SUGGESTED SUPPORT SYSTEM FOR A MINING TUNNEL IN THE E1 LONGWALL PANEL OF THE PARVADE1 UNDERGROUND COAL MINE: THE FINITE ELEMENT METHOD

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ABSTRACT

One the most important tasks after excavation of tunnels is the implementation and installation of a support system. Tunnel collapse poses a safety hazard and can cause worker injuries. In addition, it may have a severe economic impact because tunnel collapse can stop production and ore transportation. Therefore, an appropriate and well-designed support system is necessary for collapse prevention and to help stabilize the tunnels. In this research, we suggest a support system for the Parvade1 underground coal mine. The study case is a common mining roadway tunnel in the E1 longwall panel in this mine. To design an appropriate support system, we used the finite element method (Phase2 software). The results of this research can be used to design support systems for future tunnels in this mine and any coal mine that has similar conditions.

KEYWORDS

Stability, Support system, Tunnel, Finite element method, Coal mining

INTRODUCTION

Since the advent of underground excavation techniques, one of the most important problems has been instability of tunnel walls and roof collapse in tunnels and other underground openings. Loose rocks and layers have always had a tendency to drop into tunnel, except in very hard rock mines. Roof collapse, falling rocks and loose layers in tunnels are significant health and safety risks. These risks can halt mining operations, and ore production and transportation and therefore have serious economic consequences. Therefore, one of the most important actions that must be taken into account after the excavation of tunnels is stabilization of the roof and walls. To achieve this goal, the appropriate design and implementation of a support system is essential and necessitates knowledge of stresses around the tunnel (i.e. stability analysis). In recent years, numerical computer programs have commonly been used to perform stability analysis relating to underground openings.

The most commonly applied numerical methods for rock mechanics problems are (Jing & Hudson, 2002):

(1) continuous methods – Finite Difference Method, Boundary Element Method, and Finite Element Method (FEM);
(2) discrete methods – the Discrete Element Method and Discrete Fracture Network Method; and
(3) hybrid continuous/discrete methods.

The choice of continuous or discrete methods depends on many problem-specific factors, and mainly on the problem scale and fracture system geometry (Jing & Hudson, 2002). Continuous methods offer fast computer run time; however, detachment of elements is not permitted. Discrete methods are well suited for representing highly jointed rock masses, and allow representation of detachment of elements in the models. However, the amount of time that it takes to obtain the solution is the main disadvantage of discrete methods (Quang, Cai, & Hebblewhite, 2008).

Finite Element Method (FEM)

The FEM is perhaps the most widely applied numerical method across science and engineering. Since its origin in early 1960s, much of the FEM development work has been specifically oriented towards rock mechanics problems. This is owing to the fact that it was the first numerical method that had enough flexibility for the treatment of material heterogeneity, non-linear deformability, complex boundary conditions, in situ stresses and gravity (Jing & Hudson, 2002).

Phase2 software (Rocscience Inc.) is one of the programs that is based on the FEM and is used for stability analysis around underground openings such as tunnels. In this research, Phase2 software has been used to perform stability analysis and to suggest a support system for the tunnel in question. Phase2 is a 2-dimensional finite element program that calculates stresses and displacements around underground openings. It can be used to solve a wide range of mining and civil engineering problems that involve:

- elastic or plastic materials;
- staged excavation (up to 50 stages);
- multiple materials;
- support (bolts/shotcrete);
- jointed rock; and
- groundwater (include pore pressure in analysis).

Parvade1 underground coal mine

The Tabas coalfield in Iran includes 5 zones: Parvade 1–4 and Eastern Parvade. The coal reserves in Parvade 1 are 74.37 million tonnes (Oraee, 1997). The E1 longwall panel is located at Parvade 1 underground coal mine in the Tabas area located in central Iran. In the E1 panel, the first panel extracted was 170 m wide and 980 m long; this was carried out using the retreating method. There are 6 types of rocks from floor to roof (Table 1). In this paper a support system is suggested for a mining roadway tunnel in the E1 longwall panel.

