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A Model for Determining the Breaking Characteristics of Immediate Roof in Longwall Mines

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ABSTRACT

Nowadays, the longwall mining is one of the most prevalent methods being used in coal mines. For the safety and success of such mines, one of the most important parameters is determination of the periodic roof weighting interval. As a matter of fact periodic roof weighting interval (PRWI) is not selected. Design and selection of support in this mining method should be correctly selected considering PRWI. Consequently, the current paper tries to develop a new model for determining the periodic roof weighting interval of coal mines. For this, the roof weighting interval is modeled by applying an analytical method and presented a model for determining the roof weighting interval. The results are compared with some case studies at coal mines. It is found that that the proposed model can confidently be used for determining the roof weighting interval in coal mines.

Keywords : Analytical method, Immediate roof, Longwall mining, Numerical modeling, Roof weighting interval.

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INTRODUCTION

The longwall mining is one of the main underground methods with high production rate in coal mines. This is a usual method applied for layered deposits with low dip. In this process, the powered supports are applied for supporting of the roof with the advancing of coal face. An overall view of the longwall mining method is shown in Fig. 1. As longwall mining moves along the direction of mining in a longwall panel, there are two distinctive phase of overburden movements. The first phase of movement includes the distance from the setup entry to the point when the immediate roof begins to cave. The distance from the setup entry to the first weighting is defined as the **first weighting interval.**

The second phase begins right after the first weighting and extends to the completion of the panel mining. During this period the roof pressure at the face area increases and decreases cyclically due to the cyclical breakage of the immediate roof. This phenomenon is called the **periodic roof weighting** and the distance between two consecutive roof weightings is called the **periodic roof weighting interval** (Peng et al., 1984). The immediate roof in coal mines may contain rocks ranging from soft to hard. As such, in many cases, the immediate roof is stable and does not fall immediately and it overhangs at a distance that it can apply high pressure to the support system. Fig. 2a shows the overhanged immediate roof (Peng et al., 1982; Peng et al., 1984). Determining the roof weighting interval in the longwall mining is very important because determining a length less than the real size could prove hazardous to miners by selecting a scrimpy support system. Also, determining the length more than its real size (for periodic roof weighting interval) constrains additional mining costs by applying stronger support system. The current paper has used the analytical method to model the behavior of immediate roof in coal mines.

HISTORY OF RESEARCH

Three methods are being applied to determine the roof weighting interval of coal mines i.e. coal mine roof classification, analytical method and numerical method. The first popular coal mine

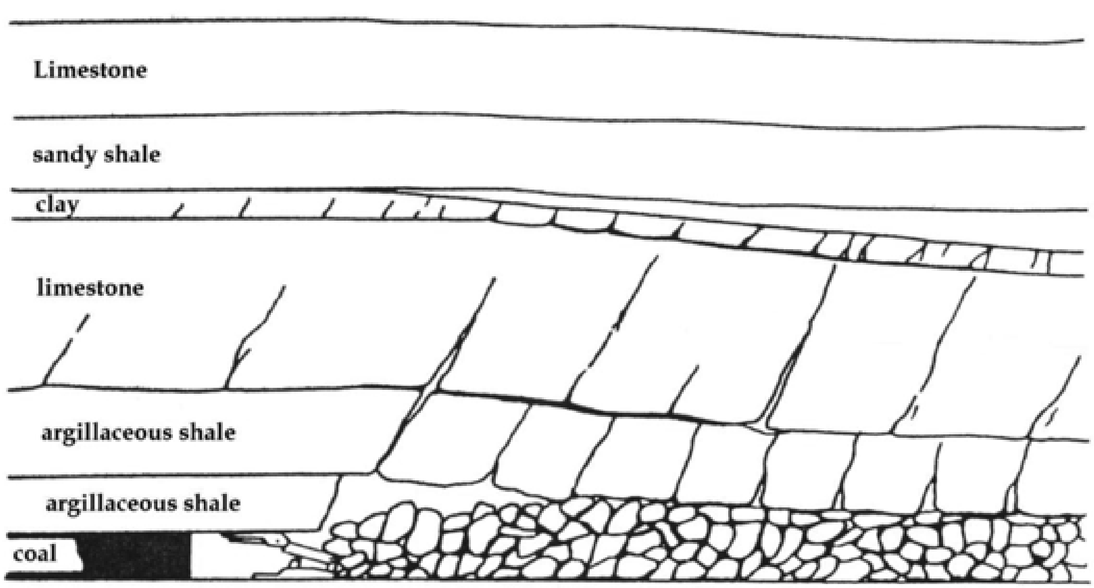

Figure 1. Overall view of the longwall mining method.

