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Geotechnical Stability Assessment of Road-cut Slopes: A Case Study of Srinagar, Garhwal Himalaya, India

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ABSTRACT: The reason for the occurrence of landslides along the cut slopes of road corridors in the Himalayas is the repeated movement along thrust planes, which weakens rock slopes and makes them susceptible to stress and failure. Consequently, landslides are a prevalent phenomenon in this region. Slope stability along mountain roads is a major concern, as slope failures can cause considerable distress to local communities and sever transport links. It is crucial to conduct stability assessments of cut slopes along highways in such areas. The various challenges faced during the study were inaccessible areas making it difficult to collect data and understanding the complex interactions between these factors and developing accurate prediction models is a complex task. Landslides can be triggered by a variety of factors, including, seismic activity, slope instability and human activities. This leads to vagaries of the landslides Despite all the challenges, twenty-two geologically diverse sites along National Highway 58 (A significant transportation route for pilgrims in the Garhwal Himalaya.) from a 17 km stretch between Srinagar and Sirobagarh were selected for detailed geological and geotechnical analysis and evaluation of slope stability using rock mass classification methods, kinematic analysis and numerical modeling. To evaluate the strength of the rock mass for stability assessment, the geological strength index and rock mass rating were employed. Subsequently, the slope mass rating and continuous slope mass rating were determined. The identification of potential unfavorable planes was carried out using kinematic analysis. Furthermore, the stability of three major landslide zones in the area was critically analyzed using large scale mapping with the help of total station. The evaluated values of SMR, CSMR confirm the poor geotechnical properties of a few of the locations and this is corroborated with the field conditions. The results obtained from the study show the weak planes along which the probability of landslides is more and concrete measures can be taken to stabilize those slopes through the concrete walls, mesh, etc.

Keywords: Road Cut Slopes, SMR, CSMR, Kinematic Analysis, Total Station, Topography.

INTRODUCTION

In any mountainous terrain, landslides are relatively common phenomena – they represent a major hazard that can cost hundreds of lives and incur huge losses in terms of livestock and infrastructure, as well as negatively affecting the economic development of the region. In a geo-dynamically active region like the Himalayas, the repeated activation of major thrusts weakens the rock slopes, making them particularly vulnerable to stress and potential failure.

Landslides are known to occur frequently along the main highways in the Himalayas, especially during the monsoon season, due to the seepage of rainwater as gravity overcomes the natural cohesion of slope. In recent years, large-scale infrastructure development, and especially the widening of roads, has aggravated landslide problems (Umrao *et al*., 2011). By undertaking appropriate planning and assessment measures, the loss of life and damage to property can be reduced, and inconvenience caused by the disruption of transportation corridors can be minimized. The researchers evaluate the slope stability using rock mass classification tools. The classification of rock mass aids in understanding and interpreting its properties. However, it relies on various parameters, such as the inherent characteristics of the slope, the strength of the rock mass, the condition of discontinuities, local hydrogeological conditions and the rate of weathering and erosion (Bieniawski, 1979; Felsberg *et al*., 2022).

National Highway 58, a main transportation road that serves as an important pilgrimage route from Rishikesh to Badrinath and Kedarnath, is frequently affected by landslides due to the complexity of the surrounding geology (Sati *et al.,* 2007). The areas surrounding these discontinuities exhibit significant instability in their slopes. Moreover, the continuous erosion of the base caused by winding river channels results in a gradual deterioration of the materials above (Nainwal *et al.,* 1986). We conducted slope stability studies on road cut slopes along different sections of the highway between Srinagar and Sirobagarh using (Marinos & Hoek 2000), rock mass rating (RMR) (Bieniawski, 1979; Kirchner *et al*., 2021; Olefs *et al.,* 2021; Schaffer, 2021) slope mass rating (SMR) (Romana, 1985; Ozturk *et al.,* 2021) and continuous slope mass rating (CSMR) (Umrao *et al.,* 2009; Tomas *et al.,* 2007; Maraun *et al.,* 2022; Basha *et al.,* 2019). Kinematic analysis, and large-scale mapping of active landslide zones was done to understand the mechanism of failure (Umrao *et al.,* 2009; Siddique *et al.,* 2017; Pradhan *et al.,* 2011; Knevels *et al.,* 2020; Doblas-Reyes *et al.,* 2021, Schlögel *et al.,* 2020; Sharma *et al.,* 2022). The rocks in this area are rendered unstable by the region's climate and natural processes, including weathering, erosion, and adverse hydrological conditions. Slope failures regularly occur in road cuttings, which is worsened by the ongoing down cutting of the Alaknanda River adjacent to the road. To comprehend the processes underlying slope instability in the study area, locations with varying lithologies and slope conditions were chosen, and their geological and geotechnical characteristics were thoroughly investigated. The slope stability of these sites was then evaluated using the afore-mentioned methods. Three active landslide sites: Srikot, Pharasu and Kaliasaur were studied in detail and mapped. The analysis of already failed slopes has strong potential for helping in infrastructure planning and hazard avoidance.

