THE ANALYSIS OF SABO DAM PERFORMANCE AS A SEDIMENT CONTROL STRUCTURE IN PUTIH RIVER, MT. MERAPI

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ABSTRACT

Mt. Merapi's eruption which occurred on 26 October 2010 had disadvantageous impact for human life that live surrounds it. The primary disaster was pyroclastic cloud that destroyed villages surround it. In addition, the secondary disaster continuously became a threat for human life around the rivers that destroyed at Mount Merapi. One of the secondary disasters is Putih River's volcanic material overflowing into Yogyakarta-Magelang Highway. The series of Sabo dam which had been built along the river could not handle that phenomenon. Sabo dam was built and expected to accommodate volcanic material or at least to resist the velocity of volcanic material (sediment controlling), so the damage caused by the flow became relatively small. However, this function could not work at that phenomenon. In order to know the function of sediment control of Sabo dam in Putih River, it is necessary to study the performance of Sabo dam. This research used Kanako software ver. 2.04 and reviewed Sabo dam PU-D1 Mranggen and PU-C8 Ngaglik. There were four simulated scenarios in this research: a scenario without Sabo dam; with Sabo dam PU-D1 Mranggen; with Sabo dam PU-C8 Ngaglik, and the last with two of Sabo dams. The simulation was based on 23 January 2011 event and simulated for 18.000 s. From this research, it can be concluded that Sabo dam PU-D1 Mranggen can reduce the total volume passing through about 43,998.6 m^3 or 1.53 % for 5 hours, and reduce the sediment volume that passing through about 28,482 m^3 or 52.59 % for 5 hours. Sabo dam PU-C8 Ngaglik can reduce the total volume that passing through about 255.6 m^3 or 0.01 % for 5 hours, and reduce the sediment volume that passing through about 124.8 m^3 or 0.33 % for 5 hours, and Sabo dam PU-D1 Mranggen and PU-C8 Ngaglik in series can reduce the total volume that passing through about 2,340.6 m^3 or 0.08 % for 5 hours, and reduce the sediment volume that passing through about 157.8 m^3 or 0.41 % for 5 hours

Keywords: Cold Lava, Kanako software, performance of Sabo Dam

1 INTRODUCTION

The secondary disaster caused by Merapi eruption, continuously became a threat for human life around the rivers that disgorge at Mount. Merapi. One of the secondary disasters is Putih River's material overflowing into Yogyakarta-Magelang Highway. The series of Sabo dam built along the river could not handle that phenomenon. Sabo dam was built and expected to accommodate volcanic material, or at least to resist the velocity of volcanic material (sediment controlling), so the damage that caused by the flow became relatively small. However, this function could not work at that phenomenon. In order to know the function of sediment controlling of Sabo dam in Putih River, it is necessary to study the performance of Sabo dam. This research used Kanako software ver. 2.04.

This research was using one dimension analysis on production and transportation area and two dimension analysis on sedimentation area. This research reviewed Sabo dam PU-D1 Mranggen and PU-C8 Ngaglik, and was based on 23 January 2011 event.

This research has a goal to model the phenomenon that happens and knows the performance of Sabo Dam in sediment control function. This research is expected to prove that software Kanako can be used to analyze debris flow, so that the next research will be practical and cheaper.

2 LITERATURE REVIEW

2.1 Related Research

Sumaryono (2009), conducted a research about sabo dam planning in Cipanas using software Kanako Version 1.40. Their research concluded that Kanako Version 1.40 can describe debris flow phenomenon, and also analyze the performance of the proposed sabo dam. From the research, there were various debris flow discharges, final slope was produced various sabo dam types. The research concluded that the sediment discharge was reduced gradually downstream because the slope was decreased.

Nakatani (2009), conducted a research which simulated the debris flow disaster that occurred in Houfu, Yamaguchi Prefecture, Japan on 21 July 2009 using Kanako 2D. The model can simulate the disaster well, and simulate installed sabo dam as a solution for the mitigation. Moreover, the result showed that the sabo dam could control the disaster.

