Kinematic Analysis of Rainfall Induced Rock Slide Along Roadcut Slopes – A Case Study on Dhalli Landslide, Himalayan Region

C. Prakasam,* Aravinth. R,* Varinder S Kanwar* and B. Nagarajan**

Abstract

The Himalayas is one of the highly prone regions for landslide disasters in the world. State and National Highways along the Himalayan region are unstable and are prone to various landslide disasters is of major concern in the region. Unplanned excavation of the slopes has caused instability among the slopes leading to rock and soil failure. The research focuses on studying Kinematic analysis of Rainfall induced Rockslide and its slope stability along NH-22 near Dhalli Tunnel in Shimla town. Dhalli landslide which occurred in September 2017 is a structurally controlled landslide that occurred along a Road cut slope without proper toe support. Initial Studies about the orientation of the landslide is conducted through Kinematic analysis. Four different types of joint intersections were found in which J1 and J2 forming intersection line dipping away from the slope indicating it is a wedge failure. The final output reveals that the slope is partially stable with an SMR rating of 45. Slope stability analysis has been performed through SWEDGE model using the results derived from the field investigation. The results computed the total wedge area of the joint 1 is 297.33 sq. mts and wedge area for the joint 2 is 1587.52 sq. mts. The total factor of safety of this critical slope is derived as 0.9 which is below the required value. A suitable Economically viable measure has been proposed like a Reinforced Wire Mesh Shotcrete as Slope Stabilization measure with a FOS value of 1.45 providing stability and support to negate the future occurrences of the slope failure.

Keywords: Dhalli Landslide, Slope Stability, Kinematic Analysis, Rainfall Threshold, SWEDGE.

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Introduction

"Landslides are simply defined as the downslope movement of rock, debris and or earth material under the influence of gravity. The sudden movement of materials causes extensive damages to lives, properties and local economy, etc." Sharpe (1938); Varnes (1978); Cruden (1991). Natural hazards happen due to variety of complex factors that are completely out of human control, where some disasters may have had human interventions. Some hazards are more prevalent and life-threatening such as floods, drought, windstorm, earthquakes, flash floods and cloud burst, etc. Landslide ranks 7th largest disaster and contributes to higher mortality rate (Alimohammadlou, Najafi and Yalcin, 2013). Landslide occurs due to various natural and anthropogenic factors. These causes include cloudburst, thunderstorms, Antecedent rainfall, and anthropogenic activities (Geological Survey of India, 2001). Landslides are mostly restricted to hilly terrains due to their rugged topography, steep slopes, soil content etc. Among other Geohazard landslide is found to be the fast-spreading epidemic due to various morphodynamic process and improper interaction of human beings with nature (Martha et al., 2013). On a global scale landslide is one of the major disasters worldwide that contribute a higher rate of causalities and economical losses. According to the report submitted by "International Association of Engineering Geology (IAEG)" on worldwide landslide events (1971 to 1975) to the UNESCO they have reported that landslide accounts for about 14 per cent causalities from natural hazards (Froude and Petley, 2018). In a report given by the International Disaster Database (EM-DAT) the landslide event occurred between 1990 and 2015covers about 4.9 per cent of the all the disasters that occurred in Asia (Guha-Sapir et al., 2018). In India, about 0.42 million sq. km are of landslide-prone areas. These areas include the North Western and North Eastern Himalayas and the Western & Eastern Ghats (Geological Survey of India website). While Nature being one of the dominant factors for active landslide anthropogenic activities have sped up the process in himachal Pradesh due to unplanned urban construction, deforestation, increasing in housing boards, hydro power projects, etc. (Chandrasekaran et al., 2013; Iverson, 2000). These factors not only threaten the damage and interpretation of transportation and other economic factors but also threaten human lives. Among other factors, Earthquake and Rainfall precipitation are being the two dominant factors that, while rainfall is the most significant in the initiation of mass movement of landslides (K. Sarkar, Singh and Verma, 2012; Singh, Verma and Sarkar, 2010).