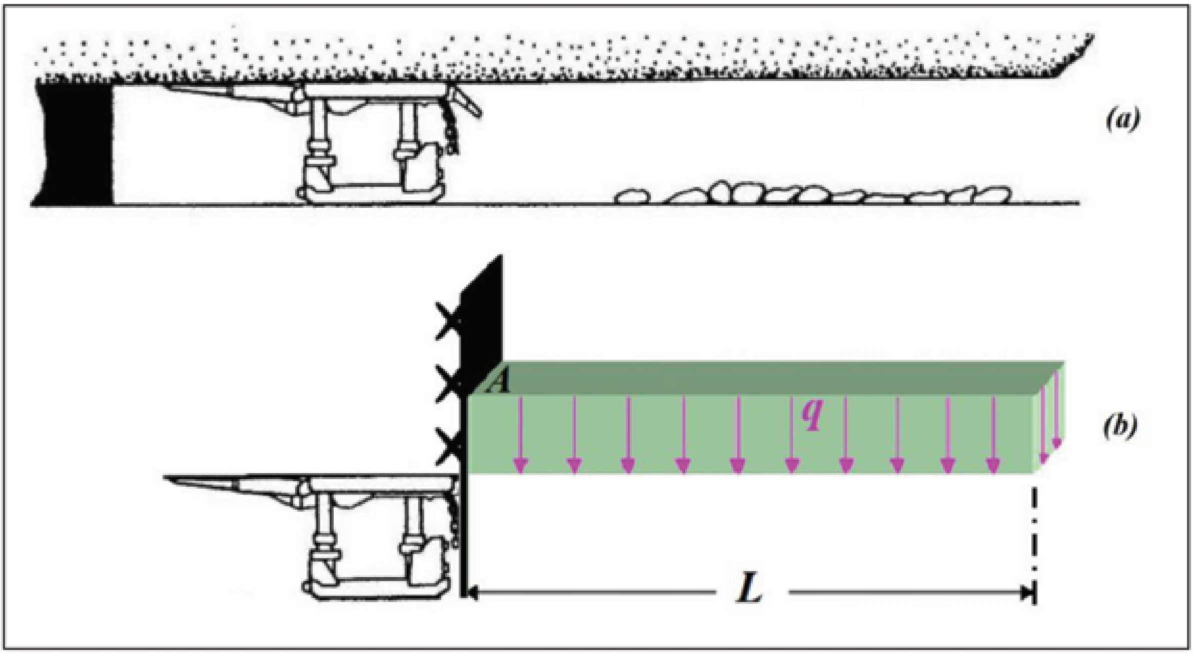

Figure 2. (a) Overhanged immediate roof; (b) Analytical model of overhanged immediate roof.

roof classifications were Russian and Polish (Peng et al., 1982). Thereafter, yet another Russian classification was developed based on the uniaxial compressive strength, the joint spacing as well as the engineering index (Korovkin, 1980; Peng et al., 1984).

