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Geotechnical evaluation of rock cut slopes using basic Rock Mass Rating (RMR_{basic}), Slope Mass Rating (SMR) and Kinematic Analysis along Islamabad Muzaffarabad Dual Carriageway (IMDC), Pakistan

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Key words: IMDC-Pakistan, Slope mass rating, Kinematic analysis, Basic RMR, Remedial measures for rock cut slopes.

Abstract

Present study focuses on the geotechnical evaluation of rock instability along Islamabad -Muzaffarabad Dual Carriageway (IMDC). Review of the recent literature helped devising the methodology and accordingly activities for field studies were planned. Field studies included identifications of instability prone sites, recording of slope geometry, undertaking discontinuity surveys to record characteristics of the discontinuity for onward slope/rock mass characterization and classification, and rock/soil sampling at the representative locations for each rock/ soil units. Some field testing on rock samples was also undertaken. The field data was empirically and kinematically analyzed for the appraisal of slope failures and quality of rock mass. As outcome of the kinematic analyses, 38% sections have potential for plane and wedge failures. The rock quality lies in fair category as the result of rock mass rating (RMR). The slopes are partially stable to completely unstable according to slope mass rating (SMR). In view of the stability assessment of the studied sites and prevailing failure mechanisms, appropriate remedial measures were proposed for short as well long-term stability comprising rock benching, scaling off of loose rock blocks on the slopes, widening and periodic cleaning of catchment ditches, rehabilitation of existing retaining walls, shotcreting and rock bolting.

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Introduction

Slope stability is an important issue for construction of roads in hill slopes. The excavation of cut slopes without proper designing can cause different slope stability issues and failures. Plane and wedge failures, rock topples and rock falls are the common form of slope failures (Hoek & Bray, Rock Slope Engineering, 1981). The probability of slope failures is greater than any other geological hazard such as tornadoes, floods and earthquake (Schuster, 1992).

The disruption in natural slopes can cause catastrophic slope failures that may endanger the human life, damage the properties and ultimately blockage of roads. To avoid these disastrous events, the study of cut slopes using the empirical and kinematic investigations for the proper designs is always emphasized (Shakoor, 1995) & (Hoek & Brown, 1980). For designing safe and stable cut slopes, comprehending the behavior of rock/soil mass and its geological and geotechnical characteristics is indispensable.

Various researchers had published their work on slope studies using similar slope stability techniques. Gurocak, *et al.*, (2008) published their work on slope stability of dam in Turkey. Abad, *et al.*, (2011) used kinematic analysis and slope mass rating for the stability analysis of slopes of Johor. Akram & Farooq, (2014) evaluated the cut slopes of Sherton hotel, Islamabad for stability analysis in similar rocks of present studies. Hussain, *et al.*, (2015) investigated the slopes of national highway in India, by using similar techniques. Majeed & Bakar, (2015) utilized the joint orientation data for rock slopes in Choa Saidan Shah, Pakistan. Noor, *et al.*, (2017) presented their research on back analysis for the design of a landslide in Mansehra, Pakistan.

Slope instabilities increases when slopes are cut in weak rocks. Islamabad-Muzaffarabad Dual Carriageway (IMDC) road was constructed by excavating the slopes in weak rocks of Murree Formation of Early Miocene age to connect the capital of Pakistan with Azad Kashmir. The induce slope failures blocked the road for the couple of hour(s) to days which can cause the economic loss and harmful for travelers from Pakistan to Azad Kashmir. The detail geotechnical studies were conducted for designing the stable slopes along the road. The present study focuses on the identification of potential slope failures susceptible sites, geotechnical evaluation of identified rock cut slopes and remedial measures. Twelve (12) representative sites were selected along the entire route.