Geology and Structure of the Study Area. Study area (Fig. 1) has a complex geologic and structural setting with a combination of folds, joints, faults, thrusts and shear zones, and the structure and tectonics of the area have caused intense crushing and shearing of rock units. Structurally, the area forms a part of an inverted recumbent anticline trending ENE-WSW in the Alaknanda valley (Kumar & Aggarwal 1975).

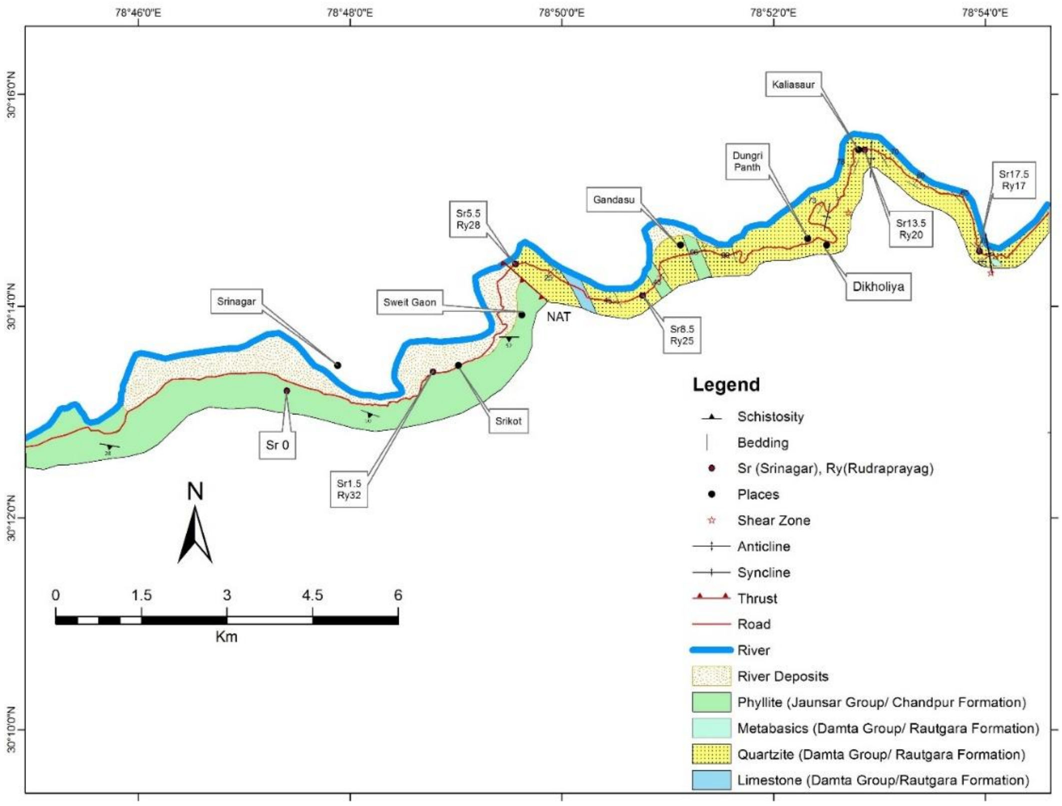


Fig. 1. Geology and Structure of study area.

Regionally, the area is bounded by two major faults, the North Almora Thrust (NAT) in the south and the Alaknanda Fault in the north. Various lithological units are exposed in tight isoclinal folds between these two major tectonic features. Rocks in the Srinagar area belong to the Chandpur Group, which consists of Srinagar phyllites and associated metavolcanics, and the Garhwal Group, consisting of the Koteshwar quartzite, followed by the overlying Garhwal slate and Marora limestone. The area is demarcated by the NAT in the northeastern part, which is crossed by two transverse faults, the Barakot Fault and the Koteshwar Fault, trending NE-SW and NNE-SSW, respectively (Shekhar *et al*., 2006) (Fig. 1). In addition, another major fault, the Kaliasaur Fault, trends E-W and is known to be a major reason for the occurrence of the Kaliasaur landslide (Nainwal 2000; Valdiya 1980). NAT, a wide shear zone around Srinagar marks the contact between the Srinagar phyllites and Koteshwar quartzites. The upper unit, the Srinagar phyllite, is highly folded and fractured and is present in some places as pulverized material. Similarly, the Koteshwar quartzites are strongly folded and jointed and show a high degree of weathering at a few locations along the thrust planes. In the area of study, six levels of fluvial terraces on either bank of the Alaknanda have been marked (Sati *et al.*, 2007, Devrani *et al.*, 2015). These terraces are very well developed at Swet, Srinagar, Choras, Pharasu, and Dungripanth. Poorly sorted clasts, boulders and pebbles dominate the terrace deposits.

Chronological data on the sequencing of fluvial landforms has demonstrated that the NAT and associated lineaments have been very active during the late Quarternary Period (Devrani *et al.*, 2015). The ancient and recent landslide debris dominates the slopes around Srinagar. Three major landslide areas *viz.* Srikot, Pharasau and Kaliasaur characterized by variation in lithology and structure have been selected for studying slope instability and for determining the stability of all the slopes in the region. The structural interpretation and mapping of these three landslide areas was done by studying the orientation of slope angle, structure, joint aperture and joint spacing using Total Station.