Table 1 – Rock mass input parameters in numerical modeling (Manteghi, Shahriar, & Torabi, 2012)

Rock definition	Siltstone	Sandy siltstone	Silty mudstone	Coal	Mudstone	Sandstone
Definition code	1	2	3	4	5	6
Density (MN/m^3)	0.0272	0.0271	0.0268	0.016	0.0263	0.027
Internal friction angle (φ)	27.42	31.75	22.17	15.76	20.13	43.52
Cohesion c (MPa)	0.357	0.443	0.257	0.084	0.231	0.767
Modulus of elasticity E	2238	2818	1778	749	1995	3548
Tensile strength (MPa)	0.012	0.007	0.005	0.002	0.013	0.017
Poisson's ratio v	0.25	0.25	0.28	0.25	0.31	0.25
Bulk modulus [a] (K) (MPa)	1492	1878	1347	499	1750	2365
Shear modulus [b] (G)	895	1127	695	299	761	1419
Uniaxial compressive	0.273	0.287	0.114	0.015	0.165	1.01

[a] $K = E/3(1-2v)$
[b] $G = E/2(1+v)$

MODELING

The first step in numerical analysis with Phase2 software is modeling underground openings. In this stage, we enter and edit the model boundaries, in situ stresses, material properties and create the finite element meshes. The model created with Phase2 software is shown in Figure 1.

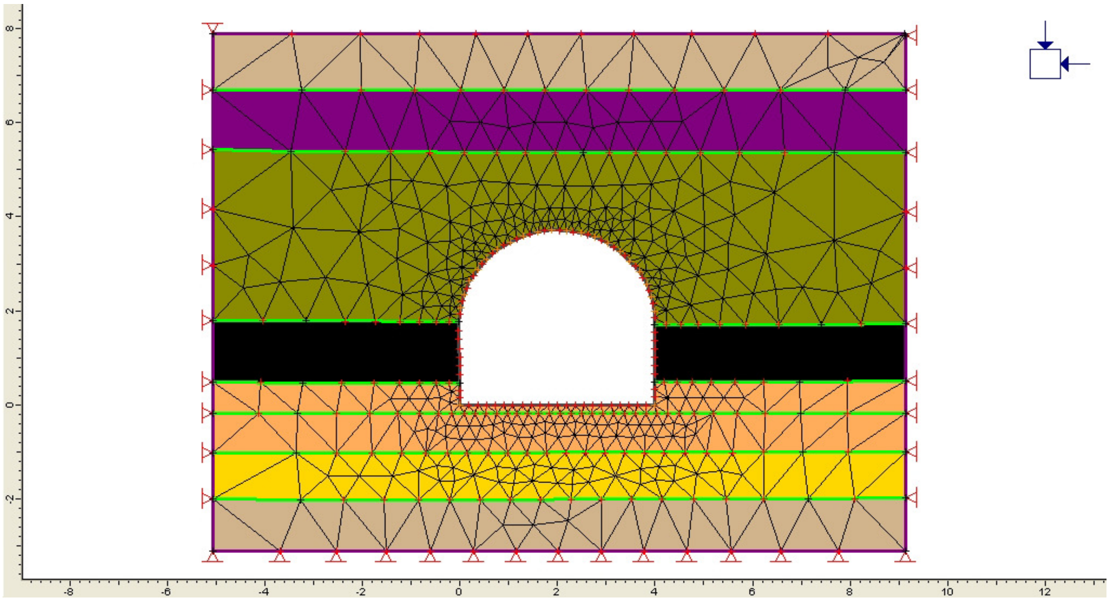

Figure 1 – The created model of the Parvade 1 tunnel in Phase2 software

Extracted results from Phase2 are shown in Figures 2 and 3, which show that the displacement around the tunnel is high and safety factors are low; therefore, the tunnel needs a support system.

