Design Optimization of Longwall Chain Pillars

Kazem Oraee[1], Behdeen Oraee[2], Amir H. Bangian[3]*

1. Stirling University, UK, s.k.oraee-mirzamani@stir.ac.uk
2. University College London, UK, b.oraee@ucl.ac.uk
3. Azad University, Tehran, Iran, ah.bangian@gmail.com

Abstract

Determination of the optimum design of chain pillars has a significant effect on the economics and safety of Longwall operations. Most pillar design formulae are based on empirical methods with supplemented by local experience. They therefore lack versatility of application under different geotechnical conditions.

In this paper, in order to illustrate the shortcomings of the above, a typical real coal pillar in Tabas coal mine has first been studied and the conventional formulae have been used to determine the optimum dimensions. The results show that a wide difference exists between the predicted and the real field data. The Oraee-Hosseini formula has then been applied to this mine in order to determine the optimum design. The results from this formula demonstrate a close fit between the theoretical values and those produced by laboratory tests and in practice. It is further demonstrated that the wide discrepancy between the results obtained from the two formulae is attributed to the dissimilarities between geotechnical conditions of Tabas and the original regions whose data were used to devise the empirical formulae.

It is finally concluded that the application of numerical simulation methods and experimental equations together with engineering judgment used by the mining design engineer, will provide the most accurate design characteristics.

Key words: Chain pillar, Longwall mining, numerical methods, pillar design, pillar optimization

1. Introduction

Longwall is an underground mining method which has a high rate of production capacity and mechanization ability. This mining method which is appropriately applied for soft rock flat-lying bedded ore bodies gradually became a widespread mining method amongst European coal mines at the beginning of the 19th century. It was then applied in some of the US coal mines by the development of self advancing support mechanisms in early 1960's (Oraee 2001).

Production rate of coal from underground coal mines exploited around the world using Longwall mining method during 1990s and beyond was twice as much as before. The main reasons which provided the requirements for this improvement, were containing high level of mechanization ability, providing desirable safety, adequate design of panels and functional ventilation systems (Peng 2006).

An appropriate design of panels consists of an accurate layout of the entries, to create proper ventilation condition, to provide a satisfactory level of the safety in the entries and face and also to set a superior system for conveying of the extracted coal in front of the face.

The appropriate height of the overburden over a Longwall panel may vary from 60 m to 820 m (200 ft to 2700 ft). Design of a panel to provide stability and safety condition of the entries at deep depth is more complex than a moderate or shallow range of panel depths (Hartman 2000). Therefore, the number and the width of chain pillars in both sides of a dip panel should be increased to provide the required safety level. Thus the recovery rate of coal in a deep Longwall mining project is decreased by increasing the number and the width of the chain pillars. Total cost of the project under such circumstances is raised by decreasing the recovery rate of coal extraction. Also to apply multiple and extensive coal pillars causes the increase in cost of ventilation's processes (Hosseini 2007). It is therefore proved that pillar design has to be carried out based on a highly accurate procedure including assessment of load distribution on pillars and stress analysis in order to provide adequate safety rate and also through the achievable minimum pillar's dimensions.

2. Tabas Coal Mine

Tabas coal region is one of the most comprehensive coal resources in Iran. Large volume of the coal reserve and appropriate geometry of coal seams in Tabas, have created the required condition for application of Longwall mining method. The most important coal seam in Tabas region is C1 with the average thickness 1.8 m (6 ft). In this region Longwall mining method has been applied for just a section of C1 seam. Development and opening of the orebody have been carried out through inclined openings. The width of the panels (length of the faces) is from 200 m to 220 m (670 ft to 733 ft), the length of the panels is about 1000 m (3330 ft) and Longwall mining is carried out based on retreating method (Hosseini 2008). Table 1 shows the average geomechanical parameters of coal and overburden rocks of C1 Tabas seam coal.

