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CONSIDERATIONS IN DEVELOPING AN EMPIRICAL STRENGTH CRITERION FOR BIMROCKS

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The strength of geological materials is one of the fundamental input parameters used in the design of civil and mining engineering works; including those projects to be constructed in complex geological mixtures or fragmented rocks such as mélanges, fault rocks, coarse pyroclastic rocks, breccias and sheared serpentines. These often chaotic, mechanically and/or spatially heterogeneous rock masses are composed of relatively rock inclusions surrounded by weaker matrix, and maybe be considered bimrocks (block-in-matrix-rocks). It is almost always impossible to prepare standard core samples from bimrocks in order to perform laboratory studies. Therefore, for these rocks, determination of the mechanical parameters such as cohesion, friction angle and uniaxial compressive strength is extraordinarily challenging. Although there is sparse literature describing empirical and laboratory studies on bimrocks, there is no widely accepted empirical approach among the rock mechanics community due to the limitations of the existing empirical equations, which were developed largely for more tractable, relatively homogenous rock masses. In this study, an exhaustive database was developed by literature overviews and laboratory studies. Artificial bimrocks were also prepared in the laboratory for uniaxial and triaxial compression testing. Plaster of Paris, bentonite, cement and water were mixed in different ratios to fabricate matrix types with various strengths. In addition, real tuff and andesite blocks, fragmented to centimeter sizes to create blocks, were mixed with the matrix materials to create artificial bimrocks. Uniaxial and triaxial compression tests were conducted on specimens of pure matrix and artificial bimrock mixes having different block proportions. Finally, a series of statistical regression analyses were applied to the results of the laboratory strength tests to develop an empirical approach for estimating the overall strength of bimrock mass, by incorporating the Mohr-Coulomb strength model and the Hoek-Brown empirical criterion, both of which are widely used in rock engineering. The empirical approach based on the Hoek-Brown empirical equations was found to yield a slightly better predictive performance than an empirical approach based on the Mohr-Coulomb.

Keywords: Bimrock; Hoek and Brown; Mélange; Mohr-Coulomb.

1. Introduction

Strength and deformation parameters of geologic materials are highly important input parameters used in the design stage of an engineering application such as tunnels, dams, foundations and slopes. However, it is almost impossible to obtain these parameters from problematic geological materials such as block in matrix rocks (bimrcoks) due to the strength contrast between block and matrix material surrounding the blocks by conventional laboratory studies. To overcome this difficulty, there are some attempts to propose empirical equation in literature (Lindquist, 1994; Gokceoglu 2002, Sonmez et al., 2004, Sonmez et al., 2005, Sonmez et al., 2006). Nevertheless, there is no widely accepted empirical approach among the rock mechanics community due to the limitations of the existing empirical equations, which were developed largely for more tractable, relatively homogenous rock masses. The main target of this study is to propose some empirical equations for determining of the strength parameters of bimrocks. The required database was established by laboratory studies employed on artificial matrix and bimrock cores.

2. Establishment of the Database

In the first stage, two matrix compositions having different uniaxial compression strengths were investigated. For this purpose, Plaster of Paris, bentonite, cement and water were mixed in different ratios by weight to fabricate matrix types with various strengths. The amount of water in the mixture was used as %50 by weight to prepare mortar which can be filled easily into the mold having 54 mm diameter and 110 mm height. The samples were released for drying in laboratory condition at least 30 days. The weight of samples was measured during the drying stage (Figure 1). The drying rate of samples decreases after about 15 days (Figure 1). However, all compression tests employed in this study were carried out on core samples dried in 30 days.

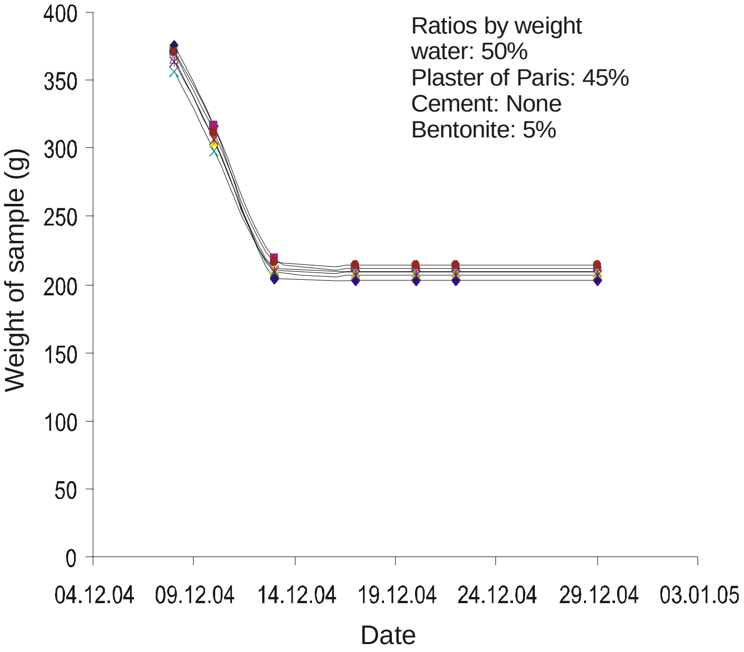

Fig. 1. The drying rate of a core sample.

