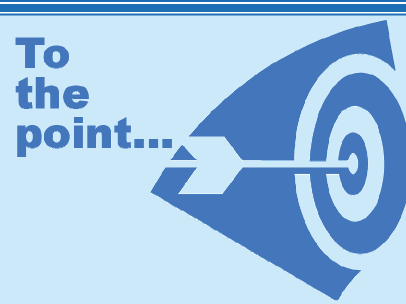
ERDC/GSL GeoTACS TN-13-1
September 2013

US Army Corps of Engineers®

Testing Procedure for Estimating Fully Softened Shear Strengths of Soils Using Reconstituted Material

by Isaac Stephens and Al Branch

PURPOSE: A consistent method for reconstituting soil samples is needed for the purpose of creating normally consolidated samples to be used to predict fully softened shear strength. The US Army Engineer Research and Development Center (ERDC) in conjunction with Virginia Tech University and under the direction of the US Army Corps of Engineers, Fort Worth District (SWF), developed a procedure to estimate fully softened strengths using reconstituted samples and direct-shear testing equipment. This technical note describes the procedure used to reconstitute soil and the insights gained from using this method.



Fully softened shear strength refers to a decreased strength experienced by some soils over time. A simple, consistent test has been developed to determine this strength in laboratory conditions. The procedure and techniques developed at the Engineer Research and Development Center and described here use common soil testing equipment and address the stress-dependent nature of the fully softened strength envelope.

BACKGROUND: Fully softened shear strength refers to a condition in which the shear strength of stiff clays and shales decreases over time. This phenomenon was first observed by Skempton (1964) in the 1950s and 1960s in slopes cut into stiff London Clay. Later studies revealed cyclic wetting and drying could also cause fully softened strengths to develop (Wright et al. 2007). Skempton (1970, 1977) and others found that the fully softened strength was numerically equivalent to the peak strength of a clay in its normally consolidated state.

The fully softened strength is characterized by a non-linear strength envelope and a zero-cohesion intercept. Because of the nonlinearity of the strength envelope, it is useful to determine the strength at more confining stresses than a material with a more linear behavior. It has been found that in most cases, five confining stresses adequately define the curved strength envelope. The fully softened strength can thus be expressed as a secant friction angle, which is simply the inclination of a line from the origin to a point on the curve at a specific confining stress. In general, the fully softened secant friction angle decreases with increasing liquid limit, effective confining stress, and clay fraction.

The key to this procedure is to ensure that the soil sample is thoroughly disaggregated so that clay particles are not left clumped together. A technique developed in the 1960s and 1970s to

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Testing Procedure for Estimating Fully Softened Shear Strengths of Soils Using Reconstituted Material**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U. S. Army Corps of Engineers,Vicksburg,MS, 39180**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

ensure consistent classification of clay shale known as *blenderizing* was adapted for this procedure (USACE 1970, Appendix III).

SAMPLE PREPARATION: Approximately 3 to 4 kg of material are needed to ensure sufficient sample size for the breadth of testing that includes index and strength tests. To increase the uniformity of material used for each test (both index and strength tests), a bulk sample is shaved/shredded and then mixed by hand. Material to be used for tests that do not require blenderizing (hydrometer/sieve, specific gravity, moisture content, and ASTM method Atterberg limits) is separated, and the remaining material is prepared according to the blenderized preparation method.

The direct-shear testing requires 250-300 g for each soil sample in the 3-in.-square by 1-in.-high shear box. With five confining stresses tested, a total of approximately 2,000 g of blenderized material is needed for the shear testing and blenderized Atterberg limits.

Figure 1. Shredding clay shale sample.

Blenderized Sample Preparation. The sample is shaved or shredded at its natural water content. Figure 1 shows this with a shale sample. Samples with a liquid limit greater than 50 percent are dried for at least 48 hr to a constant weight at a temperature less than 50 °C and a relative humidity below 30 percent.

Figure 2. Mechanical blenders.

