Journal of Novel Applied Sciences
Available online at www.jnasci.org
©2015 JNAS Journal-2015-4-4/453-456
ISSN 2322-5149 ©2015 JNAS

The effect of arch radius in vaulted tunnels on the stability parameters

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ABSTRACT: This paper presents numerical analysis of tunnel arch by means of elasto-plastic finite element method. The modeling always implies simplification, and it is necessary to select from all the geological data those which are meaningful for the design of the structure. In numerical analysis, a 2D finite element program with software Phase2 is utilized together with the convergence-confinement method. Models are generated with different upper arches for vaulted tunnels with widths of 4, 6, 8 and 10 meters that excavated in shale rocks. The results of the evaluations show that the arch radius of tunnels plays an important role in the stability of tunnels and the optimal arch radius in vaulted tunnels is twice the width of tunnel.

***Keywords*:** Radius of tunnel arch; Vaulted tunnels; Surface settlement; Yielded elements.

INTRODUCTION

During the construction of the tunnel, many failures happened as a result of the instability in the surrounding rock mass. All of these problems will generate considerations on the safety of the tunnel engineering (Wang and Xie, 2008). Tunnelling is associated with ground movements such as surface settlement and face stability. Prediction of ground settlement is considered as highly significant in the design of tunnels. The empirical equations have been developed for the settlement profile. They provide very good results when tunnelling conditions are well known. The numerical methods such as the finite-element method could be used for predicting of settlement of ground surface.

Significant progresses in tunnelling technology decrease construction time with reduce in cost. But with new equipment, experience has shown (e.g., Attewell and Farmer, 1974) that subsidence take place in areas above to tunnels passing through soft rocks and soils. These deformations may basically affect nearby structures and should be considered.

Due to excavation of tunnels, yielding in around tunnels occurs because tangential stresses overcome to rocks strength. Therefore, the yielded elements have important role in the stability of tunnels. The size and shape of tunnels have an important role in number of yielded points in around tunnels. Select the appropriate shape for tunnels can reduce the number of yielded elements and increase the stability of tunnels.

This paper attempts to evaluate the effect of upper arch of tunnel in the surface settlement of ground, displacement of tunnel roof and yielded elements around vaulted tunnels.

Geomechanical properties of the rock masses

The rock mass properties such as the rock mass strength (σcm), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) are calculated by the Rock-Lab program defined by Hoek (2002). This program has been developed to provide a convenient means of solving and plotting the equations presented by Hoek (2002).

In Rock-Lab program, both the rock mass strength and deformation modulus are calculated using equations of Hoek , 2002, and the rock mass constants are estimated using equations of Geological Strength Index (GSI) (Hoek , 2002) together with the value of the shale material constant, mi (Table 1). Also, the value of disturbance factor (D) that depends on the amount of disturbance in the rock mass associated with the method of excavation, is considered equal to 0.2 for the rock masses, it means these rocks would be disturbed slightly during blasting.

Finally, the shear strength parameters of the rock mass (C and φ) for the rock masses are obtained using the relationship between the Hoek–Brown and Mohr–Coulomb criteria (Hoek and Brown, 1997) and are presented in Table 1.

Table 1. Geomechanical parameters of shale rock masses obtained by using Roclab software

Input and output of Roclab software						
Hoek-Brown classification				Hoek-Brown criterion		
Hoek Brown Classification				Hoek Brown Criterion		
σ_{ci}(Mpa)	GSI	m_i	D	mb	s	a
Intact Uniaxial compressive strength	Geological strength index	Constant Hoek-Brown criterion for intact rock	Disturbance Factor	Hoek-Brown criterion		
35	33	6	0.2	0.420	0.0003	0.518
Parameters of the Mohr - Coulomb equivalent		Rock Mass Parameters				
Mohr-Coulomb Fit		Rock Mass Parameters				
C (Mpa)	φ (degree)	σ_t (Mpa)	σ_c(Mpa)	σ_{cm}(Mpa)	E_{rm}(Mpa)	
Cohesion	Friction angle	Tensile strength	Uniaxial compressive strength	Golobal strength	Deformation modulus	
0.196	39.35	-0.029	0.561	2.777	526.71	

Numerical analysis of the upper arch tunnels

Numerical analyses of the upper arch of tunnels in the shale rock masses are done using a two-dimensional hybrid element model, called Phase2 Finite Element Program (Rocscience, 1999). This software is used to simulate the three-dimensional excavation of a tunnel. In three dimensions, the tunnel face provides support. As the tunnel face proceeds away from the area of interest, the support decreases until the stresses can be properly simulated with a two-dimensional plane strain assumption. In this finite element simulation, based on the elasto-plastic analysis, deformations and stresses are computed. These analyses used for evaluations of the tunnel stability in the rock masses. The geomechanical properties for these analyses are extracted from Table 1. The generalized Hoek and Brown failure criterion is used to identify elements undergoing yielding and the displacements of the rock masses in the tunnel surrounding.

To simulate the excavation of tunnels in the shale rock masses, a finite element models is generated with different upper arches for vaulted tunnels with widths of 4, 6, 8 and 10 meters. (for example Fig. 1) The outer model boundary is set at distances of 7 times the tunnel radius and six-nodded triangular elements are used in the finite element mesh.

