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Evaluation of the unconfined compressive strength of rocks using nail guns

Levent Selçuk [a,*], Kamil Kayabali [b]

[a] Yüzüncü Yıl University, Architectural-Engineering Faculty, Department of Geological Engineering, 65080 Van, Turkey
[b] Ankara University, School of Engineering, Department of Geological Engineering, 06100 Ankara, Turkey

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A B S T R A C T

The penetration depth is one of the major index parameters for indirect determination of the unconfined compressive strength (UCS) of rock. That is, the weaker the rock, the deeper the nail penetration should be, and vice versa. However, the penetration depth depends on the strength of material, the impact energy and nail diameters of nail guns. In order for an empirical equation relating the penetration depth to the UCS to be widely used, the equation should be related to all varieties of gasnailers.

The scope of this investigation is to develop an empirical equation relating the nail penetration depth (h) obtained through nail guns of different energy levels (e) and nail diameters (d) to UCS. In this context, a series of gasnailers with different energy levels and nail diameters were performed on 65 rock blocks. The results of laboratory conducted unconfined compressive test were correlated with nail penetration depth (h), nail gun energy (e) and nail diameter (d) and an empirical equation was established using multiple regression analysis. It covers a relatively wide range of energy levels and nail diameters for commercial gasnailers. The proposed equation can be used to estimate the UCS of intact rocks, thus providing the technical features needed for using commercial gasnailers.

1. Introduction

Uniaxial compressive strength (UCS) is one of the widely used parameters for the mechanical characterization of rocks in engineering practices. The standard method for the direct determination of UCS is performed as required by standard of ASTM or ISRM. While the standard direct method appears to be relatively simple, it is time consuming, comparably costly, and requires carefully prepared rock samples. Additional difficulties exist in relation to the extraction of quality samples. The preparation of standard cylindrical rock samples in weak to very weak rock blocks is quite difficult, if not impossible. For these reasons, the general trend for estimating the compressive strength of intact rocks is to use indirect methods. Although these indirect methods offer great advantages, a large part of the methods require carefully prepared hand specimens or small size rock samples, such as the point load test, PLT (Broch and Franklin, 1972; Bieniawski, 1975; Gunsallus and Kulhawy, 1984; Kahraman, 2001; Yilmaz and Sendir, 2002; Sonmez and Osman, 2008), block punch index, BPI (Ulusay et al., 2001), core strangle test, CST (Yilmaz, 2009), impact strength test, IST (Hobbs, 1964; Singh, 1981; Goktan, 1988; Fener et al., 2005), reconstructed cores, RC (Mehrabi Mazidi et al., 2012), indentation test, IT (Zausa and Civolani, 2001), and single particles load test, SPLT (Cheshomi and Sheshde Ahmadi, 2013). The main advantages of indirect methods are practicability, portability, and cost effectiveness, and they employ quick and non-destructive devices for widespread usability. In this respect, some methods have these properties and usually do not require sample preparation, such as the Schmidt hammer rebound (SHR) and the ultrasonic pulse velocity (UPV) tests (Schmidt, 1951; Deere and Miller, 1966; Aufmuth, 1973; Inoue and Ohomi, 1981; Shorey et al., 1984; O' Rourke, 1989; Shalabi et al., 2007; Vasconcelos et al., 2008; Mishra and Basu, 2013). However, calibration and improper functioning of instruments, surface irregularities of the rock, the existence of nearby discontinuities, surface conditions, and pores and fractures are the main common factors affecting SHR and UPV values. These factors control the consistency and reliability of these indirect index tests. For these reasons, the nail penetration test (NPT) was proposed as an alternative to indirect in-situ test methods (Kayabali and Selcuk, 2010). The major tool for the test technique is a gasnailer, commercially known as "Power Fasteners Tract It-C4®." The gasnailer operates using a gas cartridge that exerts as high as 120 J of power on a pointy nail 2.6 mm in diameter. For this technique, the depth of nail penetration is an indicator of rock strength. The deeper the nail penetration of the nail, the weaker the rock should be, and vice versa. However, the results obtained through the NPT method are valid only for the gasnailer mentioned above. Commercially available gasnailers have a wide range of energy levels and nail diameters. The other available gasnailers are expected to yield different results, unless they have similar features such as the

* Corresponding author.
E-mail addresses: lselcuk@yyu.edu.tr (L. Selçuk), kayabali@ankara.edu.tr (K. Kayabali).

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applied energy and type of nail. In order for an empirical equation relating the nail penetration depth to UCS to be widely used, the equation should be related to all varieties of gasnailers.

The objective of this investigation is to develop an empirical equation between the UCS and nail penetration depth (h), energy level (e), and nail diameter (d) for gasnailers. In order to determine the best empirical correlations between the UCS and the variable parameters (i.e., h, e, and d) of the gasnailers, a wide range of experimental data was analyzed using regression analysis. The most remarkable aspect of this investigation has been that almost all commercial gasnailers with different energy levels and nail diameters can be used for determining the compressive strength of the intact rocks.

2. Nail penetration test (NPT)

The nail penetration test was proposed by Kayabali and Selcuk (2010). The hypothesis for their investigation is that there should be a relationship between nail penetration depth and the intact rock strength. That is, the weaker the rock, the deeper the nail penetration should be, and vice versa.

