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Stability Analysis of Rock Slopes along Gangadarshan, Pauri, Garhwal, Uttarakhand

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ABSTRACT

The rock mass rating (RMR) and slope mass rating (SMR) has been carried out to classify the slope in terms of slope instability. To understand the RMR and SMR various geostructural, geomorphologic and hydrological parameters of the slopes were measured and analyzed. 32 rock slopes/rock cum debris slopes were identified in the study area. The present RMR and SMR study is an outcome of extensive field study along a stretch of about 10 km on road leading from Srinagar to Pauriarea along Alaknanda valley. The technique followed incorporates the relation between discontinuities and slope along with rock mass rating (RMR) and slope mass rating (SMR). The analysis of the 32 studied slopes shows that in the Gangadarshan area out of six rock slope facets, two falls in class II (stable) and four in class IV (unstable). It is significant to note that the slope facets coming under class IV are comprised of active landslide portions. While the slopes under class II show minor failure or old landslide debris.

INTRODUCTION

The feasibility and preliminary design stage of any engineering project, slope mass its stress and hydrologic characteristics, the use of a rock mass and slope mass classification scheme are of considerable benefit. This may involve using the classification scheme as a check-list to ensure that all relevant information has been considered. On the other hand of the spectrum, one or more rockmass classification schemes can be used to build up a picture of the composition and characteristics of a rock mass to provide initial estimates of support requirements, and to provide estimates of the strength and deformation properties of the rock mass.

In the Alaknanda basin, evidences pertaining to the landslide damming of the rivers are limited to the higher Himalayan ranges around the Main Central Thrust (MCT). The zone of the MCT is not only seismically active, but also characterised by intensive rainfall zone. Away from the MCT towards the south, there is no evidence for river damming in the geological past.

Rock mechanics is considered as a modern engineering discipline, however, as early as 1773; Coulomb, included results of tests on rocks. Karl Terzaghi (1936) addressed first international conference on soil mechanics and foundation engineering. Terzaghi (1936) and Terzaghi and Voight (1979), stated that "the catastrophic descent of slopes of the deepest cut of Panama canal issued a warning that we were overstepping the limits of our ability to predict the consequences of our action". During 1920 to 1958, Josef Stini published more than three hundred papers and was probably the first to emphasize the importance of structural discontinuities on the engineering behaviour of rock masses. During the early part of twentieth century, scientists and engineers from different disciplines did some significant work on behaviour of rocks. King (1912), Griggs (1936), Ide (1936), Terzaghi (1945), Ramamurthy (2004) and Naithani (2007), worked on the failure of rock materials.

Slope instability is the condition which gives rise to slope movements (Crozier, 1989). Instability of slope represents the condition in which the limit of stability reduces to zero. The slope stability assessment was carried out in the Alaknanda and Bhagirathi valley by some workers (Mehrotra et al. 1994, Nainwal and Prasad, 2001, Chakraborty and Anbalagan, 2008).

The basic outcome of the study is to estimate the rock mass rating and slope mass rating of the various rock slopes present in the study area. Based on the RMR, calculation of slope mass rating, the various slopes present in the study area has been categorised of slope in terms of instability.

STUDY AREA

Administratively, the study area falls in the Pauri district of Uttarakhand Himalaya.

It also falls in lesser Himalayan region along Srinagar-Pauri (Alaknanada valley) Garhwal Himalaya, Uttarakhand (Fig.1). The investigated area is approachable from Rishikesh and Srinagar by road (NH-119). The study area is bounded by 30.2112°N, 78.7654°E to 30.2099°N, 78.7477°E , covering a stretch of about 10 km length of road section. Survey of India toposheet number 53 J/15 and 53 J/16 on a scale of 1: 50,000 were used to prepare base map.

Geological Setup

The study area lies on the national highway-119. Geologically, Chandpur phyllite region and specifically in the locality of the Gangadarshan which is virgin area according to the RMR and SMR study point of view. The study of the RMR and SMR of the area could help in figuring out the stability categorization of the area.

METHODS

Rock Mass Rating (RMR) Study

The geo-mechanical properties of slopes were evaluated by rock mass rating (RMR) system following I.S. code 13365 Part 3 (1997). The RMR is determined by adding the rating values of the following parameters: (i) uni-axial compressive strength of the rock, (ii) rock quality designation (RQD), (iii) spacing of discontinuities, (iv) condition of discontinuities and (v) groundwater condition.

