2009

Estimation of Coal Pillar Strength by Finite Difference Model

K. Oraee
University of Stirling

N. Hosseini
Islamic Azad University, Tehran

M. Gholinejad
Islamic Azad University, Tehran South

ESTIMATION OF COAL PILLAR STRENGTH BY FINITE DIFFERENCE MODEL

Kazem Oraee[1], Navid Hosseini[2], Mehran Gholinejad[3]

ABSTRACT: Longwall mining is now predominately used in coal mines where somewhat difficult conditions exist. As in the case of all other underground mining methods, pillars are integral part of modern mine design. The process of pillar design in longwall mining entails the selection of a safety factor, which is done by estimating the magnitude of the load applied on the pillar and the load bearing capacity of such pillars. Finite difference modelling principles have been applied to a typical coal pillar design. The pillar strength is then estimated with various width/height ratios. These results have been compared with the results obtained from the conventional pillar design methods. The effect of roof and floor quality on the strength of the typical pillar has also been evaluated in the same manner. Although the finite difference method is not always the perfect method for such estimation, nevertheless, the results clearly demonstrate that it produces more acceptable design than the conventional method, especially under undesirable conditions regarding the interface between pillars, roof and floor. An additional advantage of such method is its capability of being applied in situations where complex parameters prevail.

INTRODUCTION

In recent years, significant research has been carried out on the determination of the coal pillar strength, and various formulas are introduced. The majority of these formulas are empirical, based on pillar shape effect, dimension and laboratory testing of coal. The work of Gaddy, Holland, Obert & Duvall, Salamon & Munro, and Bieniawski formulas (Hosseini Navid, 2007) are notable examples. The results obtained from empirical formulas are reliable only with special limits. These limits are determined based on the initial condition of formula presentation. In addition, the empirical formulas are not considering the effect of surrounding roof and floor on coal pillar strength. While the friction at the interface of coal seam and footwall and hanging wall have significant effects on coal pillar bearing capacity.

Numerical techniques such as finite difference, finite element, distinct element, etc. are other methods of estimating the coal pillar strength. Based on these methods the varieties of software are presented. In this paper, finite difference method (FDM) and FLAC code (ITASCA, 2005) are used for modelling and strength analysis of coal pillar. For logical estimate of coal pillar strength the essential parameters considered are; coal properties, pillar geometry as well as the condition of surrounding roof and floor.

NUMERICAL MODELLING

FLAC software

The Fast Lagrangian Analysis of Continua (FLAC) provided by Itasca Consulting Group, Inc., and is a two-dimensional explicit FDM program. FLAC is well accepted by social mining and rock mechanics engineers and this is why it was selected for this study.

Pillar design by using FDM modelling

FDM modelling technique was used for prediction of coal pillar strength. The main advantage of this method is the integration of the surrounding roof and floor conditions on coal pillar strength.

For modelling of pillars, the two-dimensional FDM model is used. A typical coal pillar with 3.0 m (10 ft) in height was selected, and then the compressive strength of coal pillar for W/H ratios of 1 to 15 is calculated, based on different widths. Figure 1, shows two coal pillars with 3.0 m (10 ft) height and different widths.

[1] *Professor, University of Stirling, UK*
[2] *PhD Student, Islamic Azad University, Tehran, Iran*
[3] *Assistant Professor, Islamic Azad University, South Tehran Branch, Iran.*

In FLAC modelling, the strain-softening model is used to produce the peak strength behaviour for the pillar and the pillar behaviour by FISH functions is monitored. For determining the pillar bearing capacity, the downward force is applied on the top surface of the model, until the pillar fails. During the pillar failure simulation, the average of vertical stress at mid height of the pillar was calculated at regular intervals and the peak value of this stress was considered to represent the peak pillar strength. Also, by averaging the displacement values between the top and bottom of the pillar and dividing by the original length, the pillar strain is thus obtained. Therefore, the pillar stress–strain curve could be developed.

