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New method for estimating unconfined compressive strength (UCS) using small rock samples

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ABSTRACT

In restricted sampling conditions such as oil well drilling, appropriate rock samples do not exist for measuring unconfined compressive strength (UCS) using conventional standard methods during the excavation. Loading on small rock samples is one of the new feasible methods for assessment of UCS in restricted sampling conditions. In this paper 510 small rock samples of three types of sedimentary rocks (micritic limestone, crystalline limestone and sandstone) are tested in three different sizes (3–5 mm). All samples were loaded with flat ended cylindrical indenters (1 mm diameter) which can apply load on two parallel faces of cubic shaped small rock samples. The rate of displacement in performing load on samples was 1 mm per minute so it can be said that the condition of loading was quasi-static. The test was named as modified point load (MPL) and the obtained results from the MPL test introduced as modified point load force (MPLF). Obtained MPLF from different sizes of small rock samples was correlated with UCS. The high values of coefficient of determination ($R^2 \geq 0.9$) indicate the accuracy of empirical relations. Each group of small rock samples with different sizes had different empirical relations because of the dimension effect of small rock samples. Dimension effect of obtained MPLF is omitted by exchanging the values to tensile stress (σ_{MPL}). The general empirical relation is generated by establishing the UCS–σ_{MPL} correlation ($R^2 = 0.91$). The accuracy of empirical relation was evaluated by assessment of UCS from obtained MPLF values. The estimated UCS values comparatively have 89% conformity with the measured UCS. Therefore, the defined empirical relations have adequate accuracy in estimating UCS from small rock samples.

1. Introduction

Unconfined compressive strength (UCS) has been widely used in civil engineering, mining, geotechnical, and infrastructure projects as one of the most significant geotechnical properties of rocks and its importance has been mentioned by many researchers (Hoek, 1977; Bieniawski, 1976; Barton et al., 1974).

The limitations and strictness in standard methods for determining UCS (American Society for Testing Materials, 1984a, 1984b; ISRM, 1979, 1985) make them all tedious, time consuming, and expensive (Singh et al., 2012). Moreover, obtaining standard core samples is often impossible, especially during oil or gas well drilling. Although indirect experimental or in-situ tests are often used to predict the UCS-such as Schmidt rebound number, point load index, impact strength and sound velocity test-there are not any obtained big scale and usable samples from oil and gas well during the drilling operation for real time UCS prediction by conventional indirect test methods (Garcia et al., 2008). Even the new developed indirect USC estimation methods such as block punch index test (Sulukcu and Ulusay, 2001), core strangle test (Yilmaz, 2009), nail penetration test (Kayabali and Selcuk, 2010), and edge load strength test (Palassi and Pirpanahi, 2013) need large amount and big sizes of rock samples which are not available in these conditions. Conditions in which there are not big scale samples for evaluating the UCS (or any other mechanical properties of rocks) by direct and indirect conventional tests, are named as restricted sampling condition in this paper.

Due to lack of appropriate rock samples, real-time monitoring of the drilled rocks strength parameters is one of the most important geotechnical problems under the restricted sampling condition. The real time monitoring of mechanical properties of drilled formations during the long term deep oil and gas well excavation projects can be vital for estimation of well wall stability (Zausa et al., 1997; Jaramillo, 2004), formation sand production (Nouri et al., 2006), drill bit selection (Uboldi et al., 1999) and drillability of formations (Yarali and Soyer, 2013).

The shortage of samples in restricted sampling condition for real time estimation of rock strength parameters by conventional

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methods has encouraged the researchers to develop nonconventional techniques and methodologies to estimate rock strength using small rock samples. Previous studies have confirmed that tests made on small rock samples can be used to obtain the strength of rock parameters (Ringstad et al., 1998). In 1996, AGIP (trademark of the Italian group ENI) presented a program capable of assessing formations, based on measurements on drilling cuttings. These efforts led to the result that drilling cuttings are sufficiently representative of the formation and are a reliable source of information about their strength's parameters (Santarelli et al., 1996). Consequently, many efforts were performed in the field of the estimation of UCS under restricted sampling condition by using the drilling cuttings such as indentation test (Mateus et al., 2007), continuous wave technique (Nes et al., 2001), loading on reconstructed cores (Mehrabi Mazidi et al., 2012), scratch test (Richard et al., 2012) and single particle loading test (Cheshomi and Ahmadi Sheshde, 2013).