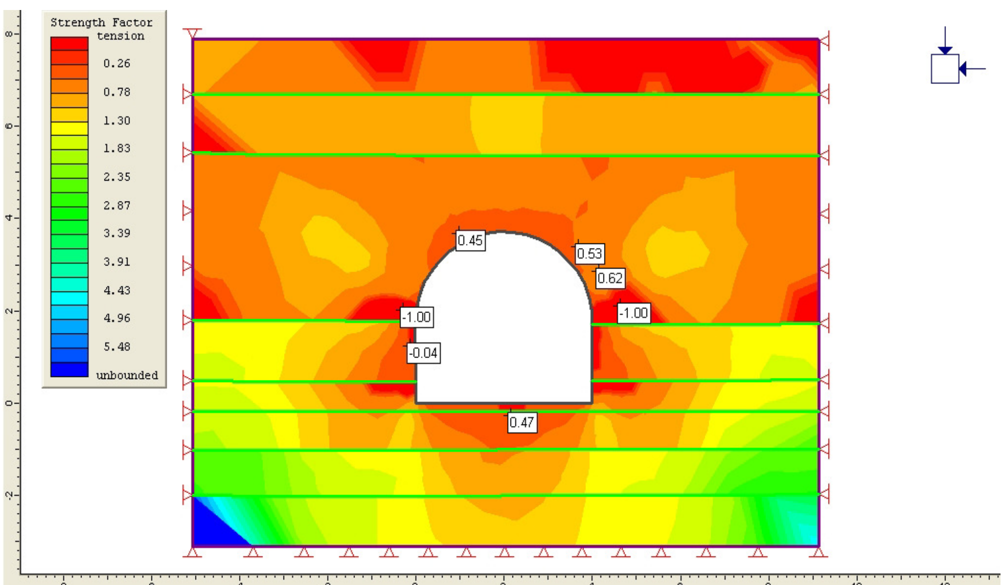

Figure 2 – Safety factor around the Parvade 1 tunnel before using the support system

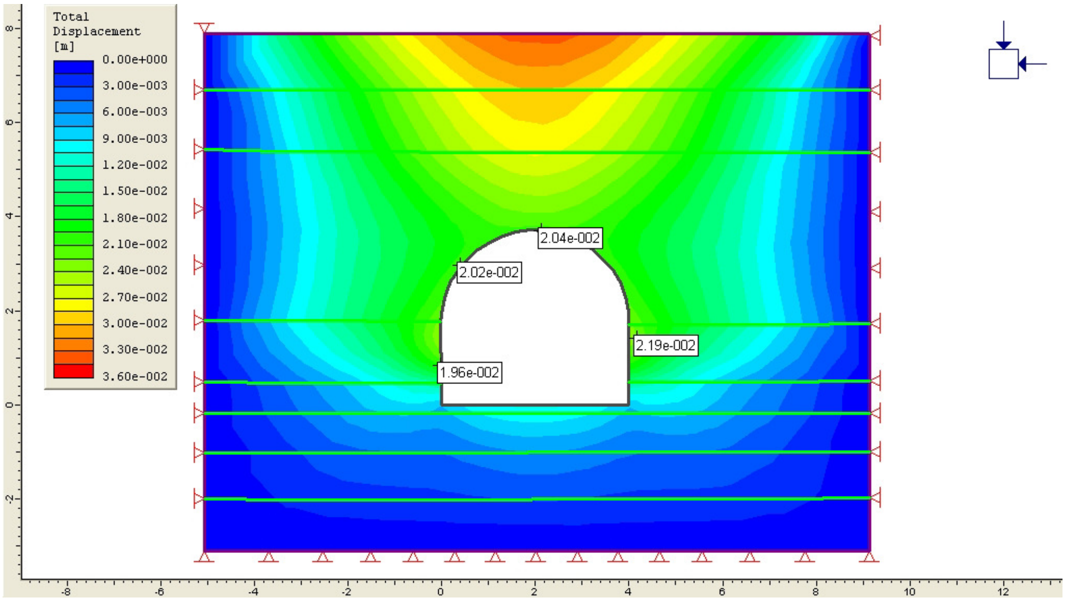

Figure 3 – Total displacement around the Parvade 1 tunnel before using the support system

Suggesting the support system

Commonly, support systems in coal mines in Iran use a steel arch; therefore, we designed suitable support systems with this in mind. To achieve this goal, the pressure that steel arches apply to the walls and the roof of the tunnel was calculated (Table 2).