Based on geomechanic rock mass rating, Bieniawski proposed a scheme which could predict the stand up time for a specified unsupported roof (Bieniawski, 1979; Peng et al., 1984; Goodman, 1989). Peng divided the immediate roof into three categories i.e. unstable, medium stable and stable (Peng et al., 1984). Another roof classification is based on bed separation resistance which is measured by borehole penetrometer (Kidybinski, 1979; Kidybinski, 1982). Kidybinski presented a roof classification based on the rebound number of Schmidt hammer type N (Kidybinski, 1977; Ataee, 2005). Considering conditions at Russia's Dones Coalfield, Proyavkin classified roof into twenty-six groups (Oraee, 2002; Ataee, 2005). Unrug & Szwilski defined rock quality index (RQI) dividing the roof to six groups from weak to very strong (Unrug et al., 1982). Staff proposed the roof classification scheme and applicable types of supports for various combinations of immediate and main roofs in China (Staff, 1982). Another roof classification is based on the effect of stratigraphic sequences (Peng, 1984). Qualitative roof classification can utilize the condition and convergence of roof with block size of fractured rocks (Bieniawski, 1984). Mark & Molinde defined the coal mine roof rating (CMRR) according to their experiences in American mines (Molinda et al., 1994; Mark, 1999; Butcher, 2001; Mark et al., 2002).

Das proposed a roof classification based on Indian coal mines. He divided the coal mines' roof into six groups (Das, 2000). Then presented the coal measure classification (CMC) based on the coal mines in England (Whittles et al., 2007).

The second way to determine the roof weighting interval is the analytical method which is advantageous while comparing the roof classifications. In other words, the results of analytical methods are quantitative in nature. Peng & Chiang defined the first model for determining the roof weighting interval (Peng et al., 1984).

Singh & Dubey proposed yet another model for the first roof weighting interval where they applied effects of joints by a weakness coefficient factor (Singh et al., 1994). Korovkin defined an equation for the periodic roof weighting interval (Korovkin, 1980), however; he did not apply the effects of joints of strata in this equation.

In the present study, the authors intend to come up with an equation to determine the periodic roof weighting interval by regarding joints of strata.

These days, software is available for the numerical modeling in coal mines hence; this is being used to analyze the roof weighting interval or to design coal mines' supports. For instance, the numerical modeling has been used in Chinese coal mines to determine deformation and failure of top strata (Xie et al., 1999). In Turkey, the numerical modeling was used for longwall mining with the top coal caving at the Omerler underground mine (Yasitli et al., 2005). Another numerical modeling is used in multiple seam mining and their interactions in the longwall mining (Morsy et al., 2006). It is also applied for the roof weighting interval by Singh et al. (Singh et al., 2009) as well as for the roof caving to assess dilution in the longwall mining by Saeedi et al. (Saeedi et al., 2010).

ANALYTICAL MODEL OF IMMEDIATE ROOF

According to the Beam theory (Peng, 1978), the immediate roof in the periodic roof weighting behavior is a beam where the weight of immediate roof is an active force. Fig.2a highlights the typical view of overhanged immediate roof whereas Fig. 2b shows a simple analytical model of this immediate roof. In the Figure, L and q are the length of overhanged immediate roof and the uniformly distributed load per length of beam, respectively. Fig. 2b does not apply dip of the immediate roof. In other words, once the dip is applied to the model, the overall view of coal face will be the same as Fig. 3. To analyze the periodic roof weighting, a cross section of Fig. 3 is needed first (as shown in Fig. 4a) and then forces can be analyzed. Fig. 4b shows a simple model of the immediate roof considering dip and forces applied to the fixed end of the beam. Accordingly, the figure shows:

$$\sum F_x = 0 \Rightarrow A_x = 0 \quad (1)$$

$$\sum F_y = 0 \Rightarrow A_y = q\,L\cos\alpha \quad (2)$$

$$\sum M = 0 \Rightarrow M_A = \frac{q\,L^2\cos\alpha}{2} \quad (3)$$

To continue analyzing the model, it gradually needs to have a cut from the model indicated by Fig. 4b.Therefore, the model will be in accordance with Fig. 4c and can be written as:

$$\sum F_x = 0 \Rightarrow p = 0 \quad (4)$$

$$\sum F_y = 0 \Rightarrow v = A_y - qx\cos\alpha \quad (5)$$

$$\sum M = 0 \Rightarrow \quad (6)$$

$$\Rightarrow M = M_A - A_y.x + q.\frac{x^2}{2}\cos\alpha \quad (7)$$

Combining equations (2) & (5), a new equation can be as follows:

