Slope Stability Evaluation based on Empirical Methods and it's Potential Remedy at Lesser Himalayan Zone (A Case Study of Bhalam-Hill Slope, Kaski)

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ABSTRACT

The study area lies in Bhalam, Kaski district nearly 2 km from Batulechour main district road network near Gandarva community residing near Kali Khola river. The study area is comprises of several lithological factors. Field observation, sampling, lab analysis, geological survey with GPS, compass, geological hammer and tape are the main methods utilize to evaluate slope stability and possibility of failure in the study area. From the study it is found that there are few major discontinuities which play vital role in determining slope failure around the study area. The major failure due to discontinuity are planar failure, wedge failure and somewhere block failure. High ground water table approximately 0.06m, steep slope varying from 25^0 to 60^0, improper road cutting, weathering of rock mass are major factor contributing to rock fall and landslide in the study area. The study also shows FOS<1(0.937 and 0.569) at two different places which is most critical and make slope unstable. SMR is calculated on the basis of RMR_b, GSI is calculated on the basis of RQD and UCS is calculated on the basis of empirical methods which uses pulse velocity and porosity chart for determining related equation. The calculated value of RMR_b, SMR and FOS shows less stability of study area along Bhalam-Batulechour road section near Kali- Khola river with possibility of impact on Bhalam road bridge and two lane road section. There need a corrective measure in slope for sustainable stability in the long run.

KEYWORDS

Bio-engineering, Discontinuity, Empirical methods, FOS, GWT, Slope stability, Structural supports, UCS

INTRODUCTION

Dripping of water, with large amount of jointed structure of rock mass are prevalent at about 4-5 kmat Bhalam-Batulechour road section of Kaski district. Rock mass seem to be unstable with some fall and slope failure are being observed.

Landslide encompasses different kinds of mass movement, which includes rock-fall, toppling, and wedge as well as debris flow (Kahlon et al., 2014).To understand the slope failure and its prevention rock mass characterization is very important (Bartarya et al., 1998).

Rock Mass Rating (RMR_b) is very much useful in characterization of rock mass which is mostly utilize in engineering field (Bieniawski,1974) which was later modified for several times over a year. It has certain problem with regard to solving geological problem so, geological strength index (GSI) along with RMR_b is utilize to understand behaviour of fracture/jointed rock mass.

GSI is important parameter, which reflects the description of rock structure, and block surface condition, which varies between 0 and 100 (Vasarhelyi, 2016). It is now a day mostly utilize as an engineering index for the categorization of rock mass quality. Three locations have been selected and identified in the study area for the estimation and evaluation of RMR_b, GSI and SMR. Factor of safety (FOS) is determined at two locations to evaluate the slope stability.

The GSI is estimated in the field by using Hock-Brown(2013) equation and by using equation (4).For calculation of RMR_b, UCS is determine on basis of predetermined equation (1) and(2) (Kessler et al., 2017).Finally RMR_b is determine using equation (3).Slope Mass Rating (SMR) is estimated using equation (5) which was derived from the RMR_b classification system and possess adjustment factors which rely on the discontinuity condition, slope orientation and the excavation method respectively.

FOS has been calculated using slope stability software tool, which utilize slope angle, surface ground water table and elevation of the study area, which ranges from 905m to 921m respectively. The comparison helps to strengthen current evaluation approach and guides a pathway to outline problem of instability.

Statement of the problem

Every year a lot of slope failure occurs in Kaski district which is hazardous during monsoon season with huge loss of life and property. Bhalam hill slopes along Bhalam-Batulechour section cannot be left behind regarding this aspect. Steep slope ranging from 30^0 to almost 60^0, colluvial soil, several discontinuity in rock mass and excessive cutting along road alignment are major problem regarding the study area. High ground water table (0.06m), high pore- water pressure due to excessive rainfall and infiltration are major factors pertaining to slope instability problem in the study area. In addition, due to higher rate of surface run-off, slowly rock starts splitting from uphill and the block/fragments are brought down which is major problem to be evaluated for its stability.

Significance of the study

This study is important regarding to slope stability which is associated with rural road safety. The study will benefit to evaluate risk of slope failure and measures for slope stability such that different debris flow can be prevented in Kaski district. It assists to DOR and Government body which work on soil conservation for effective planning and management regarding to slope failure and rural road safety.

