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Finite difference modelling in underground coal mine roadway

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FINITE DIFFERENCE MODELLING IN UNDERGROUND COAL MINE ROADWAYS

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ABSTRACT: This paper presents stability analysis of roadways of the Tabas coal mine in Iran. Tabas Coal Mine is the first fully mechanised coal mine in Iran, producing 1.5 million tons of coal per year. The mine extracts coal by both longwall and room and pillar methods. The results gathered from field investigations and the geomechanical properties of rocks, were determined in the laboratory and indicate that the rock masses of this area are weak. So, the excavated roadways need to have suitable support. For this purpose, the roadways were modeled with FLAC-2D software. The Finite Difference Method (FDM) models were calibrated to study the interaction between rock mass and support. The use of V29 and V36 section arches are under consideration. After modelling these roadways in FLAC^{2D} software the results achieved from this model show that; displacements of around the roadways are high and safety factors are very low, so roadways need to be support. The extracted results from this software show that; steel arch V36 with a spacing of 1m is the best support system for these roadways. With this type of support system, displacements around the roadway are low and safety factors are in suitable values. After installation it was observed that the critical strain values on roadway walls and roof were less than the permitted values, which demonstrated the roadway stability.

INTRODUCTION

Coal is one of the most important minerals used in many smelting factories of Iran. Most of the coal mines of Iran are located in the Tabas Coal field located in the east of Iran. Most of these mines have difficult geological conditions. Most of them have weak rocks with low thickness and high slopes. With these conditions excavated roadways in these coal seams usually have many support problems. Tabas coal mine is one of the mines that provide coal for Isfahan Iron smelting factory of Iran. For exploiting of this mine Longwall mining method is used. In this research the geomechanical conditions of these rocks and the stability of the main-roadway in the mine were studied. Roof stability issues and the development of cavities in the immediate roof are a key concern for underground longwall mines. New technologies have enabled a greater knowledge and understanding of geological factors and *in situ* stresses in an underground environment, leading to a more accurate prediction of roof stability. These facilitate a safe working environment, which is imperative to all mining operations.

LONGWALL MINING

Longwall mining is the most common method of underground coal extraction used in the world today. Longwall mining extracts coal in large rectangular blocks, defined during development, in a single continuous operation (Aziz, *et al*, 2007). Each block of coal, known as a panel, is developed by driving a set of headings on either side of the panel off the main access roads. The start of the working face is created by the joining of these roadways. The longwall face is supported by hydraulic roof supports, whose main function is to provide a safe working environment as the coal is extracted and the longwall equipment advances. A goaf is formed as the immediate roof is allowed to collapse behind the mined out area. Figure 1 shows a schematic of a typical longwall retreat method. The thickness of a coal seam is another major contributing factor in the selection of the longwall mine design. Economically, maximising the recovery in thick seams can prove to be highly beneficial; however

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mining thick coal seams can often lead to roof stability issues that must be alleviated to maximise the benefits.

SEAMS PROPERTIES

Tabas underground coal mine is located about 85 km on the southern area of Tabas, Birjand Province, Iran. This mine is the first fully mechanised coal mine in Iran and produces 4000 tons of coal per day. The East 2 longwall panel has a face width of 180 m and panel length of 1200 m. Figure 2 shows the location of the extraction panels (East1 and East2). The C1 working seam thickness varied from 1.8 to 2.2 m with dip varying between 11◦ and 26◦. The roof of the coal seam contained 0.1- to 0.2 m mudstone, siltstone/sandstone interfaces, and sandstone. The C1 seam had a uniaxial compressive strength of less than 5 MPa. The other seams near the C1 seam were C2 and D1 above, and B1 and B2 below (IRITEC, 1992). The studied roadways were the main roadways of this mine. This roadway is located 350 m depth from surface with 2.2 m average thickness and 20^{o} stone, siltstone, silty sandstone and sandy siltstone. Table 1 displays the intact rock and rock mass properties such as uniaxial compressive strength, the material constant and the geological strength index.

