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Design of Support System and Stability Evaluation for Underground Workings of Gare Palma Coal Mine – A Case Study

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Abstract

In underground coal mines, a number of fatal accidents have been occurred due to roof fall. The roof fall mainly occurs in newly exposed working sections of coal mines during development and final extraction of coal. The main factor which contributes to the roof failure in coal mines is the re distribution of stresses and geotechnical discontinuity. If a proper support system is not provided in time the layers get detached and fall down causing major causalities in the mines. Rock mass rating (RMR) plays important role in design and selection of adequate support system. In Indian coal mines, Central Mining Research Institute- Indian School of Mines - Rock Mass Rating (herein after referred to as (CMRI-ISM RMR) is mostly used for formulating design guidelines for supports. In this paper study for stability of II seam working was assessed. Later on study was extended to determine rock load for II seam applying empirical and numerical approaches and finally design of support has been formulated.

Key words

Roof fall, rock load, support design, CMRI-ISMS RMR.

1. Introduction

The main cause of roof failure in coal mines is generally due to the occurrence of geological discontinuities. The accident due to roof fall constitutes the major challenges faced by field engineer [8]. Thus, proper care should be taken to increase the stability of workings by characterising the roof fall also execution of proper plan to arrest the movement of layered strata which are liable to fall when the stresses acts upon them. Rock mass classification systems have constituted an integral part of empirical mine design for over 100 years [4]. An important contribution of the RMR is that the system has stimulated the development of a plethora of more specialized system of ground evaluation particularly in mining application [9]. They provide guidelines for stability assessment and also to select appropriate support system [5]. Roof fall generally takes place due to detachment of lower strata since the process of re-distribution of stresses takes place around the excavation made [2,3]. Thus, proper support design for mine openings is considered as a major factor in stability of the roof strata [1]. The design of support for underground excavations has been described as art as well as science. The design process in rock excavation is considered to be a tedious job due to lack of control over geological and stressed conditions [15]. A research work was carried out is to obtain an optimum and advanced Rock Mass Rating system for underground coal mine. As in situ rock exhibits DIANE behaviour [6,7] discontinuous, inhomogeneous, anisotropic, and non-linearly elastic) and using the laboratory resulted factors like Uniaxial Compressive Strength and that to at small scale (sample) oversights our estimation. Consequently, the rock mass classification and rational design of support plays an important role for stability of the workings. Now a day, numerical modeling is also gained popularity and is being used as an important tool for various assessments [21]. In this research paper, application of both these technique is used for determining the stability of the workings.

2. Study Area

At Gare Palma IV/4 mine, seam II and seam III is developed. The thickness of seam II is 2.5 m and that of III seam is 4.5 m to 10.23 m. The width of gallery is 4.8 m in both of the seams and height of galleries are 2.5 m for II top seam and 3 m in III seam respectively. Pillars are 25m x 25m and also 36 m x 36 m centre to centre and the depth of cover is 30m to 160m (approx.). Main aim of the study is to determine the stability of II seam workings.

3. Objective of the Study

The main objective of the study is stated bellow

a) To ascertain the stability of development workings of seam II.

b) Design of support system for seam II.

4. Geotechnical Studies

The immediate roof of seam II is composed of sandstone. Random joints were observed in the roof. The average layer thickness in sandstone is 8 cm. There is percolation of water from the mine roof at some places around II seam where drift is proposed for III seam. The compressive strength of sandstone is 110 kg/cm^2 and the density is 2.1 t/m^3. The first cycle slake durability index of sandstone is 88.7%.

5. Determination of Rock Mass Rating for II seam

RMR of immediate roof (Sandstone) of seam II has been determined using Central Mining Research Institute- Indian School of Mines - Rock Mass Rating [10,20]. Ratings of different parameters are shown in Table 1.

Table 1. Parameters of RMR with Their Ratings

Parameter	**SANDSTONE**	
	Description	**Rating**
Layer thickness	8 cm	14
Structural features	Joints (Indices-11)	10
Weatherability	88.7 %	10
Compressive strength	110 kg/cm^2	03
Groundwater	Moist/ Dripping	09
RMR		**46**

Adjustment of RMR

For adjustment, 10% reduction for solid blasting has been made in the RMR, Hence,
Adjusted RMR = 46 x 0.9 = **41.4,**

The roof is classified as **III A, Fair**

6. Estimation of Rock load by CMRI – ISM RMR - A Numerical Approach

Rock load was estimated for galleries [20] and junctions [12] using following equations:

Rock load in gallery (t/m^2) $= B.D.[1.7 - 0.037.RMR + 0.0002.RMR^2]$ (1)

Rock load at junction (t/m^2) $= 5.B^{0.3}.D.(1 - RMR/100)^2$ (2)

where, B = Roadway width (m), and

D = Dry density (t/m^3).

