Evaluation Rock Mass Deformation Modulus based on Fuzzy Logic

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Paper Reference Number:

Name of the Presenter: 07-56-3332
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Abstract

The purpose of this paper is to study of rock mass deformation modulus based on fuzzy logic. In this paper, evaluation of deformation module was conducted based on Fuzzy Multiple Criteria Decision Making and Fuzzy Analytical Hierarchy Process. Therefore, there are used 8 empirical relationships to estimate the modulus and 6 criteria to evaluate the empirical relations. In this paper, a program written by visualbasic software is used. In end of the study, there is identified by Fuzzy Analytical Hierarchy Process, that Mehrotra empirical relation get the highest score.

Key words: Deformation modulus of rock mass, multi-criteria decision making, fuzzy Analytical Hierarchy Process

1. Introduction

Rock mass deformation modulus is one of the most important properties and features mechanical behavior of rock mass. Deformation modulus is ratio of its corresponding stress-strain behavior, which it is, included elastic and plastic behavior of rock mass. Correct determination and estimation of this module is very important because incorrect determination of the modulus in designing structures that are located within or on the the rock mass can due to very heavy financial and nonfinancial. Thus, many researchers such as geotechnical have considered determining the modulus of rock mass ductility change. Deformation modulus of rock mass through empirical relationship is one of the low-cost, easiest and fastest available methods to estimate the modulus. Some scientists have studied to provide an appropriate empirical relationship to more correct estimation of the module. Most of these researchers have provided their empirical relationships based on using parameters of rock mass classification. But lack of confidence and certainty to the used data are the most important problems for using these equations. Many researchers have tried to get certainty of these relations by different methods.

In this study, there have been studied these empirical relationships by using fuzzy logic. This article deals with estimating 8 empirical relationships that they were used to estimate rock mass deformation modulus and 6 criteria for studying these 8 empirical relationships by using Fuzzy Multiple Criteria Decision Making (FMCDM) and Fuzzy Analytical Hierarchy Process (FAHP).

2. Studied criteria

In this paper, six criteria have been used to investigate the considered options. These six criteria have been selected based on CSIR geomechanical classification with Bieniawski rock mass scoring, as one of the methods for classifying multi criteria of rocks. According to relationship(1), these six criteria are scores for RMR rock mass.

$$\mathrm{RMR} = \mathrm{R_S} + \mathrm{R_{RQD}} + \mathrm{R_{sd}} + \mathrm{R_{cd}} + \mathrm{R_w} + \mathrm{R_{od}} \quad (1)$$

$\mathrm{R_S}, \mathrm{R_{RQD}}, \mathrm{R_{sd}}, \mathrm{R_{cd}}, \mathrm{R_w}$ and $\mathrm{R_{od}}$ are six determinant parameters of rock mass rating and the same six defined criteria, which they are single-axis compressive strength score for intact rock, score of RQD index, score of joints situation, score of joints position, scores related to groundwater conditions, score of relative direction of joints respectively.

3. Estimation of rock mass deformation modulus

There are different methods for identifying deformation modulus of rock mass, which empirical relationship is one of the low-cost, easiest and fastest available methods to estimate the modulus. Many researchers have studied to provide an appropriate empirical relationship to more correct estimation of the module [8]. According to Table 1, the investigated relationship in this study is as following.

Reference	Explains	Empirical Equations
Bieniawski (1978) [1]	RMR > 55	$E_m = 2RMR - 100$
Serafim and Pereira (1983) [2]	RMR < 55	$E_m = 10^{\frac{RMR-10}{40}}$
Mehrotra (1992) [3]	-	$E_m = 10^{\frac{RMR-20}{38}}$
Read et al (1999) [4]	-	$E_m = 0.1(\frac{RMR}{10})^3$
Diederich and Kaiser (1999) [5]	-	$E_m = 7(\pm 3)\sqrt{Q'}$ $Q' = 10(\frac{RMR-40}{21})$
Gokceoglu et al. (2003) [6]	-	$E_m = 0.0736 \times EXP(0.0755RMR)(Gpa)$
Aydan (1997) [6]	-	$E_m = 0.0097 \times RMR^{3.54} \times 10^{-3}(Gpa)$
Mohammad (1997) [6]	-	$E_m = 0.562 \times RMR + 0.183(Gpa)$