Srikot Landslide. A stretch of road nearly 2 km in length could be identified as the damage zone of the Srikot landslide (Fig. 2). Tectonics plays a pivotal role in the instability in this area because the area is sandwiched between the Barakot and North Almora Thrust faults. Dominantly, phyllites topped by Quaternary material consisting of loose sediment and boulders are exposed in the landslide area. The phyllites are highly weathered, fragile, and weak.

Augen structures in the phyllites are common, and their widths increase to form pinch and swell structures as we travel along the road. The intensely weathered, highly jointed and folded rock slope is characterized by high- angle joints at 37-45° dipping 25-33° towards west, which is similar to the slope orientation, facilitating planar failure.

However, due to intense weathering, the failure surface appears curved, similar to soil slopes. Furthermore, it was assumed that this highly jointed and weathered rock mass is subjected to high erosion even under moderate stress and flow energies. Landslide debris travels down the valley to the Alaknanda River Choe, which can choke the dam and cause flood-like situations.

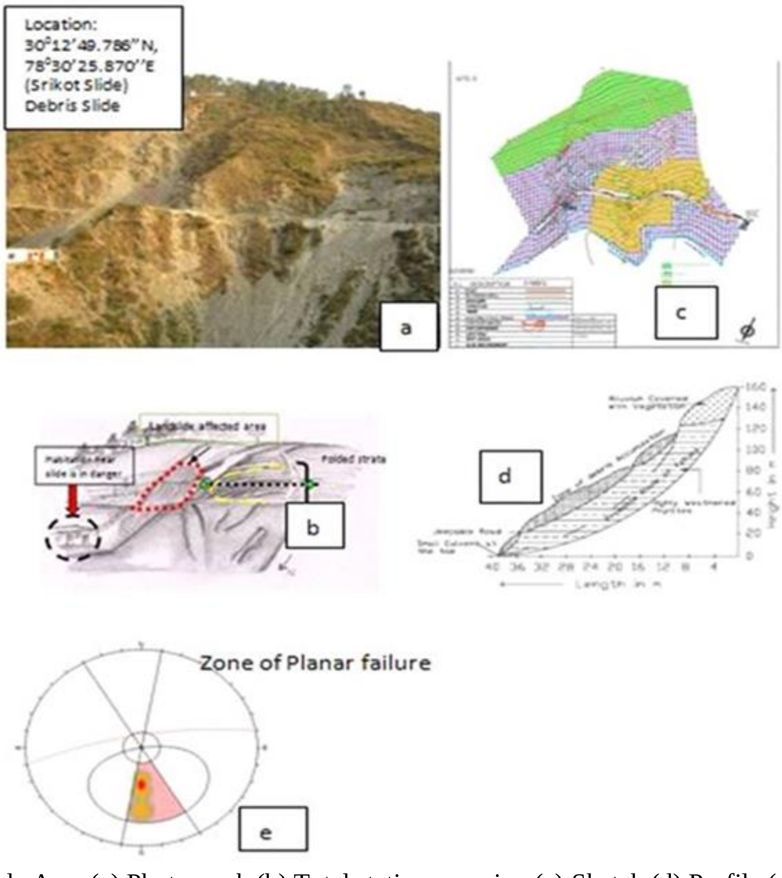


Fig. 2. Srikot Landslide Area (a) Photograph (b) Total station mapping (c) Sketch (d) Profile (e) Kinematic analysis.

Pharasu Landslide. This landslide is located near Pharasu village, 5-6 km from Srinagar (Fig. 3). Pharasu village is located on a river terrace. Jointed quartzites with highly weathered phyllite intercalations overlain by Quaternary alluvium comprise the landslide slope. A maximum of 4 sets of joints is recorded in this area. In places, joint openings from a few millimeters to centimeters are observed. These spaces are filled with secondary and weathered material. The Alaknanda River also plays a major role at this site by undercutting the slope at its toe.

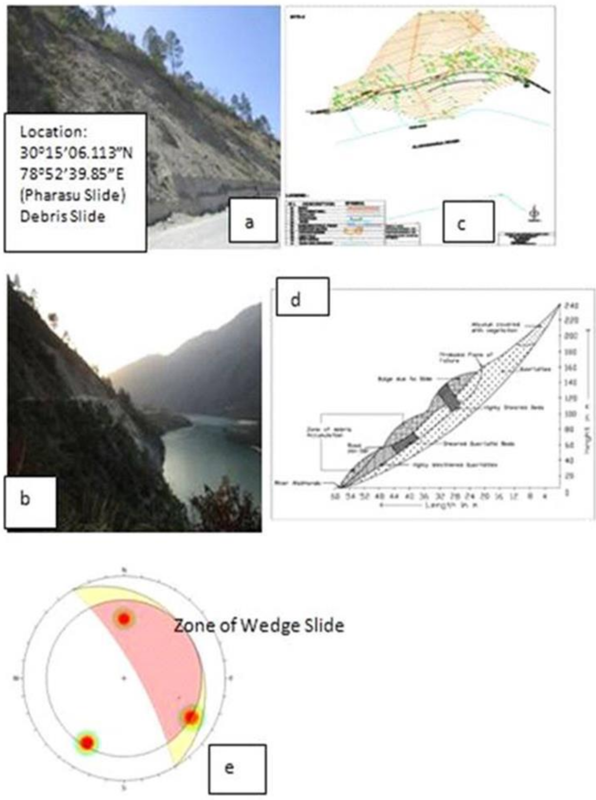


Fig. 3. Pharasu Landslide Area.

