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Geotechnical Investigation on Slopes Failures along the Mughal Road from Bafliaz to Shopian, Jammu and Kashmir, India

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ABSTRACT

In this paper, the results of geotechnical investigations on the slope stability condition carried along the historical Mughal road (an important economic corridor of the state) from Bafliaz (Jammu province) to Shopian (Kashmir province) linking NH144 and NH444 respectively is presented. The basic rock mass rating (RMRb), slope mass rating (SMR) techniques (both discrete and continuous functions) with kinematics analysis was applied to analyse the rock mass and slope conditions at 20 selected sites. The RMRb results obtained reveal the slopes can be categorized into very good (5%), good (55%) and fair (40%) whereas SMR results reveal that the slopes are partially stable (50%), unstable (30%) and completely unstable (20%) with probable planar failure mode (20%), toppling failure mode (27%) and wedge failure mode (53%). The discrete and continuous SMR index reveals maximum variation in the end results within an average difference of 4.7 ±6. The kinematic analysis results support inter dependency of RMRb, SMR and critical joint-slope orientation relationships.

INTRODUCTION

With expanding road networks the problem of slope instability along the hilly roads is consistently enlarging all over the world and has become focus of the geo-scientific researches. During the recent years frequency of landslide/slope failures has considerably increased in comparison to other natural calamities (Yin et al., 2010). Landsliding is a potentially damaging phenomenon that limits within specified period of time and the area (Varnes, 1984; Mohammady et al., 2012). Due to explosion of population in India there has been tremendous pressure on development of road networks particularly in the Himalayan region which in turn has contributed its bit in climate change and increase in natural hazards especially landslides (Bhat et al., 2002; Bhandari, 2006; Kuriakose et al., 2009a; Haigh and Rawat, 2011; Siddique et al., 2015; Kumar et al., 2016). India has the second major road-networks in the world (4.24 million km) next only to US (6.43 million km) (NHAI, 2014-15). The hazard affected roads in India are more than 0.49 million km which constitutes over 15 % of the country's area (NDMA, 2009). In the Himalayan region, landslides rank third in terms of number of deaths due to natural disasters and the estimated average losses due to landslides account for 200 lives and Rs 550 crore every year (NDMA, 2009). The frequency of these landslide induced losses is abnormally on the rise along the new road sections within the sensitive Lesser Himalayan terrain (Valdiya, 2003; Pant and Luirei, 2005; Singh, 2006; Jaiswal and Van Westen, 2009). The main reason of occurrence of landslides is underestimation of the geological factors needed to be considered during road construction and lack of awareness about the pre-assessing *insitu* signatures that trigger landslides/slope instability. The most important factors to be considered before construction include prior knowledge on the rock mass strength and slope stability, geological settings, active tectonics and the quality and conditions of the rock masses (Sarkar et al., 2006; Singh and Bhat, 2010; Singh et al., 2013; Singh et al., 2014; Hussain et al., 2015). Ignorance of these factors is widely prevalent in the majority of the hilly roads being constructed in the Himalayan region.

One such example is the Mughal road (approximately 83.9 km) constructed through Lesser Himalaya in Jammu Province which is affected by numerous landslides/slope failures after its construction, disrupting traffic movement and cause loss to life, property, destroying the precious forest/meadows cover, erosion, damming of streams/ drainage, etc. The road passes through the Hirpur wild life sanctuary and the increasing incident of slope failures also poses threat to wildlife habitation of this sanctuary. Restoration of the Mughal road for vehicular movement added a ray of hope of development and enlightened socio-cultural and ethical aspirations of the local inhabitants of the remote districts of Rajouri, Poonch and Shopian in particular and people of all walks of life in general. The best part of this road network is that it reduces the travel distance from 541 km to 126 km within the administrative division of Poonch and Shopian district across the Lesser Himalayan Orogen (Pir Panjal range) with Srinagar. The Lesser Himalayan Orogen, tectonically active region (Bhat et al., 2002; Shah, 2013), is bounded by two major intra-crustal thrusts, i. e., the Main Boundary Thrust (MBT) in the south and Panjal Thrust (PT=MCT) in the north (Kumar and Pande, 1972).

In order to assess the vulnerability of slopes, rock mass characterization by means of classification systems is very significant tool (Umrao et al., 2011) which includes the inputs obtained from intact rocks and discontinuity properties which have major influence on engineering behavior of the rock mass (Sarkar et al., 2006). There are several rock mass classification techniques with specific aims available in the geotechnical rock engineering literature such as static and dynamic analysis, and numerical modeling, etc. (Singh et al., 2010; Vishal et al., 2015; Sarkar et al., 2016). But largely accepted and endorsed geomechanics classification systems specifically designed for calibration of slopes such as RMRb (basic Rock Mass Rating); SMR (slope mass rating) in original and as modified form and kinematics analysis are best fitted to analyze the slope stability of this particular work. In this study for the first time, we attempted to evaluate landslide trigger potential of these factors along the Mughal road through Lesser Himalayan Orogen of the NW Himalaya.