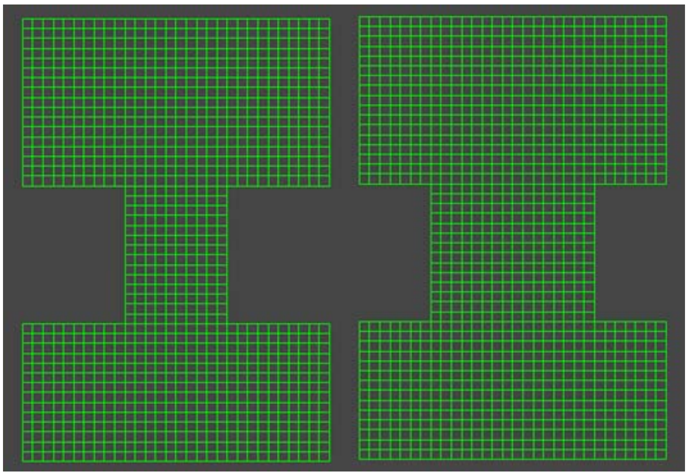

Figure 1 - Modelled coal pillar with 3.0 m (10 ft) height and different widths

To develop the study, the various conditions of roof and floor in FDM model are also applied. Typical coal pillars with both soft and strong roof and floor are considered. In this modelling, the height of the pillar is also 3 m (10 ft) and different widths are selected. Thus, the pillar strength for both soft and strong conditions of roof and floor, for various W/H ratios are calculated. In addition, to study the role of coal strength in coal pillar strength, two pillars with different coal strength properties were modelled by FDM. Following this study, the effect of parting in coal seam on coal pillar strength was analysed. For this purpose, the typical pillar with parting in coal seam was modelled and the effects of parting with different properties of rocks for various W/H ratios were determined. Typical coal pillars modelled by FDM in conditions of, with and without parting of the coal seam, is shown in Figure 2.

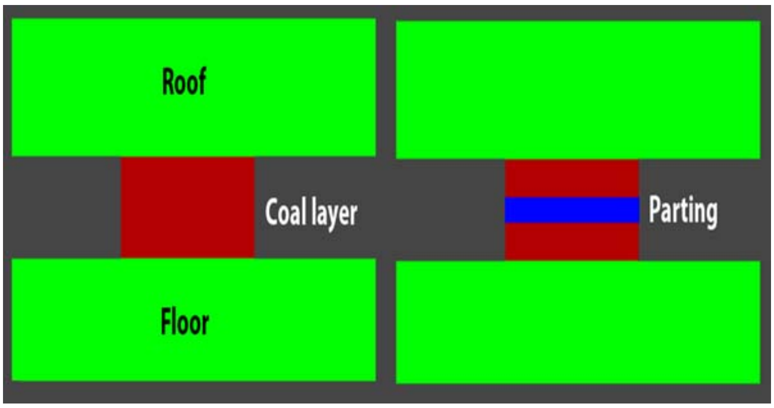

Figure 2 - Typical coal pillars modelled by FDM, with and without parting

COMPARING FDM MODELING RESULTS WITH EMPIRICAL FORMULAS

The compressive strength of typical coal pillar with 3 m (10 ft) height and different widths, based on modelling by FDM, was thus calculated. The selected coal properties were similar to US Pittsburg colliery (Maleki H, 1992) as shown in Table 1. The results and their comparison with strength values obtained by conventional formulas are shown in Figure 3.

Table 1 - Coal properties

property	*values*
Young's modulus	4 GPa
Poisson's ratio	0.30
Bulk modulus	3.3 GPa
Shear modulus	1.5 GPa
Uniaxial compressive strength	8 MPa
Density	1400 Kg/m^3
Tensile strength	0.9 MPa
Cohesive	0.8 MPa
Friction angle	30 degree
Dilation angle	0 degree

As demonstrated in this figure, up to W/H ratio of 4, the results of empirical formulas and FDM are similar. By increasing the W/H ratio, the resembling of these results decreases, except the result of Salamon & Munro formula, in which increases in W/H ratios, the results tallied reasonably with to FDM modelling values. According to previous studies (Daniel W. H. Su, Gregory J. Hasenfus, 1999; Oraee K., Hosseini Navid, 2007), the validity of empirical formulas results is up to W/H ratio of 4, however the FDM estimates of the coal pillar strength for higher W/H ratios are considered as valid. The comparison of FDM modelling results and several field data are illustrated in Figure 4.