Uniaxial compressive strength (UCS) tests were applied on artificial matrix cores to get proper mixture ratios to be used in the preparation of artificial bimrock (Table 1). Natural rock pieces prepared from tuff and andesite blocks, which have average UCS values 10.55 MPa and 49.55 MPa (Sonmez *et al.*, 2006), respectively, were used in artificial bimrocks. The strength ratio between blocks and matrix of bimrock should be at least two (Medley, 1994; Lindquist, 1994; Lindquist & Goodman, 1994). Otherwise the geological mixture can not be evaluated as bimrock. By considering the average UCS values of blocks and the threshold value of strength contrast for bimrocks, two matrix composition having 1 MPa and 4 MPa UCS values were selected (Table 1). The mixture ratios by weight of Plaster of Paris, cement and bentonite of selected matrix compositions are %45, %0, %5 (labeled as A group) and %25, %35, %0 (labeled as B group) for UCS values of 1 MPa and 4 MPa, respectively (Table 1). To determine failure envelope of the selected two matrix types, the trixial compression tests were employed on the selected matrix under cell pressures of 75 kPa, 100 kPa, 150 kPa and 300 kPa.

Table 1. Uniaxial compressive strength of matrix types mixed in different ratios by weight of Plaster of Paris, cement and bentonite)

	Uniaxial compressive strength (MPa) (mixture ratios by weight of %Plaster of Paris-%cement-%bentonite)							
Sample No	**40-00-10**	***45-00-05****	**50-00-00**	**30-20-00**	**20-30-00**	**00-40-10**	**00-50-00**	**25-35-0***
M-1	1.08	***0.97***	0.82	1.8	1.92	3.33	4.54	**4.25**
M-2	1.26	***0.94***	0.79	1.75	1.87	2.92	6.98	**4.14**
M-3	1.27	***0.91***	0.83	1.84	1.94	2.83	4.92	**3.84**
M-4	1.19	***0.92***	0.70	1.58	2.01	2.75	7.35	**3.95**
M-5	1.05	***0.97***	0.67	1.74	1.91	2.52	7.04	**4.12**
M-6		***1.03***	0.73	1.72	1.81	3.10	5.14	**4.22**
Average (MPa)	1.17	***0.96***	0.76	1.74	1.91	2.91	5.99	**4.09**

*selected matrixes compostions.

In the second stage of the laboratory studies, artificial bimrock cores were prepared by mixing of rock pieces (tuff and andesite) and matrix (A and B group matrixes) in different ratios by weight. For this aim, four artificial bimrocks goup (A_T: mixtures of A group matrix and tuff rock pieces, A_A: mixtures of A group matrix and andesite rock pieces, B_T: mixtures of B group matrix and tuff rock pieces, B_A: mixtures of B group matrix and andesite rock pieces) having %0 (only matrix), %10, %30 and %50 block content by weight were prepared and used in the uniaxial and triaxial compressive strength testing program. The preparation stages of samples were given in Figure1. The amount of water in the mixture was used as %50 by weight to prepare mortar as considered in the preparation of matrixes. Triaxial compressive strength tests were applied under pressures of 75 kPa, 100 kPa, 150 kPa and 300 kPa. The summary result of the test program is given in Table 2. The volumetric block portion of each sample was calculated by using block ratio by weight and unit weight of block and matrix in phase relation equations.

Table 2. The summary of the test program employed on artificial matrix and bimrock cores.

Group label	Type of bloof matrixk	Strength contrast between block and matrix	Block ratio by weight (%)	Volumetric blok ratio (%)	Cohesion, c (kPa)	Internal friction angle, ϕ (derece)	UCS (kPa)
A	None	-	0	0	285.2	24.8	897.6
A_A	Andesite	55.2	10	6.5	276.2	26.3	906.5
A_A	Andesite	55.2	30	20.8	247.8	30.2	842.1
A_A	Andesite	55.2	50	36.3	222.2	33.7	815.7
A	None	-	0	0	285.2	24.8	897.6
A_T	Tuff	11.8	10	8.0	275.8	25.8	885.5
A_T	Tuff	11.8	30	26.1	251.7	28.4	862.1
A_T	Tuff	11.8	50	44.4	218.8	32.8	798.4
B	None	-	0	0	1248.6	26.2	4102.2
B_A	Andesite	12.1	10	7.5	1171.6	29.3	3954.5
B_A	Andesite	12.1	30	23.9	1117.3	31.1	3894.3
B_A	Andesite	12.1	50	41.7	954.5	36.2	3686.6
B	None	-	0	0	1248.6	26.2	4102.2
B_T	Tuff	2.6	10	9.2	1200.1	27.2	4004.2
B_T	Tuff	2.6	30	30	1057.8	31.9	3854.3
B_T	Tuff	2.6	50	51	926.7	37.4	3626.4

Fig. 2. Preparation stages of the artificial bimrock.