Table 1: Geomechanical parameters of coal and overburden rocks of C1 Tabas seam coal (Hosseini 2008)

Parameter	Quantity
Compressive strength of a cubic coal sample	6.5 MPa
Pillar Height	3.2 m (11 ft)
Pillar Length	40 m
Pillar Width	different
Depth from ground surface	45 m (150 ft)
Specific weight of overburden rock	26.5 KNm^{-2}

3. Pillar Design Methods

Pillar design in coal underground mines should be carried out so as to achieve two goals. These include the provision of a high level of safety and coal recovery. Before development of personal computers, mining designers designed coal pillar by manual procedures. The manual procedures were difficult processes with different limitations. Therefore the empirical designing methods were gradually created to design coal pillars based on experimental results. Nowadays coal pillar design is carried out by using advanced personal computers with high speed calculations but the design procedure has not been changed. The empirical design procedures are limited to experimental data, therefore they have no ability to theoretically develop. Currently empirical coal pillar design methods are acceptable procedures in the world (Oraee et al. 2009a).

Empirical formulae are the equations which have been developed based on the extracted experimental data of a given coal pillar. These formulae have been achieved using static analysis on field data. Therefore the attained results from empirical formulae have a good conformity with the original field data obtained from the experimental tests. Since 1960 coal pillar design is carried out through one of the two analytical and empirical methods, none of these two methods are able to analyse mechanism for loading on coal pillars (Hosseini 2007). Developments of personal computers and numerical methods have allowed the mining designers to apply numerical methods to coal pillar design. In this approach some main criteria are compounded together and then the obtained results are applied to coal pillar design.

3.1. Customary equations for assessment of coal pillars strength

Up to the present, several studies regarding coal pillar design have been carried out. Also several equations have been developed based on empirical, analytical and numerical methods. Some of the most applicable formulae to assess coal pillars strength have been developed by Bunschinger (1876), Bieniawski (1967), Bieniawski (1968), Holland (1973) and Oraee-Hosseini (2007), which are presented in Equations 1 to Equation 5 respectively (Peng 2008; Hartman 2000; Hosseini 2007; Oraee et al. 2009b).

$$\sigma_p = \sigma_1(0.778 + 0.222\frac{w}{h}) \qquad \text{Eq. (1)}$$

$$\sigma_p = \sigma_1(0.64 + 0.36\frac{w}{h}) \qquad \text{Eq. (2)}$$

$$\sigma_p = \sigma_1 \frac{w^{0.16}}{h^{0.55}} \qquad \text{Eq. (3)}$$

$$\sigma_p = \sigma_1\sqrt{\frac{w}{h}} \qquad \text{Eq. (4)}$$

$$\sigma_p = \sigma_1\, exp\left[-0.43 + 0.668\sqrt{\frac{w}{h}}\right] \qquad \text{Eq. (5)}$$

Where σ_p is the pillar compressive strength, σ_1 is the compressive strength of the cubic coal sample, w is the width of the pillar and h is the height of the pillar.

Although loading capacity of a coal pillar depends on several criteria, the ratio of the width to the height of a pillar $(\frac{w}{h})$ and also the Uniaxial Compressive Strength (UCS) of intact coal have the most important roles (Oraee et al. 2009b). The above mentioned formulae also defines the compressive strength of a coal pillar.

3.2. Numerical Modeling

Numerical coal pillar design methods in recent times have found a widespread use in engineering modeling by development of personal computers and progressing of advanced numerical techniques. These methods are unlike empirical methods that simulate and analyse the stress during loading of coal pillars. In this project, FLAC^{3D} software was used to analyse coal pillar strength and its stability. FLAC^{3D} software processes based on 3D distinct elements, which has been presented by ITASCA Company (ITASCA 2010) and it has a widespread application in rock mechanics.

In order to determine loading capacity of a coal pillar, a typical coal pillar has been modeled on the basis of the average coal characteristics of Tabas coal mine in this project. In the model the height of the coal pillar is 3.2 m (11 ft), the length of the coal pillar is 40 m (133 ft) and the width of the coal pillar varies from 20 m to 60 m (67 ft to 200 ft). In this procedure, the loading rate on the coal pillar increases according to increase of the width of the coal pillar up to the yield of the elements. Thus the ultimate coal pillar strength for each limit of the width is achieved from the result of the mentioned procedure. Figure 1 shows a sample of the modeled coal pillars by FLAC^{3D} software in this project.

