Geotechnical Assessment and Optimization of XV Seam Mining Operations at Moonidih Colliery: A Multidimensional Study on Planning and Operational Challenges

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Abstract

This paper highlights into the geotechnical challenges faced by Moonidih Colliery in XV Seam mining operations, exploring the multidimensional aspects of planning and operational challenges. It aims to address poor roof conditions leading to frequent strata issues, and the impact of on-field constraints on production targets. The overarching goal is to optimize strata stabilization and ventilation, ensuring the successful implementation of the proposed mining project.

Introduction

India, a significant player in the global steel industry, heavily relies on metallurgical coal imports to meet its soaring demands. In 2022-23 alone, the country imported 56.05 million metric tons of metallurgical coal, comprising 90% of its requirements. The surge in steel production is poised to escalate coal imports, emphasizing the critical role of coking coal—a resource exclusively produced by Bharat Coking Coal Limited. The Jharia field, with estimated reserves of 19.4 billion tonnes, stands as India's sole source for coking coal.

The Moonidih mine, situated in the Western Jharia area of Bharat Coking Coal Limited (BCCL), plays a pivotal role in the extraction of coking coal from significant depths. Originally designed in the early 1960s under Polish consultation, the mine employs the horizon system of mining to extract coking coal from the XVIII to XV bottom seam. Two shafts with insets positioned at depths of 220m, 280m, 400m, and 500m, open up four horizons to facilitate coal extraction. The coal seams exhibit a general dip towards the southwest, with an average dip angle ranging between 7 and 12 degrees. Classified as a DEGREE III mine, the XVI seam, with a thickness of 2.8m, is particularly susceptible to gaseous explosions [1, 2].

Presently, the mine is operational, producing approximately 0.6 million metric tons (MT) of coal annually. The extraction process employs the longwall retreating with caving method, featuring full-height coal seam extraction. This method incorporates bi-directional cutting by a shearer and construction of galleries using advanced machinery such as bolter miners and road headers. Fig. 1 illustrates the schematic diagram of a retreating longwall panel at Moonidih mine, highlighting the adoption of a U-type ventilation system.

In an effort to boost annual production, the XV seam has been developed utilizing the Mine Development Operator (MDO) mode. The approach involves accessing the seam through two separate inclines, each measuring 5.7 × 4 m². Subsequently, four dip rise trunk galleries, with dimensions 5.7 × 3.6 m² (two in number), and 4.8×2.8m² (two in number), along with eleven level galleries, have been developed using bolter miners and road header machines. Additionally, plans were devised for five panels in the XV top seam, spanning depths from 620m to 865m. The proposed panels vary in length from 1040m to 3180m, with an expected width of 250m. The primary objective of these dimensions was to exploit around 2.5 MT of coal per annum utilizing Powered Support Longwall Technology.

However, challenges arise as the Rock Mass Rating (RMR), indicative of the strength of underground strata falls in poor category as outlined in Table 1. This necessitates a comprehensive geotechnical assessment to address the stability concerns associated with the XV seam mining operations at Moonidih Colliery. The subsequent sections will detail out the proposed objectives, existing literature, and methodologies employed in addressing these challenges and optimizing the mining operations.

Table 1 The strata details for different U/G developments below 400m depth

Structure	RMR	Rock Load (t/m^2)
Trunk roadway in XV top seam	34.65-39.6 (Poor)	7.1-8.51
Trunk roadway in XV bottom seam	30.24-34.56 (Poor)	6-7
Gate roads in XV top seam	34.65 (Poor)	8.51
Gate roads in XV bottom seam	30.24 (Poor)	7