The quantitative classification of rock mass provides not only a basis for understanding characteristics of the different groups of rock

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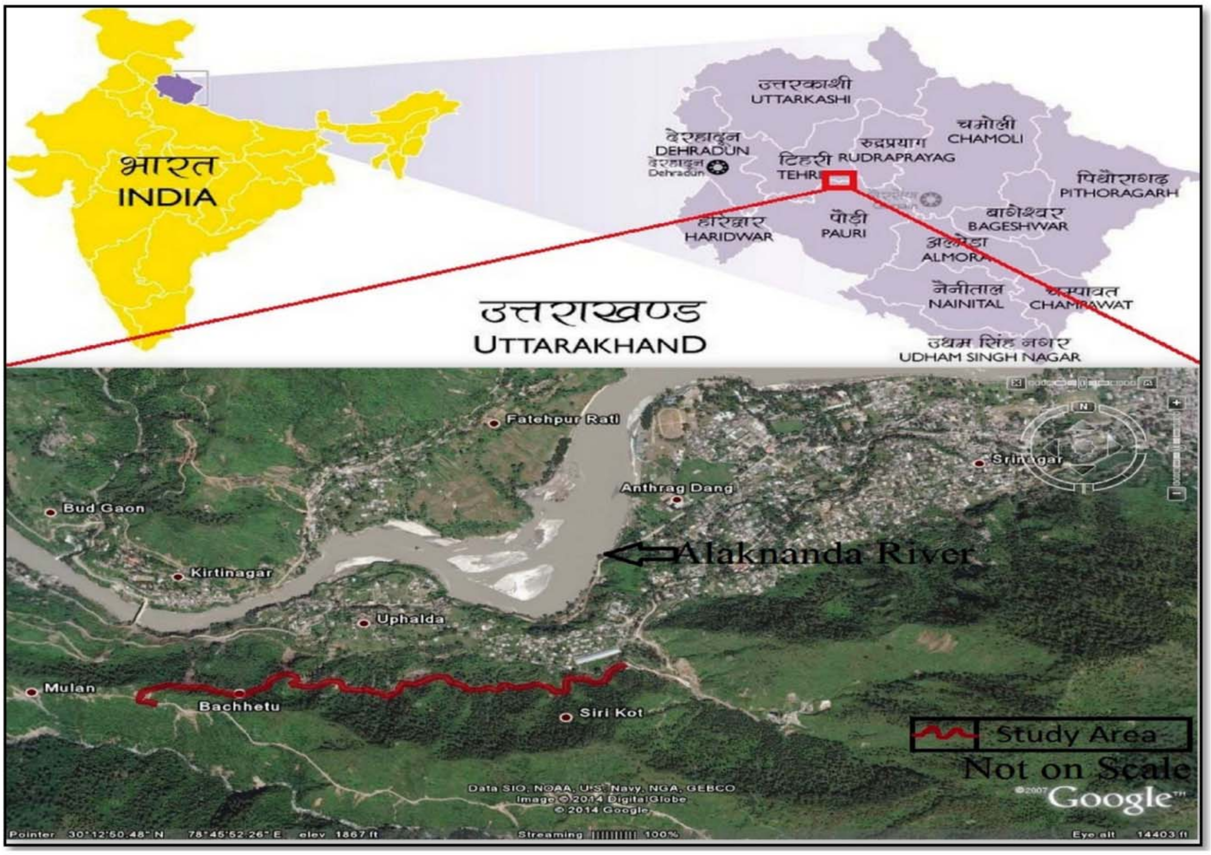

Fig.1. Location map of the study area.

masses, but also provide quantitative data for designing suitable civil engineering structures. The RMR ranges from 0 to 100, computed on the basis of the rating value of the various parameters (Table 1), following the methodology of I.S. Code 13365 Part 3 (1997), Bieniawski (1979), Romana (1985) and Palmstrom (1995).

Demarcation and identification of rock slopes and rock cum debris slopes: Most of the rock and rock cum debris slopes were observed along Pauri road up to Gangadarshan, therefore, this sector was chosen for RMR study. Total 32 rocks and rock cum debris slopes were identified and selected for the study. The field study reveals that 32 slopes represent rock or rock cum debris slopes and the remaining slopes are either constituted by soil/debris and mainly by tectonic activity. The slope angle with direction using Brunton Compass, extent of weathering and nature of rock types with altitude were assessed on the basis of field evidences. All the data collected in the field pertaining to rock and rock cum debris slopes are summarized in the following Table 1.

