International Journal of
Science and Engineering Investigations vol. 4, issue 40, May 2015
ISSN: 2251-8843

The Effect of GSI on the Stability Parameters in the Vaulted Tunnels

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Abstract- This paper presents numerical analysis of the effect of geological strength index (GSI) on the stability parameters by means of elasto-plastic finite element method. In numerical analysis, a 2D finite element program with software Phase2 is utilized. The vaulted tunnels are modeled with the height of 7 meters and widths of 4, 6, 8 and 10 meters, and the values of GSI is selected equal to 25, 33, 45, 55 and 65. The results of the evaluations show that by increasing GSI, the surface settlement, displacement and yielded elements around tunnels have decreased and the effect of radius of tunnel arch in the stability parameters has reduced. Furthermore, by increasing GSI, the ratio of optimal arch radius to width of tunnel has reduced.

Keywords- *Geological Strength Index (GSI); Vaulted tunnels; Stability parameters*

I. INTRODUCTION

In general, strain-softening is the effect of localization of deformation and is founded in the incremental theory of plasticity (Hill, 1950; Kaliszky, 1989), that was developed in order to model plastic deformation processes, in which a material is characterized by a failure criterion and a plastic potential. The strain-softening behaviour is characterized by a gradual transition from a peak failure criterion to a residual one and can be seen in rocks with geological strength index between 25 and 75 (25<GSI<75) (Alejano et al. 2009). Therefore, the quality of the rock mass is considered as the GSI and it was chosen to signify the rock mass quality in the proposed support pressure formula. By using GSI, it possible to estimate the support pressure for tunnels in various rock mass qualities. For support pressure estimation, the modified GSI has to be used for very poor or poor rock masses where the GSI<27 (Osgoui and Ünal, 2005).

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.

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

II. 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 et al. (2002). This program has been developed to provide a convenient means of solving and plotting the equations presented by Hoek et al. (2002).

In Rock-Lab program, both the rock mass strength and deformation modulus are calculated using equations of Hoek et al., 2002, and the rock mass constants are estimated using equations of Geological Strength Index (GSI) (Hoek et al., 2002) together with the value of the shale material constant, mi. 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). The geomechanical parameters of shale rock masses for different values of GSI is obtained and presented in Figs. 1 to 5.

