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Research on the stability of deep tunnels in bedding and joint rocks driven by top advance and bench method

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ABSTRACT

In the building process of large-sized underground constructions, especially underground constructions with big height, using top advance and bench method has many advantages in tunnelling. In the paper, analytical solutions are achieved for circular tunnels, which are driven in full face and ignored the characters of bedding and joint networks rocks. This paper introduces assessment the stability of large-sized tunnels driven by top advance and bench in bedding and joint networks rocks.

1. Introduction

Nowadays, excavation of deep tunnels for mining is increasing not only much more in Viet Nam but also in other countries. Further, excavating and building tunnels, hydroelectric power cave, and big volumes (Tran Tuan Minh et al, 2010, 2012; А.Н. Панкратенко, 2002; Б.А. Картозия etal, 2002) by using multiply phases are selected for improving the stability of rock mass around tunnels. On the other hand, this method will raise speed building tunnels in the detailed conditions. However, analytical solution method is not interested in problems consisting of parameters of joints in rock mass. Closed solution methods usually are solved by using the theory of elastic and isotropic rock (Károly Széchy, 1970; Dimitrios Kolymbas, 2005; Н.С. Булычев, 1994; И.В. Баклашов et al).

In the field of underground designations, solving the stability of deep tunnels with consideration to changes of structures of rock mass is more interesting (Tran Tuan Minh et al, 2010). This paper introduces the analysis of stability of deep tunnels by using top advance and bench excavation in bedding and joint networks rocks via numerical method by PHASE 2 software.

2. Verification between PHASE 2 software and analytical solutions

The verification problems are compared to the corresponding closed solutions. For examples, a short statement of the problem is given by the presentation of the analytical solution and a description of the PHASE 2's model. Some typical output plots to demonstrate the field values are presented along with a discussion of the results. Finally, plots of stresses and displacement are included.

This problem provides a verification of stresses and displacements for the case of a cylindrical hole in an infinite elastic medium subjected to a constant in - situ stress field of as

$P_0 = 30$ MPa

The material is isotropic and elastic, with the following properties:

Young's modulus E = 67778 Mpa;

Poisson's ratio v = 0,21.

The radius of hole is 1 m and is assumed to be small compared to the length of the cylinder. Therefore, 2D plane strain conditions are in effect.

2.1. In case of analytical solution

The classical Kirch’s solution can be used to find the radial and tangential displacement fields and stress distributions, for a cylindrical hole in an infinite isotropic elastic medium under plane strain conditions.

The stresses σ_r, σ_θ and $\tau_{r\theta}$ for a point at polar coordinate (r,θ) near the cylindrical opening with radius in Figure 1 can be written as

$$\sigma_r = \frac{p_1+p_2}{2}\left(1-\frac{a^2}{r^2}\right)+\frac{p_1-p_2}{2}\left(1-\frac{4a^2}{r^2}+\frac{3a^4}{r^4}\right)\cos 2\theta$$

$$\sigma_\theta = \frac{p_1+p_2}{2}\left(1+\frac{a^2}{r^2}\right)-\frac{p_1-p_2}{2}\left(1+\frac{3a^4}{r^4}\right)\cos 2\theta$$

$$\tau_{r\theta} = -\frac{p_1-p_2}{2}\left(1+\frac{2a^2}{r^2}-\frac{3a^4}{r^4}\right)\sin 2\theta$$

The radial and tangential displacement, assuming conditions of plane strain, are given by equations as

$$u_{\tilde{n}} = \frac{p_1+p_2}{4G}\frac{a^2}{r}+\frac{p_1-p_2}{4G}\frac{a^2}{r}\left[4(1-v)-\frac{a^2}{r}\right]\cos 2\theta$$

$$u_\theta = -\frac{p_1-p_2}{4G}\frac{a^2}{r}\left[2(1-2v)+\frac{a^2}{r}\right]\sin 2\theta$$

where G is the shear modulus and v is the Poisson ratio.