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 $p_{i\,max}$ (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	305	97	1	$p_{i\,max} = 19.9D^{-1.23}/s$
	203	203	67	2	$p_{i\,max} = 13.2D^{-1.3}/s$
	150	150	32	3	$p_{i\,max} = 7.0D^{-1.4}/s$
					$\varepsilon_{max\,av} = 0.30\%$
I section rib	203	254	82	4	$p_{i\,max} = 17.6D^{-1.29}/s$
	152	203	52	5	$p_{i\,max} = 11.1D^{-1.33}/s$
					$\varepsilon_{max\,av} = 0.26\%$
TH section rib	171	138	38	6	$p_{i\,max} = 15.5D^{-1.24}/s$
	124	108	21	7	$p_{i\,max} = 8.8D^{-1.27}/s$
					$\varepsilon_{max\,av} = 0.55\%$
3 bar lattice girder	220	190	19	8	$p_{i\,max} = 8.6D^{-1.03}/s$
	140	130	18		$\varepsilon_{max\,av} = 1.35\%$
4 bar lattice girder	220	280	29	9	$p_{i\,max} = 18.3D^{-1.02}/s$
	140	200	26		$\varepsilon_{max\,av} = 1.30\%$
Grouted rockbolts or cables spaced on a s x s metre grid. Maximum average strain is approximately 0.2%, excluding setting strain for faceplates and anchors and fibre-glass rods and cables.	34 mm rockbolt			10	$p_{i\,max} = 0.354/s^2$
	25 mm rockbolt			11	$p_{i\,max} = 0.267/s^2$
	19 mm rockbolt			12	$p_{i\,max} = 0.184/s^2$
	17 mm rockbolt			13	$p_{i\,max} = 0.10/s^2$
	SS39 Split set			14	$p_{i\,max} = 0.05/s^2$
	EXX Swellex			15	$p_{i\,max} = 0.11/s^2$
	20mm rebar			16	$p_{i\,max} = 0.17/s^2$
	22mm fibreglass			17	$p_{i\,max} = 0.26/s^2$
	Plain cable			18	$p_{i\,max} = 0.15/s^2$
	Birdcage cable			19	$p_{i\,max} = 0.30/s^2$
Support type	**Thickness - mm**	**Age - days**	**UCS - MPa**	**Curve number**	**Maximum support pressure $p_{i\,max}$ (MPa) for a tunnel of diameter D (metres)**
Shotcrete or concrete lining. Maximum average strain ($\varepsilon_{max\,av}$) is approximately 0.1%.	1m	28	35	20	$p_{i\,max} = 57.8D^{-0.92}$
	300	28	35	21	$p_{i\,max} = 19.1D^{-0.92}$
	150	28	35	22	$p_{i\,max} = 10.6D^{-0.97}$
	100	28	35	23	$p_{i\,max} = 7.3D^{-0.98}$
	50	28	35	24	$p_{i\,max} = 3.8D^{-0.99}$
	50	3	11	25	$p_{i\,max} = 1.1D^{-0.97}$
	50	0.5	6	26	$p_{i\,max} = 0.6D^{-1.0}$

In coal mines in Iran, steel arches of type TH section are often used. To find the suitable support system from Table 2, different types of TH section steel arches with different spacing are used. The support's pressure is input into the Phase2 software and the output shows that the TH section steel arch with curve number 6, a weight of 38 kg and a spacing of 1 m is the suitable support system for this tunnel. Figures 4 and 5 show that using the TH section steel arch with curve number 6 (which applies 2.8 MPa pressure to the walls and the roof of the tunnel), means that the safety factor around the tunnel is a suitable and safe value and that the displacement around the tunnel is low compared to before using the support system (Figures 2 and 3).

