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Geotechnical investigation for support design in depillaring panels in Indian coalmines

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In Indian coalmines, CMRI- RMR and NGI-Q Systems are mostly used for formulating design of support in rock engineering. Geotechnical investigation of the roof rocks plays an important role in the selection of different parameters used in rock mass classifications. In India, Bord and Pillar Method of mining is very much in practice in underground coalmines. Roof support, which is an important aspect of ground control, involves maintaining roof competency to ensure a safe and efficient mining environment. This paper deals with a case study where CMRI- RMR and NGI Q- Systems are used for estimation of rock load for design of support in a coalmine in India in semi-mechanized depillaring workings with desired success.

Keywords: Depillaring, Coalmines, Rock engineering, CMRI-RMR system, NGI-Q system

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Introduction

India is perhaps the only major coal producing country in the world where Bord & Pillar Method of mining is still very much in practice in underground coalmines. In this Method, coal (20-30%) can be recovered during development in seams, which can be developed to a maximum width (4.8 m) and height (3 m).

Due to complicated geometry of developed panels and complex and slope procedures of pillar extraction (splitting and slicing), rock mechanics and strata behaviour in bord and pillar depillaring workings are different from other common underground coal mining methods[1]. Mainly two empirical approaches, CMRI Geomechanical Classification (CMRI-RMR) system[2,3] and NGI Rock Mass Quality Classification (NGI-Q) system[4-7], are being used for design of support system for bord and pillar depillaring operation. CMRI-RMR system is used for design of support system in roadways during development stage of the mine and NGI-Q system is used for design of support during final extraction (depillaring). In the present study, a case study of GDK 8 Incline, SCCL is discussed in details in respect of support design and geotechnical investigations during depillaring of panels. It has been aimed to collect relevant geotechnical information, to appraise the existing geomining condition and to estimate rock load at galleries, splits, slices and goaf edges in depillaring areas. An attempt has also been made to suggest the SRF value, which can be used to calculate the rock load for existing galleries or splits in depillaring, which is presently estimated using CMRI-RMR system.

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Study Area

GDK 8 Incline mine, located in Godavari Valley near Godavari Khani in Karimnagar District (AP), is under Ramagundam (RG) II Area of Singareni Collieries Company Ltd (SCCL). In this mine, IV Seam (3-3.2 m thick) dipping 1 in 8.3 due S83°5′49″E is developed by Bord and Pillar Method. The galleries are 4.5 m wide and 3 m in height. Pillars are 35 m × 35 m (centre to centre) and 30.5 m × 30.5 m (corner to corner). It is proposed to depillar SSI panel of IV seam with stowing using Load Haul Dumper (LHD) or Side Dump Loader (SDL). The depth of cover is around 270 m. The overlying III Seam (10 m thick) had been extracted by Blasting Gallery (BG) method. The parting between IV seam and III seam at this mine is around 10 m. A few cases of roof falls have been reported in the developed workings of IV seam mainly at the junctions. The maximum height of these falls is around 2 m at 55L/3D and 71L/1D junction. Side spalling is also observed at few locations leading to the widening of existing galleries.

Table 1—Stratigraphic succession of the study area

Age Million Y	Formation	Thickness *m*
Upper Cretaceous (99 – 65)	Deccan trap	65
Upper Jurassic to lower Cretaceous (159 – 99)	Chikiala Sandstone	300
Lower to early middle Jurassic (206 – 176)	Kota	675
Middle to upper Triassic (242 – 206)	Maleri	1000
Upper Permian to Lower-Triassic (256 – 242)	Kamthi	1300
Middle Permian (269 – 260)	Barren Measures	500
Upper part of lower Permian (282 – 269)	Barakar	300
Lower Permian (290 – 282)	Talchir	350
	Unconformity	
Upper Proterozoic (900 – 543)	Sullavai	545
Lower Proterozoic (2500 – 1600)	Pakhal	3335
	Unconformity	
Archean (3800 – 2500)	Basement	

Geotechnical studies have been conducted to design a suitable support system for existing galleries, splits, slices and goaf edges for depillaring panels. Required rock strength properties of the roof rocks are determined in the laboratory. The immediate roof of IV seam is composed of medium to fine grained sandstone. In general, two sets of joints are prominent in the roof, some are random joints, and most of them are rough, planar and unaltered. Slips are also observed in the roof. Side spalling, observed at some locations, led to widening of galleries up to 6 m. Prominent cracks due N 220°, noticed in the roof at 7D/48LS junction, are observed where side spalling is prevalent, and mainly across the gallery. The average layer thickness in the sandstone is found to be 15 cm. In general, the mine roof has been observed to be moist in nature.

