ESTIMATION OF FIRST ROOF WEIGHTING INTERVAL INCORPORATING ROOF STRATA CAVABILITY CONCEPT

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Abstract: First roof weighting interval in mechanized longwall mining is related directly to the applied loads on support system and thus, has important role on stability, safety, and continuity of operation. This paper presents an innovative approach based on cavability of immediate roof to estimate first roof weighting interval. Nine inherent parameters of roof strata and its surrounding environment which affect caving process were taken into account to develop a classification system, incorporating fuzzy hybrid multi criteria decision-making technique. Roof Strata Cavability index (RSCi) was defined as summation of ratings for all parameters. Subsequently, the relationship between RSCi and extracted volume until the first caving moment (i.e. the extraction height× panel width × first roof weighting interval) was determined using linear and non-linear regression models. Models were proposed and validated using the actual field data collected from different longwall panels around the world. Results indicated that the quadratic polynomial model gave a better performance in the estimation of first roof weighting interval, compared to the other models. It was concluded that the proposed approach is an accurate and flexible tool to estimate first roof weighting interval in longwall mining.

Keywords: Coal, longwall mining, Immediate roof, Cavability, First roof weighting interval.

INTRODUCTION

In longwall mining, a part of the overburden loses its natural support due to the extraction and advancement of the extraction face. Once a certain unsupported span is reached, the nether strata of the immediate roof fractures, and subsequently, falls. The distance, from the starting point to the caving point, is first roof weighting interval (main caving span or main fall distance). After that, as mining processes further, the upper strata will break periodically, leading to a periodic weighting interval (periodic caving span or periodic fall distance). Generally, the first roof weighting interval is greater than periodic weighting interval, and produces higher induced stresses. In the caving process, caved rocks provide a support for the upper layer and transfer their loads to the floor. This reduces stress levels at abutments and ahead of the longwall face. A proper caving guarantees the success of this mining method, while delayed or/and poor caving will lead to severe consequences such as face jamming, rock burst on the face, and airburst. A thorough understanding of strata mechanics and caving mechanism are imperative in the planning stage for subsidence and ground control design, stability prediction of face, roadways and gates, determination of the load capacity of longwall shields, designing the pillars, and length of the longwall panels.

A number of empirical (Pawlowicz, 1967; Bilinski and Konopko, 1973; Singh and Singh, 1979; Unrug and Szwilski, 1980; Singh and Singh, 1982; Peng and Chiang, 1984; Ghose and Dutta, 1987; Sarkar, 1998; Banarjee et al., 2016; Mohammadi et al., 2018) and analytical (Obert and Duvall, 1967; Peng and Chiang, 1984; Manteghi et al., 2012; Shabanimashcool and Li, 2015) models have been developed in the literature to predict first roof weighting interval. Although these models have provided significant contribution to the topic, they suffer from some shortcomings. The empirical methods which were developed on the basis of real databases which are not practical for other cases. On the other hand, analytical methods have various assumptions, leading to a reduction in their practical applications. In order to overcome these drawbacks, this paper proposes an approach to estimate first roof weighting interval by incorporating cavability concept of immediate roof strata. Accordingly, Roof Strata Cavability index (RSCi) was presented by developing a novel rating system to incorporate significant parameters that affect caving process. Predictive models were developed by determining the relationship between RSCi and extracted volume in the first roof weighting moment, to make a database of worldwide longwall experiments.

METHODS

RSCi was introduced using a combination of fuzzy analytical network process (ANP) and fuzzy decision-making trial and evaluation laboratory (DEMATEL) methods. ANP is the general extension of AHP method that provides a general framework to deal with complex real problems, with independencies within a cluster and among the different clusters (Saaty, 1996). ANP forms a super matrix of the problem, in which the inner and outer dependencies are merged together to calculate the weight of each parameter. DEMATEL is a robust method used in formulating the sophisticated structures; it models the interdependent relationships within a set of criteria under consideration (Gabus and Fontela, 1972; Fontela and Gabus, 1974, 1976). In this paper, the inner-dependence among parameters was evaluated by fuzzy DEMATEL. Outer-dependencies as well as weighting of clusters were determined using fuzzy ANP procedure through pairwise compression.