DESCRIPTION OF THE STUDY AREA

The study area Mughal road covered in the Survey of India toposheets 43K part 6, 10, 11 and 14 on scale 1:50000. The total length of the road stretch under study is about 83.9 km of which 45 km is highly zigzag (Fig. 1) and traverses across the Pir Panjal range through narrow sacred Pir Ki Gali pass (altitude 3474.72 m), situated close to northwestern border of POK. The average elevation in the study area varies from 1500m to 4600 m. The area is drained by two major streams i.e. Suran river and Riambiara river and is fed by numerous ephemeral streams of various orders. The area receives high average annual precipitation, i.e., 1572.7 mm/year (IMD, MoES,

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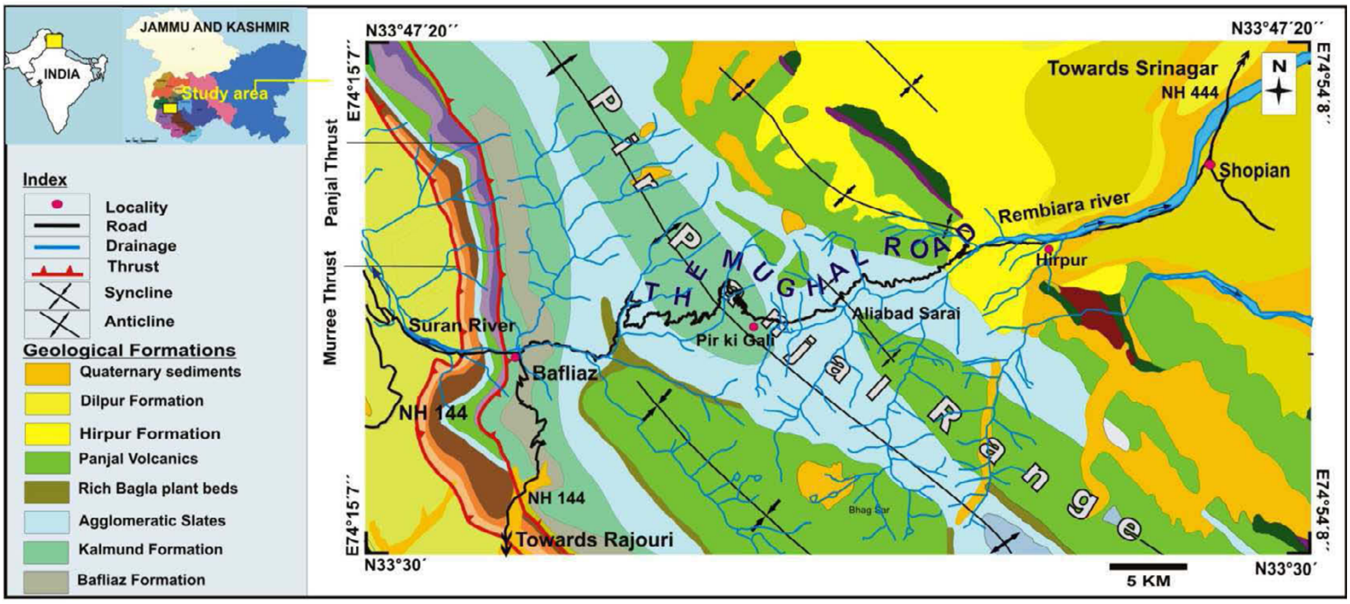


Fig 1. Geological setup of the study area (Base map after Geological Survey of India, 1997)

2015). The annual precipitation is high during June to September and recedes in October. The area experiences heavy snowfall from November onward and also shows great variation in the vegetation and soil types. Seismically the area falls under seismic zone IV/V based on the seismic zoning map of India.

GENERAL GEOLOGICAL SETUP OF THE STUDY AREA

The area under investigation comprises of complex geological and tectonic setup of lesser Himalayan succession (Fig. 1). Most of the previous works conducted in this area are restricted to Paleontology, Stratigraphy and Structural geology. The important geological formations exposed along the Mughal road (Table 1) are represented by Bafliaz Formation comprising of phyllite, quartzite, limestone and basic lava flow rocks; Kalmund Formation comprises of schistose, flaggy quartzite and basic volcanic rocks, both constitute the Dogra Group (Wadia, 1937) of undifferentiated Proterozoic age (the oldest rocks exposed in the study area); Agglomeratic slates comprises of slate, pebbly slate, carbonaceous slate, conglomerate and tuff of upper Carboniferous age is succeeded by a zone of tuffaceous and clastic sediments which yields floral elements and fish fossil equivalent to Nishatbagh Formation. The Panjal Volcanics comprises of andesite to basaltic flows of lower Permian age (Wadia, 1939; Ganju, 1944; Bhat et al., 1981; Shellnutt et al., 2012) and generally overlie the agglomeratic slates and the rich bagla plant horizons. The Karewa Group (Burbank and Johnson, 1982) constitutes the glacial, fluvial and lacustrine sediments of Plio-Pleistocene age is the youngest stratigraphic rock unit exposed along the Mughal road. Structurally the area is traversed by the regional Main Boundary Thrust (MBT) and Panjal Thrust (PT) and is also delineated by number of local faults namely Chandimarh, Beharamgala, Dugrian faults (Wakhaloo and Shah, 1968; Shah, 1971, 1978).