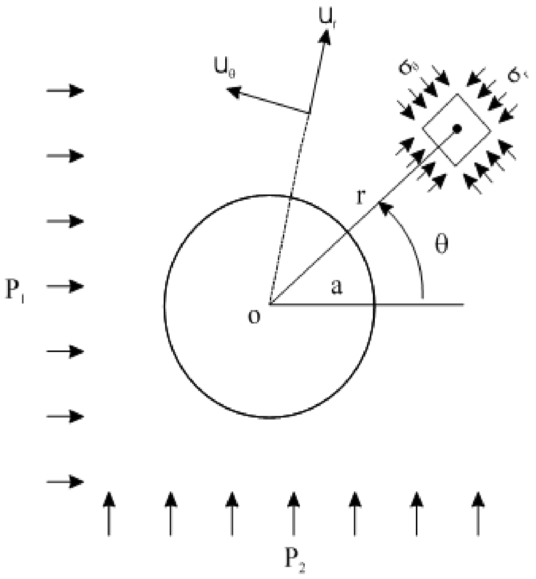


Figure 1. Cylindrical hole in an infinite elastic medium

2.2. PHASE 2’s model

The Phase 2 model for this problem is shown in Figure 2. It consists of:

a - Radial mesh

40 - Segments around the circular opening

8 - Nodded quadrilateral finite elements

Fixed external boundary, located 21m from the centre of hole that is 10 diameters from the hole boundary.

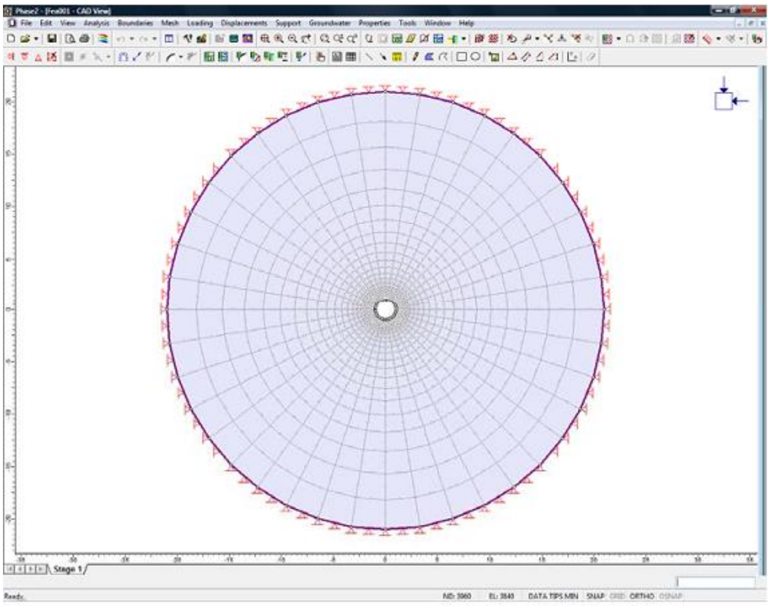


Figure 2. Model for Phase 2 analysis of a cylindrical hole in an infinite elastic medium

2.3. Discussion about results for two cases

Figures 3 and 4 show the radial and tangential stress as well as the radial displacement along a line (either the X - or Y - axis) through the center of model. The Phase 2 results are in very close agreement with the analytical solutions. A summary of the error analysis is given in Table 1.