Geology of the Area

GDK-8 incline, a part of Godavari valley coalfield trending in northwest southeast, is characterized by an undulating topography with low hillocks. The Barakar formation contains 3 to 10 coal seams, of which only 4 to 5 coal seams are persistent and workable (Table 1).

Table 2—Rock Mass Rating of different parameters

Parameter	Description	Rating
Layer Thickness	15 cm	18
Structural Features	Joints/Slips (Indices = 8)	14
Weatherability (1st cycle slake index)	92%	11
Compressive Strength	218 kg/cm^2	05
Ground Water	Moist	09
RMR		57

Geotechnical Studies and Rock Mass Classification

CMRI-RMR and NGI-Q were used in classifying the roof rocks and for rock load estimation.

CMRI-RMR System

It has been used to determine the RMR of the roof rock in existing galleries and splits in depillaring area, using five parameters (Table 2).

Adjustment of RMR

For overlying workings, RMR value was reduced (20%) for adjustment.

Adjusted RMR = 57 × 0.8 = 45.6, Class IIIA, Fair

NGI-Q System

In this system, Q is determined using the following relationship (Table 3):

$$Q = (RQD/J_n) \times (J_r/J_a) \times (J_w/SRF)$$

where, RQD = Rock quality designation, J_n = Joint Set Number, J_r = Joint Roughness Number, J_a=Joint Alteration Number, J_w= Joint Water Reduction Factor, and SRF= Stress Reduction Factor.

As no borehole core of immediate roof is available, the RQD needed in NGI-Q system is determined from joint volume (J_v) i.e. number of joints per cubic meter of rock mass from the following relationship[1]:

$$RQD = 115 - 3.3\ J_v$$

In the present study, J_v was found to be 14 to 17 joints/m^3, and RQD is calculated to be 60–70 percent. However, RQD value (60%) was considered to estimate Q. Other parameters are determined as follows: J_n= 2 sets of prominent joint and random

Table 3—Parameters used in NGI-Q system

Parameters	*RQD*	J_n	J_r	J_a	J_w	*SRF* Slices	*SRF* Goaf edges	*Q* Slices	*Q* Goaf edges
Value	60	9	1.5	1	1	5	10	2	1

Table 4—Support resistances for various support items[8]

Support item	Support resistance t/m^2
Pit prop	
About 3 m long, made of mild steel pipes (100 mm diam, 5mm wall thickness, 0.5–1.0 long), wooden piece (100 mm diam) inserted axially into the pipe.	20
Timber chock	
a) Seasoned round timber cogs (1.2 × 1.2 m area, 3 m high).	30
b) Flat chockmat (1.0 × 1.0 m) made of slippers (100 × 75 mm section) sawn from the seasoned hard wood.	30
Steel chock	
Made of steel cog stool (0.9 × 0.9 × 0.9 m) fabricated from box steel pipes (48.5 × 48.5 mm section, 3.65 mm wall thickness) following any standard accepted design.	30
Rock Bolt	
1.5 m long, full column cement grouted made of ribbed tor steel (20-22 mm diam).	8

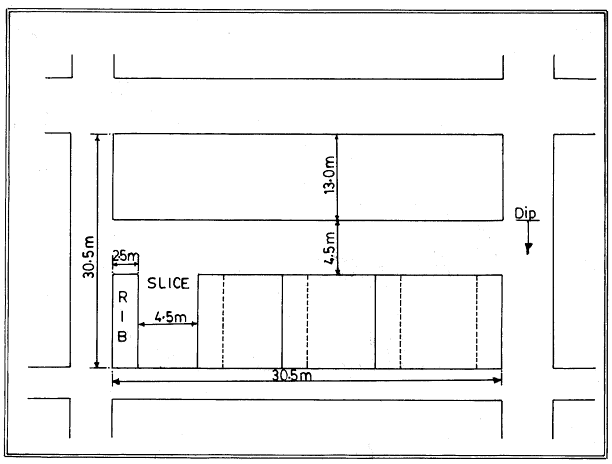

Fig. 1—Proposed method of splitting and slicing of a pillar during extraction at GDK-8 Incline

joints; J_r = rough and planer joint surface; J_a = unaltered joint surface; and J_w = groundwater condition is generally moist.

