3D strain softening modelling of coal pillars in a deep longwall mine

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In longwall coal mines, the entries on both sides of the panel play a significant role in production rate and safety of operation. With increasing production amount, the rate of conveying material through such entries increases. Therefore, it is required to design wider entries. Support of these entries, particularly in deep mines is difficult.

In this paper, by using FLAC3D program code a deep longwall coal mine is modeled. The coal seam has a strain softening property, and the analysis index of stress and deformation of ribsides and coal pillars at different loading levels are determined. Strain softening parameters is studied separately for each modeled coal pillar, and based on conventional formula the pillar strength are calculated. In a modeled longwall mine, the caving material at goaf zone are fully compact. The results shows that based on Mohr-Coulomb model, the strain softening occurs at maximum cohesion and friction, and at region of decreasing the strength of pillar in stress-strain curve. Because of 3D nature of analyses, the effect of front and side abutment load on stability of pillar are studied simultaneously. Therefore, the results of this study could be suitable criteria for appraisal of pillar design method at deep longwall coal mines.

Keywords: Longwall, Pillar, Strain softening, Modelling

1.Introduction

The longwall mining is a method with high production capacity and highly mechanized potential. Its development backs to 17 century in European collieries at the begging of 19 century this method with development of self-advanced support system also has been applied in united state mining [1]. However, in the recent years, by using the longwall mining, the coal production is increasing; the main reasons can be highly mechanized potential and safety of this method. For high safety, perfect design for panel and entries on both sides, are two essential parameters.

For increasing of production, entries on the both sides of panel must be wider in design. Therefore, multi-entry system is used preferably [2]. The multi-entry system is increasing conveying capacity and improves mine safety. In the multi-entry system, for stability, a row of coal pillars remains within the entry and hence the entry is divided in two separate sections. The stability analysis of these pillars, particularly in the deep longwall mines is complex. In fact, each entry located within two panels and the state of applied loads on pillar, depends on mining operation in adjacent panels and width of entry. The exploitation operation with powerful shearer machines and self-advanced power support system causes the simultaneous static and dynamic applied loads.

2.The state of applied load on pillar

Based on mining operation conditions in panels adjacent to the entry, five different stages of loading are applied on pillar [3], which illustrated in figure (1).

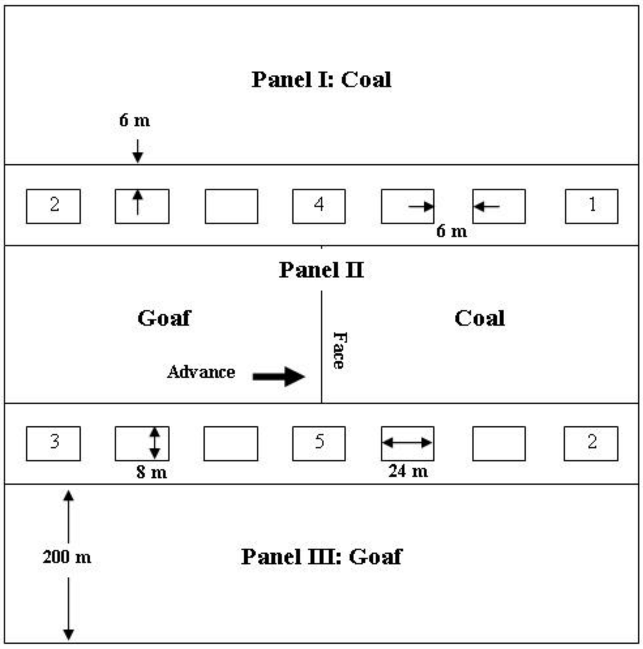

Figure 1: Different stages of loading on pillar

In this figure, number 1 is a pillar, which at it's both sides is virgin coals and hence, this pillar resists only static applied loads. The number 2 indicating the pillar located within two panels, at one side is virgin coal and other side, goaf, and therefore, the states of applied loads on this pillar are unbalanced. The number 3 denoting a pillar, which at it's both sides, is goaf, due to caving, the applied load of roof on pillar increases. Such load can increases up to a limit equal to pillar bearing capacity, but fortunately, the life of entry is ending. Because, by complete extraction panels of both sides entry the stability of entry will not be needed usually. The number 4 show a pillar with face at one side and coal at others, therefore, the movement of coal cutter machine and the load of power support influencing on this pillar. Finally, the number 5 show state of the pillar with one side, face and other, goaf, therefore, the highest level of stress with turbulent distribution is applied on this pillar. However, the main aim of this paper is to study evaluation of the mentioned 5 stages of loading on pillar with 3D modelling.

