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Application of artificial neural networks and multivariate statistics to estimate UCS using textural characteristics

Amin Manouchehrian [a], Mostafa Sharifzadeh [b,*], Rasoul Hamidzadeh Moghadam [a]

[a] Department of Mining Engineering, Sahand University of Technology, Tabriz, Iran
[b] Department of Mining, Metallurgy and Petroleum Engineering, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

Before any rock engineering project, mechanical parameters of rocks such as uniaxial compressive strength and young modulus of intact rock get measured using laboratory or in-situ tests, but in some situations preparing the required specimens is impossible. By this time, several models have been established to evaluate UCS and *E* from rock substantial properties. Artificial neural networks are powerful tools which are employed to establish predictive models and results have shown the priority of this technique compared to classic statistical techniques. In this paper, ANN and multivariate statistical models considering rock textural characteristics have been established to estimate UCS of rock and to validate the responses of the established models, they were compared with laboratory results. For this purpose a data set for 44 samples of sandstone was prepared and for each sample some textural characteristics such as void, mineral content and grain size as well as UCS were determined. To select the best predictors as inputs of the UCS models, this data set was subjected to statistical analyses comprising basic descriptive statistics, bivariate correlation, curve fitting and principal component analyses. Results of such analyses have shown that void, ferroan calcitic cement, argillaceous cement and mica percentage have the most effect on USC. Two predictive models for UCS were developed using these variables by ANN and linear multivariate regression. Results have shown that by using simple textural characteristics such as mineral content, cement type and void, strength of studied sandstone can be estimated with acceptable accuracy. ANN and multivariate statistical UCS models, revealed responses with 0.87 and 0.76 regressions, respectively which proves higher potential of ANN model for predicting UCS compared to classic statistical models.

1. Introduction

In many rock engineering projects, the uniaxial compressive strength of intact rock (UCS) is not measured by laboratory tests, because performing such tests needs high quality samples and sophisticated equipments. In many situations it is too difficult to prepare standard core samples from weak, stratified (thinly bedded), highly fractured and block-in-matrix rocks. For solving this problem which arises during the core sample preparation, some predictive models considering simple index parameters such as Schmidt hammer, point load, block punch, and physical and petrographical properties were developed by many researchers [1–8], because these index tests require relatively small samples when compared with the uniaxial compressive strength test samples. Despite some deficiencies, index tests, when coupled with experienced judgment, can provide initial estimate of rock properties required at the feasibility and design stage.

As view of structural point, rock is the combination of some minerals and the cement exist between them which various combinations of them forms rocks with various properties (physical properties, chemical properties, mechanical properties, magnetic properties, etc). Mechanical properties of rocks are a function of its structure such as mineral content, porosity, number of weak planes and texture of itself. In fact, mineral content and porosity explain the genus of forming materials and their packing density, quality of structural materials will be explained by considering the number of micro cracks exist in the body of rock and configuration of forming materials and their linkage will be explained by texture of rock. By knowing these three parameters, mechanical properties of every composite material will be recognized more accurately.

In recent years, many researchers have focused on the relationship between textural and mechanical properties [1,5,9–13]. Results have shown that mechanical properties of rocks are a function of the

* Corresponding author. Tel.: +98 (21) 6454 2952.
E-mail address: sharifzadeh@aut.ac.ir (M. Sharifzadeh).

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textural properties. These research results show that mechanical properties of rock depends on its textural characteristics and most effective parameters are mineral content, grain size, grain shape and porosity. Thus some researchers by using classic statistical methods and recently by developing intelligent techniques, by using them have established models based on textural characteristics to estimate mechanical parameters of rock [1,14–19]. In these models textural characteristics were chosen as inputs of models which were not easy to determine. So these models didn't become popular ones.

Singh et al. (2001) employed ANN to estimate mechanical parameters of rock. In their studies they used parameters as inputs of predictive models which were not simple to determine and needed to use up much time and use specific equipments [16]. Also Tamrakar et al. (2007) established models to estimate mechanical parameters of sandstone which their studies suffered from the above problem [17].

In this paper, two ANN and multivariate statistical models are presented which have potential of predicting UCS with acceptable accuracy using some simple textural parameters. This ease of use can cause popularity of this method for estimating different parameters of rocks such as mechanical properties, physical properties, magnetic properties, etc.

2. Siwalik sandstone

Analyses that were carried out in this study on the relationships between UCS and rock textural characteristics have been based on the data obtained by Tamrakar et al. (2007) [17]. They tried to find relationships among mechanical, physical and petrographic properties of Siwalik sandstones, central Nepal sub-Himalayas by performing statistical analyses. Textural configurations and UCS of studied samples are summarized in Table 1. Also two representative thin-section images of studied samples are shown in Fig. 1.

