DOI: https://doi.org/10.68732/c57b3c4f1deac73d

ISBN: 978-9989-2053-6-1

Assessing the uniaxial compressive strength of limestones using indirect testing methods

N. Salčin
Hidrozavod DTD, Belgrade, Serbia
nino.salcin@hidrozavoddtd.rs
0009-0002-3884-616X

M. Marjanović
Faculty of Mining and Geology, Belgrade, Serbia
milos.marjanovic@rgf.bg.ac.rs
0000-0002-9675-1401

Abstract

The uniaxial compressive strength of rocks is a key design parameter, but its reliable determination remains a challenge due to the heterogeneity, cracking, and anisotropy of rock materials. Standard laboratory testing of uniaxial compressive strength gives the most accurate results, but is challenging, expensive, and often limited by sample quality and availability. Therefore, indirect methods are widely used in practice. This paper presents research on limestones from the Belgrade area to determine correlations between compressive strengths obtained using different indirect testing methods. A total of 156 samples were tested, on which needle penetration tests, Schmidt hammer tests, and point load tests were conducted. Numerous existing correlations across different tests and lithologies were considered; a testing procedure combining all three tests was given, and the results can serve as a basis for optimizing future geotechnical investigations of Sarmatian limestones in the Belgrade area.

Keywords

Uniaxial compressive strength, Needle penetration test, Point load test, Schmidt hammer test.

1 Introduction

Uniaxial compressive strength (UCS) is one of the basic parameters in geotechnical design. Although direct laboratory testing is considered the most reliable, it is often expensive, time-consuming, and limited by sample quality. Therefore, indirect methods are widely used in practice, enabling a quick and economical assessment of strength in the field or with minimal sample preparation.
Some methods for the indirect determination of compressive strength include the point load test, the Schmidt hammer test, and the needle penetrometer test. These methods do not directly measure a strength value but instead index parameters that are translated into UCS via empirical correlations. However, the reliability of these correlations depends strongly on rock type, so it is recommended to determine local correlations when possible.

2 Geology and sampling

The samples used in the study were obtained from exploratory boreholes drilled in the Belgrade territory as part of geological investigations for the construction of the metro system. Lithologically, the samples belong to Sarmatian limestones. A significant variability in physico-mechanical properties has been observed, despite the similar lithology. Some samples are characterized by compact, high-strength limestones, Fig 1, while others consist of sandy, more porous limestones with considerably weaker mechanical properties, Fig 2. This heterogeneity significantly impacts test results.



Fig. 1 High-strength limestones.



Fig. 2 Weaker sandy limestones.

3 Methodology

To estimate uniaxial compressive strength, three indirect methods were used: the Point Load Test (PLT), the Schmidt hammer test, and the needle penetration test. The obtained results were interpreted using existing empirical correlations.

The Point Load Test was performed on unprepared core samples with a diameter of 83 mm. The obtained point load strength index was initially corrected to the standard sample diameter of 50 mm, in accordance with the recommendations of the International Society for Rock Mechanics (ISRM 1985), and then multiplied by a correction factor to estimate the uniaxial compressive strength.

Various empirical relationships from the literature were used to estimate UCS, among which the most commonly applied are those proposed by Broch and Franklin (1972) and Bieniawski (1974). See Eq.1.

$$UCS = 24 \times Is_{(50)} \tag{1}$$

Where UCS Unconfined compressive strength
24 Correction factor
$Is_{(50)}$ Corrected point load strength index

Although this correlation is straightforward, numerous authors report significant variability in the coefficients depending on the type of rock being tested (Kahraman, 2001; Tsiambaos and Sabatakakis, 2004), which limits its application without local calibration.

The Schmidt hammer test is a very fast and simple method that measures the rebound, which is then used to indirectly determine uniaxial compressive strength. Despite its simplicity, different correlations are used depending on the rock type. In this study, an L-type hammer was used, which is suitable for testing rocks of lower strength. Empirical correlations proposed by Deere and Miller (1966), Singh et al. (1983), and Kilic and Teymen (2008) were used to estimate UCS. However, as noted by numerous authors, there is no universal correlation applicable to all rock types, since the results are significantly influenced by factors such as surface roughness (Hucka 1965), moisture content (Sumner and Nel 2002), and the degree of rock weathering (Williams and Robinson 1983).