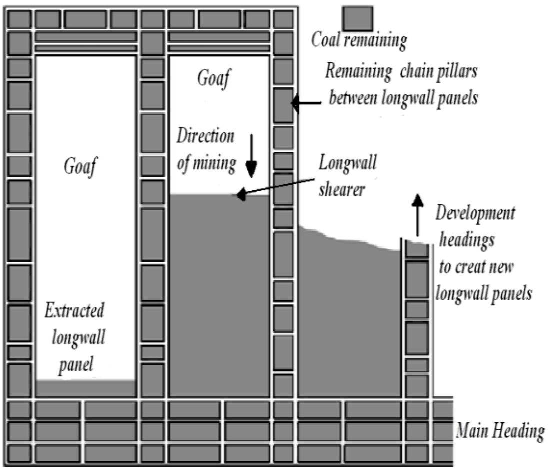


Figure 1: Longwall retreat mining (Aziz *et al,* 2007)

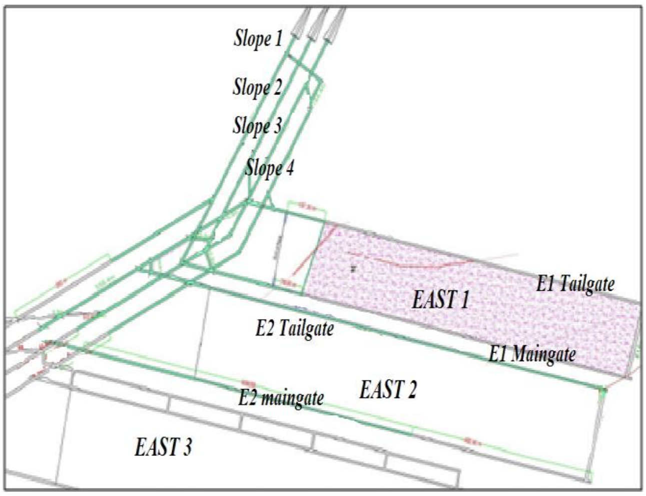


Figure 2: Extraction panels of East 1 and East 2 (IRITEC, 1992)

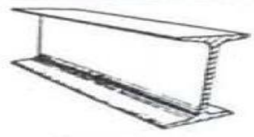
Table 1: Intact rock and rock mass parameters (IRITEC, 1992)

Depth into Roof (m)	Intact Rock		Rock Mass								
	UCS (MPa)	m*	GSI	m	s	C (MPa)	Φ (deg)	Tensile Strength(Mpa)	Compressive Strength(Mpa)	E (Gpa)	υ
Coal	5	1	25	0.1	0.0002	0.1	20	0	0.5	0.7	0.3
0 - 2.12	32	7	31	0.6	0.0004	0.5	21	0.02	0.5	1.7	0.3
2.12 - 3.35	73	13	39	1.5	0.001	1	44	0.05	2.2	3.5	0.3
3.35 - 3.8	32	7	36	0.7	0.0008	0.6	31	0.03	0.8	2.7	0.3
3.8 - 4.75	73	13	39	1.5	0.001	1	44	0.05	2.2	3.5	0.3

STABILISATION

The usual support system for coal mines in Iran is steel arches, so a suitable arrangement for this kind of support system must be designed. The pressure that steel arches induct to walls and roof of roadways must be calculated. For this purpose Table 2 is used (Hoek, 1999). In coal mines of Iran, usually steel arches of type TH section is used (Table 2). To finding the best support system from Table 2, different types of TH section steel arches (different profile number) with different spacing are used. After finding the support pressure, it is applied to FLAC-2D software. The extracted results from this software show that; steel arch V29 and V36 with spacing of 1 m is the best support system for these roadways.

Table 2: Maximum support pressure to walls (Hoek, 1999)

Support type	Flange width - mm	Section depth - mm	Weight – kg/m	Curve number	Maximum support pressure p_{imax} (MPa) and average maximum strain $\varepsilon_{max\ av}$ for a tunnel of diameter D (m) and a support spacing of s (m)
 Wide flange rib	305 203 150	305 203 150	97 67 32	1 2 3	$p_{i\,max} = 19.9D^{-1.23}/s$ $p_{i\,max} = 13.2D^{-1.3}/s$ $p_{i\,max} = 7.0D^{-1.4}/s$ $\varepsilon_{max\ av} = 0.30\%$
 I section rib	203 152	254 203	82 52	4 5	$p_{i\,max} = 17.6D^{-1.29}/s$ $p_{i\,max} = 11.1D^{-1.33}/s$ $\varepsilon_{max\ av} = 0.26\%$
 TH section rib	171 124	138 108	38 21	6 7	$p_{i\,max} = 15.5D^{-1.24}/s$ $p_{i\,max} = 8.8D^{-1.27}/s$ $\varepsilon_{max\ av} = 0.55\%$

Gate roadways were driven with a 12 m^2 cross section, using yielding steel sets of 29 TH profile with a spacing of 1.2 m (Figure 3). Figure 4 shows a gate roadway at A station without deformation. The support system was yielding steel sets with a lower segment (Figure 3) and spacing of 1.00 m.

