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Estimation of uniaxial compressive strength by Brazilian tensile strength in offshore industry

Estimation de la résistance à la compression uniaxiale à partir de la résistance à la traction brésilienne dans l'industrie offshore

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ABSTRACT: In offshore industry, the Uniaxial Compressive Strength (UCS) of rock is an important parameter (e.g. for pile design). For this purpose rock samples should be provided and tested. In offshore industry it is sometimes difficult to get good quality core samples, this was the case for an offshore project in Europe. In some depths of several boreholes, it was not possible to prepare a sample for UCS testing. In order to have some idea about the rock strength, Brazilian Tensile Strength (BTS), a test which requires less material, was considered. For the aforementioned project, a detailed study is performed to find the reliable UCS-BTS correlation in order to find the UCS value for the parts where only a BTS value is available.
All the samples of BTS and UCS tests were observed. It was an area of focus for the samples that their compression and tensile strengths can be compared. For this purpose several criteria are considered. The selected samples for the UCS and BTS should be close to each other, consist of the same material and should have the same diameter to avoid the scale effect issues. After the tests, the fracture patterns of the failed samples are observed to see if they are failed in the normal fracture patterns. The samples that are failed on weaknesses are not considered. Between all the tested samples 154 samples which fulfil the above criteria, are found and their compression and tensile strengths are compared. An average over 154 UCS/BTS ratios is achieved.

RÉSUMÉ: Dans l'industrie offshore, la résistance uniaxiale à la compression (UCS) de la roche est un paramètre important (par ex. pour la conception de pieux). Donc, des échantillons de roche devraient être fournis et testés. Dans l'industrie offshore, il est parfois difficile d'obtenir des échantillons de bonne qualité. C'est le cas pour un projet offshore en Europe. A certaines profondeurs de plusieurs forages, il n'a pas été possible de préparer un échantillon pour l'essai UCS. Afin d'avoir une idée de la résistance de la roche, la résistance à la traction brésilienne (BTS) nécessitant moins de matériau a été prise en compte. Une étude détaillée est effectuée pour établir la corrélation fiable UCS-BTS afin de trouver la valeur UCS à partir de la valeur BTS.
Tous les échantillons d'essai BTS et UCS ont été observés. Les échantillons devaient permettre de comparer leurs résistances à la compression et à la traction. Donc, plusieurs critères sont pris en compte. Les échantillons sélectionnés pour l'UCS et le BTS doivent être proches l'un de l'autre, être composés du même matériau et avoir le même diamètre pour éviter les problèmes liés à l'effet d'échelle. Après les essais, les schémas de fracture des échantillons sont observés pour voir si la rupture est normale. Les échantillons dont la rupture est liée à des faiblesses locales ne sont pas pris en compte. Parmi tous les échantillons testés, 154 échantillons répondent aux critères ci-dessus. Une moyenne de 154 ratios UCS / BTS est atteinte.

Keywords: UCS-BTS correlation; offshore industry; boreholes; rock sample; fracture pattern

1 INTRODUCTION

In offshore industry one of the important tests in order to identify the rock strength of the seabed foundation for pile designing is the uniaxial compressive strength (UCS). Sample with larger diameter is always more representative and preferable. However, sample with larger diameter needs also longer length to be acceptable for UCS test. ASTM (2002) indicates that the sample for the UCS test should be a right circular cylinder with a height to diameter ratio of 2–2.5. ISRM (2007) mentions that the UCS sample shall be right circular cylinders and requires a height to diameter ratio of 2.5-3.0. It means that for a normal core with 10 cm diameter, at least a sample of 20 cm long is needed to be acceptable for UCS test.

In offshore industry it is sometimes difficult to get good quality core samples with adequate length. It was the case for an offshore project in Europe where the core diameter was 10 cm. In some depths of several boreholes, it was not possible to have a sample with 20 cm length (or longer) for UCS test.

