Predicting the Vulnerable Area of Tsunami Hazard Using CADMAS Surf 3D Case Study: Kolaka City, Southern Sulawesi, Indonesia

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Abstract. Tsunami is an unpredictable disaster. However, efforts to anticipate the tsunami disaster must be done. This research is done based on the earthquake’s history around Kolaka. Based on the location of the point of an earthquake and coastal area in Kolaka City, a numerical simulation analysis was performed using CADMAS Surf 3D to predict the speed and wave height when tsunamis happen after the earthquake. The tsunami analysis indicates that the affected area is based on wave velocity, wave height and topography condition in the coastal area of Kolaka City. Spatial analysis is used to delineate the tsunami-affected areas in Kolaka City. Based on the delineation of affected areas, local governments can take other preventive measures such as making maps of tsunami-prone areas with attributes such as evacuation routes, safe areas, temporary evacuation sites, and so on.

1. Introduction

Earthquakes and tsunamis are the terrifying natural phenomena in human civilization. Both of these natural disasters strike without warning, affecting all levels of society, with losses of life, injury, property damage, and socio-economic structure changes. Several major earthquakes caused a tsunami which subsequently affected coastal and island communities [1].

Tsunamis can be generated by geophysical phenomena such as earthquakes, volcanoes, submarine landslides, and meteorite impacts. Historically, tsunami events worldwide (1790-1990) were mostly generated by earthquakes (90.3 percent), volcanoes (6.4 percent), and landslides (3.3 percent) [2].

Based on the existing data, Kolaka Beach has experienced seaquake on February 19, 2005, with a strength of 6.9 SR. The earthquake point was in the sea that is assumed to be 50 kilometers south of Butung Island, or within 260 km from the Kolaka City.
The history of the occurred earthquake around Kolaka shows that Kolaka City is rarely affected by the earthquake (see figure 1). However, efforts to anticipate the threat of tsunami waves are still done by making a tsunami wave simulation with 6m, 8m, and 10m. The forecast of the epicenter is to the
north of the Flores Sea and the southern island of Sulawesi with a distance of 50 km south of Butung Island as shown in figure 2 above.

2. Methods

To estimate tsunami wave propagation, CADMAS-Surf / 3D is used to perform numerical simulations. The equation consists of the continuity equation, the Navier-Stokes equation in the x, y and z directions as the advection equation for tracing the water level. The last equation includes the function, \( F (x, y, z, t) \) as the ratio of the volume of water in each numerical cell. In the above equation, \( t \) is the time, \( x, y \) and \( z \) are the horizontal and vertical coordinates. Also, \( p \) is the pressure, \( u, v \) and \( w \) are the horizontal velocity components \((x, y)\) and vertical, in each of the terms [3].

\[
\frac{\partial \gamma_x u}{\partial x} + \frac{\partial \gamma_y v}{\partial y} + \frac{\partial \gamma_z w}{\partial z} = S_p
\]

\[
\lambda_v \frac{\partial u}{\partial t} + \frac{\partial \gamma_x uu}{\partial x} + \frac{\partial \gamma_y vu}{\partial y} + \frac{\partial \gamma_z wu}{\partial z} = -\frac{\gamma_v}{\rho} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left\{ \gamma_x v \left( \frac{2 \partial u}{\partial x} \right) \right\}
\]

\[
+ \frac{\partial}{\partial z} \left\{ \gamma_y v \left( 2 \frac{\partial u}{\partial y} \right) \right\} - \gamma_u D_u u - R_x + \gamma_v S_u
\]

\[
\lambda_u \frac{\partial v}{\partial t} + \frac{\partial \gamma_x uv}{\partial x} + \frac{\partial \gamma_y vv}{\partial y} + \frac{\partial \gamma_z vw}{\partial z} = -\frac{\gamma_u}{\rho} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left\{ \gamma_x v \left( \frac{2 \partial v}{\partial x} \right) \right\}
\]

\[
+ \frac{\partial}{\partial y} \left\{ \gamma_y v \left( 2 \frac{\partial v}{\partial y} \right) \right\} - \gamma_v D_v v - R_y + \gamma_v S_u
\]

