

Investigation of Rib Pillar Stability at Ömerler Underground Mine by Numerical Modelling

N.E.Yaşıtlı, B.Ünver & M.M.Ceyhan

Department of Mining Engineering, Hacettepe University, Ankara, Turkey

ABSTRACT: Due to dynamic nature of longwall mining method, strata behavior is rather complex leading to an ongoing variation of stress distribution around production areas. Modelling of strata response to production activity is a prerequisite to maintain a safe and efficient production. In this sense, numerical modelling is a very useful and powerful tool in understanding strata behavior and resultant stress distribution. This paper briefly presents the results of numerical modelling carried out by using FLAC^{3D} at Ömerler Underground Mine. A special emphasis has been given to modelling of stress distribution and stability of the rib pillar left between M2 and M3 longwall panels.

1 INTRODUCTION

Longwall mining is the only viable method of extracting thick coal seams in Ömerler Underground Mine. Leaving a sufficiently wide rib pillar between longwall panels is the common practice in the mine. An important aspect of the design of a safe longwall system is the dimensioning of rib pillars. Unfortunately, design of such systems is not well established, due to insufficient understanding of the yielding mechanism in coal pillars. Many coal bumps and roof fall accidents in coal mines are potentially associated with rib pillars and can be reduced by improving rib pillar design methodologies.

There have been numerous attempts in estimating the stability of rib pillar depending mainly on in situ measurements, physical and numerical models. This paper presents 3-D numerical stability analysis of rib pillar left between M2 and M3 panel at Ömerler Underground Mine. The numerical model was formed by using the commercially available software called FLAC^{3D}, based on the finite difference (FD) technique.

2 ÖMERLER UNDERGROUND MINE AND PRODUCTION METHOD

Ömerler Underground Mine is a subsidiary of Turkish Coal Enterprises and is located in the inner Aegean District of Turkey near Tunçbilek-Tavşanlı, Kütahya Province. The total proven lignite reserve in the district is approximately 330 million tons. The proven reserves suitable for underground and surface

production are 263 and 67 million tons, respectively. The average calorific value of lignite in Tunçbilek District is 4500 kcal/kg, with an average sulfur content of 1.5%.

Production started at Ömerler Underground Mine in 1985 by retreat longwall with the top-coal-caving method. A conventional support system had been used until 1997, and then a fully mechanized face was established in 1997. The average depth below surface is approximately 240 m, and the 8 m thick-coal seam has a slope of 10° (Ünver & Yaşıtlı 2002).

Figure 1. A generalized stratigraphic column at Ömerler Coal Mine (Yaşıtlı 2002)

Thickness	Uthology	Formation
1 m	3a	Top soil
24 m	1	Calcareous marl
189 m	2	Marl
17 m	3a 3b	Claystone Soft claystone
8 m	4	Coal
4 m	3c	Claystone

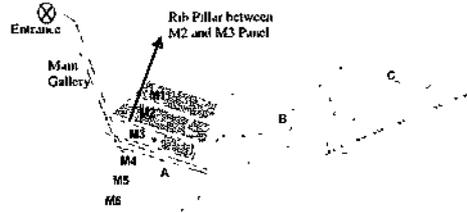


Figure 2. A simplified plan view of Ömerler Underground Mine (Yaşılı & Ünver, 2005).

A generalized stratigraphic column showing the coal seam together with roof and floor strata is presented in Figure 1. Three main geological units named as claystone, calcareous marl and marl are present in the mine area (Destanoğlu et al. 2000) Physical and mechanical characteristics of coal and other units are presented in Table 1.

As seen in Figure 2, six panels were planned for extraction by means of fully mechanized production method in sector A. At the time of this study, two adjacent longwall panels namely M1 and M2 had been completed and the production was carried out at M3 panel. Coal has been produced by means of longwall retreat with top-coal-caving production method where a 2.8-m-high longwall face was operated at the floor of the coal seam (Fig. 3). Top slice coal having a thickness of 5.2 m was caved and produced through windows located at the top of shields.

