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Probabilistic stability analysis of crushed fault zone in the Zaker-Sorkhedizaj tunnel, NW Iran

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ABSTRACT: Stability analysis of tunnels is a geotechnical engineering problem characterized by many sources of uncertainty. Therefore, rock characteristics could not be defined by deterministic values and probabilistic methods would be as a suitable alternative. The Zaker-Sorkhedizaj tunnel in NW Iran is a road tunnel to cross the Western Alborz Mountain Range through 530 m in length with 11.2 m span and 8 m height. The final segment of tunnel is composed of porphyry andesites and a strike-slip fault with reverse component has caused the crushed zone with 20-25 m extent and 20 m cover. To use probabilistic analysis, the best fitted distributions to rock mass characteristics were first obtained. Using point estimate method (PEM) method we combine probabilistic input variables such as deformation modulus and intact uniaxial compressive strength, and evaluate the distribution of the output variables such as total displacement. The obtain results show that probabilistic approach, when it is possible to have sufficient data on the quality of the rock mass, leads to a better understanding of the project risks.

***Keywords*:** Probabilistic analysis; Zaker-Sorkhedizaj tunnel; Tunnel stability.

INTRODUCTION

In the analysis of tunnel stability, there are uncertainties that caused by different sources. Often the parameters required for stability analysis of tunnels are not well known. In these cases it is favorable to perform a parametric study where model behaviour is examined for a range of possible inputs. Therefore, probabilistic methods are used in these cases and here the point estimate method (PEM) has been applied. The purpose of the method is to be able to combine probabilistic input variables and to evaluate the distribution of the output variables. The rule of PEM is to compute solutions at various estimation points and to combine them with appropriate weighting in order to get an estimation of the distribution of the output variables (Rocsceince, 2012).

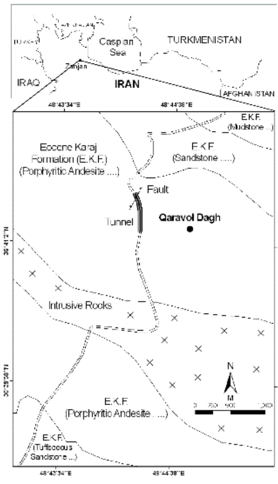


Figure 1. Sketch maps showing the location of Zaker-Sorkhedizaj tunnel and distribution of rock masses in the area

Due to ongoing movement of faults in the Iran plateau, crushed fault zones have been formed around of prominent faults. These tectonically crushed zones directly influence the safety of the working site, the choice of the tunnel support, and the long term behaviour of the construction (Burgi et al., 2001). Fault rocks fall within the category of weak or soft rocks, and usually cause problems such very high development of plastic zone in above part of openings and rock falls in the excavated spaces. For this reason, knowing the geomechanical characteristics of these rocks is very important in rock engineering.

This paper attempts to present probabilistic analysis of the crushed rock masses in the fault zone and evaluating their behaviours in the Zaker-Sorkhedizaj tunnel in northwest of Iran. This tunnel, with about 530 m in length and 11.2 m span, is to run through Qaravol Pass in Western Alborz Mountain Range in Zanjan province (Fig. 1).

GEOLOGY

The studied area is located in Western Alborz zone (Aghanabati, 2004) which deforms by strain partitioning of oblique shortening onto range-parallel left-lateral strike-slip and thrust faults. The whole rocks under investigation in this study belong to the Eocene Karaj Formation. The Zaker-Sorkhedizaj tunnel is located in unit that composed of porphyry andesite with sandstone and green tuff at the base.

In the studied area, the faults are the most basic structures that have subjected especially porphyry andesites and caused very dense fracturing in these rocks. Because of very extensive development of the fracturing in the porphyry andesites, a crushed fault zone with 20 to 25 m extent could be distinguished in the around of the most prominent fault in the site of project. This fault with trend of NE-SW is a strike-slip fault with reverse component that dips 75-85 degree to northwestward. Angel of this fault with axis of tunnel is 70 to 75 degree (Fig.1). The crushed zone of this fault in form of disruption and fragmentation of porphyry andesites can be saw in outlet of tunnel to downward of Qaravol pass. Situation of crushed fault zone was shown in the longitudinal sketch of the tunnel (Fig.2).