The Himalayas being one of the youngest mountains on the earth surface undergoes complex slope movements due to tectonic and erosional activities leading to geomorphic denudation (Ashutosh and Panthee, 2016; Avşar, Ulusay and Mutlutürk, 2015). Landslides of various types Shallow, Deep, Complex, Pose severe hazards in the Himalayan region, where climate is the ultimate control in the process of initiation of landslides. Some of the worst disasters in the world have been caused by landslides (Pham et al., 2017; S. Sarkar, Roy and Raha, 2016). Most of the landslide in Himachal Pradesh occurs during monsoon seasons and very few occur during the winter seasons suggest that the landslides are initiate by extensive rainfall coupled with dynamic nature of Himalayan terrain. Due to such reasons the mechanism and induced parameters behind rainfall-induced landslide is being studied extensively all round the world and especially in the Himalayan region. Such studies have been able to quantify few relationships between rainfall precipitation and local landslide characteristics parameters.

Fig. 9.1: A section of Road has been washed away due to heavy downpour inBalichowki area, Mandi District (August 2019) source: Indiatoday, Landslide Along NH-21 (Chandigarh – Manali), December 2015. source: Indiatoday

Intensity and Duration of the rainfall are two controlling factors of the rainfall-induced landslides (Bhambri et al., 2015; H. Rahardjo, T.T. Lim and M.F. Chang 1995).

Prolonged rainfall on a soil surface generally, leads to deep-seated landslide failure while short outburst of intense rainfall leads to shallow failure. Shallow failure of landslides occurs due to the reduced Soil or Debri Shear Strength thereby shear strength reduction. Moreover prolonged or rainfall causes increased positive pore water pressure that further reduces the stability material along the slopes and ultimately prone to failure (Crosta and Frattini 2008). (K,undu et al., 2017) stated that one of the important aspects to consider is the ground vibrations caused due to the passing of heavy vehicles along the road cur slopes which have not been addressed much in any studies. Increased ground vibrations due to the movement of light and heavy vehicles on landslide mass can be 0.5 times stronger than gravitational vibrations which lead to increased shear stress and gradually reducing the Factor of Safety (FOS) of the material (Singh, Verma and Sarkar, 2010; Singh et al., 2016; K. Sarkar, Singh and Verma, 2012).

Himachal Pradesh situated along the Himalayan region is very prone to hazards like landslides throughout the year, especially during the monsoon season. They pose a considerable threat to local settlements, transportation corridor and human lives. The National Highway 05 (NH – 05) is an important transportation corridor that connects upper reaches of Kinnaur, Lahul and Spiti, Kullu districts to the rest of India. Rampur – Jhakri area located in Rampur Tehsil of Shimla district along NH-05 is one of the hotspots for shallow Debri landslide due to its thick deposits of soil materials. Seasonal rainfall coupled with road cut slopes for highway maintenance causes recurrent Debri and soil failure along this area leading blockage of roads and loss of communication for a long period of time. Many research worldwide has previously addressed the problems of landslide specific to geologic and geotechnical investigations (Hungr et al., 2001; Luigi and Guzzetti, 2016; Karabulut, Durgun and Durmus, 2004; Alimohammadlou, Najafi and Yalcin, 2013). Notable authors in India to work with various aspects of landslide, especially at local level landslide studies, are (Anbalagan and Parida 2,013; Anbalagan and Singh, 1996; Ansari, Ahmad and Singh, 2014; Bali, Bhattacharya and Singh, 2009; Bhattacharya et al., 2013; Ganapathy and Hada, 2012; D. P. Kanungo et al., 2006).

