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Study of slope instability on the Bhaderwah–Bani Highway, Jammu and Kashmir, India

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ABSTRACT

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Northwest Himalaya has witnessed lot of mass movements during the Quaternary period which have led to palaeoenvironmental degradation and deposition of erratic size sediments. These sediments have developed as fossil slides along the mountain slopes. In last few decades, the frequency of landslides has increased due to various factors such as complex geology, geotechnical properties of the rocks and anthropogenic activities. The investigation of rock slopes require geo–engineering evaluation to assess the instability of critical slopes leading to landslides particularly in the Himalayan region, where rocks are highly folded, faulted, jointed and weathered. In the present study, a total of 15 rock slopes have been selected for rapid assessment of instability condition using rock mass rating basic (RMRb), slope mass rating (SMR) and kinematics analysis techniques along Bhaderwah–Bani Highway in Jammu and Kashmir. Field surveys were conducted regarding required input data collection followed by laboratory works. The results of RMRb show two classes of rock mass, i.e., Class II–Good (86.58%) and Class III–Fair (13.42%). The SMR index classify rock slopes into different stability class results, which infers completely unstable (L4 and L14), unstable (L1, L2, L3, L8, L9, L11, L12 and L13), partially stable (L5, L6 and L7) and stable (L10 and L15) categories. The final output of kinematic analysis verify different modes of structurally controlled slope failures i.e., planar (30.72%), wedge (57.6%) and toppling (11.52%), representing all 15 sites in the study area.

Key–words—Slope Instability, Rock Mass Rating Basic, Slope Mass Rating, Kinematic Analysis.

भदेरवाह–बनी राजमार्ग जम्मू एवं कश्मीर, भारत पर ढाल अस्थिरता का अध्ययन

इमरान फ़ारूक़, जी.एम. भट्ट, एस.के. पंडित, रामेश्वर सांगड़ा, अर्जुन सिंह, गुलज़ार हुसैन, युधबीर सिंह एवं एहसान उल हक

सारांश

पश्चिमोत्त्र हिमालय में चतुर्थमहाकल्प अवधि के दरम्यान काफी स्थूल संचलन सहे हैं जिसने अनियमित आकार के अवसादों का पुरापर्यावरणीय तलावचन व निक्षेपण पथ प्रस्तुत किया है। ये अवसाद पर्वत ढ़ालों के साथ–साथ जीवाश्म स्लाइडों के रूप में विकसित हुए हैं। पिछले कुछ दशकों में चट्टानों के सम्मिश्र भू–विज्ञान, भू–तकनीकी गुण–धर्मो तथा मानवजनिक हलचलों जैसे तमाम कारकों की वजह से भू–स्खलनों की आवृत्ति में इज़ाफ़ा हुआ है। खास–तौर पर हिमालयी अंचल, जहां चट्टानें अत्यधिक मुड़ी, भ्रंशित, संधित और अपक्षीण हैं में भू–स्खलनों में अग्रणी नाजुक ढालों की अस्थिरता को आंकने में चट्टान ढ़ालों के अन्वेषण में भू–इंजीनियरिंग मूल्यांकन की ज़रूरत है। मौजूदा अध्ययन में, भदेरवाह–बनी राजमार्ग, जम्मू एवं कश्मीर के सटे हुए चट्टान द्रव्यमानी कोटि निर्धारण मूलभूत (आर एम आर–बी), ढाल द्रव्यमानी कोटिनिर्धारण (एस एम आर) तथा शुद्धगतिकी विश्लेषण तकनीकें प्रयुक्त करते हुए अस्थिरतता स्थिति के द्रुत मूल्यांकन हेतु कुल मिलाकर 15 चट्टान ढालों को चुना गया। प्रयोगशाला कार्यों के अनुगामी अपेक्षित योगदान आंकड़ा संग्रहण के बारे में क्षेत्रीय सर्वेक्षण आयोजित किए गए थे। आर एम आर–बी के निष्कर्ष चट्टान द्रव्यमानों के दो वर्ग अधति वर्ग द्वितीय–अच्छा (86.58%) और वर्ग तृतीय–उचित (13.4%) दर्शाते हैं। एस एम आर अनुक्रमणिका चट्टान ढ़ालों को अलग–अलग स्थिरता वर्ग निष्कर्षों में वर्गीकृत करते हैं, जो पूर्णतः अस्थिर (एल 4 एवं एल 14), अस्थिर (एल 1, एल 2, एल 3, एल 8, एल 9, एल 11, एल 12 व एल 13,) आंशिक स्थिर (एल 5, एल 6 व एल 7) तथा स्थायी (एल 10 व एल 15) वर्गों में अनुमानित हैं। अध्ययन क्षेत्र में समस्त 15 स्थलों को द्योतित करते हुए, शुद्धगतिकी विश्लेषण के निर्णायक निर्गत संरचनात्मक रूप से नियंत्रित ढाल विफलताओं अर्थात, तलीय (30.72%), फन्नी (57.6%) और ढहते (11.52%) की विविध प्रावस्थाएं साबित करते हैं।