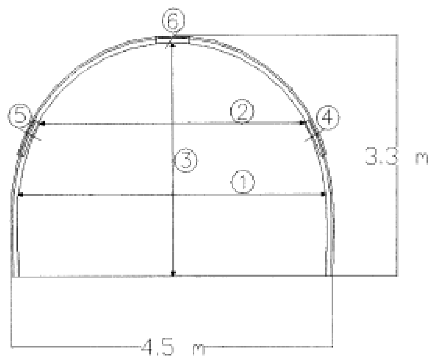


Figure 3: TH V29 steel set support (IRITEC, 1992)

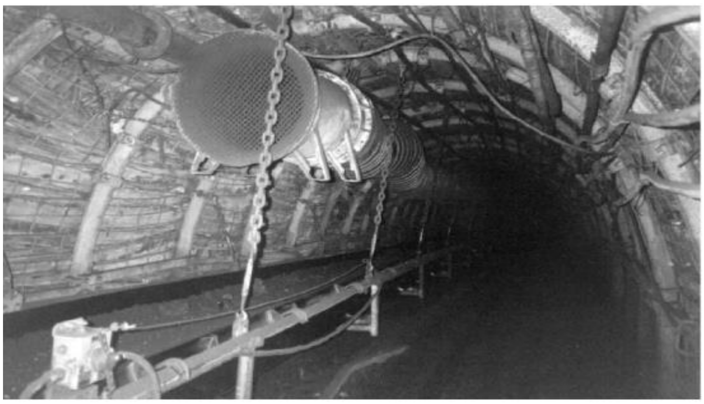


Figure 4: The roadway East 2 roadway profile (IRITEC, 1992)

SIMULATION OF YIELDING STEEL SUPPORT

Due to the complexity of the behaviour of the yielding steel set support, some simplifications are always necessary to simulate it by a pressure inside the excavation. It is based on very simple assumptions (Figure 5). Analysing the top of the support, it can be seen that an axial load at the legs clamps F (where the segments slide) produces a constant pressure p against the rock mass over the crown of the arch given by:

$$p = \frac{F}{a \times s} \quad (1)$$

where a is the radius of the excavation and s the steel sets spacing. If F_{lim} is the tangential load which causes sliding of steel segments, then the internal pressure equivalent to the steel set action when it is yielding is:

$$p_{lim} = \frac{F_{lim}}{a \times s} \quad (2)$$

In the horizontal direction, i.e. analysing the right part of the support, the value of the constant pressure due to a load F, is:

$$p = \frac{F}{2 \times a \times s} \quad (3)$$

then the equivalent pressure is $p_{lim}/2$.

The value of F_{lim} for the used steel set type estimated from laboratory test is 250 kN, but a more realistic value of 230 kN has been used. Taking into account that the half width of the roadway is 2.25 m, the radial pressure equivalent to the support when the steel sets spacing is 1.20 m is 0.085 MPa. If the steel sets spacing is 1.00 m, then the pressure is 0.10 MPa.

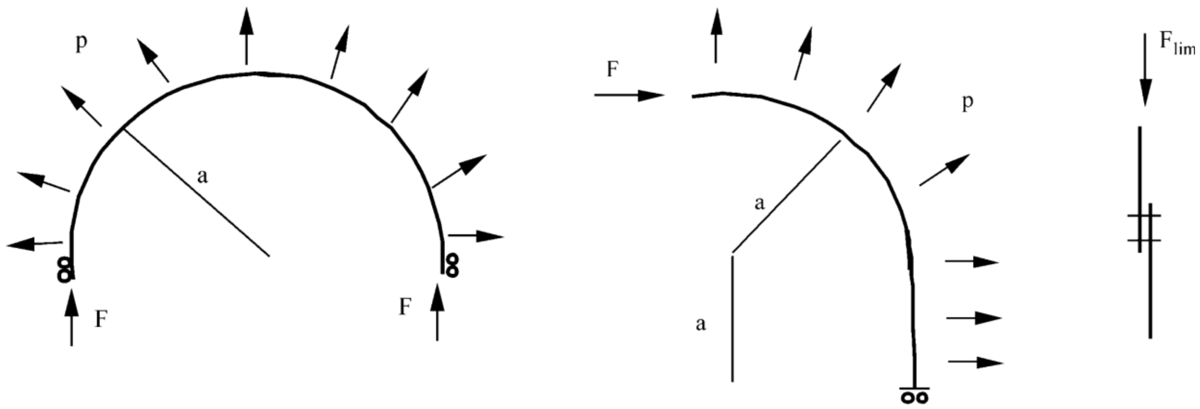


Figure 5: Basic assumptions to estimate the pressure equivalent to a yielding steel set (Torano *et al*. 2002).

