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(RESEARCH ARTICLE)

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Effect of wave height on harbor wall height in coastal waters using computational fluid dynamics

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Abstract

An essential aspect of the sustainable design of harbor walls is the determination of the design wave condition. It is predicted by utilizing severe wave conditions from the past 10 to 20 years. The tourism harbor in Central Maluku, Indonesia, is located where extreme wave conditions occur. Therefore, this research studies the wave height before and after constructing a harbor wall in the harbor area. The wave height was simulated using numerical modelling. The methodology was performed by using the coastal modelling software of the CFD model. The result shows the highest design wave height values of 0.5 m, 0.75 m, and 1 m in the direction from the southeast to harbor height 1 m. The simulation results show that the wave height is 1.5 m and the harbor height is still safe. Further study is needed to simulate the extension of harbor wall length to meet the criteria for wave height in the harbor basin.

Keywords: Wave height; Harbor Wall; Wave Modelling; CFD; Central Maluku

1. Introduction

Indonesia is the world's biggest archipelagic country consisting of five large islands and thousands of small islands, and 70% of the territory is ocean. Various activities on seas, either for sea transportation activities, fisheries, marine resources exploration, and also development in marine sector are very sensitive to weather and sea condition changes. 260 cases were due to natural factor which increased with years [1]. Among various natural factors, one that greatly influences marine activities is wave, and therefore, in the marine meteorological services, in addition to wind information, wave information is the most important part that should exist in every kind of marine weather information [2,3]. The existence of extreme high tides could threaten the safety on sea and may result in great losses

When the waves approach the shoreline, a wave transformation occurs due to shoaling, refraction, and diffraction. Shoaling occurs when the water depths are less than half of the wavelength and causes a reduction of wave velocity. Refraction is a change of the direction of the wave that occurs when the wave velocity is reduced and the wave becomes more aligned with the depth contours. Diffraction occurs when a wave propagates into an obstacle such as harbor walls and travels to the area behind it [3,4]. The extreme wave condition at tourism harbor, Cetral Maluku, disrupts passengers' loading and unloading and has a safety concern. A harbor wall facility can protect the harbor area by reducing the extreme wave height [5].

Many studies have been conducted about harbor wall reducing a wave height by different location studies and different types of harbor wall specifications. Each study has its limitations [6,7,8], while an analysis facing directly to the Indonesian Ocean with a double non-overtopping harbor wall is not much studied earlier.

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Figure 1 Conditions in the Tulehu Harbor area, Salahutu District, Central Maluku Regency, were damaged by tidal waves and floods

This study aims to analyze the reduction of the extreme wave condition at the harbor area at eastern Maluku by creating a wave simulation with the condition before and after the harbor wall construction. A CFD model can simulate the characteristics of waves coming towards the shoreline and harbor wall [9]. Therefore, this study used a Surface Modelling System (SMS) using CFD model to create wave simulation for analyzing the wave characteristic around the harbor wall. The result of this study is the wave height that occurs at the harbor area and the percentage of wave height reduction after the construction of the harbor wall.

2. Material and methods

The investigation was conducted numerical analysis for estimating wave height effect using CFD investigation at wall Harbor.

2.1. Model

The particulars model of wall harbor shown in Figure 2 with wall height 1 m. The test was conducted at various wave height 0.5 m, 0.75 m and 1 m.

