# Estimation of Coal Pillar Strength by Finite Difference Model

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**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 parts of the mining design. The choice of shape and dimensions of the pillars has significant impact on the recovery and hence on overall productivity of the mine. 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.

In this paper, finite difference modeling principles have been applied to a typical coal pillar. The pillar strength is then estimated with various width/height ratios. These results have been compared with the results obtained from the conventional methods of pillar design. The effect of roof and floor quality on the strength of the typical pillar has also been evaluated in the same manner.

It is concluded that although the finite difference method is not always the perfect method for such estimation, but 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 shown to be its capability of being applied in situations where complex parameters prevail.

**Keyword:** coal pillar, FDM, modelling, strength, bearing capacity

## Introduction

In recent years, many research works have been done for determination of the coal pillar strength, and the various formulas are introduced. The majorities of these formulas are empirical, obtained based on shape, effect dimensions and laboratory testing of cubic coal samples. For example, the Gaddy, Holland, Obert & Duvall, Salamon & Munro, and Bieniawski formulas [1] are notable ones. The results obtaining by empirical formulas are reliable only in special limits. These special limits are determined based on the initial condition of formula presentation. In addition, inherently the empirical formulas are not considering the effect of surrounding roof and floor on coal pillar strength. While the friction in 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 [2] are used for modeling and strength analysis of coal pillar. For logical estimate of coal pillar strength the essential considering parameters are; the coal properties, pillar geometry as well as the condition of surrounding roof and floor. Because, assuming that the friction and interaction of coal pillar and surrounding roof and floor play a significant role in strength and bearing capacity of coal pillar.

## FLAC software

The FLAC (Fast Lagrangian Analysis of Continua) is 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 selected for this study.

## Pillar design by using FDM modelling

For prediction of coal pillar strength, one method is FDM modeling technique. The main advantage of this method is applying of surrounding roof and floor condition on coal pillar strength.

In this paper for modeling of pillars, the two-dimensional FDM model is used. A typical coal pillar with 10 feet height is selected, and then the compressive strength of coal pillar for W/H ratios of 1 to 15 are calculated based on different widths. In Figure 1, two coal pillars with 10 feet height and different widths are shown.

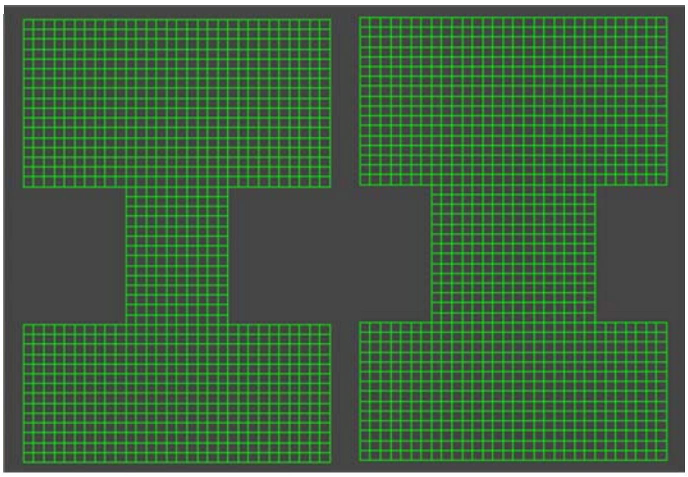

Figure 1: Modeled coal pillar with 10 feet height and different widths

To develop the study, the various conditions of roof and floor in FDM model are also applied. For this purpose, typical coal pillars with both weak and strong roof and floor are considered. In this modeling, the height of the pillar is also 10 feet and different widths are selected. Thus, the pillar strength for both soft and strong condition of roof and floor for various W/H ratios are calculated. In addition, to study the role of coal seam strength in coal pillar strength, two pillars with different coal seam strength properties are modeled by FDM. In following of this study, the effect of parting in coal seam on coal pillar strength is analyzed. For this purpose, the typical pillar with parting in coal seam is modeled and the effects of parting with different properties for various W/H ratios are determined. The typical coal pillars that have been modeling by FDM in states with and without parting in coal seam depicted in figure 2.

