GeoScience Engineering

DETERMINATION OF THE UNIAXIAL COMPRESSIVE STRENGTH OF ROCKS FROM THE STRENGTH INDEX

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ABSTRACT

The uniaxial compressive strength (UCS) is classified as one of the basic mechanical properties of rocks, which is widely used in mining and construction practice. For example, it allows geomechanics to classify individual rocks and soils into groups with the same or similar mechanical properties. An example is the (RMR) Rock Mass Rating, Barton's Q system. [1,2]. As a rule, only an indicative determination of the uniaxial compressive strength is sufficient for this classification. The uniaxial compressive strength is determined in the laboratory on regular test pieces. The preparation of these test bodies is often a time-consuming and costly process, and in some cases, the recommended shape cannot be prepared for a small amount of rock sample or, in the case of highly fractured and friable rock. For this reason, alternative methods for determining compressive strength are being sought. These methods are supposed to be faster and cheaper and to provide results directly in situ. The paper presents information obtained from the indirect determination of the uniaxial compressive strength according to the strength index measured with a field press on various rock types from the Czech Republic.

Keywords: Point load index; Rock testing; Uniaxial compressive strength.

1 INTRODUCTION

One of the most commonly measured mechanical properties of rocks is uniaxial compressive strength (UCS). Its precise determination is usually performed in laboratory conditions due to the preparation of test samples of regular shape and testing using a laboratory testing machine. For this reason, alternative methods are used in practice to determine the uniaxial compressive strength. One of them is the measurement of the point load index using a field press. The determination of uniaxial compressive strength is then calculated from the point load strength index using different correlation coefficients, which differ according to different studies. The differences in individual correlation coefficients can be caused, on the one hand, by different types of rocks on which individual measurements and research were performed and, on the other hand, by the methodology of determining uniaxial compressive strength (EN 1926 [3], ISRM [4], etc.).

Currently, in the Czech Republic, the field press is not commonly used to determine uniaxial compressive strength, so these correlations are not determined or are determined only for specific types of rocks in certain localities. For this reason, the subject of research was to observe the interdependence between compressive strength and point load strength index on various types of rocks taken throughout the Czech Republic and compared with compressive strength determined according to EN 1926. Based on the results of measurements in the research, a correlation relation was specified by which it is possible to determine the compressive strength of rocks. [3]

As part of this research, we focused on the main types of rocks occurring in the Czech Republic, which include igneous, metamorphic, and sedimentary rocks. Separate correlations have been established for these rock groups. The article presents the knowledge gained in the solution of this project, measurement results, and derived correlation relations for the calculation of uniaxial compressive strength from the point load strength index.

2 METHODOLOGY

The first step for the implementation of the measurements was a literature search to find out information on sample preparation and testing, processing of the measured data, and their interpretation.

2.1 Determination of the uniaxial compressive strength

The research showed that two methodologies are currently used for the laboratory determination of uniaxial compressive strength. These are the European standard EN 1926, and the methodology recommended by ISRM [3,4].

Due to the fact that the individual methodologies differ mainly in the slenderness ratio of the test body, which significantly affects the resulting measured strength value, the results are not fully comparable. For this reason, it is always advisable to state according to which methodology the uniaxial compressive strength was determined. In the case of the data presented in this paper, it was EN 1926.

2.2 Determination of strength according to ČSN (Czech National Standard) EN 1926

The EN 1926 standard defines the procedure for the determination of uniaxial compressive strength in the CEN member countries. In simplified terms, the test procedure can be described as follows. For the tests, it is necessary to prepare test samples of a regular cube or cylinder shape with a slenderness ratio of 1:1. The contact surfaces must be ground. The rock sample shall be loaded in one axis by means of a laboratory press at a continuous and constant loading rate of (1±0,5) MPa/s. The loading is carried out until the sample is destroyed. The resultant compressive strength is calculated as the ratio of the maximum force at the moment of failure of the sample to its area corresponding to the cross-section of the test sample before the start of the test. The resulting strength value shall be determined as the average of measured test samples.

