Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Runout Analysis of Landslide Using RAMMS (Rapid Mass Movement Simulation) Debris Flow Module – A Case Study of Jure Landslide

Roshan Shrestha [a], Ram Chandra Tiwari [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] roshan.shrestha052.9.21@gmail.com, [b] rctiwari1975@gmail.com

Abstract

In the research related to landslide damming, determining the landslide volume and the post run out parameters has always been a challenging task. The goal of this work is to comprehend the process of landslide damming using factors such as the size of the dam, the layout of the valley, the composition of the material, the friction and turbulence caused by the material, etc. The Jure Landslide is taken as the study area. The research area has already experienced landslide damming and suffered significant losses. The RAMMS (Rapid Mass Movement Simulation) Debris Flow Variant is used to simulate debris flows. The results indicate that the maximum velocity ranges from 39.77 to 55.68 m/s when the water table lies at the bottom of the debris. Additionally, with the aid of parameters identified from the debris flow simulation, the geomorphic indices HDSI (Hydro morphological Dam Stability Index) and MOI (Morphological Obstruction Index) have been determined. The Sunkoshi River would be blocked, and the ensuing dam would be unstable, according to the results of geomorphological indices.

Keywords

Landslide Damming, Jure, RAMMS, MOI, HDSI

1. Introduction

Nepal has and will witness a number of hazards, including earthquakes, landslides, floods, and others. Landslides are one of the most destructive among them, destroying the majority of the population's homes and possessions every year. Additionally, these landslides frequently block rivers, leading to the creation of landslide dams. When these dams are prevalent, they frequently cause flooding in the upstream areas, and when they fail, they cause flooding in the downstream areas. In the small river valleys, the landslide damming is a typical geomorphic phenomenon [1] and is common in the mountainous environment [2]. Depending on the size, material, stream power, upstream catchment area, and valley width of the dam, the duration of the damming operation before it breaches may range from days to years. [3] [2]. These dams can be formed as a result of debris flows, rock falls and even avalanches.

For identifying which landslides are most likely to become dams, it has been found that the following factors are crucial: The volume, stream power, and valley topography of the slide, together with pre- and post-failure slope behavior, were also examined [4]. Run-out analysis helps to explain the behavior of landslides after a failure [5] [6] [7]. These techniques could be broken down into categories under statistical, dynamical, and empirical categories [8].Dynamic models have been considerably more accurate for site-specific problems due to their flexibility in rheology, solution approach, reference frame, and entrainment.[9].Although many numerical models offer different advantages and disadvantages, Voellmy rheology-based rapid mass movement simulation [10] [11]is a common option (RAMMS) In addition to the pre- and post-failure pattern, it is essential to consider the valley's morphology, stream power, and landslide volume when determining the likelihood of landslide damming. Geomorphic indices that predict the possibility of landslide dam construction and their temporal stability include the Morphological Obstruction Index (MOI) and Hydromorphological Dam Stability Index (HDSI). [2] [12] [13].

2. Study Area

The study area is located in Sindhupalchowk distict of Nepal. It is located 70 km to the northeast of Kathmandu Valley between latitudes of 27°45'19.75" and 27°47'29.75"N and longitudes of 85°54'15.37" and 85°51'39.77"E. The study region has a generally mountainous topography with a river running through it. The area is traversed by the Araniko highway, which runs alongside the Sunkoshi River and connects to the Chinese border at Kodari. It has a subtropical, temperate, and alpine climate. The range of temperatures is 28.5° to 4.0° C, and there is 3604.3 ml of rainfall, of which 80 percent falls during the monsoon season (Nepal Tourism Board 2008). The Kuncha formation, which is composed of fine-grained quartz-conglomerates, phyllitic quartzites and meta-sandstones, and rare basic rock types, is part of the region's highly active geology (amphibolitic) volcanic layers. The region has had numerous large landslides at various points in time.