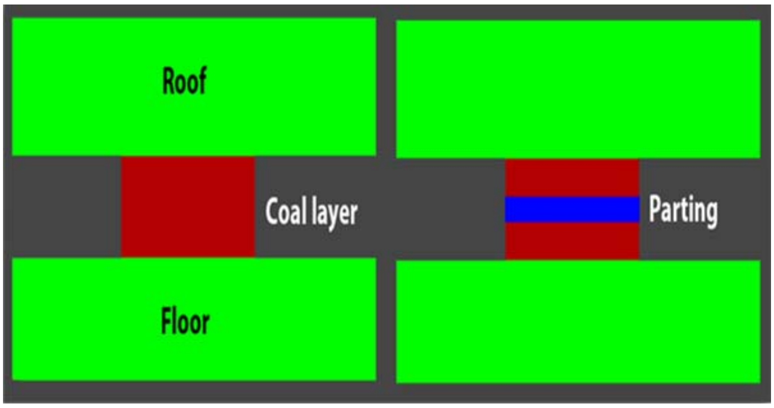


Figure 2: The typical coal pillars modeled by FDM, with and without parting

## Comparing FDM modeling results with empirical formulas

The compressive strength of typical coal pillar with 10 feet height and different widths based on modeling by FDM is calculated. The selected coal properties are similar to US Pittsburg colliery [3]. The results and their comparison with strength obtained by conventional formulas by applying the same condition are shown in figure 3.

As demonstrated in this figure, up to W/H ratio 4, the results of empirical formulas and FDM are similar. By increases the W/H ratio, the resembling of these results decreases, except the result of Salamon & Munro formula, as with increases the W/H ratios, again its result nearing to FDM modeling. According to previous studies [4,5], the validity of empirical formulas results is up to W/H ratio 4, but the FDM estimates the coal pillar strength for higher W/H ratios. The comparison of FDM modeling results and several field data are illustrated in figure 4.

In this modeling, the roof and floor condition are strong. The field data [5] collected from failure pillars in US Pittsburg colliery. As, seen in the figure 4, the FDM model is well agreed with field data. One of field data resembling with modeling results graph, and another is very near. Based on probability of error in field measuring, perhaps the measuring accuracy is reason of last data field approximately corresponding.

## The effect of surrounding roof and floor on coal pillar strength

The majorities of empirical estimation formulas of coal pillar strength inherently do not consider the effect of surrounding roof and floor on coal pillar strength [6]. In figure 5, two coal pillars with same condition for various W/H ratios are modeled. The only applied different in two models, is the state of roof and floor strength. The result of FDM modeling shows that the strength of surrounding roof and floor can be effective on coal pillar strength.