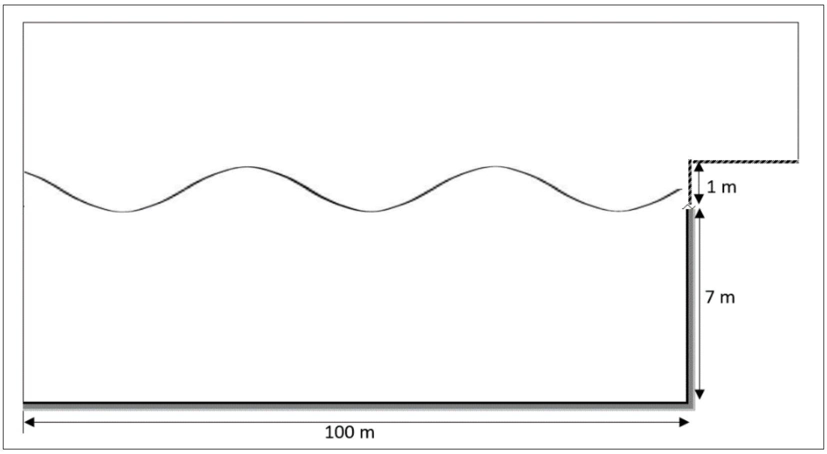

Figure 2 Wave Height effect at Wall Harbor Simulation

2.2. CFD Analysis

Computational Fluid Dynamics (CFD) technique, of a varying degree of complexity, may be used to predict various resistance components. Potential code may be applied to derive the pressure resistance due to inviscid flow characteristics (wave pattern resistance). The boundary layer integral method may be used to estimate the boundary layer growth in areas where separation and circulation do not occur. The method would provide some insight into the pressure form drag. Full Reynolds-Averaged Navier-Stokes (RANS) codes may be used to predict the flow where separation and circulation occur, thus potentially providing good estimates of form factor and possible scale effect; however, these methods are extremely computationally intensive, particularly for the computation of high Reynolds number flow.

The boundary conditions are set as follows as suggested by [10] and [11]. The inlet is defined wall with oscillating motion located at upstream is defined as a uniform flow with velocity equals the wave. The outlet boundary, at a location of downstream is given as that the pressure equals the undisturbed pressure, ensuring no upstream propagation of disturbances. Furthermore, the distance with two sides of boundary is made 10 m and distance of deep water with bottom boundaries is set 7 m. The boundary condition at the hull surface is defined as no-slip boundary and at the (parallel to the flow direction) horizontal and vertical walls bounding the flow domain as free-slip boundary. Details of the description can be seen in Figure 4.

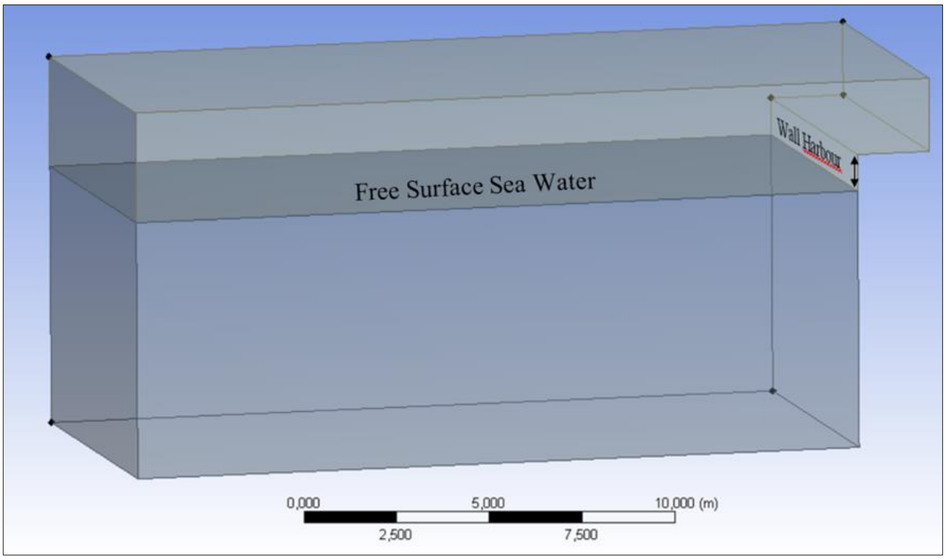

Figure 3 Domain Setting of Wall Harbor Simulation

The choice of turbulence models is found to be very crucial in the simulation of wake fields. The turbulence model used in the current study is the SST (Shear Stress Transport) model and the SST model has been used and validated by several researchers with successful results. The viscous flow field is solved using RANS (Reynolds Averaged Navier-Stokes) solver implemented in ANSYS CFX. The RANS, turbulence k-ε and turbulence SST equations are shown in Equations (1), (2) and (3).