Study area

The study area is located along the Bhalam-Batulechour road section, ward No-29. The study area has elevation of 910melevation with $28^0$13’08’’N and $83^0$58’28’E which connect Bhalam with Batulechour. The rock detachment along with its fall and slide are observed during rainy season (Asadh and Shrawan) which generally obstruct the traffic flow movement in the particular section of the road.

Objectives of the study

The major objectives of the study include:

i) to estimate the strength of the rock mass on the basis of RMR_b and GSI.

ii)to determine the slope stability on the basis of factor of safety (FOS) and SMR.

iii)to recommend suitable remedial measure (support) for slope stability.

Literature review

Rock mass rating (RMR) is essential tool for rock mass characterization which is commonly used for planning and design in engineering applications introduced by Bieniawski (1974) which was later modified several times over the years. The rock mass is sorted into five classes of RMR_b value:

1. Very good (100-81),
2. Good (80-61),
3. Fair (60-41),
4. Poor (40-21) and
5. Very poor (<20) (Beniawski, 1993).

The application of Rock mass rating ($RMR_{b)}$ has certain limitations to address engineering geological problem. Therefore combination of geological strength index (GSI) and RMR_b is necessary to study the nature of fractured rock mass. The rock quality designation (RQD) is the most important parameter to find RMR_b as well as GSI (Zhang, 2015).

Slope unstable processes are cumulative of local geomorphic, hydrologic and geological conditions, which can also be said as geodynamic processes due to vegetation, land use practices, human activities, frequency and intensity of precipitation and seismicity.

Geologically, the area lies in Zone 4 (lesser Himalayan Zone).The rock on these group comprises of moderately hard and soft rock of sedimentary and metamorphic horizon Dahal 2006, Figure 1).The combination of elevated peaks, steep slopes, weak rock and thick soil cover over intact bedrock along with the monsoon climate make each zone of Nepal very hazardous. Bad construction practices guided by donor agencies and interest of local leader people lack national standards and guidelines which leads to ultimate slope failure with huge losses of life and property every year. The study of rainfall pattern of Nepal shows that more than 80% of rainfall occurs in monsoon season and all landslides occur in this period (Dahal et al., 2006).

If cumulative rainfall of 24-hours is likely to occur more than 260mm, then flow like landslide or debris flow can occur where- as for a rainfall ranging between 230mm to 250mm shallow landslide will occur (Dahal & Kafle, 2003). As per previous studies, it shows that if the soil is thick colluvium deposit, the threshold of rainfall is 230mm (Khanal et al., 2005).

During rainy season, yearly hundreds of landslides seem to be occurring in Nepal. These results wipe out of many villages, blockage in road network, buried irrigation canal and road side drain. Further, entire mountains seems to be moving leading to huge disaster. Basically, there are four trained of landslide occurring in Nepal which are rock glacier creep, rock and debris fall, slump with solifluction and rock slide with slump. Mostly in lesser Himalayan zone, rock like red phyllite, slate, quartzite with chlorite schist and smooth topography prevail along with agricultural land. The rate of percolation is heavy and weathering is deep nearly up-to 100feet.During rainy season (Asadh and Shrawan) nearly 20% of its volume, the water is soaked by colluvium soil which leads to increase nearly 15% and slump occurs. It has been found from several observations that wherever there is an agricultural land on hill top or road and canal passing in the lower side along with higher ground water table there will be invariably slide from the top. The angle of repose for stability in such terrain is found to be less than 30^0 slope in rainy season where as it can stand on 40^0 in dry season.

Rock slide with slum is dominant form of above mentioned slide where road, canals passes through the dip plane of the rock, more to say especially when topography follows dip slopes and deep river cutting at the base of the hill. In Nepal, Himalayas zone there are many horizons of carbonaceous shale containing the pyrite. This shale when exposed to atmosphere is oxidized and pyrite turns into sulpheric acid. It starts chemically weathering the rock and generate landslide which can also be observe in lesser Himalayan zone too (Sharma, 1977).