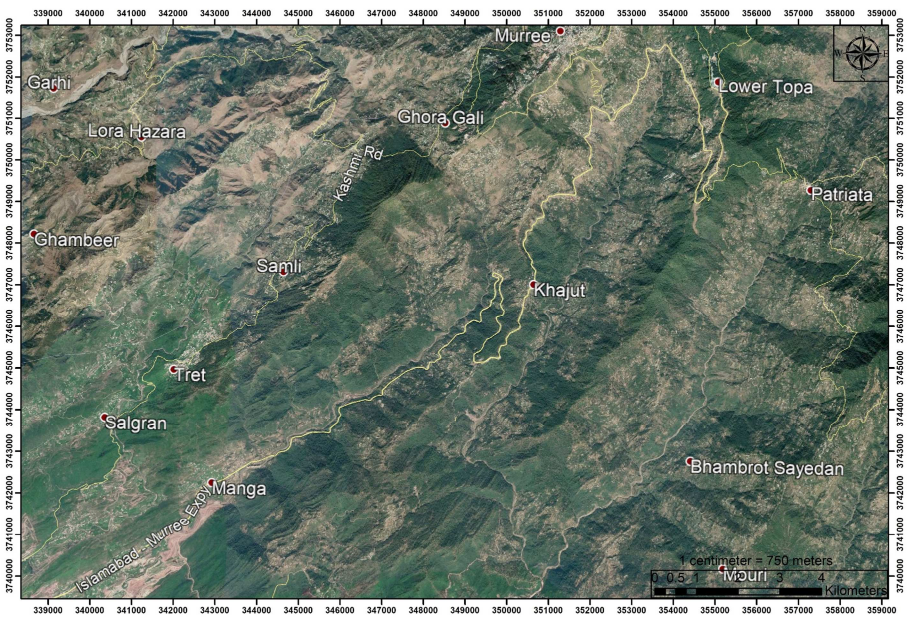

Fig. 1. Location Map of the Area under Consideration.

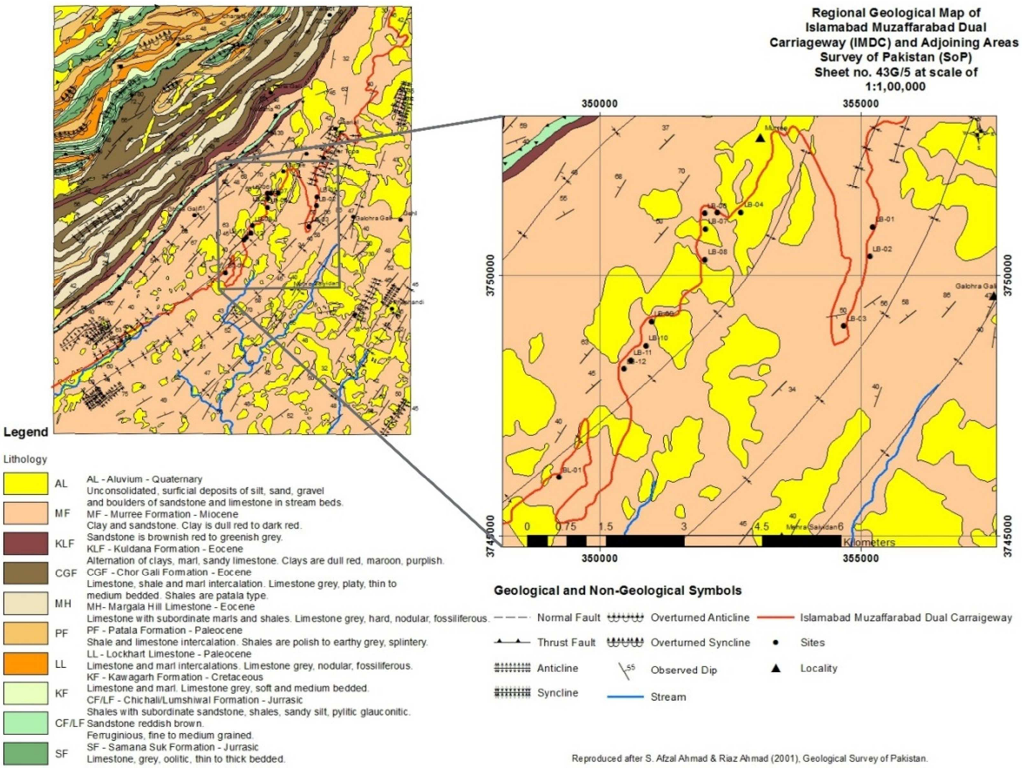

Fig. 2. Regional Geological Map of the Area after S. Afzal Ahmed & Riaz Ahmed (2001).