FINDINGS AND ARGUMENT

Roof Strata Cavability index (RSCi) is defined as summation of ratings for nine significant parameters including roof strata UCS, roof strata thickness, number of joint sets, orientation of joint sets, dip of joint sets, spacing of joint sets, persistence of joint sets, groundwater flow and mining depth. Rating system were either presented continually in form of equation and chart, or discretely in form of table as shown in Figures 1 to 3 and Tables 1 to 3.

In this study, strata thickness and UCS are considered as representative characteristics of strata that reflect the overall roof strength. Therefore, Equivalent Immediate Roof Strength (EIRS) is defined to represent stratification of coal mines roof as:

$$EIRS = \frac{\sum_{i=1}^{n} S_{c_i} \times UCS_i}{\sum_{i=1}^{n} S_{c_i}} \quad (1)$$

where S_{c_i} is the stratum coefficient of ith stratum, i is the stratum number and n is the number of stratum within immediate roof. The order of stratum (layer or unit) number is from the coal seam.

The stratum coefficient consists of two parts, thickness of stratum and proximity to the coal seam. This coefficient is defined as:

$$S_{c_i} = t_i \times PF_i \quad (2)$$

where PF is the proximity factor to the coal seam as:

$$PF_i = RCT_{n+1-i} \quad (3)$$

where RCT is the ratio of cumulative thickness as:

$$RCT_i = \frac{\sum_{i=1}^{i} t_i}{\sum_{i=1}^{n} t_i} \quad (4)$$

The height of immediate roof (equal to the caving height) is determined as:

$$t_1(BF_1 - 1) + t_2(BF_2 - 1) + ... + t_n(BF_n - 1) = h_c \quad (5)$$

where ti is the thickness of the ith stratum, BFi is the bulking factor of the ith stratum, n is the number of the immediate roof stratum and hc is the extraction height. This means that the strata which satisfy Eq. (5) actually form the immediate roof and the summation of their thicknesses is the height of the immediate roof.