सूचक शब्द—ढाल अस्थिरता, चट्टान द्रव्यमानी, कोटिनिर्धारण मूलभूत, ढाल द्रव्यमानी कोटिनिर्धारण, शुद्धगतिकी विश्लेषण।

INTRODUCTION

INDIAN Himalaya, in last few decades, experiences numerous landslide hazardous events throughout its extension, utterly due to complex geological and geotechnical setting of this neotectonic orogenic belt. Besides, glacial activities during the Quaternary period have resulted into land degradation in the form of erosion and mass movement. These processes have deposited erratic and different size sediments on the mountain slopes which have developed as fossil slides with the passage of time. These fossil slides have become active due to the orogenic processes in the Himalaya. The present scenario on slope instability problem all over the world is alarming specifically along the hilly road networks and has become focus of the geo–scientific researches (Siddique *et al.*, 2017; Anbazhagan *et al.*, 2017; Sangra *et al.*, 2017; Singh *et al.*, 2017). In last few decades, Indian Himalayan region experienced several fatal incidents of natural hazards in terms of slope failures, floods, earthquakes, cloud burst and forest fires, etc. but one of the most recognized natural hazard is landslide which often becomes disastrous where population pressure and anthropogenic interruptions are growing in the form of road and other infrastructural developments, specifically in Lesser Himalayan terrains (Siddique *et al.*, 2017; Sangra *et al.*, 2017; Sarkar *et al.*, 2012; Singh *et al.*, 2010; Umrao *et al.*, 2011, Bhat *et al.*, 2002). The increasing slope failure incidents along these hill road networks owing to the unplanned excavation and negligence or poor understanding of geotechnical properties of slope material leads to disruption of traffic, loss of life and properties and above all environmental degradation (Sangra *et al.*, 2017; Hussain *et al.*, 2015; Siddique *et al.*, 2015; Aleotti & Chowdhury, 1999). In general, hill slopes may become stable after failure or persist due to change in slope gradient and for some time until acted by some external forces and anthropogenic activities which further aggravates failure in such failed slopes (Saranaathan & Kannan, 2017). Due to various causative factors, the behaviour of landslides is complex and unpredictive (Aghdam *et al.*, 2017). Hard rock slopes are usually traversed by multiple discontinuities leading to reduce their strength and stability. In addition, blasting and unplanned excavation during road construction further deteriorate stability of slope (Singh *et al.*, 2014). Rock mass characterization by means of geomechanical classification system provides good estimation on various inherits and structural parameters defining qualitative and quantitative nature of rock slopes (Mondal *et al.*, 2016; Taherniya *et al.*, 2014; Pantelidis, 2009). The slopes along Bhaderwah–Bani Highway are marked by several vulnerable landslides which often disrupt human livings and block routine