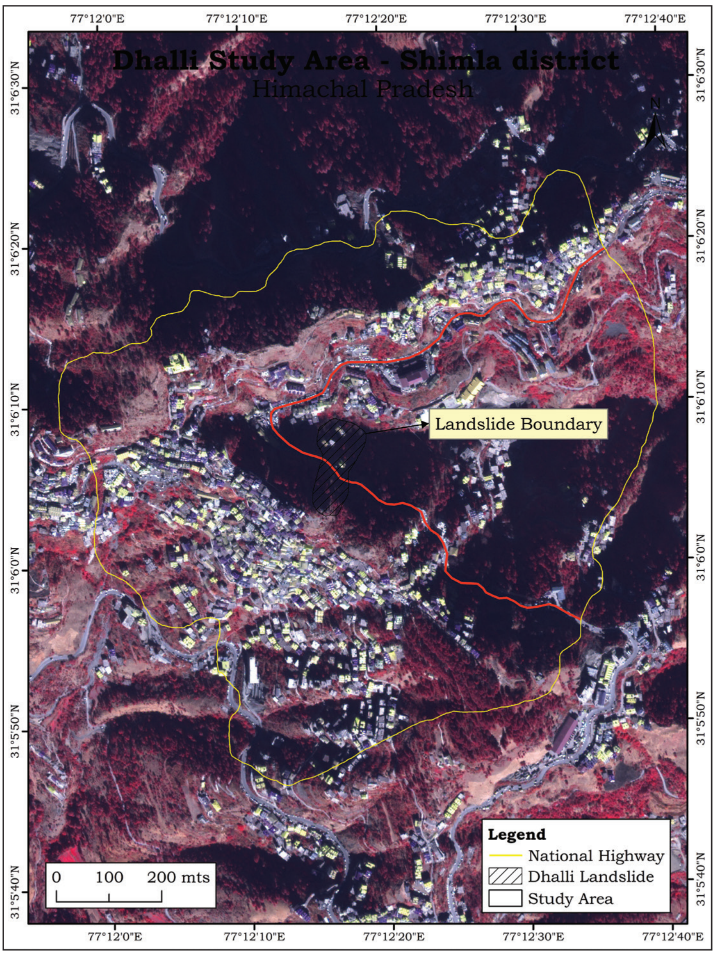
Need for Research

In the current research, an effort has been made to study the various causative factors of a recurring Rock failure along the Dhalli area based. Additionally, rainfall threshold investigation has been conducted for seasonal monthly and annual rainfalls to study the relation between landslide initiation and rainfall variations. Post failure slope stability assessment has carried out to estimate the critical FOS of the slide area and finally, stabilisation measures have been suggested to prevent the reactivation of landslide in near future.

Study Area

The Rock Slided area is located along the Dhalli Tunnel in Shimla town. The study area extends between 310546 and 310624 latitude and 771155 to 771240 longitude with a total geographical area of 0.85 Sq. km. The total height of the landslide from crown to runout distance extends for about 76.7 mts and the width of the landslide extends for about 18.6 mts. Due to the Rockslide nearby Settlements along the downhill and few parked vehicles have been damaged. Soil is mostly Sandy loam in nature and geology is mostly composed of Black Pyrite, Phyllite and Slate which are moderately strong according to GSI. The average rainfall of the area is about 999 mm with most of them occurring during rainfall season.

Fig. 9.2: Study Area



Data Used and Methods

The base map of the study area is digitised from "Survey of India" Toposheets 53E/04 at 1: 50,000 scale. Soil samples and other required information will be acquired through detailed Geological and geotechnical investigation of the landslide sites and also results retrieved from lab tests.

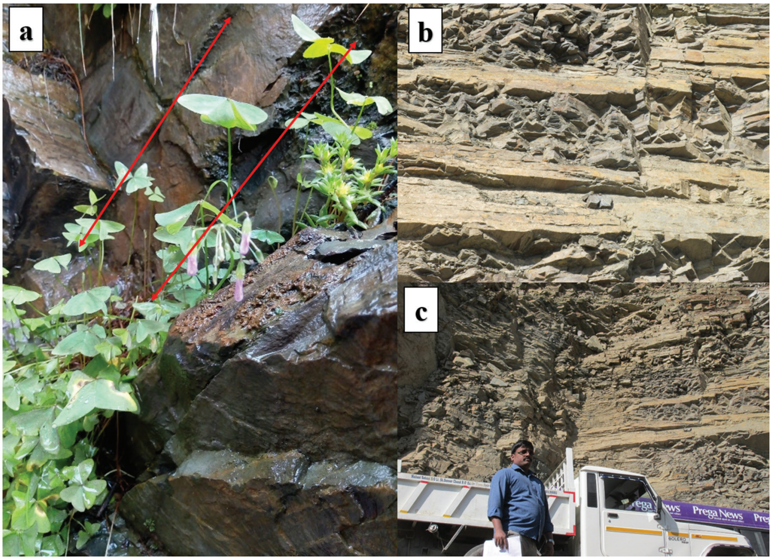
Table 1: Data used for the Research

Sl. No	Data	Source	Year	Resolution
1	Toposheets	Survey of India	1974	1:50,000
2	Large scale mapping	Worldview 2	2017	0.4mts
3	Geo-technical information	Field survey and lab analysis	2017 - 2019	-