METHODOLOGY

In this study we followed the basic rock mass rating (RMRb) scheme of Bieniawski (1989) and slope mass rating (SMR) schemes using discrete and continuous functions after Romana (1985) and Tomas et al. (2007) in conjunction with kinematics analysis techniques after Hoek and Bray (1981). After preliminary study 20 potential sites were selected in the study area along the Mughal road from Bafliaz to Zaznar near Hirpur (Fig. 2) for detailed investigation and collection of various data sets. The representative rock samples from the selected sites were collected from the field for determination of index properties following ISRM (1985). In the absence of core samples the rock quality designation (RQD) was obtained from joint volumetric count, i.e., the number of joints per cubic meter proposed by Palmstrom (2005).

Basic Rock Mass Rating (RMRb)

The RMRb system provides estimates of rock mass quality by

Table 1. Geological setup along the Mughal road between Bafliaz and Shopian (after GSI, 1997)

Lithological unit	Formation	Group	Age
Alluvium/Moraine			Quaternary
Golden Brown Silt	Dilpur Formation	Karewa Group	Middle Miocene to lower Pleistocene
Gravel, Loamy Clay and Silt	Nagum Formation		
Sand, Clay, Conglomerate and Lignite	Hirpur Formation		
Andesite to Basaltic flow	Panjal Volcanics		Lower Permian
Tuffaceous and Clastic sediment	Rich Bagla plant bed ≈ Nishatbagh Formation		Lower Permian
Pebbly Slate, Quartz arenite Conglomerate, purple Quartzite	Agglomeratic Slates		Lower Permian
Schistose and Flaggy Quartzite and Volcanics	Kalmund Formation	Dogra Group	Undifferentiated Proterozoic
Phyllite, Quartzite, Limestone, Basic Lava flows	Bafliaz Formation		

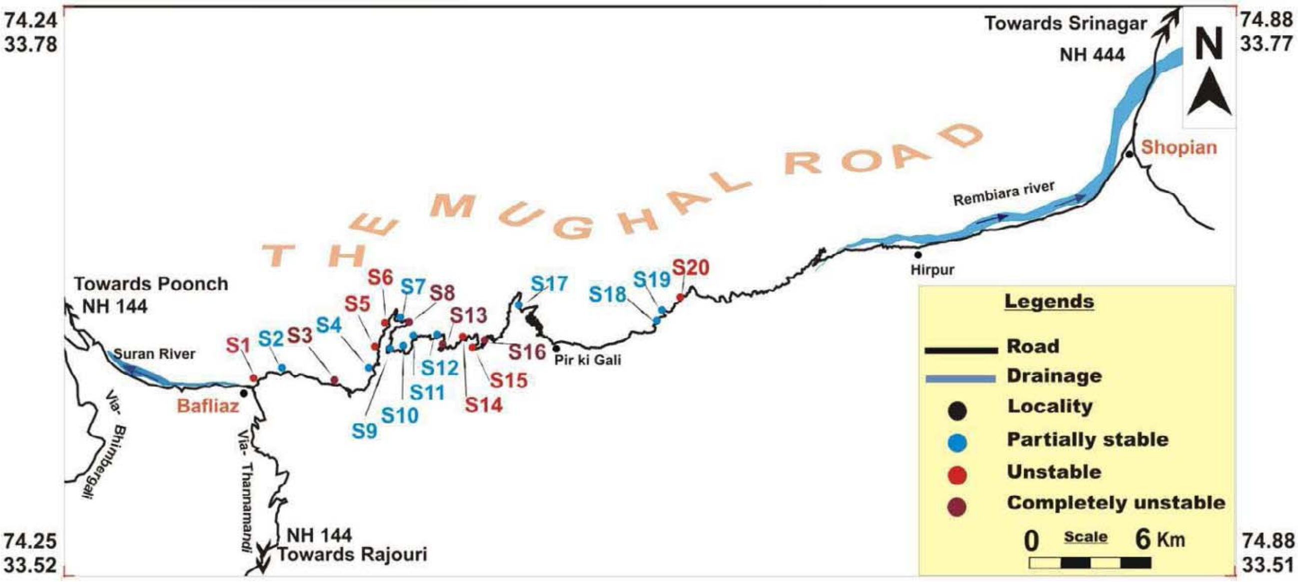


Fig 2. Map showing different stability class of investigated slopes in the study area

evaluating following five parameters: uniaxial compressive strength (UCS), rock quality designation (RQD), discontinuities spacing (DS), discontinuities condition (DC) and groundwater conditions (GWC). The RMRb was computed for the representative samples according to Bieniawski's (1989) classification of rock masses by adding rating values for five parameters and the results obtained are given in Table 2.