Kaliasaur Landslide. This major landslide is located near Sirobagarh along the NH-58, and spreads over an area of approximately 45000 sqm (Fig. 4). The Kaliasaur landslide is almost one hundred years old, and slope failure occurs on a regular basis. The site is located at a sharp meander of the Alaknanda River, which continuously erodes the toe of this zone. The slope is composed of highly weathered, folded and jointed quartzites in shades of pink, white and purple. These quartzites are intruded by metavolcanic rocks that are exposed on the southern and western flanks of the landslide. The Kaliasaur Fault runs in the E-W direction through the landslide area and has led to the accumulation of very large scree deposits over the crown of the slide. The slope angles 55° toward S 25° W. There are two prominent planes of weakness running through the center of slide area: one zone dips f33° towards N65°W, and the other dips 25° toward S10°W. The eastern flank dips 63° toward S48°E and 50° toward S45°W. The western flank is truncated by a series of local faults where quartzites terminate abruptly along a scree zone. The spacing between the joints varies from 100-200 cm, and in general, the joints exhibit a 2-5 cm gap filled with pulverized material. Joint planes continue for distances of 10-15 m. Three different cross sections of Kaliasaur landslide have been selected to understand the slope stability. Kinematically, the slope is unstable and is prone to wedge and toppling failure along any plane of discontinuity.

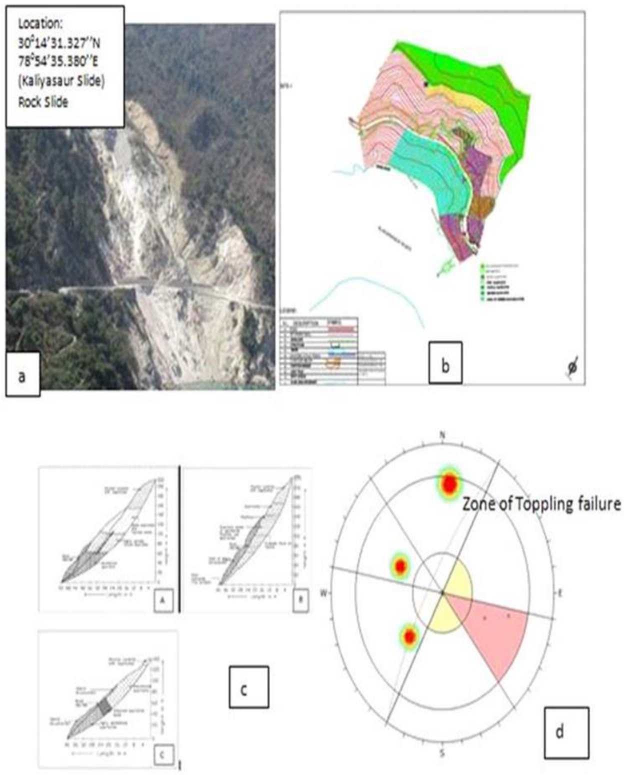


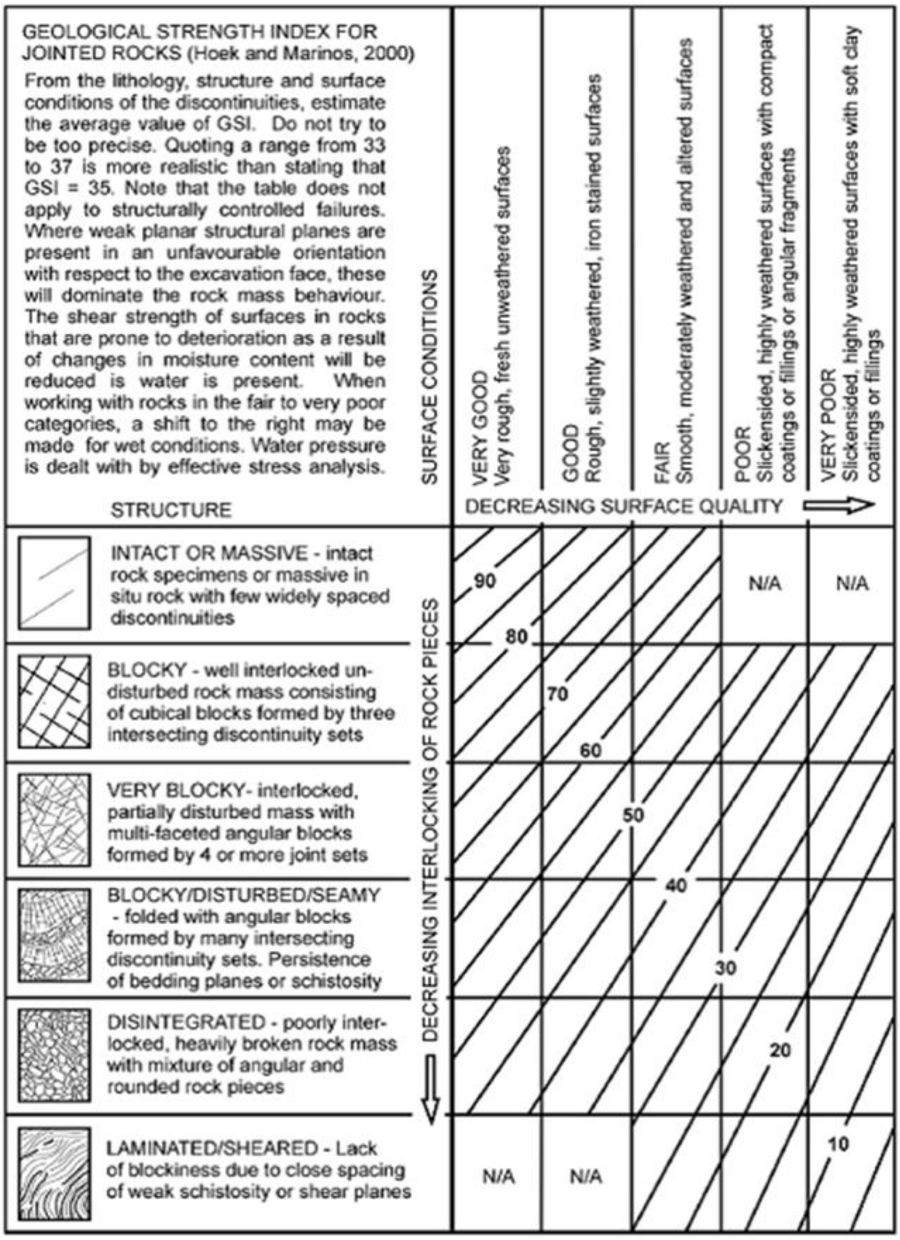
Fig. 4. Kaliasaur Landslide Area.