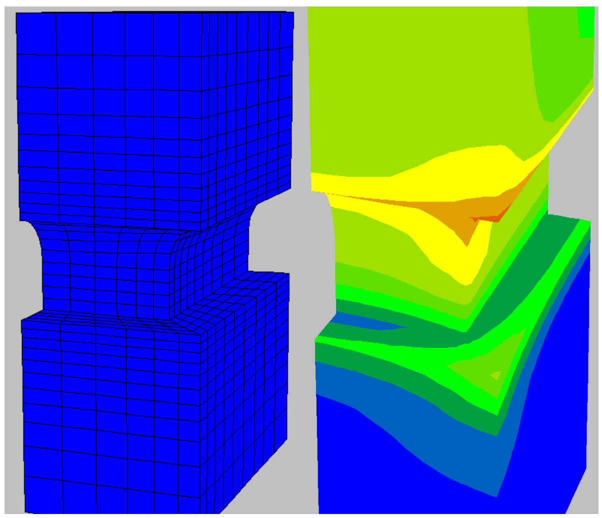

Figure 1: a sample of the modeled coal pillars by FLAC^{3D} software and the displacement velocity model

3.3. Comparison of the different coal pillar strength assessment methods

At this stage the results of the comparison of the different coal pillar strength assessment by the presented formulae in Equation 1 to Equation 5 and also FLAC^{3D} software for Tabas mine project is presented. The assessment has been carried out on the basis of the geometry and geomechanical coal pillar specifications. Figure 2 shows the results of the comparison between the different coal pillar strength assessment in Tabas coal mine.

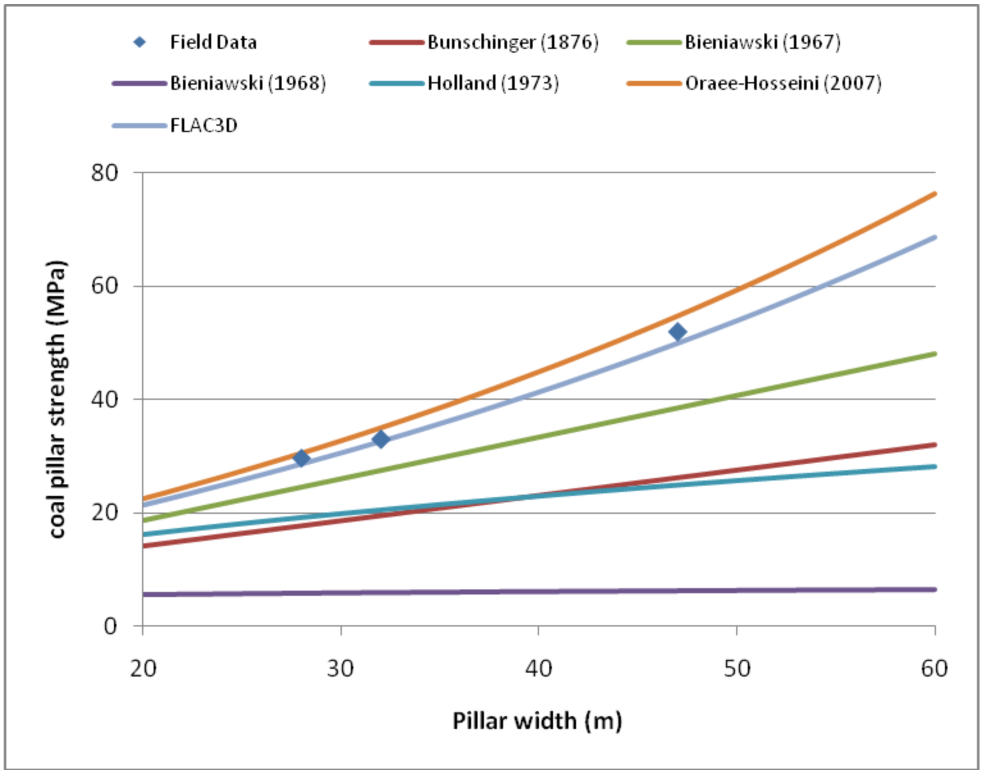

Figure 2: the results of the comparison of the different coal pillar strength assessment in Tabas coal mine

As it seems in Figure 2, several field data have been measured in Tabas coal mine which have been presented on the diagram of Figure 2. According to the diagram of Figure 2, the achieved coal pillar strength by all of the customary formulae was less than the actual data. In fact, underestimated value of the results of the customary formulae is attributed to particular physical and mechanical coal specifications of Tabas coal mine.

