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Assessment of rock slope stability in Kulekhani watershed, central Nepal

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ABSTRACT

Study area lies in the Kulekhani watershed of central Nepal and comprises metasandstone, phyllite, schist, quartzite and marble. There is a wide variation in slopes in Kulekhani watershed as topographical variance. The watershed has been facing several slope failures during the past decades. The landslides and debris flows were observed mostly on the steep upper reaches of the Kulekhani watershed. Large plane rockslides are found on the slopes west of Phedigaun, where the hillslope angle ranges from 40º to 60º. Kinematic analysis of the slopes was carried out at fifteen different locations of the study area in order to interpret the rock slope stability. At each location, around seventy five measurements of joint orientation were analyzed. The analysis at Palung-Kulekhani area showed the high possibility of toppling failure in phyllites of Kulikhani Formation whereas wedge failure found to be prominent in marble beds of Markhu Formation. Probability of plane failures is seen in Kulikhani and Markhu formations. The slopes with dip angle between 30º and 65º have faced many failures and even further chance of failures is high in these slopes. The haphazard excavation is one of the major reasons for instability along the highway. Other causes are torrential rainfall and differential weathering of rocks in the area.

Keywords: Rock slope stability, Kinematic analysis, Kulekhani watershed, Central Nepal

INTRODUCTION

The potential danger of instability generally occurs at places where tectonically disintegrated and weathered rocks prevail and where a great number of overhangs gradually losing their stability developed. For this purpose, kinematic analysis is generally used to examine the potential for the various modes of rock slope failures that occur due to the presence of unfavorably oriented discontinuities (Greif and Vlcko, 2017). The analysis of rock slope stability has many applications in the design of rock slopes, roofs and walls of tunnels. When the instability is dictated by the presence of pre-existing discontinuities, the instability takes the form of plane sliding, wedge sliding or toppling (Zamani, 2008). Thus, analysis is performed in selected sites in the Kulekhani watershed of central Nepal with measured discontinuity data.

STUDY AREA

The study area covers section of Tribhuvan Highway between Khanigaon of Thaha Municipality in north and Shikharkot in the south. Further towards southeast from Shikharkot, the study area is extending up to Kiteni village. Similarly, following the road trail towards northwest from Shikharkot, the area touches Chaubas village. Towards southeast, the area follows Markhu and reaches up to Kulekhani Dam-site. Geographically, the study area starts at Chaubas village in the north-west (latitude 27°38’37” N and longitude 85°5’46’’ E) and Kulekhani dam is in the south-east (latitude 27°35’44” N and longitude 85°9’58’’ E).

Kulekhani watershed mostly comprises the steep and complex rocky slopes of Lesser Himalayan Zone. The terrain of the watershed is rugged and consisting of several folds of sloping hills with a number of streams and rivers (Chandra et al., 2002). The average annual precipitation over the watershed is about 1500 mm (Shrestha et al., 2014). Review of the past literatures shows that the frequent occurrences of slope failures such as landslides, debris flows and rockslides are common in this area and majority of the studies are found to be concentrated in post-disaster inventory and landslide susceptibility analysis (Dhital et al., 1993; Dhakal et al., 1999; Kayastha et al., 2013). Therefore, this study focuses more specifically the rock slope stability to know various modes of rock slope failures namely plane failure, wedge failure and toppling failure by analyzing discontinuity data.

