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Estimating the Shear Strength of Natural Joints Using Gene Expression Algorithm

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Abstract

Studying the shear behavior of rock joints is very important due to its significant effect on the stability of structures. Many empirical and theoretical models have been proposed to estimate the joint shear strength Through known parameters without carrying out tests. This study investigates the shear behavior of natural rock joints without filling, obtained from core drilling . The surface morphological characteristics of the natural joints were captured by Close-Range Photogrammetry. The direct shear tests were performed on the Constant Normal Load condition. The Gene Expression Programming algorithm was used to obtain the relationships between variables. In order to develop the model 70% of data was used to train, and the rest of data was used to test. Overall, four models were run and a mathematical relationship was introduced to estimate the shear strength of natural rock joints. To evaluate the efficiency of the models, valid criteria were used such as: R^2, MSE, MAE, RSME. Results showed that the GEP algorithm had an appropriate accuracy for the estimation of the output variable

Keywords

Shear strength, Gene expression programming, Natural rock joint, Direct shear test, Photogrammetry.

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1- Introduction

The rock mass is an assemblage of joints and rock blocks. The presence of joints controls the strength and deformation properties of natural and engineering structures, such as rock slopes and underground excavations. Natural joints inherently possess asperities that radically alter the mechanical behavior. Mechanical properties of rock joints govern the strength and deformational behavior of a rock mass. The responses of a rock joint to shear and normal loadings highly depend on its surface properties, block size, and matching state. In rock mass stability analysis, one of the most crucial factors to be considered is the joint shear strength. The existence of rock joints significantly decreases the strength and considerably influences the instability of rock masses along which sliding can easily occur. Understanding the shear behavior and predicting the shear resistance parameters of rock joints is a key step in the design of shallow depth geotechnical projects.

Nowadays, developing models based on surface morphological characteristics is more accepted among researchers due to its reasonable accuracy and lower cost. The final aim of using the models based on surface morphology is to estimate the joint shear resistance using known parameters without performing tests. These criteria have some shortcomings which were well explained by Li et. al..

This study investigates the shear behaviour of natural rock joints without filling obtained from core drilling . The surface morphological characteristics of the natural joints were captured by Close-Range Photogrammetry. The direct shear tests were performed on the Constant Normal Load condition. The Gene Expression Programming algorithm was used to obtain the relationships between variables. In order to develop the model, 70% of data was used to train, and the remaining 30% to test. Overall, four models were run and a mathematical relationship was introduced to estimate the shear strength of natural rock joints. To evaluate the efficiency of the models, valid criteria were used such as: R^2, MSE, MAE, RSME. Results showed that the GEP algorithm had an appropriate accuracy for estimation of the output variable.

2- methods

To investigate the shear behavior of natural rock joints, direct shear tests have performed on 52 natural sample joints under Constant Normal Load conditions. The samples were cores obtained from different burial depths. The close-range photogrammetry (CRP) was used to survey the 3D surface morphology of joint samples (Fig.1).