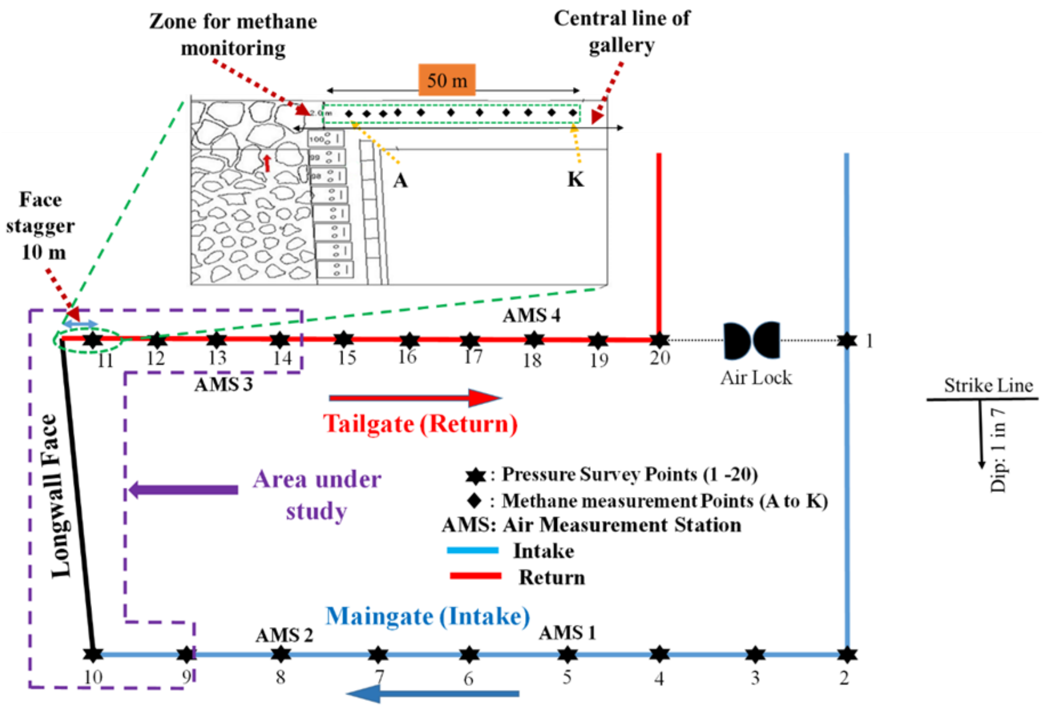
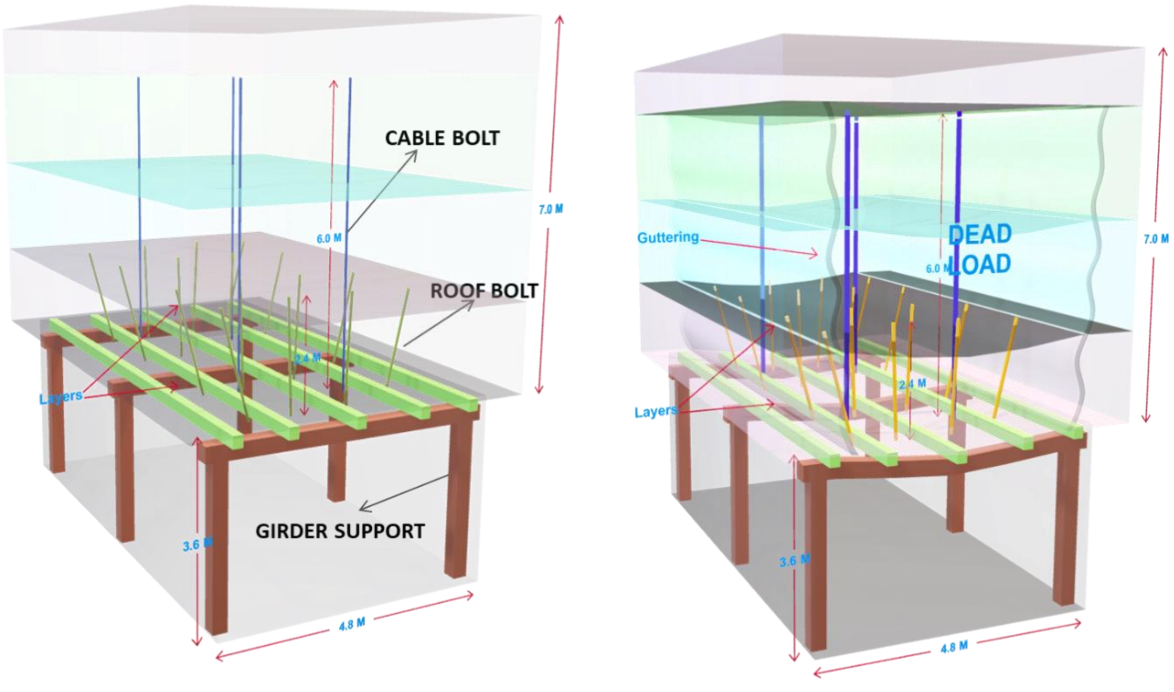


