

SAMPLING
FOR
DETERMINING TOTAL HARDNESS
FOR
EVALUATING TBM BOREABILITY

by

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CONSIDERATIONS IN SAMPLING

General

The identification, classification, and testing of the products of nature constitute a synthetic procedure because these materials are infinitely varied and do not lend themselves to man-made distinctions and categories. Similarly, because of the complexity of natural materials, no one method is best suited for all materials and all applications.

Analytical methods and testing techniques in the field of soil and rock mechanics have become highly developed while the geotechnical techniques for site evaluation appear to have lagged behind. Very little exists in the literature that deals with the subject of sample selection, particularly rock, and beyond a desire for undisturbed samples.

The purpose of selective collection of rock samples for testing is to obtain test results, which will represent the anticipated rock properties pertinent to project design, potential methods of excavation, support, and stability analyses. In this discussion, only some of these aspects will be discussed.

A well-planned site investigation will include exploration, sampling, sample selection, and testing, pertinent to the proposed facility, engineering design, construction, and operation. It must also take into account how much is known about the natural materials and how these might affect various aspects of project development.

The proposed engineering operation and the associated domains of concern will determine the frequency and type of samples to be tested and the appropriate test method to be used. The testing ought to reflect the engineering and construction concerns, which we wish to address, elucidate, and resolve.

Anticipated methods of construction will dictate the need for evaluation of rock strength, drillability, boreability, stability, compressibility, and permeability. In each domain, appropriate tests and measures of intact and rock mass properties are available for quantitative measure and characterization.

Consequently, the most appropriate methods of geotechnical sampling and testing intimately rely on the purpose and the result that is desired. This is an aspect of rock sample selection too often overlooked particularly when "statistical sampling" is performed without rigorous professional judgment or specific design on how to represent the rock mass to be bored.

We must remember that sampling is not an end in itself; it is a means to an end. Sampling is a part of a much more important operation, namely, a site investigation, which requires professional judgment, and competence relevant domains of concern, such as boreability.

Unique Aspects of Rock Sampling

There are certain aspects of rock sampling that are fundamentally different than in soil mechanics. These are:

- Obtaining undisturbed rock samples is, under the majority of conditions, less difficult than for soil sampling,
- The entire borehole contents are cored and recovered and in some respects it is the bit that is lost that may in some cases be most important, and
- Rock properties are controlled by the imperfections rather than the perfections.

In most cases of rock sampling, the problem is when and where to select appropriate samples for testing.

SAMPLING AND TESTING FOR ANTICIPATED TBM BOREABILITY

Sampling to determine boreability requires the representation of the average and most adverse conditions which will limit TBM performance and which will require specific design consideration. For actual boreability, it is generally the rock strength, hardness, or associated properties that are pertinent. Therefore, the most adverse conditions will include the hardest, most abrasive, and toughest intact rock.

The most adverse conditions may also be defined by a rock mass containing discontinuities, being weathered or altered, or in any way weakened. In such cases, the most adverse conditions are defined by qualitative descriptions (alteration, weathering) or quantitative measures, (frequency, orientation, etc. of discontinuities or pocket penetrometer measure of consistency and character). Samples of weak or soft materials are rarely tested for strength or hardness, particularly for boreability.

Since a speculation that the lowest value of strength or hardness may be equal to or close to zero (0), at least in weathered or altered zones, is likely true, it does not require specific investigation except for determining its extent. On occasion, such zones may be investigated when project conditions, the method of construction, or other requirements are sensitive to such conditions and variations or if such zones are extensive.

Once quantitative test on the rock are started, the problem moves from the geological domain which is observational and qualitative to the engineering approach which is quantitative, and based on applications that are empirical, experimental, and practical.

Unconfined Compressive Strength

Historically, the unconfined compressive strength of rock has generally been provided in association with rock tunneling contracts even though it has been found to be misleading for evaluating boreability.

Use of uniaxial strength tests are not reliable or recommended for use in predicting boreability because the test is particularly susceptible to sample discontinuities, weathering, alteration, sample preparation tolerances, and other vagaries associated with the test, sample preparation, testing procedure, or a combination of both.

The current state-of-the-art for independent prediction of TBM penetration rates and cutter costs has utilized the Total Hardness (Tarkoy, 1979; Tarkoy, 1989).

