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Evaluation of floor heaving in galleries by numerical analysis

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This paper is concerned with a study on the floor heaving in the transport road of the GLI Omerler Colliery in Tuncbilek-Turkey. This gallery has been opened at the depth of 200 m through the formation of marl in 4.6 m width and 3.5 m height in cross section.

Floor heaving occurred up to 70 cm in height in maximum and caused severe problems in railway and band-conveyor transportation in the main road. In addition; after the current panel mined out, the shield support units could not be transferred to the new panel because of the deformation of roadway cross-section. The I-profile steel arch supports also sank into the weak floor rock.

This situation has been studied by numerical analysis using the *FLAC^{3D}* finite difference program in order to investigate the rock mass behaviour around the opening. The obtained outputs of the numerical model have showed consistency with the amount of floor heaving in the gallery at 200 m depth.

A new gallery has been driven at the depth of 115 m and M4 longwall panel has just been taken to production. So as not to encounter with the same problems at 200 m depth, especially longwall face moving problem, various numerical models have been studied in order to keep the floor heaving in the acceptable limits required to move shield support units.

Keywords: Floor heave, Numerical modelling, *FLAC^{3D}*, Failure criteria, RocLab

Introduction

Tuncbilek coal mine is an important company producing 6 millions tons coal per year from both underground collieries and open pits. Although the most amount of coal is being produced from open pits, underground mining has to be carried out because of the decrease in the reserves of open pits. For this reason, fully mechanized system has been applied for trial purpose in order to be able to extract coal more efficiently and economically[1]. The mine layout has been shown in Figure 1.

The transport road was opened in order to reach to the coal, and longwall panels have been planned in the both sides of the transportation road as it can be seen from the Figure 1. M1, M2 and M3 longwall panels were mined out by using fully mechanized system.

Floor heave occurred in the transport road of the M1, M2 and M3 longwall panels and caused severe problems in railway and band-conveyor transportation in the main road. In addition; after the current panel mined out, the shield support units could not be transferred to the new panel because of the deformation of roadway cross-section. The I-profile steel arch supports also sank into the weak floor rock. In contrast, any negative effect of floor heave has not been encountered in terms of ventilation since the coal was produced from only one panel.

The amount of floor heaving was measured approximately 70 cm during the 7 months' of extraction period which was started 11 months after the gallery was opened. The miners had to dig out the heaving rock in the floor of the gallery to keep the floor in order. This extra work resulted in spending time and labour costs. But, the same amount of floor heave has been observed again 7 months later. A photograph showing floor heave in the transportation road can be seen from Figure 2.

Floor heave is one of the most important problems in galleries in underground mining. Generally, there are two reasons for floor heave. The first is the occurrence of high tensile stresses within the floor rock and the second is the loss of tensile strength of the weak floor rock (marl)[2].

The new panel M4 has just been prepared for production and currently, the coal extraction started at this panel[3]. The geometric dimensions of all panels are given in Table I.

The aim of this study is to predict possible floor heave in the gallery at the depth of 115 m by using finite difference numerical method. For this purpose, a commercial program called *FLAC^{3D}* was used.

So as not to encounter the same problems with this gallery, various numerical models have been studied to find out a suitable support system for controlling floor heave.

Numerical analysis

In the prediction of floor heave of the transportation road for the Deep Seam District of GLI Mine, *FLAC^{3D}* which is three-dimensional explicit finite difference program for engineering mechanics computation has been employed. Materials are preserved by polyhedral elements within a three-dimensional grid that is adjusted by the user to fit the shape of the object to be modelled. Each element behaves according to a prescribed linear or non-linear stress/strain law in response to applied forces or boundary restraints. The material can yield and flow, and the grid can deform and move with the material that is represented. The explicit, Lagrangian, calculation scheme and the mixed-discretization zoning technique used in *FLAC^{3D}* ensure that plastic collapse and flow are modelled very accurately. Because no matrices are formed, large three-dimensional