Petrographic analyses have shown that quartz, feldspar and lithic fragments vary from 32% to 66%, 3% to 16% and 0 to 24%, respectively in these samples (Table 1). Quartz is mostly undulosed monocrystalline to polycrystalline, and some are non-undulosed. Feldspar is both K-feldspar and plagioclase. Lithic fragments are often quartz-mica tectonite, quartz-mica aggregate, quartz-mica-feldspar aggregate, and argillite-shale. Among the micas, biotite and muscovite are substantial whilst chlorite is minor. Heavy minerals form minor constituents in sandstones. Matrix forms 0% to 18% and occurs as primary and secondary alteration products. Total cement ranges between 6% and 41%. Ferroan calcitic cement occurs as pore occluding, replacing and fracture-filling cements. Besides, ferruginous and argillaceous cements occur as grain coats and

Table 1
Some properties of the rock samples.[17]

No.	Q (%)	Fl (%)	Cfc (%)	Cf (%)	Cs (%)	Ca (%)	M (%)	n (%)	Mx (%)	L (%)	Mz (mm)	UCS (MPa)
1	49	6	1	0	7	8	1	9	12	7	2.13	7.9
2	52	5	7	10	6	3	2	7	3	4	2.11	11.2
3	48	14	0	1	3	3	4	4	17	5	2.8	12.6
4	32	9	10	1	7	8	15	4	9	2	3.01	51.6
5	55	4	3	3	2	1	3	4	12	9	1.74	28.8
6	41	7	0	0	15	5	18	1	11	1	2.97	49.8
7	66	5	9	1	3	3	3	1	5	3	2.55	47.5
8	59	3	0	10	6	3	2	5	5	7	2.15	29.4
9	32	8	0	2	4	15	15	8	13	2	3.12	28.7
10	36	8	2	1	5	9	8	9	16	5	2.64	18.5
11	50	12	0	0	5	7	5	9	9	2	2.77	12.6
12	39	9	0	2	2	2	16	10	18	1	2.76	34.8
13	53	6	0	4	6	8	3	5	10	4	2.54	29.3
14	48	10	0	14	5	4	3	6	8	2	2.44	15.2
15	37	13	2	8	5	14	3	8	6	4	2.58	1.29
16	54	8	1	1	4	5	3	7	5	11	1.53	9.57
17	41	8	21	1	0	1	5	6	2	14	1.44	19
18	31	12	32	0	0	0	8	4	1	10	1.96	32.2
19	44	6	24	4	1	3	4	6	4	4	2.07	9
20	34	8	28	1	1	0	5	1	1	20	1.72	19.2
21	36	8	25	0	0	0	2	7	1	20	0.95	21.8
22	23	3	34	3	3	1	19	4	10	0	2.74	31.9
23	38	7	23	0	0	0	3	3	1	1	0.78	42.7
24	32	15	14	7	0	1	12	5	2	1	0.99	9.8
25	34	16	14	0	0	0	8	6	2	2	0.99	21.4
26	27	9	21	2	0	2	11	9	3	1	1.08	24
27	28	9	29	0	0	0	12	12	6	3	1.22	11.7
28	40	8	31	0	0	0	2	1	1	2	1.05	48.4
29	38	8	27	0	0	0	7	7	1	2	1.01	15.4
30	27	11	33	0	0	1	9	2	2	1	1.05	33.4
31	35	7	32	0	0	1	4	3	1	1	0.99	36.4
32	35	8	30	0	0	1	10	3	1	2	1.07	24
33	37	8	30	0	0	1	5	8	1	3	0.94	8.2
34	29	14	37	0	0	1	7	1	1	2	1.05	48.4
35	35	8	34	0	0	1	6	2	1	1	0.87	25
36	35	7	31	0	0	0	9	6	1	1	0.77	27.8
37	32	10	33	0	0	1	9	3	1	1	0.88	27.9
38	30	15	34	1	0	0	8	1	1	2	0.77	41.4
39	38	12	29	0	0	0	6	2	1	4	1.16	40.4
40	33	12	31	0	0	1	5	1	1	3	0.84	31.6
41	42	11	27	0	0	1	3	2	1	9	0.91	38.5
42	34	11	32	0	0	0	6	1	1	3	0.96	48.4
43	35	9	33	0	0	0	6	1	3	3	0.99	43.2
44	32	7	26	1	0	1	9	8	3	2	0.86	7.9

Note: Q, Quartz; Fl, Feldspar; M, Mica; Cfc, Ferroan calcitic cement; Cf, Ferruginous cement (brown to reddish brown iron hydroxides); Cs, Siliceous cement; Ca, Argillaceous cement; n, Void; Mx, Matrix; L, Lithic fragments; Mz, Mean grain size; UCS, Uniaxial compression strength.