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Circular Tunnel Driven in an Elasto-Plastic Isotropic Rock Mass Subjected to Non-Uniform In-Situ Stresses

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by

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1. Introduction

Generally, the in-situ stresses in a rock mass are non-uniform and have different magnitudes in the vertical and horizontal directions. For cases when the in-situ stresses are uniform, one can refer to Simanjuntak (2016). This report presents the mechanical response of an elasto-plastic isotropic rock mass to circular excavation subjected to non-uniform in-situ stresses, based on numerical studies. There are two cases investigated depending on whether the in-situ vertical stress is greater than the in-situ horizontal, or not.

2. Objectives

The study objectives are to investigate the behaviour of an elasto-plastic isotropic rock mass to circular excavation subjected to non-uniform in-situ stresses, and to verify the numerical results with the reference results.

3. Non-Uniform In-Situ Stresses

The in-situ horizontal stress, σ_h, can be expressed in the product of the corresponding vertical in-situ stress, σ_v, and a coefficient of earth pressure at rest, k. The mean in-situ stress in the rock mass is calculated using the following expressions (Carranza-Torres and Fairhurst, 2000):

$$\sigma_o = \frac{\sigma_h + \sigma_v}{2} = \frac{k\sigma_v + \sigma_v}{2} = \frac{(k+1)\ \sigma_v}{2} \tag{1}$$

in which: $k < 1$ if the in-situ vertical stress is greater than the in-situ horizontal stress.
$k > 1$ if the in-situ horizontal stress is greater than the in-situ vertical stress.

In cases of elasto-plastic isotropic rock masses whose in-situ stresses are non-uniform, the radial deformations at the tunnel walls, u_r, can be expressed in dimensionless form (Anagnostou and Kovari, 1993; Schürch and Anagnostou, 2012) as:

$$\frac{E_r\, u_r}{\sigma_o\, R} = f\left(\frac{\sigma_{ci}}{\sigma_o}, k, \nu, m_b, s, \psi\right) \tag{2}$$

where E_r is the rock mass modulus, R is the radius of excavation, σ_o and σ_{ci} are respectively the mean in-situ stress and the uniaxial compressive strength of the intact rock, k is the in-situ stress ratio, m_b and s are parameter constants that depend on the structure and surface conditions of the joints in the rock mass, ν is the Poisson's ratio and ψ is the dilation angle.

4. Numerical Results

The tunnel being considered is straight, long and has circular geometry. Therefore, the plane strain conditions are applicable along the tunnel axis. The radius of excavation, R, is 2 m and it is assumed that the excavation process results in minimal disturbance. The data are adopted from Amberg (1997), and are listed in Table 1.

Table 1. Rock Mass Data (Amberg, 1997)

GSI	σ_{ci} (MPa)	m_i	m_b	s	ψ (°)	E_r (GPa)	ν_r	σ_o (MPa)
65	75	17	4.87	0.02	0	20.5	0.25	40

Case A – The In-Situ Vertical Stress is Greater Than The Horizontal

In this case, the in-situ stress ratio, *k*, was taken as 0.80 meaning that the in-situ vertical stress is 44.44 MPa, whereas the in-situ horizontal stress is 35.56 MPa. The numerical results of radial deformations and radial stresses are shown in Fig. 1. While Fig. 1a depicts the excavation-induced radial deformations, Fig. 1b shows the excavation-induced radial stresses.

