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Strength of chalk derived from on-site needle penetration testing

Estimation sur site de la résistance de la craie à partir d'essais de pénétrabilité à l'aiguille

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ABSTRACT: On-site needle penetration tests on chalk samples can provide important information for sample quality management, early engineering decisions and project schedule. The needle penetration test provides a laboratory strength index. The test method is covered by the ISRM suggested methods for rock characterization. Presented project experience draws from more than 1000 needle penetration tests, point load strength index tests and unconfined compression tests. The results show that common correlations between needle point resistance (NPR) and uni-axial compressive strength can reliably be adopted for chalk.

RÉSUMÉ: Les essais de pénétrabilité à l'aiguille effectués sur site sur des échantillons de craies peuvent fournir des informations importantes pour la gestion de la qualité des échantillons, les études préliminaires d'ingénierie et le calendrier du projet. Cet essai fournit l'indice de résistance en laboratoire et sa méthodologie est définie dans les méthodes de gestion des roches proposées par l'ISRM. Le présent article s'appuie sur une expérience forte de plus de 1000 essais de pénétrabilité à l'aiguille, d'essais Franklin et d'essais de résistance à la compression uni-axiale sans confinement. Les résultats montrent que des corrélations générales entre la résistance à la pointe de l'aiguille (NPR) et la résistance à la compression uni-axiale peuvent être adoptées de manière fiable pour la craie.

Keywords: Needle penetrometer, chalk, on-site laboratory testing, compressive strength

1 INTRODUCTION

On-site needle penetration tests on chalk samples can provide important information for sample quality management, early engineering decisions and project schedule. The needle penetration test provides a laboratory strength index. The test method is covered by the ISRM suggested methods for rock characterization (ISRM, 2014).

This paper documents needle penetrometer experience gained as part of marine site investigations in areas with chalk (Figure 1). The focus is on using the needle penetrometer for prediction of laboratory uni-axial compressive strength. The selected reference test method is the unconfined compression test (UCT), from which uni-axial compressive strength can be derived. The term unconfined compressive strength (UCS) is used hereafter.

Figure 1. Chalk areas of North Sea and Baltic Sea, water depths of < 50 m (after Ziegler, 1990)

Chalk is an extremely weak to weak limestone rock. Lord et al. (2002) and Mortimore (2012 and 2018) provide summaries of extensive studies of and experience with geotechnical engineering in and on chalk. Its engineering behaviour may be idealised as for most other rock types:

- Soil-like continuum behaviour, where post-diagenesis processes led to intensive weathering and/or mass movements;
- Discontinuous rock behaviour, i.e. dominated by natural rock mass features;
- Material behaviour substantially changed by human activities such as foundation installation and dredging.

2 NEEDLE PENETROMETER

2.1 Test method

Needle penetration resistance (NPR) is a strength index for rock. The test method requires a needle penetrometer (Figure 2) and relies on recording the axial force and displacement of a needle pushed slowly into rock, typically to a penetration of 10 mm. The needle has a length of 40 mm and a diameter ranging from 0.3 mm near the truncated cone tip to 0.8 mm. Test results are expressed as NPR, defined as the ratio of axial force to penetration. NPR considers a mean value of at least 3 sets of measurements of axial force and displacement.

Figure 2. Needle penetrometer

2.2 Applicability

In terms of applicability and cost, the needle penetration test competes primarily with the point load strength index test (e.g. ISO, 2017a and 2017b). Both test types are quick and easily allow on-site testing. Results of the unconfined compression test (UCT) are generally regarded as reference for rock classification and calculation models. The UCT typically requires an office-type laboratory environment. The longer test duration and more extensive UCT apparatus imply significantly higher cost.

A needle penetrometer can record NPR values between 0 and 100 N/mm. The upper value typically correlates to a UCS value in the order of 20 MPa (ISRM, 2014). This upper value corresponds to a rock material classification of “weak”, i.e. UCS values between 5 MPa and 25 MPa, according to ISO (2017b). The measurement range of the needle penetrometer covers most chalks. Chalk can also be classified in terms of density measurements (Table 1). Note that Table 1 includes strength terms that differ from ISO (2017b).

