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Hydrodynamic Characteristics of Semi-circular Breakwaters: Review Article

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ABSTRACT

The Semicircular Breakwater (SBW) is a recently emerging topic, on which researchers are focusing considerable attention on its hydrodynamic performance characteristics worldwide, particularly, in Japan and China. The SBW has a semicircular-shaped hollow caisson founded on a rubble mound. It is cast as different elements and made of prestressed concrete. Since the caisson is hollow, its weight and the materials to be used are significantly less. The stability against sliding for SBW is good, since, the horizontal component of the wave force is smaller as compared to the vertical component; in addition, the vertical component is applied downward the curved wall. The SBW enhances the scenery compared to the conventional rubble mound breakwaters. Due to high stability against the wave action, it is expected that it can also serve well as offshore-detached breakwaters adopted for the protection of the coast against erosion. The different concepts of SBW are (1) the solid type in which case, its surface is impermeable; (2) the front wave dissipating type with seaside wall facing the waves being perforated; (3) the permeable type with its seaside and leeside walls being permeable and (4) the rear wave dissipating type with its leeside along being perforated. In this review paper, the results of detailed experimental investigations conducted by the author on hydrodynamic characteristics of SBW such as dimensionless hydrodynamic pressure, wave forces, reflection and transmission characteristics for surface piercing and submerged conditions are explained. The effects of perforations, water depth and rubble mound height are also explained.

Key words: Breakwaters, surface piercing, hydrodynamic characteristics, reflection characteristics

INTRODUCTION

The Semicircular Breakwater (SBW) is a composite breakwater consisting of a semicircular caisson resting on a rubble mound. The SBW function as a barrier dissipates the incident wave energy and creates tranquility on its leeside. A detailed survey of literature on the wave structure interaction problem is discussed below.

Sasajima *et al.* (1994) have reported the results obtained on measured pressures and forces on the rear wave dissipating type SBW constructed at Miyazaki port in Japan. The variation of measured highest 1/3 wave pressure, pressure at the time to maximum force and maximum wave pressure at different elevations along the wall have been compared to the modified theoretical formulation of Goda and Suzuki (1976). Sundar and Raghu (1997) from their model tests on a solid type SBW subjected to regular waves concluded that the reflection coefficient, Kr for a solid SBW varied from 0.5 to 0.9 for waves with steepness, H/L upto 0.12 for relative water depths, hw/L ranging from 0.1 to 0.4 where, H is wave height, L is wave length and hw is the water depth. The results also indicated that the variation of Kr with H/L was less than its variation with hw/L. The measured dynamic pressures on the seaward face was reported to be lesser at still water level (SWL) and greater at locations below SWL compared to their corresponding theoretical values of the semi empirical formula of Goda and Suzuki (1976). This trend in the variation of pressures was found to be for intermediate water depths, whereas, a reverse trend in their variation was noticed for deepwater conditions. Priya *et al.* (2000) claimed that their experimental results on the variation of the dynamic pressures on an impermeable SBW compared well with the two dimensional finite element model of Sundar *et al.* (2001). However, their results indicated that the measured values were less than the modified formulation of Goda and Suzuki (1976), particularly closer to the SWL, similar to the conclusions drawn by Sundar and Raghu (1997). Further, the dimensionless pressures were found to reduce with increase in the scattering parameter, ka, where, k is the wave number and a is the radius of the semicircular caisson. In addition, the pressures were reported to be less for higher hw/ht, where, ht is the total height of the model, that is, the height of the rubble mound plus the height of the semicircular caisson.

In many cases, the design of breakwater is difficult since the construction takes place in severe environment caused by high waves and poor ground conditions. Due to advances in the design and construction, several new concepts of breakwater are being introduced. One such concept is the Semicircular Breakwater in which, many researchers are focusing, especially in Japan and China. Jia (1999) obtained numerical solution for incident stokes waves passing the submerged obstacles and extended the method the calculation of wave run-up on a slope for estimation of over topping. Xie (1999) has given the new calculation method to estimate the wave forces acting on a submerged semicircular breakwater and verified with the results of seven related physical model tests and adopted in the design of south estuary jetty of the Yangstze river estuary of China. It is cast as different elements and made of prestressed concrete. As the caisson is a prefabricated structure, it can easily be transported, handled and placed at site. In addition the above, it has got excellent hydraulic characteristics compared to other types of breakwaters like, greater sliding stability against waves, horizontal component of a wave force applied to semicircular surface is smaller than that of applied to an upright wall, light in weight (since the structure is hollow), the soil sub grade reaction is less and ideally suited for poor ground conditions and curved structure provides increased member strength.

Gunaydin and Kabdasli (2004) investigated the performance of solid and perforated U-type breakwaters subjected to both regular and irregular waves for different immersion depths. They concluded that, the results of irregular wave tests are higher than those of regular wave tests for both solid and perforated model. Vijayalakshmi *et al.* (2007) studied the regular wave interaction with a twin concentric porous circular cylinder system consisting of an inner impermeable cylinder and an outer perforated cylinder through physical and numerical models. They concluded that, the maximum wave runup on the perforated cylinder is almost same as the incident wave height. Liu *et al.* (2007) studied the hydrodynamic performance of a breakwater consists of a perforated front wall, a solid back wall and a submerged horizontal porous plate installed between them based on an analytical solution. They concluded that, with suitable geometric porosity of the front wall and horizontal plate, the reflection coefficient would be always rather small if the relative wave absorbing chamber width exceeds a certain small value. In addition, the wave force and moment on the horizontal plate decrease significantly with the increase of the plate porosity. Liu *et al.* (2008) examined the hydrodynamic performance the breakwater with an upper submerged horizontal porous plate and a lower submerged horizontal solid plate using eigen function expansion method and calculated reflection, transmission, energy-loss coefficients and also the wave forces acting on the plates. They concluded that, the transmission coefficient will be always small if the dimensionless plate length exceeds a certain moderate value.

Sundar *et al.* (2001) reported the results of hydrodynamic characteristics of impermeable SBW. Dhinakaran *et al.* (2002, 2008, 2009, 2010) reported the results of various hydrodynamic characteristics of surface piercing and submerged SBW and their study concentrated on effect of perforations, water depth and rubble mound height and concluded that effect perforations played vital role compared to effect of water depth and rubble mound height. An optimum percentage of perforations and height of the SBW were arrived.

EXPERIMENTAL INVESTIGATIONS

Test facility: The detailed experimental studies were carried out in a 72.5×2.0×2.7 m sized wave flume in the Department of Ocean Engineering, Indian Institute of Technology Madras, India and is capable of generating both regular and random waves. The water depth in this flume can be varied from 0.4 to 2 m. One personal computer, which is connected to servo actuator, is used to give the input values like wave height and wave period to the wave maker and the same is used for data acquisition of the signals from wave probes and pressure transducers through an amplifier. The details of the flume along with the positions of the wave gauges and the model are shown in Fig. 1.

Test model: The model basically consists of two parts, the bottom frame and the top semicircular shaped caisson. The caisson was made with 1 mm thick aluminium sheet rolled into a semicircular shape of radius 0.5 m. This sheet is fixed to a bottom frame of 50 mm height made up of ISA (Indian Standard Angle) 50×50. Rods of 12 mm diameter as stiffeners were provided at ends and at the center of the hollow semicircular caisson in order to provide the necessary rigidity for the wall of the model. A 30×3 mm flat was provided along the inner surface of the semicircular caisson to retain its shape. The caisson was fabricated in two units to facilitate easier handling. The central