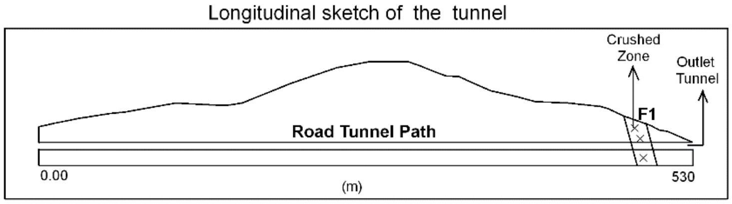


Figure 2. Longitudinal sketch of the Zaker-Sorkhedizaj tunnel showing location of crushed fault zone in the tunnel

MATERIAL CHARACTERISTICS OF CRUSHED ROCKS

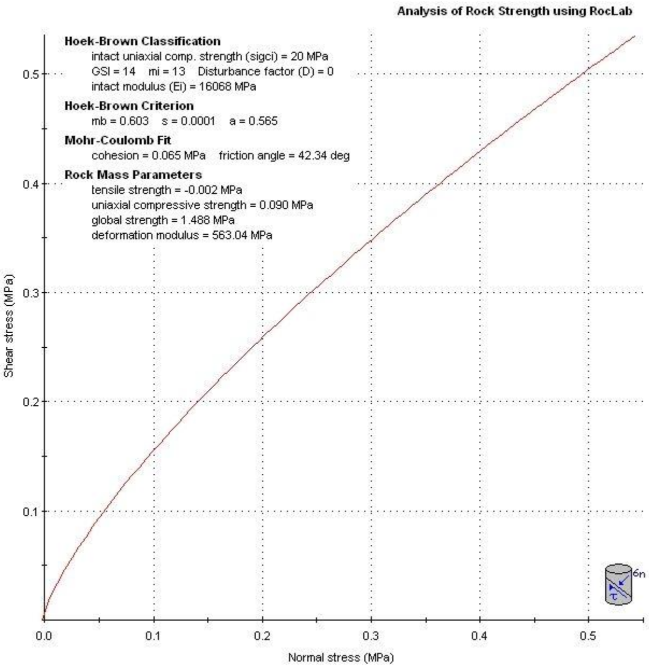
The values of minimum and maximum UCS varies from 12 to 27 MPa, respectively, and the average value of 20 MPa. The low values of the UCS are mainly due to fragmentation nature of these rocks. Therefore, according to (ISRM, 1981) the crushed rocks proved to be weak rocks. In addition, based on (Deere and Miller, 1966) using the UCS, very low strength was suggested for these rocks.

The average value for the rock material constant mi was determined using (Hoek and Brown, 1988) failure criterion. The value of mi for the crushed rocks was obtained equal to 13.

MECHANICAL PROPERTIES OF THE CRUSHED ROCK MASSES

The rock mass properties such as the rock mass strength (σ_{cm}), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) were calculated by the Rock-Lab program defined by (Hoek et al., 2002) (Fig. 3). 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 were calculated using equations of (Hoek et al., 2002). In addition, the rock mass constants were estimated using equations of Geological Strength Index (GSI) (Hoek et al., 2002) together with the value of the porphyry andesites material constant (mi). Mean RMR values have been used to estimate the GSI index for the crushed andesites. Also, the value of disturbance factor (D) that depends on the amount of disturbance in the rock mass associated with the method of excavation, was considered zero for the crushed rock masses, it means these rocks would not be disturbed more than this during blasting.



