Universal Shear Device

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The direct simple shear device is a way to measure undrained shear strength of soils that reflects a the average shear strength mobilized in the field during failure of embankments on soft soil foundations and deep excavations in clay. Many soils develop different undrained shear strengths on different angles of the shear plane due to anisotropy. For example in Boston Blue Clay, a triaxial extension test shears along a plane oriented at 45-ϕ/2 and gives an undrained strength ratio (s_u/σ'_{vc}) about half of that measured in a triaxial compression test which shears along a plane oriented at 45+ϕ/2. Ladd (1990) and others have shown that the effects of strength anisotropy average out for many cases to a strength ratio similar to that measured in a direct simple shear device.

Boston Blue Clay

Stress Condition	Value
Triaxial Compression, s_u/σ'_{vc}	0.32
Triaxial Extension, s_u/σ'_{vc}	0.16
Direct Simple Shear, s_u/σ'_{vc}	0.22
Average of Compression and Extension	0.24
Average of Comp., Ext., and DSS	0.23

The undrained direct simple shear test is a simpler test to run than a triaxial test. Backpressure saturation is not required so the test chamber and testing procedures are simpler. Typically, a test specimen 1 inch high and 2 to 3 inches in diameter is sheared along a horizontal plane in an undrained condition. The undrained condition is achieved by maintaining the test specimen at a constant volume. Since the test chamber keeps the specimen area constant, constant volume requires maintaining the height of the specimen constant during shear.

The constant volume direct shear test was first investigated at MIT in 1948 under the direction of Prof. Taylor (Taylor, 1953). These tests were actually run by then young T. William Lambe (2003). They equipped a direct shear device to measure the vertical force required to keep the height of the specimen constant during horizontal shearing. Measurements on Boston Blue Clay stressed to a normally consolidated condition gave a s_u/σ'_{vc} of 0.22-0.23 Taylor concluded "*direct shear data obtained under properly controlled conditions are probably sufficient for the great majority of investigations, and they can be obtained in much less time than required for triaxial data.*"

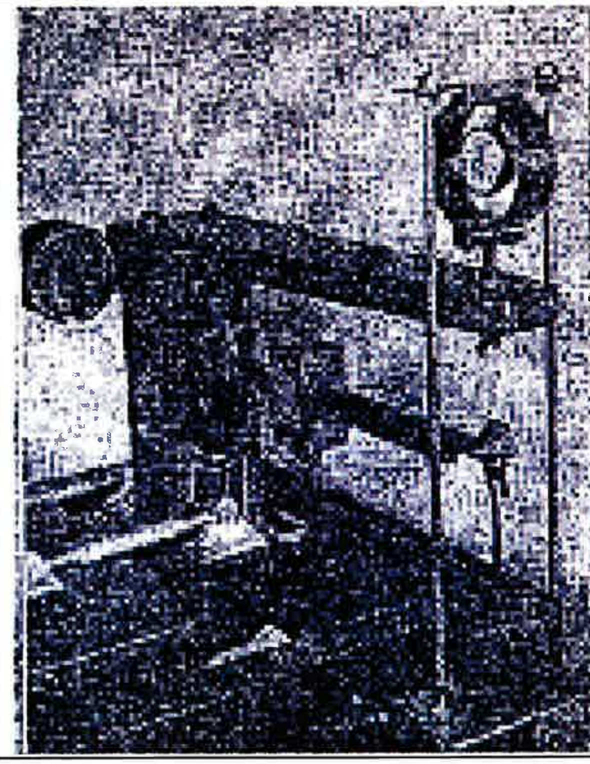


Figure 1: MIT Constant Volume Direct Shear Device

Kjellman, 1951 described a device in which a cylindrical specimen was constrained by a rubber membrane reinforced with wire rings. The wire rings maintained a constant area but allowed the specimen to experience uniform shear when stressed by a horizontal force. This device produced an improvement over the direct shear device because it produced a more uniform

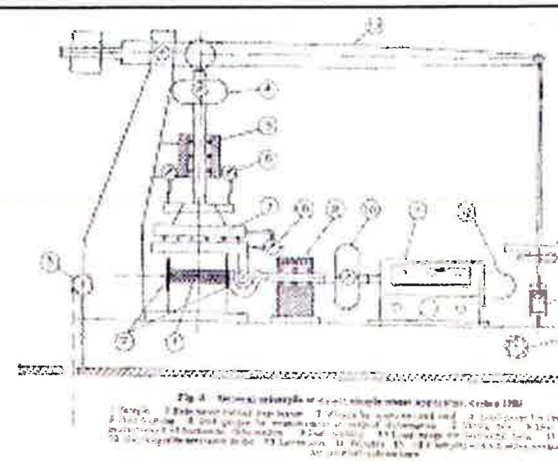


Figure 2: Geonor Direct Simple Shear Device

shear strain throughout the specimen, whereas the direct shear box creates non-uniform shear strains and forces the failure to occur through the mid-plane of the specimen. NGI developed a direct simple shear device using the Kjellman approach (Bjerrum and Landva, 1966) that was to become the standard research device for direct simple shear testing to measure undrained shear strength.

