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TECHNICAL NOTE

A Classification System for the Slope Stability Assessment of Opencast Coal Mines in Central India

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1 Introduction

There are many empirical methods of rock mass classification, which are directly or indirectly used for the purpose of slope designs in opencast mines. Most of these empirical methods are basically derived from the rock mass rating (RMR) system (Bieniawski 1973) either by extending or by modifying the existing system. Duran and Douglas (2000) also observed that most of the RMR techniques have been based upon or are similar to Bieniawski's RMR system. The latest version of RMR system (Bieniawski 1989) has a total rating of 100 of which only 15 is contributed from the intact rock strength (IRS). The rock quality designation (RQD), discontinuities and ground water, which account for a maximum rating of 20, 50 and 15, respectively, are one-fifth, half and about one-sixth part, respectively, of the total rating in RMR system. The RQD indirectly includes the effect of discontinuity spacing, and thus discontinuity effects grossly override the influence of intact rock in the assessment of RMR. This appears to be more logical in cases, where rock mass behavior in slopes is controlled more by structures than by IRS. Furthermore, the effect of water is reflected in the ratings of IRS and discontinuity condition. The effect of water can be better accounted for during the stability analysis.

The other empirical classification systems like MRMR (Laubscher 1977), SMR (Romana 1985), M-RMR (Unal 1996), SRMR (Robertson 1988) and GSI (Hoek et al. 1995) also place more significance on the structures than on the IRS. The ratings of structural effects account for 70–80 out of the total rating of 100 in these systems. The IRS has a maximum rating in the range of 15–30 in these systems. The SRMR system allows a maximum rating of 30 for IRS and provides a rating of 17 for the rock strength of 5–25 MPa as against a rating of 2 in the RMR system. The other factors in SRMR system are similar to RMR system, except that SRMR system includes the handled RQD and handled discontinuity spacing. Robertson (1988) proposed this system based on his studies at Island Copper Mine, USA and cautioned that more case studies were required before the system could be used with confidence. The SMR system is an extension of RMR system and includes adjustment factors for discontinuity orientation vis-à-vis the slope and the method of excavation. Romana (1985) derived SMR system from the studies of natural and cut slopes along the roads. The application of this system to open pit slopes is not yet fully established and can be applied only to slopes, where slope stability is mainly controlled by structures.

The M-RMR system as developed by Unal (1996) is also based on the RMR system and includes additional features for the characterization of weak, stratified, anisotropic and clay bearing rock masses. The system is based on a limited database of three mines only and hence has inherent limitations. The ratings for uniaxial compressive strength (UCS), RQD, joint condition, joint spacing, ground water and joint orientation are indicated by I_{UCS}, I_{RQD}, I_{JC}, I_{JS}, I_{GW} and I_{JO}, respectively. F_c stands for

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weathering coefficient and A_b and A_w are the adjustment factors for blasting and major planes of weakness, respectively. Unal (1996) suggested separate formulae for the determination of individual ratings of above parameters and proposed the following equation for the determination of M-RMR (Eq. 1). This system appears to be a little complicated for the purpose of rock mass assessment.

$$\text{M-RMR} = A_b A_w (F_c (I_{UCS} + I_{RQD} + I_{JC}) + I_{JS} + I_{GW} + I_{JO}) \quad (1)$$

The above mentioned empirical systems are used basically to define the rock mass and hardly take into account other extraneous parameters, which define the actual slope condition in mines. In view of the above, these classification systems are not fully suited to appropriately assess the rock mass of the opencast coal mines from the slope stability point of view.

2 The Origin of New Classification System for the Slope Stability Assessment

The system is conceived and developed based on the author's research work and experience on slope stability of six opencast coal mines in Wardha Valley Coalfield (WVC). The WVC is a NW–SE elongated structural basin with its coal bearing zone spreading over an area of 800 km^2 along a length of 116 km and is situated toward the south of the city of Nagpur in the central region of India (Jhanwar 2010). This coalfield has around 40 opencast coal mines, with annual coal production from each mine ranging mostly between 0.5 and 1.5 million tonnes and mine depths varying mainly between 70 and 150 m.

The slope stability scenario in WVC is typically governed by several factors like the thickness of soil, condition of sandstone rock mass, presence of major and minor strike faults, infiltration of rainwater into slope, presence of external loads on slopes in the form of overburden dumps, etc. The rock slope failures in the mines, where study was conducted involved mainly the failures of very weak to weak sandstone rock. The RMR of the sandstone rock masses in these mines varied from 35 to 46 and the corresponding maximum rating of IRS was 4 only. More specifically, the IRS of sandstone varied predominantly in the range of 5–25 MPa and contributed a rating of only 2 in the total RMR of 40.

