Failure mechanism of Rangvamual landslide, Aizawl, Mizoram, India

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Abstract

Mizoram is one of the most landslide prone states of India. The prime causes of the landslides in Mizoram, can be listed as rugged topography, sedimentary geology, steeper slopes, rainfalls and seismicity. The failure mechanism of the present slide has been revealed based on integrated analyses of field database, GIS database (Satellite Data IRS P6/ LISS4 -5.8 Mts. Resolution) using ARCGIS 9.3. The fault and fracture buffer show very high activity. Alarmingly, the slide section is spotted on an active fault trending NE-SW. The slide section is forming a dip slope, with an angle varying between 37^o – 39^o.

"Rose/Stereonet diagrams" plotted for the beds of the slide section show a "mean direction- 272.5° by Limit Equilibrium Method (LEM) analysis by Slide 6.0 software method found factor of safety of 0.719 by Bishop simplified method .and 0.706 for Janbu simplified method. These values fall much below the acceptable limit for a safe slope (>1.2).With all the evidences accumulated through field/ LEM/GIS based study conducted on the slide section and conclude that "Rangvamual Landslide" is a case of 'dip slip failure' and it is sitting on an active fault. It is strongly recommended that authorities proclaim the area as No Development Zone.

Keywords: Landslide, DEM, Fault/Fracture Buffer, Rose Diagram, Lithology, Failure, LEM.

Introduction

Mizoram is located in the north eastern part of India and it shares 722 km long international borders with Bangladesh on the west and Myanmar on the east. Topographically, it is a rugged sedimentary terrain with steep slopes and deep valleys which results in slope failure at several sections in the vicinity of Aizawl, the capital city of Mizoram [18, 19]. The Mizoram state is located in the tectonically active zone[15].

Geology and Structure: The Mizoram Hills (Lushai Hills) are an integral part of the "Indo- Myanmar Mobile belt". Geologically, Mizoram is a component of Tripura - Mizoram Mio-geosyncline and constitutes a part of the 'Assam - Arakan Geosynclinal Basin' [9-11].

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Mizoram is an active accretionary prism under the effect of the Indian and Burmese plate collision tectonics. Due to dynamism in the vicinity of the Indo-Myanmar Mobile Belt, a compressive tectonic stress is prominent in the region and the resultant strain is reflected in the rocks in form of faults, joints and shear zones and resultant slope instability.

These weak planes are one of the main triggering factors for the frequent occurrence of landslides. Majority of the landslides in the state are triggered by the natural factors like climate (especially rainfall), physiography and geo environment. The prime causes of the landslides in the state can be listed as rugged topography, Tertiary sedimentary geology, steeper slopes, heavy rainfall and location in Seismic zone –IV. The rock types of the region are prone to weathering, erosion and to subsequent failure under external factors. In addition, the rush of the unplanned human urbanization and deforestation, the anthropogenic factors have emerged as another major cause of landslides in the region.

The rocks of Aizawl represent 'Surma Group' and comprise of sandstones, shales and mudstones[17]. Regional strike of Mizoram rocks is N-S in response to the anticlinal folding perpendicular to the major operating E-W directional force of Indo-Myanmar plate collision and the dips of the beds also reflect the true character of an anticline i.e. towards east in the eastern part, and towards west in the western part. The rocks of the region are moderate to high dipping.

The study section "Rangvamual" lies in the northwestern part of Aizawl town and its exact coordinates are 23^o 45' 06.83" - 23^o 45' 07.97" N latitudes and 92^o 41' 10.41" - 92^o 41' 11.20" E longitude .The section is located on Aizawl-Silchar Highway NH-44A. Figure 1 shows the exact location of the slide section (including Google Earth image and slide pictures).

Rangvamual Slide: Rangvamual landslide was triggered excessively by heavy rain (approximately 1375 mm) between May to September 2014. It occurred in September 2014.The landslide disturbed traffic and blocked the highway for a month.