Human induced landslides have substantial impact, especially in terms of loss of agricultural productivity, which possess severe economic effects both locally and nationally (Petley, 2007). Large failures at different places like frequent rock fall in Siddha-Baba road section; Landslide and frequent debris flow during rainy season at Chitwan-Narayangadh-Mugling road section are causing serious economic disruption to our country Nepal and severe human fatalities too.

Three locations have been selected and identified for the estimation and analysis of RMR_b, SMR, and GSI (Figure 2). FOS is determined at study area as well as other landslide prevailing zone at Bhalam hill slope respectively to evaluate existing slope stability.

The GSI is estimated in the field by using equation (4). For calculation of RMR_b, UCS is determined on basis of predetermined equation (equation 1 and 2) (Kessler et al., 2017). FOS has been performed using slope stability software tool. The comparison helps to strengthen current evaluation approach and guides a pathway to outline problem of instability.

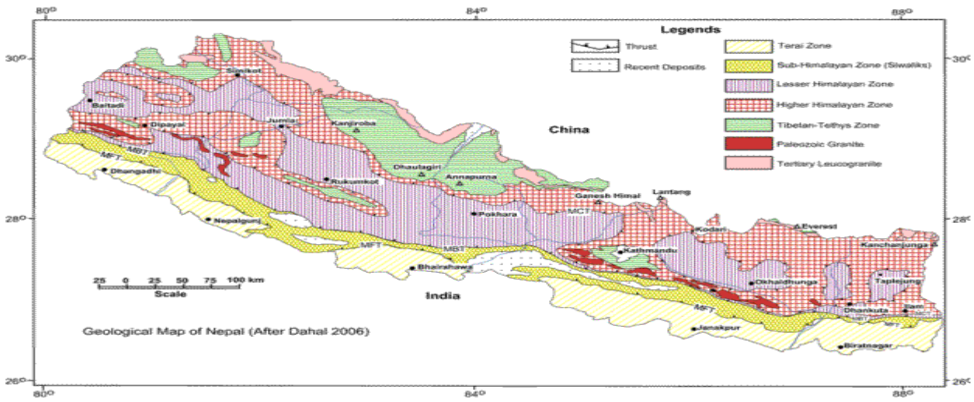

Figure 1: Geological Map of Nepal (Dahal, 2006)

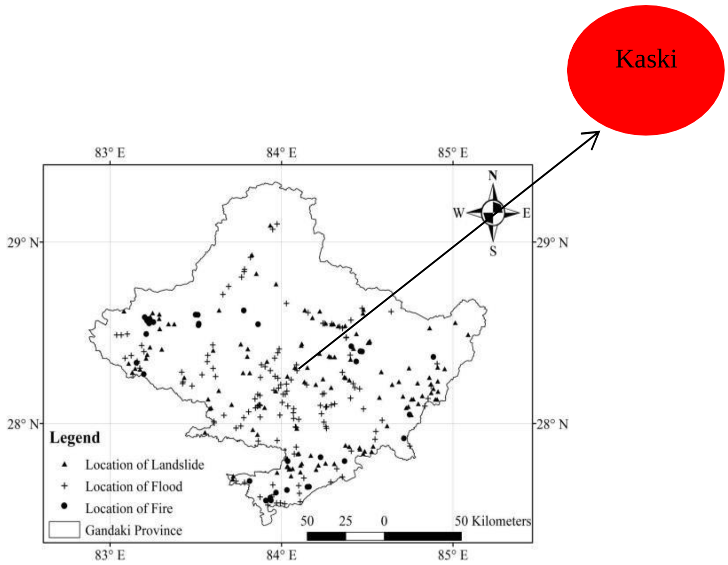

Figure 2: Location of Landslide Risk in Kaski
(Source: Feasibility Study Report of Disaster Risk Area, Gandaki Province, 2019)

METHODOLOGY

The critical zone regarding to slope instability are identified by observation. The discontinuity in rock are observed. Geological compass, GPS, are utilize to calculate RMR_b, SMR and elevation of study area respectively. Likewise, FOS regarding slope stability identification is calculated using software. The uniaxial compressive strength (UCS) is calculated by using standard empirical method, which use pulse velocity and porosity chart respectively. Similarly, GSI (Geological strength index) are plotted with respective calculated RMR_b value with the help of linear regression to identify failure in rock mass of respective sample taken into consideration for the study.