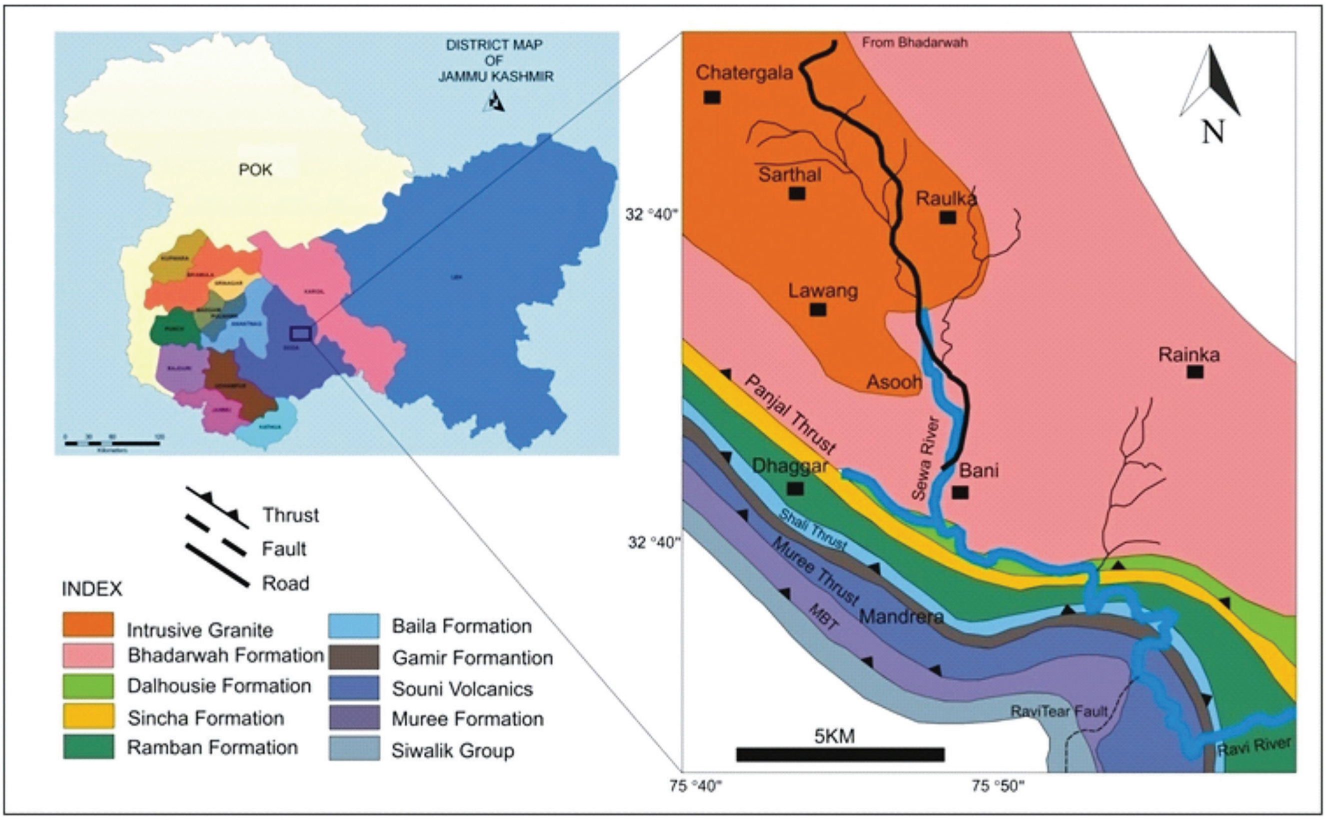

Fig. 1—Geological and structural map of the study area (after Choudhary, 2010).

traffic movement in the region. The impact of glaciations is preserved in the form of thick debris deposited on both the flanks of mountain slopes. The mass movement in this area is dominated toward the northern slope where thick boulder and erratic sediment supply has been noticed with reasonable extension. A detailed geological field investigation is an important means to characterize a slope and helps predicting future behaviour of slope mass. Keeping in view the importance of field investigation in order to understand the failure mechanism and the influence of various parameters the geotechnical data on various parameters has been recorded from the field. Various studies in this region have been carried out by various workers (e.g., Bhat *et al.*, 2002; Singh, 2006; Singh & Bhat, 2010; Singh *et al.*, 2014; Hussain *et al.*, 2015; Sangra *et al.*, 2017) and they are of the opinion that slope instability in the region is influenced either by the dynamics of Lesser Himalaya or combine action of various parameters such as geology, geomorphology, precipitation, geotechnical properties of rocks and tectonics regime of the area.

STUDY AREA

The Bhaderwah–Bani Highway situated between the Latitude/Longitude, N32°60' & N32°40' / E75°40' & E75°60' on Survey of India toposheets 1: 50,000 scale has been used for preparation of base map. The prominent physiographic feature of the area is the rugged snow covered mountain peaks, cut into precipitous ridges and deep defiles. Raised terraces, deep gorges and rocky cliffs are the characteristics feature of the area. The mountain slopes have very high gradient and at places reaches an angle of 83°. Seismically the area has been classified as seismic zone–IV and V. The area receives significant rainfall in the months of July to September and remains snow covered from mid December to March. The average annual rainfall for the last five years (2012–2017) is 1284.58 mm (IMD GOI).

GEOLOGICAL LAYOUT

The regional geological setup of the study area (Fig. 1) falls under Lesser Himalayan Division. The study area lies north of Main Boundary Thrust (MBT) and south of Main Central Thrust (MCT) which is locally known as Panjal Thrust (PT) in this region (Fuchs, 1975; Gansser, 1981; Thakur, 1981). The other thrust in this area includes Shali Thrust (ST) which is the footwall imbricate of Panjal Thrust (PT) and Murree Thrust (MT). Recognized lithounits exposed along the road are comprised mainly of slate, quartzites, volcanics, phyllite, gneiss, schist, shale and limestone strata (Table 1). The oldest rocks in this area are represented by Bhaderwah Group of Precambrian age composed of grey phyllitic slates, calcareous slates and talc bearing slates, overlain by Dalhousie Formation comprising of augen gneisses and banded gneisses (McMohan, 1885). The Dalhousie Formation is overlain

Table 1—Regional tectonostratigrahic setup of the study area (after Choudhary, 2010).

