Hydrodynamic Performance Characteristics of Emerged Perforated Quarter Circle Breakwater

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ABSTRACT: Breakwaters are one of the most important harbour structures constructed to withstand and dissipate the dynamic energy due to the action of the waves. Due to fast growing need of the universe and advances in technology different types of breakwaters are being developed. Quarter circle breakwater is a new type of breakwater emerged from semi-circular breakwater and the first model was developed in Peoples Republic of China (2006). The present study investigates the wave reflection, wave runup and rundown on an emerged seaside perforated quarter circle breakwater of radius 55 cm and with ratio of spacing to diameter of perforations (S/D) equal to 4 for different water depths.

KEYWORDS: Quarter Circle Breakwater, Perforations, Wave reflection, Wave runup and Wave rundown.

I. INTRODUCTION

Quarter circle breakwaters (QBW) are new type breakwaters first proposed by Xie et al. (2006) on the basis of SBW concept. The superstructure of QBW consists of a quarter circular surfaces facing incoming wave, a horizontal bottom and a rear vertical wall mounted on rubble mound foundation (Refer Fig. 1). Quarter circle breakwater with perforations possess merits of caisson as well as perforated breakwaters such as low weight, requires less materials, suited for poor soil conditions, easily transported, handled and placed at the site, aesthetically pleasing, cost effective, eco-friendly and stable. The most important benefit of QBW is the reduction in the volume of concrete as well as rubble mound foundation, because of the smaller bottom width (HanbinGu et al. 2008).

Jarlan (1961) introduced the concept of perforated breakwater with a front perforated wall, a wave energy dissipating chamber and a solid back wall. Significant damping of incoming wave can be achieved by the generation eddies a turbulence near the perforations in the front wall (Jarlan, 1961). With the evolution of different forms of perforated breakwater, researchers conducted a lot of experimental studies introducing new concepts in the design of perforated breakwater. Xie et al. (2006) evaluated the hydraulic characteristics of quarter circle breakwater (QBW) by a numerical flume and concluded the main reason for the difference of wave forces on the quarter circle and the semicircular breakwater (SBW). Jiang et al. (2008) conducted a 2-D (vertical) wave numerical model and physical model studies to
research the performances of QBW by comparing the hydraulic behaviours of SBW and QBW under same hydraulic conditions. Qie et al. (2013) conducted a series of physical model tests acted by irregular waves to investigate the wave force distribution on the seaward side of QBW. Studies conducted so far on QBW were mainly concentrated on wave reflection and wave forces on impermeable QBW. Therefore it is necessary to carry out detailed studies to investigate the various hydrodynamic performance characteristics of emerged perforated QBW.

II. EXPERIMENTAL INVESTIGATIONS

The physical model study for regular waves was conducted in a two dimensional wave flume at National Institute of Technology, Karnataka, Surathkal, Mangalore which is 50 m long, 0.71 m wide and 1.1 m deep (Refer Fig.1). Waves of height ranging from 0.03 m to 0.24 m heights and periods from 1.0 sec to 3.0 sec can be generated with this facility. To simulate the field conditions of wave height, period and diameter of perforation by application of Froude’s law (Hughes, 1993) a geometrically similar model scale of 1:30 was selected for the present experimental investigations.

![Fig.2 Longitudinal Section of Wave Flume (Not to Scale)](image)

For the experimental studies QBW models of radius \( R = 0.550 \) m and S/D ratio equal to 4 is selected for the study. The model dimensions are selected to satisfy the condition that the model will be emerged at all water depths (\( d = 0.35 \) m, 0.40 m and 0.45 m) and remains non-overtopped under all wave conditions.

![Fig. 3 Cross section of Sea side perforated QBW](image)

The proposed model of QBW consists of two parts, the bottom concrete slab and the top quarter circle shaped caisson (Refer Fig. 2 and Fig. 3). Galvanized Iron sheet of 0.002 m thickness was used to fabricate the quarter circle caissons of radius 0.55 m, 0.575 m and 0.60 m. The sheet is fixed to the slab with the help of stiffeners made up of flat plates of cross section 0.025 m x 0.005 m. The model is then placed over the rubble mound foundation of thickness 0.05 m and stones weighing from 50 gm to 100 gm.

