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Rock mechanical investigation of strata loading characteristics to assess caving and requirement of support resistance in a mechanized powered support longwall face

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ABSTRACT

Longwall mining is one of the most acclaimed and widely used in underground method for coal extraction. The interaction of powered supports with the roof is the key issue in strata mechanics of longwall mining. Controlled caving of rock mass is a prerequisite for thriving exploitation of coal deposits by longwall retreat with caving technique and support resistance has evolved as the most promising and effective scientific tool to predict various aspects related to strata mechanics of such workings. Load density, height of caving block, distance of fractured zone ahead of the face, overhang of goaf and mechanical strength of the debris above and below the support base have been found to influence the magnitude of load on supports. Designing powered support has been attempted at the different countries in different methods. This paper reviews the mechanism of roof caving and the conventional approaches of caving behaviour and support resistance requirement in the context of major strata control experiences gained worldwide. The theoretical explanation of the mechanism of roof caving is still continuing with consistently improved understanding through growing field experiences in the larger domain of geo-mining conditions and state-of-art strata mechanics analysis and monitoring techniques.

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1. Introduction

Principles of longwall mining have been traced back to the latter part of the 17th century to Shropshire and other counties in England, where it was described as a 'totally different method of mining' and called the 'Shropshire Method'. Many modifications in the original methods have occurred, but all longwall mining has involved extracting coal from a longwall face [1–3]. Today, longwall mining has emerged globally as the dominant mass production method and recognized as the safest, the most productive and cost effective underground method for coal extraction. According to coal statistics about 50% of total coal production in the world accounted from longwall mining technology [4,5]. In India, longwall technology was introduced in 1960s and the first mechanised longwall face was introduced in 1978 at Moonidih colliery in Bharat Coaking Coal Limited (BCCL) with an objective to achieve higher production with safety [6,7]. However, majority of the longwall mines in India have not become as successful as they were envisaged mainly due to inadequate assessment of geological

parameters and poor understanding of aeromechanics of caving process under different geo-mining condition [8,9]. A proper and thorough understanding of geo-mechanics and caving process is essential for an effective longwall design [10,11]. In view of this, there is a need for continuous strata monitoring in powered support longwall panel to overcome roof hazards.

2. Role of support resistance in longwall face

Support resistance has evolved as the most promising and effective scientific tool to predict various aspects related to strata mechanics of such workings. Mehta and Dasgupta [12] observed that load density, height of caving block, distance of fractured zone ahead of the face, overhang of goaf and mechanical strength of the debris above and below the support base have been found to influence the magnitude of load on supports [13–16]. A reliable prediction of the caving behaviour of strata and support capacity requirement for longwall workings has always been a challenge for mining engineers. Strata behaviour in terms of uncontrolled roof caving and face instability, coupled with damage of face supports, has been led to a major bottleneck in large-scale adoption of longwall technology under such strata conditions. For these

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reasons, the prediction of caving behaviour and support requirement has been a major topic of research since the introduction of longwall faces [17,18]. However, the support resistance observation of load on support and face convergence for these en masse caving cases were not representative of the actual field condition. It also indicated for requirement of further study to propose a suitable approach which could be integrated with the results of the support resistance to assess the dynamic load due to en masse caving of strata and to estimate the rapid yield valve requirement to ensure safe working of supports [19].

3. Theoretical model for support capacity estimation

A number of approaches based on theoretical analysis and field experience have been developed to address the problems of roof control including prediction of caving behaviour and support capacity requirement for safe and sustainable working of a longwall panel. Theoretical models for prediction of main fall and periodic caving span are based on plate-beam theory and bending moment approach [20,21]. A number of empirical models have been developed on the basis of either certain concept or some field experience to assess the caving behaviour of strata. Some of these approaches suggested roof classifications for qualitative assessment of caving behaviour [22–24]. Some other models proposed quantitative relation to predict the span of main fall [25]. Similar relations have been proposed by various researchers to estimate the span of periodic caving [26–28]. A few models gave both the options of the qualitative assessment of roof caving and the quantitative assessment of caving span [29].