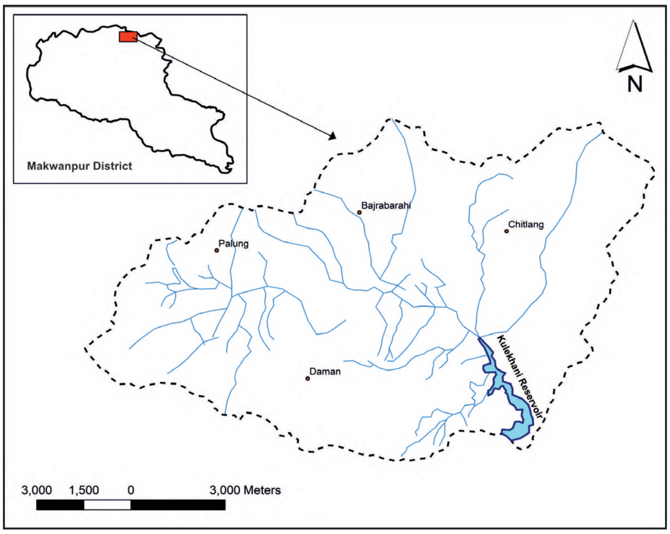

Fig.1: Location map of the study area

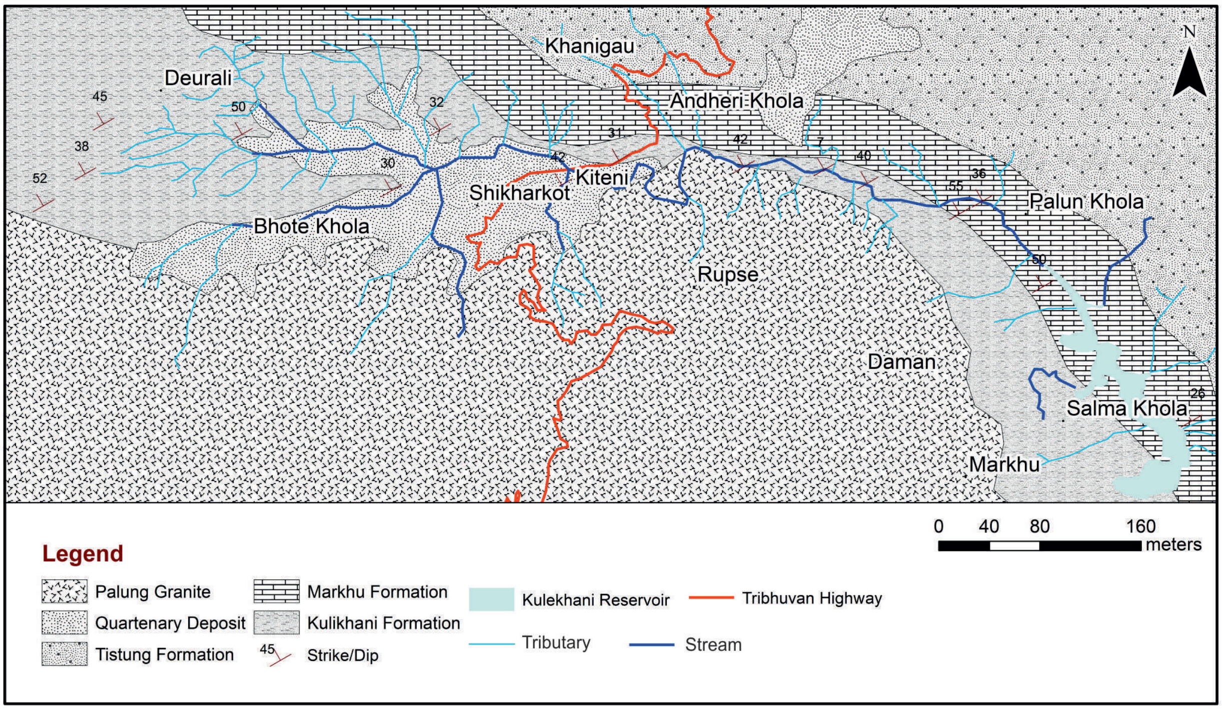

Fig. 2: Geological map of the study area (modified after Stöcklin and Bhattarai, 1977; Stöcklin, 1980)

Geology of the study area comprises the Lesser Himalayan rocks of the Kulikhani Formation, Markhu Formation and the Tistung Formation (Fig. 2). Granitic intrusion is found in the south-western region and Quaternary deposits are distributed as major stream valley-filled deposits. Palung valley consists of granite and phyllite whereas Markhu area is dominated by marble. In general, phyllite, schists and quartzite are mostly found in the Kulekhani watershed. Combination of variable topography, alternating hard and soft rocks, deep weathering of granite and frequent extreme weather event, and the area is susceptible to slope failures which are spatially occurred in different locations (Figs. 3a, b, c, d).