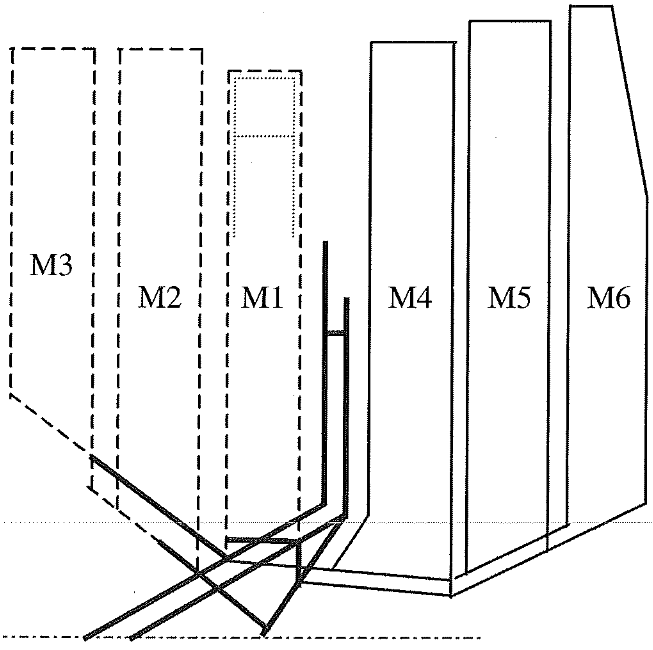


Figure 1. Mine layout for GLI

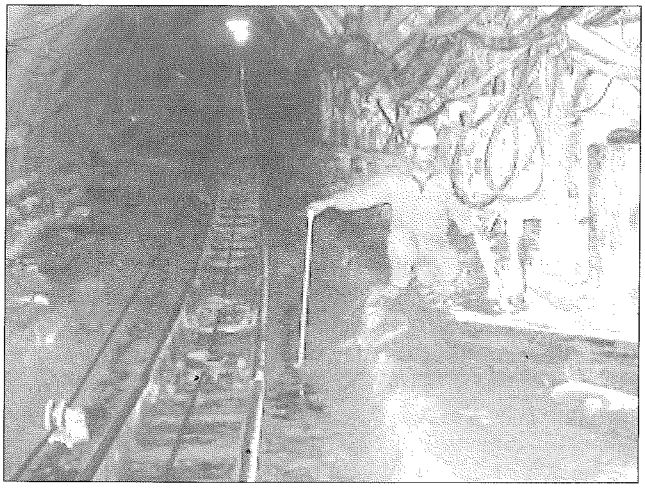


Figure 2. A photograph showing floor heave in GLI underground mine

Table I
Panel dimensions

Panel length	460 m, 370 m, 260 m (M1, M2, M3)
Face length	90 m (for trial)
Seam thickness	7–8 m
Slice height	2.5 m

calculations can be made without excessive memory requirements. *FLAC*^{3D} offers an ideal analysis tool for solution of three-dimensional problems in geotechnical engineering[4].

Numerical models

Geomechanical properties of rock mass in the district

The geomechanical structure of the site has been investigated by MTA (General Directorate of Mineral Research and Exploration) Institute, which made drilling works in the site[5].

The success of the numerical model analyses of underground openings depends on determining the geomechanical parameters introduced for any numerical model study. In our study, the geomechanical properties of the marl were taken from MTA report. However, this report does not give any knowledge about discontinuity properties. Discontinuity properties therefore were derived from the approach proposed by Priest and Hudson[6].

The uniaxial strength and tensile strength of the marl were found as 11.2 MPa, 1.5 MPa respectively from laboratory tests. All tests were conducted on air-dry samples because of dispersing marl in the water. Young's modulus and Poisson ratio of marl were determined as 4732 MPa and 0.25 respectively. RQD value for marl was found approximately 61.4 per cent. According to the Deere's classification system proposed in 1994, marl is in the group of fair rock[7]. RMR value was calculated according to RMR classification described by Bieniawski in 1979[8]. Geomechanical parameters together with their ratings are shown in Table II.

According to the classification system proposed by Bieniawski in 1979, marl is in the group of poor rock with the RMR value of 37. After determining RMR value for marl, Geological Strength Index (GSI)[9] was calculated as 32 by using Equation [1].

$$GSI = RMR - 5 \quad [1]$$

Modelling parameters dealing with rock mass

Geomechanical properties of marl such as Young's modulus, Poisson ratio, bulk modulus, shear modulus, tensile strength and density were introduced as input to the *FLAC*^{3D} program[4]. These parameters are determined by carrying out laboratory tests on intact and unfractured rock samples. In fact, rock masses are not intact in terms of their nature. So, laboratory results do not represent *in situ* rock mass properties entirely. It has been observed that rock mass showed elastic behaviour when the modelling parameters introduced to the program were taken as the same values with the geomechanical properties determined in the laboratory. However, many authors have proposed that Young's modulus of various rock masses should be introduced to numerical programs after being reduced to 1/5 of the value found in the literature. But, Agbabian *et al.* declared that rock masses show excessive plastic behavior when Young's modulus is used in the modelling studies as being reduced in the ratio of 1/5. Also, Kidybinski and