The research area is located between Bhara Kahu and Lower Topa, Pakistan. The area lies between 331069 to 355140 Easting and 3735372 to 3751572 Northing. The project area is 15 Km away from Islamabad and 6 Km away from Murree respectively, easily accessible through Islamabad Muzaffarabad Dual Carriageway (IMDC). Fig. 1 showing the location map of the study area. The geology along IMDC mainly comprised of alternative beds of siltstone/sandstone and claystone/ shale of Murree Formation of Early Miocene age. Sandstone is present in massive and blocky while shale is thinly bedded and laminated (Ibrahim Shah, 1977) & (Kazmi & Jan, 1997). The project area is bounded by Himalayan Frontal Thrust (HFT) in South and Main Boundary Thrust (MBT) in North designated as Sub-Himalayas. The regional geological map of the area is given in Fig. 2.

Materials and methods

The study of cut slopes accomplished in three substantial steps, i.e., field investigations, identification of potential instability prone sites and slopes stability analysis by using empirical rock mass and kinematic analyses.

Identification of instability prone sites

During the reconnaissance survey from Bhara Kahu, Islamabad to Lower Topa, Murree, twelve (12) representative sites were selected. Each site was designated a number with the acronym of Lower Topa (L) and Bhara Kahu (B) separated by hyphen where LB referred to the expedition from Lower Topa to Bhara Kahu and vice-versa, e.g., LB-01. Some sites had more than one representative sections. They were assigned with the additional letter 'S' and a numeric digit. During site visit, information regarding problems associated with stability of slopes was gathered.

Field investigations

A field investigation is as a definite and most crucial part of every similar study. It was conducted for collecting data regarding discontinuity characteristics, hydrologic conditions and sampling of various identified lithological units.

Discontinuity data

Window mapping method as an effective method in such case was used for collecting discontinuity data by following the guidelines of International Society of

Rock Mechanics (ISRM). In window mapping method, all discontinuities are measured within a representative area or "window" (Wyllie, 2018). In this study, orthogonal joint sets were observed. In addition to these joint sets, random joints were witnessed. Discontinuity orientation (strike/ dip or dip direction/ dip) measurements were made using a Brunton compass and smartphone application Clino (Farny, 2017) & (Midland Valley Exploration Ltd, 2016). Discontinuity spacing was calculated by measuring the perpendicular distance between two adjacent joints of the same joint set using a measuring tape. Discontinuity aperture was measured using a ruler. The continuity of discontinuities was determined using a measuring tape. The profilometer was used to record joint wall roughness.

Estimation of rock strength

The strength of the rocks is the most important factor to be determined in geotechnical investigations. In course of present study, the strength of rocks is estimated by following methods.

Wall strength by Schmidt Rebound Hammer

During the field studies, Schmidt rebound hammer was used for indirect estimation of rock strength. Rebound number (Rn) value was determined from Schmidt rebound hammer by subjecting it perpendicular on the joint wall surface. According to ISRM standard guidelines, Rn value is correlated with unit weight using correlation chart to find uniaxial compressive strength (Miller, 1965).

Uniaxial compressive strength by Point Load Test

Rock samples can loose moisture contant when transported to laboratory, hence its strenght can also varies if tested in the field and laboratory (Vásárhelyi & Ván, 2006). For estamiting the strength of rocks, point load load testing machine (PLTM) was utilized at the site to avoid the loss of moisture contant. Testing was performed according to ISRM suggested method. 150 irregular samples were subjected to fail under PLTM for the determination of point load index (I_s) using the correlation given below:

$$I_s = \frac{P}{{D_e}^2}$$

where, ${D_e}^2$ = 4A/ π

$$A = WD$$

where, A is a minimum cross-sectional area

W = sample width or diameter;

D = platen separation

The I_s values were then corrected to correspond to a 50-mm diameter core sample by multiplying with a size correction factor, F, as follows:

$$I_{s50} = F \times Is$$

Where F = $(De/50)^{0.45}$

According to (Khan, 2016), a relation of Uniaxial Compressive Strength (UCS) and Point Load Test for Murree Formation rock units as shown in Fig. 3, i.e.,

$$UCS = 21.016 \times Is_{50}$$

The same correlation was used in the present study for indirect estimation of UCS from Point Load Index (Is_{50}).

