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# Measurement of effective stress shear strength of rock

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ABSTRACT: Although the shear strength properties of rock can be quite important for geotechnical design, they are difficult to measure. Rock samples obtained from coring are usually not long enough for laboratory strength tests. The ones that are long enough are from rock of higher quality and may not be representative of the rock mass. Often these cores are only used for unconfined compressive strength tests, and as a result the angle of internal friction cannot be measured. The rock borehole shear test (RBST) is an in-situ direct shear test performed against the sidewalls of the cored borehole. The shear plates are embedded into the rock using normal stresses up to 80 MPa. The shear head is pulled upward shearing the rock, and the maximum shear stress is recorded. After the shear head is retracted and then rotated 45°, a higher normal stress is applied to the rock and the rock is sheared again. Up to four sets of test data are recorded and plotted. The best fit line is drawn through the data, giving the rock's effective cohesion and angle of internal friction. The resulting coefficient of correlation usually exceeds 0.98. Some case studies are presented showing the reliability and repeatability of the test method.

## 1 INTRODUCTION

While borehole shear tests have been successfully used for many years for evaluating the effective shear strength of soil, the rock borehole shear test, which is essentially a robust version of the borehole shear test, is now being used to rapidly measure the shear strength properties of rock. These rock properties have been difficult for the designer to predict. As a result, foundation design in rock has typically been very over-conservative and costly.

The rock borehole shear test head is conveniently lowered down a NX-sized (76 mm) cored hole. A normal stress is applied to the rock and the shear head is pulled upwards, failing the rock in shear. Usually four sets of normal stress/shear stress data points are obtained at the test depth. The testing time is approximately ½ hour. The results of plotted and a best fit line is drawn through the data. Usually a coefficient of correlation of 0.98 or higher results.

## 2 ROCK BOREHOLE SHEAR TEST PROCEDURES

The rock borehole shear test is capable of applying 80 MPa of normal stress and 50 MPa of shear stress to the sidewalls of a cored hole. The device is screwed onto wire-line casing and lowered into the borehole. Figure 1 is a photograph of the rock borehole shear head. Pressure tubing that is used to apply and remove the normal stress is threaded through the wire-line. An acme all-thread rod is coupled to the wire-line casing and is inserted into a hollow cylinder piston. This piston pulls the casing and shear head upward shearing the rock. The stress caused by the weight of the wire-line casing is deducted from the total shear stress to calculate the rock shear stress. Figure 2 is a photograph of the rock borehole shear control unit.

A piston inside the shear head applies the normal stress. The normal stress is held for about 5 minutes to assure that the stress is fully engaged into the rock prior to shearing. The hollow piston is extended upward, pulling the shear head and thus shearing the rock. (Figure 3) If the rock does not chip and smears instead during the shear, the shear head can simply be rotated 45° and the next higher normal stress can be applied to the rock. If the rock chips, the shear head must be removed from the borehole and cleaned. It is then lowered to 50 mm above the previous shear depth and the next higher stress is applied to the rock. Typically a set of four normal and shear stress increments are applied to the rock. The results are plotted and the best fit line

Figure 1. Rock borehole shear head.

Figure 2. Rock borehole shear control unit.

is drawn through the data. The cohesion and angle of internal friction are the y-intercept and slope of that line, respectively.

## 3 GEOTECHNICAL DESIGN APPLICATIONS

Until now the shear strength of rock has been difficult to measure. As a result, historically geotechnical design has been at best ultra-conservative and empirical. Schmertmann and Hayes (1997) compared Osterberg load test results with design engineers' predicted

Figure 3. Rock borehole shear test piston extending upward shearing the rock.

ultimate rock socket capacities. As shown on Figure 4, engineers under-predict rock socket capacity by a whopping factor of about 10!

### 3.1 *Rock slope stability*

Rock slopes generally fail as block failure surfaces. Failures can be along existing joints and through intact rock. The shear strength of joints can be modeled as having a frictional resistance (i.e. tan($\phi$)) and a cohesive intercept of zero, while the shear strength of intact rock can be modeled as having a frictional resistance and a cohesive intercept. The engineer or geologist should map the profile of the rock, delineating the zones where the potential failure surface is in the direction of existing joints and where the failure is either through intact rock or against the joints. Based on the rock borehole shear test results, the shear strength values are then assigned to each layer. Presented as Figure 5 is diagram showing assigned shear strength parameters for suggested rock slope stability design approach.

