ESTIMATION OF DEBRIS FLOW SEDIMENTATION VOLUME THROUGH NUMERICAL MODELLING

HEIRLINA MAWARNI BINTI JAMRI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Geotechnics)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JANUARY 2019

DEDICATION

This project report is dedicated to my mother, Saadiah binti Abd. Rashid, who continually provides her moral support, spiritual, emotional and gave me strength when my spirit dwindled and almost gave up. I also dedicated this project to my late father, Jamri bin Ajar, who has been a source of inspiration

ACKNOWLEDGEMENT

My full gratitude towards Allah The Almighty, The Most Gracious Most Merciful for providing the path and guidance in completing my research. I would also like to extend my heartfelt gratitude and appreciation to the people who provided assistance to me directly and indirectly in materializing this study. First, I would like to thank my main supervisor, Dr. Siti Norafida binti Jusoh for her guidance and always open whenever I ran into trouble or had questioned about my research or writing. Not to forget, Prof. Dr. Aminaton binti Marto as my co-supervisor for steering me in the right direction whenever I needed it. A big thanks to Mr Kamarul Azlan bin Mohd Nasir as he taught me about hydrology as part of this study.

Second, I must thank to the experts, Dr Maziah Mohammad, Datuk Ir Dr Che Hassandi bin Abdullah, Ir Hj Shabri Shaharom, Ir Wan Ibrahim, Ir Edayu Salleh and Mr Roslan Majid from Jabatan Kerja Raya who had encouraged me to further my studies. I would also like to thank Mr Mohd Izzham bin Ismail, Mr Ahmad Ashraf bin Yusof and Mr Azmi bin Mamat as they always help in setting up modelling using Kanako 2D software, writing thesis and the right procedure in using GIS software.

Finally, I must express my very profound gratitude to my mother and family for providing me with unfailing support and continuous encouragement. I am filled with hope that this paper will be able to become reference and benefit those wanted to learn and delve into slope related study.

ABSTRACT

Implementation of potential debris flow hazard in Malaysia has been conducted by Jabatan Kerja Raya 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 the easiest and competent way to evaluate the risk level. There are more than 10 cases reported regarding debris flow occurrence from 1995 until 2015 in Malaysia. All these cases have caused severe damage to facilities and have involved a huge number of fatalities. Hence, an effective strategy is required on reducing the impact from these damages especially debris flow catastrophe. One of the structural measures for debris flow is a Sabo dam. This study 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 used in Japan and it is equipped with graphical user interface. A crossed verification upon numerical modelling and actual field data collection, and mitigation situation model that include Sabo dam has been conducted. Results show that Kanako 2D software has a precise output where the sedimentation volume is slightly higher in the range of 5 to 15 % compared to actual field data. It also proved that Sabo dam can reduce the impact of debris flow as it can bear the sedimentation volume about 91%.

