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# Scale effects in rock strength properties. Part 2: Point load test and point load strength index

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ABSTRACT: In rock mechanics and engineering geology, the point load test is regarded as a valuable field test to give an estimate of the unconfined compressive strength. Well known is the scale effect concerning the point load strength since the first comprehensive paper by Broch & Franklin (1972). After carrying out a large high number of point load tests in different rock types and with different devices, the result of this contribution is more an examination of evaluation methods of this apparently simple rock test. Since the $I_s$ is highly dependent on the sample size, determination of the $I_{50}$ seems still to be the major problem. In this paper, a size correction method for obtaining point load strength index $I_{50}$ is presented using logarithmic regression analysis from a series of performed tests.

## 1 SCOPE

In rock mechanics and engineering geology, the point load test often serves as a "last chance" for estimating the unconfined compressive strength

- when core samples cannot be gained out of faulted or weathered rock mass,
- when a value for foliated metamorphic rock has to be obtained perpendicular to schistosity and foliation is inclined in the cores, or
- when the strength of small components is to be determined for special purposes e.g. drilling or cutting problems.

Since the test is very simple, problems arise due to calculation of the point load strength, standardization of specimen shape and size and the calculation of the unconfined compressive strength out of the point load index.

Well known is the scale effect concerning the point load strength since the first comprehensive study by Broch & Franklin (1972). Taking the cross-sectional area of the rock sample into account instead of the squared,diameter, was an important step forward in the 1980s (Brook 1985, ISRM 1985) but little progress has been made during the last decade concerning the evaluation of the testing results.

After many years of point load testing in the TU Munich laboratory, an exceptional number of tests have been conducted on different rock types and with different devices. The result of this work is more an examination of evaluation methods of this apparently simple rock test. Since the point load strength $I_s$ is highly dependent on the sample size, determination of the point load strength index $I_{50}$ still seems to be a major difficulty in geotechnical practice.

In this paper, a size correction method for obtaining point load strength index $I_{50}$, including statistical properties of a series of performed tests, is introduced. The method, involving logarithmic regression analysis, abbreviated "Logar method", was developed during a dissertation work (Thuro 1996) and since then successfully applied in practice.

## 2 DEFINITIONS AND CALCULATIONS

Broch & Franklin (1972) started with a simple formula taking an idealized failure plain of a diametral core sample into account (Figure 1):

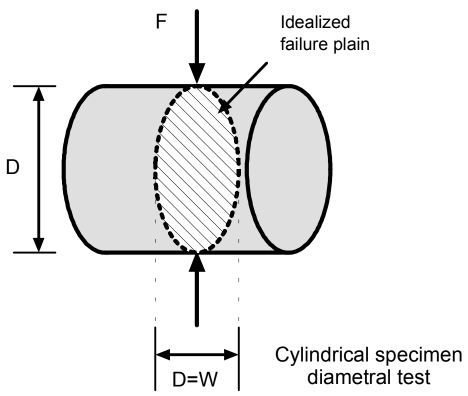


Figure 1. Specimen dimensions for a diametral point load test on cores. Conceptual model for derivation of formula (1).

$$I_S = \frac{F}{D^2} \quad (1)$$

where $I_S$ = point load strength; $F$ = load; $D$ = core diameter.

Since then, this formula varied little, even though physical basis for it has been forwarded. An argument can be made that the formula should be written as:

$$I_S = \frac{4 \cdot F}{\pi \cdot D^2} \quad (2)$$

taking the circular area of the core into account.

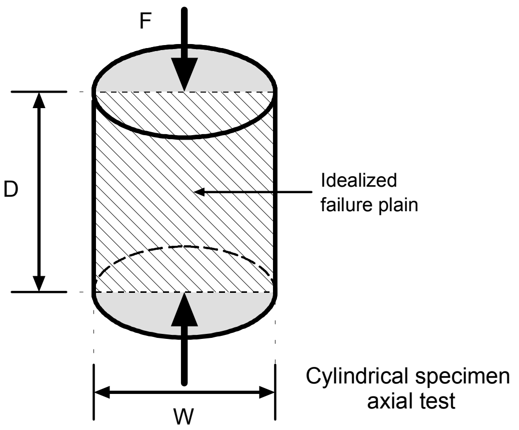


Figure 2. Specimen dimensions for an axial point load test on cores. Geometry for derivation of formula (3).