Results and Discussion

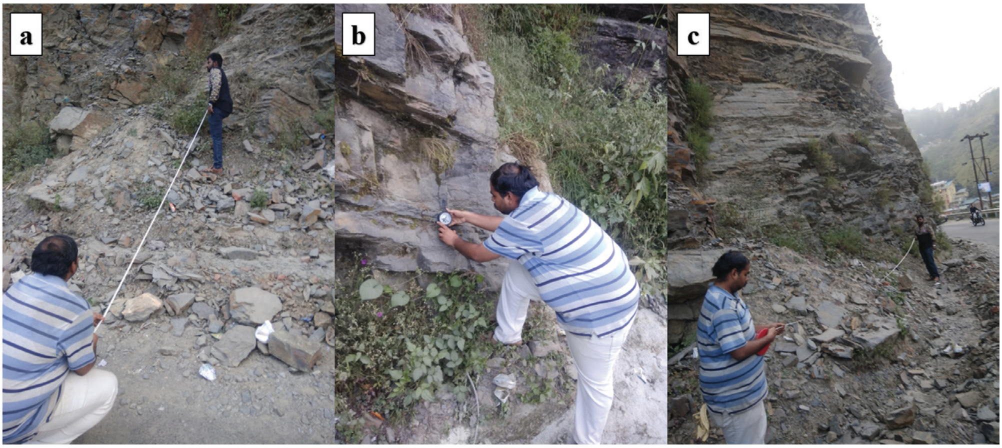
The Geological field investigation was conducted in the landslide area. The kinematic analysis was performed to analyse the type of rock failure in the study area. Kinematic analysis emphasis the use of Intersection of various joints and rock surfaces to estimate their potential weak zones and mode of failure. The mode of failure occurred in the study area is a wedge failure when two Joint sets plunge in the same direction as Slope face with plunge angle less than the slope angle.

Fig. 9.3: (a) Exposed Joint sets along the Surface the landslide; (b) Bedding plane and exposed joint surface along the study area; (c) Filed Investigation collecting various results on Geotechnical Parameters



Based on the data collected stereonet analysis was performed to determine the mode of failure for Dhalli landslide. Stereonet uses Circular graphs to represent the orientation of the Joint faces in terms of Dip direction and Dip amount.

Fig. 9.4: Collection of various joint sets from Study Area



The joint set J0 runs parallel to the bedding plane. Four different types of joint intersections were found as shown in the (Fig. 9.5).

Table 9.2: Various Joint sets

Sl.no	Joints	Dip Amount	Dip Direction
1	J0	33°	230°
2	J1	68°	2°
3	J2	71°	127°
4	J3	77°	80°
5	Slope face	81°	116°