The needle penetration test is a highly practical method that can be easily applied to rocks with weaker physico-mechanical properties, where more complex testing cannot be performed. This method measures the needle's penetration depth under a defined load, yielding the needle penetration index (NPI). The NPI values were then used to estimate UCS through empirical correlations from the literature (Ulusay and Erguler 2012; Aydan and Ulusay 2013; Kahraman et al. 2017). As with the previous methods, it has been observed that correlation coefficients vary significantly with lithology, confirming the need to determine conversion factors specific to the rock type being tested (Aydan 2012).

4 Results and discussion

In total, 156 point load tests, 125 Schmidt hammer tests, and 76 needle penetration tests were performed, providing a representative database for analyzing relationships among different strength-determination methods.
During testing, the most effective sequence was to first perform the Schmidt hammer test. If the rebound value of the L-type Schmidt hammer was below 10 or if surface damage occurred, the use of the needle penetration test was recommended. If the rebound value exceeded 10, it was advisable to skip the needle penetration test to avoid damaging the needle and to perform the Point Load Test instead. This is the reason why not all tests were conducted on every sample. If the needle penetration test is used, it is recommended to perform it on an undamaged, flat surface and on a homogeneous sample without cracks that could lead to excessive needle penetration.

In the point load test, it was observed that different empirical relationships produce a similar trend in strength variation, but the absolute values differ significantly, in some cases by more than 200%. Despite this, the test demonstrates relatively stable behavior and can be considered reliable when an appropriate correction factor is applied for the specific lithology.
The results of the needle penetration test indicate its good applicability to weaker, more porous samples, for which other methods give unreliable results. However, its sensitivity to testing procedure and sample surface quality can lead to significant errors, since the maximum penetration depth is only 10 mm, and even small reading errors can result in large discrepancies.
The Schmidt hammer test shows certain limitations when applied to weaker rocks. In sandy limestones, rebound was often absent due to surface damage, rendering the Schmidt hammer method unusable. For stronger samples, the test results were usable but showed significant dependence on the selected correlation equation.

The results show considerable discrepancies in the UCS values obtained from different correlations across all three methods. Since no direct uniaxial compressive strength tests were performed, it was not possible to determine an exact correlation factor for the tested limestones. Nevertheless, certain relationships between the index parameters obtained from different tests can still be established. Fig 3 shows a linear correlation between the needle penetration index and point load strength, and Fig 4 shows a linear correlation between the Schmidt hammer rebound value and point load strength.

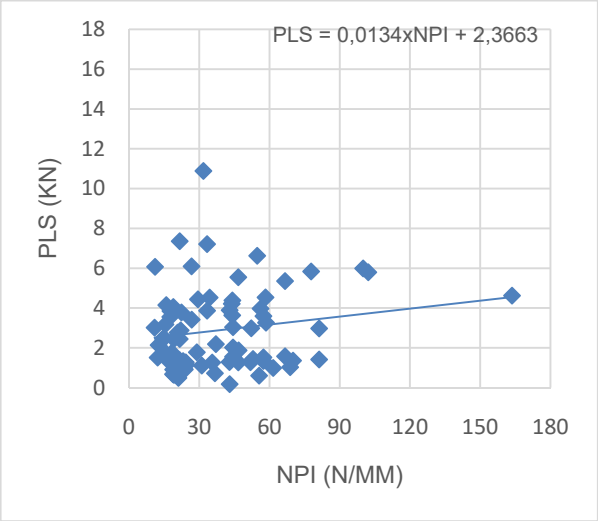


Fig. 1 PLS-NPI correlation in limestones (linear).

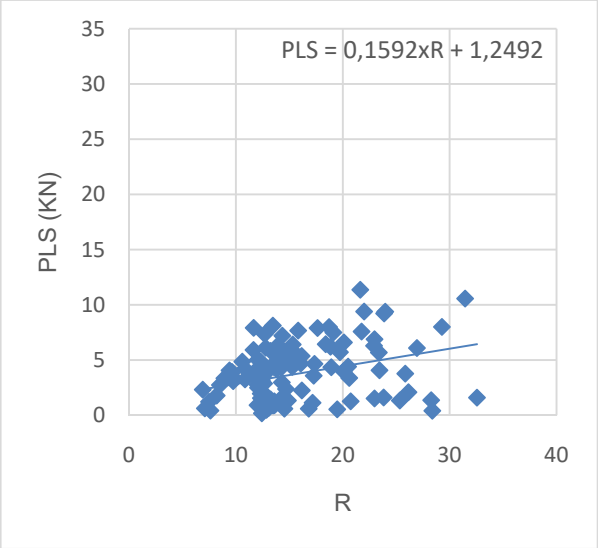


Fig. 2 PLS-R correlation in limestones (linear).