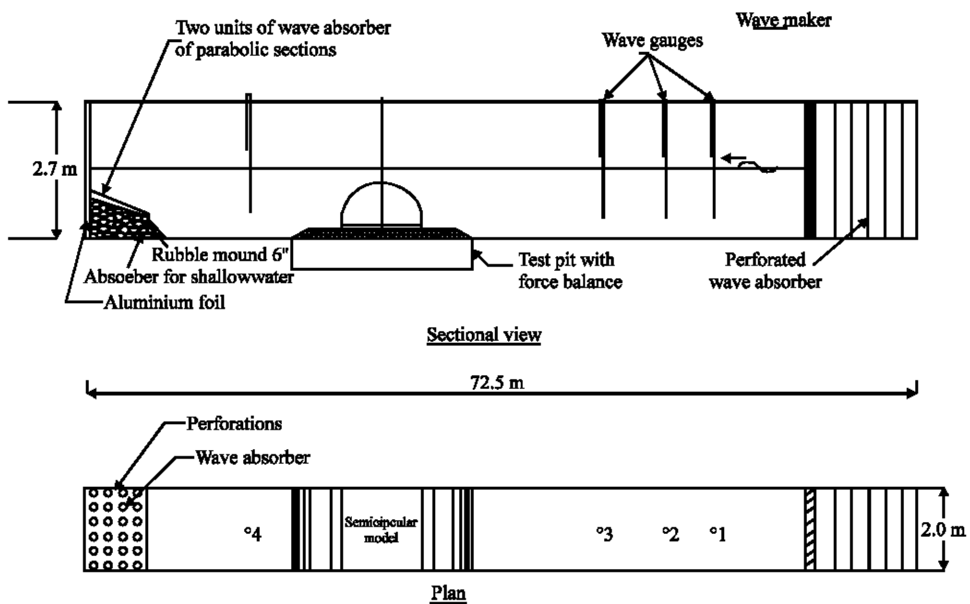

Fig. 1: Experimental setup for the study

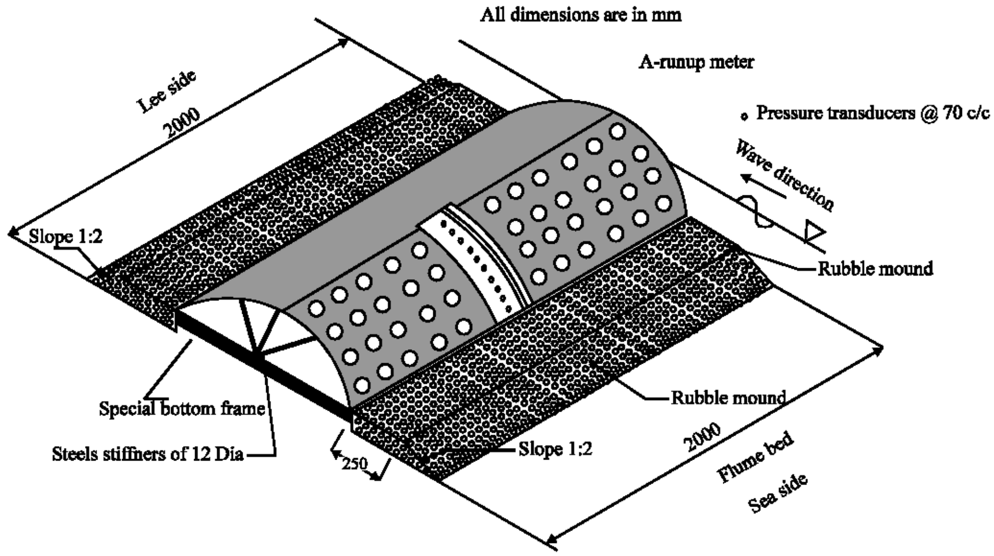

Fig. 2: Isometric view of the Seaside perforated SBW model

part of the caisson of about 200 mm width was fabricated using 4 mm thick perspex sheet onto which the Churchill runup meter was fixed. The bottom frame was fabricated using channels ISMC (Indian Standard Medium Channel) 100×50. It was ensured that this frame did not have contact with the flume sidewalls or with the flume floor. The scale adopted for the study was 1:20 and is derived from the rear dissipating SBW available in Miyazaki port, Japan. The mound was formed using coarse aggregates (granite stones) of weight varying from 50 to 100 g. The slope on both sides was maintained the same as 1 in 2. The weight of stones in model is the cubic root of weight of stones in prototype. Two frames of width 25 mm and height 120 mm were initially fabricated and kept on either side of the caisson. A gap of 5 mm was maintained between the caisson and the frames on either side. By providing a gap of 5 mm gap between the frame in which rubble mound was placed and the caisson, it was ensured that the force exerted on caisson only measured by the six component force balance. Rubble mound was placed on this frame, thus its height, h_r being maintained at 120 mm. Hence, for this model its total height, h_t is equal to h_r plus radius of the caisson, h_s plus height of the bottom frame of 50 mm (0.12+0.5+0.05 = 0.67 m). Four more frames each of 100 mm high were also fabricated. After the tests with h_r equal to 120 mm, the rubble mound was removed and the additional frames were placed on which the rubble stones were placed. In this way tests were also carried out with h_r equal to 220 and 320 mm. Isometric view of the SBW model is shown in Fig. 2.

Instrumentation: In order to obtain the incident and reflected wave heights from the structure, three wave gauges were positioned in front of structure at 7 m away from the breakwater model. The distances between the gauges, which were a function of the wave period, were calculated by considering the requirements as proposed by Mansard and Funke (1980). Three set-ups were calculated for the frequencies ranging from 0.50 to 0.60, 0.70 to 0.90 and 1.0 to 2.0 Hz. The positions of the wave gauges were changed accordingly. One wave probe was kept on the leeward direction of the model to register the transmitted wave height. The SBW model was subjected to the action of regular and random waves, of periods ranging from 0.8 to 2 sec at intervals of 0.2 sec. For

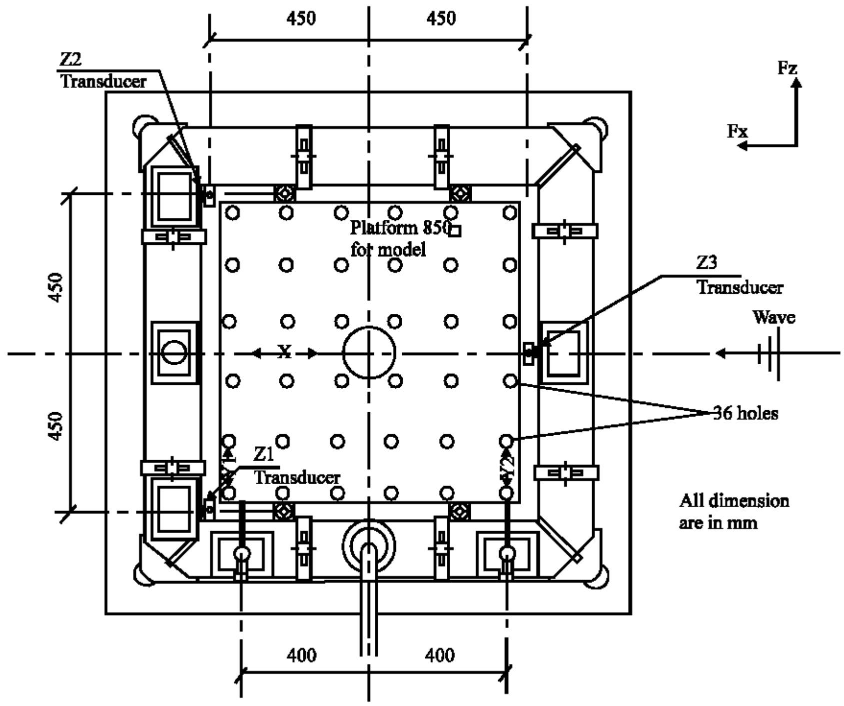

Fig. 3: Details of 6-component force balance

each period atleast five different wave heights ranging from 0.03 to 0.18 m at intervals of 0.03 m were generated. Thus, one test setup of the model was subjected to about 35 combinations each for regular and random waves. Details of six-component force balance are shown in Fig. 3. The experiments were performed with model mounted on the six-component force balance. The force balance R67 measures 6 components in a rectangular co-ordinate system. The resolution of the resulting force to be measured into the 6 components is effected mechanically by way of spring joints and measurement of the individual components unaffected with the help of strain gauge type force transducers.

All parts of the force balance are made of hard steel with good corrosion resistance against water. The six transducers are water proofed and can be used to a depth of 5 m. The balance, which is to be mounted in a recess at the bottom of the flume floor, has a platform of 850×850 mm flush with flume floor. The platform is suspended with 6 coupling rods with flexures at the both the ends and six force transducers. The force transducers are connected to a frame. This frame has to be fixed to the foundation at its four corners. In the direction of wave propagation, one force component X is measured. Vertically, the three components Z_1, Z_2 and Z_3 are measured which are at a distance of 900 mm between each other. The side of the force balance with the Z_3 transducer is placed towards the wave maker. The force transducers are connected to a data acquisition system through carrier frequency amplifiers. The sensitivity of the transducers at their rated loads is about ±2 m v/v, which means that, even for much smaller forces than the rated loads, the amplifiers can give full scale indication. The force balance is initially calibrated before starting the experiments and again after completing the experiments. Both the calibration values are one and the same. The calibration of force balance was done by placing known weights and recording the corresponding voltages. A spring balance is made use of to measure the horizontal pull and the corresponding voltage is noted. The model is fixed to the force balance consisting of a machined stainless steel plate of about 12 mm thickness with 36 threaded borings using M_{12} stainless steel bolts.

RESULTS AND DISCUSSION

In this study selected results on various hydrodynamic characteristics of SBW for surface piercing and submerged conditions are presented to make potential reader/researcher to understand the effect on various parameters. The experiments are conducted for 7, 11 and 17 percentages of perforations provided on seaward side (front dissipating type) and on both sides (fully perforated type).

Surface piercing breakwater

Reflection characteristics

Effect of perforations and water depth: The variations of K_r (reflection coefficient) with h_w/L for SBW0, SBW7, SBW11, SBWf7, SBWf11 and SBWf17 models for $h_w/h_t = 0.6$, 0.7 and 0.8 for a constant $h_r/h_t = 0.18$ due to regular waves are reported in Fig. 4a-c. The value of K_r varies from 0.5 to 0.9 for SBW0, whereas these values are 0.35 to 0.65, 0.28 to 0.51, 0.3 to 0.57, 0.24 to 0.49, 0.2 to 0.39 and 0.15 to 0.33 for SBW7, SBW11, SBW17, SBWf7, SBWf11 and SBWf17 respectively. The results indicate that K_r increases with an increase in h_w/L for all the h_w/h_t tested and for all the models of seaside and fully perforated SBWs tested. When the waves of shorter wave length run over the curved surface, they feel the presence of perforations on the caisson for a shorter distance, because of which the energy dissipated due to the turbulence is less and hence the reflection is more for higher h_w/L. In the case waves of long period, it runs over a curved surface for a greater distance and energy dissipated is more and hence lesser reflection. The reflection coefficient, K_r decreases with an increase in perforation upto 11 percentage and it increases with a further increase in perforations to 17 percentage. For the SBW models upto 11 percentage perforations, the

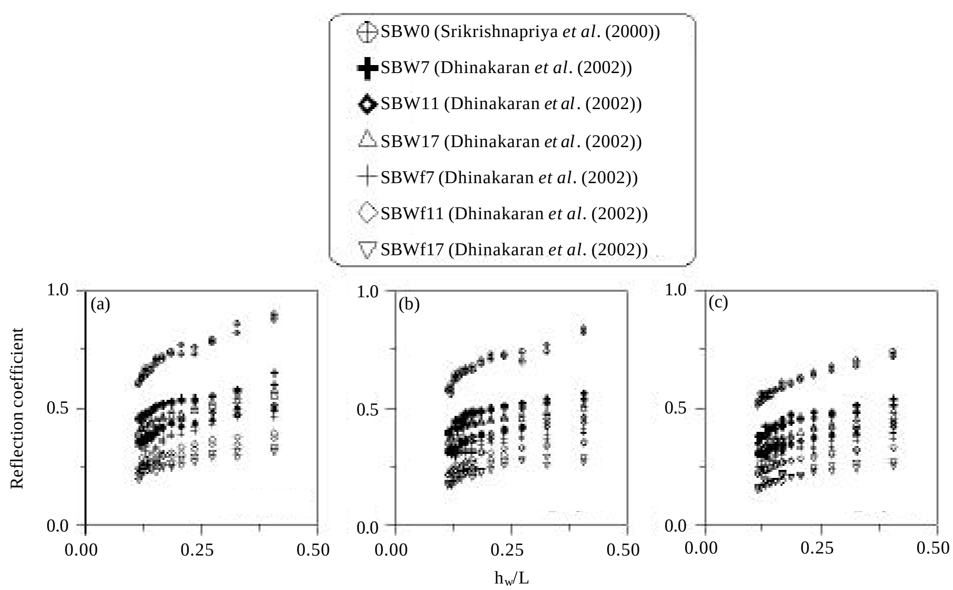

Fig. 4: Effect of perforations on K_r due to regular waves. (a) $h_w/h_t = 0.6$, (b) $h_w/h_t = 0.7$ and (c) $h_w/h_t = 0.8$

energy is dissipated irrespective of wave periods, whereas, for the model with 17 percentage perforations, waves of smaller periods dissipates lesser energy and hence more reflection for this model. Even long period waves dissipate lesser energy in the case of SBW17 because of its size of perforation compared with models upto 11percentage perforations.