The diameter of the needle penetrometer implies that its applicability should be limited to rock material with a predominant grain size of less than about 0.12 mm. Chalk fits this applicability criterion. Tests on rock material with a larger predominant grain size can be inconsistent because of significant influence of larger grains. The upper limit is in the lower end of a grain size classification of “medium grained” (values between 0.063 mm and 2 mm), according to ISO (2017b) classification.

Table 1. Chalk density classification according to Lord et al. (2002)

CIRIA density method				
Identification method	**Low density**	**Medium density**	**High density**	**Very high density**
Intact dry density	< 1.55 Mg/m^3	1.55 to 1.70 Mg/m^3	1.70 to 1.95 Mg/m^3	> 1.95 Mg/m^3
Approximate UCS	< 3 MPa	3 to 5 MPa	5 to 12.5 MPa	> 12.5 MPa
BS 5930 strength term	Very weak and lower end of weak	Upper end of weak	Moderately weak	Moderately strong

2.3 Instrument calibration and measurement uncertainty

The needle penetrometer requires calibration, primarily for axial force. This can be performed in many accredited geotechnical laboratories and calibration laboratories, according to ISO (2017a) or equivalent. ISRM (2014) provides no specific guidance for calibration. A summary of the current (2018) Fugro procedure is as follows:

- Force calibration by application of reference dead weights;
- Load increments of 22 N to 90 N axial force and increments of 4 N to a maximum force of 102.6 N;
- Error tolerance of 6 %;
- Validity of calibration certificate of 2 years.

Measurement uncertainty (JGCM, 2012) of laboratory test results can be important for assessment of reliability of structures, as described in, for example, Annex D of ISO (2015). In general, the measurement uncertainty of laboratory test results is unknown. This is because measurement uncertainty for soil and rock is typically defined relative to a true quantity value of the measurand, which is in situ UCS for the purpose of this paper. However, approximate estimates of the true quantity value can be made.

For needle penetration tests, the authors are not aware of results of interlaboratory comparisons (ISO, 2017a), i.e. "organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions or equivalent" (ISO/IEC, 2010).

Calibration results and a general comparison of results from multiple tests and test types can provide some indication of measurement uncertainty, as shown below.

3 UNCONFINED COMPRESSION TEST

3.1 Test method

The unconfined compression test (UCT) for rock is widely used and covered by e.g. ISRM (2014) and ASTM (2014). No ISO standard is available.

3.2 Applicability

In terms of rock strength, the applicability of an unconfined compression test can cover the usual rock strengths encountered for chalk. Similarly, the UCT can cover the predominant grain size ranges for chalk.

3.3 Instrument calibration and measurement uncertainty

The UCT requires calibration and verification for axial force, linear displacement and specimen geometry. Particularly, measurement results can be sensitive to details in specimen geometry, which in turn can affect axial force measurement because of system compliance effects resulting from e.g. non-axial forces. Some geotechnical laboratories have accreditation according to ISO (2017a) for performing UCT activities (e.g. UKAS, 2018).

As for the needle penetrometer, the authors are not aware of published results of interlaboratory comparisons for the UCT, and more specifically, unconfined compression testing on chalk.

A general comparison of test results can provide some indication of measurement uncertainty, as indicated for the needle penetrometer.

4 CORRELATION RESULTS

Figures 3 and 4 present correlation results for NPR and UCS for chalk samples recovered from sites located in the North Sea and the Baltic Sea. Recovery depths were between 6 m and 74 m below seafloor. The sample recovery method was rotary core sampling (triple tube) according to ISO (2014). Needle penetration tests were performed shortly after sample recovery. UCTs were performed in an office laboratory, i.e. after sample packaging, storage and transport.

The selection of NPR values for pairing with UCS values was based on shortest distance between test specimens, typically less than 0.2 m. One NPR value was selected in case of multiple NPR results at the same distance from a UCS specimen. No pairing was done for distances exceeding 1 m. The presented dataset excludes pairs with NPR < 1 N/mm.