Fig. 1. Schematic diagram of longwall panel in XVI seam of Moonidih mine.

In an effort to tackle the poor roof conditions in the underground workings of Moonidih Colliery's XV seam, extensive studies were conducted by the Central Institute of Mining and Fuel Research (CIMFR),Dhanbad and the Indian Institute of Technology (Indian School of Mines), Dhanbad. These studies proposed elaborate support plans, which were subsequently approved by the Directorate General of Mines Safety (DGMS). The suggested support system, as depicted in Fig.2(A), involved the use of roof bolts, cable bolts, wire mesh, and W plates for supporting the underground trunk roads and gate roads. Passive supports, such as cogs and steel girders, were also implemented in disturbed zones to enhance the overall stability of the underground workings.

Despite the comprehensive support plans endorsed by CIMFR and approved by DGMS, the XV seam operations continued to face recurring strata issues. The poor conditions were manifested in the form of guttering observed in the roof and side walls, indicating unfavorable horizontal stress conditions, as illustrated in Fig. 2(B). To address these concerns, cable bolting was employed with reduced spacing, effectively arresting the observed guttering. However, this solution came at a cost—compromising the speed of mining operations.



(A) **(B)**

Fig.2 A representative diagram of support system followed in XV seam

Furthermore, an inherent challenge arose from the fact that the support plan, while theoretically sound and approved by regulatory bodies, did not fully account for the on-field constraints imposed by the machineries deployed on the mining face. This oversight led to the under-utilization of crucial machinery, contributing to delays in achieving the production targets outlined in earlier analyses.

Given these challenges and the need for a more pragmatic approach, the study aims to articulate a problem statement related to both strata stabilization and ventilation optimization. By addressing these key issues, the objective is to pave the way for the successful implementation of the proposed project. This paper attempt to highlight the need of innovative solutions, share insights, and formulation of strategies that can lead to improved operational efficiency, enhanced safety, and ultimately, the attainment of production goals in the XV seam of Moonidih Colliery.

Objectives

The objectives of this comprehensive study encompass a meticulous examination of strata and ventilation-related challenges in the active workings of the XV seam. The research endeavors to re-assess the current working methodology concerning strata stabilization and ventilation practices. Simultaneously, on-field constraints will be integrated into the analysis to gauge their impact on the existing working method. Leveraging these analyses, the study aims to propose a novel and efficient method for recommencing mining operations under stable and secure working conditions.

Literature Review

The foundation of this study is built upon the extensive scientific studies conducted by CIMFR,Dhanbad and IIT(ISM), Dhanbad. These studies, ranging from ventilation planning to strata control and insitu stress measurement, have provided crucial insights into the challenges encountered in XV Seam mining at Moonidih Colliery.

Study 1: "Modeling and Simulation Studies for Designing Ventilation System of XV Seam, Moonidih Colliery, Indu Projects Limited, Hyderabad" (IIT(ISM), Dhanbad, 2013) [3]. This study focuses on ventilation planning, estimating the fan quantity required for specific configurations and recommending a ventilation system for XV seam extraction.

