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Research paper



Investigation of Wave Overtopping from Various Geometrical Configurations of Coastal Breakwater Ramps

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Abstract

Breakwater is often required for erosion protection. The effectiveness of breakwater structure as a coastal defence could be determined through overtopping wave surpass onto its crest freeboard structure. The common design practice of breakwater structure is using a linear ramp configuration. There is still a limited knowledge on the contribution of various configuration ramps shape into breakwater efficiency. Thus, this study attempts to investigate a few other's configuration of ramp geometries through overtopping discharge rate performance and identified its relationships with the crest freeboard. Three configurations of ramp geometries (convex, concave and cubic) have been investigated using numerical simulation of CFD-Flow 3D software. The result indicates that, there are significant influences of ramp configuration parameters on the overtopping rate and the highest overtopping rate is contributed from cubic shape ramp geometry. It is recommended that the detail study on cubic ramp shape geometry for determining its capability in increasing overtopping rate.

Keywords: *Overtopping Wave; Breakwater Ramp; CFD-FLOW3D.*

1. Introduction

Many sandy beaches around the world globally are eroding due to the nature characters of waves and threaten to population around the coastal area. Countermeasures against beach erosion include beach nourishment, sand bypassing, groins, detached breakwaters and rubble mound breakwaters [1]. The rubble mound breakwater is the most popular built along the coast to reduce the impact of waves. It has advantages of environmental friendly and the least optical interference with the aesthetic value of coastal landscape [2].

The consideration on overtopping wave over the rubble mound breakwaters is an important aspect in determining the effectiveness of breakwater structure as a coastal protection. Numerous researchers have contributed in the investigation of physical and theoretical overtopping models. In [3] has introduced the prediction model of overtopping wave from his experimental result of impermeable, smooth, rough, linear ramp and beamed slope breakwater. Then, it has been extended by [4-5] who concerned on rock armoured, impermeable, slope with crown wall and tetrapod structure. While, at the same time, in [6] has compared the geometrical configuration of seven different sea wall/revetment designs and produced a slightly different prediction model associated [3]. The current researchers [7] has extended the models ability by includes the effect of rock armoured rather than impermeable and permeable slopes with crow wall and followed by [8] who manages to study the overtopping wave on vertical wall. Meanwhile, in [9-13] who can be classified as an expert on overtopping wave extremely studies on few overtopping parameters including rock armoured, smooth slope, roughness slope, vertical wall, linear ramp and etc. The review in this part has indicated that, the importance of overtopping wave over the breakwater performance. Most of them had focus on the breakwater structures, types, materials and permeability parameter. There is a little information on the contribution of breakwater ramp shape configuration over the overtopping discharge performances.

The attention on ramp shape geometrical configuration could only be discovered from research articles of the breakwater for energy purposes. It includes [14] who applies blow JET ramp to increase overtopping wave for TAPCHAN wave converter, in [15] highlights in his overtopping wave energy device test at concave ramps provide a higher protection compared to linear and convex ramps. In [16] also present the contribution's shapes of ramps on the overtopping discharge and suggested for further investigate to study on the ramp shape's parameters both for energy and costal field. Therefore, a solid understanding of the interaction between overtopping waves and ramp's shape is thus vital, especially in ramps with relatively crest freeboards which are more commonly presented. Consequently, the objectives of this study will be emphasized to compare overtopping discharge over the various ramp shape designs such as linear, convex, concave and cubic configuration and identify its relationships with crest freeboard by using current CFD method.