Therefore, if coal pillar design is carried out based on one of these formula, a large volume of extractable coal will be included in the coal pillar limits, while Oraee-Hosseini formula produces more accurate results than the other customary formulae. According to the diagram it is important to note that the determined coal pillar loading capacity by Oraee-Hosseini formula is overestimated. Therefore if the safety factor is not in a high rate of safety, it can cause to appear an insecure situation for the coal mine. Oraee-Hosseini formula also produces highly overestimated results under such circumstances with simultaneously increase of width of the coal pillar.

Numerical modeling is extremely dependent on the entering data and the structure of the model. As an example, mesh dimensions of modeling by FLAC^{3D} software can highly affect on the produced results of the model. Accuracy of the entering data also has significant effect on the reliability of the results. However, as numerical modeling has been frequently applied in different field of engineering modeling, its results have been accepted by different engineering institutions. It is important to note that FLAC^{3D} Software is also a well known software in field of numerical modeling in field of rock mechanics engineering.

In this project, the results of numerical modeling by FLAC^{3D} software according to Figure 2, have the most conformity with the field data. In other words, the determined coal pillar strength by the numerical method is more reliable for different widths of coal pillars, and it can also be applicable for coal pillar design.

At the next stage in order to proximity of the achieved results by FLAC^{3D} software and by Oraee-Hosseini formula, the effects of UCS of intact coal were considered deals with the coal pillar loading capacity. A coal pillar with 35 m (117 ft) width with UCS of intact coal 4 MPa to 9 MPa, has been modeled to obtain the required results. In this stage, other rock mechanical coal characteristics have been assumed according to Tabas coal mine specifications. The trend of coal pillar strength is presented in Figure 3.

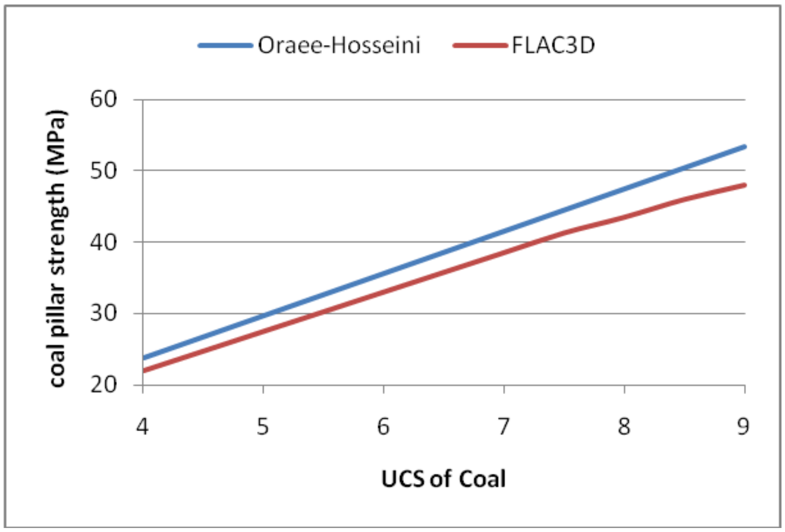

Figure 3: The trend of coal pillar strength with respect to increase UCS of intact coal

According to the diagram of Figure 3, coal pillar loading capacity increases by increase of the UCS of intact coal. The increase trend of the attained data by Oraee-Hosseini formula is also a linear trend, whereas the obtained results by FLAC^{3D} software are not exactly on a linear trend. The diagram shows that the coal pillar loading capacity slightly decreases by the increase of UCS of intact coal.

At the next stage, the trend of the dissimilarities amongst the achieved coal pillar strengths by Oraee-Hoseini formula and FLAC^{3D} software was considered. The considered range of UCS of intact cubic coal sample was 6 MPa and 8 MPa. The increase trends of the results of the two considered models are presented in Figure 4.