Fig. 9.5: Stereonet with all Joint planes plotted

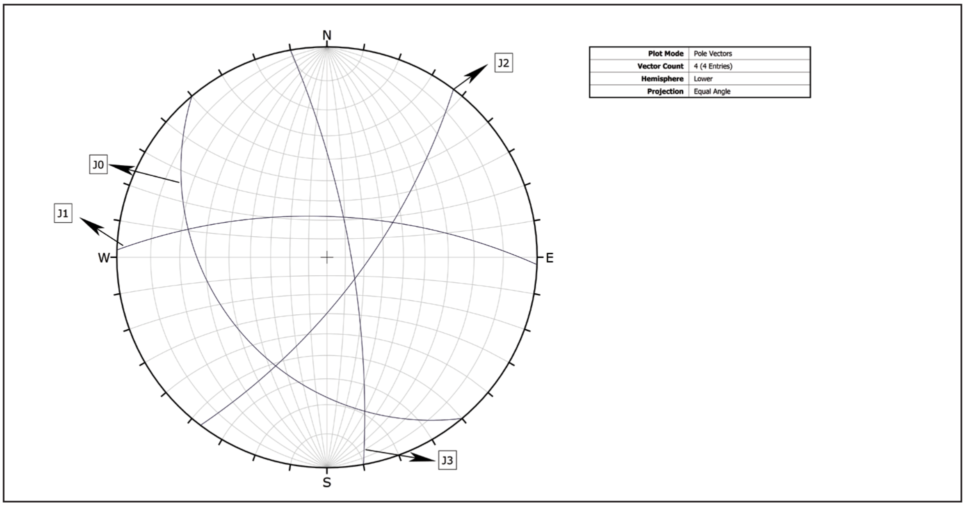


Fig. 9.6: Kinematic analysis of Dhalli landslide indicating Wedge failure

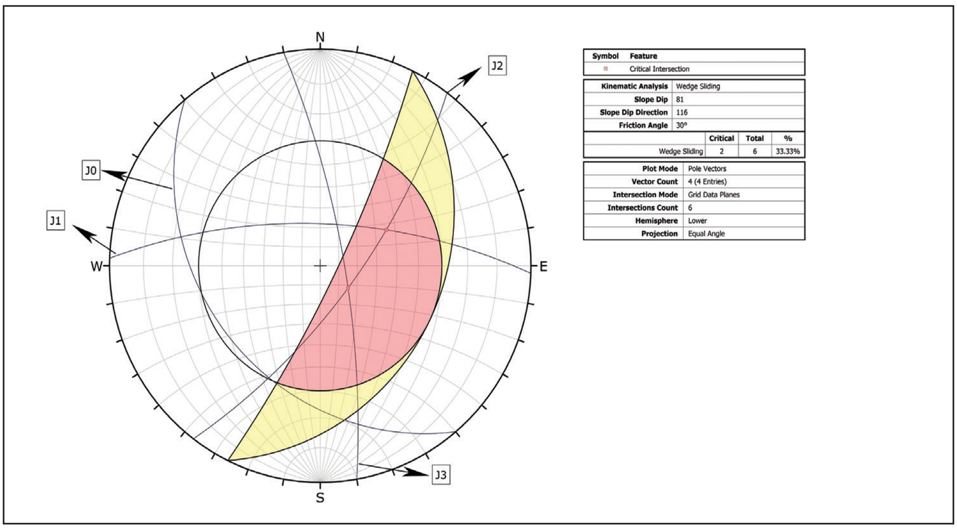
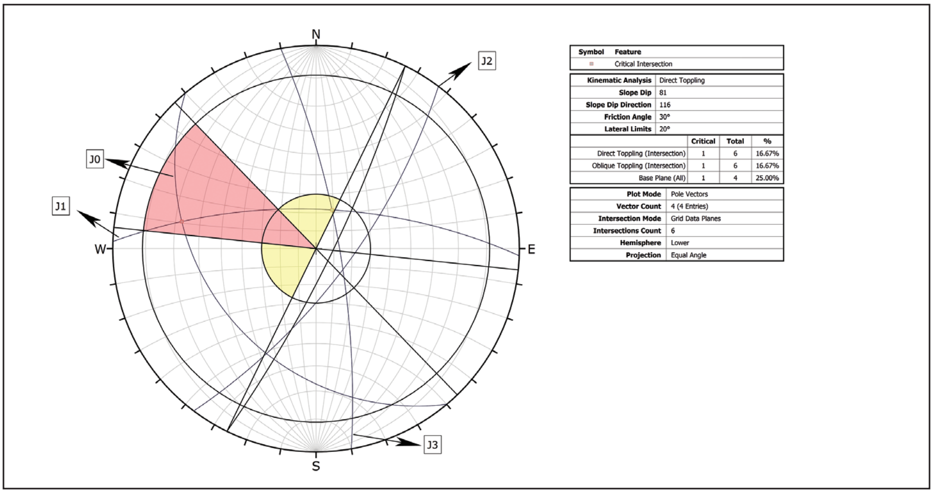


Fig. 9.7: Kinematic analysis of Dhalli landslide indicating Direct Toppling failure



Two lines J1 and J2 forming intersection line dipping away from the slope indicating it is wedge failure (Fig. 9.14). In (Fig. 9.14) the area indicated by pink colour represents the wedge failure conditions and unstable region for wedge failure. Point A represents the intersection of J1 and J2 and lies in a more unstable region, compared to the intersection of J2 and J3 (Fig. 9.15).