3. Statistical Evaluations

A series of statistical analyses were carried out by considering uniaxial compressive strength (UCS), Mohr-Coulomb parameters (c and ϕ) and Hoek-Brown m_i parameter. To generalize the empirical equations, all input values were normalized by using the values of matrix. The relations between volumetric block portion (VBP) and normalized values are given in Figure 3. The empirical equations are summarized in Eq. (1) for Mohr-Coulomb and Eq. (2) for Hoek-Brown (Hoek *et al.* 2002).

$$c_N = 1.25 - \exp\left(\frac{VBP - 100}{75}\right) \qquad c_{bimrock} = c_N x c_{matrix} \tag{1a}$$

$$\phi_N = \exp\left(\frac{8xVBP}{1000}\right) \qquad \phi_{bimrock} = \phi_N x \phi_{matrix} \tag{1b}$$

$$UCS_N = 1 - \exp\left(\frac{VBP - 100}{25}\right) \qquad UCS_{bimrock} = UCS_N x UCS_{matrix} \tag{1c}$$

$$UCS_{bimrock} = \frac{2c\cos\phi_{bimrock}}{1-\sin\phi_{bimrock}} \qquad \sigma_1 = UCS_{bimrock} + (\frac{1+\sin\phi}{1-\sin\phi})\sigma_3 \tag{1d}$$

$$m_{i\_N} = \exp(0.015xVBP) \qquad m_{i\_bimrock} = m_{i\_N} x m_{i\_matrix} \tag{2a}$$

$$\sigma_1 = \sigma_3 + UCS_{bimrock}\sqrt{(m_{bimrock}\frac{\sigma_3}{UCS_{bimrock}} + 1)} \tag{2b}$$

where, c and ϕ are cohesion and internal friction angle, UCS is uniaxial compressive strength, m_i is m parameter of intact sample. σ_1 and σ_3 are major and minor principal stresses.

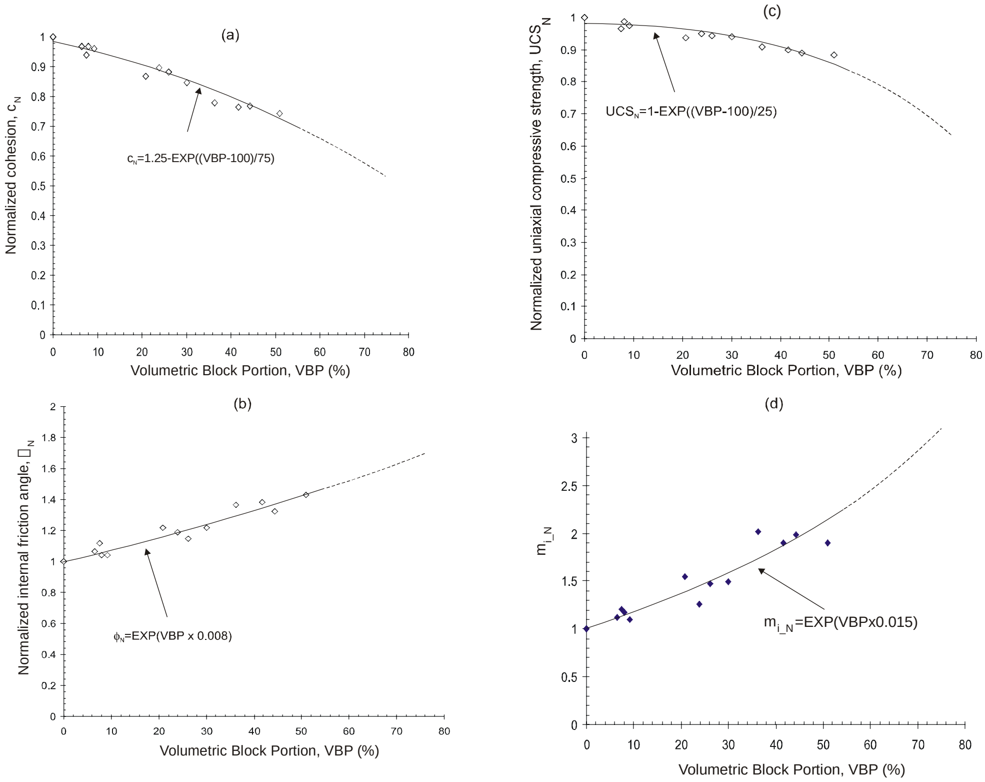

Fig. 3. The relations between normalized values and volumetric block portion (VBP).