In order to have some idea about the rock strength, Brazilian tensile strength (BTS), a test which requires less material, was considered. It should be noted that the thickness to diameter ratio of about 0.5 matches with ISRM recommendations for Brazilian test (ISRM 2007). It means that for the core with 10 cm diameter, a sample of 5 cm long is acceptable Brazilian test. Having a sample with 5 cm length normally is not an issue in coring.

It is always a discussion how to correlate the BTS-values to UCS-values, and several strength ratios can be found in the literature (Karaman et al., 2015). However, there is a general estimation that compressive strength of rock is about 10 times greater than its tensile strength (Kahraman et al., 2012). For the mentioned project a detailed study is made to find a reliable UCS/BTS correlation.

2 METHODOLOGY AND EXPERIMENTAL TECHNIQUES

All the tested samples in both Brazilian tensile strength (BTS) test and uniaxial compressive strength (UCS) test were observed. However, in order to define a reliable UCS/BTS correlation, comparable test samples should be selected. For this purpose several criteria are considered both before and after the tests. The selected samples for comparison between the UCS and BTS tests should be close to each other. By visual observation they should be considered as the same material and they should have the same diameter to avoid the scale effect issues (Hoek and Brown 1980; Tavallali 2010; Tavallali and Vervoort 2013).

After the tests, the fracture patterns of the failed samples were observed to see if they are failed in the normal fracture patterns (Szwedzicki 2007; Tavallali and Vervoort 2010a; Tavallali and Vervoort 2010b). The samples that are failed in weakness (and the failure just incorporated a small part of the sample and close to the loading area) are not considered.

2.1 Fracture pattern for UCS samples

Cylindrical rock sample under uniaxial compressive stress, due to localised stress concentrations around microscopic discontinuities, can fail in tension, in shear or in combination of tension and shear stresses (Szwedzicki 2007). Szwedzicki and Shamu (1999) suggested for hard and brittle cylindrical rock samples, five distinct modes of failure: simple extension, multiple extension, multiple fracturing, multiple shear and simple shear (see Figure 1).

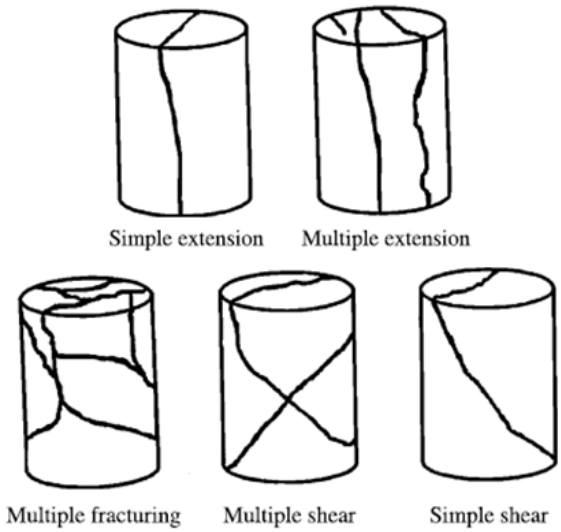

Figure 1. Modes of failure for cylindrical sample (Szwedzicki 2007).

2.2 Fracture pattern for BTS samples

Similar to the idea introduced by Szwedzicki (2007) for UCS-tests, Tavallali and Vervoort (2010a) suggested different fracture patterns for Brazilian tested samples. By considering the samples after failure different types of fractures are observed for transversely isotropic (layered) rock material (see Figure 2):

(1) Some fractures are parallel to the isotropic layers which are called “layer activation”.

(2) Some fractures are roughly parallel to the loading direction and they are located in the central part of the sample between the two loading lines. The central part is arbitrarily defined as 10% of the diameter on both sides of the central line. These fractures are called “central fractures”.

(3) Fractures outside the central part are also observed. If they do not correspond to layer activation, they are called “non-central fractures”. The latter are often curved lines, starting at or around the loading platens.

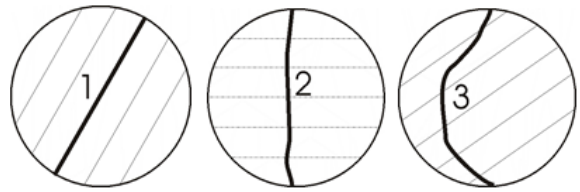

Figure 2. Schematic representation of different fracture types in Brazilian test. (1) Layer activation, (2) Central fracture, and (3) Non-central fracture (Tavallali and Vervoort 2010a).