### 3.2 *Rock socket capacity*

Provided that good construction techniques are used, the capacity of a rock socket depends on the shear strength of the rock. This capacity is comprised of the frictional resistance between the concrete and rock sidewall interface and the classical end bearing resistance of the rock. Side friction can be predicted from fluid pressure of the concrete and the rock shear strength that includes a friction angle and an empirical "roughness factor." End bearing is more challenging because the failure mechanism is less definitive,

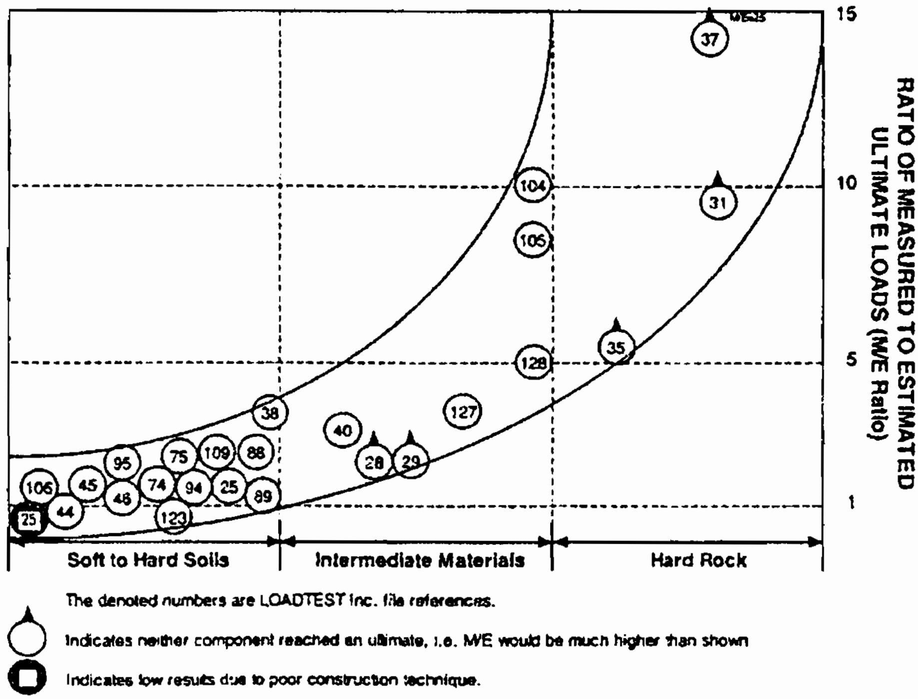


Figure 4. Engineers' underprediction of rock socket capacity.

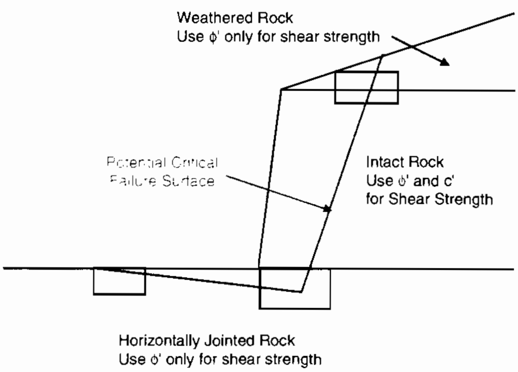


Figure 5. Assigning shear strength parameters for a typical rock slope.

so design usually involves an application of Terzaghi bearing capacity theory, which requires a separate consideration of cohesion and internal friction.

Quality control can be achieved with an O-cell that simultaneously pushes upward and downward at the bottom of a completed shaft. As both the O-cell and RBST are relatively new, future comparisons of O-cell data with rock borehole shear strengths measured in-situ should allow a better understanding of the failure mechanisms and the development of more accurate design procedures.

## 4 CASE STUDIES

At this point, the authors have been able to practically, rapidly, and efficiently perform rock borehole shear tests to determine the effective stress shear strength of rock. Additional load tests will improve design methods and their correlation coefficients. Four case studies are presented that demonstrate the value of the rock borehole shear test method.

### 4.1 *Ohio Route Route 23/Interstate I-470 Underpass Ramp–Columbus, Ohio*

To avoid a traffic-congested area, a 30-foot (9-meter) deep cut through shale was planned in the median of existing Route 23 for the new merge ramp. The shear strength of the shale was required for the design of the lateral support of the cut. Three boreholes were drilled and rock borehole shear tests were performed at various depths within the cored hole. The shale tended to be more weathered near the surface and improved with depth. The results of these tests are presented in Figure 6.

