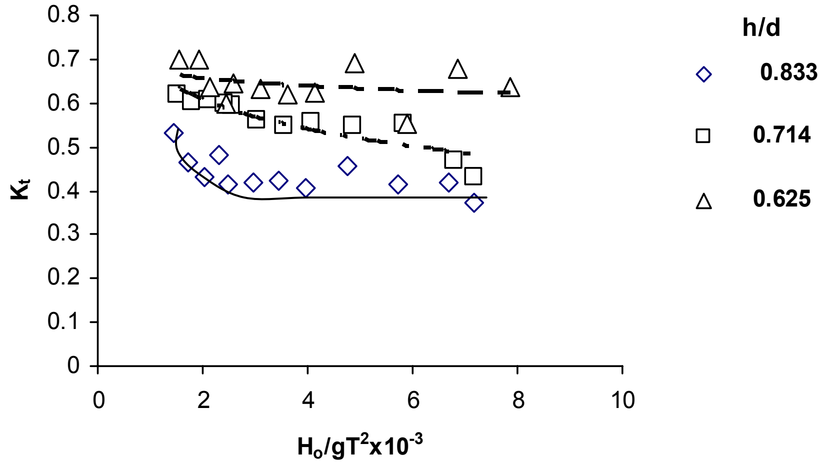

Fig. 8. Variation of transmission coefficient (K_t) with deep water wave steepness (H_o/gT^2).

Damage level (S)

The trends of damage level (S) with varying wave steepness parameter (H_o/gT^2) for increasing depths of water of 0.3m, 0.35m and 0.4m i.e. increasing ranges of depth parameter (d/gT^2) are shown in Fig. 9.

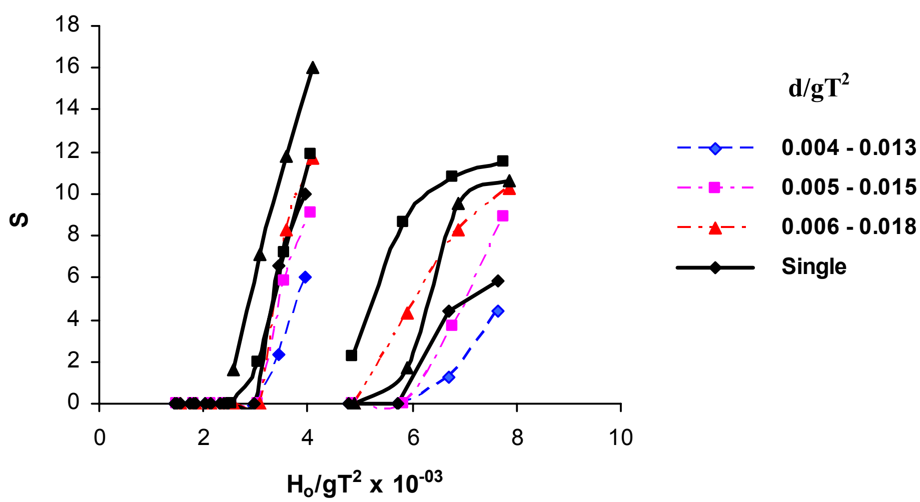

Fig. 9. Variation of damage level (S) with deep water wave steepness (H_o/gT^2).

The damage due to wave period of 2.0 sec is seen as sand witched between that for wave periods of 2.5 sec and 1.5 sec on left and right side respectively and there is no damage for period of 2.5 sec. For shallower depth (i.e. $0.004 \leq d/gT^2 \leq 0.013$) the damage progresses slowly as wave steepness increases.On the contrary, for relatively higher depths (i.e. $0.005 \leq d/gT^2 \leq 0.015$ and $0.006 \leq d/gT^2 \leq 0.018$) the damage level increases sharply with the increasing of wave steepness. The maximum damage level for a wave periods of 1.5 sec and 2 sec are respectively 10.25 and 11.74. When comparing with the conventional breakwater for a wave period of 1.5 sec, the damage level decreases up to 25%, and it decreases up to 39% for a wave period of 2.0 sec.

CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn.

1. The maximum run up and run down for a reef protected breakwater are up to 46% to 32% less respectively compared to that of conventional single breakwater.
2. K_t values ranges from 0.37 to 0.7 which reduces the wave loading on breakwater.
3. Damage levels for tandem breakwater are up to 39% and 25%, lower than the conventional single breakwater for the wave period of 2.0sec and 1.5sec respectively.

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