Fig. 3: Slope failures in different parts of the Kulekhani watershed (a) landslide in Khanigau, Thaha Municipality (b) Landslide at Chisapani (c) Slope along the road near Kulekhani dam-site (d) wide view of slopes in Palung valley vulnerable to failure (dip-slope condition)

KINEMATIC ANALYSIS

The kinematic stability analysis can be performed using the stereographic projection technique, which is a robust tool for discontinuity data collection and presentation (Mandalawi et al., 2016). Data required to carry out this method are dip direction and dip amount of the discontinuities and hill-slope orientation. Priest (1985) has used kinematic analysis to model the stability of wedges, rock blocks and any possible rock displacements at the slope surface. Oztekinm et al. (2006) also stated that joints constitute the main discontinuity type at the excavated slopes, and these geological structures have to be typically defined. Thus, rock slope failures often occur on critical pre-existing discontinuities which are daylighting at the toe of the slope (Gray 1988).

This study has evaluated the rock slope stability in the Kulekhani watershed by kinematic analysis (Fig. 1). A total of fifteen spots mostly slope along the roads and river banks are chosen for the analysis (Fig. 4). At each location, around seventy five discontinuity data were measured. The details of the methodology of kinematic analysis for a slope at Khanigaon landslide are presented (Fig. 5a). The measured orientation of joints were plotted as poles (Fig. 5b) and converted to contour plot (Fig. 5c) in order to obtain the dominant joint sets on the slope (Fig. 5d). The concentration after contouring provides the peak values that after transferring to equal area stereonet give the different joint sets in the slope (Table 1). Similar process was repeated for the remaining slopes. Three spots in Chaubas village, five in Palung valley, three in Khanigau landslide area, one in Thado Khola village and one in Kulekhani dam-site were selected for the study. Hill-slope orientation in terms of slope angle and slope direction was also plotted. The analysis was done by using Rocscience Dips 6.

Table 1: Major joint sets at Khanigaon rockslide

Joint sets	Dip direction	Dip angle
J_1	281	34
J_2	99	60
J_3	177	45
J_4	15	48

Three basic modes of failure: plane, wedge and toppling were analyzed from all selected spots. Moderate to high chance of wedge failure in marble slope is likely to occur in Thado Khola village near Kulekhani reservoir. The road section near Kulekhani reservoir mainly consists of jointed marble beds. The analysis shows the probability of toppling and wedge failure in this area. The analysis carried out in the exposure of quartzite and schist slopes indicates the high probability of toppling failure. The chance of wedge failure is moderate to high in this area. Rupse village is dominated by the Palung Granite, where toppling and wedge failure seems to occur random pattern. The Khanigaon landslide along the Tribhuvan Highway has highly jointed marble beds and there are possibilities of all three modes of failures: plane failure, toppling failure and wedge failure with moderate to high chance. Any kind of failure at Khanigaon is likely to affect the vehicular movement thereby blocking the road. The slopes along Gharti, Shankhamul and Kiteni Khola