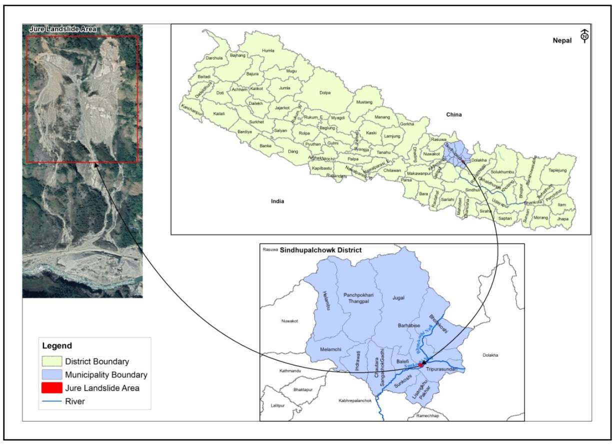

Figure 1: Landslide Area

3. Methodology

The methodology included gathering of secondary data in the form of soil parameters required for analysis as well as the study of satellite images, geomorphic indices, and run-out modeling. Information about each is provided below.

3.1 Secondary Data Collection

Various unpublished as well as published researches have been studied to gather information required for the runout analysis of the slope. The parameters which have been used for the soil have been extracted from an unpublished research of Jure landslide which states that the soil samples from the field were collected and then tested in the lab to determine the shear strength parameters of both the rocks and the debris. The crucial input component for the model is the digital elevation model (DEM), which describes the terrain of the study area. The digital elevation model (DEM) must be in TIFF format for RAMMS. The DEM is prepared in ArcGis software. The data such as spot height contour and river networks were gathered from the Survey Department. These data were exported to ArcGis and then the final DEM of the study area was prepared.

Table 1: Satellite Imagery Details

Satellite Data Used	Date of Data	Spatial Resolution
Google Earth Imagery	2022/06/1	2.5m

3.2 Run out Modeling using RAMMS (Debris Flow Module)

RAMMS (Debris Flow Module) was used to study the post-failure behavior of the landslide area. A dynamic numerical modeling software program called RAMMs (Rapid Mass Movements) was created by the Swiss Federal Institute initially for Snow Avalanche Research (WSL/SLF) to study snow avalanches. [14] [15] [16] [17] [18]. However, by including certain tools it can be further applied to other landslides types: lahars, rock avalanches and debris flow [19] [20]. The 2-D model is used to predict the flow heights, flow velocities, and flow pressures. The RAMMS for debris flow splits the frictional resistance into a dry Coulomb-type friction (μ) and a viscous turbulent friction (ζ), using the Voellmy friction law. S (Pa) is the frictional resistance. Numbered equation:

$$S=\mu \text{ N} + \delta \text{ g } u^2 / \zeta \tag{1}$$

Where, N = δhg cos(ϕ) is the normal stress on the running surface, δ is density, g is gravitational acceleration, ϕ is slope angle, h is flow height, and u = (u_x, u_y) is the flow velocity in the x and y directions. Along with other input factors, this study uses a range of friction (μ) and turbulence (ζ) values to assess output uncertainty.

The values for friction (μ) and turbulence (ζ) are often established by simulating genuine real events, reconstructing them, and then comparing the dimensional properties of the real and simulated events. Because the landslide in the study zone merges with the river bed or is close by, there is no failed material from the earlier event to rebuild. On account of the topography of the landslide slope and run-out path, the landslide's composition, similar landslide events or compositions, and the results of past studies and models [21] [7] [15], the values for friction (μ) and turbulence (ζ) and were chosen from a range. The depth of landslide is taken from the stability analysis. The position of water table is placed at the bottom of the debris. There was no information available regarding the spatiotemporal pattern of discharge at the landslide area. Since the flow path (such as a gully) and its potential discharge on the slope are unclear, the release area concept was adopted as a result (RAMMS v.1.7.0). As per the manual of RAMMS, the value for the turbulence coefficient was chosen between 100 to 200, whereas the value for the friction coefficient shall not be greater than 0.4 to obtain realistic run out values.

