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Road-cut Slope Stability Assessment along Himalayan National Highway NH-154A, India

Kanwarpreet Singh* and Virender Kumar
Civil Engineering Department, National Institute of Technology, Hamirpur – 177 005, India
E-mail: *singhkanwarpreetnit@gmail.com*; sardavk@yahoo.com*

ABSTRACT

The Himalayan range, being a complex terrain, is highly prone to slope instability in many parts because of the natural conditions and human interference. In the present study, road cut slope stability assessment has been carried out along Chamba-Bharmour Section (Chamba District, Himachal Pradesh) along Chakki (Pathankot, Punjab) - Bharmour (Chamba, Himachal Pradesh). The cut slopes with the potential of failures have been identified taking into consideration the geological and geotechnical complexities in the selected zone. Rock mass characterization methodologies have been used for the assessment of slope instability . The varying stability classes of the rock slopes have been calculated using rock mass rating (RMR) and modified slope mass rating (SMR) methods. The kinematic analysis approach has been utilized for the identification of different failure modes in heavily jointed, fractured and structurally controlled rock masses. Fourteen potentially unstable slopes were selected to assess their criticality by RMR and modified SMR approaches and their stability classes were identified.

INTRODUCTION

Road networks play a vital role in improving the development and economy of a country. However, inconvenience along the road network is often witnessed by slope failures due to natural disasters (e.g. landslides, subsidence, toe erosion etc) and human interferences (e.g. road construction and widening and other development activities). This in turn requires quick stability evaluation of slopes and appropriate treatment with a view to reduce risk to life and property. Because of the large numbers of landslide contributory factors, the prediction of the landslide is complex (Aghdam et al. 2017). Some of the natural disasters are interlinked with each other which get initiated by locational elements such as slope, height, drainage pattern etc. Variations in geology, geomorphology, soil, land use land cover (LULC), and hydrologic conditions in the vicinity of an area have been proposed as major landslide triggering factors (Varnes, 1984; Anbalagan, 1992; Hutchinson, 1995; Bhattacharya, 2018). Human intervention, for developmental activities, converts natural slopes into cut slopes which makes them more susceptible to failure (Vishal et al. 2010). Unplanned excavation and blasting for the road construction are also one of the major reasons for creating slope instability. The identification of the unstable slope zones is a critical task for developing such kinds of areas (Ramesh and Anbazhagan, 2015). The whole Himalayan belt, particularly the state of Himachal Pradesh in India, is tectonically active, and monsoon rains in the state initiate floods resulting in the landslides (Kundu et al. 2017). The slope failure, which causes loss of life and property, is provoked by natural and human activities along the highway corridor cut slopes in the fragile rocky terrain. The unfavorable hydro-geological circumstances in the fragile Himalayan ecosystem of lesser Himalaya also initiate landslides (Singh et al. 2017). Hence, it becomes very challenging for the responsible authorities to construct the infrastructure in such regions. On the other hand, the anthropogenic activities like construction of roads and the hydroelectricity projects, escalate the slippage of the slope surface in the various parts of Himalaya (Singh et al. 2010). The mitigation measures are very costly, and sometimes become ineffective because of huge change in the lithological features and the discontinuous orientations (i.e. a geological breaks such as joints, faults, bedding planes, foliation, and shear zones, that can potentially serve as failure planes) in the Himalayan region (Ghosh et al. 2014). In such situations, the slope stability investigations form an important component for evaluating the risk of slope failures and are thus, required to be routinely studied in order to have a check over the rapid rock mass slippage (Siddique et al. 2015; Sah et al. 2017). There are several techniques, i.e. kinematic analysis, limit equilibrium (LEM), numerical and empirical based approaches, for evaluating the slope stability. The kinematic analysis is commonly known for predicting the potential of various structural failure modes like planar, wedge, and toppling on the basis of two dimensional stereonet projections (Price and Cosgrove, 1990). The LEM can be used to determine the factor of safety of the slope, based on the mobilizing and resisting forces acting along the sliding plane (Coggan et al. 1998). The numerical modeling can be used to study the effect of shear stress distribution of any slope (Wyllie and Mah, 2004). Rock mass classification systems or empirical methods are the preliminary investigation steps for carrying out slope stability analysis and for suggesting the appropriate mitigation measures (Duran and Douglas, 2000). A number of rock mass classification methods are available, and its detailed information can be referred from Aksoy (2008) and Romana et al. (2015). The rock mass classification systems are widely adopted because of their simplicity and lesser use of the detailed inputs (Duran and Douglas, 2000). In the earlier stages, these systems were proposed for the underground excavations (Hoek, 2007). They were established on the basis of the important parameters to which the weights in the form of numerical value (rating) are to be assigned (Hack et al. 2003). These types of ratings are useful for designing the various underground engineering projects (Bieniawski, 1993). Although, these empirical systems were proposed for underground stability evaluation, however, some of these systems were also utilized for the surface excavations in case of road cut slopes by calibrating the required parameters (Pentelidis, 2009). The process of the characterization of the rock mass and conditions of discontinuities is essential for various empirical methods (Basahel and Mitri, 2017). This rock mass rating (RMR) classification method has been introduced and modified by Bieniawski (1973, 1974, 1975, 1976, and 1989). In order to improve the accuracy of rock stability assessment, Romana (1985) developed a slope mass rating (SMR) system for jointed rock mass, which was further modified by Anbalagan et al. (1992). These modified SMR and RMR systems were widely adopted by various researchers worldwide (Luay et al. 2014; Umrao et al. 2011; Kumar et al. 2017; Basahel and Mitri 2017).