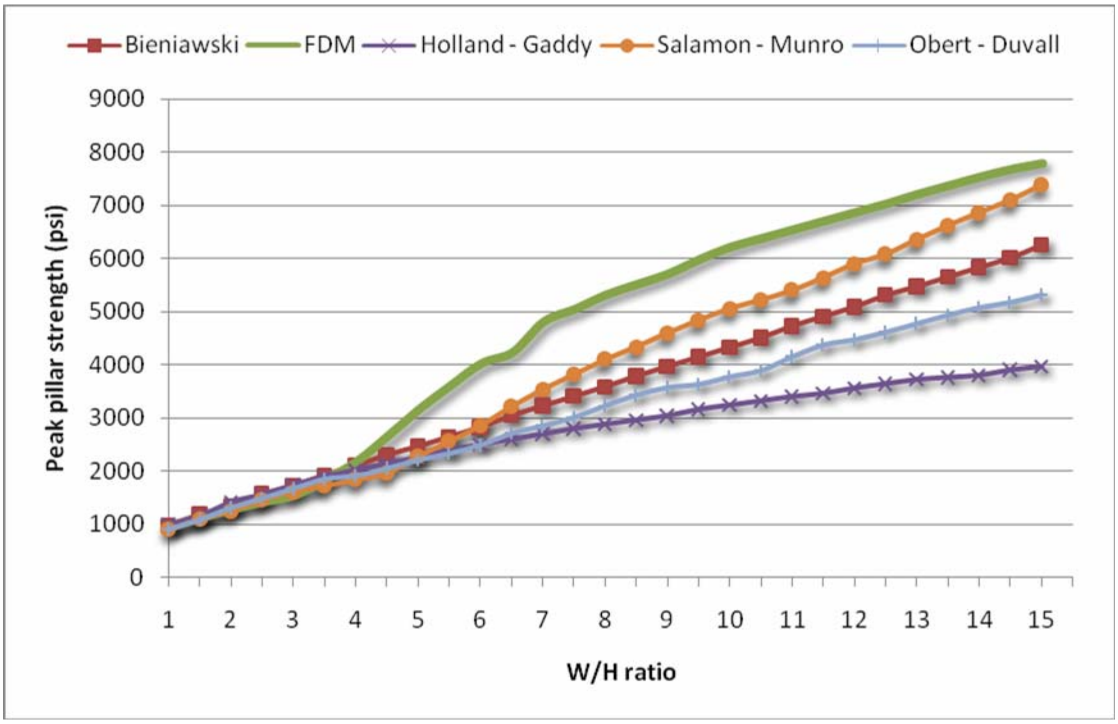


Figure 3: The comparison of coal pillar strength by FDM modeling with empirical formulas

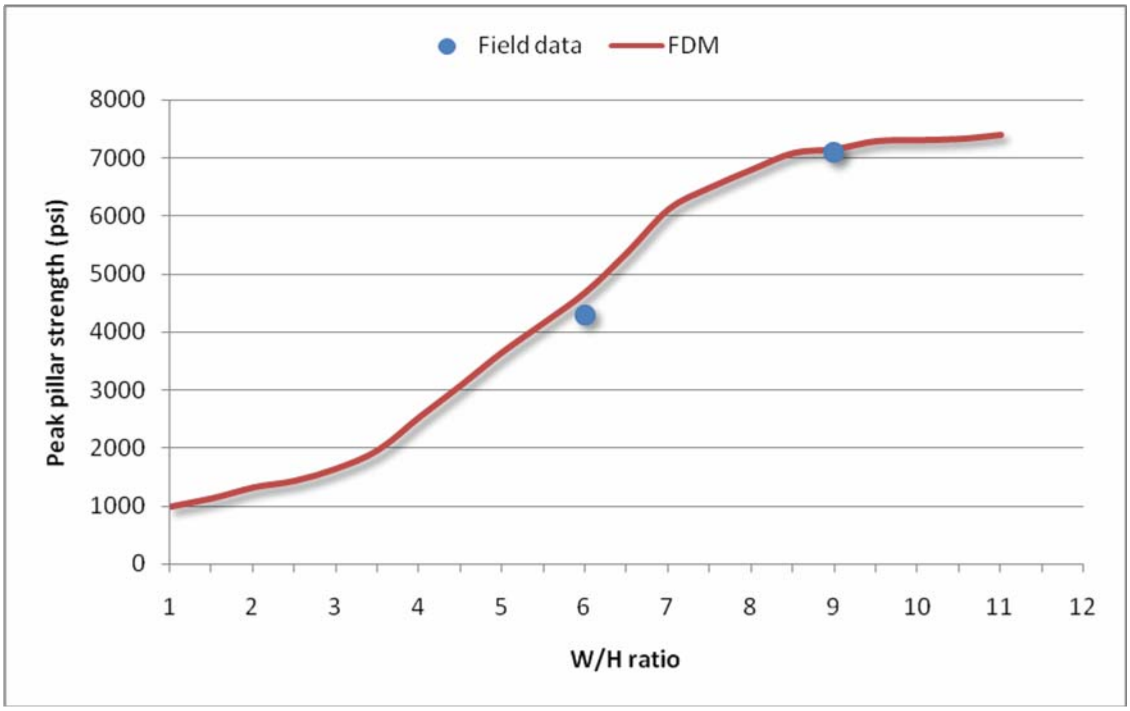


Figure 4: The comparison results of FDM model and field data

With increasing the W/H ratio, the effect of surrounding roof and floor strength is increases, until the coal pillar strength more of 50 percent is changed. In figure 5, the results of FDM modeling also comparing with several field data [5] with soft surrounding roof and floor. As seen in figure, the results of FDM modeling and field data are approximately similar.