It is observed that, K_r decreases with an increase in h_w/h_t. For $h_w/h_t = 0.6$, only smaller height of the semicircular portion of the caisson is exposed to waves, that is, the effect of curvature is less pronounced, thus, resulting lesser dissipation and more reflection. This trend is reversed for higher h_w/h_t. i.e., for higher water depth condition, in which case, the waves are exposed to greater area of perforations leading to greater dissipation of energy and there by, resulting in lesser reflection. In addition, the effect of curvature also plays a role in dissipating more energy by permitting waves to run over a longer distance. Especially for $h_w/h_t = 0.8$, a partial over topping of waves also permitted which caused the reduction of K_r. However, the rate of reduction in reflection coefficient due to the effect of water depth is not that significant, compared to the effect of perforations.

It is also to be noted that, the values of K_r increase while perforation ratio increases from 11 to 17 percentage in the case of seaside perforated SBW and shows reverse trend for fully perforated SBW (i.e., K_r decreases from perforation ratio 11 to 17 percentage). It is due to fact that, increase in perforation ratio from 11 to 17 effected decrease in energy dissipation with higher percentage of perforation ratio in the case of seaside perforated SBW, whereas in the case fully perforated SBW, the scenario is different. Though perforation ratio increases, openings on the shoreward side of the breakwater permits higher amount of energy through transmission, the values of K_r gets reduced in SBWf17 compared to SBWf11. This is one reason why SBWf17 was not recommended due to large transmission of energy, which will definitely affect the tranquillity condition of the harbour.

Effect of rubble mound height: The effect of rubble mound height on the reflection characteristics of the surface piercing seaside perforated SBW models were studied for three different h_r/h_t ratios of 0.18, 0.29 and 0.36 with a constant water depth, h_w of 0.54 m. In this case, the rubble mound heights (h_r) were changed from 0.12 to 0.32 m. The variation of K_r for various SBW models subjected to regular waves due to the effect of rubble mound height is reported in Fig. 5a-c. The value of K_r varies from 0.34 to 0.74 for SBW0, whereas these values are 0.24 to 0.54, 0.16 to 0.44, 0.18 to 0.48, 0.19 to 0.34, 0.14 to 0.33 and 0.12 to 0.27 for SBW7, SBW11, SBW17, SBWf7, SBWf11 and SBWf17, respectively. The results clearly indicate that, the rate of reduction in reflection coefficient is significant from $h_r/h_t = 0.18$ to 0.29 and is less significant from when h_r/h_t is changed from 0.29 to 0.36. It is understood that for higher h_r/h_t of 0.36, the rubble mound action is predominant. The rate of reduction due to increase in h_r/h_t is less in the case of seaside perforated semicircular breakwaters compared to an impermeable SBW, since the combination of rubble mound height and perforations play a dominant role in the dissipation of energy in former type of breakwater.

Runup characteristics

Effect of perforations and water depth: The variations of dimensionless run-up, R_u/H_i with h_w/L for SBW0, SBW7, SBW11, SBW17, SBWf7, SBWf11 and SBWf17 models for h_w/h_t of 0.6.0.7 and 0.8 for a constant h_r/h_t of 0.18 due to regular waves are reported in Fig. 6a-c. The R_u/H_i decrease with an increase in h_w/L due to the fact that, for long period waves more run-ups occurs on the caisson. In the case of lesser period waves (larger h_w/L), most the energy contained in the incident

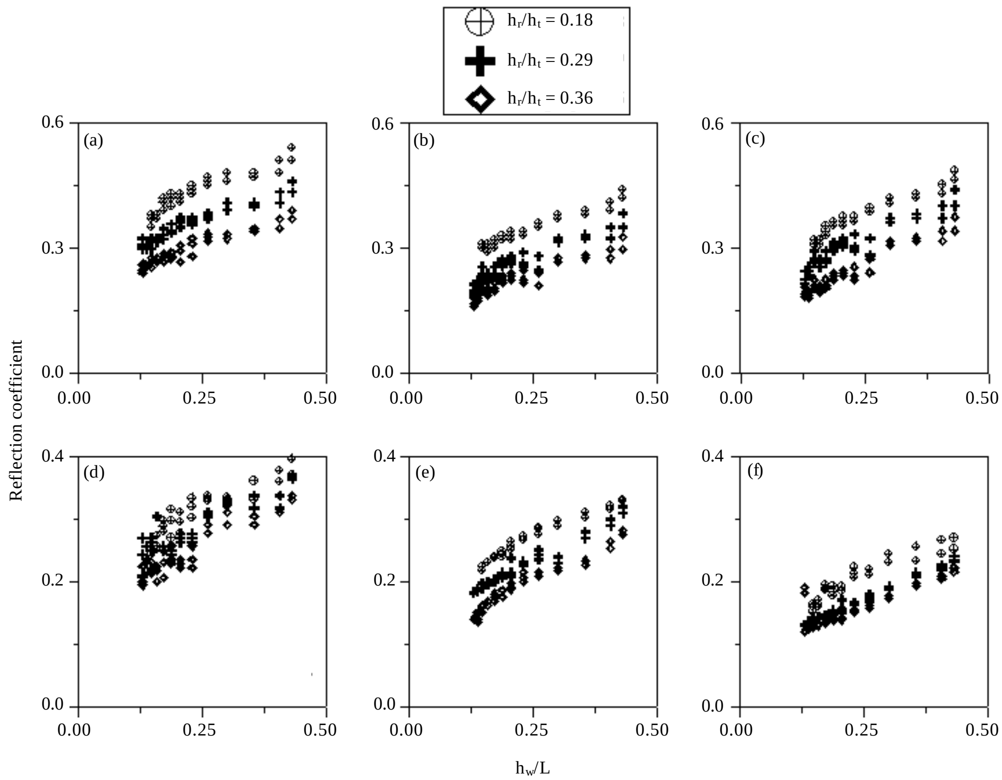

Fig. 5: Effect of rubble mound height on K_r due to regular waves. (a) SBW7, (b) SBW11, (c) SBW17, (d) SBWf7 (e) SBWf11 and (f) SBWf17

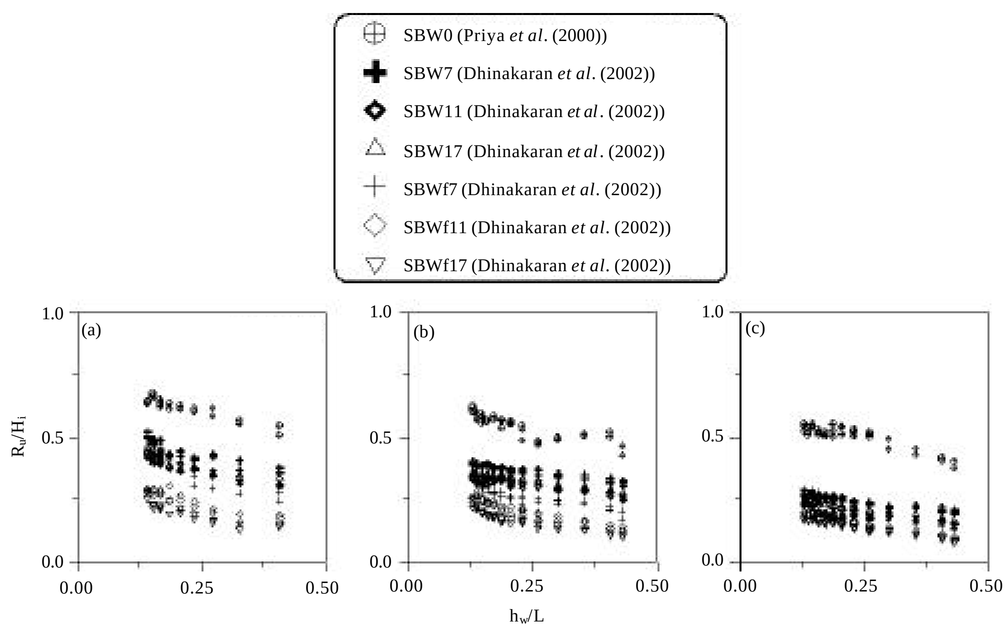

Fig. 6: Effect perforations on R_u/H_i due to regular waves. (a) h_w/h_t = 0.6, (b) h_w/h_t = 0.7 and (d) h_w/h_t = 0.8

waves gets reflected as discussed earlier and hence only lesser energy will be available for the run-up. This explains the phenomena of run-up decreasing with an increase in h_w/L. The results also demonstrate that R_u/H_i decreases with an increase in h_w/h_t due to the reason that as h_w/h_t increases, the effect of curvature is more pronounced and hence lesser run-up. This can be as explained below. For higher h_w/h_t, though the distance travelled over the caisson is more, the run-up being a vertical projection will be less. In addition, for higher h_w/h_t, larger area of the structure exposed to waves, which leads to more energy dissipation and subjected to lesser run-up. The R_u/H_i also decreases with an increase in percentage of perforations up to 11. Further increase in the perforation to 17 percentage results in an increase in the run-up, where as in case of fully perforated SBWs, run-up values gets reduced with increase in perforations even up to 17 percentage, due to reason that, it permits more transmission.