2.2 Debris Flow

Debris flows are extremely mobile, highly concentrated mixtures of poorly sorted sediment in water (Hübl, et al., 2009). The material incorporated is inherently complex, varying from clay sized solids to boulders of several meters in diameter. Due to their high density (exceeding that of water by more than a factor of two) and their high mobility, debris flows represent a serious hazard for people, settlements, and infrastructure in mountainous regions (Hübl, et al., 2009).

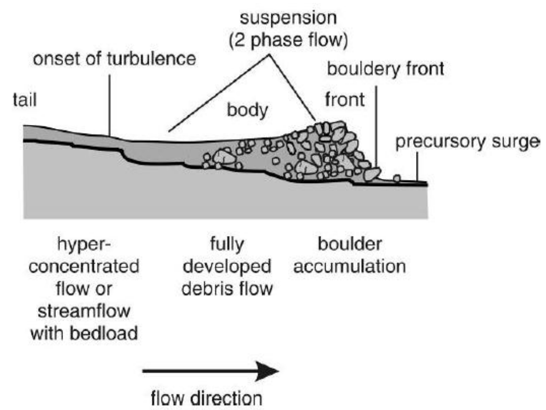

Figure 1. Sketch of debris flow surge

The head of debris flow usually consists of large gravel with greater height than the height of the following flow (Kang, 1985, in Wang, 1996). It was found from experiments that the particles' velocity in the front of the debris flow wave is lower than the particles moving in the following part and the propagation velocity of the debris flow wave is much lower than the flow velocity of the main body of the debris wave (Wang and Zhang, 1990).

One of parameters to determine debris flow criteria is a sediment concentration. Takahashi equation for equilibrium concentration of debris flow is described below,

$$C_d = \frac{\rho . \tan\theta}{(\sigma - \rho)(\tan\phi - \tan\theta)} \quad (1)$$

where C_d is the sediment concentration, ρ is the mass density, θ is the slope of the river bed, σ is the mass density of bed material, and Φ is the internal friction angle.

If the result obtained the value of $C_d > 0.9\ C_*$, so that $C_d = 0.9\ C_*$ is used. In addition, if $C_d < 0.2$, so that $C_d = 0.2$. (Nakatani, 2009)

2.3 Sabo Dam

Sabo dam functions as a sediment blocker, accumulator and controller and as a series, sabo dam creates a new slope, which can decrease the velocity so that the material settles at the upstream (International Sabo Network, 2011).

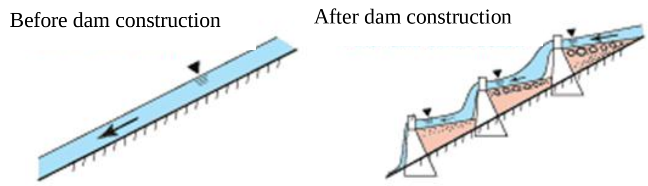

Figure 2. Influence of sabo dam

2.4 Software Kanako

This software was calculated in two parts. First is the calculation in production and transportation area using 1 Dimensional analysis, and the second is deposition area using 2 dimensional analysis (Nakatani, 2009).

The parameters used in this software are mass density of bed material, mass density of a fluid phase, gravity acceleration, concentration of movable bed, concentration of material, Manning's roughness coefficient, coefficient of erosion rate, coefficient of accumulation rate, and diameter of material.

