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Wave-Structure Interaction for Submerged Quarter-Circle Breakwaters of Different Radii - Reflection Characteristics

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***Abstract*—**The paper presents the results of a series of experiments conducted on physical models of Quarter-circle breakwater (QBW) in a two dimensional monochromatic wave flume. The purpose of the experiments was to evaluate the reflection coefficient K_r of QBW models of different radii (R) for different submergence ratios (d/h_c), where d is the depth of water and h_c is the height of the breakwater crest from the sea bed. The radii of the breakwater models studied were 20cm, 22.5cm, 25cm, 27.5cm and submergence ratios used varied from 1.067 to 1.667. The wave climate off the Mangalore coast was used for arriving at the various model wave parameters. The incident wave heights (H_i) used in the flume varied from 3 to 18cm, and wave periods (T) ranged from 1.2 s to 2.2 s. The water depths (d) of 40cm, 45cm and 50cm were used in the experiments. The data collected was analyzed to compute variation of reflection coefficient $K_r=H_r/H_i$ (where H_r=reflected wave height) with the wave steepness H_i/gT^2 for various R/H_i (R=breakwater radius) values. It was found that the reflection coefficient increased as incident wave steepness increased. Also as wave height decreases reflection coefficient decreases and as structure radius R increased K_r decreased slightly.

***Keywords*—**Incident wave steepness, Quarter-circle breakwater, Reflection coefficient, Submergence ratio.

I. Introduction

THE principle purpose of a breakwater system is to intercept the incident waves and cause them to break or reflect, thereby reducing energy of the incoming waves [1]. The submerged type breakwaters, of late, are more frequently used as a ‘soft’ solution in mitigating coastal engineering problems like providing tranquility in harbors, bays etc. A submerged breakwater is a wave barrier with its crest at or slightly below the still water level. According to [2] submerged coastal structures are widely perceived to be capable of providing beach protection, without the adverse impacts (including loss of beach amenity and aesthetic conditions) often associated with more conventional structures such as revetments and groins. In situations where complete protection from waves is not required, submerged breakwaters offer a potentially economic solution. Submerged breakwaters have been effectively used to protect harbor entrances, to reduce siltation in entrance channels, for beach erosion mitigation, and for creation of artificial fishing grounds [3]. Quarter-circle breakwater (QBW) is a new type breakwater first proposed by [4] on the basis of semicircular breakwater (SBW) concept. Similar to SBW, QBW is usually placed on a rubble mound foundation and its superstructure consists of a quarter circular surface facing the incident waves, a horizontal bottom and a lee-side vertical wall. The present paper considers a comprehensive laboratory investigation to evaluate the reflection characteristics of the submerged QBW for different radii of physical models, still water levels, wave heights, wave periods etc.

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II. Literature Review – Physical and Numerical Models

Reference [5] reports “A physical model is a precision device used to predict the behavior of a physical phenomenon. A model can be regarded as reliable only if it is designed correctly”. A few physical and numerical model studies have been carried out by researchers in this area. A series of two-dimensional (vertical) wave numerical model and also physical model studies have been conducted by [6] to research the performances of QBW by comparing the hydraulic behaviors of SBW and QBW under same hydraulic conditions. As far as reflection is concerned they found that the reflection coefficient values of QBW and SBW are closer, with values less than 1.0 under same conditions, even if h_c reaches 2 to 3 times of incident wave height. The reflection coefficient K_r increases with h_c/H_i increasing. They concluded, the flow fields in front of the breakwater in both the cases of submerged and emerged are similar, which imply the resemblance of reflection coefficients for both breakwaters.

Reference [7] discusses about a series of regular and irregular wave experiments conducted to study the reflection and transmitting performances of quarter-circle breakwater in comparison with those of the semicircular breakwater. There were two kinds of reflection coefficients discussed: a). “Resolution reflection coefficient” based on the standard concept of reflection coefficient with the expression of $K_r=H_r/H_i$ which represents the whole effect of wave reflection by breakwater, and b). “Circular-surface reflection coefficient” which was denoted as K_{rc} which was used to describe the reflective effect by circular surface on the adjacent flow field in front of the breakwater. They found that the fact of $K_{rc}<K_r$ at the same relative freeboard height (h_c/H_i) indicates that the entire reflective effect of QBW is stronger than that by circular surface on the adjacent flow field. They

also stated that the reflection and transmission performances of QBW are more sensitive to the relative freeboard height (h_c/H_i) than to the wave steepness (H_i/L_i).