As it can be seen in Figure 2, there is a 16 m wide rib pillar between M2 and M3 panels. This value was determined by a previous study (Taşkın 1999). In this study, induced stresses and yielding characteristics of the lib pillar have been studied by means of numerical modelling.

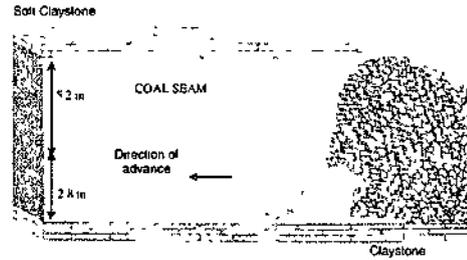


Figure 3. Longwall with top coal caving method as applied at Ömerler Underground Mine (Yaşılı & Ünver, 2005).

3 GENERAL MODELLING PROCEDURE

Modelling was carried out with FLAC^{3D} which is used for stress and deformation analyses around surface and underground structures excavated in both soil and rock. This software is based on the finite difference numerical method with the Lagrangian calculation. The finite difference method can be better applied to modeling of stress distribution around underground mining excavations in comparison to other numerical techniques. (Itasca 1997, Yaşılı & Ünver 2005).

Modelling for estimation of stresses around the longwall panel has been performed in five steps. The steps called A, B, C, D and E are as follows:

- A- Determination of boundaries and material properties,
- B- Formation of the model geometry and meshing
 - Determination of the model behavior,
- C- Determination of the boundary and initial conditions,
 - Initial running of the program and monitoring of the model response,
- D- Réévaluation of the model and necessary modifications,
- E- Obtaining of results.

Table 1. Physical and mechanical properties of coal and surrounding rocks (Taşkın 1999, Yaşılı 2002).

Formation	Definiton code	Unit Weight (MN/m ³)	Uniaxial compressive strength (MPa)	Indirect tensile strength (MPa)	Internal friction angle ϕ	Cohesion c (MPa)	Modulus of elasticity E (MPa)	Poisson's Ratio ν
Calcareous mail	1	0.023	29.2	3.9	47	12.5	5520	0.26
Marl	2	0.022	16.1	1.9	31	5.0	2530	0.25
Claystone	3 a	0.021	14.4	2.3	32	3.18	1480	0.28
Soft claystone	3b	0.023	8.7	1.8	15-35	-	2040	-
Claystone	3c	0.024	26.5	3.5	40	2.90	2085	0.31
Coal	4	0.013	15.9	-	15-25	-	1733	0.25

4 MODELLING OF STRESSES AND FAILURE ALONG THE RIB PILLAR

A full-scale model of the M3 longwall panel and its surrounding has been prepared as seen in Figure 4. Face length, panel length and depth below surface values were taken as 90 m, 450 m and 240 m, respectively. There was a 16-m-wide nb pillar between M3 panel and the adjacent worked-out M2 panel. In order to accurately estimate stress distribution around the longwall face, this area was divided in the form of a closer meshing in comparison to other regions during numerical modelling (Fig.4).

Intact rock properties in most cases are found by means of laboratory testing. However, there is an important diversity between rock material and rock mass characteristics. It is compulsory to determine representative physical and mechanical properties of the rock mass instead of intact rock material. In this study, rock material properties were converted into rock mass data by using empirical relationships widely used in the literature, i.e. Hoek and Brown (1997) failure criterion, Bieniawski's (1973, 1989) RMR classification system and Geological Strength Index (GSI) (Hoek 1995, Sönmez 2001, Sönmez &

Ulusay 1999).

Modelling of caved area is another important step that affects the results. It is a well-known fact that it is a rather difficult task to model the goaf material. Therefore, the goaf was characterized by using the following expression for modulus of elasticity as suggested by Xie et.al. (1999):

$$E = 15 + 175(1 - e^{-1.25t}) \text{ (MPa)} \quad (1)$$

where, t is time in seconds

For the goaf material in Tunçbilek Region, Köse & Cebi (1988) suggested a modulus of elasticity interval of 15-3500 MPa, whereas Yavuz and Fowell (2001) suggested a Poisson's Ratio of 0.495. These values were used for the characterization of goaf material throughout the analysis. Hence, change in the characteristics of goaf material depending on the level of compaction could be taken into account.