The present study has been carried out using RMR and the modified

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SMR approaches, as these methods are simple, time saving and have high economic viability (Harrison and Hudson, 2000). In the present study, Chamba to Bharmour stretch along Chakki (Pathankot District, Punjab) - Bharmour (Chamba District, Himachal Pradesh) NH-154A has been selected to evaluate hazardous conditions of high rock cut slopes. This route is of strategic importance. This road leads to Bharmour – the base town for world famous annual Manimahesh lake Yatra route and also connects with many other temples in the area. Because of its significance, this section has been selected for evaluation of hazardous conditions of the high cut rock slopes. The potentially unstable slopes observed during ground investigations were selected for the detailed kinematic analysis. It is expected that the outcomes, of the rock mass classification systems and the kinematic analysis adopted, will be helpful in mitigating the unstable rock slopes in the study area.

STUDY AREA

For the identification and characterization of the conditions of the terrain, field investigations were conducted in the parts of Chamba Himalayas along National Highway-154A from Chamba to Bharmour stretch in Himachal Pradesh, India. The selected corridor of NH - 154A starts from Chamba (32°33'12.24"N, 76°7'32.88"E) and ends at Bharmour city (32°26'34.08"N, 76°31'58.44") as shown in Fig.1b. The study area falls in Survey of India 1:50,000 Scale Toposheet Nos. 52 D/2, 52 D/3, 52 D/6, 52 D/7, 52 D/10, and 52 D/11. The major river along NH-154A is the river Ravi which is a major tributary of the Trans-Himalayan Indus river. Ravi river flows through Bara Bhangal, Bara Bansu and Chamba in Himachal Pradesh then it enters in the Punjab state. The river Ravi coming from the Kangra district, HP starts flowing along NH-154A at Khara Mukh junction where a tributary of Ravi (*Budhil Nala*) coming from Bharmour side joins with Ravi.

The area is surrounded by the Zanksar hills in the north and the Dhauladhar range in the south of the Chamba valley. The trend of the valley is in a northwest-southeast direction (Wadia, 1931) while the deformation activities mostly occur in the southern direction (Kumar and Mahajan, 2001). The lesser Himalaya lies between the main boundary (MBT) and main central thrusts (MCT) present in the region

