

Estimation of Debris Flow Sedimentation Volume Through Numerical Modelling

Heirlina Mawarni Jamri¹, Siti Norafida Jusoh², Aminaton Marto³, Kamarul Azlan Mohd Nasir⁴, Muhammad Azril bin Hezmi² and Khairun Nissa Mat Said²

¹ Highway Division, Malaysian Public Works Department, Johor Bahru

¹ Department Geotechnics and Transportation, School of Civil Engineering, UniversitiTeknologi Malaysia, Johor Bahru, MALAYSIA

² Department of Environmental Engineering & Green Technology, Malaysia-Japan International Institute of Technology, UniversitiTeknologi Malaysia Kuala Lumpur, MALAYSIA

³ Department Water, School of Civil Engineering, UniversitiTeknologi Malaysia, Johor Bahru, MALAYSIA

(E-mail: azril@utm.my)

Abstract. Implementation of potential debris flow hazard in Malaysia has been conducted by JabatanKerja Raya (JKR) in 2011. However, evaluation of this hazard level cannot deny the consequent to the nearest facilities. Thus, run-out analysis based on numerical modelling is easiest and competent way to evaluate the risk level. This paper presents a study on debris flow sedimentation volume with and without sabo dam by numerical simulation using Kanako 2D software. Kanako 2D software is widely being used in Japan and it is equipped with graphical user interface (GUI). A crossed verification upon numerical modelling and actual field data collection, and mitigation situation model that include sabo dam has been conducted. Results showing that Kanako 2D software have a precise output where the sedimentation volume is slightly higher around 5-15 %. It also proven that sabo dam can reduce the impact of debris flow because it can bear the sedimentation volume about 91%. In speeding up the process of setting landform in Kanako 2D, it recommended to use GIS to generate appropriate data. Thus, a laser scanning of topographical data is required.

1. Introduction

A debris flow could be defined as a mixture of loose soil, rocks, trees and muddy water that flows from hillside to lower ground due to repulsive force (Hung, 2005; Takahashi, 2007). It is one type of sediment related disaster besides landslide and slope failure (JICA, 2014). The velocity of debris flow can have speed between 20 to 40 km/h (JICA, 2014). Debris flow usually occurs in steep valley between hills, it's having steep channel bed, it has wide watershed area, occurs at weak geological condition at channel slope or along the channel bed and it involve long run out distance (Abdullah *et al.*, 2015). These entire characteristic plays important role to determine level of debris flow impact (Wilford *et al.*, 2004; Wang *et al.*, 2018).



Heavy rainfall can make worse of the condition. Therefore, in Malaysia, with high precipitation rainfall in a year and complex geological earth profile, it is important to investigate the occurrence and effects of debris flow. In the meantime, hazard assessment is an indication of potential damaging event or phenomena. Risk assessment is indication the probability of harmful consequence or expected losses (JabatanKerja Raya, 2009). Therefore, it is important to generate risk map as one of decision making tool. Assessment of risk debris flow is difficult without assistance from numerical modelling. Impact of debris flow can be visualize and measure effortlessly and effectively with the application of numerical simulation method (Jakob, 2005; Lin *et al.*, 2011; Liu *et al.*, 2013; Wang *et al.*, 2018). The advantages of numerical simulation are set up the modelling quickly, calculate easily and faster, result is quick and display it clearly (Wang *et al.*, 2018; Liu *et al.*, 2013; Meloet *al.*, 2017). In addition, numerical simulation can estimate travelling time of the debris flow. Combination of travelling time with early warning system give precautious action such as evacuation can be taken timely (Jakob, 2005). As numerical modelling method can provide required measurement in easy and faster way plus great visualization of debris flow simulation, this method was adopted. Thus, there is a need to have crossed verification upon numerical modelling and actual field data collection in order to have a precise outcome which will result in constant authentication.

There are several numerical simulations of debris flow applications and each application has its own advantages and drawbacks. For this research, Kanako 2D Debris flow simulator will be used. Therefore, in this study, a verification of sedimentation volume of debris flow modeling via debris flow simulation Kanako 2D to the actual field data is carried out. The objectives of this study are to identify debris flow channel, alluvial fan and watershed area using GIS software, to determine the percentage difference of sedimentation volume between actual field data and numerical modelling using debris flow simulator Kanako 2D software and to verify the effectiveness of sabo dam in reducing sedimentation volume. The purpose from this study is to have legibility of debris flow hazard and risk assessment. A debris flow event was chosen which is in SimpangPulai, Cameron Highland as a case study.