4. Performance Evaluations

The performance of the empirical relations given in Eqs. (1 and 2), for Mohr-Coulomb and Hoek-Brown, respectively, were evaluated by re-calculated major principal stress (σ_1) in Eqs. (1d and 2b). The derived σ_1 values and measured σ_1 values were evaluated in the following equation to obtain error ratio.

$$\text{Error ratio}(\%) = \left(\frac{\text{derived } \sigma_1 - \text{measured } \sigma_1}{\text{measured } \sigma_1}\right)\text{x}100 \tag{3}$$

The cumulative frequency distribution of error ratio obtained from Mohr-Coulomb and Hoek-Brown was given in Figure 4.

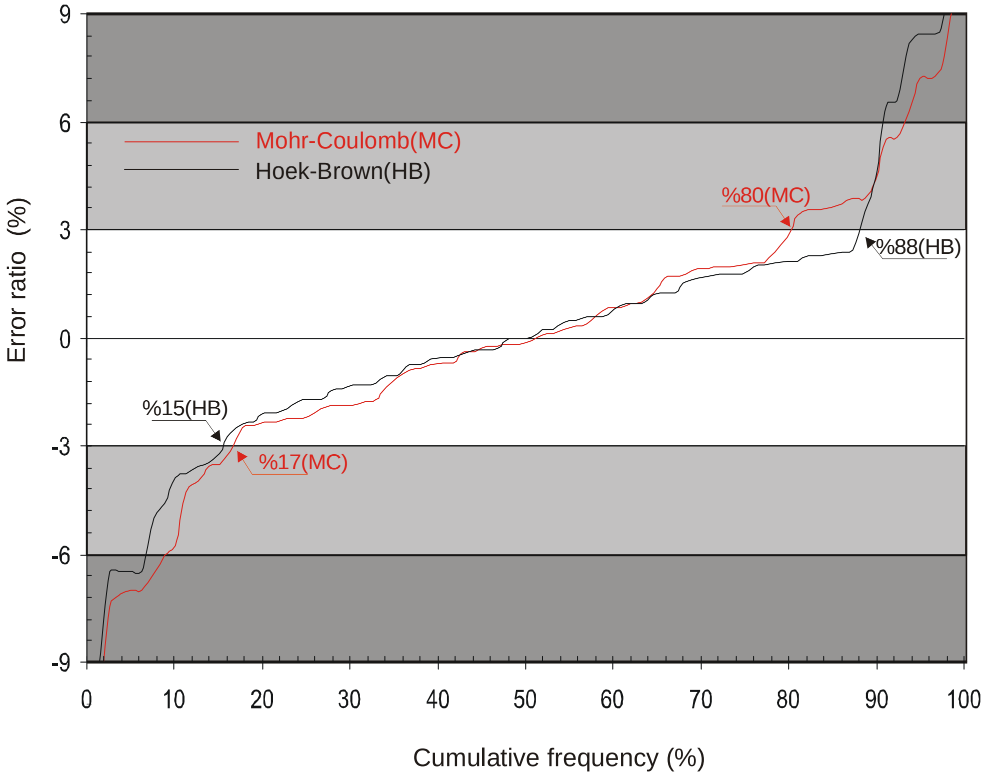

Fig. 4. The cumulative frequency distribution of error ratio obtained by using σ_1 values predicted by the proposed empirical equations considering Mohr-Coulomb and Hoek-Brown.

As can be seen from Figure 4, 73% and 65% of data have error ratio less than 3% for the proposed empirical equations which consider Hoek-Brown and Mohr-Coulomb, respectively. Therefore, it can be stated that the empirical approach based on the Hoek-Brown empirical equations was found to yield a slightly better predictive performance than an empirical approach based on the Mohr-Coulomb.

5. Conclusions

This study is a preliminary attempt to construct a general empirical approach for bimrock. The important points can be underlined in this study are summarized as follows:

i) The overall bimrock strength is not influenced by block strength, as long as there is sufficient block/matrix strength contrast to force failure surfaces around blocks. However, the findings of the studies performed on the Ankara agglomerate by Sonmez *et* *al*. (2005) reveal that the strength of block influences the overall strength of agglomerate. It should be remembered that agglomerate is a volcanic bimrock since welding plays an important role on the strength behavior of block-matrix contact.

ii) The empirical equations proposed in this study should not be used alone in design stage of an engineering application.

iii) The empirical equations are open to improvement depending on the case studies.

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