Total Hardness

The Total Hardness has been in use for over a quarter of a century and has been used for predicting tunnel boreability almost two decades and its use has been described by Tarkoy (1973, 1974, 1975a&b, and 1981).

Since the Total Hardness is used to identify the range of rock hardness, which directly and adversely affects TBM performance (penetration and cutter wear), it is essential to define the upper limit of the Total Hardness. Defining the upper limit is more difficult than one might imagine. Most engineers and geologists are poor judges of what hard rock looks like, or its basis for selection.

Sampling should always be biased towards selecting hard rock because:

- It is difficult to reliably select hard rock,
- The hardest rock will be critical to TBM design, and
- Hard rock will produce some of the lowest penetration rates and the highest cutter costs,
- Rocks at the softer end of the scale do not always or necessarily produce proportionately better performance than the harder rock.

The usefulness of the Total Hardness relies on its empirical relationships with TBM penetration rates and cutter costs. Adherence to standards of sampling and testing are crucial to reliable use of these empirical correlations. Deviations from prescribed methods of testing and departures from use of prescribed equipment and practice will invalidate use of empirical relationships and will mislead contractors. The method of testing is best described in Tarkoy (1973). Details of equipment design, modification, and details of custom-built components are currently being compiled.

Variations and deviations from test methods, specified equipment, and procedures in the domain of boreability testing, have resulted in very costly construction problems. On some tunnels, variations observed in the test results, a performance prediction might vary by a minimum of \$100,000 of cost to the contractor. In the worst case, if this variation occurs in the upper half of the Total Hardness range for the site, the cost impact may be many times more.

Inappropriate sample selection will have an effect on test results, impact on time duration of TBM excavation (labor costs), and tool (cutter) costs.

CSM Indices and Methods of Prediction

The indices provided by Colorado School of Mines are extensive overkill. The excessive number of indices produces risk by providing multiple baselines for boreability. Some of the indices are no longer used in the industry, have questionable value, or produce little more than income for the laboratory. The testing appears to be performed by CSM students, rarely the same, changing from time to time, thus producing a continuing learning curve.

Furthermore, the CSM equation to predict boreability and cutter wear is not published, not available, and continually changing.

University of Trondheim System

We have used this method successfully and believe the method to be reliable. However, the testing takes excessive amount of time, is expensive, and can only be done in Norway.

SAMPLE SELECTION for TOTAL HARDINESS

General

Since selection of test samples is most commonly from rock core retrieved from core borings, the limitations of the core borings must be taken into account when sampling. It is important to sample and test the hardest rock possible from each lithologic, geologic, and rock type unit encountered by the core boring to define the upper limit of rock hardness to be encountered.

Sampling for Anticipated Rock Hardness

Specimens obtained for laboratory tests shall be representative of the hardest rock to be encountered **at tunnel grade**. Hard rock may be found by looking for samples having a high percentage of:

- Hard minerals,
- Compact, fine grained, and dense rock,
- Minerals having a high iron silicate content,
- Minerals having a high silica content,
- Minerals having a dense molecular structure,
- Cemented matrix, equiangular equigranular, and interlocking texture,

and avoiding core:

- With joints, fractures, fissility, bedding, discontinuities, or banding, and
- Altered, weathered, decomposed, friable, or otherwise weak rock.

The number of samples should represent the full range of variation in each of the lithological units in terms of the various components of fabric stated above.

Sampling for Encountered Rock Hardness

Sampling for establishing encountered rock hardness conditions is unique because:

- The location of sampling sites has limitations,
- The rock hardness distribution is unknown and undeterminable from visual inspection, and
- It has to reflect the widest range of rock hardness for amenability to developing cause and effect relationships for the range of performance and the range of encountered hardness.

The selection of sampling locations should be:

- At reasonably consistent spaced intervals,
- Sampling locations that have consistent and representative penetration rates throughout the shove and shift surrounding the sample location,
- Sampling that is representative of a wide range of penetration rates,

Sample Requirements

The test surface of all specimens, either in the laboratory or in the field, shall be smooth and flat over the area to be tested. The sample should be free of cracks, discontinuities, weathering, and alteration, of the rock mass.