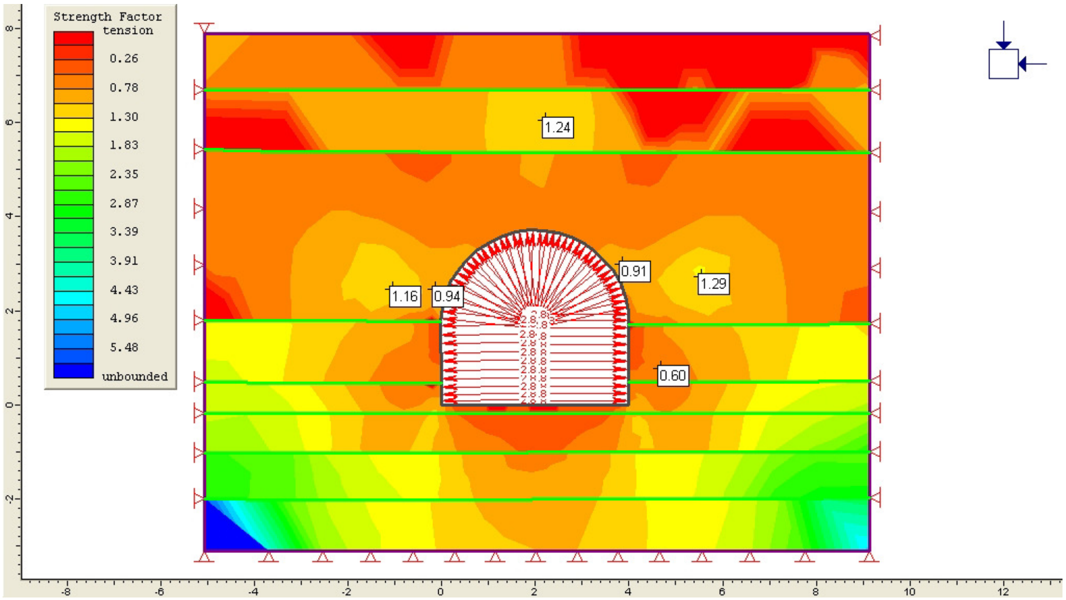

Figure 4 – Safety factor around the Parvade 1 tunnel, after using support system

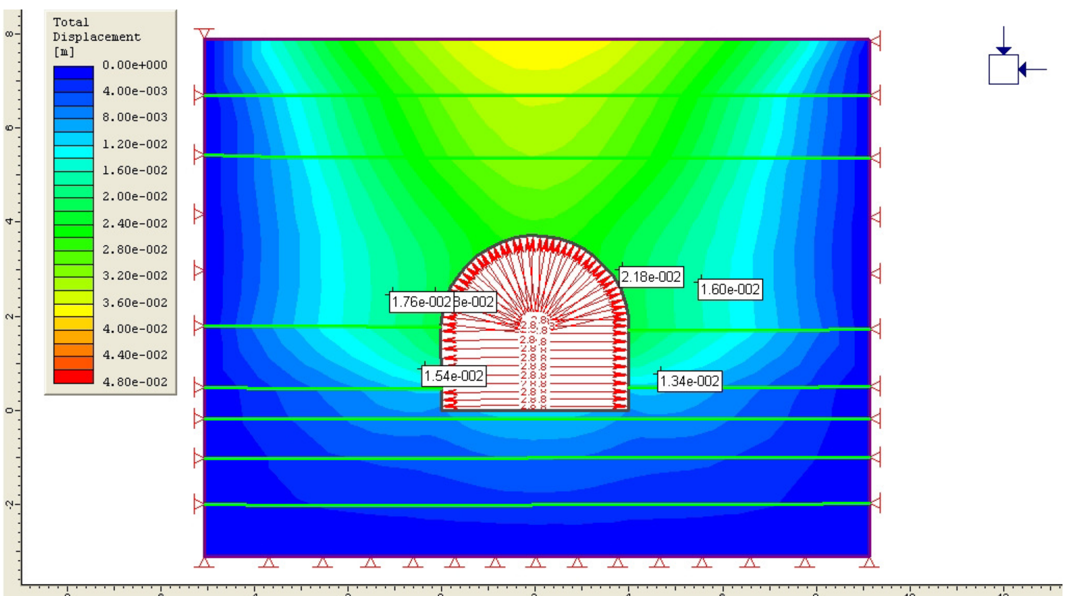

Figure 5 – Total displacement around the Parvade 1 tunnel after using support system

CONCLUSIONS

This research recommends a support system for a mining tunnel roadway in the E1 longwall panel in the Parvade 1 underground coal mine in Iran. The FEM was used to perform stability analysis and to suggest a support system. The tunnel was modeled with Phase2 software before imposing a support system. The software output showed that the safety factor was low and total displacement around the tunnel was high; therefore, the tunnel needed a support system. After finding the pressure that the support system applies to the tunnel, the software indicated that TH section steel arch with curve number 6 and a spacing of 1m is the suitable support system. With this type of support system, the safety factor is within an acceptable range and the total displacement is lower than prior to using a support system.

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