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Geotechnical aspects of representative hardrock sampling

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ABSTRACT: Rock mechanical parameters gained from laboratory investigations (i.e. Unconfined Compressive Strength, Tensile Strength, Shear Strength or Abrasivity) are key values for the mechanical description and classification of any hardrock type. Consequently such investigations are of crucial importance in the course of any preliminary site investigation program conducted for infrastructure projects in hardrock conditions. Especially under the aspect of increasing measuring accuracy and increasingly complex hardrock testing methods the fact has to be faced, that the accuracy of the gained parameters may not only be connected to the (precisely defined) testing setup and (precisely defined) testing circumstances but in an increasingly manner influenced by the process of sampling. This paper represents theoretical backgrounds and practical approaches (including an easy-to-use "flow-chart" like guideline) on hardrock sampling. A special focus is put on the sampling and treatment of anisotropic and non-durable rock types and aspects of block sampling as an alternative sample source to core drillings.

1 INTRODUCTION

Rock mechanical parameters gained from laboratory investigations (i.e. Unconfined Compressive Strength, Tensile Strength, Shear Strength or Abrasivity) are key values for the mechanical description and classification of any hardrock type. Consequently such investigations are of crucial importance in the course of any preliminary site investigation program conducted for dams, mining or infrastructure projects in hardrock conditions.

The testing procedures used in the field of rock mechanics and engineering geology are topic of various national and international standards, suggestions and testing recommendations (such as ASTM, DIN EN ISO, BS standards or ISRM Suggested Methods) and will lead to comparable testing results (at least within the framework of one applied system). Especially under the aspect of increasing measuring accuracy and increasingly complex testing methods the fact has to be faced, that the accuracy of the gained parameters may not only be connected to the (precisely defined) testing setup and (precisely defined) testing circumstances but in an increasingly manner influenced by the process of sampling.

This paper resumes some theoretical background and practical suggestions on the topic of hardrock sampling. A special focus is put on the sampling of anisotropic and weak rock types and aspects of block sampling as an alternative sample source to core drillings.

2 BASIC DEMANDING FOR REPRESENTATIVE HARDROCK SAMPLING

When it comes to the planning of a complex investigation program in the course of a dam, mining or infrastructure project in hardrock conditions, the choice of the kind and quantity of investigations remains one of the most challenging tasks for the engineering geologist.

The general demands for the sampling can be defined according to European Standard Eurocode 7 (EC7): "…type and quantity of samples to be gained must be planned in accordance to the aim of the investigations, the site specific geological circumstances, the complexity of the geotechnical structure and the type of construction to be build." As soon as investigation aims, necessary rock parameters and testing procedures have been defined, the necessary type and quantity of samples to be gained arise from the technical aspects of rock testing as well as from the characteristics of the geological unit to be investigated.

3 TECHNICAL ASPECTS OF ROCK TESTING

In order to provide the necessary quantity of suited samples for rock testing, all working steps from sampling to transportation, storage, formatting and testing (Fig. 1) should be kept in mind. In order to provide maximum effectiveness, all samples selected in the field should match the requirements of every single step of further processing.

4 REPRESENTATIVITY OF SAMPLES

In order to match the criterion of representativity, a rock sample must be typical for the geological unit it belongs to in respect of certain characteristics, however chosen. Nevertheless, this "simple" requirement raises many questions on the overall quantity of samples to be taken and the distribution of sampling locations.

There are some practical suggestions available for the minimum number of necessary samples for standard tests like Unconfined Compressive Strength Tests, Brazilian Tensile Strength Tests and Triaxial Compressive Strength Tests (Table 1) from European Eurocode 7 (EC7). In this suggestion, the minimum number of samples is related to the variation (standard deviation) of the measured parameter and the grade of experience with this parameter under the specific geological circumstances (none—medium—extensive experience).

Besides the fact, that the quantity and distribution of samples must be carefully chosen in order to allow a representative statement for one geological unit or strata, it should be additionally noted that if more units are found to be relevant, the characteristics of these

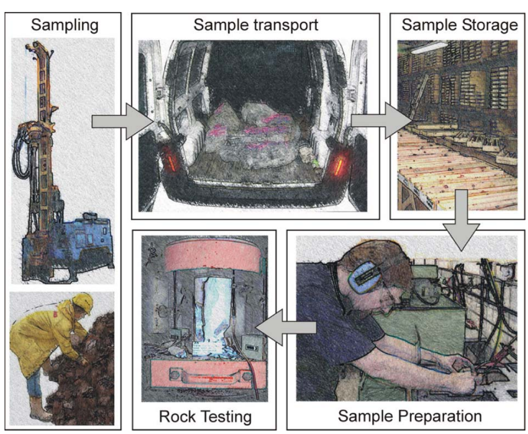

Figure 1. Scheme for the processing of a rock sample from sampling to testing.