Relationship of the calculation [3]:

$$R = \frac{F}{A} \; [MPa] \qquad \textbf{\textit{(1)}}$$

2.3 ISRM strength determination

The essence of the International Society for Rock Mechanics (ISRM) uniaxial compressive strength test is almost identical to EN 1926. The only difference lies in the preparation of the rock sample, which should be prepared at a slenderness ratio of 2.5–3:1. Due to the higher slenderness ratio, the resulting strength according to this methodology is lower than the 1:1 ratio (according to ČSN EN 1926) [3,4].

2.4 Determination of the strength index

The point load strength test can be referred to as an index test, which is used for indicative determination of rock strengths, e.g. in practice for rock mass classification, dimensioning of rock pillars, etc. It is used as an indirect method for the determination of uniaxial compressive strength. The measurement of the strength index is carried out on a field press. The advantage of this test is that it is relatively quick and does not require the preparation of rock samples, which may be irregular in shape. The method is thus applicable in the field.

The main disadvantages are that it is an indicative method of determining the uniaxial compressive strength. The strength is most often determined on the basis of conversion relationships that have been obtained by testing large numbers of samples both under laboratory conditions and by field pressing. [4]

Figure 1. *Point Load test (photo by ŠANCER,2022)*

The measurement principle is as follows. The field press consists of a frame, hydraulic pistons and a cone-shaped jaw with a rounded tip. The essence of the measurement is to record the maximum force exerted by the tips on the test body at the moment of destruction of the samples. During the test, a smooth movement of the jaws (cone-shaped tips) by means of the hydraulic piston must be maintained as far as possible. Breakage of the test body should occur between 10 and 60 sec. Due to heterogeneity and anisotropy; the measurement should be repeated at least ten times.

The force that causes the destruction of the sample is denoted as P. The distance between the conical tips is denoted as D; this variable is used to calculate the area on which the force P acts.

Calculation of the strength index:
The strength index is calculated as the load applied to the surface.

$$I_s = \frac{P}{D_e^2} \qquad \textbf{(2)}$$

where P is the breaking force [N],
D_e^2 is: D^2 applies to the diametral test body [mm^2].
If the test body is loaded axially, D_e is determined according to Fig. 2.
$D_e = 4A/\pi$ for axial, block and irregular body, A = W*D. [4]

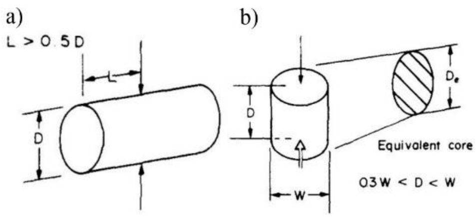

Figure 2. *Calculation of surface D_e diametral (a), axial (b) test body [4]*

Vol. 68 (2022), No. 2
pp. 158–166, ISSN 1802-5420
DOI 10.35180/gse-2022-0078

Figure 3. *According to ISRM (a-c) valid test, (d) invalid test for the diametrically loaded body [4]*

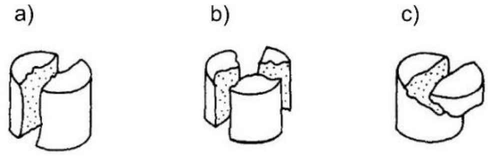

Figure 4. *According to ISRM (a-b) valid test, (c) invalid test for the axially loaded body [4]*

3 METHODS OF CONVERSION I_S FOR UNIAXIAL COMPRESSIVE STRENGTH

The research showed that there are quite a large number of conversion relationships. Most of these conversion factors were derived from research on rocks occurring in a particular locality, or at least rocks of the same type. It is clear from the list of conversion relationships below that the methodologies for converting strength index to uniaxial compressive strength can vary considerably from author to author. Therefore, selecting an appropriate methodology for determining strength from the strength index can be difficult. For this reason, the authors of this paper aimed to develop and validate a conversion relationship or relationships (with respect to the rock type) that would be recommended for practical use in geotechnical and rock mechanics within the Czech Republic.