In the study area,

RMR = 41.4,

Density of shaly sandstone, D = 2.1 t/m^3, and

Width of gallery, B = 4.8 m

Rock load for galleries = 5.15 t/m^2 Rock load height for galleries = 2.45 m

Rock Load for junctions = 5.76 t/m^2 Rock load height for junctions = 2.73 m

7. Estimation of Rock load by CMRI – ISM RMR - A Numerical Approach

Numerical modelling was done using 3D finite difference software FLAC^{3D} developed by ITASCA Consultant Group of USA. Input parameters used for the modelling are discussed below [22].

7.1 In-situ Stress

In the absence of measurements of the in-situ stresses values at the seam II, theoretical values can be taken. A study [20] under grant-in-aid project funded by Ministry of Coal S & T has established a relationship between horizontal in situ stress and depth of cover for coal measures rock based on measurements done in Indian coal mines.

The vertical in situ stress

$$S_v = \gamma H \quad \text{MPa} \tag{3}$$

γ= Unit rock pressure, 0.025 MPa / m

H = Hard rock cover below surface, m

The horizontal in-situ stress

$$S_H = S_h = 2.0 + 0.01\,H \quad \text{MPa} \tag{4}$$

where, S_H & S_h are the major and minor horizontal in situ stresses, MPa

H is the depth of cover, m

7.2 Rock Mass Strength and Safety Factor Evaluation

The strength of rock mass has been estimated using an empirical criterion proposed by Sheorey [19] for the present study. This criterion reads as:

$$\sigma_1 = \sigma_{cm}\left(1+\frac{\sigma_3}{\sigma_{tm}}\right)^{b_m} \tag{5}$$

where,

σ_1 = major principal stress required for failure of rock mass when the minor principal stress is σ_3.

$$\sigma_{cm} = \sigma_c \exp\left(\frac{RMR-100}{20}\right) \tag{6}$$

$$\sigma_{tm} = \sigma_t \exp\left(\frac{RMR-100}{27}\right) \tag{7}$$

$$b_m = b^{RMR/100} \tag{8}$$

σ_c, σ_{cm} = compressive strength of intact rock and rock mass respectively, MPa

σ_t, σ_{cm} = tensile strength of intact rock and rock mass respectively, MPa

b, b_m = exponent in failure criterion of intact rock and rock mass respectively

RMR = Rock Mass Rating.

To estimate the stability or instability of the rock mass, safety factors are evaluated for each and every element in the numerical model. The safety factor is defined as

$$F = \frac{\sigma_1 - \sigma_{3i}}{\sigma_{1i} - \sigma_{3i}} \tag{9}$$

except when $\sigma_{3i} > \sigma_{tm}$

$$F = \frac{\sigma_{tm}}{-\sigma_{3i}} \tag{10}$$

where σ_{1i} and σ_{3i} are the major and minor induced stresses from numerical model output.

The sign convention followed here is negative for tensile stresses and positive for compressive stresses.

7.3 Rock Properties used for Modelling

The material properties used for numerical modelling are given in the Table.2. The first three parameters are the elastic constants and density, which are essential for running the numerical model. However, the other three parameters are the strength parameters, which are necessary for finding the safety factors. For numerical modelling purpose, the unadjusted RMR has to be used since the numerical model itself takes into account the adjustment factors.

Table 2. Properties Used in the Modelling

Rock type	Modulus of elasticity, GPa	Poisson's ratio	Rock density Kg/m^3	Intact compressive strength, MPa	b	RMR
Roof of seam II	5.0	0.25	2100	11.0	0.5	46

7.4 Modelling Methodology

The following geo-mining data were used for preparing the numerical model. These parameters were chosen taking the prevailing geo-mining condition at the mine site into consideration.