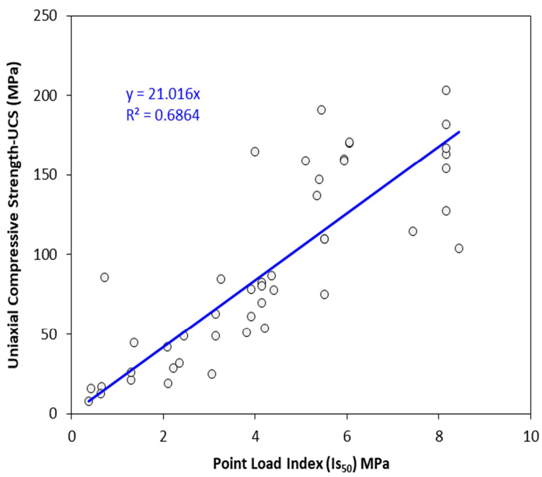

Fig. 3. Relation of UCS and Point Load Test for Murree Formation.

Estimation of geotechnical parameters

Geotechnical parameters including Joint volumetric count (Jv) and Rock quality designation (RQD) were estimated using the (Palmstrom, 1995) correlations in below:

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots \frac{1}{S_n} + \frac{N_R}{5}$$

$$RQD = 110 - 2.5J_V$$

Here, S_1, S_2, S_3...S_n represents the spacing of joints in meters for joint set 1,2,3 and so on. N_R is the number of random joints and according to (Palmstrom, 1995), the spacing of 5m should be used for random joints and RQD is the rock quality designation in percentage (%).

Kinematic analyses

Potential for the various modes of failures (wedge, plane and toppling) are analyzed using the kinematic analysis. The angles of slope face with discontinuity planes defines the modes of failure. A wedge is formed by the intersectin of two discontinuities such that line of intersection is parallel or near parallel to slope face having plunge less than slope face but greater than friction angle (Markland, 1972) & (Hoek & Bray, 1981). If the discontinuity plane (parallel or near parallel to slope face) is steeper than angle of friction and gentler than slope face angle, plane failure is likely (Markland, 1972) & (Hoek & Bray, 1981). The steeply dipping discontinuities parallel to the slope face with inside dipping may topple about their pivot point when the center of gravity is outside the base of toppling block (Markland, 1972), (Goodman, 1989) & (Hoek & Bray, 1981).

Rock mass analysis

In present study, the rock mass is empirically analyzed using basic rock mass rating (RMR_{basic}) and slope mass rating (SMR). In RMR, the discontinuities parameters including persistence, aperture, roughness, infilling and extent of weathering defines the condition of joints along the slope. The other parameters include rock quality designation (RQD), spacing, compressive strength and water condition of joints for the rock mass analysis. The final rating is determined by adding up the rating contribution of each individual parameter (Bieniawski, 1989). The slope mass rating system was introduced by Romana (Singh & Goel, 2011), modified by Anbhalagan and Tomas *et al* (Singh & Goel, 2011) by defining the orientation adjustment condition of joints for the slopes. They introduced four additional parameters F1, F2, F3 and F4 for this adjustment. Romana defined the discrete rating system for these adjustment factor where the ratings decreases abruptly at the margin of the conditions. The graphical continuous rating system for the adjustment factors were introduced by (Tomás, Roberto, Marchal, José, & Serón, 2007).

Results and discussions

Kinematic analyses

Dips V.7.0 software of rocscience (Rocscience Inc., 2016) is based on stereographic projection technique and allows the determination of mode of failures. The advance kinematic analysis option was utilized for all 21 sections. During the investigations, 63 different analyses were performed in *Dips*. The data was imported in the form of dip/dip direction and equal angel projection technique was used. In the present study, the plane and wedge failures are common modes of failure because of the steeply dipping nature of discontinuities. While, toppling failures are not found along slopes. The modes of failure along each site are given in **Error! Reference source not found.** and stereographic projections showing likelihood of planar and wedge failures at various sites as given in Fig. 4. The Joint Set 2 is mainly contributing to plane as well as to wedge failures. Thus, it can be predicted that J_2 will ultimately result in wedge failures causing slope instability.

Table 1. Summary of Results of Kinematic Analyses.

