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Slope Mass Rating Around Malekhu-Thopal Khola Corrider, Malekhu, Central Nepal Lesser Himalaya

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Abstract: The Malekhu-Thopal Khola area is rich in metamorphic rocks. The extension of road along the Malekhu-Thopal Khola can lead to the instability of stream bank slope. The road of the Malekhu Khola corridor has been extended from the Prithvi Highway to the southern remote area, and the road of the Thopal Khola corridor has been extended from the Prithvi Highway to the North in Dhading Besi. The study is focused on the Slope Mass Rating (SMR) of the road cut slope as well as the streambank slopes along the Malekhu Khola and the Thopal Khola (Malekhu-Dhading road).The result shows that the 38% slope of the study area is stable in terms of plane failure. The slopes lying across the Malekhu Formation and the Kalitar Formation are unstable. Considering the slopes in terms of toppling failure, 41% of the slopes are found to be stable, whereas some range from partially stable to stable slopes to the partially stable to the unstable slopes. Similarly, 50% of the slopes are stable to partially stable in terms of wedge failure, whereas some other slopes lying in the Fagfog Quartzite, Malekhu Limestone, Kalitar Formation and the Kulekhani Formation lie in unstable slope category. If the slope stability of the whole stream corridor is considered, only 20–25% of the slope area is completely stable while the remaining is vulnerable due to various slope failures.

Keywords: Slope Mass Rating (SMR), Rock Mass Rating (RMR), Toppling Failure, Plane Failure, Wedge Failure, Lesser Himalaya

1. Introduction

The Malekhu Khola corridor and the Thopal Khola corridor are the major places where roads have been extended towards the part of remote area and the Northern part (Dhading Besi), respectively from the Prithvi Highway. The stream corridors are frequently subjected to bank erosion, slope movements and flash flooding (Shrestha and Tamrakar 2007a). Therefore, stream bank slopes are required to be characterized for their condition. However, analyzing the past experiences of Nepal, thousands of lives and properties are being lost every year due to natural disaster such as landslide, flood and debris flow (Upreti and Dhital 1996). The behavior of rock slope is governed by intact rock material properties and discontinuities (Sen 2003). Knowing the characteristics of rock mass, we can minimize such hazards caused by natural disasters (Singh and Tamrakar 2013). Slope Mass Rating (SMR) system has been to forecast stability problems in future road construction and was derived from the basic RMR (Bieniawski 1989). The SMR proposed by Romana (1985) was obtained from RMR by subtracting a factorial adjustment factor depending on the joint-slope relationship and adding a factor depending on the method of excavation. The main aims of this study are to characterize rocks of the slope and to evaluate stability status.

2. Geological Setting

The study area lies in the Lesser Himalaya (Figure 1), which is bordered in the south by the Main Boundary Thrust (MBT) and in the north by the Main Central Thrust (MCT).

The Lesser Himalaya is divided into the Kathmandu Complex and the Nawakot Complex (Stöcklin and Bhattarai, 1977; Stöcklin, 1981). The study area includes the Lower and the Upper Nawakot Groups of the Nawakot Complex (Figure 2) and the Bhimphedi Group of the Kathmandu Complex (Figure 3). These groups extend roughly NW-SE with regional dipping towards the South, and constitute the northern limb of the Mahabharat Synclinorium (Stöcklin, 1981).

The Nawakot Complex and the Kathmandu Complex are separated by the Mahabharat Thrust (Stöcklin, 1980). The Lower Nawakot Group is subdivided into Kunchha Formation, Fagfog Quartzite, Dandagaun Phyllite, Nourpul Formation and the Dhading Dolomite in ascending order. The Upper Nawakot Group is subdivided into the Benighat Slate, Malekhu Limestone and the Robang Formation. The Nawakot Complex is composed exclusively of low grade meta-sediments.

The Bhimphedi Group comprises medium-grade metamorphic rocks and has been divided into six formations: Raduwa Formation, Bhaisedobhan Marble, Kalitar Formation, Chisapani Quartzite, Kulekhani Formation and the Markhu Formation in ascending order from north to south (Figure 2).