Seam II thickness: 2.5 m

Extraction height of II seam : 2.5 m

Pillar size: 36 m x 36 m (centre to centre)

Depth of cover: 106 m (approx)

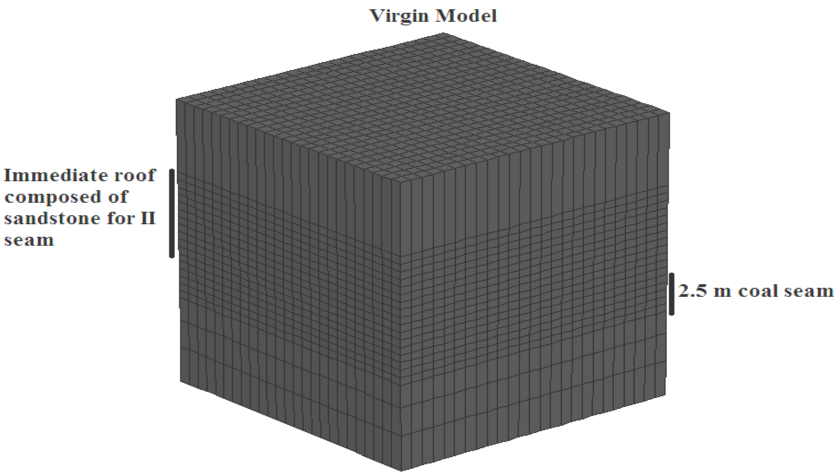

Fig.1. Virgin Model for II Seam Showing the Grid Pattern Used for Modelling.

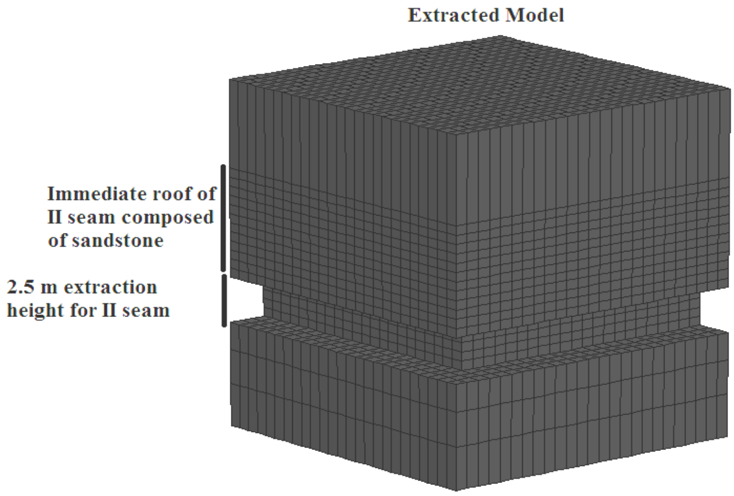

Fig.2. Virgin Model for II Seam Showing the Grid Pattern Used for Modeling

Numerical models were run to estimate the requirement during development of II top seam by bord and pillar method. In modelling drivage of 4.8 m x 2.5 m has been in coal to develop pillars of 36 m x 36 m size. Stability of the immediate roof is assessed by safety factors of different colours contours at different heights. The safety factors colour contours from 0.5 to 1 show the unstable zone height which has to be supported.

7.5 The Modelling Study Has Been Conducted in the Following Stages

Stage 1: Virgin model with the elastic constants, density, in-situ stresses boundary conditions etc., as input parameters (Figure 1.).

Stage 2: Extracted model with drivage of 4.8 m x 2. 5 m in II top seam (Figure 2.).

Stage 3: Evaluation of safety factor for galleries and junctions and estimation of rock load height (Figure 3).

7.6 Numerical Modelling Results

Safety factor contours for II top seam, are shown in Figure 3.

1. The safety factor contours obtained in the seam II for galleries is less than 1.0, up to the height of 1.5 m (Figure 3). Thus the load is therefore, likely to come up to the height of 1.5 m in the immediate roof according to the model and thus need to be reinforced/supported up to 1.5 m height of galleries.

2. Similarly for junctions, safety factor contours obtained for II top seam is less than 1.0, up to the height of 2.0 m (Figure 3). Thus the load for junctions, likely to come up to the height of 2

m in the immediate roof according to the model and thus need to be strengthens/ supported to take care of 2 m height in junctions.