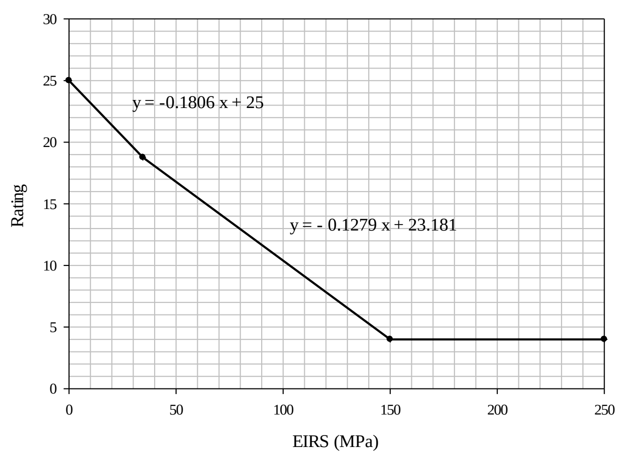


Fig.1 EIRS rating scale

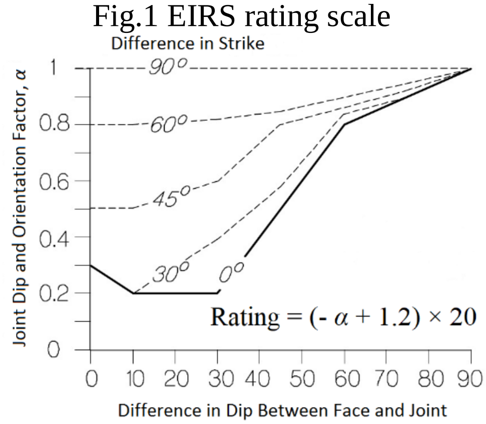


Fig.2 Joint dip and orientation factor

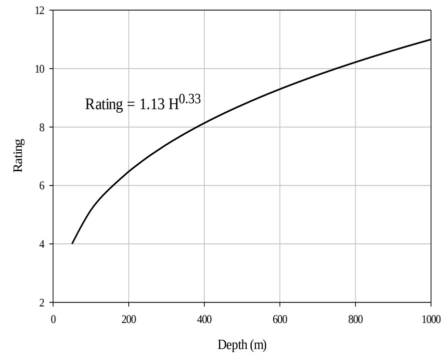


Fig.3 Mining depth rating scale

Table 1. Joint set rating

Joint set number	Rating
Massive, no or few joints, no obvious bedding planes	0
Only bedding planes or a joint set	3
Bedding planes plus a joint set or two joint sets	6
Bedding planes plus two joint sets or three joint sets	9
Heavily jointed, crushed rock, earthlike	12

Table 2. Joint spacing and persistence rating

Persistence	Spacing				
	> 1.8 (m)	0.6 – 1.8 (m)	0.2 – 0.6 (m)	60 – 200 (mm)	< 60 (mm)
0 – 1 (m)	5	8	12	16	21
1 – 3 (m)	7	10	14	17	21
> 3 (m)	8	11	15	19	21

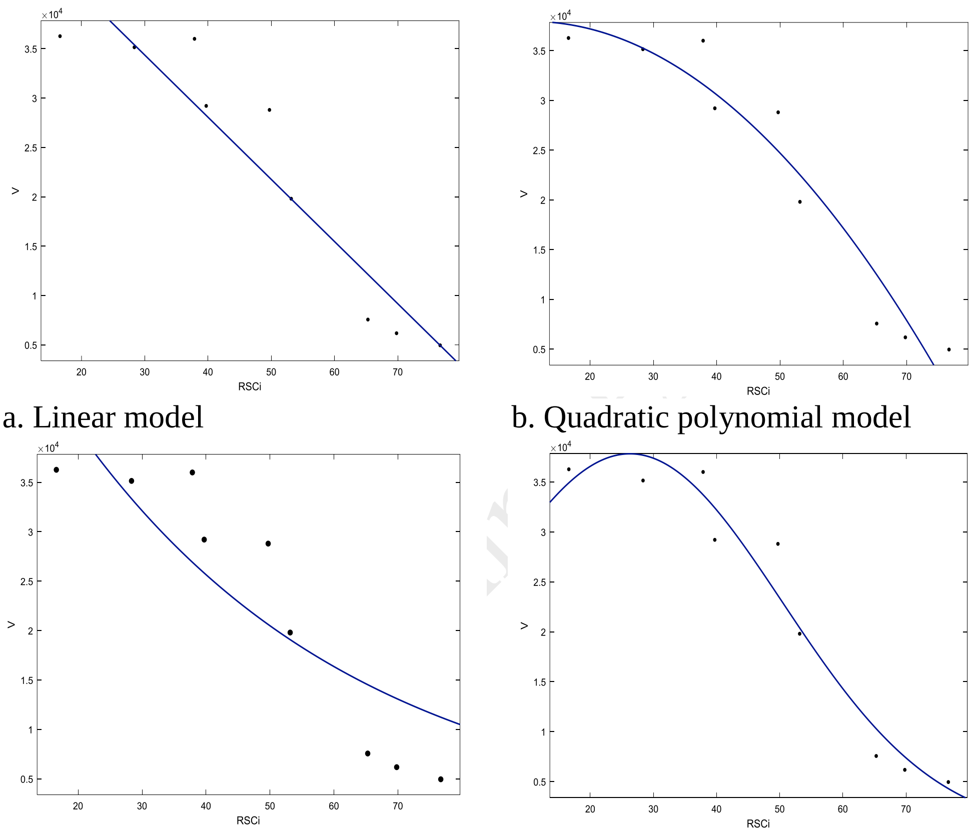
Table 3. Groundwater rating system

Flow volume	Observation of flow	Rating
None	None	0
Very low	None visible	2
Low	Light seepage/ dripping	6
Medium	Steady seepage/flowing	9
Large	Heavy seepage/gushing	11

In order to investigate the relationship between RSCi and extracted volume in the first roof weighting moment (called V which is extraction height × panel width × first roof weighting interval), the curve fitting approach was applied. Accordingly, several curves were fitted on the 75% of data, and the RMSE and R^2 values were calculated as shown in Table 4 and figure 4.