Data Collection

Data for the study are collected on the basis of field data which are achieved by field observation using survey instruments (Table 2) and predetermined equation were also used as obtained in previousresearch regarding slope stability.

Data Analysis

The data analysis include Rock Mass Rating system(Bieniawski,1974).The uniaxial compressive strength(UCS) are calculated on the basis of predetermined equation related to pulse velocity and porosity from a collected rock sample equation1 & 2 (Kessler,2017)in the study area. Geological strength index (GSI) is also calculated by standard formula equation 4 (Vasarhelyi, 2016). Similarly, Slope Mass Rating (SMR) is calculated by using adjusting factors F1, F2, F3, F4 respectively with calculated value of RMR_b (Table 3) and finally probability of failure are defined long with failure mode of study area (Table 4). Slope stability evaluation are also made using software as shown in (Figure 3,Figure 4 & Figure 5) by calculating factor of safety(FOS).The total of 3 slopes were examined along with FOS and additional one slope to determine FOS for testing the reliability of the study.

$Y=0.0838x- 86.477$ ($R^2=0.7937$)…. (1) $V_p=$

2598.4ƒ -2366(R^2=0.9078)….. (2)
RMR_b=UCS+RQD+DS+DC+GW….. (3)
GSI=1.5(Joint wall condition) + 0.5RQD… (4)
SMR=RMR_b+ (F1*F2*F3) + F4…… (5)

Table 1: Lithological factors

Slope name	Lithology
S-01	Lesser Himalayan Zone, Rocky type Clayey soil, pebble, sand, gravel mostly Metamorphic and sedimentary rock origin, high ground water table.
S-02	
S-03	

Table 2: Dip and dip direction of the discontinuity sets in the rock mass forming the slope

Type of discontinuity	Dip (degree)	Dip Direction (degree)	Strike
Joint set- 01	21^0	136^0	$N226^0E$
Joint set-02	12^0	11^0	$N191^0E$
Joint set-03	15^0	61^0	$N241^0E$

Table 3: RMR_b, GSI and SMR value of the Bhalam hill slope, Kaski

Location	RQD	SD	CD	UCS	Bulk density(gm/cm^3)	RMR_b	SMR	GSI
Slope-01	1.08%	8.4	0.1	16Mpa	2.04	24	14.13	13.29
Slope-02	1.13%	4.9	3.6	30Mpa	2.29	44	40.0	13.315
Slope-03	1.09%	8.0	1.0	30Mpa	4.1	52	66.55	14.04

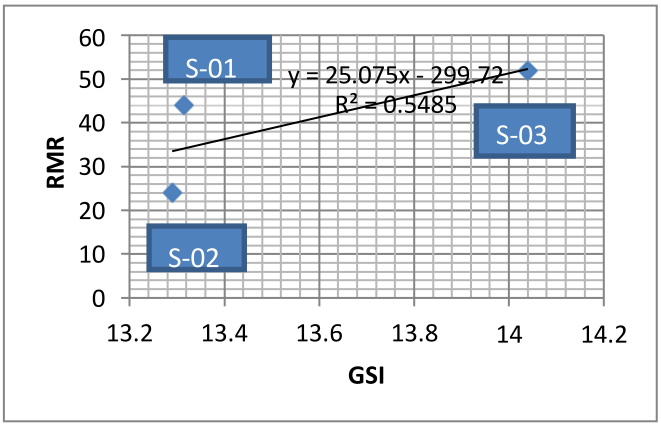

Figure 3: Graphical Analysis of RMR_b and GSI of Bhalam Hill Slope, Kaski

Table.4: SMR Rating/Classes of the Slopes and their Descriptions (Romana, 1993)

Slope name	SMR	Class	Rock Mass Description	Stability	Failures	Probability of failure
S-01	14.13	V	Very bad	Completely unstable	Big planar/soil like or circular	0.9
S-02	40.25	IV	Bad	Unstable	Planar or big wedge	0.6
S-03	66.55	II	Good	Stable	Some block failure	0.2

Table 5: Slope stability analysis results and SMR support recommendation for studied slope at Bhalam hill slope, Kaski