2. Methodology

The Computational Fluid Dynamic (CFD) namely Flow-3D software was used in this study. It is based on the Reynold Average Navier-Stokes (RAN) equation and designed for turbulence simulation together with Volume of Fluid (VOF) for free surface computation tracking methods [17]. The advantages of this method are cheaper and faster solution compared to experimental model [18]. It has been progressively used for investigating the hydrodynamic behaviors and structural design performance, mostly in the aspect of wave overtopping discharges [19-23]. The pioneer in this technique, [22] who mostly studied on the reliability of Flow-3D as a design tool by investigating an interaction between wave motion (regular and irregular waves) with several types of coastal struc-

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tures. The method had also been used by [20, 24] who studies the reliability of 3D numerical simulation over the structure response and overtopping wave of rubble mound breakwater. Thus, it is proved the reliability of approach used in this study. The work-flow diagram for this study is given in Fig. 1.

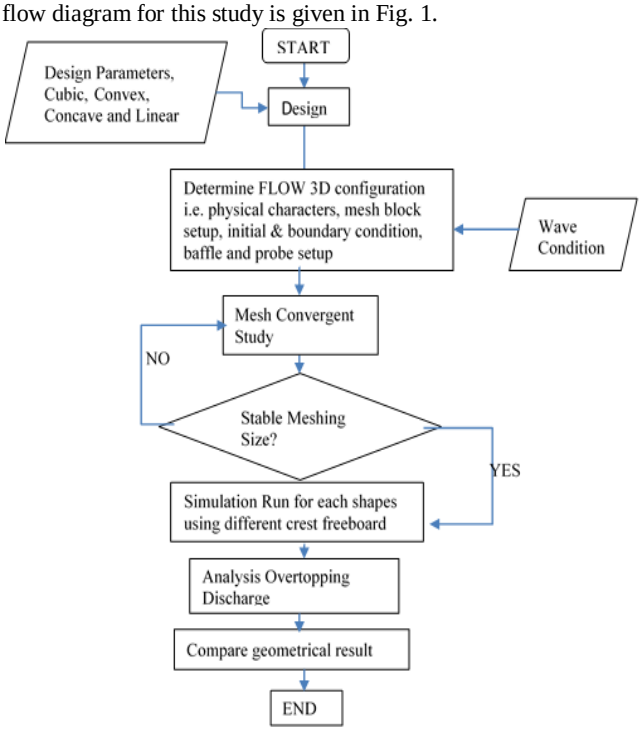


Fig. 1: Workflow diagram

Breakwater design has been divided into two main layers; armor rock structure, which located from the bottom of the breakwater to ramp and continue with ramp into the crest of breakwater (Fig. 2). Four types of geometrical configuration of ramps shapes namely as concave, convex, cubic and linear were investigated. Five crest freeboard (*Rc*) in range of 1.2m to 2.4m were chosen in order to cover the most possible effects of overtopping wave. A constant angle ramp of 19 degrees was kept based on traditional breakwater design; horizontal length (*L*) of ramp is constant setup to 11.1m, whereas height of ramps (*R*) is varied as shown in Fig. 2 and Fig. 3.

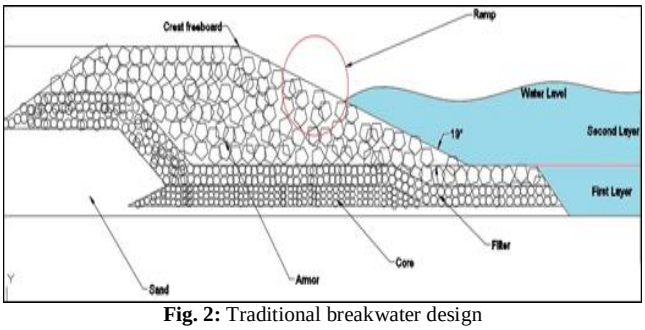


Fig. 2: Traditional breakwater design

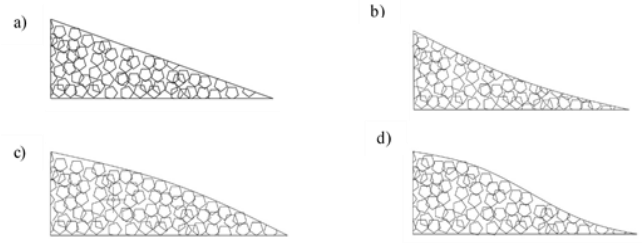


Fig. 3: Ramps shape parameter (a. linear, b. concave, c. convex and d. cubic)

