GLOBAL OPTIMIZATION OF NUMERICAL TWO-LAYER MODEL USING OBSERVED DATA: A CASE STUDY OF TSUNAMI IN THE 2018 LATERAL COLLAPSE OF ANAK KRAKATAU VOLCANO IN SUNDA STRAITS, INDONESIA

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1. Introduction: A large landslide occurred on the southwest part of the Anak Krakatoa volcano because of its eruption. Landslide generated large tsunami around the Sunda Strait, Indonesia, on 22 December 2018. Upon entering the sea, it caused a huge tsunami that traveled approximately ~5 km across the strait basin and inundated the shore of Sumatra and Java with vertical runup of up to 13 m. (**Muhari et al., 2019**). Following the event, observed field data, GPS measurements of the inundation and multibeam echo soundings of the straits bathymetry, were collected and provided (**Syamsidik et al, 2019**). Figure 1 shows a map of the Sunda Straits in addition to the location of the Anak Krakatau in a middle of the straits. The point of this study is to investigate the possible source of the 2018 Sunda Straits tsunami using preliminary data. This study focus on the tsunamis generated by subaerial/submarine landslide and the method to find the source is to apply an optimization procedure to determine unknown landslide parameter through comparison between measured and simulated bathymetry in an inverse modeling methodology.

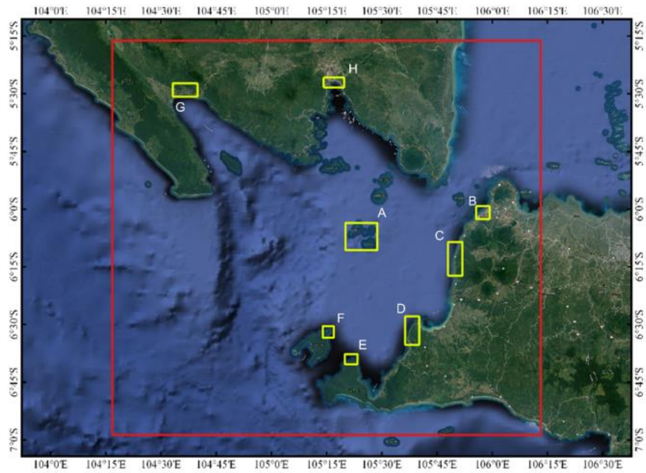

Fig. 1 Study area, Bathymetry data, Simulation results and Population density in the study area

2. Methodology: This research has been supported by 3 components, dataset (hypothesis of tsunami source model and digital topography model), two-layer of shallow water equation and optimization algorithm.

2.1 Dataset: The hypothesized landslide locations on the Anak Krakatau are shown in Fig. 2, and these landslides can be detected by the satellite image in before and after. The landslides are located in different area of coast line and were the main cause of the studied tsunami. The change of the coast line was used to consider the landslide model, using the 3D ellipsoid modeling.

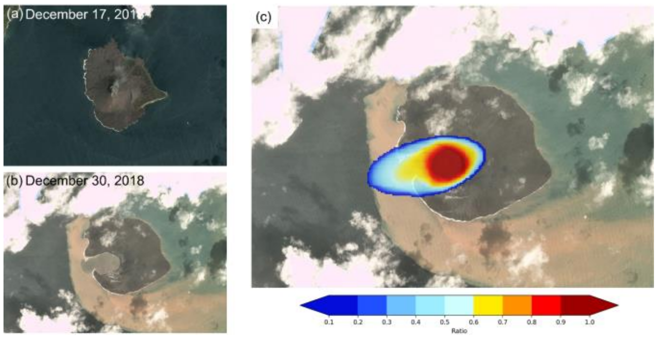

Fig. 2 Hypothesis of landslide location.