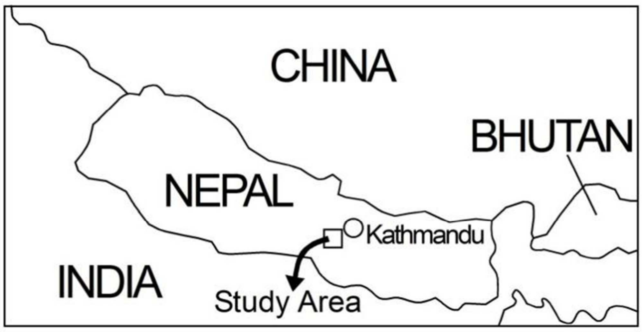

Figure 1. *Map showing the location of the study area.*

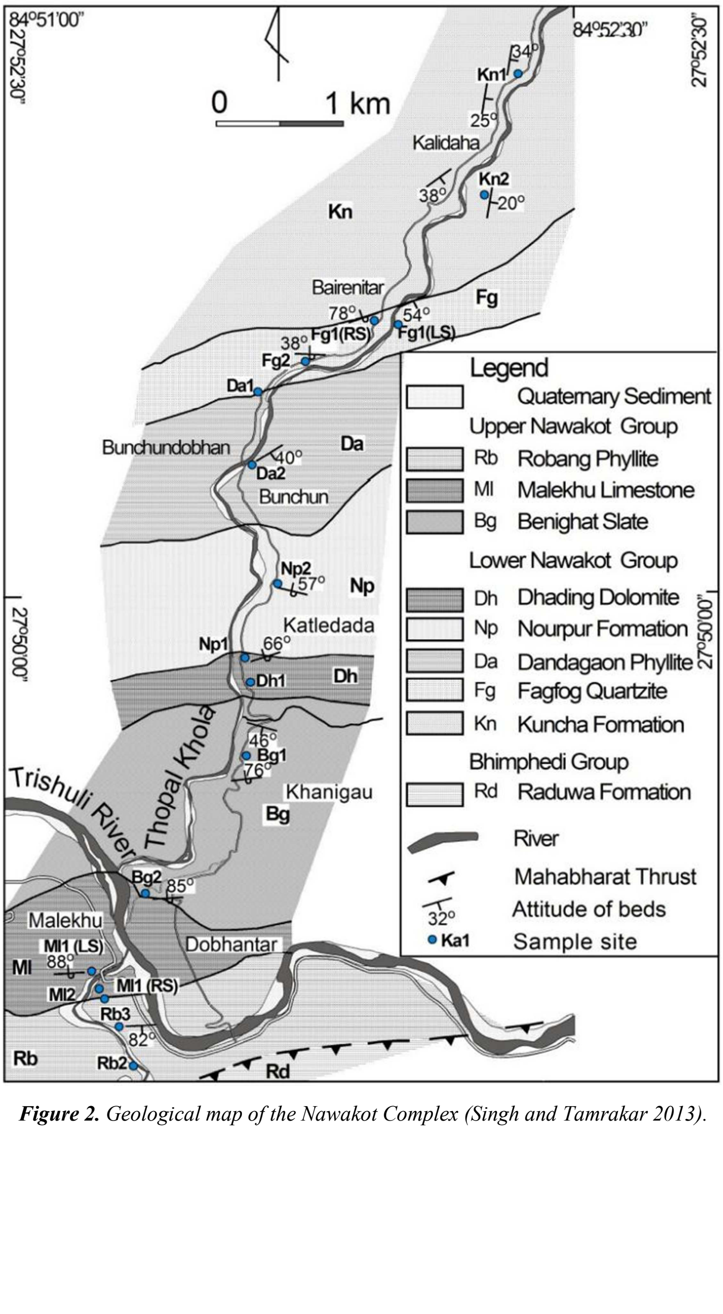

Figure 2. *Geological map of the Nawakot Complex (Singh and Tamrakar 2013).*

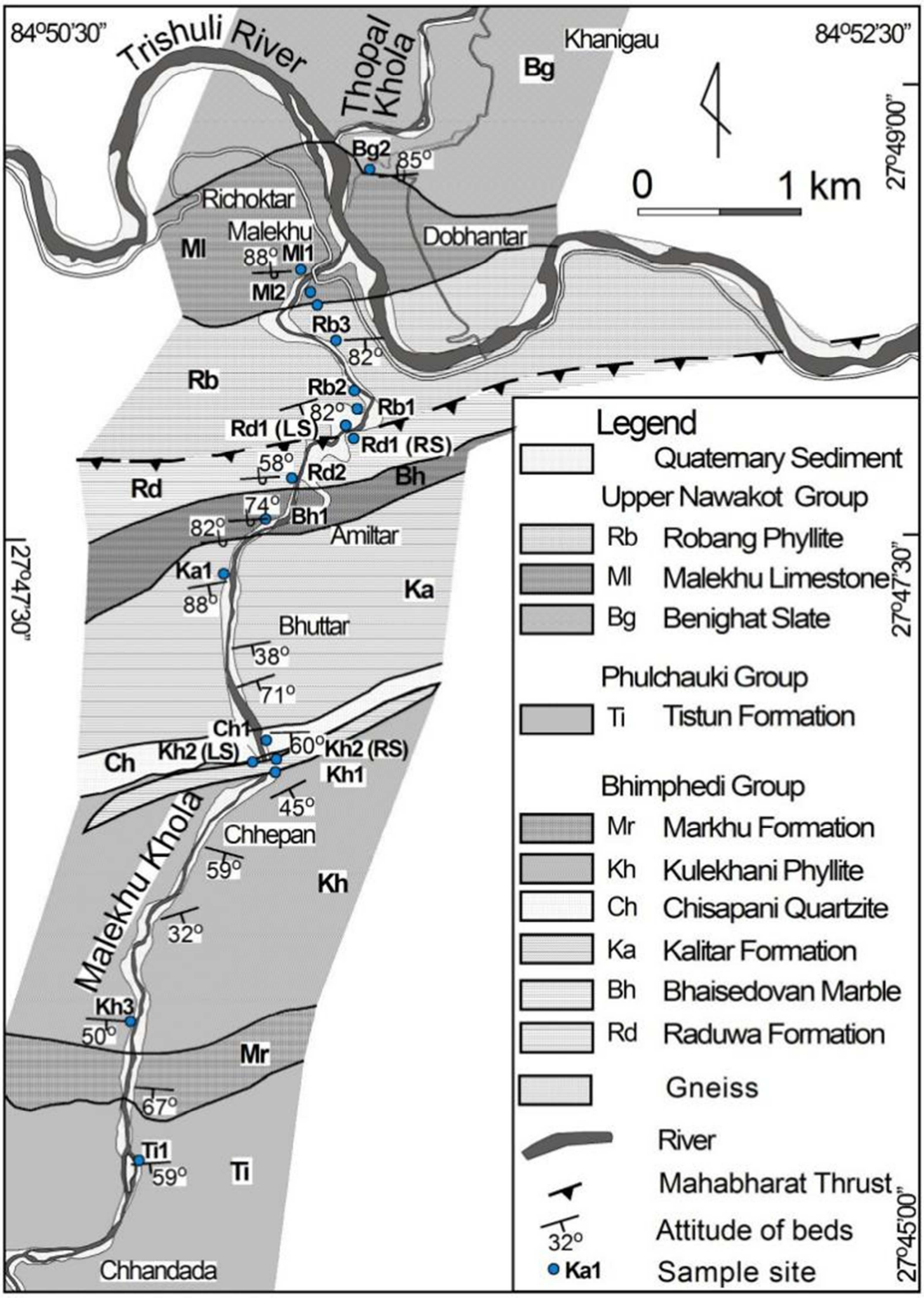

Figure 3. *Geological map of the Bhimphedi group (Singh and Tamrakar 2013).*

3. Methodology

Slope mass rating of the study area was estimated by discrete method on the basis of Romana (1985). This geomechanical index SMR was calculated using four factors (F1, F2, F3 and F4) adding the basic RMR of Beiniawski (1989). For the present study all of these factors were calculated on the basis of data collected in the field.

The geomechanical index SMR was obtained from the basic RMR by subtracting a factorial adjustment factor (F1, F2, F3 and F4) depending on the joint-slope relationship (geometric relationship between discontinuity, slope) and adding a factor depending on the method of excavation.

$$SMR=RMR+(F1+F2+F3)+F4 \quad (1)$$

The RMR was computed according Bieniawski's (1989) proposal, adding rating values for five parameters: (i) strength of intact rock; (ii) RQD; (iii) spacing of discontinuities; (iv) condition of discontinuities; and (v) water inflow through discontinuities.

The adjustment rating for joints was the product of three factors as follows:

(a) F1 related to the parallelism between joints dip direction, α_j, (or the trend of intersection line, α_i, in the case of wedge failure) and slope dip, α_s, Its range is from 1.00 to 0.15.

(b) F2 which depends on the probability of discontinuity shear strength, related to the discontinuity dip, βj in the case of planar failure, and plunge of the intersection line, βi, in case of wedge failure. For toppling failure, this parameter was assigned 1.0. This parameter

(c) F3 related to the relationship between slope, β_s, and discontinuity, β_j, dips (toppling or planar failure cases) or the plunge of the intersection line (wedge failure case). This parameter retains the Bieniawski's (1989) adjustment factors that vary from 0 to -60 points and expresses the probability of discontinuity outcropping on the slope faces for planar and wedge failure.

The parameter, F4 is a correction factor that depended on the excavation method used. The eq. (1) can be written as:

$$SMR=RMR+(\Psi * F3)+F4 \quad (2)$$

Where, F1*F2 has been grouped in the same term (Ψ) that varies from 0 to 1.

To perform the classification, attitude of major joint, bedding plane, slope height and slope direction were recorded in field to estimate F1, F2, F3, and F4 for each case (plane, topple and wedge) with the help of the table (Table 1). Then SMR was calculated using the equation (2), and classified using stability class (Table 2).