Table 1- Empirical Equations

4. Cheng fuzzy Analytical Hierarchy Process method

For the first time, Professor Lotfi Asgrzadeh created fuzzy logic by publishing an article entitled Fuzzy Sets in Information and Control Magazine [7]. One of the most efficient applications of theory of fuzzy sets in fuzzy logic is fuzzy decision-making problems [8]. Fuzzy Analytical Hierarchy Process (FAHP) method is one of the most important procedures in fuzzy decision-making. Many researchers have used fuzzy Analytical Hierarchy Process method in different applications such as Zare et al (2009) [9] for selecting underground mining technique in Jajrom Boxit Mine, Iran, and Ja'afari Moqadam (2009) [10] for selecting appropriate excavating machine for small cross-section tunnels.

Chang is one of the researchers who have provided studies and techniques for fuzzy Analytical Hierarchy Process methods. In a fuzzy multiple criteria decision making at fuzzy Analytical Hierarchy Process based on Chang, there have been defined seven steps for this technique by m option and n criteria.

4.1. First step: drawing a hierarchical graph

In this step, there is dealt with hierarchical graph about the studied matter. This graph has been drawn in three levels: first level (goal), second level (criteria), third level (the studied options). Of course, the second level, i.e. decision-making level may includes decision-making sub criteria.

4.2. Second step: Define fuzzy numbers to perform paired comparisons

Fuzzy numbers that can be used are triangular or trapezoid fuzzy numbers, and then we get scale fuzzy of numbers by considering to each selected fuzzy number and their membership functions.

4.3. Third step: creating paired comparison matrix ($\tilde{A}$) by using fuzzy numbers

Paired comparison matrix ($\tilde{A}$)will be as the following:

$$\tilde{A} = \begin{pmatrix} 1 & \tilde{a}_{12} \ \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 \ \dots & \tilde{a}_{2n} \\ \vdots & \vdots \ \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} \ \dots & 1 \end{pmatrix}$$

Fuzzy numbers of the matrix are:

$$\tilde{a}_{ij} = \begin{cases} 1 & \text{i=j} \\ \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} \ \text{ or } \ \tilde{1}^{-3},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & \text{i} \neq \text{j} \end{cases}$$

4.4. Fourth step: calculating each rows of the paired comparison matrix

If i and j represent row and column numbers in the following relationships respectively, and M_{gi}^{j} indicates triangular fuzzy numbers in the paired comparison matrix, $\sum_{j=1}^{m} M_{gi}^{j}$, $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}$ and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ amounts are calculated by the following relations [11]:

$$\sum_{j-1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (2)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \qquad (3)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \qquad (4)$$

4.5. Fifth step: Calculate magnitudes' degree in comparison with each other

In this step, we compare magnitudes' degree of every amount with each other. In general, if $S_2 = (L_2, m_2, u_2)$, $S_1 = (L_1, m_1, u_1)$ are considered as two triangular fuzzy numbers, the following equation is used for identifying their magnitudes' degree. Fig. 1 represents this ratio.

$$V(S_2 \geq S_1) = hgt(S_1 \cap S_2) = \mu s_{2(d)} \begin{cases} 1 & \text{if } m_2 \geq m_2 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (5)$$

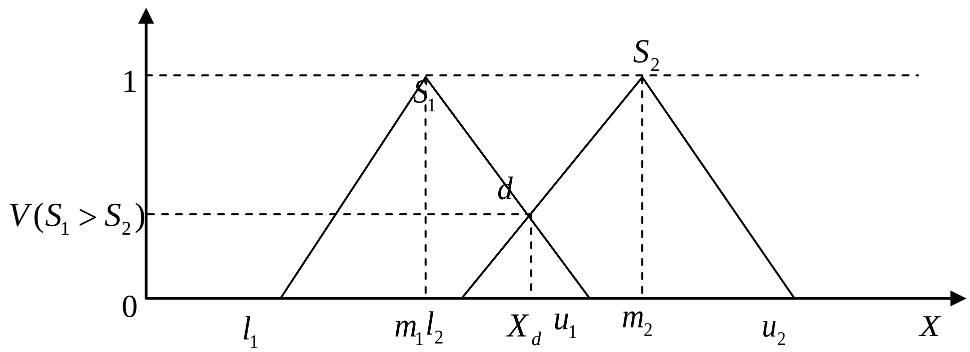

Fig.1: The largeness degree of two triangle fuzzy numbers S_1 , S_2 in relation to each other