MATERIAL AND METHODS

Field studies were carried out to investigate lithological and structural variations in rock slopes and to assess slope stability at twenty-two selected sites. Slopes at these locations were studied and classified by their rock mass quality and stability. Core values were collected and UCS, Point load and Slake durability tests were performed. The focus of this study is the estimation of rock mass properties and the characterization of rock masses on the basis of geological strength index (GSI) and RMR; and the stability of the slope is further assessed by calculating SMR and CSMR.

GSI was introduced by Hoek (1984), and further developed by Marinos & Hoek (2000). The GSI serves as a gauge to evaluate the reduction in rock mass strength in different geological conditions, as observed in the field. This estimation is founded on the visual perception of the rock structure, specifically the surface state of the discontinuities and the degree of blockiness, as interpreted from the joint roughness and alteration (Marinos & Hoek 2000). The GSI values are assigned from 10 to 90. The laminated or sheared rocks assigned the lowest GSI values, whereas the intact or massive rocks are assigned the highest values (Table 1).

Table 1: Characterization of rock mass based on interlocking and joint alteration (Hoek and Marinos 2000).



RMR is representative of the comprehensive rock mass quality and has wide applications in the design and construction of tunnels, roads, slopes, foundations, mines and rock excavations (Bieniawski, 1979).

Ratings are determined for all parameters *viz*. Lithology, Uniaxial Compressive Strength, RQD, Condition of discontinuities (weathering, roughness, persistence, aperture)/Spacing, and Ground water conditions (completely dry/damp/wet/dripping/flowing) on the basis of field observations and laboratory tests. RMR is then computed by adding these rating values as suggested by (Bieniawski, 1979). The RMR classification results and the calculated RMR values are given in Table 2.

Romana (Romana 1985) established SMR for the assessment of slope stability, taking into account the orientation of a slope in relation to orientation of discontinuities. This approach is one of the most widely used methods to assess slope stability. SMR is obtained from the RMR by the addition of four adjustment factors (F1, F2, F3, F4) (Romana, 1985).

The first three adjustment factors depend on the relative orientation of joints and the slope, while the fourth (F4) depends on the method of excavation. SMR values range from 0 to 100 and are classified into five different stability classes. Several modifications have also been made to SMR by various researchers (Anbalagan *et al.*, 1992; Romana 2003; Romana *et al.*, 2001; Tomas *et al.*, 2004). In this study, we obtained SMR for all 22 selected sites by following the protocol of Romana (Marinos & Hoek 2000; Zarrillo *et al.*, 2020); Anabalgan *et al.* (Anbalgan *et al.*, 1992) for the application of the four adjustment factors to the RMR (Table 3).

Table 2: Estimated Ratings and RMR value at selected sites (Bieniawski, 1979).

