Point load index tests for the indication of the directional strength behaviour of soft sedimentary rocks

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ABSTRACT: For a better understanding of the directional strength behaviour of siltstone and shale rocks point load tests were carried out applying different load angles. For this purpose, the specimen had to undergo a special preparation procedure. Although, standard application recommendations stood against performing point load index tests on soft rocks the results look comprehensible. Formerly performed tests on similar rock types in the same region could be confirmed. The compressive strength for load conditions perpendicular to the foliation/stratification (load angle $\alpha = 0°$) decreased to about 20 % for load angles of about $\alpha = 60 - 70°$. By these test results also the strong variance of results of compressive strength tests performed before the point load test campaign could be explained.

1 GENERAL

The point load index test is a simple test for estimation of rock parameters. Usually, a correlation between the uniaxial compressive strength and the point load index is developed. For strong rocks the correlation factor c reaches values $c > 20$, for soft rocks it might be $c = 10$ or less.

In most cases the orientation of discontinuities is not of interest as long as strong rock conditions are prevailing and the shear failure is not dominated by joints, fissures, foliation or similar discontinuities. For soft sedimentary rocks the failure mechanism is depending on the direction of loading. A simple assumption might result in the idea that loads parallel to discontinuities may result in low strength values, whereas the rock shows stronger resistance for perpendicular loads.

Few authors and studies paid attention to this effect since usually soft sedimentary rocks are classified as very poor to poor rocks and, therefore, strength is weak and strengthening by engineering measures might be required or the design and/or location of the construction is changed in favour of meeting better conditions. For the design of tunnels and caverns in large soft rock formations where the feasibility of a project may be depending on the shear strength behaviour of the rock the situation is different. A precise knowledge of the directional strength behaviour might be required in order to accomplish design and approve the technical and economic feasibility.

In order to investigate the directional shear strength behaviour of the present soft sedimentary rock point load index tests were carried out by a number of 106 of which 94 were successful. The results confirmed the uniaxial compressive test results showing very weak to weak shear strength varying with the load direction. The results of the case study could confirm the rarely existing benchmark values for sedimentary rocks. Additionally, the variation of the strength depending on the load direction angle could be determined, which is helpful for design works when designing and modelling underground structures.

2 BASICS

2.1 Point load index

The point load index i_S [kN/m²] is defined as the quotient of the breaking force F_B [kN] and the corresponding area of the specimen A [m²].

$$i_s = \frac{F_B}{A} \tag{1}$$

The corresponding area is depending on the type of failure and is to be determined after the failure according to the failure/breaking mode. The point load index is taken for an estimation of the uniaxial compressive strength UCS* (also: σ^*_u) [kN/m²] (indexed by '*' for being an estimation by point load tests) by introducing an empirical correlation factor c [-].

$$UCS^* = \sigma^*_u = c \cdot i_s \tag{2}$$

In order to harmonize test results the point load index $i_{s(50)}$ is referring to an equivalent load distance of 50 mm.

$$i_{s(50)} = \left(\frac{A}{2500}\right)^{0,225} \cdot i_s \tag{3}$$

The basic of the testing procedure and recommendations of the German Geotechnical Society are provided in Thuro (2010) (see also ISRM; 1985). It is noted that plastic deformations do have a strong influence on the results. This is especially valid for soft rocks. Thuro (2010) dictates that the point load index is not suitable for soft rocks such as shales or brittle sandstones when local plastification exceeds 5 % of the load distance. Also the size of specimen does have an effect on the results (Wang & Daemen 2004).

The authors performed tests on soft rocks in form of siltstone and shales in order to investigate the directional strength behaviour. The warning by Thuro (2010), that those tests may not lead to reasonable results, were considered. However, the tests were performed in spite of this warning since the aim was not to have accurate point load index values for the estimation of the compressive strength but a rough strength behaviour characterization, which take into account the foliation or the general orientation of discontinuities of the rock specimen.

