Estimation of Hoek and brown failure criteria parameters for noghre kamar roadway Tunnel in Tafresh

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Abstract

One of the provinces in the center of Iran is called Markazi, located between Esfahan, Lorestan, Hamedan, Tehran and Qom provinces. To connect two cities of this province named Tafresh and Arak, it is necessary to drive a roadway tunnel for reducing the travel time and expenses, in addition to reduce the safety problems. To do this, it is decided to open a 750 m roadway tunnel with horse-shoe cross section located at 34? 37' to 34? 38' N and 49? 50' to 49? 55' E, called Noghre Kamar in the south-west of Tafresh. The average thickness of the overlaying strata is 50 m with poor geological conditions. The rock mass consists of layers of shale having sandstone and limestone with three joint sets. As the rock mass quality is low, it is necessary to use a support system. So far, many software were developed to design support system using failure criterion around the tunnel. One of them is Hoek & Brown failure criterion, in which different constant parameters must be evaluated. The aim of this article is to evaluate these constants by means of rock mass classification method applying field observations and laboratory tests.

Keywords: *Road ways, tunnel, Tafresh, failure criteria, Hoek & Brown*

Introduction

Determination of the rock mass parameters is important probiem in rock engineering. This can be achieved using the rock mass rating system and the Hoek and Brown Failure Criteria.

For constructing engineering structures such as tunnels, etc. we need to use failure criterion for identifying the behavior of rock. Rock is affected by stress and stress causes the deformation and ultimately breaks the rock. Stress and strain represent behavior of the rock, but the stress is commonly used parameter in defining the failure criterion.

Different failure criteria based on classical theory and experimental results exists in geotechnical engineering. We use them to review and determine the behavior of rock mass. But the classical criteria are not appropriate for use in rock mass. Several empirical criteria have been proposed for the rock. The most important experimental failure criteria for rock are Hoek-Brown and Mohr-Coulomb criteria. These two criteria have been in use in rock engineering to appropriately represent the rock mass behavior. The rock mass parameters are determined and used effectively for modeling the behavior of rock mass.

In this paper, the Hoek and Brown parameters for intact rock have been determined using laboratory triaxial test results. The parameters for rock mass are then estimated using the relationships between the intact rock parameters, the uniaxial strength (UCS) and the rock classification parameters like GSI, RMR etc. The rock mass parameters for Noghre Kamar tunnel were estimated based on the laboratory tests on the samples from the site and the general information of tunnel.

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Methodology

The Hoek-Brown failure criterion (2002) was originally proposed for hard rock masses and was later generalized to include poor and very poor qualities of rock masses. The generalized Hoek-Brown failure criterion is expressed as (Hoek et al., 2002)

$$\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + S\right)^a \quad (1)$$

Where σ_1 and σ_3 are the major and minor principal stresses, respectively; σ_{ci} is the uniaxial compressive strength of the intact rock; and m_b, s and a are the Hoek-Brown constants for the rock mass before yielding, given by (Hoek et al., *op cit*)

$$m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right) \quad (2)$$

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \quad (3)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad (4)$$

D is a factor which depends upon the degree of disturbance to which the rock mass has been subjected by blast damage and stress relaxation. It varies from 0 for undisturbed in situ rock masses to 1 for very disturbed rock masses (Hoek et al., *op cit*).

Where the results of laboratory triaxial or shear strength tests are available, the constants m and σ_c can be determined as follows. (Hoek and Brown, 1988)

$$\sigma_c = \sqrt{\frac{\sum y}{n} - \frac{\sum x}{n}\left(\frac{\sum xy - (\sum x \sum y)/n}{\sum x^2 - (\sum x)^2/n}\right)} \quad (5)$$

$$m = \frac{1}{\sigma_c}\left(\frac{\sum xy - (\sum x \sum y)/n}{\sum x^2 - (\sum x)^2/n}\right) \quad (6)$$

Where

$x = \sigma_3$

$y = (\sigma_1 - \sigma_3)^2$

n= number of σ_1, σ_3 data pairs.

The E_{mass} and σ_{cmass} of tunnel have been estimated using the following relations:

The rock mass modulus of deformation is given by: (Hoek et al., *op cit*)

$$E_{mass} = \left(1 - \frac{D}{2}\right)\sqrt{\frac{UCS}{100}} \times 10^{((GSI-10)/40)} \quad (7)$$

Equation (5) applies for $\sigma_{ci} \leq 100$ MPa. For $\sigma_{ci} > 100$ MPa, use equation (6) (Hoek et al., *op cit*).

$$E_{mass} = \left(1 - \frac{D}{2}\right) \times 10^{((GSI-10)/40)} \quad (8)$$

To determine uniaxial compressive strength of rock mass is used from the following relations.

