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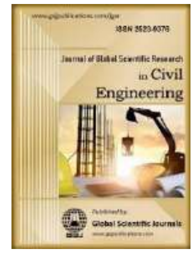

CFD Simulation of Waves over Mound Breakwater

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ABSTRACT

The action of waves, which is considered to be one of the most hydraulic phenomena that have been covered by history, hits the stones or any concert blocks that formed breakwater, which caused the development of breakwaters to become necessary so that an equilibrium shape could be achieved by filling the voids with more stones. In light of the difficulty of the experimental work and the increased expense of the models, it is imperative that numerical simulations using CFD methodology be researched in order to demonstrate the capability of the Flow 3D software to represent the wave behavior over mound breakwater with three types of inclination angle (30,45 and 60) degree for submerge state with head 6 cm above crest. The findings demonstrate an advancement in that the Flow 3D program is now able to produce and simulate the behavior of waves for varying heights and times.

1. Introduction

Studies conducted using a variety of simulation programs have contributed the lion's share to the current body of research on the use of CFD to breakwater modeling. The findings of these investigations, which used FLOW 3D to model a variety of different hydraulic structures, indicated a reasonable concordance with the experimental data and the conventional design guidelines. However, there are many other kinds of software packages that are used to model the flow through breakwater and study its hydraulic behavior. These comprise of information on the effective applications of CFD software and Fluent software, as well as comparisons of CFD and Fluent. In the earlier researches that deal with hydraulic issues, FLOW 3D and Fluent were considered to be effective applications for advanced problems involving fluid-solid interaction when taking into account the significant results that could be supplied. This conclusion was reached based on the findings of those earlier researches.

Grilli et al., 1994, generated the breaking of single waves across breakwaters using a nonlinear potential model in the laboratory. Waves may collapse over the crest, break backward or forward over submerged breakwaters, or do all three depending on the height of the incident wave. In the course of the experiments and tests, wave transmission and reflection coefficients were determined. It was reported that the transmission coefficient increased to reach (55-90) percent across the breakwaters that were submerged. In the case of the submerged

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breakwaters, the nonlinear potential model calculations demonstrate agreement with the laboratory results, particularly for wave heights that are lower. The calculations of this model provide an accurate estimation of the limit of collapse beyond the height of submerged breakwaters.

This numerical model addressed the SKYLLA technique, which was built to mimic breaking waves on coastal buildings. This approach was utilized by Petit et al., 1995, to simulate plunging breakers using the 2D Navier-Stokes equation. The approach known as the Volume of Fluid method is used in the process of solving two-dimensional Navier-Stokes equations. In a computational domain, water waves may enter and exit the domain as a result of a border that reflects light very little; hence, impermeable barriers may be used. When compared to the results of physical model testing for waves on a submerged structure with a 1:20 slope, the findings indicate that the two-dimensional Navier-Stokes equations have successfully simulated waves over a structure with a low crested height.

The SOLA-SURF approach was used by Hayakawa et al., 1999, in order to do a numerical simulation of wave fields revolving around a submerged breakwater in two and three dimensions. For the three-dimensional calculation of the laboratory tank, the results of numerical models should be checked with experimental data, and the non-viscous side wall boundary condition, slip wall type, should be used. The numerical technique demonstrates a realistic application of the issue on the field.

According to Kawasaki's research from 1999, a numerical simulation of the breaking and post-breaking wave deformation process around a submerged breakwater for a two-dimensional wave field in the vertical plane was performed using a model that combined a non-reflective wave generator with VOF approach and dissipation zone with open boundary conditions. In addition to studying wave breaking over a submerged breakwater, the model that was developed looked at the distortion of waves after they broke. In order to verify the reliability of the model, we ran certain experiments in the lab. The height of different incident waves as well as the frequency of wave amplitude are looked at. The findings of both the calculations and the observations demonstrate that a wave-breaking-induced circulating flow arises on the onshore side of the breakwater that is submerged. The proposed numerical wave model is proven to properly mimic wave deformation both before and after wave breaking by comparing its results to experimental data.