$$v = (qL - qx)\cos\alpha \quad (8)$$

$$\frac{\partial M}{\partial x} = 0 \Rightarrow v = 0 \quad (9)$$

Equations (8) & (9) $\Rightarrow$

$$v = (qL - qx)\cos\alpha = 0 \quad (10)$$

$$\Rightarrow qL - qx = 0 \Rightarrow x = \frac{q\,L}{q} = L \quad (11)$$

Equations (2) & (3) & (7) & (11) $\Rightarrow$

$$M_{\min}(x = L) = (q\frac{L^2}{2} - q\,L^2 + q\frac{L^2}{2})\cos\alpha = 0 \quad (12)$$

$$M_{\max}(x = 0) = q\frac{L^2}{2}\cos\alpha \quad (13)$$

For a beam with rectangular section (Tahoony, 2009), an equation can be as;

$$\sigma_t = \frac{MC}{I} \quad (14)$$

$$C = \frac{h}{2} \quad (15)$$

$$I = \frac{b\,h^3}{12} \quad (16)$$

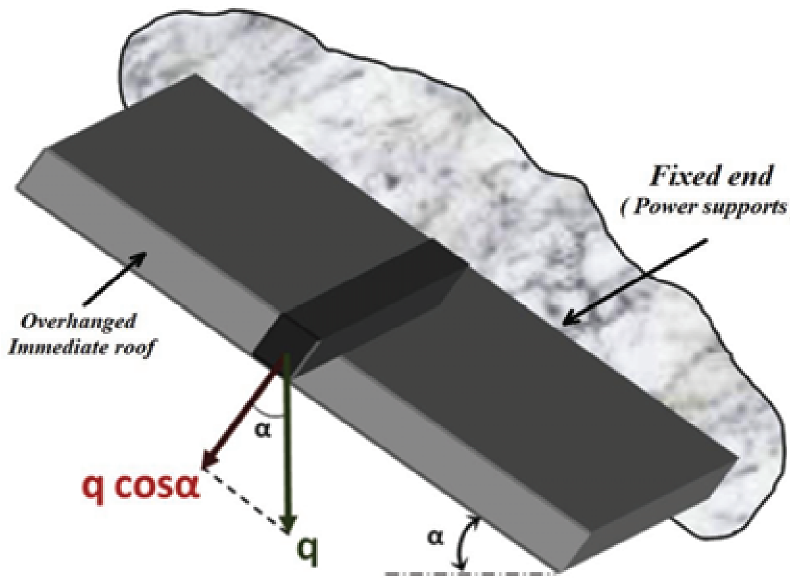

Figure 3. Overall view of immediate roof with dip.

