Numerical Simulation of Some Debris Flow Events in Central Java for Predicting Run-out Distributions

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ABSTRACT: The occurrence of several landslides followed by the debris flow, such as Sijeruk Landslide on January 4, 2006, Jemblung Landslide on December 12, 2014 and Pasir Panjang Landslide on Februari 22, 2018 has make a lot of casualties and terrible destruction in some parts of Central Java. In general, debris flow can be divided into source area, flow track and depositional area. This study will focus on modelling the run-out of debris materials, starting from the source area to the distribution of debris materials at the depositional area.
In this study, debris flow simulations were used to better understand with regard of predictions of volume, run-out mechanisms, flow rate of materials and the distribution of debris materials. In general, the results of this study will be very useful to predict the run-out of any potential similar debris flows in some areas of Indonesia which might experience the similar events as well as the determination of mitigation measures to minimize the negative impact of these events.
Keywords: landslide, debris flow, run-out, modeling.

1. INTRODUCTION

The occurrence of several landslides followed by the debris flow, such as Sijeruk Landslide on January 4, 2006, Jemblung Landslide on December 12, 2014 and Pasir Panjang Landslide on Februari 22, 2018 has make a lot of casualties and terrible destruction in some parts of Central Java.

From Stiny (1910) in Jacob and Hungr (2005), debris flow begins with the description of a flood in a mountain torrent, carrying suspended load and transporting quantities of bedload. As the amount of sediment carried by the flow increases, at certain limit it has change into a viscous mass consisting of water, soil, sand, gravel, rocks and wood mixed together, which flows like a lava into the valley. Meanwhile, Varnes (1978) in Blijenberg (2007) describe that debris flows are mass movements consisting of granular solids, water and air moving as a viscous flow.

In general, debris flow zonation can be divided into three parts, which are source area, flow track and depositional area of debris materials. The Geometri of debris flow can be seen in Figure 1. The first part is source area which an area where the accumulation of debris material occurs. The accumulation of debris materials might be consist of materials of slope itself or material that make natural dam. The second part is flow track which an area where debris materials flow through stream to the valley. The third part is depositional area which a plain for sedimentation of debris materials. The Distribution of debris flow in depositional area depends on topography. If in the depositional area still has a difference in slope angle with slope below, secondary flow track maybe occurs which will make secondary depositional area (multiple depositional area).

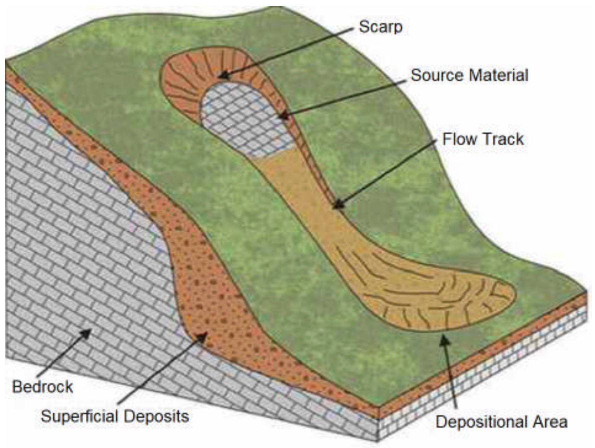

Figure 1 Block diagram of debris flow geometry (Modified from Nettleton et al., 2005)

Debris flows always occur in an area which has hill morphology with high intensity of rainfall. Slope angle and river stream are factors that determine the process of debris flow. Debris flow will happen if a slope has huge amount of debris material with huge amount of water supply as its stream. Debris flows always occur after or when heavy rain. Debris flows has high specify gravity which make a boulder flow through the stream to the toe of depositional area.

2. METHODS

This study will focus on run-out modeling of debris materials, since the flow of debris materials started to distribution of debris materials in the depositional area, which is usually found in the plain areas of foot slope. Some of debris flow events in Central Java are selected to be modeled in this research by mean of numerical simulation technique with Graphical User Interface (GUI). The software that used in this simulation is kanako ver.2.01. From Takahashi and Nakagawa (1991) in Nakatani, et al. (2008), the modeling concept in 2D based from the equations for momentum, continuation, riverbed deformation, erosion/deposition and riverbed shearing stress.