Slope Mass Rating (SMR)

The Slope Mass Rating system (SMR) using discontinuous and continuous functions is computed by adding rating values of the five scoring categories of basic RMR into a group of four rating adjustment factors (F1, F2, F3 and F4) of which first three adjustment factors (F1, F2, F3) describe the relative rock slope and joint set geometries and fourth one (F4) account for the way of slope excavation. Discrete SMR was computed according to Romana (1985) scheme whereas; Continuous SMR was calculated according to relationships established for rating adjustment factors F1, F2 and F3 by Tomas et al. (2007). The final SMR results are presented in Table 3.

Kinematic Analyses

Kinematic analyses on joint data recorded from the field (Table 4) were analyzed according to Hoek and Bray (1981). The probability of failures results were obtained (Table 4) using SMR Tool v2.02 beta (Riquelme et al., 2014). The stereoplots were obtained using Dip Analyst 2.0 program of unstable and completely unstable sites. The results are plotted in Figure 3.

RESULTS AND DISCUSSION

The study reveals most of the rock slopes in the study area have intact rock strength greater than 25Mpa. The average strength rating varies between 1 to 15 with minimum for the S14 and S16 sites and maximum for the S9, S17 and S20 sites (Table 2). In all 20 sites, four major sets of joints were observed (Fig. 4A). The joint density (volumetric joint count) for the 20 selected sites varies from 2m/m^3 to 32m/m^3. The minimum joint density was recorded at the S10 site and

Table 2. Basic Rock Mass Rating values calculated at different sites in the study area using Bieniawski's (1989) classification

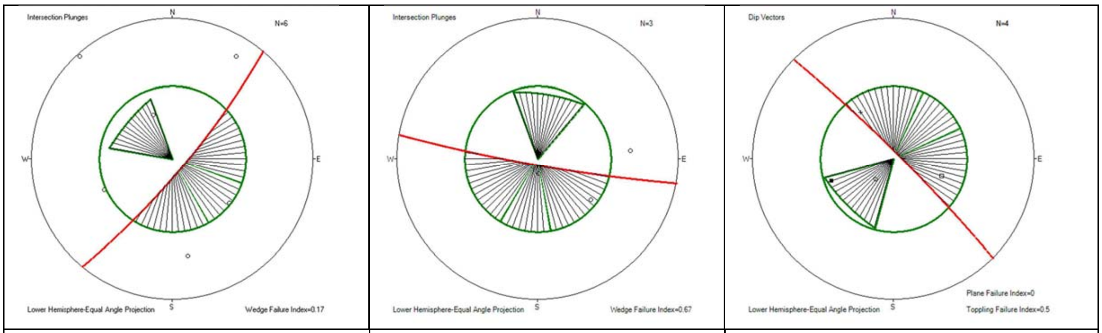
Site No.	Point load strength	RQD from Jv	Joint spacing	Joint condition	Ground water condition	RMRb value	Rock class	Rock mass Description
S1- 0.4 km	12	17	10	25	15	79	II	Good
S2- 1.9 km	07	17	08	20	15	67	II	Good
S3- 4.8 km	07	17	10	20	07	61	II	Good
S4- 8.7 km	12	14	10	20	15	71	II	Good
S5- 10.1 km	07	13	08	20	10	58	III	Fair
S6- 11.6 km	12	17	10	20	15	74	II	Good
S7- 14 km	07	17	10	20	10	64	II	Good
S8- 15.5 km	04	13	08	20	15	60	III	Fair
S9- 16.4 km	15	08	08	20	04	55	III	Fair
S10- 17.3 km	04	20	15	25	10	74	II	Good
S11- 19.6 km	12	08	08	20	10	58	III	Fair
S12- 20.4 km	12	13	08	20	15	68	II	Good
S13- 22 km	07	13	10	20	15	65	II	Good
S14- 23.5 km	01	13	08	20	10	52	III	Fair
S15- 25.8 km	07	08	08	20	10	53	III	Fair
S16- 26.7 km	01	08	08	20	15	52	III	Fair
S17- 33.7 km	15	08	08	10	07	48	III	Fair
S18- 49.5 km	12	13	08	20	15	68	II	Good
S19- 50.5 km	12	08	08	20	15	63	II	Good
S20- 51.3 km	15	17	10	25	15	82	I	V. Good