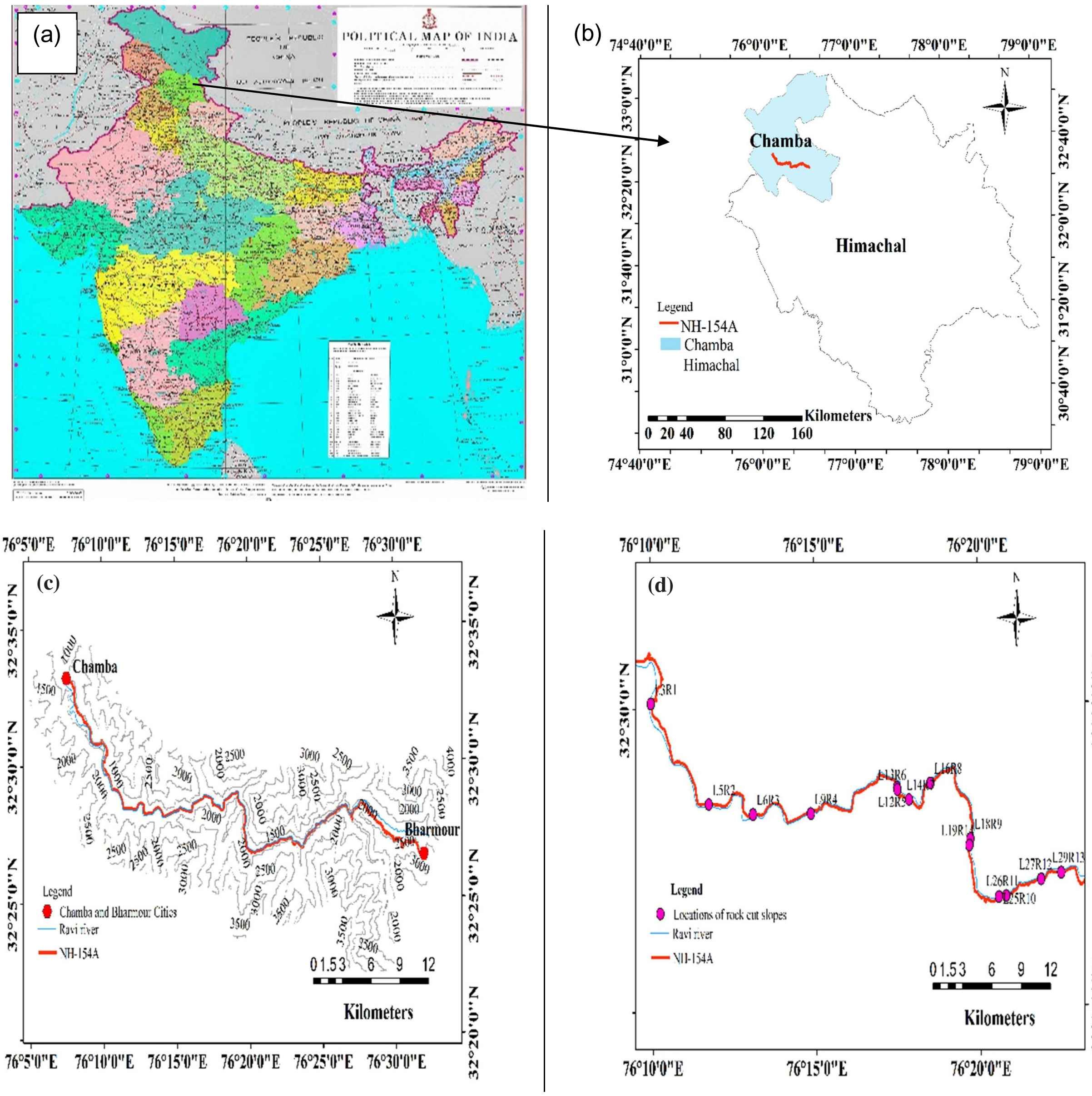


Fig.1. The location map of the study area. **(a)** Location of Himachal Pradesh state in India. **(b)** Location of Chamba district in Himachal Pradesh. **(c)** Contour map along Chamba-Bharmour section of NH-154A. **(d)** Location of selected rock cut slopes along Chamba-Bharmour section of NH-154A

(Deeken et al. 2011). The structurally controlled features in the Chamba region are represented by several kilometers long anticlines and synclines (Frank et al. 1995). The geological map and lineaments of the study area were delineated from the ground water prospects maps published by (NRSA) Government of India at scale 1:50,000 are shown in Fig 2a, 2b, and 2c.

METHODOLOGY

The rock mass assessment of cut slopes includes both quantitative as well as qualitative assessment of litho-units belonging to various geological formations (Fig. 2b and 2c). A number of conventional methods have been used to determine the rock slope stability as mentioned above. In the present investigation, the cut slope stability assessment was carried out by way of using rock mass rating (RMR) and modified Slope Mass Rating (SMR) including kinematic analysis of discontinuities/ joints involved in the failure.

Rock Mass Rating Classification

The rock mass rating, also known as geo-mechanics classification system is an empirical approach based on the detailed field and laboratory investigations. Bieniawski (1979) recommended five parameters namely unconfined compressive strength (UCS) of intact rock, rock quality designation (RQD) index, spacing of discontinuity, condition of discontinuity, and ground water conditions, based on which RMR, also known as RMR basic is determined. This system is easy to use and also applicable in the fields involving slopes, tunnels, mines and foundations etc.