Table 1. Error (%) analysis for the hole in elastic medium

	Average	Maximum	Hole boundary
u_r	2,32	5,35	1,10
σ_r	0,62	2,50	---
σ_θ	0,41	1,42	0,43

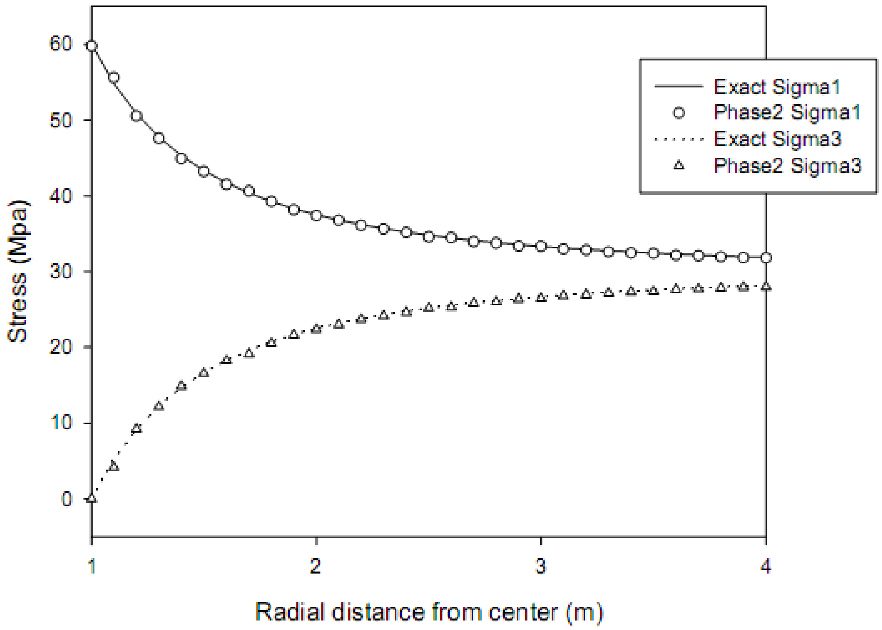


Figure 3. Comparison of σ_r and σ_θ for the cylindrical hole in an infinite elastic medium

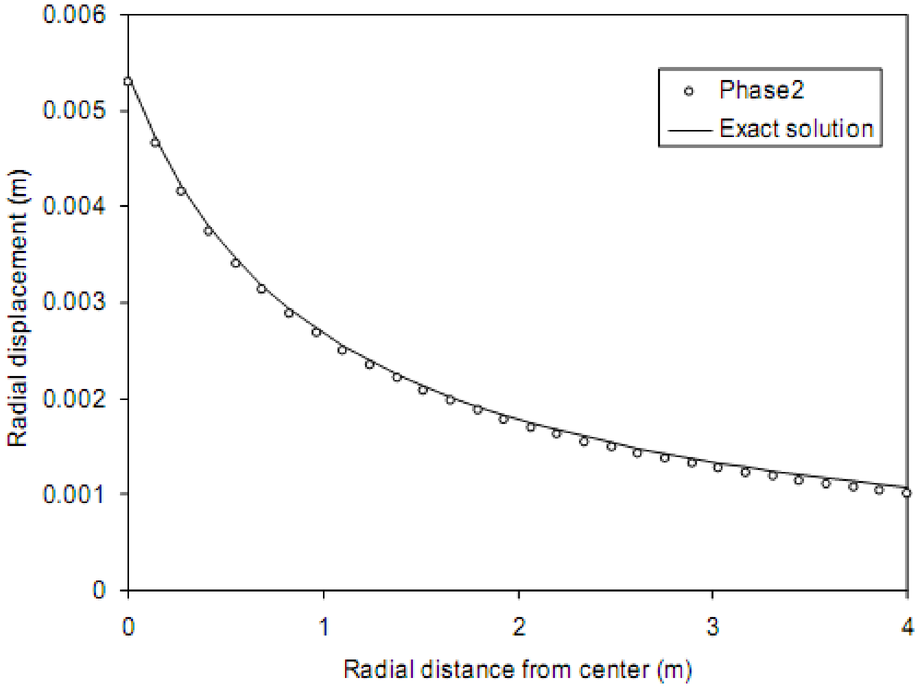


Figure 4. Comparison of u_r for the cylindrical hole in an infinite elastic medium

3. PHASE 2's model for case study

The problem assumption in this case consists of tunnel with arc crown and vertical wall. The height of tunnel 10m, span of tunnel 10m and excavated in joint rocks. The depth of tunnel 100m compared with surface. Properties of rock mass can be seen in Table 2, and characterizes of joint networks can be assembled in Tables 3 and 4. Theoretical model can be seen in Figure 5, and by PHASE 2 software. Simulation model for this case is shown in Figure 6.