Description of parameters: Detailed field investigations were

Table 1. Rock Mass Rating (RMR) rating (IS Code 13365 Part 3, 1997)

Strength of intact rock	Uni-axial Compressive strength	>250 Mpa	100-250 Mpa	50-100 MPa	25-50 MPa	5-25Mpa	1-5MPa	<1MPa
	Rating	15	12	07	04	02	01	0
Drill core quality	RQD	90-100%	75-90%	50-75%	25-75%	<25%		
	Rating	20	17	13	8	3		
Joint Spacing	Spacing	>2 m	0.6-2.0 m	0.20-0.60 m	0.60-0.20 m	<0.60 m		
	Rating	20	15	10	8	5		
Condition of discontinuities	Details	Very rough surfaces. Discontinuous No separation. Unweathered wall rock	Slightly rough surfaces. Separation <1mm Slightly weathered walls.	Slightly rough surfaces Separation<1 mm Highly weathered walls	Slickenside surfaces, or gouge <5mm thick or Separation 1-5 mm. Continuous.	Self gouge >5mm or Separation >5mm Continuous.		
	Rating	30	25	20	10	0		
Ground water condition	Details	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating	15	10	7	4	0		
Total		100	79	57	34	10		

carried out for all the rock or rock cum debris slopes to collect the data of various parameters needed for assessment of slope stability. The descriptions of the various parameters collected in the field are as follows

Uni-axial Compressive Strength: The Schmidt hammer is a device, which estimates the strength of joint wall as well as the rocks by measuring the rebound of a spring impelled hammer striking on the surface of the rock or joint wall (Barton et al., 1976). In field, each surface was tested 20 times and the average value of the rebound number was used for obtaining the uni-axial compressive strength.

Rock quality designation (RQD): It is expressed as a percentage of the total length drilled and based on the percentage of core recovery. In the present work, the RQD value was estimated from the surface observations (fracture frequency) as suggested by Franklin et al. (1971). In Table 2 correlation between the RQD (%) and fracture frequency/m is presented along with the ratings.

Table 2. Rating of Rock Quality Designation (RQD) in relation to fracture frequency

Quality classification	RQD (%)	Fracture frequency/m	Rating
Very poor	0-25	Over 15	3
Poor	25-50	15-18	8
Fair	50-75	08-05	13
Good	75-90	05-01	17
Excellent	90-100	Less than 1	20

Spacing of Discontinuity: The joint spacing is a perpendicular distance between the adjacent joint planes and normally refers to the mean or model spacing of a set of joints. The strength of a jointed rock mass is controlled by the block shape and size as well as their surface characteristics determined by intersecting discontinuities (Hoek et al., 1992). The individual joint spacing also influences the mass permeability and seepage characteristic of the slope.In the present study, vertical and horizontal scan lines were drawn for each exposure and the intersection of discontinuities were measured as suggested by Piteau (1970), Robertson (1971) and Priest and Hudson (1981).

***Condition of Discontinuities**:* Discontinuity is a collective term commonly used for most types of joints, bedding planes, cleavage and schistosity, fissures, faults, shear zones etc. For the present work, several discontinuity features were studied in the field and their rating were awarded by following IS Code 13365 Part 3, (1997), Palmstrom (1995), Barton (1978) and Bieniawski (1973). There are various discontinuities conditions are present which are: **(a) Joint Roughness**: It defines the inherent roughness and wavy nature relative to the mean plane of a discontinuity. In field, the joint roughness are recognized as very rough, slightly rough and slickenside or very smooth surfaces. **(b) Joint Length/Persistence:** The persistence of discontinuities refers to its extent. The size and length of discontinuity is often a function of the thickness or separation of the discontinuity. In this work, the joint continuity was taken as continuous joints that terminate against other joints and discontinuous joints that terminate in massive rock. **(c) Joint wall characters and Alteration**: It represents both the strength of the joint wall and the effect of filling and coating material. The joint wall rock is either hard or soft depending upon the degree of weathering. The field survey revealed that generally quartzite has hard joint walls, however, moderate to highly weathered quartzite and phyllites have very soft joint walls. **(d) Joint opening and filling material**: The joint opening is the perpendicular distance between adjacent wall rocks of a discontinuity. Such opening is commonly filled up by some material/water or they may be vacant. In field, a number of readings were taken with the help of measuring tape in joint plane for such openings and their mean values were considered for rating. The joint opening in quartzite is of high order, which is followed by phyllites. The strength of filling material is generally low than the parent rock. Common filling materials within the discontinuities in the area are sand, silt, clay, crushed quartz etc.