In order to simulate the change in the characteristics of stress distribution around the face, a progressive modelling has been earned out depending on face advance. Therefore, the model was progressively modified after each run as the face was advanced 30, 60, 90, 120 and 150 m away from the face start line.

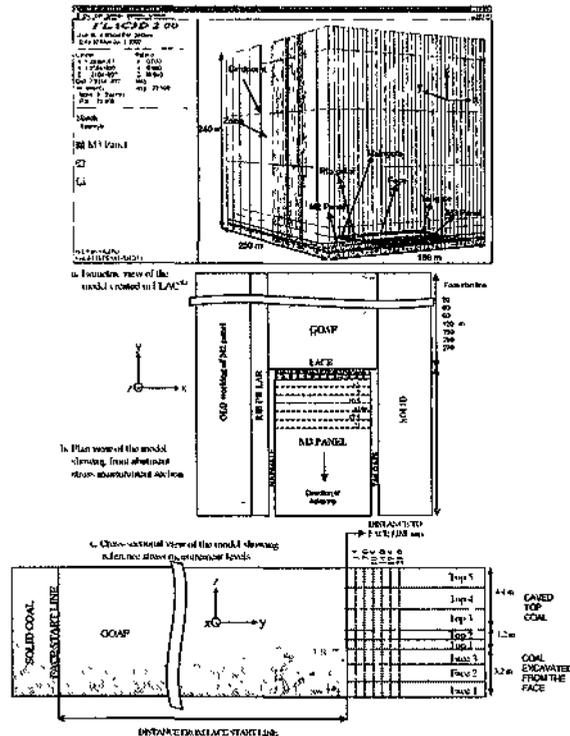
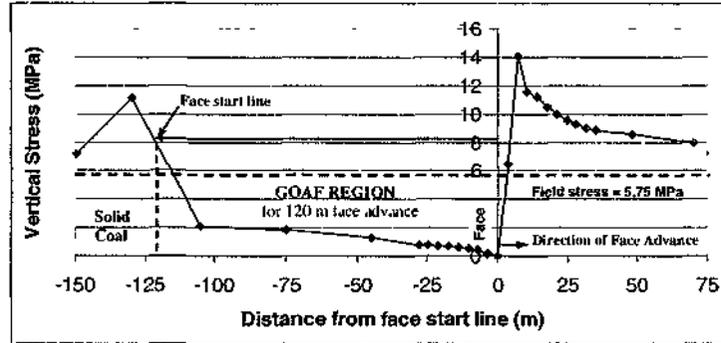
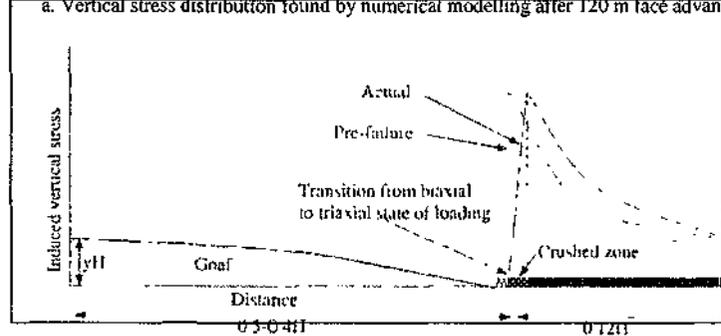


Figure 4. Details of model geometry of Ömerler Underground Mine (Yaşılı & Ünver, 2005).



a. Vertical stress distribution found by numerical modelling after 120 m face advance



b. Vertical stresses distribution based on in situ measurements (Whittaker & Singh, 1979).

Figure 5. Stress distribution at a longwall found by in situ measurements and numerical modelling.