Table 3. Results of Discrete SMR and Continuous SMR

Site no.	Observed failures	Adjustment factors			Geomechanics classifications			Inferred stability class	Failure index
		F1.F2.F3		F4	RMRb (Bieniawski, 1989)	SMR (Romana, 1985)	CSMR (Tomas et al., 2007)		
		Romana (1985)	Tomas et al. (2007)						
S1	P- J1	-20.4	-26.6924	0	79	58	52	IV, Unstable	P = 0.25
	T- J4	-25	-24.78			54	54		T = 0.25
	W- J1&J2	-51	-46.5925			28	32		W=0.17
S2	P- J1	-7.65	-17.6389	0	67	59	49	III, Partially stable	-
S3	P- J2	-20	-30.0505	0	61	41	30	V, Completely unstable	P = 0.67
	P- J3	-20	-30.574			41	30		W=0.67
	W- J2&J3	-35	-41.2893			26	19		
S4	W- J2&J3	-24	-16.7393	0	71	47	54	III, Partially stable	W= 0.33
	W- J3&J4	-16.8	-14.7341			54	56		
S5	T- J2	-21.25	-24.1025	0	58	36	33	IV, Unstable	T = 0.5
	T- J3	-10	-9.897			48	48		
S6	P- J1	-29.4	-39.6453	0	74	44	34	IV, Unstable	P = 0.33
S7	T- J2	-17.5	-18.0716	0	64	46	45	III, Partially stable	T = 0.33
S8	P- J2	-42	-47.9088	0	60	18	12	V, Completely unstable	P = 0.25
	T- J4	-17.5	-21.1122			42	38		T = 0.25
	W- J2&J3	-7.65	-13.7832			52	46		W = 0.17
S9	W- J1&J3	-9	-9.0709	0	55	46	45	III, Partially stable	W = 0.33
	W- J2&J4	-9	-8.9683			46	46		
S10	T- J3	-10	-13.4689	-8	74	56	52	III, Partially stable	T = 0.33
	W- J1&J2	-9	-16.8677			57	49		W = 0.33
S11	W- J1&J3	-7.65	-12.207	0	58	50	45	III, Partially stable	W = 0.17
S12	W- J1&J2	-29.4	-30.3104	0	68	38	37	III, Partially stable	W = 0.17
	W- J2&J3	-20	-18.8491			48	49		
S13	W- J2&J3	-60	-54.918	0	65	05	10	V, Completely unstable	W = 0.17
S14	T- J4	-17.5	-21.675	0	52	34	30	IV, Unstable	T = 0.25
	W- J2&J3	-7.65	-15.5968			44	36		W = 0.17
S15	T- J4	-17.5	-18.1584	0	53	35	34	IV, Unstable	T = 0.25
	W- J1&J3	-7.65	-11.6168			45	41		W = 0.17
S16	W- J1&J2	-51	-48.3206	0	52	01	03	V, Completely unstable	
	W- J1&J4	-24	-24.96			28	27		W = 0.5
	W- J2&J4	-51	-50.6125			01	01		
S17	T- J1	-3.75	-5.5636	0	48	44	42	III, Partially stable	-
S18	T- J4	-3.75	-8.3381	0	68	64	59	III, Partially stable	T = 0.25
S19	W-J1&J2	-7.65	-14.93	0	63	55	48	III, Partially stable	W =0.33
S20	P- J2	-42	-48.591	0	82	40	33	IV, Unstable	P = 0.6
	P- J4	-42	-40.3736			40	41		T = 0.2
	T- J1	-10	-13.5174			72	68		W = 0.5
	W- J2&J3	-24	-21.1451			58	60		
	W- J4&J5	-24	-18.911			58	63		

Table 4. Data on Joint – Slope orientation relationship, DD= Dip direction, DA = Dip amount