Group/Formation	Lithology	Age
Bhaderwah Group	Phyllite, schist and slate	Precambrian
Dalhousie	Augen gneiss and granite (granodiorite to quartz diorite)	Precambrian
	——— Panjal Thrust (= Jutogh Thrust) ———	
Sincha	Sandy dolomite occasionally phosphatic, pinkish, grey limestone having zebra type banding	Precambrian
Ramban	Grey to dark grey shale/slate with bands of grey quartzite, bluish grey phyllitic slate	Precambrian
Baila	Calcareous shale, nodular and lenticles of limestone, black to carbonaceous slate	?Neoproterozoic
	——— Shali Thrust (= Sudh Mahadev Thrust) ———	
Gamir	Quartzite, bands of conglomerate and cherty shale and bands of limestone and purple shale	Mesoproterozoic
Souni Volcanics	Greenish and greyish–green basalts	Palaeoproterozoic
	——— Murree Thrust ———	
Murree	Sandstone, mudstone and shale	Miocene
	——— Main Boundary Thrust ———	
Upper Siwalik	Sandstone and conglomerate	M. Pleistocene

by Sincha Formation which consists of bluish–grey sandy dolomite and pinkish limestone. The Sincha Formation is followed by Ramban Formation, i.e. Dogra Slates (Wadia 1931). The Ramban Formation is overlain by Baila Formation composed of limestone and greenish grey calc–argillite. The Baila Formation conformably overlies Gamir Formation which is represented by white quartzite, ferruginous quartzite, cherty shale, calcareous and flaggy quartzites with bands of limestone (Jangpani *et al.*, 1986). Souni Volcanics composed of basaltic lava overlies the Gamir Formation comprises of alternate beds of sandstone and mudstone along Murree Thrust. The Murree Formation is overlain by Siwaliks which constitute the youngest lithounits in this area (Karunakaran & Ranga Rao, 1979).

METHODOLOGY

To determine the stability of rock slopes in the study area, the basic rock mass rating (RMRb) system developed by Bieniawski (1989) and slope mass rating (SMR) system developed by Romana (1985) in association with kinematics analysis (Hoek & Bray, 1981) has been practised. A detailed field investigation has been carried out in the study area to collect the data on varoius parameters to determine the RMRb, SMR and kinematic analysis. To estimate the strength of the rock mass, intact rock samples were collected, following ISRM (1985) from each location. Rock quality designation was determined from joint volumetric count using indirect relation proposed by Palmstrom (2005). The other parameters such as condition of discontinuities, spacing of discontinuities and groundwater condition were directly recorded from the field and rated accordingly following Bieniawski (1989) and Romana (1985).

BASIC ROCK MASS RATING (RMRb)

The RMRb system signify rock mass quality assessed by analyzing five basic parameters, viz. uniaxial compressive strength (UCS), rock quality designation (RQD), discontinuities spacing (DS), discontinuities condition (DC) and groundwater conditions (GWC). According to Bieniawski's (1989) classification, RMRb has been calculated by adding rating values for five parameters and the results obtained are given in Table 2.

SLOPE MASS RATING (SMR)

The slope mass rating (SMR) in the study area has been calculated from RMRb by adding four factorial adjustment factors (F1, F2, F3 and F4) (Romana, 1985). The first three adjustment factors (F1, F2, and F3) depict the relation between rock slope and joint set geometries and fourth one (F4) represents the method of excavations. The SMR results obtained are given in Table 3.

Table 2—Basic rock mass rating results (Bieniawski, 1989).