Input data parameters obtained from field conditions and the results of physical properties analysis of materials, geomorphology conditions and hydrogeological conditions. These parameters are used to modeling source area of debris flow. Shape of river was used as analogy of flow track. These parameters which used as input data can be seen in Table 1. Based on input data parameters, a series of numerical simulation techniques performed by several stages. First stage is conversion contour elevation into the form of a grid system with a scale adapted to the area affected. Second stage is define engineering properties of rocks as the model's variable input and flow tracks. Third stage is analysis of supply hydrograph for indicating the influence of water that would affect flow behavior. Last stage is simulate to predict the volume, run-out mechanisms, the flow rate, as well as the distribution of debris materials that formed.

Table 1 Input Parameters

Parameters	Unit
Simulation Duration	second
Calculation time interval	second
Diameter of materials	m
Mass density of bed materials	kg/m^3
Mass density of fluid phase (water, mud, and silt)	kg/m^3
Consentration of movable bed	unitless
Gravity acceleration	m/s^2
Coefficient of erosion rate	unitless
Coefficient of accumulation rate	unitless

Table 1 Input Parameters (Cont.)

Internal friction angle	°
Minimum depth at the front of debris flow	m
Minimum flow depth	m
Manning's roughness coefficient	unitless
π (Phi)	22/7

Consentration of sediments in the slope when debris flow occurs determine by using equation 1 (Takahashi et al., 2001 in nakatani, et al., 2011):

$$C_d=(\rho \tan \theta)/((\sigma- \rho)(\tan \varphi-\tan\theta)) \quad (1)$$

where:

σ = Mass density of bed material
ρ = Mass density of liquid
φ = Internal friction angle
θ = Slope angle of river
C_d = Consentration of debris flow

If the consentration of sediments have been determine, the value of peak of sediments supply in debris flow can be calculated using equation 2 from "Sabo Master Plan for Debris Flow" (NILIM Japan, 2007 in Nakatani, et al., 2011):

$$Qsp = 0.01 \times \Sigma Q \quad (2)$$

$$\Sigma Q = (V_{dq}\, C_*)/C_d \quad (3)$$

where:

Qsp = Peak of the sediment supply per second (m^3/second)
ΣQ = Total amount of moveable material that define in equation 1 (m^3)
V_{dq} = Volume of the sediment (m^3)
C_* = Consentration of moveable bed

3. CASE STUDY

3.1 Sijeruk Village, Banjarnegara, Central Java, January 4 2006

Debris flow occurred in Pawinihan Hill, Sijeruk Village, Banjarnegara Regency at coordinates S 07° 19 '16.1"and E 109° 42' 08.3" with elevation 994 m. Over the incident, as many as 77 people were killed, 8 people missing. Pawinihan Hill composite rock consists of flow breccia flow, pyroclastic, lava, and alluvium (Condon W.H., et al., 1996). The slopes of Mount Pawinihan have a slope of between 20° to 60°. The direction of landslide at the crown on the slopes of Pawinihan Hill is towards the southeast (N 145° E). In the former landslide area, remnants of breccias that experienced landslide still visible.

Debris flow in the Sijeruk Village has uniqueness in the flow path, which is encounter a sharp deflection. It is alleged that the deflection is caused by a ridge that blocks the flow track of the flowing material that move southeast. The ridge causes the direction of the flow that originally toward the southeast transformed to the east. The depositional area tends to the southeast following the slope of the valley of Pawinihan Hill. The topographic of the Pawinihan Hill can be seen in Figure 2 with 1 grid representing the 25x25 meter area. The length of debris flow in Sijeruk Village reached about 1.1 km.

The modeling of the debris flow using scenario of the viscosity value 0.45. The process of direction deflect in flow track and the distribution of sediment in the deposition area can be seen in Figure 3 and 4. When the material enters the flow track, material moves at speed 21.17 km/hour. The flow of materials is slowly moving in the deposition area at speed 5.4 km/hour. The time it takes the debris flow material to reach the depositional area is 891 seconds. The volume of debris flow material which flow reaches 127,735 m^3.