A scale of 1:15 was used in numerical simulation set up based on typical of previous experiment arrangement. Numerical wave flume was prepared consists of lengths 1m, 25m, 1.5m in x, y and z direction respectively. The slopes are setup with zero degrees for a distance of 6.5 m towards with a 1:98. The computational domain is divided into two sub-domains; coarse mesh block domain represents sea water and fine block domain indicating structural geometry as shown in Fig. 4. Mesh convergence studies have been conducted by using seven meshing parameters to estimate the most appropriate meshing sized in order to reduce computational burdens (Table 1). The ratio between fine and course mesh is 1:2 as suggested by FLOW 3D inventor.

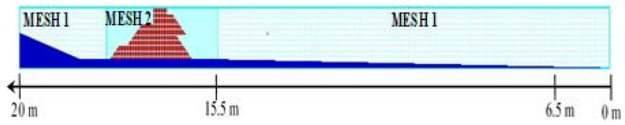


Fig. 4: Computational boundary and meshing setup

Table 1: Mesh convergent study parameters

	Fine (Mesh Block 1)	Coarse (Mesh Block 2)	Ratio	Average O/T Discharge (m^3/s)
B1	0.01	0.02	1:2	0.07
B2	0.009	0.018	1:2	0.309
B3	0.008	0.016	1:2	0.319
B4	0.007	0.014	1:2	0.366
B5		0.012	1:2	0.386
B6	0.005	0.01	1:2	0.385
B7	0.004	0.008	1:2	0.39

Three history probes were used; at the toe of the breakwater, middle and at the wave generator. The probe setup location is based on the suggestion by [17]. The incident and reflected spectra were determined using the approach of [25]. The Pierson Moskowitz wave spectrum (random waves) with 10m/s of moderate breeze wind speed based on Beaufort scale was used in this study as a wave input data. The wave containing approximately 100 waves with range of H_{mo} (1.5m to 2.4m).

The boundary condition was setup by using domain block contains virtual waves flow and outflow in y direction, symmetry in x and pressure boundary z direction. The details of boundary conditions setup are shows in Fig. 5.

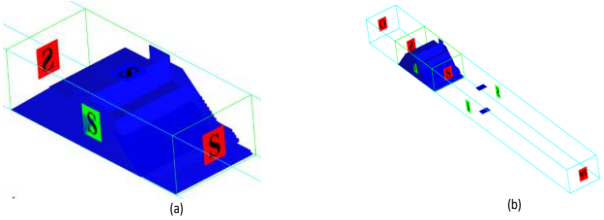


Fig.5: Boundry condition on: (a) the OBREC mesh block. (b) the wave flume mesh block

A series of 20 (4 model x 5 crests) numerical simulations cases were carried out by using several machines built with Processor Type Intel(R) Core(TM) i7 CPU, 2.67GHz with the RAM capacity is 16Gb. The outputs of simulations are then being analyzed using general accepted equations for presenting overtopping wave in costal engineering. It could be expressed in (1) and (2).

$$q^* = \frac{q}{\sqrt{g.H_{mo}^3}} \quad (1)$$

$$Rc^* = \frac{Rc}{H_{mo}} \quad (2)$$

where q* is non dimensional overtopping discharge, q denotes for overtopping wave (output simulation), H_{mo} is wave height at the toe of structure while Rc and Rc* are crest freeboard and its non-dimensional respectively.

3. Results and Discussion

In this research, the results from the analyses are compared through the qualitative observation on the graphs as regards to a

similar trend within the aspects of data distribution, gradient of the graph, correlation between the variables, trend line, etc. There are two main part has been separated as indicated in previous section; which are preliminary of mesh convergent study and comparison of various ramp shapes configuration.