Then magnitude degree of a triangular fuzzy number is obtained from another triangular fuzzy number K in the relationship.

$$V(S \geq S_1, S_2, ..., S_k) = V\left[(S \geq S_1) and (S \geq S_2) and ... and (S \geq S_k)\right] = \mathrm{MinV}(S \geq S_i), \quad i=1,2,3 \quad (6)$$

4.6. Sixth step: Calculate weight of each criteria and alternatives in the paired matrices

$$d'(A_i) = MinV(S_i \geq S_k) \qquad \text{K-1,2,...,n}, \ k \neq i \qquad (7)$$

There is obtained un-normalized weight vector by the following relations:

$$w'(d'(A_i), d'(A_2), ..., d'(A_n))^T \qquad (8)$$

4.7. Seventh step: determine and calculate final weight vector

At this stage, we normalize the calculated weight vector in the previous step to obtain the final weight vector.

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \qquad (9)$$

5. Evaluation of rock mass modulus ductility changes

We use seven steps of Chang's method to evaluate empirical relations in table 1, based on Chang's fuzzy Analytical Hierarchy Process (FAHP) method and according to the six considered criteria.

5.1. Drawing Analytical Hierarchy Process diagram to evaluate empirical relations

Hierarchical structure for evaluating the experimental relations is based on Fig. 2.

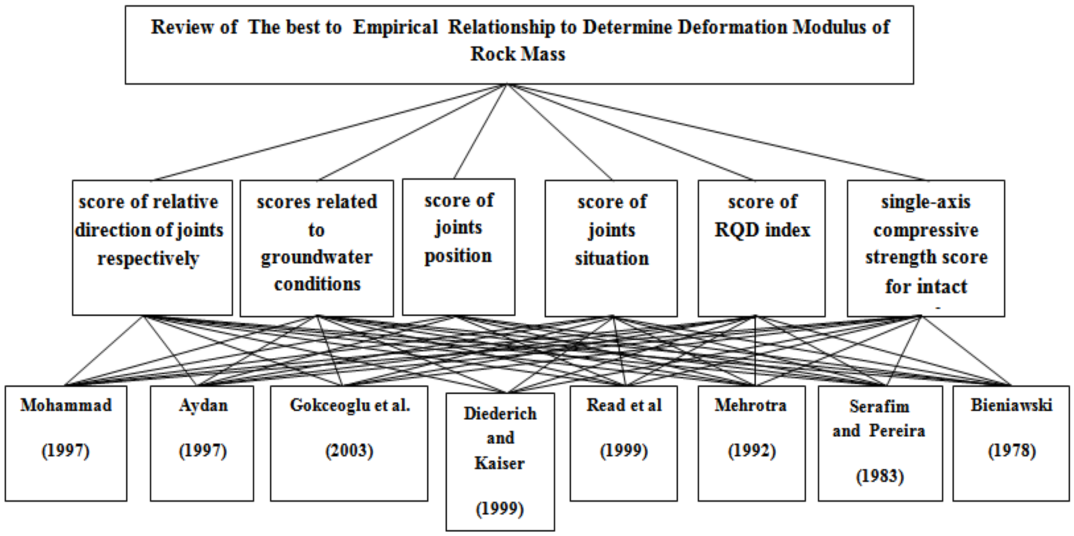

Fig. 2: hierarchical diagram to evaluate empirical relations

5.2. Introduce the considered fuzzy numbers

Used fuzzy numbers in this study are as the following numbers:

$$\tilde{1} = (1,1,1)$$

$$\tilde{2} = (1,2,4) \qquad \tilde{2}^{-1} = (\frac{1}{4},\frac{1}{2},1)$$

$$\tilde{3} = (1,3,5) \qquad \tilde{3}^{-1} = (\frac{1}{5},\frac{1}{3},1)$$

$$\tilde{4} = (2,4,6) \qquad \tilde{4}^{-1} = (\frac{1}{6},\frac{1}{4},\frac{1}{2})$$

$$\tilde{5} = (3,5,7) \qquad \tilde{5}^{-1} = (\frac{1}{7},\frac{1}{5},\frac{1}{3})$$

$$\tilde{6} = (4,6,8) \qquad \tilde{6}^{-1} = (\frac{1}{8},\frac{1}{6},\frac{1}{4})$$

5.3. Create paired comparison matrix and performing steps 1 to 7

We create paired comparison matrix by six introduced criteria and eight considered empirical relations, by using available documentations, and then perform necessary calculations for each row in paired comparison matrix; after that, we measure their magnitude degree in comparison with others because these steps require high attention in calculations, and they are time consuming, so we perform these calculations by visualbasic software and the written program, and finally obtain weight of each alternative and criteria and then normalize them. Obtained values for each alternative in comparison with the measured criteria are as figures 3 to 10.