Modified Slope Mass Rating (SMR)

Romana (1985) extended the basic RMR by proposing adjustment rating for joints and proposed a lump-rating classification system for the rock slopes following fundamental equation for planar, wedge, and topple failures to find SMR values. The SMR score can be determined by adding the factor values depending upon the joint slope relationship and method of excavation.

$$SMR = RMR + (F_1 \times F_2 \times F_3) + F_4 \quad (1)$$

Here F_1, F_2, F_3 and F_4 are the adjustment factors related to joint orientation with respect to the slope orientation and F_4 is an adjustment factor depending on the method of excavation. The values of the adjustment factors for different joint orientations can be calculated as suggested by Romana (1985) in the case of planar and topple failure and the same methodology was further implemented for the case of wedge failure by Anbalagan et al. (1992). SMR value for the different failure modes represents class of SMR and its description

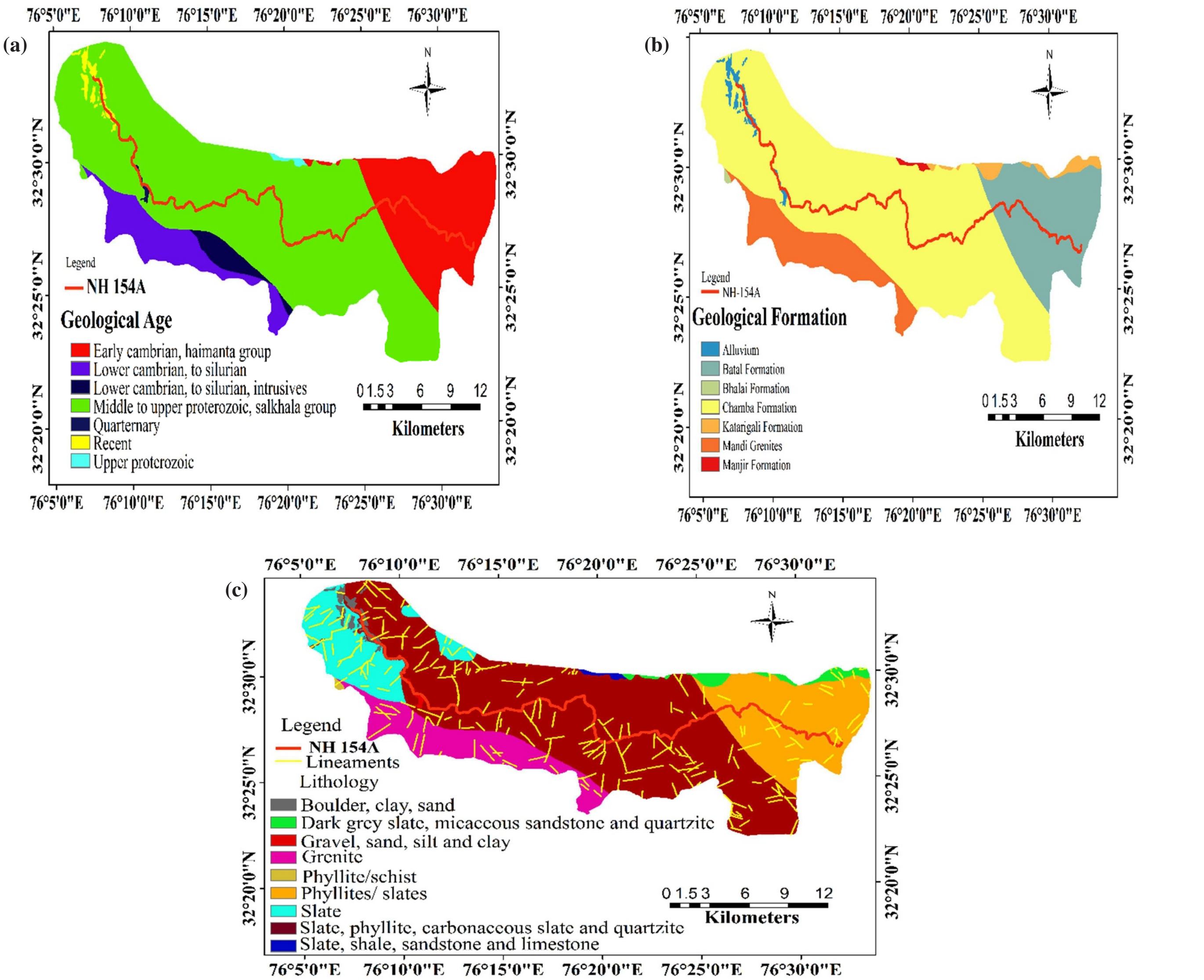


Fig. 2. Thematic maps showing **(a)** Geological age, **(b)** Geological Formation and **(c)** Lineaments of the study area overlaid on the lithology map.

from which, grade of stability of rock mass can be calculated and accordingly mitigation measures can be suggested. The recommendations of the SMR system gives the first estimation during the initial steps of a project construction (Romana et al., 2015).