2.4.1 Basic equation in software Kanako

The equations used in Kanako are

a) Momentum equation of x direction

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = g\sin\theta_{wx} - \frac{\tau_x}{\rho h} \quad (2)$$

where u is the x-axis direction flow velocity, θ_{wx} is the flow surface gradients in the x-axis, τ_x is the riverbed shearing stresses in the x-axis, g is the gravity acceleration, ρ is the mass density of fluid phase, and h is the flow depth.

b) Momentum equation of y direction

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = g\sin\theta_{wy} - \frac{\tau_y}{\rho h} \quad (3)$$

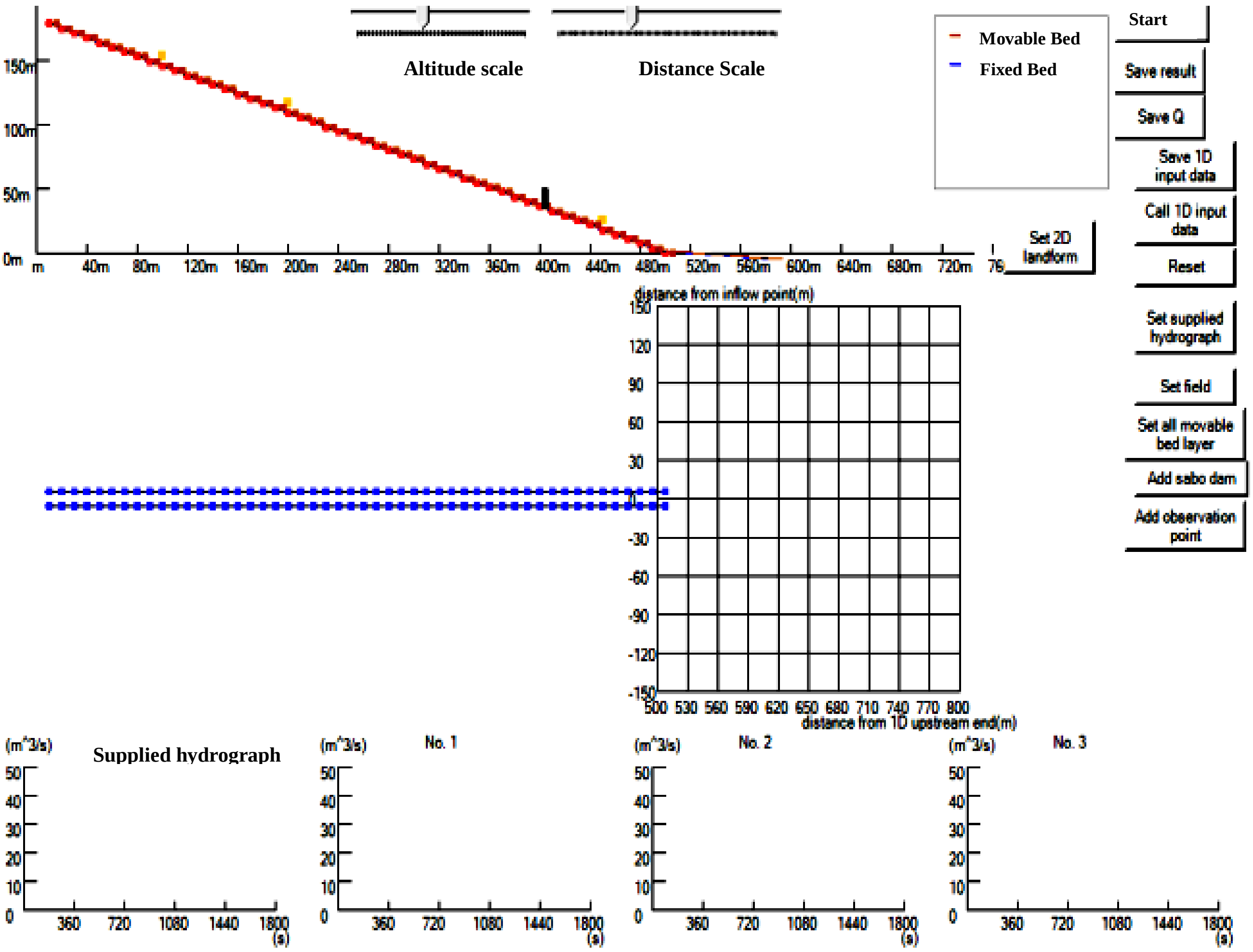

Figure 3. Appearance of Software Kanako

where v is the y-axis direction flow velocity, θ_{wy} is the flow surface gradients in the y-axis, and τ_y is the riverbed shearing stresses in the y-axis.