Figure 1. The modeling of vaulted tunnels with width of 4 meters and different arch radius (A.R. is arch radius of tunnel to meter)

By run of models, the values of displacement in the roof of tunnel, the surface settlement of ground and the number of yielded elements is determined for each tunnel (for example Fig. 2) and the obtained results are shown in Figs. 3 to 5.

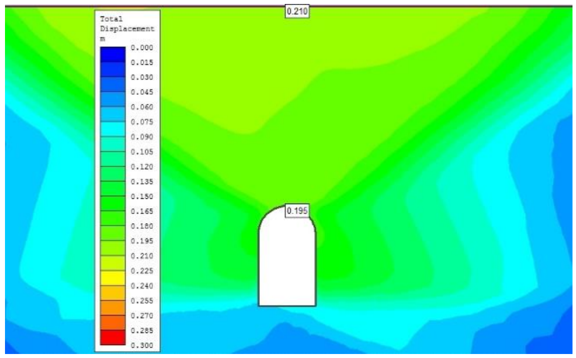

Figure 2. The values of displacement and surface settlement of ground in a vaulted tunnel with arch radius of 2 meters

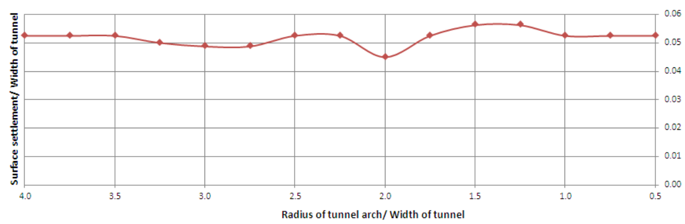

Figure 3. The normalized diagram shows ratios surface settlement of ground for different radius of tunnel arch

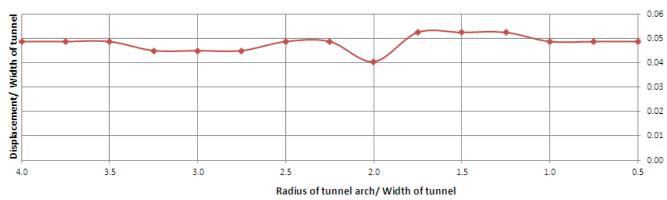

Figure 4. The normalized diagram shows ratios displacement of tunnel roof for different radius of tunnel arch

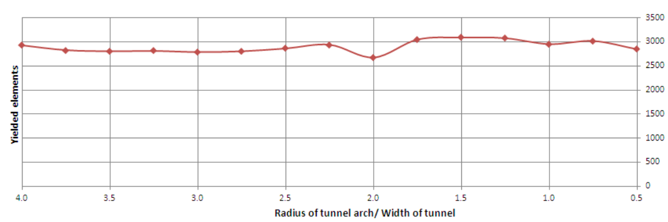

Figure 5. The normalized diagram shows number of yielded points around tunnels for different radius of tunnel arch

As the above diagrams show, in all tunnels, the optimal arch radius is twice the width of tunnel. The diagram in Fig. 3 shows that although the surface settlement of ground shows fluctuations, but the minimum of settlement is obtained when ratio of arch radius of tunnel to width of tunnel is equal to 2. The diagram in Fig. 4 shows that fluctuations of displacement in the tunnels roof are lower than surface settlement of ground in previous diagram, but in this case, the minimum of displacement is obtained when ratio of arch radius of tunnel to width of tunnel is equal to 2. The diagram in Fig. 5 also shows that the minimum of yielded elements around tunnels is obtained when ratio of arch radius of tunnel to width of tunnel is equal to 2. This suggests the relative stability of tunnels in this situation. Due to above mentioned we can conclude the following equation:

$$R_{opt} = 2W$$

where R_{opt} is the optimal arch radius and W is width of tunnel.

Results of this analysis show when using the optimal arch radius, the surface settlement, displacement of tunnel roof and yielded elements reduce 15, 19 and 8 percent, respectively.

CONCLUSION

This study provides an estimation of the effect of the upper arch of tunnels and could be used for modeling of vaulted tunnels. The following conclusions could be noted:

- In modeling of vaulted tunnels, the radius of tunnels arch plays an important role in the stability of tunnels.
- The optimal arch radius in vaulted tunnels is twice the width of tunnel.
- The surface settlement of ground, the displacement of tunnel roof and the yielded elements around tunnels reduce significantly when using the optimal arch radius.

REFERENCES

Attewell PB and Farmer IW. 1974. Ground deformations resulting from shield tunnelling in London Clay. Canadian Geotechnical Journal 11: 380-395.

Hoek E and Brown T. 1997. Practical estimates of rock mass strength. Int. J. Rock Mech. Min. Sci. 34 (8): 1165–1186.

Hoek E, Carranza-Torres C and Corkum B. 2002. Hoek–Brown Failure Criterion—2002 Edition. Rocscience.

Rocscience. 1999. A 2D finite element program for calculating stresses and estimating support around the underground excavations. Geomechanics Software and Research. Rocscience Inc., Toronto, Ontario, Canada.

Wang YQ and Xie YL. 2008. The development and research of the arch tunnel in China. Highway, 8: 216-219 (in Chinese).