Interestingly, the basic RMR (Bieniawski 1989) of failed slopes of these opencast mines varied from 36 to 43, which was not very much different from the overall range of RMR in these mines and signified upper bound of poor and lower bound of fair rock mass, according to the RMR specified rock mass classes. The failed sandstone rock masses were classified mainly as very weak to weak with IRSs varying predominantly between 4 and 15 MPa (ISRM 1981). However, the IRS accounted for a rating of 1–2 only in the overall RMR of failed rock slopes. This indicated that the RMR system did not adequately reflect the actual rock mass condition (RMC) in these coal mines from the slope stability point of view.

Furthermore, it was observed that the actual slope behavior in these opencast coal mines was not only controlled by rock mass, but also by the extraneous factors controlling the respective slope conditions as mentioned earlier. In view of this, it was felt that apart from the rock mass assessment, it was equally important to assess the existing slope condition also to make a practical assessment of the slope stability of a given coal mine. In view of the above, an empirical system was developed, which took into account all the intrinsic and extraneous parameters/factors, which were significant to the slope stability in opencast coal mines of WVC.

3 Details of the Slope Stability Assessment System

3.1 General Description

Based on the experience gained during his research work, the author developed a new classification system to assess the slope stability status of opencast coal mines of WVC (Jhanwar 2010). The developed system was named as "OPCASSTA-COAL" (Opencast Slope Stability Assessment System for Coal Mines). A broad flowchart of this system is depicted in Fig. 1. The system was applied to assess the RMC, the slope condition and the slope failure hazard in two coal mines of WVC and was found to be of practical application. This system could be used to identify discrete sectors in a given coal mine based on the slope condition and slope failure hazard.

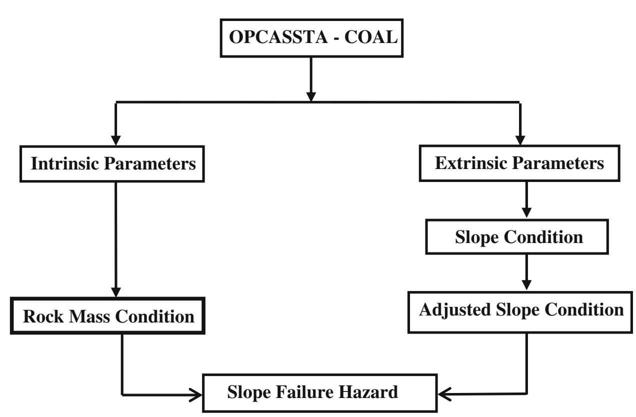

Fig. 1 Flowchart for the slope stability assessment of opencast coal mines

The parameters that formed the basis of "OPCASSTA-COAL" were identified by the author during his slope stability studies in various opencast coal mines, and thus were based upon his experience and engineering judgment. The basic advantages of this system are mentioned below:

1. It is simple and easy to be applied in the opencast coal mines,
2. The RMC, the slope condition and the slope failure hazard can be assessed concurrently with the progress of mine workings, and
3. Slope control measures can be derived and implemented on real time basis based on the slope failure hazard.

The system essentially consists of two components: one that deals with the intrinsic parameters of rock mass is named as RMC (Table 1) and the other that deals with the extrinsic parameters is named as slope condition (SC) (Table 2). The slope condition is adjusted on the basis of certain parameters, which may have variable significance specific to a given opencast coal mine as shown in Table 3 and is rated in four different classes (Table 4). Based on the various combinations of RMC and adjusted SC, the slope failure hazard (SFH) is estimated as shown in Table 5.

3.2 Assessment of Rock Mass Condition

The RMC assessment involves two steps viz. determination of IRS and the determination of volumetric joint count (J_v). The J_v is measured as the total number of joints intersected in the unit volume of rock mass and signifies the resulting block size in the in situ rock mass. The line mapping method was mainly used for structural mapping in the field. The IRS and J_v are rated separately and the sum of their ratings is grouped into five discrete classes signifying different RMCs as shown in Table 1.

3.3 Assessment of Slope Condition

The slope condition is assessed based on the influence of strike fault near or within the mine workings, spoil dump near the slope crest, localized instabilities on the benches and drainage condition in the mine. The ratings for different parameters are shown in Table 2.