3. Rock load obtained for galleries and junctions for seam II is 3.15 t/m^2 & 4.2 t/m^2.

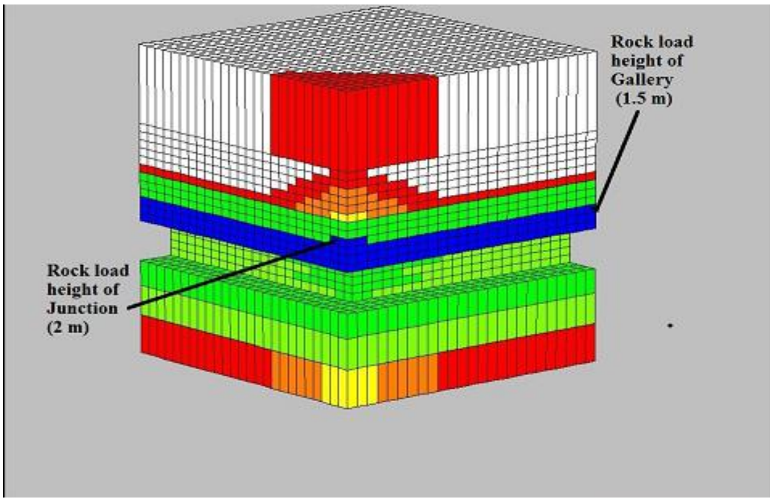

Fig.3. Numerical Model Showing Rock Load Height for Galleries and Junctions for Seam II

8. Comparisons of Approaches in Terms of Rock Load and Rock Load Height

Table 3. Rock Load Obtained from Empirical and Numerical Approach for II Seam.

S. no	***Rock load height (m)***		***Rock load (t/m^2)***	
	Galleries	Junctions	Galleries	Junctions
Empirical Approach	2.45	2.73	5.15	5.76
Numerical Approach	1.5	2.0	3.15	4.2

Although Numerical approach is showing less rock load height and rock load compare to the empirical approach, rock load height and rock load obtained from empirical approach is considered for design of support system for better safety (Table.3).

9. Design of Support System

At Gare Palma IV/4 mine, seam II is developed and immediate roof consists of sandstone. The geotechnical studies of roof rocks revealed that adjusted RMR of sandstone is 41.4 which categories the roof rocks to Class III A, "Fair Roof". The rock load calculated using formula (1 & 2), comes to 5.15 t/m^2 for gallery and 5.76 t/m^2 for junctions.

9.1 Design of Support System for Gallery

Based on the studies, support design has been formulated. The gallery is supported with four bolts in a row at an interval of 1.2 m leaving 0.6 m space towards the pillar on both sides and the bolting rows spaced at 1.2 m (Figure. 4). The two side bolts is inclined at an angle of 60^0 towards pillar & two central bolts grouted vertical. The bolt length is 1.8 m and diameter kept as 20-22mm, made of TMT ribbed bar. The hole suggested diameter is not more than 32 mm.

All bolts are grouted full column using resin capsules. The bolts are tightened immediately along with bearing plates and nut. The support resistance offered by suggested support system comes to 10.41 t/m^2 which provides a safety factor of 2.0, considering 15 tone load bearing capacity of each bolt.

$$\text{Support Resistance} = \frac{\text{No. of roof bolt x Anchorage strength (t)}}{\text{Width of gallery (m) x Row spacing (m)}}$$

$$= (4 \times 15) / (4.8 \times 1.2)$$

$$= 10.41 \text{ t/m}^2$$

$$\text{Safety Factor} = \text{Support Resistance / Rock load}$$

$$= 10.41 / 5.15$$

$$= 2.0$$

9.2 Design of Support System for Junctions

The rock load at junction has been calculated using Formula (2), which comes to 5.76 t/m^2. Hence, the junction is supported with four bolts in a row at 1.2 m interval along with and the row spaced at 1.2 m. Thus, five rows, (20 bolts) required to support the junction of 4.8 x 4.8 m (Figure. 4). The support resistance offered at junction has been found to be 13.02 t/m^2 with safety factor of 2.26.

$$\text{Support Resistance} = (4\times5\times15)/ (4.8\times4.8) = 13.02 \text{ t/m}^2$$

$$\text{Safety Factor} = \text{Support Resistance / Rock load}$$

$$= 13.02 / 5.76$$
$$= 2.26$$

10. Result and Discussion

Rock load and rock load height estimated is illustrated in Table.4. The rock load obtained from empirical approach is higher and has been considered for design of support system for enhancement of safety. The support design for galleries is four bolts in a row with bolt and row spacing of 1.2 m and 1.2 m respectively. Junctions are also supported with four bolts in a grid pattern of 1.2 m. The safety factor calculated for workings of II seam is not less than 2 for both galleries and junctions, hence the workings of II seam is stable and safe. It was also observed that after the application of suggested support system the mine is working successfully.