TH arches are of the yielding type and the load capacities quoted from the test results are obtained by ensuring that the yield clamps do not slip. This is usually achieved by welding them together. In underground use, of course, the clamps can slip and this type of arch is designed to close (i.e. reduce its internal cross section) as load is applied. Yielding arches can accept a higher degree of strata movement than conventional rigid arches. However, high lateral movement or eccentric loads can result in the clamps locking which can lead to early failure of support. An even load distribution around the arch is critical if optimum performance is to be achieved with a TH arch. It could be argued that a long life decline is the very place where yield and hence closure cannot be tolerated. In this case, a strong, rigid arch would be preferable (MRDE, 1970).

NUMERICAL MODELLING

Computer modelling in the rock mechanics field has undergone significant developments in recent years. Developments in software and computers, allied with more sophisticated measurement of rock parameters, now allow the rock mechanics engineer accurately to simulate ground conditions and behavior (Garratt, 1997). Consequently computer numerical modelling now predominates as the method used by Rock Mechanics engineers to design support and reinforcement patterns for underground openings, including mine roadway support. The Finite Element method and Finite Difference method are alternative analysis techniques both based on discretising the domain to be analysed.

FLAC-2D stresses and displacements induced by underground excavations. FLAC solves a wide range of mining and civil engineering problems. Materials in the model can be linear elastic and nonlinear (Mohr–Coulomb and Hoek–Brown failure criterion), and discontinuities may be incorporated into the model. This feature was used to model the movements of blocks in the roadway (Itasca, 2004). FLAC is a two-dimensional code and these problems were analyzed on the assumption of plane strain along the axis normal to the plane of the model. This is of course an approximation and prevents the investigation of some important factors. In the case of roadways for example the assumption of plane strain implies that one of the principal stress directions is aligned along the roadway axis. It is known that the orientation of the principal stresses relative to a mine roadway can have an important influence on its behavior (Itasca, 2004). The first step of numerical analysis with FLAC-2D software is modelling of underground openings in a computer. In this part the model boundaries, *in situ* stresses, boundary conditions, material properties, and creating the finite element meshes are discussed.

Geometry of the model

The geometry of the area modelled was 40 m by 40 m with a roadway width of 4.5 m and height of 3.5 m. The coal seam was modelled as 2 m thick and dipping at 20°. The roadway immediate roof stratification sequence consisted of siltstone and sandstone above the roof. The geometry of the model defined is shown in Figure 6.

Boundary conditions

The model assumes plane strain state, nil displacements at the boundaries and constant field stresses. If the model is used to simulate convergence without longwall influence, then it is assumed that only the stress due to the pressure of the overburden at that depth is acting.

In situ stresses

Measured values for the *in situ* stresses were available from existing measurements at the mine, the closest being at the outbye end of the preceding district roadway. The measured stress direction is consistent and places the gate roads in a favorable direction approximately in line with the maximum horizontal stress. There is more discrepancy between the measured horizontal stresses magnitudes. Giving greater significance to the nearest measurements, the lateral stress acting across the gate roadways is expected to lie in the range 5-10 MPa. The depth of cover increases to approximately 350 m at the inbye end of the district. A representative value of 13 MPa was therefore chosen for the vertical stress component.

The critical strain

Here, the Sakurai method (Sakurai, 1997) was used to investigate the roadway stability. The method evaluates the critical strain in the elastic region. Since the rock mass is under triaxial stress, using the maximum critical strain for investigation of roadway stability is sensible (Sakurai, 1970). They suggested Eqs. (4) and (5):

$$\log \varepsilon_c = -0.25 \log E - 1.22 \quad (4)$$

$$\gamma_c = (1 + \nu)\varepsilon_c \quad (5)$$

Where; E= Young's modulus of intact rock($\frac{kgf}{cm^2}$), ε_c= critical strain in uniaxial strenght compressive, γ_c= critical strain, ν = Poisson's ratio.