Table 1. Suggested minimum number of samples per geological unit for UCS, BTS or triaxial tests (from: DIN EN 1997-2, EC 7, Table W1).

Standard deviation s of the measured parameter [% of mean value]	Comparable experiences		
	None	Medium	Extensive
s > 50	6	4	2
20 < s < 50	3	2	1
s < 20	2	1	0*

*only valid for very homogenous rock types and extensive experience from nearby localisations.

additional units should be investigated with the same care. There are a couple of projects known to the authors, where one unit was subject of excessive investigations, whilst other—also relevant—rock units have not been investigated at all, initiating a vast risk potential for the project.

5 SAMPLE SIZE

Geometrical effects and size effects may play an important role for rock mechanical investigations. Depending on the investigations scheduled the most important effects, namely scale effects, shape effects and inhomogenities should be considered for the choice of sampling methods, sample size, drill diameters, etc. The effects described in the following chapters relate to Unconfined Compressive Strength (UCS) testing, where such influencing factors have in the past been subject to extensive investigations, but can in a similar way be observed for many more testing layouts like tensile strength, shear strength, triaxial strength or abrasivity testing.

5.1 *Scale effects in UCS testing*

Scale effects describe the phenomenon of different testing results from one rock type when derived from samples with differing size. Such phenomena are well known since the works for example by Hoek & Brown (1980) or Hawkins (1998). Theoretically they are explained by an increase in the amount of inhomogenities and microcracks with increasing sample size.

Newer results have been presented by Thuro et al. (2001). Based on their investigations on selected homogeneous and isotropic rock types (limestone, granites), the authors resume that for those rock types no significant scale effects could be recognized for the strength properties (UCS, Young's modulus, destruction work) within a usual range of UCS samples from diam. 45 mm to 80 mm (Fig. 2).

5.2 *Shape effects in UCS testing*

The so-called "shape effect" describes the impact of variation of the length/diameter ratio of a cylindrical specimen ("core") on rock strength properties. The results from Thuro et al. (2001) show that—in contrast to scale effects - the strength parameters UCS, Young's modulus and destruction work can be clearly related to the specific length/diameter ratio of the samples. Based on this research, in between a ratio range of 1:1.0 to 1:3.0 the influence on the destruction work, Young's modulus and the tensile strength is quite significant with about 30% variation. In comparison, the effect on Unconfined Compressive Strength is much lower with only 5% variation (Fig. 3).

5.3 *Sampling inhomogeneous rocks*

For inhomogeneous rock types the sample size has to be adapted to the size of inhomogenities (e.g. mineral grains). As a rule of thumb, a ratio of 10:1 for the diameter of the specimen in

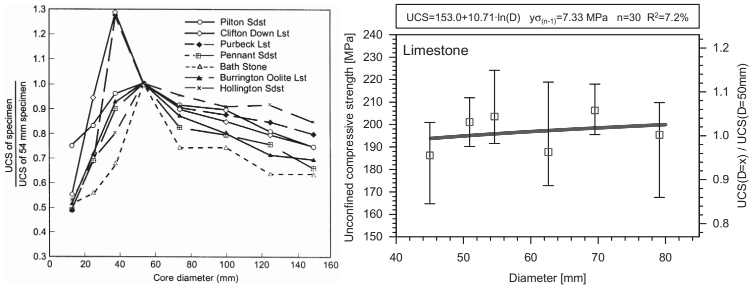

Figure 2. Figures on size effects in UCS testing: Left: Diagram according to Hawkins (1998), showing a significant drop in UCS with increasing sample size, right diagram for a homogenous and isotropic limestone according to Thuro et al. (2001) showing no significant change in UCS.