The rate of reduction in dimensionless runup is calculated by taking SBW0 as the reference and calculated for seaside perforated and fully perforated SBWs. The percentage of reduction in dimensionless run-up compared to an impermeable type (SBW0) varies from 19 to 40% for seaside perforated SBWs and 35 to 68% in the case of fully perforated SBWs for lower h_w/h_t. These reductions vary from 48 to 60% for seaside perforated SBWs and 47 to 76% for fully perforated SBWs for higher h_w/h_t. For $h_w/h_t = 0.8$, the free board is only 13 cm, some of the waves longer wave periods and heights, over top the crest in case of an impermeable SBW (SBW0) and hence higher reduction run up was observed in perforated SBWs. Among the three water depths tested, $h_w/h_t = 0.7$ exhibits considerable reduction in runup, which will reduce the force experienced by the caisson. By taking effect of perforation in reduction, SBW11 and SBWf11 cause higher reduction in the case of seaside and fully perforated SBWs, respectively.

Effect of rubble mound height: The variations of dimensionless run-up, R_u/H with h_w/L for SBW0, SBW7, SBW11, SBW17, SBWf7, SBWf11 and SBWf17 models for h_r/h_t of 0.18, 0.29 and 0.36 for a constant $h_w = 0.54$m due to regular waves are reported in Fig. 7a-f. The R_u/H_i decreases with an increase in the rubble mound height, since rubble mound absorbs certain amount of energy leading to lesser energy available for run-up on the semicircular caisson. The rate of reduction in dimensionless run-up is similar as seen earlier and confirming the variation of K_r.

Transmission characteristics

Effect of perforations and water depth: In case of fully perforated SBW the transmission of waves take place since both seaside and leeside are perforated. The variations of transmission coefficient, K_t with h_w/L for SBWf7, SBWf11 and SBWf17 models for h_w/h_t of 0.6.0.7 and 0.8 for a constant h_r/h_t of 0.18 due to regular waves are reported in Fig. 8a-c. The value of K_t varies from 0.2 to 0.43 for SBWf7, whereas these values are 0.23 to 0.49 and 0.32 to 0.59 for SBWf11 and SBWf17 respectively for regular waves. In the case of SBWf17, the energy transmitted exceeds 50 percentage of the incident energy, which will affect the tranquility condition inside the harbor. The increase in perforation ratio from 7 percentage to 17 percentage decreases the energy loss in general. The K_t increases and K_l decreases with increase in percentage of perforations. It is also observed that, higher the hw/ht, higher the transmission. However, the reduction in K_l for the fully perforated SBW models is less significant. From the three models tested with different h_w/h_t ratios, SBWf11 gives the optimum results both in terms of reflection and transmission point of view.

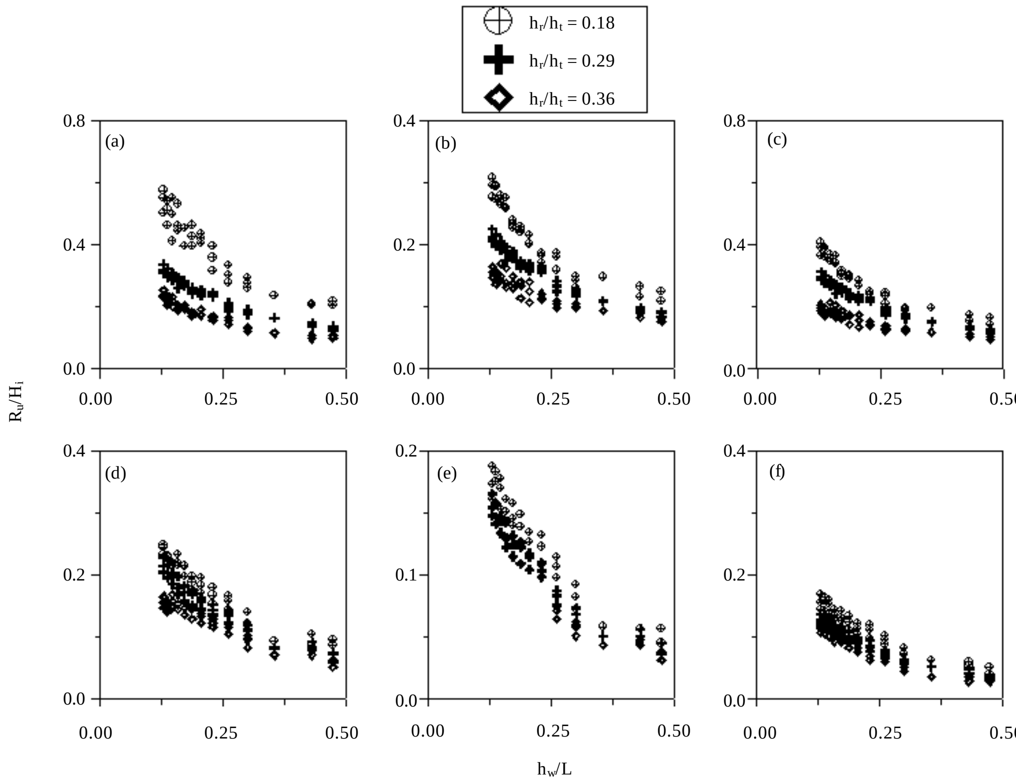

Fig. 7: Effect of rubble mound height on R_u/H_i due to regular waves. (a) SBW7, (b) SBW11, (c) SBW17, (d) SBWf7 (e) SBWf11 and (f) SBWf17

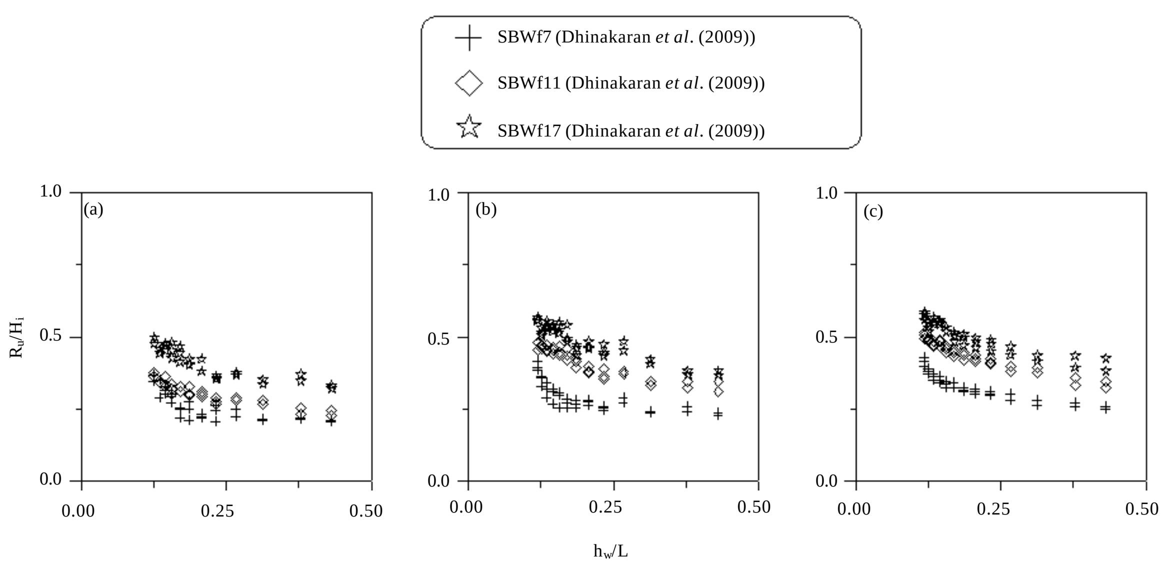

Fig. 8: Effect perforations on K_t due to regular waves. (a) h_w/h_t = 0.6, (b) h_w/h_t = 0.7 and (d) h_w/h_t = 0.8

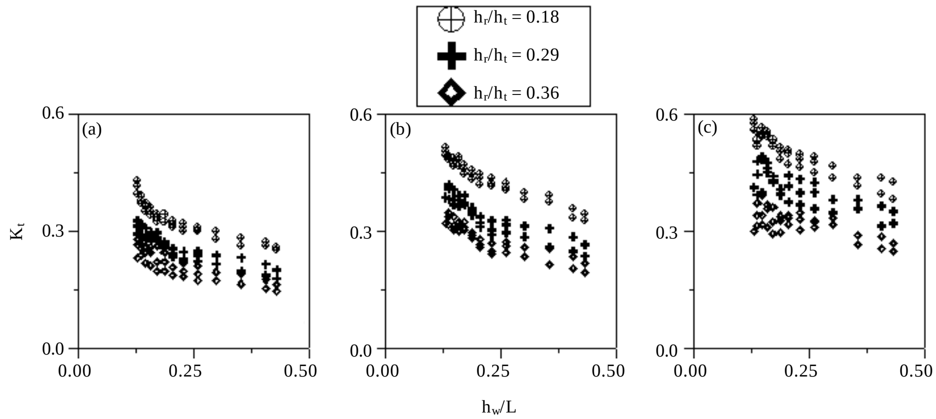

Fig. 9: Effect of rubble mound height on transmission coefficient due to regular waves. (a) SBWf7, (b) SBWf11 and (c) SBWf17

Effect of rubble mound height: The variations of transmission coefficient, K_t with h_w/L for SBWf7, SBWf11 and SBWf17 models for h_r/h_t of 0.18, 0.29 and 0.36 for a constant water depth of 0.54 m due to regular are reported in Fig. 9a-c. In general, increase in perforation ratio increases transmission and for SBWf17 the energy transmitted exceeds more than 50 percentage of incident wave energy, which will affect the tranquillity condition of any harbour and an optimal transmission occurred in SBWf11. Considering the effect of rubble mound height for all the cases fully perforated SBW cases, the rate of reduction is significant, when h_r/h_t increased from 0.18 to 0.29 and insignificant from 0.29 to 0.36. It was understood that, when h_r/h_t increased from 0.29 to 0.36, the rubble mound action was predominant than that of composite action and hence h_r/h_t = 0.29 is an optimal value from the experiment s conducted.