The basis for stopping in RAMMS is momentum (m_v). It added up the moments of all grid cells for each dump step (calculation step) and compared them to the maximum momentum total. RAMMS terminates the simulation and considers the debris flow to have occurred if this percentage falls below a user-defined threshold value [15]. The suggested threshold number ranges from one to ten percent (1 percent -10 percent). The 5 percent threshold number was used for this study.

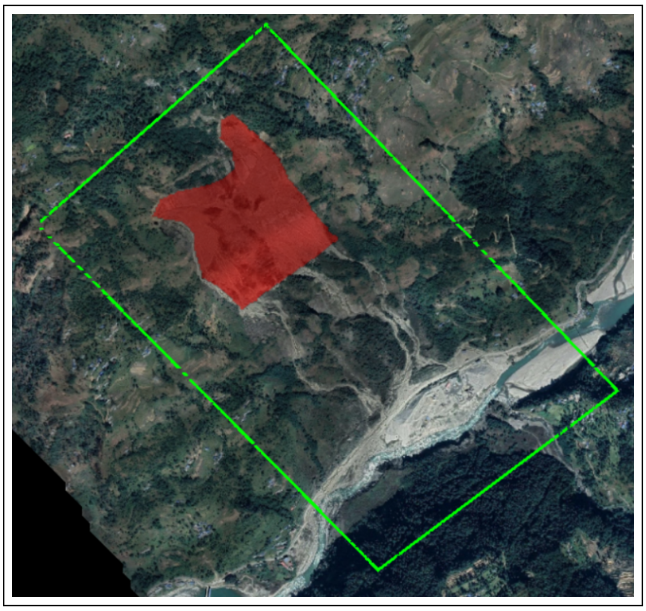

Figure 2: Release Area for RAMMS Simulation

The failure zone is determined with the help of the result of slope stability analysis. The result is as shown in the figure.

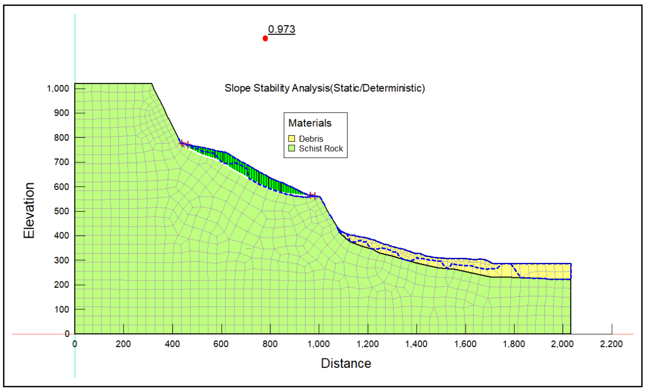

Figure 3: Failure Zone Determination

3.3 Geomorphic Indices

Two geomorphic indices namely MOI (Morphological Obstruction Index) and HDSI (Hydromorphological Dam Stability Index) are used to determine the possibility of landslide dam formation. They are determined as follows:

1. MOI(Morphological Obstruction Index)

$$MOI=Log(V_1/W_V) \tag{2}$$

2. HDSI(Hydrmorpholigical Dam Stability index)

$$HDSI=Log(V_d/A_b*s) \tag{3}$$

Where, $V_d(damvolume) = V_l(landslidevolume, m^3)$, A_b = upstream catchment area in km^2, W_v = width of the valley in meters and S = local slope gradient of river channel in mm^-1
By utilizing the dataset of 300 landslide dams of Italy, [13] have classified the MOI into:

1. Non-formation domain (MOI<3.00)
2. Uncertain evolution domain (3.00<MOI>4.60)
3. Formation domain (MOI>4.60).

By utilizing the same dataset, [13] defined the HDSI into following categories:

1. Instability domain (HDSI<5.74)
2. Uncertain determination domain (5.74<HDSI>7.44)
3. Stability domain (HDSI>7.44).).

Table 2: Material Properties used for RAMMS simulation (Source:Unpublished Research of Jure Ladnslide)

Material Type	Material Depth(m)	Dry Unit Weight (KN/m^3)	Cohesion (KN/m^2)	Friction Coefficient (μ)	Turbulence coefficient(m/s^2) (ζ)
Debris	27.12	18	5	0.05, 0.1, 0.15, 0.2, 0.25	100, 150, 200

The width of the river is determined by taking average of the whole reach of the river valley and is taken is 30m. The slope of the river is taken as 5percent which is determined from the profile of the river obtained from Google Earth. The upstream catchment which would contribute to the flow up to the point of landslide occurrence is calculated with the help of ArcGiS software. The upstream catchment area is as shown in the figure below:

Figure 4: Upstream Catchment Area

4. Results

The maximum velocity of flow along with the flow pressures and the flow heights are determined from RAMMS simulation for different cases. The output obtained for each cases are tabulated below:

Table 3: Overall Maximum Velocity along with Release Volume obtained in RAMMS

μ	g	Overall Maximum Velocity (m/s)	Release Volume(m^3)
0.05	100	45.90	7156219
0.1	100	44.27	7156219
0.15	100	42.77	7156219
0.2	100	41.27	7156219
0.25	100	39.77	7156219
0.05	150	51.57	7156219
0.1	150	49.48	7156219
0.2	150	45.82	7156219
0.25	150	44.01	7156219
0.05	200	55.68	7156219
0.1	200	52.79	7156219
0.15	200	50.66	7156219
0.2	200	48.63	7156219
0.25	200	46.76	7156219

The maximum velocity ranges from 39.77 to 55.68 m/s. The value is maximum when the value of friction coefficient and turbulence coefficient is 0.05 and 200 respectively. Similarly, the value is minimum when the friction and the turbulence coefficient is 0.25 and 100 respectively. The results further indicate that the volume of landslide is approximately 71,56,219m3. This data is further used to determine the value of the geomorphic index.

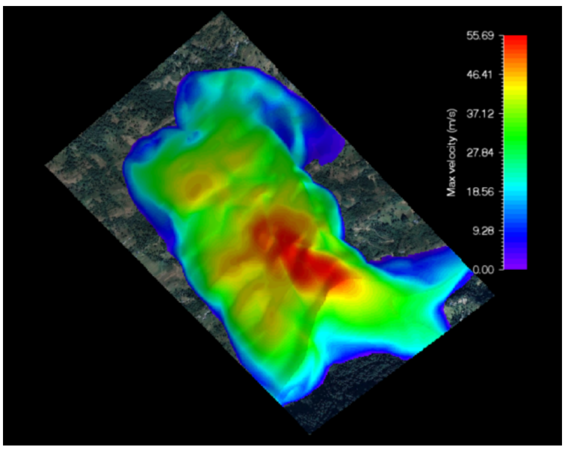

Figure 5: : Overall Maximum Velocity(Lower Limit)

The value of first geomorphological index i.e. MOI

Table 4: Calculation of Geomorphological Indices

Volume of Landslide(m3)	Width of the valley(m)	Upstream catchment Area(km2)	Local Slope Gradient of River Channel (mm-1)	MOI	Domain	HDSI	Domain
71,56,219	30	2490.57	0.05	5.38	Formation Domain	4.76	Instability Domain
55,00,000	30	2490.57	0.05	5.38	Formation Domain	4.75	Instability Domain

