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Slope mass rating and kinematic analysis of slopes along the national highway-58 near Jonk, Rishikesh, India

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ABSTRACT

The road network in the Himalayan terrain, connecting remote areas either in the valleys or on the hill slopes, plays a pivotal role in socio-economic development of India. The planning, development and even maintenance of road and rail networks in such precarious terrains are always a challenging task because of complexities posed by topography, geological structures, varied lithology and neotectonics. Increasing population and construction of roads have led to destabilisation of slopes, thus leading to mass wasting and movement, further aggravation due to recent events of cloud bursts and unprecedented flash floods. Vulnerability analysis of slopes is an important component for the "Landslide Hazard Assessment" and "Slope Mass Characterisation" guide planners to predict and choose suitable ways for construction of roads and other engineering structures. The problem of landslides along the national highway-58 (NH-58) from Rishikesh to Devprayag is a common scene. The slopes along the NH-58 between Jonk and Rishikesh were investigated, which experienced very heavy traffic especially from March to August due to pilgrimage to Kedarnath shrine. On the basis of slope mass rating (SMR) investigation, the area falls in stable class, and landslide susceptibility score (LSS) values also indicate that the slopes under investigation fall in low to moderate vulnerability to landslide. More attentions should be paid to the slopes to achieve greater safe and economic benefits along the highway.

1. Introduction

Himalayan orogeny is the result of collision of Indian and Eurasian plates. This zone is extensively deformed, having major thrust faults as discontinuities, such as Himalayan Frontal Thrust (HFT), Main Boundary Fault (MBT) and Main Central Thrust (MCT). Landslide along the national highway-58 (NH-58) in the Himalayan terrain is a very common and frequent natural disaster, causing loss of life and property. Slopes along this highway failed many times at different locations and have become more vulnerable to sliding due to unplanned development, as witnessed during the Uttarakhand hazard. The hill slopes in Lesser Himalayas are well known for their instability due to the dynamic nature of slopes, geomorphology, snowfall, heavy and sustained rainfall, and ongoing neotectonic activity. Increasing anthropogenic activities in recent years appear to be an additional factor for instability of slopes in the Himalayan terrain. There are many major or minor landslides that happened at different places (Sati et al., 2011). Unplanned excavation and vibrations caused by blasting along the NH-58 near Badarinath and Rishikesh for construction and road widening project during last few years have enhanced the vulnerability of slopes to landslide. Stability studies of road cut slopes in Rudraprayag area have identified critical slopes at certain locations by numerical simulation with the factor of safety (FOS) less than 1 (Singh et al., 2008). For safer construction and reducing slope failure, proper investigations and slope characterisation are required. The analysis of slope characterisation depends upon many parameters and database related to slope, rock mass, meteorology, etc. (Pradhan et al., 2011, 2014; Trivedi et al., 2012). Stability studies were conducted for 50 road cut slopes using rock mass rating (RMR) and geological strength index (GSI) classification systems in the region of Garhwal Himalayas to identify the vulnerable slopes along the NH-58 (Sarkar et al., 2012a). Rishikesh has an average elevation of 372 m (1745 ft). According to the latest weather update by Skymet Meteorology Division in India, the temperature is around 20 °C–22 °C. According to the Koppen-Geiger climate classification system, Rishikesh lies in humid to sub-tropical area. Rainfall in Rishikesh

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varies significantly in different seasons; the maximum precipitation happens from July to September with the magnitude of approximately 490 mm, while the minimum precipitation up to 10 mm can be seen in April. Slope mass characterisation is necessary for geotechnical studies, which is based on different parameters of rock/rock mass, aiming to classify a terrain into different kinds of slope classes and also their vulnerability to landslide, so that corresponding support measures can be proposed. The quantification of all the intrinsic properties of rock mass and external factors acting on the slope can be used to illustrate the present condition of slopes and to predict their behaviours in future.