Table 1. *Adjustment rating for joints for SMR (Romana, 1985).*

Case		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
P	$\|\alpha_j-\alpha_s\|$	>30°	30° to 20°	20° to 10°	10° to 5°	<5°
T	$\|(\alpha_i-\alpha_s)-180°\|$					
W	$\|\alpha_j-\alpha_s\|$					
P/T/WAF1		0.15	0.40	0.70	0.85	1.00
P	$\|\beta_i\|$	<20°	20° to 30°	30° to 35°	35° to 45°	>45°
W	$\|\beta_i\|$					
P/WBF2		0.15	0.40	0.70	0.85	1.00
T		1.00	1.00	1.00	1.00	1.00
P	$\beta_j-\beta_s$	>10°	10° to 0°	0°	0° to (-10°)	<-10°
W	$\beta_i-\beta_s$					
T	$\beta_j+\beta_s$	<110°	110° to 120°	>120°	_	_
P/W/TCF3		0	-6	-25	-50	-60
Adjustment rating for method of excavation of slopes						
		Natural slope	Pre-splitting	Smooth blasting	Blasting or mechanical	Deficient blasting
	F4	15	10	8	0	-8

P=planar failure; T=toppling failure; W=wedge failure

β_j=joint dip; β_s=slope dip

β_i=angle of plunge of the intersection line of two sets of discontinuities;

α_j=joint dip direction; α_s=slope dip direction; α_i=dip direction of the intersection line of two sets of discontinuities

SMR=RMR+(F1. F2. F3)+F4

Table 2. *Stability classes as per SMR values (after Romana 1985).*

class	I	II	III	IV	V
SMR	81-100	61-80	41-60	21-40	0-20
Rock mass description	Very good	Good	Normal	Bad	Very bad
Stability	Completely stable	Stable	Partially stable	Unstable	completely unstable
Failure	None	some block failure	Planer along some joints or many wedge failure	Planer or big wedge failure	Big planer or soil- like or circular
Probability of failure	0	0.2	0.4	0.6	0.9

4. Result: Determination of Slope Mass Rating (SMR)

Out of two study sites (Kn1 and Kn2) in the Kuncha Formation, slopes in Kn1 lie in stable category (class II) in terms of plane failure and topple failure, but in partially stable to stable slopes (class III to IV) in terms of wedge failure (Table 3). The slopes in Kn2, which reach 60° become unstable in terms of plane failure due to joint J2 (15°/54), and wedge failure due to J2 and J4. But the slopes are stable to partially stable considering toppling failure.

Three sites (Fg1(LS) left hillslope site, Fg1(RS) right hillslope site and Fg2) across the Fagfog Quartzite, were studied. Fg1(LS) is stable considering plane failure and wedge failure, but it is partially stable considering toppling failure. The condition of slope driving the toppling failure is shown in Figure 4. Fg1(RS) is unstable to stable in terms of plane failure, stable in terms of toppling failure, and is stable to completely unstable considering wedge failure. Fg2 is completely stable in terms of plane and toppling failures and few is stable in terms of wedge failure.

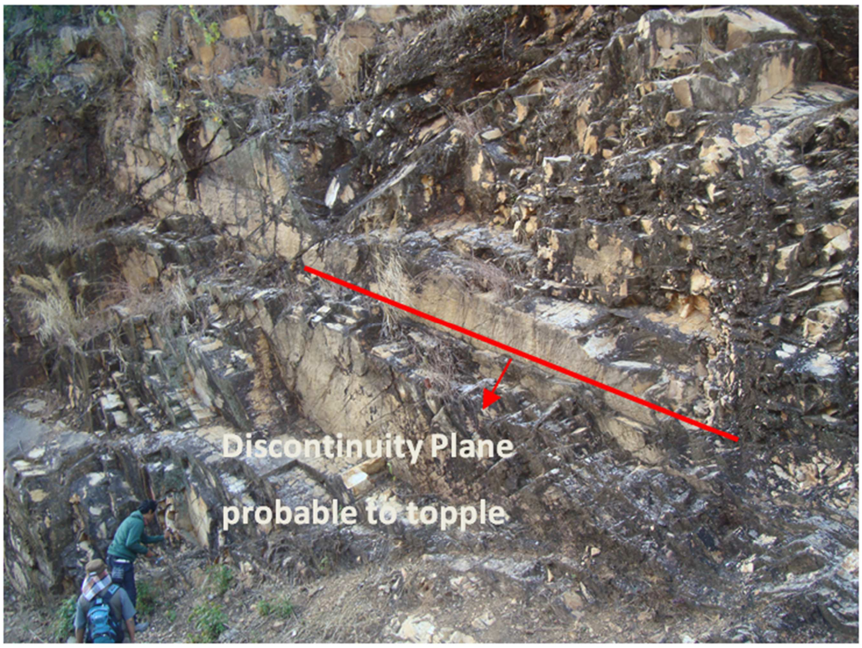

Figure 4. *Hill slope of Fagfog Quartzite, near Kali Daha, Malekhu-Dhading road (location Fg1).*

Da1(slope of Dandagaun Phyllite) is partially stable (class III) in terms of all three failure modes.