III. Dimension Analysis and Test Models

Dimensional analysis was carried out using Buckingham's π theorem. The variables considered in the present investigations are as follows: d, depth of water; L, wavelength; H_i, incident wave height; T, wave period; g, acceleration due to gravity; h_c, height of structure crest (from sea bed). Considering H_i and g as repeating variables, the dimensional analysis yielded following non-dimensional π terms: H_r/H_i (=reflection coefficient K_r), H_i/gT^2 (incident wave steepness), d/h_c (submergence ratio). Four physical models of different radii i.e. 20cm, 22.5cm, 25cm and 27.5cm were used in this study. Each model consisted of two parts, the base slab and the top quarter-circle shaped caisson. The fabrication of the model was done in two steps, one - the casting of base slab, and secondly - the fabrication of the quarter-circle caisson. The bottom slabs of sizes 0.3m X 0.73m X 0.05m, 0.325m X 0.73 m X 0.05m, 0.35m X 0.73m X 0.05m and 0.375m X 0.73m X 0.05m were used in the experiments. These dimensions were chosen in order to maintain the weight of the QBW to make them stable during the wave attack.

Galvanized Iron (G.I.) sheet of 0.002m thickness was used to fabricate the quarter-circle shaped caisson and the sheet was coated with cement slurry to simulate concrete surface. The sheet was fixed to the base slab with the help of stiffeners made up of flat plates. Models were then placed over the rubble mound foundation of thickness 0.05m on a scale of 1:30. The prototype minimum thickness of 0.5m is prescribed by [8] and stones weighing from 50 gm to 100 gm were used to form the foundation. A typical submerged QBW model cross section of 0.2m radius is shown in Fig. 1 with all relevant details.

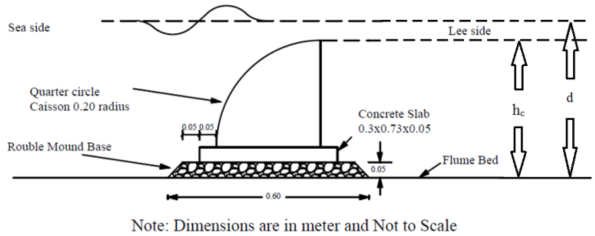

Fig. 1 Quarter-circle breakwater model section of radius 0.2m

IV. Experimental Setup

The present study is conducted in the monochromatic wave flume of the Marine Structures laboratory of the Department of Applied Mechanics and Hydraulics, National Institute of Technology Karnataka (N.I.T.K.), Surathkal, Mangalore, Karnataka state in India. The model was placed in the flume 28m away from the wave flap, above the rubble mound foundation. The slope used for the rubble foundation is 1:2 as shown in Fig. 2. Three capacitance type wave probes were used for measuring the incident, reflected and transmitted wave heights. The wave probes were placed at a distance of 4 m from the centre of the model. Three probes were kept in front of the breakwater to measure the reflected waves using the three-probe method proposed by [9]. The spacing between the probes is kept equal to L/3, where L is the wavelength. A burst of five waves are generated to avoid the successive reflection. For the measurement of transmitted waves, a single probe is placed at the leeside of the breakwater. The surface elevation measured by the probes are recorded by the wave recorder and voltage signals are converted into wave heights and wave periods using the laboratory wave recorder software provided by Environmental Measurements and Controls (E.M.C.O.N), Kochi, India.

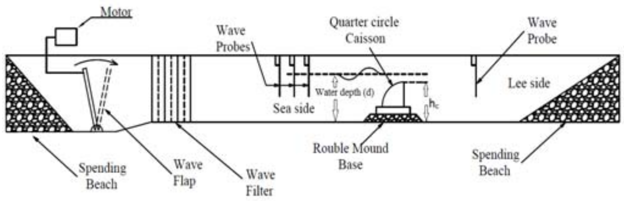

Fig. 2 Monochromatic wave flume setup used for the investigation

TABLE I
Experimental Variables and Their Range of Values

Parameters	Experimental range
Wave-specific parameters	
Incident wave height, H_i (m)	0.03, 0.06, 0.09, 0.12, 0.15, 0.18
Wave period, T (sec)	1.2, 1.4, 1.6, 1.8, 2.0, 2.2
Depth of water, d (m)	0.40, 0.45, 50
Submergence ratio, d/h_c	1.06-1.667
Structure-specific parameters	
Radius of the Quarter-circle caisson (m)	0.2, 0.225, 0.25, 0.275