Table 2 Rating system for the assessment of slope condition

Serial number	Parameter description	Rating
1	Presence of strike fault	(0–20)
	No	20
	Yes	(0–15)
	(D_f = 0–5, 5–10, 10–20, 20–30, >30)	0, 3, 7, 10, 15
	(D_f is the distance of fault from workings, m)	(corresponding values)
2	Spoil dump on the slope	(0–20)
	[H is the height of dump (m) and D is the distance of dump from slope crest (m)]	
	D: 0–15; H: <10, 10–20, 20–30, >30	15, 10, 5, 0 (corresponding values)
	D: 15–30; H: <10, 10–20, 20–30, >30	17, 15, 12, 10 (corresponding values)
	D: 30–50; H: <10, 10–20, 20–30, >30	20, 18, 15, 12 (corresponding values)
	D: >50 m or no dump	20
3	Presence of localized slope instabilities/cracks (yes–no)	(0–20)
4	Drainage pattern (bad–good)	(0–10)
5	Total rating	0–70

3.4 Adjustment of Slope Condition

The slope condition is adjusted for different parameters of variable significance. The adjustment parameters like the presence of fire in the developed coal seam and/or underground workings, rainfall pattern, etc. are essentially mine specific and are of variable significance. In this category, an undefined parameter, which may have an overriding influence on slope stability, is also included for adjustment.

Table 1 Rating system for the assessment of rock mass condition

Parameters		Range of values				
1	Intact rock strength (MPa)	0.25–1	1–5	5–15	15–25	25–50
	Rating	0	1	2	3–5	6–10
2	Number of joints/m^3 (J_v)	>30	10–30	3–10	1–3	0
	Rating	0	1–3	4–7	8–10	12
	RMC (class)	Extremely poor (1)	Very poor (2)	Poor (3)	Fair (4)	Good (5)
	Total rating (1 + 2)	0–4	5–9	10–14	15–20	>20

Table 3 Adjustment of rating for slope condition

Serial number	Parameters	Adjustment rating
1	Presence of active fire in the developed coal seam and/or unstable underground workings	−10 to −20
2	Rainfall	+5 to −25
	(A) Cumulative rainfall in the last 45–60 days: >150 mm	−5 to −20
	(1) Extremely weak to weak rock	−20
	(2) Fair rock	−10
	(3) Good rock	−5
	(B) Rain in the last 7–10 days: 50–75 mm	−5
	(C) No rain in the last 10 days	+10
3	Any other parameter, which may have an influence on the slope stability	−5 to −20
4	Total adjusted rating	0–80

Table 4 Definition of slope condition rating

Rating	Slope condition (level)
0–25	Very poor (1)
26–45	Poor (2)
46–65	Fair (3)
66–80	Good (4)

Table 5 Matrix for the assessment of slope failure hazard

RMC	SC			
	Very poor (1)	Poor (2)	Fair (3)	Good (4)
Extremely poor (1)	A	A	A	B
Very poor (2)	B	B	C	C
Poor (3)	B	B	C	D
Fair (4)	B	C	D	E
Good (5)	C	D	E	E

This parameter can represent any mine specific factor/situation, which is not taken into account in any of the categories mentioned in Table 2. Different adjustment parameters with their ratings are shown in Table 3. Based on the adjusted slope condition rating, a slope is classified into a specific class between very poor and good as indicated in Table 4.

3.5 Assessment of the Slope Failure Hazard

Based on the assessment of RMC and SC, an assessment of the SFH is made as indicated in Table 5. This is done through a matrix of RMC and SC, which indicates a measure of the SFH based on the various combinations of RMC and SC (Table 6).

Table 6 Definition of ratings for slope failure hazard

Rating	Meaning
A	Very high
B	High
C	Medium
D	Low
E	Very low

4 Validation of the Slope Stability Assessment System (OPCASSTA-COAL)

4.1 General Details of the Opencast Mines

The “OPCASSTA-COAL” was applied to the slopes of two opencast coal mines viz. Navin Kunada Opencast (NKOC) and Dhorwasa Opencast (DOC) mines of WVC to test its validity. These mines are situated close to each other at a distance of around 125 km south of the city of Nagpur in central India. The annual coal production of each mine is in the range of 0.5–0.6 million tonnes. The current depths of these mines vary from 55 to 65 m, whereas the ultimate depth will vary from 85 to 100 m (Jhanwar 2010). The overburden at these mines mainly consists of soil of thickness varying from 6 to 30 m followed by Kamthi sandstone and Barakar sandstone. There is only one coal seam with a thickness of 15–20 m, which has a gradient of 1 in 4 to 1 in 7 and dips toward S 11°W. Groundwater is found at a depth of 26–32 m in Kamthi sandstone.