Kinematic Analysis

The possible direction of failure in case of a jointed rock mass can also be geometrically examined by kinematic analysis. The angular relationship of the various discontinuities with the surface of the slope has been used to measure the stability potential of the rock mass based on the Markland's test as it is suggested for planar and wedge failure as given in Hoek and Bray (1981). The angle of internal friction, ϕ, has been taken as mentioned by Bieniawski (1979, 1993).

RESULTS

The discrete potentially unstable slopes along Chamba-Bharmour section of NH-154A, found to be highly vulnerable because of the structurally controlled possible modes of failure as shown in Fig. 1d and 3. The intensely jointed rock mass having 2-3 set of joints were found at the selected locations, along Chamba-Bharmour section of NH-154A.

The geotechnical parameters related to the rock mass classification system were determined for the analysis. The database, related to the orientation of the discontinuities, was prepared during the field survey, thereafter, the rock mass classification was performed using RMR and modified SMR systems. From the Table 1, it can be noted that the RMR values range from 55 to 78. Based on these RMR values, the rock mass stability grades have been determined. It can be noted that the locations L16R8, L25R10, L26R11, L27R14, and L29R13 belong to fair rock slope (class III), whereas the remaining rock slopes are of good rock (class II) category.

In order to reduce the subjectivity in the rock slope stability evaluation obtained from RMR system, due to the absence of the orientation of discontinuity parameters namely dip, strike, slope inclination, and azimuth, the modified SMR method was then applied in the present study. The modified SMR method is the revision of the RMR system in which some of the factorial adjustment factors were added (F_1, F_2, F_3 and F_4). The structural failure modes like planar, wedge, and toppling are controlled by the orientation of the discontinuities at the rock surface. The highly fragile terrain conditions because of the heavily jointed rock masses were examined in the study area. Hence, the database related to the orientation of discontinuities was developed during detailed field survey. The orientations of the discontinuities and slopes have been recorded with the help of Brunton compass as given in Table 2. The stereographic projections were prepared using data collected related to the orientations of discontinuities to give ratings to the adjustment factors (F_1, F_2, F_3 and

Table 1. Results of the RMR system for examined road cut slopes

Location No.	Rock Type	UCS	RQD	S	Condition of Discontinuity					GW	RMR	Class
					P	s	R	I	W			
L3R1	Quartzite	12	20	8	4	0.66	6	6	6	15	77	Good rock
L5R2	Quartzite	12	17	10	4	0	5	6	5	15	74	Good rock
L6R3	Quartzite	12	20	10	3.5	1	5	6	6	15	78	Good rock
L9R4	Quartzite	12	17	8	4	0	5	2	5	15	68	Good rock
L12R5	Slate	12	17	10	4	0	5	6	5	15	74	Good rock
L13R6	Slate	12	13	10	4	0	5	6	5	15	70	Good rock
L14R7	Slate	12	17	8	4	0	5	6	1	15	68	Good rock
L16R8	Slate	12	17	10	4	0	1	2	1	10	57	Fair rock
L18R9	Slate	12	13	8	4	6	5	6	5	15	73	Good rock
L19R14	Slate	12	8	8	4	0	6	6	8	15	64	Good rock
L25R10	Slate	12	17	8	4	1	1	2	3	10	58	Fair rock
L26R11	Slate	12	8	8	4	0	3	6	5	10	56	Fair rock
L27R12	Slate	12	8	8	4	0	5	6	5	10	58	Fair rock
L29R13	Slate	12	13	10	4	0	1	2	3	10	55	Fair rock

Table 2. Attitude of discontinuities at different locations and probable failure pattern

Location No.	Slope orientation (Dip amount° / Dip direction°)	Orientations of Discontinuities/Joints (Dip amount° - Dip direction°)				ϕ	Type of Failure
		*J*1	*J*2	*J*3	*F*		
L3R1	85º/N280º	50º/ N 270º	42º/N130º	-	52º/N45º	35º	Planar (*J*1)
L5R2	85°/N180°	85°/N30°	25°/N20°		70°/N100°	45º	-
L6R3	85°/N180°	30°/N160°	30°/N25°	65°/N135°	65°/N60°	40°	-
L9R4	80°/N170°	27°/N195°	75°/N140°	-	60°/N65°	45º	-
L12R5	75°/N90°	45°/N190°	85°/N260°	-	55°/N20°	40°	-
L13R6	55°/N40°	80°/N270°	75°/N190°	-	35°/N25°E	40°	-
L14R7	60°/N320°	76°/N290°	60°/N210°	-	20°/N340°	40°	-
L16R8	75°/N	30°/N160°	70°/N280°	-	50°/N5°	35°	Planar (*F*) Wedge (*F* and *J*2)
L18R9	85°/N120°	20°/N130°	35°/N200°	-	55°/N53°	40°	-
L19R14	85°/N280°	60°/N260°	40°/N80°		45°/N35°	35°	Planar (*J*1)
L25R10	75°/ N350°	70°/ N290°	65°/N180°	-	50°/ N35°	40°	Wedge (*F* and *J*1)
L26R11	85°/N355°	46°/ N275°	50°/ N210°	-	72°/ N55°	24°	Wedge (*F* and *J*1)
L27R12	80°/N5°	60°/N25°	71°/N275°	-	40°/N10°	35°	Planar (*F*) Planar (*J*1) Wedge (*F* and *J*2)
L29R13	60°/N30°	70°/N220°	56°/N315°	-	45°/N40°	30°	Planar (*F*) Wedge (*F* and *J*2)

