Hydrodynamic flow characteristics of tsunami waves impact on bearing wall layout

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Abstract. Coastal zones management of a tsunami-prone area should be implemented with an effective and eco-friendly layout of near-shoreline structures. Eco-friendly layout term in this study means the layout produced a minimal bed scouring at the bottom of the structures. In this research, we studied the hydrodynamic flow caused by tsunami wave’s propagation on the bearing walls in coastal area. This flow which occur in 2 (two) bearing wall layout variations were analysed using the Computational Fluid Dynamic (CFD) modelling program. The data and condition of the simulation are utilizing the bathymetric and topographic data of coastal area in the south of Yogyakarta, Java Island Indonesia. The simulation result shows that wave propagation reduction of square bearing wall 45° and 0° layout are 52.99% and 59%, respectively. The square bearing wall 0° is not recommended to be applied due to its highest tsunami wave impact force on the wall structure. The square bearing wall of 0° has a higher shear force and lateral force. This forces can caused an unstable structure wall. The wave impact forces on wall structure area and layout is important parameter for changing the scouring parameter influenced.

Keywords: Hydrodynamic characteristic, tsunami waves, layout, bearing wall, CFD.

1. Introduction

Tsunami had caused destruction throughout the country [1]. Indonesia is an archipelagic country with more than 17,500 islands with coastline reaching 99,093 km [2]. In addition Indonesia is a meeting place of 3 large tectonic plates, namely indo-Australia plate, Eurasia and pacemaker. Indonesia is the second country after Japan which has the most vulnerable to tsunami disaster if compared with other countries. Indonesia also has the largest death toll, caused by tsunami, in the world [3]. Therefore a further review of the impact of tsunamis with coastal mitigation structures should be taken into account in order to protect coastal areas from the tsunami [4].
Buildings located in coastal areas can serve as a drag on tsunami waves. The building is not only beach buildings / coastal structures such as sea wall or breakwater, but also houses or high rise buildings located on the beach / coastal area [5]. The multi-story building should be able to withstand the tsunami waves and reduce the run-up height of the tsunami waves. So as to protect the area that is behind it. The height, width, and thickness of the building will affect the rate of tsunami waves and the distance of the incoming reach to land (run-up tsunami waves) [6]. Other factors affecting the high run-up of tsunami waves are the porosity of the building, the location pattern, the coastal slope, the tsunami wavelength, and the tsunami wave height [7].

To get a suitable building design for the coastal areas then need further research. In this research will be discussed about the effect of tsunami wave’s propagation on buildings using CFD (computational fluid dynamic) calculation method to further review the hydrodynamic flow characteristics that occur based on data obtained from coastal construction manual by FEMA [8].

The results of calculations from CFD (computational fluid dynamic) program will then be compared with a similar test but using a 2-D physical model or a prototype laboratory test [9]. The result of this research are the pattern of flow / current around the coastal building at the time before the tsunami propagation, during the propagation and after passing the coastal building. Also, the changing of forces due to the variation layout of structures.

2. Research Methods

2.1. Study Area

Hydrodynamics data, topographic and bathymetric map of southern Yogyakarta coastal area is utilized for the modelling. The topographic and bathymetric map of southern Yogyakarta coastal area shows that there are some infrastructures such as fishing port (Tanjung Adikarto Port) and tourism area of Glaga Beach also it would be planned Yogyakarta International Airport surrounding the coastal area. This tsunami prone in this area, due to Java Subduction in the Indian’s Ocean. [11] (Figure 1)
2.2. Computational Fluid Dynamic (CFD)

It is a computer based simulation. CFD program enables the prediction of fluid flow under designed condition. The objective of CFD approach is to get the values of the flow quantities at a large number of points in the system [10]. The simulation of real flows by using numeric equations. The equation of two dimensional steady state flow is as follows [10]:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  
\[
\rho \left[ \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right] = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[ \mu \frac{\partial u}{\partial x} \right] + \frac{\partial}{\partial y} \left[ \mu \frac{\partial u}{\partial y} \right]
\]
\[
\rho \left[ \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right] = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[ \mu \frac{\partial v}{\partial x} \right] + \frac{\partial}{\partial y} \left[ \mu \frac{\partial v}{\partial y} \right]
\]

The corresponding equations of Reynolds are:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]
\[
\rho \left[ \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right] = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[ \mu \frac{\partial u}{\partial x} - \rho u'v' \right] + \frac{\partial}{\partial y} \left[ \mu \frac{\partial u}{\partial y} - \rho u'v' \right]
\]
\[
\rho \left[ \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right] = -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left[ \mu \frac{\partial v}{\partial x} - \rho u'v' \right] + \frac{\partial}{\partial y} \left[ \mu \frac{\partial v}{\partial y} - \rho v'v' \right]
\]

The term \(-\rho u'u'\), \(-\rho u'v'\) and \(-\rho v'v'\) behave like stress terms, \(-\rho u'u'\) and \(-\rho u'v'\) are normal stresses and \(-\rho u'v'\) is a shear stress term. These terms characterize the effect of the fluctuating velocity component on the mean velocity field.

