Mass Movement Using the Bingham Fluid Model and the Voellmy Fluid Friction Model. (Case Study of Songan Village, Kintamani, Bali)

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Abstract— Indonesia is located on the Ring of Fire of Pacific Rims. This condition makes Indonesia at risk of geological disaster. One possible occurrence is mudflow. On February 10, 2017, mudflow occurred in Songan Village, Kintamani, Bali, which destroyed 6 houses and killed 13 people. Further study is needed to predict this type of occurrence. This study aims to identify the characteristics of the soil at the deposition area of mudflow and verify the duration, flow depth, and velocity of mudflow. To achieve these objectives, a rheological study is conducted using the Bingham fluid model and the Voellmy fluid friction model in Flo-2D and Rapid Mass Movement Simulation (RAMMS), respectively; the simulation results of both models are compared. From the results of the program simulations, RAMMS' results are found to exhibit a higher velocity of mass movements than that of Flo-2D's results. From the results of this analysis, small viscosity is observed to result in small flow depth and high velocity of mass movements. Keywords—Mudflow, Bingham, Voellmy, Flo-2D, RAMMS

1. Introduction

Mass movement disasters often occur in several regions in Indonesia. One of the causes is the poor stability of the soil in these areas. People's ignorance about this soil stability condition also causes the mass movement disaster to be a major threat, especially in populated areas. The landslide that occurred in Songan Village, Kintamani, Bali, on February 10, 2017, is an example of this case. This disaster destroyed 6 houses of local residents and caused the death of 13 people. A mass movement is a gravitational displacement of a material, such as a soil, rock, or other material mixture, that forms a slope [1]. Mass movements generally occur on steep terrain, which presents poor stability [2,3].

This study aims to analyze the impact of a mass movement that occurs in accordance with the geotechnical parameters. The final results of this analysis can be used to increase public knowledge on geotechnical natural disasters in the form of mass movement. Flow depth, flow velocity during transportation, flow direction of mass movement, and the impacted area of mass movement can be predicted using the Bingham fluid model and the Voellmy fluid friction model. These predictions are applied to the mass movement disaster that occurred in Songan Village, Kintamani, Bangli Regency, Bali.

Figure 1. Mudflow in Songan Village, Bali

2. Methodology

This study focuses on mass movement, which is classified as mudflow; the reason is that the movement of the soil occurs similar to a flow on a long path and the water content of the soil is greater than the liquid limit of the soil [4,5].

2.1 Field Study

A field study is conducted by visiting the location of mass movement in Songan Village, Kintamani, Bali, to describe the mass movement in the location. According to interviews that was conducted to local villagers, the mudflow occurred in the early morning around 00:30 local time and occurred for approximately 5–10 min. The mudflow destroyed 1 temple and 6 houses and caused the death of 13 people. The locations and areas impacted by the mudflow are shown in Fig. 2. The impacted area is estimated to be approximately 14250 m^2 and the estimated deposition depth ranges from 3.0 m to 4.0 m. After the interview, soil sampling is conducted on soil deposition of 30 kg for laboratory test and a documentation is performed to serve as a reference for this study. Thereafter, the materials in the mass movement location are investigated. From the results of the investigation conducted at Batur Geopark Museum, the materials in the mass movement location are found to be agglomerates, lava, and tuff and a small amount of lava and ignimbrite.

Figure 2. Impacted Area

2.2 Laboratory Test

Geotechnical laboratory tests are conducted to find the parameters needed in the analysis of mass movement. Two parameters, namely, geotechnical and rheological parameters, are needed in the analysis of mass movement. The geotechnical parameters obtained from laboratory tests are specific gravity, concentration coefficient based on volume, Atterberg limit, and grain size distribution of soil. The rheological parameters obtained from laboratory tests are yield stress and viscosity [6]. Yield stress is derived using fall cone penetration test. Flow box test is conducted to determine viscosity [7], and the results are presented in Table 1.

Table 1. Laboratory Test Results

w (%)	37
LL	36.1
PL	18.62
LI	1.05
G_s	2.68
C_v	0.5
(kPa)	3.67
(Pa·s)	0.02
USCS	SC

2.3 Bingham Fluid Model

Bingham's fluidity and plasticity model in this study is based on Maxwell and Prandtl's models; the equation of the modeling is simplified by Bingham into Eq. 1 [8].

$$_{y} \quad , \qquad (1)$$

where τ is the shear stress (kPa), τ_y is the yield stress (kPa), is the viscosity (Pa·s), and is the shear strain rate (s^{-1}). In this study, the application of the Bingham fluid model on mudflow analysis is performed with the support of Flo-2D [9]. The required data are contour, hydrograph, soil parameters, and rheological parameters that will be modeled in Grid Developer System and simulated in Mapper.