3.Numerical modelling

In this study, a hypothetical longwall mine with multi-entry system is modeled using FLAC3D software. According to figure 1 the width of extraction panel, entry, and pillar are 200, 6 and 6 meters, respectively. In addition, the length of pillar is 24 m. This generated model is depicted in figure 2. The considered thickness of the coal seam is 2 m with strain softening property and roof applied constant load of 20 MPa.

The known, Mohr-Coulomb strain-softening model is selected for this study. This model needs not only cohesive, dilution and friction angles, but also ratio of cohesive and friction angle, which are the function of plastic strain (εp) at post peak region. For evaluation of these parameters, back analysis based on conventional Bieniawski criteria [4] is used.

Thereafter, for determination of pillar strength another separated pillar is modeled by Mohr-Coulomb strain softening model, which depicted in figure 3. Due to symmetrization, only one corner of pillar is modeled and obviously, the result obtained is applied to whole pillar. In this model, the roof and floor of pillar having elasticity property and total mechanical characterization is according to table 1. Applying 20 MPa roof load on pillar, calculates the distribution of stress and amount of displacement. This modeling is made on three different groups of cohesive ratio of 20, 35 and 50 MPa/εp. In each group, based on four different width/height (W/H) ratio of 1, 2, 3 and 4 the four models have been made. Therefore, the total sum of modeling is 12. However, the displacement condition in pillar in the model with W/H ratio of 3 and cohesive ratio of 35 MPa/εp after applied stress is shown in figure 4 as an example.

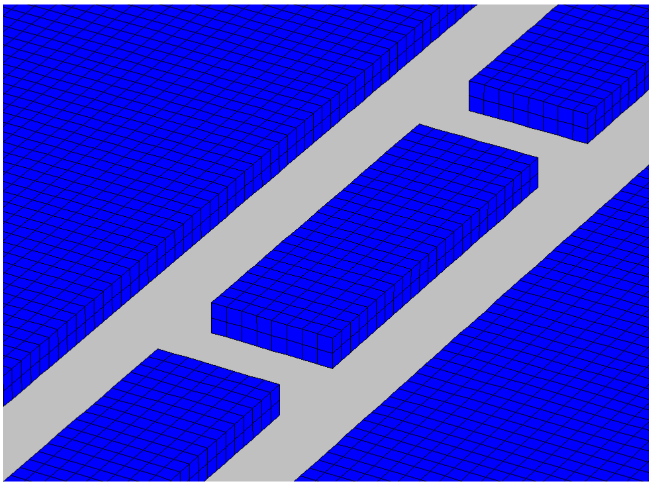

Figure 2: 3D modelling with FLAC3D software

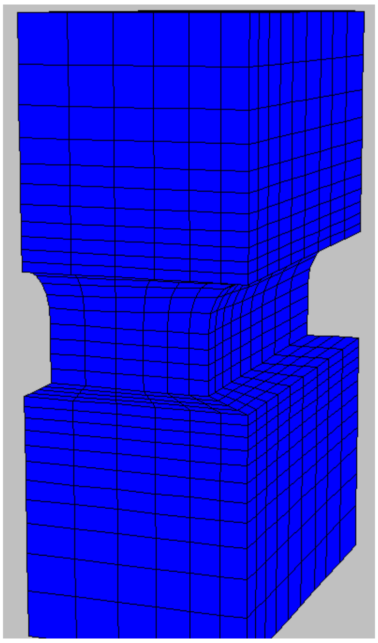

Figure 3: The modeled separated pillar for determination of Mohr-Coulomb strain softening parameters

In this figure red and blue color indicating the highest and lowest rate of displacement, respectively. As expected, the displacement progress starts from the corners and expand toward its center.

The results of 12 developed models are depicted in figure 5. In this figure, also the estimated pillar strength by using Bieniawski criteria for comparison is presented.