It damaged a cold storage building and destroyed the power transmission lines and thereby disrupted the supply to the western towns Mamit and Kanhmun. The normal traffic between Aizawl to Lengpui airport and also to Silchar (Assam), was interrupted for nearly 3 years.

Figure 1: Location and Google Earth Image

Review of Literature

Xianyu et al[20] have worked on the preparation of Landslide Susceptibility Maps (LSMs) to effectively analyze and predict regional landslides.

However, the traditional methods of producing LSM, using remote sensing images, digital elevation model, geological and topographic map and landslide surveys were applied in the Zigui-Badong in the “Three Gorges Reservoir Area”. Further, a geographic weighted regression (GWR) was applied.18 environmental factors were selected as LSM factors. Lithology plays a key role in determining slopes stability as it controls the nature of weathering and erosion for a rock slope[1] and ultimately determines the type of failure. Ngaizel Landslide, Aizawl, Mizoram, India, is a good example of structural control on slope failure. The multiple joint systems in the Ngaizel section, caused wedge failure[18].

Rock Slope Stability along the road cut of Kulikawn to Saikhamakawn of Aizawl, Mizoram has been examined by Sardana et al[14] and the study reveals the complex structural control on the slope stability in the section.

Fan et al[4] have also supported strong control of physiographic factors upon the probability of slides as evidenced by their case study from the Kaoping River Basin Slide, Taiwan. Most of the landslides of Mizoram are of similar mechanism. Nahid et al[8] have worked on probabilistic and sensitivity analyses of effective geotechnical parameters on rock slope stabilities in their case study of an urban area in Northeast Iran.

Dip Slip failure mechanism of sliding was observed in the case of ‘Laipuitlang’ and it was on a very large scale and had many causalities[19]. Another matching example was presented by Lee et al[6] who have carried out numerical modeling work/forensic investigation on a catastrophic roadside due to dip slope failure in Taiwan. Rao and Verma[3] have carried out similar investigation and submitted the same in form of a detailed report to Department of Science and Technology, Government of India.

Zorgati et al[21]and Ozioko et al[12] have done similar GIS-based landslide susceptibility mapping using bivariate statistical methods in North-western Tunisia. Other workers[7] have formulated slope stability analysis using the limit equilibrium method and two finite element methods. Sun et al[16] have devised a method of Limit-Equilibrium Analysis of Stability of Footwall Slope with respect to biplanar failure. Rawat et al[13] have also worked on the “analysis of nailed slope’ using Limit Equilibrium Analysis and “Finite Element method”.

Material and Methods

The failure mechanism of the present slide has been revealed on the basis of integrated analyses of field database using Survey of India Toposheet No. 84 A/9 at 1:20000 scale, GIS database (Satellite Data IRS P6/ LISS4 -5.8 Mts. Resolution) using ARCGIS 9.3. In addition, Limit Equilibrium Analysis (LEM) was also carried on the slide section. The methodology for the present study has been divided into field and laboratory studies.

Field Study*:* In the field, direct investigation of the road section and specially, the slide site has been studied with the consideration of the causative factors viz. lithology, interrelation and attitude of primary and secondary discontinuities. Representative samples were collected from the ‘Rangvamual Slide section” for geotechnical analysis. Field photographs were captured for records.

Laboratory Studies

Geological Components: The data collected in the field were plotted on the online app “visible geology” to generate 2-D and 3-D stereographs and also the “Rose diagram”. The prominent lithology was examined through the visible outcrops. Based on visible evidences, the prime causes of the slide were established. Lithology and structure map of the ‘Hunthar-Rangvamual section’ has been prepared for this particular study.

GIS Components: In this task, procurement of Satellite imagery, digitization and preparation of various thematic layers, assigning the weightage for different parameters and finally the preparation of the Severity of Landslides Map were taken care.

Limit Equilibrium Method: Limit Equilibrium Method (LEM) analysis was carried out by Slide 6.0 software using Bishop simplified method[2] and Janbu simplified method[5] for the stability assessment. The safety factor of slope based on ‘Mohr- Coulomb Criterion’ for the slide section was determined in dry conditions.