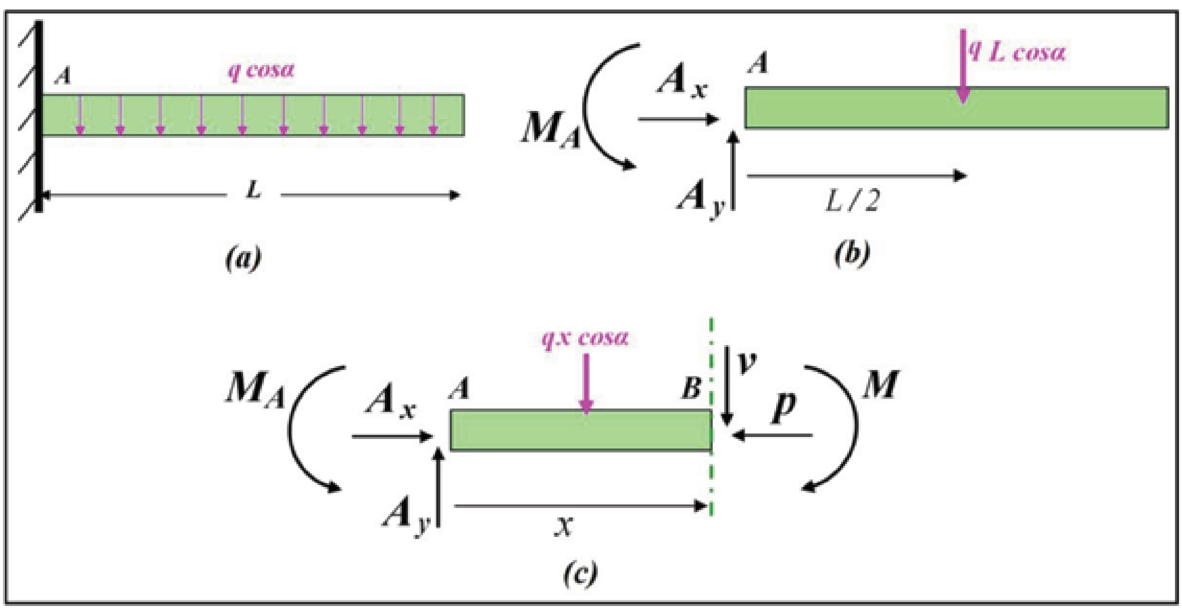

Figure 4. (a) Cross section of immediate roof with dip; (b) Simple model of the immediate roof considering dip and forces applied to the fixed end of the beam; (c) The cut of immediate roof's beam.

Where σ_t, M, and C are tensile strength of the beam, the bending moment and the distance from the neutral axis to surfaces of the beam, respectively. I, h and b indicate second moment of area, thickness of the beam and width of the beam, respectively.

According to the plane strain theory (Ajalloeian, 2000) realizing that (b=1):

$$I = \frac{h^3}{12} \tag{17}$$

From equations (14), (15) & (17), it can be written as:

$$\sigma_t = \frac{6M}{h^2} \tag{18}$$

This equation along with equation (13) will result in:

$$\sigma_t = \frac{3\,q.L^2}{h^2}.\cos\alpha \tag{19}$$

$$\Rightarrow L = \sqrt{\frac{\sigma_t\ h^2}{3q\cos\alpha}} \tag{20}$$

On the other hand;

$$q = \gamma h \tag{21}$$

Where q is the uniformly distributed load per length of beam, γ is the weight per unit volume of beam and h is the thickness of the beam. As such equation (20) can be changed into;

$$L = \sqrt{\frac{\sigma_t\ h}{3\ \gamma\ \cos\alpha}} \tag{22}$$

According to Hoek -Brown (2002), the failure criterion for rock masses (Hoek et al., 2002) are:

$$\sigma_t = \frac{s\sigma_{ci}}{m_b} \tag{23}$$

$$S = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \tag{24}$$

$$m_b = m_i \exp\frac{GSI - 100}{28 - 14D} \tag{25}$$

Where σ_t is tensile strength of rock mass, m_b is the reduced value of material constant m_i, S is the constant for the rock mass, *GSI* is the Geological Strength Index, and *D* is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses (Hoek et al., 2002).

From equations (22)-(25)$\Rightarrow$

$$L = \sqrt{\frac{\exp\left(\frac{GSI - 100}{9 - 3D}\right) h\sigma_{ci}}{3\gamma m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)\cos\alpha}} \tag{26}$$

Amount of *D* for longwall with shear loader mining machine is 0, therefore the equation (26) changes to:

$$L = \sqrt{\frac{\left(\exp\left(\frac{GSI - 100}{9}\right)\right) h\sigma_{ci}}{3\gamma m_i \exp\left(\frac{GSI - 100}{28}\right)\cos\alpha}} \tag{27}$$

Where *L* is periodic roof weighting interval (m), σ_{ci} is the uniaxial compressive strength of intact rock material (MPa), *h* is the thickness of immediate roof (m), *GSI* is the Geological Strength Index, γ is the weight per unit volume of immediate roof (MN/m3), m_i the constant of intact rocks, α is the dip of immediate roof (degree).