Critical displacement values based on the critical strain are obtained by following equation (Sakurai, 1997:

$$\varepsilon_c = \frac{U_c}{a} \quad (6)$$

Where; U_c = Allowable displacement; a = radius of the roadway. In No support state, it can be also seen in Table 3, which shows the maximum displacement values and in Table 4. The critical strain values over the walls are more than the allowable strain values, which indicate roadway instability. Table 5 shows properties of V29 and V36 steel arch.

Table 3: Horizontal and vertical displacement of around East 2 roadway (mm)

Model	Roof	Floor	Right hand Rib	Left hand rib
No Support	18.9	17.3	51.3	66
TH Arch V29	4.5	5.98	3.3	8.96
TH Arch V36	3.6	4.23	2.8	6.65
Critical Displacement	10.2	10.2	18.3	18.3

Table 4: Maximum shear strain increment around East 2 roadway (*10^-3)

Model	Roof	Floor	Right hand Rib	Left hand rib
No Support	4.35	40.6	55.3	94.4
TH Arch V29	1.26	2.16	2.93	1.31
TH Arch V36	0.95	2.02	1.75	1.10
Sakurai Shear Strain	4.54	4.54	6.48	6.48

Result of numerical modelling with FLAC 2D software that using TH Arch V29 and TH Arch V36 for support of East 2 roadway is very good. As observed the critical strain values on roadway walls and roof are less than the permitted value which demonstrated the roadway stability. The geometry of the model defined is shown in Figure 6. In Figure7 shows coal layer deformation due to the increasing stress around East 2 roadway. The total displacements of ribs of roadway are shown in Figure.8. Figure 9 shows vertical displacement after steel arch V36 support in East 2 roadway that has good agreement with experimental results.

Table 5: V29 and V36 steel arch properties (IRITEC, 1992)

Arch Type	Wx (cm^3)	Ix (cm^4)	Area (cm^3)	Width (mm)	Height (mm)	Weight (kg/m)
TH Arch V29	94	616	37	151	124	29
TH Arch V36	102	618	41	162	138	36

