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Physical model studies on the stability of emerged seaside perforated semicircular breakwaters

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Present study discusses experiments conducted in a two dimensional monochromatic wave flume to determine the critical (minimum) weight required to resist the sliding of an emerged seaside perforated semicircular breakwater model. It is observed from a detailed review that there is hardly any literature, stressing the critical weight determination for the sliding stability of this breakwater type. Hence, the present research was taken up to study the variations in the critical weight required for sliding stability with different wave and structural specific parameters. The variations were recorded graphically using non-dimensional parameters obtained from a dimensional analysis using Buckingham's π theorem.

[**Keywords:** Semicircular breakwater, Incident wave steepness, Dimensionless stability parameter, Dimensionless depth parameter, Buckingham π theorem, Sliding stability]

Introduction

Semicircular breakwater (SBW) have many advantages over conventional, rubble mound breakwaters. These advantages have made them popular and attract the interest of coastal scientists. The SBW has been recognized as being an excellent coastal protection structure for a wider range of water depths[1], especially when the seaside wall is perforated[2]. SBW has high overturning stability because of its arch type shape[3]. The stability can be increased further by perforating the base slab, as this will reduce the uplift pressure[4]. The dynamic force acting on the wall of SBW always passes through the centre of the circle creating a uniform sub-grade reaction. As a result, the sub-grade reaction per unit area is minimal and hence, SBW can be installed on a relatively soft foundation[5]. The cost of construction of SBW is comparatively lower than that of conventional rubble mound breakwaters by about 20%[6]. There is also ease of construction since it is of modular type. Furthermore, arch type of construction provides an advanced aesthetic value compared to others. Sasajima et al. (1994) studied the forces and pressures on the SBW erected at the Miyazaki port in Japan[4]. The result of force and pressure variations obtained by the modified theoretical formula of Goda and Suzuki (1976) were found to be greater when compared with experimental values obtained on measured highest 1/3rd wave pressure, pressure at the time of maximum force, and maximum wave pressure at different elevations along the seaward side[7]. Sundar and Raghu (1997) conducted experiments on wave runup, wave reflection, and dynamic pressures on SBW subjected to random waves[8]. The pressure spectrum at still water level (SWL) results in lesser energy compared to that of a location immediately below the SWL, which is due to the intermittence effect. Pressure spectra were found to decrease towards the sea bed. The 0th spectral moment at a location (z/d=- 0.10), immediately below the SWL, was nearly 60 to 75% greater than that exerted at the SWL. The shape of the pressure spectra is slightly broader than the corresponding wave spectrum. The shoreward peak pressures follow a Raleigh distribution. Sri Krishnapriya et al. 2010 in their results on the variation of the dynamic pressures revealed that the measured values were less than those of the modified formulation of Goda (1974)[9, 10], particularly when nearer to the SWL, and conclusions were similar to that of Sundar and Raghu (1997)[8]. Dhinakaran et al. studied how the perforations, water depth and rubble mound height of a SBW affect the non-breaking wave transformations[11]. The SBW model for three different perforation ratios with 7%, 11% and 17% were selected to study the variation of reflection, transmission, runup characteristics and dimensionless horizontal and vertical forces as a function of relative water depth. The results were compared with an impermeable SBW and seaside perforated SBW models. The dimensionless vertical force is very much higher than the dimensionless horizontal force for the perforated SBW models tested and the vertical force acts on the semicircular caisson, adding stability to the breakwater. The studies carried out showed that long period waves exert more force on the caisson, short period waves transfer less force, and an increase in water depth causes an increase in force. The variations of force and pressure directly influence the stability, i.e. the minimum weight required to ensure that the stability of semicircular breakwater increases with an increase in force and pressure.