The RANS model was used by Hwang et al. (2004) in order to simulate the impermeable submerged double breakwaters and to get an understanding of the behavior of waves advancing, vortex development, and the dissipation that was created. Both the k–e model and the height function may be thought of as representations of turbulent dynamics. The free surface is represented by the height function. the equations that regulate the system were discretized using a limited-volume approach that centers on a grid structure that varied in height and breadth. Initially, a series of recommended numerical solutions were examined and developed analytically; after that, a numerical model was confirmed by part of the experimental data. The findings of numerical models demonstrate an acceptable level of agreement, and these models may be regarded as a potentially cost-effective tool for predicting flow and wave fields near coastal structures.

Hur, et al,. 2008, The researchers utilized a numerical simulation to model the nonlinear interaction between the ocean waves, the bottom, and the submerged breakwater. This allowed them to simulate the effects of varied wave conditions on the nonlinear dynamics of the waves on the submerged breakwater. Laminar flow is used as the flow condition in the numerical modeling of the seafloor so that the resistance of fluid as it passes through the porous material may be controlled. The flow results of wave–seabed–breakwater interaction were examined for cross-section of the submerged breakwater. These findings were exposed to changes in incident wave circumstances as well as changes in pore water pressure. According to the numerical findings, the breakwater was effective in preventing the flow field as well as the volatility.

Hajivalie and Bakhtary, 2009, explore the influence of steepness breakwater on the waves standing and the steady streaming by studying the effect of turbulence based on the (RANS) equations using a 2D numerical model to study the effect of turbulence on the waves. A numerical model known as the k-turbulence model was used, and the method known as the Volume of Fluid (VOF) was used to monitor the form of the free surface waves. The numerical results compared well with the experimental findings about the standing waves caused by the breakwater. In addition to the wall on the vertical axis, such as a 1:2 and 2:1 inclined breakwater, three simulations were built for various types of breakwaters. A constant flow that recirculates the cell over which may be regulating the scouring at the toe of a breakwater is caused by the modest slope that is present.

According to the findings that were presented in Hur et al(2011) .'s study, the results of the research into the effects of slope gradient were as follows: Using a recently developed numerical model, we take into account the flow through a porous medium that has inertial, linear, and nonlinear resistance components. As a consequence of this, the numerical model is able to simulate the interaction between the wave and the bottom for a breakwater that is buried underwater. Within a wave field that is just two dimensions deep, the LES turbulence model computed the eddy viscosity. In a comparison between the model and experimental data, the model was shown to be accurate for predicting the wave deformations that were caused by the rectangular permeable submerged breakwater. When the slope gradient is reduced, the transmission coefficient will drop, and the wave breaking on the submerged breakwater will migrate towards the sea. Additionally, a circulation flow in the counterclockwise direction was produced behind the submerged breakwater.

Uemura (2013) uses numerical simulation to explore the erosion and wave transmission for a submerged breakwater. Breakwaters have been constructed as a solution to these problems in order to decrease the effects of coastal erosion. Additionally, breakwaters have been designed in order to lower both the mean water level and the wave transmission. After performing the spectrum analysis, determining the sea water level, and calculating the height of the waves, the numerical computation in two dimensions was carried out. submerged banks with a large number of vertical impermeable plates were numerically estimated, and then the results produced were compared to the data that was really collected. The planned submerged bank demonstrated a reduction in the transmission of both short and long waves, while also causing a drop in water level behind the submerged breakwater.

In their 2015 study, Hajivalie and colleagues employed numerical modeling to evaluate the impact of vertical breakwater size on the hydrodynamics of waves, as well as the generation of vortices around the breakwater. Two dimensionless parameters, such as Keulegan–Carpenter and the breakwater submergence, have been constructed. The computational model consisted of the k–turbulence model as well as the (RANS) equations and a free surface that was traced using the VOF method. This research used a total of ten distinct models, each of which produced a unique set of values for the submerged breakwater depths. When the a/Hi ratio is increased, the transmission coefficient also rises. A fast rise can be seen in the transmission coefficient for the waves that were analyzed. This design was recommended for the breadth of the breakwater, such that increases in a/Hi would generate reductions in the turbulence intensity on the coastline of the barrier. The ideal a/Hi ratio should have a high energy dissipation rate while also having a shallow scour depth.

