

CE EN 341
Soil Mechanics Laboratory
Fall 1994
Section 6

The Direct Shear Test on Sand

Submitted to:
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by
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I. Introduction

Purpose for Running the Test

The shear strength of a sand is given by the equation:

$$s = \sigma' \tan \phi.$$

- s is the shear strength of the soil.
- σ' is the effective normal stress applied to the soil.
- ϕ is the angle of friction of the soil.

The purpose in running the direct shear test is to determine the angle of friction of a soil. The angle of friction is a function of the relative density of compaction of sand, grain size, shape, and distribution in a given soil mass. When designing an earth dam or needing to make calculations which have to do with the stability of a slope, the angle of friction is a very useful quantity.

II. Test Procedure

We performed the constant head permeability test using the following procedure:

First, we weighed some dry sand in a large porcelain dish. We filled the shear box with sand in three small layers, compacting the layers as we went. After filling the shear box, we weighed the sand in the porcelain dish.

Second, we determined the dimensions of the soil specimen in the shear box (although we did not determine the height each time).

Third, we placed the loading head on top of the soil specimen and assembled the shear box.

Fourth, we added the normal load (10 kg) to the specimen by applying weights to the hook on the side of the specimen.

After we finished loading the soil specimen, we completed the assembly of the shear box and attached the loading head to the specimen.

We then attached the horizontal and vertical dial gauges to the shear box to measure the displacements during the test.

Finally, we applied a horizontal load, S , to the specimen. We recorded the shear force and vertical displacement at every 10 increments on the horizontal displacement gage. We terminated the test after the shear force reached a maximum.

We repeated the test with loads of 20 and 40 kg.

III. Results

Graphs and Tables

Table 1: Direct shear test results for Ottawa sand with a load of 10 kg (22.05 lb) applied.

| | | |
|--------------------|--------|-----------------|
| Area of Specimen = | 6.25 | in ² |
| Normal Load = | 22.046 | lb |

Normal stress = 3.52736 lb/in²

| Horizontal Displacement (in.*10 ³) | Horizontal Displacement (in.) | Vertical Displacement (in.*10 ³) | Vertical Displacement (in.) | Dial Reading | Shear force S (lb) | Shear Stress τ (lb/in. ²) |
|--|-------------------------------|--|-----------------------------|--------------|--------------------|--|
| 10 | 0.01 | 0 | 0 | 87 | 35.844 | 5.73504 |
| 20 | 0.02 | -0.9 | -0.0009 | 154 | 63.448 | 10.15168 |
| 30 | 0.03 | -1.5 | -0.0015 | 212 | 87.344 | 13.97504 |
| 40 | 0.04 | -2 | -0.002 | 260 | 107.12 | 17.1392 |
| 50 | 0.05 | -2.1 | -0.0021 | 303 | 124.836 | 19.97376 |
| 60 | 0.06 | -2 | -0.002 | 338 | 139.256 | 22.28096 |
| 70 | 0.07 | -1.3 | -0.0013 | 377 | 155.324 | 24.85184 |
| 80 | 0.08 | -0.2 | -0.0002 | 388 | 159.856 | 25.57696 |
| 90 | 0.09 | 1 | 0.001 | 403 | 166.036 | 26.56576 |
| 100 | 0.1 | 2.2 | 0.0022 | 416 | 171.392 | 27.42272 |
| 110 | 0.11 | 4 | 0.004 | 424 | 174.688 | 27.95008 |
| 120 | 0.12 | 5 | 0.005 | 462 | 190.344 | 30.45504 |
| 130 | 0.13 | 5 | 0.005 | 530 | 218.36 | 34.9376 |
| 140 | 0.14 | 4.9 | 0.0049 | 608 | 250.496 | 40.07936 |
| 150 | 0.15 | 4.8 | 0.0048 | 670 | 276.04 | 44.1664 |
| 160 | 0.16 | 5.1 | 0.0051 | 728 | 299.936 | 47.98976 |
| 170 | 0.17 | 5.8 | 0.0058 | 780 | 321.36 | 51.4176 |
| 180 | 0.18 | 7 | 0.007 | 755 | 311.06 | 49.7696 |
| 190 | 0.19 | 8.2 | 0.0082 | 741 | 305.292 | 48.84672 |
| 200 | 0.2 | 10 | 0.01 | 725 | 298.7 | 47.792 |
| 210 | 0.21 | 10.6 | 0.0106 | 730 | 300.76 | 48.1216 |
| 220 | 0.22 | 10.9 | 0.0109 | 750 | 309 | 49.44 |
| 230 | 0.23 | 11 | 0.011 | 760 | 313.12 | 50.0992 |
| 240 | 0.24 | 11.1 | 0.0111 | 790 | 325.48 | 52.0768 |
| 250 | 0.25 | 11.2 | 0.0112 | 806 | 332.072 | 53.13152 |
| 260 | 0.26 | 11.3 | 0.0113 | 811 | 334.132 | 53.46112 |
| 270 | 0.27 | 11.4 | 0.0114 | 823 | 339.076 | 54.25216 |