The following are the relationships for determining the uniaxial compressive strength from the strength index published in the literature:

D'Andrea et al.	[5]	UCS = 15.3 * $I_{s(50)}$ + 16,3
Bieniawski	[6]	UCS = 23 * $I_{s(50)}$
Hassani et al.	[7]	UCS = 29 * $I_{s(50)}$
Gunsallus and Kulhawy	[8]	UCS = 16.5 * $I_{s(50)}$ + 51,0
ISRM	[4]	UCS = 20...25 * $I_{s(50)}$
Chargill and Shakoor	[9]	UCS = 23 * $I_{s(54)}$ + 13
Chau and Wong	[10]	UCS = 12.5 * $I_{s(50)}$
Grasso et al.	[11]	UCS = 9.30 * $I_{s(50)}$ + 20,04
EN 1926 Annex B	[3]	UCS = 22 * $I_{s(50)}$

Is (50) according to ISRM point load test performed on a sample with a diameter of 50 mm (D = 50 mm) [4].

4 ROCK SAMPLING

The Czech Republic has a relatively complex geological structure, which is evident from the geological map shown in Figure 5. For this reason, it was decided to take samples representing all three rock types (sedimentary, metamorphosed and igneous) during the research. The sampling locations are shown in Figure 5. Specifically, the rock samples were those listed in Table 1.

Vol. 68 (2022), No. 2
pp. 158–166, ISSN 1802-5420
DOI 10.35180/gse-2022-0078

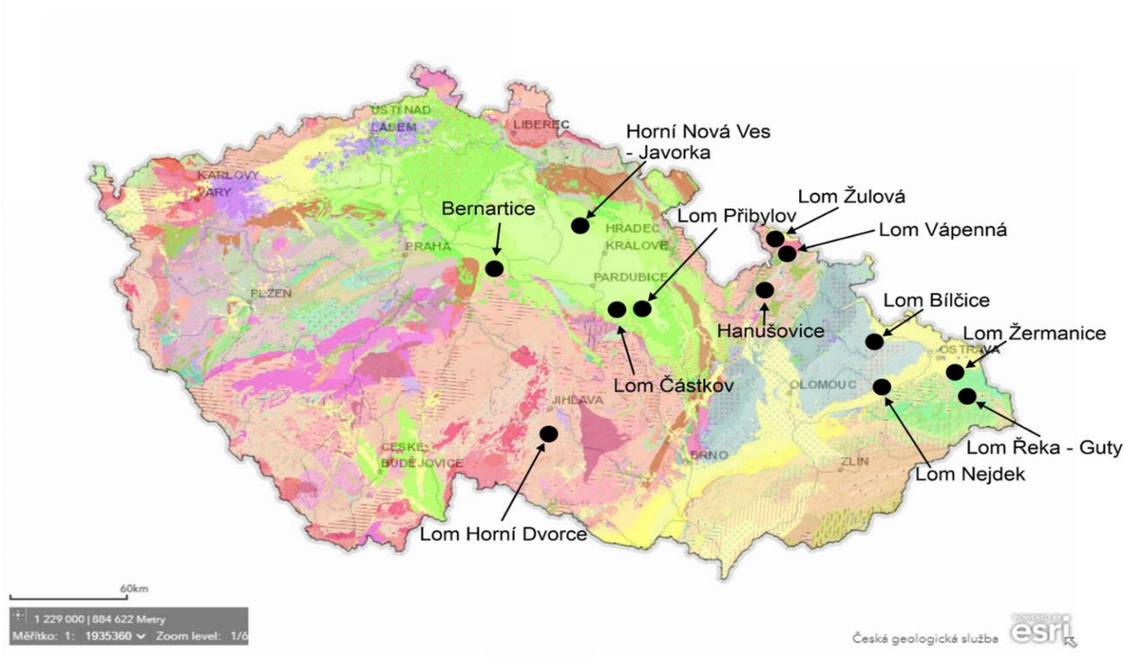

***Figure 5.** Sampling sites of rock samples [12]*
Legend: Metry – Metres, Měřítko – Scale, Česká geologická služba – Czech Geological Survey