c) Continuation equation for the total debris flow volume

$$\frac{\partial h}{\partial t}+u\frac{\partial uh}{\partial x}+v\frac{\partial vh}{\partial y}=i \tag{4}$$

where i is the sediment erosion/deposition velocity.

d) Continuation equation for the material volume debris flow

$$\frac{\partial Ch}{\partial t}+u\frac{\partial Cu}{\partial x}+\frac{\partial Chv}{\partial y}=i.C_* \tag{5}$$

where C is sediment concentration by volume in debris flow and C_* is the sediment concentration by volume in movable bed layer.

e) Equation for determining change in bed surface elevation

$$\frac{\partial z}{\partial t}+i=0 \tag{6}$$

where z is the bed elevation.

f) Sediment erosion/deposition velocity (i)

In case of erosion,

$$i=\delta_e\frac{C_\infty - C}{C_* - C_\infty}\frac{q}{d} \tag{7}$$

where δ_e is the coefficient of erosion velocity, q is discharge of debris flow per unit width, d is mean particle size and C_∞ is equilibrium grain concentration.

In case of deposition,

$$i = \delta_d \frac{C_\infty - C}{C_*} \frac{q}{d} \tag{8}$$

where δ_d is the coefficient of deposition velocity.

g) Riverbed shearing stresses in the x-axis direction (τ_x)

For stony type debris flow ($C \geq 0.4C_*$)

$$\frac{\tau_x}{\rho h} = \frac{u\sqrt{u^2+v^2}d^2}{8h^3\left\{C+(1-C)\frac{\rho}{\sigma}\right\}\left\{\left(\frac{C_*}{C}\right)^{1/3}-1\right\}^2} \tag{9}$$

where σ is the density of material.

For immature debris flow ($0.01 < C < 0.4C_*$)

$$\frac{\tau_x}{\rho h} = \frac{1}{0.49}\frac{u\sqrt{u^2+v^2}d^2}{h^3} \tag{10}$$

For bed load transportation or turbulent-muddy-type debris flow ($C \leq 0.01$ or $h/d \geq 30$)

$$\frac{\tau_x}{\rho h} = \frac{g n_m{}^2 u\sqrt{u^2+v^2}}{h^{4/3}} \tag{11}$$

where n_m is the Manning's roughness coefficient.

2.4.2 Calculate the Discharge of Debris Flow

For calculating the discharge of debris flow, debris flow's 23 January 2011 event was analyzed. From the video, river width and flow depth can be predicted. Then using the Froude number equation, the discharge can be calculated.

$$F_r = \frac{Q}{\sqrt{g\left(\frac{A^3}{T}\right)}} \tag{12}$$

where F_r is the Froude Number, A is the area and T is the top width.

3 RESEARCH METHODOLOGY

Flow chart of research implementation is presented in Figure 4.

