Stress distribution characteristics in the vicinity of coal seam floor

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Abstract. Although longwall top-coal caving (LTCC) has been a popular, more productive and cost-effective method in recent years, roadway floor heave and rock bursts frequently appear when exploiting such coal seams with large dip angle. This paper proposes addressing this problem by adopting three-dimensional roadway layout of stagger arrangement (3-D RLSA). In this study, the first step was to analyse the stress distribution characteristics in the vicinity of coal seam floor based on the stress slip line field theory. In the second step, numerical calculation using FLAC3D was conducted. Finally, an evaluation of the 3-D RLSA for solving this particular issue was given. Results indicate that for this particular mine the proposed 3-D RLSA results in 24% increase in the coal recovery ratio and a modest reduction in excavation and maintenance costs compared to the conventional LTCC method.

1. Introduction

There is a considerable amount of lignite reserve in the form of thick seams in Turkey, and a numerical modelling of stresses around a longwall panel at Omerler has been carried out by FLAC3D [1]. In Australia, there are approximately 17.5 billion tonnes of coal belonging to the thick-seam category. The longwall top-coal caving (LTCC) can not only improve the production efficiency but also decrease the spontaneous combustion risk in longwall operations [2]. In Western Turkey, a 30-35 m thick lignite coal seam at Soma Eynez coal mine is extracted by a combination of the conventional LTCC methods. Basarir et al. [3] analysed the stresses around main and tail gates during top coal caving by 3-D numerical analysis. Jeromel et al. [4] studied the multi-level longwall top coal caving process by numerical simulations and in-situ measurements during coal excavation at different locations in the Velenje Coal Mine. However, when exploiting these seams with LTCC method, the roadway floor heave and rock bursts frequently occur in the process of face advancing, especially in regard to the deep mines. Roadways in these coal seams experience serious deformation damage with high cost of maintenance, making it difficult to exploit these resources and slowing down the speed of face advancing, so the three-dimensional roadway layout of stagger arrangement (3-D RLSA) has been proposed as shown in Figure 1.

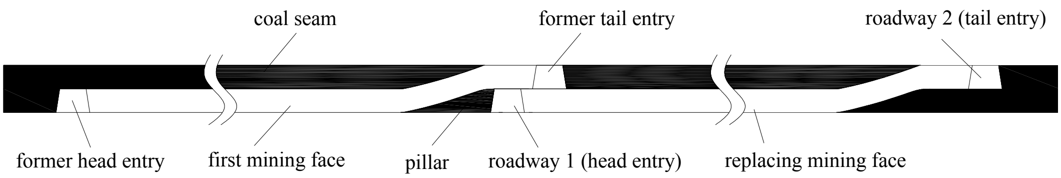
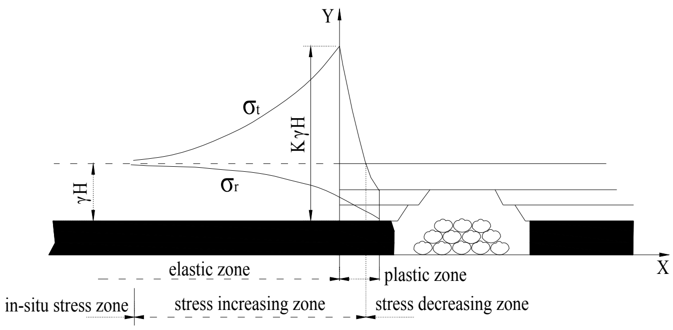


Figure 1. Inner staggered roadway layout of 3-D RLSA method

The 3-D RLSA consists of roadway 1 (head entry) beside the triangular pillar at gob side and roadway 2 (tail entry) along the roof, respectively (see Figure 1). Few studies have been conducted on the vicinity of coal seam floor near the pillar in relation to stress-distribution characteristics with the stress slip line field theory in plasticity. Furthermore, the textbooks [5, 6, 7, 8] only give the abutment pressure distribution in the front of working faces for selecting the location of roadways as shown in Figure 2. In this paper, the stress distribution characteristics in the vicinity of coal seam floor was analysed as a reference when extracting these coal seams.



