Laboratory Testing for Soft Rock – a Challenge

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ABSTRACT: Especially for weak or highly fractured rocks, the acquisition and preparation of samples often results in a highly biased selection of stronger samples due to difficulties in specimen preparation. Besides the problem of sampling (e.g. disturbed or undisturbed specimens), many standardized procedures are either suitable for pure rock or soil. This paper shows some examples of how to determine the mechanical parameters for weak rock in the laboratory.

1 INTRODUCTION

Both the design engineering and the construction in soft rock conditions often cause difficulties. The determination of representative mechanical parameters and the calculations for such an intermediate region between rock and soil is a challenge to the engineer, because most procedures are either suitable for rock or soil. First of all we need relevant parameters to describe the soil and rock material behavior. For weak or highly fractured rocks, the acquisition and preparation of samples for compression tests often results in a highly biased selection of stronger samples due to difficulties in specimen preparation. Therefore we have to attach great importance to the exploration and conduct of the sampling and testing procedures. There are some methods, like the integral sampling method that are applicable even to fractured and weak rock (Rocha & Barroso 1971). But only a geometrical model, including fractures and their infillings can be obtained, because the mechanical behavior of the sample changes due to the reinforcement.

The sampling, the storage and the specimen preparation need careful handling. This topic is part of the draft for EN ISO 22475-1 Geotechnical investigation and testing - Sampling by drilling – Part 1: Technical execution, drawn up by the Technical Committee CEN/TC 341 (2004).

2 PROCEDURE IN GENERAL

To achieve a realistic evaluation, specifying representative procedures, a sampling and testing program is necessary. The determination of parameters in the laboratory and in in-situ tests is an essential part of the characterization process. As rocks and the rock masses are inhomogeneous, we have to deal with wide distributions in the parameter values and to determine which parameters are necessary for a given rock mass to properly convey lab behavior to the real situation.

Geotechnical parameters could be divided into different groups, like geophysical -, mineralogical -, hydrological –, and mechanical parameters in addition to parameters that describe the rock mass structure. However, one should always take all these groups into account, because they can interact and so influence the material behavior. For instance, a variation in the mineralogical and hydrological parameters influences the mechanical parameters. The relevant boundary conditions and parameters for a certain project should be discussed in the investigation phase. For this complex matter, teamwork between geologists, geophysicists, and engineers is necessary to adequately characterize complex geologic situations for engineering purposes.

The goal of the characterization process should be to evaluate the physical characteristics of the rock mass that have the largest influence on the excavation behaviour (i.e. key parameters); this process should be site and rock mass specific, Schubert & Riedmüller (2001). To describe the rock mass behavior, one can proceed in the following stages: identification, classification, characterization, interpretation and verification. Quantifying the rock and the rock mass behavior will always be a challenge; appropriate testing procedures and analyses are the first step for a more realistic evaluation. Therefore, sampling and testing should not be irrespective of the entire project.

3 SAMPLING

In the draft standard EN ISO 22475-1 for given ground conditions, different categories of sampling methods related to the best obtainable sample class for laboratory are defined. Also the handling, transport and storage of samples are specified. Nevertheless, it is necessary to make a personal effort to achieve good quality samples of weak rock. This is not a contradiction when the physical properties of the sample reflect the in-situ situation as good as possible. In particular, the transition zone between rock and soil causes difficulties. However, especially this zone is often very important in geotechnical engineering. Examples are fault zones, disturbed schistose rocks, etc. To exemplify this, a picture of a phyllitic rock is shown in Figure 1.

Figure 1. Phyllit, multiple deformation phases give rise to complex foliation assemblage.

Figure 2. Disturbed core.

In such weak rock types it is sometimes impossible to get appropriate samples, even if a double or triple tube core barrel is used. In addition to existing joints, the fabric of composite minerals with different strength in a weak matrix is often responsible for a sample defect due to drilling (see Fig. 2). Another sampling method is the block sampling. In this method the samples are obtained from a trial pit, heading, shaft etc. by using special samplers or manual work with cutting procedure (see Fig. 3). If the material has no adequate cohesion we have to treat it like soil, but the existence of larger blocks should be taken into account.

Figure 3. Sampling with manual work using a cutter.