The NH-58 is the lifeline for the people living in the cities of Rishikesh, Devaprayag, Srinagar, Rudraprayag, Gochar, Chamoli and Joshimath. Several cases of obstructions due to landslides along the road were reported and created lots of difficulties to travellers and pilgrims. This investigation was carried out to identify the safe zones and the areas affected by the geo-hazards, their present situation and future vulnerability to landslides, and to characterise the rock mass along NH-58 near Laxman Jhula between Jonk and Rishikesh.

Geological investigations were conducted at the start of 2014, a period without rainfall. The values of rock mass parameters were recorded for slope stability analysis by RMR proposed by Bieniawski (1979), slope mass rating (SMR) geomechanics classification by Romana et al. (2003) and landslide susceptibility score (LSS) by Central Building Research Institute (CBRI), Roorkee. Such methods for slope stability analysis have been applied for understanding the stability and probability of failure for natural and engineered slopes (Singh et al., 2010, 2013; Gupte et al., 2013; Vishal et al., 2010, 2015).

The present study incorporates the assessment of slopes along the NH-58 near Jonk, Rishikesh. Field investigations include data collection from five locations on the either side of the road. The characterisation of rock mass is also presented in this paper and corresponding support measures are proposed.

2. Investigation area

The area under investigation (Fig. 1) is a part of Lesser Himalayas, lying in between longitudes of 78°19′–78°21′ and latitudes of 30°8′–30°9′. The rock mass studied belongs to Krol A one which lies in doubly plunging synform (Valdiya, 2010) comprising of quartz-bearing argillaceous limestone of Mahi Formation of Neoproterozoic age (Jiang et al., 2002; Srivastava et al., 2011). Five locations can be identified as per latitudes and longitudes, as listed in Table 1.

Table 1
Different locations under investigation.

Location	Longitude	Latitude
D-1-1	E78°19′31.99″	N30°8′3.13″
D-1-2	E78°19′50.6″	N30° 8′5.82″
D-2-1	E78°20′6.65″	N30° 8′5.42″
D-2-2	E78°20′3.24″	N30°8′4.22″
D-2-3	E78°19′57.89″	N30° 8′1.89″

3. Method of study

The assessment of rock mass quality implies both qualitative and quantitative assessment of various components of the rock mass. This study focuses on the rock mass characterisation by RMR, SMR and LSS.

RMR is based on detailed field and laboratory techniques which include the collection of field data related to discontinuities in terms of spacing, orientation with respect to slope, conditions of joints, groundwater and unconfined strength of rock material measured in laboratory according to Indian Standard Code 11315 (1987). SMR identifies different classes of slopes and their vulnerability to instability and is based on RMR system and adjustment factors related to strike and dip of discontinuities with respect to slope parameters. SMR was proposed by Romana (1985) and later updated in 2003 which was obtained by subtracting "adjustment factors" (F_1, F_2 and F_3) from RMR_B, depending upon slope and discontinuity relationship from RMR value and by adding a factor depending upon the nature of slope (F_4):

$$SMR = RMR_B + F_1F_2F_3 + F_4$$

LSS given by CBRI, Roorkee is based upon angle of slope, hydrology, overburden thickness, joint fractures, weathering, lithology, type of rock mass and vegetation density. According to the value of LSS, rock mass is categorised, and greater LSS values lead to higher susceptibility to slope instability. If the value of LSS is greater than 300, slope is highly susceptible to failure; LSS value of 200–300 means slope is moderately stable; and if LSS value is less than 200, slope is stable.

Field investigations have been carried out at five locations to study the natural slope stability and rock mass parameters.

Fig. 1. Satellite imagery of 2013 showing investigation area. Five locations are marked with green symbols.

Determination of laboratory parameters is a key to these types of researches (Vishal et al., 2011, 2012; Sarkar et al., 2012b). Laboratory experiments were also conducted to determine the strength of the samples by Schmidt hammer test according to Brencich et al. (2013) and unconfined compression test. Correlation chart for Schmidt hammer rebound values, rock density, compressive strength and rebound number on smooth surfaces was used to estimate unconfined compressive strength (UCS) (Miller, 1965). However, Schmidt values are not reliable because they are only used to correlate with the data obtained from UCS (Bell, 2005). Weathering conditions were also determined from slake durability index test to work out “weathering index” given by Goodman (1989).