\[
\lambda_w \frac{\partial w}{\partial t} + \frac{\partial \gamma_x uw}{\partial x} + \frac{\partial \gamma_y vw}{\partial y} + \frac{\partial \gamma_z zw}{\partial z} = -\frac{\gamma_w}{\rho} \frac{\partial p}{\partial z} + \frac{\partial}{\partial z} \left\{ \gamma_x v \left( \frac{2 \partial w}{\partial z} \right) \right\}
\]

\[
+ \frac{\partial}{\partial y} \left\{ \gamma_y v \left( 2 \frac{\partial w}{\partial y} \right) \right\} - \gamma_v D_z w - R_z + \gamma_v S_u - \frac{\gamma_v p \cdot g}{\rho}
\]

\[
\gamma_u \frac{\partial F}{\partial t} + \frac{\partial \gamma_x uF}{\partial x} + \frac{\partial \gamma_y vF}{\partial y} + \frac{\partial \gamma_z wF}{\partial z} = S_F
\]

Then \( \rho \) is the fluid density, \( v \) is the sum of the molecular kinematic viscosity of the molecule and the eddy kinematic viscosity, \( g \) is the acceleration of gravity. While \( v \gamma \) is the porosity, \( \gamma_x, \gamma_y \) and \( \gamma_z \) is the component of the porosity of the air, \( S_F, S_u, S_v \), and \( S_w \) is a source of wave generation, \( D_x, D_y \) and \( D_z \) are coefficients for sponge layer and \( R_x, R_y \) and \( R_z \) is a resistance component due to porosity on the \( x, y \) and \( z \)-axes. Performing a simulation using 3 D-Surf CADMAS needs consecutive timing in a row based water level and velocity of the fluid at an initial limit of certain channels so that it can generate tsunami waves with such profiles. This study assumes the initial profile of the bore wave in the offshore region, and the speed profile used by bore wave profile in this study is obtained by utilizing the equation below [4].

\[
U = \frac{C \xi}{H} = \xi \sqrt{\frac{g(H + h)}{2H(H - \eta \xi)}}
\]
In this equation, \( U \) means the average water depth velocity and \( g \) means the acceleration of gravity. \( H = h + \zeta \) means the total depth of datum and \( \zeta \) also means the height of the temporal bore. \( \eta \) is the coefficient obtained from the ratio between the initial water depth in the total depth area of propagation and is set as 1.03 in this study.

Figure 3. Flume Used for Simulation

Figure 3 is a wave flume scheme for numerical simulation in this study. The flume is 750m long and 35m high. The depth of the offshore wave is maintained as 10m. The slope of the beach is 1/25. While the grid size for numerical simulation in the direction of \( x \) and \( z \) is set respectively \( \partial x = 0.25m \), \( \partial y = 0.25m \) and \( \partial z = 0.25m \). The measurement point in the simulation is \( X_1 = 400m \) \( X_2 = 625m \) [5].

Figure 4 is a tsunami travel time from the epicentre (earthquake point) to reach the location of the planned power plant. By using a shallow water wave equation (equation 6), the travel time of the wave from the point of the earthquake to the location of the plan can be estimated.

Figure 4. Time of Wave Propagation from Earthquake Point to the Location

\[
v = \sqrt{gh}
\]

(7)

Information:
\( v \) = velocity (m/s)
\( g \) = gravity (m/s²)
\( h \) = sea depth (meters)
The above equation shows that the tsunami wave will arrive at the location at 6624 seconds (1.84 hours) after the earthquake or 1 hour 50 minutes after the earthquake. This is because the distance between the epicentre to the location is about 260 km and the depth of the sea in the epicentre is 2000 m.

3. Result

To conduct wave-to-surface propagation analysis, an analysis of waves with three different wave heights, i.e. 6 meters, 8 meters and 10 meters was done, below is the explanation. The measurement is done at the wave height and also wave velocity at some point measure.