Table 4. Fitted models and associated RMSE and R2

Model	Function	RMSE	R2
Linear	$V = -629.88 RSCi + 53250$	4852	0.88
Quadratic polynomial	$V = -8.5088 RSCi^2 + 179.7 RSCi + 36995$	3905	0.94
Exponential	$V = 63120 \exp(-0.02251 RSCi)$	7094	0.75
Gaussian	$V = 37822.41 \exp(-(\frac{RSCi - 26.28}{34.18})^2)$	3171	0.96



a. Linear model
b. Quadratic polynomial model
c. Exponential model
d. Gaussian model

Fig.4 Fitted models plot

Performance of the proposed model were evaluated using three cases. In this regard, the extracted volume was calculated using developed models, then, the first roof weighting interval was computed based on their actual panel width, and extraction height. A comparison between the measured and estimated first roof weighting interval values is shown in Figure 5. In addition, for quantitative comparison, four criteria including RMSE, MAPE, and VAF were used. The calculated values of these indices for the proposed models are presented in Table 5.

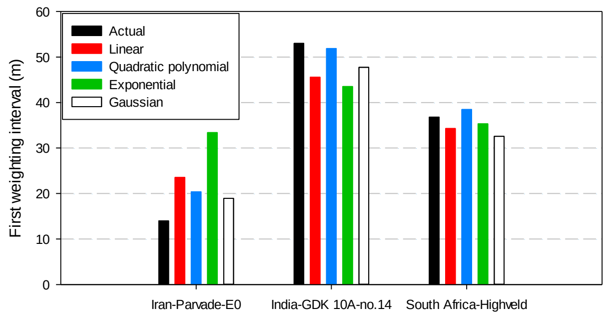


Fig.5 Comparison between measured and estimated interval values

Table 5 Calculated performance criteria for proposed models

Model	RMSE	MAPE (%)	VAF (%)
Linear	7.13	29.65	80.14
Quadratic polynomial	3.87	17.44	96.24
Exponential	12.49	53.47	42.12
Gaussian	4.83	18.90	91.78

According to the visual comparison (Figures 5) and the performance criteria (Table 5), it is inferred that the quadratic polynomial model is capable to estimate the first roof weighting interval with a reasonable accuracy. Also, it showed higher accuracy when compared to other models.

It should be noted that as a general index, RSCi can be used for ample variability of geo-mining environment in underground coal mines, particularly in longwall mining. Undoubtedly, the obtained relationships are not applicable to all cases, nevertheless, the proposed approach as a general model is valid. Since the reliability of the proposed relationships are largely dependent on the size, quality, and consistency of the database, therefore, more cases would always lead to production of new relationships with higher reliability.

CONCLUSION

Estimation of first roof weighting interval in longwall mining was carried out using an approach based on cavability concept of immediate roof strata. Roof Strata Cavability index (RSCi) was introduced by incorporating a fuzzy hybrid decision-making method to integrate significant parameters of caving process. Predictive models were determined by investigating the relationship between RSCi and extracted volume until first roof weighting moment. The following main conclusions are drawn from this investigation:

- The uniaxial compressive strength is the most significant parameter of cavability with 13% of weight in total. Strata thickness (12%) and number of joint sets in immediate roof (12%) were placed after that.
- It is noted that roof discontinuities properties have more than 50% influence on the cavability.
- The best-fitted curves on the data to define the relationship between RSCi and extracted volume were a quadratic polynomial with R^2 and RMSE values of 0.94 and 3905, respectively.

- Model validations indicated that the quadratic polynomial model gives a higher performance to estimate the first roof weighting interval with R^2 and RMSE values of 0.96 and 3.87, respectively.

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