V. Analysis of Results and Discussion

According to [10] when waves get reflected by a structure, the reflected waves cause increased agitation of the water in front of the structure. Clearly, a part of the energy of the incident waves is always reflected by the submerged structure. The amount of reflection depends on the wave parameters and the depth of submergence. The graphs are plotted to understand the variation of K_r with H_i/gT^2 for the range of d/h_c and R/H_i values used in the experiments. Figs. 3-14 show the variation of reflection coefficient K_r with the incident wave steepness H_i/gT^2 for various submergence ratios d/h_c and different R/H_i ranges. The values of d/h_c used are in the range 1.06-1.66 and R/H_i values in the range of 1.1-9.5. In all the cases depicted by Figs. 3-14, it may be observed that the reflection coefficient increases logarithmically (best-fit) as incident wave steepness increases for all values of d/h_c and R/H_i. Clearly, whatever may be the depth, caisson radius, height of structure crest (from sea bed), there is always increase in reflection coefficient with increase in wave steepness. Hence, steeper waves (greater wave height and lesser wave periods) cause more of reflection from the breakwater structure.

Figs. 15-17 show the variation of reflection coefficient K_r with R/H_i (ratio of model radius to incident wave height) for different d/gT^2 values, and for all the values of h_c. As R/H_i increases K_r is found to decrease in a logarithmic variation (best-fit). Fig. 15 shows the same for the d/gT^2 range of 0.008 to 0.028 (d=50 cm). Similarly Figs. 16, 17 represent the same variation for d/gT^2 ranges of 0.009 to 0.0318 (d=45 cm), and 0.01 to 0.035 (d=40 cm) respectively. In other words, as the structure radius R increases, K_r decreases. Further, as wave height decreases, reflection coefficient also decreases.