Location	Uniaxial compressive strength	RQD	DS	DC	GWC	RMRb	Rock mass description
L1	7	17	10	25	4	63	Good
L2	15	17	10	25	10	77	Good
L3	7	17	10	25	7	66	Good
L4	15	20	10	25	7	77	Good
L5	7	17	5	25	7	61	Good
L6	7	13	8	25	4	57	Fair
L7	7	17	10	25	7	66	Good
L8	7	13	5	20	7	52	Fair
L9	15	17	10	25	7	74	Good
L10	12	13	5	25	15	70	Good
L11	7	17	10	25	15	74	Good
L12	7	17	5	25	10	64	Good
L13	12	17	10	25	10	74	Good
L14	7	17	5	25	7	61	Good
L15	12	17	10	25	7	71	Good

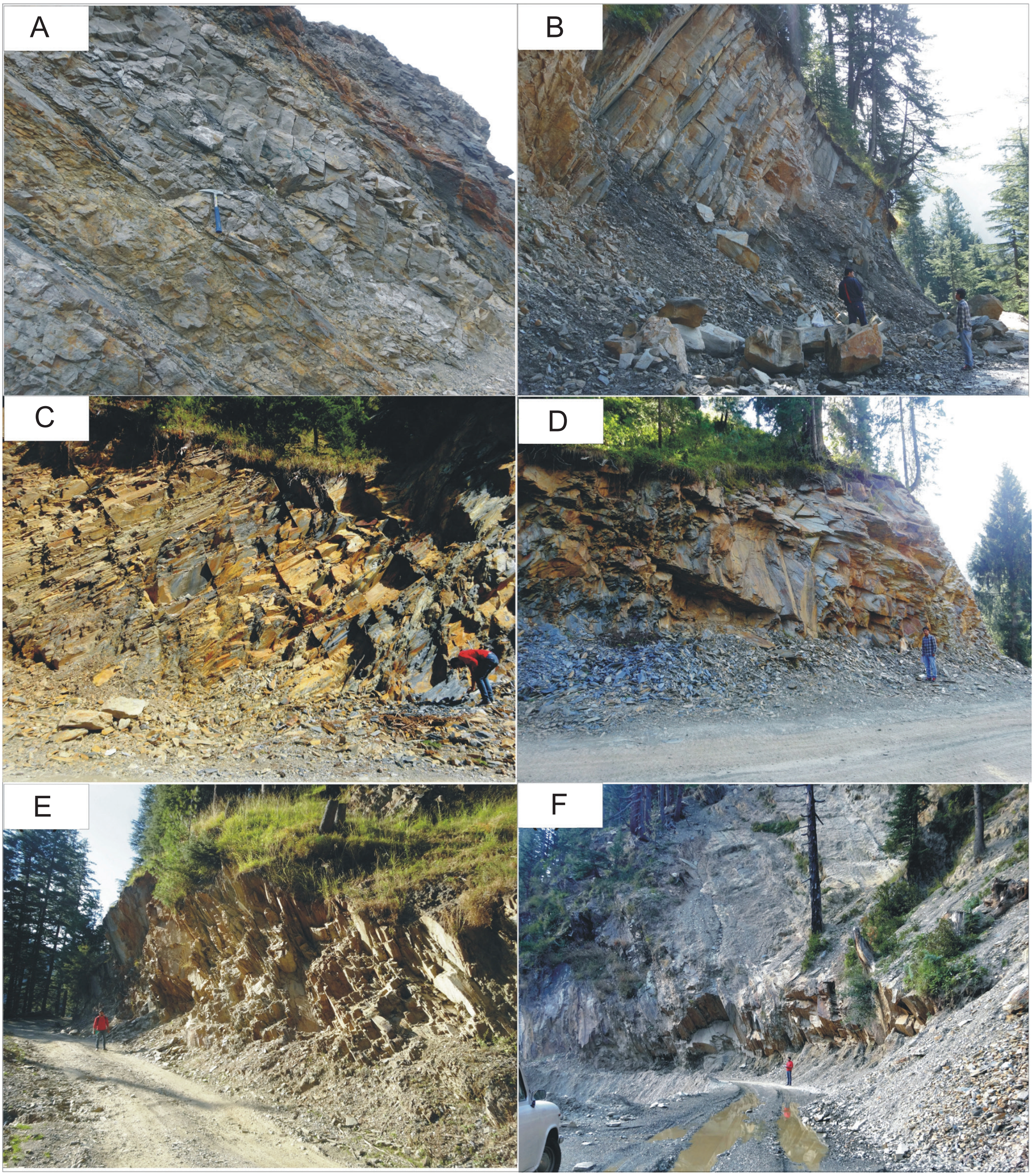

Fig. 2—Field photographs showing vulnerable rock slopes, (A) Slope face showing failure due to intersection of bedding plane and joint set (B) Large block of rock failures (C) Closely spaced joint in phyllitic rock (D) Wedge failure in highly fractured rock mass (E) Rock slope showing highly blocky structure (F) Slope face showing wedge failure due to intersection of joints.