Study 2: "Scientific Study for Rock Mass Rating and Design of Support System for Tunnels, Trunk Roadways, and Longwall Gate Roadways of XV Seam at Moonidih Coal Block, Indu Projects Limited" (CSIR-CIMFR ,Dhanbad , 42013) []. Concentrating on strata control, Study 2 proposes support designs for trunk roadways and junctions, introducing cable bolting in depth beyond 600m.

Study 3: "Advice for Coal Extraction in XV(T&B) Seam at Moonidih Colliery and Design of Longwall Workings with No Adverse Subsidence Impact on Surface, Considering Parting Stability and Other Related Rock Mechanics Aspects with Empirical and Numerical Modeling Techniques" (CSIR-CIMFR ,Dhanbad, 2017) [5]. This study delves into the design of longwall panels with a focus on barrier pillar stability, providing recommendations for coal extraction in XV(T&B) Seam.

Study 4: "Field Investigation & Support Design for Trunk and Gate Roads Developed by Bolter-Miner in Moonidih XV Seam" (IIT(ISM), Dhanbad, 2020) [6]. With a practical approach, Study 4 conducts field investigations to design effective support systems for trunk and gate roadways, addressing specific challenges posed by the Bolter-Miner.

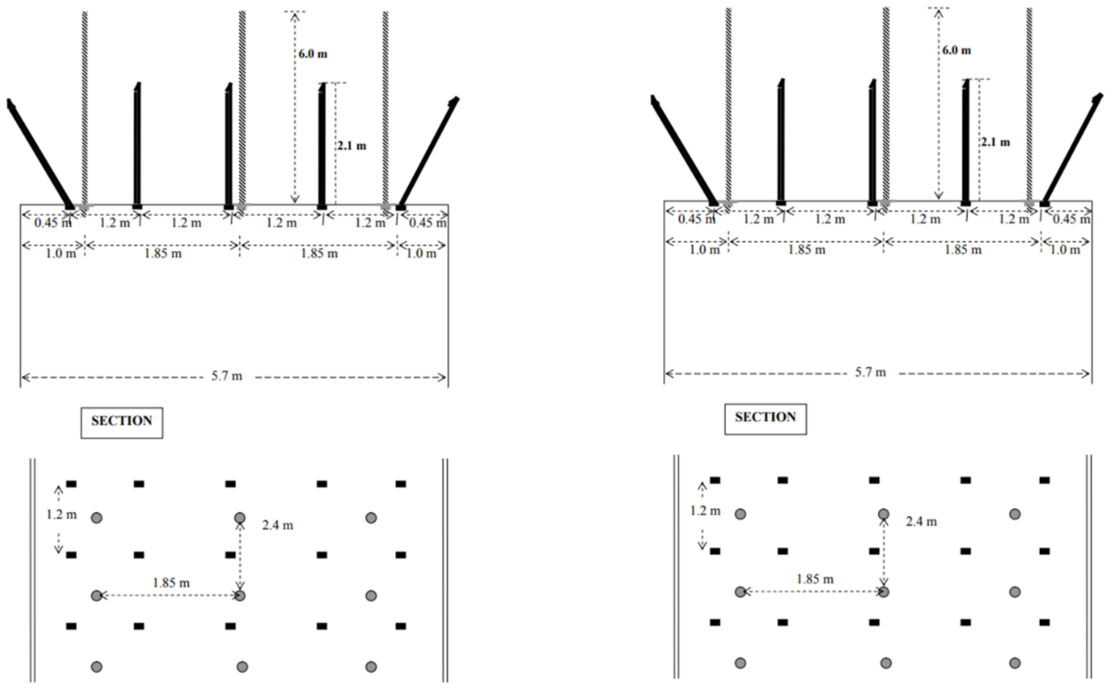
Study 5: "Insitu Stress Measurement in Moonidih and Churcha Mine" (IIT(ISM), Dhanbad, 2023) [7]. The latest addition to the studies, Study 5 employs innovative techniques like hydraulic fracturing to measure insitu stress conditions in XV Seam, providing valuable insights into stress dynamics.The inferences of the studies are tabulated in Table 2.