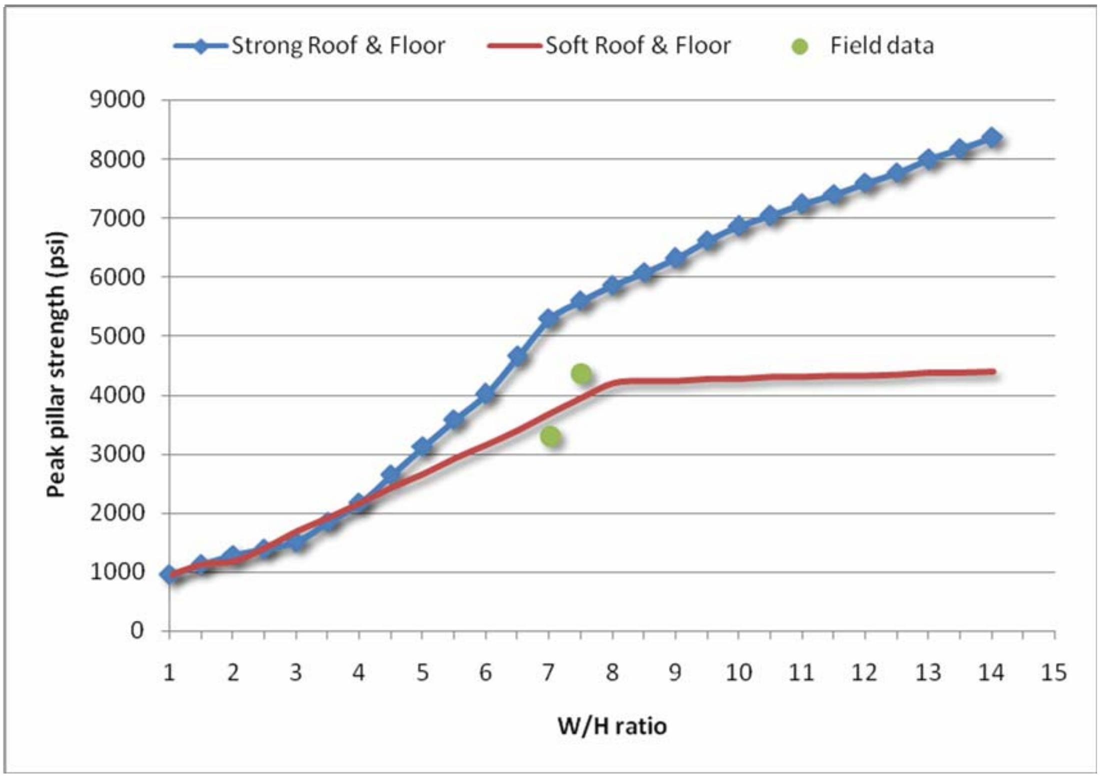


Figure 5: The effect of surrounding roof and floor strength on coal pillar bearing capacity and comparison the results of FDM modeling with field data

In figure 6, the results of FDM model for strong surrounding roof and floor, is compared with Bieniawski formula and field data [5]. Up to W/H ratio 4, the results of FDM model and Bieniawski formula are similar. However, with increasing the W/H ratio, the estimating strength of FDM modeling is significantly higher than the Bieniawski formula results. In addition, the results of FDM for strong surrounding roof and floor and field data of failure pillars that have been strong surrounding roof and floor are approximately same. Whereas, exist the significant difference in the field data and the Bieniawski formula results. The main reason is in empirical nature of Bieniawski formula. Because, the Bieniawski formula is based on studies of coal pillars with soft surrounding roof and floor [7] and therefore, only for such condition has validity and reliability.

In figure 7, the results of FDM model for soft surrounding roof and floor with Bieniawski and Holland & Gaddy formulas and field data are compared. As seen in figure, the results of FDM modeling and field data of failure pillars with soft surrounding roof and floor are approximately similar. In addition, in low W/H ratios the results of Bieniawski formula and field data is approximately same. Therefore, in result, the Bieniawski empirical formula only for low W/H ratios and soft surrounding roof and floor is valid. However, the Holland & Gaddy formula that is proposed based on soft surrounding roof and floor [7], underestimate the coal pillar strength, and therefore results are conservative.

