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Genetic programming approach for estimating the deformation modulus of rock mass using sensitivity analysis by neural network

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ABSTRACT

We use genetic programming (GP) to determine the deformation modulus of rock masses. A database of 150 data sets, including modulus of elasticity of intact rock (*Ei*), uniaxial compressive strength (*UCS*), rock mass quality designation (*RQD*), the number of joint per meter (J/m), porosity, and dry density for possible input parameters, and the modulus deformation of the rock mass determined by a plate loading test for output, was established. The values of geological strength index (*GSI*) system were also determined for all sites and considered as another input parameter. Sensitivity analyses are considered to find out the important parameters for predicting of the deformation modulus of rock mass. Two approaches of sensitivity analyses, based on "statistical analysis of *RSE* values" and "sensitivity analysis about the mean", are performed. Evolution of the sensitivity analyses results establish the fact that variable of *UCS*, *GSI*, and *RQD* play more prominent roles for predicting modulus of the rock mass, and so those are considered as the predictors to design the GP model. Finally, two equations were achieved by GP. The statistical measures of root mean square error (*RMSE*) and variance account for (*VAF*) have been used to compare GP models with the well-known existing empirical equations proposed for predicting the deformation modulus. These performance criteria proved that the GP models give higher predictions over existing empirical models.

1. Introduction

The deformation modulus of a rock mass is one of the crucial parameters that must be considered in the design stage of surface and underground rock engineering structures. However, the determination of this modulus remains one of the most troublesome tasks in the field of rock mechanics. The direct procedures for estimating the modulus, such as plate jacking, plate loading, radial jacking, flat jack, etc., requires extensive, time consuming and difficult procedures.

Due to the difficulties encountered during the in situ tests, developing of predictive models to estimate the deformation modulus based on the rock mass properties was always an attractive study domain among the rock engineers [1–19]. In this regard, there are too many parameters that affect the deformability of rock mass, and so it is generally impossible to develop a universal model that can be used in any practical way to predict the modulus of rock mass.

In recent years, new soft computing methods such as artificial neural networks (ANN), fuzzy logic and neuro-fuzzy systems were employed to estimate the modulus of deformation [16,17]. These techniques become more attractive because of the information processing characteristics of those, such as non-linearity, high parallelism, robustness, fault and failure tolerance and their capability to generalize. In spite of that, these methods are thriving in prediction; their insufficiency to clearly give prediction equations can cause problems in practical circumstances. Genetic programming (GP) is another soft computing method which can be a candidate to overcome this problem. However, a genetic programming model to determine the modulus of rock masses is still not available. The present study involves application of the genetic programming concept, as the first attempt to predict the deformation modulus of rock masses. The main advantage of GP based approaches is their ability to generate prediction equations which can be manipulated in practical circumstances without any difficulty.

The purpose of the current research involves selection of the input parameters, among the rock mass properties, for preparing GP model with the aid of sensitivity based neural network analyses, construction of new prediction formulae for estimation of the modulus based on GP approach using plate loading test data, and comparison between the results of GP models and existing empirical equations.

2. Structure of database

The data used in this study were collected from the galleries and the geotechnical boreholes at the four dam sites, namely,

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Siah-Bishes dam site, Parsian dam site, Bakhtiari dam site, and Gotvand dam site located on Asmary Formation in Iran. This formation is heavily jointed and so determination of the in-situ deformation modulus is very important for optimizing engineering design of similar projects.

The data sets include the modulus deformation of rock masses, were determined by using plate loading tests: modulus of elasticity (E_i), uniaxial compressive strength (*UCS*), rock mass quality designation (*RQD*), dry density (density), porosity (n), number of joints per meter. To determine the uniaxial compressive strength and modulus of elasticity, intact core rock specimens having a diameter of 54 mm were taken from the geotechnical boreholes. *RQD* and the number of joints per meter of length were measured using the rock cores obtained from boreholes with 7 m depth driven exactly under the plate loading test section. Also, the values of geological strength index (*GSI*) system was determined for all sites and considered as an input parameter. As is well-known from the literature, the value of *GSI* is one of the vital parameter used in the Hoek and Brown failure criterion. Hoek and Brown empirical failure criterion has been modified many times by its originators and some other researchers [21–25]. The *GSI* system was introduced to the Hoek and Brown failure criterion by Hoek and Brown [22]. The *GSI* system concentrates on the description of two factors, rock structure and blocks surface conditions and is widely utilized for the estimation of the rock mass strength and the rock mass deformation parameters [10]. Only visual interpretation is used in the original

Table 1
Statistical evaluations of the parameters and a summary of the discontinuity properties of the rock masses gathered from studied location.

Property	Location	Min	Max	Mean	Count
E_m (GPa)	Siah-Bisheh	2	15	9.43	21
	Parsian	4.5	19	9.85	30
	Bakhtiari	3	28	11.3	56
	Gotvand	1	10	5.78	43
E_i (GPa)	Siah-Bisheh	12	65	45.62	21
	Parsian	10.5	53	39.11	30
	Bakhtiari	42	85	74.84	56
	Gotvand	3	56	37.25	43
UCS (MPa)	Siah-Bisheh	49	85	78.26	21
	Parsian	20	102	75.65	30
	Bakhtiari	55	180	141.43	56
	Gotvand	10	125	82.72	43
GSI	Siah-Bisheh	39	64	48.16	21
	Parsian	48	76	57.35	30
	Bakhtiari	35	82	54.71	56
	Gotvand	26	71	51.65	43
RQD	Siah-Bisheh	20	82	51.52	21
	Parsian	45	90	64.47	30
	Bakhtiari	45	98	55.81	56
	Gotvand	25	80	47.25	43
J/m	Siah-Bisheh	5	14	8.87	21
	Parsian	2	11	6.65	30
	Bakhtiari	1	10	6.85	56
	Gotvand	5	13	8.18	43
Porosity	Siah-Bisheh	0.02	19.7	7.68	21
	Parsian	0.03	15.45	6.32	30
	Bakhtiari	0.6	24.6	5.17	56
	Gotvand	0.5	15.6	5.83	43
Density (g/cm^3)	Siah-Bisheh	2.21	2.85	2.48	21
	Parsian	2.38	2.67	2.55	30
	Bakhtiari	2.42	2.83	2.58	56
	Gotvand	2.25	2.75	2.54	43
Bedrock type	Siah-Bisheh	Shale, sandstone-quartzite and limestone			
	Parsian	Limestone			
	Bakhtiari	Limestone and marl-lime stone with silica-veins			
	Gotvand	Sandstone, siltstone and mudstone			
Roughness of discontinuity[a]	Siah-Bisheh	Generally slightly rough and infrequently rough			
	Parsian	Generally slightly rough and infrequently rough			
	Bakhtiari	Slightly rough			
	Gotvand	Slightly rough			
Spacing of discontinuity[a]	Siah-Bisheh	Generally close and infrequently moderate			
	Parsian	Generally moderate and infrequently wide			
	Bakhtiari	Generally moderate and infrequently wide			
	Gotvand	Generally close and infrequently moderate			
Weathering degree[a]	Siah-Bisheh	Slightly weathered			
	Parsian	Slightly weathered			
	Bakhtiari	Unweathered, occasionally slightly weathered			
	Gotvand	Slightly to moderate weathered			

[a] According to the ISRM's classification [20].