2.2 Two-later modeling on shallow water equation: Tsunami model in the Palu Sea are assessed on two-layer numerical model that was developed to solve nonlinear shallow water equations within two interfacing layers with appropriate kinematic and dynamic boundary conditions at the seafloor, interface, and water surface (**Pakoksung et al., 2019**). The two fluids, water and fluidized debris, are immiscible, hypothesizing in this study. The governing equation writes as follows:

Continuity equation of layer 1st.

$$\frac{\partial Z_1}{\partial t}+\frac{\partial Q_{1x}}{\partial x}+\frac{\partial Q_{1y}}{\partial y}=0$$

Momentum equation of layer 1st, in X and Y direction.

$$\frac{\partial Q_{1x}}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_{1x}^2}{D_1}\right)+\frac{\partial}{\partial y}\left(\frac{Q_{1x}Q_{1y}}{D_1}\right)+gD_1\frac{\partial Z_1}{\partial x}+gD_1\frac{\partial Z_2}{\partial x}-\tau_{1x}=0$$

$$\frac{\partial Q_{1y}}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_{1x}Q_{1y}}{D_1}\right)+\frac{\partial}{\partial y}\left(\frac{Q_{1y}^2}{D_1}\right)+gD_1\frac{\partial Z_1}{\partial y}+gD_1\frac{\partial Z_2}{\partial y}-\tau_{1y}=0$$

Continuity equation of layer 2nd.

$$\frac{\partial Z_2}{\partial t}+\frac{\partial Q_{2x}}{\partial x}+\frac{\partial Q_{2y}}{\partial y}=0$$

Momentum equation of layer 2nd, in X and Y direction.

$$\frac{\partial Q_{2x}}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_{2x}^2}{D_2}\right)+\frac{\partial}{\partial y}\left(\frac{Q_{2x}Q_{2y}}{D_2}\right)+gD_2\frac{\partial Z_2}{\partial x}+gD_2\frac{\rho_1}{\rho_2}\frac{\partial Z_1}{\partial x}-\tau_{2x}=0$$

$$\frac{\partial Q_{2y}}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_{2x}Q_{2y}}{D_2}\right)+\frac{\partial}{\partial y}\left(\frac{Q_{2y}^2}{D_2}\right)+gD_2\frac{\partial Z_2}{\partial y}+gD_2\frac{\rho_1}{\rho_2}\frac{\partial Z_1}{\partial y}-\tau_{2y}=0 \quad (1)$$

where index 1 relates to the upper layer and index 2 is the second layer. $Z_i(x,y,t)$, $i=1,2$ is the level of the layer at each point (x,y) at time t, the level value measured from a given reference level. $q_i(x,y,t)$, $i=1,2$ is the vertically integrated discharge in x and y direction. g is the gravity acceleration, ρ_1 and ρ_2 are the density of 1st layer and 2nd layer, respectively. $\tau_i(x,y,t)$ is the bottom stress in each layer at each point (x,y) at time t. In system 1, interaction between the layer 1st and layer 2nd is done by fifth term of the momentum equation.

2.3 Optimization algorithm: The grid search method initializes that the result of the sum square error in a spare of a parameter is complex with a gradient-based minimization process, was unsuccessful to get stuck in a local minimum. Then, a global optimization procedure was selected to test the parameter space. The Differential Evolution (DE) procedure as provided by **Storn and Price, 1997**, was selected and implemented. On a stochastic search method, it is started from the random generation of parameter vectors, and new trial vectors are determined by disturbing a target vector from the existing vectors. The two-layer model is run by the trial vector parameters if its result of the objective function is lower than the trial vector replaces the target vector.

3. Results and Discussion

Fig. 3 shows amplitude time series at the tidal gauge with de-tide sea level that the simulation tsunami waves at the location of observation gauge agree well, in a period and amplitude. For the effects of the tsunami (from the best parameter), as shown in **Fig. 4**, along the coastline of Palu Bay are considered in the area D on **Fig. 1**. In the flood area on the coast, the observed tsunami height has an average value of approximately 10.5 m, with a maximum of 13.5 m at 10 km. A comparison of the simulation height with the surveyed sport presented in the underestimation as shown in **Fig. 4b**.