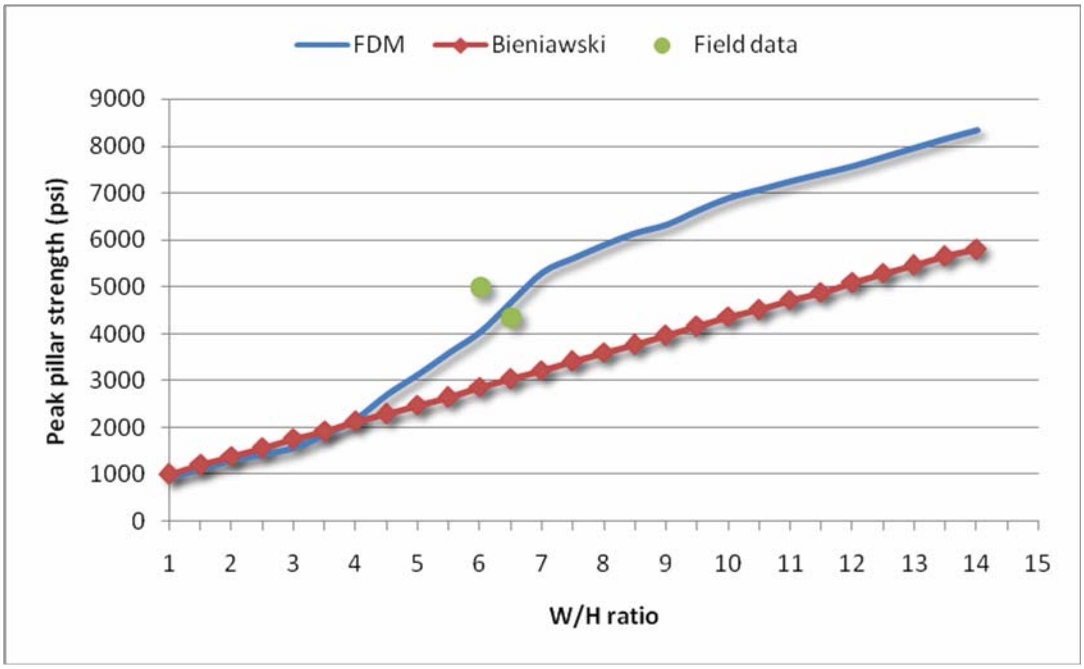


Figure 6: Comparison the coal pillar strength of FDM modeling for strong surrounding roof and floor with Bieniawski formula and field data

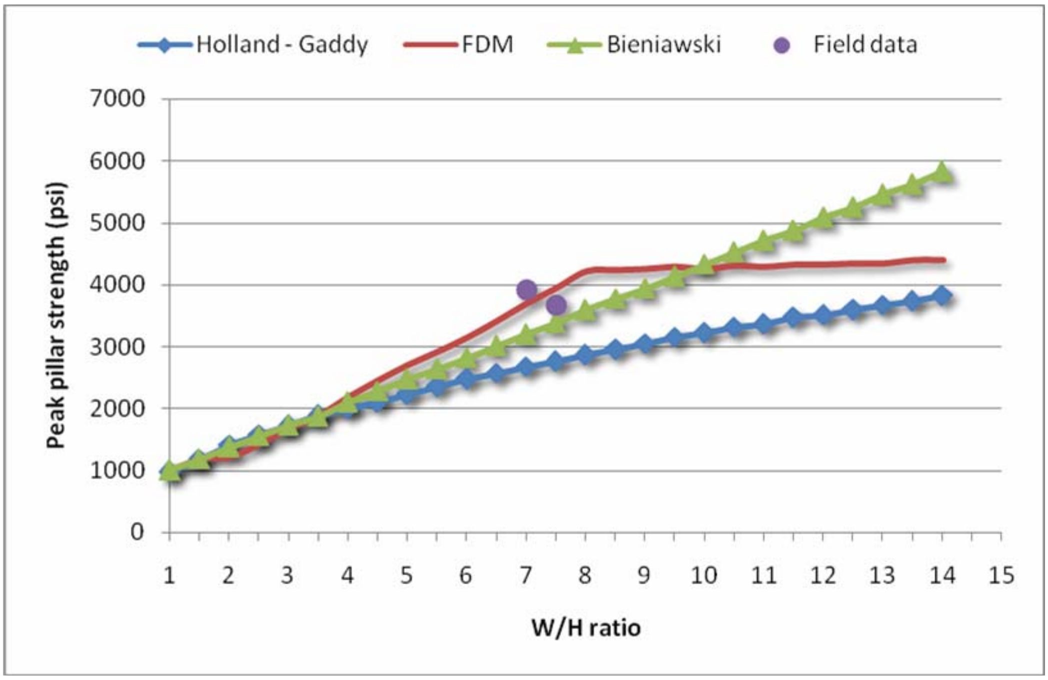


Figure 7: Comparison the coal pillar strength of FDM modeling for soft surrounding roof and floor with Bieniawski and Holland & Gaddy formulas and field data