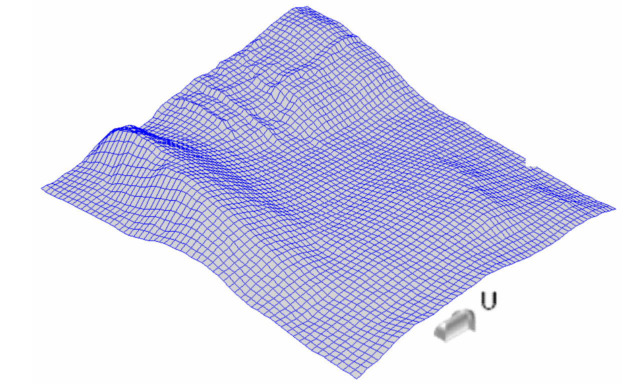

Figure 2 Topographic area around Pawinihan Hill

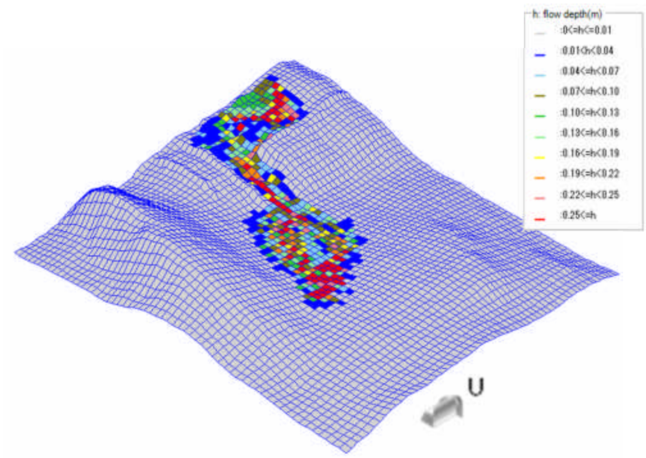

Figure 3 The distribution of debris flow with viscosity 0.45 at 891 seconds that seen from southeast

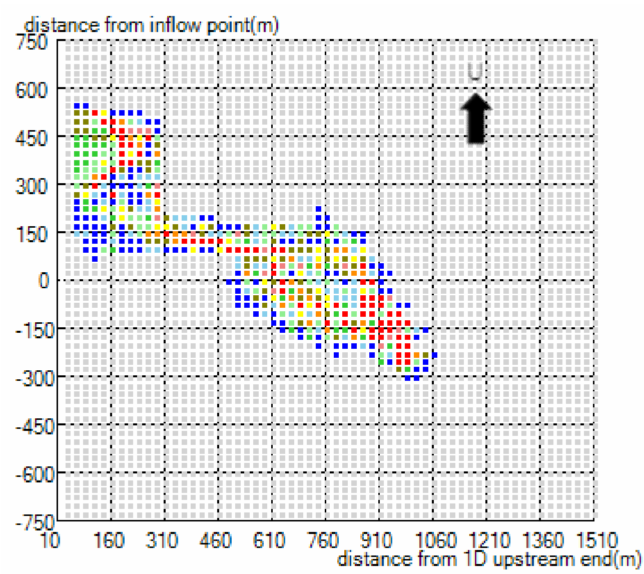

Figure 4 The distribution of debris flow with viscosity 0.45 at 891 seconds that seen from top

3.2 Jemblung Village, Banjarnegara, Central Java, December 12 2014

The location is on Jemblung Village, Banjarnegara Regency which has steep topography that has angle reached 75°. Landslide occurs in the southern slope of Jemblung Village with coordinate 7° 16' 51.6" S and 109° 43' 12.6" E. The victims died reached 95, 24 people missing, and dozens more injured. From December 9 to 11, Banjarnegara has high intensity of rainfall reached 100 mm. Material compilers in the slopes of Jemblung Village are Jembangan

Volcanics (Qj) which consists of Andesitic lava and volcaniclastic (Condo et al., 1996) and have largely been strongly weathered. These materials became source of the debris material. Figure 5 shows the debris flow area and surrounding area with 1 grid representing an area of 14.55 (west-east) x 15.31 (north-south) meters which seen from northeast.