Dyvik et al (1988) showed that conventional constant volume simple shear tests gave results equivalent to truly undrained simple shear tests on normally consolidated Drammen clay. They also concluded that the assumption that the change in applied vertical stress necessary to maintain constant volume during simple shearing is equivalent to the excess pore pressure that would have developed in an undrained test on saturated soil.

Ladd and Edgars (1972) compared results of constant volume direct simple shear tests on Boston Blue clay obtained with a Geonor device with the original undrained direct shear results obtained by Taylor (1953). Figure 3 reproduces their results. They show remarkable agreement with the Taylor results for normally and over consolidated conditions even though the results were obtained twenty years apart with different devices.

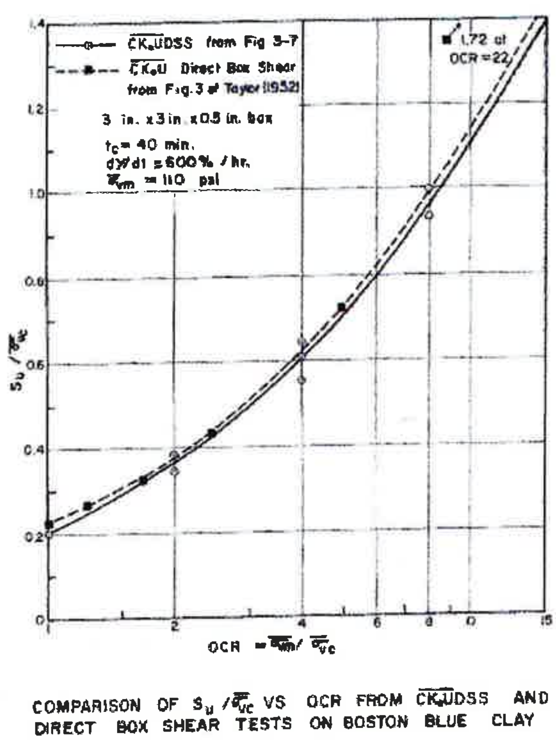


Figure 3: DSS Results for Boston Blue Clay

Over xxx Geonor direct simple shear devices were placed around the world with most of them going to universities. These devices were expensive to purchase and required almost constant attention during consolidation and shearing of the sample. As a result, direct simple shear testing has not been widely used in engineering practice. Recent models from Geonor use automated controls to reduce the required labor but the equipment cost has increased.

Ladd (1990) in his Terzaghi lecture clearly illustrated how to use the strength measured in direct simple shear to evaluate stability of embankments on normally and overconsolidated clay foundations for initial conditions. He also showed how to incorporate the increase in undrained strength that occurs with consolidation by using the relationship among undrained strength measured in direct simple shear, vertical effective stress and pre-consolidation stress.

GEOCOMP Corporation has made a breakthrough in equipment design that allows its direct shear device to run undrained direct simple shear tests. The device can also run direct shear tests to measure drained strength and consolidation tests to measure compressibility and stress history. Essentially all of the fundamental soil parameters for strength and compressibility can be obtained from this single device.

The breakthrough comes from using PID adaptive control technology to apply vertical and horizontal forces to the test specimen. The adaptive control permits rapid and precise control to produce the following operations:

- Apply and maintain a constant vertical force
- Adjust vertical force to maintain constant height of specimen
- Apply vertical force to specimen to achieve a constant rate of vertical strain
- Apply and maintain a constant horizontal force
- Apply horizontal force to specimen to achieve a constant rate of horizontal displacement