NUMERICAL MODELING OF IMMEDIATE ROOF

For modeling the periodic roof weighting interval, this study has utilized the Phase2 computer code based on the finite element (FE) method with triangular elements and nodal averages

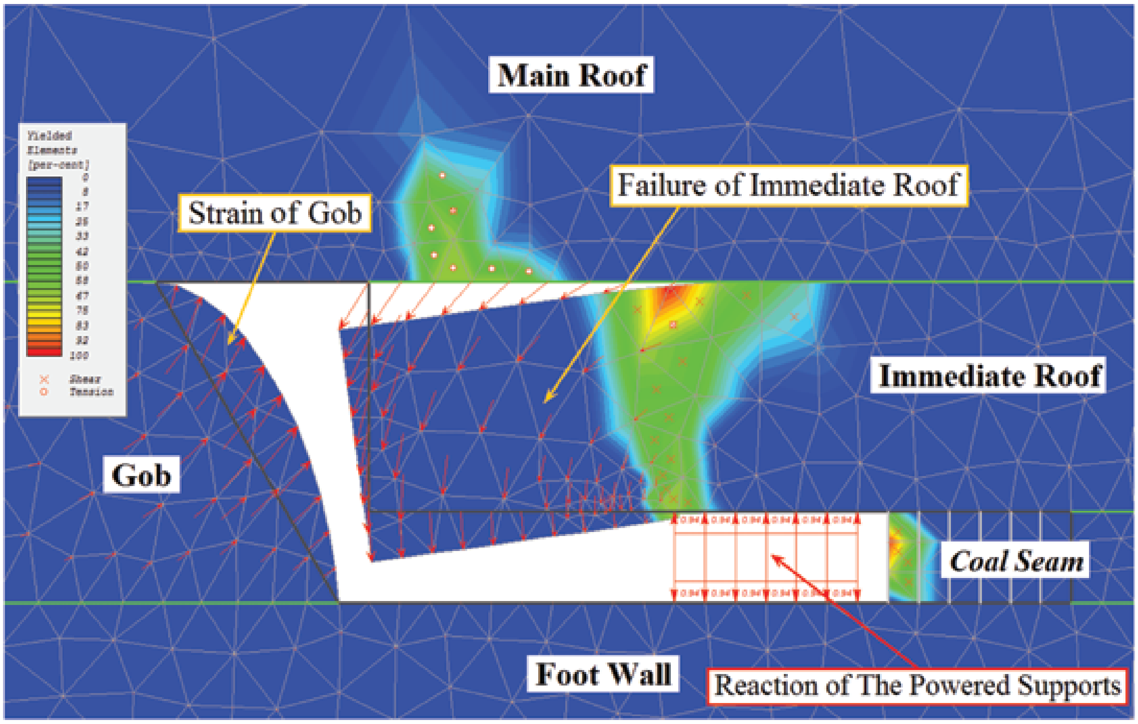

Figure 5. Numerical model of longwall face and failure of the immediate roof.

(Rocscience Inc. 1999 and 2001). Fig. 5 shows the numerical model of longwall face and failure of immediate roof by the advancing of powered supports. The geometrical model and parameters are selected based on the average real conditions of the longwall mining operation. Table 1 shows the parameters that are applied in numerical models (Afsarinejad 1999; Hoek et al. 1997; Peng 2008).

The results of the numerical models have been indicated in Fig. 6. As seen, in GSI=20 the immediate roof is unstable and with advancing powered supports it will cave, but in GSI=65 the immediate roof is stable and the roof weighting interval is 9 m.

A comparative result of the finite element (FE) data and the analytical model (Equation 27) is shown in Fig. 7. Here, it can be observed that the roof weighting interval from the FE data and the analytical model are very near together.

CASE STUDIES

Three Iranian and Indian mines have been taken into account in order to examine the results of the model (Equation 27):

Case Study 1

Parvadeh-1 is an underground coal mine, located at Iran's Tabas coal field. In this mine, seam C is one of workable seams with an average height of 2 m, an average 350 m depth below the surface and 22° dip. The immediate roof consists of siltstone, sandstone and shale. The panel has the length of about 170 m while GSI and height of its immediate roof are 50-60 and 5.48 m, respectively. The average weight per unit volume of the immediate roof is 0.027 (MN/m3) and the uniaxial compressive strength of the intact rocks is 33.7 (MPa) (Tabas, Inc., 1995; Saeedi et al., 2010). Taking into account the proposed model, the periodic roof weighting interval in this mine was determined 3.7 m against the real amount of 4.4 m, with merely

Table1. Applied parameters in the numerical modeling (Afsarinejad 1999; Hoek et al. 1997; Peng