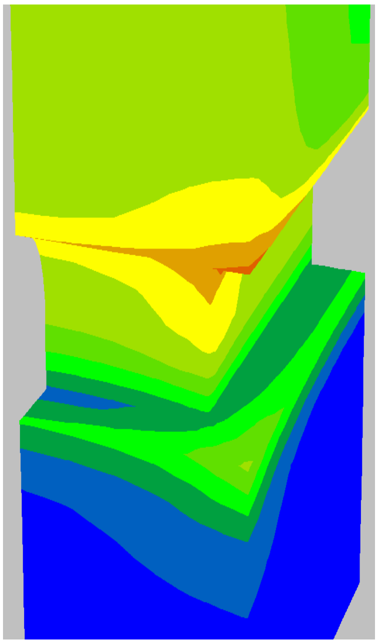

Figure 4: The state of displacement in pillar (W/H = 3, cohesive ratio = 35 MPa/εp) after the applied stress

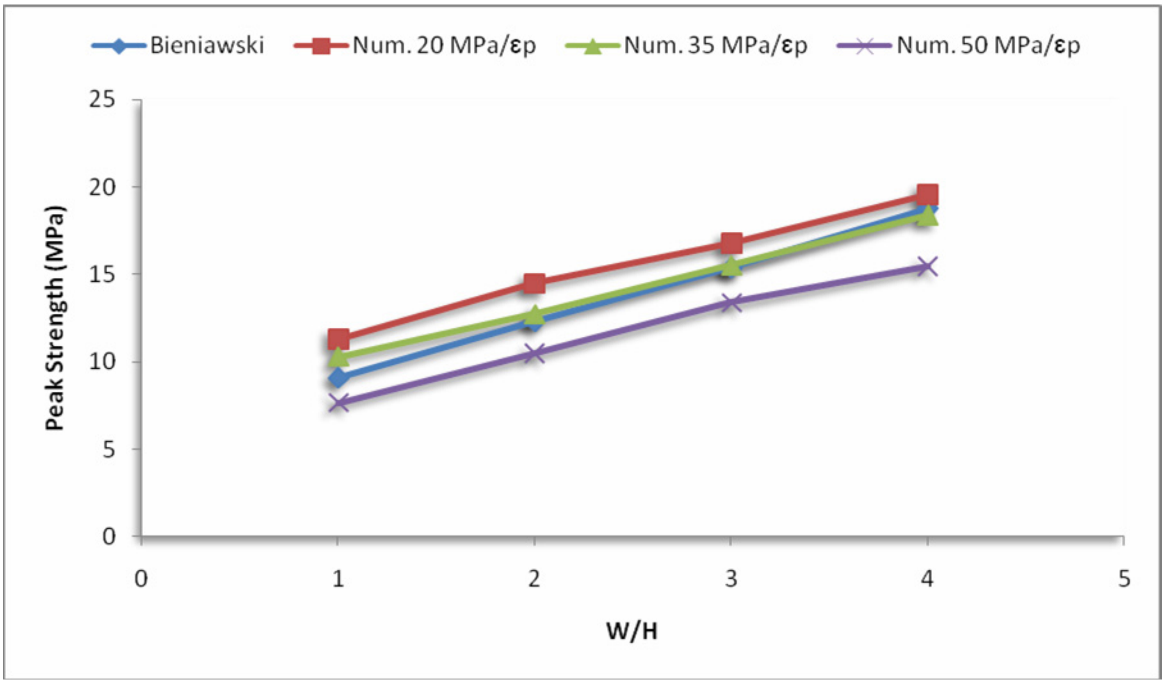

Figure 5: The modeled pillar strength and its comparison with Bieniawski criteria

According to the figure 5, the estimated strength in numerical model for W/H ratio 3 and cohesive ratio 35 MPa/εp is well agreed with Bieniawski conventional criteria. In modelling of a longwall mine with W/H ratio 3 of pillar, the selected cohesive ratio is 35 MPa/εp.

With applying these properties in longwall mine model, various stages of loading on pillar is modeled and hence the state of stress distribution and deformation of pillar and rib side are studied. The used mechanical properties in this longwall mine modelling presented in table 1.