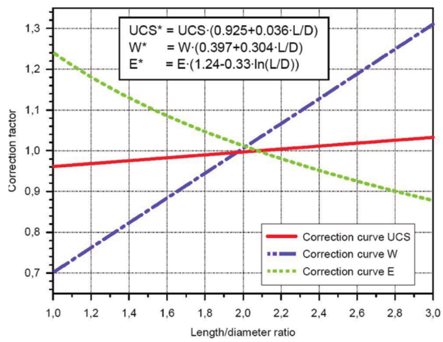

Figure 3. Shape correction curves for Unconfined Compressive Strength (UCS), Destruction work (W) and Young's modulus (E) (from Thuro et al. 2001).

relation to the size of the largest grain has long been used (e.g. ISRM 1979) and proven as a good guideline.

6 SAMPLING OF WEAK (NON-DURABLE) ROCK

Weak or non-durable rock types—mainly clastic sediments, but also some metamorphic and igneous rock types—are primarily known to show more or less rapid disintegration when exposed to water or the atmosphere. But even if a sample seems intact and shows no traces of disintegration, the mechanical properties may be significantly influenced by changes in water content (Fig. 4).

Consequently, when dealing with potentially weak rocks, two main goals in sampling should be:

- to clearly identify if a rock type is subject to weakening effects section 6.1),
- and—if yes—to preserve the natural moisture content and to avoid additional drying or wetting of samples (section 6.2).

6.1 *Identification and classification of weak rocks*

Recent investigations (Nickmann 2010) have shown that the testing methods stipulated in national standards (ASTM, DIN EN) or international suggested methods (e.g. IAEG, ISRM) are not suitable to clearly identify any type of weak rock. Simple and easy to carry out field tests (e.g. "smear test", "water reaction test", see ISRM 1994) as well as laboratory tests (several wetting tests, e.g. acc. to DIN EN 14689-1) are only capable of detecting rocks with medium to high slake durability and show cracking or disintegration during first water contact.

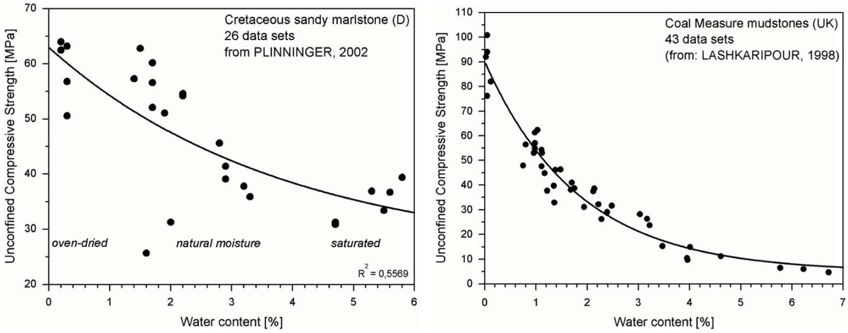

Figure 4. Examples for the dependency of rock strength (UCS) from water content for cretaceous marlstone (data from Plinninger 2002, left) and mudstones (data from Lashkaripour 1998, right).

Figure 5. Examples for sealing measures for weak rock samples: Setting a silicone plug at the ends of a plastic inliner (left), simple plastic wrapping of a large block sample taken from a tunnel face (right).

Although these rock types are especially sensitive to changes in water content, also rocks with low slake durability can show a successive weakening by several changes in water content (wetting and drying) and a significant variation in mechanical properties.

The identification of rock types with a low susceptibility to decay—which can only be recognized after several cycles of changes in humidity—can from the authors point of view only be done by using a cyclic slaking test. Subsequently, the identification procedure proposed by Nickmann (2006) combines a 3-cycle wetting-drying-test with a crystallization test and is suited to identify and to classify almost any type of weak rocks.

6.2 *Preservation of weak rock types during sampling*

Besides any technical measures, time will be the most critical aspect when it comes to the preservation of weak rocks in their natural moisture state, which should be taken into account before sampling. Additionally, there are a number of practical measures in order to preserve weak rocks samples and to avoid additional disintegration:

- choosing a sampling method that prevents the sample from artificial contact with water (block sampling, use of plastic inliners, use of air flushing where possible);
- immediate sample documentation and sample choice on site;
- immediate sealing by use of aluminium/plastic foils, wax or silicone plugs, etc. (Fig. 5);
- padding and isolation of samples with wood chips, Styrofoam, PU-foam or similar in order to avoid mechanical damages to the samples during transport;
- immediate and horizontal transportation to the laboratory;
- immediate sample preparation using air-cooled or oil-flushed preparation techniques for preparation of samples;
- immediate testing in the laboratory.