### 4.2 *Route 7 Rock Slope–Marietta, Ohio*

This slope consisted of a blocky sandstone formation overlying and shale/siltstone formation. The cut had

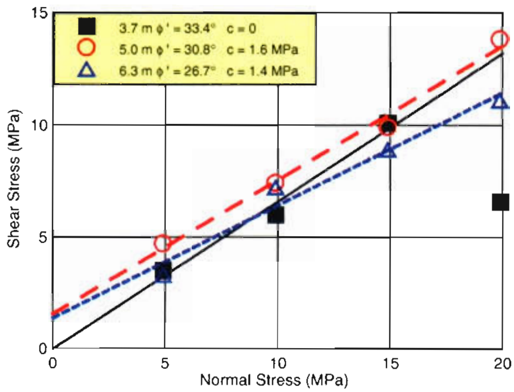


Figure 6a. Rock borehole shear test results from Boring T-10A.

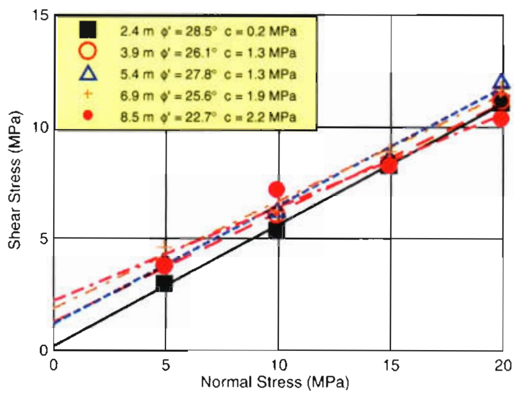


Figure 6b. Rock borehole shear test results from Boring T-19A.

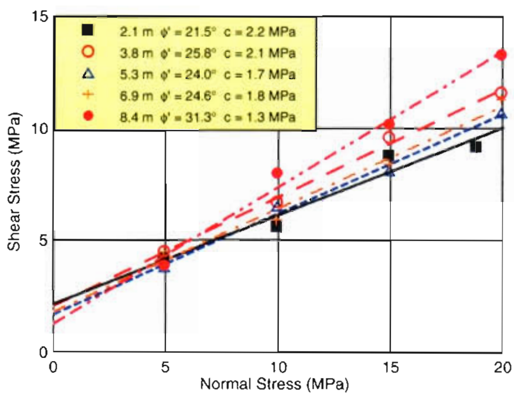


Figure 6c. Rock borehole shear test results from Boring T-25A.

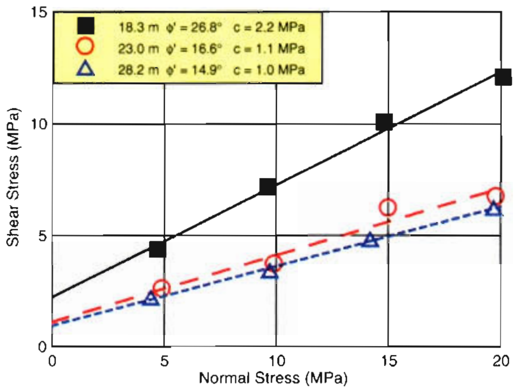


Figure 7a. Rock borehole shear test results from Boring 1046-1.0.

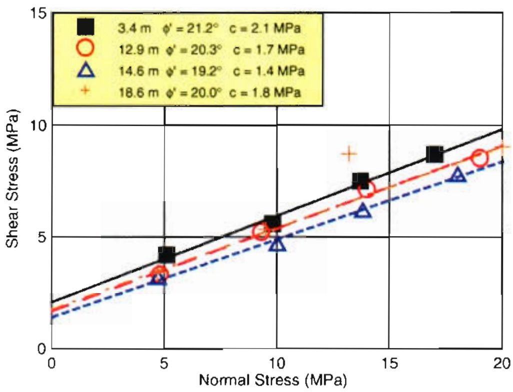


Figure 7b. Rock borehole shear test results from Boring 1054-1.0.

been made about 50 years ago and significant weathering had occurred to the shale/siltstone formation. Some weathering to the exposed shale was so severe that it had undermined the sandstone. A few years ago, two large sandstone blocks had tumbled down the slope and struck the concrete barrier that was protecting the road. When that impact occurred, a piece of concrete was ejected into the roadway. The Ohio department of transportation closed this section of roadway until the slope could be stabilized. Many rock borehole shear tests were performed in the shale/siltstone formation for the rock slope stabilization design. The results of these tests are presented in the Figure 7.