ABSTRAK

Pembangunan tahap bahaya bagi potensi aliran puing di Malaysia telah dijalankan oleh Jabatan Kerja Raya pada tahun 2011. Walau bagaimanapun, penilaian terhadap tahap bahaya ini tidak dapat menidakkan pentingnya risiko atau impak aliran puing terhadap fasiliti berhampiran. Oleh itu, adanya keperluan untuk menilai risiko dengan penggunaan aplikasi numerik yang dapat memodelkan dan memberi keputusan dengan kadar segera dan lebih kompeten. Lebih dari 10 kes aliran puing telah direkodkan di Malaysia sejak tahun 1995 hingga 2015. Kesemua kes ini memberi kesan yang besar terhadap ekonomi dan ada antaranya melibatkan kadar kematian yang tinggi. Maka, satu strategi yang berkesan bagi mengurangkan impak aliran puing amat diperlukan. Salah satu strategi mengurangkan impak aliran puing adalah pembinaan empangan Sabo. Kajian ini telah memodelkan aliran puing menggunakan aplikasi Kanako 2D. Model dibina dalam dua keadaan iaitu keadaan sebenar (tanpa empangan Sabo) dan dalam keadaan terkawal (beserta empangan Sabo) bagi mendapatkan jumlah isipadu sedimen yang terhasil akibat aliran puing. Aplikasi Kanako 2D dilengkapi dengan grafik yang mudah difahami dan ianya telah digunakan secara meluas di Jepun. Verifikasi aplikasi ini dibuat dengan membandingkan isipadu sedimen yang dihasilkan dari model numerik dengan data sebenar ditapak. Bagi model keadaan terkawal iainya bertujuan melihat keberkesanan empangan Sabo dalam mengurangkan isipadu sedimen. Keputusan menunjukkan perbezaan jumlah isipadu antara model numerik dan isipadu sebenar di tapak adalah 5 hingga15 %. Manakala verifikasi kedua telah membuktikan bahawa dengan wujudkan empangan Sabo, isipadu sedimen dapat dikurangkan sehingga 91 %.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Kanako 2D	-	Debris flow simulation software
JICA	-	Japan International Cooperation Agency
MLIT	-	Ministry of Land, Infrastructure, Transport and Tourism
JKR	-	Jabatan Kerja Raya, Malaysia
NSMP	-	National Slope Master Plan (Malaysia)
Sabo	-	Sand protection or Sustainable Actions Basin Oriented
LIDAR	-	Airborne Laser Scanning
DTM	-	Digital Terrain Model
DEM	-	Digital Elevation Model
GIS	-	Geographic Information Systems

LIST OF SYMBOLS

τ	-	shear stress
c	-	soil or gravel cohesion
δ	-	normal stress
u	-	pore water pressure
ϕ	-	internal friction angle
h	-	thickness of accumulated layer
C_d	-	concentration of material ($0.3 \leq C_d \leq 0.54$)
C_*	-	concentration of moveable bed (approx. 0.6),
σ	-	mass density of bed material (kg/m3),
ρ	-	mass density of fluid phase (kg/m3),
φ	-	internal friction angle (degrees),
θ	-	channel bed gradient (degrees).
C_o	-	Cohesive component
μ	-	coefficient of viscosity
dv/dz	-	velocity gradient
$f(c)$	-	function of sediment concentration
τ_y	-	yield shear stress which not depend on velocity gradient
d	-	grain size in diameter
l	-	mixing length
v	-	velocity
Q_{sp}	-	debris flow peak discharge (m^3/s),
ΣQ	-	total discharge of debris flow (m^3),

V_{dqp}	-	sediment predicted to be run-off by a single wave debris flow (including voids) (m^3),
Q_p	-	discharge of clear water under rainfall (m^3/s),
K_q	-	coefficient,
P_{24}	-	rainfall intensity (mm/daily),
K_{f1}	-	peak run-off coefficient
K_{p1}	-	coefficient (120)
A	-	watershed area (km^2)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Debris flow is a movement of mass or slurry comprising of loose soil, rock, and water to down slope. It is capable of moving trees, boulder and even structures because of the momentum generated under the influence of the gravity. In Malaysia, debris flow is referred as mud flow or in other word, landslide.

Debris flow usually occurs when unstable soil from hillside collapsed and blocked the valley area. Heavy rainfall will worsen the condition whereby when water level becomes too high causing overflow, weakening the already unstable debris eventually leading to flow down. Normally the flow stops at region 2° to 3°gradient (JICA, 2014).

The worst debris flow cases recorded in Malaysia were in 1996 at Pos Dipang, Perak and Keningau, Sabah. 38 fatalities with estimated damage cost about RM69 million for the former and 302 fatalities with estimated damage cost about RM459 millions for the latter.

In Japan, a comprehensive contingency plan and countermeasures are conducted after experiencing countless losses on debris flow-related incidents in the past. Early mitigation measures have been carried out such as early warning system and evacuation system, producing hazard map and designation of special team based on Sediment Disaster Prevention Act, raising awareness of residents and locals to ensure that they are well aware with the hazard map, and the expansion of Sabo dam especially at debris-flow prone areas (JICA, 2014).