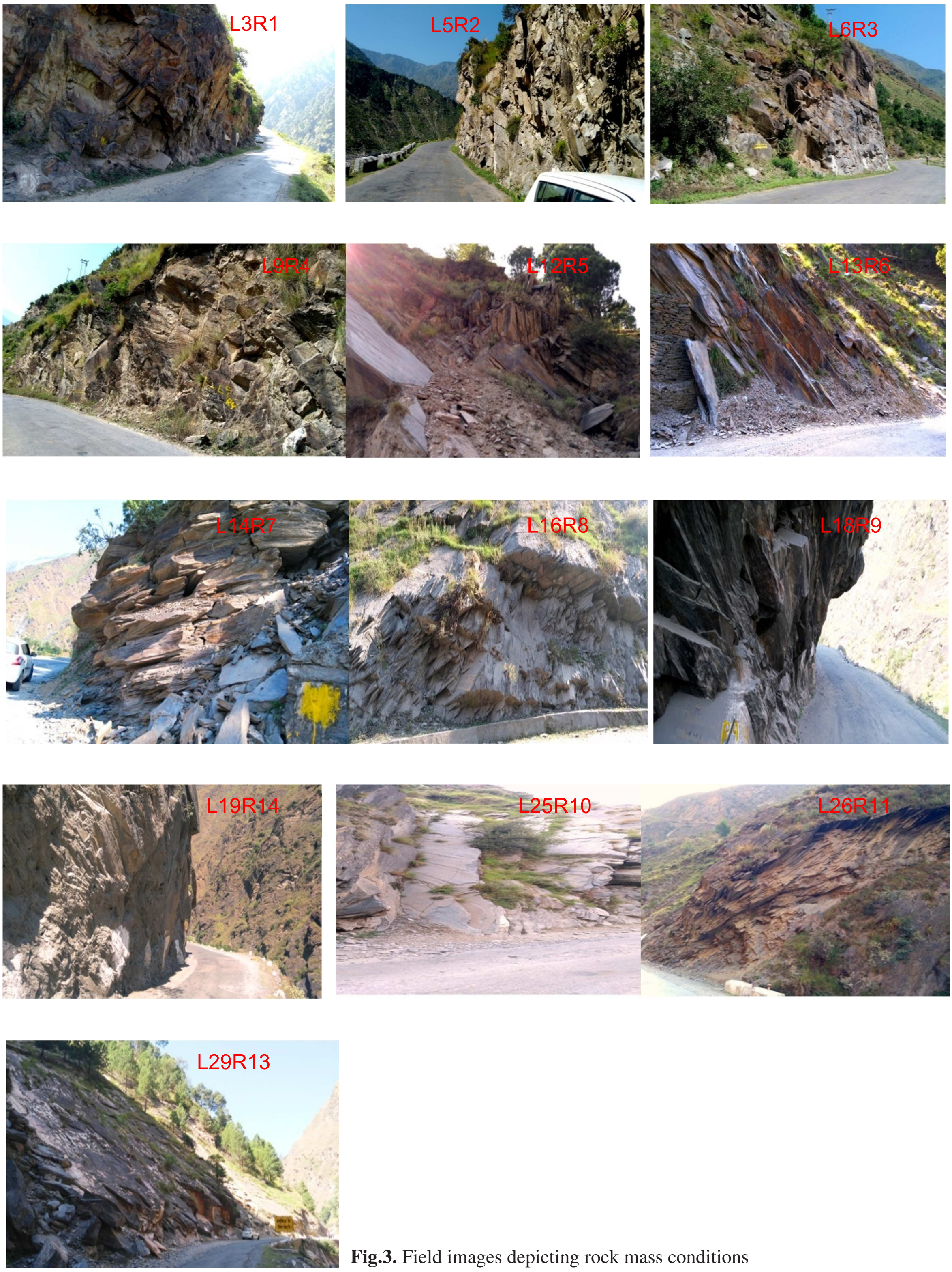


Fig.3. Field images depicting rock mass conditions

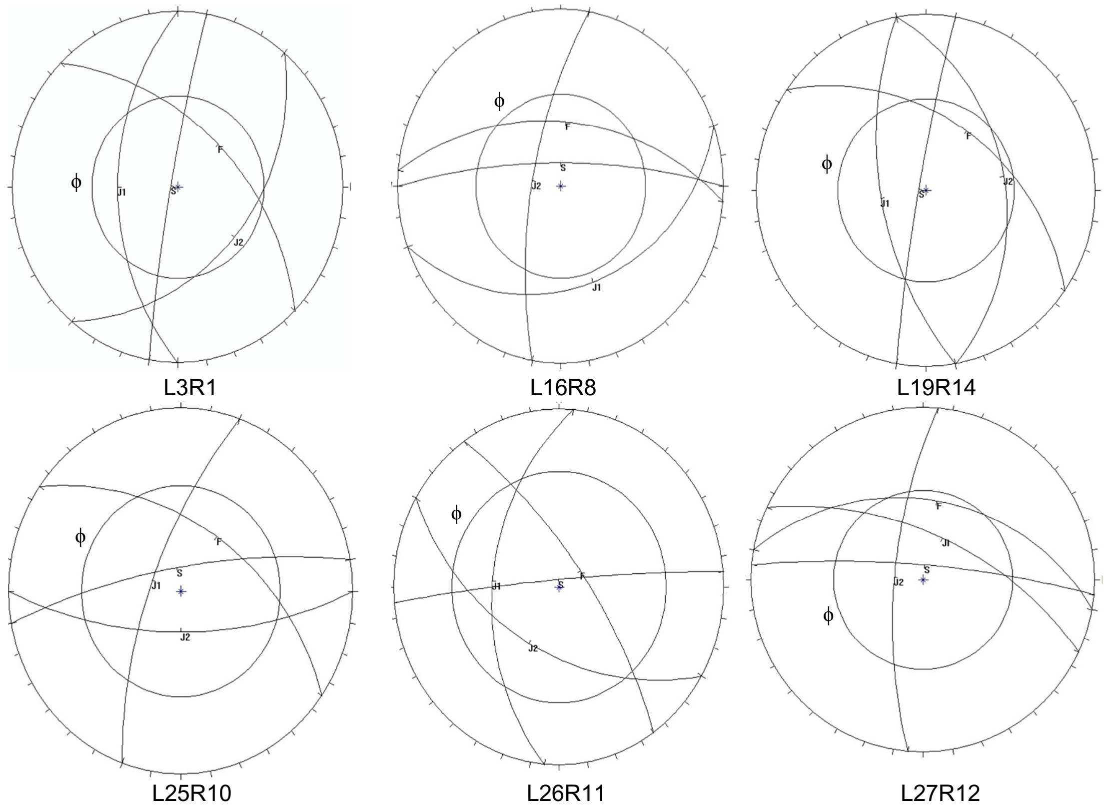
F_4). The stereoplots of the rock cut slopes where failure has been identified are shown in Fig.4.

The values of these adjustment factors for different joint orientation are given in Table 3. The different possible modes of the slope failures (planar and wedge) were identified with the help of the kinematic analysis. It has been noted in the field that most of the investigated rock slopes are affected by the deficient blasting. For the determination of the grade of stability of each road cut slope under investigation, the total slope mass rating values have been calculated as given in Table 3.

In Table 3, J_1, J_2 and J_3 denotes the joint set number 1, 2 and 3, respectively, 'NF' denotes no unstable zone (stable slope) and F denotes foliation. The SMR value has been found to be range from 6-38. Based on these SMR values, the analyzed slopes have been classified into unstable and completely unstable class as per slope mass rating classes.

CONCLUSION

The rock mass classification system used in the present study i.e. RMR basic gives information about various parameters of rock mass



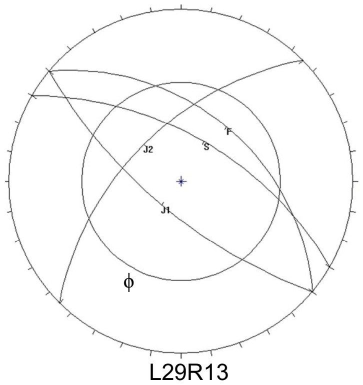


Fig. 4. Kinematic analysis illustrating mutual geometrical relationship between slope face and discontinuities at selected locations in study area