Figure 4: GEOCOMP Universal Shear Device

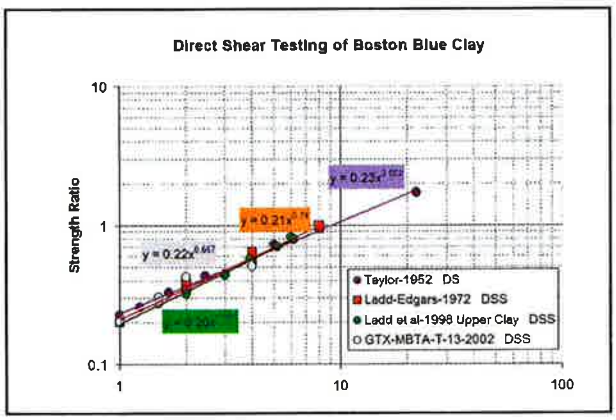
Computer control runs the test automatically which greatly reduces the labor required for these tests. Readings on all sensors are taken automatically, displayed graphically in real-time and saved to a disk file as a permanent record of the test.

With this system the steps to measure undrained shear strength for a stability analysis are reduced to:

- Trim sample to fit tightly inside wire-reinforced latex membrane
- Mount specimen into test device
- Set values of vertical stress for consolidation steps and shear rate
- Start test
- Monitor progress of consolidation and shearing
- Remove specimen, examine and measure moisture content
- Prepare test report

These steps require less than one hour of labor and typically 1 to 3 days of elapsed time.

Figure 5 compares undrained strength of Boston Blue clay measured with the new device to that obtained at three different times by other people and different equipment. Taylor's data were collected over



50 years ago at MIT from constant volume direct shear tests on undisturbed samples. Ladd and Edgar's data were obtained 35 years ago with a Geonor direct simple shear device with manual control and reconstituted samples of Boston Blue Clay. Ladd et al (1999) data were obtained 5 years ago on undisturbed samples from Boston using a Geonor direct simple shear device with automated control. The GTX tests were run on undisturbed samples of Boston Blue Clay obtained from the MBTA Courthouse Station Silver Line site in Boston, MA. They were obtained with the GEOCOMP automated direct shear box using a Geonor wire reinforced membrane to hold the sample in simple shear. Interestingly, they were obtained by lab technicians who were just becoming familiar with the GEOCOMP device and who had no knowledge of what the prior results had been.

The agreement in the results is truly remarkable. They indicate that we can define the undrained simple shear strength of Boston Blue Clay with the equation:

$$s_u = 0.21 * \sigma'_{vc} * \left[\frac{\sigma'_p}{\sigma'_{vc}} \right]^{.73} \quad or$$

$$s_u = 0.21 * \sigma'^{0.27}_{vc} * \sigma'^{0.73}_p$$

This result has been previously reported by Ladd et al (1999) with slightly different coefficients.

Terzaghi et al (1996) provided an elegant review of the measurement of undrained strength. They concluded that the mobilized field strength in failed embankments and deep excavations in clays is best indicated by strength measurements with a field vane modified with the Bjerrum correction factor. They also demonstrate that this approach gives a similar result to that obtained with the direct simple shear laboratory test. Therefore we can conclude that the mobilized field strength for embankments and deep excavations involving clays is well defined by the direct simple shear test. As has been shown by Ladd (1991) strength behavior can be generalized to the form:

$$s_u = A * \sigma'_{vc} * \left[\frac{\sigma'_p}{\sigma'_{vc}} \right]^{m} \quad or$$

$$s_u = A * \sigma'^{(m-1)}_{vc} * \left[\frac{\sigma'_p}{\sigma'_{vc}} \right]^{m}$$

By running a few direct simple shear tests on specimens with various values of $(\sigma'_p / \sigma'_{vc})$, to determine the coefficients A and m, the complete undrained strength for all values of pre-consolidation stress and vertical effective stress can be computed for a specific clay. The engineer can then determine undrained strength for design for any combinations before and during construction and operation by obtaining the pre-consolidation stress of the material and the vertical effective stress with depth at the time of interest. Pre-consolidation stress is best determined by running laboratory consolidation tests on high quality samples, preferably using constant rate of consolidation tests to better define the pre-consolidation stress. Vertical effective stress is obtained by calculation of the vertical total stress from a stress analysis and a determination of the pore water pressure, preferably by field measurement.

Direct simple shear tests provide a relatively simple way to determine undrained strength for cohesive soils as a function of pre-consolidation stress and vertical effective stress. A large body of research shows that DSS undrained strength gives a very good indication of field strength (See Ladd and DeGroot, 2003 for an excellent summary.) New developments in automated testing have lead to a less expensive version of the DSS equipment that can be used for DSS, direct shear and consolidation testing. The engineer now has a powerful tool to help determine the appropriate strength for stability analysis of geotechnical facilities.

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