2.2 Correlation of point load index and compressive strength

Point load test results show frequently a strong variance. Akram & Bakar (2007) are reporting from an inaccuracy of 100%. But the test is a cheap and easy testing method and it is usually used in combination with uniaxial compressive strength tests in the laboratory. Point load tests are often performed immediately on site in order to gain quick and rough results since the test rig is small and easy to carry and handle.

Equation (2) shows the correlation of the point load index and the uniaxial compressive strength which is usually represented by the factor c. This factor is generally assumed to be c = 24 for average conditions of strong rocks (Broch & Franklin 1972). For soft rocks Bowden et al. (1998) provide a range of c = 10 – 20, others go beneath this value c < 10 depending on the way of testing, the specific rock and its properties.

Rusnak & Mark (2000) refer to a data basis of approximately 10.000 point load and compressive strength tests and confirm a range of c = 10 – 20 for soft rock types (Figure 1). On average the correlation factor c shows a range of 20 to 25 for medium and strong rocks which supports the general assumption of c = 24 as Broch & Franklin (1972) suggested.

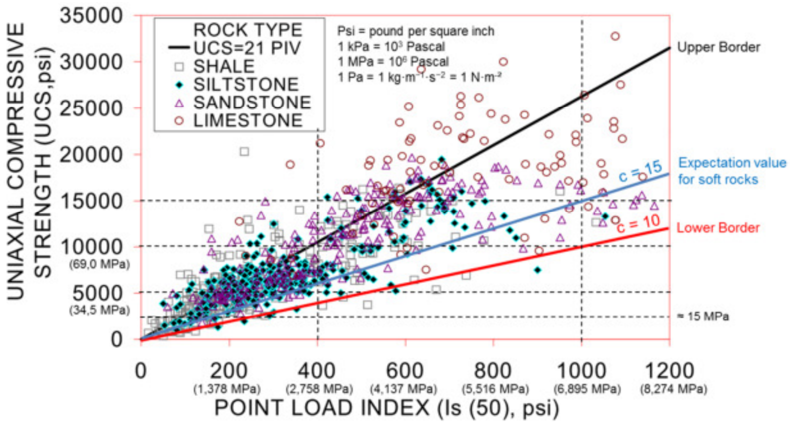

Figure 1. Results of point load index and compressive strength tests adapted from Rusnak & Mark (2000).

Other studies concentrate on soft rocks and provide values, e.g., c = 12.5 for shales and c = 17.4 for sandstones (Mark & Molinda 1996). Similar results are obtained by Das (1985).

It is noted that most of the point load tests studies were performed without taking into consideration the foliation/stratification of the rock. Therefore, neither the load angle nor the foliation angle were considered. The authors believe that the strong variance documented in these studies might also be a result of those neglects. For weaker and softer rocks the strength dependency on the load direction might be more decisive as for stronger rocks. Due to the limited investigation of the influence of the stratification/foliation on the point load strength reliable correlations are not available corresponding to the knowledge and experience of the authors.

2.3 General rock properties for siltstones and shales

The properties of shale and siltstone, and generally of all rocks, depend strongly on the specific genesis. Nevertheless, some general rock characteristics are listed in order to provide a rough indication of what should be expected when dealing with soft rocks such as siltstones and shales. Although, the two mentioned rock types could be distinguished mainly by colour and fabric the geotechnical properties are quite similar so that there is not distinguation between the two types in following Table 1. Rocks showing a UCS < 20 MPa [=MN/m²] are frequently called "soft rocks". Rocks with UCS < 27.5 MPa are defined as very weak rocks (JahanGer 2013).