Forces on the semicircular caisson

Effect of perforations and water depth: The shoreward horizontal force, $[F_h]_{max}$ and vertical force, $[F_v]_{max}$ exerted on the semicircular caisson in the presence of the submerged mound measured, were normalized by dividing them by $[\gamma alH_i]$. The variation of the dimensionless shoreward horizontal force $[F_h]_{non} = [(F_h)_{max}/(\gamma alH_i)]$ and vertical force $[F_v]_{non} = [(F_v)_{max}/(\gamma alH_i)]$ on SBW0, SBW7, SBW11, SBW17, SBWf7, SBWf11 and SBWf17 for three different h_w/h_t ratios are shown in Fig. 10a-c and 11a-c due to regular waves. The horizontal force component is found to decrease with increase in h_w/L irrespective of the type of SBW. It is due to fact that, long period waves exert more force on the caisson and short period waves transfer lesser force. The increase in h_w/h_t increase forces on the semicircular caisson due to a fact that, higher the water depth, higher the area of the SBW model exposed to wave action and hence the increase in h_w/h_t causes increase in $[F_h]_{non}$. The percentage of reduction is about 55 to 76% for seaside perforated SBWs for all h_w/h_t tested and this percentage of reduction of dimensionless forces varies from 75 to 95% in case of fully perforated SBWs while comparing with SBW0. Hence it is understood that, effect of perforations plays a major role in reduction of forces on semicircular caisson.

Effect of rubble mound height: The variation of dimensionless horizontal and vertical force due to regular waves are depicted in Fig. 12a-f and 13a-f to understand the effect of rubble mound

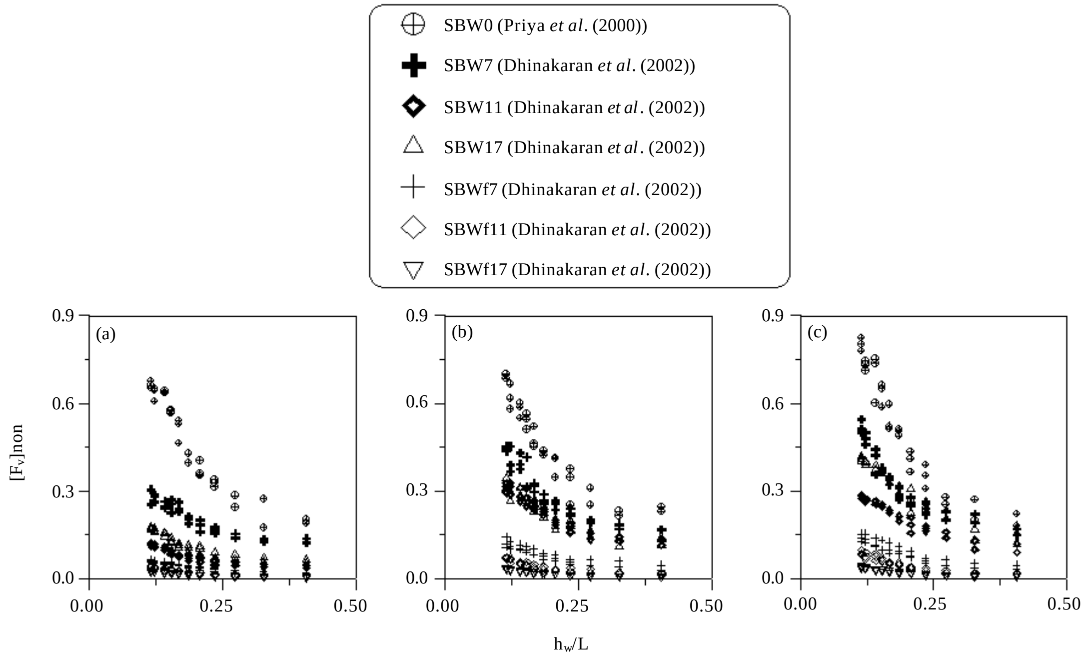

Fig. 10: Effect of perforations on dimensionless shoreward horizontal force due to regular waves (a) $h_w/h_t = 0.6$, (b) $h_w/h_t = 0.7$ and (c) $h_w/h_t = 0.8$

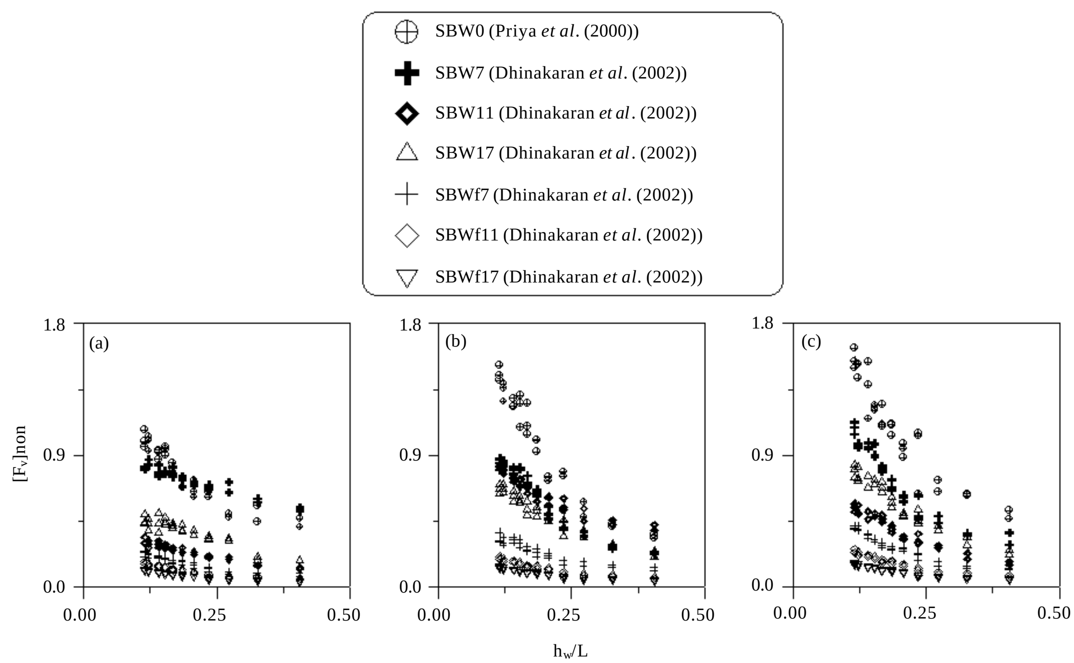

Fig. 11: Effect of perforations on dimensionless shoreward horizontal force due to regular waves (a) $h_w/h_t = 0.6$, (b) $h_w/h_t = 0.7$ and (c) $h_w/h_t = 0.8$

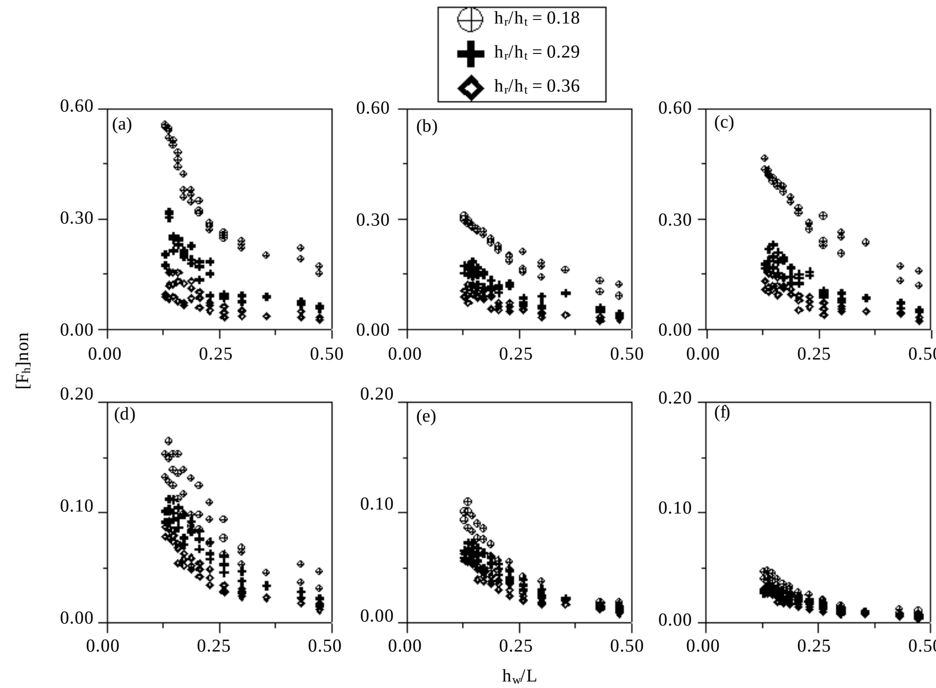

Fig. 12: Effect of perforations on dimensionless shoreward horizontal force due to regular waves (a) SBW7, (b) SBW11 and (c) SBW17, (d) SBWf7, (e) SBWf11 and (f) SBWf17