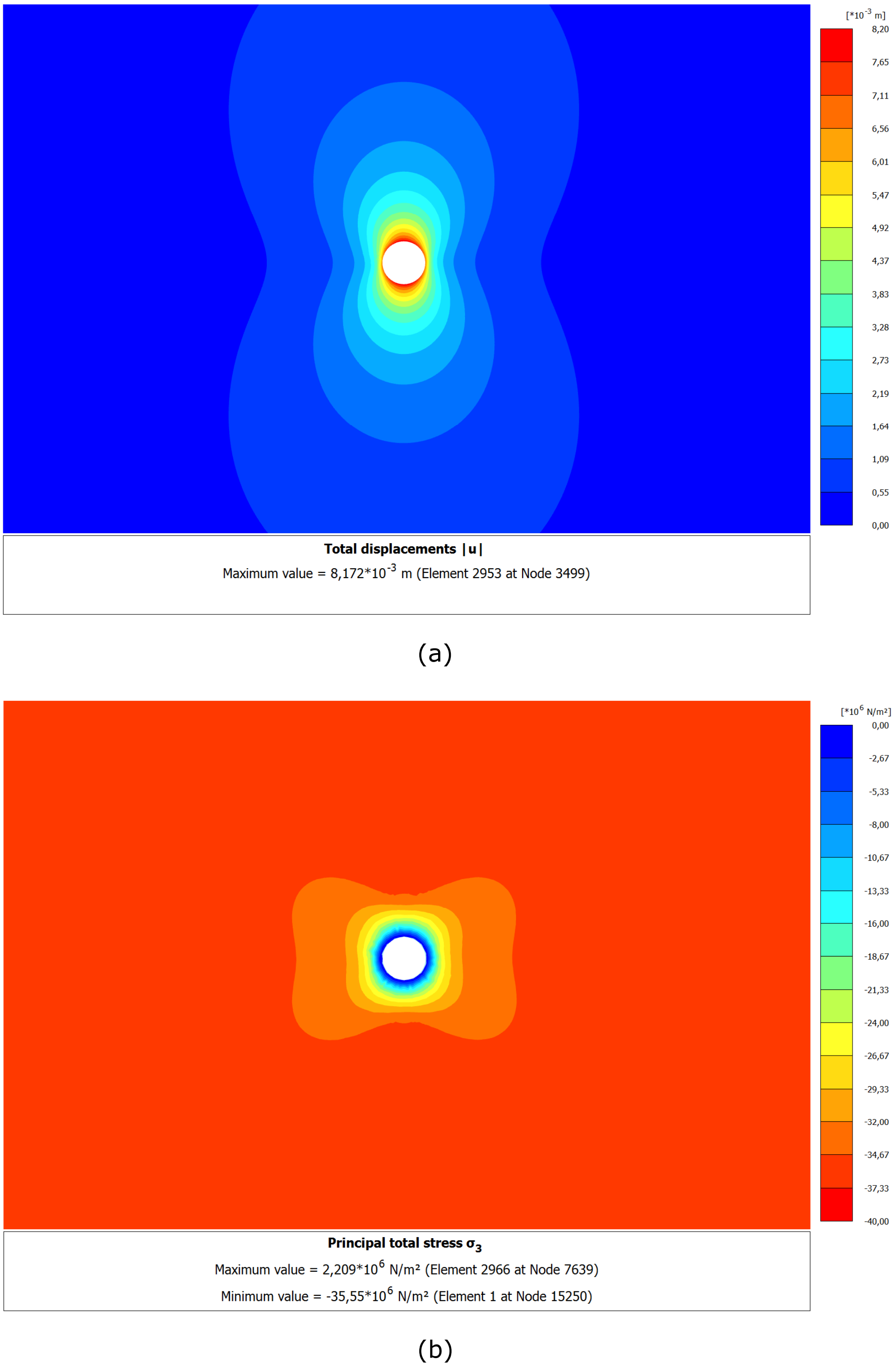
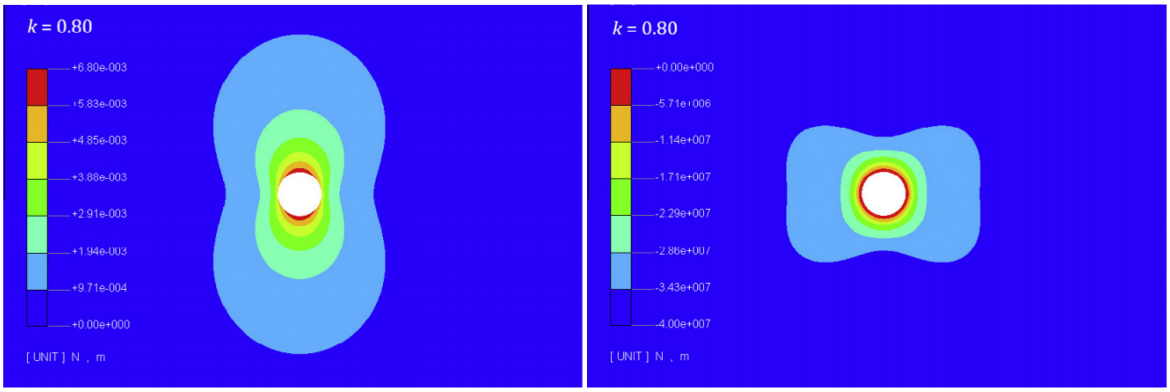