3.1. Mesh Convergent Result

Mesh convergence analysis has been done using seven meshing parameters to estimate the most appropriate meshing size. Fig. 6 shows the result of volumetric of overtopping discharge over simulation time, while Fig. 7 is average overtopping against fine mesh size.

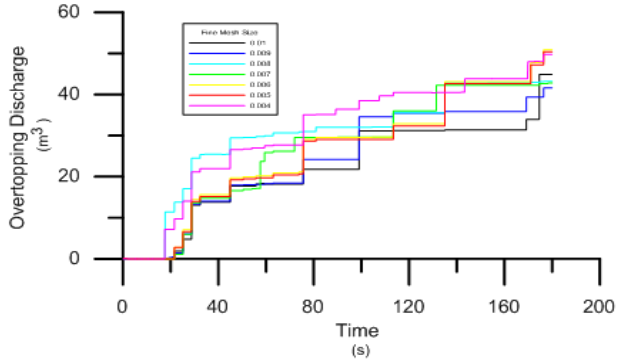


Fig. 6: Time series of mesh convergent study

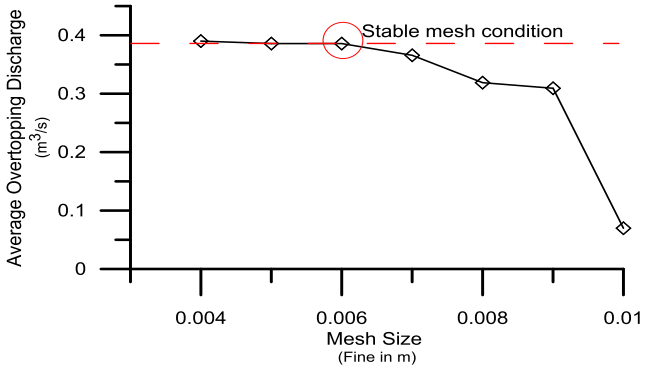


Fig. 7: The most suitable mesh sized

The result shows that the changes of mesh size give a crucial impact to the overtopping output. The smaller mesh size will run up more water to overtop compare to bigger mesh. It demonstrated the smaller mesh size gives a batter result accuration, where more precisions of calculation are made it. However, the smaller mesh size will increase CPU running time and sometime it is impossible for run the program with low computer specification. Therefore, the nearest mesh size at stable condition (0.006) is selected for further analysis.

3.2. Comparison between Various Ramps Configuration

Typical numerical simulation results of 2D-dimensional and 3D-overtopping compared as shown in Table 2. An incoming wave approaches the device from the right side as shown in Fig. 7 (a) and 7(b). While, Fig. 7(c) displays the wave is piling up and breaking. The water then quickly runs up over the device ramp. Finally, overtopping occurs when the flows pass over the crest freeboard. The processes are consistently with the wave behavior obtained by most of the previous researchers such as [26-28] who has presented the wave activities in the same manner.

Table 2: Snapshot comparison overtopping wave of various ramp shape

Ramp Shape	Fig. 7(a)	Fig. 7(b)	Fig. 7(c)
Linear			
Convex			
Concave			
Cubic			

The snapshot also illustrated that there are few major factors, which possibly affected the overtopping wave. The main finding is due to wave run-up energy carried by each shape. It can be seen in a cubic image snapshot which has brought a larger volume (high mass) than any other shapes. At the same time, the volume was pushed by wave velocity, and indirectly creating a higher mass momentum or energy. This has consistently with the finding by [29] who stated that the massive mass momentum would increase run up or overtopping wave. It also has been quotes by the study of [30-31].

Meanwhile, Fig. 8 shows non dimensionless overtopping comparison of all ramp shapes. The graph shows that as the crest freeboard is increased, the overtopping rate declines and vice versa. Based on the coefficient of determination, R^2 in statistical modeling Linear shape has shown 96% of the variation in non-dimensional average overtopping discharge associated with variation in relative crest freeboard, R_c^* and whilst cubic, concave and convex have 98%, 76% and 78% variation respectively. It indicates that both regression lines of the simulated results of all ramp shapes is fitted with the simulated result.