Table 2. Characteristics of rock mass for analysis

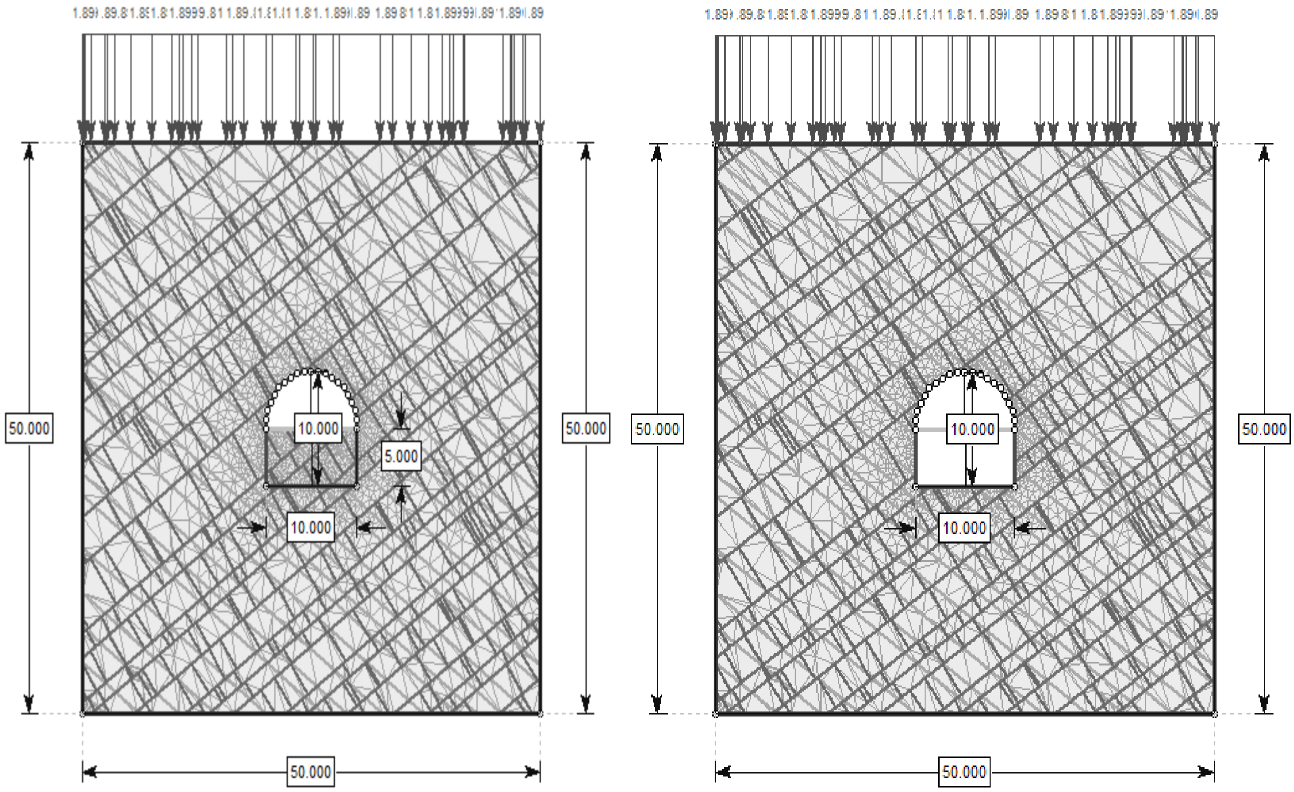
N^0	Parameters	Symbol	Values	Units
1	Unit weight	γ	0,027	MN/m^3
2	Strength of tension	σ_k	0	MPa
3	Cohesion	c	0,3	MPa
4	Friction angle	φ	40	Degree
5	Module elastic E	E	20000	MPa
6	Coefficient Poisson	μ	0,25	-
7	Expansion angle	ψ	0	Degree
8	Depth of tunnel	H	100	m