Table II
RMR calculation for marl

Parameter	Value	Rating
Uniaxial compressive strength	11.2 MPa	2
RQD	61.4%	13
Spacing of joints	80–200 mm	8
Condition of joints	Slightly rough surfaces, Separation <1mm, soft joint wall rock	20
Groundwater	115.2 lt/min	4
Joint orientation	Unfavourable	-10
	RMR	37

Babcock (1973) found that Young's modulus, which was determined in the laboratory, of coal and shale layers were higher 3 or 4 times than *in situ* values when they compared the displacements measured in the field with the results found by using finite element method[10].

Although Hoek-Brown failure criterion for rock mass is widely accepted and has been applied in rock engineering applications around the world, Mohr-Coulomb criterion is used in *FLAC^{3D}*. To incorporate Hoek-Brown criterion in the numerical models, Hoek *et al.* have recommended the use of windows program called 'RocLab' to find an acceptable equivalent friction angle and cohesive strength for a given rock mass[11]. So, geomechanical properties used in our model studies have been obtained by using 'RocLab' software[12].

During the calculation of equivalent Mohr-Coulomb parameters, disturbance factor (D), a factor defined in the Hoek-Brown failure criterion-2002 edition to allow for the effects of blast damage and stress relaxation[11], is taken as 0.9 because of very poor quality blasting in poor quality rock mass.

Rock mass' geomechanical properties obtained from RocLab software and used in numerical models is given in Table III.

Modelling parameters dealing with the support system

Support system used in underground mine in GLI consist of I-profile steel arches for every 1 metre along the gallery in conjunction with wooden support as is shown in Figure 3[1].

Also, dimensions of support system are given in Table IV.

Steel supports are modeled by using shell elements and their Young's modulus and Poisson ratio are taken as 200 GPa, 0.3 respectively in our models. Young's modulus and Poisson ratio of modeled wooden support between the steel arches are taken as 10.5 GPa, 0.25 respectively[13].

Numerical model geometry has been designed as the model boundaries to be 10 times higher than the gallery dimensions in order to keep boundary effects minimum. The generated model is shown in Figure 4.

Studied models

Firstly, the gallery at the depth of 200 m has been modelled (Model A). The purpose of this model is to compare the numerical modelling results with the measured data in the field. The deformed grid and displacement vectors are shown in Figure 5. As it can be seen from Figure 5, the gallery has deformed mainly in the floor (floor heave). This situation complies with the situation observed in the site, including the sink of steel supports into the floor.

Secondly, the gallery at the 115 m depth has been modelled to predict the deformation, especially in terms of floor heave, in advance (Model B). It is clear that floor heave can be anticipated as a result of model output which is given in Figure 6.

To eliminate the anticipated floor heave in the site, various numerical models with the different supports for the reinforcement of the floor are examined. In one of these models (Model B1), I-profile steel is placed and linked to both ends of every steel arch. The other model (Model B2) has been constructed as I-profile steel is placed and linked to both ends of one in every two steel arch. Deformed grid and displacement vectors of these models are shown in Figure 7a and Figure 7b.

Vertical displacements have been monitored at the certain grid points (history points 1, 2 at the roof and 3, 4 on the

Table III
Geomechanical properties used in numerical models

Property	for 200 m depth	for 115 m depth
Poisson ratio	0.25	0.25
Bulk modulus (MPa)	435.4	435.4
Shear modulus (MPa)	261	261
Tensile strength (KPa)	4	4
Friction angle (°)	10.27	12.58
Cohesion (KPa)	112	83
Density (kg/m^3)	2500	2500
Dilation angle (°)	0	0

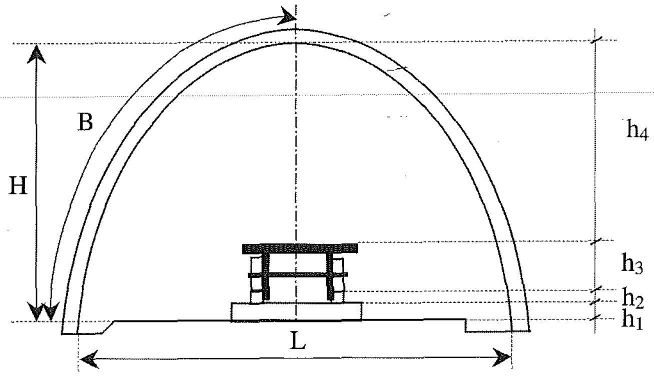


Figure 3. Cross-section of steel support system

Table IV
Dimensions of steel support system

Type	Cross-Section area (m^2)	Excavation area (m^2)	L (m)	H (m)	B (m)	h_1 (cm)	h_2 (cm)	h_3 (cm)	h_4 (m)
B-14	14	17.5	4.60	3.50	3.30	6.5	18	34.5	2.91