2.3. RANS Equation

$$\rho \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = \rho \bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right] \quad \text{.................................(1)}$$

k-ω, equation

$$\frac{\partial k}{\partial t} + U_j \frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left[(\nu + \sigma_k \nu_T)\frac{\partial k}{\partial x_j}\right] \quad \text{................................ (2)}$$

Menter's SST Equation

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = P - \beta^* \rho\omega k + \frac{\partial}{\partial x_j}\left[(\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_j}\right] \quad (3)$$

3. Results and discussion

The results of the simulation regarding the effect that wave height has on the height of the wall harbor are presented in greater detail in Figures 4-6. In the calm water state, there is no rising water or sea water clashing with the harbor wall, so the water seems peaceful with a height (depth) of 7 meters, as illustrated in Figure 4. When the conditions are like this, it is assumed that the water is in its ideal state because there are no disturbances from the surrounding air or sea currents. The red color indicates seawater fluid, and the blue color indicates air fluid.

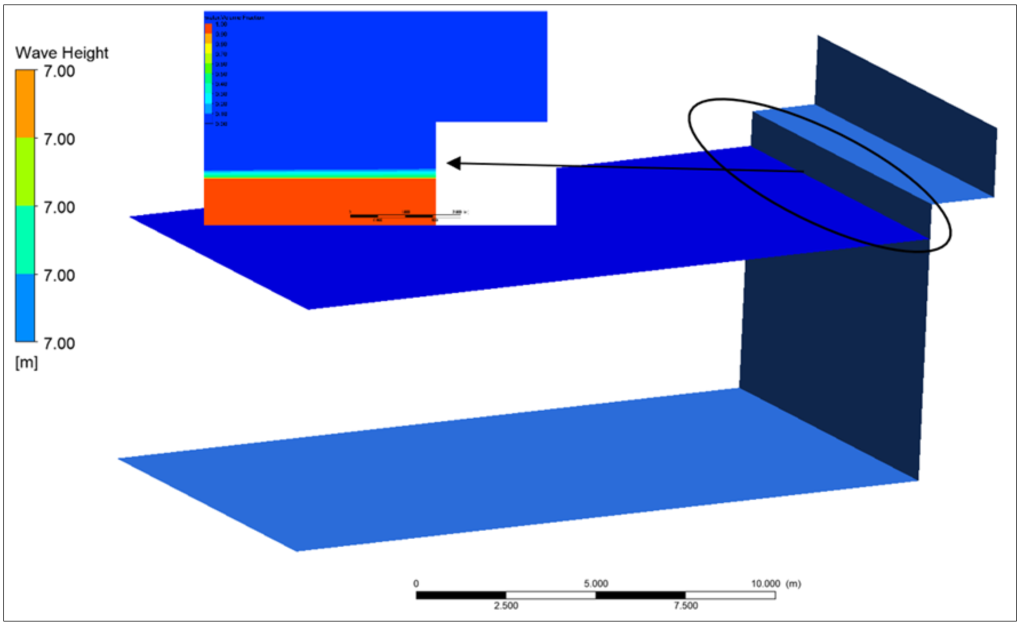

Figure 4 Wave height 0 m (calm Water)