Cawangan Kejuruteraan Cerun, Jabatan Kerja Raya (JKR) had started to study and understand the elements and factors of debris flow since 2008 with cooperation of Japan consultant. A report on triggering factors of debris flow in Malaysia was produced in 2010 (Jabatan Kerja Raya, 2011). A plan of producing hazard map for potential debris flow for all Federal Route in Malaysia is already in the arrangement and JKR is planning to launch the hazard mapping monitoring system in the near future.

Therefore, as initiative, JKR has done a pilot project in producing potential debris flow map for selected federal routes. This potential debris flow was digitized purely from Airborne Laser Scanning Data (LIDAR) integrated with Geographic Information System (GIS) which has no physical verification on site.

Physical verification of potential debris flow on site is difficult and effect on time consuming. It requires vast man-hour to verify all components of identified slopes and sometimes can be risky for high slopes. As an alternative, verification using numerical modelling is put forward. This type of verification will give stronger prediction of the type of hazard and the mitigation measures should there be any incidents.

1.2 Problem Statement

Hazard assessment is an indication of potential damaging event or phenomena, while risk assessment is an indication the probability of harmful consequence or expected losses (Jabatan Kerja Raya, 2009). Therefore, it is important to potential debris flow generate risk map as one of the decision making tool in mitigation work. Assessment of risk debris flow is difficult without assistance from numerical modelling. As numerical modelling method can provide required measurement in an easy and faster way plus interactive visualization of debris flow, this method was adopted. It can visualize pattern of debris flow spreading at alluvial fan. However, 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.

1.3 Objective

The aim of this study is to verify sedimentation volume of debris flow in Kanako 2D simulation with actual field data using. The objectives of this study are:

i. To identify debris flow channel, alluvial fan and watershed area by using GIS software

ii. To determine the percentage difference of sedimentation volume between actual field data and numerical modelling using debris flow simulation Kanako 2D software

iii. To verify the effectiveness of Sabo dam in reducing sedimentation volume via Kanako 2D software

1.4 Significance of the Study

This study focus on verification of debris flow sedimentation volume between Kanako 2D simulation and actual site study. This verification will give assurance to legibility of hazard and risk map, which in turn will have implication on deciding the best method for mitigation work in future.

1.5 Scope of the Study

A case study located at Simpang Pulai, Cameron Highland is used to verify the sedimentation volume. The debris flow incident occurred in 12 April 2006 at KM 33, Jalan Simpang Pulai-Cameron Highland Highway. There were no casualties reported and the total estimated loss was around RM 354.65 million. The catastrophe led to gridlock to all vehicles and many activities in Cameron Highland were affected. Site investigation and geotechnical forensic work were carried out by Cawangan Kejuruteraan Cerun, Jabatan Kerja Raya to determine the cause of the incident.

In this study, numerical modelling is used to verify the sedimentation volume by using debris flow simulation Kanako 2D. This software has been widely used especially in Japan due to its proven result in showing the best solution in providing countermeasures of the failure. After verification process is complete, simulation was continues to ascertain the effectiveness of Sabo dam to reduce the sedimentation volume. For this study, three numbers of Sabo dam were applied with 15m height and adopted closed type of Sabo dam.

REFERENCES

Abdullah, C.H., Ahmed, J. and Kuraoka, S. (2015). Some Debris Flow Cases In Peninsular Malaysia. In *4th International Conference on Slopes Malaysia 2015*. Kuala Lumpur, Malaysia.

Bernama (2006). Tanah runtuh: Peniaga nyaris maut. *Utusan Malaysia*. Available at: http://ww1.utusan.com.my/utusan/info.asp?y=2006&dt=0412&pub=Utusan_Malaysia&sec=Dalam_Negeri&pg=dn_10.htm.