Nishanth (2008) carried out experiments to find the hydrodynamic performance characteristics of emerged seaside perforated and non-perforated breakwater models and showed that the reflection coefficient increases with an increase in incident wave steepness and depth parameter[12]. Ganesh (2009) conducted studies on seaside perforated, as well as both sides (seaside and leeside) perforated semicircular breakwater model with S/D ratios of 8, 4, and 2 for various wave heights and wave periods in different water depths[13]. The obtained results showed that as the percentage of perforations increased or the S/D ratio decreased, the value of the reflection coefficient, relative runup and relative rundown decreased, but the value of the transmission coefficient was found to be increased. The conclusions of Vishal (2010) were the same as that of Ganesh (2009) for perforated models with different S/D ratios[8, 14].

It is clear from the literature review that there is hardly any research available regarding the sliding stability of emerged seaside perforated SBW. Earlier investigations have stressed on the pressure, reflection, runup, rundown, and dissipation aspects of the breakwater, but have not considered the sliding stability. Hence, present research work was taken up to study the sliding stability of the emerged seaside perforated semicircular breakwater models.

Materials and Methods

Experiments were carried out to study the stability of a seaside perforated SBW and to ascertain the critical weight required to resist sliding and to determine the effect of water depth and wave parameters on its sliding stability. The variation $W/\gamma H_i^2$ with incident wave steepness H_i/gT^2, for different ranges of the dimensionless depth parameter d/gT^2, for a constant value of the radius (R) to total height (h_t) ratio, R/h_t of 0.92 was studied.

The breakwater model used consists of two parts: a top semicircular shaped caisson and a base (Figure 1). A galvanized iron (GI) sheet with a thickness of 0.002m was used to fabricate the semicircle shaped caisson as well as the base. The base GI plate dimensions of a seaside perforated semicircular breakwater with a 0.60 radius (R=0.60 m) are of 1.3 m × 0.73 m × 0.002 m. The model is perforated with 0.016m diameter circular perforations. The degree of perforation is chosen so that the ratio of centre to centre spacing between perforations (S) to diameter of perforations (D) is constant (S/D=8). The structure's dimensions are chosen so that the structure should slide for the least value of incident wave height (H_i) and time period (T) used in the experiments. This enables additional weights to be added, making it possible to find the critical weight required to resist sliding of the model.

The model was coated with a thin layer of cement slurry to simulate the concrete surface used in prototype. The semicircular caisson was fixed to the base GI plate with the help of stiffeners. The model was then positioned over the rubble mound foundation with a thickness of 0.05 m on a scale of 1:30 [equivalent to the minimum recommended prototype thickness of 150 cm prescribed[15]]. Rubble weighting from 50 gf to 100 gf was used to form the foundation. The total height of the model, including the rubble mound foundation (h_t), was of 0.652 m. The weight of the model was measured and found to be 372.78 N. A typical emerged, non-perforated SBW model with a cross section of 0.6 m radius is shown in Fig. 1 with all pertinent details.

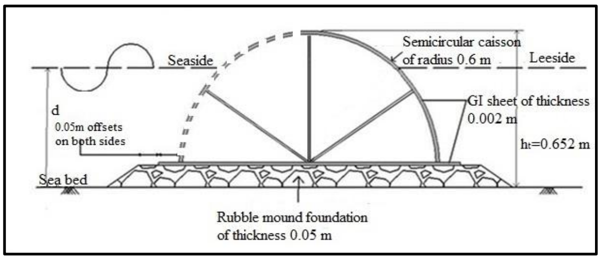

Fig. 1-Semicircular breakwater model cross section on Rubble foundation of slope 1:2 (not to scale)

Experiments were conducted in a two dimensional monochromatic wave flume in the Marine Structural Laboratory of the Department of Applied Mechanics and Hydraulics, at the National Institute of Technology Karnataka, Surathkal, Mangaluru, India. The model was positioned on a rubble mound foundation having a slope of 1:2, as shown in Figure 1 and placed 28 m away from the wave flap. The three probe method proposed by Isaacson (1991) was used for measuring the incident and reflected wave heights.