Hoek-Brown Classification
intact uniaxial comp. strength (sigci) = 20 MPa
GSI = 14 mi = 13 Disturbance factor (D) = 0
intact modulus (Ei) = 16068 MPa

Hoek-Brown Criterion
mb = 0.603 s = 0.0001 a = 0.565

Mohr-Coulomb Fit
cohesion = 0.065 MPa friction angle = 42.34 deg

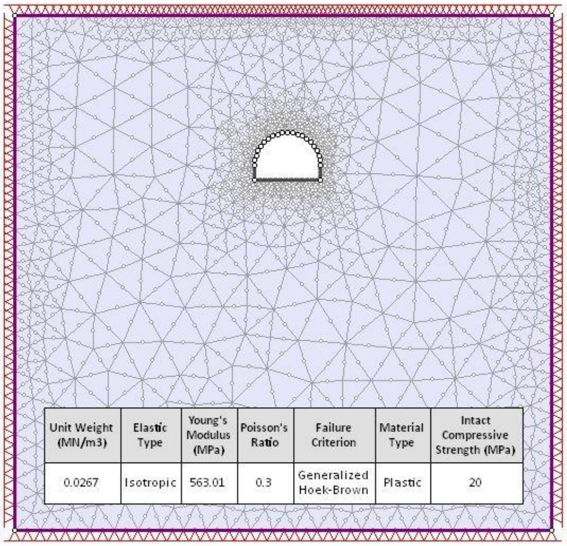
Rock Mass Parameters
tensile strength = -0.002 MPa
uniaxial compressive strength = 0.090 MPa
global strength = 1.488 MPa
deformation modulus = 563.04 MPa

Figure 3. Geomechanical rock mass parameters

PROBABILISTIC STABILITY ANALYSIS OF THE TUNNEL

Probabilistic stability analysis of tunnel deformations in the crushed rock masses were accomplished 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 were computed. These analyses used for evaluations of the tunnel stability in the crushed rock masses. The geomechanical properties for these analyses were extracted from Figure 3.

To simulate the excavation of tunnel in the crushed rock masses, a finite element models was generated with horseshoe section and 11.2 m span. The outer model boundary was set at a distance of 5 times the tunnel radius and six-nodded triangular elements were used in the finite element mesh (Figure 4).



Unit Weight (MN/m3)	Elastic Type	Young's Modulus (MPa)	Poisson's Ratio	Failure Criterion	Material Type	Intact Compressive Strength (MPa)
0.0267	Isotropic	563.01	0.3	Generalized Hoek-Brown	Plastic	20

Figure 4. Numerical modeling of Zaker-Sorkhedizaj tunnel

Probabilistic stability analysis of the tunnel includes analysis on the state of displacement in the roof of tunnel. The best guess for the Hoek and Brown parameters enter and run the analysis. However, the properties of these parameters are not well known, so we will run a statistical analysis by varying the parameters in a systematic way to see the range of possible behaviours. The first, numerical model of the tunnel is run on the state of deterministic analysis and displacement values in the tunnel roof are shown in Fig. 5. As can be seen, displacement values away from the tunnel roof are decreased.