2.3. Variation of bearing wall shape and layout

Various structure shape and layout are simulated to get the most effective to reduce tsunami wave. The shape of bearing wall utilized for this study is a square of 20 m x 20 m, and wall thickness of 0.8 m (Figure 2). There are 2 (two) types of bearing wall layout used in this study (Figure 3). The magnitude of tsunami flow velocity and water depth applied for analysis of flow hydrodynamic flow characteristics are based on FEMA [6] (Table 1).

Figure 2. Shape of Bearing Wall

Figure 3. Layout of bearing wall
Table 1. Bearing wall layout for various flow velocity and water depth

| Nr. | Variation | U (Tsunami flow velocity) m/sec | Water depth (m) |
|-----|-----------|---------------------------------|-----------------|
| 1   | B1        | 6                               | 1               |
| 2   | B1        | 10                              | 2.25            |
| 3   | B1        | 12                              | 3.6             |
| 4   | B1        | 16                              | 6               |
| 5   | B2        | 6                               | 1               |
| 6   | B2        | 10                              | 2.25            |
| 7   | B2        | 12                              | 3.6             |
| 8   | B2        | 16                              | 6               |

3. Results and Discussion

3.1. Flow velocity calculation using CFD

The calculation is conducted by CFD program by using 4 various tsunami flow velocity of 6 m/s, 10 m/s, 12 m/s and 16 m/s, shows that the velocity of tsunami wave is increasing in the direction to shoreline. It can be seen from the changes of colour from light yellow, dark yellow, orange and to red (Figure 4). The darker the colour, the higher the flow velocity.

3.2. Flow characteristics and flow pattern surround the bearing wall

The B1 variation (square 45°) simulation result shows a lot of water reduction. Also, the incoming water flow is spreading to the right and left of bearing wall which caused a risk for other structures surround this bearing wall. In the centre and the sides of bearing wall, the flow velocity is 500 cm/s and 950 cm/s, respectively (Figure 5). This higher velocity at the sides is caused by oscillatory flow. On the other hand, for B2 variation (square 0°), the water hits the bearing wall and is reduced so that the velocity is decreasing (Figure 6). However, the bearing wall received high force of water pressure so that, it requires higher strength of structures in order to prevent structures failure. There is a significant velocity reduction in both variation. Variation B2 shows the highest reduction which shown by a lot of green (800 cm/s) and light blue (380 cm/s) colour or around (52.99 %). This velocity decline is due to the impact the reduction of the moving mass of water and the lowering of drag forces as the water flows around the bearing wall.

Figure 4. CFD result of flow velocity calculation
3.3. Flow characteristics and flow pattern at the bottom of the bearing wall

At the bottom and at the sides of bearing wall square 45°, the flow velocity are 1 – 3 m/s and 7 m/s, respectively. While, at the bottom and at the sides of bearing wall square0°, the flow velocity are 1 – 2 m/s and 7 m/s, respectively.
3.4. Comparison of physical and CFD program

The study of tsunami force on square bearing wall with both position of 45° and 0° as being done in this study, was conducted using lab scale hydrodynamic flow modeling [7]. The height of bearing wall are 15 cm, 17 cm and 19,2 cm. The result of the study are as follows:

| Types of bearing wall | Wave Force       | Average | Reduction (%) |
|-----------------------|------------------|---------|---------------|
| No bearing wall       | 99,8             | 127,4   | 166,8         | 131,3         |
| Square 45°            | 47,2             | 51,7    | 49,2          | 49,4          | 62,41        |
| Square 0°             | 62               | 51,9    | 62,4          | 58,8          | 55,25        |
| Source: [9]           |                  |         |               |

| Types of bearing wall | Flow Velocity |
|-----------------------|---------------|
|                        | 6m/s  | 10m/s  | 12m/s  | 16m/s  |
| Circle                | 7.1    | 12     | 14     | 18.8   |
| Square 0              | 6.5    | 12.1   | 14.1   | 18.9   |
| Square 45             | 6.7    | 12.1   | 14.1   | 18.9   |
| average               | 6.8    | 12.1   | 14.1   | 18.9   |

4. Conclusion

The result shows wave propagation reduction of square bearing wall 45° and 0° layouts are 52.99% and 59%, respectively. The square bearing wall of 0° has higher tsunami wave impact force on the structure wall compare to the 45°. As a consequence, the square bearing wall of 0° has a higher shear force and lateral force. This forces can caused an unstable structure wall such as higher impact due to bed scouring.

The simulation result can be utilized for evacuation plan. The area within square bearing wall 45° is a safe place when the tsunami wave occur, as shown in the flow pattern. From the running model shown higher flow velocity occur at the side or in between the structures. This higher velocity at the sides is caused by oscillatory flow. Further analysis on the dimension and layout of tsunami protection wall should be conducted. Also, a comparison using other hydrodynamics software to gain more accurate should be performed.

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