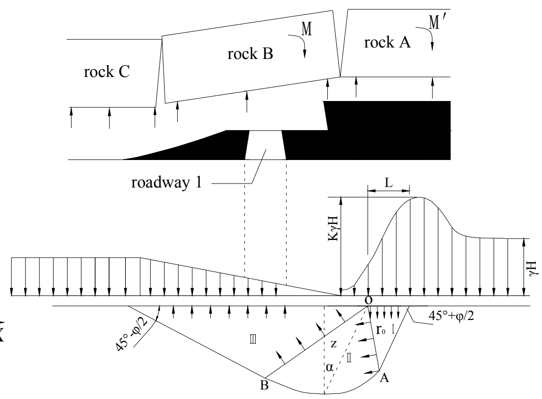


Figure 2. Abutment pressure distribution **Figure 3.** Stress analysis model of the stress on the floor

2. Theoretical analysis in 3-D RLSA

Coal exploitation inevitably results in the movement and destruction not only in the overlying strata but also in the floor strata. During the process of the face advance, the top coal and immediate roof caves and the basic roof tends to break on both sides of the working face in the coal seam. In addition, the movement and rotary sinking of basic roof leads to the abutment pressure acting on the floor on both sides of working face, making plastic deformation appear in a certain zone of the floor. Therefore, the range of plastic deformation is related to the extent of mining and the stress distribution around gob. Moreover, the range of plastic deformation can be calculated on the basis of the stress slip line field theory in plasticity [9]. Then the limit equilibrium zone of plastic deformation in the floor can be divided into three parts, namely the active area (zone Ⅰ), transitional area (zone Ⅱ) and passive area (zone Ⅲ) as shown in Figure 3.

The depth of the plastic boundary in the floor can be calculated as follows: in zone Ⅰ, rock mass tends to squeeze itself to both sides of the area with the increasing concentration factor of abutment pressure. In addition, sliding surfaces always appear in pairs and the angle between the floor and sliding surface is $45^{\circ}+\varphi/2$. Similarly, there is also a pair of sliding surfaces in zone Ⅲ, whereas the angle between the floor and sliding surface is $45^{\circ}-\varphi/2$. However, the sliding surface in zone Ⅱ is a logarithm spiral line whose radius is marked as r which can be expressed as:

$$\mathrm{r}=r_0 e^{\theta\tan\varphi} \tag{1}$$

Where θ is the angle between segment OA and segment OB; r_0 is the length of segment OA and it can be calculated as:

$$r_0 = \frac{L}{2\cos\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)} \tag{2}$$

Therefore, the depth of the plastic boundary in the floor strata (z) can be calculated as:

$$z = r\cos\alpha = r_0 e^{\theta\tan\varphi}\cos\alpha \tag{3}$$

In 3-D RLSA, although the gob is situated in the stress decreasing zone, the floor of roadway 1 is exactly in the passive area (zone Ⅲ) with the influence of abutment pressure, becoming the window of stress release. Therefore, the integrity and stability of the floor are also important to control the overall process of roadway maintenance, especially when exploiting thick coal seams with large dip angle. In addition, equations derived above can be used as a theoretical reference for the design of roadway support.

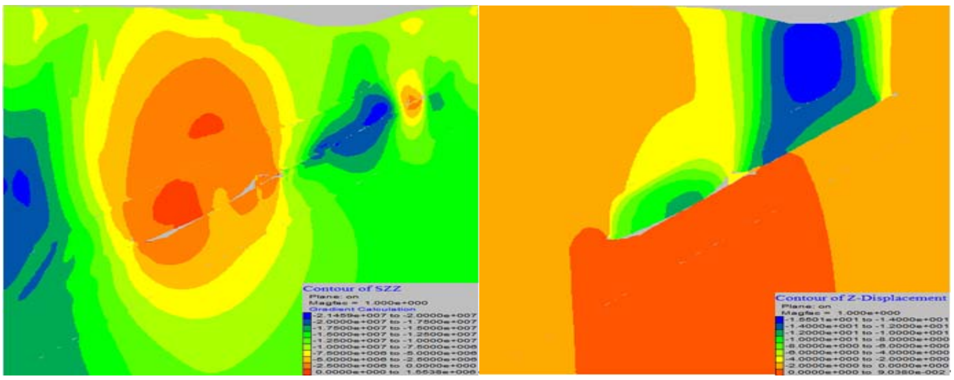
3. Numerical simulation with FLAC^{3D}

3.1. Establishment and calculation of *the FLA*C ^{3D} model

Based on the working face Y294 in Tangshan Mine, a numerical model was formed using FLAC3D [10,11,12,13,14]. The basic model was used to simulate the inner staggered roadway layout with a triangular pillar in 3-D RLSA along the strike direction and inclination direction. The extraction was simulated and recorded by cutting the seam in intervals of 5 m. The model was established as follows: given a rectangular solid model whose length, width and height are 430 m, 424 m and 103.9 m, respectively, with a total of 168000 units and 177633 nodes. Overburden stress conditions of the mine were simulated by applying the pressure (with a value of 10 MPa) on the top of the model. Afterwards, the lateral pressure coefficient was given a value of 1.4 with constraints of vertical movement on the bottom boundary.

