University of Waterloo
Department of Civil Engineering

CIV E 353 - Geotechnical Engineering I
Direct Shear Test

Purpose

Determine the shear strength of dry cohesionless sand with the direct shear box apparatus.

Required reading Das 2006 Sections 11.1 to 11.7 (pages 374 to 389).

Theory

The general shear strength equation (Mohr-Coulomb failure criterion) in terms of effective stresses is

$$\tau_f = c' + \sigma'_{f'} \tan \phi'$$

where τ is shear strength, c' is the effective apparent cohesion, ϕ' is the effective angle of friction, and σ' is the effective stress $(\sigma - u)$ and subscript f represents shear stress at failure.

For cohesionless soil (sand, gravel and some silt) the effective cohesion (c') is zero and the shear equation reduces to

$$\tau_f = \sigma'_f \tan \phi'$$

The direct shear test set up consists of placing a soil sample in a split box having a cross-sectional area (A) and subjecting the test sample to a vertical normal load (N). Testing proceeds by displacing the lower half of the split box and measuring the horizontal shear forced (T) transmit through the soil to the upper portion of the box. Testing continues by displacing the lower box horizontally until the shear force increases to a maximum value and then decreases or remains essentially constant.

During testing it is often assumed that the sample cross-sectional shear area (A) remains constant. Therefore, the normal stress σ'_f on the failure plane may be calculated using

$$\sigma_{f'} = \frac{N}{A} = \frac{\textit{vertical normal force}}{\textit{cross-sectional area}}$$

The shear stress (τ) on the shear plane may also be calculate using

$$\tau = \frac{T}{A} = \frac{\textit{shear force}}{\textit{area}}$$

The maximum shear stress on the shear plane may be determined using

$$\tau_{\max} = \frac{T_{\max}}{A}$$

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Testing consists of determining the maximum shear for at least three test samples with three different applied normal stresses that are selected to be representative of anticipated field stresses. Since a decrease in the sample void ratio will increase the soil internal angle of friction, test specimens are initially placed to the same density (unit weight). Shear strength parameters c' and ϕ' are determined by determining a best-fit line (y-intercept and slope) of the σ'_f (abscissa) vs τ_{max} (ordinate) plot.

Apparatus

Three direct shear boxes can be mounted on a single frame and they can be loaded independently or together. Each box is provided with a hanger system to permit the application of normal stress. Weights may be applied directly through the vertical hanger for small stresses or through a lever system for large stresses. The horizontal load is applied through a motor-driven gear system and the magnitude of the load is determined using a load transducer. Vertical and horizontal deformations are measured using displacement transducers with an electronic measurement system to collect and store the data.

Procedure

1. Fasten together the two halves of the shear box by tightening the vertical lock screws and insert the bottom plate, porous stone and serrated grating plate in the shear box.

2. Determine the area, *A*, of the sample box and the distance from the grating (bottom of serrations) to the top of the box.

3. Weigh out the amount of dry sand required for the sample as given by the instructor.

4. Pore the sand loosely in one smooth layer approximately 20 mm thick. Tamp the sample as directed by the instructor.

5. Measure the distance from the top of the sample to the top of the box and calculate the height of sample.

6. Put the upper grating plate, stone and loading block on top of the sample. Be careful to avoid vibration if a very loose sample is being tested.

7. Put the ball and hanger on the loading block and attach the transducers to measure the vertical and horizontal displacement of the sample.

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8. Repeat steps 1 to 7 for the other two samples and apply the appropriate normal load for each sample as given by the instructor. **Note the amount of compression of the sample when the normal load is applied; subtract this value from the original height of sample.**

9. Separate the upper and lower parts of the shear box by removing the vertical lock screws and raising the upper frame by turning the thumbscrews one revolution. This will raise the upper frame approximately 1.5 mm to provide sufficient clearance. Back off the thumbscrews. The entire vertical load is now being transferred from the top to the bottom of the shear box through the sample.

10. Bring the loading piston into contact with the shear box. The test is now ready to begin. The test should be run at a shearing rate of approximately 1.3 mm/min. (0.05 in./min)

11. Continue the test until a maximum reading on the load transducer has been passed and the readings have begun to decrease to a constant value. **Do not continue the test past a horizontal displacement of 10 mm**.

Results

1. Calculate the shear stress on the sample. Assume that the area of the sample did not change during the test and use the original area for all calculations.

2. Plot shear stress (τ) vs. horizontal shear strain (ε_h) and sample volume change (ε_v) due to vertical settlement vs ε_h for each sample tested by your group. Plot all three normal stress curves on the same graph.

$$\varepsilon_h = \frac{\delta_h - \delta_{h0}}{L_0} * 100$$

where δ_{ho} is the horizontal displacement reading at the start of the test, δ_h is the horizontal displacement reading at a given time, and L_0 is the initial length of sample in the direction of shear at the start of the test.

$$\varepsilon_v = \frac{\delta_v - \delta_{v0}}{H_0} * 100$$

where δ_{vo} is the vertical displacement reading at the start of the test, δ_v is the vertical displacement reading at a given time, and H_o is the height of sample at the start of the test.

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3. Calculate the dry unit weights and void ratios of the samples tested by your group.

4. Plot on one graph peak shear strength (maximum shear stress) against normal stress for each test. Use the same scale for each axis.

5. Determine the effective angle of internal friction, ϕ' by drawing a best fit straight line through the data points. Hint: Assume an appropriate c' for dry sand.

6. Did the samples tested by your group increase in volume during the test? Why?

7. a) How does increasing the normal stress influence peak shear strength and horizontal strain at peak shear stress?

   b) How would the soil friction angle change if failure were defined as one percent horizontal strain (ε_h)?

Selected References

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4. Lambe, T.W., 1951, Soil Testing for Engineers, N.Y., Wiley

5. Lambe, T.W., and Whitman, R.V., 1969, Soil Mechanics, N.Y., Wiley

6. Peck, R.B., Hanson, W.E. and Thornburn, T.H., 1974, Foundation Engineering, 2nd Edition, N.Y., Wiley

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Direct Shear Test Data Sheet

Sample Identification____________________ Date _______________

Sample: Dry Mass, M_s, ___________ g; Height, H_o,____________mm

Sample: Length, L_o, ____________ mm, Width, W_o, ____________ mm

Area, A_o, ____________ mm^2

Specific Gravity of Solids, G_s, __________

Applied Normal Stress, σ'_n, ______________ kPa

Sample Identification____________________ Date _______________

Sample: Dry Mass, M_s, ___________ g; Height, H_o,____________mm

Sample: Length, L_o, ____________ mm, Width, W_o, ____________ mm

Area, A_o, ____________ mm^2

Specific Gravity of Solids, G_s, __________

Applied Normal Stress, σ'_n, ______________ kPa

Sample Identification____________________ Date _______________

Sample: Dry Mass, M_s, ___________ g; Height, H_o,____________mm

Sample: Length, L_o, ____________ mm, Width, W_o, ____________ mm

Area, A_o, ____________ mm^2

Specific Gravity of Solids, G_s, __________

Applied Normal Stress, σ'_n, ______________ kPa