***Table 1.** List of rocks investigated*

Name	Location – Quarry	UCS (MPa)	$I_{S(50)}$ *Diametral test* (MPa)	$I_{S(50)}$ *Axial test* (MPa)
Belohrad Sandstone	Horní Nová Ves – Javorka	53	1.27	1.21
Těšín Sandstone	River – Guty	145	4.06	3.6
Pribylovská opuka	Skuteč II	109	4.21	3.58
Limestone	Butkov (SK)	75	3.92	3.29
Moravian droba	Nejdek	138	7.58	8.23
Granite	Horní Dvorce	160	4.93	4.25
Grandiorite	Višňové Tunnel (SK)	169	5.91	5.17
Granite	Granite	114	8.24	7.43
Chesedic	Whitefish	283	16.89	11.04
Enjoy	Zermanice quarry	127	5.68	5.97
Diorite	Částkov (Žumberk)	183	11.79	10.56
Marble	Omya	75	1.99	2.91
Rula	Hanušovice	125	8.01	7.59
Serpentinite	Bernartice	148	3.35	2.57
Amphibolite	Hanušovice	155	4.29	5.76

5 MEASURED DATA

The measurements were used to obtain a set of data which was processed and analysed for the uniaxial compressive strength and the strength index. Due to the possible anisotropy of the rocks, the measurements were carried out in two mutually perpendicular directions.

The measured data were also plotted in the form of graphs showing the dependence of the uniaxial compressive strength and the strength index for illustrative purposes (Figures 6–9). The resulting dependencies were compared with one another and statistically processed. This processing resulted in correlation and conversion relationships for the determination of the uniaxial compressive strength from the strength index, both by individual rock types (sedimentary, metamorphosed and igneous) and a universal relationship for all rock types. Finally, the conversion relationships were compared with the results published by other authors mentioned above.

5.1 Determination of strength under diametral loading

The graphs in the figures below show the results of the investigation of the relationship between the strength index and the uniaxial compressive strength. The graphs show the correlation between the individual variables, and the conversion factor is given as well.

The following Figures 6–7 express the relationship between the strength index and the uniaxial compressive strength. These results are processed for a test body loaded diametrically according to the scheme in Figure 3. From the regression in Figure 6, it is possible to propose a correlation relationship for the determination of the uniaxial compressive strength in the form UCS = 19 * $I_{s(50)}$, with a coefficient of determination of $R^2 = 0.89$.