Fig. 1. Distribution of (a) Radial Deformations and (b) Radial Stresses for *k* = 0.80

From Fig. 1a, it is seen that the radial deformation at the tunnel sidewalls was found as 6.7 mm or corresponds to the radial convergence $u_r/2R$ of 0.17%, whereas at the tunnel roof and invert it was 8.2 mm or is equal to the radial convergence of 0.20%. Since the tunnel is unsupported, the radial stress along the tunnel perimeter is zero. For verification, the reference results are presented in Fig. 2. The comparison of results are summarised in Table 2.



(a) (b)

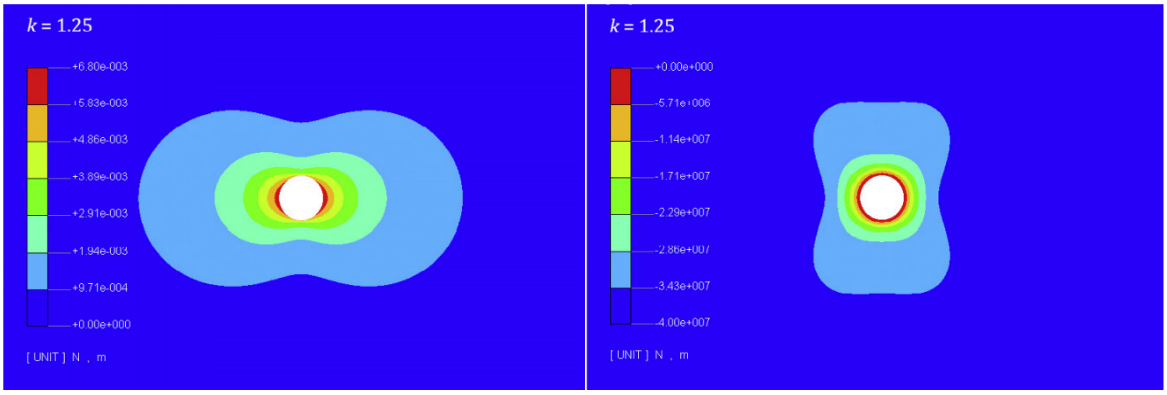
Fig. 2. Reference Results: (a) Radial Deformations and (b) Radial Stresses for k = 0,80

Table 2. Comparison of Results for k = 0,80

k = 0,80	$u_r/2R$ (%)		σ_r/σ_{ci} (%)	
	Roof/Invert	Sidewalls	Roof/Invert	Sidewalls
Simanjuntak et al. (2014)	0.17	0.12	0	0
PLAXIS	0.20	0.17	0	0

Case B – The In-Situ Horizontal Stress is Greater Than The Vertical

In this case, the in-situ stress ratio, k, was taken as 1.25, which means that the in-situ vertical stress is 35.56 MPa, while the in-situ horizontal stress is 44.44 MPa. Analogously, the reference results are depicted in Fig. 3 and the numerical results using PLAXIS are illustrated in Fig. 4.