Table 1. General rock properties of siltstones and shales and test results

Source	UCS	Density ρ	Porosity n	Modulus of Elasticity E
	[MN/m²]	[g/cm³]	[%]	[MN/m²]
Project test results[A)]	3 – 16	2.43 – 2.71	3 – 15	300 – 2,400
Fecker / Reik (1996)	50 – 80	2.50 – 2.60	-	2,000 – 7,000
Prinz (1990)	1.5 – 25	1.90 – 2.60	-	1,500 – 3,000
Dachroth (2002)	10 – 30	2.35 – 2.45	-	-
Zhang (2005)	1 – 5	2.06 – 2.66	4 – 33	< 2,500
EPFL (2008)	5 - 100	2.00 – 2.40	20 – 25	5,000 – 30,000

[A)] Compressive strength tests with strain measurement

2.4 *Anisotropy of rock strength*

Rusnak & Mark (2000) report that their test results showed a strong influence of the load direction. Especially for sedimentary rocks this is a logical consequence since the strength is heavily depending on the genesis of the rocks. Perpendicular to foliation the strength should be strongest. Broch (1983) is reporting that the point load index is a reliable tool for investigating the directional strength behaviour of also soft to medium rocks such as Micaschists (Figure 2). The strength reduction is strongest for load direction angles α = 30 - 60° referring to the foliation/stratification. Parallel to the foliation/stratification the obtained values were weakest. In the course of another project a similar test series was carried out on Rhine shale rocks several decades ago. The aim of these tests was also to determine the directional strength behaviour of the shale. The difference was that only compressive strength tests were performed and no point load tests (Figure 3).

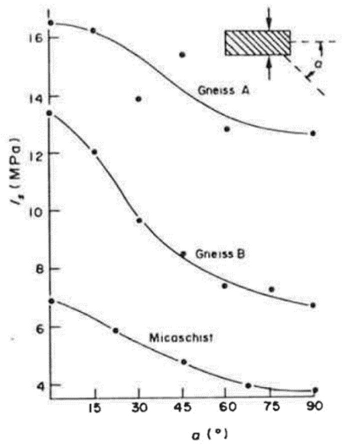

Figure 2. Point load tests on different rocks applying varying load angles (taken from Broch 1983).

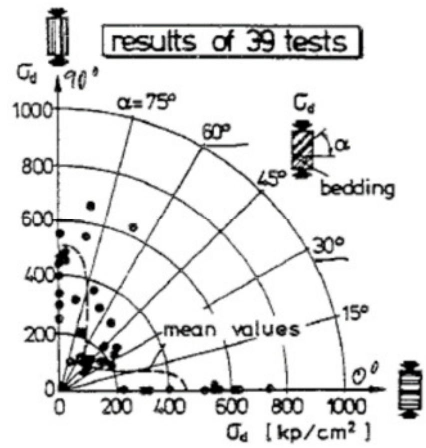

Figure 3. Compressive strength tests on Rhine shale showing different load angles.

The results clearly indicated that the strength was heavily influenced on the load direction. Relative strong values were obtained perpendicular and parallel to the foliation/stratification, lowest values resulted at load angles of α = 30 – 60°. The average strength values are reduced to approximately 20% of $UCS_{\alpha=0°}$ in maximum. The UCS value increased again for α > 60°. This is also reported in Barton (2008).

3 TESTS, RESULTS AND INTERPRETATION

3.1 *General*

In the course to the project several core drillings were performed before so that sufficient specimen were available for testing. Also because of the unpredictable results of this point load testing campaign it was decided to perform "only" about 100 tests. For each rock type six classes of the load direction were defined:

1. Class 1: α = 0° - 15°
2. Class 2: α = 15° - 30°
3. Class 3: α = 30° - 45°
4. Class 4: α = 45° - 60°
5. Class 5: α = 60° - 75°
6. Class 6: α = 75° - 90°

The samples were taken from core drillings which were performed with a diameter of 100 mm. The samples were prepared in order to show a load distance of 50 mm. Since the drilling were performed perpendicular the samples were cut in different pieces in order to obtain the required load angles enabling a planar placement of the specimen into the test rig. Planar and smooth surfaces were established for an optimum load induction. Although, the cores were stored quite a long period the samples were still considered to be fit for testing since not the absolute value of the point load index was of interest but a relative strength decline in respect to the load angle. Of course, the way of sample treatment plays a decisive role for the test results (Agustawijaya 2007).

3.2 Testing and results

A number of 106 tests was performed of which 94 tests resulted in reasonable test results and comprehensible failure mechanism. For the rest the failure resulted in an uncontrolled fracturing of the specimen for which no load distance or reference area could be determined anymore.