The amalgamation of these studies forms the basis for understanding the existing challenges and paves the way for proposing solutions to optimize XV Seam mining operations. The subsequent sections elaborate on the methodologies employed in key studies, detailing their research designs and outcomes.

Table 2 Inferences from the scientific studies

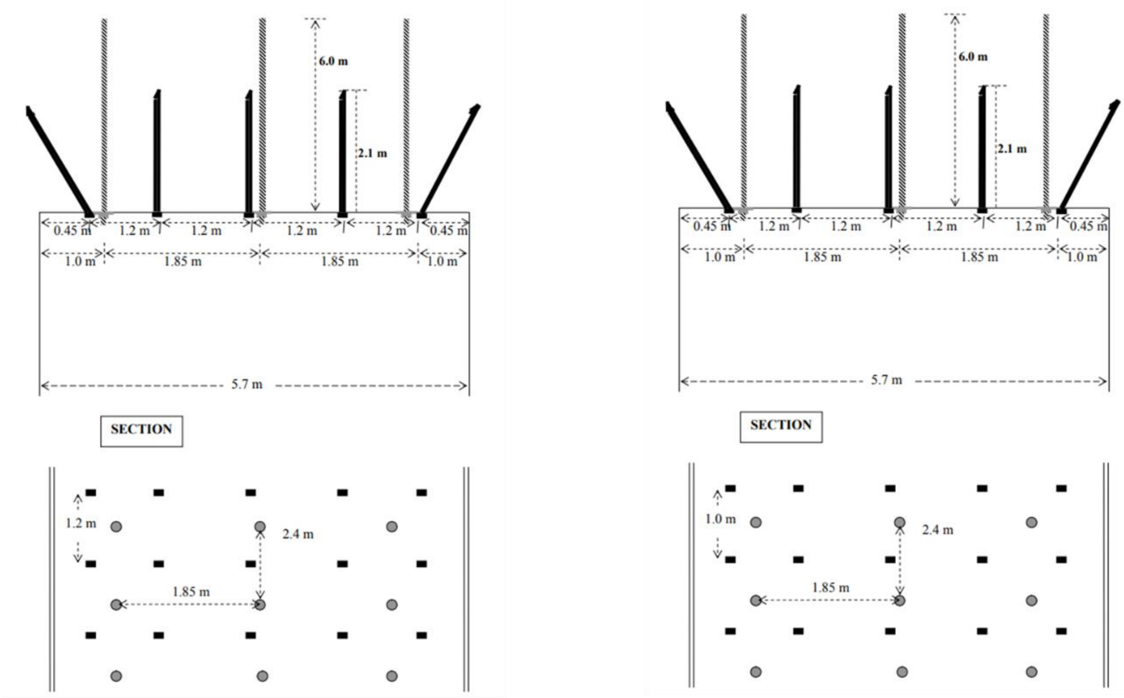
Heads	Study 1	Study 2	Study 3	Study 4	Study 5
Subject	Ventilation	Strata Control	Strata Control	Strata Control	Strata Control
Inferences	1. For fan quantity of 190m^3/s, the pressure of 137.7mm wg is estimated. 2. In this configuration LW receives 51 m^3/s while 2 bolter miner faces receive 41.5 m^3/s and 37.4 m^3/s of air. 3. Air is driven in XV seam with two inclines as intake and one shaft as return. 4. The mine would have 4 trunk ways. 2 intake trunk ways with one with monorail and other with belt conveyor system. 5. To improve the air quality and quantity at the working LW faces, two boreholes are to be driven at the maingate of LW panels. This would also reduce the fan pressure, which in	1. The strata condition of XV (T&B) seam is poor (refer Table 1). 2. Support design for trunk roadways and junctions and other galleries have been designed (refer Fig. 3 to 5). 3. Cable bolting have been introduced in the strata strengthened by roof bolts. 4. Further, to strengthen the junction, the supports have been mandated to increase by 25%. 5. The bolter miner driven galleries have 3 numbers of side supports each side. 6. The road header driven galleries have 2 number of support each side.	1. Based on the stability criteria of chain/barrier pillars, it is recommended that chain pillars of width at least 80 m be left between longwall panels having length not less than 195 m for the long-term stability of the pillars. 2. As per DPR, the width of chain pillar should not be less than 55m. In that case, the FOS is 1.14 which is less than designed FOS 2. Therefore, a pattern of side bolting is preferred. 3. XV (B) seam can be worked with not less than 3 m thick parting in between. 4. After XV(T) seam extraction, the safety factor of parting varies	1. Boreholes were drilled in XV(T&B) seam were drilled, and physico-mechanical properties & RMR of roof were estimated. 2. Additionally, rock load for roadway width of 5.7m and 4.8m were determined. 3. The support designs were then estimated for fault free and fault zones separately. 4. In this study, the cable bolts were not used in support design. 5. In 5.7m gallery in fault free zone, 8 roof bolts and 4 side bolts in addition to wire mesh were used in XV(T) seam, and 6 roof bolts and 4 side bolts in XV(B) seam. In this design the FOS ranged between 2 to 2.3 for gallery at different depths.	1. Hydro fracturing technique has been used to estimate in situ stress conditions of XV seam at Moonidih colliery. 2. Vertical stress, major and minor horizontal stress, stress ratio and direction of major principal stress were calculated. 3. Stress ratio is 2.34 implying that roof failure occurs under shear failure.