For slices, where the stress concentration would be moderately high, *SRF* is taken as 5. At goaf edge, obviously there would be high stress concentration, *SRF* is considered as 10.

Estimation of Rock Load in Depillaring Areas

Rock Load in Galleries and Splits

Rock load (t/m^2) in the galleries and splits in depillaring areas has been determined using the following empirical relationship of CMRI-RMR System:

$$Rock\ load = B \times D\ (1.7 - 0.037 \times RMR + 0.0002 \times RMR^2)$$

where, B (width of galleries/splits) = 4.5 m, D (average rock density) = 2.29 t/m^3 and RMR = 45.6.

Hence, rock load in galleries and splits = 4.41 t/m^2.

Rock Load at Junction

Rock load at junction of gallery and split in depillaring areas has been estimated using the following empirical equation of CMRI-RMR system:

$$Rock\ load = 5 \times B^{0.3} \times D\ (1 - RMR/100)^2$$

Hence, in the present study, rock load at junctions = 5.32 t/m^2

Rock Load in Slice and Goaf Edge

Rock load (P_{roof}) in slice and goaf edge was estimated using NGI-Q system from the following empirical relation:

$$P_{roof} = 2/3\ (J_n^{1/2} / J_r)\ x\ (5Q)^{-1/3}$$

where, J_n = 9, J_r = 1.5, Q = 2 for slice and Q = 1 for goaf edge.

Hence, rock load in slice, P_{roof} is 6.19 t/m^2; and rock load at goaf edge, P_{roof} is 7.79 t/m^2.

Design of Support System for Depillaring Areas

It has been proposed to depillar the panel by splitting and slicing of pillars (Fig. 1, Table 4). There

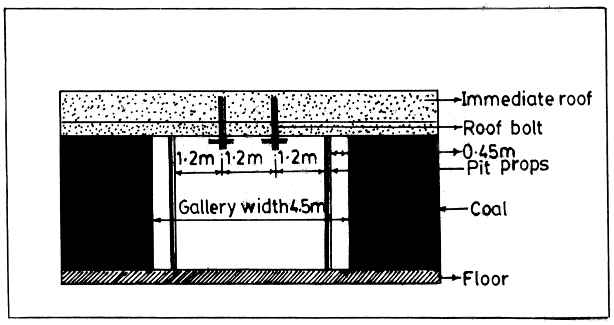

Fig. 2—Design of support for splits

should be one level split (4.5 m wide) in the center of the pillar and four slices (4.5 m wide) leaving ribs (2.5 m wide).

Support for Galleries and splits

Galleries (4.5 m wide) would be supported with full column cement grouted rock bolts (1.5 m long) in conjunction with pit props. Two bolts would be installed in middle portion whereas the props would be on either side. The spacing between bolts and props in a row would be 1.2 m and the row would be 1.2 m apart (Fig. 2). In existing galleries, where the gallery width has increased up to 5.5 m or even up to 6 m due to side spalling or there are cracks in the roof, two additional bolts (4 bolts) would be installed in a row with two side props. In splits, when slices are driven, two props would be removed from the junction formed and placed towards the goaf edge side for the movement of LHD/SDL and additional four bolts would be grouted.

Calculation of Safety Factor (SF)

For 4.5 m wide galleries/split, two bolts and two props would support every 1.2 m length of the roadway. The support resistance offered by this support system would be:

Support resistance= $[(2 \times 8) + (2 \times 20)] / (4.5 \times 1.2) = 10.37$ t/m^2

Hence, SF = 10.37/4.41 = 2.35

Design of Supports at Junctions

The existing junctions would be supported with four bolts at 1.2 m interval in a row and the spacing of rows would be at 1 m whereas props would be at the corners (Fig. 3). Total 20 bolts and 4 props (considering tributary areas just at the inset of the junction) would support the junction. At places where the size of the junction is more due to side spalling or

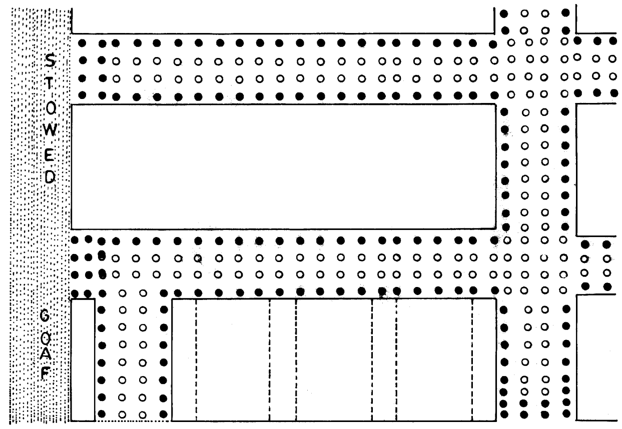

Fig. 3—Support plan of IV seam depillaring panel in GDK-8 Incline

there is presence of cracks in the roof, two additional bolts (6 bolts) in a row would be installed in conjunction with the props.