Table 1. Range of values of experimental variables used in the present work

Parameters	Experimental range
Wave specific parameters	
Incident wave height, H_i (m)	0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18
Wave period, T (s)	1.4, 1.6, 1.8, 2.0, 2.2, 2.5
Water depth, d (m)	0.35, 0.40, 0.45
Structure specific parameters	
Radius of the structure, R (m)	0.60
Total height of the structure, h_t (m)	0.652
Weight of the model, W (N)	372.78

The first probe was placed at a distance, L, from the centre of the model, and the distance between each of the probes is equivalent to L/3, in which L is the wave length. Waves were produced in bursts of five to avoid successive reflections. The surface elevations measured by the probes were recorded with the wave recorder and the voltage signals were converted into wave heights and wave periods with the use of the lab wave recorder software provided by Environmental Measurements and Controls (EMCON), Kochi, India. Table 1 shows range of values of experimental variables used in the present work. Fig. 2 shows the diagrammatic representation of the wave flume used in the present study.

The test conditions used in the semicircular breakwater experiments are as follows:

- Flume bed is horizontal and rigid.
- Secondary waves during wave generation are not considered.
- Wave reflection from the structure does not interfere with freshly generated incident waves, since the waves are generated in bursts.
- The density difference between fresh water and seawater is not considered and fresh water was used in the flume.
- Generated waves are of a monochromatic nature.

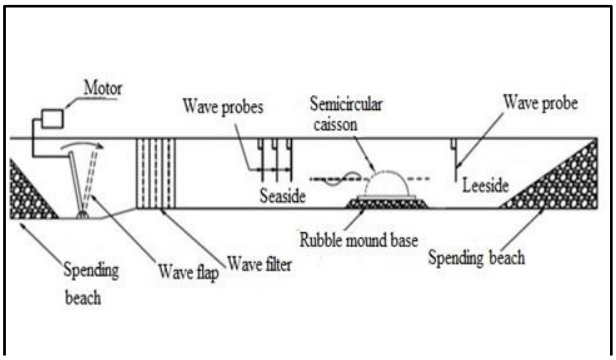

Fig. 2 Diagrammatic representation of the wave flume used

Results and Discussion

An analysis of the stability against sliding is carried out to determine the critical weight (W) for an emerged perforated SBW subjected to wave parameters of the Arabian Sea on the Mangaluru coast, Karnataka, India. Table 2. shows equations for variation of $W/\gamma H_i^2$ with H_i/gT^2 for all four ranges of d/gT^2, for R/h_t=0.92 for S/D=8. Fig. 3 shows the deviation of $W/\gamma H_i^2$ with H_i/gT^2 for all four ranges of d/gT^2 and for a constant R/h_t of 0.92 and constant S/D ratio=8. As incident wave steepness increases, the dimensionless stability parameter experimentally decreases. This is because long period waves exert more force on the caisson versus the short period waves which transfer less force. The sliding disturbance caused by the increase in force is stabilized by an increasing of the normal reaction originated by an increasing in the weight of the breakwater. It is also found that as the depth parameter d/gT^2 increases, the value of $W/\gamma H_i^2$ too increases. This is because the higher the water depth, the greater the area of the SBW model exposed to wave action, and hence, the increase in d/gT^2 imparts more force therefore increasing in $W/\gamma H_i^2$.

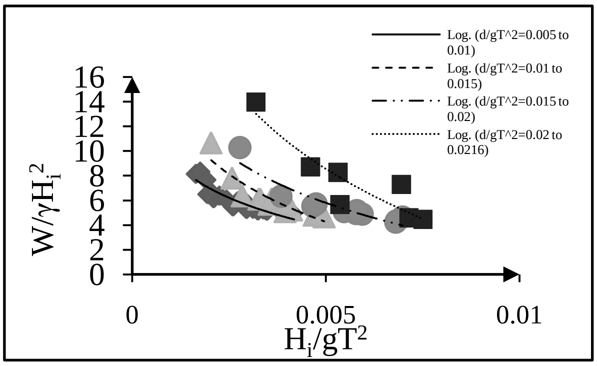

Fig. 3 Variation of W/γHi2 with Hi/gT2 for different ranges of d/gT2 for R/ht=0.92 and S/D=8