Table 1: The used mechanical properties

property	*values*
Mine depth	700 m
Stress gradient	0.027 MPa/m
X, Y, Z stress	20 MPa
Coal elastic modulus	4 GPa
Coal Poisson's ratio	0.25
Coal strength	8 MPa
Coal density	1400 Kg/m3
Roof and floor elastic modulus	20 GPa
Roof and floor Poisson's ratio	0.25
Roof and floor density	2700 Kg/m3
Coal cohesive	0.5 MPa
Coal friction angle	20 degree
Roof and floor cohesive	0.8 MPa
Roof and floor friction angle	35 degree

In figure 6, the state of displacement distribution in longwall model is presented. As, the goaf is assumed compacted, obtaining a perfecting bearing capacity. Based on this condition, the deformation of rib side is minimized. However, for pillar, as stated by Wilson's Confined Core theory [5], the state of stress and displacement are formed in concentric rings, which increasing from center, outwards.

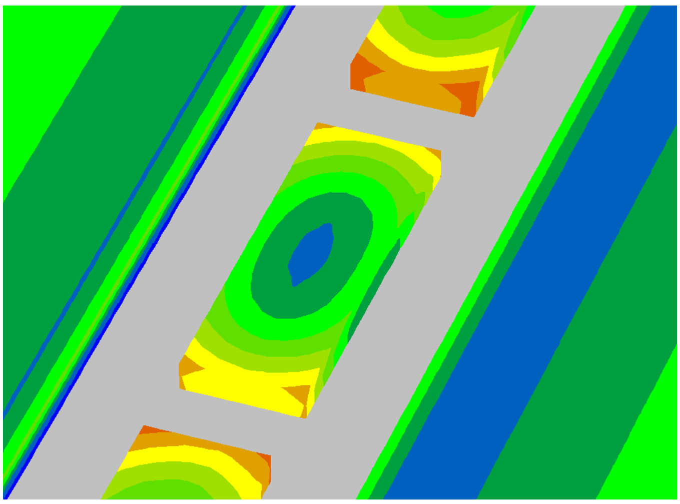

Figure 6: The displacement distribution in a longwall coal mine

4.Results and discussion

The Mohr-Coulomb model is unable to simulate the state of pillar in post peak strength. Nevertheless, such simulation by strain softening Mohr-Coulomb model can be performed successfully. In figure 7, the modeled stress-strain curve based on Mohr-Coulomb model and strain softening Mohr-Coulomb model are illustrated. W/H ratio of pillar is 3 and geometrical properties are given in figure 1 and mechanical properties in table 1.

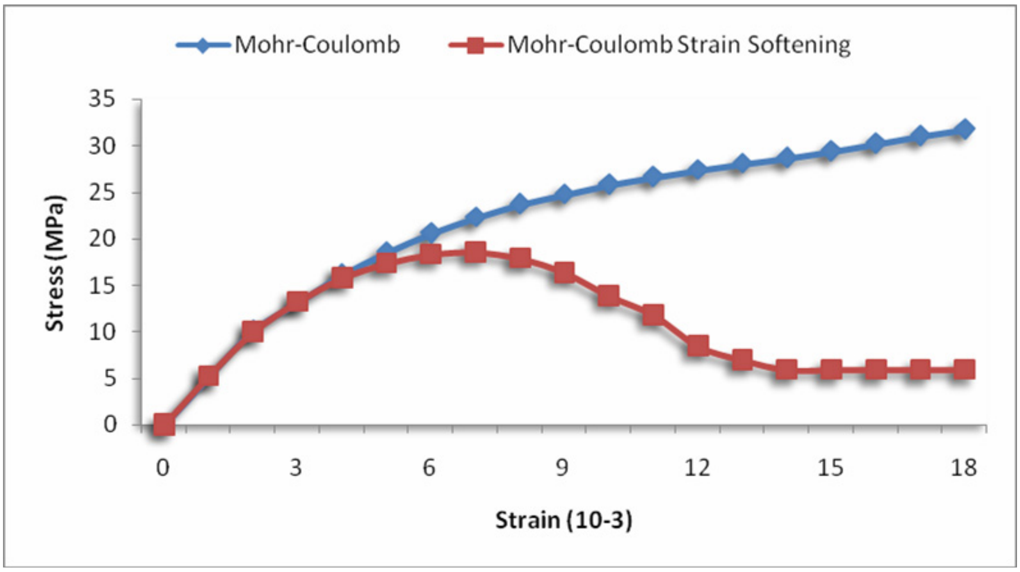

Figure 7: The stress-strain curve based on Mohr-Coulomb model and strain softening Mohr-Coulomb model

The rate of displacement in five stages of loading on pillar is up to a level that the state of pillar after reaching to peak strength should be studied. Therefore, is required to use strain-softening models with simulation ability of post peak strength.

