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Review

Conventional approaches for assessment of caving behaviour and support requirement with regard to strata control experiences in longwall workings

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ABSTRACT

Effective control of roof strata is very important for trouble free operation and regular face advance in mechanised longwall workings. It is now technically possible to exploit coal seams in difficult geo-mining conditions with the help of newer innovations in longwall face machineries. A reliable assessment of caving behaviour and support capacity requirement helps in selecting supports of adequate capacity and making operational preparedness for timely and confident solution of impending problems. This paper reviews the mechanism of roof caving and the conventional approaches of caving behaviour and support requirement in the context of major strata control experiences gained worldwide. The review shows that a number of approaches are being used for advance prediction of caving behaviour and support capacity requirement in a variety of geo-mining conditions. The theoretical explanation of the mechanism of roof caving and the design function of roof supports have been worked out through staged development of approaches, their evaluation followed by their gradual modification and enrichment of synthesized findings. This process is still continuing with consistently improved understanding through growing field experiences in the larger domain of geo-mining conditions and state-of-art strata analysis and monitoring techniques. These attempts have contributed significantly to improving the level of understanding and reducing the gap of uncertainty in planning and design of longwall operation in a given geo-mining condition.

1. Introduction

Strata mechanics in longwall mining has been a grey area of research since its introduction to underground coal mining industry worldwide. 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 (Obert and Duvall, 1967) and bending moment approach (Majumdar, 1986). 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 (Zamarski, 1970; Arioglu and Yuksel, 1984; Zhao, 1985; Peng et al., 1986, 1989). Some other models proposed quantitative relation to predict the span of main fall (Pawlowicz, 1967; Bilinski and Konopko, 1973; Singh and Singh, 1979, 1982; Unrug and Szwilski, 1980; Peng and Chiang, 1984). Similar relations have been proposed by various researchers to estimate the span of periodic caving (Kuznetsov et al., 1973; Peng and Chiang, 1984; Sarkar and Dhar, 1993; Sarkar, 1998). A few models gave both the options of the qualitative assessment of roof caving and the quantitative assessment of caving span (Ghose and Dutta, 1987; Sarkar and Dhar, 1993; Sarkar, 1998).

Theoretical models for support capacity estimation have been suggested by Terzaghi (1965) and Evans (1975) based on soil mechanics approach. Empirical models have been proposed by Barry et al. (1969), Ashwin (1975), Wade (1976), Josien and Gouilloux (1978), Qian (1982), Peng and Chiang (1984), Shi (1985), Budirsky and Martinec (1986), Majumdar (1986), Wilson (1986), Bigby (1987), Peng et al. (1987, 1989), Porter and Aziz (1988), Jackson and Newson (1989), Jiang et al. (1989), Peng (1992), Sarkar and Dhar (1993), Das (1994), and Sarkar (1998).

Singh (2004) and Singh et al. (2004) conducted a performance study of the existing cavability assessment models for estimation of main fall and periodic caving span in longwall panels. The results of

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model observed span for 15 longwall panels were compared with the field observed values. 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. Empirical and theoretical models are developed based on idealization of many complex mechanisms and are not expected to respond properly due to their inbuilt limitations. It is also felt that any attempt to develop a reliable support capacity estimation model must be integrated with prediction of caving behaviour. It is highly erroneous to predict the support requirement without reasonable assessment of caving behaviour of strata in a given geo-mining condition.

Medhurst and Kevin (2005) 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. (2005) in seven categories: detached block theory, yielding foundation theory, empirical nomograph, load cycle analysis, neural networks, numerical models, and ground response curves. They concluded that the existing approaches offer important contributions towards understanding strata-support interactions, but do not provide effective means of support specification. They proposed an alternative conceptual approach based on load cycle analysis. It is meant for diagnosis of strata-support problems rather than prediction.

This paper reviews the salient points related to the strata mechanics and various other aspects related to this subject and the state-of-art of the existing approaches. A methodological description of the numerical modelling based approach suggested by the authors is also described. 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 rock support interaction and compiles a review of the state-of-art on these subjects as well. A state-of-art of various approaches used worldwide for assessment of caving behaviour 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.

2. Potential models for assessment of caving behaviour

The cavability classification of the coal measure rocks in former Czechoslovakia (Zamarski, 1970) 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 (Pawlowicz, 1967) have developed rock quality index, L, to assess the caving behaviour of strata:

$$L = 0.016C_s d \tag{1}$$

where C_s is the in situ compressive strength of roof rock in kg/cm^2, and d is the mean discernible thickness of immediate roof strata in cm.

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 (Bilinski and Konopko, 1973). The final equation was proposed as follows:

$$L = 0.0064C^{1.7}K_1K_2K_3 \tag{2}$$

where C is the UCS of roof rock measured on dry specimens in laboratory (kg/cm^2); K_1 is the in situ strength coefficient, which is 0.33 for sandstone, 0.42 for mudstone, and 0.5 for claystone or siltstone; K_2 is the creep coefficient, which is 0.7 for sandstone and 0.6 for mudstone, clay stone or siltstone; K_3 is the in situ water content coefficient, which is 0.6 for sandstone with 50% relative humidity, 0.4 for clay stone and mudstone with 50% relative humidity.

Based on the value of L, the roof is categorised in six groups having different values of allowable area of exposure. Good caving of strata is achieved up to a value of L equal to 130 (Class IV roof). A relation has also been established between the span of main fall (S_m) and the roof quality index (L):

$$S_m = 4.47L^{0.4} \tag{3}$$

2.1. Plate and beam model

Obert and Duvall (1967) developed an equation, based on theory of plates (Timoshenko and Woinowsky-Krieger, 1959), for tensile failure of a gravity-loaded plate clamped on all edges, simulating the condition of failure of roof during main fall at a longwall face and computed the maximum tensile stress at failure:

$$\sigma_{max} = \frac{6\beta\gamma_e a^2}{t_p} \tag{4}$$

where σ_{max} is the maximum tensile stress (MPa); β is the empirical constant (Table 1) based on ratio b/a (Timoshenko and Woinowsky-Krieger, 1959); b is the longer lateral dimension of the plate (m); a is the smaller lateral dimension of the plate (m); t_p is the plate thickness (m); and γ_e is the effective unit weight of rock (MPa/m), which can be calculated by

$$\gamma_e = \frac{E_1 t_1^2 \sum_{i=1}^{n} \gamma_i t_i}{\sum_{i=1}^{n} E_i t_i^3} \tag{5}$$

where E_i is the Young's modulus of the ith rock layer, γ_i is the unit weight of the ith rock layer, and t_i is the thickness of the ith roof layer.

Eq. (5) is utilised for the purpose of extra loading to the weighting roof layer when the thickness of the upper roof layer is lesser than that of the lower layer.

For a value of $b/a>2$, the effect of smaller lateral dimension becomes negligible. In such cases, Obert and Duvall (1967) suggested to apply the beam formula presented as follows:

Table 1
Values of β for different values of b/a.

b/a	β
1	0.0513
1.25	0.0665
1.5	0.0757
1.75	0.0806
2	0.0829
>2	0.0833