Water seepage: Seepage of water through rock masses usually takes place through the discontinuities. In the present study, visual observations were made for seepage conditions or extent of moisture in the open and filled joints. They are as completely dry, damp, wet, dripping and flowing.

Estimation of Rock Mass Rating (RMR): The field data for strength of rock masses, rock quality designation (RQD), joint spacing, conditions of discontinuities (joint length, joint roughness and joint alteration) and ground water conditions for all slope facets were collected. Numerical weight ages were assigned to them following the IS Code 13365 Part 3 (1997).

Table 3. Description of Rock Mass Rating (RMR) classes

Class	Description of Rock Mass	RMR – Sum of rating increment
I	Very good rock	81-100
II	Good rock	61-80
III	Fair rock	41-60
IV	Poor rock	21-40
V	Very poor rock	0-20

Slope Mass Rating (SMR) Study

Slope mass rating is a rock mass classification scheme developed by Romana (1985, 1995) to describe the strength of an individual rock outcrop or slope. The system is founded upon the more widely used RMR scheme (Bieniawski, 1989), which is modified with quantitative guidelines to the rate of the influence of adverse joint orientations (e.g. joints dipping steeply out of the slope). Rock mass classification schemes are designed to account for a number of factors influencing the strength and deformability of a rock mass (e.g. joint orientations, fracture density, intact strength), and may be used to quantify the competence of an outcrop or particular geologic material. Scores typically range from 0 to 100, with 100 being the most competent rock mass.

SMR uses the same first five scoring categories as RMR:

1. Uni-axial compressive strength of intact rock,
2. Rock Quality Designation (or RQD),
3. Joint spacing,
4. Joint condition (the sum of five sub-scores),
5. Groundwater conditions.

The final sixth category is a rating adjustment or penalization for adverse joint orientations, which is particularly important for evaluating the competence of a rock slope. SMR provides quantitative guidelines to evaluate this rating penalization in the form of four sub-categories, three that describe the relative rock slope and joint set geometries and a fourth which accounts for the method of slope excavation. SMR addresses both planar sliding and toppling failure modes, no additional consideration was made originally for sliding on multiple joint planes. However, Anbalagan et al. (1992) adapted the original classification for wedge failure mode. The final SMR rating is obtained by means of the expression:

$$SMR = RMR_b + (F_1 \times F_2 \times F_3) + F_4$$

Where RMR_b is the RMR index resulting from Bieniawski's rock mass classification without any correction. F_1 depends on the parallelism between discontinuities, αj (or the intersection line, αi, in the case of wedge failure) and slope dip direction. F_2 depends on the discontinuity dip (βj) in the case of planar failure and the plunge, βi of the intersection line in wedge failure. As regards toppling failure, this parameter takes the value 1.0. This parameter is related to the probability of discontinuity shear strength. F_3 depends on the relationship between slope (βs) and discontinuity (βj) dips (toppling or planar failure cases) or the immersion line dip (βi) (wedge failure case). This parameter retains the Bieniawski adjustment factors that vary from 0 to –60 points and express the probability of discontinuity outcropping on the slope face for planar and wedge failure. F_4 is a correction factor that depends on the excavation method used which ranges from +15 (natural slope), to –8 (deficient blasting).

Following the above rating criteria SMR can be obtained, which has a range of 0 to 100. The adjustment rating and the stability classes is presented in the Tables 4 and 5.

Table 4. Adjustment rating for discontinuities (Romana, 1985)

Case	Very Favourable	Favourable	Fair	Unfavourable	Very Unfavourable
P(aj-as) T(aj-as-180°)	>30°	30°-20°	20°-10°	10°-5°	<5°
P/Tf1	0.15	0.40	0.70	0.85	1.00
P(Bj)	<20°	20°-30°	30°-35°	35°-45°	<45°
P f2	0.15	0.40	0.70	0.85	1.00
T f2	1	1	1	1	1
P(Bj-Bs)	<10°	10°-0°	0°	0°-(-10°)	<-10°
T(Bj-Bs)	<110°	110°-120°	>120°	—	—
T f3	0	-6	-25	50	60

Remarks: P: Planer Failure, as: Slope direction, aj: Joint dip direction, T: Toppling failure, Bs: Slope angle, Bj: Joint dip.