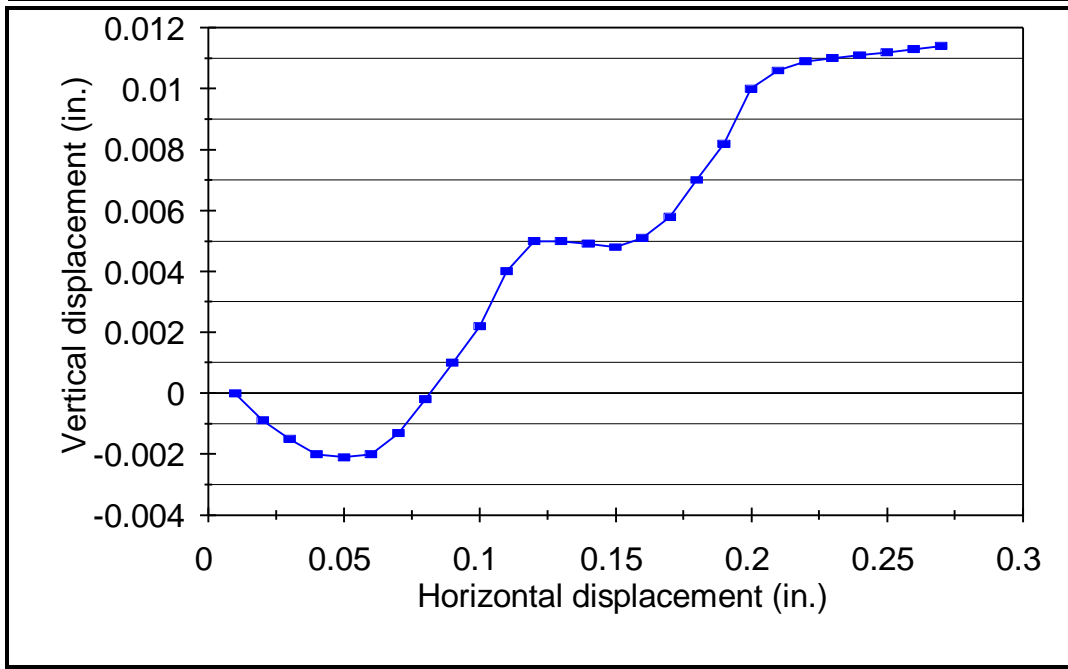
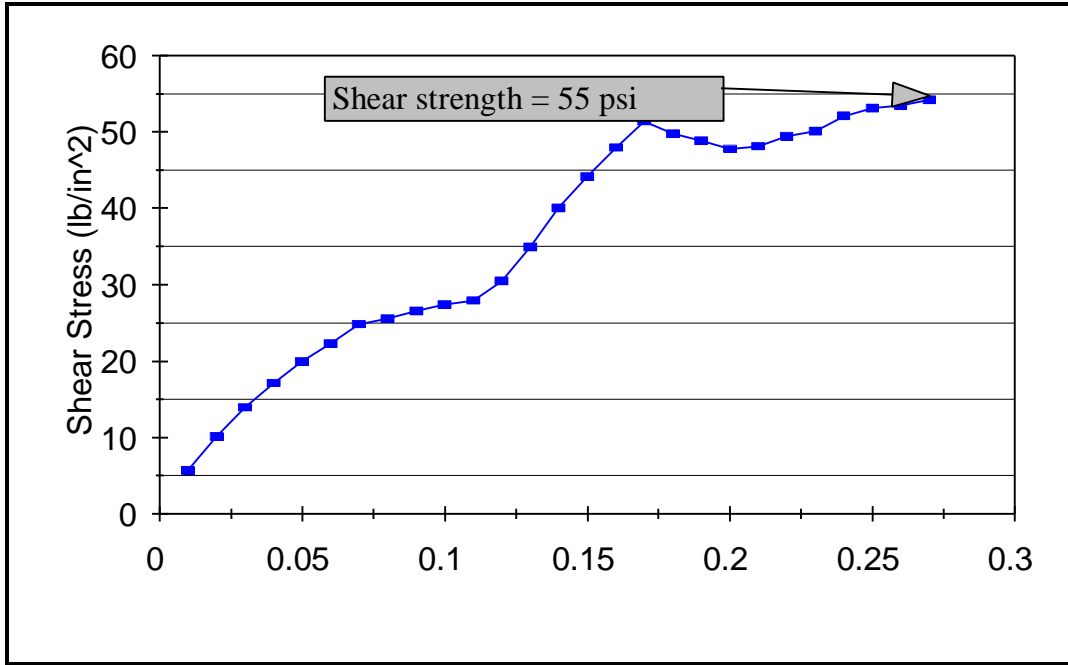