Users of this test soon noticed, that the results of a diametral test (Figure 2) were about 30% higher than those for an axial test using the same specimen dimensions. It seems that Brook (1985) and also the ISRM (1985) suggestions acknowledge this difference by applying a size correction and introducing the "equivalent core diameter":

$$I_S = \frac{F}{D_e^2} = \frac{\pi \cdot F}{4 \cdot W \cdot D} \quad \text{and} \quad W \cdot D = A = \frac{\pi}{4} D_e^2 \quad (3)$$

where $I_S$ = point load strength; $F$ = load; $D_e$ = equivalent core diameter; $D$ = thickness of specimen; $W$ = width of specimen; $A$ = minimum cross-sectional area of a plane through the platen contact points (see also Figure 3).

Using the simple physical law σ = F/A, the formula for determining point load strength should be written as:

$$I_S = \frac{4 \cdot F}{\pi \cdot D^2} \quad \text{for cores and} \quad (4)$$

$$I_S = \frac{F}{W \cdot D} \quad \text{for blocks and irregular lumps} \quad (5)$$

with dimensions after Figure 3. For the authors it is not understandable why this has never been corrected given that the original equations date from the early 70ties.

Given the deficiencies in the derivation by the quoted authors, equation (3) has been used for determining the pont load index for comparisons sake.

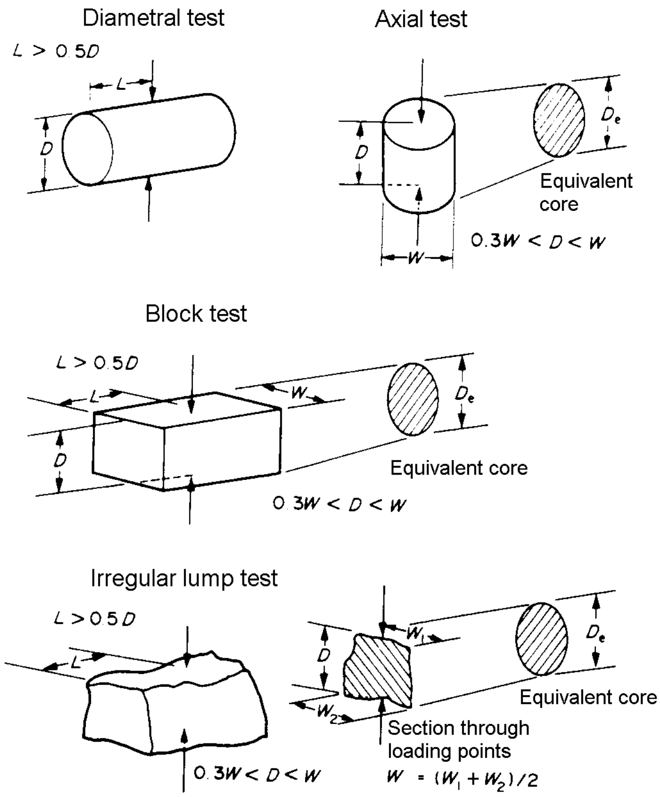


Figure 3. Specimen shape requirements for different test types after Brook (1985) and ISRM (1985).

## 3 APPROACHES TO OVERCOME SCALE EFFECTS

### 3.1 *From Broch & Franklin (1972) to ISRM (1985)*

Known from the onset of testing, the point load strength is highly dependent on the size of the specimen as well as the shape.

Using thick instead of tall specimens for the block and the irregular lump test and standardizing the general shape of the specimens were steps forward (Broch & Franklin 1972, Brook 1985, see Figure 3) to obtain more reliable testing results with a smaller standard deviation. But still analysis and evaluation werte limited by size variation and the lack of a reliable and easy-to-comprehend method for size correction.