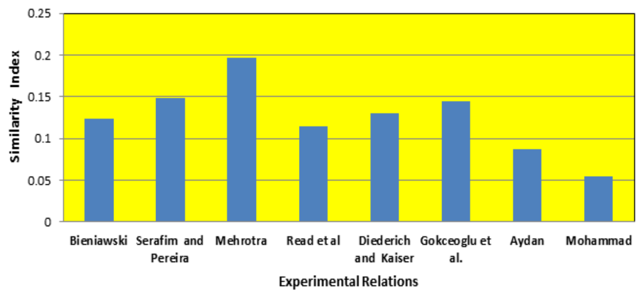

Fig 3: Diagram of Normalized' weight than criteria of single-axis compressive strength score (Rs)

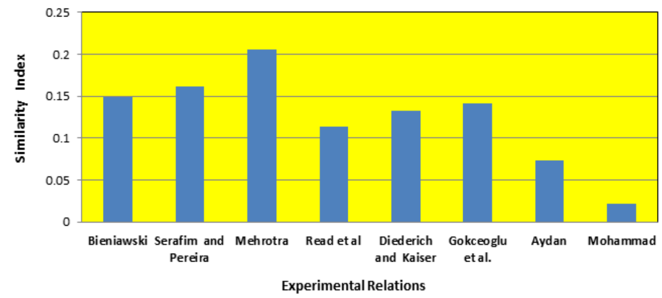

Fig 4: Diagram of Normalized' weight than the index score criteria RQD (R_{RQD})

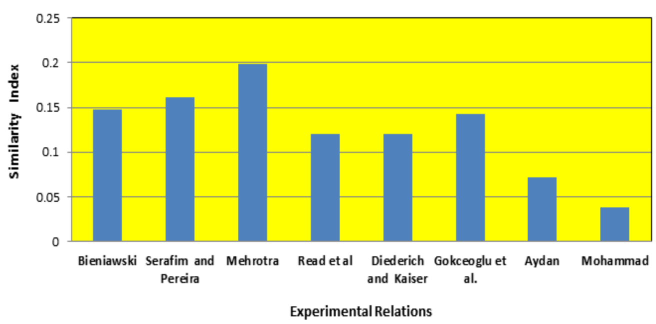

Fig 5: diagram of Normalized' weight than criteria of joints distance (R_{sd}) score

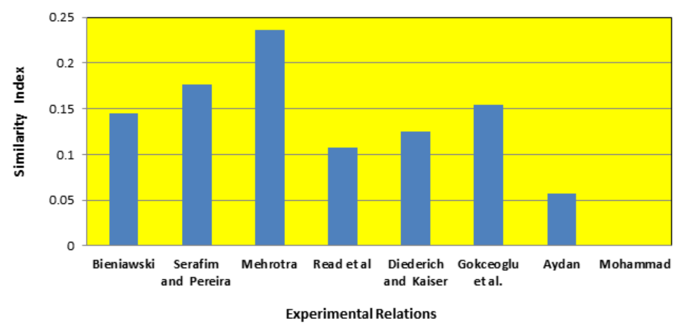

Fig 6: diagram of Normalized' weight than criteria of joints position (R_{cd}) score