A specific weak rock type is a mixture of competent blocks of rock encased in weak matrix, called bimrock (block-in-matrix) introduced by Medley (1994). The overall mechanical properties of bimrocks are dominated by matrix strength, volumetric block proportion, block orientations, block shapes and block size distributions. This condition can be found at different scales, from mineral to tectonic plate size.

4 LAB WORK

The determination of mechanical parameters in the laboratory has some advantages over in-situ tests. They are easier too handle, independent from accessibility, various test set-ups and controllable boundary conditions are possibly and last but not least the costs are lower. Lab tests require appropriate samples as mentioned before. For huge projects sometimes large-scale in-situ tests are performed, but there are also quick index in-situ tests (e.g. torque vane, penetrometer) and geophysical borehole tests, which should be used to confirm the mechanical parameters. Of capital importance is always the reference to the geotechnical model. Lab work is part of the characterization process and as aforementioned a cooperation of all parties concerned is imperative.

State-of-the-art testing equipment allows new types of testing procedures to determine the mechanical parameters of joints and intact rock. Highresponse servo hydraulic systems (Fig. 4) with digital control technology, strain measurement equipment mounted onto the specimen and programmable control modes, enable new types of test procedures, which are tailored to the specific problem (Blümel, 2000). The correct interpretation of test results depends on the quantity and especially on the quality of the laboratory tests. The goal of such procedures is to obtain as much information as possible about the rock properties from a single test.

Figure 4. Equipment for a rock mechanic laboratory. Left: stiff load frame for UCS and triaxial tests. Centre: direct shear frame. Right: control unit.

5 TEST METHODS

5.1 *Laboratory sample preparation*

“Intact samples” are specimens that allow cylindrical or block shape preparation. Frequently used tools to dissect the specimens are diamond saws, wire or chain saws, handsaws, cutters, core drills and grinding tools. On very weak specimens the grinding of the end planes is sometimes not possible. Therefore it is necessary to reinforce the end plane area (e.g. resin) to ensure a plan-parallel end plane for loading (see Fig. 4). The strain gages, however, have to be fixed onto the unaltered part of the specimen.

Figure 5. Specimen with resin reinforced end planes.

The expression “intact sample” stands for a finish-worked core or block specimen, which should represent the in-situ situation. “Intact” does not mean that the sample material is of good quality. It is very important to act with consideration, because the behavior of such weak rock specimens is mostly complicated, especially the water content is of great importance.

Completely destroyed samples, like sheared loose rock material can be handled like soil, but the existence of larger gain sizes (e.g. harder blocky materials) often causes difficulties.

5.2 *Tests*

On “intact specimens” the standard testing procedures can be performed as long as the testing equipment is in the range of the accuracy class for very weak samples. Therefore we also use soil mechanic devices.

The ability to apply different stress paths and boundary conditions to a given sample or suite of samples allows different failure modes to be investigated in the laboratory. The unconfined compressive test (uniaxial test) is the most frequently used rock mechanics test, but provides only elastic properties and a single failure value derived from a very simple stress path (Brosch et al. 2000). With computer controlled feedback it is possible to follow different stress paths by varying the ax symmetric confining pressure and the axial compression of a rock cylinder. The use of computed automated controls allows us to perform multiple loading cycles on the same specimen. After each peak load for a given confining pressure, the deviatoric stress is reduced to zero and the sample is loaded hydrostatically to the next confining level.

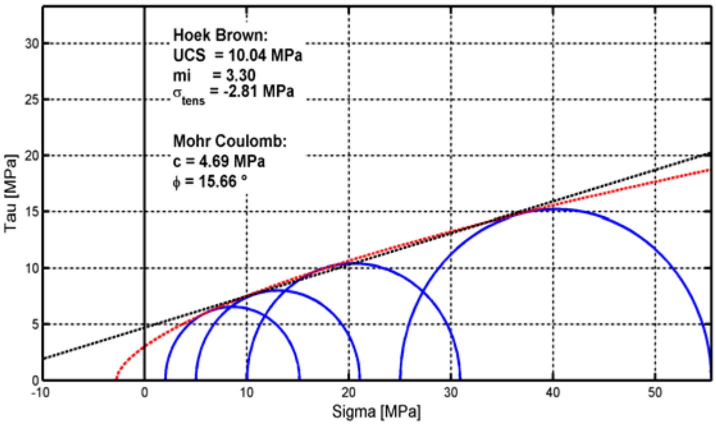


Figure 6. Multiple failure state triaxial test, using Hoek-Brown and Mohr Coulomb failure criterion.