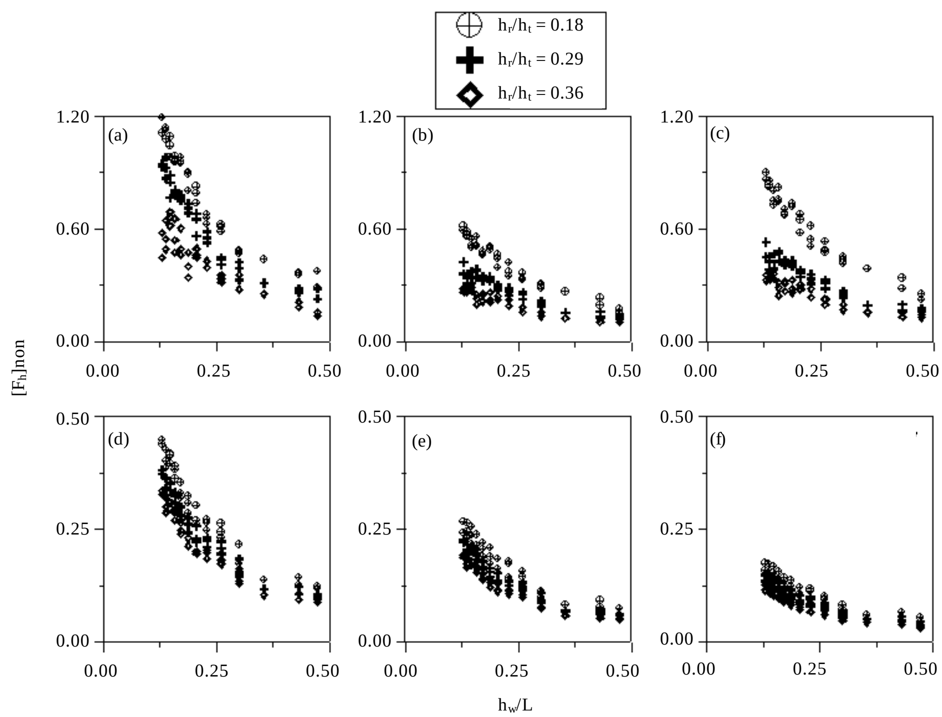

Fig. 13: Effect of perforations on dimensionless shoreward horizontal force due to regular waves (a) SBW7, (b) SBW11 and (c) SBW17, (d) SBWf7, (e) SBWf11 and (f) SBWf17

height for all the perforated SBWs. Both $[F_h]_{non}$ and $[F_v]_{non}$ decrease with increase in h_w/L. It is due to a fact that higher the rubble mound height, higher the energy dissipation and lesser the energy transferred on the SBW model. Both in dimensionless horizontal and vertical forces the rate of reduction is more from $h_r/h_t = 0.18$ to 0.29 and further increase in h_r/h_t to 0.36 does not cause more reduction. It is clear that, the rate of reduction decreases from h_r/h_t 0.29 to 0.36. As seen in horizontal component, similar trend was observed in vertical component also.

Submerged breakwater

Reflection and transmission characteristics: The reflection coefficient, K_r was evaluated from the measured time histories for each of the tests based on the methodology of Mansard and Funke (1980) by decomposing the composite wave elevations measured the three wave gauges placed on the seaward side of the model. The transmission coefficient, K_t (H_t/H_i) was evaluated from the wave surface elevation obtained from the wave gauge positioned on the leeside of the structure. The loss coefficient, K_l is evaluated as

$$K_l = \sqrt{[1-(Kr^2 + Kt^2)]}$$

The variations of K_r with scattering parameter, ka, for SBW7, SBW11 and SBW17 obtained from the present study are compared with that of SBW0 for a constant h_r of 0.12 m and for $h_w/h_t = 1$, $h_w/h_t = 1.2$ and $h_w/h_t = 1.4$ in Fig. 14a-c to study the effect of perforations. It is observed that K_r varies from 0.16 to 0.35 for SBW7, from 0.12 to 0.34 for SBW11 and from 0.15 to 0.32 for SBW17, whereas, K_r for SBW0 vary from 0.18 to 0.39. For a particular water depth, K_r is found to decrease with increase in percentage of perforations which is due to the fact that, provision of perforation dissipates more energy by creating turbulence and the curvature of the structure also enhances this phenomena. Furthermore, K_r is found to decrease with increase in scattering parameter, which clearly demonstrates that the structure reflects more energy for long period waves and lesser energy for short period waves. In addition, K_r decreases with increase in water depth due to a fact that, the effect of the structure on the propagating waves will be less pronounced, since the relative depth of submergence is more. The percentage reduction in K_r due to perforations compared to that for the impermeable SBW, $[K_r]_{red}$ is more for short period waves for SBW7, SBW11 and SBW17 models for $h_w/h_t = 1.0$, that is when the SWL is in level with the crest of the caisson. ($[K_r]_{red}$ or $[K_t]_{red}$ is the percentage of reduction in K_r or K_t of either SBW7 or SBW11 or SBW17 with respect to K_r or K_t of SBW0). For long period waves, wave energy dissipated is more irrespective of type of SBW and hence the $[K_r]_{red}$ is low for higher 'ka'. However, for the cases, $h_w/h_t = 1.2$ and $h_w/h_t = 1.4$, the $[K_r]_{red}$ decreases with increase in scattering parameter, since smaller waves passes the structure without much attenuation.

It is observed from the Fig. 16, that K_t varies from 0.42 to 0.85 for SBW7 and from 0.21 to 0.80 for SBW11, 0.17 to 0.73 for SBW17 and from 0.46 to 0.91 for SBW0. For $h_w/h_t = 1$, the value of K_t decreases with increase in 'ka'. The long period waves are expected to have larger displacements in the direction of wave propagation and the obstruction extending over the entire water depth would lead to substantial dissipation of orbital motions, leading to a lesser K_t for larger 'ka'. However, for the conditions of $h_w > h_t$ (i.e., $h_w/h_t = 1.2$ and $h_w/h_t = 1.4$), a greater amount of energy gets transmitted past the structure being greater in the case of longer period waves which explains the probable reason for the above stated phenomena. The $[K_t]_{red}$ for the SBW7, SBW11 and SBW17 compared to SBW0 clearly indicates that for ka >2.4, $[K_t]_{red}$ is more for SBW11 and for ka <0.3,

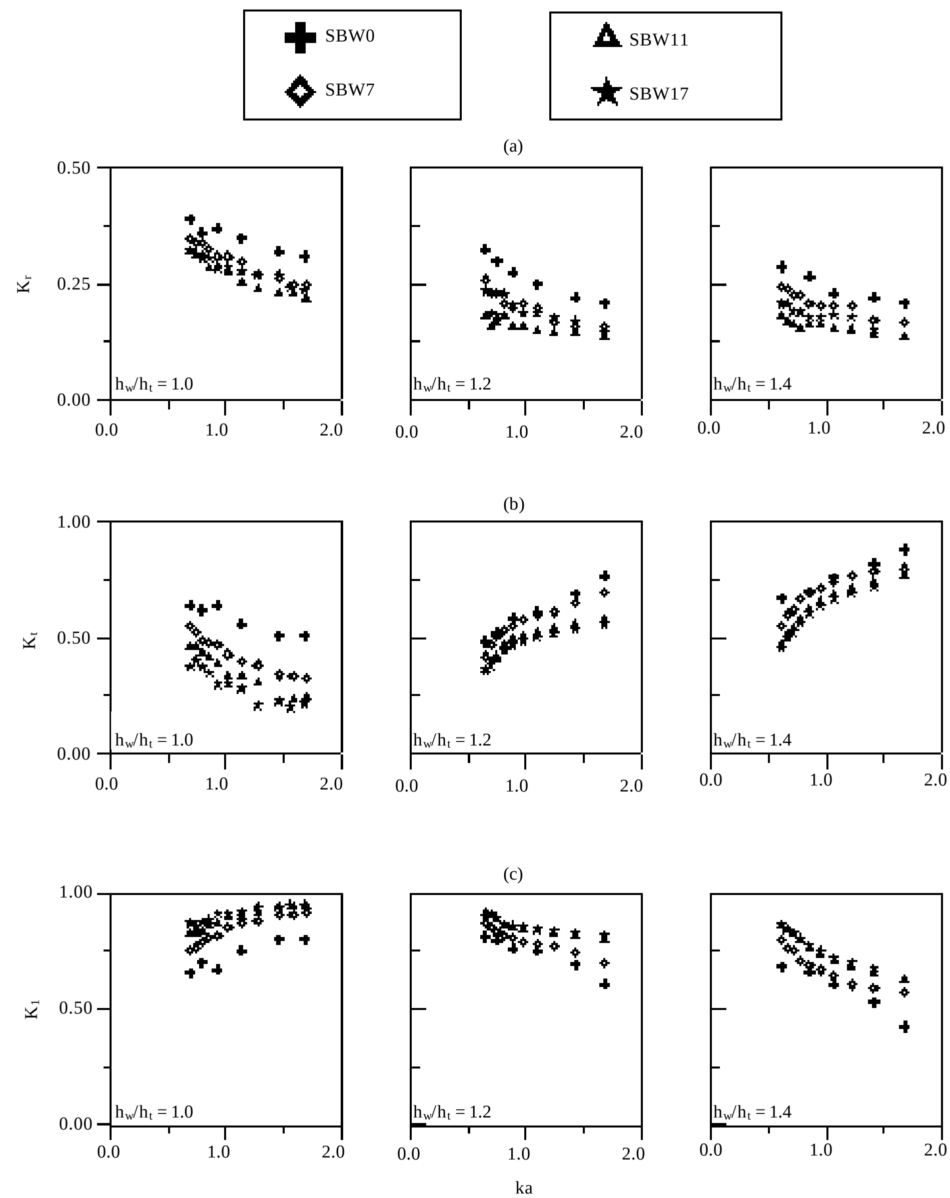

Fig. 14: Effect of perforations on (a) K_r, (b) K_t and (c) K_l

$[K_t]_{red}$ is more for SBW17. The rate of $[K_t]_{red}$ decreases with increase in water depth due to the fact that more transmission occurs irrespective of the type of SBW for higher relative depth of submergence. The values of K_l were calculated from the law of conservation of energy as stated above and are shown in Fig. 14. The energy dissipation is more in case seaside perforated SBW, in which the perforation plays a major role in dissipating the incident wave energy. The value of K_l varies from 0.49 to 0.91 for SBW7, 0.58 to 0.95 for SBW11 and for SBW17 it falls between SBW7 and SBW11where as for SBW0, it varies from 0.36 to 0.84. It is inferred from the results that in addition to the curvature, the effect of perforations plays a significant role.