Broch & Franklin (1972) offered a size correction chart with a set of curves to standardize every value of the point load strength $I_S$ to a point load strength index $I_{50}$ (= $I_{s(50)}$) at a diameter of D = 50 mm. The purpose of the function was to describe the correlation between $I_s$ and D and to answer the question, wether this function is uniform for all rock types (as Broch & Franklin 1972 stated it) or if it depends on the rock type together with grain size, composition of mineral bonds, grain cleavage etc.

Brook (1985) and the ISRM (1985) suggest three options to evaluate the results of a test set:

1 Testing at D = 50 mm only (most reliable after ISRM).
2 Size correction over a range of D or $D_e$ using a log-log plot (Figure 5).
3 Using a formula containing the "Size Correction Factor" f:

$$I_{50} = f \cdot \frac{F}{D_e^{\,2}} = f \cdot \frac{\pi \cdot F}{4 \cdot W \cdot D} \tag{6}$$

where

$$f = \left(\frac{D_e}{50}\right)^{0,45} = \left(\frac{D_e^{\,2}}{2500}\right)^{0,225} \tag{7}$$

## 3.2 *Logarithmic regression analysis*

Beginning with the conzept of size correction over a range of D or $D_e$ as discribed by ISRM (1985), the point load strength values are plotted in a $I_s$ – $D_e^2$ - diagram (which can be semi-logarithmic). It is recommended to use 15 to 30 single $I_s$–values regularly distributed between approx. 30 and 70 mm. For the data set, a logarithmic regression curve is calculated in the common form f(x) = a + b·ln (x) following the procedure described below (Figure 4):

1 Calculation of all
   $I_s = F/D_e^2$
   of the data set with formula (3)
2 Calculation of a logarithmic regression curve

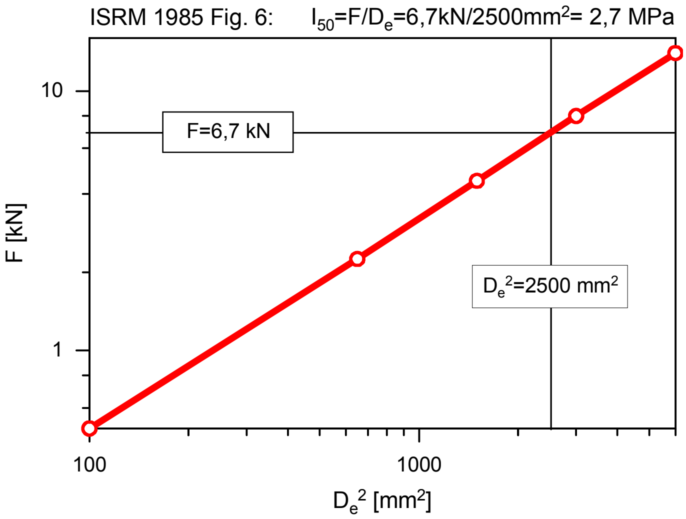


Figure 5. Procedure for graphical determination of $I_{50}$ from a set of results at $D_e$ values other than 50 mm (taken from ISRM 1985, Fig. 6).