Thus, the progressive stress history of a single sample can be monitored instead of using different samples (with different microstructure?) at each stress state and combining the results to estimate the progressive stress behavior of the "intact" rock (Fig. 6). This allows a more realistic evaluation of the intact rock strength, and thus the rock mass strength, results in more realistic predictions and interpretations of the in-situ rock mass behavior.

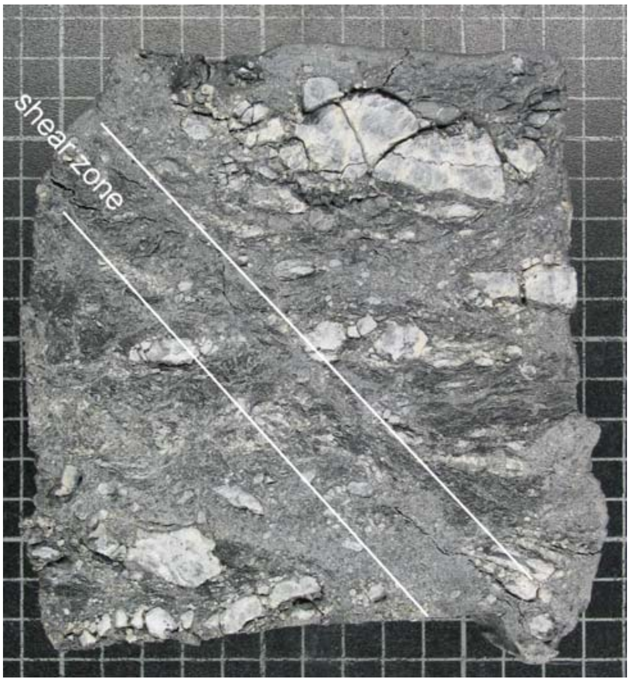


Figure 7. Sliced specimen after a triaxial test.

The preparation effort of block samples is much less for direct shear testing and allows the testing of weaker material, as well as the highly competent material using the same testing procedures. To determine the anisotropic behavior, a sample can be placed at any orientation within the shear box to evaluate the strength and failure processes associated with a shear direction that is not directly parallel to the preexisting discontinuity structures (Button & Blümel (2002).

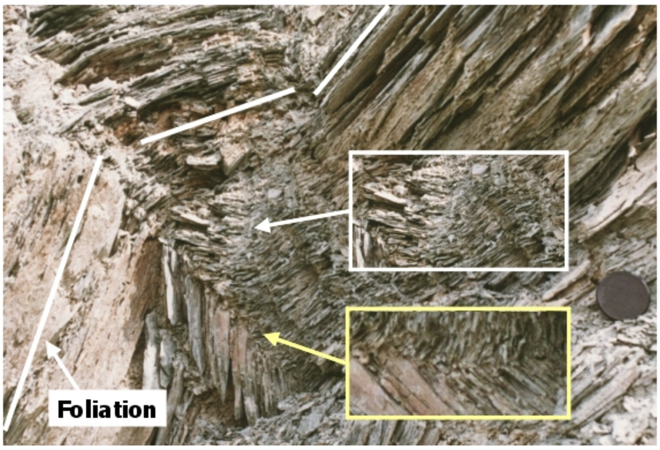
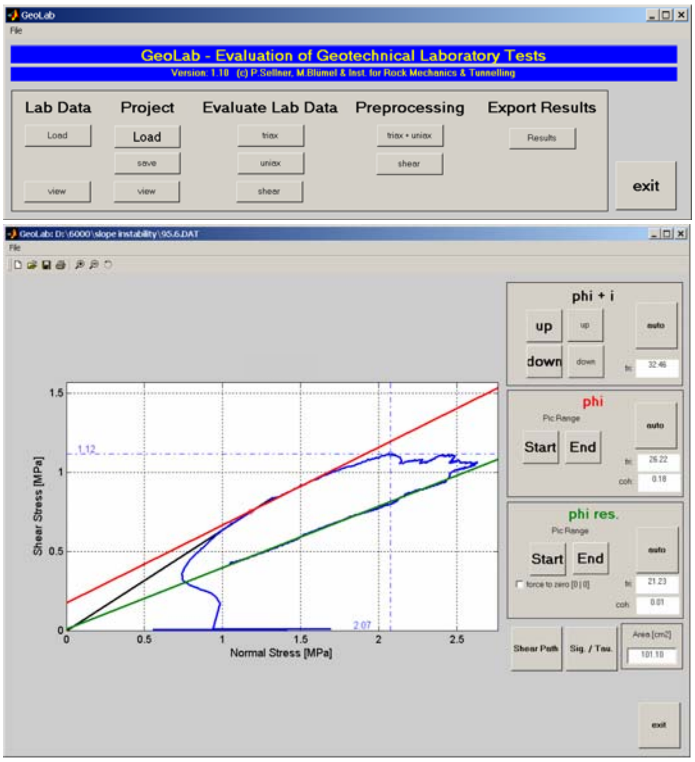