Table 3. Mechanical properties of joints

N^0	Parameters	Values and units		
		Joint 1	Joint 2	Joint 3
1	Standard of rock mass: Mohr - Coulomb	-	-	-
2	Strength of tension	0	0	0
3	Cohesion	0	0	0
4	Friction angle	20	25	27
5	Normal stiffness	100000	250000	250000
6	Shear stiffness	10000	10000	100000

Table 4. Parameters of joint networks

Parameters	Values
Joint networks 1	
Joint model Joint properties	Parallel statistical Joint 1
Inclination of joints	-36^0
Spacing of joints Distribution of joints Standard derivation of joints	2m Normal 1m
Joint networks 2	
Joint model Joint properties	Cross jointed Joint 2, joint 3
Orientation of joints Bedding inclination of joints Cross joint inclination	 35^0 -35^0
Mean bedding spacing of joints Distribution of joints Standard derivation of joints	3m Normal 1m
Mean cross joint spacing Distribution of joints Standard derivation of joints	2m Normal 2m



a) The first excavated stage b) The second excavated stage

Figure 5. Theoretical model for problem

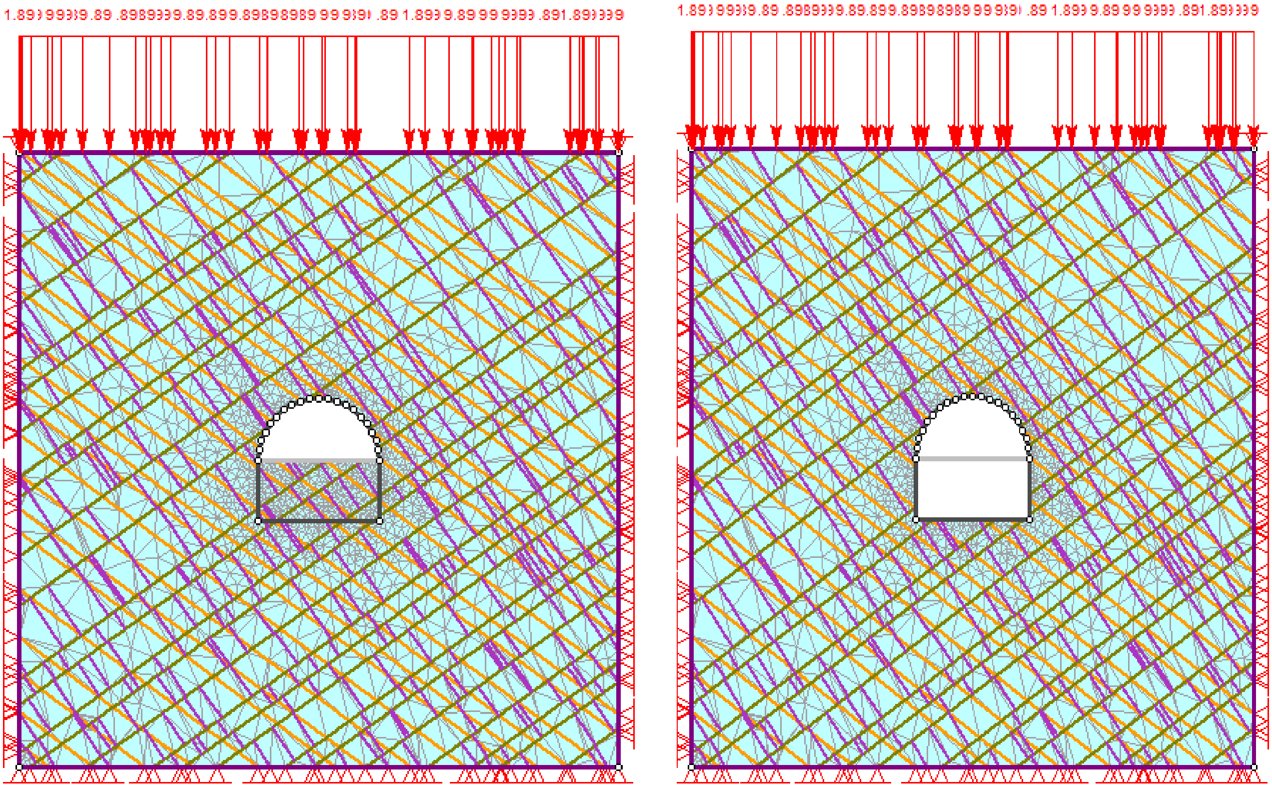
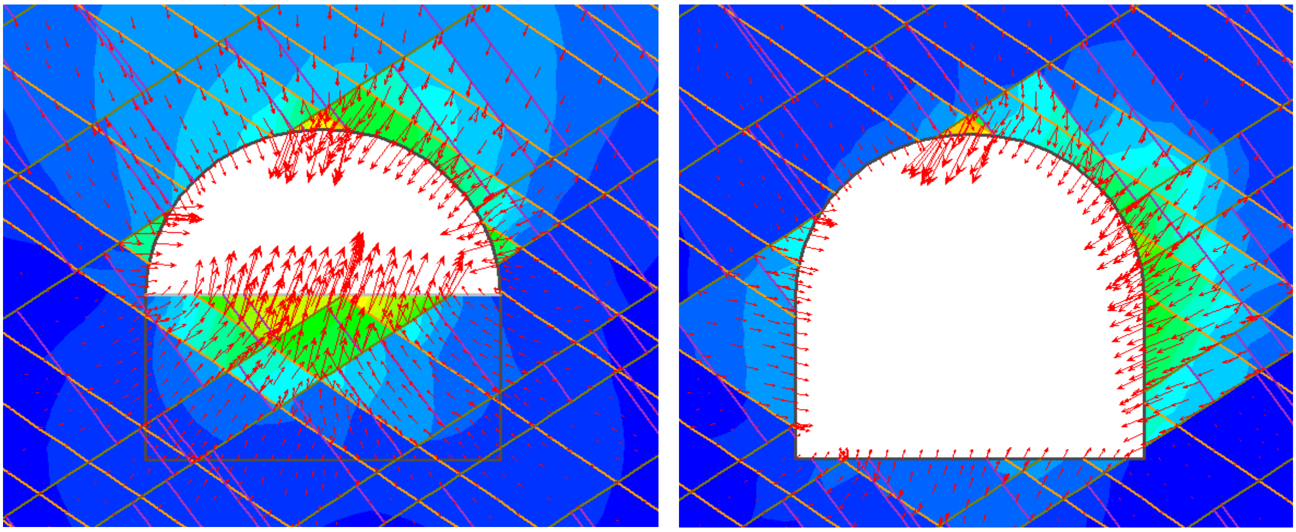
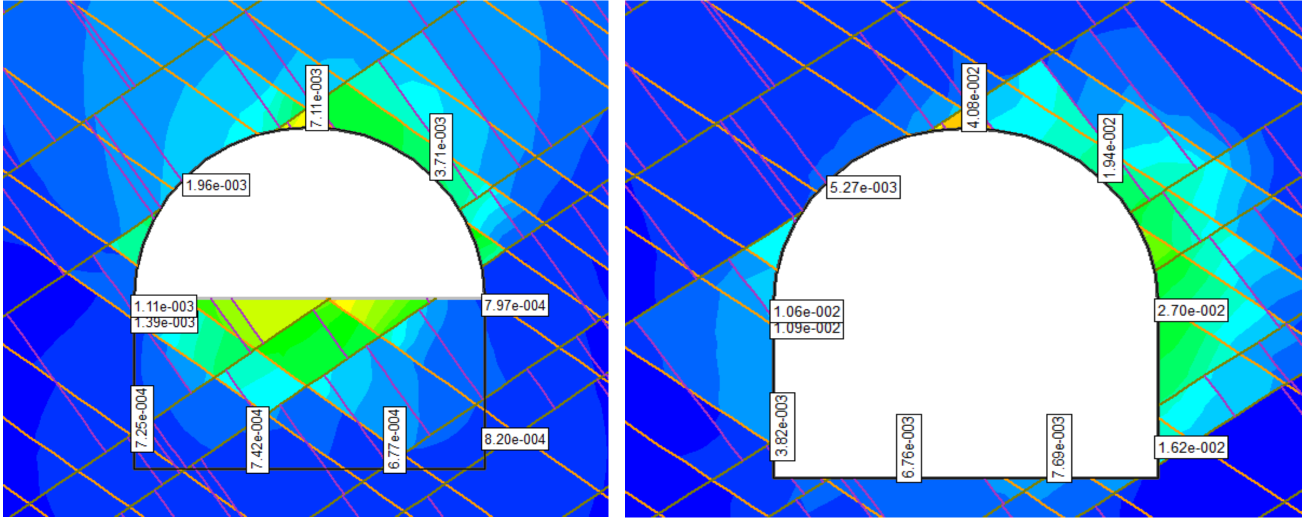