In this modelling, the roof and floor condition are strong. The field data (Daniel W. H. Su, Gregory J. Hasenfus, 1999) were collected from failed pillars in US Pittsburg colliery. As, can be seen in Figure 4, at least one field data is in agreement with the FDM model, and the other is close . Based on probability of error in field measurement, perhaps the measuring accuracy is the reason of the last data field results not corresponding with the FDM model.

The effect of surrounding roof and floor on coal pillar strength

The majority of empirical estimation formulas of coal pillar strength inherently do not consider the effect of surrounding roof and floor rocks on coal pillar strength (Oraee K., Hosseini Navid, Qolinejad M., 2008a). In Figure 5, two coal pillars with same condition for various W/H ratios are modelled. The only applied difference in two models is the state of roof and floor strength. The result of FDM modelling shows that the strength of surrounding roof and floor rocks can influence coal pillar strength.

With increasing the W/H ratio, the effect of surrounding roof and floor strength increases, until the pillar coal strength changes more than 50%. Figure 5 shows the results of FDM modelling compared with several field data (Daniel W. H. Su, Gregory J. Hasenfus, 1999) with soft surrounding roof and floor. The results of FDM modelling and field data are reasonably close.

In Figure 6, the results of FDM model for strong surrounding roof and floor, is compared with Bieniawski formula and field data (Daniel W. H. Su, Gregory J. Hasenfus, 1999). The FDM model results and Bieniawski formula are similar up to W/H ratio 4. However, with increasing the W/H ratio, the estimated strength of FDM modelling is significantly higher than Bieniawski formula results. In addition, the results of FDM for strong roof and floor formation and that the field data of failed pillars under similar conditions are close. However, the field results differ significantly when compared with Bieniawski formula results. The main reason is in the empirical nature of Bieniawski formula. Bieniawski formula is based on studies of coal pillars with soft surrounding roof and floor (Oraee K., Hosseini Navid, Qolinejad M., 2008b) and therefore, only for such condition the formula is valid. Figure 7 shows the results of FDM model for soft roof and floor formation as compared with each of Bieniawski, Holland and Gaddy formulas and the field data. As can be seen in the figure, the results of FDM modelling and the field data of failure pillars are fairly close with soft surrounding roof and floor. In addition, in low W/H ratios the results of Bieniawski formula and field data is approximately the same. Therefore, in result, the Bieniawski empirical formula is valid only for low W/H ratios and soft surrounding roof and floor. However, the Holland and Gaddy formula is based on soft roof and floor formation (Oraee K., Hosseini Navid, Qolinejad M., and 2008b), underestimate coal pillar strength, and therefore the results are conservative.