RMR_B= Basic RMR =∑Ratings (Bieniawski, 1979)							
Parameters	Site Number	1	2	3	4	5	6
Lithology		Phyllite	Limestone	Phyllite	Quartzite	Quartzite	Quartzite
Uniaxial compressive strength(approx.) (MPa)		26	37	27	130	140	102
Ratings		**4**	**4**	**4**	**12**	**12**	**12**
RQD		<25%	25-50%	<25%	90-75%	50-75%	50-75%
Ratings		**3**	**8**	**3**	**17**	**12**	**13**
Condition of Discontinuities due to Weathering, Roughness, Persistence, Aperture, Infilling		Highly weathered, Rough, Low, Partly open	Highly weathered, Rough, Low, Partly open	Highly weathered, Rough, Low, Partly open	weathered, Smooth surface, Continuous, Partly open	weathered,Smooth surface, Continuous, partly open	weathered, Smooth surface, Continuous, partlyopen
Ratings		**8**	**8**	**5**	**15**	**15**	**15**
Spacing (m) (>2/0.6-2/0.2-0.6/0.06-0.2/<0.06)		Very close spacing (0.2-0.06)	Close spacing (0.6-0.2)	Very close spacing (0.2-0.06)	Close spacing (0.06-0.2)	Close spacing (2-0.6)	Close spacing (0.06-0.2)
Ratings		**8**	**10**	**8**	**10**	**15**	**10**
Ground water conditions (Completely Dry/Damp/Wet/Dripping/Flowing)		Damp	Damp	Damp	Damp	Damp	Damp
Ratings		**10**	**10**	**10**	**10**	**10**	**10**
RMR Value (Sum of Ratings)		**33**	**40**	**30**	**64**	**64**	**60**

Table 3: Standard SMR Classification of Rock slope.

SMR= RMR_B+(F_1×F_2×F_3) + F_4 (Romana, 1985)						
Adjusting factors for joints (F_1,F_2,F_3)	α_j=Dip direction of joints α_S=Dip direction of slope β_j=Dip of joint β_s=Dip of slope					
Adjustment factors	Case of slope failure	Very favorable (Very low failure probability)	Favorable	Fair	Unfavorable	Very unfavorable (Very high failure probability)
F_1	Planar (P) $\|\alpha j-\alpha s\|$ Wedge (W) $\|\alpha_j-\alpha_s\|$	$>30^0$	30^0-20^0	20^0-10^0	10^0-5^0	$<5^0$
	P/WF_1 rating	0.15	0.40	0.70	0.85	1.00
F_2	Planar (P) $\|\beta_j\|$ Wedge (W) $\|\beta_i\|$	$<20^0$	20^0-30^0	30^0-35^0	35^0-45^0	$>45^0$
	P/W F_2 rating	0.15	0.40	0.70	0.85	1.00
	TF_2 rating	1.00	1.00	1.00	1.00	1.00
F_3	Planar (P) $\|\beta_j-\beta_s\|$ Wedge (W) $\|\beta_j-\beta_s\|$	$>10^0$	10^0-0^0	O^0	0^0-(-10^0)	$<-10^0$
	T $\|\beta_j+\beta_s\|$	$<110^0$	110^0-120^0	$>120^0$	-	-
	P/W/T F_3 rating	0	-6	-25	-50	-60
F_4 Adjusting factor for excavation method		Natural slope	Presplitting	Smoothblasting	Blasting or mechanical	Deficient blasting
	F_4 rating	+15	+10	+8	0	-8

Tomas *et al.* (2007) proposed the continuous slope mass rating (CSMR) method as an alternative to accurately assess stability grades. The CSMR employs an equation similar to that of SMR, but the difference lies in how the adjustment factors (F1, F2, and F3) are calculated, while F4 for CSMR is the same as for SMR. Unlike SMR, which uses decision-based and discrete adjustment factors, CSMR is less reliant on decisions and provides continuous values (Tomas *et al.*, 2007). For each slope in CSMR, a unique value is assigned to each adjustment factor, resulting in a more precise value of SMR.

Kinematic analysis was carried out to determine the possible modes of failure. Since the orientation of discontinuities plays a major role in slope stability, this analysis reveals the type and possible direction of failure movement along with identification of potentially unfavourable joint planes. The Rocscience software was used to plot the measured orientation data on stereo plots. The spatial attitudes of all discontinuities, such as joints, folds, faults, and shears, were recorded in detail in the field, which helped identify the extents of the discontinuities.

RESULTS AND DISCUSSION

The Indian Himalaya is very prone to landslides due to its complex geology and tectonic set-up along with high intensity rainfall and aggravated slope conditions as a result of anthropogenic activities. Landslide hazard assessment is very essential before any hill development construction activity begins. Engineering geological investigation forms the primary basis for any slope stability assessment leading to plan for any construction so that landslide occurrences are minimized. Engineering geological data for rock slope stability assessment can be very easily collected from the field. These data can be used for rock mass characterization and classification such as Geological Strength Index (GSI), Rock Mass Rating (RMR) and Slope Mass Rating (SMR). The paper describes these rock mass classification techniques and presents some field examples. The paper also presents application of these techniques to derive some relevant geotechnical parameters for numerical analysis to determine the stability of slopes in terms of factor of safety.

Large-scale geological and geotechnical mapping from Srinagar to Kaliasaur was carried out at twenty-two sites to map potential landslide zones. GSI, RMR, SMR, CSMR and kinematic analysis were calculated for the selected sites, and the estimated ratings for these sites are given in Tables 4-6.

The geotechnical data for all the selected slopes of the study area was compiled and analyzed for the stability of those slopes. Our engineering geological in situ analysis combined with laboratory tests confirm the poor geotechnical properties of a few of the locations, which corresponds to the field conditions. Some of these material properties are also used as input to determine GSI, RMR, SMR, CSMR and kinematic analysis (Huda *et al.,* 2018; Jaiswal *et al*., 2023).