Table 5. Description of Slope Mass Rating Classes (Romana, 1985)

Class No.	V	IV	III	II	I
SMR	0-20	21-40	41-60	61-80	81-100
Description Stability	Very bad Completely unstable	Bad Unstable	Normal Partially stable	Good Stable	Very good Completely stable
Failure	Big planar or soil like	Planar or big wedge	Some joints or many wedges	Some blocks	None

DATA COLLECTION AND ANALYSIS

By the help of various geological instruments like Schmidt hammer, Brunton compass, hand lens, GPS, hammer and other field observations the following various data has been collected and given in Table 6-8.

[JC (Joint condition) = JL (Joint persistence) x JR (Joint roughness) / JA (Joint alteration)]

The wedge failures are the most prevalent in hard rock masses (Chatziangelou et al., 2002). On the basis of the various slope facets and field observations the following various data has been collected and given in the Table 9-10 for the study of the slope mass rating.

Table 6. Morpholithological parameters of the rock slopes or rock cum debris slope investigated in the study area

Sl. No.	Type of slope	Slope Attitude	Extent of Weathering	Attitude of Rock	Lithology
01.	Rock cum debris slope	72^0/N30^0	Moderate to high	N3°/64°/ N93°	Phyllite
02.	Rock slope	60°/N290°	Moderately weathered	N35/26°/ N125°	Phyllite
03.	Rock slope	87°/N290°	Moderately weathered	N13°/60°/ N105°	Phyllite
04.	Rock slope	84°/N10°	Slightly weathered	N218/60°/ N308°	Phyllite
05.	Rock cum debris slope	75°/N35°	Moderately weathered	N115°/27°/ N205°	Phyllite
06.	Rock slope	88°/N5°	Slightly weathered	N103°/61°/ N13°	Quartzite
07.	Rock slope	88°/N5°	Slightly weathered	N90°/49°/ N0°	Phyllite
08.	Rock slope	78°/N25°	Slightly weathered	N103°/58°/ N13°	Quartzite
09.	Rock slope	75°/N30°	Moderately weathered	N145°/43°/ N55°	Phyllite
10.	Rock slope	59°/N300°	Slightly weathered	N282°/58°/ N192°	Phyllite
11.	Rock slope	88°/N130°	Moderately weathered	N108°/71°/ N19°	Phyllite
12.	Rock slope	65°/N20°	Slightly weathered	N138°/55° /N48°	Quartzite
13.	Rock slope	65°/N0°	Moderately weathered	N192°/32° /N102°	Phyllite
14.	Rock slope	65°/N15°	Slightly weathered	N168°/37°/ N76°	Phyllite
15.	Rock slope	52°/N47°	Moderately weathered	N96°/54°/ N6°	Phyllite
16.	Rock slope	88°/N45°	Slightly weathered	N228°/39°/ N136°	Phyllite
17.	Rock slope	71°/N60°	Slightly weathered	N242/45°/ N138°	Phyllite
18.	Rock slope	85°/N65°	Moderately weathered	N246°/34°/ N156°	Phyllite
19.	Rock slope	87°/N55°	Moderately weathered	N203°/23°/ N122°	Quartzite
20.	Rock slope	88°/N0°	Slightly weathered	N198°/42°/ N105°	Phyllite
21.	Rock slope	90°/N5°	Moderately weathered	N282°/69°/ N195°	Phyllite
22.	Rock slope	90°/N315°	Moderate to high	N309°/29°/ N225°	Phyllite
23.	Rock slope	90°/N320°	Moderately weathered	N208°/55°/ N297°	Phyllite
24.	Rock slope	73°/N40°	Moderately weathered	N250°/51°/ N278°	Phyllite
25.	Rock slope	55°/N10°	Moderately weathered	N210°/41°/ N308°	Phyllite
26.	Rock slope	10°/N40°	Moderately weathered	N206°/58°/ N303°	Phyllite
27.	Rock slope	75°/N345°	Moderately weathered	N180°/60°/ N267°	Phyllite
28.	Rock slope	65°/N0°	Moderately weathered	N213°/46°/ N297°	Phyllite
29.	Rock slope	85°/N345°	Moderately weathered	N12°/37°/ N283°	Phyllite
30.	Rock slope	19°/N345°	Slightly weathered	N8°/20°/ N283°	Phyllite
31.	Rock slope	75°/N350°	Slightly weathered	N220°/65°/ N135°	Phyllite
32.	Rock slope	75°/N340°	Moderately weathered	N198°/80°/ N107°	Phyllite