The above criteria resulted in 164 sets of paired NPR UCS values, for a total database containing 1220 NPR values. Note that the 164 sets show NPR values of up to 15 N/mm, where the total database covers NPR values of up to 67 N/mm. More UCT laboratory results will be available to the authors in the near future, for further study.

The primary factors that influence the prediction of UCS from NPR are:

- Measurement uncertainty of NPR values;
- Measurement uncertainty of UCS values;
- Pairing of specimens for NPR and UCS;
- Correlation equation.

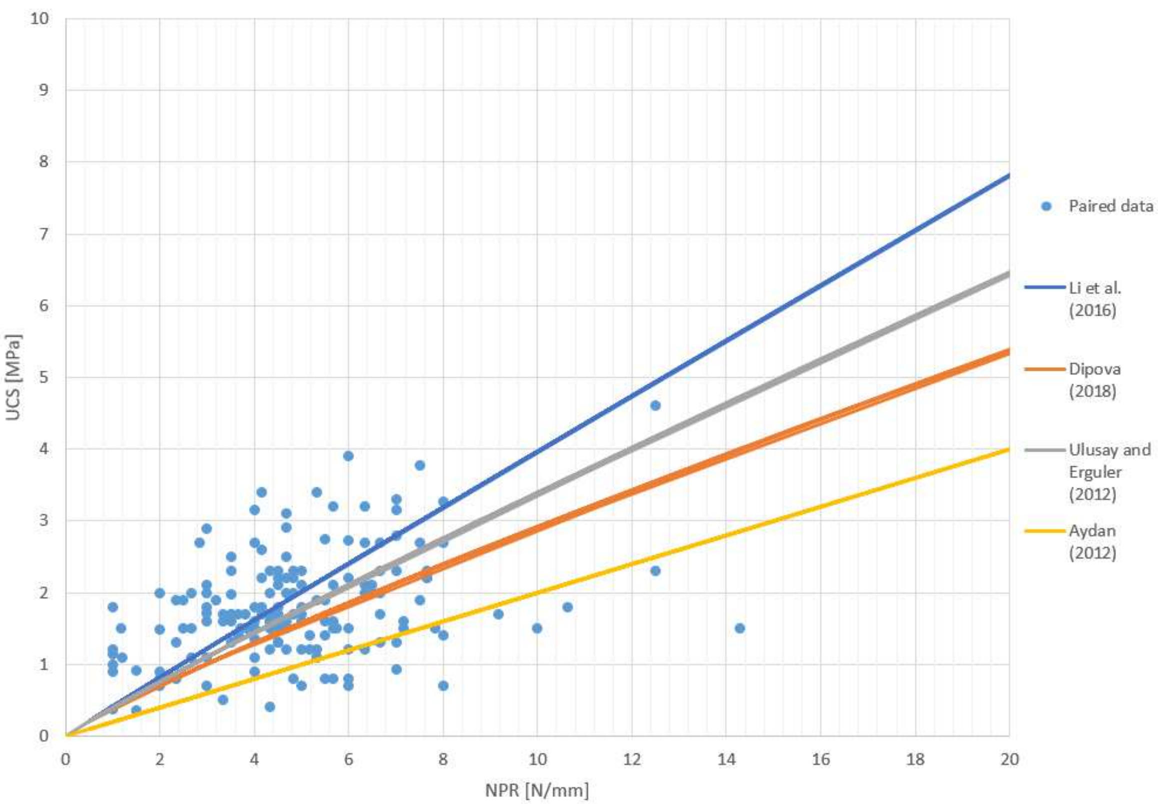

Figure 3. Correlation of NPR and UCS

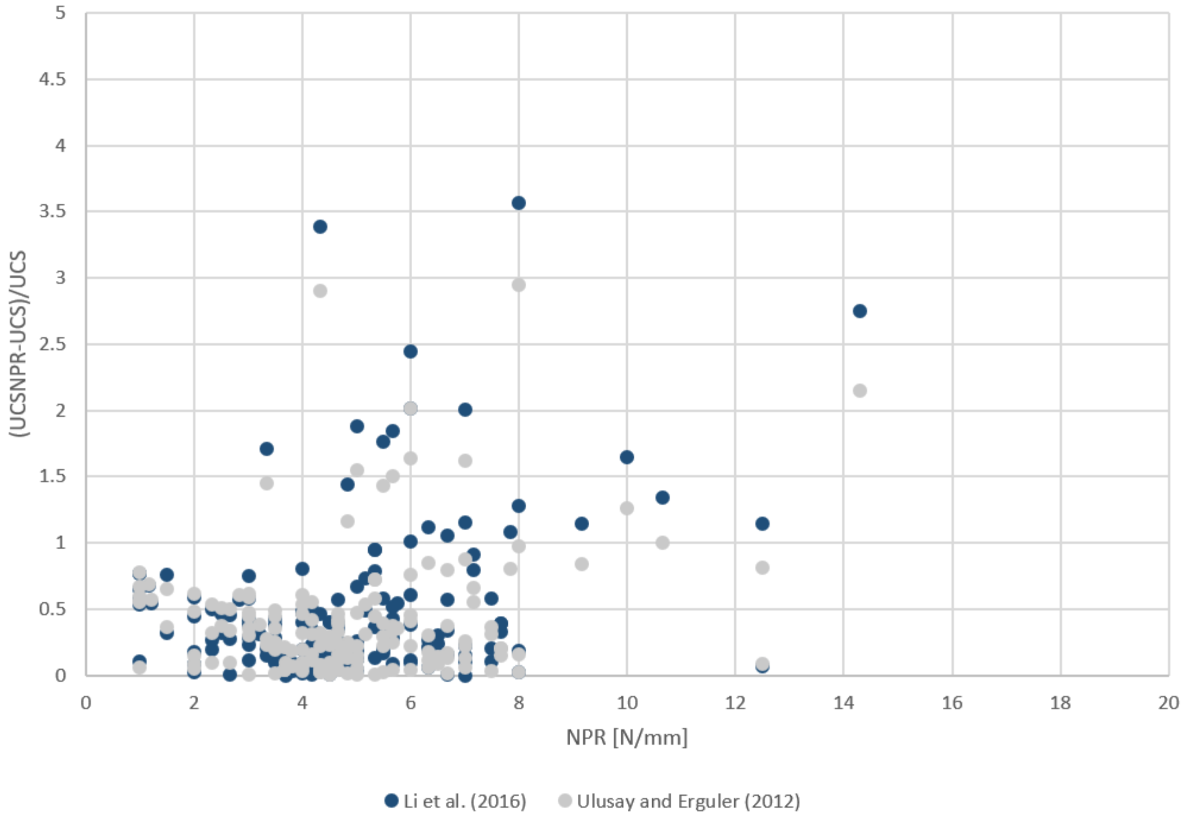

Figure 4. Indication of predictive capabilities of two published correlation equations

The dataset was checked for trends, including depths of the samples below seafloor and pairing distance for NPR and UCS values. No trends were found.

Figure 3 includes selected published correlation equations. It can be seen that the correlations by Li et al. (2016) as well as Ulusay and Erguler (2012) can serve as indication for a best estimate prediction of UCS (r = 0.89 for Ulusay and Erguler, 2012). The correlation by Aydan (2012) can serve as a low estimate.

Figure 4 shows NPR plotted versus the difference between UCSNPR and UCS, where UCSNPR is the value of the UCS predicted from NPR according to two of the correlation equations of Figure 3, namely Li et al. (2016) and Ulusay and Erguler (2012). The mean value of (UCSNPR-UCS) / UCS is 0.57 for the correlation equation of Li et al. (2016) and 0.49 for the correlation equation of Ulusay and Erguler (2012), with no clear trend with the actual value of NPR.

5 MAIN POINTS

On-site needle penetration tests on chalk samples can provide important information for sample quality management, early engineering decisions and project schedule.

The results show that common correlations between needle point resistance (NPR) and uni-axial compressive strength can reliably be adopted for chalk. This is a promising conclusion, considering the usual uncertainties associated with laboratory test results on weak rock.

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