Test samples should consist of core, no less than 2 in (50 mm) in diameter and no less than 6 inches (15 cm) in length. Samples should be free of joints, fractures, or other incipient breaks.

Smaller diameter Nq or Ncx core may be accommodated with metal inserts in the anvil, however, this difference in size may have an effect on the test results in spite of the anvil adapters. The Schmidt (L-type) Hammer Hardness (HR) tests were designed for use on Nx (2-1/8 in; 5.4 cm;) diameter core. Although Nq (1-7/8 in; 4.76 cm;) diameter core may be used with inserts in the test anvil, it has been noted from experience (Tarkoy, 1975b) that the use of Nq core may yield lower readings than on Nx core. Larger diameter core can be accommodated if absolutely necessary with the use of a larger anvil and various inserts.

Use of inserts shall be specifically reported with the test results. Highly experienced individuals with TBM and Total Hardness testing experience may be able to adjust test results to nullify the effect of core smaller than the minimum diameter.

Sampling Typical and Hardest Materials

It is essential to sample the range of rock from the typical to the hardest materials anticipated. The hardest rock is of interest and concern to assure that:

- the design of the TBM will be 100% efficient for the entire rock hardness range (cutter spacing, mucking, thrust),
- the TBM is efficient within the range of average to maximum hardness for best performance,
- an adequate normal cutter load is available to cut the upper limit of rock hardness,
- an adequate tangential cutter load is available to rotate the cutterhead through the softer rocks,
- lower strength, softer rock and fractures will probably cause lower penetration, not the higher penetration that might be predicted, and
- less than full penetration occurs only in the softer materials where it represents no loss in cutting efficiency.

Sampling From Core

Selection of samples for testing from continuous core should consider and take into account the geotechnical structure, lithological distribution, depth of rock cover over the tunnel, and

It is essential to:

- select from tunnel horizon/elevation,
- sample hardest rock,
- avoid sampling above or below tunnel horizon unless required lithology, formation, sample, etc. is unavailable in the tunnel horizon,
- make clear in remarks the purpose of departure from standard practice,
- try to get samples whose properties are unaffected by departures from the tunnel horizon, and
- have the sample selection be carried out by an engineering geologist trained and experienced in Total Hardness testing, rock mechanics, principles of structural mineralogy, principles of rock hardness and abrasability, and tunnel boring.

Sampling from Rock Blocks

If only outcrop or block samples are available, Nx cores may be drilled no less than 4 to 6 inches (10-15 cm) in length. The core drilled from the rock block should be oriented consistent with normal exploratory borings.

It is essential to record the source of samples accurately and note the sample condition, particularly with respect to alteration and weathering when sampling a surface outcrop.

The use of surface samples is generally discouraged unless they truly represent subsurface rock conditions or if no other samples are available. Some adjustments to such values should be made, based on experience.

When sampling surface outcrops, care should be taken to avoid sampling of the inherent surface weathering and alteration as unrepresentative of subsurface conditions.

SHIPPING SAMPLES

Samples should be packed to protect them from damage or other alteration from original in-situ conditions (moisture, confinement, etc.) during shipping.

Wrapping samples for cushioning should be utilized to protect core from rough physical handling. Rock types susceptible to slacking, dinking, swelling, expansion, drying, or any moisture content related effects, should be sealed, and packaged appropriately. When sealing core in wax, it is important to wrap core first in aluminum foil to protect the core from the wax and then in gauze to serve as reinforcement for the wax.

The container for shipping should consist of a wooden crate able to sustain the weight of the core as well as the handling associated with heavy freight. The shipping container should be marked:

"Rock samples for testing only, no soil content, value \$1"

TOTAL HARDNESS TESTING

The procedures, use of specified equipment, and recommended reporting techniques should be followed. The specifications have been standardized and are expected to be published in the near future.

Particular adherence to the following is essential:

- recommended sampling practices,
- recommended testing practices, and
- use of equipment according to specifications (specified instrument models, instrument modifications, and specifications for the standard anvil.

Procedures for sampling and testing and equipment borrowed from other specifications should not be used or mixed with the standards set forth for the Total Hardness testing. The testing method (except for testing equipment specifications) is prescribed by Tarkoy (1973b).

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