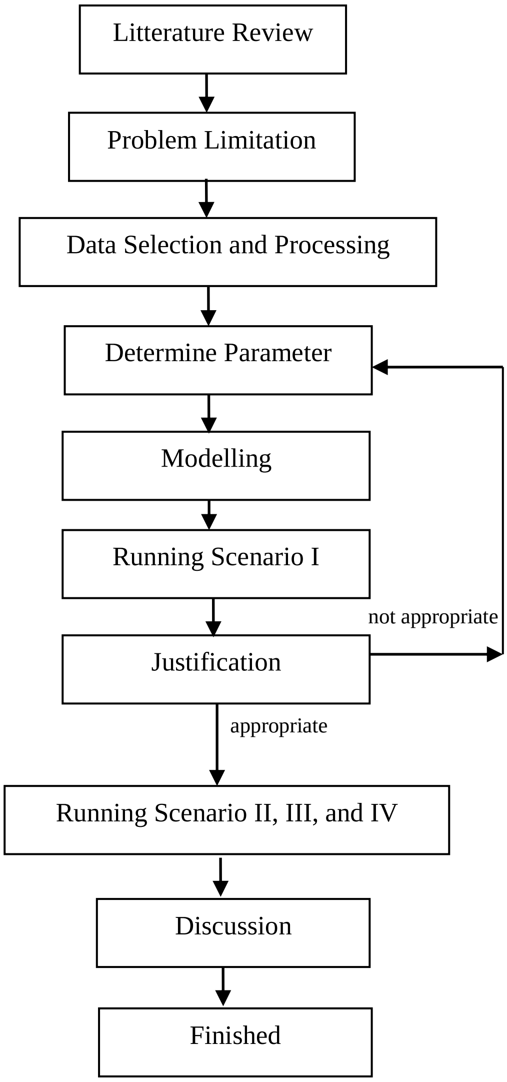

Figure 4. Flowchart of Research Implementation

3.1 Data and Debris Flow Parameter in Putih River

The research used long section data, cross section data and contour map Putih River's area. The values of C_* and C have to be determined to fulfill the continuation equation for the material volume debris flow. C_* is set to 0.65 due to the research which was done by Takahashi. Moreover, the value of C is set to 0.9 time C_*, it is 0.585. Gravity acceleration is 9.81 m/s^2, and mass density of bed material is 2,830 kg/m^3.

Coefficient of erosion rate was determined to be 0.0007 and coefficient of deposition rate was 0.05 based on Takahashi research (Nakatani, 2008).

Manning's roughness coefficient was determined based on survey and compared with photos which were collected by U.S. Geological Survey. The river bed material condition of Putih River was matched with one of the photos and the Manning's roughness coefficient is then set 0.03.

The characteristic of river material is described by diameter of material. The diameter is 10 mm.

Figure 5. Photo of Putih River (left) compared with one of photos from U.S Geological Survey (right) to determine Manning value

3.2 Boundary Condition

There is boundary condition in this research; hydrograph supply is needed in the upstream. This research is based on the 23 January event. The discharge and the time are predicted by watching the video. From the video, it was known that the flow depth was 1.5 m. There is supercritical flow happen, where the Froude number is greater than 1. The Froude number was determined as 2 (Hübl, et al., 2009), with the river width as 25 m, so that the discharge can be calculated.

$$Q = F_r\sqrt{g\left(\frac{A^3}{T}\right)} = 2.\sqrt{9.81\left(\frac{(2.5x1.5)^3}{25}\right)} = 287.7m^3/s$$

The peak discharge is 287.7 m^3/s and the simulation time is 5 hours. There was a constraint to determine the hydrograph; the volume was predicted 2.5 million m^3 so that the hydrograph can be determined.

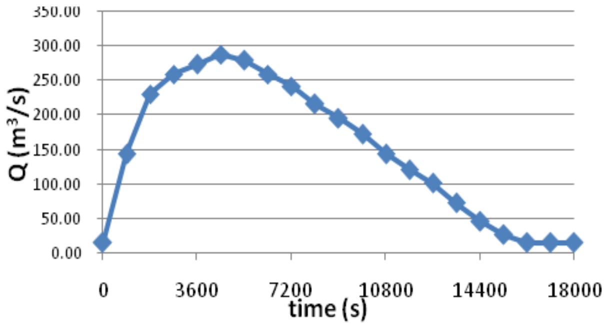

Figure 6. Hydrograph of Debris Flow

3.3 Modeling

The areas in this research consist of Sabo dam PU-D1 Mranggen and Jogja-Magelang national road. 1D area is shown by upstream dotted lines, and 2D area is shown by downstream dotted lines. Kanako provides 100 point of calculation in 1D area.