Table 7. Details of various parameters considered for evaluation of RMR

Sl. No.	S	JF	JS	JL	JR	JA	WC
01	19	31	<0.06-0.19	0.95	Smooth, Stepped, Planer	Thin filling- clay	Wet
02	37	18	<0.06-0.27	1.50	Rough, Stepped	Clean joint/fresh rock	Wet
03	30	23	<0.06-0.36	0.63	Interlocking, rough, Planer	Thin filling-Iron	Dry
04	27	16	<0.06-0.60	0.92	Planer, Rough	Clean Joint	Dry
05	13	66	<0.06	1.56	Planer, Rough	Clean joint/fresh rock	Wet
06	41	6	18-31	0.39	Planer, Rough	Thin filling-Iron, Quartz	Dry
07	36	48	<0.06-0.19	0.61	Planer, Rough	Thin Filling-Clay	Wet
08	40	20	<0.06-0.25	0.46	Stepped, Slightly Smooth	Clean joint/less altered	Dry
09	48	29	<0.06-0.30	0.80	Planer, Rough	Thin Filling-Clay	Wet
10	29	36	<0.06-0.24	0.62	Planer, Rough, Interlocking	Clean joint/less altered	Wet
11	17	19	<0.06-0.43	0.26	Planer, slightly rough	Thin filling-clay, Quartz	Dry
12	43	31	<0.06-0.32	0.22	Stepped, Smooth, Interlocking	Thick filling-Iron, Clay	Dry
13	23	20	<0.06-0.72	1.23	Stepped, rough, Planer	Clean joint/fresh rock	Wet
14	20	31	<0.06-0.55	0.79	Interlocking, Smooth, Stepped	Clean joint/fresh rock	Wet
15	18	40	<0.06-0.29	0.78	Slightly Rough, Planer	Clean joint/fresh rock	Dry
16	17	24	<0.06-0.37	0.93	Planer, rough, Stepped	Clean joint/fresh rock	Dry
17	34	27	<0.06-0.20	0.60	Planer, Slightly rough	Clean joint/fresh rock	Dry
18	45	57	<0.06-0.25	1.08	Slightly smooth, Planer	Thick filling- Clay	Wet
19	35	31	<0.06-0.29	0.66	Planer, Rough	Clean joint/fresh rock	Dry
20	47	9	<0.06-0.61	0.74	Stepped, Smooth, Planer	Thin filling- clay	Wet
21	28	33	<0.06-0.25	0.98	Planer, Rough, Interlocking	Thin Filling, Iron Rusting	Wet
22	25	53	<0.06-0.11	0.62	Smooth, Planer, Stepped	Thin filling/ clay	Dry
23	21	36	<0.06-0.08	1.03	Slightly Rough, Planer	Thin filling/ clay	Wet
24	25	13	<0.06-0.43	0.93	Rough, Planner, Stepped	Thin filling/ clay	Wet
25	26	13	<0.06-0.57	0.73	Slightly Smooth, Planer	Coated with Clay	Semi Dry
26	29	17	<0.06-0.23	0.22	Rough, Planer	Thin fill/Clay	Dry
27	14	12	<0.06-0.27	0.25	Slightly Smooth, Planer	Thin fill/Clay	Dry
28	31	39	<0.06-0.32	0.22	Rough, Planer	Thin fill/Clay	Semi Dry
29	23	34	<0.06-0.15	0.28	Slightly Rough, Planer	Clean joint/fresh rock	Dry
30	23	24	<0.06-0.22	0.14	Slightly Smooth, Planer	Clean joint/fresh rock	Dry
31	28	18	<0.06-0.28	0.22	Slightly Smooth, Planer	Thin fill/Clay	Dry
32	26	16	<0.06-0.27	0.19	Slightly Smooth, Planer	Thin fill/Clay	Dry

Remarks: S = Strength of rock in MPa; JF = Joint frequency/m; JS = Joint spacing in m; JL = Joint length in m; JR = Joint roughness; JA = Joint alteration and WC = water conditions.