4.2 Geology and Rock Mass Condition at NKOC Mine

The rock mass in the dip side of NKOC mine is classified as poor with RMR in the range of 34–40. However, the RMR of the sandstone in lower regions goes up to 50. The dip side slope can typically be characterized as poorly stable with signs of small-scale instabilities and the fractured nature of rock mass (Fig. 2). However, any large scale slope instability is not apparent. Sandstone in the dip side is more fractured and weathered than in the rise side. A 120 m throw fault runs along the strike on the dip side of this mine. The fault plane is partly exposed after the slide of overlying sandstone rock mass (Fig. 3).

The rise side rock mass is characterized as poor to fair with RMR in the range of 35–55. No small or large scale instability is observed on the rise side slope. Bedding joint is prominent all over the mine. The intact rock is very

Fig. 2 Dip side slope of NKOC mine showing the localized instabilities

Fig. 3 A view of the dip side slope of Navin Kunada Opencast mine

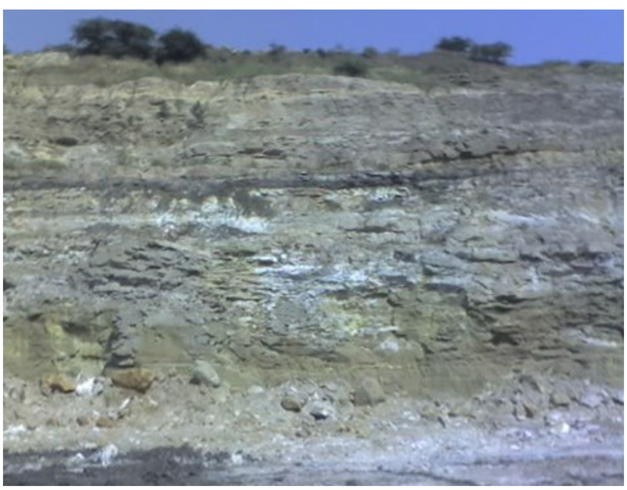

Fig. 4 A view of the rise side slope of Navin Kunada Opencast mine

weak to medium weak with a compressive strength of 3–25 MPa. A clay band of 2.0–2.5 m thickness existed just above the coal seam. Typical views of dip and rise side slopes of this mine are shown in Figs. 3 and 4, respectively.

4.3 Geology and Rock Mass Condition at DOC Mine

A major fault of 135 m throw exists along the slope in the dip side of DOC mine. A fault is partly exposed after a localized instability on the dip side (Fig. 5). The dip side

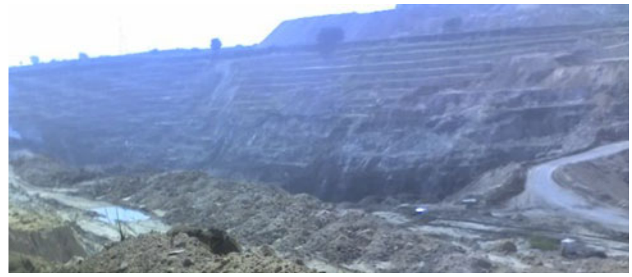

Fig. 5 A view of the dip side slope of Dhorwasa Opencast mine

slope is fractured and disturbed in the upper regions. A localized slope failure involving three benches in sandstone apparently induced by a fault is observed in the dip side. The fault plane is partly exposed and is visible also (Fig. 5). The sandstone rock mass is moderately to highly weathered and is very weak to weak. The rise side slope is apparently stable, moderately jointed with no visible instabilities.

4.4 Assessment of Rock Mass Condition at NKOC and DOC Mines

The RMC of NKOC and DOC mines were assessed based on the different parameters as shown in Table 1. The IRS was measured in the field from the Schmidt hammer rebound tests. The volumetric joint count (J_v) was approximated as the number of fractures/joints encountered in the unit volume of rock mass. Based on the J_v, the rock mass at these mines consisted of small- to medium-sized blocks as per the description of ISRM (1981). The RMC was rated as extremely poor in the upper region of dip side, and as very poor to poor in the lower region of dip side and rise side of NKOC mine, and as extremely poor to very poor in the dip and rise sides of DOC mine (Table 7).