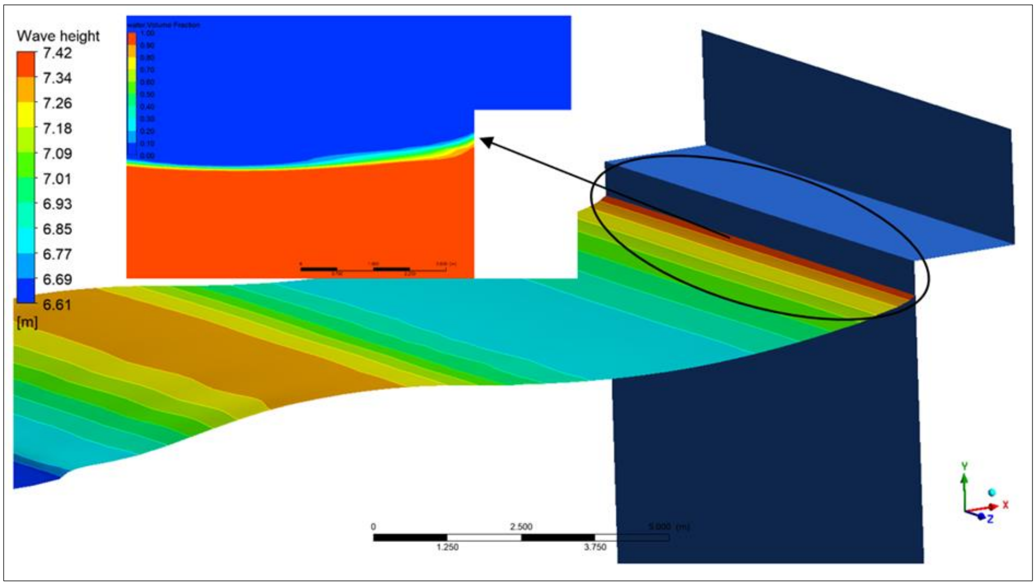

Figure 5 Wave height 1 m

The interaction of the sea waves with the harbor wall is depicted very clearly in Figure 5. Splashes are produced on the wall of the port as a result of this. When using a wave height of 1 meter in a CFD simulation, the resulting splashes have a tendency to be lower, which is around 0.84 meters. The effect of the harbor wall, which is able to unravel the sea waves at that height, is responsible for this phenomenon.