Results and Discussion

Field Study: Authors have done extensive field work covering the entire road section from Aizawl town to Lengpui Airport. Pertinent to the present section, the lithology map of the Hunthar Veng to Rangvamual Section (Fig. 2A) has been prepared by using ‘Survey of India’ toposheet No. 84 A/9, based on field data generated as shown in table 1.

Based on the field investigation, the Rangvamual slide section (Fig. 2B) has been identified. Specific attitude data of the very slide section has been presented in table 2. The lithological map of the section along with the map of adjoining sections was used to digitize the lithology layer as shown in figure 4F. The field investigation reveals that the slide section is an outcrop of sandstone–shale intercalation. The rocks dip uniformly due west varying from 37°-39°and form a dip slope towards west (Fig. 2B).

Table 1
Field data of Hunthar- Rangvamual road section

Station Number	Station Coordinates		Locality	Description		Attitude (*Dip Amount/Direction)*		Remarks
	Latitude	**Longitude**		**Lithology**	**Height (Ft.)**	**Beds**	**Joints**	
1.	23° 44’ 38.9”	92° 41’ 31.1”	Hunthar Veng	Sandstone/Shale Intercalations	35	45/270 40/272 54/180	x	Shear
2.	23° 44’ 36.4”	92° 41’ 17.9”	“	Shale	35	60/00	70/180	4-6 feet thick beds, Moderately weathered
3.	23° 44’ 45.4”	92° 41’ 0.8”	“	Sandstone/Shale Intercalations	55	58/180 42/270 40/270	70/180 56/00	Two shears
4.	23° 44’ 57.70”	92° 41’ 01.7”	Rangvamual	Sandstone/Shale Intercalations	40	45/180 58/90	38/225	Shear
5.	23° 45’ 06.83”	92° 41’ 11.20”	“	Sandstone Shale Intercalations	100	38/272	X	Debris
6.	23° 45’ 07.97”	92° 41’ 10.41”	“	Shale	120	40/273	75/00	Massive Sst. Moderately weathered
7.	23° 45’ 16.15”	92° 41’ 04.8”	“	Sandstone Shale Intercalations	60	30/271	Vertical Joint	Shear
8.	23° 45’ 22.75”	92° 41’ 03.06”	“	Sandstone Shale Intercalations	45	30/272	Vertical Joint	Shear

Table 2
Slide section data

S.N.	DIP amount (Degree)	DIP direction (Degree)
1	39	272
2	38	273
3	38	272
4	37	273

The approximate width of section is 80 feet and the height is 100 feet. The measurement of dip amount and dip direction has been taken across the slide width, at a regular interval of 20 feet (marked as 1, 2, 3 and 4), hence four recordings. The dip amount and dip direction of the slide section are presented in table 2. The same data is used for the stereo plots (Fig. 3A) and Rose diagram (Fig. 3B). Both the stereo-plot and the Rose diagram confirm that the mean direction is 272.5 (that is roughly west) and dip of the bed is varying from 37^o to 39^o and the values are in accordance with the field/GIS data.

Profile thickness has been prepared for the slide section (Table 4). Data from tables 2, 3 and 4 have been used for Limit Equilibrium Analysis.

GIS Components: GIS database (Satellite Data IRS P6/ LISS4 -5.8 Mts. Resolution) using ARCGIS 9.3, was applied for digitization and preparation of various thematic layers. Fault/fracture buffer, Lithology, Land Use/Land Cover, Drainage Density, Digital Elevation Model (DEM), slope and rainfall maps, were prepared. Finally, a "Severity of Landslide Map" was generated after assigning due weightage for different thematic layers. The weightage scheme is – Slope (25%), Lithology (25%), LULC (20%) Rainfall (15%) and Drainage Density (15%). All the thematic layers are shown in Figure.4 (A-F).