Table 3. Results of the SMR system for examined road cut slope

Location No.	Rock Type	RMR	Type of failure	F_1	F_2	F_3	F_4	SMR	Class	Grade of stability
L3R1	Quartzite	77	Planar (*J*1)	0.70	1	-60	-8	27	IV	Unstable
L5R2	Quartzite	74	NF	NF	NF	NF	NF	NF	NF	Stable slope
L6R3	Quartzite	78	NF	NF	NF	NF	NF	NF	NF	Stable slope
L9R4	Quartzite	71	NF	NF	NF	NF	NF	NF	NF	Stable slope
L12R5	Slate	74	NF	NF	NF	NF	NF	NF	NF	Stable slope
L13R6	Slate	70	NF	NF	NF	NF	NF	NF	NF	Stable slope
L14R7	Slate	68	NF	NF	NF	NF	NF	NF	NF	Stable slope
L16R8	Slate	57	Planar	0.85	1	-60	0	6	V	Completely Unstable
			Wedge (*F* and *J*2)	0.70	1.0	-60	0	15	V	Completely Unstable
L18R9	Slate	73	NF	NF	NF	NF	NF	NF	NF	Stable slope
L19R14	Slate	64	Planar (*J*2)	0.40	1	-60	-8	32	IV	Unstable
L25R10	Slate	58	Wedge (*F* and *J*1)	0.85	0.85	-60	0	31	IV	Unstable
L26R11	Slate	56	Wedge (*F* and *J*1)	0.40	0.40	-60	-8	38	IV	Unstable
L27R12	Slate	58	Planar (*F*)	0.85	0.85	-60	0	15	V	Completely Unstable
			Planar (*J*1)	0.40	1.0	-60	0	34	IV	Unstable
			Wedge (*F* and *J*2)	0.70	0.85	-60	0	22	IV	Unstable
L29R13	Slate	55	Planar (*F*)	0.70	0.85	-60	0	19	V	Completely Unstable
			Wedge (*F* and *J*2)	0.40	0.85	-60	0	35	IV	Unstable

which finally empirically calculated to arrive at RMR basic value of rock mass to have a preliminary assessment of quality of rock mass. RMR basic gives preliminary information about the rock mass during the preliminary stage of slope stability assessment. The road cut slopes along 62km long National Highway -154A corridor from Chamba to Bharmour in the state of Himachal Pradesh (India) were chosen for the present study because of the highly fragile nature of the rocks in this area. The major cause of landslides along Chamba-Bharmour section, are Litho-structural control, condition of rock mass and tectonics, followed monsoon rainfall and other anthropogenic activities like road widening etc. The tourists, pilgrims, and local people suffer many problems like road blockage and traffic jams because of the landslide activities every year. The rock mass classification systems applied on the selected potentially unstable rock slopes in the present study are RMR and modified slope mass rating.

It is observed that, based on RMR, the locations L16R8, L25R10, L26R11, L27R14, and L29R13 belong to fair rock slope (class III), whereas the remaining rock slopes are of good (class II) category. The different possible modes of the slope failures (planar and wedge) have been identified with the help of the kinematic analysis showing that seven sites L5R2, L6R3, L9R4, L12R5, L13R6, L14R7, and L18R9 are free from any type of failure and hence stable. Nevertheless, out of the remaining seven unstable slopes, two were having a planar failure (L3R1 and L19R14), two having wedge failure (L25R10 and L26R11) while remaining three were having both planar and wedge failures (L16R8, L27R12, and L29R13). The modified SMR method has been applied on the seven sites L3R1, L19R14, L25R10, L26R11, L16R8, L27R12, and L29R13 where failures were identified during kinematic analysis. The SMR value was found to be ranging from 6-38 which categorized the analyzed slopes into a unstable and completely unstable class. It has been noted that the planar failures at sites (L3R1, L19R14, and L27R12) were unstable and fall in SMR class IV. The location L27R12 has another planar failure which is completely unstable and fall in SMR class V. The remaining planar failures at sites (L16R8 and L29R13) are also completely unstable and fall in SMR class V. The wedge failures at sites (L25R10, L26R11, L27R12, and L29R13) were of unstable SMR class IV, and the remaining wedge failure at site (L16R8) was of completely unstable SMR class V. The assessment of the grade of stability carried during the current study is in good agreement with the current field conditions. Such kind of the rapid rock mass stability assessment should be made to maintain and construct the new roads in case of the potentially unstable zones of Himalayas. Mitigation measures to these unstable slopes can be suggested and applied accordingly. Overall this study will help the engineers, designers, and various other stake holders to get relief from this landslides triggering hazardous threat.

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