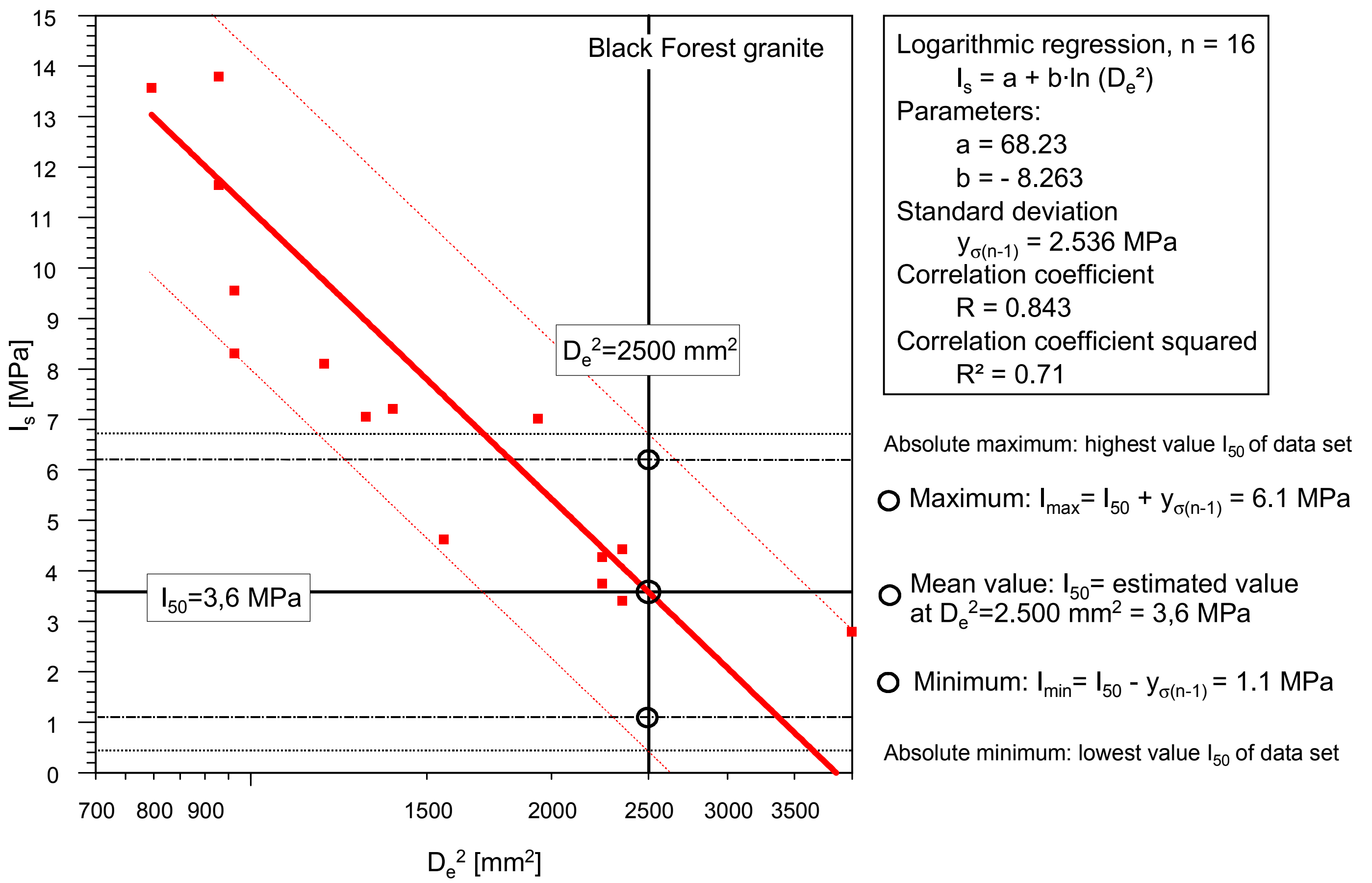


Figure 4. Logarithmic regression analysis for a point load data set of Black forest granite. Semi-logarithmic plot with mean value $I_{50}$, statistical minimum and maximum, absolute minimum and maximum and statistical parameters.

$I_s = a + b \cdot \ln (D_e^2)$

3 Calculation of
$I_{50} = a + b \cdot \ln (2500)$
with derived values of a and b

4 Calculation of the standard deviation $y_{\sigma(n-1)}$ and the correlation coefficient $R^2$ as statistical properties

5 Calculation of the statistical minimum as
$I_{min} = I_{50} - y_{\sigma(n-1)}$
and the statistical maximum as
$I_{max} = I_{50} + y_{\sigma(n-1)}$

6 Plotting all $I_s$-$D_e^2$-values in a diagram to validate the distribution pattern ($D_e$, $D_e^2$ or log $D_e^2$)

# 4 TESTING AND EVALUATION OF RESULTS

In the following section, several examples are given for different evaluation methods.

## 4.1 *Evaluation of different size correction methods*

Figure 6 shows the application of the log-log plot suggested by Brook (1985) and the ISRM (1985). There is no way to get a sensible mean value for the point load strength index. In Figure 7 the attempt is made to use the formula given by the same authors. After calculating the "Size Correction Factor" there should be no dependence on $D_e^2$ – all values should plot on the horizontal line givig one mean value of $I_{50}$. Although these two methods have been tried many times in different data sets and rock types, they never proved to be of any practical benefit.