3. Section Modulus 4. Inertia moment

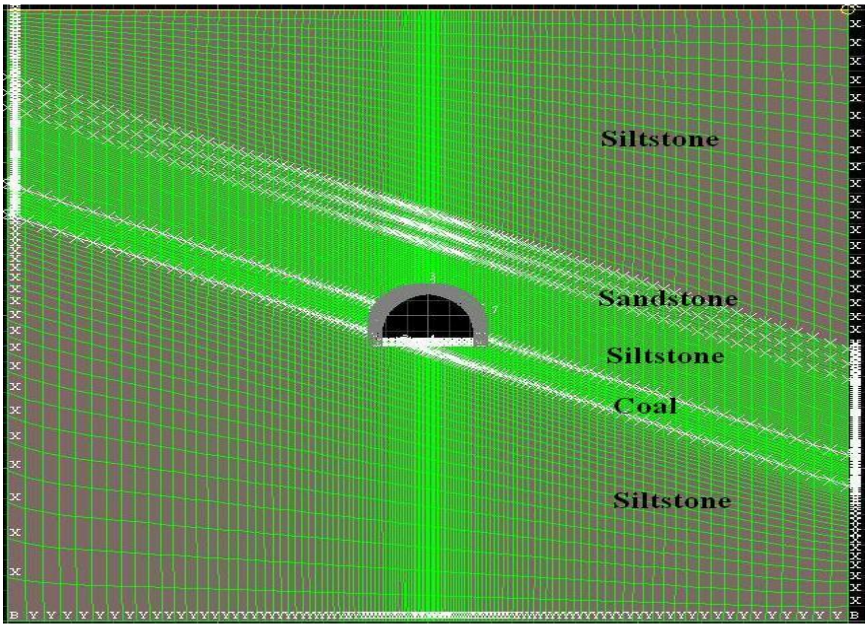


Figure 6: Model roadway profile, layers, and V36 arcs numerical modelling

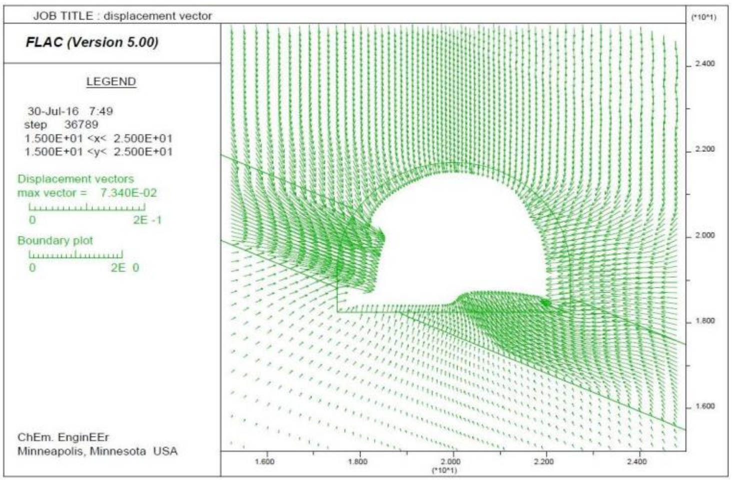


Figure 7: Total displacement around the roadway (mm)

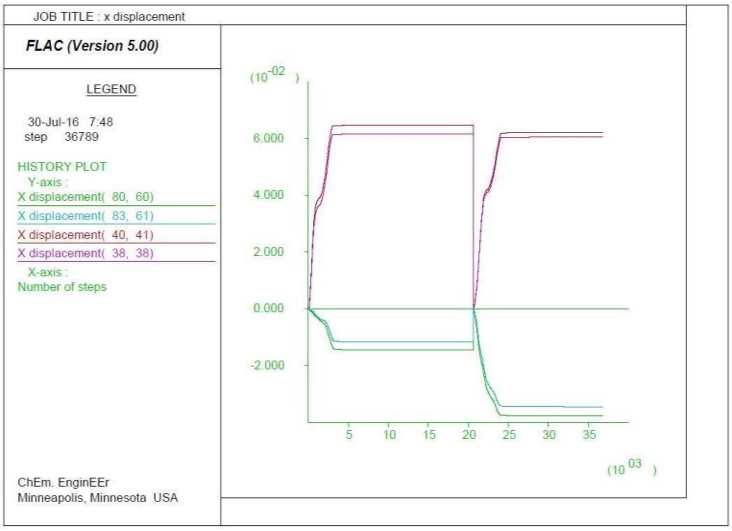


Figure 8: Displacements horizontal of right and left hand rib (mm)

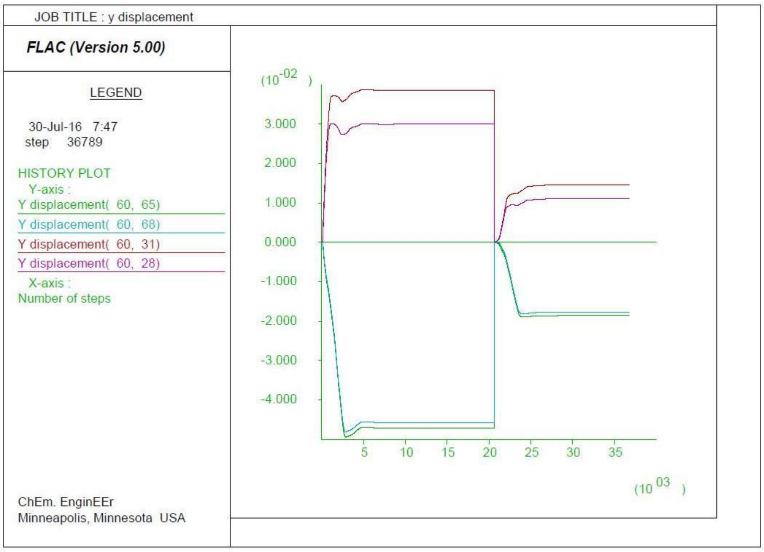


Figure 9: Displacement vertical at different levels (mm)

CONCLUSION

This research is about stability analysis of East 2 roadway in Tabas coal mine of Iran. The results extracted from software show that; displacements around the roadway are high and safety factors are low, so the roadway needs to have a support system. To find the best support system, different types of TH section steel arches (Different profile number) were modeled. The extracted results show that steel arch V36 with spacing of 1 m is the best support system for this roadway. With this type of support system, displacements around the roadway are low and safety factors are of suitable values. From the numerical simulations the following conclusions can be inferred.

- Measurement devices for roof movement must be capable of detecting roof movement over the required range.
- Enough measurement devices should be installed to minimise the risk of undetected movement occurring between measurement points.
- A measurable level of roof movement must occur before ground control failure.

- Roof movement must be measured sufficiently in advance of ground control failure to allow effective early warning.

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