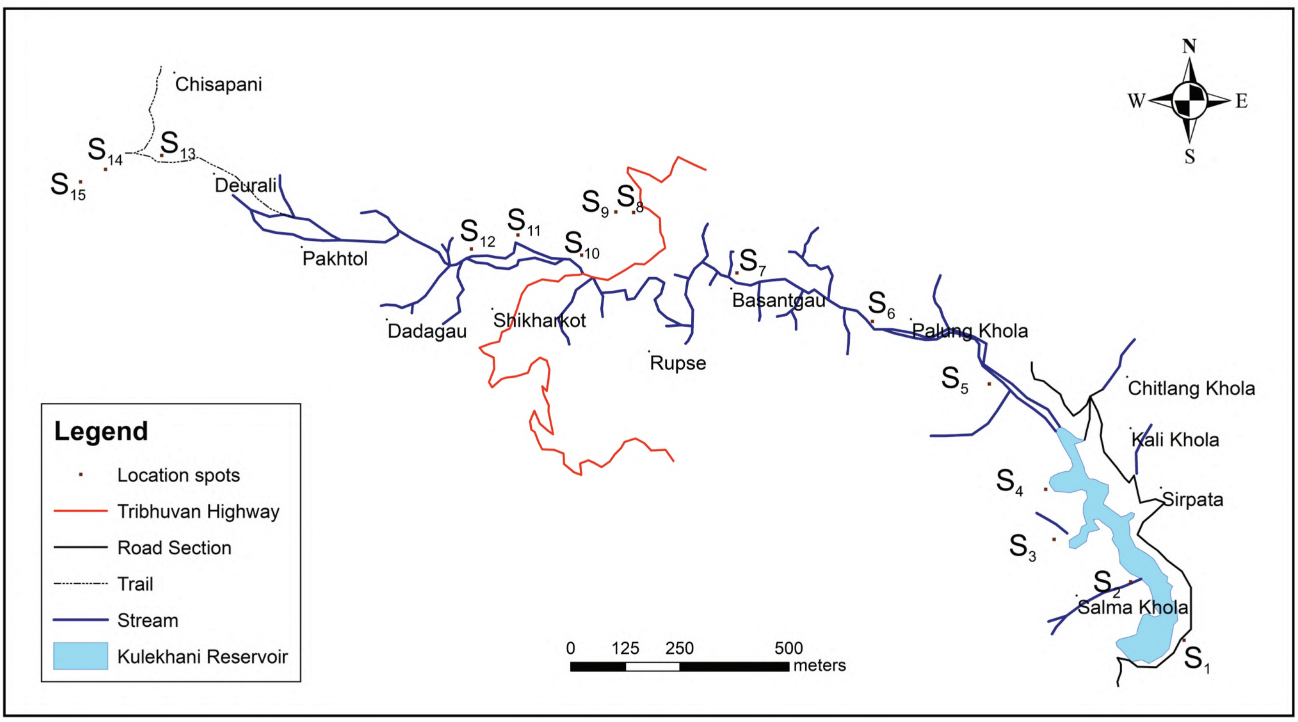

Fig. 4: Map showing the locations of kinematic analysis

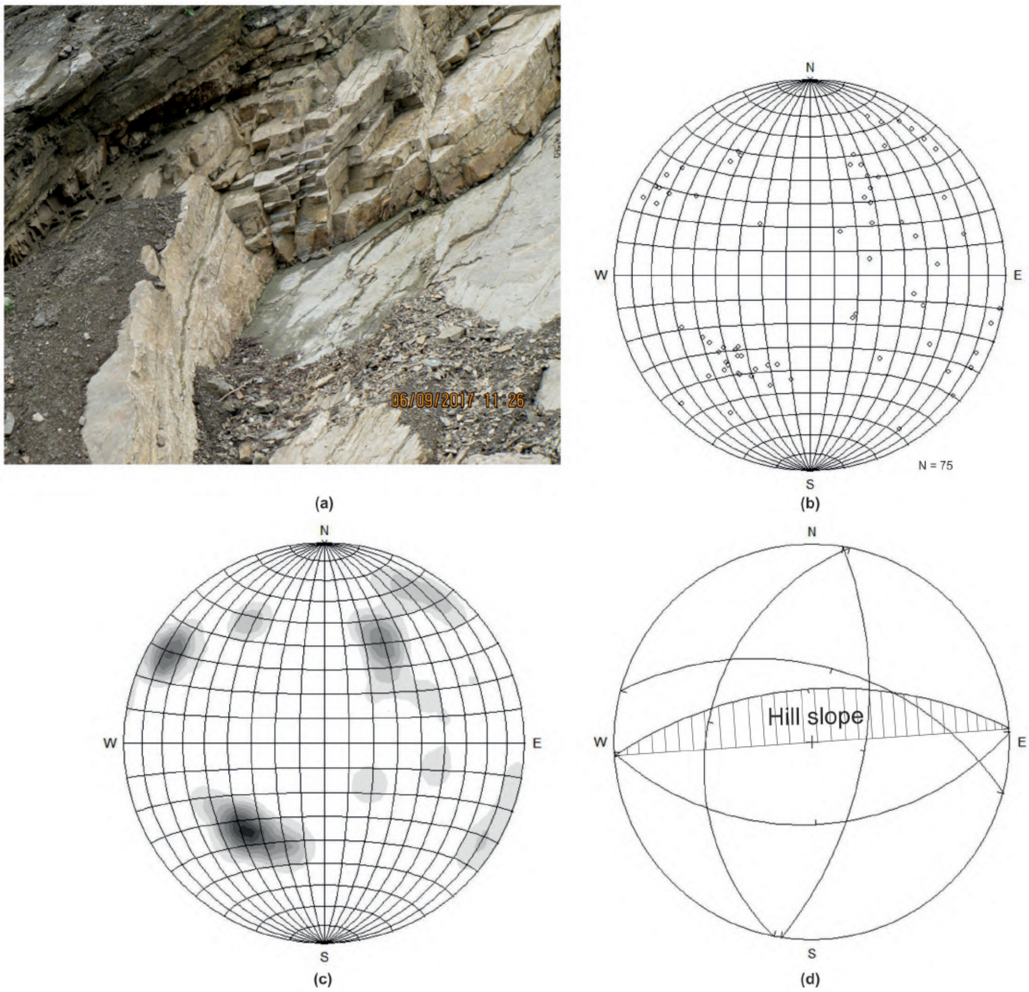

Fig. 5: Rock-slope stability analysis at Khanigaon (a) slope-face of rock outcrop (b) distribution of major discontinuity poles (c) density stereo-plot of major discontinuities (d) hill-slope and orientation of joints

in Palung valley are likely to undergo all three kinds of failures (plane, toppling, wedge) in slopes comprising schist. The slopes composed of schist and quartzite in Chaubas area are likely to fail as wedge and plane failures.

The slope near Kulekhani dam may fail as plane failure and there is moderate chance of wedge failure. Among the six studied slopes in the Palung valley, up-slopes around the Shankamul Khola seem to be more susceptible. The geology of the area consisting of alternating meta-sandstone and phyllite have undergone translation and wedge failures. Rock slope in the Markhu Formation has probability of potential wedge failure.

Concisely, rock slopes ranging 40°–60° might undergo high probability of failure (Fig. 6a). Similarly, the slope dipping 60°–80° also has high chances of slope failure. Probability of rock slope failures analyzed is shown in Fig. 6b, among which wedge failure (moderate - 20%, high - 30%) as a whole is likely to occur in many slopes. Plane failure (23%) and toppling failure (27%) are also found.

CONCLUSIONS

The kinematic analysis in selected sites of the Kulekhani watershed indicated that the probability of toppling failure is high in phyllites of the Kulikhani Formation whereas wedge failure seems to be prominent in marble beds of the Markhu Formation. The slope in range 30º–65º has undergone failure in past years. This study indicates the chances of failure are very high in the slope lying in the range of 40º–60º. Almost all of the fifteen spots are susceptible to wedge failure. Plane failure possibility is found to be present in the Kulikhani Formation and the Markhu Formation in which toppling failure is especially critical in slopes of the Kulikhani Formation. Rock slope stability analysis showed that wedge failures with moderate probability are 20% and high probability are 30%, plane failures are 23% and toppling failures are 27%.