The sample is then soaked in distilled water for at least 48 hr. The effects of this drying and slaking are described by Haley and McIver (1971). The resulting slurry of soaked material and water should have a water content above 300 percent, or more than double the estimated liquid limit, whichever is greater. About 500 ml of slurry is placed in a mechanical blender (Figure 2). The soil water slurry is then blenderized without interruption for 10 min. After mixing, it is washed through a No. 40 sieve into plaster of Paris dishes lined with filter paper (Figure 3). These dishes help wick out excess water from the slurry. A combination of this and air drying is used to bring the water content of the soil near the liquid limit. The resulting material is then combined into one homogenous sample by working with a steel spatula on a glass plate to make sure that no clay clumps, extraneous nodules, or other *coarse* non-clay particles remain. Nodules that cannot be crushed or otherwise disaggregated using a spatula and moderate hand pressure may be discarded. The result is a fully hydrated sample with a uniform consistency containing no visible clay clumps or oversized particles exceeding 0.004 in. (one-sixth of the target gap between upper and lower shear-box segments) that would likely interact with the shear-box halves during shear. The sample is worked this way until just slightly wetter than the liquid limit. This is determined by using a Casagrande liquid limit cup. The material is considered to be at the correct water content when the groove cut into the sample closes at 23 blows.

Figure 3. Wicking excess water from slurry.

Molding Sample for Fully Softened Strength (FSS) Testing. A sample cutter or mold with the same inside dimensions as the shear box is used to mold the soil before placing it into the shear box. After positioning the mold on a sheet of wax paper over a smooth surface, the soil is carefully placed into the mold with a spatula or similar tool to avoid creating air voids (Figure 4). The mold is turned over, and any remaining voids are filled.

Figure 4. Placing soil into mold.

The top is smoothed with a straightedge so that the top and bottom are flush with the mold. The mass of the sample and mold is recorded, and the sample is extruded into the assembled shear box (Figure 5).

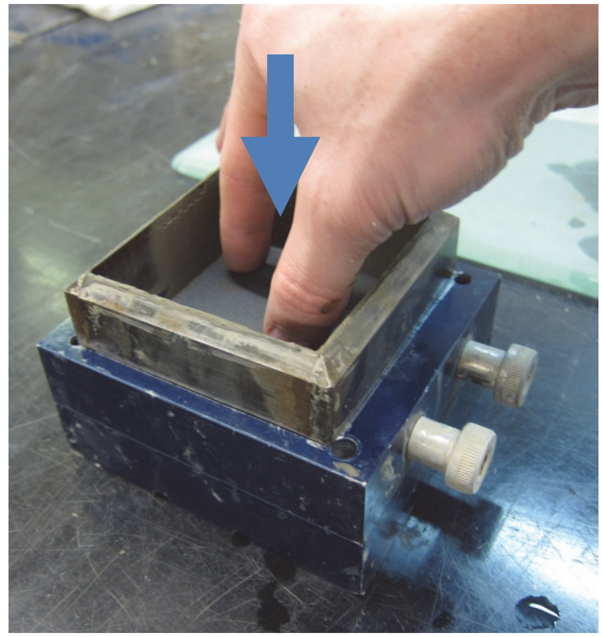


Figure 5. Extruding sample from mold to shear box.

An alternative method is to form the sample directly in the shear box by using a spatula or by piping the soil with a pastry bag. Whichever technique is used, great care must be taken to avoid introducing air voids into the sample. Careful preparation can result in variations of less than one gram in weight among each of the five samples molded from one soil type.

The shear box is assembled with filter paper and porous stones on top and bottom and placed into the shearing device. A seating load is applied, and the sample is inundated with water. A consistent water level is maintained so that the specimen is at all times effectively submerged. During the consolidation stage of testing, the upper and lower shear-box halves are held in contact with each other with alignment screws.

Direct-shear Testing Procedure. The ASTM (2004) D3080 procedure is followed for the remainder of the test except where indicated otherwise. The soil sample is incrementally consolidated to the required confinement stress. Loading increments can be started at 70-125 psf and are incremented in steps of no more than double the previous load. Each load increment is allowed to remain on the specimen until it is determined that primary consolidation is complete. This is determined by observing when subsequent readings indicate that secondary consolidation has begun. After primary consolidation is complete, the alignment screws or pins are removed from the shear box, and the gap screws are used to open a 0.025-in. (0.64-mm) gap between the shear-box halves. Once the proper gap is established, the gap screws are backed out so as not to interfere with the shearing.