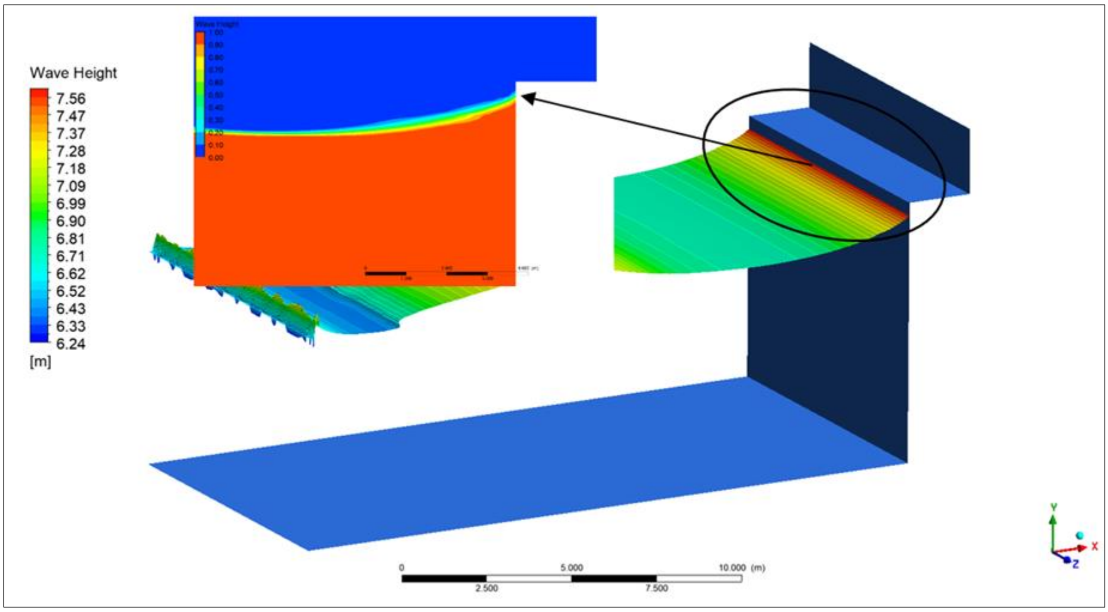

Figure 6 Wave height 1.5 m

Figure 6 presents an unmistakable illustration of how the harbor wall affects the diffraction of ocean waves. Splashes are produced on the wall of the port as a result of this. When using a wave height of 1.5 meters in a CFD simulation, the splashes that result have a tendency to be lower, which is approximately 1.12 meters. The action of the harbor wall, which is able to unravel the sea waves at that height, is responsible for this phenomenon.

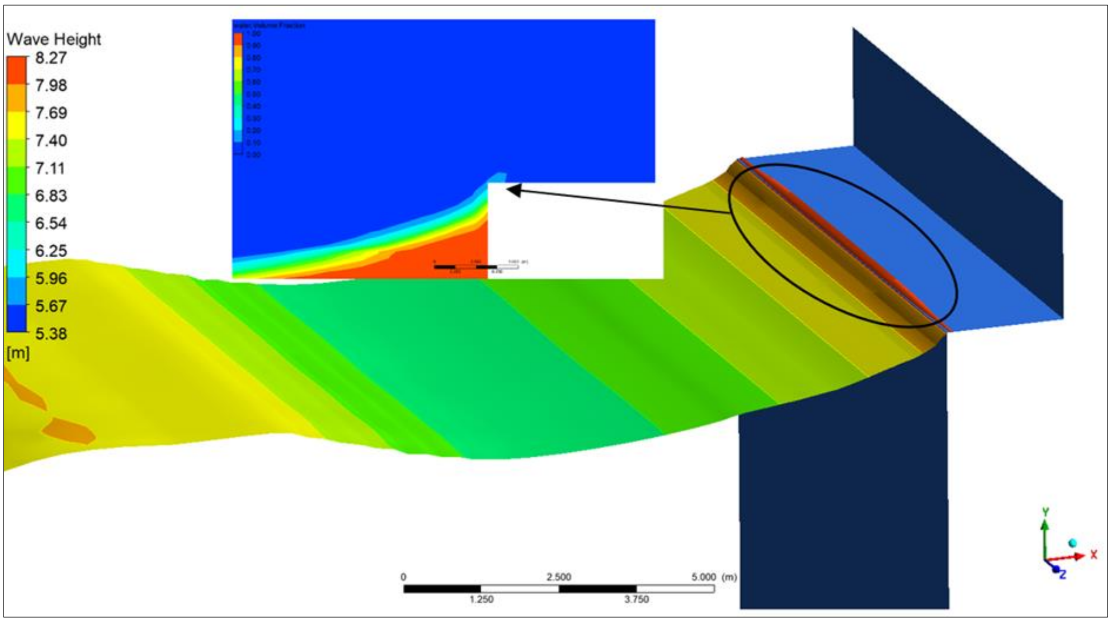

Figure 7 Wave height 2 m

The interaction of the sea waves and the port wall is seen quite well in Figure 7. Splashes will appear on the harbor wall as a result of this. When doing a CFD simulation with a wave height of 2 meters, the average height of the splashes produced is around 2.54 meters. Splashes of ocean water are created as a consequence of this phenomenon, which is induced by the impact of the harbor wall being at the same height throughout its whole and resulting in the height of the harbor wall.

4. Conclusion

The impact of waves on a harbor wall can be visualized in great detail using CFD-based wave simulation. CFD simulation has proven to be of good advantage in early studies on this topic. Some of the results from this CFD simulation include an increase in sea water level in the form of diffraction on the harbor wall as high as 0.54m with the same height as seawater waves, which is 2 m, while at a wave height of 1.5 m and 1 m, it looks safe with no splashes of sea water that exceed the height of the harbor.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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