Table 4. Design of Support for II Seam Workings

S. No	**Rock load height (m)** Galleries	Junctions	**Rock load (t/m^2)** Galleries	Junctions
Empirical Approach	2.45	2.73	5.15	5.76
Numerical Approach	1.5	2.0	3.15	4.2

Design of Support with Safety Factor

Galleries	Junctions	Support Resistance (Galleries)	Support Resistance (Junctions)	Factor of Safety (Galleries)	Factor of safety (Junctions)
4 bolts in row. Row Spacing (1.2 m) Bolt Spacing (1.2 m)	4 bolts in row. Row Spacing (1.2 m) Bolt Spacing (1.2 m)	10.41	13.02	2.0	2.26

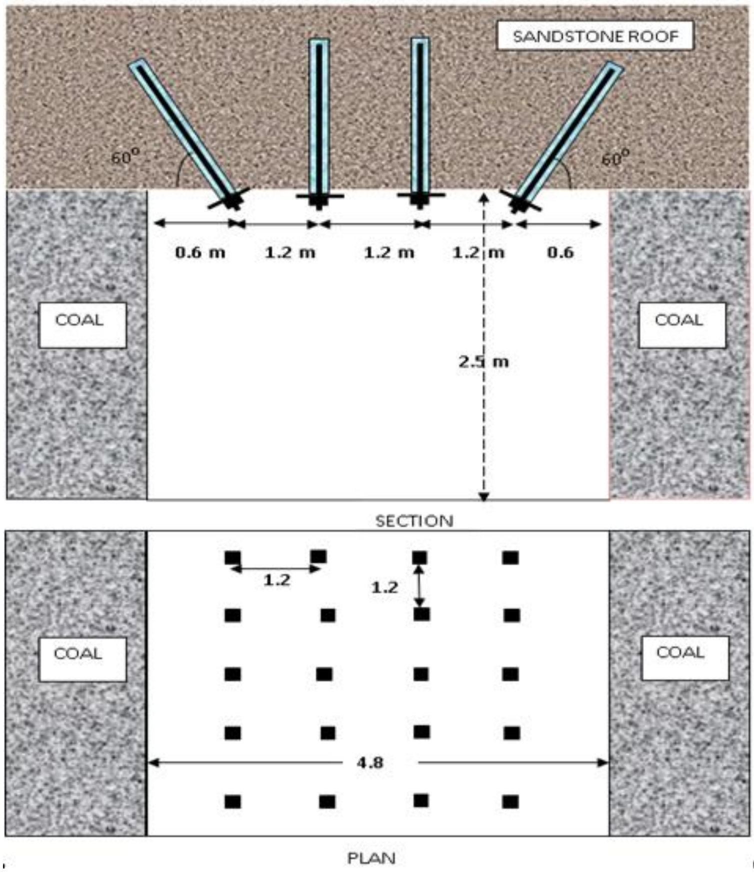

Fig. 4. Design of Support System for II Seam Workings at Gare Palma IV/4 Mine

Conclusions

1. Rock Mass Rating (RMR) was determined for II seam, Gare Palma IV/4 mine, applying CMRI –ISM RMR Classification System.

2. .Rock Load height and Rock Load is estimated by using both empirical and numerical approaches.

3. The RMR of the roof rocks for II seam is 41.4 (III A Fair roof) and the rock load height values for gallery and junctions from empirical and numerical approaches are 2.45 & 2.73 and 1.5 & 2.0 respectively.

4. The bolt length suggested for II seam working is 1.8 m.

5. The rock load estimated for galleries and junctions from empirical and numerical approaches are 5.15 t/m^2 & 5.76 t/m^2 and 3.15 t/m^2 & 4.2 t/m^2 respectively, however for safety prospects, support design is done by taking the rock load values which is obtained by empirical approach.

6. Gallery is supported with four full column resin grouted bolts in a row at 1.2 m interval leaving 0.6 m space towards the pillar on both sides and the bolting rows are spaced at 1.2 m. Central bolts are vertical and the side bolts installed at an inclined of 60^0 towards the pillar (Figure.4). The support resistance offered by suggested support system comes to 10.41 t/m^2 and provides a safety factor of 2.0.

7. Junctions are supported with three full column resin grouted bolts in a row at 1.2 m interval and the rows are spaced at 1.2 m. The support resistance provided with this support system has been found to be 13.20 t/m^2 with a safety factor of 2.26.

8. The safety factor calculated for workings of II seam is not less than 2 for both galleries and junctions, hence the workings of II seam is stable and safe. It is also observed that after with suggested support system the mine the workings are safe and stable.

9. It was further suggested that in case of any side spalling of pillars, side bolting should be done as and when required. The bolt length should be 1 m, 20/22 mm dia made up of TMT ribbed steel bar grouted full column using cement capsule.

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