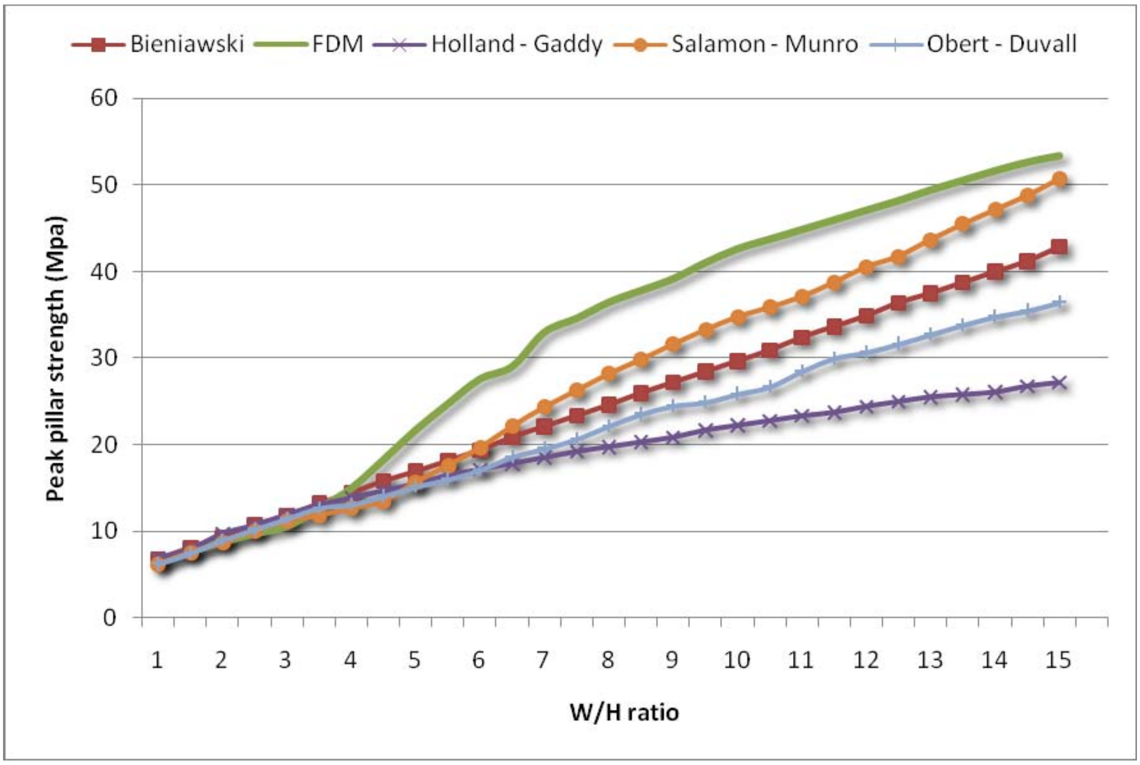

Figure 3 - The comparison of coal pillar strength by FDM modelling with empirical formulas

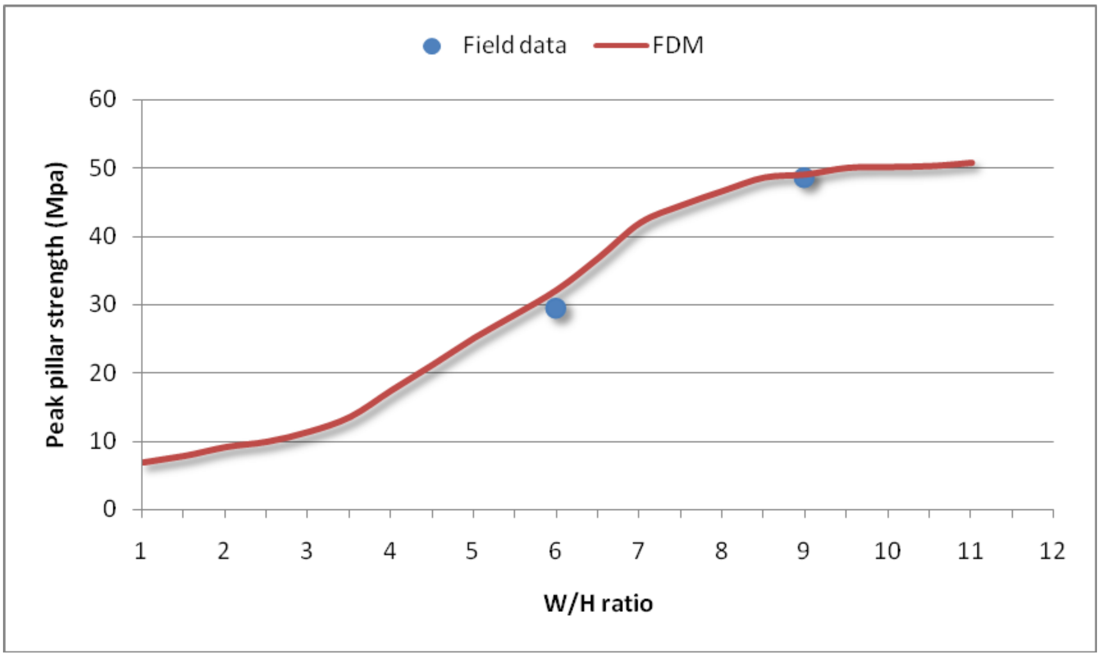

Figure 4 - The comparison results of FDM model and field data

Generally, the results of FDM modelling for soft surrounding roof and floor have more validity than the results of the empirical formulas. Because, the FDM results and the field data are very close. Similar results can be seen for strong surrounding roof and floor formation. Large differences exist between the results of the empirical formulas and the field data. Therefore, only the FDM estimation can be considered as credible.