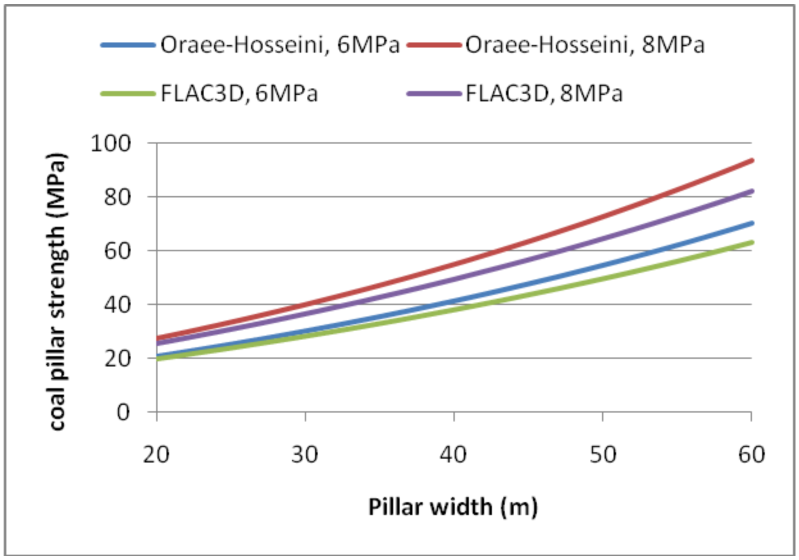

Figure 4: The increase trends of the obtained data by Oraee-Hosseini formula and FLAC^{3D} software based on the changes of the width of the pillar and the intact coal sample UCS

According to the diagram of Figure 4, the obtained data by Oraee-Hosseini formula has a uniform increase trend whereas the attained data by FLAC^{3D} software does not have a uniform increase trend.

4. Conclusion

Chain pillar design has a significant effect on safety, economic situation and operational methods of Longwall coal mining. The results of this project show that both Oraee-Hosseini formula and FLAC^{3D} software for modeling of assessment of the coal pillar strength in Tabas coal mine are applicable methods on the basis of the unique coal specifications in this mine. Although as Oraee-Hosseini formula have been developed based on the specifications of coal in the Tabas mine, the obtained conformity amongst the achieved results and the field data was predictable. On the other hand, FLAC^{3D} software is an accepted software by different engineering institutions so the data produced using this software are a good reference. As the produced data of Oraee-Hosseini formula are in a lower rate than the produced data of FLAC^{3D} software, a higher safety factor than the results of FLAC^{3D} software will need to be applied. In other words, the obtained results of the FLAC^{3D} software have a higher safety level. It is also concluded that loading capacity of coal pillars increases by increase of compressive strength of the intact coal. The ratio of the obtained results by Oraee-Hosseini formula has a linear trend however, the obtained results by the FLAC^{3D} software for the range of UCS of the intact coal more than 7.5 MPa, the ratio is not linear and has a decreasing trend. It was also proved that increase of UCS of the intact coal and increases of the width of the coal pillar simultaneously, create a higher level of loading capacity for the coal pillar with an exponential trend. The attained results were proved by both Oraee-Hosseini formula and FLAC^{3D} software and it is finally concluded that, using simultaneously Oraee-Hosseini formula and FLAC^{3D} software can provide with reliable results for coal pillar design in Tabas coal mine.

References

Hartman, Howard L., (2000), “SME Mining Engineering Handbook”, Published by: Society for Mining, Metallurgy, and Exploration, Inc. (SME), Littleton, Colorado, p. 2260.

Hosseini, N., (2007), “Modelling of pillars in longwall method using advanced numerical techniques”, M.Sc. Thesis, Islamic Azad University, South of Tehran branch, p. 235.

Hosseini, N., (2008), “The Geo-Mechanical Study of C1 Coal Seam–Tabas Collieries”, Technical Report, Madankavan Bisotun Co., Tehran, Iran, p. 218.

ITASCA Inc., FLAC^{3D} Software manual (2010), Available (03/02/10): http://www.itascacg.com

Oraee K., (2001), “Underground Coal Mining”, Polytechnic University Press, Tehran, Iran, p. 251.

Oraee, K., Hosseini, N., and Gholinejad, M., (2009a), “Estimation of Coal Pillar Strength by Finite Difference Model”, In: Proceedings of the 2009 Coal Operators’ Conference, Wollongong, Australia, pp. 53-60.

Oraee, K., Hosseini, N., and Gholinejad, M., (2009b), “Coal Pillar Strength Based On The Ground Reaction Curve – A New Approach”, In: Proceedings of the 28th International Conference on Ground Control in Mining, Morgantown, W.V., pp. 21-24.

Peng S. S., (2006), “Longwall Mining, 2nd edition”, published by: Society for Mining, Metallurgy, and Exploration, Inc. (SME), p. 621.

Peng S. S., (2008), “COAL MINE GROUND CONTROL, 3rd edition”, published by: Society for Mining, Metallurgy, and Exploration, Inc. (SME), p. 764.