KINEMATIC ANALYSIS

A kinematic analysis is purely a geometric observation of slope with respect to differently oriented discontinuity data sets (Fig. 2). In present study kinematic analysis was performed on discontinuity data sets documented from the field (Table 4) following Hoek and Bray (1981). The stereonet plots were drawn using Dip Analyst 2.0 program which helps to identify the mode and type of failures. The results are given in Fig. 3.

RESULTS AND DISCUSSION

In this study, a total of 15 potential rock slope sites were selected for detailed geotechnical investigation following RMRb, SMR and Kinematics. The results of uniaxial compressive strength (UCS) rating for each site were obtained using point load strength index value determined through International Society for Rock Mechanics (ISRM) (1985). At each location joint data were recorded and three to four major joint sets plus random joints were observed, and joint

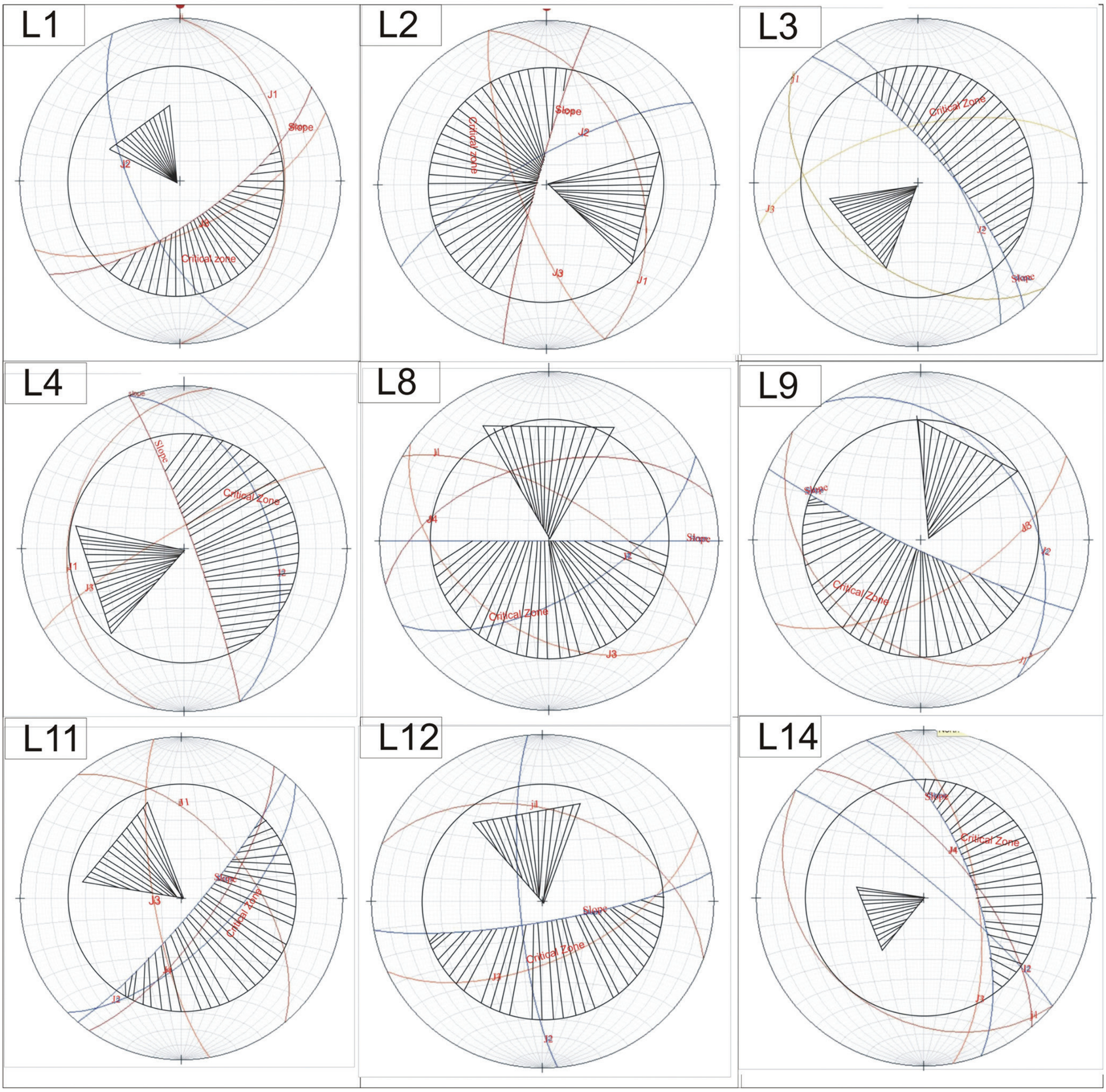

Fig. 3—Graphical presentation of geometrical relationship between slope face and discontinuity data recorded at different locations in the study area.