Fixed bed altitude, movable bed altitude and river width are needed to model 1D area. The interpolated river bed data are used to fill movable bed altitude data, while the river width was determined 25 m.

The 2D area was determined from 240 m of Sabo PU-C8 Ngaglik's downstream till 150 m Jogja-Magelang Highway's downstream. The area was 600 m x 900 m and the interval was 15 m. Therefore, there was 2400 point. Figure below shows the 2D area model.

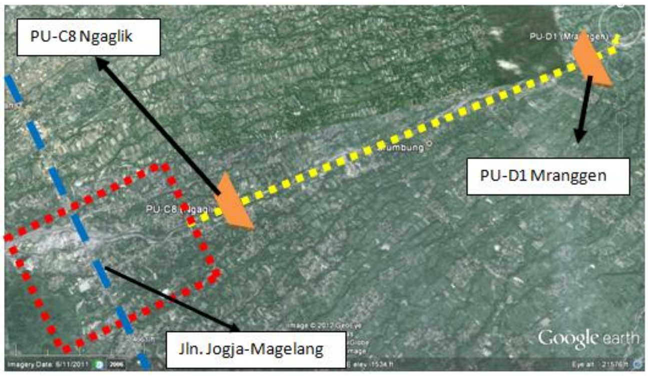

Figure 7. Area of Putih River being analyzed

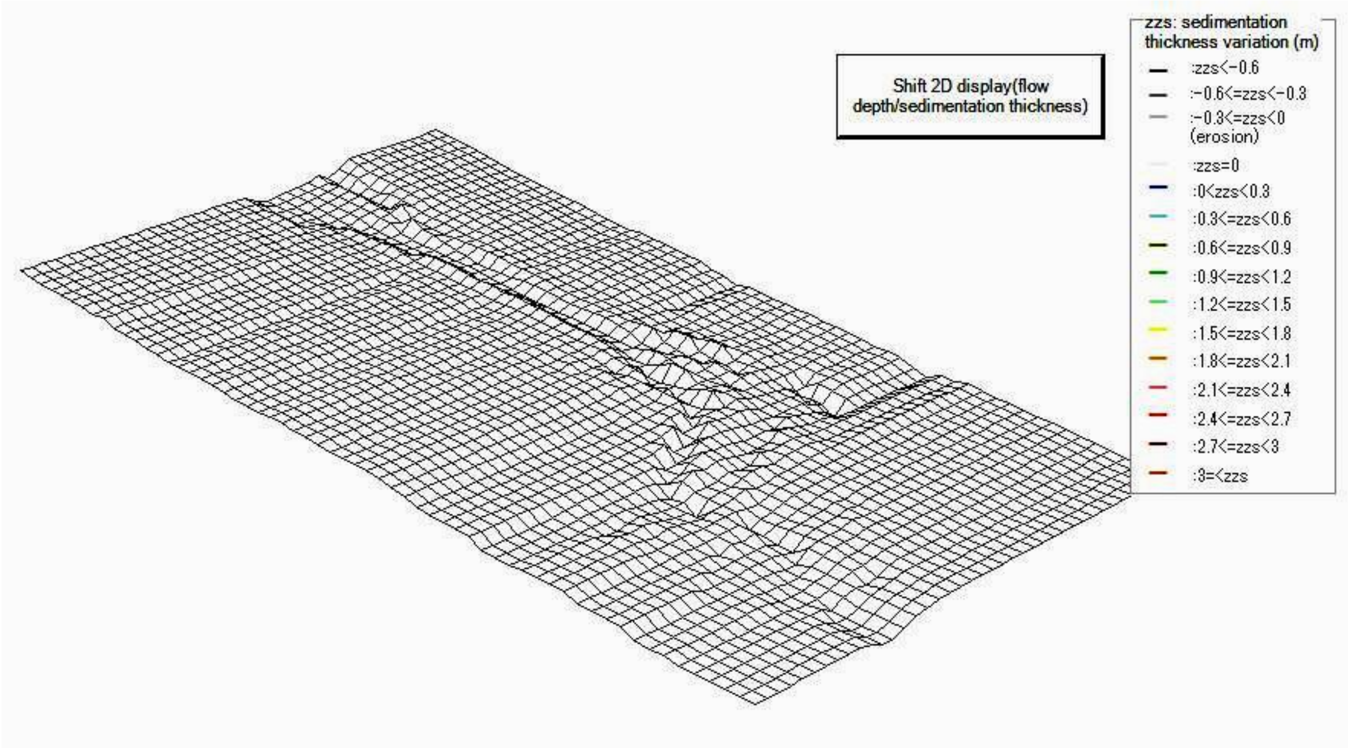

Figure 8. Appearance of 2D Model

This research only reviewed two of Sabo dams, the below table (Table 1) describes about them (DGWR, 1992).

Table 1. Data of Sabo Dam

Name	Type of Sabo	Height of Sabo Dam
PU-D1 Mranggen	closed	7 m
PU-C8 Ngaglik	closed	2 m

3.4 Scenario of Simulation

To obtain the performance of Sabo, there were four scenarios in this research (see Table 2).