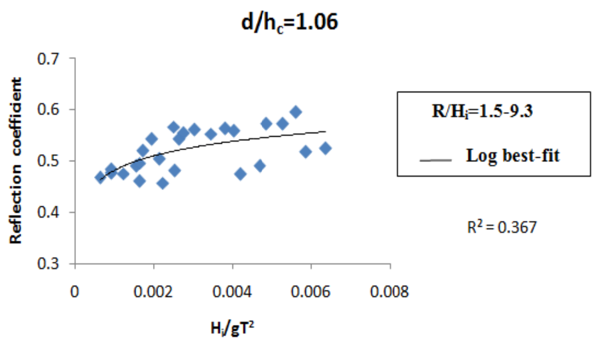

Fig. 3 Variation of K_r with H_i/gT^2 for R/H_i=1.5-9.3

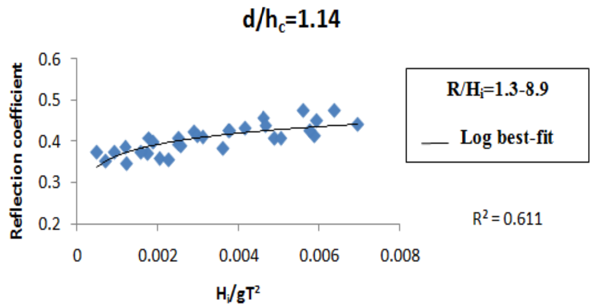

Fig. 4 Variation of K_r with H_i/gT^2 for R/H_i=1.3-8.9

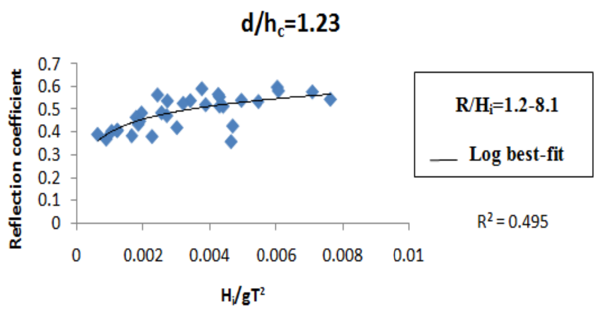

Fig. 5 Variation of K_r with H_i/gT^2 for R/H_i=1.2-8.1

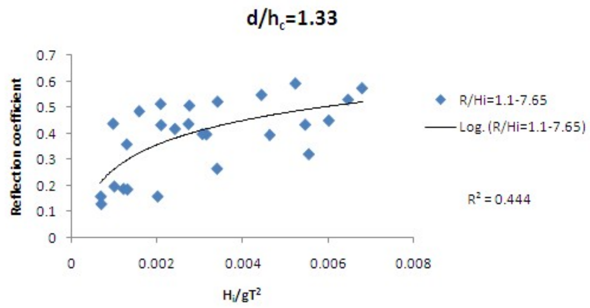

Fig. 6 Variation of K_r with H_i/gT^2 for R/H_i=1.1-7.65

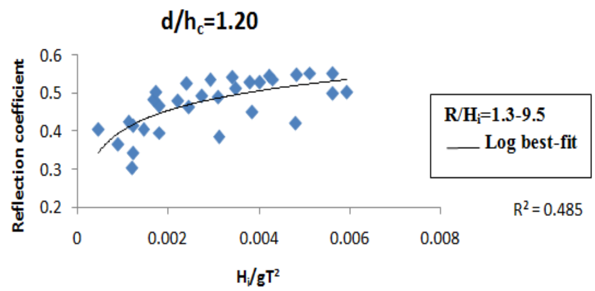

Fig. 7 Variation of K_r with H_i/gT^2 for R/H_i=1.3-9.5

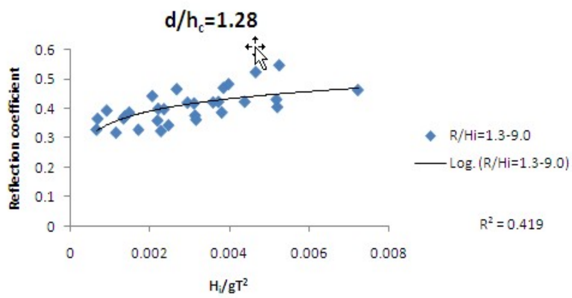

Fig. 8 Variation of K_r with H_i/gT^2 for R/H_i=1.3-9.0

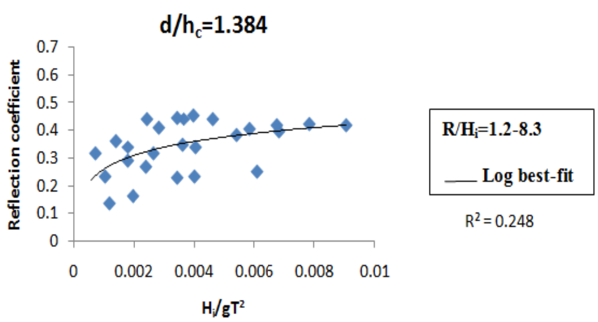

Fig. 9 Variation of K_r with H_i/gT^2 for R/H_i=1.2-8.3

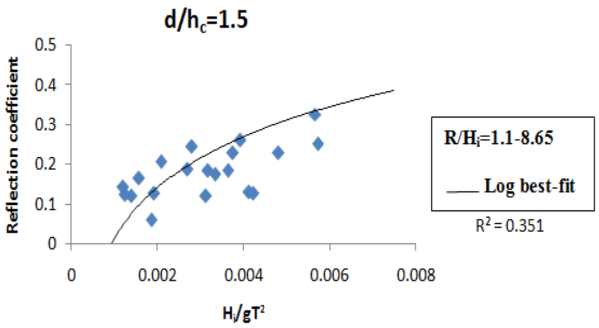

Fig. 10 Variation of K_r with H_i/gT^2 for R/H_i=1.1-8.65

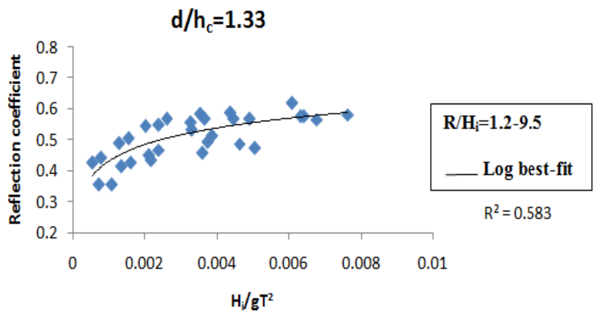

Fig. 11 Variation of K_r with H_i/gT^2 for R/H_i=1.2-9.5

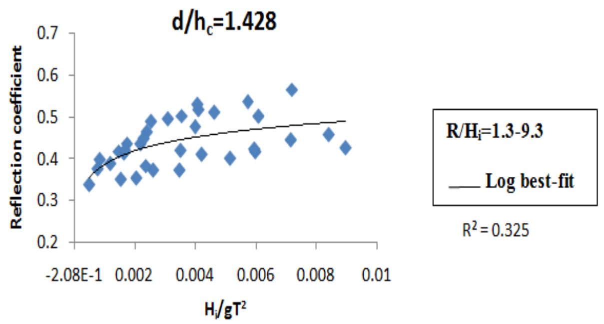

Fig. 12 Variation of K_r with H_i/gT^2 for R/H_i=1.3-9.3

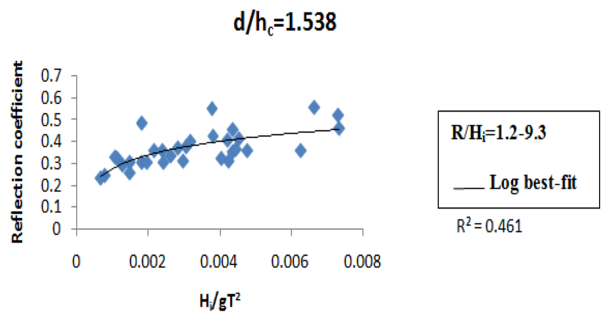

Fig. 13 Variation of K_r with H_i/gT^2 for R/H_i=1.2-9.3