Figure 6. Simulation for deep tunnel driven by top advance
and bench excavation in joint rocks by PHASE 2



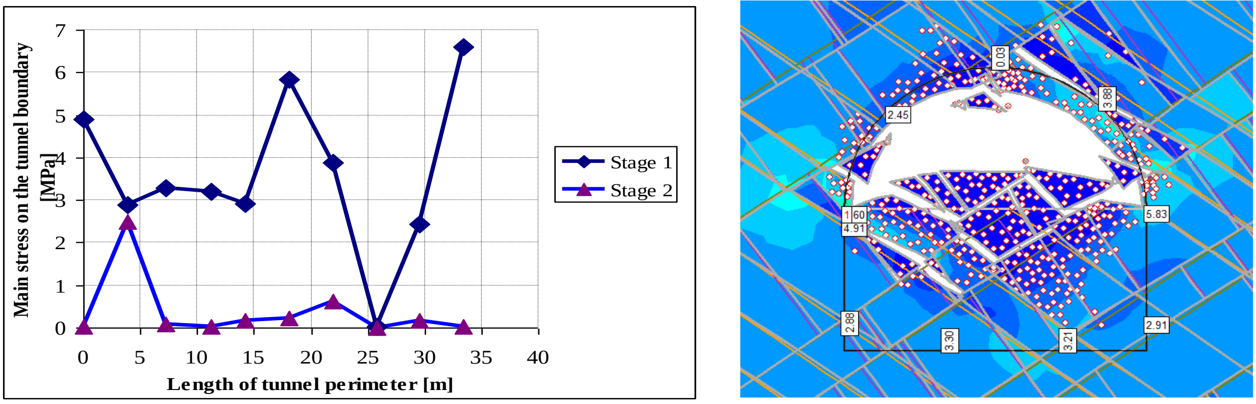
a) Around top advance b) Full face

Figure 7. Displacement vector of rock mass on the tunnel boundary with excavated stages