III. EXPERIMENTAL RESULTS

The data collected from the studies was expressed as non-dimensional parameters. The variation of reflection coefficient \( K_r \), relative wave runup \( R_u/H_i \) and relative wave rundown \( R_d/H_i \) for varying incident wave steepness \( (H_i/gT^2) \), relative water depth \( (d/H_i) \) was analyzed separately by plotting non-dimensional graphs.
Figure 4 shows the variation of $K_r$ with $H_i/gT^2$ for different water depths with radius of breakwater constant ($R = 55$ cm) and S/D ratio equal to 4. The values for $K_r$ increases with increase in $H_i/gT^2$ for all values of $d/h_s$ and S/D=4. Considering all values d/h, and for breakwater radius of 55cm, the reflection coefficient, $K_r$ varies from 0.2090 to 0.3780 for $6.24x10^{-4} < H_i/gT^2 < 6.4x10^{-3}$. The highest value for $K_r$ observed was 0.3780 at a wave height of 0.12 m and a wave period of 1.4 s ($H_i/gT^2 = 6.241 \times 10^{-3}$) and at water depth equal to 35cm ($d/h_s$, equal to 0.569). The lowest $K_r$ observed was 0.2090 at a wave height of 0.03 m and a wave period of 2s ($H_i/gT^2 = 7.645 \times 10^{-4}$) and at water depth equal to 45cm ($d/h_s$, equal to 0.732).

Figure 5 shows the variation of $R_u/H_i$ with $H_i/gT^2$ for different water depths with radius of breakwater constant ($R = 55$ cm) and S/D ratio equal to 4. The values of the relative runup, $R_u/H_i$ varies from 1.140 to 2.552 for $6.24x10^{-4} < H_i/gT^2 < 6.4x10^{-3}$. The maximum $R_u/H_i$ observed was 2.552 at a wave height of 0.03 m and a wave period of 1.8 s ($H_i/gT^2 = 9.439 \times 10^{-4}$) and at water depth equal to 35cm ($d/h_s$, equal to 0.569). The minimum $R_u/H_i$ observed was 1.140 at a wave height of 0.09 m and a wave period of 1.2s ($H_i/gT^2 = 6.3710 \times 10^{-4}$) and at water depth equal to 45cm ($d/h_s$, equal to 0.732).

For water depth equal to 45cm and QBW radius equal to 55cm, the maximum value for $R_u/H_i$, was 1.739 at a wave height of 0.03 m and a wave period of 1.8 s ($H_i/gT^2 = 9.439 \times 10^{-4}$). At the same water depth, the minimum value of $R_u/H_i$ obtained was 1.140 for $H_i/gT^2 = 6.371 \times 10^{-4}$. 

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Fig. 4 Influence of $H_i/gT^2$ on $K_r$ for S/D=4 and at different water depths

Fig. 5 Influence of $H_i/gT^2$ on $R_u/H_i$ for S/D=4 and at different water depths
For water depth equal to 40cm ($d/h_s$ equal to 0.650), the maximum value for $R_u/H_i$ observed was 2.139 for $H_i/gT^2 = 9.439 \times 10^{-4}$. The minimum value of $R_u/H_i$ obtained was 1.402 for $H_i/gT^2 = 6.371 \times 10^{-3}$. At a water depth equal to 35cm ($d/h_s$ equal to 0.569), the maximum and the minimum value for $R_u/H_i$ observed was 2.552 and 1.715 for $H_i/gT^2 = 9.439 \times 10^{-4}$ and $6.241 \times 10^{-3}$ respectively. As water depth increases from 0.35 m to 0.40 there is a reduction in $R_u/H_i$ by 16.18% to 18.25%. When water depth increases from 0.35 m to 0.45m there is a reduction in $R_u/H_i$ by 31.85 to 33.53%.

For $S/D$ equal to 4, the maximum value of $R_d/H_i$ observed was 1.2643 at a wave height of 0.03 m and a wave period of 1.6 s ($H_i/gT^2 = 1.1946 \times 10^{-3}$) at water depth equal to 45cm ($d/h_s = 0.732$). The maximum value of $R_d/H_i$ observed was 1.0350 at a wave height of 0.03 m and a wave period of 2.2 s ($H_i/gT^2 = 6.318 \times 10^{-4}$) and at water depth equal to 40cm ($d/h_s = 0.650$). The maximum value of $R_d/H_i$ observed was 0.8549 at a wave height of 0.03 m and a wave period of 1.8 s ($H_i/gT^2 = 9.439 \times 10^{-4}$) and at water depth equal to 35cm ($d/h_s = 0.569$).