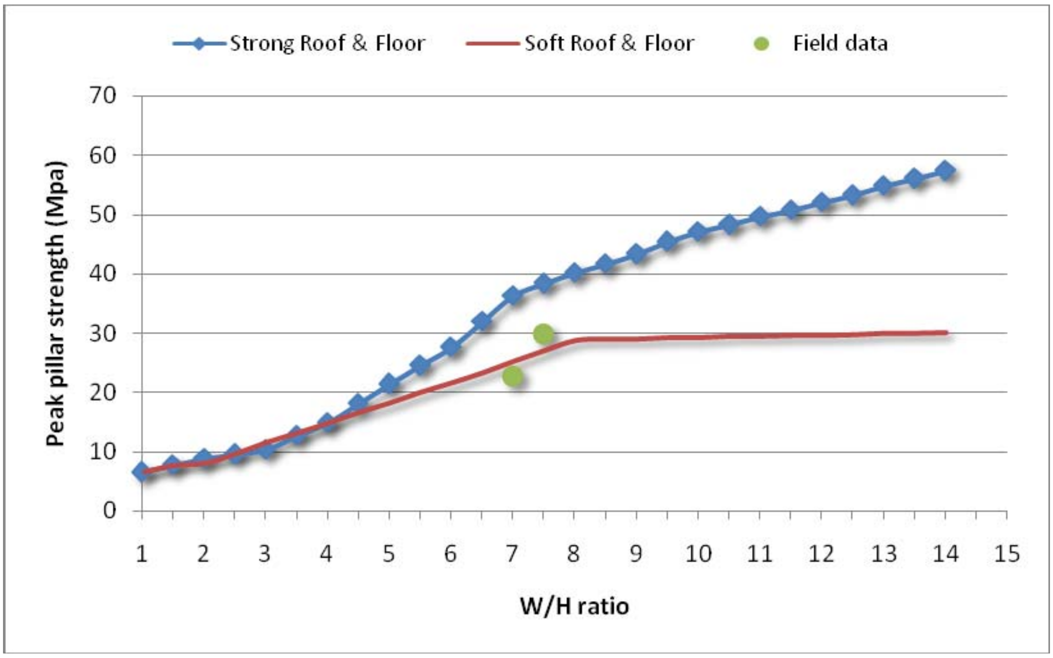

Figure 5 - The effect of surrounding roof and floor strength on coal pillar bearing capacity and comparison the results of FDM modelling with field data