Interpretation of the Thematic Digital Layers: The slide location is shown as the black dot [⬣]. Figure 4 A represents the Digital Elevation Model and Fault/Fracture buffer. The position of the slide spot shows an intermediate elevation of nearly 850 meters and the same is gradually reducing towards west. The same figure shows that the Rangvamual slide spot is falling on a major fault line trending NE- SW. It is noteworthy that the whole region is tectonically active and well indicated by the fault and fracture buffer. Slope of the Slide location as shown in Fig.4B, is in the range of 30^o to 45^o. The dip of the beds in the slide section also, falls within the same range that is 37^o to 39^o, thus confirming a 'dip slope'. The drainage density is very low (Fig. 4C).

According to Land Use/Land Cover Map (Fig.4 D), the slide location falls under wasteland (barren rocky area). The entire region falls in the tropical monsoon climate and the slide location falls in the zone of 2500 mm/year (Fig.4E). It can be seen from the lithology layer that the slide zone is predominantly massive sandstones with intercalations of shales (Fig. 4F). Importantly, all the digitized layers are in accordance with the actual field measures.

The final picture of the "Severity of the Landslide Map' (Hazard Zonation Map) has come up after sandwiching these layers, assigning the weightage scheme mentioned earlier. According to this map, the Rangvamual landslide falls in the "very high hazard zone" (Fig. 5).

LEM Analysis: Limit Equilibrium Method (LEM) analysis was carried out by Slide 6.0 software using Bishop simplified method and Janbu simplified method[2,6] for the stability assessment. The safety factor of slopes based on Mohr- Coulomb criterion for the study area was determined in dry condition. The field data used in the analysis were- Slide Section Data (Table 2), Geomechanical Parameters (Table 3) and Profile Thickness (Table 4). The slope amount used for the LEM has been taken from the average of values obtained from the table 2 i.e. 38^o.

The factor of safety for Bishop simplified method was 0.719 and for Janbu simplified method was 0.706 which fall below the acceptable limit for a safe slope (>1.2).