Slope name	Failure mode	SMR	Stability	Recommended support
S-01	Big Planar or soil like or circular	14.13	Completely unstable	Re-excavation
S-02	Planar or big wedge	40.25	Unstable	Importance/corrective
S-03	Some block failure	66.55	Stable	Occasional

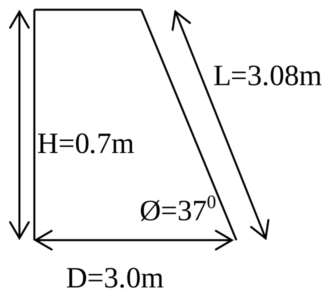

Figure 4: Slope dimension of Study Area
Factor of Safety (FOS) = 0.937, (Unstable)

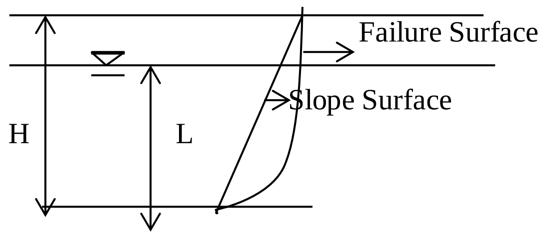

Figure 5: Stability of Bhalam Hill slope

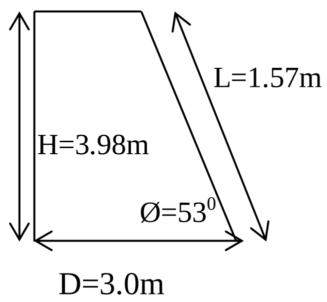

Figure 6: Slope dimension (Bhalam Hill Slope failure),
FOS= 0.569 (Unstable)

RESULTS

From the data analysis the rock slope range from very bad(S-01), bad (S-02) and good (S-03, Figure 3, Table 4) along with SMR completely unstable (S-01) unstable (S-02) and except at S-03 stable (Table 5). FOS calculation with reference to ground water and elevation were 0.937 and 0.569 at two different location (Figure 4, Figure 5 and Figure 6) which were less than one, which ensure unstable of Bhalam hill slope along Bhalam-Batulechour road section.

DISCUSSION

RMR and GSI in combination are the best empirical methods for analysis of rock mass stability along with SMR and FOS to study slope stability. In previous study of landslide at 'Application of Slope Mass Rating System In Slope Stability Class Evaluation' (Rasyikin et al., 2019),'Slope Stability Analysis Based on Rock Mass Rating, Geological Strength Index and Kinematic Analysis in Vindhyan Rock Formation' (Kumar et al., 2021) quite similar result had been obtain regarding to slope stability. The calculated value of R^2 obtained is 0.5485(Figure 3) in the study related to RMR_b and GSI and FOS=0.937 and 0.569 which are less than one on the basis of ground water and elevation at two different location of the study area had shown more reliability of the study.

LIMITATIONS

i) Kinematic analysis using stereo net plot has not been made during evaluation of the study.
ii) Factor of safety is calculated based on elevation and depth of ground water.
iii) Detail soil investigation of the study area has not been done.

CONCLUSION AND RECOMMENDATION

This study concludes that the rock fall character in the Bhalam hill slope along Bhalam-Batulechour road section of Kaski is hazardous with probability of failure 0.9, 0.6 and 0.2 m leading to mostly planer and block failure with some wedge failure (Table 4).These needs structural counter measures, as well as different bio-engineering measures for maintaining slope stability and safety to road users as well as Kali khola, Bhalam bridge of design span 37.0m respectively. Basically, translational slide along with some block failures, mostly planar/circular failure as well as some where wedge failure seems to occur due to unfavourable orientation of the discontinuity sets in colluvial soil of study area. Breaking pattern of metamorphic as well as sedimentary rock, high ground water table, weathering and debris flow are prevalent and re-occurring in nature. Rock fall barrier system, anchored rock mesh, rock netting system, rock shed are basic structure require for the stability of the slope of the study area. In addition bio-engineering measure such as bamboo plantation, jute netting, brush layering too help to stabilize such critical failure and discontinued rock mass which can be implemented in similar type of study area having a similar topography and lithological factors(Table 1) of Lesser Himalayan Zone.

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