2. Case Study

The site for selected case study is located at KM 33, JalanSimpangPulai (FT 185), Cameron Highland. This site is a part of main range that forms the backbone of Peninsular Malaysia. It has been reported was strike by debris flow event on 12 April 2006. Due to this catastrophic event, all activities in Cameron Highland was put into a halt and affected mostly economic activities as Cameron Highland was famously known as tourist spot and agricultural sites. This event almost claimed casualty to a local patron who was driving from Brinchang (Bernama, 2006). Figure 1 shows aftermath photos of the disaster of upstream, downstream and illustration of section at the debris flow event. The debris flow consisted of mud, gravel and driftwood. In addition, there was a sign of shallow landslide at the upper area. Based on JKR report (2011), the channel bed gradient is recorded more than 30° and the average width is 7.9 m. Maximum grains size found at site are 100 cm while the minimum is 10 cm. The channel length measured is 463 m and the measured sedimentation volume is 1752 m^3 .

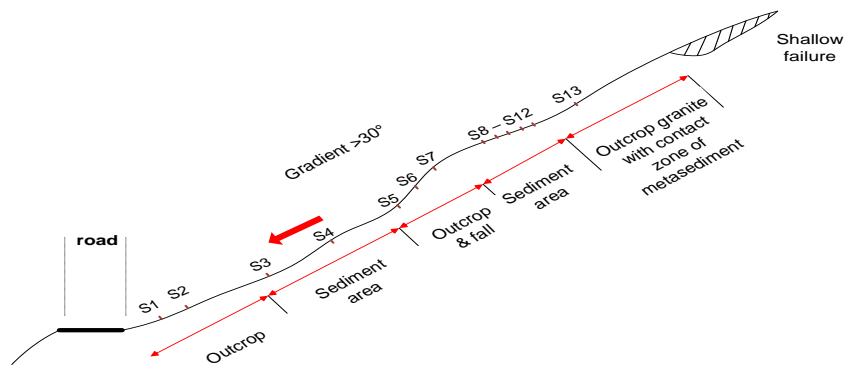
Laboratory test of soil indicated type of soil at this site is Silty SAND with little of gravel (JKR, 2011). Rainfall record was procured from Meteorology Department of Malaysia which specifically referred to rainfall station no. 42421 located at MARDI, Cameron Highlands. The location of rainfall station was 15 km from the site. Cumulative rainfall for a week was recorded at 209.3 mm and the highest rainfall was 76.6 mm on 6th April 2006.



(a)



(b)



(c)

Figure 1. Picture of debris flow event at KM33 SimpangPulai (a) at top of the upstream, (b) at downstream where is nearby road, (c) illustration of cross section. (JabatanKerja Raya, 2011)

3. Numerical Simulation in Kanako

Simulation process in Kanako 2D is shown as Figure 2. Two different modelling have been developed for a green field condition modelling (without sabo dam) and mitigation modelling (with addition of sabo dam). Each of modelling was simulated with two (2) different value of peak discharge. In setting supplied hydrograph, this study adopted two (2) different method to calculate debris flow peak discharge (Q_{sp}) which are i) based on sediment run-off (method 1) or ii) based on rainfall (method 2) (MLIT,2007).

4. Result and Discussion

Output in Kanako 2D were flow depth, velocity and sedimentation thickness. Flow depth is debris flow intensity related to velocity to see the impact of debris flow pressure (Hürlimann et al., 2006). Whereas, sedimentation thickness is affected the channel or alluvial fan bed after debris flow where erosion and deposition usually occur. This result was available in display image and CSV format. In order to obtain sedimentation volume, total thickness of each grid will times grid interval widths which depend on the setting. In this case study the setting for interval of 2D-x and 2D-y is 5 m x 5 m.

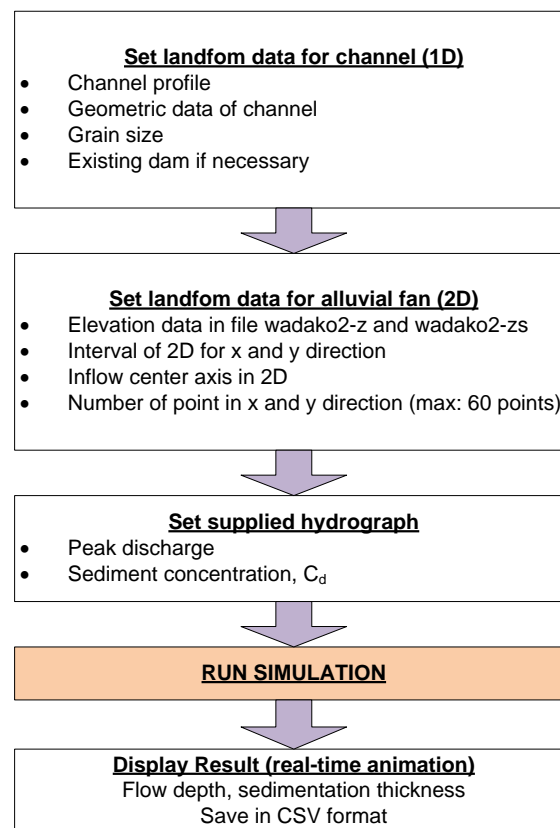


Figure 2. Kanako 2D stages of complete simulation

4.1 Green field modelling results

In 2D landform, the simulation indicates the debris flow spreads in road area and continues to flow downstream and stop until it reaches flat area. Figure 4 shows the pattern of flow depth and sedimentation volume for both peak discharges. From the image, flow depth or sedimentation thickness only show insignificant changes. Based on the result, sedimentation thickness is more than 3 m near to the reference point and the total of sedimentation volume are 2013m³ for $Q_{sp.A}$ and 1844 m³ for $Q_{sp.B}$. Both numerical simulation results were then compared to sedimentation volume measured on actual field and it was shows that both numerical simulation results obtain slightly higher which is around 5% to 15%.