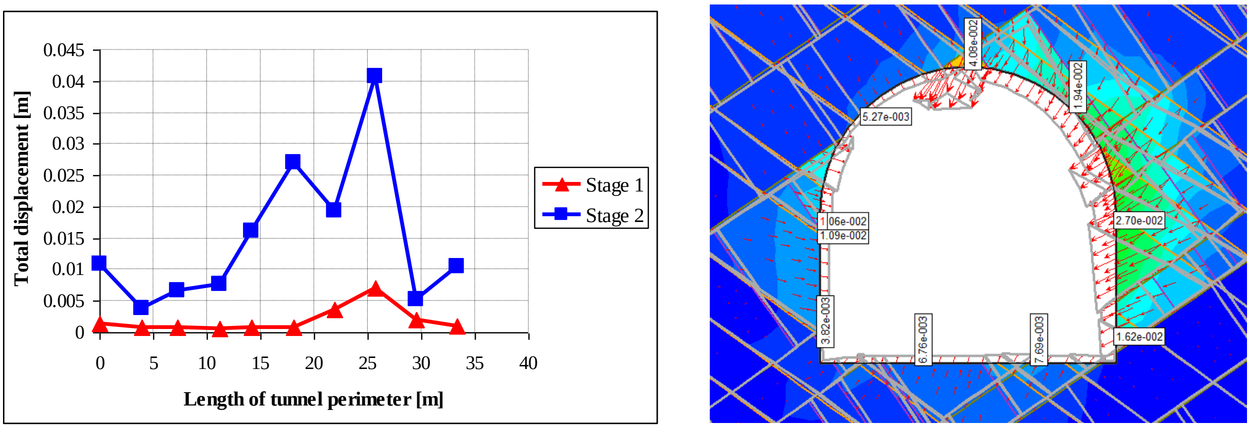


a) Around top advance *b) Full face*

Figure 8. The distribution of total displacement of rock mass (a) and failure zone (b) around tunnel after analysis by PHASE 2



Stage 1 - excavation top advance; Stage 2 - to full face;
Coordinate indicates for point the right corner of tunnel
Figure 9. The relationship between main stress on the tunnel boundary and excavation stages (left) and failure elements (right)



Stage 1 - excavation top advance; Stage 2 - to full face;
Coordinate indicates for point the right corner of tunnel
Figure 10. The relationship between total displacements on the tunnel boundary and excavation stages (left) and movement of rock wedge around tunnel (right)

From the results in PHASE 2 software, the relationship of displacement vectors of rock mass is achieved around tunnel in other excavated stages in Figures 7a and 7b.

By analysis, we also can remain the values of displacement of rock mass on the tunnel boundary and failure zone of rock around tunnels, the results in this case are shown in Figures 8a and 8b.

Through results via numerical method in PHASE 2 software. One can establish the relationship between the values of stress and displacement on the boundary of tunnel with other excavated stages, as shown in Figures 9 and 10.

Results in Figures 9 and 10 indicate that the stress and displacement on the tunnel boundary are smaller due to the small section excavation with excavation of top advance. When expansion surface is working with full face (the second stage), the values of displacement and stress are increased. The values of these are not symmetry as same as in the elastic theory. This can be explained in this case that the rock mass around tunnel consists of joint networks. The maximum values of displacement are achieved at rock wedge in Figure 10 on the right.

4. Conclusion

By building model and above analysis, one concludes that excavation with stages has influence on alteration process of stress and displacement of rock mass around designation tunnels. In the detailed conditions by using top advance and benching method, when expansion of tunnels to full face (benching), the values of stress and deformation on the top of tunnel's crown are less changes (seeing diagram of stress and displacement on the tunnel's boundary in Figures 9 and 10). In fact, in case of installation of supports on the boundary of top advance, benching stage has no influence on the values of stresses and displacements on the boundary of crown. The results also show that top advance and benching method is more widely used in the field of construction tunnels with big height. On the other hand, this scheme also improves excavated speed when appropriated arrangement works in any cycle.

When driven tunnel in joint networks rock mass in above model, using spot bolt or other supports has many advantages on economies and avoid over supports and sections. However, in case of heaven joint networks of rock mass, shotcrete support can be used on the boundary of designation tunnels.

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