Table 2. Scenarios of Simulation

Scenario	PU D1 Mranggen	PU C8 Ngaglik
I	Not installed	Not installed
II	Installed	Not installed
III	Not installed	Installed
IV	Installed	Installed

3.5 Justification

There was no calibration in this research. Safety was the main factor not to record the variable used to calibrate. This research uses justification, to judge the model whether seemly appropriate with the real or not.

4 RESULT AND DISCUSSION

4.1 Model

The model uses 100 point of calculation in 1D area, with 60 m interval's distance (see Figure 9). In the 2D area, 600 m x 900 m was modeled with 15 m interval's distance. Sabo PU-D1 Mranggen was modeled at point 4, and Sabo PU-C8 Ngaglik at point 94. Concentration of sediment was 0, not brought the sediment.

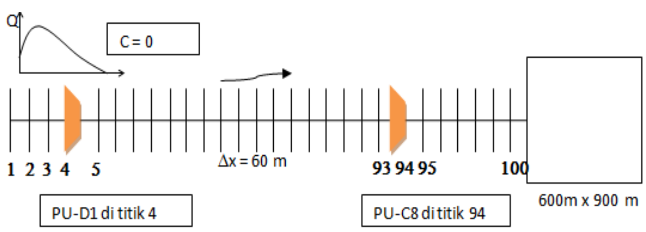

Figure 9. Sketch of Modeling

4.2 Result of Modeling

The material can be transported until 2D area (see Figure 10).