Lianga, 2015, studied numerically the transmission wave over double trapezoidal submerged breakwaters utilizing non-hydrostatic wave. The model stated that a non-hydrostatic wave model called SWASH (Simulating Waves until Shore) is utilized to simulate wave transmission. Lianga's research was published in 2015. The findings of the physical model were compared to those of the numerical model; thus, the SWASH model, which is capable of forecasting wave transmission via double submerged breakwaters, was explored, as was the impact of sea current on wave transmission. When the relative submerged depth is maintained at 1.0, the optimal relative breakwater spacing is about 1.11 meters apart. When it comes to component dissipation, super harmonic waves have a greater visibility than lesser harmonic waves do.

Sasikumar, et al., 2018, search numerically the effect of a submerged breakwater for climate change adaptation, as known, mean sea level rise when the climate warming cause more frequent storm occurrences in coastal regions. Sasikumar, et al., 2018, search numerically the effect of a submerged breakwater for climate change adaptation, as known, mean sea level rise when the climate The breakwaters will be subjected to several instances of waves overtopping them, with the height of the incident waves exceeding the design state on many occasions. As a consequence of these impacts, it is possible that they will have an effect on the functioning of the breakwater constructions. To estimate the optimal dimensions of a submerged breakwater that would be operated as a breakwater construction in coastal locations, researchers developed a computer model. The relative changes in the breadth and submergence parameters were explored with different variations in transmission coefficient. According to the findings, a submerged breakwater was rendered ineffective in the instance of Kiberg, Norway, when it was positioned in front of an already existing rubble mound barrier. This model offered the optimal form that should be constructed to safeguard coastal areas, and it was employed by the wave prediction model CGWAVE, which used the finite element approach on a small scale.

Using FLOW 3D software as a computer model for normal waves, Ahmed and Abo-Taha (2019) analyze the hydrodynamic performance of half pipes submerged breakwater along Egyptian beaches. Three various diameters of a precast pipe in the form of a half pipe are utilized to find the relative structural height that provides the optimum amount of energy dissipation. Two of the half pipes are positioned horizontally, while the third half pipe is positioned vertically. The models are then subjected to a numerical analysis in order to compute the wave energy dissipation, transmission coefficient, and reflection coefficient. The findings of the numerical analysis demonstrate an ability to forecast the hydrodynamic performance of half pipe submerged breakwaters. Abd Alall, in the year 2020, conducted research on a numerical model of the hydrodynamic performance of double submerged breakwaters. This model employed precast concrete half pipes submerged breakwater as natural coastal protection, which helped avoid beach erosion along the Egyptian coastline. The split half pipes underwater breakwater were analyzed using a computational model for linear waves implemented in the FLOW 3D program. Using two different models, we were able to estimate the optimal distance between the half pipes that make up the breakwater. The transmission coefficient, denoted by Kt, the reflection coefficient, denoted by Kr, and the wave energy dissipation were all determined using numerical methods. The experimental findings gave their stamp of approval to the numerical results, and those results were utilized to make an estimate of the hydrodynamic performance of submerged half pipes. (Khassaf and Abbas, 2018).

2. Flow 3D Approach

Flow 3D (V.11.2) software for solving cartesian co-ordinates of the Naiver-Stock equations that alternated a grid functions by dividing the flow field into the rectangular-form-groove sub division mesh of the flow in comparatively tiny areas nominated as cells and calculating the numerical flow value. This software was developed by Flow 3D. The development of a suitable mesh domain that responds in an acceptable manner to the behavior of the phenomena is the primary prerequisite for all numerical models. (Al Shaikhlia and Khassaf, 2021). To provide a variety of distinct numerical approximations to the control equations, control volumes are developed in the area around each variable point. Surface fluxes, surface stresses, and body strengths are all able to be estimated in relation to the variable values that are present in the surrounding environment for each control volume. After that, these figures are included into an estimate for the protection laws that the movement equations point to, (Ismaeel, etal., 2021).

Numerical Model Set-Up

The general configuration of the model was very comparable to that of all the controlled breaking wave simulations. On the Global Tab, the following were specified for each example: a fluid, an incompressible flow, and either a free surface or a sharp contact. In addition, the parameters of the fluid were determined for each simulation to be the same as those for water at 20 degrees Celsius. In general, a number of other factors were not altered in any way, and the following sections will be discussed in further detail.