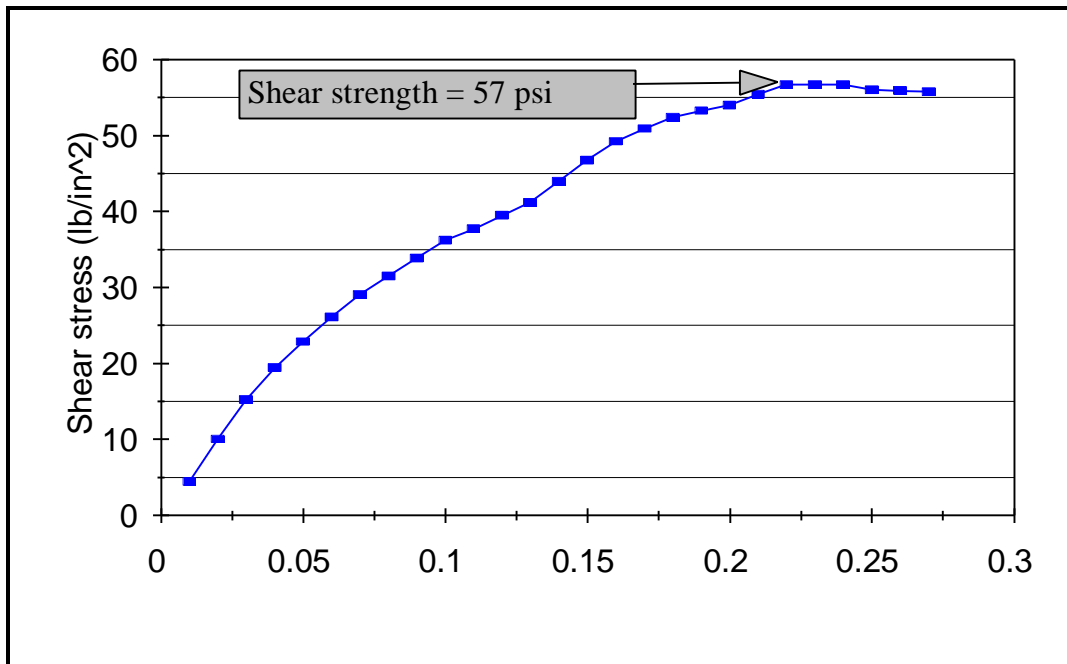
Figure 1: Shear stress-displacement curve and horizontal displacement-vertical displacement curve for Ottawa sand at a load of 10 kg.

Table 2: Direct shear test results for Ottawa sand with a load of 20 kg (44.1 lb) applied.

| | | |
|--------------------|---------|--------------------|
| Area of Specimen = | 6.25 | in ² |
| Normal Load = | 44.092 | kg |
| Normal stress = | 7.05472 | kg/in ² |

| | | |
|--|-------------|--------------|
| | Shear force | Shear Stress |
|--|-------------|--------------|