Site	Existing Slope Angle (Deg)	Plane Failure Potential	Wedge Failure Potential	Toppling Failure Potential
LB-01	49	No	No	No
LB-02	64	No	No	No
LB-03	54	No	No	No
LB-04	68	No	No	No
LB-05	68	No	No	No
LB-06	60	Yes	Yes	No
	85	Yes	Yes	No
LB-07 S-1	70	Yes	Yes	No
LB-07 S-2	62	No	No	No
LB-07 S-3	45	No	No	No
LB-08 S-1	48	No	No	No
	82	Yes	Yes	No
LB-08 S-2	42	No	No	No
LB-08 S-3	46	No	No	No
	69	No	No	No
LB-09 S-1	48	No	No	No
LB-09 S-2	40	No	No	No
LB-10 S-1	58	Yes	Yes	No
LB-10 S-2	60	No	No	No
LB-10 S-3	60	Yes	Yes	No
	70	Yes	Yes	No
LB-11 S-1	79	Yes	Yes	No
LB-11 S-2	70	Yes	Yes	No
	81	Yes	Yes	No
LB-12 S-1	51	No	No	No

BL-01	61	Yes	Yes	No

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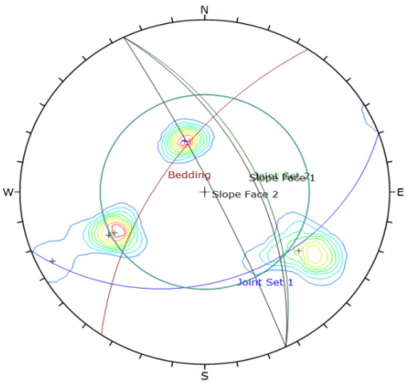
(a) Plane Failure along Joint Set 2 is likely. Wedge Failure along the line of intersection of Bedding Joint & Joint Set 2 is not likely but Slide will occur along Joint Set 2.



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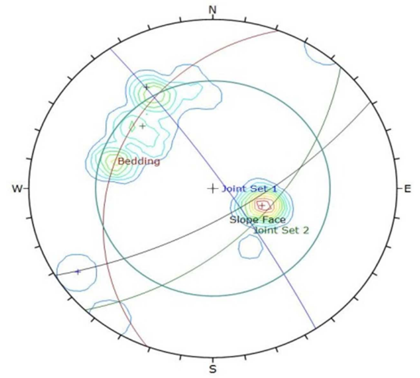
(b) Plane Failure along Joint Set 2 & Wedge Failure along the line of intersection of Joint Sets 1 and 2 are likely.



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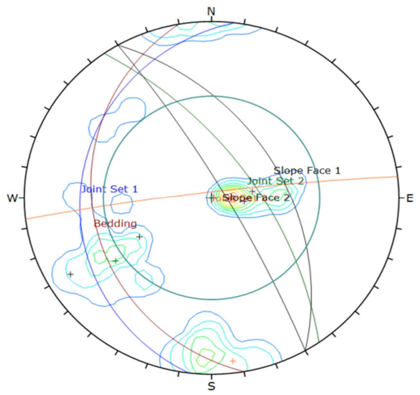
(c) Plane Failure along Joint Set 2 & Wedge Failure along the line of intersection of Joint Sets 2 and 3 are likely.



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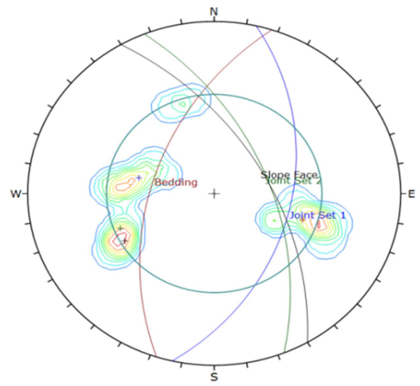
(d) Plane Failure along Joint Set 2 is likely. Wedge Failure along the line of intersection of Bedding Joint & Joint Set 2 is not likely but Slide will occur along Joint Set 2.