Calculation of SF

The support resistance offered by such support systems at the existing junctions would be as follows:

Support resistance =$[(20 \times 8)+(4 \times 20)]/ (4.5 \times 4.5) = 11.85$ t/m^2

Hence, SF = 11.85/5.32 = 2.23

At the split junctions, additional bolt should be installed in between the existing rows of bolts in staggered fashion. In total, 20 numbers of bolts and 4 props (considering tributary areas just at the inset of the junction) should be there to support the junction. The support resistance offered by the support system would be as follows:

Support resistance= $[(20 \times 8) + (4 \times 20)] / 4.5 \times 4.5 = 11.85$ t/m^2

Hence, SF = 11.85/5.32 = 2.23

Design of supports at Slices

Slices (4.5 m wide) would be supported with two full column cement grouted bolts and two props in a row. The spacing of the rows would be 1 m. At the junctions, two props from split gallery would be removed and placed towards the goaf edge (Fig. 3). Additional two roof bolts would be installed afresh at the place of removal of props of the opening.

Calculation of SF

The support resistance offered by such support systems would be as follows:

Support resistance = $[(2 \times 8) + (2 \times 20)] / 4.5 = 12.44$ t/m^2

Hence, SF = 12.44/6.19 = 2.0

Table 5—List of mines where NGI-Q system has been successfully used

Mines	Seam/ thickness	Immediate roof	Q		P_{roof}	
			Slice	Goaf	Slice	Goaf
Bera Colliery	III seam, 3.8 m	Coal & sandstone	2.4	1.2	5.8	7.34
Basta colla	II seam, 6m	Sandstone	1.96	0.98	6.2	7.8
Satpura II (E – 5 Panel)	LWS, 4 m	Shaly sandstone to compact SS	6.52	0.52	5.11	14.52
GDK - 8	IV seam	Sandstone	2.0	1.0	6.19	7.79
GDK-9	IV seam	Sandstone	1.63	0.81	6.62	8.34
Govinda Colliery, SECL, (P – 7 panel)	Middle Kotma seam, 3 – 3.5 m	Shale 0.3 – 0.5 m, CSS- 3 – 4 m, Massive SS	7.5	0.3	2.66	11.65
Duman Colliery, SECL, (K – 39 B panel)	Kaparti seam, 3.3 m	Carbonaceous shale, 0.3 – 0.5m Coal, 0.7 – 0.9m Carbonaceous shale, 0.8 m Sandstone	1.7	0.88	8.0	9.96
Pathakhera Colliery (20 L district)	Lower workable seam , 3.5 – 4.0 m	Shaly sandstone to compact SS	6.53	0.52	5.11	14.52
Shyamsundar Colliery (24 depillaring panel)	Jambad seam, 4.5 m	Sandstone	1.28	0.64	10.7	13.54
Bankola Colliery (R VII/4 & VII/5 panel)	R VII seam, 4.2 m	Coal and sandstone	1.95	0.98	9.4	11.8
GDK Incline (12 t panel)	III seam, 11 m	Coarse grained SS inter bedded many times	3.07	0.30	5.36	17.33

Support Design at Goaf Edges

Goaf edges would be supported with four pit props in a row. There should be two rows of props at 0.6 m interval (Fig. 3).

Alternatively, chocks (1.2 × 1.2 m) constructed of seasoned round timber cogs would be set at all goaf edges at the intervals of not more than 30 cm. Three such chocks would be placed at each goaf edges.