Physics

Even though there are a lot of other physical options available to choose from, there were only two options that required to be active in order to generate correct simulations of the data that was desired for this research. The gravity option was turned on when the acceleration of gravity in the vertical, also known as the z-direction, reached a value of -9.81 meters per second. When Newtonian viscosity and the selection of an appropriate turbulence model were applied to the flow, the option to activate viscosity and turbulence was also engaged at the same time. After the FLOW 3D model has been completely built, and provided that the two-equation (k-w) model has been chosen, just one turbulence model will be applied. According to the remarks in the FLOW 3D user's manual, the option of (k-e) turbulent model is the best model for simulating breaking waves in the program. It is also the best model that is currently available (2007).

Geometry

The preparation for the numerical model geometry was quite different for the other breaking waves that were modeled previously by FLOW 3D. According to the findings that were obtained from the experimental inquiry, the geometry that was used in the simulations was provided in the form of a stereo lithography, or STL, image. This picture was created in Auto CAD and exported in STL format. In the event that the appropriate network is able to be constructed.

As part of this investigation, it was anticipated that the typical value of concrete ruggedness for the flume geometry would be ignored, and the geometry component continued to serve as the default option for all of the models that were developed.

Conditions at the Boundary and at the Beginning

An important and beneficial computer tool is the capacity to perceive the pressure condition on one or more boundaries of the computing domain. This ability may apply to any number of borders. Compact fluid reservoirs, environmental laboratory conditions, and the mechanical pressures that are applied are all considered to be examples of pressure limitations. There are often two different kinds of pressures, which are referred to as static or stationary pressures. In a case when nothing is moving, the pressure on both sides of the border is more or less continuous, and a value that is based on a typical zero derivative condition on both sides of the border is assigned to the speed that is allowed on the limit. There are several sorts of flow issues that may benefit from more optimal outflow boundary conditions. For instance, particular boundary treatments have been created for wave spreading problems. These therapies try to detect the speed and direction of waves approaching the boundary and then set boundary conditions in such a way as to allow for the minimal amount of reflection over the border. An early and effective instance of this kind of treatment, which is also frequently referred to as a radiation limiting condition (Orlanski, 1976).

The Boundary Conditions of the Turbulence Model

Other cell-centric factors, such as density, are taken into account in conjunction with the energy of turbulence and the dissipation functions at all borders, with the exception of rigid barriers that prevent sliding. Due to the fact that there are zero-speed derivatives across the frontier, there are no special conditions that must be satisfied at symmetry limits. This results in the generation of no turbulence. There is also a zone with zero flow, which means that neither advective nor diffusive flows are guaranteed to take place there. In spite of this, particular considerations are necessary for stiff, non-slip borders, since the numerical resolution is often not high enough to accurately fix the characteristics of a laminar border layer region. The wall shear-stress model was constructed with the assistance of a turbulent velocity profile. Determining the wall limits for the turbulence energy and the dissipation of turbulence functions is necessary in order to maintain consistency.

In spite of the FAVOR approach, which allows solid walls to be sliced across a mesh cell at any angle, it is not clear how these restrictions may be satisfied. Consequently, one ought to use this strategy. Turbulence energy and dissipation values are defined for every cell that has either a partially blocked or completely blocked no-slip, rigid border. The Wall boundary values are determined by starting with an assumed velocity profile (an approximation of the logarithmic law), and then proceeding with the assumption of a local balance between turbulent production and decay processes.

Boundaries of the Free Surface

The normal stress and the requisite pressure, condition on the free surface, are both satisfied by the pressure setting methodology that is provided in the Incompressible SOR method (Only single fluid problems have free-surface boundaries requirements). All speed derivatives that include components of velocity that are outside the surface are null, which results in the free-surface tangent stresses having a value of zero. However, fluid advection should be carefully taken into mind, and speeds should be changed at every cell line between surface cells and empty cells. This may be accomplished in two steps. First, the value for each speed component on a side close to the empty cell is assigned to the opposite face of the surface cell where the empty cell is located. During the second step, the surface cell will have a virtual adjustment made to it in an effort to bring the velocity divergence of the cell down to zero. Only the speeds are altered in this method on the sides of the operation that are open for empty cells. Due to the fact that the correction is likewise proportional to the percentage of fluid that is contained inside the cell, the divergence in cell velocity cannot be reduced to zero.