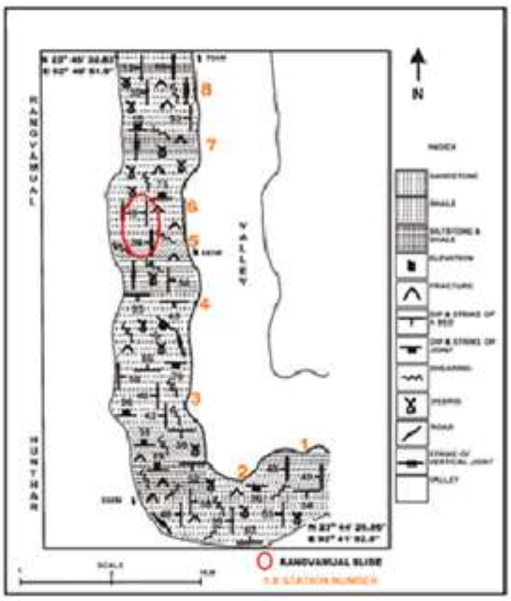

Fig. 2A: Lithological Map of Hunthar – Rangvamual Section

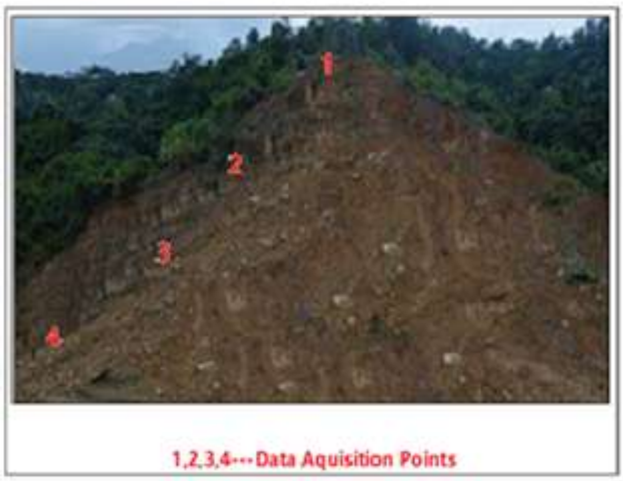

Fig. 2B: Rangvamual Section

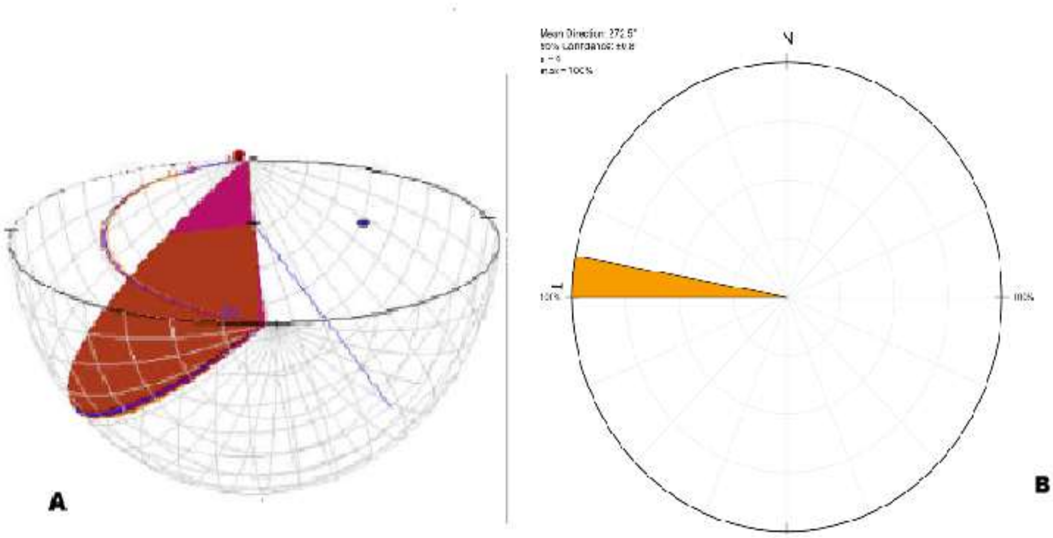

Figure 3: Stereoplot and Rose Diagram

Table 3
Geomechanical parameters for LEM

S.N.	Property	Unit and Symbol	Sandstone	Intercalated Shale and Siltstone
1	Color			
2	Strength Type	-	Mohr-Coulomb	Mohr-Coulomb
3	Unit Weight	[kN/m3]/΄Ydry	24.3	22.7
4	Cohesion]	[kPa} / C	25.1	27.9
5	Friction Angle	Degrees / o	34.9	27.7
6	Water Surface	-	None	None
7	Ru Value	-	0	0

Table 4
Profile thickness for LEM

Unit (Rock type)	Height from ground level (Ft.)	Thickness (Ft.)
Sandstone	104.5	8.5
Shale and Siltstone	96	20
Sandstone	76	20
Shale and Siltstone	56	10
Sandstone	46	4
Shale and Siltstone	42	1
Sandstone	41	1
Shale and Siltstone	40	2.5
Sandstone	37.5	0.5
Shale and Siltstone	37	2.5
Sandstone	34.5	8.5
Shale and Siltstone	26	6
Sandstone	20	1.5
Shale and Siltstone	18.5	0.5
Sandstone	18	5.5
Shale and Siltstone	12.5	12.5