3.2. Analysis of data

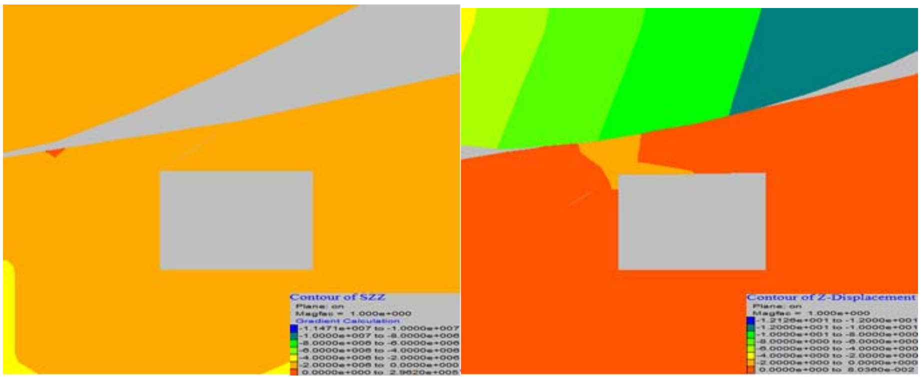
In this numerical simulation, the advance in the replacing working face began after extraction in the first working face was over. Vertical stress and displacement distribution were recorded along both strike direction and inclination direction during the advance in the replacing face.



(a) Vertical stress distribution (b) Vertical displacement distribution

Figure 4. Vertical stress and displacement distribution in the first and replacing faces along inclination direction

Figure 4 shows the vertical stress and displacement of overburden strata when the extraction in the replacing face was over. Vertical displacement at different locations in the working face presented an arch distribution, and the displacement value at the central part of the face was greater than that at the upper part of the face which was greater than that at the lower part of the face. In addition, the replacing face and first working face joined together which was similar to extraction of an "ultra-long" working face. The key strata of the two adjacent working faces formed a more stable one in the higher overburden layer. Therefore, we can divide a panel into several "ultra-long" working faces with different lengths when adopting 3-D RLSA method for extracting thick coal seams in variable geological conditions, such as large dip angles, folds and etc. It was conducive to safety and efficiency during extraction in working faces.



(a) Vertical stress around head entry (b) Vertical displacement around head entry

Figure 5. Vertical stress and displacement distribution around head entry in the replacing face

Figure 5 shows the vertical stress and displacement of head entry in the replacing face when the extraction was over. The data exported from FLAC3D (y=10 m in head entry) was processed as shown in Table 1. The stress and displacement values around head entry were relatively low as a result of its location in this method.

Table 1. Vertical stress and displacement of head entry in the replacing face

Location	Right side	Left side	Roof
Vertical stress (MPa)	4.3	4.1	3.9
Displacement (mm)	33	25	19

Compared with the previous roadway layout in conventional LTCC, the top-coal above the supports at both ends of working face can be extracted in 3-D RLSA (see Figure 1). In addition, the roadway floor heave and rock bursts have been relieved with more stable advance rate of the working face in Tangshan Mine in spite of large dip angle.

4. Conclusion

The stress distribution characteristics in the vicinity of coal seam floor was analysed based on the stress slip line field theory, together with numerical calculation using FLAC3D. The main conclusions are as follows:

(1)Vertical stress distribution model was established to analyse stress distribution characteristics in the vicinity of coal seam floor in 3-D RLSA method. The roof of head entry only bears the pressure coming from the overlying caved strata in gob, due to the protection of voussoir beam structure. Moreover, the depth of the plastic boundary in the floor strata (z) can be calculated as:

(2) According to the results from numerical simulation (FLAC3D), it is demonstrated that the head entry is located in the vertical stress decreasing zone, which is favourable to roadway excavation and maintenance. In addition, the principle of maintaining head entry in 3-D RLSA should mostly focus on the roof when exploiting thick coal seams with large dip angle.

(3) Vertical stress and displacement values at central part of the face are greater than those at the upper part of the face, which are greater than those at the lower part of the face. It is conducive to the drawing process of top-coal and improves the recovery ratio of top-coal.

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