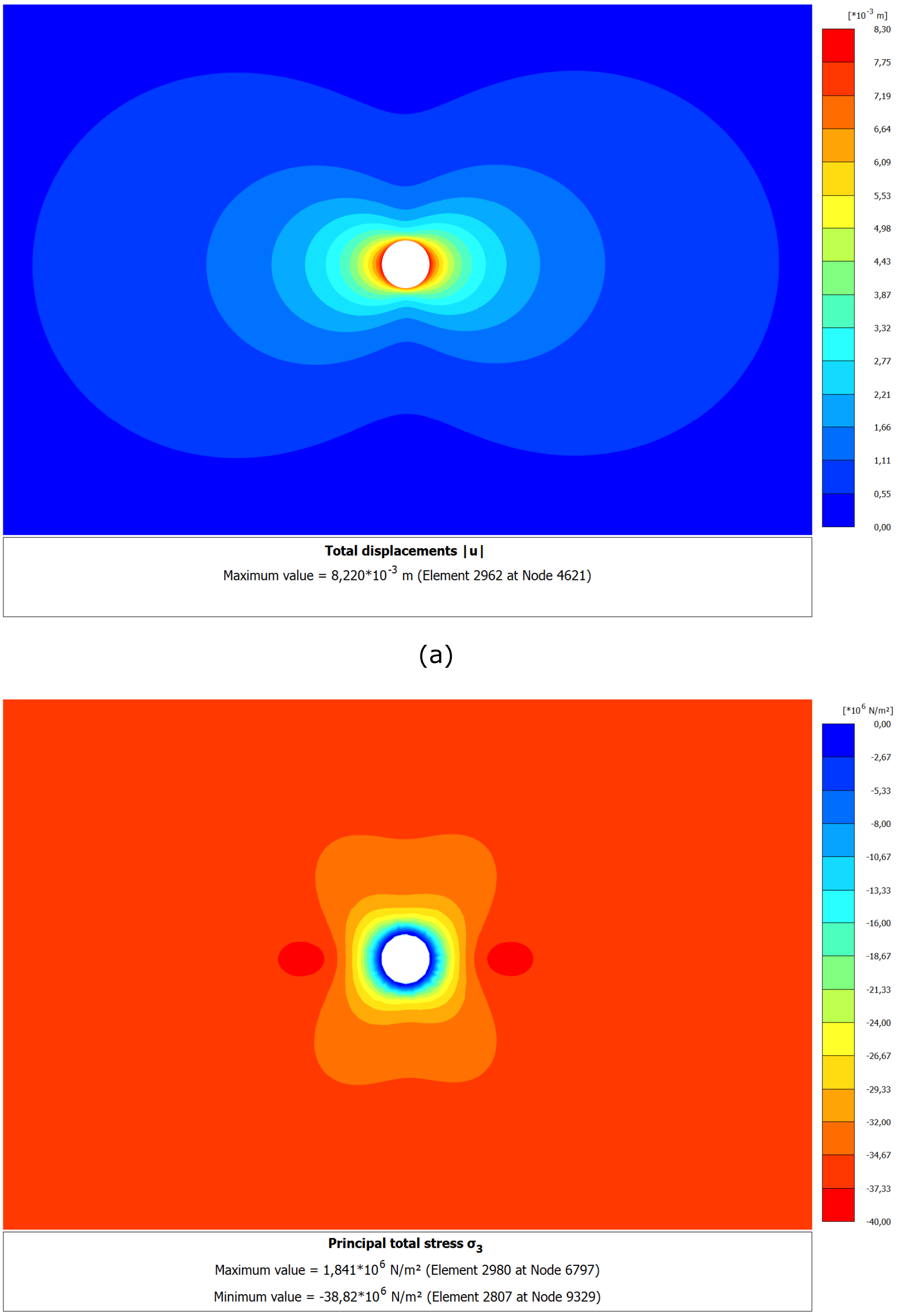


(a) (b)

Fig. 3. Reference Results: (a) Radial Deformations and (b) Radial Stresses for k = 1.25

Table 3. Comparison of Results for k = 1,25

k = 1,25	$u_r/2R$ (%)		σ_r/σ_{ci} (%)	
	Roof/Invert	Sidewalls	Roof/Invert	Sidewalls
Simanjuntak et al. (2014)	0.12	0.17	0	0
PLAXIS	0.17	0.20	0	0



(a)

(b)

Fig. 4. Distribution of (a) Radial Deformations and (b) Radial Stresses for *k* = 1.25

Fig. 4a suggests that the radial displacement at the tunnel sidewalls is 8.2 mm or corresponds to the radial convergence $u_r/2R$ of 0.20%, while at the tunnel roof and invert it was 6.7 mm or it is equivalent to the radial convergence of 0.17%. The comparison between the numerical using PLAXIS and reference results are presented in Table 3 and it can be seen that the results using PLAXIS are comparable with the reference results.

5. Concluding Remarks

This report presents the mechanical response of an elasto-plastic isotropic rock mass to circular excavation subjected to non-uniform in-situ stresses. Two cases are studied based on whether the in-situ vertical stress is greater than the horizontal or the in-situ horizontal stress is greater than the vertical.

This study suggests that the distribution of excavation-induced radial deformations and radial stresses for a specific value of *k* of the horizontal-to-vertical stress coefficient is identical to that of 1/*k* by rotating the tunnel axis by 90°. This corresponds to those that have been investigated by Carranza-Torres and Fairhurst (2000) and Simanjuntak et al. (2014).

6. References

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