Rock quality designation (RQD, %) was calculated by field survey using mean discontinuity spacing (Singh and Goel, 1999). Kinematic analysis was performed to illustrate the potential for various modes of rock slope failures (plane, wedge, toppling failures) that occur due to the presence of unfavourably oriented discontinuities (Hoek, 2007). The analysis was based on Markland’s test as described by Hoek and Bray (1981). According to the Markland’s test, a planar failure is likely to occur when a discontinuity dips in the same direction (within 20°) as the slope face, at an angle less than the slope angle but greater than the friction angle along the failure plane. A wedge failure may occur when the line of intersection of two discontinuities forming the wedge-shaped block plunges in the same direction as the slope face and the plunge angle is less than the slope angle but greater than the friction angle along the failure plane. A toppling failure may happen when a steeply dipping discontinuity is parallel to the slope face (within 30°) and dips into it (Yoon et al., 2002).

4. Results and discussion

Field data recorded in Table 2 were taken from five locations along the NH-58, consisting of two sets of joints in Krol A limestone (Fig. 2). Orientations of bedding and joints were recorded from the field measurements for 2–3 times, and the average values of orientation, persistence, aperture, filling, roughness and water conditions from each location are listed in Table 2. UCS of 25 samples was determined for five locations by plate load test and the results were crosschecked with the correlation chart (Miller, 1965). Average values from plate load test were taken into consideration during the rock mass characterisation reported in Table 3.

Degree of weathering plays a significant role in slope stability. Slake durability test was performed to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting. For rock containing clay minerals, exchange of ions takes place due to adsorption and absorption of water which swells the rock. The slake durability test was performed based on the standards given by Goodman (1989) for weathering, and the percentage obtained after the 1st and 2nd cycles indicates that the area under investigation falls in moderate to high durability for weathering.

Table 2
Field data obtained from five locations near Rishikesh.

Location D-1-1: near the Laxman Jhula, Rishikesh							
Outcrop at D-1-1			Slope: N20°/35°SE, 13–14 m in height				
Type	Strike (°)	Dip/Direction	Persistence (m)	Aperture (mm)	Filling	Roughness	Water condition
Joint J_1	150	26°/SW	7.7–6	2	Quartz	Smooth	Dry
Joint J_2	150	70°/NE	4.5–6.3	1.5	Quartz	Smooth	Dry
Bedding	130	65°/NE	–	–	–	–	Dry
Location D-1-2: near the Laxman Jhula, Rishikesh							
Outcrop at D-1-2			Slope: N10°/25°SE, 15–16 m in height				
Type	Strike (°)	Dip/Direction	Persistence (m)	Aperture (mm)	Filling	Roughness	Water condition
Joint J_1	139	68°/NE	5–6	2	Quartz	Smooth	Dry
Joint J_2	30	80°/SE	6–6.5	1.5–2	Quartz	Smooth	Dry
Bedding	132	72°/NE	–	2.5	–	–	Dry
Location D-2-1: between the NH-58 and the Gangas at Jonk							
Outcrop at D-2-1			Slope: 40°/15°SE, 9–10 m in height				
Type	Strike (°)	Dip/Direction	Persistence (m)	Aperture (mm)	Filling	Roughness	Water condition
Joint J_1	40	67°/NW	10	2–1	Quartz	Smooth	Dry
Joint J_2	142	69°/NE	14	1	Quartz	Smooth	Dry
Bedding	140	56°/NE	–	–	–	–	Dry
Location D-2-2: between the NH-58 and the Gangas at Jonk							
Outcrop at D-2-2			Slope: N40°/20°SE, 8–10 m in height				
Type	Strike (°)	Dip/Direction	Persistence (m)	Aperture (mm)	Filling	Roughness	Water condition
Joint J_1	140	78°/SW	10–14	2.5–3	Quartz	Smooth	Dry
Joint J_2	30	73°/NE	15–20	2	Quartz	Smooth	Dry
Bedding	142	65°/NE	–	–	–	Smooth	Dry
Location D-2-3: near the Laxman Jhula, Rishikesh							
Outcrop at D-2-3			Slope: N35°/20°SE, 10–12 m in height				
Type	Strike (°)	Dip/Direction	Persistence (m)	Aperture (mm)	Filling	Roughness	Water condition
Joint J_1	146	71°/SW	9–13	2–3	Quartz	Smooth	Dry
Joint J_2	5	65°/SE	11–12	1–1.5	Quartz	Smooth	Dry
Bedding	142	65°/NE	–	–	–	Smooth	Dry