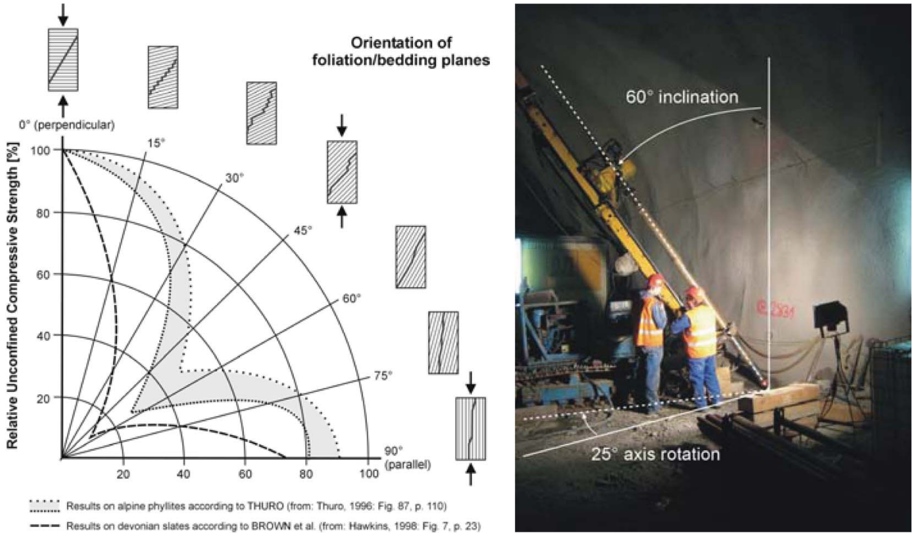

Figure 6. Left: Examples for the dependency of rock strength (UCS) from the orientation of anisotropic features (bedding, lamination, etc.). Right: Inclined core drilling from inside a tunnel in order to gain samples of defined orientation in an alpine molasse series (Achrain tunnel, Austria, 2007).

7 SAMPLING OF ANISOTROPIC ROCK

The term "anisotropy" relates to rock types with differing properties or differing characteristics in differing directions—features that are widely encountered in clastic sediments (e.g. bedding/lamination of siltstones, sandstones) and metamorphic rocks (e.g. foliation of slates, schist, gneiss).

In such rock types the sample orientation may have a much higher impact on the gained rock parameters than the testing setup and testing conditions itself. Consequently, samples with defined orientation, usually perpendicular or parallel to the axis of anisotropic elements are preferred for testing. For the example of UCS testing (Fig. 6, left) such orientated tests are of crucial importance since it may not be possible to judge on the maximum strength from tests on cores with inclined bedding/foliation.

If larger block samples can be gained, specimen of defined orientation can easily and precisely be formatted by overcoring or cutting on site or in the laboratory. This preparation is supported by the fact that on large samples even fine bedding or anisotropic elements of larger spacing can be recognized much easily than on small scale cores.

If samples can only be gained by core drilling, the necessary orientation of the drill string is relatively easily done for horizontal or subhorizontal strata. In inclined or folded geological circumstances the orientation of the drill string should be adapted carefully to the local circumstances by inclining and rotating the drill rig and boom (Fig. 6, right). Even then, further problems may arise, if the orientation of bedding or foliation changes with increasing depth.

8 EXPERIENCES WITH BLOCK SAMPLING

Block sampling represents a very effective, fast, easy and consequently very economical sampling method. It can be conducted in any location where a relevant rock type is exposed at a surface (e.g. natural outcrops, investigation pits or shafts, slopes, quarries, mines or conventional tunnel drivages).

The sample size depends on whether the block has to be handled manually or with aid of excavators and lorries, but should not be smaller than about $0.3 \times 0.2 \times 0.2$ m (Fig. 7, left).

Figure 7. Sampling of fresh claystone for laboratory testing from the muckpile of a tunnel drivage (left) and overcoring of a large limestone block on site by use of a electric core drill (right).