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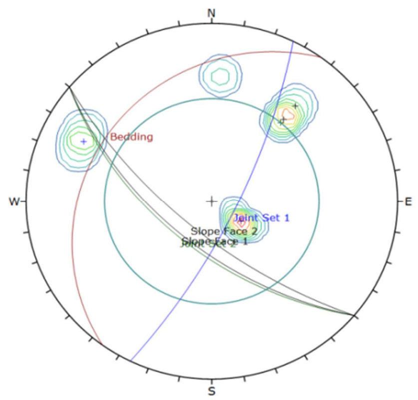
(e) Plane Failure along Joint Set 2 is likely. Wedge Failure along the line of intersection of Joint Sets 1 and 2 is not likely but Slide will occur along Joint Set 2.



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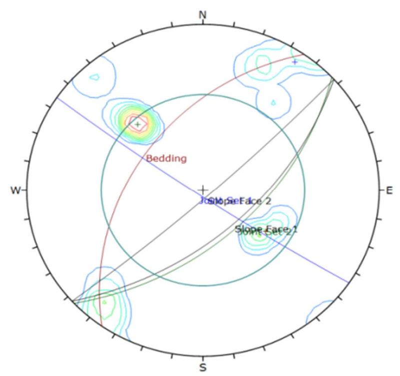
(f) Plane Failure along Joint Set 2 & Wedge Failure along the line of intersection of Joint Sets 1 and 2 are likely.



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(g) Plane Failure along Joint Set 2 & Wedge Failure along the line of intersection of Joint Sets 1 and 2 are

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(h) Plane Failure along Joint Set 2 & Wedge Failure along the line of intersection of Joint Sets 1 and 2 are

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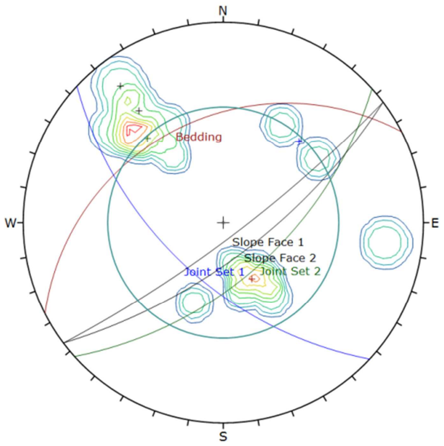
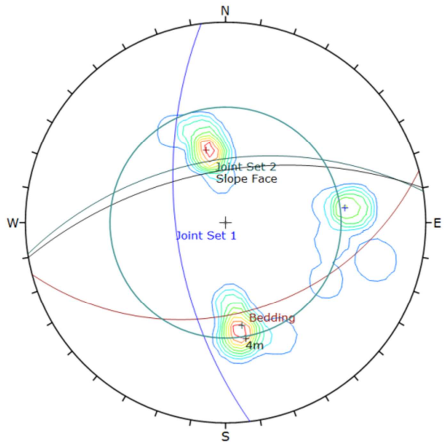
likely.	likely.
	

Fig. 4. Stereographic Projections (a) LB-06, (b) LB-07 S1, (c) LB-08 S1, (d) LB-10 S1, (e) LB-10 S3, (f) LB-11 S1, (g) LB-11 S2 & (h) BL-01.

Empirical Rock Mass Analysis

The discontinuity parameters recorded during field data collection were utilized for the empirical rock mass analysis. The ratings of individual parameters were given according to the guidelines of Bieniawski. In the present study, the sum of ratings of individual parameter are in the range of RMR that lay between 42 to 60 and rocks were characterized as fair.

The detail of rating of each site is given in **Error! Reference source not found.**. The results of kinematic analysis were used for the adjustment factor of orientation using slope mass rating guidelines of Romana and Tomas. The SMR results showed that the slopes were partially stable to completely unstable. The slopes with no mode of failures were not analyzed under slope mass rating. The detail results of SMR are attached in Table 3.

Table 2. Rock Mass Rating (RMR) for Slopes.