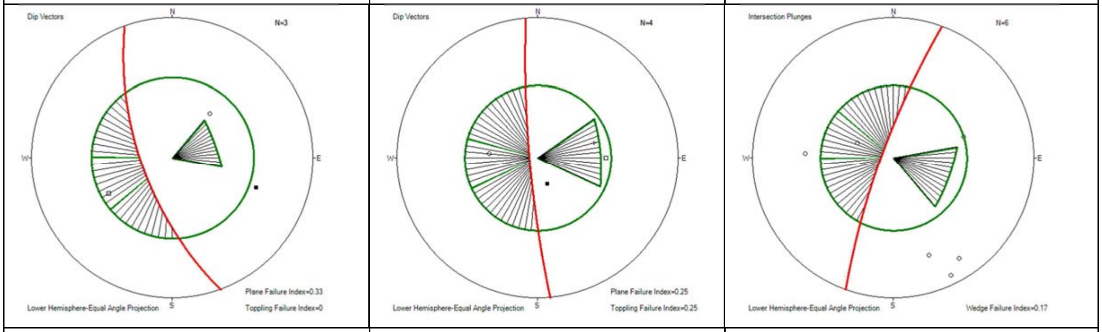
Site no. (Km)	Slope orientation DD/DA	Joints orientation					Probability of failures Planar - P; Topple - T; Wedge - W
		J1 DD/DA	J2 DD/DA	J3 DD/DA	J4 DD/DA	J5 DD/DA	
S1 (0.4)	130/80	110/37	48/76	230/35	308/56	-	P- J1; T- J4; W-J1&J2
S2 (1.9)	140/65	110/45	30/62	295/40	-	-	P- J1
S3 (4.8)	190/85	145/40	210/80	170/78	-	-	P- J2; P- J3; W- J1&J2; W- J2&J3
S4 (8.7)	100/80	70/86	20/65	160/38	65/58	-	W- J2&J3; W- J2&J4; W- J3&J4
S5 (10.1)	45/85	110/50	220/68	250/40	325/46	-	T- J2; T- J3
S6 (11.6)	250/65	240/35	40/45	110/25	-	-	P- J1
S7 (14)	235/75	190/55	40/70	200/80	-	-	T- J2
S8 (15.5)	265/83	90/38	275/52	160/67	75/45	-	P- J2; T- J4; W- J2&J3
S9 (16.4)	342/82	90/55	250/55	330/84	310/62	-	W- J1&J3; W- J1&J4; W- J2&J4
S10 (17.3)	190/84	215/65	300/84	30/45	-	-	P- J1; T- J3; W- J1&J2
S11 (19.6)	120/65	210/54	50/60	80/82	50/21	-	W- J1&J3
S12 (20.4)	165/75	155/33	230/75	135/80	40/55	-	W- J1&J2; W- J2&J3
S13 (22)	290/80	70/35	355/74	243/69	225/36	-	W- J2&J3
S14 (23.5)	210/70	65/33	285/48	175/64	20/73	-	T- J4; W- J2&J3
S15 (25.8)	325/80	10/45	190/65	50/52	160/80	-	T- J4; W- J1&J3
S16 (26.7)	150/60	90/55	200/52	140/80	110/50	-	W- J1&J2; W- J1&J4; W- J2&J4
S17 (33.7)	270/75	45/70	14/80	92/32	-	-	T- J1; T- J2
S18 (49.5)	120/80	25/75	110/15	260/80	270/75	-	T- J3; T- J4
S19 (50.5)	55/80	110/42	25/62	240/25	-	-	W- J1&J2
S20 (51.3)	190/80	30/50	180/60	90/80	205/70	175/75	P- J2; P- J4; P- J5; T- J1; W- J2&J3; W- J2&J5; W- J3&J4; W- J3&J5; W- J4&J5



S1 – Wedge failure towards southeast.

S3 – Wedge failure towards south.

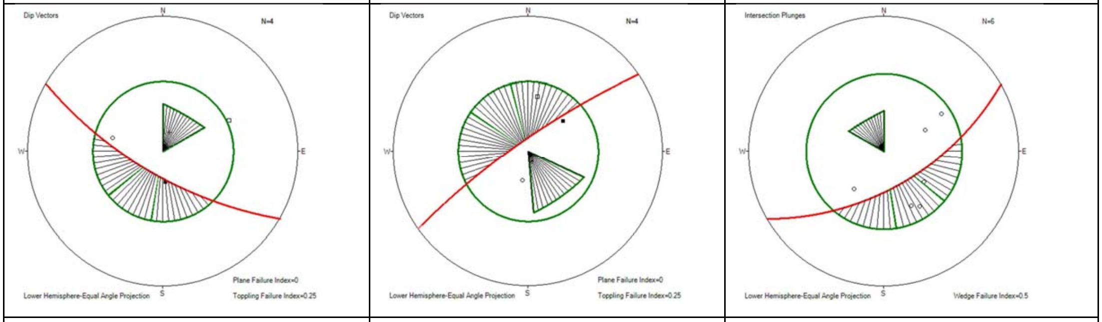
S5 – Topple failure towards northeast.



S6 – Planar failure towards southwest

S8 – Planar failure towards west.

S13 – Wedge failure towards northwest.



S14 – Topple failure towards southwest

S15 – Topple failure towards northwest.