Three sites Np1, Np2 and Np3 lying in the corridor across the Nourpul Formation were studied. Np1 is generally partially stable considering all three modes of failure, and there is few stable case of toppling. Np2 is partially stable in terms of both plane and wedge failures but is partially stable to unstable considering toppling. The slope of observation Np3 is stable in terms of all three failure modes.

Table 3. *Estimation and categorization of slope mass rating (SMR) of the study area.*

Study site	Failure	R1	R2	R3	R4	R5	F1	F2	F3	F4	RMR	SMR	Class	Stability
Kn1	Plane	8	13	9	12	15	0.15	0.85 to 1	(-6) to 0	8	57	64 to 65	II	S
	Topple						0.015	1	(-6) to 0	8		64 to 65	II	S
	Wedge						0.15-0.7	0.4 to 0.85	(-60)to(-5)	8		48-65	III-II	PS-S
Kn2	Plane	7	13	11	12	7	0.15-0.7	1	(-50) to 0	15	50	30-65	IV-II	U-S
	Topple						0.15-0.4	1	(-25) to (-6)	15		55-64	III-II	PS-S
	Wedge						0.15-0.7	1	(-60)-(-0)	15		23-64	IV-II	U-S
Fg1(LS)	Plane	12	17	10	13	10	0.15-0.4	0.15-1	(-60)-(-0)	8	62	61-70	II	S
	Topple						0.15-0.7	1	(-25) to (0)	8		52-70	III-II	PS-S
	Wedge						0.15-0.4	0.15-1	(-60)-(-0)	8		61-69	II	S
Fg1(RS)	Plane						0.15-0.85	0.15-1	(-60)-(-0)	8		27-70	IV-II	U-S
	Topple						0.15-1	1	(-25) to (0)	8		66-70	II	S
	Wedge						0.15-1	0.15-1	(-60)-(-6)	8		20-69	V-II	CU-S
Fg2	Plane	12	20	12	11	15	0.15	0.15-1	(-60)-(-0)	15	70	83-85	I	CS
	Topple						0.15-0.85	1	(-25) to (0)	15		81-85	I	CS
	Wedge						0.15-0.7	0.15	(-60)	15		81-85	I	CS
Da1	Plane	4	3	9	18	10	0.15-0.85	0.15-1	(-60)-(-6)	10	44	48-53	III	PS
	Topple						0.15-0.7	1	(-25) to (0)	10		50-54	III	PS
	Wedge						0.15-0.7	0.15-1	(-60)-(-6)	10		49-52	IV-III	U-PS
Np1	Plane	9	8	9	16	10	0.15-0.7	1	(-60)-(-0)	10	54	53-62	III-II	PS-S
	Topple						0.15-0.85	1	(-25)	10		40-58	III	PS
	Wedge						0.15-0.7	0.15-1	(-60)-(-50)	10		54-60	III	PS
Np2	Plane	7	13	9	10	10	0.15-0.85	0.4-1	(-60)-(-6)	10	49	49-59	III	PS
	Topple						0.15-1	1	(-25) to (0)	10		34-59	IV-III	U-PS
	Wedge						0.15-0.85	0.15-1	(-60)-(-0)	10		51-59	III	PS
Np3	Plane	10	17	10	17	10	0.15-0.85	0.4-1	(-60)-(-0)	15	64	71-79	II	S
	Topple						0.15	1	(-25) to (0)	15		75-79	II	S
	Wedge						0.15	0.15	0.15	15		70-75	II	S
Dh1	Plane	7	3	8	24	10	0.15-0.7	0.15-1	(-60)-(-0)	15	52	65-67	II	S
	Topple						0.15-0.4	1	(-25) to (0)	15		63-67	II	S
	Wedge						0.15-1	0.15-1	(-60)-(-0)	15		24-67	IV-II	U-S

Study site	Failure	R1	R2	R3	R4	R5	F1	F2	F3	F4	RMR	SMR	Class	Stability
Bg1	Plane	4	3	5	22	4	0.15	1	(-60)-(-0)	15	38	44-53	III	PS
	Topple						0.15	1	(-25) to (0)	15		49-53	III	PS
	Wedge						0.4-1	0.15-1	(-60)-(-6)	15		45-52	III	PS
Bg2	Plane	4	3	5	17	7	0.15	0.7-1	(-60)-(-0)	15	36	44-51	III	PS
	Topple						0.15-0.4	1	(-25) to (0)	15		47-51	III	PS
	Wedge						0.15	0.15-1	(-60)-(-6)	15		42-50	III	PS
Ml1(LS)	Plane	12	8	8	14	15	0.15	0.4-1	(-60)-(-0)	15	57	21-72	IV-II	U-S
	Topple						0.15	1	(-25) to (0)	15		68-72	II	S
	Wedge						0.15-0.85	0-1	(-60)	15		21-70	IV-II	U-S
Ml1(RS)	Plane						0.15-0.4	0.15-1	(-60)-(-0)	15		48-72	III-II	PS-S
	Topple						0.15-0.7	1	(-25) to (0)	15		68-72	II	S
	Wedge						0.15-0.7	0.15-1	(-60) to (50)	15		30-70	IV-II	U-S
Ml2	Plane	12	13	9	13	10	0.15	1	(-60)-(-0)	15	57	63-72	II	S