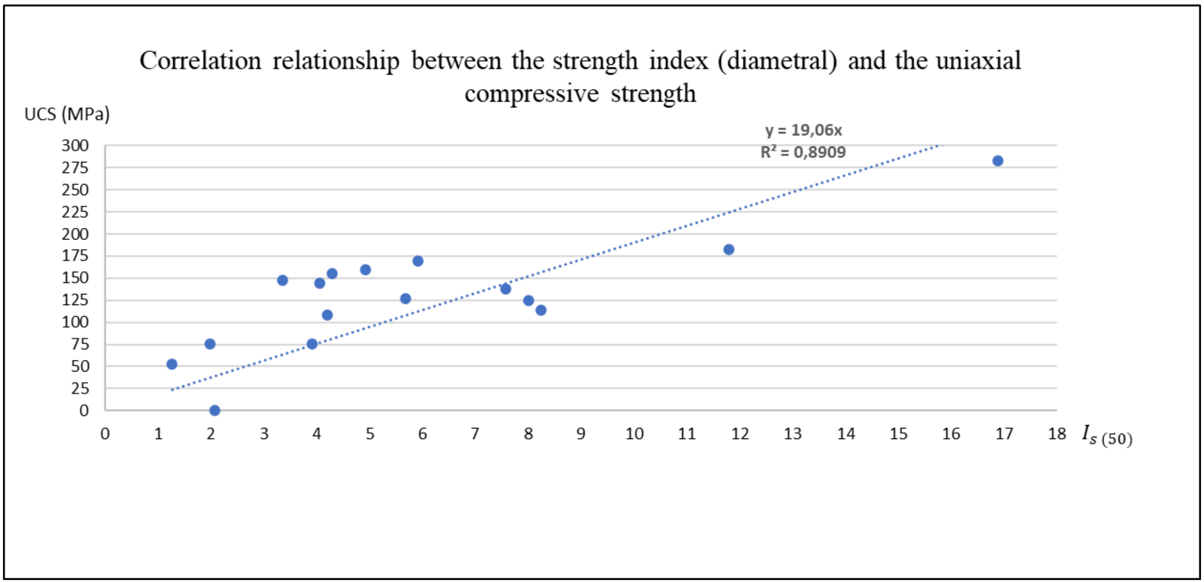

Figure 6. *Determination of the strength index (diametral sample)*

Figure 7 shows the evaluation of the correlation dependence for each rock type. For igneous rocks tested on the diametral body, the conversion factor UCS = 17.1 * $I_{s(50)}$, with a coefficient of determination of $R^2 = 0.95$, can be used. For sedimentary rocks, the conversion factor UCS = 22.6 * $I_{s(50)}$, with a coefficient of determination of $R^2 = 0.82$, can be applied after rounding. The metamorphosed rocks then exhibit the conversion relationship UCS = 23.6 * $I_{s(50)}$, with a coefficient of determination of $R^2 = 0.92$.

Vol. 68 (2022), No. 2
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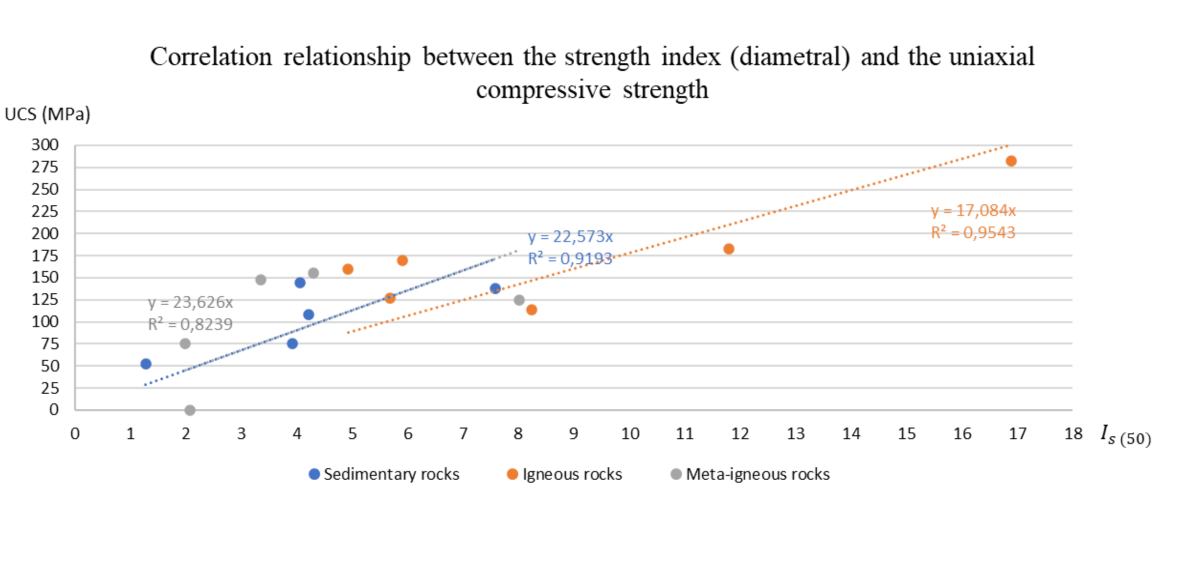