The quality of the rock mass was determined using GSI and RMR. The study area's diverse rock types yield GSI and RMR values that range from 20-60 and 30-65, respectively (as presented in Table 4-5). The selected sites exhibit SMR and CSMR values that range from 33-65 and 10-55, respectively (as detailed in Table 5&6 and shown in Fig. 5). Nonetheless, some sites' SMR values do not align with actual field conditions. The use of continuous functions through CSMR seems to address this concern and provide the most accurate assessment of slope stability grades.

Kinematic analyses have further helped reveal potential failure modes (Table 6 and Fig. 6) and can be utilized in further planning for mitigation in zones with specific landslides.

The rock mass conditions, geotechnical properties and SMR, CSMR for the three landslide sites (Srikot, Pharasu, and Kaliasaur) validate and confirm the already initiated failure zones. This indicates that the slopes in these regions are highly unstable. These results are in harmony with the real-field situation and indicate instability and detachment of the slope mass.

Table 4: Estimated GSI Values for Selected sites.

Site	Rock Type	Rock Strength Classification	Weathering	Rock Structure	GSI Value
1.	Phyllite	Very Weak	Very Poor	Disturbed/folded	25-28
2.	Limestone	Very Weak	Very Poor	Disintegrated	20-25
3.	Phyllite	Weak	Poor	Disturbed/folded	20-25
4.	Quartzite	Very Strong	Fair	Blocky	55-60
5.	Phyllite	Very Weak	Very Poor	Disturbed/folded	25-28
6.	Quartzite	Strong	Fair	Blocky	50-55
7.	Quartzite	Strong	Good	Blocky	55-60
8.	Quartzite	Strong	Good	Blocky	55-60
9.	Quartzite	Strong	Good	Blocky	55-60
10.	Quartzite	Very Strong	Fair	Blocky	55-60
11.	Quartzite	Very Strong	Fair	Blocky	55-60
12.	Quartzite	Very Strong	Fair	Blocky	55-60
13.	Quartzite	Very Strong	Fair	Blocky	55-60
14.	Quartzite	Very Strong	Fair	Blocky	55-60
15.	Quartzite	Very Strong	Fair	Blocky	55-60
16.	Quartzite	Very Strong	Fair	Blocky	55-60
17.	Quartzite	Very Strong	Fair	Blocky	55-60
18.	Quartzite	Very Strong	Fair	Blocky	55-60
19.	Quartzite	Strong	Fair	Blocky	50-55
20.	Quartzite	Strong	Fair	Blocky	50-55
21.	Quartzite	Strong	Fair	Blocky	50-55
22.	Quartzite	Strong	Fair	Blocky	50-55

Table 5: Derived values of F1, F2, F3 and F4 for SMR.

Site No.	RMR	F_1	F_2	F_3	F_4	SMR	Stability Classification
1.	48	0.15	1.00	-25	0	44	III/ Partially Stable
2.	53	0.15	0.85	-6	0	52	III/ Partially Stable
3.	53	0.15	0.85	-50	0	47	III/ Partially Stable
4.	64	0.15	1.00	-6	0	63	II/ Stable
5.	50	0.15	1.00	-6	0	49	III/ Partially Stable
6.	60	0.7	0.15	-60	0	54	III/ Partially Stable
7.	64	0.15	1.00	-6	0	63	II/ Stable
8.	50	0.15	1.00	-25	0	46	III/ Partially Stable
9.	55	0.15	0.85	-6	0	54	III/ Partially Stable
10.	58	0.15	1.00	-6	0	57	III/ Partially Stable
11.	60	0.15	0.85	-6	0	59	II/ Stable
12.	53	0.15	1.00	-50	0	45	III/ Partially Stable
13.	52	0.7	0.85	0	0	52	III/ Partially Stable
14.	62	0.15	1.00	-6	0	61	II/ Stable
15.	64	0.15	1.00	-25	0	60	II/ Stable
16.	70	0.7	1.00	-6	0	65	II/ Stable
17.	72	0.15	0.85	-25	0	69	II/ Stable
18.	68	0.15	0.85	-6	0	67	II/ Stable
19.	60	0.15	1.00	-25	0	56	II/ Stable
20.	58	0.7	1.00	-6	0	53	II/ Stable
21.	55	0.15	0.85	-6	0	54	III/ Partially Stable
22.	50	0.15	1.00	0	0	50	III/ Partially Stable

Table 6: The stability classes of CSMR for 22 sites.