Rock Slope stability assessment and stabilisation measures for Dhalli landslide

Dhalli landslide which occurred in September 2017 is a structurally controlled landslide that occurred along a Road cut slope without proper toe support. Various joint sets running through the rocks made it prone for Shallow translational Wedge failure. Based on the data collected from field and lab analysis the slope stability of the landslide is computed using SWEDGE model through various computer simulations (Fig. 9.4a). The joint sets are plotted using a deterministic analysis of Mohr-Columb failure criterion. "The Mohr-Coulomb (MC) failure criterion is a set of linear equations in principal stress space describing the conditions for which an isotropic material will fail, with any effect from the intermediate principal stress being neglected". The Equation is represented as

$$\tau f = C_t + \sigma' n \tan\emptyset$$

Where τf = Shear strength of Intact rock
C_t = Cohesion of the Rock material
$\emptyset$ = Internal friction of the angle

Fig. 9.8: 3D view of the Dhalli Rock slope

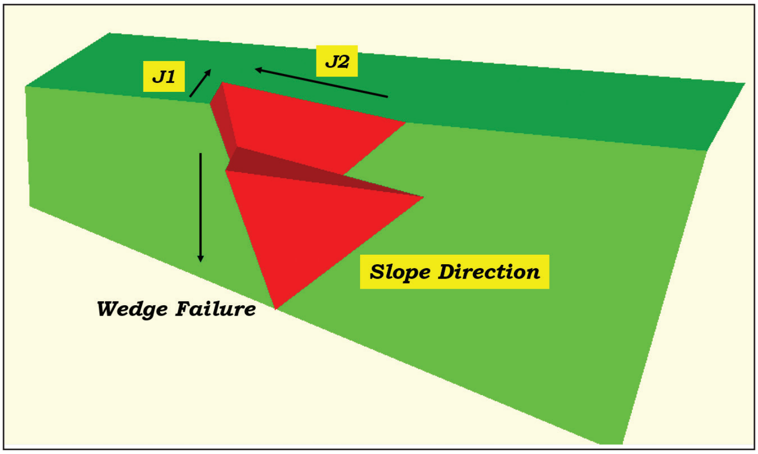
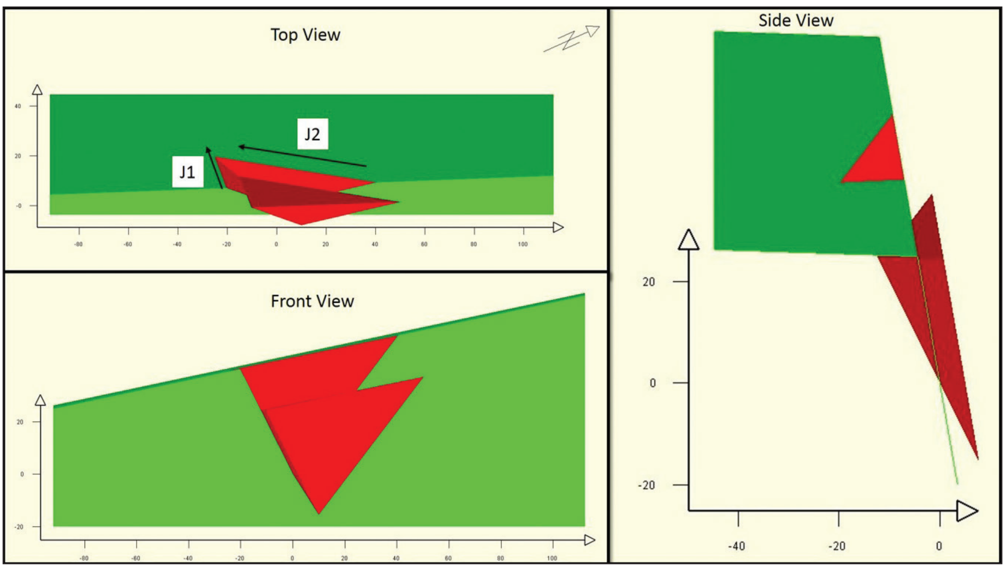
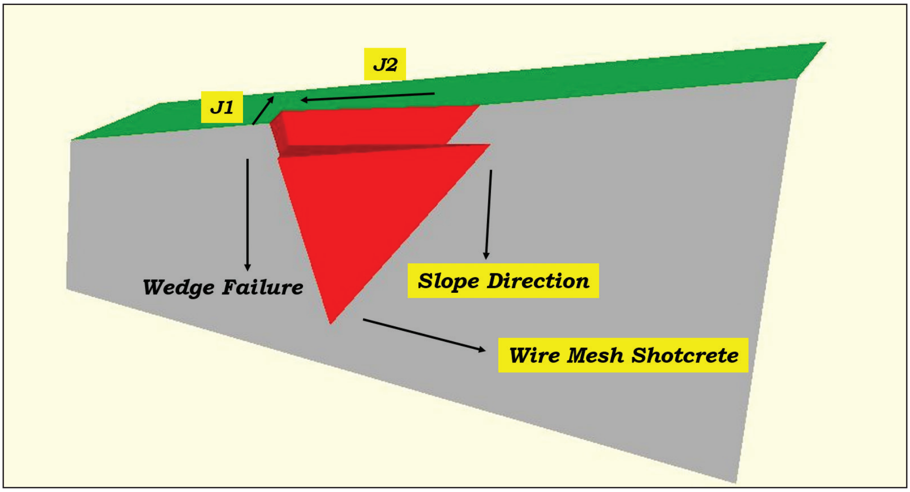