Deriving correlations between UCS and NPI of R via PLS has proven to be imprecise due to large differences in compressive strength if the correction factor is changed. See Eq.1

5 Conclusion

Based on the conducted research, it can be concluded that the selection of a method for estimating uniaxial compressive strength (UCS) largely depends on the rock's physico-mechanical properties.

The Point Load Test proved to be the most universal method; however, it requires careful selection of the appropriate correlation when calculating UCS. The needle penetration test is particularly suitable for weak rocks, where other methods do not yield reliable results. The Schmidt hammer test is a good alternative to the needle penetrometer when dealing with stronger rocks where the needle penetrometer cannot be used effectively. However, as with all indirect methods for determining compressive strength, caution is required when selecting the equations used to estimate UCS.

Based on the results, it can be concluded that a reliable estimate of UCS cannot be based on a single method or correlation. Instead, it is necessary to combine multiple methods and perform local calibration based on direct testing. Additionally, the results obtained can serve as a basis for optimizing future geotechnical investigations of Sarmatian limestones in the Belgrade area.

6 References

Aydan Ö (2012) The inference of physico-mechanical properties of soft rocks and the evaluation of the effect of water content and weathering of their mechanical properties from needle penetrometer tests. American Rock Mechanics Association, Alexandria, VA

Aydan Ö, Ulusay R (2013) Geomechanical evaluation of Derinkuyu antique underground city and its implications in geoengineering. Rock Mechanics and Rock Engineering 46(4): 731–754. https://doi.org/10.1007/s00603-012-0301-7

Bieniawski ZT (1974) Estimating the strength of rock materials. Journal of the Southern African Institute of Mining and Metallurgy 74: 312–320. https://doi.org/10.1016/0148-9062(74)91782-3

Broch E, Franklin JA (1972) The point-load strength test. International Journal of Rock Mechanics and Mining Sciences 9: 669–697. https://doi.org/10.1016/0148-9062(72)90030-7

Deere DU, Miller RP (1966). Engineering classification and index properties for intact rocks. Report AFNL-TR. Air Force Weapons Laboratory, New Mexico

Hucka V (1965) A rapid method of determining the strength of rocks in situ. Scientific Coal Research Institute, Ostrava-Radvanice, Czechoslovakia

ISRM Commission on Testing Methods, Working Group on Revision of the Point Load Test Method (1985). Suggested method for determining point load strength (Coordinator Franklin JA). International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts 22: 51–60. https://doi.org/10.1016/0148-9062(85)92327-7

Kahraman S (2001). Evaluation of simple methods for assessing the uniaxial compressive strength of rock. International Journal of Rock Mechanics and Mining Sciences 38: 981–994. https://doi.org/10.1016/0148-9062(85)92328-9

Kahraman S et al (2017) The needle penetration test for predicting coal strength. Journal of the Southern African Institute of Mining and Metallurgy 117(6): 587–591. https://doi.org/10.17159/2411-9717/2017/v117n6a9

Kilic A, Teymen A (2008) Determination of mechanical properties of rock using simple methods. Bull Eng Geol Environ (2008) 67:237–244 DOI 10.1007/s10064-008-0128-3

Singh RN, Hassani FP, Elkington PAS (1983) The application of strength and deformation index testing to the stability assessment of coal measures excavations. Proceedings of the 24th US Symposium on Rock Mechanics, Texas A&M University, Balkema, Rotterdam, pp 599–609

Sumner P, Nel W (2002) The effect of rock moisture on Schmidt hammer rebound: tests on rock samples from Marion Island and South Africa. Earth Surface Processes and Landforms 27(10):1137 – 1142 DOI:10.1002/esp.402

Tsiambaos G, Sabatakakis N (2004) Considerations on strength of intact sedimentary rock. Engineering Geology 72: 261–273. https://doi.org/10.1016/j.enggeo.2003.10.001

Ulusay R, Erguler ZA (2012) Needle penetration test: evaluation of its performance and possible uses in predicting strength of weak and soft rocks. Engineering Geology 149–150: 47–56. https://doi.org/10.1016/j.enggeo.2012.08.007

Williams RBG, Robinson DA (1983) The effect of surface texture on the determination of the surface hardness of rock using the Schmidt hammer. Earth Surface Processes and Landforms 8: 289–292. https://doi.org/10.1002/esp.3290080311