Budhu, M. (2011). *Soil Mechanics And Foundations* 3rd ed., United States of America: John Wiley & Sons, Inc.

Burrough, P.. (1989). Fuzzy mathematical methods for soil survey and land evaluation. *Journal of Soil Science*. 40(3), 477–492. Available at: https://doi.org/10.1111/j.1365-2389.1989.tb01290.x.

Choi, S.-K., Lee, J.-M. and Kwon, T.-H. (2018). Effect of slit-type barrier on characteristics of water-dominant debris flows: small-scale physical modeling. *Landslides*. 15(1), 111–122. Available at: https://doi.org/10.1007/s10346-017-0853-4.

Gregoretti, C., Degetto, M. and Boreggio, M. (2016). GIS-based cell model for simulating debris flow runout on a fan. *Journal of Hydrology*. 534, 326–340. Available at: http://dx.doi.org/10.1016/j.jhydrol.2015.12.054.

Han, Z., Wang, W., Li, Y., Huang, J., Su, B., Tang, C., Chen, G. and Qu, X. (2018). An integrated method for rapid estimation of the valley incision by debris fl ows. *Engineering Geology*. 232(November 2017), 34–45. Available at:

https://doi.org/10.1016/j.enggeo.2017.11.007.

Hungr, D.M.J.• P.O. (2005). *Debris Flow Hazards and Related Phenomena* 1st ed., Springer-Verlag Berlin Heidelberg.

Hürlimann, M., Copons, R. and Altimir, J. (2006). Detailed debris flow hazard assessment in Andorra: A multidisciplinary approach. *Geomorphology*. 78(3–4), 359–372.

Isogai, N., Kinoshita, A., Takahara, T. and Ishizuka, T. (2000). The Use of LiDAR in Identifying High-risk Slopes at Sites of Deep-seated Catastrophic Landslides. , 302–308.

Jabatan Kerja Raya, C.K.C. (2009). *NATIONAL SLOPE MASTER PLAN 2009-2023 Sectoral Report – Volume 1*, Kuala Lumpur, Malaysia.

Jabatan Kerja Raya, C.K.C. (2012). *Potential Debris Flow Report*, Kuala Lumpur, Malaysia.

Jabatan Kerja Raya, C.K.C. (2011). *Study on Debris Flow Controlling Factors and Triggering System in The Peninsular Malaysia*,

Jakob, M. (2005). A size classification for debris flows. *Engineering Geology*. 79(3–4), 151–161.

Jefferson, I. (2012). Section 3 : Problematic soils and their issues. *ICE manuals of geotechnical engineering*. 1, 311–312.

Jefferson, I. and Rogers, C.D.F. (2012). Collapsible soils. *ICE manuals of geotechnical engineering*. 1, 391–411.

JICA (2014). *Textbook for the Group Training Course in Disaster Management for Landslide and Sediment-Related Disasters (triggered by Heavy Rainfall, Earthquake and Volcanic Activity)* 1st ed., Tokyo: Japan International Cooperation Agency.

Kim, N. (2015). *Numerical Study on Debris Flow Behavior with Two Sabo Dams*. Kyoto University.

Lin, J., Yang, M., Lin, B. and Lin, P. (2011). Risk assessment of debris fl ows in Songhe Stream , Taiwan. *Engineering Geology*. 123(1–2), 100–112. Available at: http://dx.doi.org/10.1016/j.enggeo.2011.07.003.

Lin, M.-L., Wang, K.-L. and Huang, J.-J. (2005). Debris flow run off simulation and verification ‒ case study of Chen-You-Lan Watershed, Taiwan. *Natural Hazards and Earth System Science*. 5(3), 439–445.

Lin, P., Lin, J., Lin, S. and Lai, J. (2006). Hazard assessment of debris flows by statistical analysis and GIS in Central Taiwan. *International Journal of Applied Science* …., 165–187. Available at: http://www.cyut.edu.tw/~ijase/2006/4.2-08-001-5new.pdf.