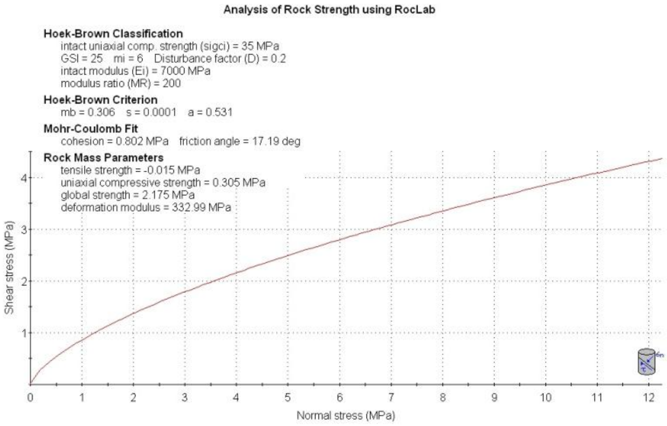

Fig.1. The geomechanical parameters of shale rock masses for GSI of 25

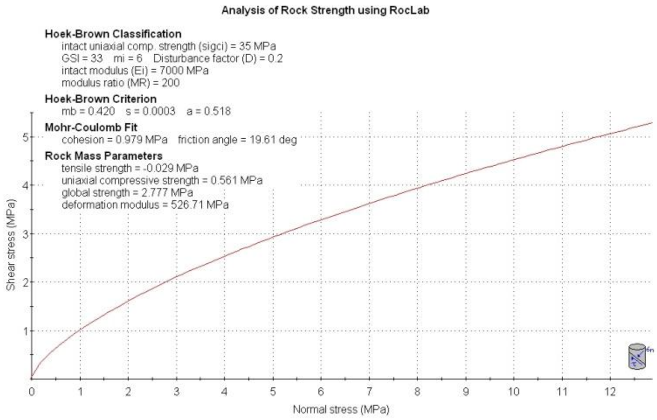

Fig.2. The geomechanical parameters of shale rock masses for GSI of 33

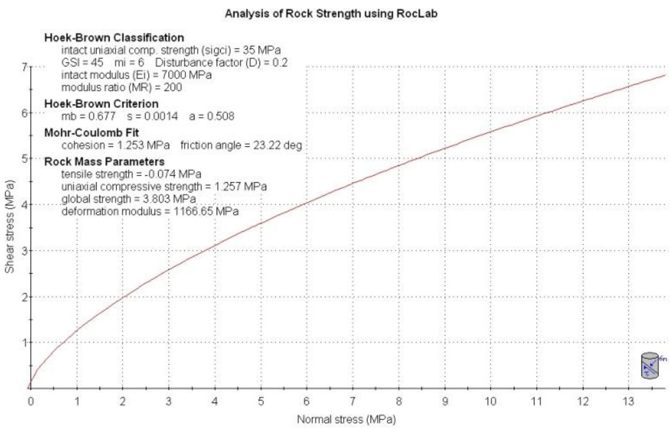

Fig.3. The geomechanical parameters of shale rock masses for GSI of 45

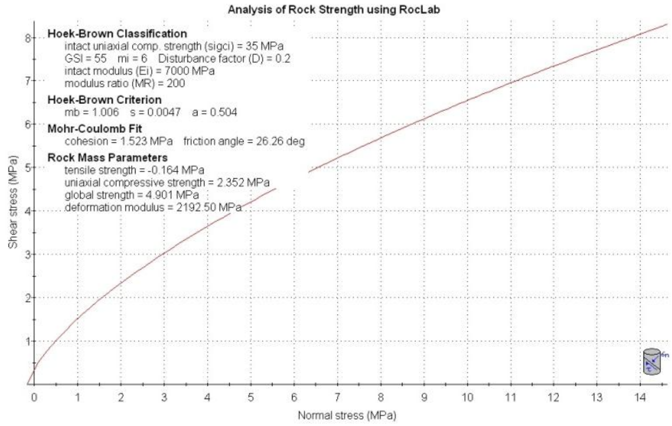

Fig.4. The geomechanical parameters of shale rock masses for GSI of 55

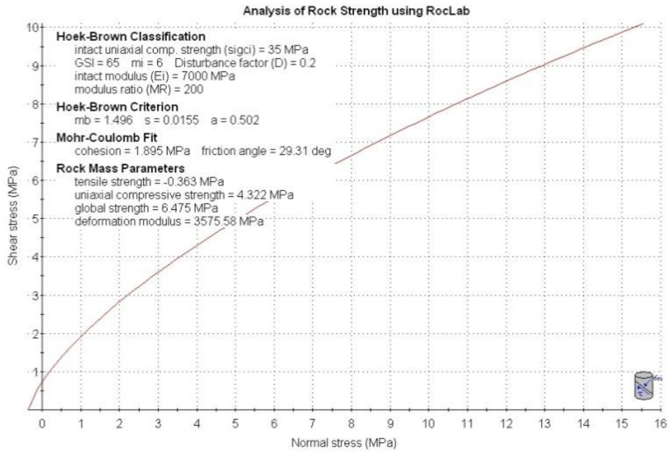

Fig.5. The geomechanical parameters of shale rock masses for GSI of 65

III. NUMERICAL ANALYSIS OF THE UPPER ARCH TUNNELS

Numerical analyses of the GSI in the vaulted tunnels 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 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 Figs. 1 to 5. 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 and the height of 7 meters (for example Fig. 6). 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.

Fig. 6. 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. 7) and the obtained results are shown in Figs. 8 to 10.

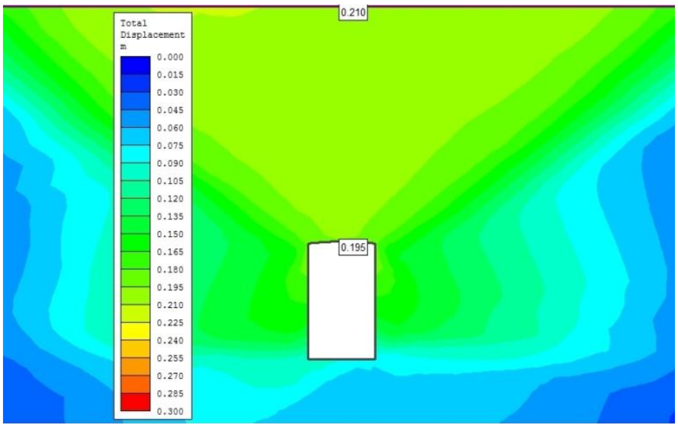

Fig. 7. The values of displacement and surface settlement of ground in a vaulted tunnel with arch radius of 16 meters and height of 7 meters and GSI of 33