Theoretical models for support capacity estimation have been suggested by Terzaghi [30] based on soil mechanics approach. Empirical models have been proposed by researchers [31–35]. Medhurst and Kevin [36] proposed a ground response curve for assessment of support performance at a longwall face. It was devised on the basis of data obtained from automatic data acquisition system for leg pressure monitoring, leg stiffness test and routine underground observations. The model was used for projecting the support requirement under a different geo-mining condition at the same mine. These approaches as mentioned in this section have been classified by Trueman et al. [37] in seven categories: detached block theory, yielding foundation theory, empirical monograph, load cycle analysis, neural networks, numerical models, and ground response curves. They proposed an alternative conceptual approach based on load cycle analysis. It is meant for diagnosis of strata-support problems rather than prediction. Singh and Singh et al. [38] conducted a performance study of the existing cavability assessment models for estimation of main fall and periodic caving span in longwall panels. The study concluded that a better approach is required to bridge the gap of uncertainty in predicting the caving behaviour of strata. The caving span estimation using empirical approach is not sufficient to assess the progressive nature of caving and a suitable numerical model is required to predict the failure and caving of strata, and support performance with progressive face advance. It is highly flawed to forecast the support requirement without reasonable assessment of caving behaviour of strata in a given geo-mining condition.

This paper reviews the salient points related to the strata technicalities, support resistance and various other aspects related to this subject and the state-of-art of the existing approaches. The subject matter covered under this section of the course work presents a systematic description of the issues pertaining to assessment of caving behaviour and estimating the support capacity requirement for longwall working in a given geo-mining condition. It covers the rock mechanics issues related to the caving behaviour and strata support interaction and compile a review of these subjects as well. A state-

of-art of various approaches used worldwide for assessment of caving behaviour and support resistance of strata is presented. Important aspects for assessment of support requirement are discussed. The requirement of strata control monitoring is emphasized for performance evaluation and better design of mining structures. It is helpful for improving the safety against strata control hazards, and achieving higher recovery of mineral reserve.

4. Different caving behaviour assessment models

The cavability classification of the coal measure rocks in former Czechoslovakia [39] considered the average unbroken length of cores to categorise the roof in three types. Regular caving of strata is achieved if its unbroken core length is less than 10.5 cm (category II).

Polish scientists have developed rock quality index, L , to assess the caving behaviour of strata:

$$L = 0.016C_s d \quad (1)$$

where C_s = compressive strength of rock in-situ (kg/cm^2) and d = mean discernible thickness of immediate roof strata layers (cm).

The compressive strength of immediate roof strata ' C_s ' is determined from the relation:

$$C_s = CK_1 K_2 K_3 \quad (2)$$

where C = uniaxial compressive strength (kg/cm^2) and K_1 = coefficient of strength utilization.

For, sandstone $K_1 = 0.33$, mudstone $K_1 = 0.42$, claystone $K_1 = 0.5$, K_2 = coefficient of creep taking into account the time factor.

For, sandstone $K_2 = 0.7$, mudstone and claystone $K_2 = 0.6$, K_3 = Factor of influence of moisture content in time in mine air.

The uniaxial compressive strength ' C ' is determined using NX (50 mm) rock samples of the immediate roof strata. The test samples of length: diameter ($L:D$) ratio = 1:1 and are loaded at a rate between 2 and 5 kg/cm^2 per minute (~ 0.2 to 0.5 MN/m^2). The mean discernible thickness (d) of the immediate roof strata is determined during the development stage in the coal seam. There is, however, a relationship between the uniaxial compressive strength of the rock types ' C_s ' and the mean discernible thickness and is given by the formula:

$$d = 0.4C^{0.7} \quad (3)$$

where ' C_s ' in kg/cm^2 thus, roof quality index (RQI).

The above formula was improved by correlating the in situ strength test result with its uniaxial compressive strength (UCS) test result obtained in laboratory and establishing an empirical relationship between the UCS of roof rock in laboratory and mean discernible thickness of immediate roof. The final equation was proposed as follows:

$$L = 0.0064C^{1.7} K_1 K_2 K_3 \quad (4)$$

According to the obtained value of L the roof conditions may be identified using the roof classification system given in Table 1.

Now, width of the immediate roof, i.e. the maximum distance between the face line and the line of caving of immediate roof is given.

Initial face advance prior to first caving:

Definite relationship which has been observed is as follows:

$$R = 4.47L^{0.4} \quad (5)$$

where R = initial face advance prior to first caving (m) and L = roof quality index (RQI).

Calculation of width of immediate roof:

$$W = L_c + S + e \quad (6)$$

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