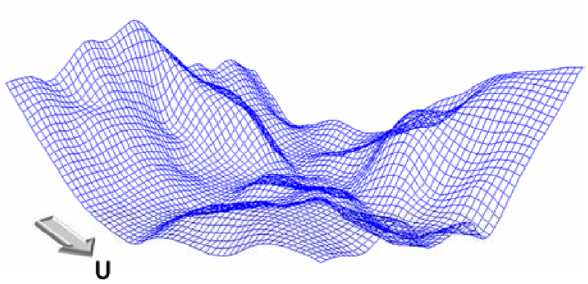

Figure 5 Topographic area northern Jemblung Village

The viscosity value of 0.5 became the closest scenario to Jemblung debris flow in 2014. The higher viscosity of the fluid is due to the volume of water flowing much more than the sedimentary material carried by the water stream. The sediment material carried by the debris flow has a relatively small size. Figure 6 and 7 show the distribution of debris flow material seen from the northeast and top. In the flow track, material speed is estimated to reach 66.14 km/hour. The volume of material flowing into the deposition area is estimated to reach 111,962 m^3 with an average speed of 16.53 km/hour. The time it takes the material to reach the deposition area is estimated for 420 seconds. The length of debris flow in JemblungVillage reached about 1 km.

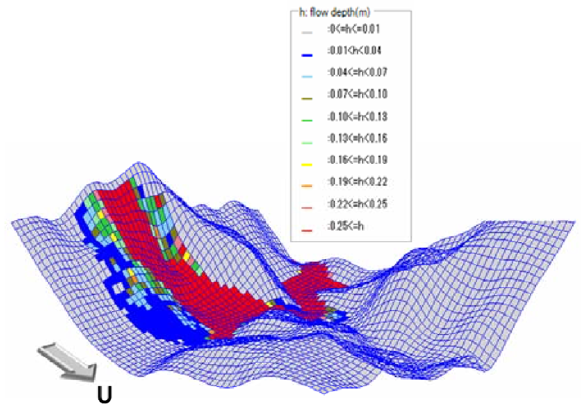

Figure 6 The distribution of debris flow with viscosity 0.5 at 420 seconds that seen from northeast

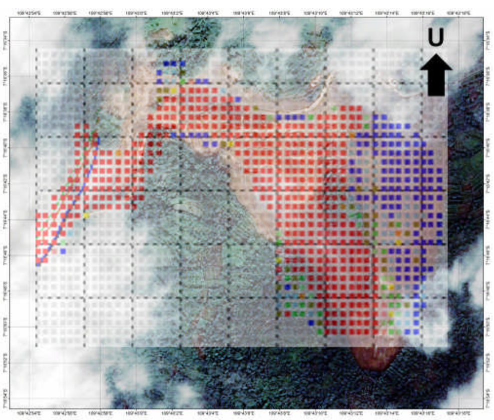

Figure 7 The distribution of debris flow with viscosity 0.5 at 420 seconds that seen from top which have been overlayed image after landslide from Pleiades (2004)

3.3 Pasir Panjang Village, Brebes, Central Java, February 22 2018

Landslide incident occurred in Pasir Panjang Village, Brebes Regency with coordinates 108° 47' 19.68" E and 07° 7' 6.59" S. Victims that recorded are 18 peoples who work as farmer in the southeast landslide location. Landslide occurs on hills morphology with steep slope. The hill consists of Tapak Formation which composed of greenish sandstone in the lower part that gradually grades upward into greenish sandstone with some intercalation of grey to yellowish sandy marl (Kastowo, 1975). The Landslide that flows toward southeast in slopes that have angle between 35° - 45°. Soil cover in the landslide location is light-reddish brown sandy clay with 5 m depth on top of dark grey marl. Figure 8 shows the geometry of the debris flow from southwest direction and topography around Pasir Panjang Village with 1 grid representing area 29.57 (east-west) x 25.35 (north-south) meters. The length of debris flow in Pasir Panjang Village reached about 2.3 km.