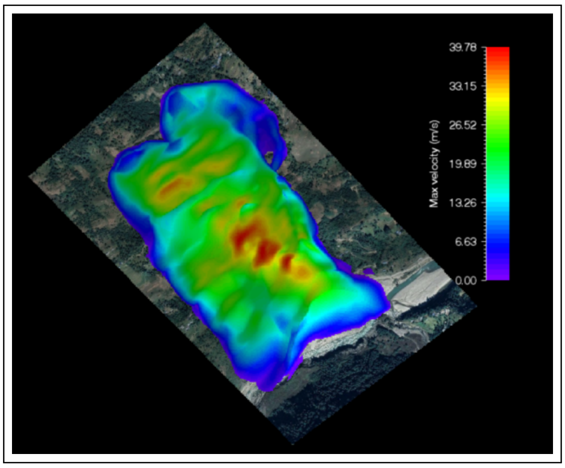

Figure 6: : Overall Maximum Velocity(Upper Limit)

obtained is greater than 4.60 which is why the landslide thus considered falls on the "Formation Domain" which indicates that there is possibility of formation of a natural dam. The value of second geomorphological index i.e. HDSI obtained is less than 5.74 which is why the landslide thus considered falls on the "Unstable Domain" which indicates that the natural dam thus formed due to Jure landslide will be unstable in its own and has the possibility of breaching after formation.

The result can be validated by refering to previously done research. The study area has undergone previous disastrous incidents of slope failure in the past. The latest one dates back to 2 August 2014. The natural dam thus created prevailed for around 36 days after which it was breached. The results further indicated that the rock fragments fell with the speed of 50 to 60m per second. Furthermore, the volume of landslide was estimated to be approximately 5-6 million cubic meters [22] with the help of which the geomorphic indices were determined which concluded that there is possibility of landslide dam formation and the resulting dam would be unstable in its own.

5. Conclusion

Landslide damming is a complex phenomenon which is difficult to analyze. Hence, this study is a simple methodology to study this phenomenon. The pre failure analysis can be done in any FEM based tool to determine the failure zone after which any runout analysis tool can be used to obtain the runout parameters. Hence, different models have been proposed to study this phenomenon worldwide. Among them, RAMMS is one of the most widely used and versatile simulation software which is based on Voellmy friction model. The most important part of this simulation is to determine the friction parameter (μ) and the turbulence parameter (ζ). Due to lack of availability of field data the parameters chosen relies wholly on the suggestions given in the manual. Furthermore, the data obtained from the simulation is then used to determine the geomorphic indices. The first index i.e MOI is used to check the possibility of natural dam formation whereas the second index i.e HDSI is used to check the stability of the dam if there is dam forming possibility. Thus, the results showed that there is possibility of natural dam formation. The results further indicated that the resulting natural dam would be unstable on its own.

Acknowledgments

The authors are thankful to the co-ordinator of Department of Geo-Technical Engineering, Pulchowk Campus. The authors are thankful to Mr. Uddhav Lal Karki and Er.Smaran Dahal for providing assistance related to the use of ArcGis and preparation of maps.

References

[1] Stephen G Evans, Keith B Delaney, Reginald L Hermanns, Alexander Strom, and Gabriele Scarascia-Mugnozza. The formation and behaviour of natural and artificial rockslide dams; implications for engineering performance and hazard management.

In *Natural and artificial rockslide dams*, pages 1–75. Springer, 2011.

[2] John E Costa. Documented historical landslide dams from around the world. us. *Geological Survey Open-File Report*, 91(239):1–486, 1991.

[3] Tianchi Li, Robert L Schuster, and Jishan Wu. Landslide dams in south-central china. In *Landslide dams: Processes, risk, and mitigation*, pages 146–162. ASCE, 1986.

[4] Vipin Kumar, Vikram Gupta, Imlirenla Jamir, and Shovan Lal Chattoraj. Evaluation of potential landslide damming: Case study of urni landslide, kinnaur, satluj valley, india. *Geoscience Frontiers*, 10(2):753–767, 2019.