To ensure that drained-strength conditions are met, the specimen is sheared at a relatively slow rate so that no excess pore pressure exists at failure. The rate is a function of the time required to achieve 50 percent consolidation (t_{50}) and the horizontal displacement at failure (d_f). ASTM (2004) D3080 suggests using a d_f of 0.5 in. for normally or lightly over-consolidated, fine-grained soils, but numerous tests by the author and others indicate that 0.15 in. is a much better estimation of the displacement to failure.

The rate of shear (d_r) can be determined using the equation

$$d_r = \frac{d_f}{50 \bullet t_{50}}$$

After adjusting the device to the calculated rate, shearing is begun and applied continuously until a maximum shear stress is reached. This peak value is considered to be the fully softened strength (FSS).

After removing the shear box and sample, the shear-box halves are separated with a sliding motion along the failure plane. At some high consolidation pressures, this may be difficult to do by hand. The failure surface is then photographed. A close-up photograph of a typical shear failure surface is shown in Figure 6. A section is obtained from the center of the sample to determine the water content at the end of shearing.

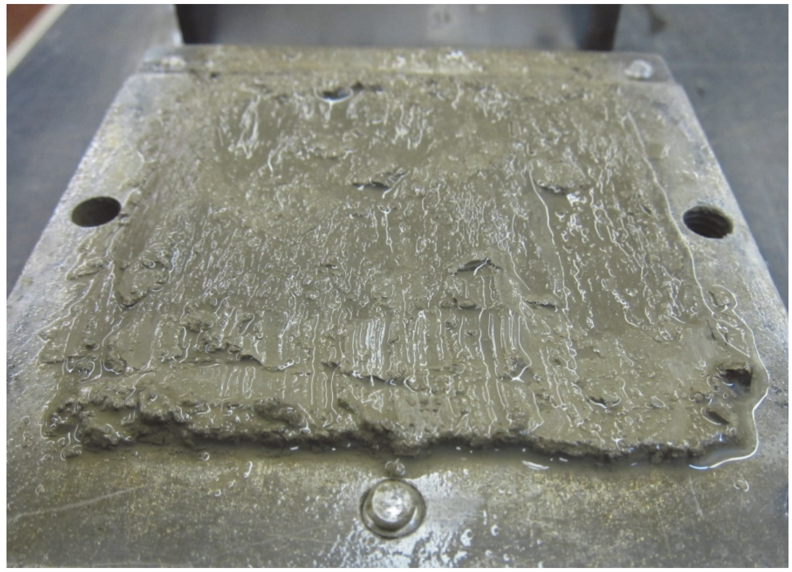


Figure 6. Exposed shear surface.

REFERENCES

American Society for Testing and Materials (ASTM). 2004. *Standard test method for direct shear test of soils under consolidated drained conditions*. Designation D 3080. West Conshohocken, PA: American Society for Testing and Materials.

Haley, B., and B. N. MacIver. 1971. *Engineering properties of clay shales, Report 1: Development of classification indexes for clay shales*. Technical Report S-71-6. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

Skempton, A. W., and I. A. Delory. 1957. Stability of natural slopes in London Clay. In *Proceedings of the 4th International Conference on Soil Mechanics,* 2:378-381. London, England.

Skempton, A. W. 1964. Long-term stability of clay slopes. *Geotechnique* 14(2):77–101.

Skempton, A. W. 1970. First-time slides in over-consolidated clays. *Geotechnique* 20(3):320–324.

Skempton, A. W. 1977. Slope stability of cuttings in brown London clay. In *Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, 10-15 July,* 3:261-270. Tokyo, Japan.

US Army Corps of Engineers (USACE). 1970. *Laboratory soils manual*. EM 1110-2-1906. Vicksburg, MS: US Army Corps of Engineers Waterways Experiment Station.

Wright, S. G., J. G. Zornberg, and J. E. Aguettant. 2007. *The fully softened shear strength of high plasticity clays*. Austin, TX: Center for Transportation Research, University of Texas at Austin.

Permission to publish was granted by Director, Geotechnical and Structures Laboratory.