Figure 7. *Determination of the Strength Index (diametral sample), for each group*

5.2 Determination of strength under axial loading

During this loading, the strength index was determined according to the scheme shown in Figure 4. The measured values are shown and evaluated in Figures 8 and 9.

Figure 8 shows a linear regression of the relationship between the strength index and the uniaxial compressive strength obtained by evaluating all the test bodies tested. From this regression, a correlation relationship can be proposed UCS = 22.1 * $I_{s(50)}$. The coefficient of determination for this case is based on $R^2 = 0.89$.

Figure 9 shows the sample evaluation by rock type. The figure shows that for igneous rocks, we recommend the conversion relationship UCS = 21.4 * $I_{s(50)}$, for sedimentary rocks UCS = 22.3 * $I_{s(50)}$, and for metamorphosed rocks UCS = 23.1 * $I_{s(50)}$.

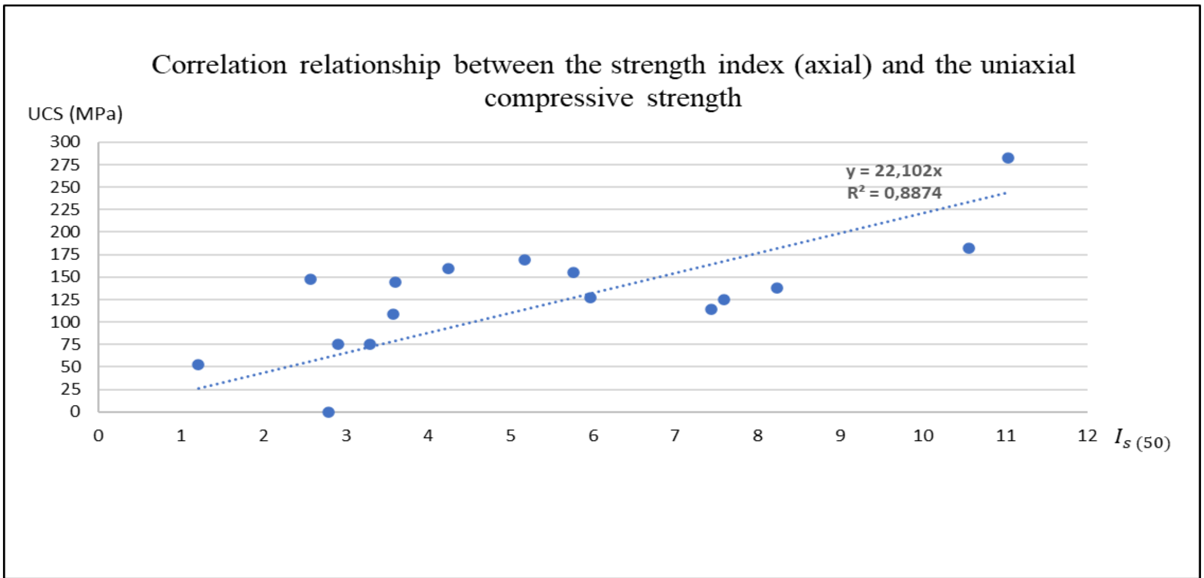

Figure 8. *Determination of the strength index (axial sample)*

Vol. 68 (2022), No. 2
pp. 158–166, ISSN 1802-5420
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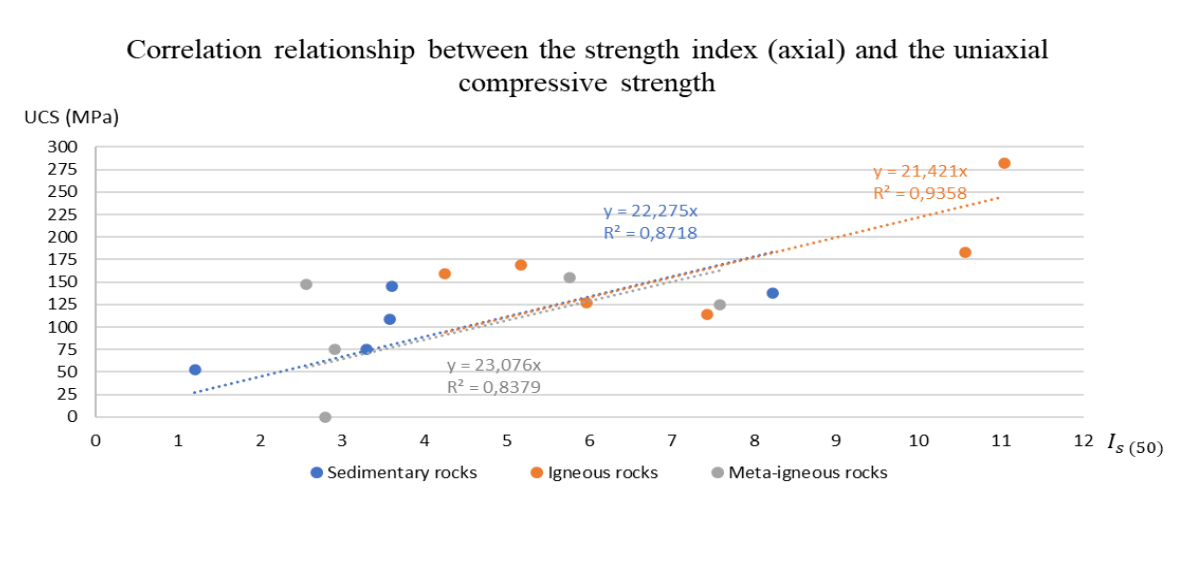

Figure 9. *Determination of the strength index (axial sample) for each group*

6 CONCLUSION

A total of 15 rock samples representing the basic rock types occurring in the Czech Republic were collected and tested during the research. From the research described above and the measured data, it can be stated that the conversion from the strength index obtained from the field press measurements can be used for indicative determination of the uniaxial compressive strength. For some practical applications (e.g., rock mass classification methods, RMR, Barton's Q system), the indicative strength value obtained in this way is fully sufficient. Moreover, in some cases where regular shaped test bodies are not available or cannot be prepared (small amount of rock sample, highly disturbed and friable rock), the field press test is essentially the only feasible test.

Annex 3 of ČSN EN 1926 gives the recommended conversion UCS = 22 * $I_{s(50)}$. However, it should be noted that a note in this annex states that the conversion corresponds to the uniaxial compressive strength carried out according to the ISRM methodology (slenderness ratio 2.5–3:1) and not the 1:1 recommended for testing according to ČSN EN 1926. For this reason, this research was carried out on test bodies prepared according to EN 1926 so that the resulting converted strength corresponds to the standard in question. The authors of this paper recommend the use of the conversion relation UCS = 19.1 * for a slenderness ratio of 1:1 $I_{s(50)}$ for diametrically stressed bodies and UCS = 22.1 * $I_{s(50)}$ for axially loaded bodies. Additional conversion relationships listed in this article may be recommended for more accurate conversion for specific rock types.

ACKNOWLEDGEMENTS

This research was supported by VŠB – Technical University of Ostrava within the project SP2021/93 "Determination of the correlation between the strength index obtained by field press and laboratory determination of uniaxial compressive strength on selected rock samples".

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Vol. 68 (2022), No. 2
pp. 158–166, ISSN 1802-5420
DOI 10.35180/gse-2022-0078