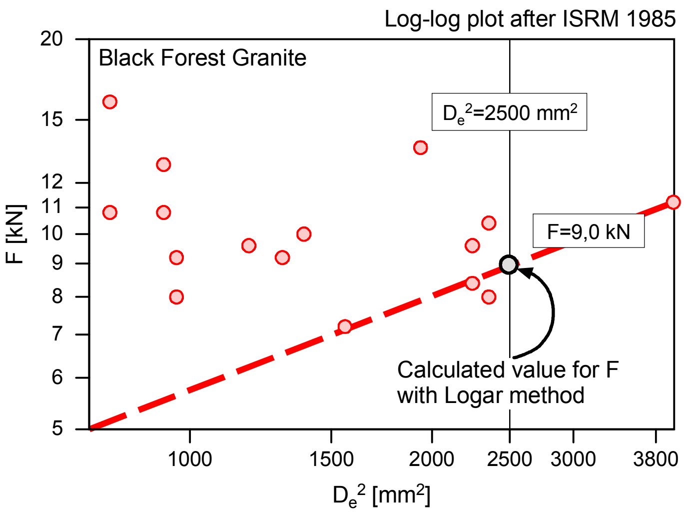


Figure 6. Application of the log-log plot after ISRM 1985 on the Black forest granite data set. Dashed line is target line as in Figure 5, F is back calculated with Logar method.

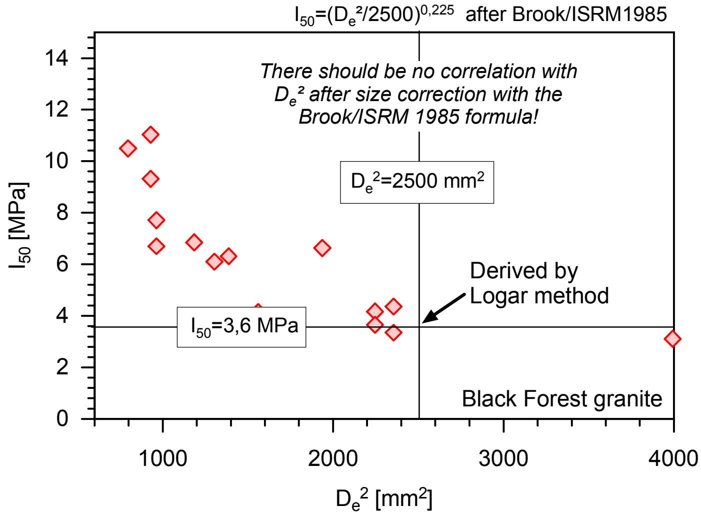


Figure 7. Application of the formula after Brook 1985 and ISRM 1985 on the Black forest granite data set.

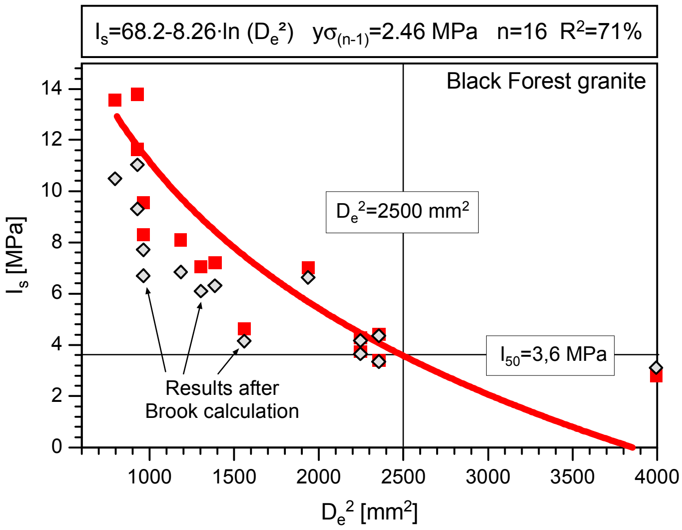


Figure 8. Application of the logarithmic regression analysis on the Black forest granite data set using $D_e^2$ as x-axis. Results calculated with the Brook formula are plotted for comparison.