Site No.	RMR	F1	F2	F3	F4	CSMR	Class/Stability
1.	48	0.251	0.797	-59.05	0	36.19	IV/ Unstable
2.	53	0.126	0.4932	-59.71	0	46.28	III/ Partially Stable
3.	53	0.106	0.3734	-59.77	0	50.64	III/ Partially Stable
4.	64	0.156	0.875	-59.90	0	55.83	III/ Partially Stable
5.	50	0.157	0.875	-59.82	0	41.78	III/ Partially Stable
6.	60	0.156	0.918	-59.814	0	51.44	III/ Partially Stable
7.	64	0.121	0.785	-59.803	0	58.32	III/Partially Stable
8.	50	0.157	0.875	-59.823	0	42.79	III/Partially Stable
9.	55	0.156	0.875	-59.903	0	46.83	III/Partially Stable
10.	58	0.120	0.968	-59.838	0	51.05	III/Partially Stable
11.	60	0.104	0.973	-59.833	0	53.95	III/Partially Stable
12.	53	0.150	0.984	-59.85	0	44.17	III/Partially Stable
13.	52	0.152	0.986	-59.85	0	43.04	III/Partially Stable
14.	62	0.154	0.957	-59.82	0	53.19	III/Partially Stable
15.	64	0.154	0.975	-59.83	0	55.02	III/Partially Stable
16.	70	0.169	0.988	-59.85	0	60.01	IV/Stable
17.	72	0.152	0.343	-59.76	0	68.89	IV/Stable
18.	68	0.158	0.952	-59.82	0	59.01	III/Partially Stable
19.	60	0.15	0.957	-59.82	0	51.42	III/Partially Stable
20.	58	0.120	0.990	-59.85	0	50.89	III/Partially Stable
21.	55	0.152	0.961	-59.80	0	46.27	III/Partially Stable
22.	50	0.156	0.746	-59.79	0	43.05	III/Partially Stable

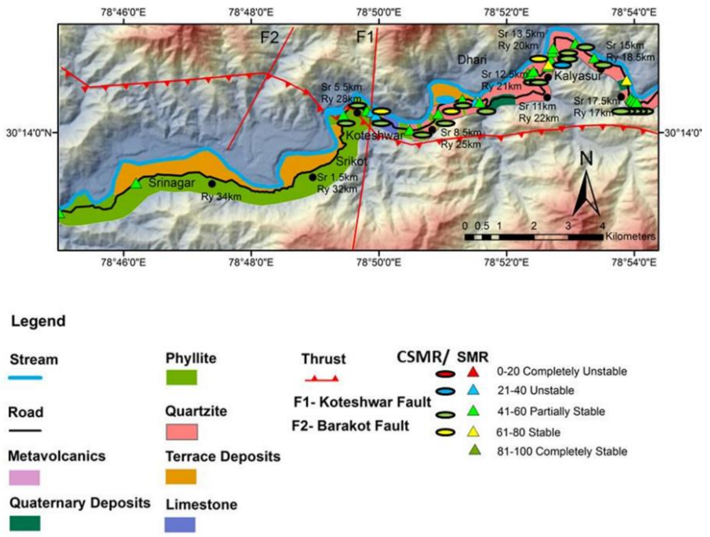


Fig. 5. Stability classes on Geology Map and Terrain Model.

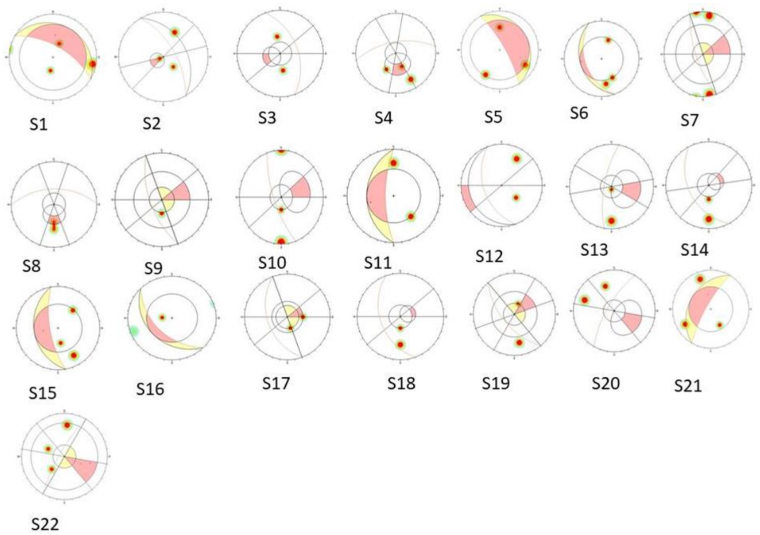


Fig. 6. Kinematic Analysis of selected slopes.

CONCLUSIONS

In determining the quality of a rock mass, RMR and GSI play vital roles, and our findings are consistent with that existing understanding. SMR and CSMR values provide the most precise evaluation of the slope stability grades. Kinematic analysis helps identifying planes of weakness and this information can further be utilized for planning mitigation measures to avoid landslides in such zones. Slope stability along mountain roads is a significant concern due to the potential for slope failures, which can result in traffic disruptions and the loss of property and/or life. Appropriate landslide mitigation strategies should be carried out based on the findings and recommendations of geotechnical experts. A fundamental technique for the stabilization of a slope is to improve the surface and subsurface drainage conditions. Undesirable surface waters should be drained into natural stream channels using lined drains or diverted to sites where running water will not affect the area. In addition to the above geotechnical approaches, suitable bio-remedial strategies need to be adopted, such as planting along the exposed areas that result from excavation for the widening of roads, as these areas are susceptible to saturation during the rainy season.

FUTURE SCOPE

The study can be furthered by integrating it with remote sensing data. More direct method using Geotechnical Engineering Stability Analysis combined with GIS can be done.

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Conflict of Interest. None.

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