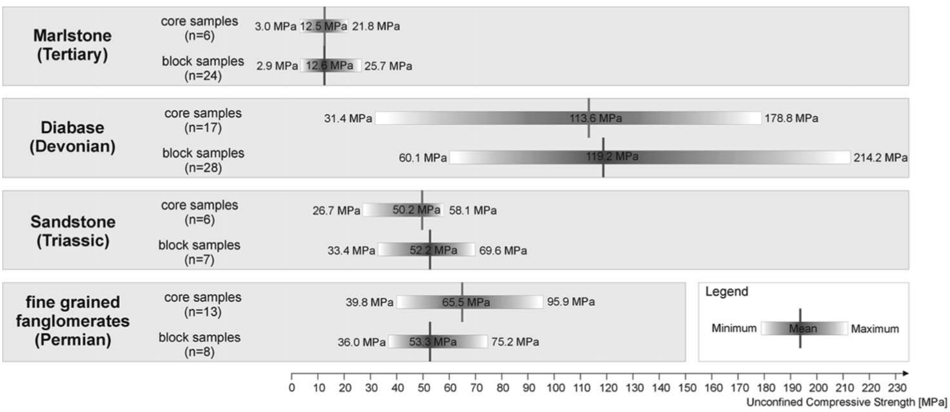

Figure 8. Direct comparison of UCS values measured for diabase, sandstone and fanglomerates on muckpile samples and core drillings.

If the rock is of a very coarse grained or cavernous type, the minimum size should be adapted similar to the considerations presented for inhomogeneous rock types in section 5.3 of this paper. Especially if used for strength testing, the sample should be thoroughly checked and jointed or precracked blocks should be discarded.

After checking, documentation and labelling, the blocks may then be transported into the laboratory (sealing and isolation, if necessary, see section 6) for further preparation or can be overcored on site by use of small size core drills (Fig. 7, right) in order to reduce the necessary transportation volume.

According to the author's experience, there is no evidence for any significant influence on the testing result coming from the sampling method. Based on the analysis of three drill and blast tunnel projects, where both methods have been conducted in similar rocks, a good correlation of values can be recognized (Fig. 8).

These results are especially interesting for sampling in the course of drill and blast tunnelling, where lots of discussions have in the past been conducted on the representativity of block samples. If the sample is taken with care, the argument, that blocks will show significantly lower strength values due to precracking have turned out as wrong as the controversial argument, that such blocks will show significantly higher values due to the weak parts of the rock mass being destroyed by blasting and being therefore not available for sampling.

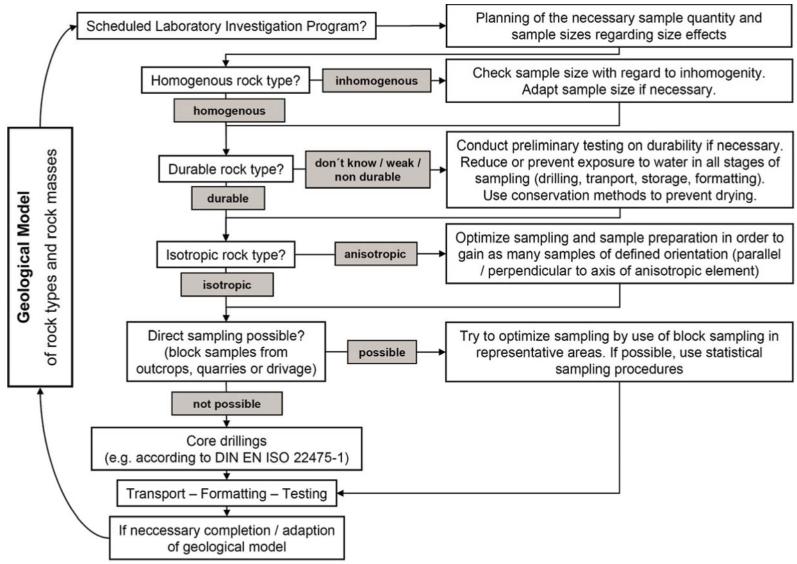

Figure 9. Flowchart guideline for representative hardrock sampling taking into account some of the most relevant influencing factors.

9 CONCLUSION

Based on the experiences presented in the chapters before, an easy-to-use flowchart like guideline has been developed (Fig. 9).

Even if this guideline may be helpful for checking some of the most important geotechnical aspects of hardrock sampling, simple tools may never replace the knowledge and judgement of an experienced engineering geologist. The development of a geological model and the judgment on the representativity of gained rock parameters in the course of the preparation of the final geological and geotechnical report will nevertheless remain a challenging task.

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