Table 3. *Continued.*

Study site	Failure	R1	R2	R3	R4	R5	F1	F2	F3	F4	RMR	SMR	Class	Stability
	Topple						0.15	0.15-1	(-25)	15		68.25	II	S
	Wedge						0.15-1	0.15-1	(-60)	15		12 to 70	V-II	CU-S
Rb1	Plane	15	3	9	15	15	0.15	0.15-1	(-60)-(-0)	15	57	68-72	II	S
	Topple						0.15-0.85	1	(-25) to (0)	15		50-72	III-II	PS-S
	Wedge						0.15-1	0.15-1	(-60)-(-0)	15		63-72	II	S
Rb2	Plane	7	8	9	11	10	0.15-1	0.15-1	(-60)-(-6)	15	45	58-59	III	PS
	Topple						0.15	0.15	(-25) to (0)	15		56-60	III	PS
	Wedge						0.15	0.15	(-60)	15		58-51	III	PS
Rb3	Plane	12	17	12	15	10	0.15-0.85	1	(-50)-(-0)	15	66	73-81	II-I	S-CS
	Topple						0.15	1	(-25) to (0)	15		59-81	III-II	PS-S
	Wedge						0.15	0.15-1	(-60)-(-6)	15		73-80	II	S
Rd1 (LS)	Plane						0.15-1	0.4-1	(-50)-(0)	15	60	75	II	S
	Topple						0.15-0.85	1	(-6)-(-0)	15		69-75	II	S
	Wedge						0.15	0.15-1	(-60)-(-0)	15		67-75	II	S
Rd1 (RS)	Plane	7	20	12	11	10	0.15-0.7	0.4-1	(-60)-(-0)	15	60	67-75	II	S
	Topple						0.15-1	1	(-25) to (0)	15		57-74	III-II	PS-S
	Wedge						0.15	0.15-0.85	(-60)	15		67-74	II	S
Rd2	Plane	7	13	10	10	10	0.15-0.85	0.85-1	(-50)-(-0)	15	50	58-65	III-II	PS-S
	Topple						0.15-0.7	1	(-25) to (0)	15		61-65	II	S
	Wedge						0.15-0.4	0.15-0.85	(-60)-(-25)	15		55-63	III-II	PS-S
Bh1	Plane	7	8	9	10	10	0.15-0.4	1	(-6)-(-0)	15	44	56-59	III	S
	Topple						0.15-0.7	1	(-6)-(-0)	15		54-59	III	S
	Wedge						0.15	0.4-1	(-60)-(-0)	15		53-59	III	S
Ka1	Plane	4	13	8	10	4	0.15	1	(-60)-(-0)	15	39	11to54	V-III	CU-PS
	Topple						0.15	1	(-50)-(-25)	15		46-50	III	PS
	Wedge						0.15-1	0.15-1	(-60)	15		12 to 53	V-III	CU-PS
Ch1	Plane	7	13	11	12	15	0.15-0.85	0.4-1	(-50)-(-0)	15	38	65-73	II	S
	Topple						015-0.85	1	(-25) to (0)	15		51-73	III-II	PS-S
	Wedge						0.15	0.15-1	(-60)-(-50)	15		65-71	II	S
Kh1	Plane	7	3	8	19	10	0.15-1	1	(-60)-(-6)	15	47	58-61	III-II	PS-S
	Topple						0.15	1	(-6)-0	15		57-62	III-II	PS-S
	Wedge						0.25	0.15-1	(-60)-(-50)	15		19-60	V-III	CU-PS
Kh2(LS)	Plane	15	20	20	12	15	0.15-1	1	(-60)-0	15	82	88-97	I	CS
	Topple						0.15	1	(-25)-0	15		93-97	I	CS
	Wedge						0.15	0.15-1	(-60)-0	15		91-97	I	CS
Kh2(RS)	Plane						0.15-0.7	1	(-6)-0	15	82	92-97	I	CS
	Topple						0.15-0.7	1	(-6)-0	15		96-97	I	CS
	Wedge						0.15-0.4	0.15-1	(-60)-(-6)	15		80-96	II-I	S-CS
Kh3	Plane	12	13	9	15	10	0.15	0.85-1	(-6)-0	15	59	73-74	II	S
	Topple						0.15	1	(-6)-0	15		73-74	II	S
	Wedge						0.15-1	0.15-1	(-60)-0	15		54-74	III-II	PS-S
Ti1	Plane	7	13	11	11	7	0.15	1	(-60)-(-50)	15	49	55-56	III	PS
	Topple						0.15	1	(-25)	15		60.25	II	S
	Wedge						0.15-0.4	0.85-1	(-60)	15		40-58	IV-III	U-PS

R1=strength in intact rock material, R2=Rock Quality Designation, R3=spacing of discontinuity, R4=condition of discontinuity, R5=ground water conditions=stable, CS=completely stable, PS=partially stable, U=unstable, CU=completely unstable

Dh1 (Dhading Dolomite) is totally stable in terms all three failure modes, but few unstable wedges exist due to J1 and J4.