The aforementioned constraints are enforced such that the flow is guaranteed to be made up of internal obstructions. The construction of appropriate boundary conditions has a considerable impact on the degree to which the outcomes of the numerical model reflect the real-world situation that was tried to be replicated. In this particular scenario, the data from surface free fluxes were requested in the mesh block (1), and as a result, the top boundary was defined as atmospheric pressure, while the bottom border was defined as wall. In order to get an accurate representation of the channel bed, the bottom boundary of the model's geometry was moved so that it was just below the input form, and the top edge was moved so that it was just above the highest water level in either the vertical or the z-direction grid.

In order to make the simulation equivalent to the experimental work, the change in mean water depths and wave heights was created by determining the upstream limit as a given stress with a fluid height. This was done in order to make the simulation more accurate. The simulation also chose to set the downstream border to wall; however, various additional boundary choices, such as defined wave with specified length and height, this wave options selected under the limits of Fourier series method, and the solution of Stokes and Cnoidal, were provided in the software that was used in the upstream boundary. These choices were provided by the software that was used in the upstream boundary. In the y-direction, a symmetry option for the mesh has been updated with several new settings. (1) The starting condition was defined as the fluid area at the top border of the mesh, and at the same boundary, the hydrostatic pressure was created.

3. Results and Alternatives Derived from Numerical Simulations

As was just discussed, the numerical tab of the FLOW 3D model setup provides users with a diverse variety of options to choose from. These decisions have shown an adaption of the Reynolds equations, which are the primary equations that underlie the FLOW 3D model, into the Navier Stokes (RANS) averaged equations. The bulk of the simulations that have been completed have used the default settings for their choices.

The time step parameters were kept at their default values, and the simulation was able to continue running without crashing with an error message stating that the time step was less than the bare minimum. In order to find a convergent solution for this problem, it was sometimes necessary to use a shorter ending time. Simulations of the pressure resolution using the Generalized Minimum Residual (GMRES) method with the settings left as they were. An explicit solution is progressively resolved in each computer cell by stepping over time, but the time step is constrained to meet the stability constraints. This is how simulations were traditionally completed off by the default explicit solver settings. Implicit solution carried out at each stage by making use of prior knowledge of a different phase; this method does not impose any time limits but requires iterative or matrix solutions that are more precise. The majority of simulations were run with a default button selected in the volume of fluids advection section of the Numeric tab. This allowed the software solver to pick the single fluid free surface option automatically, based on the parameters that were specified in the global tab. The results of the final simulation model are shown in figures 1,2 and 3 for turbulent energy and maximum flow depth. This information can be found in the 3D handbook of FLOW 3D users (2007). All simulations were also performed during solution of both continuity and momentum equations and with first order momentums.

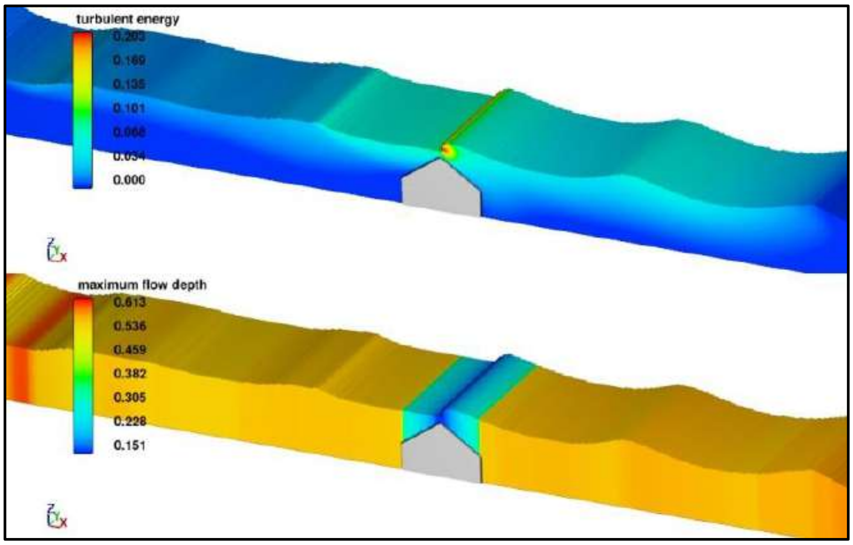

Figure 1: FLOW 3D results in three dimension for 30 degree inclination.