	turn reduce fan related investments. 6. Subsequently, a fan with operating range of 170-210m^3/s with corresponding pressure range 107-155mm wg is recommended.		btw 1 and 2.5. To accomplish this, the width of chain/barrier pillar will be increased by 11.4m as compared to those of top section.	In the faulted zone, the support configuration remained same. However, the spacing btw bolts reduced. Additionally, FOS also reduced. 6. In 4.8m width gallery, 6 roof bolts and 4 side bolts in top seam, & 4 roof bolts and 4 side bolts in bottom seam. Wire mesh is used in both cases. The FOS ranged between 2 and 2.43. In faulted zone, both XV(T&B) seam would have 6 roof bolts and 4 side bolts. 7. The strata monitoring plan has been given to measure any dilation or convergence. 8. Four point tell-tale extensometer, telescopic extensometer, rock bolt load cell have been suggested in report to monitor the strata condition.	



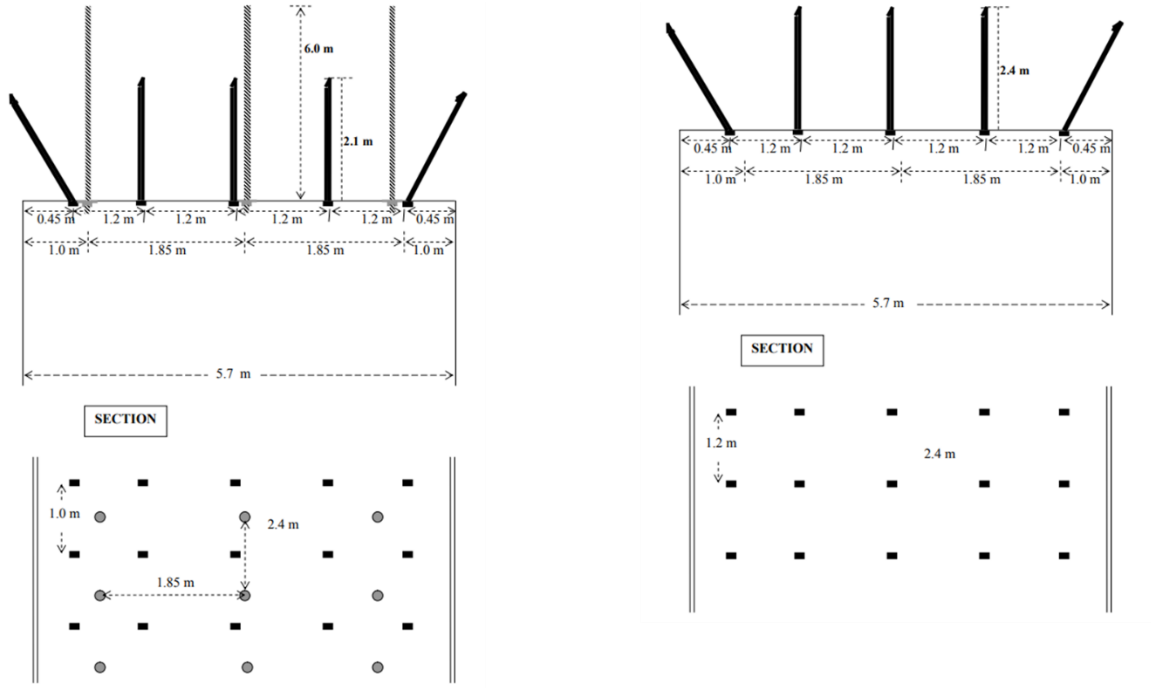
(a) (b)