4.2 Mitigation modeling result: Sabo Dam

A total of three (3) numbers of closed type sabo dam with 15 m height with respective locations were proposed in the modelling (Figure 3). Locations of sabo dam were positioned. The other input parameters and variables are set similar as green field modelling. Differ to simulation of debris flow without sabo dam, this modelling shows the debris flow is not spreading to the nearby road. The sediment is concentrated in one location which is after reference point. The sedimentation volume for both peak discharges is similar which is 172 m³. Comparison between debris flow modeling without sabo dam shows that addition of sabo dam can reduce sedimentation volume more than 90% (Table 1). Hence, the result proves that with an addition of sabo dam it can reduce the impact of debris flow at alluvial fan area. In addition, it lowers the risk ranking of debris flow in this area.

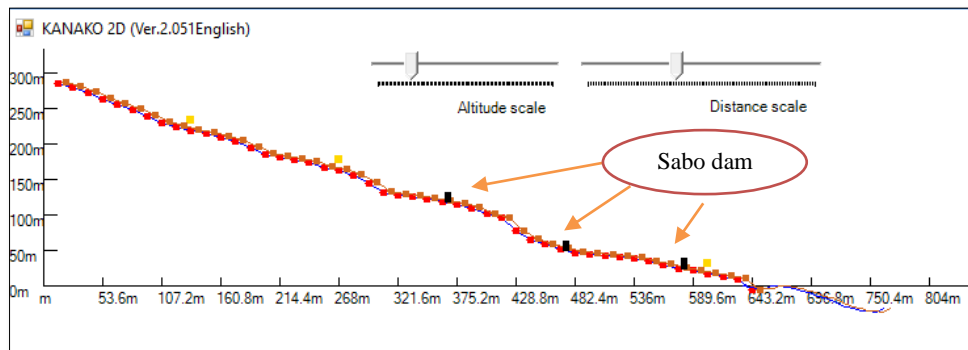


Figure 3. Embedded of sabo dam to reduce the debris flow and sedimentation volume in Kanako

Table 1. Summary of sedimentation volume and their comparison

Supplied hydrograph	Actual Field Data	Modelling without sabo dam (real situation)	Percentage different (actual field data)	Modelling with addition of sabo dam (mitigation)	Percentage different (real situation)
	A	B	(A – B)	C	(B – C)
$Q_{spA} = 18.19 \text{ m}^3/\text{s}$	1752 m^3	2013 m^3	14.90 %	172 m^3	91.46 %
$Q_{spB} = 16.76 \text{ m}^3/\text{s}$		1844 m^3	5.25 %	172 m^3	90.67%

5. Conclusions

The results obtained and the comparison made in this study has drawn some conclusions as follows:

- 1) Determination of watershed becomes easy, faster and highly accurate using GIS because data was interpreted and extracted directly from LIDAR data. Watershed area playing important role in calculating peak discharge based on rainfall. The bigger the watershed, the higher the peak discharge and this lead to accumulate high impact debris flow.
- 2) Kanako 2D was successfully verified that it produces reasonable result and can show the sediment spreading at alluvial fan. In addition, travelling time of the debris flow also can be estimate. Thus, it support finding that impact of debris flow can be visualize and measure effortlessly and effectively with the application of numerical simulation method (Jakob, 2005; Lin *et al.*, 2011; Liu *et al.*, 2013; Wang *et al.*, 2018). Result of cross verification upon numerical modelling and actual field data shows that numerical modelling had slightly higher 5-15% sedimentation volume. It indicate that performance of Kanako 2D is accurate and precise. Indirectly, it also gives assurance to legibility of hazard map which in turn will have implication on deciding the priority for slope remedial work and finally predicting the hazard level. However, this result is depending on input of peak discharge in Kanako 2D. Thus, it was recommended to use both methods to calculate peak discharge in order to cross check the value.
- 3) Percentage different of sedimentation volume between real situation modelling (debris flow model withoursabo dam) with mitigation modelling (model with sabo dam) is more than 90%. Itshows that sabo dam was successfully in reducing the impact of debris flow. However, this percentage is depending on dimension, type, numbers and location of the sabo dam in the channel. In order to get less sedimentation volume, sabo dams have to be positioned randomly as try and error until reaching the volume required. In real mitigation case, peak discharge for designing sabo dam was calculated based on hundred years of the 24 hour rainfall return period.

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