Bg1 and Bg2 (slopes of the Benighat Slate) are classified into partially stable in terms of all three failure modes.

Ml1(LS) is unstable to stable considering plane and wedge failures, while it is stable in terms of toppling. The plane failure mode is unstable due to J1. Ml1(RS) is partially stable to stable in terms of plane failure, stable for toppling and unstable to stable due to wedge. Ml2 is stable for plane and toppling failures, whereas it is completely unstable to stable considering wedge failure.

Rb1(site of the Robang Formation) is mostly stable. Slopes are partially stable in Rb2. Rb3 is stable to completely stable, partially stable to stable and is stable respectively in terms of plane toppling and wedge failure modes. Although the SMR shows stable slope of Rb1 in terms of toppling failure, such failure is generated by toe cut due to river flow as shown in Figure 5.

Rd1(LS) and Rd1(RS) (sites of the Raduwa Formation) both are considered stable taking all three failure modes. There also exists partially stable toppling mode. R2 is partially stable to stable considering plane and wedge failures, whereas it is stable considering toppling.

Bh1 is partially stable in all failure modes. Ka1 comprises partially stable to completely unstable plane and wedge failure modes, but partially stable toppling failure. Ch1 is generally stable considering all the modes, but partially stable toppling mode also exists.

Kh1 is stable to partially stable in terms of plane and toppling failure and is completely unstable in terms of wedge failure due to discontinuity J1-J2. Kh2 is almost completely stable in terms of all the failure modes. Kh3 show stable slopes in terms of plane and toppling while partially stable to stable slopes due to wedge failure mode.

Ti shows partially stable, stable and unstable to partially stable plane, toppling and wedge failure modes, respectively.

As per the standard classification, the SMR in the present study ranges from 0 to 97 for plane failure, 12 to 97 for wedge and 34 to 97 for toppling failure. This is all due to the variation of orientation of discontinuity and the slope attitudes of the study area. Thus only stable (II) conditions in terms of plane failure are reflected by slopes of Kn1, Fg1(LS), Np3, Dh1, Ml2, Rb1, Rd1(LS, RS), Ch1, and Kh3 (Table 3). Partially stable (III) to stable (II) conditions are met in Np1, Ml1 (RS), Rd2, and Kh1. But discontinuities in Ti1, Bh1, Bg1, Bg2, Np2 and Da1 have all partially stable condition of plane failure mode. Stable to unstable slopes are found in Kn2, Fg1(RS), and Ml1 (LS). Completely unstable to partially stable slopes are found in Ka1 and Rb2. Completely stable slopes are found in Fg2, Kh2(LS), and Kh2(RS).

Figure 5. *Unstable slope of the Robang Formation; Toe cut and newly constructed road damaged (right).*

Considering the toppling failure, slopes in Da1, Np1, Bg1, Bg2, Rb2, Bh1, and Ka1 are found to be partially stable. Slopes in Kn1, Kn2, Fg1(RS), Np3, Ml1(RS), Ml2, Rd1 (LS), Rd2, Kh3, and Ti1 are found to be stable. Slopes are in Fg1(RS), Dh1, Rb1, Rd1(RS), Ch1, and Kh1 are found to be partially stable to stable. Slopes in Np2 and Rb3 are partially stable to unstable and partially stable to completely stable, respectively. Completely stable slopes are found in Fg2, Kh2

(LS) and Kh(RS).

The wedge failure mode is the most pronounced of all the three failure modes as intersection of discontinuities produces several wedges which are probable to failure. Among them completely stable slope is found in Kh2 (left, right) slope, and completely unstable slope is found in Kh1.

5. Discussion

Based on the basic RMR and the SMR assessment in different study sites, the slopes of the sites have been categorized from I (stable) to V (completely unstable) for all types of failure. The number of major prominent discontinuity in the study area is observed to be from three to six. Slopes are found to be gentle to very steep. After detail observation of the rock slopes, those of the Fagfog Quartzite (Fg2) and the Kulekhani Formation (Kh2) are found completely stable in terms of plane and toppling failure because of their massive beds.

The completely stable to stable slopes found in the Robang Formation (Rb3) are due solely to rock mass character.