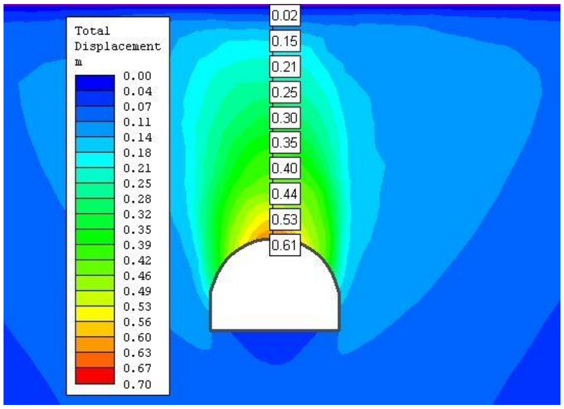


Figure 5. Displacements in the tunnel roof in deterministic analysis

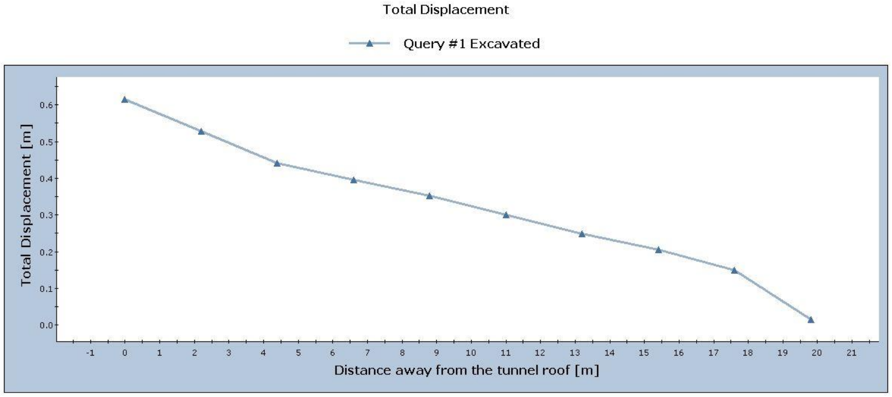


Figure 6. Displacement status away from the tunnel roof in deterministic analysis

The plot in Fig.6 indicates the displacement values in terms of distance away from the tunnel roof. This diagram is composed of three parts that are jointed as distinctive.

In the second stage, probabilistic stability analysis is started by selecting the standard deviation to 3 for deformation modulus. The displacement values in the tunnel roof are shown in Fig.7. As can be seen, the displacement values compared to deterministic analysis have slightly changed and the rate of variations is decreased.

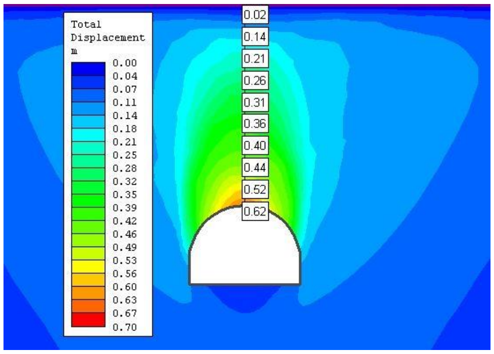


Figure 7. Displacements in the tunnel roof in probabilistic stability analysis

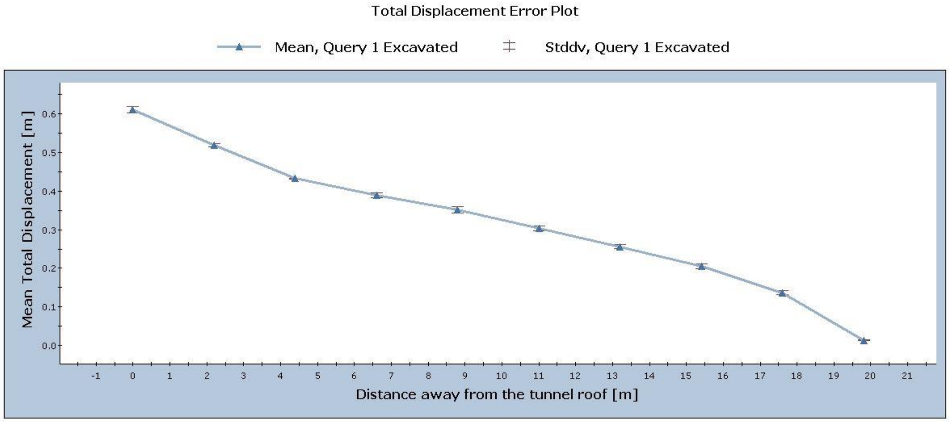


Figure 8. Displacement status away from the tunnel roof in probabilistic stability analysis

The error plot in Fig.8 indicates the range of possible roof displacements that can be expected for the standard deviation to 3 for deformation modulus.

In the third stage, probabilistic stability analysis is accomplished by selecting the standard deviation to 3 for both deformation modulus and intact uniaxial compressive strength. The displacement values in the tunnel roof are shown in Fig. 9. As can be seen, the displacement values this time is increased uniformly across the tunnel roof and the displacement compared to earlier stage is increased again.