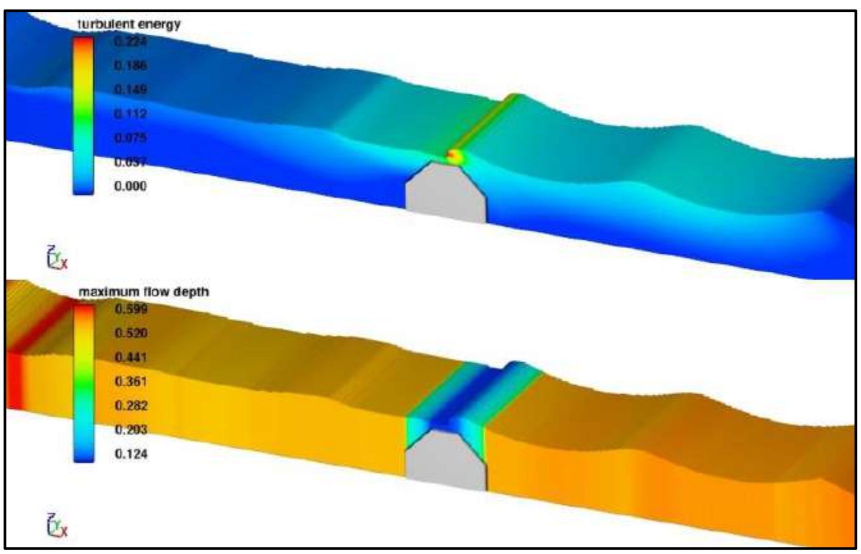

Figure 2: FLOW 3D results in three dimension for 45 degree inclination.

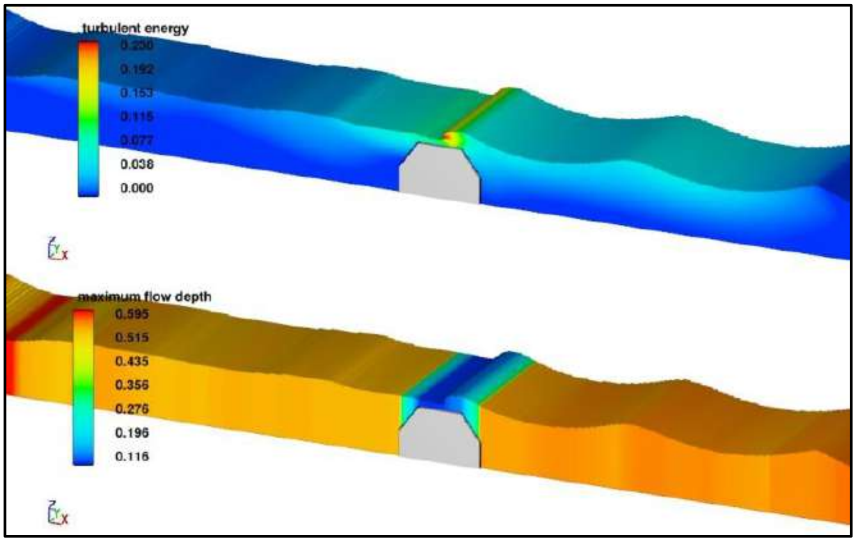

Figure 3: FLOW 3D results in three dimension for 60 degree inclination.

4. Conclusions

The numerical simulation of wave behavior based on Flow 3D choices and the Fourier series method reveals an increase in the Flow 3D software's ability to create waves and their breaking behavior with varying heights and periods since the CFD methodology was utilized. FLOW 3D Software version 11.2, as a simulation tool, has the ability to study, identify and simulate all breaking waves models over breakwaters under all conditions that difficult to investigated at lab. So that, the increase in side inclination degree cause an increase in wave transmission coefficient for height of wave (6) cm, until the shutdown point occur at head more than or equal (10) cm above breakwater crest.

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