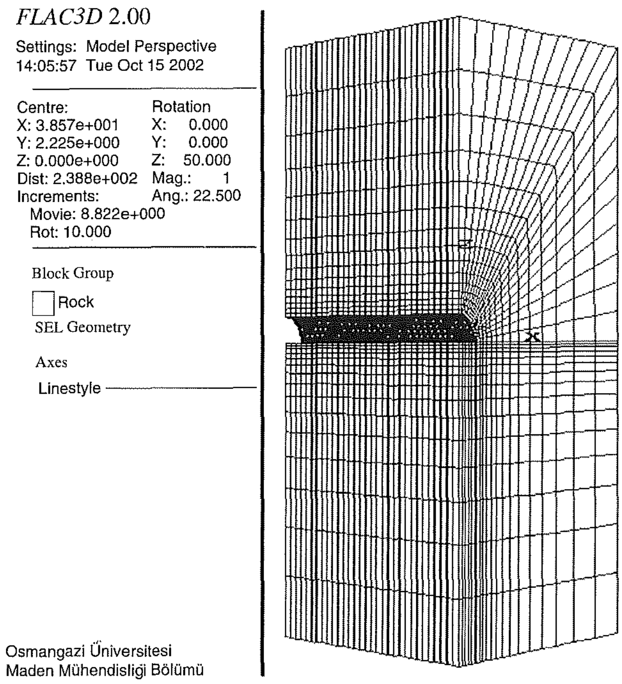


Figure 4. Designed model geometry

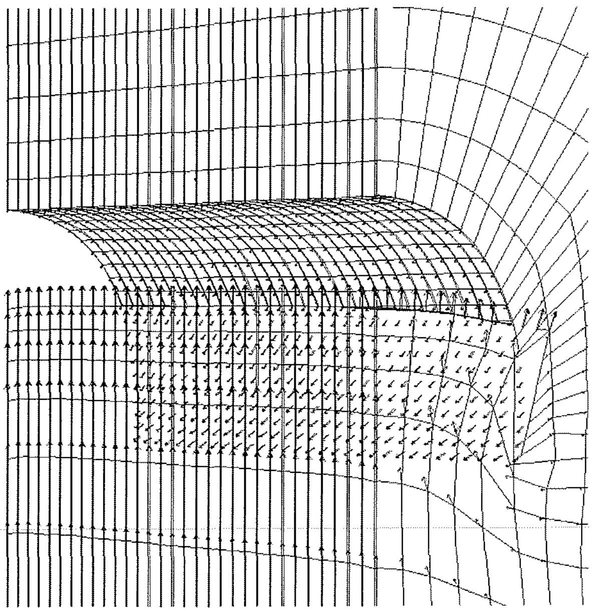


Figure 5. The deformed grid and displacement vectors in the Model A

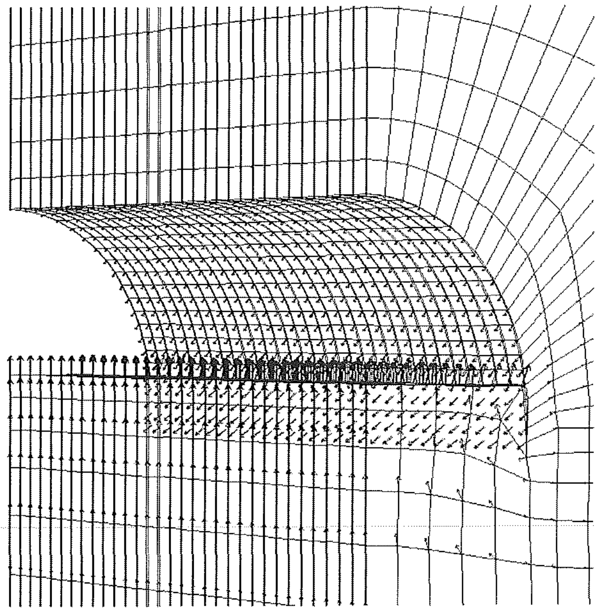
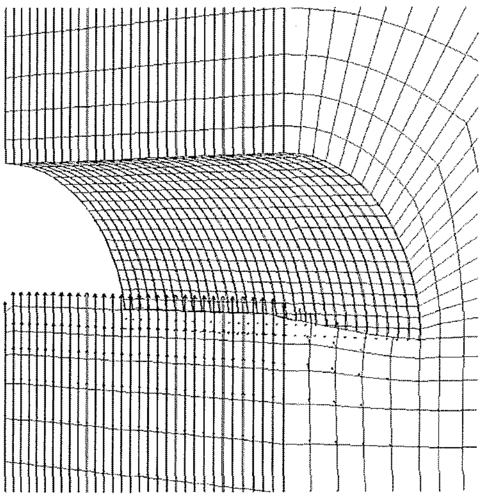
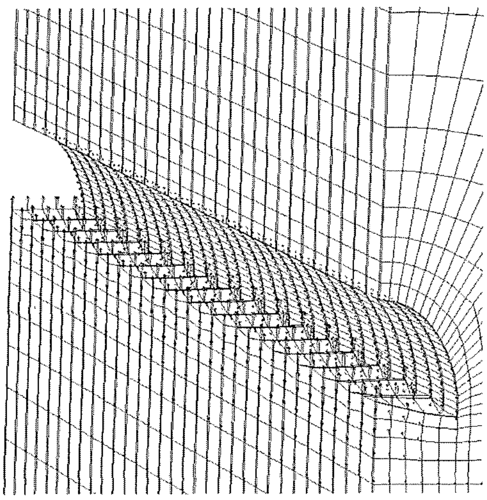


Figure 6. The deformed grid and displacement vectors in the Model B



7a. Model B1



7b. Model B2

Figure 7. The deformed grid and displacement vectors for reinforced floor

floor) in all numerical model runs. The observed results are given in Table V.

Conclusions

The amount of deformation and displacement which is anticipated in the transportation gallery opened for new coal panels has been predicted by using the results of numerical model studies. Firstly, transport road for M1, M2 and M3 coal panels, which were extracted currently, is modelled to investigate the floor heaving. In the result of this model study, 171 cm floor heaving has been observed in this transportation road at 200 m depth. It can be said that the amount of deformation obtained from numerical study shows consistency with the deformation observed in the field where 70 cm floor heaving was dug out twice in every 7 months. At the end of 14 months, the gallery was abandoned due to the fact that coal extraction was finished.

The experienced floor heave modelling study has led us to model the new transportation road at the depth of 115 m opened to service for M4, M5 and M6 panels. When the model output has been analysed, 65 cm floor heaving and 9 cm closure of the roof have been observed. So, this total amount of deformation will prevent the transportation of powered support units during the face move. The minimum height of the opening required for transporting