The graphics pattern in figure 5 shows that the speed of waves in Kolaka with wave setting levels is as high as 6 m, 8 m, and 10 m. The wave velocity in the simulation can reach 4.0 to 10 m/sec (14.4-36 km/h). The natural physical conditions in the slightly hilly site directly result in the slowing of the wave rate of seawater entering the land due to surface friction between the wave and mainland. The magnitude of friction between the waves of seawater and the land was able to reduce the wave velocity significantly from about 10 m/s to about 4 m/sec. (see table 1)

![Figure 5. Graph of Wave Velocity](image)

![Figure 6. Screenshot Tsunami Simulation Results](image)

The setting of the wave height in the first simulation is 6 m, and after touching the shoreline (coastal area) then the wave breaks creating terrible turbulence in the coastal area. This has an impact on the decrease of wave height coming about 5.85 meters 400m from the beach. The wave propagation that
came to the ground after the wave broke out on the beach and continued to enter the land was only about 2.18 meters. The wave velocity at the setting of a wave height of 8 m and 10 meters can be seen in table 1. Figure 7 below is a screenshot of the tsunami simulation result by using numerical simulation using bore wave.

The chart with the red line in Figure 7 below shows that the wave height at Kolaka beach is about 1.23-2.18 meters where the ground-level propagation becomes stable at 1.23 m.

![Graph of Wave Height](image)

Although the possibility of tsunamis in the location plan is very small and if it happens, the wave propagation would require considerable time for the evacuation of around 1 hour 50 minutes. One thing to note is the design of the building at a fixed location should be designed to respond to the threat of a tsunami.

| Table 1. Wave Velocity and Wave Height in Simulation |
|-----------------------------------------------|
| WAVE HEIGHT | WATER LEVEL (M) | VELOCITY (M/DT) |
| X1= 400 M | X2=625 M | X1= 400 M | X2=625 M |
| 6 m | 5.85 m | 1.23 - 2.18 m | 6.15 m/dt | 5.25 m/dt |
| 8 m | 7.68 m | 1.65 - 3.15 m | 8.32 m/dt | 7.65 m/dt |
| 10 m | 9.72 m | 2.34 - 3.61 m | 10.41 m/dt | 9.35 m/dt |

Table 1 is the result of the measurement of wave velocity and wave height at the point of 400 meters and 625 meters at Kolaka beach. This table shows the difference in height and waves velocity from the tip of the flume until propagation reaches the land as far as 625 meters. The measurement results of wave propagation with altitude difference show the same pattern from one to another, the reduction of height and the wave velocity is greatly influenced by the natural topography at the location. With a distance of about 625 m, wave height at Kolaka Beach can reach 3.61 meters.
Figure 8. Approximate Map of Tsunami Inundated Area in Kolaka

The color red indicates a tsunami inundated area height of fewer than 2 meters; the orange color indicates the tsunami inundated area range with a height between 2.00 meter to 3.00 meters, yellow areas indicate high tsunami inundated area height between 3.00 meters to 4.00 meters. In the event of a tsunami, the first wave will come to inundate a relatively low area in Kolaka. The wave propagation will be forwarded to the rear of the site only in the red zone with a wave height of fewer than 2 meters.

4. Conclusions
The analysis result can provide conclusions and recommendations, namely:
  a. Building unit in the affected area should be made to hang (panggung house) so that the organization of space for important zones is far from the reach of the wave
  b. Water-prone electronic equipment and laboratory equipment can be put on the 2nd floor and so on
  c. The construction of the building at the bottom can be arranged in such a way that the walls can be designed to be easily removed if it is hit by waves, for example in the form of partitions
  d. The use of space on the ground floor can be functioned as a car park and other secondary functions
  e. Partition walls on floors 1 and 2 aim to reduce the building load on it when added to the load from the volume of tsunami waves crashing the building.

Taking into account the high reach of waves up to the second floor (about 6 m), it is necessary to consider some site selection if the coastal areas are to be used for functions with important facilities such as power plants, nuclear reactor laboratories and the like. In this case, it may increase the construction costs because there is a cut and fill process when choosing land that is located higher than the previous location and also wavy.

5. References
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