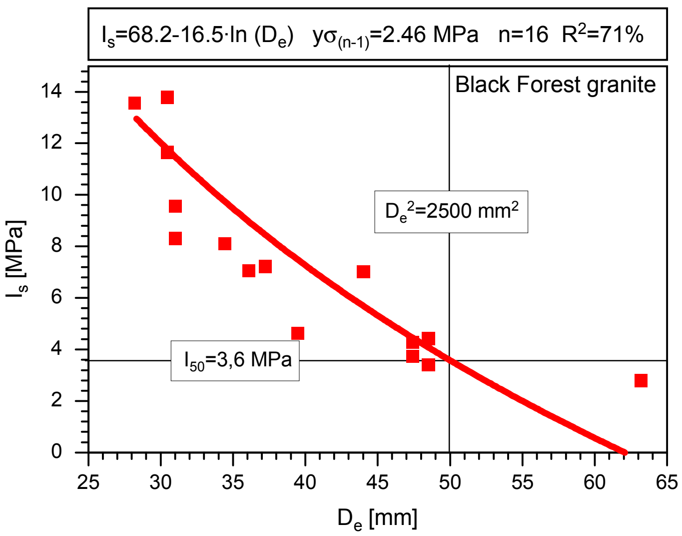


Figure 9. Application of the logarithmic regression analysis on the Black forest granite data set using $D_e$ as x-axis. Note that the graph parameters are slightly different from Figure 8.

In Figure 8 and Figure 9 the same data set is treated with the "Logar method" giving a mean value by using the derived curve parameters and estimating the $I_{50}$ at $D_e^2$=2500 mm². The curves are plotted together with statistical properties. For comparison, in Figure 8 the results calculated with the Brook formula from Figure 7 are also plotted. Figure 9 only uses $D_e$ (which may be more common in some laboratories) as the x-axis and slightly different graph parameters are therefore obtained. The results of $I_{50}$ and $y_{\sigma(n-1)}$ are the same.

Typically the deviation range is highest for smaller cross sections ($D_e^2$). Therefore, specimen diameters lower than 30 mm ($D_e^2$ < 700 mm²) should be avoided. As a prerequisite, the range of tested diameters (or specimen cross-sectional areas) should follow a homogeneous distribution between approx. 30 to 70 mm if possible.

### 4.2 *Other examples evaluated by Logar method*

Figure 10 and Figure 11 show another example for a logarithmic regression analysis applied to a Hallstatt dolomite data set using $D_e^2$ and log $D_e^2$ plotted on the x-axis.

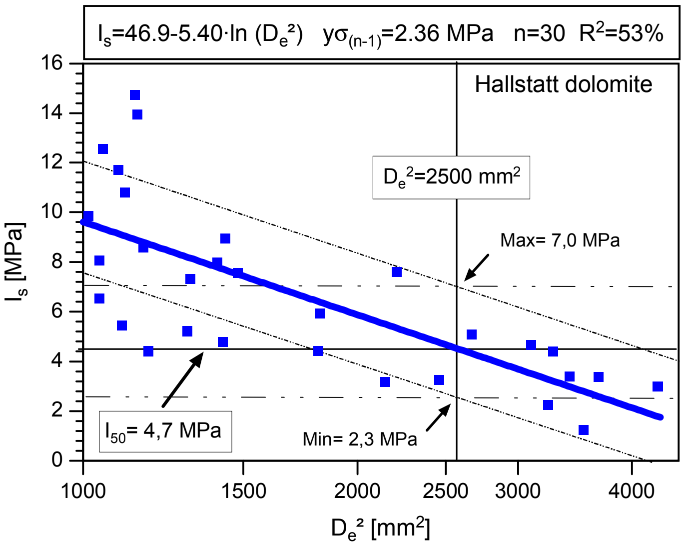


Figure 10. Application of the logarithmic regression analysis on the Hallstatt dolomite data set using log $D_e^2$ as x-axis. Standard deviation in dashed lines.