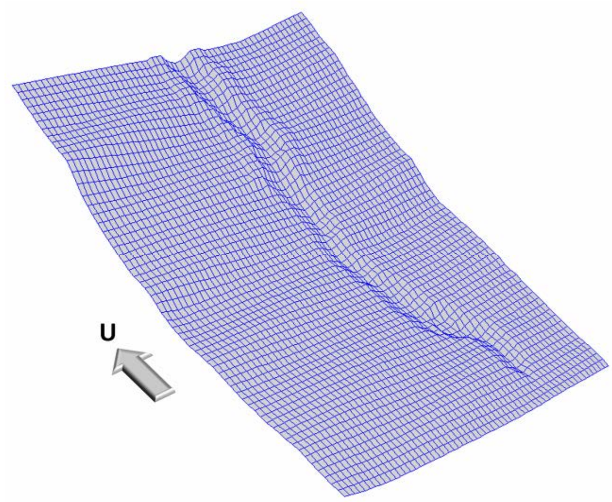

Figure 8 Topographic area northern Pasir Panjang Village

The scenario viscosity value of 0.38 shows the most closely of debris flow conditions. Materials flow with an average flow rate 8.68 km/hour on deposition area. Meanwhile in flow track, the flow rate reaching 25.58 km/hour. The volume of debris materials that flow from the slope is estimated about 275,295 m^3. In the deflection area, strong lateral erosion increase supply of debris materials. Figure 9 and 10 show the distribution of debris flow from the southwest and from the top. Depositional area which located southeast form the landslide location used as rice fields. The time needed for debris materials to reach the depositional area is estimated for 828 seconds.

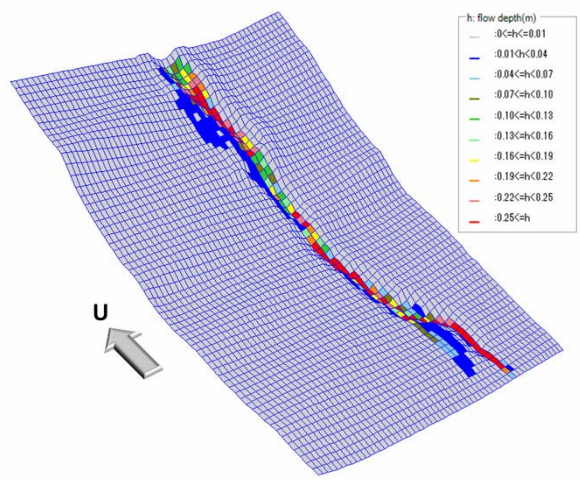

Figure 9 The distribution of debris flow with viscosity 0.38 at 828 seconds that seen from southwest

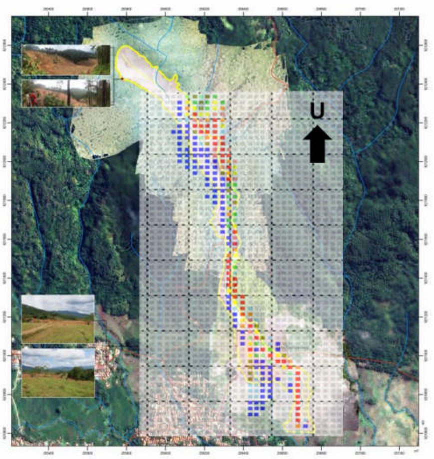

Figure 10 The distribution of debris flow with viscosity 0.38 at 828 seconds that seen from top which have been overlayed with Centre of Volcanology and Geological Hazard Mitigation (CVGHM) and Geospatial Information Agency (GIA) aerial mapping (2018)

4. CONCLUSION

All of the debris flow simulations were used to better understand with regard of predictions of volume, run-out mechanisms, flow rate of materials and the distribution of debris materials. Table 2 shows the viscosity, flow rate, volume of material and the length of flowing material closest to debris flow conditions of all cases.

Table 2 Summary of simulations were closest to debris flow conditions

Results	**Sijeruk Landslide**	**Jemblung Landslide**	**Pasir Panjang Landslide**
Viscosity	0.45	0.5	0.38
Flow rate in flow tract (km/hour)	21.17	66.14	25.58
Flow rate in depositional area (km/hour)	5.4	16.53	8.68
Volume of material (m^3)	127,735	111,962	275,295
Length of flowing material (km)	1.1	1	2.3

Debris flow in the Sijeruk Village has uniqueness in the flow path, which is encounter a sharp deflection. It is alleged that the deflection is caused by a ridge that blocks the flow track of the flowing material that move southeast. The ridge causes the direction of the flow that originally toward the southeast transformed to the east.

In Jemblung landslide, debris flow has higher viscosity of the fluid is due to the volume of water flowing much more than the sedimentary material carried by the water stream. The sediment material carried by the debris flow has a relatively small size.

In Pasir Panjang landslide case, it has the longest length of flowing material. It occurs because the volume material which flowing is very huge supported with relatively straight flow track in 35° - 45° of slope angle. Although it has smallest viscosity of all cases.

In general, the results of this study will be very useful to predict the run-out of any potential similar debris flows in some areas of Indonesia, especially in Central Java which might experience the similar events as well as the determination of mitigation measures to minimize the negative impact of these events

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