Table 2. Equations for variation of $W/\gamma H_i^2$ with H_i/gT^2 for all four ranges of d/gT^2, for R/h_t=0.92 for S/D=8

Sl. No.	Range of depth parameter, d/gT^2	Equation for $y=W/\gamma H_i^2$ ($x= H_i/gT^2$)
1	0.005 – 0.010	y = -3.423ln(x) - 14.301
2	0.010 – 0.015	y = -5.583ln(x) - 25.336
3	0.015 – 0.020	y = -5.519ln(x) - 23.445
4	0.020 – 0.0216	y = -9.964ln(x) - 44.234

Nomogram for computation of critical weight of semicircular breakwater

Fig. 4 represents the nomogram used for finding the critical weight to be used for the purpose of designing an emerged seaside perforated SBW. The values of $W/\gamma Hi^2$ are plotted against H_i/gT^2 for a range of d/gT^2 from 0.005 to 0.0216, for a constant R/h_t of 0.92 and constant S/D=8. For a design example consider the case of an emerged perforated SBW standing in a water depth of 12 m, with a 0.18 m semicircular caisson radius, 0.48 m diameter perforations at a spacing of 3.84 m (S/D=8), base slab thickness of 0.06 m resting on a 1.5 m thick rubble mound base, with a total structure height of 20.1 m, subjected to action of waves of 4.5 m height and 10 s wave period.

The value of $W/\gamma H_i^2$ can be found from the nomogram for R/h_t=0.92, d/gT^2=0.0122, and H_i/gT^2=0.00459 as 6.027. Hence, the critical weight required per unit length of the model to resist sliding is of 1134.05 N and the critical weight required per unit length for prototype breakwater (W) is =1.021 MN. Now, a suitable factor of safety may be applied to obtain the design weight of the caisson for prototype.

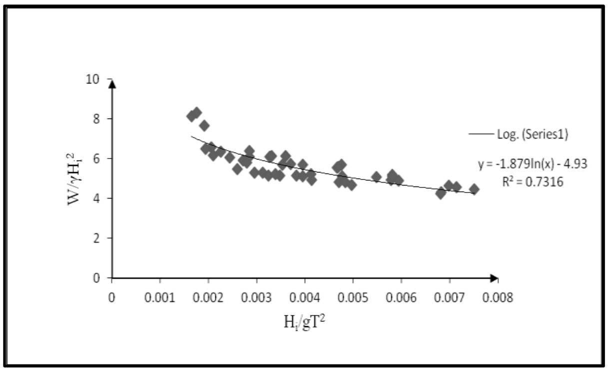

Fig. 4 Nomogram showing variation of W/γHi2 with Hi/gT2 for d/gT2 =0.005 to 0.0216 for R/ht=0.92 and S/D=8

Conclusions

Based on the results obtained following conclusions have been drawn for emerged perforated SBW models with S/D=8 and R/h_t=0.92. $W/\gamma H_i^2$ was found to decrease as H_i/gT^2 increased, for the emerged perforated Semicircular breakwater for all the depth parameter ranges. $W/\gamma H_i^2$ was found to increase with an increase in d/gT^2 for the given incident wave steepness, i.e. as the depth parameter increased, critical weight required for stability against sliding also increased. The nomogram presented gives critical weight required for stability against sliding for the prototype breakwater.

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Notations

d	- Water depth
g	- Acceleration due to gravity
H_i	- Incident wave height
h_t	- Height of the structure
R	- Radius of the SBW
T	- Wave period
γ	- Specific weight of water
W	- Critical (minimum) weight required to resist the sliding per unit length of the model
$W/\gamma H_i^2$	- Dimensionless stability parameter

d/gT^2 - Dimensionless depth parameter
H_i/gT^2 - Incident wave steepness
S/D - Ratio of spacing to diameter of perforations

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