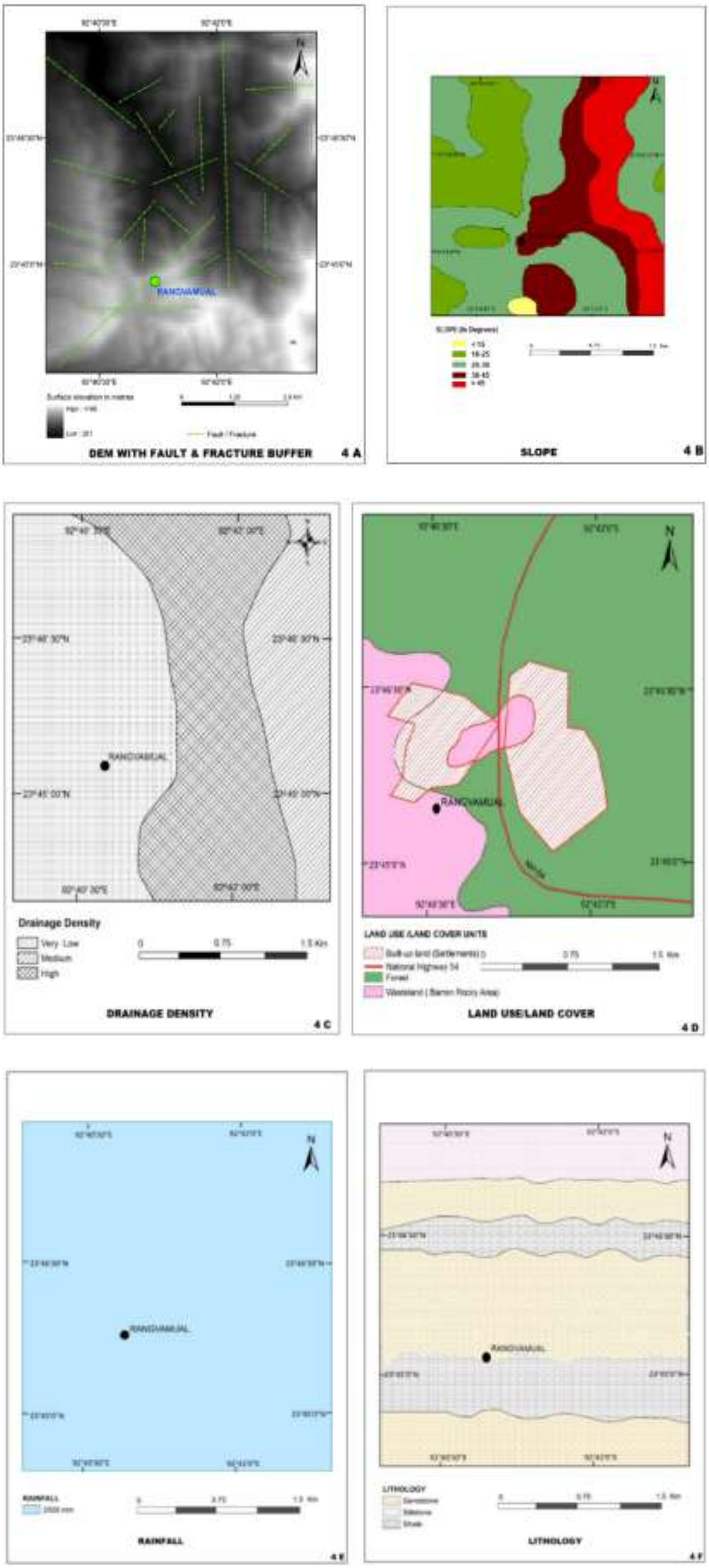

Figure 4: Thematic Layers

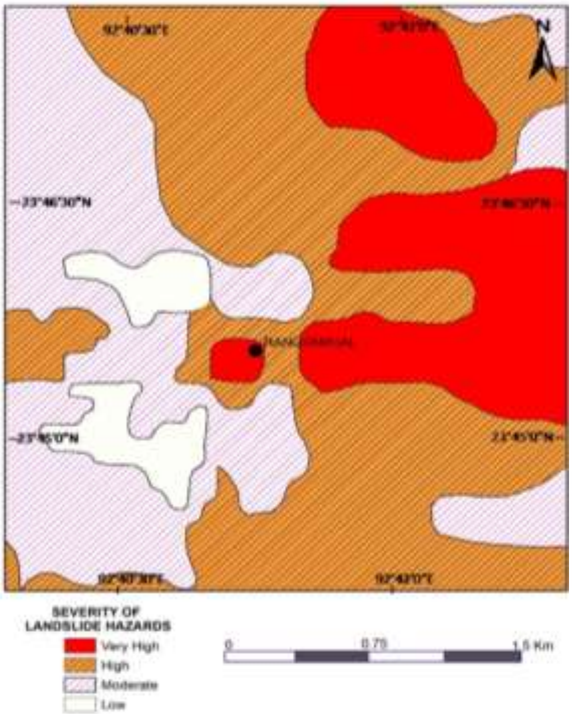

Figure 5: Severity of the Landslide Map (Hazard Zonation Map)