Table 3—Slope mass rating results (Romana, 1985).

Location	RMRb	Failure	F1xF2xF3	F4	SMR	Stability
L1	63	P	0.85x1x–50	0	20.5	Unstable
		W1	0.15x1x–60		54	
		W2	0.15x1x–60		54	
L2	77	W	0.85x1x–60		26	Unstable
L3	66	P	0.85x1x–50	0	34.5	Unstable
		W	0.15x1x–60		68	
L4	77	P	1x1x–60	0	17	Completely Unstable
		W	0.70x0.85x–60		41.3	
L5	61	W	0.15x0.15x–60	0	59.65	Partially Stable
L6	57	T	0.40x1x–25	0	47	Partially Stable
L7	66	W	0.15x0.85x–60	0	58.4	Partially Stable
L8	52	T	0.70x1x–25	0	34.5	Unstable
		W	0.40x0.85x–60		31.6	
		W	0.15x1x–60		43	
L9	74	W	0.70x0.85x–60	0	38.3	Unstable
L10	70	W	0.15x1x–60	0	61	Stable
L11	74	P	0.70x1x–60	0	32	Unstable
		W	0.15x1x–60		65	
		W	0.15x1x–60		65	
L12	64	P	0.70x1x–60	0	22	Unstable
		T	0.40x1x–25		54	
		W	0.40x1x–60		40	
L13	74	P	0.70x0.85x–60	0	38.3	Unstable
		W	0.15x0.85x–60		66.4	
L14	61	P	0.85x1x–50	0	18.5	Completely Unstable
L15	71	P	0.85x0.15x–60	0	63.35	Stable

density recorded from these locations vary between 03.50 to 13.05 m/m^3. The result of RMRb value ranges between 52 to 77 representing only two classes of rock mass, i.e. Class II–Good (86.58%) and Class III–Fair (13.42%) (Table 2). The SMR results obtained from the study area classify the rock slopes into four stability class, i.e. completely unstable (L4 and L14); unstable (L1, L2, L3, L8, L9, L11, L12 and L13); partially stable (L5, L6 and L7) and stable (L10 and L15) categories. The final slope mass rating results obtained (Table 3) reveal that 20% of the investigated sites (Fig. 4) fall under partially stable category with least rated SMR score of 47 at L6 site which is potentially favourable for topple failure, and the SMR score of 59.65 and 58.4 at site L5 and L7 is favourable for wedge failure. The eight sites fall under unstable category comprising of 53.28% of the investigated sites with minimum SMR score of 20.5 and 22 at L1 and L12 favouring the planar failure. The other two sites with SMR score of 68 at L3 site and 34.5 at L8 site is potentially favourable for wedge and topple failure. The two sites (L4 and L14) comprising of 13.32% of the investigated sites fall under completely unstable category. The L4 site having SMR score of 17 favouring planar failure whereas, L14 site

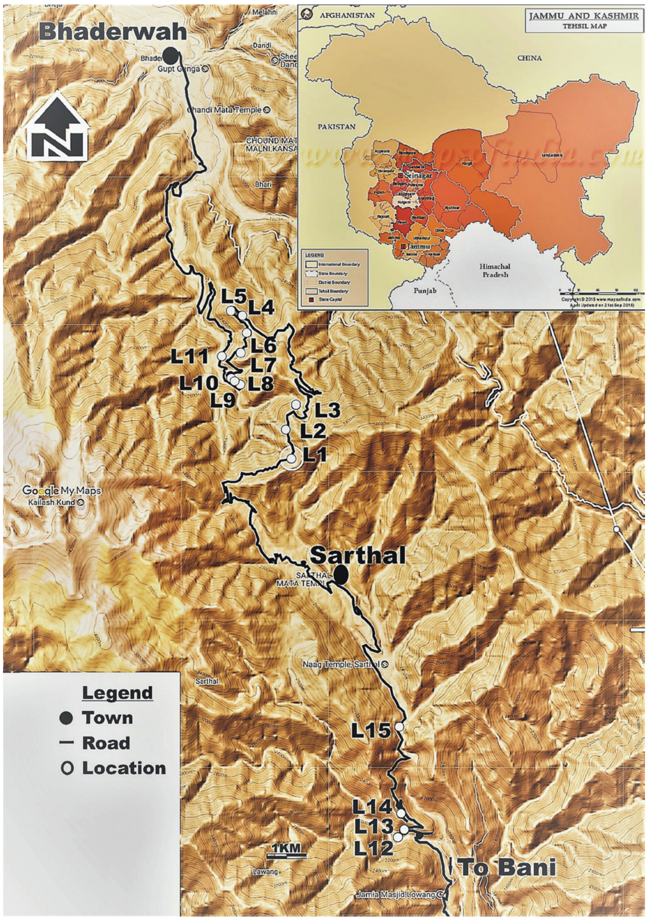

Fig. 4—Spatial distribution of investigate slopes.