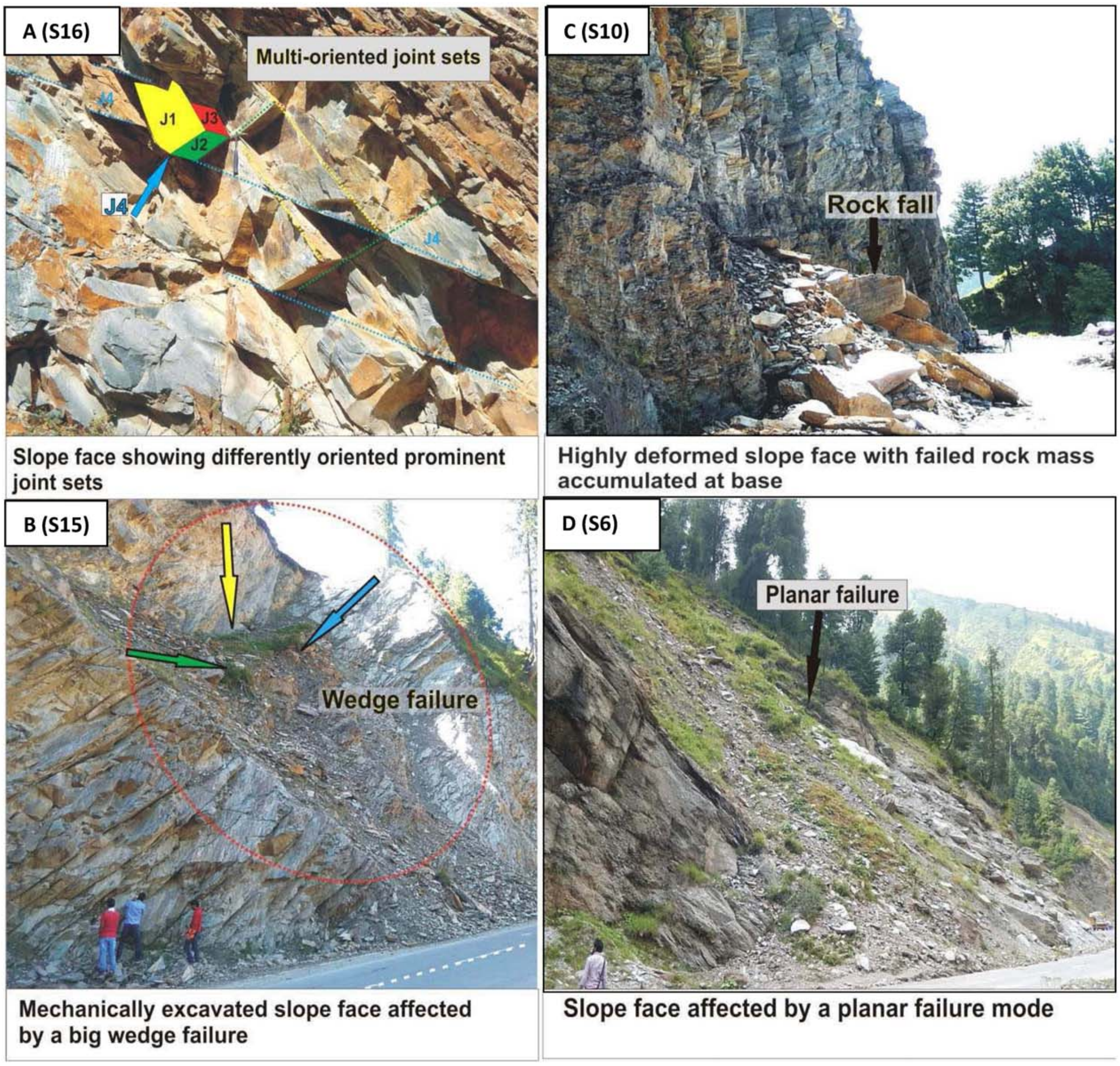
S16 - Wedge failure towards southeast.