The 3D property of this model, make the condition of studying front and side abutment loads. In generated model, the face is advanced by replacing of coal with caving material of roof. With increase of face advancing, distribution of stress on pillar is unbalance. Based on the five stages of loading shown in figure 1, after passing face from adjacent pillar and the goaf near pillar, the level of horizontal loading on pillar is increasing. The applied horizontal stress decreases the bearing capacity of pillar [6]. However fortunately, at this step the period of pillar application is ending. The estimated coal pillar strength for different W/H ratio based on Mohr-Coulomb strain softening model is shown in figure 8.

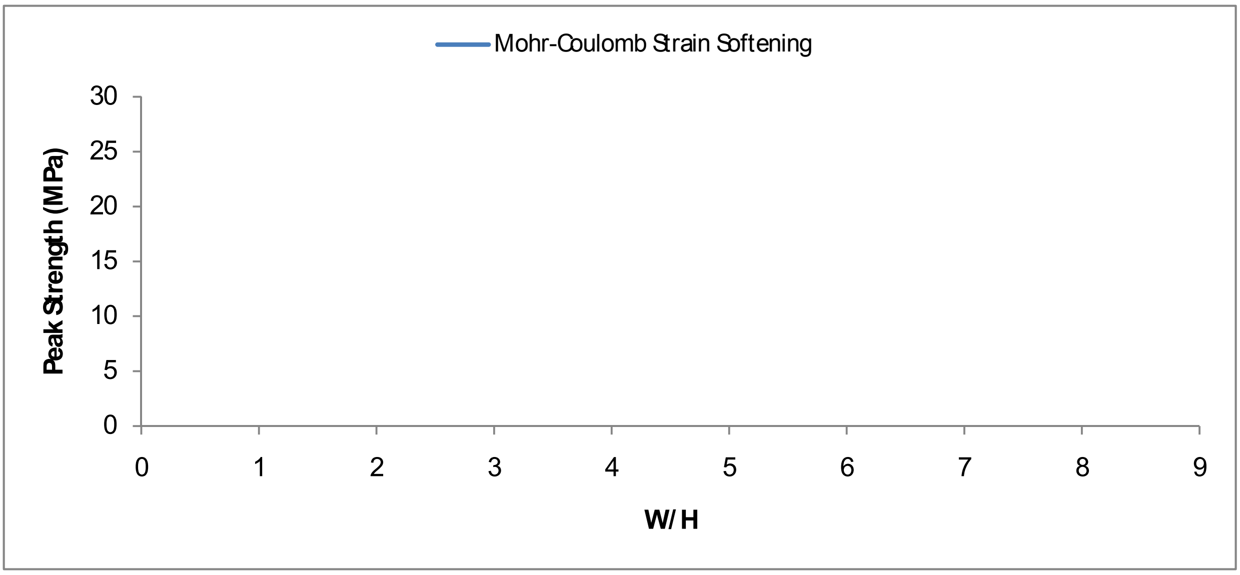

Figure 8: The estimated of coal pillar strength

As, seen in the figure, with increasing the W/H ratio of pillar, strength and in fact, the bearing capacity of pillar increases. However, the rate of increasing after W/H ratio 4 gradually reduces. Nevertheless, with increasing W/H ratio, the volume of remained coal as pillar increases and the applicable cross-area of entry decreases. Such variation influences the ventilation, transport and mine recovery. Therefore, selection of W/H ratio for amount above 4 needs adequate attention.

5.Conclusions

In this study, the stability of pillars in a deep longwall mine by using FLAC3D software is simulated. The results obtain show that for analyzing the rib side and pillar stability, the behavior of post peak must simulate. The Mohr-Coulomb strain-softening model can simulate behavior post peak. The pillar strain-softening base on this model occurs at maximum rate of cohesive. In longwall mine operation, 5 different stages of loading on pillar are applied. The results of this study prove the stress distribution in chain pillar of longwall mine, well agreed with Wilson's Confined Core model. However, based on different stages of loading and various type of operation at panels adjacent to pillar, the rings of stress or/and displacement distribution is not uniform. In this study, the 3D property of modeling occasioning the consideration of the influences of horizontal stress, front and side abutment loads. It can be concluded that, the results of this study can assist the mining engineer in deigning of coal pillar in a deep longwall coal mine.

6.References

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