In fact the demand to obtain strength properties which could offer quicker, cheaper, more feasible and accurate results, paved the way for the development of some index tests. One of the most popular of these tests is point load strength index test which was developed about half a century ago and widely used to estimate the USC of rocks (Hiramatsu and Oka, 1966; Jaeger, 1967; ISRM, 1973). With the idea of this well-known method in mind, we introduced the new experimental instrument called modified point load test (MPLT) as an indirect measurement method to estimate UCS using the strength of small rock samples such as drilled rock cuttings.

The main purpose of this paper is to verify the empirical relation between modified point load force (MPLF) and UCS of intact rocks. A total number of 510 small rock samples in three different sizes (3–5 mm) were tested. The average of MPLF for each type of rocks was used for analysis to reduce variation in the dataset. The correlations between MPLF of each size of small rock samples and the corresponding UCS were computed and the obtained experimental relations were used to estimate UCS of obtained MPLF from particles with related sizes.

2. Methodology

Under restricted sampling condition, there are not any big scale rock samples to use in conventional methods for estimating UCS. This paper presents a new simple laboratory method for indirect measurement of UCS of rocks from occasionally obtained small rock samples in restricted sampling condition such as drilling cuttings. The used procedure for UCS estimation in this study consists of development of correlations between obtained UCS from running standard UCS tests on rock cylinders and MPLF obtained from MPLT which were performed on small rock samples as simulated drilling cuttings obtained from the sample cylinders. Procedures which were followed to reach our purpose are as follows which are elaborated in further sections:

– Experimental sample preparation
- Core sampling and preparation from rock blocks.
- Preparation of small rock samples.

– Experimental tests and data acquiring
- UCS test on standard cylindrical rock samples.
- MPLT on small rock samples.

– Experimental data analysis
- Development of correlation between UCS and MPLF.
- Evaluating the dimension effect of small samples on UCS–MPLF correlation.
- Data verification.

3. Sample preparation

Two kinds of samples were prepared in this paper. The first one was the cylindrical core samples used for UCS, obtained from rock block samples and prepared exactly based on ASTM D4543 (American Society for Testing Materials, 2010). Totally 17 rock blocks of limestone and sandstones were collected from different outcrops which are shown in Table 1. Five cores were drilled from each block samples. All cores were checked to be free of cracks, fissures, veins and other discontinuities, which would act as circumstantial surface of weakness and cause an undesirable change of the real properties of intact rock strength.

Small rock samples can be of various shapes including prepared cylindrical or cubic samples or irregular small rock samples with specified dimensions obtained from drilling cuttings. All rock samples were prepared in cubic form. Samples with the same shape were selected to ensure the repeatability of data. Purposefully, in order to evaluate the sample's size effect on experimental

Table 1
Sampling sites, stratigraphic and physical properties of rock samples.

Sample ID	Sampling site	Formation	Age	Rock type	Dry density (g/cm^3)
M-1	Golpanbe-Khorramabad	Asmari	Oligocene	Micritic Limestones	2.60
M-2	Golpanbe-Khorramabad	Asmari	Oligocene		2.72
M-3	Meshgar-Khorramabad	Asmari	Oligocene		2.63
M-4	Khorramabad	Asmari	Oligocene		2.61
M-5	Meshgar-Khorramabad	Asmari	Oligocene		2.64
M-6	Abolabas Dam	Asmari	Oligocene		2.53
M-7	Davan-Kazeroon	Asmari	Oligocene		2.60
C-1	Abnik-Tehran	Mobarak	Carboniferous-Devonian	Crystalline Limestones	2.53
C-2	Abnik-Tehran	Mobarak	Carboniferous-Devonian		2.57
C-3	Abnik-Tehran	Mobarak	Carboniferous-Devonian		2.55
C-4	Garmabdar-Tehran	Lar	Upper-Jurassic		2.48
C-5	Garmabdar-Tehran	Lar	Upper-Jurassic		2.77
C-6	Abnik-Tehran	Mobarak	Carboniferous-Devonian		2.57
S-1	Lorestan	Shemshak	Jurassic	Sandstones	2.39
S-2	Fasham	Shemshak	Jurassic		2.46
S-3	Tehran	Laloon	Cambrian		2.83
S-4	Tehran	Zagoon	Cambrian		2.33