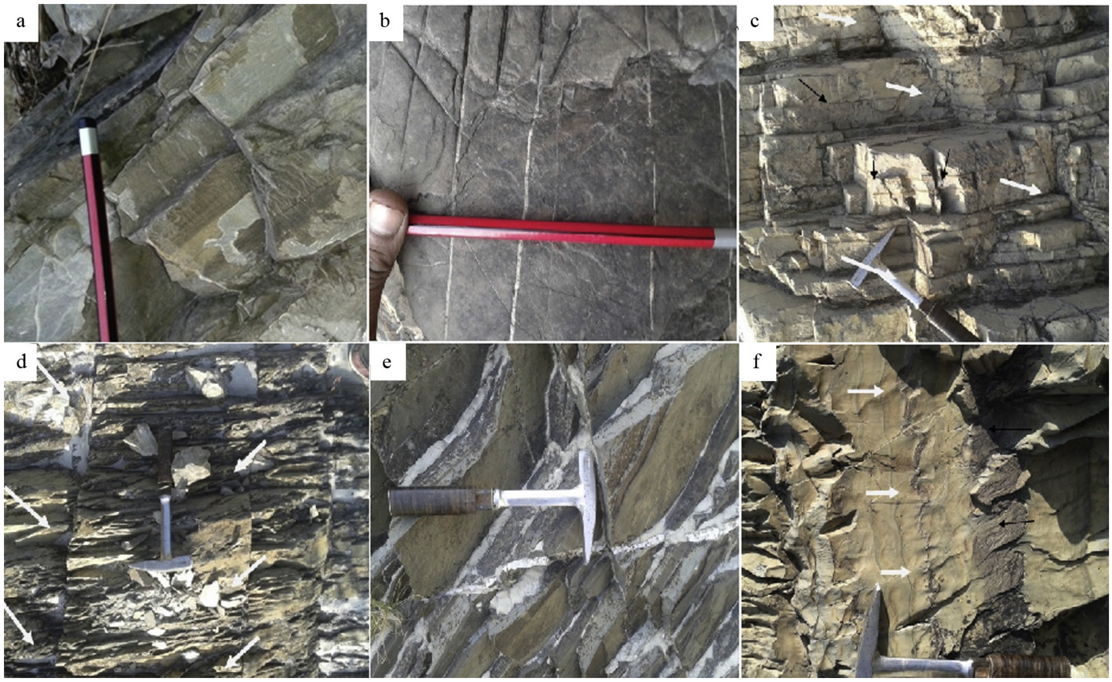

Fig. 2. Field photographs: (a) Bedding in Krol limestone as discontinuities along the NH-58 near the Laxman Jhula, Rishikesh; (b) Discontinuities filled by secondary material in Krol limestone along the NH-58 near the Laxman Jhula, Rishikesh; (c) Two sets of discontinuities with horizontal and vertical bedding planes in Krol limestone, respectively, near Jonk between the NH-58 and the Gangas, Rishikesh; (d) Joints in plan view in Krol limestone between the NH-58 near Jonk and the Gangas, Rishikesh; (e) Heavily healed joints filled with crystallised calcite in Krol limestone near Jonk; and (f) Solution structure in Krol limestone showing stylolitic joints and plumose markings near Jonk.