Table 8. Estimation of Rock Mass Ratings and Stability Classes

Sl. No.	S	JF	JS	JL	JR	JA	WC	RQD	RMR & Classes
01	2	20	8	4	1	8	7	20	57.50, III
02	4	20	10	2	4	1	7	20	69.00, II
03	4	20	10	4	4.5	4	15	20	73.50, II
04	4	20	10	4	3	1	15	20	81.00, I
05	2	20	5	2	2	6	7	20	54.67, III
06	4	13	10	4	1.5	4	15	13	56.50, III
07	4	20	8	4	2	8	7	20	60.00, III
08	4	20	10	4	2.5	1	15	20	79.00, II
09	4	20	10	4	2	6	7	20	62.39, II
10	4	20	10	4	6	6	7	20	65.00, II
11	2	20	10	4	1.5	6	15	20	68.00, II
12	4	20	10	4	3	4	15	20	72.00, II
13	2	20	10	2	2	6	7	20	59.67, III
14	2	20	10	4	2.5	6	7	20	60.67, III
15	2	20	10	4	2	1	15	20	75.00, II
16	2	20	10	4	2	6	15	20	68.33, II
17	4	20	8	4	1.5	6	15	20	68.00, II
18	4	20	10	2	3	8	7	20	61.75, II
19	4	20	10	4	1.5	6	15	20	70.00, II
20	4	17	15	4	1	3	7	17	61.33, II
21	4	20	10	4	4.5	4	7	20	65.50, II
22	2	20	8	4	1	8	15	20	65.50, II
23	2	20	8	2	1.5	8	7	20	49.00, III
24	2	17	10	4	4	8	7	17	55.00, III
25	4	17	10	4	1	8	15	17	63.50, II
26	4	20	10	4	2	4	15	20	71.00, II
27	2	17	10	4	1	4	15	17	62.00, II
28	4	20	10	4	2	4	15	20	71.00, II
29	2	20	8	4	1.5	1	15	20	71.00, II
30	2	20	10	4	1	1	15	20	71.00, II
31	4	20	10	4	1	4	15	20	70.00, II
32	4	20	10	4	1	4	15	20	70.00, II

Table 9. Orientation of discontinuities and slope

Slope facet	aj	Bj (F2)	as	Bs	Aj-as (F1)	Bj-Bs (F3)	Probable failure
I	11°	31°	29°	73°	-18°	-42°	Wedge
II	26°	46°	17°	82°	9°	-36°	Wedge
III	43°	33°	120°	72°	-77°	-39°	Wedge
IV	133°	45°	31°	58°	102°	-13°	Planar
V	60°	32°	37°	84°	23°	-52°	Wedge
VI	150°	42°	345°	58°	-195°	-16°	Planar

Table 10. Calculation of Slope Mass Rating (SMR) and description of stability classes

Slope facet	RMR	Rating for adjustment factor				SMR	Class	Stability
		F1	F2	F3	F4			
I	66.67	1.00	0.70	-60	+15	34.67	IV	Unstable
II	62.54	0.85	1.00	-60	+15	26.54	IV	Unstable
III	66.85	1.00	0.70	-60	+15	39.85	IV	Unstable
IV	67.84	0.15	0.85	-60	+15	75.19	II	Stable
V	65.32	0.40	0.70	-60	+15	63.52	II	Stable
VI	70.33	1.00	0.85	-60	+15	34.33	IV	Unstable

DISCUSSION

Failure of a slope in the form of wedge can occur when rock masses slide along two intersecting discontinuities, both of which dip out of the cut slope at an oblique angle to the cut face (Hoek and Bray 1981); here the slope face I, II, III and V shows forming a wedge-shaped block. These rock wedges are exposed by excavations that daylight the line of intersection forming the axis of sliding.