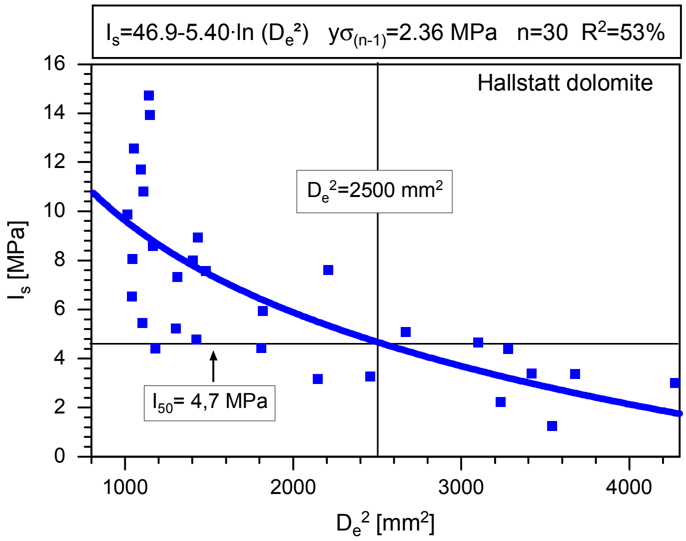


Figure 11. Application of the logarithmic regression analysis on the Hallstatt dolomite data set using $D_e^2$.

## 5 ESTIMATING UNCONFINED COMPRESSIVE STRENGTH

The point load strength index is primarily used to estimate unconfined compressive strength rather than as a property of its own. Therefore, many authors (e.g. Becker et al. 1997, Brook 1993, Gunsallus & Kullhawy 1984, Hawkins 1998, Thuro 1996) have established conversion factors for $I_{50}$ to UCS dependent on the tested rock type. As there are reported values in the literature varying between 10 and approx. 50 there is surely no single factor to be applicable to all rock types. In our experience it is only sensible to derive such a factor when using a broad and comprehensive point load strength index and unconfined compressive strength data base. Also, statistical properties should be calculated from a regression analysis to validate the derived conversion factor, e.g. as shown in Figure 12 for a single quartzphyllite data set.

In contrast to Figure 12, the diagram in Figure 13 shows an over-all statistical mean value derived from numerous tests and rock types compiled over a number of years. Thus it is not possible to establish a regression line for each rock sample, especially when cores can not be obtained from broken or highly jointed rock masses. In such cases such a conversion chart is very useful and very often better than nothing.

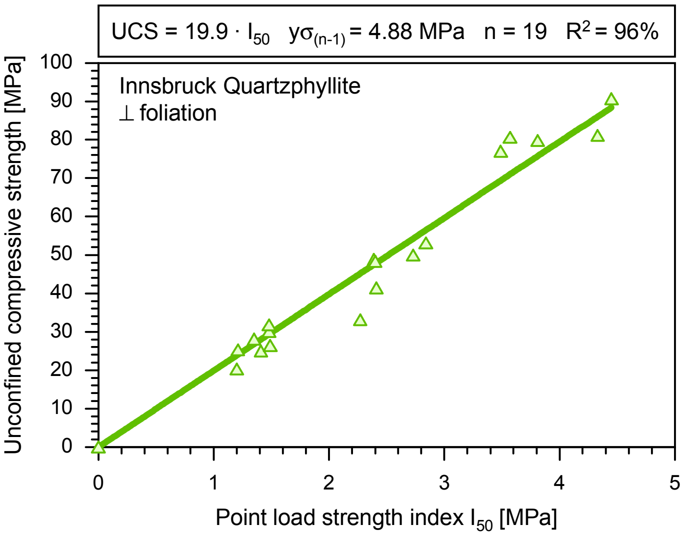


Figure 12. Calculation of the UCS correlation factor of a single quartzphyllite data set tested perpendicular to foliation.