[5] O Hungr, GC Morgan, and Rolf Kellerhals. Quantitative analysis of debris torrent hazards for design of remedial measures. *Canadian Geotechnical Journal*, 21(4):663–677, 1984.

[6] K Hutter, B Svendsen, and D13886070858 Rickenmann. Debris flow modeling: A review. *Continuum mechanics and thermodynamics*, 8(1):1–35, 1994.

[7] Dieter Rickenmann and Christian Scheidl. Debris-flow runout and deposition on the fan. In *Dating torrential processes on fans and cones*, pages 75–93. Springer, 2013.

[8] Dieter Rickenmann. Runout prediction methods. In *Debris-flow hazards and related phenomena*, pages 305–324. Springer, 2005.

[9] Rev Deliverable Responsible Controlled by Date. Living with landslide risk in europe: Assessment, effects of global change, and risk management strategies. 2011.

[10] Adolf Voellmy. *On the destructive force of avalanches*. Alta Avalanche Study Center, 1964.

[11] B Salm. Flow, flow transition and runout distances of flowing avalanches. *Annals of Glaciology*, 18:221–226, 1993.

[12] L Ermini and N Casagli. Prediction of the behaviour of landslide dams using a geomorphological dimensionless index. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, 28(1):31–47, 2003.

[13] Carlo Tacconi Stefanelli, Samuele Segoni, Nicola Casagli, and Filippo Catani. Geomorphic indexing of landslide dams evolution. *Engineering Geology*, 208:1–10, 2016.

[14] Yves Bühler, Marc Christen, Julia Kowalski, and Perry Bartelt. Sensitivity of snow avalanche simulations to digital elevation model quality and resolution. *Annals of Glaciology*, 52(58):72–80, 2011.

[15] P Bartelt, Y Buehler, M Christen, Y Deubelbeiss, C Graf, and BW McArdell. Ramms–rapid mass movement simulation, a modeling system for debris flows in research and practice, user manual v1. 5, debris flow, manuscript update: 31 january 2013. *WSL Institute for Snow and Avalanche Research SLF, available at: http://ramms. slf. ch/ramms/downloads/RAMMS_DBF_ Manual. pdf (last access: 27 February 2015)*, 2013.

[16] Alejandro Casteller, Marc Christen, Ricardo Villalba, Hugo Martínez, Veronika Stöckli, Juan Carlos Leiva, and P Bartelt. Validating numerical simulations of snow avalanches using dendrochronology: the cerro ventana event in northern patagonia, argentina. *Natural Hazards and Earth System Sciences*, 8(3):433–443, 2008.

[17] Marc Christen, Perry Bartelt, and Julia Kowalski. Back calculation of the in den arelen avalanche with ramms: interpretation of model results. *Annals of Glaciology*, 51(54):161–168, 2010.

[18] Jan-Thomas Fischer, Julia Kowalski, and Shiva P Pudasaini. Topographic curvature effects in applied avalanche modeling. *Cold Regions Science and Technology*, 74:21–30, 2012.

[19] L Quan. Dynamic numerical run-out modeling for quantitative landslide risk assessment. *Thesis of University of Twente, ITC*, 206:1–237, 2012.

[20] Demian Schneider, Perry Bartelt, Jacqueline Caplan-Auerbach, Marc Christen, Christian Huggel, and Brian W McArdell. Insights into rock-ice avalanche dynamics by combined analysis of seismic recordings and a numerical avalanche model. *Journal of Geophysical Research: Earth Surface*, 115(F4), 2010.

[21] Marcel Hürlimann, Dieter Rickenmann, Vicente Medina, and Allen Bateman. Evaluation of approaches to calculate debris-flow parameters for hazard assessment. *Engineering Geology*, 102(3-4):152–163, 2008.

[22] Narendra Raj Khanal and Deo Raj Gurung. Icimod rapid field investigation: Jure landslide dam site jure, sindhupalchowk district, nepal. *Lalitpur: ICIMOD*, 2014.