the powered support through the road (h_4 shown in Figure 3) is 2.30 m. But, this distance was determined to be 2.17 m in the numerical model. It is clear that reinforcement of the floor is needed to keep the floor heaving in the tolerable limit of which the powered support units can be transported. When the results of Model B1 and Model B2 have been analysed, it is considered that observed total closure at the gallery in both models will not cause any problem during face move. However; as we look at the deformation patterns at the both models (Figure 7), in model B1, the floor of the gallery has deformed uniformly whereas the floor has undulated where I-profile steel was not placed in model B2.

Table V
Vertical displacements at history points

	History point 1	History point 2	History point 3	History point 4
Model A	171 cm	170 cm	20.3 cm	22.6 cm
Model B	65.2 cm	65.3 cm	7.1 cm	8.9 cm
Model B1	45.17 cm	33.05 cm	7.15 cm	9.15 cm
Model B2	49.87 cm	47.86 cm	2.32 cm	2.31 cm

Although the reinforcement at the gallery floor modelled in the model B2 costs less than the reinforcement in the model B1, the use of reinforcement in the model B1 is recommended for the site application because of uniform deformation pattern observed in the numerical model. This may help to prevent delay in the production schedule and extra future works such as digging out the floor periodically to keep the gallery floor at the original level.

Finally, this study shows that *FLAC^{3D}* is valuable and useful tool for rock engineering applications. It can be said that the use of equivalent Mohr-Coulomb parameters of Hoek and Brown failure criteria in *FLAC^{3D}* gave similar results with the measured field data.

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