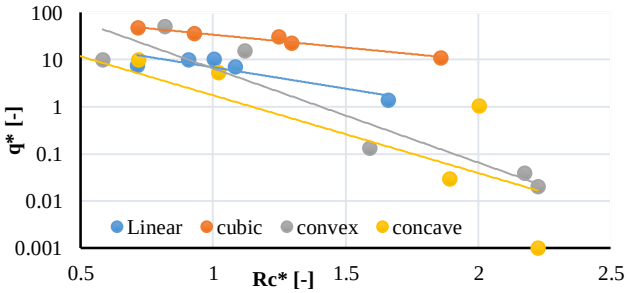


Fig. 8: Non dimensional overtopping discharge of various ramps

Moreover, in comparison by the different ramp shapes, shows the cubic shape has given the higher overtopping rate compared to other shapes for every changes of crest freeboard height. It was demonstrated that cubic shape is a good shape for absorbing transition wave but incompatible for reflecting the wave to the sea, thus it probably unsuitable for coastal protection. Meanwhile, linear and convex ramps result show a lower overtopping rate than cubic shape. The graph shows at lower crest convex give higher overtopping compare to linear but it changes when a crest become larger. At lower crest, the gradient of convex shape at sea level is small; this allows the wave overtop into the structure as much as possible, however, at large crest the gradient will become higher and it indirectly will decrease overtopping. This situation is slightly different with linear ramp where, the gradient of its geometries is consistent for every change in crest. The concave shapes result express that, it has given a lower overtopping wave compare to other shapes. This proved that concave shape is the most suitable shape for reflecting wave to the sea which similar with the suggestion from many researchers [32].

A clear comparison of average overtopping wave over different ramp shape configuration was also be presented in Fig. 9. It demonstrated that cubic shape gives up to three times more overtopping compare to linear, which indicate it may not be suitable for reflecting wave to the sea, convex 21% and concave 71% respectively lower than linear ramp.

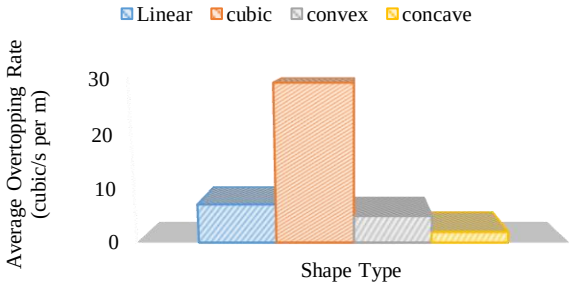


Fig. 9: Average overtopping discharge for different shape

In overalls, the comparison of ramps shape was indicated that the cubic shape is the highest configuration for overtopping wave. Among of reason for this finding are due to accumulation of wave run-up energy, which provides a large platform for gathering the volume of water. It indirectly increases mass momentum of run-up wave above the ramp shape. This is supported by [32] manual assessment, which indicates the same matter concerning the influences of a curved dike breakwater into wave overtopping. Thus, it is suggested to detail study on cubic ramp shape geometry for tackle coastal protection and energy problems.

4. Conclusion

In this paper, four shapes of breakwater ramp have been investigated using CFD. The comparison of overtopping wave between each shape over crest freeboard indicated that concave shape had been smaller overtopping wave and indirectly reflecting more water to the sea. While, cubic shape had amazing higher overtopping wave result which up to 3 times compared the linear ramps. It shows more water will be passing through the breakwater, thus it may good opportunities for energy researchers to take a benefit from that water waste. The convex and linear shape result shows in the middle between cubic and concave. It proved that the practical application for protective breakwaters construction did not use the optimal shape for reflecting the wave to sea. Therefore, it is strongly suggested for further investigation to take into account the shape parameters for developing more protective breakwaters.

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