Figure 8. Foliated rock, shear zone.

Figure 9. Deformations of weak faulted phyllite, brittle cataclastic flow – interlayer shear.

Figure 10. Deformations of intact pyllite tensile failures, interlayer shear and rigid block rotation.



GeoLab

GeoLab - Evaluation of Geotechnical Laboratory Tests

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Figure 11. Stiffness controlled shear test evaluation.

To investigate the shear behavior and failure characteristics of both fracture surfaces and weak intact rock we use automated testing procedures to perform tests with different boundary conditions. This enables the execution of modified shear tests, which are behavior specific. The simplest case for shear failure is a single block resting on a plane. In this simple case we need a failure criterion in which the principal stress situation is not changed. This can be performed in the laboratory with a constant normal load direct shear test. In many cases, the failure mechanism will not be this simple and more representative boundary conditions should be used. Usually we have to deal with embedded blocks side by side where the acting normal stresses, due to the dilation are changed and so the overall principal stress distribution varies.

For example, stiffness controlled tests can be used to evaluate the ultimate shear strength for different boundary conditions, and also allows the recognition of the different failure modes that occur during shearing. The volumetric strain behavior, the so-called dilation or contraction is used as the feedback control mode for the vertical stress. This test method is the most appropriate test method for evaluating a material’s shear behavior yielding the shear and normal stiffness, dilation potential, cohesion, and the initial and ultimate friction angles. In Figure 11, a screenshot of the laboratory data evaluation program for a stiffness controlled shear test is shown. Multiple failure state shear tests (under constant normal loads) as well as various combinations of test control procedures can be performed on a single sample eliminating the effects of sample variability on the failure envelope.

In Figure 9 and Figure 10 pictures of a weak faulted Phyllite specimen, and a hard intact Phyllite tested normal to the foliation, are shown, which were taken after a constant normal stiffness test. The observed failure modes look similar to different zones within the failing rock mass shown in figure 8. The evaluation of such shear tests shows that the strength is influenced by a complex interaction between sliding friction, dilation, and cohesion. The use of constant normal load shear tests (CNL) does not really test the rock strength but the resistance to shear at a certain normal load, which may be appropriate under certain boundary conditions. Constant normal stiffness testing procedures (CNS) can be used to define a sample’s “ultimate shear strength” which is the natural response to simple shearing (Fig. 12).

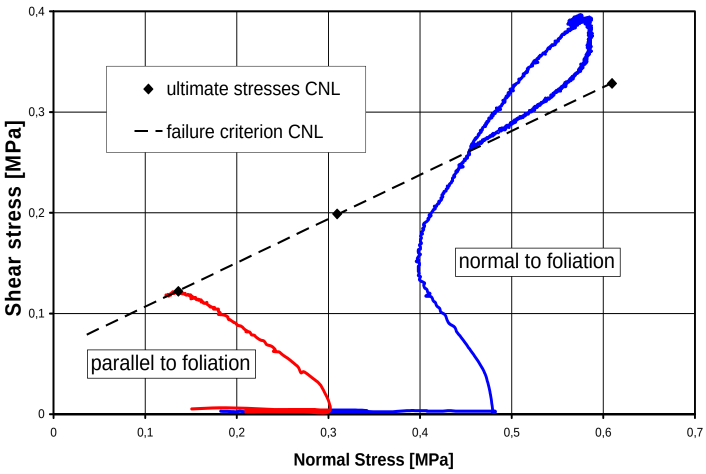

Figure 12. Diagram of stress paths depending on shear direction and control mode.