The Hoek et al. (2002) empirical equation:

$$\sigma_{cmass} = \sigma_{ci} s^a (MPa) \quad (9)$$

The Aydan and Dalgic (1998) empirical equation:

$$\sigma_{cmass} = \frac{RMR}{RMR + \beta(100 - RMR)} \sigma_{ci} (MPa) \quad (10)$$

Where $\beta = 6$

Results and Discussions

Noghre Kamar tunnel

Noghre Kamar tunnel is part of road tunnel connecting Tafresh-Ashtiyan. This tunnel is being constructed to minimize the dangerous curve and also to minimize the problems of ice and storm during the winter. This tunnel is 750 meters long and is designed for two way vehicular traffic.

Figure (1) shows the section of the tunnel and various geological zones.

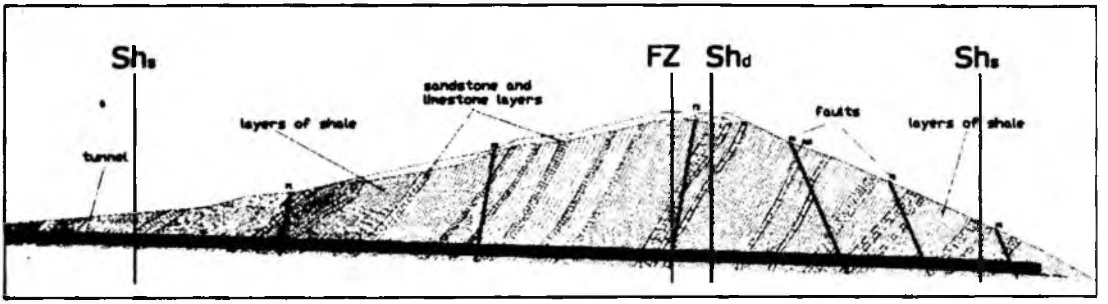

Fig. 1: Tunnel Section and various geological zones

Tests

Rock mass parameters are obtained according to test results as given in Table 1.

Table 1: UCS and density and t of tunnel

Parameter		Value		
		Sh_s	Sh_d	FZ
parameters of intact rock	Uniaxial strength(MPa)	20	30	30
	Dry density(gr/cm$^{3)}$	2.5	2.6	2.5
	Tensile strength(MPa)	8	41	19

According to joint studies, results obtained are presented in Table 2.

Table 4: laboratory result for the rock of tunnel's zones

Parameter	Value		
	Sh_s	Sh_d	FZ
GSI	22.5	30	22.5
UCS(MPa)	20	30	30
m_i	6	8	8
D	0.5	0.5	0.5
Density(ton/m^3)	2.5	2.6	2.5
Overlaying(m)	22	100	100
Cohesion(MPa)	0.068	0.403	0.292
Internal friction angle	38.3	39.7	37.1
Tensile strength(kPa)	8	41	19
Elastic modulus(GPa)	0.689	1.299	0.844

Table 2: Joint study for tunnel

No	Declivity	Direction	Thickness (cm)	Roughness	Protraction (m)	Opening (mm)	Weathering	Filling-in	Water Conditions
J1	**70**	**325**	**30-60**	Wavy and the average roughness	**2.5**	**7**	Minor weathering	Empty and shale	Internal flow over 10 liters per minute and on-site faults more than 20 liters per minute
J2	**60**	**35**	**50-100**	Almost straight and smooth	**0.75**	**1**	Without weathering	Limestone and shale	
J3	**60**	**80**	**30-50**	Almost straight and slightly coarse	**1.5**	**3.5**	Minor weathering	Clay	
Stratification	**32**	**252**	**30-300**	-	-	-	-	-	

Table 3: Rock Mass Classification parameters of tunnel

Classification method	Value		
	Sh_s	Sh_d	FZ
RMR (adjusted(	30	35	25
Q	0.2	0.27	0.15
GSI	22.5	30	22.5

The rock mass Classification parameters of the tunnel are presented in Table 3. The laboratory test results for the samples at various geological zones are presented in Table 4.

Table 5: Hoek and Brown parameters for rock mass

parameter	Value		
	Sh_s	Sh_d	FZ
E_{mass}(GPa)	0.689	1.299	0.844
σ_{cmass}(MPa)	1.333	2.470	1.579
m_b	0.150	0.285	0.200
s	3.25x10^{-5}	8.843x10^{-5}	3.25x10^{-5}
a	0.537	0.522	0.537
$\sigma_1 =$	$\sigma_3+\sigma_{ci}\left(0.150\frac{\sigma_3}{\sigma_{ci}}+3.25\times10^{-5}\right)^{0.537}$	$\sigma_3+\sigma_{ci}\left(0.285\frac{\sigma_3}{\sigma_{ci}}+8.843\times10^{-5}\right)^{0.511}$	$\sigma_3+\sigma_{ci}\left(0.2\frac{\sigma_3}{\sigma_{ci}}+3.25\times10^{-5}\right)^{0.522}$

Conclusions

The rock mass parameters for Noghre Kamar tunnel were estimated based on the onsite rock mass classification and based on the laboratory tests conducted on the samples from various sections. The estimated Hoek and Brown parameters for the tunnel are listed in Table 5.

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