Table 3
UCS values for each location by direct and indirect methods.

Location	Schmidt value	Average Schmidt value	Estimated UCS from graph (MPa)	Average UCS calculated from plate load test (MPa)
D-1-1	28, 26, 30, 22	26.5	55	46
D-1-2	34, 38, 38, 36, 32, 36, 38, 38	36.25	75	41
D-2-1	46, 42, 36, 40, 44, 50, 48, 38, 42	42.8	82	47
D-2-2	28, 22, 26, 26, 20	24.4	53	39
D-2-3	20, 28, 22	23.3	52	43

Table 4
Slake durability indexes for estimating the degree of weathering of samples.

Type of sample	Initial dry weight (A) (g)	Dry weight after the 1st cycle (B) (g)	Dry weight after the 2nd cycle (C) (g)	Retained ratio after the 1st cycle ($100B/A$) (%)	Retained ratio after the 2nd cycle ($100C/B$) (%)
Chips	54	52	51	96.29	98.07
Rectangular pieces	106	102	100	96.22	98.03

Chips and small rectangular blocks were taken to conduct the slake durability test. Instead of limestone lithology, weathering condition of rock is good as the limestone at the site is quartz-bearing and micritic in nature. Due to the micritic nature, modal analysis during microscopic studies was impossible. The results obtained from slake durability tests (Table 4) indicate that Krol A limestone is resistant to weathering due to its quartz-bearing nature. Photomicrograph was used to confirm lithology, i.e. fine-grained micritic limestone with fine-grained quartz and argillaceous matter (Fig. 3). Thin section studies also confirmed the composition of veins seen on the outcrop across the vein in the intact rock where the thin section sample was chipped.

LSS is a national classification system which was developed by CBRI, Roorkee. This classification scheme was conducted to correlate the slope grade obtained by SMR. LSS takes overburden, weathering and vegetation density into account to determine slope stability. To analyse the study area in a broad sense and cover more parameters affecting slope stability, LSS was used. Detailed field investigation was performed to calculate LSS values for each location to assign weight to various factors of rock mass reported in Table 5. LSS value for each location ranges from 193 to 246 which categorises the rock mass into moderate vulnerability to landslide. The LSS results show a good correlation with the SMR data.

To assign the weight to different factors of rock mass, careful and detailed field investigation was conducted to calculate the LSS value for each location. The average value of LSS is 134. Therefore, the rock mass under investigation has “low susceptibility” to landslide.

Fig. 3. Photomicrograph under X-Nicol showing fine-grained quartz-bearing micritic limestone having vein of calcite in Krol A limestone near Rishikesh.

Table 5
LSS values of rock mass along the NH-58 near Jonk, Rishikesh.

Factor	Rank × weight				
	D-1-1	D-1-2	D-2-1	D-2-2	D-2-3
Slope	8 × 7	8 × 5	8 × 2	8 × 5	8 × 5
Hydrology	9 × 1	9 × 1	9 × 1	9 × 1	9 × 1
Overburden thickness	7 × 6	7 × 9	7 × 9	7 × 6	7 × 6
Slope discontinuity relation	6 × 9	6 × 5	6 × 5	6 × 5	6 × 5
Joint fractures	5 × 9	5 × 4	5 × 4	5 × 4	5 × 4
Weathering	4 × 2	4 × 2	4 × 2	4 × 5	4 × 5
Lithology	8 × 2	8 × 2	8 × 2	8 × 2	8 × 2
Rock mass	3 × 3	3 × 3	3 × 3	3 × 3	3 × 3
Vegetation density	7 × 1	7 × 1	7 × 1	7 × 1	7 × 1
LSS value = Σrank × weight	246	202	215	193	193

RMR_B was calculated within the guidelines of Bieniawski (1979) and the rating values of each parameter are given in Table 6. UCS obtained by unconfined plate load tests ranges from 39 MPa to 48 MPa. RQD values range from 82% to 95%, which were obtained by field survey using graph of mean discontinuity spacing and density as the core samples were not available. Ratings were given according to the average values of mean discontinuity spacing (mm), roughness, separation, continuity and groundwater condition of joints.