Generally, the results of FDM modeling for soft surrounding roof and floor have more validity than results of empirical formulas. Because, the FDM results and field data are very close. The similar results can be seen for strong surrounding roof and floor, in this condition, the large difference exist between the results of empirical formulas and field data. Therefore, only the FDM estimating is perfect.

**The effect of coal seam strength on cola pillar strength**

Usually, assuming that the coal seam strength has a significant role on coal pillar strength [1], but it is a wrong concept. The results of two modeled coal pillars are shown in figure 8. All conditions of both pillars assumed same except in coal seam strength.

As seen in figure 8, the results of FDM modeling for both pillars with 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.

**The effect of parting on cola pillar strength**

The parting can be effective on coal pillar strength. In figure 9, three FDM modeled pillars with same properties are shown. The only exception is the parting. One of modeled pillars is without parting, another with the parting stronger than coal seam, and last one with the parting but softer than coal seam.

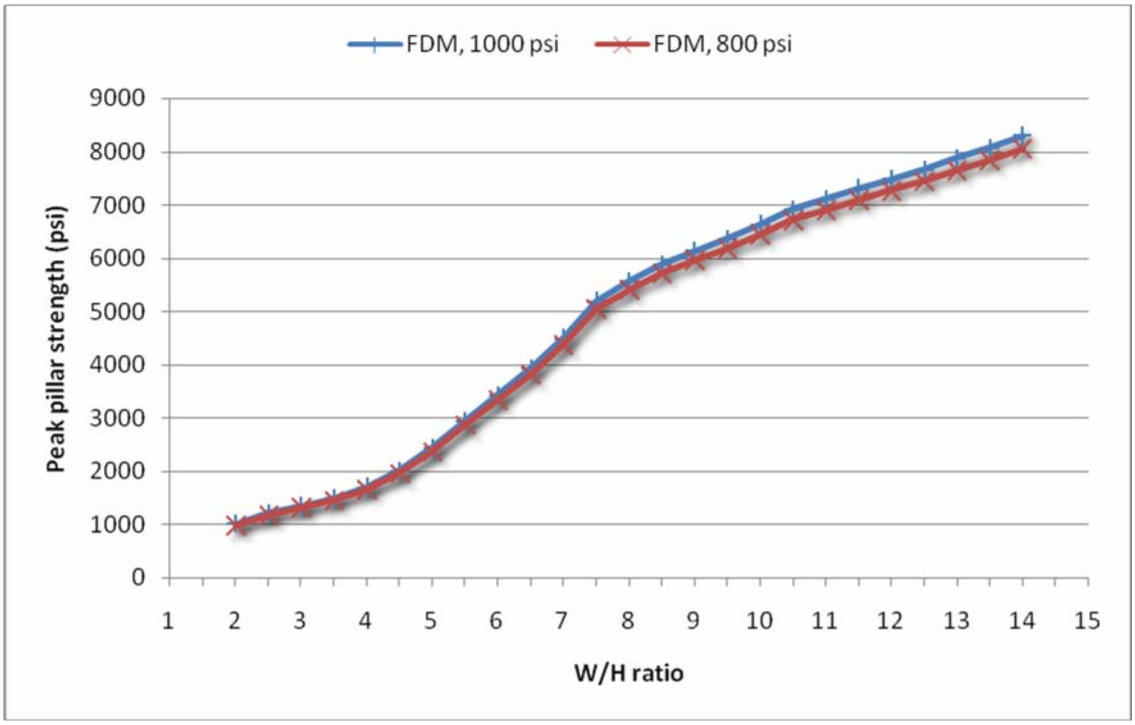


Figure 8: The effect of strength properties of coal seam on coal pillar strength in FDM modeling