For completely destroyed samples, like sheared loose rock material, a frame shear laboratory test can be done on remolded specimens. For a standard soil mechanic shear test the maximum gain size is 4 mm. In a larger shear frame it is possible to test a remolded rock-soil mixture, like is often found in natural shear zones (Fig. 13). The different results of both shear tests are shown in Figure 14. In this case, the determined friction angle and the cohesion on the sieved material were almost the same, but the residual friction of the fine grained material after shearing several times on the shear joint was about half the value when compared to the material that still contained blocky material in the matrix.

Figure 13. Picture of large-scale shear box test for remolded specimens (30 x 30 cm).

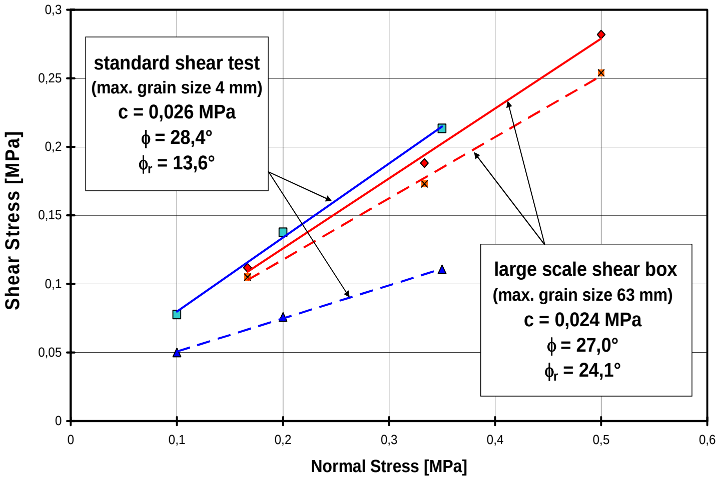

Figure 14. Mohr-Coulomb envelope for large-scale shear box test for remolded specimens (maximum grain size 63 mm) and standard shear test (maximum grain size 4 mm).

6 CONCLUSIONS

The challenges of determining the mechanical properties of weak rock are multifarious. The limited accuracy in prediction of rock mass behavior has its roots in the difficulty of obtaining representative samples and test results, in the strong influence of singular features and in over simplified modeling techniques.

At first we need to recover samples of a quality sufficient to assess the general suitability of a site for geotechnical engineering purposes.

The quality of a sample is influenced by the geological, hydro-geological and chemical conditions, sampling methods, the personnel taking the sample and by the sampling equipment.

The techniques and methods for sampling by drilling and excavation shall be selected according to the purpose of the investigations in relation to the expected geological and hydro-geological conditions. Different disturbance of sample can be expected when using various sampling methods. The quality class of a sample taken with the same sampler can vary depending on e.g. the rock type to be sampled, the presence of groundwater and the sampling operation.

Different reasons can lead to sample disturbance: Mechanical sample disturbance due to compression, shearing, flushing or vibration during drilling or excavation, sample disturbance due to release of in-situ stresses and related rebound, changes in material and chemical constituents such as water content and gases.

Additionally to the sampling difficulties, the weak rock material is due to its genesis mostly heterogeneous and highly anisotropic.

Therefore sophisticated test procedures are essential to get better information about the mechanical behavior of weak rock.

The presented shear test procedure is a facility to study the behavior of weak rock with the opportunity to simulate various boundary conditions. Thus it is possible to get the ultimate shear stress and strain, and the dilatational behavior as a natural response to the shearing process for the created failure mechanism under specified boundary conditions.

Quantifying the rock and the rock mass behavior will always be a challenge; appropriate testing procedures and analyses are one step for a more realistic evaluation.

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