In most cases, two or three different fracture types occur in the same experiment (see Figure 3).

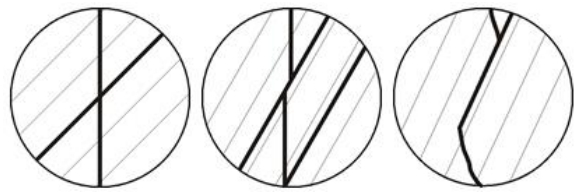

Figure 3. Schematic representation of combinations of different failure modes (layer activation and central fracture) in Brazilian test (Tavallali and Vervoort 2010a).

However, as in this project the rock material is not layered, it is mainly expected to have the failure pattern of central fracture.

3 UCS-BTS COMPARISON

About 700 tested samples (UCS and BTS) of dolomitic rock in the project are taken into account. During the geotechnical campaign, twenty-eight (28) petrographic analyses have been performed on rock samples. All analyses showed a high dolomite content with, if present, quartz as the only significant secondary constituent. Other minerals were found, but typically only as traces or in quantities below 5%. The dolomite content varies from 53% to 97%, with a mean dolomite content of 81%.

As mentioned before, different criteria have been considered for the comparison of UCS and BTS values:

1- The samples (UCS and BTS) should be close to each other (less than 1 m in depth).
2- The samples should be from the same material.
3- The samples should have the same diameter.
4- The fracture pattern of UCS samples should be one of the modes presented in Figure 1 and for Brazilian test central fracture as presented in Figure 2.

For better illustration some examples are given to show the performed procedure.

Example 1: BTS-value for two samples is 4.21 MPa and 5.32 MPa, respectively. A UCS sample close to the two mentioned samples has the UCS-value of 7.17 MPa. The UCS/BTS ratio would be 1.7 and 1.3. The ratio is very low; although all samples have the same diameter (101 mm). The UCS sample shows an initial fracture (see Figure 4). That fracture during the test is activated and sample shows less resistance and the value cannot be considered as representative. Therefore, this sample cannot be used for calculating a representative UCS/BTS ratio.

Figure 4. UCS sample that has an existing fracture (top). The fracture is activated during the test (bottom) and samples shows a low UCS-value.

Example 2: BTS for a sample is 9.83 MPa and the tested close sample for UCS shows a value of 23.6 MPa. The UCS/BTS ratio would be 2.4. However, by looking at the failure pattern of the UCS sample, it becomes clear that sample mainly failed on top part of the sample as presented in Figure 5 (due to concentration of some weak elements probably). So the ratio by considering this sample cannot be representative and it is not considered.

Figure 5. UCS sample with mainly local fracturing (at top of the sample).

Example 3: BTS for a samples 4.63. The close sample for UCS shows the value of 15.5 MPa. The UCS/BTS ratio would be 3.3. By looking at the both BTS and UCS samples, it can be observed that only UCS sample is porous (see Figure 6). In other words, although they are from the same material; the UCS sample and BTS sample have not the same condition. Therefore, they cannot be selected for the comparison.

Figure 6. Both samples from the same material. UCS sample (top) is porous but BTS sample (bottom) is not porous.

From about 700 tested samples (UCS and BTS), one-hundred fifty-four (154) pairs of samples which fulfil the mentioned criteria are found. For the acceptable selected 154 pairs, the compression and tensile strengths are compared. In Figure 7 the BTS-values and UCS-values which are relevant to be compared are presented. As can be seen there is a variation for UCS/BTS ratio mainly between 3 and 11. However, an average UCS/BTS ratio is approximately equal to 7 for this dolomitic rock. These values are considered to be the most representative values based on a visual observation. An in-depth statistical analysis is not performed.

Based on the above mentioned values, it can be concluded that UCS-value is about 7 times of the BTS-value for the rock material in this project.