Fig 3 Support design for Trunk Roads in XV(B) seam (a. 250m<depth<600m, and b. depth>600m) (Study 2)



(a) (b)

Fig 4 Support design for Trunk Roads in XV(T) seam (a. 250m<depth<600m, and b. depth>600m) (Study 2)



(a) (b)

Fig 5 Support design of Gate Roads in (a). XV(T) seam, and (b). XV(B) seam (Study 2).

Among the four studies conducted, Studies 2 to 5 primarily focus on addressing the strata control challenges in the XV seam of Moonidih Colliery. Study 2 and Study 4 specifically delve into the support design aspects related to the trunk roadways and gate roadways, respectively, while Study 3 is centered around the design of the longwall panel, with a particular emphasis on ensuring the stability of the barrier pillar.

Study 2, in its comprehensive analysis, highlights the significance of cable bolting in drivages at depths exceeding 600 meters. This emphasis on cable bolting serves as a crucial component of the support design, especially in deeper sections of the mine. Study 4 places emphasis on reducing the spacing between bolts as depth increases, recognizing the importance of adapting support configurations to varying geological conditions at different depths. It's worth noting that both studies consider a Factor of Safety (FOS) greater than 2 as a design criterion for the support systems, underlining the commitment to ensuring robust and reliable support structures.

A recent addition to these studies, Study 5, introduces a novel perspective by focusing on the measurement of in-situ stress conditions in the XV seam, particularly at a depth of around 620 meters. This study utilizes the hydraulic fracturing technique to fracture the surrounding rock, providing valuable insights into horizontal stress conditions.

Despite the extensive analyses conducted by CIMFR and IIT(ISM), Dhanbad, these studies collectively reveal that stability issues persist in the trunk roadway and gate roadway.

The persistent challenges in achieving stability highlight the complexity of the geological and geotechnical conditions in the XV seam of Moonidih Colliery. The study highlights persistent stability issues and need of fostering collaboration and discussion among industry experts, researchers, and practitioners to identify innovative solutions and refine strategies for enhanced strata control in the XV seam.

Methodology

Study 2:

Research design: For the purpose of strata analysis and support design, the samples and data were collected from borehole no. BH # IMN 005 & BH # 01 (LW) (wrt Study 2). The rock properties, XV(T & B) seam parting, and seam thickness were estimated. Further RMR is estimated. On the basis of RMR, gallery width and rock density, the rock load in gallery and junction are estimated as:

$$Rock\ load\ in\ gallery\ \left(\frac{t}{m^2}\right) = B \times D \times (1.7 - 0.037 \times RMR + 0.0002 \times RMR^2) \quad \ldots(1)$$

$$Rock\ load\ at\ junction\ \left(\frac{t}{m^2}\right) = 5 \times B^{0.3} \times D \times \left(1 - \frac{RMR}{100}\right)^2 \quad \ldots(2)$$

The support resistance provided to the rock by the support system is estimated using following equation:

$$Support\ Resistance = \frac{No.of\ roof\ bolts \times Anchorage\ Strength\ (t)}{Width\ of\ gallery\ (m) \times Row\ spacing\ (m)} \quad \ldots(3)$$

Knowing the support resistance and rock load, factor of safety (FOS) is estimated as:

$$Factor\ of\ safety, FOS = \frac{Support\ resistance}{Rock\ load} \quad \ldots(4)$$

The study estimated that to take care of deep mining conditions, and also overlying shale above coal seams, additional support in form of cable bolts/flexi bolts should be installed in between already installed roof bolts.