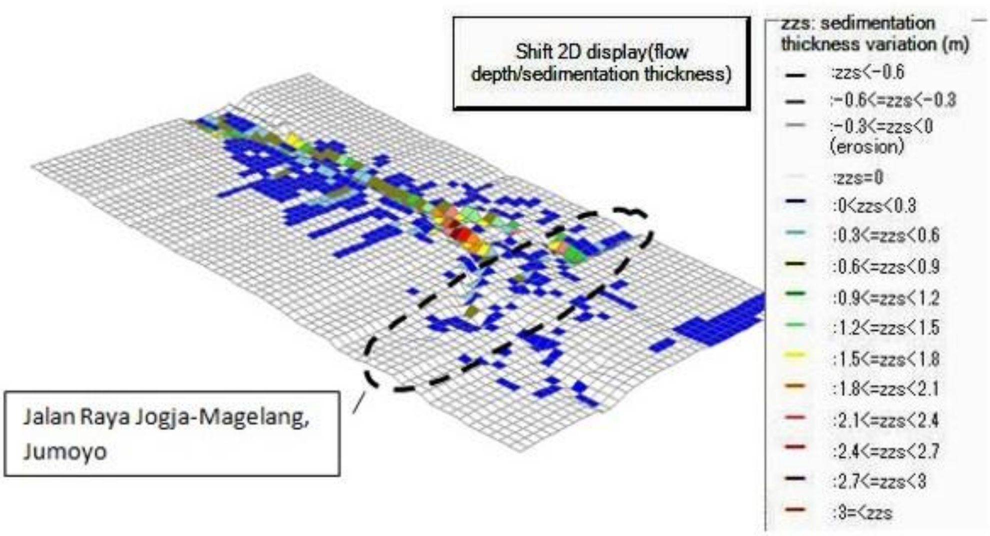

Figure 10. Spread of Sediment Thickness in 2D Area (t = 12,369 s) – Scenario I

Sabo dam has an influence to the change of the riverbed (see Figure 11 and Figure 12).

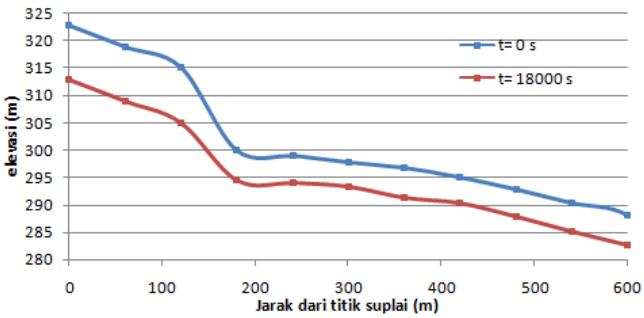

Figure 11. River Bed Level (Distance from supply point 0-600 m) – Scenario I

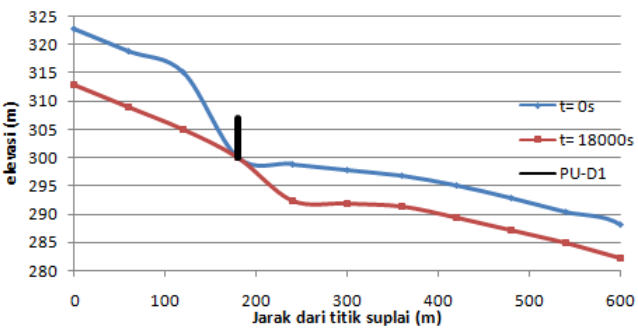

Figure 12. River Bed Level (Distance from supply point 0-600 m) – Scenario II

4.3 Performance of Sabo Dam

There were four scenarios simulated, so the performance of Sabo can be obtained.

a) Sabo dam PU-D1 Mranggen can reduce the total volume passing through about 43,998.6 m^3 or 1.53% for 5 hours, and reduce the sediment volume that passing through about 28,482 m^3 or 52.59% for 5 hours
b) Sabo dam PU-C8 Ngaglik can reduce the total volume passing through about 255.6 m^3 or 0.01% for 5 hours, and reduce the sediment volume passing through about 124.8 m^3 or 0.33% for 5 hours.
c) Sabo dam PU-D1 Mranggen and PU-C8 Ngaglik in series can reduce the total volume passing through about 2340.6 m^3 or 0.08% for 5 hours, and reduce the sediment volume that passing through about 157.8 m^3 or 0.41% for 5 hours.

5 CONCLUSION

a) Software Kanako Version 2.4E can be used to simulate the debris flow events, for erosion, deposition, and material transportation, however, accuracy is needed due to parameters (velocity, discharge and concentration) changing that happen extremely.
b) The difference of material transportation process between first, second and third model shows that the concentration of sediment influences the erosion, deposition and material transportation.
c) Third model is received because there was no extreme sediment thickness and the material can be transported until 2D area.

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