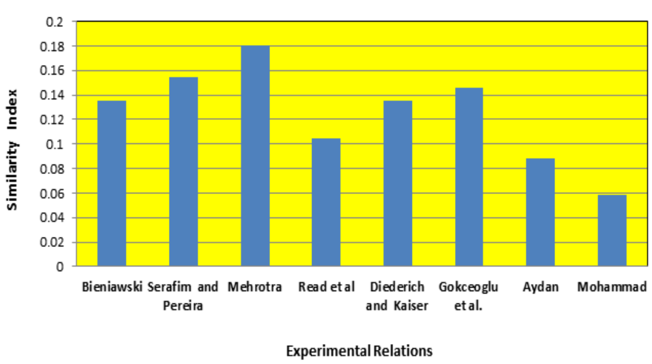

Fig 7: diagram of alternatives' weight than criteria of ground water (R_w) score

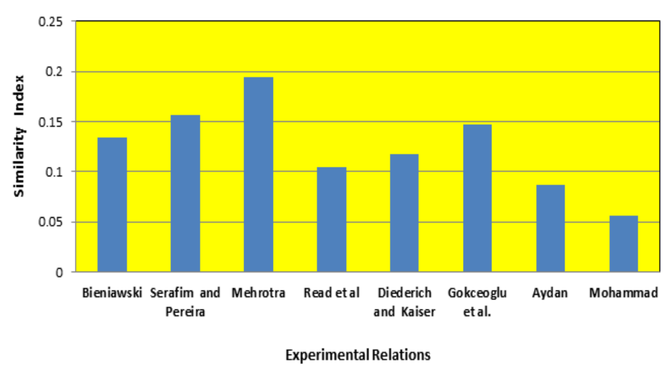

Figure 8: Diagram of Normalized' weight relative to criteria of standard points along joints (R_{od})

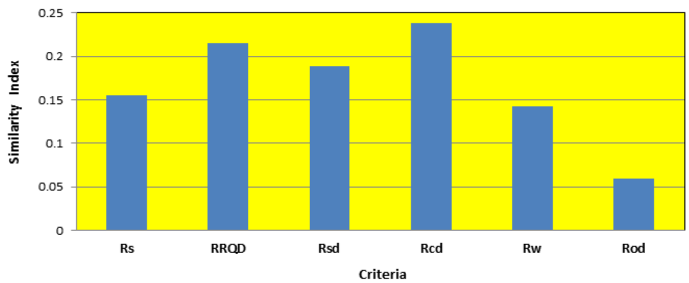

Figure 9: diagram of criteria importance in comparison with each other

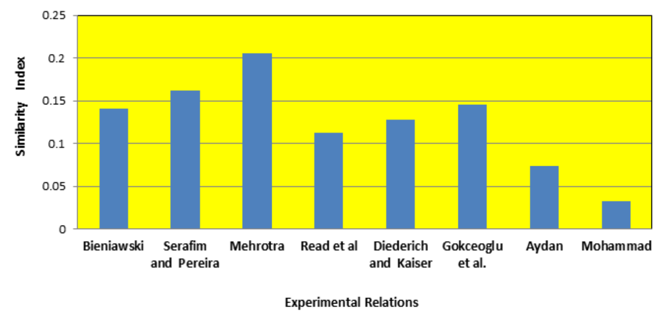

Figure 10: Diagram of final score in each studied alternative

Then obtained results are shown in Table 2 and final score for each alternative and criteria have been calculated according to the table.

	Rs	**RRQD**	**Rsd**	**Rcd**	**Rw**	**Rod**	
Weight	0.155	0.215	0.189	0.238	0.143	0.06	Final Score
Bieniawski(1978)	0.124	0.149	0.147	0.145	0.135	0.134	0.141
Serafim and Pereira (1983)	0.149	0.162	0.161	0.176	0.154	0.157	0.162
Mehrotra(1992)	0.197	0.206	0.199	0.236	0.18	0.195	0.206
Read et al(1999)	0.114	0.114	0.12	0.107	0.105	0.104	0.112
Diederich and Kaiser(1999)	0.13	0.133	0.12	0.125	0.135	0.118	0.128
Gokceoglu et al. (2003)	0.145	0.141	0.143	0.154	0.146	0.147	0.146
Aydan(1997)	0.087	0.073	0.072	0.057	0.088	0.087	0.074
Mohammad(1997)	0.054	0.022	0.038	0	0.058	0.056	0.032

Table 2: Importance coefficients paired comparison matrix and score of each studied alternative and criteria

6. Conclusion

Rock mass deformation modulus is one of the most important mechanical properties of rock. Deformation modulus of rock mass through empirical relationship is one of the low-cost, easiest and fastest available methods to estimate the modulus. Therefore decided to use the most appropriate empirical relation for estimating and identifying deformation modulus is very important. Therefore, after evaluating empirical relations based on fuzzy Analytical Hierarchy Process (FAHP), in accordance with results of Table 2, the best empirical relationship for estimating rock mass deformation modulus is Mehrotra relation.

Acknowledgements

Thanks to the dear teachers, Dr. Saba and Dr. Ghadimi, guided me during the study.

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