RMR_B was calculated on the basis of various rock mass parameters which was further used in the calculation of SMR for all five locations. Average value of RMR_B was taken for location D-2-2 as two RMR_B values were given due to small variation at the location. F_1, F_2 and F_3 were calculated on the basis of relative orientation of joints with respect to slope. The value of F_4 is equal to 15 as the rock mass under investigation in natural slopes, and no excavation was done earlier. Total value of SMR for both planar failure and toppling failure ranges from 66 to 70 as shown in Table 7. So, rock mass under investigation falls in class 2b according to SMR, which was in stable condition.

Kinematic analysis based on Markland's test was conducted using internal friction angle of rock, relative orientation of slopes and discontinuities which were measured for 2–3 times to identify any possible structurally controlled failure at locations under investigation. Kinematic analysis of slopes D-1-1, D-1-2, D-2-1, D-2-2 and D-2-3 (Fig. 4) reveals that structurally controlled failure will not occur in these slopes. Hence, these sites are safe for the construction of buildings with minor treatment.

5. Conclusions

The study was conducted to identify the safe zones and their vulnerability to sliding and present condition as the Himalayan region is very active. RQD values range from 82% to 95%, showing moderate to high durability to weathering according to slake durability index test. UCSs of intact rock range from 39 MPa to 47 MPa, indicating that the rock is moderately strong. RMR value ranges from 49 to 58 indicating that this rock mass lies in good quality. For the study region, SMR value varies from 66 to 70 indicating that the rock mass is in stable class; and some block failures may occur and require occasional support. These slopes can be supported using various techniques such as nets, spot bolting or

Table 6
RMR_B rating values of rock mass along the NH-58 (Bieniawski, 1979).

Location	UCS (MPa)	RQD (%)	Mean fracture spacing (mm)	Conditions of discontinuity	Groundwater conditions (L/min)	RMR_B value
D-1-1	4	20	10	2 + 1+1 + 4 + 5	10	54
	4	20	10	2 + 1+1 + 4 + 8	10	54
D-1-2	4	17	10	2 + 1+1 + 4 + 5	10	51
D-2-1	4	17	10	1 + 1+1 + 6 + 5	10	55
	4	17	10	1 + 4+1 + 6 + 5	10	55
D-2-2	4	20	15	1 + 1+1 + 4 + 5	15	58
	4	17	10	1 + 1+1 + 4 + 5	10	49
D-2-3	4	20	10	1 + 1+1 + 4 + 5	10	53

Table 7
SMR values along the NH-58 near Jonk, Rishikesh (Romana et al., 2003).

Location	Type of failure	RMR_B	F_1	F_2	F_3	F_4	SMR value
D-1-1	Planar	54	0.15	1.0	0	15	69
	Toppling	54	0.15	1.0	0	15	69
D-1-2	Planar	51	0.15	1.0	0	15	66
	Toppling	51	0.15	1.0	0	15	66
D-2-1	Planar	55	0.15	1.0	0	15	70
	Toppling	55	1.0	1.0	0	15	70
D-2-2	Planar	53	0.15	1.0	0	15	68
	Toppling	53	0.7	1.0	0	15	68
D-2-3	Planar	53	0.15	1.0	0	15	68
	Toppling	53	0.15	1.0	0	15	68