Study 4:

Research Design: A field visit was made during 2018, 2019 and 2020. During the field visits, samples of rocks were collected through two core drilling made at Trunk road – 4/2 Level junction and 2 Level South-East/Trunk No 4 in XV seam. During field visit and with the help of geological report, three major faults were found. Thus, the trunk road were broadly divided in two zones: Zone free from major faults, and zone falling within 20m of either side of major faults. Further, the RMR of the strata was calculated using properties of core samples. Then, the rock load, support resistance and Factor of safety were estimated to design an effective roof support system. Additionally, the study recommended the continuous strata monitoring plan, to monitor bed separation, roof to floor and side to side convergence, and load on present support system to test the efficacy of existing support plan.

Study 5:

Research Design: In this study, hydraulic fracturing is done using a hydraulic fracturing machine at depth of around 640m in XV seam. Hydraulic fracturing is a popular field investigation technique for estimating in situ stresses. The stress components are evaluated from the pressure-time history curves of water injection inside a borehole where hydraulically induced fractures are created. A fracture is induced radially in the borehole wall during a typical hydraulic fracturing experiment for in situ stress measurements. The major and minor horizontal principal stresses can be derived from the relationship between the pressures needed to initiate and reopen the fracture. The hydraulic fracturing concept relies on the fact that when a fluid is pressurized into a section of a borehole, sealed off by packers, the pressure on the walls of the borehole starts reducing. At some point, it becomes tensile. A fracture is created when the pressure inside the borehole exceeds the tensile strength of the rock. The fracture will propagate in the direction perpendicular to the minimum principal stress. The following equations are used for obtaining the principal stresses:

$$\sigma_h = P_{si} \quad \ldots(5)$$

$$\sigma_H = T + 3P_{si} - P_c - P_0 \text{ (for initial pressurisation cycle)} \quad \ldots(6)$$

where, P_0 is the pore pressure of the rock formation. The tensile strength, T, of the formation could be determined from the difference in pressure between the first breakdown pressure, P_c, and the fracture reopening pressure, P_r. The argument behind this is that the fracture closes completely between each cycle of pressurisation and that fracture just begins to reopen at P_r. Here, the value of P_r is equal to the hoop stress at the borehole wall induced by the far field stresses.

$$T = P_c - P_r \quad \ldots(7)$$

Now, T is eliminated by combining Eqns. (6) and (7).

$$\sigma_H = 3P_{si} - P_r - P_0 \text{ (for subsequent re-pressurisation cycle)} \quad \ldots(8)$$

For most hydraulic fracturing experiments, the pressurisation occurs sufficiently fast to prevent the fracturing fluid from permeating into the rock so that the pore pressure within the rock matrix is not altered.

Conclusion

The studies conducted thus far have provided valuable insights into ventilation planning, strata control, and stress measurement. However, challenges persist, particularly in roof conditions. The latest study underscores the significance of horizontal stress and advocates for a new support design to address XV Seam's unique geotechnical challenges, offering a promising avenue for future mining operations.Further, the estimation of air quantity in the proposed panels will need reassessment in light of the changes in the gallery dimensions. Pressure drop across the panels will lead to an increase in the leakage across the panels leading to gas and fire hazard. The large panel dimensions will lead to large goaf formation which have traditionally acted as methane reservoirs in the mine. Therefore, there is a need of comprehensive assessment of the mine planning for successful and safe operation at such great depth, thus unlocking the mining potential of coal extraction from reserves amidst challenges of geology, heat and humidity and methane gas hazard mitigation.

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