Fig 3. Stereonet plots of unstable and completely unstable slopes

the maximum at the S15 and S16 sites. The study also reveals that the sites with high joint density are more prone to different type of failures, i.e., wedge, topple and planar failures (Fig. 4B, 4C and 4D). The RMRb value varies from 48 to 82 representing three classes of rock mass, i.e., Class I- very good; Class II- Good and Class III- Fair (Table 2). According to the RMRb classification scheme total eleven sites (out of total twenty sites) fall under good category (55%), eight sites fall under fair category (40%) and one site (i.e. S20) fall under very good category (5%). On contrary comparison of the results of RMRb with SMR (Fig. 5) reveals sites falling in good category under RMRb fall in the partially stable and unstable category under SMR scheme. The geomechanics classification index (SMR index) specifically designed for rating slopes was assessed by both the forms (i.e., original and modified form) in assimilation with kinematics techniques. The SMR index value obtained revealed five classes of the rock slopes, i.e., very bad (V), bad (IV), normal (III), good (II) and very good (I) corresponding to the specified stability classes, i.e., completely unstable, unstable, partially stable, stable and completely stable respectively. The least rated values obtained were preferred and analyzed to arrive at the final conclusions. The final slope mass rating results obtained (Table 3) revealed that of the total twenty sites, ten sites are partially stable (comprising of 50% of the investigated sites) with least rated SMR score of 37 at S12 site which is potentially favourable for wedge failure; the SMR score of 42 at S17 site is favourable for topple failure and the SMR score of 49 at S2 site which is favourable for planar failure. Whereas, six sites are classified as unstable (comprising of 30%) with minimum SMR score of 28 at S1 site favourable for wedge failure; SMR score of 30 at S14 site favourable for topple failure and the SMR score of 33 at S20 site favourable for planar failure. The remaining four sites are categorized as completely unstable (comprising of 20%) with lowest SMR value of 1 at S16 site potential site for wedge failure; SMR scores of 12 & 38 at S8 site is favourable for planar and topple failures respectively. The results of kinematics analysis (Table 4) infer that 53 percent failures are caused due to wedge failure mode; 20 percent are due to planar failure mode and 27 percent are due to topple failure mode. The comparison of the results of RMRb and SMR index (both discrete and continuous SMR) (Fig. 5) reveals that SMR index applied in original and modified form have close proximity with an average difference within the range of 4.7±6 values indicating the results obtained and inferences made from the two methods are coincident.

CONCLUSION

The study concludes that presence of multiple sets of discontinuities are the principle governing factors affecting slope stability in the study area, despite having overall high intact rock strength and Class II (i.e. good) category of rock mass (RMRb results). The results of SMR



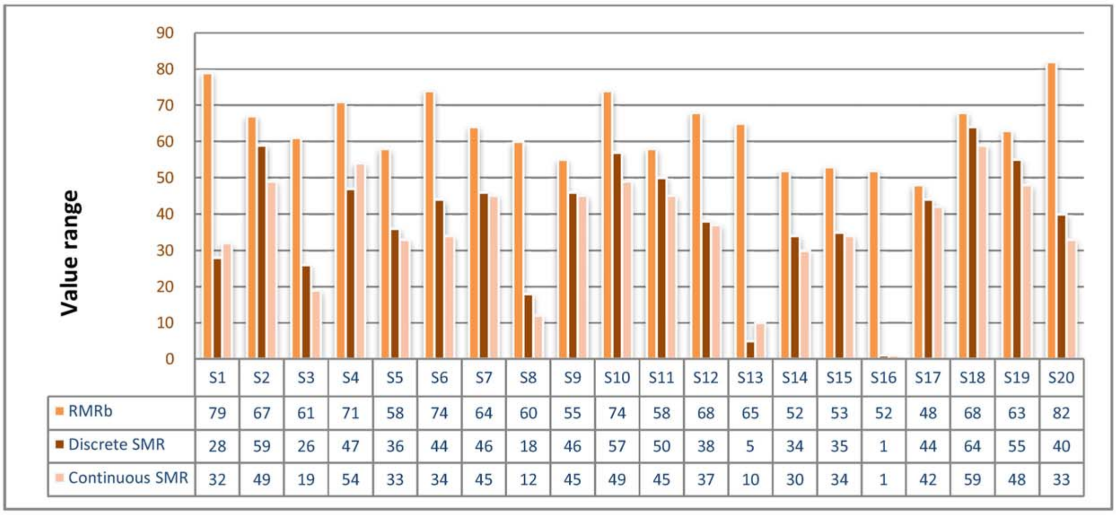
Slope face showing differently oriented prominent joint sets

Highly deformed slope face with failed rock mass accumulated at base

Mechanically excavated slope face affected by a big wedge failure

Slope face affected by a planar failure mode

Fig 4. Field photographs showing different slope face grievously affected after Mughal road construction



	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
RMRb	79	67	61	71	58	74	64	60	55	74	58	68	65	52	53	52	48	68	63	82
Discrete SMR	28	59	26	47	36	44	46	18	46	57	50	38	5	34	35	1	44	64	55	40
Continuous SMR	32	49	19	54	33	34	45	12	45	49	45	37	10	30	34	1	42	59	48	33

Fig 5. A comparison of results obtained by the RMRb and SMR for different sites

scheme reveals that of the total selected sites half of the rock slopes (fifty percent) stands partially stable and remaining half in general are unstable. The kinematic analysis of the study area reveals that mode of failures of unstable slopes is in the form of wedge, planar and topple failure which is controlled by the orientation and joint discontinuities sets with respect to slope face. The results of SMR index and kinematics analysis concludes that under natural condition most potential slope failure mechanism in the study area would be wedge failure mode (26 counts out of total 49 counts) followed by topple failure (13 counts out of total 49 counts). The topple failure of mechanically strong rock masses in the area under investigation infer greater anthropogenic interference in the form of slope cutting for road expansion. Besides this the role of tectonic activities in conjunction with the above mentioned factors also plays a vital role.

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