Hoek-Brown Criterion			Poisson's ratio	Weight per unit volume (MN/m3)		
a	S	m_b				
0.54	0.0001	0.9	0.23	0.026	GSI=20	Roof
0.53	0.0002	1	0.23	0.026	GSI=25	Roof
0.52	0.0007	1.1	0.23	0.026	GSI=35	Roof
0.51	0.002	1.4	0.23	0.026	GSI=45	Roof
0.51	0.004	1.9	0.23	0.026	GSI=50	Roof
0.50	0.007	2.4	0.23	0.026	GSI=55	Roof
0.50	0.021	3.7	0.23	0.026	GSI=65	Roof
0.51	0.002	1.5	0.22	0.027	Floor	
0.52	0.0007	0.8	0.3	0.014	Coal seam	

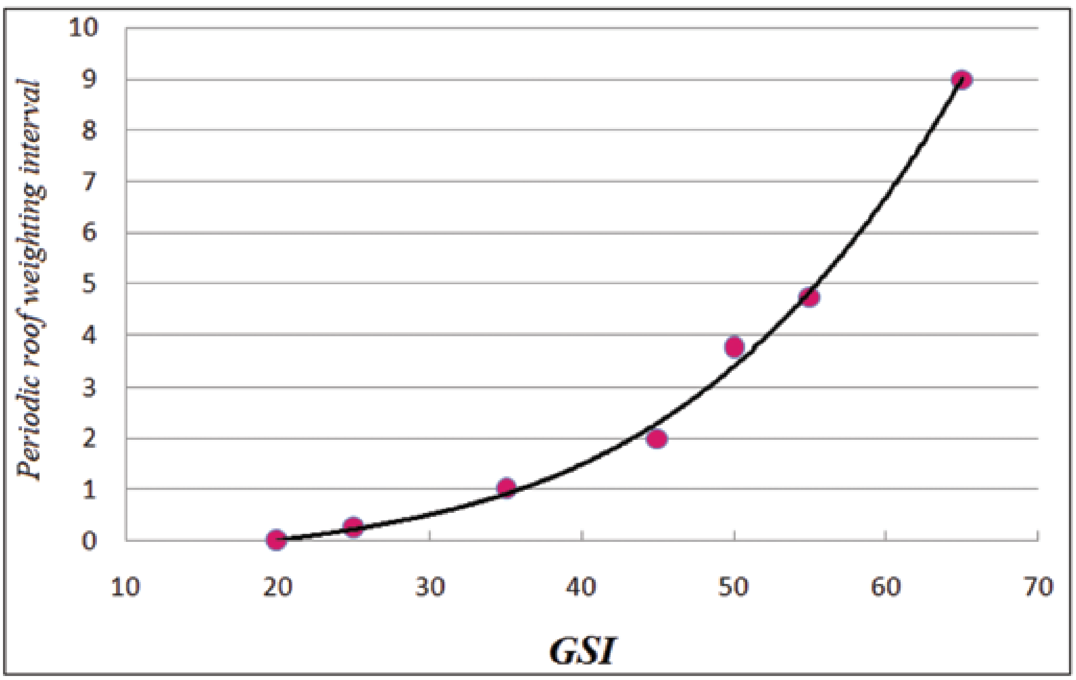

Figure 6. Results of numerical models.

15.9% difference. It is observed that there is remarkable agreement between the determined and the real amount.

Case Study 2

Pabdana-asly is located at Kerman coal field of Iran. Workable seams in this mine are d2, d4 and d6. The object panel is located in seam d2 which an average height of 1.8 m and a dip of 27°. The length of panel is 90 m. The immediate roof consists of shale, coal, siltstone and sandstone. The average weight per unit volume of immediate roof is 0.026 (MN/m3) and GSI=35-45, the average uniaxial compressive strength of the intact rocks is 52.31(MPa) (Pabdana, Inc., 1987). Based on the proposed model, the periodic roof weighting interval is 2.5 m as against the real amount of 2.2 m, thus, there is only