Planar failure of rock slope occurs when the mass of rock in a slope slides down along a weak plane (Hoek and Bray 1981); here the

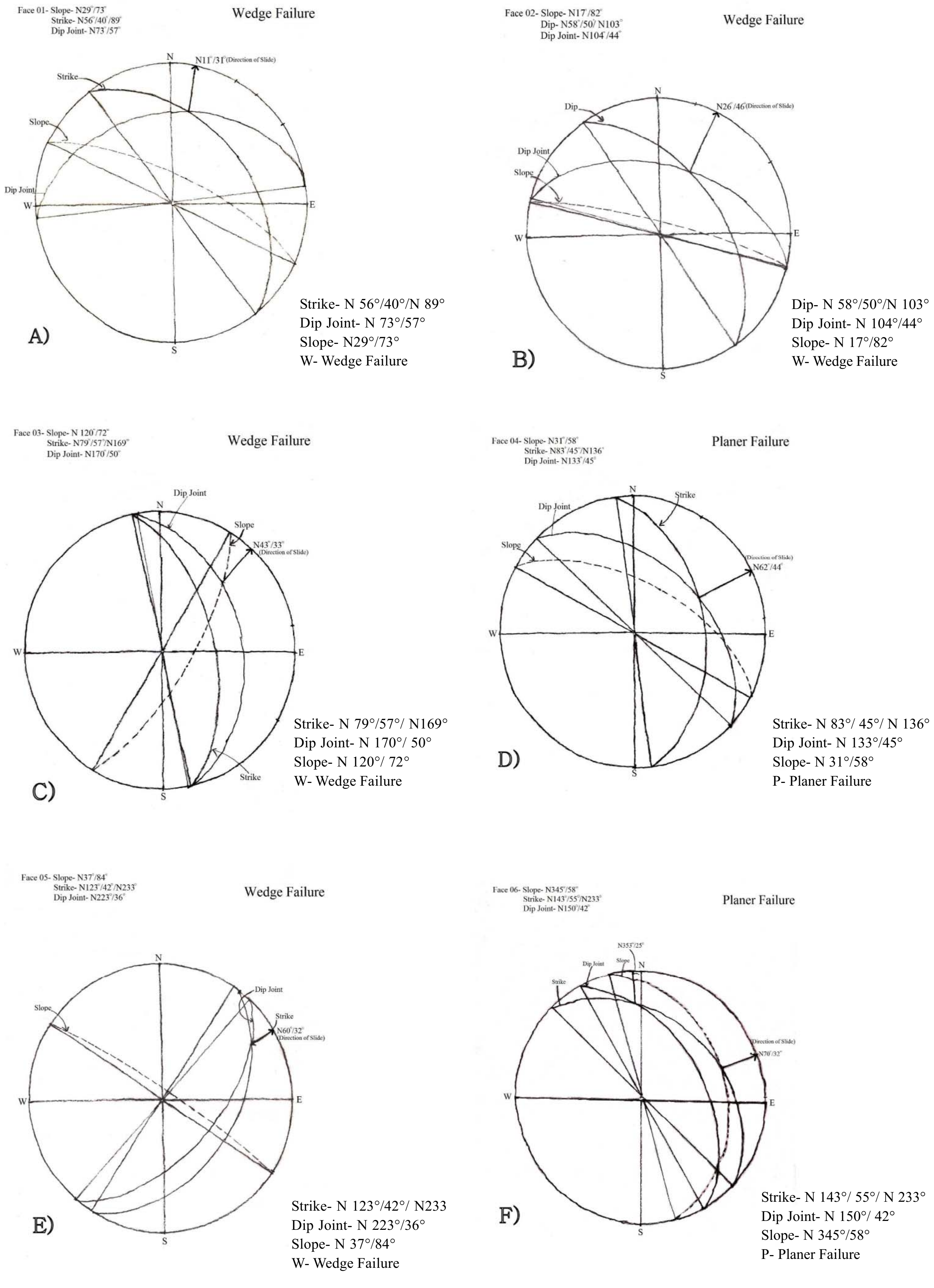

Fig.2. Stereo-plots of discontinuities for various slope facets of Gangadarshan, Srinagar, Garhwal.

32 rock slopes/rock cum debris slopes identified in the study area

Instruments

slope face IV and VI shows such type of failure.

CONCLUSION

For the studied area, the assessment of slope instability of rock slopes was done on the basis of the values of slope mass rating (SMR) so obtained. Different slope facets were categorized into five classes in terms of instability viz. completely unstable, unstable, partially stable, stable and completely stable. In this way, relative slope stability maps were prepared for the study area (from Srinagar to Gangadarshan bend along Srinagar-Pauri road) (Fig.2).

The analysis shows that in the Gangadarshan area out of six rock slope facets, two falls in class II (Stable) and four in class IV (Unstable). It is significant to note that the slope facets coming under class IV are comprised of active landslide portions. While the slopes under class II show minor failure or old landslide debris. The result of this study show that stability classes achieved for the slopes match with field conditions.

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