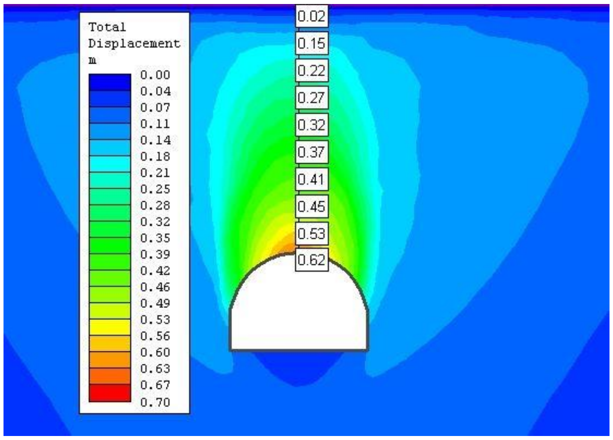


Figure 9. Displacements in the tunnel roof in probabilistic stability analysis

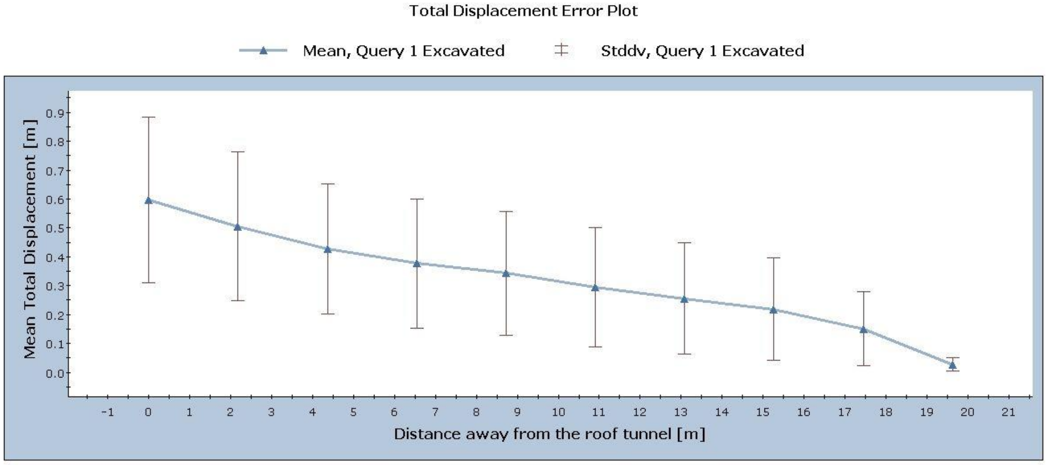


Figure 10. Displacement status away from the tunnel roof in probabilistic stability analysis

The error plot in Fig.10 indicates the range of possible roof displacements that can be expected for the standard deviation to 3 for both deformation modulus and intact uniaxial compressive strength. This diagram shows that the range of possible displacements is much larger than previous case and displacement curve is much gentler and more uniform. Therefore, the combination of probabilistic input variables gives better results compared to one probabilistic input.

The results of this analysis clearly show advantages probabilistic stability analysis to definite analysis and indicate that the deterministic description of tunnel stability with a safety factor is frequently insufficient and the probabilistic analysis will lead to a better understanding of tunnel stability and provide more complete information. A probabilistic approach, when it is possible to have sufficient data on the quality of the rock mass, leads to a better understanding of the project risks.

CONCULSION

This study provides an estimation of the crushed rock masses properties that could be used as input data for stability analysis for the Zaker-Sorkhedizaj tunnel. Due to uncertainty in rock masses properties specially, deformation modulus and intact uniaxial compressive strength, a probabilistic analysis using PEM method is accomplished for determination of displacement values around the tunnel.

Numerical solutions show that the crushed rock masses indicate instability due to their lower strength. The displacement values in the tunnel roof in the probabilistic analysis are greater and more uniform than deterministic approach. The results of this study indicated that the deterministic approach of stability analysis should be used associated with probabilistic method to analyze the tunneling projects stability condition.

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