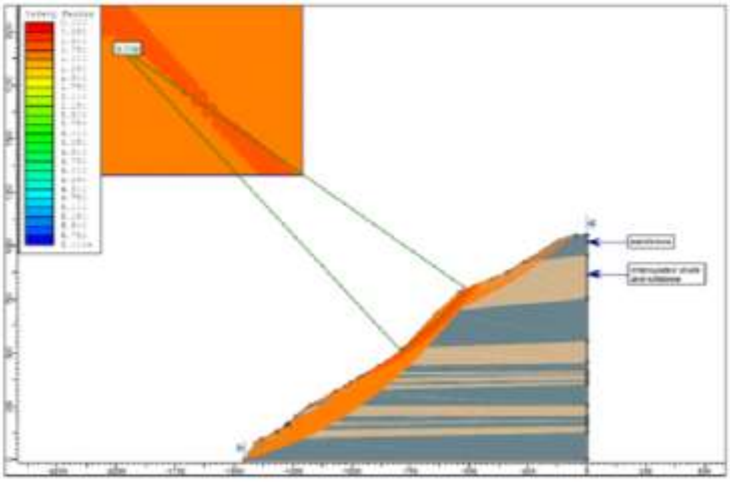

Figure 6: Bishop simplified profile of Rangvamual Landslide

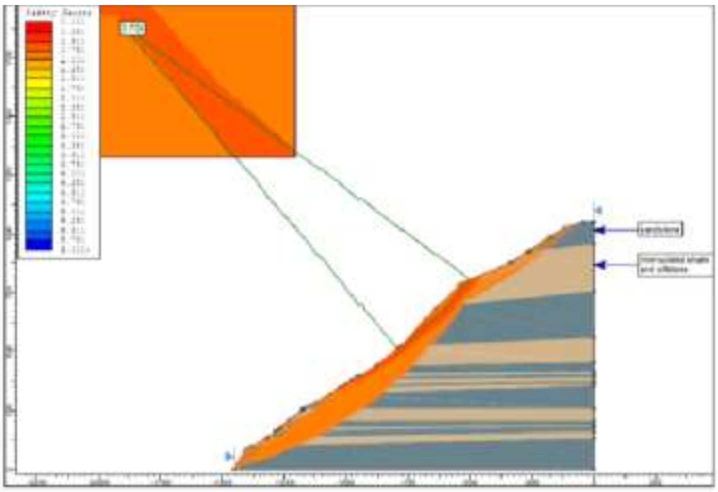

Figure 7: Janbu simplified profile of Rangvamual Landslide

Conclusion

All the evidences accumulated through field/ stereo-plots/GIS based studies, reveal that the present "Rangvamual Landslide" is a case of 'dip slip failure' under the influence of several factors such as lithology, slope, variation in the elevation, rainfall, land use landcover, drainage density and importantly, the situation on a major fault line. According to the "Severity of the Landslide Map', the Rangvamual landside falls under "very high hazard zone".

Further, the LEM analysis also confirms that the section is prone to landslide as the factor of safety was found to be much lower than the acceptable limit of >1.2 for a safe slope. They are found to be 0.719 for Bishop simplified method and 0.706 for Janbu simplified method. In reality, the rain water seeped into the shale – sandstone contacts following the dip direction and it led to the reduction in cohesive strength by addition of weight to the slope material and thereby reducing the angle of repose. The weakened slope material slides down under the conjugate factorial effect of dip, slope, lithological interface and rainfall.

Recommendation

The site lies on one of the national highways that is the life line of Mizoram as it connects the land locked state to the rest of India. Some of best suited remedial measures are: plantation in the uphill, clearing the debris, protective meshing, construction of retaining wall, contouring and terracing. However, it would be best if the local civic authorities to proclaim the area as a "No Development Zone".

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