Liu, J., Nakatani, K. and Mizuyama, T. (2013). Effect assessment of debris flow mitigation works based on numerical simulation by using Kanako 2D. *Landslides*. 10(2), 161–173.

Melo, R., van Asch, T. and Zêzere, J.L. (2017). Debris flow run-out simulation and analysis using a dynamic model. *Natural Hazards and Earth System Sciences Discussions*., 1–35. Available at: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-280/.

MLIT, N.I. for L. and I.M. (2007). *Manual of Technical Standards for Establishing Sabo Master Plans for Debris Flows and Driftwood* No. 364., I-banchi Tsukuba: NILIM.

Mt, J., Nakatani, K., Uka, S. and Ama, M. (2016). Case study s of f debris s flow disaster d scenar rio caus sed by torren ntial ra in on Kiyomizu g Hyper r KANA AKO sys stem. 13(2), 193–202.

Nakatani, K., Okuyama, Y., Hasegawa, Y., Satofuka, Y. and

Mizuyama, T. (2013). Influence of Housing and Urban Development on Debris Flow Flooding and Deposition. *J.Mt. Sci.* 10, 273–280.

Nakatani, K., Wada, T., Satofuka, Y. and Mizuyama, T. Development of " Kanako ", a wide use 1-D and 2-D debris flow simulator equipped with GUI. 60, 49–58.

Nakatani, K., Wada, T., Satufoka, Y. and Mizuyama, T. (2008). Development of "Kanako 2D (Ver.2.00)," a user-friendly one- and two-dimensional debris flow simulator equipped with a graphical user interface. *International Journal of Erosion Control Engineering*. 1(2), 62–72.

Osanai, N., Mizuno, H. and Mizuyama, T. (2010). Design Standard of Control Structures Against Debris Flow in Japan. *Journal of Disaster Research*. 5(3), 307–314.

Safaei, M., Omar, H., Huat, B., B M Yousof, Z. and Ghiasi, V. (2011). *Deterministic Rainfall Induced Landslide Approaches, Advantage and Limitation*,

Satofuka, Y. and Mizuyama, T. (2005). Numerical simulation on a debris flow in a mountainous river with a Sabo dam. *Japan Society of Erosion Control Engineerng Journal*. 58(1).

Sherchan, B. (2016). *Entrainment of Bed Sediments by Debris Flow*. Norwegian University of Science and Technology.

Sumaryono, NAKATANI, K., SATOFUKA, Y. and MIZUYAMA, T. (2009). One-dimensional numerical simulation for sabo damplanning using Kanako (Ver. 1.40): A case study at Cipanas, Guntur Volcanoes, West Java, Indonesia. *International Journal of Erosion Control Engineering*. 2(1), 22–32.

Takahashi, T. (2007). *Progress in Debris Flow Modeling* H. Springer, Berlin, ed.,

Wang, J., Yang, S., Ou, G., Gong, Q. and Yuan, S. (2018). Debris flow hazard assessment by combining numerical simulation and land utilization. *Bulletin of Engineering Geology and the Environment*. 77(1), 13–27. Available at: https://doi.org/10.1007/s10064-017-1006-7.

Wilford, D.J., Sakals, M.E., Innes, J.L., Sidle, R.C. and Bergerud, W.A. (2004). Recognition of debris flow , debris flood and flood hazard through watershed morphometrics. *Springer*. (October 2003), 61–66.

Yokoyama, O., Uchida, T., Nakano, Y., Ishizuka, T., Kasai, M. and Suzuki, R. (2012). Clarifying surface shape of mass rock creep revealed by using airborne LiDAR. *Journal of the Japan Society of Erosion Control Engineering*. 64(6).

Yuanfan, T. (2007). A Debris-flow Simulation Model for the Evaluation of Protection Structures. 4(3), 193–202.