with SMR score of 18.5 favouring wedge failure type. The remaining two sites (L10 and L15) comprising of 13.32% of the investigated sites fall under stable category. A total of 26 counts of probable failures are obtained following kinematic analysis technique of Hoek and Bray (1981). Out of these only three counts (11.52%) belong to topple failure type. Besides 8 counts belong to planar type failure (30.72%) and 15 counts show wedge type failure (57.6%). The end results of kinematic analysis confirm different modes of structurally controlled slope failures, in the form of planar, wedge and toppling, representing all 15 sites in the study area.

The past glaciations in the area have resulted into mass movements, landslides and loss of vegetation cover, thus impacting the palaeogeo-environmental conditions. The impact is clearly marked due to the absence of much older vegetation and degradation of rock mass in the southwestern slopes whereas, towards the northwestern slopes tree species have relatively responded to the glaciations.

CONCLUSION

The geotechnical investigation has been carried out along the Bhaderwah–Bani Highway by implying the most widely accepted geomechanical classification systems, viz. RMRb and SMR in association with kinematic analysis to investigate and understand the slope stability problems in study area. These kind of studies are fundamental in nature and are of immense use for better understanding of failure mechanism. The present study is of the opinion that discontinuities play an important role in slope failure along the highway because the intact strength of rock mass falls under fair and good category which clearly indicates that the stability of slope is not completely dependent on the intact strength of rock mass but also on other parameters in combination with orientation of discontinuities. The present study strongly recommends that the cut slopes need an immediate treatment in order to safeguard the loss of life, property and environment in general.

The vegetation cover and the slope stability are interrelated and may have impacted the palaeo-geoenvironmental conditions in the study area. The chronology of development of soil and glacial and interglacial events can be developed by the dating of sediments in future.

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Table 4—Slope and joint orientation data of the study area.

Location Lat–long	Orientation of discontinuities (dip direction/dip amount)				Orientation of slope
	J1	*J2*	*J3*	*J4*	*DD/DA*
L1–32°52'58.94"N 75°45'2.28"E	N090°/35°	N245°/66°	N155°/65°		N145°/70°
L2–32°53'25.20"N 75°44'56.50"E	N070°/45°	N330°/76°	N250°/76°		N285°/85°
L3–32°53'47.10"N 75°45'7.50"E	N220°/45°	N60°/73°	N345°/62°		N50°/75°
L4–32°55'7.60"N 75°44'8.70"E	N280°/29°	N70°/45°	N330°/80°		N70°/85°
L5–32°55'11.80"N 75°43'59.80"E	N310°/60°	N55°/84°	N80°/45°	N275°/65°	N10°/80°
L6–32°54'52.20"N 75°44'15.30"E	N70°/55°	N160°/75°	N340°/36°	N210°/75°	N310°/78°
L7–32°54'34.40"N 75°44'7.90"E	N220°/44°	N175°/65°	N220°/85°		N280°/80°
L8–32°54'9.90"N 75°43'59.50"E	N30°/68°	N150°/62°	N215°/45°	N345°/52°	N180°/90°
L9–32°54'6.58"N 75°44'3.85"E	N220°/38°	N55°/35°	N150°/63°		N205°/85°
L10–32°54'5.00"N 75°44'6.90"E	N255°/61°	N320°/35°	N165°/75°	N20°/35°	N195°/88°
L11–32°54'31.30"N 75°43'47.80"E	N50°/55°	N135°/65°	N260°/76°	N125°/73°	N130°/82°
L12–32°47'18.60"N 75°46'57.10"E	N20°/45°	N265°/79°	N155°/61°		N170°/80°
L13–32°47'24.50"N 75°47'3.80"E	N340°/85°	N50°/42°	N275°/25°	N255°/85°	N30°/82°
L14–32°47'39.70"N 75°47'0.70"E	N220°/30°	N40°/82°	N80°/64°	N50°/66°	N70°/65°
L15–32°48'58.50"N 75°46'59.00"E	N245°/35°	N135°/70°	N110°/25°		N120°/83°

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