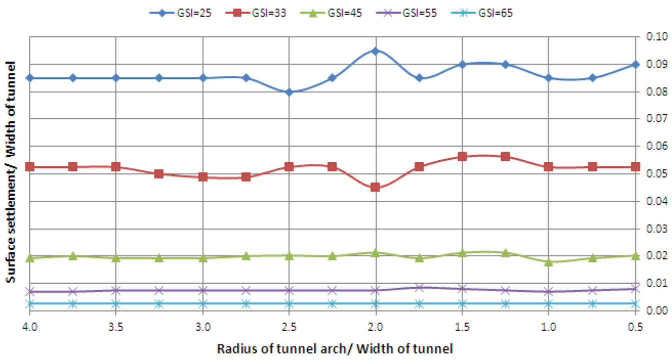

Fig. 8. The normalized diagram shows the effect of GSI in the surface settlement of ground for different radius of tunnel arch

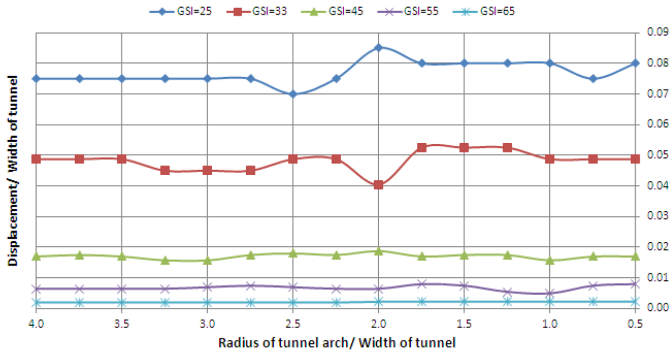

Fig. 9. The normalized diagram shows the effect of GSI in displacement of tunnel roof for different radius of tunnel arch

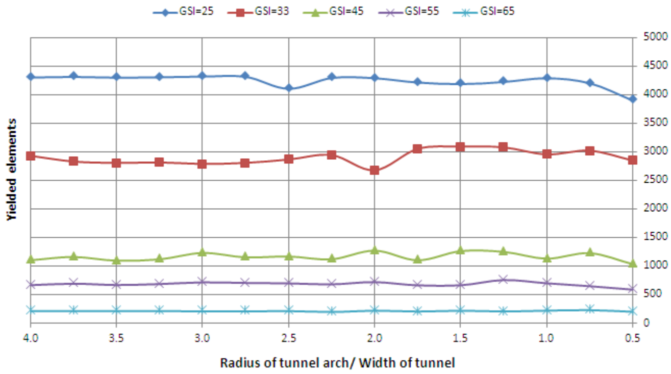

Fig. 10. The normalized diagram shows the effect of GSI in number of yielded points around tunnels for different radius of tunnel arch

As the above diagrams show, by increasing GSI, the surface settlement, displacement and yielded elements around tunnels have decreased and the effect of radius of tunnel arch in the stability parameters has reduced, so that in GSI of 65 the fluctuations of the stability parameters is completely gone. Furthermore, by increasing GSI, the ratio of optimal arch radius to width of tunnel has reduced. In GSI of 25, the optimal arch radius in tunnels is two and a half times the width of tunnel, while in GSI of 33, the optimal arch radius is twice the width of tunnel and in GSI of 45, the optimal arch radius is equal to the width of tunnel. In GSI of 55 and 65, the optimal arch radius is indeterminable.

IV. CONCLUSIONS

This study provides an estimation of the effect of GSI on the surface settlement of ground, the displacement and yielded elements around vaulted tunnels with different arch radius. The following conclusions could be noted:

- By increasing GSI, the surface settlement, displacement and yielded elements around tunnels have decreased.

- By increasing GSI, the effect of radius of tunnel arch in the stability parameters has reduced.

- By increasing GSI, the ratio of optimal arch radius to width of tunnel has reduced.

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