The major tools include a gasnailer, Tract It-C4, and a series of concrete nails ranging from 25 to 60 mm in length. Although nails are used in many different types, straight nails are more appropriate for this investigation. The nails are manufactured from grade 1060 to 1065 steel and austempered to a core hardness of Rockwell C Hardness (RC) 51 to 55 (PFI, 2010). Nails are driven into the rocks using compressed and highly flammable gases, such as butane and propane. The Track-It C4 gasnailer uses the gas cells which contain the compressed gas. As the gas supply is constant, through a repeated nailer action, the nail is driven into the material under a constant pressure. The variation of the driving power is $\pm$0.01 for all gasnailers (Selcuk et al., 2012).

The capability, reliability, and consistency of the device are very high for estimating the compression strengths of rocks. Kayabali and Selcuk (2010) reported that the UCS of very weak to moderately strong rocks (UCS < 100 MPa) can be estimated with an appreciable degree of accuracy. Researchers also used the Schmidt hammer rebound (SHR) and point load (PLT) tests to compare the reliability of the NPT. The comparisons between the measured UCS values and computed UCS values from the SHR, PLT, and NPT revealed that SHR and PLT significantly underestimate the UCS, while the NPT provides a somewhat better estimate for the UCS than the SHR or PLT.

This technique was also performed for concrete samples to determine the actual normal-strength of in-situ concrete. It was also found that the NPT provides a better estimate for concrete strength than some other common non-destructive testing (NDT) techniques, such as the ultrasonic pulse velocity test (UPV), Windsor probe test (WP), and the Schmidt hammer rebound (SRH) (Selcuk et al., 2012).

Additional advantages of NPT are that it does not require a sample preparation procedure or purposeful design of device to determine the UCS of rocks. This means that gasnailers, an extremely common tool used in many aspects of construction, particularly in residential applications, are a viable tool for testing.

Regarding its use, the gasnailer (nail gun) can be held in any position. Herein, the penetration depth readings are not affected by the orientation of the gasnailer. However, the gasnailer should be held at nearly a right angle to the rock surface (Fig. 1). Shots deviating significantly from perpendicularity cause chiseling of the rock surface and bending of the nails outside the rock. In this case, the test should be rejected and invalidated. The gasnailer is used both in-situ and laboratory studies. The applications are carried out in such a way that the shot points are sufficiently further from the edges of rock blocks (>75 mm) in order to prevent disintegration and the minimum thickness of the rock sample is about three times the expected depth of penetration. Five shots should be performed on rock block. The length of the nails outside the rock is measured by a digital caliper (sensitive to 0.01 mm), and the average penetration depth of five shots is obtained after deducting these lengths of nails from their total lengths.

The repeatability of the proposed method was also sought in their investigation. A series of nail penetration tests were conducted on large blocks of andesite and ignimbrite with machine-flat surfaces. Thirty-nine shots made on the andesite block yielded the mean and minimum and maximum values of 21.98, 20.03, and 25.16 mm, respectively. The standard deviation was 1.26 mm, and fifty shots on the ignimbrite block yielded the mean and minimum and maximum values, 34.24, 32.22, and 35.46 mm, respectively. The standard deviation for this group of measurements was 0.86 mm. Those two series of tests demonstrate that the proposed method is repeatable for gasnailers (Kayabali and Selcuk, 2010).

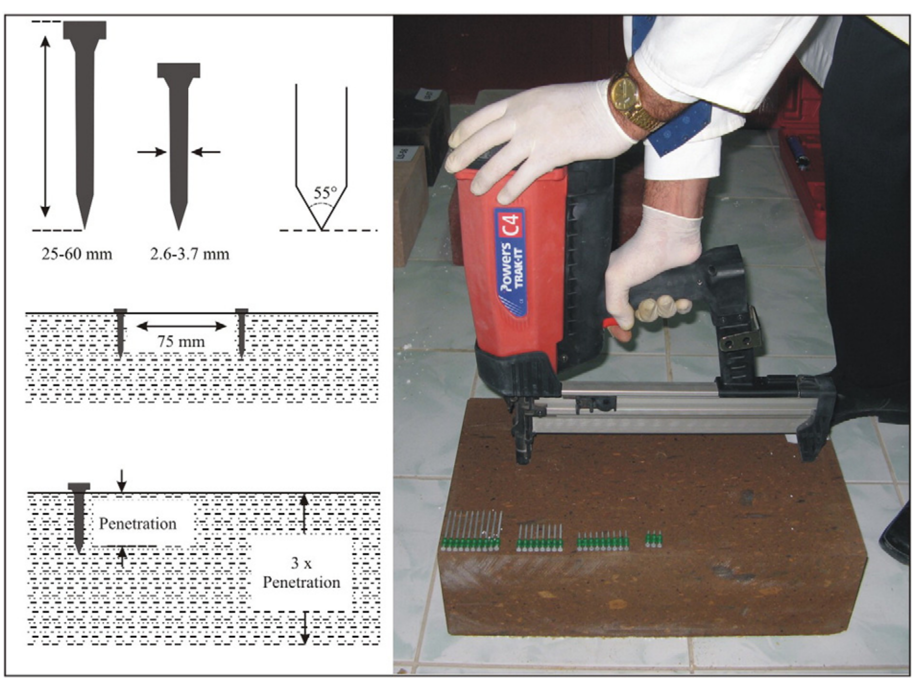

Fig. 1. The concrete gasnailer and the nail cartridges utilized in NPT.