## 4.3 *2101 Market Street Rock Socket–Philadelphia, Pennsylvania*

Drilled shaft foundations were needed to support the proposed building at this site. A borehole shear test was performed in the weathered rock and a rock borehole

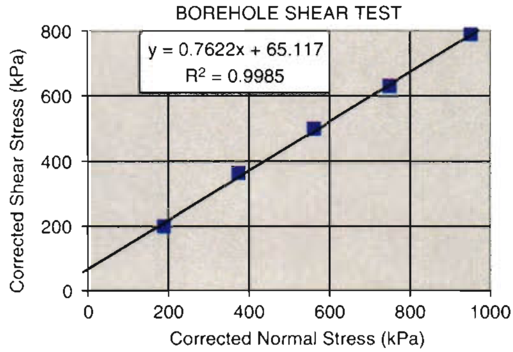


Figure 8a. Borehole shear test results in weathered rock from Boring B-11.

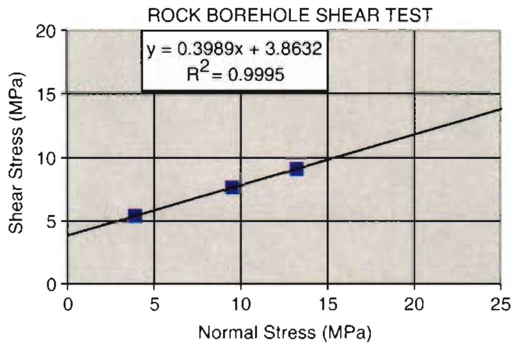


Figure 8b. Rock borehole shear test results of intact rock from Boring B-11.

shear test was performed in the intact rock. The diameter and length of the rock socket were designed based on these results. The results are shown in Figure 8.

### 4.4 *Sugar Creek Rock Slope–Iowa*

At the site of a new bridge for Highway US 63 over Sugar Creek in Wapello County, Iowa, USA, analysis of the approach embankment fill slopes indicated potential global instability problems, with a slip surface passing through layered weathered shale. For the initial analysis an assumed cohesion of 10 kPa was used in accordance with local design practice. As a result, alternatives of ground improvement and retaining walls were investigated that added significant cost to the project. In view of the high costs, a comprehensive subsurface exploration and testing program comprising RBST measurements was implemented at a relatively small cost to supplement the preliminary investigation conducted. The purpose of the RBSTs was to develop more realistic and site specific design parameters for the weathered shale layers. Two RBSTs were performed in the weathered shale zones shown

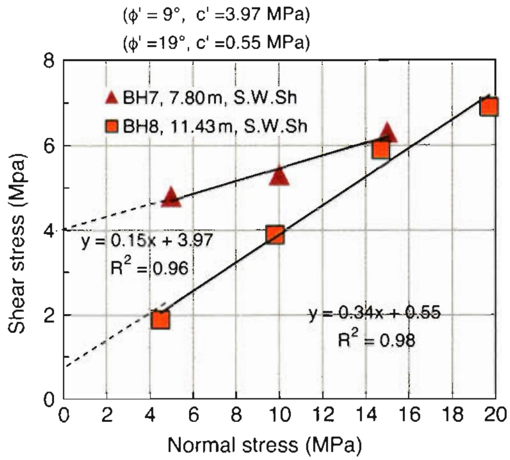


Figure 9. RBST results for the weathered shale at US 63 in Wapello County, Iowa.

in Figure 9. Results show that the tests performed well as revealed by coefficient of correlation ($R^2$) values of 0.96 and higher. As a result of this testing, the design cohesion values for slope stability analysis were increased substantially, which reduced costs associated with ground improvement and retaining walls.

## 5 CONCLUSIONS

1. The rock borehole shear test is an accurate and rapid test to measure the effective stress shear strength of rock.
2. Without these parameters, design has been based on "experience" and overly conservative. With shear strength parameter, design can be numeric, rational and accurate.
3. For rock slope stability, the rock borehole shear tests enable the engineers to perform analyses using numeric methods that have been used for many years for soil slopes.
4. For rock socket design, future comparisons of O-cell data with rock borehole shear strengths measured in-situ should allow a better understanding of the failure mechanisms and the development of more accurate design procedures.

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