Site Name	Ratings of the parameters of Rock Mass Rating (RMR)									Total RMR	Rock Quality
	Strength	RQD	Spacing	Condition of Joints					Water Condition		
LB-1	7	8	8	6	1	3	2	5	15	55	Fair
LB-2	7	13	10	2	0	3	0	5	15	55	Fair
LB-3	4	8	8	2	1	5	2	5	15	50	Fair
LB-4	2	17	10	2	0	5	0	5	10	51	Fair
LB-5	4	17	10	1	1	5	2	5	10	55	Fair
LB-6	4	8	8	4	0	5	0	5	15	49	Fair
LB-7 S-1	4	13	10	2	1	3	2	5	15	55	Fair
LB-7 S-2	7	13	10	2	0	3	0	5	15	55	Fair
LB-7 S-3	7	13	8	2	0	5	0	5	15	55	Fair
LB-8 S-1	4	8	8	2	0	3	0	5	15	45	Fair
LB-8 S-2	7	17	10	1	0	5	0	5	15	60	Fair
LB-8 S-3	4	13	10	2	0	3	0	5	15	52	Fair
LB-9 S-1	4	13	8	2	0	5	0	5	15	52	Fair
LB-9 S-2	4	8	8	2	0	5	0	5	10	42	Fair
LB-10 S-1	7	17	10	0	0	5	0	5	10	54	Fair
LB-10 S-2	4	13	8	0	0	5	0	5	10	45	Fair
LB-10 S-3	2	13	8	2	0	5	0	5	15	50	Fair
LB-11 S-1	2	13	8	4	0	5	0	5	15	52	Fair

Site Name	Ratings of the parameters of Rock Mass Rating (RMR)									Total RMR	Rock Quality
	Strength	RQD	Spacing	Condition of Joints					Water Condition		
LB-11 S-2	2	13	10	4	0	5	0	5	15	54	Fair
LB-12 S-1	4	17	10	1	1	5	2	5	15	60	Fair
BL-1	4	17	10	2	0	3	0	5	15	56	Fair

Table 3. Slope Mass Rating (SMR) of various sites.

Site no.	Slope Mass Rating (SMR)					
	Discrete	Stability	Description	Continuous	Stability	Description
LB-06	41	Partially Stable	Normal	39	Unstable	Bad
	41	Partially Stable	Normal	39	Unstable	Bad
LB-07 S1	13	Completely Unstable	Very Bad	13	Completely Unstable	Very Bad
LB-08 S1	3	Completely Unstable	Very Bad	4	Completely Unstable	Very Bad
LB-10 S1	50	Partially Stable	Normal	50	Partially Stable	Normal
LB-10 S3	42	Partially Stable	Normal	35	Unstable	Bad
	41	Partially Stable	Normal	35	Unstable	Bad
LB-11 S1	9	Completely Unstable	Very Bad	4	Completely Unstable	Very Bad
	1	Completely Unstable	Very Bad	1	Completely Unstable	Very Bad
LB-11 S2	45	Partially Stable	Normal	39	Unstable	Bad
	45	Partially Stable	Normal	39	Unstable	Bad
BL-01	47	Partially Stable	Normal	41	Partially Stable	Normal

Conclusions

Based on the results of this study, the lithology along the cut slopes of IMDC is dominantly shale/claystone (incompetent) and at some places sandstone (competent) is dominant. Murree Formation is orthogonally jointed, i.e., joint sets are perpendicular to each other. In addition to that, some random joints are also present. Kinematically some slopes are stable; however, the erosion of the underlying softer lithology may rise to the slope instability failures i.e., plane and wedge failures. The Joint Set 2 is majorly contributing to plane as well as to wedge failures. Thus, it can be predicted that J_2 will ultimately result in wedge failures causing slope instability. As outcome of the kinematic analyses, various sites are prone to basic mode of failures including LB-06, LB-07 S1, LB-08 S1, LB-10 S1, LB-10 S3, LB-11 S1, LB-11 S2 and BL-01. Empirically, the rock mass quality along IMDC falls in fair category, according to RMR, while SMR categorized the slopes as partially stable to completely unstable.

Recommendations

In view of the stability assessment of the studied sites and prevailing failure mechanisms, appropriate remedial measures are proposed such as loose weathered material on slope faces should be treated by using shotcreting. Rock anchors should be used as a stabilization measure where the incompetent rock units are relatively widely spaced joints and are likely to fall. Appropriate bench widths should be constructed so that benches do not act as direct rock falls. Construction of backslope and mid-slope drains can reduce the amount of surface runoff water and groundwater seepage. The detail study of FOS of plane and wedges is recommended. It is also recommended that rockfall simulation analysis should be performed in the further studies for the maximum effectiveness of catchment ditches. The constructed walls should be able to withstand the rockfall impact and catchment ditches should be cleaned periodically.

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