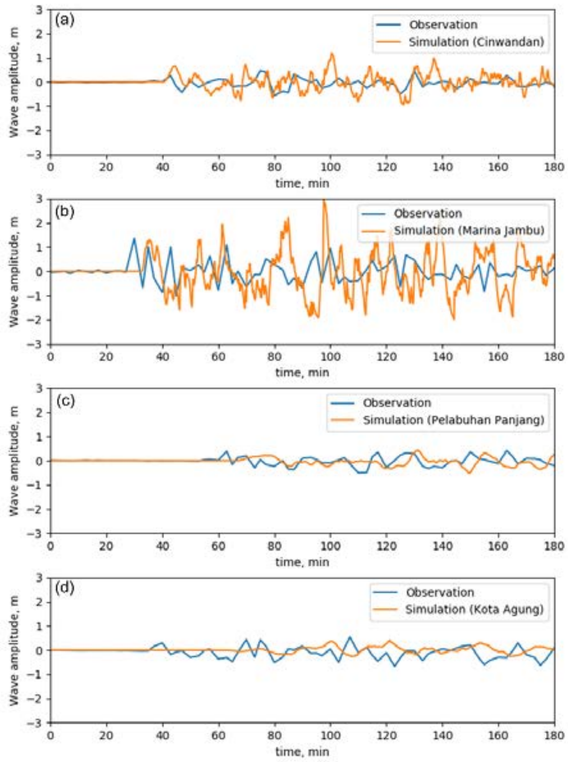

Figure 3 Comparison between observation and simulation at a) Ciwandan, b) Marina Jambu, c) Panjang, and d) Kota Agung.

4. Conclusion

A large landslide was released from the south-western flank collapse of the Anak Krakatau volcano is modeled by a Two-layer model integrated code with a global optimization model to simulated the tsunami in the Sunda Straits. The parameter of the landslide model was estimated by the global optimization using the survey bathymetry after the event. The results show that the tsunami height of the best landslide parameter could reach up to 3-10 m along the shore on the underestimation to compare with the observation data. According to the wave form, the general wave pattern was well reproduced at the tide gauge during the event. Although the results are contained by some limitations. The landslide model was hypothesized by satellite images for the shape and the 3D ellipsoid for the volume. However, tsunami simulation related to this landslide is quite consistent with observed water heights.

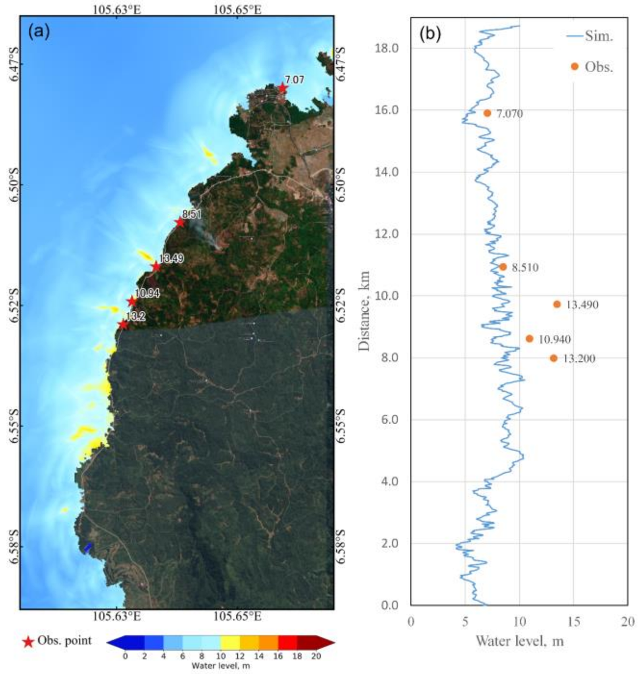

Figure 4 Impact of tsunami along the coastline in area D: a) flood extent and location of observation point; b) water level along the coastline and comparing to observation data.

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