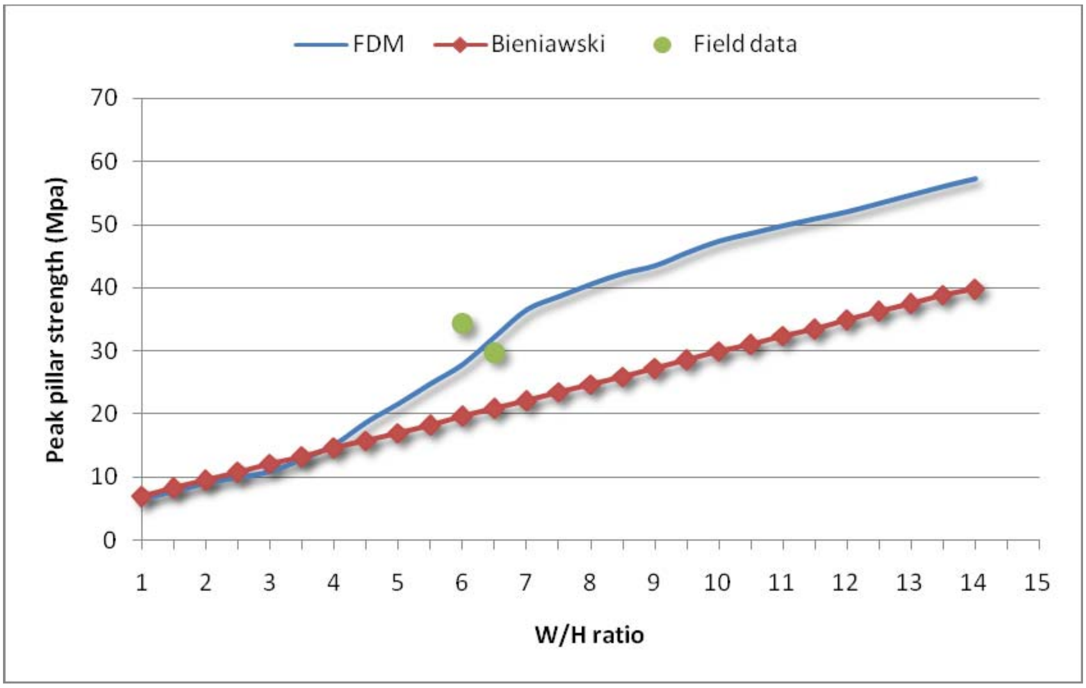

Figure 6 - Comparison the coal pillar strength of FDM modelling for strong surrounding roof and floor with Bieniawski formula and field data

The effect of coal seam strength on pillar strength

The assumption that coal strength has a significant role in coal pillar strength, is an incorrect statement The results of two modelled coal pillars are shown in Figure 8. All conditions of both pillars assumed the same except in coal seam strength. (Hosseini Navid, 2007)

As can be seen in Figure 8, the results of FDM modelling for both pillars with 5.5 and 6.9 MPa (800 and 1000 psi) coal seam strength are very close. Therefore, the effect of coal seam strength on coal pillar strength is poor and negligible.

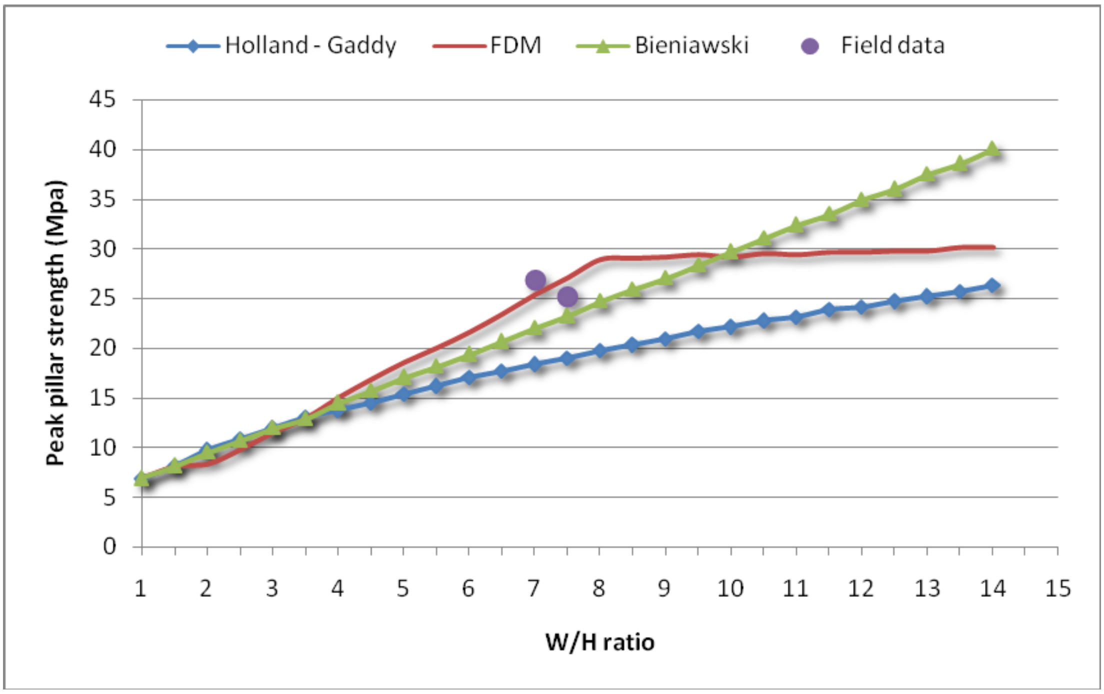

Figure 7 - Comparison the coal pillar strength of FDM modelling for soft surrounding roof and floor with Bieniawski and Holland and Gaddy formulas and field data