4.5 Assessment of the Slope Condition at NKOC and DOC Mines

The SC of NKOC and DOC mines were assessed using the rating systems as shown in Tables 2, 3 and 4. The slope conditions were assessed as fair to good in the rise sides and as very poor to poor in the dip sides of NKOC and DOC mines (Table 8).

4.6 Assessment of the Slope Failure Hazard at NKOC and DOC Mines

The SFH of different slope units at NKOC and DOC mines were estimated as shown in Table 5. The SFH at these mines varied from very high to low as shown in Table 9.

Table 7 Assessment of rock mass condition at Navin Kunada and Dhorwasa Opencast mines

Name of the mine	Slope identification	Intact rock strength (MPa)	Rating	J_v (number of joints/m^3)	Rating	Rock mass condition (total rating)
Navin Kunada Opencast mine	Upper region (dip side)	3–13	1–2	12–15	2	Extremely poor (3–5)
	Lower region (dip side)	15–25	3–5	5–10	5	Very poor–poor (8–10)
	Rise side	15–25	3–5	5–12	5–7	Very poor–poor (8–12)
Dhorwasa Opencast mine	Dip side	4–25	1–5	5–18	5–3	Extremely poor–poor (4–10)
	Rise side	5–18	2–5	7–20	4–2	Extremely poor–very poor (4–9)

Table 8 Assessment of slope conditions at Navin Kunada and Dhorwasa Opencast coal mines

Parameter description	Navin Kunada Opencast mine		Dhorwasa Opencast mine	
	Rating	Slope identification	Rating	Slope identification
Presence of strike fault				
No	20	Rise side	20	Rise side
Yes; D_f = 0–5 m	0	Upper region: dip side	0	Upper region: dip side
Yes; D_f = >30 m	15	Lower region: dip side	15	Lower region: dip side
Spoil dump on the slope	20	Dip and rise sides	20	Rise side
			10	Dip side
Presence of localized instabilities/tension cracks (yes: dip side; no: rise side)	0	Dip side	0	Dip side
	20	Rise side	20	Rise side
Drainage	5	Dip and rise sides	5	Dip and rise sides
Adjustment rating	0	–	+5	–
Slope condition (total rating)	Fair (65)	Rise side	70 (Good)	Rise side
	Very poor (25)	Upper region: dip side	20 (very poor)	Upper region: dip side
	Poor (40)	Lower region: dip side	35 (Poor)	Lower region: dip side

D_f distance of fault from mine workings (m)

Table 9 Assessment of slope failure hazard at Navin Kunada and Dhorwasa Opencast coal mines

Name of the mine	Slope identification	RMC	SC	SFH
Navin Kunada Opencast mine	Rise side	Very poor–Poor (2–3)	Good (4)	Medium–low (C–D)
	Upper region: dip side	Extremely poor (1)	Very Poor (1)	Very high (A)
	Lower region: dip side	Very poor–poor (2–3)	Poor (2)	High (B)
Dhorwasa Opencast mine	Rise side	Extremely poor–very poor (1–2)	Good (4)	High–medium (B–C)
	Dip side	Extremely poor–very poor (1–2)	Poor (2)	Very high–high (A–B)

5 Conclusions

The following conclusions are drawn from this study:

1. The existing classification systems like RMR, MRMR, SMR, M-RMR, SRMR and GSI place more significance on structures than on IRS. These empirical systems are used basically to define the rock mass and hardly take into account other extraneous parameters, which define the actual slope condition in coal mines. These systems are thus not fully suited to appropriately assess the rock mass of the opencast coal mines from the slope stability point of view.
2. Field studies by the author indicate that the IRS and the total number of joints/fractures intersecting a unit volume of rock mass are important parameters, which influence the slope stability of coal mines studied particularly in slopes built of very weak to weak sandstone rocks.
3. The proposed classification system (OPCASSTA-COAL) provides realistic assessment of the RMC, the slope condition and the slope failure hazard of two opencast coal mines. The system can be used to divide a coal mine into discrete sectors based on the slope condition/class and slope failure hazard. The main

advantage of this system is that it is simple and easy to be applied in the field.

4. The system has been developed on the basis of the experience gained from the slope stability studies in six opencast coal mines of WVC, and it needs further refinements with the help of more case studies to make it applicable for use in opencast coal mines in general.

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