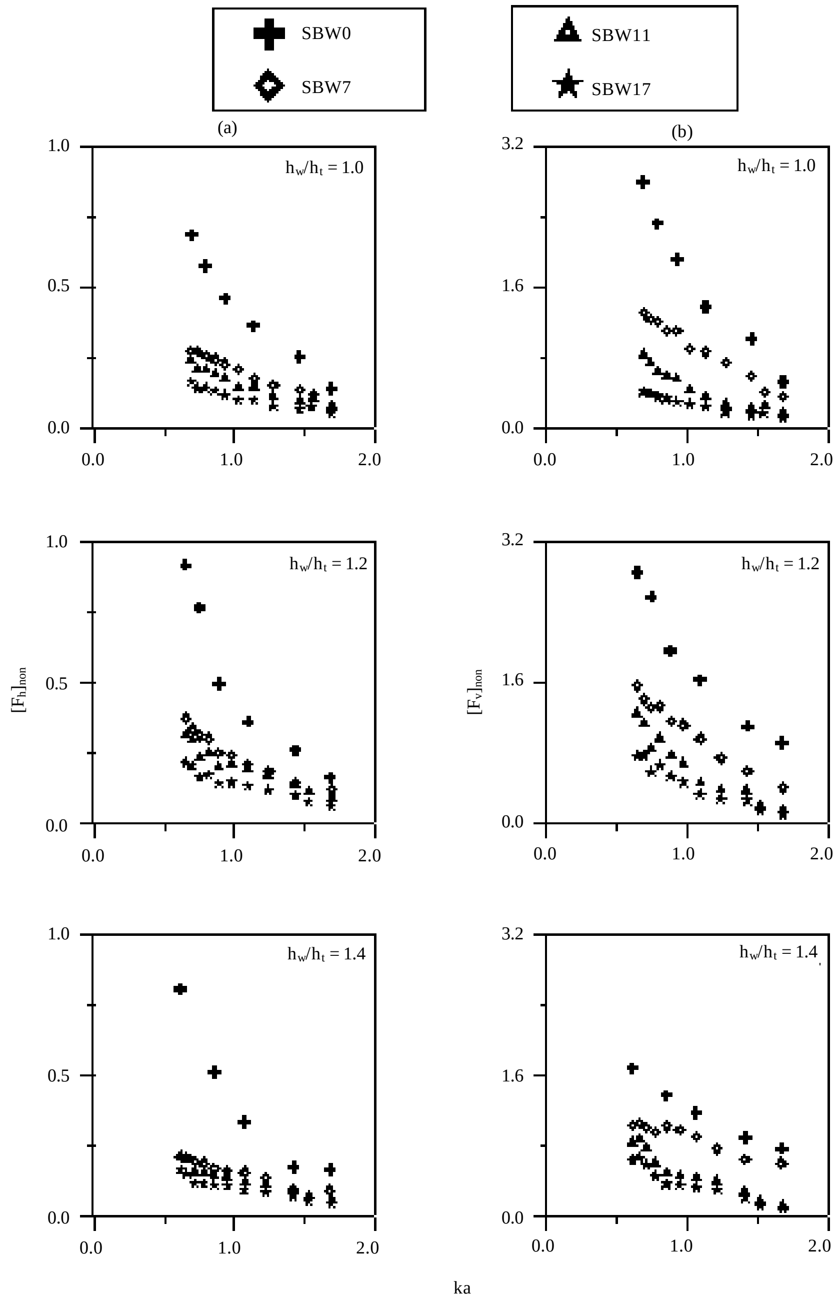

Fig. 15: Effect of perforations on (a) $[F_h]_{non}$ and (b) $[F_v]_{non}$

Forces on the semicircular caisson: The peak shoreward horizontal, $(F_h)_{max}$ and vertical, $(F_v)_{max}$ forces exerted on the semicircular caisson in presence of the submerged mound measured using six component force balance, normalized by dividing the forces with $[\gamma a l H_i/2]$. The variation of the dimensionless horizontal force, $(F_h)_{non} = (F_h)_{max}/[\gamma a l H_i/2]$ with h_w/L for the SBW7 and SBW11 are compared with the results of SBW0 in Fig. 15a and b. It is seen that $(F_h)_{non}$ decreases with increase in ka, for all the three models, the rate of decrease being drastic particularly for SBW0. SBW7 is found to experience the least force for the three h_w/h_t tested. From the results, it seen that $[F_h]_{red}$ for SBW7 ranges from 41 to 59% for $h_w/h_t = 1.0$, 36 to 67% for $h_w/h_t = 1.2$ and 40 to 73% for $h_w/h_t = 1.4$. This reduction for SBW11 is found to range from 60 to 78% for $h_w/h_t = 1.0$, 53 to 82% for $h_w/h_t = 1.2$ and 68 to 80% for $h_w/h_t = 1.4$. It is seen that $(F_v)_{non}$ decreases with increase in h_w/L, for all the three models, the rate of decrease reducing as the percentage of perforations increases. The SBW11 is found to experience the least force for the three h_w/h_t tested similar to the variation in the $(F_h)_{non}$ and hence dissipates maximum energy in seaside perforated SBWs. The $[F_v]_{red}$ in for SBW7 ranges from 22 to 47% for h_w/h_t, 32 to 56% for $h_w/h_t = 1.2$ and 20 to 36% for $h_w/h_t = 1.4$. This reduction for SBW11 is found to range from 70 to 80% for $h_w/h_t = 1.0$, 70 to 87% for $h_w/h_t = 1.2$ and 57 to 88% for $h_w/h_t = 1.4$. In addition, the percentage of reduction in forces for the seaside perforated SBW is found to slightly decrease with increase in 'ka' due to fact that, for short period waves the force exerted on the structure is less, in general, irrespective of the type of SBW. The dimensionless forces also increases with increase in h_w, that is, the structure experiences higher forces for higher water depths from $h_w/h_t = 1.0$ to 1.2 and decreases for further increase in h_w/h_t to 1.4. It is due to fact that, for $h_w/h_t = 1.4$, the dynamic action of waves influence the structure only to a lesser extent, since the depth of submergence above the model is about 40% of the total height of the model. The results clearly demonstrate that the percentage of reduction in forces for SBW11 is much greater than for SBW7. It may be recalled that the maximum percentage of reduction in K_r for SBW11 is greater than that for SBW7 as discussed earlier, which is the main attribute for the above trend. It is observed from the plots that, the rate of reduction due to increase in h_w/h_t on $(F_v)_{non}$ more for SBW0 and less for seaside perforated SBWs. The results clearly indicate that the effect of perforations play a vital role in the reduction of both horizontal and vertical forces on the caisson. The results show that the vertical force on the semicircular caisson significantly more than the horizontal force for the seaside perforated SBWs.

Dynamic pressures on SBW: The variations of dimensionless pressures, $p_c/\gamma H_i$ with ka for SBW7, SBW11 and SBW17 models for $h_w/h_t = 1.2$ compared with SBW0 for all the locations of relative depth of submergence of pressure port, z/h_w is shown in Fig. 16 to understand the phenomena. The results clearly show that, the rate of reduction in the pressures is more for the location closer to the SWL and less for the location closer towards the seabed. The pressure decay from the SWL towards the seabed is also seen. By comparing the lines of best fit for each of z/h_w superposed it is observed that the dimensionless shoreward pressure decreases with increase in 'ka' for all z/hw in general. This only reflects that the pressures exerted by the long period waves are larger. Such a trend in its variation is seen for the three water depths tested. A significant scatter in $p_c/\gamma H$ for the location closer to the SWL is observed for the model with $h_w/h_t = 1.0$ condition and is attributed to the intermittence effects, an aspect discussed by Mallayachari and Sundar (1995) and Isaacson and Subbiah (1991). The results indicate that the effect of the perforations is quite significant in reducing the pressures closer to the free surface. It is clearly observed the above results that, the structure for the condition $h_w/h_t = 1.4$, experiences least pressures among the three h_w/h_t tested due to reason that, relative depth of submergence is high in this case and effect of waves not much felt by the structure. It is inferred from the results that, submerged SBW will be ineffective in terms of hydrodynamic performance for a water depth (h_w) of 1.4 times the total height of the model (h_t).