Due to the steep slopes (72° to75°) in Ml1 (LS) and Ml2 (RS) of the Malekhu Limestone, and their favorable discontinuities, the adjustment factor is diminished giving rise to the stable to unstable slopes in terms of wedge and plane failure, respectively.

Partially stable slopes in terms of all failure modes are found in the slopes of the Benighat Slate (Bg1 and Bg2). SMR shows that toppling and plane failures in this formation could be driven by its poor rock mass quality.

6. Conclusion

The SMR of slope of the study area ranges from 0 to 97% that falls between I (completely stable) to V (completely unstable). The following categories of slope mass stability have been identified:

- Completely stable slopes: (a) The slopes of the Fagfog Quartzite (Fg2) and the Kulekhani Formation (Kh2 (LS) and Kh2 (RS)) in terms of plane failure and toppling failure, (b) the slope of the Kulekhani Formation (Kh2 (LS)) in terms of wedge failure.
- Stable to completely stable slopes: The slopes of the Robang Formation (Rb3) in terms of all failure modes, and those of the Fagfog Quartzite (Fg2) and the Kulekhani Formation (Kh2 (RS) in terms of wedge failure.
- Stable slopes: (a) The slopes of the Kuncha Formation (Kn1), Fagfog Quartzite (Fg1 (LS)), Nourpul Formation (Np3), Dhading Dolomite (Dh1), Malekhu Limestone (Ml2), Robang Formation (Rb1), Raduwa Formation (Rd1 (LS) and Rd1 (RS)), Chisapani Quartzite (Ch1), and the Kulekhani Formation (Kh3) in terms of plane failure. (b) The slopes of the Kuncha Formation (Kn1, Kn2), Fagfog Quartzite (Fg1 (RS)), Nourpul Formation (Np3), Malekhu Limestone (Ml1 (RS)), Ml2), Raduwa Formation (Rd1(LS) and Rd2), Kulekhani Formation (Kh3), and the Tistung Formation (Ti1) in terms of toppling failure. (c) The slopes of the Fagfog Quartzite (Fg1 (LS)), Nourpul Formation (Np3), Robang Formation (Rb1), Raduwa Formation (Rd1 left and right slope), Chisapani Quartzite (Ch1), Kuncha Formation (Kn1), and the Dandagaun Phyllite (Da1) in terms of wedge failure lie in this category.
- Stable to partially stable slopes: (a) The slopes of the Nourpul Formation (Np1), Malekhu Limestone (Ml1 (RS)), Raduwa Formation (Rd2), and the Kulekhani Formation (Kh1) in terms of plane failure (b) the slopes of the Fagfog Quartzite (Fg1 (RS)), Dhading Dolomite (Dh1), Robang Formation (Rb1), Raduwa Formation (Rd1 (RS)), Chisapani Quartzite (Ch1), and the Kulekhani Formation (Kh1) in terms of toppling failure, and (c) the slope of the Kuncha Formation (Kn1), Nourpul Formation (Np1), Raduwa Formation (Rd2), Kulekhani Formation (Kh3) in terms of wedge failure.
- Stable to unstable slopes: In terms of plane failure are found in the Kuncha Formation (Kn2), Fagfog Quartzite (Fg1 (RS)), Malekhu Limestone (Ml1 (LS)), and in terms of wedge failure is located at the Malekhu Limestone (Ml1 (RS)).
- Stable to completely Unstable: The slopes of the Malekhu Limestone (Ml1 (LS)), Fagfog Quartzite (Fg1-RS), Malekhu Limestone (Ml2), and the Kulekhni Formation (Kh1) in terms of wedge failure.
- Partially stable slopes: (a) the slopes of the Benighat Slate (Bg1, Bg2), Dandagaun Phyllite (Da1), Nourpul Formation (Np2), Tistung Formation (Ti1) and Bhainsedobhan Marble (Bh1) in terms of plane failure, (b) the slopes of the Dandagaun Phyllite (Da1), Nourpul Formation (Np1), Benighat Slate (Bg1, Bg2), Robang Formation (Rb2), Bhainsedobhan Marble (Bh1), and Kalitar Formation (Ka1) in terms of toppling failure, and (c) the slopes of the Nourpul Formation (Np2), Benighat Slate (Bg1, Bg2,) Robang Formation (Rb2) and the Bhainsedobhan Marble (Bh1) in terms of wedge failure.
- Partially stable to unstable slopes: In terms of topple failure mode are found in the Nourpul Formation (Np2) and in terms of wedge failure mode found in the Kuncha Formation (Kn2), Dhading Dolomite (Dh1), and the Tistung Formation (Ti1).
- Partially stable to completely unstable slopes: In terms of plane failure are found in the Robang Formation (Rb2) and the Kalitar Formation (Ka1) but in terms of wedge failure is found only in the slope of the Kalitar formation (Ka1).

As per stability of slopes of the whole study area, only 20-25% of the area is completely stable, the remaining is vulnerable due to various slope failures.

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