### IV. CONCLUSIONS

The reflection coefficient, $K_r$, increases with increase in $H_i/gT^2$ for all values of $d/h_s$. The minimum $K_r$ observed was 0.5054 for QBW of radius equal to 55cm at $H_i/gT^2 = 9.439 \times 10^{-4}$ and at water depth equal to 45cm ($d/h_s = 0.732$). The non-dimensional reflection coefficient $K_r$ decreases with increase in water depth ($d/h_s$). With respect to a water depth of 35cm, the maximum percentage reduction in $K_r$ was observed at 45cm water depth and was found to be varying from 17.35% - 19.27%, for QBW of radius equal to 55cm. When the wave steepness increases, the waves will be of short wave period which will result in the interaction with QBW for short period causing lesser dissipation of wave energy and hence higher values for $K_r$. Also at higher water depths, the curved face of the QBW is more subjected to wave action causing more dissipation of wave energy and hence lower $K_r$ values.

The relative wave run up, $R_u/H_i$ and the relative wave run down $R_d/H_i$ decreases with increase in $H_i/gT^2$ for all values of $d/h_s$. For QBW of radius equal to 55cm, the maximum value for $R_u/H_i$ observed was equal to 3.870at $H_i/gT^2 = 7.645 \times 10^{-4}$ and at water depth equal to 35cm. The maximum value for $R_u/H_i$ observed were 1.904 at $H_i/gT^2 = 7.645 \times 10^{-4}$ and at water depth equal to 45cm for QBW of radius equal to 55cm. When wave steepness increases, waves of short wave period has less contact with curved face of QBW therefore most of the wave energy is dissipated and less energy.
In the present research an attempt has been made to find the hydrodynamic performance characteristics of emerged QBW which includes reflection, wave runup and rundown. Therefore the research can be extended to find the numerical modelling using the same parameters.

REFERENCES

[1] ArkalVittalHegdeandRavikiran, L. (2013). Wave-Structure Interaction for Submerged Quarter-Circle Breakwaters of Different Radii - Reflection Characteristics. World Academy of Science, Engineering and Technology, Volume 7, No.7, pp. 1312-1316.
[2] Dattatri, J. (1993). “Waves off Mangalore harbour-west coast of India.” Journal of Waterway, port, coastal, and Ocean Engineering. Volume 99 No.2, pp39-57.
[3] Gu, H., Jiang, X.L. and Li, Y. (2008). Research on hydraulic performances of quarter circular breakwater. Chinese-German joint Symposium on Hydraulic and Ocean Engineering, Darmstadt, Aug., 24-30.
[4] Hughes, S. A. (1993). Physical models and Laboratory techniques in Coastal Engineering. Advanced series on Ocean Engineering, World Scientific, Singapore.
[5] Issacson, M. (1991). Measurement of regular wave reflection. Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, 117(6), pp553 –569.
[6] Jarlan, G.E. (1961). A Perforated vertical wall breakwater. The Dock and Harbour Authority,41(486), pp394-398.
[7] Jiang, X. L., Gu, H. B. and Li, Y. B. (2008). “Numerical simulation on hydraulic performances of quarter circular breakwater”, China Ocean Engineering, Volume 22 No.4, pp 585-594.
[8] Luwen, Qie., Xiang, Zhang., Xuelian, Jiang and Yinan, Qin. (2013). “Research on partial coefficients for design of quarter-circular caisson breakwater.” Journal of Marine Science and Application, Volume 12, pp65-71.
[9] SHI Yan-Jiao.,Mi-ling, W.U., Jiang, X., and Li Yan-bao. (2011). “Experimental researches on reflective and transmitting performances of quarter circular breakwater under regular and irregular waves.” China Ocean Engineering, Volume 25 No.3, pp469 –478.
[10] Xie, S.L., Li, Y.B., Wu, Y.Q and Gu, H.B. (2006). “Preliminary research on wave forces on quarter circular breakwater.” Ocean Engineering, Volume 24 No.1, pp14-18.