In Figure 4 the test results are shown. The load angle is α = 0° perpendicular to the foliation and α = 90° parallel to the foliation/stratification. The point load index shows a strong directional behavior. At angles between 50 t o70° the index values are below 20% of the values obtained when the load is directed perpendicular to foliation (α = 0°). This confirms also the test results performed on the same rock type shown in Figure 3.

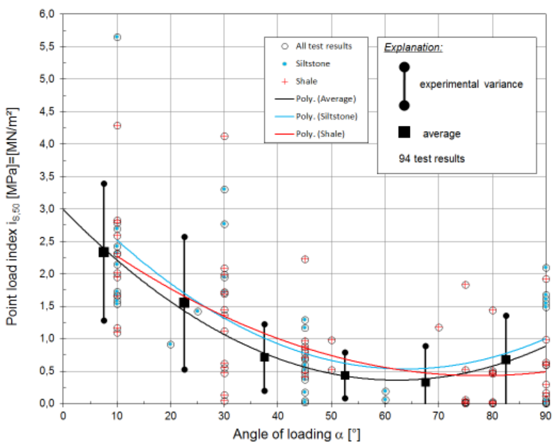

Figure 4. Angle of foliation vs. point load index for shale and siltstone.

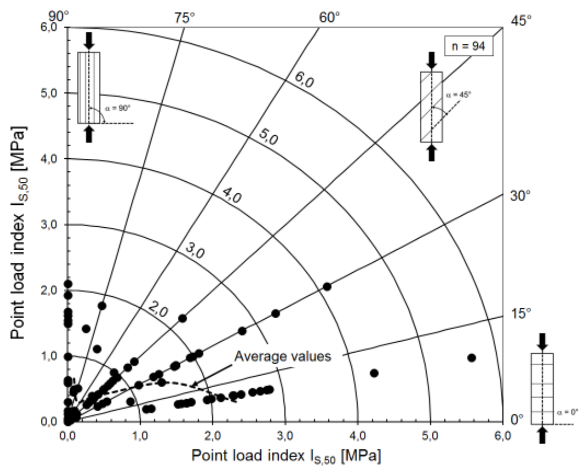

Figure 5. Point load index test results for all tests for tested load angles.

The directional strength behaviour is also illustrated in Figure 4 and 5. The results indicate a strong decrease at load angles greater than 30° and slight increase again at a load angle greater than 75°.

As given in Table 1 compressive strength test results are showing a range of UCS = 3 to 16 MPa which indicated a weak rock but shows still an immense variance. After evaluating the defined load angle classes this variance was explained by the directional strength behaviour. The weak results could be obtained from samples of class 4 and 5. The good results from "perpendicular" tests correspond to point load test results of class 1 and 2.

During the project phase when the compressive tests were performed the directional strength behaviour of the present soft sedimentary rocks were not taken into consideration so that the test results were quite confusing. Later, as the origin of the results is determined the results also help for future design works regarding rock slopes and underground structures.

Finally, it is noted that the plastic deformations frequently exceeded the recommended limit of 5% so that the results are considered to show relative strong indicative nature.

3.3 Discussion of results

The test results document a distinct load angle dependent point load index. Corresponding to the roughness of the shear surface the weakest shear strength is not obtained for loads parallel to the foliation but parallel to the roughness pattern. Thus, perpendicular to foliation the mean point load index is $I_{S,50,m,0°-15°}$ = 2.3 (Class 1) whereas it is only $I_{S,50,m,75°-90°}$ = 0.7 for Class 6 which is only 1/3 of the Class 1 results. For Class 5 the point load index $I_{S,50,m,60°-75°}$ = 0.3 shows the weakest values resulting in 1/8 of the maximum values of Class 1. For Class 5 only siltstone samples were available and no tests were performed on shale. This has also an effect on the evaluation (Figure 4, Figure 5). The test campaign has proofed that the point load index is a suitable test method for analyzing the load angle dependent strength of sedimentary rocks.

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