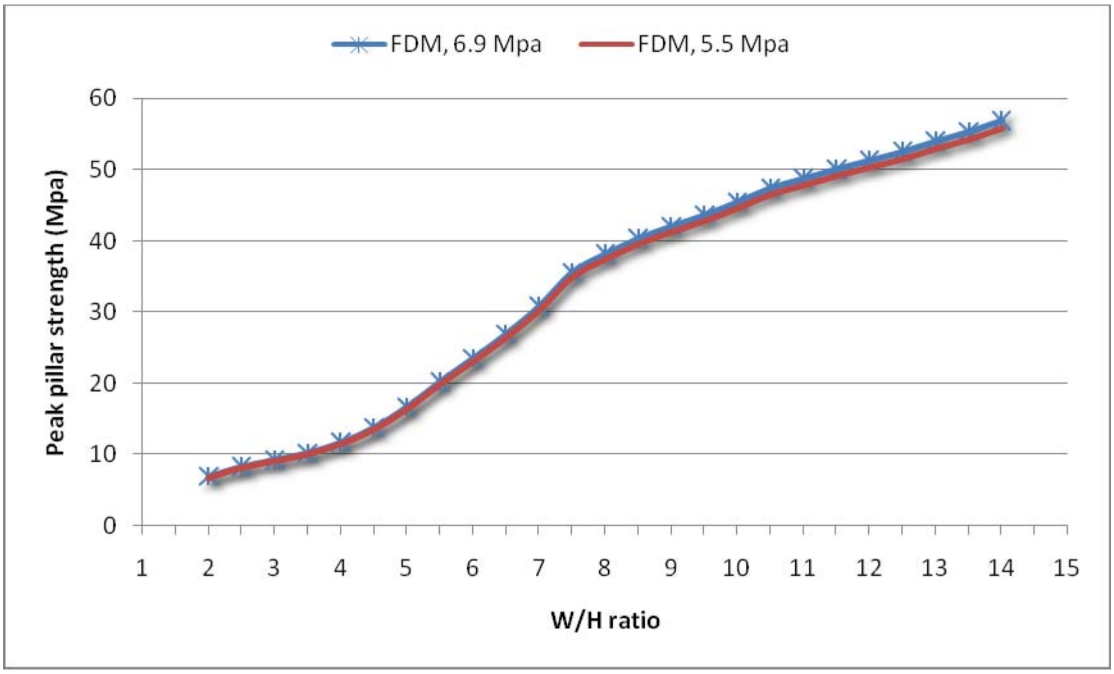

Figure 8 - The effect of strength properties of coal seam on coal pillar strength in FDM modelling

The effect of parting on coal pillar strength

Figure 9, shows three FDM modelled pillars with the same properties. The only exception is the parting. One of modelled pillars is without parting, another with the parting stronger than the coal seam, and the third with the parting but softer than the coal seam.

As shown in Figure 9, the parting is an effective parameter on coal pillar strength. The coal pillar strength is changed, based on strength properties of the parting. In theory, the distribution of field stress within pillar is disturbed by the parting. The stress concentration point within the pillar, forms and consequently, the probability of pillar failure increases. However, if the parting is stronger than the coal seam, and resists the stresses, the coal pillar strength with the parting increases. This is because, the applied stress on pillar, concentrate within the parting and hence reduces the stress in pillar coal zone.