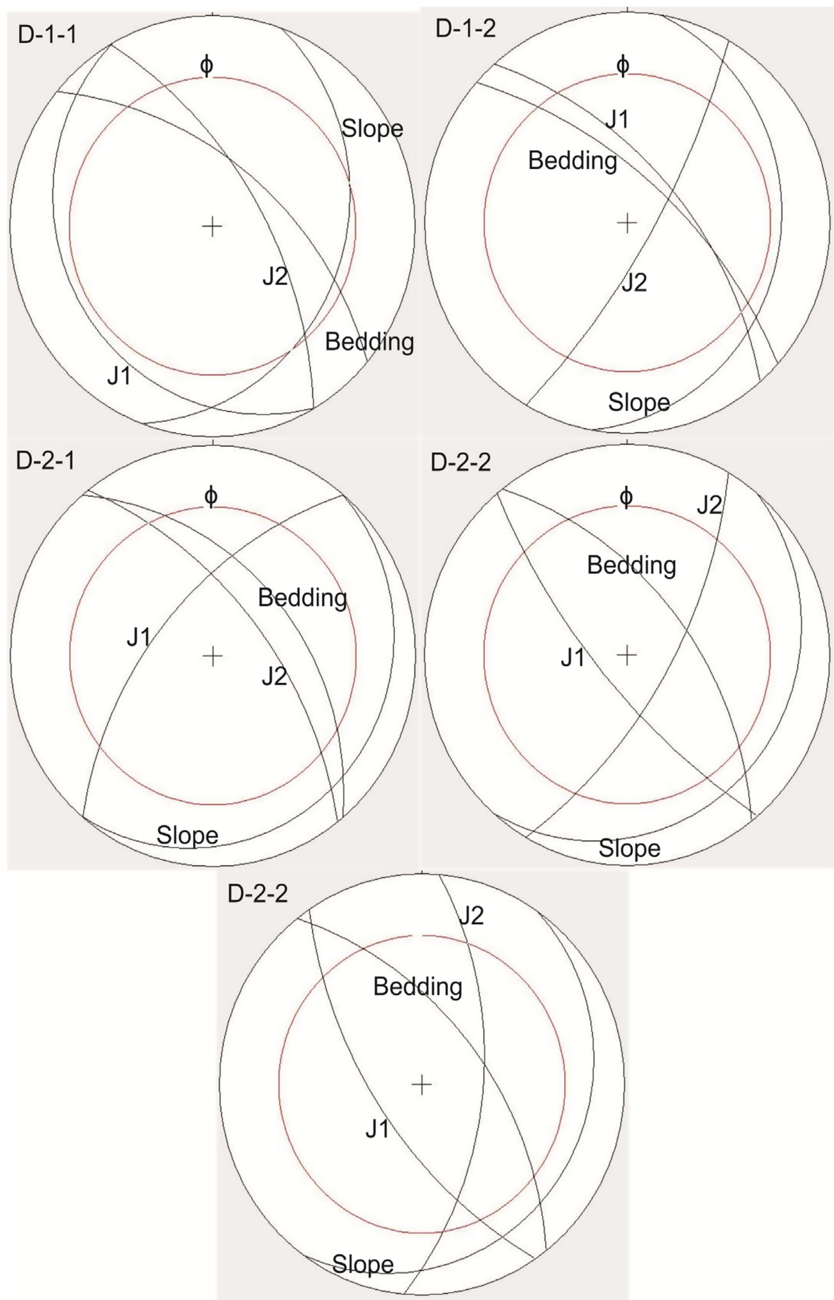

Fig. 4. Stereographic projection of five locations under investigation near Jonk, Rishikesh.

anchoring, and systematic shotcrete can also be implemented for supporting the slope. Toe wall can be constructed for extra safety depending upon the requirement of the project. LSS was calculated to crosscheck the results obtained from the SMR and to clarify the effects of certain parameters controlling slope stability which were not considered in SMR. According to LSS, the rock mass falls in the category of low to moderate vulnerability to landslide as LSS value ranges from 193 to 246. Kinematic analysis of slopes at different locations under study indicates that slopes are stable and no failure is observed. Therefore, during the whole field and laboratory investigations, the rock mass along the NH-58 near Jonk, Rishikesh, falls in partly stable condition and suitable reinforcement can prevent the slope from mass wasting processes.

Conflict of interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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