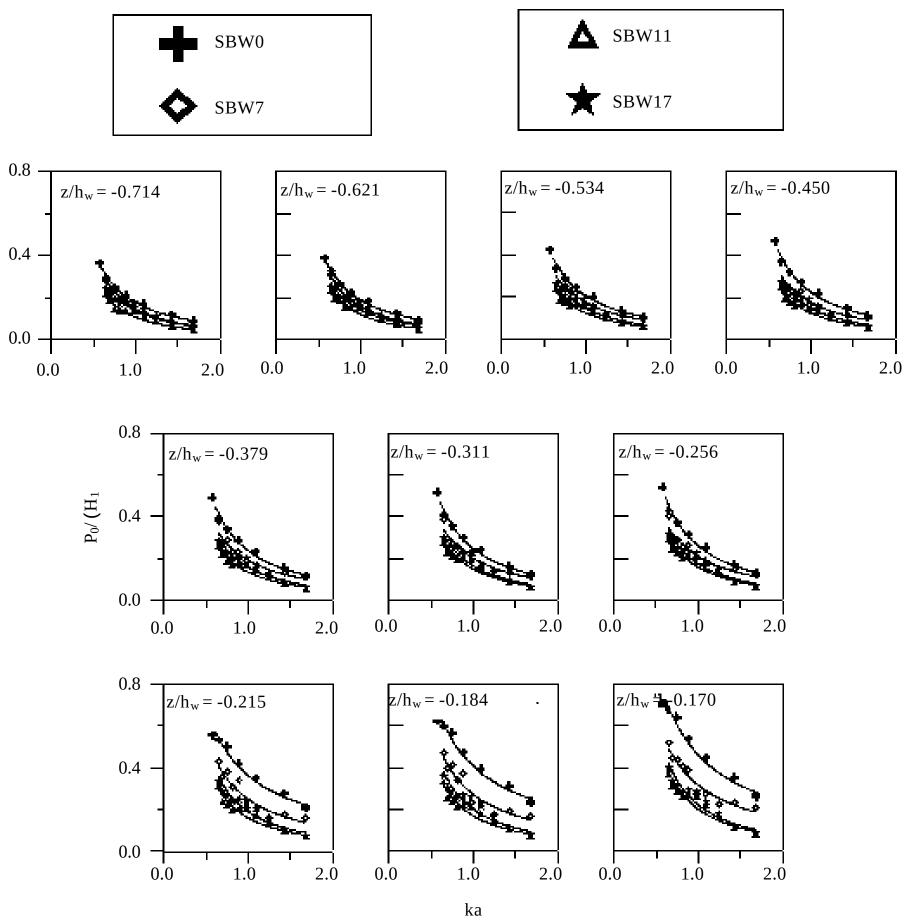

Fig. 16: Effect of perforations on dimensionless pressure for $h_w/h_t = 1.2$

CONCLUSIONS

Detailed experimental study was carried out to investigate the reflection, transmission, runup characteristics, hydrodynamic pressure and forces on seaside perforated and fully perforated SBW models for three different perforations, water depths and rubble mound height for surface piercing and submerged condition. The salient conclusions for as follows:

Surface piercing SBW: The increase in percentage of perforations from 0 to 17 decreases the reflection coefficient and dimensionless runup and in the case of seaside perforated SBWs, for the 17 percentage perforation it shows reverse trend. The transmitted wave height on the seaside exceeds 50percentage of incident wave height in case of SBW17 almost in all the h_w/h_t ratios tested and concluded that SBW17 will affect the tranquility condition on the shoreward direction. Dimensionless runup decreases with increase in water depth and perforation and in case of higher water depth, there is no much reduction in values are observed among the different cases of seaside and fully perforated SBWs. The increase in rubble mound height resulted significant reduction in reflection and transmission coefficients and runups from h_r/h_t from 0.18 to 0.29 and it is less significant for further increase in h_r/h_t to 0.36. The effect of water depth on hydrodynamic characteristics of seaside perforated SBW models is less significant compared to the effect of perforations and the effect of rubble mound height. The comparison of transmission coefficient indicates that, for submerged condition, SBW transmits lesser energy than conventional rubble mound breakwater, whereas for surface piercing condition Kt value is on the higher side for SBW (till 11 percentage perforation) than rubble mound breakwater and is within the upper bound. The dimensionless vertical force are very much higher than the dimensionless horizontal force for the all the perforated SBW models tested and it is worthy to note that, vertical force acts on the semicircular caisson adds stability to the breakwater. The optimum percentage of perforation arrived in case of fully perforated SBW is 11 from the experiments conducted. The total height of the model recommended being about 1.25 times the water depth and height of the rubble mound which is 0.29 times the total height of the model. These values can be adopted in the field for a better performance of SBW.

Submerged SBW: K_r is found to decrease with increase in water depth and increase in perforations upto 11% and further increase in perforation shows a reverse trend and hence provision of perforations beyond 11% is not recommended from the experimental investigations. The maximum reduction of 41% in K_r for seaside perforated SBWs compared to SBW0 is obtained in SBW11 for h_w/h_t = 1.2. The increase in 'ka' and percentage of perforations decreases both the dimensionless pressure and forces. The rate of decrease is more for dimensionless vertical force compare to dimensionless horizontal force. The increase in h_w/h_t from 1.0 to 1.2 increases the dimensionless forces, whereas further increase in h_w/h_t from 1.2 to 1.4 decreases the same for all the seaside perforated SBWs and hence h_w/h_t = 1.4 is not recommended. The seaside perforated SBW with 11% perforations is recommended for intermediate water depth conditions with the total height of breakwater equal to 0.83 times water depth to enable maximum energy dissipation resulting lesser pressures and forces on a structure or harbor on its leeward side.

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NOTATIONS

a = Radius of semicircular breakwater
F_h = Horizontal force
F_v = Vertical force
h_w = Water depth
h_w/L = Relative water depth
h_s = Height of semicircular caisson
h_r = Height of rubble mound
h_t = Total height of the model
H_i = Incident wave height
H_t = Transmitted wave height

k = Wave number = $2\pi/L$
ka = Scattering parameter
K_r = Reflection coefficient
K_t = Transmission coefficient
K_l = Loss coefficient
l = Width of the model across the flume
L = Wavelength
T = Wave period
x_{12}, x_{13} = Distance between wave gauges
X = Horizontal force component in the direction of wave propagation
Y_1,Y_2 = Force components rectangular to X component
Z_1,Z_2,Z_3 = Vertical components of force
γ = Specific weight of water

ABBREVIATIONS

SBW = Semicircular breakwater
SBW0 = Semicircular breakwater with no perforations
SBW7 = Semicircular breakwater with 7 percentage perforation ratio on its seaside
SBW11 = Semicircular breakwater with 11 percentage perforation ratio on its seaside
SBW17 = Semicircular breakwater with 17 percentage perforation ratio on its seaside
SBWf7 = Fully perforated semicircular breakwater with 7 percentage perforation ratio
SBWf11 = Fully perforated semicircular breakwater with 11 percentage perforation ratio
SBWf17 = Fully perforated semicircular breakwater with 17 percentage perforation ratio

REFERENCES

Dhinakaran, G., V. Sundar, R. Sundaravadivelu and K.U. Graw, 2002. Dynamic pressures and forces exerted on impermeable and seaside perforated semicircular breakwaters due to regular waves. Ocean Eng., 29: 1981-2004.

Dhinakaran, G., V. Sundar, R. Sundaravadivelu and K.U. Graw, 2008. Hydrodynamic characteristics of seaside perforated semicircular breakwaters due to random waves. J. Waterway Port Coastal Ocean Eng., 134: 237-251.

Dhinakaran, G., V. Sundar, R. Sundaravadivelu and K.U. Graw, 2009. Effect of perforations and rubble mound height on wave transformation characteristics of surface piercing Semicircular Breakwaters. Ocean Eng., 36: 1182-1198.

Dhinakaran, G., V. Sundar, R. Sundaravadivelu and K.U. Graw, 2010. Regular wave measurements on submerged semicircular breakwater. ASME. J. Offshore Mechanics Arctic Eng., 132: 034501-034506.

Goda, Y. and Y. Suzuki, 1976. Estimation of incident and reflected waves in random wave experiments. Proceedings of the 15th International Conference Coastal Engineering, (ICCE'76), ASCE, Honolulu, Hawaii, pp: 828-845.

Gunaydin, K. and M.S. Kabdasli, 2004. Performance of solid and perforated U-type breakwaters under regular and irregular waves. Ocean Eng., 31: 1377-1405.

Isaacson, M. and K. Subbiah, 1991. Numerical simulation of random wave forces near the free surface. J. Offshore Mech. Arctic Eng., 113: 14-42.

Jia, D.H., 1999. Study on the interaction of water waves with semi-circular breakwater. China Ocean Eng., 13: 73-80.

Liu, Y., Y. Li and B. Teng, 2007. Wave interaction with a perforated wall breakwater with a submerged horizontal porous plate. Ocean Eng., 34: 2364-2373.

Liu, Y., Y.C. Li, B. Teng and S. Dong, 2008. Wave motion over a submerged breakwater with an upper horizontal porous plate and a lower horizontal solid plate. Ocean Eng., 35: 1588-1596.

Mallayachari, V. and V. Sundar, 1995. Standing wave pressures due to regular and random waves on a vertical wall. Ocean Eng., 22: 859-879.

Mansard, E.P.D. and E.R. Funke, 1980. The measurement of incident and reflected spectra using a least squares method. Proceedings of the 17th International Conference on Coastal Engineering, (ICCE'80), ASCE, New York, pp: 154-172.

Priya, M.S.K., K.A. Roopsekhar, V. Sundar, R. Sundaravadivelu, K.U. Graw and S. Knapp, 2000. Hydrodynamic pressures on semicircular breakwaters. CD Proceedings of the 4th International Conference on Hydroscience and Engineering, Sept. 26-29, IAHR, Seoul, South Korea, pp: 1-10.

Sasajima, H., T. Koizuka and H. Sasayama, 1994. Field demonstration test of a semicircular breakwater. Proceedings of HYDROPORT'94, International Conference on Hydro-Technical Engineering for Port and Harbor Construction, Oct. 19-21, Port and Harbour Research Institute, Yokosuka, Japan, pp: 593-610.

Sundar, V. and D. Raghu, 1997. Wave induced pressures on semicircular breakwater. Proceedings of the 2nd Indian National Conference on Harbour and Ocean Engineering, (INCHOE'97), Cochin University of Science and Technology, Thiruvananthapuram, India, pp: 278-287.

Sundar, V., R. Sundaravadivelu, G. Dhinakaran, K.A. Roopsekhar and K.U. Graw, 2001. Pressures and forces on semicircular breakwaters due to regular waves. Oceanic Eng. Int., 5: 73-83.

Vijayalakshmi, K., S. Neelamani, R. Sundaravadivelu and K. Murali, 2007. Wave runup on a concentric twin perforated circular cylinder. Ocean Eng., 34: 327-336.

Xie, S.L., 1999. Wave forces on submerged semi-circular breakwater and similar structures. China Ocean Eng., 13: 63-72.