The fragile geology, variable topography, occurrence of extreme weather event and human intervention are the main cause of slope failures. Control measures are not implemented in many places and a very few structures constructed that are

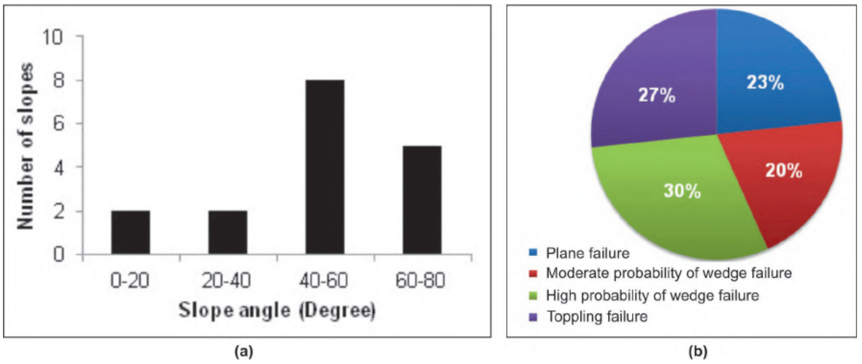

Fig. 6: Rock slope stability (a) in terms of slope angle and (b) modes of failure probability

found to be already damaged. Thus, it is recommended to implement suitable mitigation options such as slope modification, structural and non-structural measures to reduce risk of failures.

REFERENCES

Chandra, P., Rajbhandari, L. and Alam, B. and Akther, S., 2002, Application of GIS for Landslide Hazard Zonation and Mapping Disaster Prone Area: A Study of Kulekhani Watershed, Nepal. Plan Plus, v. 1(1), pp. 117–123.

Dhakal, A.S., Amada, T. and Aniya, M. 1999, Landslide Hazard Mapping and the Application of GIS in the Kulekhani Watershed, Nepal. Mountain Research and Development, v. 19(1), pp. 3–16.

Dhital, M.R., Khanal, N.R. and Thapa, K.B., 1993, the role of extreme weather events, mass movements, and land use change in increasing natural hazards. International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, 41 p.

Dhital, M.R., Manandhar, S., Rakenori, H., and Daisuke, S., 2014, Sediment accumulation in the Kulekhani reservoir due to the 1993 debris flows and landslides. 9th International Symposium on Lowland Technology, Japan, pp. 443–450.

Gray, A.P., 1988, "The problem of estimating the shear strength of unstable rock slopes". The fifth ANZ Geomechanics, Sydney, Australia.

Greif, V. and Vlcko, J., 2017, Kinematic Analysis of a Rock Slope at Strecno Castle (Slovakia) Based on the Processing of the Point Cloud Generated by UAV Photogrammetry. In: Mikoš, M., Tiwari, B., Yin, Y. and Sassa, K. (eds.), Advancing Culture of Living with Landslides, Advances in Landslide Science, v. 2, pp. 419–429.

Kayastha, P., Dhital, M.R. and De Smedt, F. 2013, Evaluation and Comparison of GIS based Landslide Susceptibility Mapping Procedures in Kulekhani Watershed. Nepal. Jour. Geol. Soc. India, v. 81, pp. 219–231.

Mandalawi, M.A., You, G., Dowling, K. and Dahlhaus, P., 2016, A more general model for the analysis of the rock slope stability. Int. Jour. GEOMATE, v. 10(1), pp. 1575–1583.

Priest, S.D., 1985, "The statical analysis of rigid block stability in jointed rock masses". Technical Report to Koolan Island at WA, Imperial College, London.

Rocscience, 2014, Dips 6.0, Toronto, Canada.

Shrestha, S., Khatiwada, M., Babel, M. and Parajuli, K., 2014, Impact of Climate Change on River Flow and Hydropower Production in Kulekhani Hydropower Project of Nepal. Environmental Processes. doi: 1. 10.1007/s40710-014-0020-z.

Stöcklin, J., 1980, Geology of Nepal and its Regional Frame. In: Jour. Geol. Soc., v. 137, pp. 1–34.

Stöcklin, J. and Bhattarai, K.D., 1977, Geology of Kathmandu Area and Central Mahabharat Range, Nepal Himalaya. Kathmandu: HMG/UNDP Mineral Exploration Project, Technical Report, New York, 64 p. (Unpubl. Rept.)

Zamani, M. 2008, A more general model for the analysis of the rock slope stability. Sâdhanâ, v. 33(4), India, pp. 433–441.