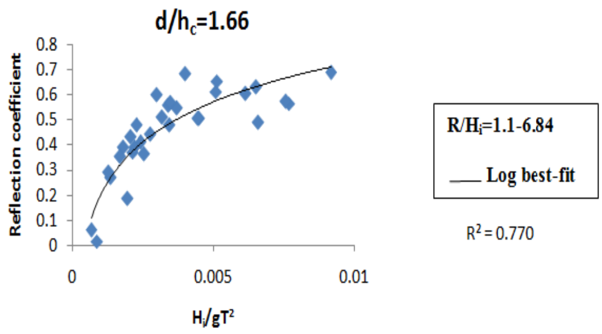

Fig. 14 Variation of K_r with H_i/gT^2 for R/H_i=1.1-6.84

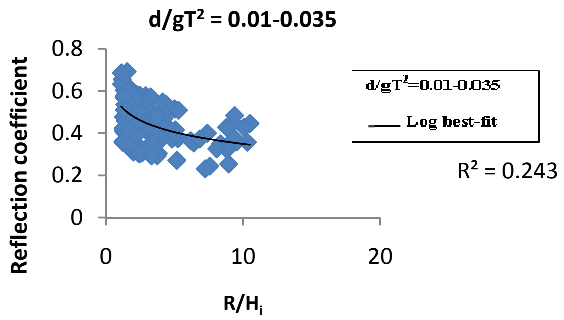

Fig. 15 Variation of K_r with R/H_i for d/gT^2=0.01-0.035

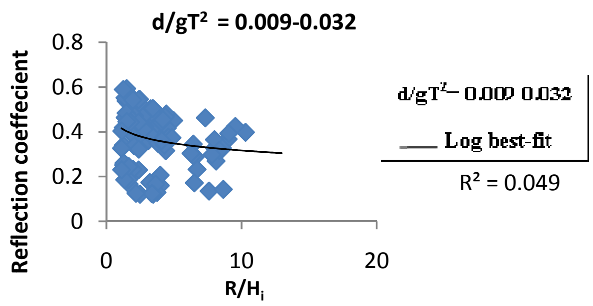

Fig. 16 Variation of K_r with R/H_i for d/gT^2= 0.009-0.032

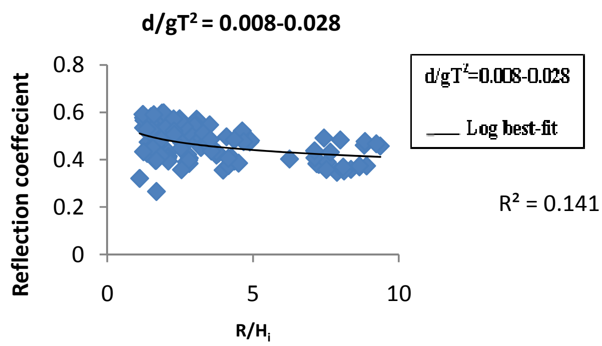

Fig. 17 Variation of K_r with R/H_i for d/gT^2=0.008-0.028

VI. Conclusions

The paper presents the reflection characteristics of a quarter circle breakwater when subjected to wave action. It is found that reflection coefficient increases logarithmically (best-fit) as incident wave steepness H_i/gT^2 increases, for all values of d/h_c and R/H_i used in the experiments. Further, for all the values of d/gT^2 i.e. from 0.008 to 0.035 used in the experiments, reflection coefficient decreases with increase in R/H_i, which varies from 1.1 to 9.5. Typically, as R/H_i increases from 1.1 to 9.5, K_r was found to decrease from about 0.55 to 0.35, which is about 40% and in the logarithmic way.

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