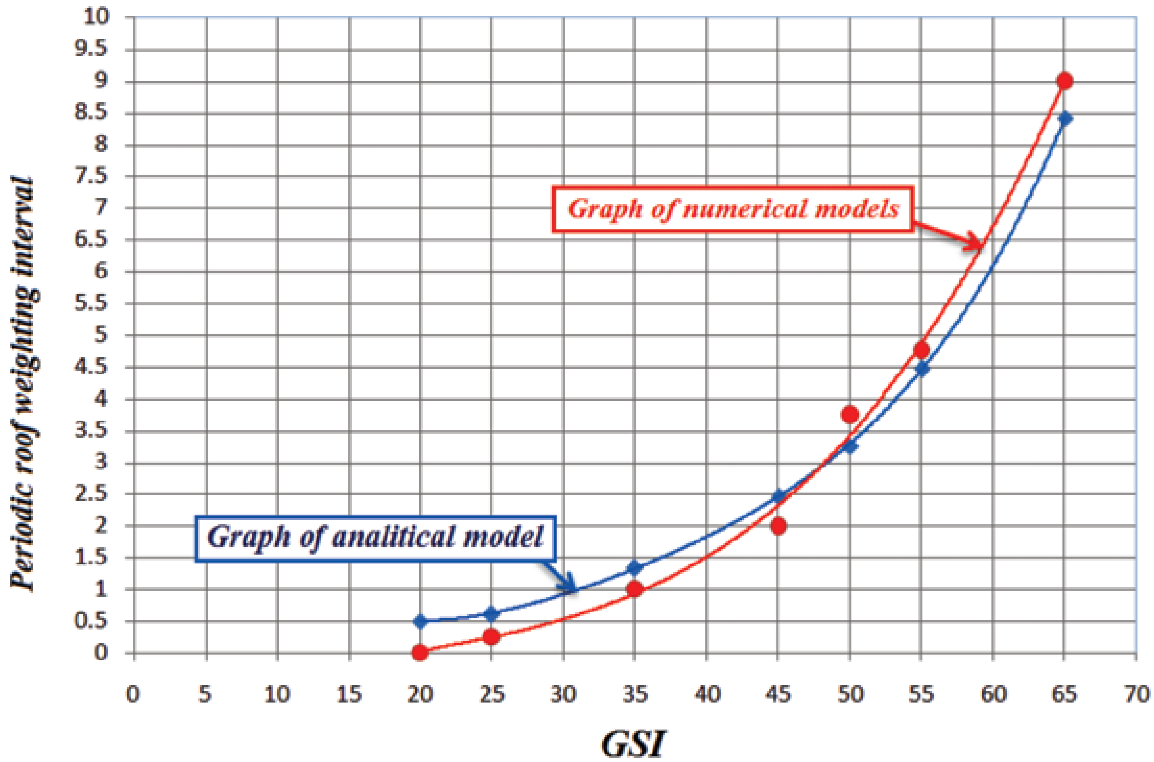

Figure 7. Comparison between numerical and analytical models.

13.6% difference.

Case Study 3

Moonidih Coal mine is the first fully mechanized face in India's Jharia coal field. Panel A4 of this mine is located in XVIII seam with 2.55 m extracting height and 95 m face length. The average depth below surface is 395m and the immediate roof consists of shaley sandstone, shale, sandy shale and sandstone. The average weight per unit volume of immediate roof is 0.019 (MN/m3) and its thickness is 5.46 m. The average uniaxial compressive strength of the intact rocks of immediate roof is 67 (MPa). The first roof weighting observed in 25 m face advancing and the periodic roof weighting interval in this panel is 10 m (Sheorey et al., 1989; Singh et al., 2009 and 2010). Through the proposed model, the periodic roof weighting interval was determined at 11 m. In other words, it has only 10 % difference with the real amount.

CONCLUSION

One of most important parameters in safety and success of coal mines applying longwall method is the weight of immediate roof that applied to powered supports. Therefore, determining the roof weighting interval is very important. Based on the analytical method, this study has proposed a model to determine the periodic roof weighting interval. The model has been tested with reference to three coal mines of Iran and India. The results corroborated that the proposed model can confidently be used to determine the periodic roof weighting interval in coal mines.

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