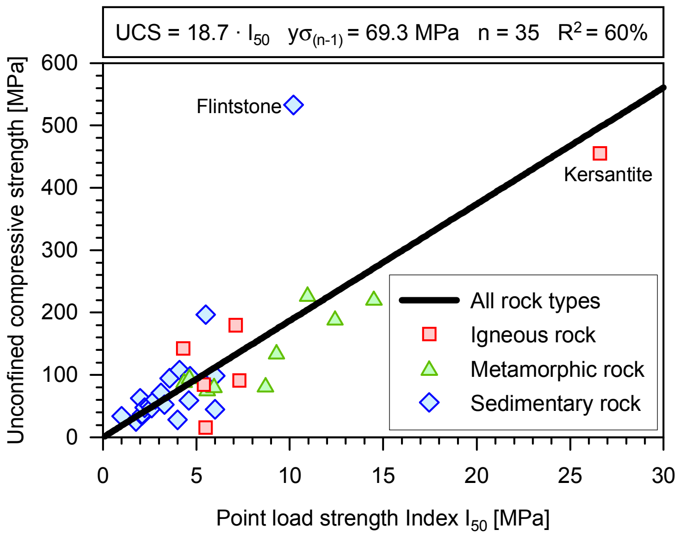


Figure 13. Calculation of the over-all UCS correlation factor using mean values of 35 different rock types (own data and data from Becker et al. 1997).

## 6 CONCLUSION

Since the size effect still is remains a question when performing point load tests, there should be a standardization of size correction methods amongst users. This is currently one of the aims in the revision of the German suggested method No. 5 for the point load test (DGEG 1982) of the Commission 3.3 on Rock Testing Methods (Arbeitskreis 3.3 Versuchstechnik Fels) of the German Society for Geotechnical Engineering.

In this contribution it was our aim to show the standard methods and their weakness when trying to apply them to a test data set. Therefore, a statistical approach was chosen, to gain reliable and comprehensive results. The logarithmic regression analysis ("Logar method") proved to be a reliable and easy-to-comprehend method for size correction. But as a prerequisite, the range of tested diameters (or cross-sectional areas) should follow a homogeneous distribution between approx. 30 to 70 mm if possible.

Especially, when used to estimate UCS values, only a broad data base can provide reliable strength values. In other words, a single point load test is not suitable to replace an unconfined compression test on a cylindrical specimen. It is therefore recommended that at least 15 to 30 single tests should be performed to calculate a mean value for the point load strength index following the suggested "Logar method" before estimating a value for unconfined compressive strength.

## REFERENCES


Becker, L.P., Klary, W. & Motaln, G. 1997. Vergleich indirekter Gesteinsprüfverfahren mit dem Zylinderdruckversuch zur Ermittlung der einaxialen Druckfestigkeit. *Geotechnik* 20 (4): 273-275

Broch, E. & Franklin, J.A. 1972. The point-load strength test. *Int. J. Rock Mech. & Min. Sci.* 9: 669-697.

Brook, N. 1985. The equivalent core diameter method of size and shape correction in point load testing. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.* 22: 61-70.

Brook, N. 1993. The measurement and estimation of basic rock strength. In J. Hudson (ed.-in-chief): *Comprehensive rock engineering. Principles, practice & projects. Vol. 3: Rock testing and site characterization:* 41-81. Oxford: Pergamon.

DGEG 1982. Empfehlung Nr. 5 des Arbeitskreises 19 - Versuchstechnik Fels - der Deutschen Gesellschaft für Erd- und Grundbau e.V. Punktlastversuche an Gesteinsproben. *Bautechnik* 1: 13-15.

Gunsallus, K.L. & Kullhawy, F.N. (1984): A comparative evaluation of rock strength measures. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr,* 21: 233-248.

Hawkins, A.B. 1998. Aspects of rock strength. *Bull. Eng. Geol. Env.* 57: 17–30.

ISRM 1985. Suggested Method for determining point load strength. ISRM Commission on Testing Methods, Working Group on Revision of the Point Load Test Method. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.* 22: 51-60.

Thuro, K. (1996): Bohrbarkeit beim konventionellen Sprengvortrieb. Geologisch-felsmechanische Untersuchungen anhand sieben ausgewählter Tunnelprojekte. Drillability in hard rock tunneling by drilling and blasting. *Münchner Geologische Hefte, Reihe B: Angewandte Geologie* B1: 1-145, I-XII.