However in this study, a comprehensive interpretation of these modelling results has not been given. Hence, only the change in vertical stress distribution around the longwall face depending on face advance has been briefly presented. Vertical stress distributions obtained after 120 m of face advance from the face start line is presented in Figure 5. Characteristics of stress distributions obtained by means of numerical modelling are in good agreement with the results of actual measurements in underground conditions. The magnitude of field stress was calculated as 5.75 MPa and presented with a dashed line in Figure 5. Front abutment pressures increase until a distance of 7 m in front of the face reaching to a maximum stress level of 14.40 MPa. After reaching to the highest front abutment pressure, it decreases gradually to initial field stress of 5.75 MPa at a distance of 70 m away from the face. The abutment stress formed at a distance of 7 m in front of the face increased 2.5 fold of the initial field stress (Yaşitli & Ünver, 2003).

Stress in the goaf behind the face decrease to 0.1 MPa levels and tends to increase at the start line of the face in a similar manner with front abutment stresses as expected. At the face start line of the panel, rear abutment stresses reach to the highest

level at 2-3 m inside the solid coal and decrease gradually to the field stress level at about 60 m inside the solid coal.

In this study, another numerical modelling was performed for evaluation of rib pillar stabilization. Loading of rib pillars is a complex phenomenon due to yielding behavior. The complexity of modelling of stress distribution on a rib pillar arises due to; first, drivage of gate roadways and crosscuts lead to an increase in the amount of load exerted on rib pillars. Second, production activity at the neighboring longwall panel results in an extra increase in the amount of load on the pillar. This results in the direct exposure of the rib pillar to the transferred load induced by the extraction of the coal in the nearby panel. This, so called, side abutment load almost certainly causes some yielding in the pillars. The pillars should be strong enough to withstand high loads in order to protect the entry between the rib pillar and the nearby panel. The third phase of loading is due to the extraction of the coal from the nearby panel. The rib pillar must protect the entry reasonably well from the front abutment stresses caused by the production at the neighboring panel.

An important study for determination of the width of rib pillar at this panel was carried out by Taşkın