It is good that the detailed investigation is done for this type of dolomitic rock, because application of the general rule and extracting the UCS-values as 10 times of BTS-values was not a safe approach.

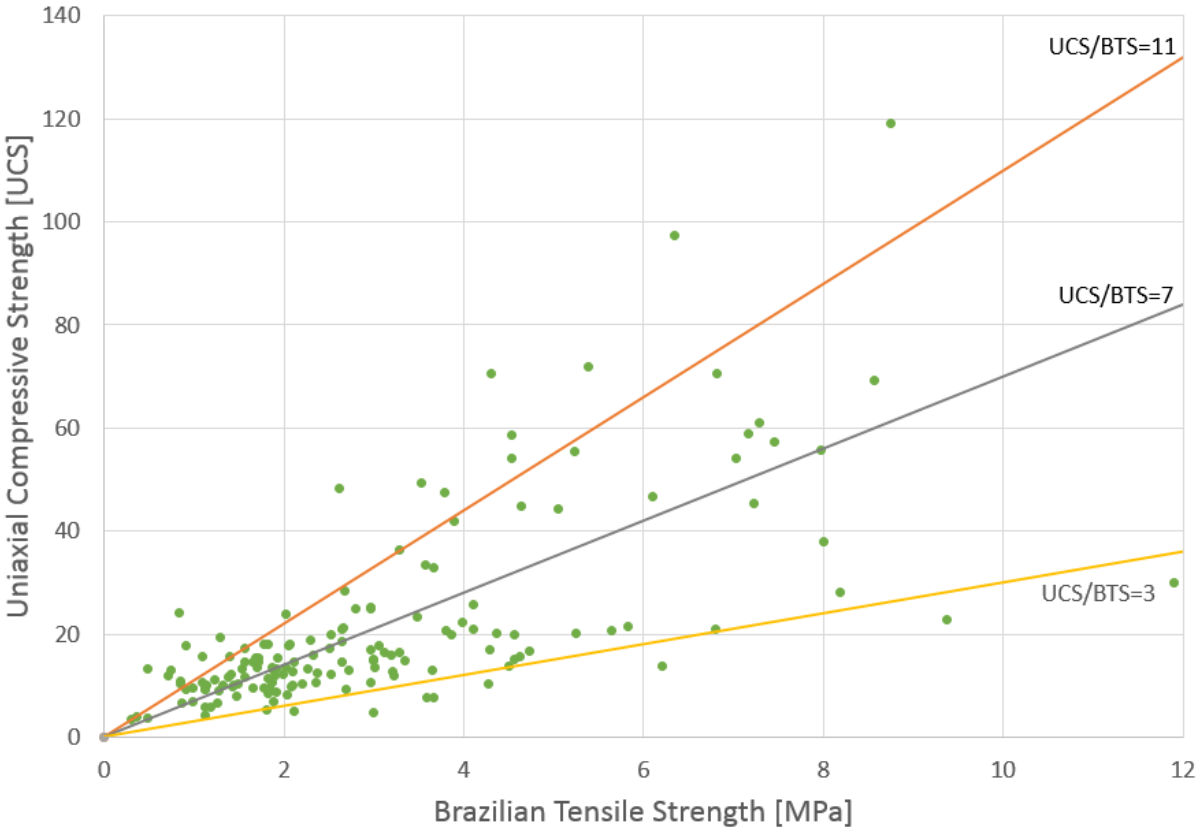

Figure 7. UCS/BTS ratio for selected pairs. The red line indicates the upper (UCS/BTS = 11) limit and the yellow line indicates the lower (UCS/BTS = 3) limit. The grey line gives an approximation of the average ratio of UCS/BTS = 7.

4 CONCLUSIONS

Based on the results of 154 pairs of samples, a reliable ratio of UCS/BTS = 7 is achieved. Therefore for the locations where long enough samples for the UCS test cannot be obtained from coring, Brazilian tests which require less material can be performed. With the project specific ratio of UCS/BTS = 7, the UCS values can be extracted from BTS values. The achieved values will be much more reliable in comparison to a ratio coming from literature.

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