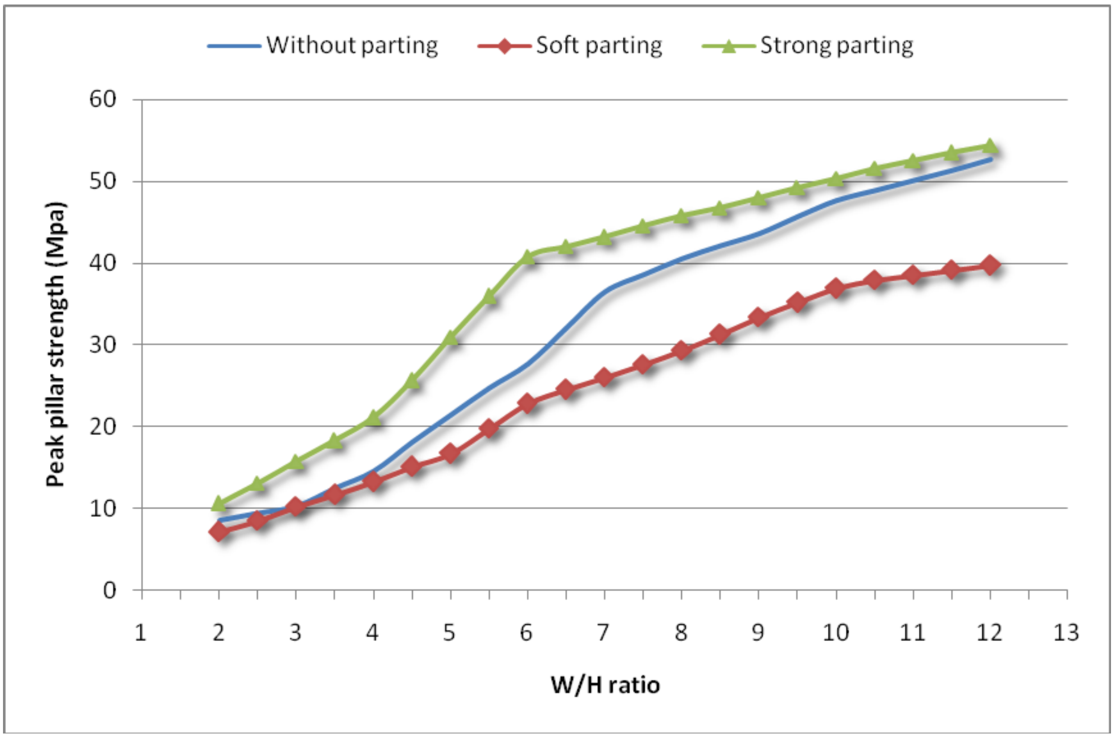

Figure 9 - The effect of the parting on coal pillar strength in FDM modelling

CONCLUSIONS

The FDM modelling can properly and accurately estimate the coal pillar strength. The strength properties of the surrounding roof and floor affect the coal pillar strength and this effect increases with increasing W/H ratio. The comparisons of FDM modelling results for the surrounding roof and floor of various conditions and field data, emphasises the effect of the state of surrounding roof and floor on the coal pillar strength, while most empirical formulas ignore the surrounding roof and floor effect.

Assuming that the coal pillar strength is directly proportional to strength properties of the coal seam, however the results of FDM modelling show that the effect of coal seam strength on coal pillar strength is negligible.

The parting within coal seam changes the coal pillar strength. If the strength of parting is more than coal seam, the coal pillar strength increases, otherwise, the coal pillar strength decreases with the parting.

REFERENCES

Daniel W. H. Su, Gregory J. Hasenfus, 1999. *Coal Pillar Strength And Practical Coal Pillar Design Considerations*, In: Proceedings of the Second International Workshop on Coal Pillar Mechanics and Design, Pittsburgh, PA, U.S. Department of the Interior, Bureau of Mines, pp. 155-163.

Hosseini Navid, 2007. *Modelling of pillars in longwall method using advanced numerical techniques*, M.Sc. Thesis, Islamic Azad University, South of Tehran branch.

ITASCA Consulting Group, INC., Minneapolis, MN. 2005. FLAC (Fast Lagrangian Analysis of Continua), Version 5.0.

Maleki H, 1992. *In situ pillar strength and failure mechanisms for U.S. coal seams*, In: Proceedings of the Workshop on Coal Pillar Mechanics and Design, Pittsburgh, PA, U.S. Department of the Interior, Bureau of Mines, pp. 73-77.

Oraee K., Hosseini Navid, 2007. Estimating coal pillar strength using finite element model, In: Proceedings of First International conference on mining and mining consequence, Mashhad, Iran, pp. 13-21.

Oraee K., Hosseini Navid, Qolinejad M., 2008. *Logical design of yield pillar base in longwall mining*, In: proceedings of MPES08 conference, Beijing, China, pp. 706-713.

Oraee K., Hosseini Navid, Qolinejad M., 2008. *3D strain softening modelling of coal pillars in a deep longwall mine*, In: proceedings of MPES08 conference, Beijing, China,