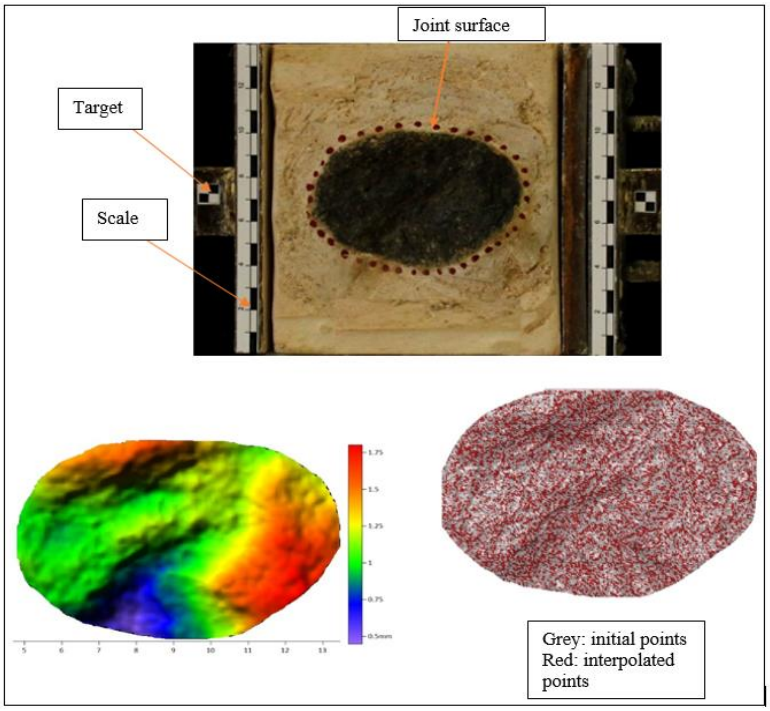

Fig. 1. Photogrammetry procedure

The uniaxial compressive strength (UCS) and Brazilian (indirect tensile) tests were used to determine the compressive and tensile strength of the specimens. Samples with length to diameter ratios of 2.2 to 2.5 and 0.5 are used to perform UCS and Brazilian tests, respectively. The saw cut samples were also used to measure the basic friction angle. To minimize the deviation of the results, each test was repeated six times. Results were presented in Table 1.

Table 1. Geo-mechanical properties of samples

Lithology	Diameter (mm)	ϕ_b (°)	σ_n (MPa)	τ_{max} (MPa)	σc (MPa)	σ_t (MPa)
Gneiss	47-63	22.7	1.4 - 1.7	1.3 - 4	30	4.2
Schist	45-63	28	1.5 – 8.9	1.7 - 3	24	4
Quartzite	45-63	25	2.7 – 4.3	2.6 - 6	40	8

3- Findings and Argument

Gene expression programming, a genotype/phenotype genetic algorithm (linear and ramified), is presented here as a new technique for relationships. The process begins with the random generation of the chromosomes of the initial population. Then the chromosomes are expressed and the fitness of each individual is evaluated. The individuals are then selected according to fitness to reproduce with modification, leaving progeny with new traits. The individuals of this new generation are, in turn, subject to the same developmental process: expression of the genomes, confrontation of the selection environment, and reproduction with modification.

The process is repeated for a certain number of generations or until a solution has been found. In order to develop the model, 70% of data was used to train, and the remaining 30% to test. To evaluate the efficiency of the models, valid criteria were used such as: R^2, MSE, MAE, RSME. MSE, MAE, RSME. Four GEP models are implemented based on different modes of combining input variables according to Table 2, and their results are described in Table 3.

Table 2. GEP models in different modes

Models	Input variables				
A	A_0	ϕ_b	σ_n/σ_t	θ_{max}/C	$A_0\,\theta_{max}/1+C$
B	A_0	ϕ_b	σ_n/σ_t	$\theta_{max}/1+C$	$A_0\,\theta_{max}/1+C$
C	A_0	ϕ_b	σ_n/σ_c	θ_{max}/C	$A_0\,\theta_{max}/1+C$
D	A_0	ϕ_b	σ_n/σ_c	$\theta_{max}/1+C$	$A_0\,\theta_{max}/1+C$

Table 3. Results of GEP models according to table 2

Models	Fitness stage	R^2	MSE	RSME	MAE	RSE	Fitness function
A	Train	0.911	0.207	0.463	0.355	0.101	682.2
	Test	0.833	0.195	0.444	0.303	0.163	688.5
B	Train	0.877	0.195	0.437	0.284	0.118	697.7
	Test	0.795	0.413	0.677	0.523	0.247	617.8
C	Train	0.908	0.171	0.428	0.299	0.111	717.3
	Test	0.546	0.615	0.735	0.618	0.688	551.5
D	Train	0.838	0.185	0.441	0.343	0.157	688.8
	Test	0.861	0.711	0.781	0.572	0.247	567.5

According to the results, the first and fourth models have the highest prediction accuracy.

4- Conclusions

- One of the capabilities of the GEP method compared to other intelligent methods was the ability to establish an implicit relationship between the input and the output variables of the model.
- The gene expression programming algorithm was able to estimate the shear strength of natural joints with acceptable accuracy.
- 36 samples were obtained based on the optimal data to provide a prediction model in this study.

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