Calculation of SF

The support resistance offered by the support system with four props at 0.6 m interval would be as follows:

Support resistance = (8 × 20)/ 4.5 × 1.2 = 29.63 t/m^2

Hence, SF = 29.63/7.79 = 3.8

The support resistance offered by the support system with chocks would be as follows:

Support resistance = (3 × 30)/ (4.5 × 1.2) = 16.66 t/m^2

Hence, SF = 16.66/7.79 = 2.13

Rock Load (P_{roof}) Estimation using NGI-Q System for Splits

NGI-Q system has been used in Indian geomining condition for determination of rock load for slices and goaf edges in depillaring panels (Table 5). Yet it has not been practiced to determine the rock load for splits and galleries. In case of splits and roadways/galleries, the rock load has been determined using CMRI-RMR system. In this study, efforts have been made to determine the rock load for splits and galleries by NGI-Q system using various values of SRF.

For this purpose, in all selected five mines [Satpura II (WCL), Bera (BCCL), Basta Cola (BCCL), GDK 9 (SCCL), GDK 8(SCCL)] rock load was calculated using CMRI-RMR. Since rock load determination using NGI-Q system depends upon SRF, hence a range of values of *SRF* (1.5-2.0) has been selected for calculation of P_{roof} for NGI-Q system. The rock load values calculated using NGI-Q system for *SRF* value 1.5 shows a comparatively better correlation (0.87) with the rock load values determined using CMRI-RMR system (Fig. 4). Therefore, for calculation of rock load using NGI-Q system, *SRF* value of 1.5 can be considered for splits and roadways (Table 6).

Conclusions

The present study has been conducted to frame suitable support design guidelines for depillaring in SSI panel of IV Seam. Geotechnical studies have been conducted in the panel and rock properties of the roof rock and parting have been determined in the laboratory. Two rock mass classification systems

Table 6—Correlation of rock load values calculated using CMRI-RMR and NGI-Q system (for SRF 1.5)

Mines	*RQD*	J_n	J_r	J_a	J_W	*SRF*	*Q*-Value	Rock Load using CMRI-RMR	Rock Load using NGI-Q
Satpura II	69	5	1.5	1	1	1.5	13.8	2.76	2.46
Bera	72.1	9	1.5	1	1	1.5	8.01	4.40	3.95
Bastacola	78	9	1.5	1	1	1.5	8.67	3.23	3.84
GDK –9	49	9	1.5	1	1	1.5	5.44	4.64	4.48
GDK –8	60	9	1.5	1	1	1.5	6.67	4.41	4.19

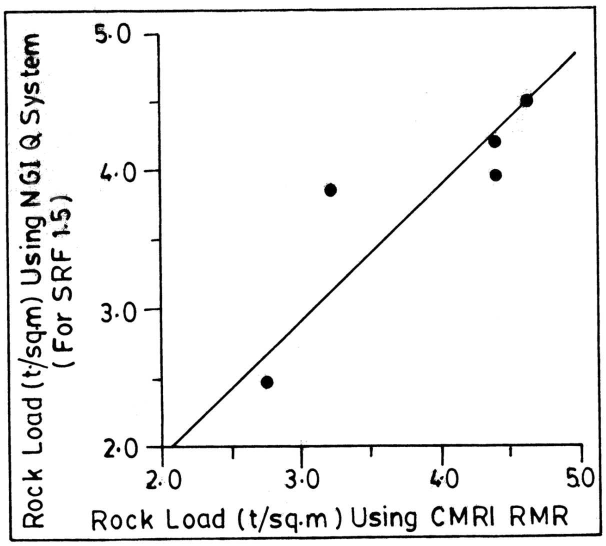

Fig. 4—Plot between rock load using CMRI-RMR and rock load using NGI-Q system

(CMRI- RMR, NGI-Q) have been applied to classify the roof rocks and also to calculate the rock load. The proposed support designs are as follows:

1 For splits and galleries, two bolts in middle portion one prop each on either side. The spacing between the bolts and props in a row would be 1.2 m and row spacing 1.2 m. At places where the gallery width has increased up to 5.5 m or even up to 6 m due to side spalling or there are cracks in the roof, two additional bolts (4 bolts) would be installed in a row with two side props.
2 The junctions of existing galleries and splits would be supported by 20 bolts and 4 props. At places where the junction size has increased up to 5.5 m or even up to 6 m due to side spalling or there are cracks in the roof, two additional bolts (6 bolts) would be installed in a row in addition to side props.
3 Slices (4.5 m wide) would be supported with two full column cement grouted bolts and two props in a row.
4 Goaf edges would be supported with four pit props in a row. There should be two rows of props at 0.6-m interval.

Alternatively, chocks (1.2 m × 1.2 m) constructed of seasoned round timber cogs would be set at all goaf edges (3 chocks per goaf) at the intervals of not more than 30 cm.

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