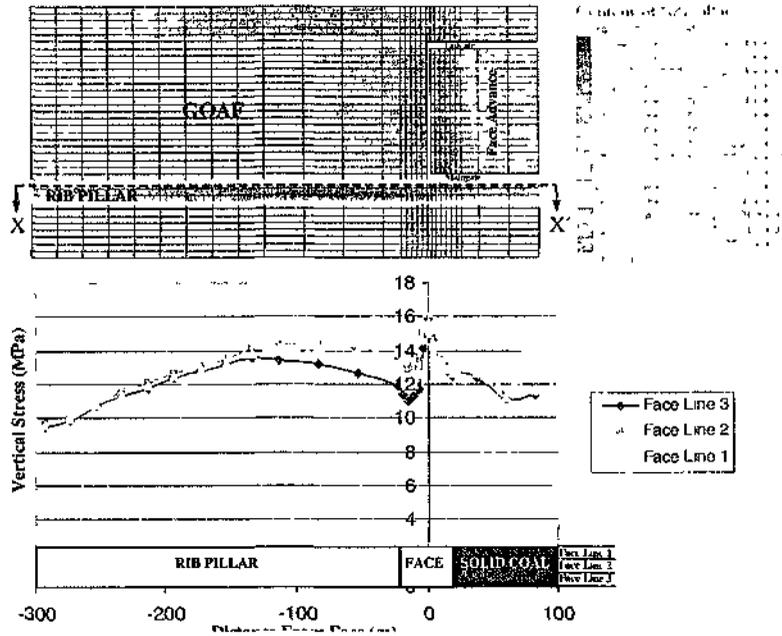


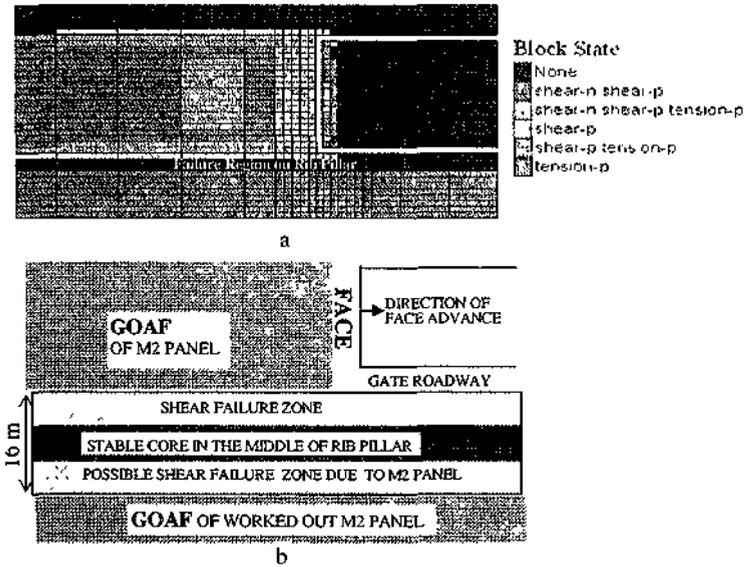
Figure 6. Vertical stress distribution along rib pillar parallel to face advance.

(1999) based on in situ measurements, and he determined the pillar width as 16 m. Consequently, width of the rib pillar between M2 and M3 panels was selected as 16 m at Ömerler Underground Mine.

The coal seam was divided into three levels in vertical direction to aid understanding of stress distribution at various heights from floor to roof of gate roadway. Vertical stress distribution along the rib pillar on X-X axis is given in Figure 6. As expected stress distribution in close proximity of the face on the rib pillar is high. Vertical stress on the rib pillar reaches to 16.1 MPa and there is a sharp decrease in vertical stress levels on the rib pillar in front of and behind the face line. The amount of vertical stress is around 14 MPa up to a distance of 115 m behind the face line. This phenomenon may be attributed to the fact that the goaf in this region is still loose to accept load from the main roof. Therefore, the amount of side abutment stress is high in this region. The amount of side abutment stress gradually decreases from a distance of 115 to 300 m behind the face line. This is due to ongoing compaction of goaf. As a result of compaction, goaf will start to accept some of the load exerted by main

roof leading to a decrease in the amount of side abutment stress on the rib pillar.

After performing the numerical modelling for determination the stresses on the rib pillar, evaluation of rib pillar stability and yielding behavior have been performed and the results are given in Figure 7. Along the rib pillar near the face line, an approximate shear failure zone of 10 m in length and 5 m in width was observed. Apart from this region, the rib pillar was found to be stable. As seen in Figure 7b, there is a stable core in the pillar with an approximate width of 5 m. According to the numerical results, the rib pillar between two panels was found stable. During in situ observations, in the gate roadway at a distance of 10 to 15 m in front of the face line, high amount of convergence had been seen possibly due to yielding of rib pillar. Hence, additional support has been applied in the form of erecting hydraulic props in the middle of the gate roadway. As it is determined by numerical modelling and verified by in situ observations, after a further distance of 10 m in front of the face line, no major stability problem has been encountered with in the gate roadway.



none- no-failure zone, shear-n: the region failed under shear loading and failure process is still in progress, shear-p: the region failed under shear loading and failure process is ceased due to lowered amount of shear forces, tension-n: the region failed under tensile loading and failure process is still in progress, tension-p: the region failed under tensile loading and failure process is ceased due to lowered amount of tensile forces.

Figure 7. State of failure around the longwall and rib pillar.

5 CONCLUSIONS

The results reveal that stresses around the longwall face can be successfully modeled by using FLAC^{3D}. The results show that maximum abutment stresses (14.4 MPa) formed at a distance of 7 m in front of the face. After reaching to the highest level the front abutment pressure decreases gradually to initial field stress level (5.75 MPa) at a distance of 70 m away from the face. Stress level in the goaf behind the face was very low (0.1 MPa) as expected. The maximum vertical stress on the rib pillar was found as 16.1 MPa. The section of the rib pillar 5 m from the gate roadway yields leaving a stable core in the middle. Therefore, the rib pillar width of 16 m as applied in the mine was found to be a proper selection.

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