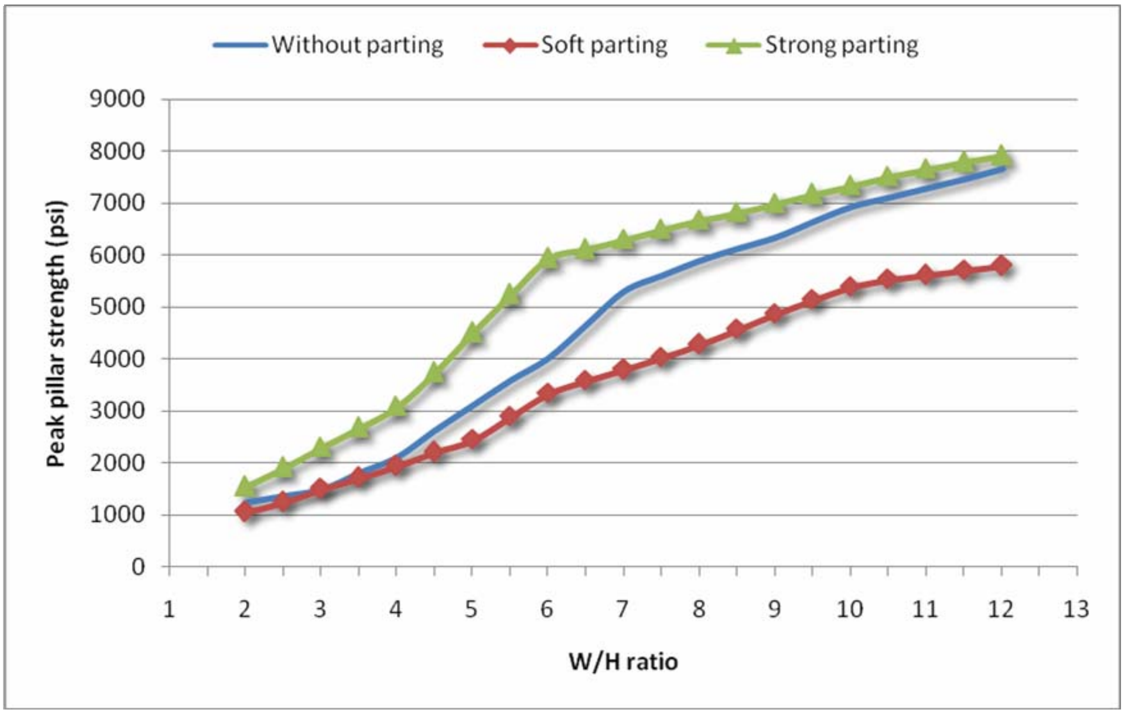


Figure 9: The effect of the parting on coal pillar strength in FDM modeling

As seen in figure 9, the parting is effective parameter on coal pillar strength. The coal pillar strength is changed, based on strength properties of the parting. In theory, the distribution field stress within pillar disturb by the parting. The stress concentrate point within pillar forms, and consequently, the probability of pillar failure increases. However, if the parting is stronger than coal seam, to resisting the stresses, the coal pillar strength with the parting increases. Because the applied stress on pillar, concentrate within the parting and hence reduce the stress in pillar coal zone.

## Conclusions

The FDM modeling can properly and accurately estimate the coal pillar strength. The strength properties of surrounding roof and floor affect the coal pillar strength and this effect increases with increasing W/H ratio. The comparisons of FDM modeling results for surrounding roof and floor of various conditions and field data, emphasizes 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.

Generally, assuming that the coal pillar strength is directly proportional to strength properties of the coal seam, but the results of FDM modeling shows 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

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

[2] ITASCA Consulting Group, INC., Minneapolis, MN. 2007. FLAC (Fast Lagrangian Analysis of Continua), Version 5.0.

[3] Maleki H, *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, 1992.

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

[5] Daniel W. H. Su, Gregory J. Hasenfus, *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, 1999.

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

[7] Oraee K., Hosseini Navid, Qolinejad Mehran, *3D strain softening modelling of coal pillars in a deep longwall mine*, In: proceedings of MPES08 conference, Beijing, China, pp. 761-768, 2008.