Fig. 9.9: Top, Front and Side view of the Dhalli Rockslide



Based on the results computed the total wedge area of the joint 1 is 297.33 sq. mts and wedge area for the joint 2 is 1587.52 sq. mts. The total factor of safety of this critical slope is derived as 0.9 which is below required value.

Fig. 9.10: Grey part indicating reinforced wire mesh with Shotcrete



Conclusion

Three different research methodologies were adopted to investigate the Geological, Geotechnical and Slope stability assessment and stabilisation measures of the study area. Site-specific Geological and Geo-technical investigation is carried out for specific landslides within the study area. The final assessment of landslide study involves estimating the stability of slopes and proposing suitable stabilisation measures. These studies are conducted through detailed geotechnical investigation of the landslides. Dhalli landslide which occurred in September 2017 is a structurally controlled landslide that occurred along a Road cut slope without proper toe support. Both field and lab studies were conducted to assess the stability of the slopes and provide suitable stabilisation measures. A geological field investigation was conducted at the landslide area. The kinematic analysis was performed to analyse the type of rock failure in the study area. Based on the data collected stereonet analysis was performed to determine the mode of failure for Dhalli landslide. Four different types of joint intersections were found as shown in the (Fig. 9.3a). Two lines J1 and J2 forming intersection line dipping away from the slope indicating it is wedge failure (Fig. 9.6b). In (Fig. 9.6b) the area indicated by pink colour represents the wedge failure conditions and unstable region for wedge failure. Point A represents the intersection of J1 and J2 and lies in a more unstable region, compared to the intersection of J2 and J3 Based on the data collected from field and lab analysis the slope stability of the landslide is computed using SWEDGE model through various computer simulations (Fig. 9.4a).

The joint sets are plotted using a deterministic analysis of Mohr-Columb failure criterion. Based on the results computed the total wedge area of the joint 1 is 297.33 sq. mts and wedge area for the joint 2 is 1587.52 sq. mts. The total factor of safety of this critical slope is derived as 0.9 which is below required value. Based on the nature of slope we applied reinforced wire mesh with Shotcrete type of stabilisation measure.

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