2.4 Voellmy Fluid Friction Model

The Voellmy model is a rheology model that also considers the frictional resistance to mass movement. In this model, the frictional resistance is divided into two, namely, dry-coulomb type friction and viscous-turbulent friction [2].

$$S = \quad H\, g \cos(\ ) + (\ g\, U^2)/\ , \qquad (2)$$

where S is the frictional resistance (Pa), is the dry Coulomb friction coefficient, is the density (kg/m^3), H is the flow height (m), g is the gravitational acceleration (m/s^2), is the slope angle (°), U is the flow velocity (m/s), and is the viscous turbulent friction coefficient (m/s^2). In this study, the application of the Voellmy model on mudflow analysis is conducted with the support of Rapid Mass Movement Simulation (RAMMS) [10]. The required data are contour, hydrograph, soil parameters, rheological parameters, and assumption of dry Coulomb and viscous turbulent friction resistance coefficients.

3. Result and Discussion

The analysis of mudflow with the Bingham and Voellmy models in this case study was conducted with simulated simulation resembling field study results, with 12 min simulation time input, 39% water content of the soil (LI = 1.17), and mudflow debit of 712.5 m^3/s for 5 min. In the RAMMS software, additional inputs are required, such as the dry coulomb friction coefficient of 0.1, the viscous turbulent friction coefficient of 100 m/s^2, and the cohesion of 2390.17 Pa.

3.1 Bingham Fluid Model

The analysis result using the Flo-2D software shows that the maximum flow depth is 4.3 m, maximum flow velocity is 4.2 m/s, mudflow directs to South West, impacted area's length is 753.18 m, and impacted area's width is 450.16 m. The impact of mudflow by the Flo-2D software is presented in Figs. 3 and 4.

3.2 Voellmy Fluid Friction Model

The analysis result using the RAMMS software shows that the maximum flow depth is 3.6 m, maximum flow velocity is 6.61 m/s, mudflow directs to South West, impacted area's length is 697.14 m, and impacted area's width is 528.72 m. The impact of mudflow by the RAMMS software is presented in Figs. 5 and 6.

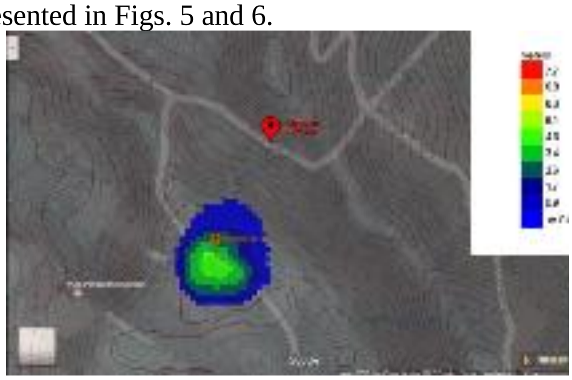

Figure 3. Flow Depth (Flo-2D)

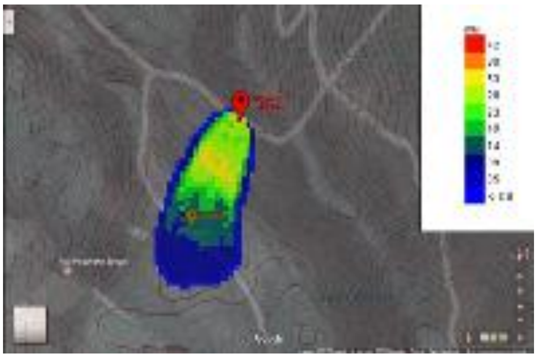

Figure 4. Flow Velocity (Flo-2D)

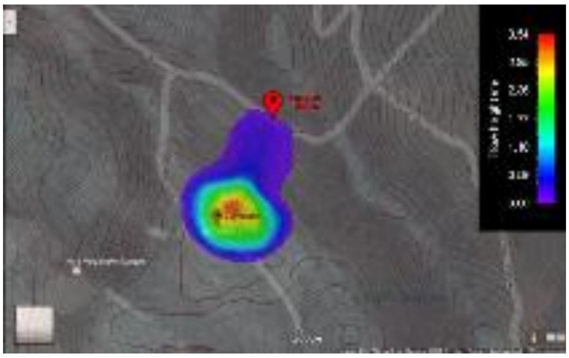

Figure 5. Flow Depth (RAMMS)

Figure 6. Flow Velocity (RAMMS)

After the simulations with Flo-2D and RAMMS are performed, the simulation results can then be compared with the interview results during the field study. RAMMS' results are highly representative of the actual occurrence as the deposition is approximately 3–4 m. This result may be attributed to that the Voellmy fluid friction model considers the frictional forces that occur during the mudflow transportation.

4. Conclusion

Analysis of mass movement (classified as mudflow) using the Bingham and Voellmy models through simulation using Flo-2D and RAMMS can verify that the assumed location of area impacted by mudflow, flow direction, and thickness of mudflow deposition resemble the actual incident. The results show that small viscosity and rapid flow result in long flow length and large flow width. The comparison conducted with varying water contents of the same soil show the same results for the Bingham and Voellmy models.

5. Acknowledgment

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