| Horizontal Displacement (in.*10 ³) | Horizontal Displacement (in.) | Vertical Displacement (in.*10 ³) | Vertical Displacement (in.) | Dial Reading | S (lb) | τ (lb/in. ²) |
|--|-------------------------------|--|-----------------------------|--------------|---------|--------------------------|
| 10 | 0.01 | 0 | 0 | 68 | 28.016 | 4.48256 |
| 20 | 0.02 | -0.5 | -0.0005 | 153 | 63.036 | 10.08576 |
| 30 | 0.03 | -1 | -0.001 | 231 | 95.172 | 15.22752 |
| 40 | 0.04 | -2 | -0.002 | 295 | 121.54 | 19.4464 |
| 50 | 0.05 | -3 | -0.003 | 347 | 142.964 | 22.87424 |
| 60 | 0.06 | -4 | -0.004 | 396 | 163.152 | 26.10432 |
| 70 | 0.07 | -4.5 | -0.0045 | 441 | 181.692 | 29.07072 |
| 80 | 0.08 | -5 | -0.005 | 478 | 196.936 | 31.50976 |
| 90 | 0.09 | -5.5 | -0.0055 | 514 | 211.768 | 33.88288 |
| 100 | 0.1 | -6 | -0.006 | 549 | 226.188 | 36.19008 |
| 110 | 0.11 | -6.5 | -0.0065 | 572 | 235.664 | 37.70624 |
| 120 | 0.12 | -6.5 | -0.0065 | 599 | 246.788 | 39.48608 |
| 130 | 0.13 | -6.9 | -0.0069 | 625 | 257.5 | 41.2 |
| 140 | 0.14 | -6.5 | -0.0065 | 667 | 274.804 | 43.96864 |
| 150 | 0.15 | -6.3 | -0.0063 | 709 | 292.108 | 46.73728 |
| 160 | 0.16 | -6 | -0.006 | 747 | 307.764 | 49.24224 |
| 170 | 0.17 | -5.5 | -0.0055 | 772 | 318.064 | 50.89024 |
| 180 | 0.18 | -4.5 | -0.0045 | 795 | 327.54 | 52.4064 |
| 190 | 0.19 | -4.5 | -0.0045 | 808 | 332.896 | 53.26336 |
| 200 | 0.2 | -3.5 | -0.0035 | 819 | 337.428 | 53.98848 |
| 210 | 0.21 | -2.5 | -0.0025 | 841 | 346.492 | 55.43872 |
| 220 | 0.22 | -1.75 | -0.00175 | 860 | 354.32 | 56.6912 |
| 230 | 0.23 | -1 | -0.001 | 860 | 354.32 | 56.6912 |
| 240 | 0.24 | -0.5 | -0.0005 | 860 | 354.32 | 56.6912 |
| 250 | 0.25 | 0 | 0 | 850 | 350.2 | 56.032 |
| 260 | 0.26 | 0 | 0 | 848 | 349.376 | 55.90016 |
| 270 | 0.27 | 0.5 | 0.0005 | 846 | 348.552 | 55.76832 |



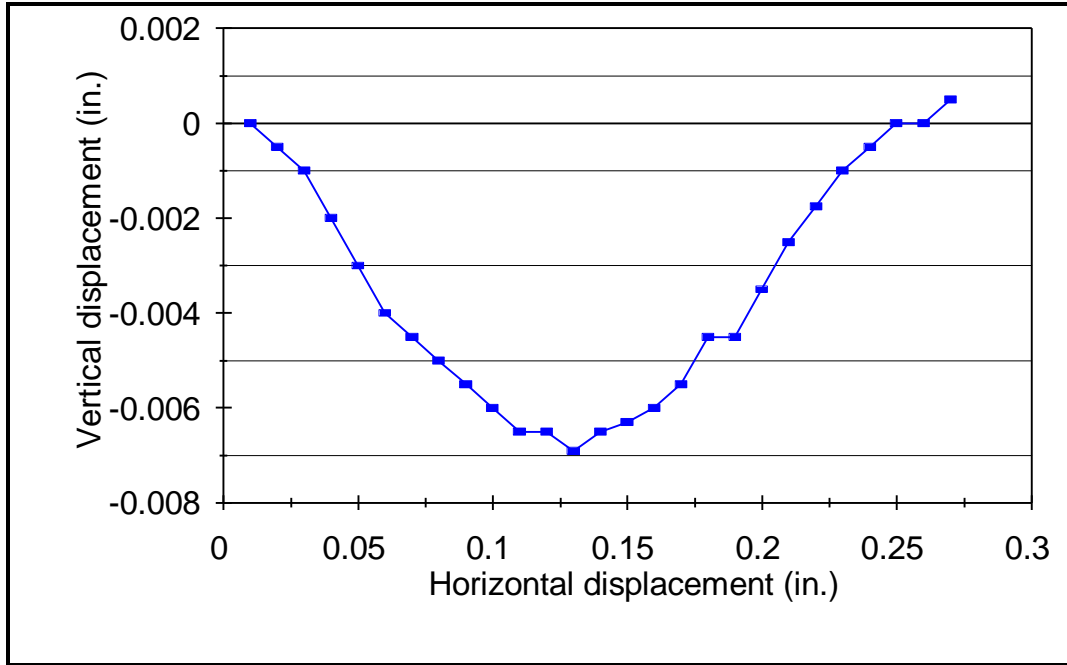


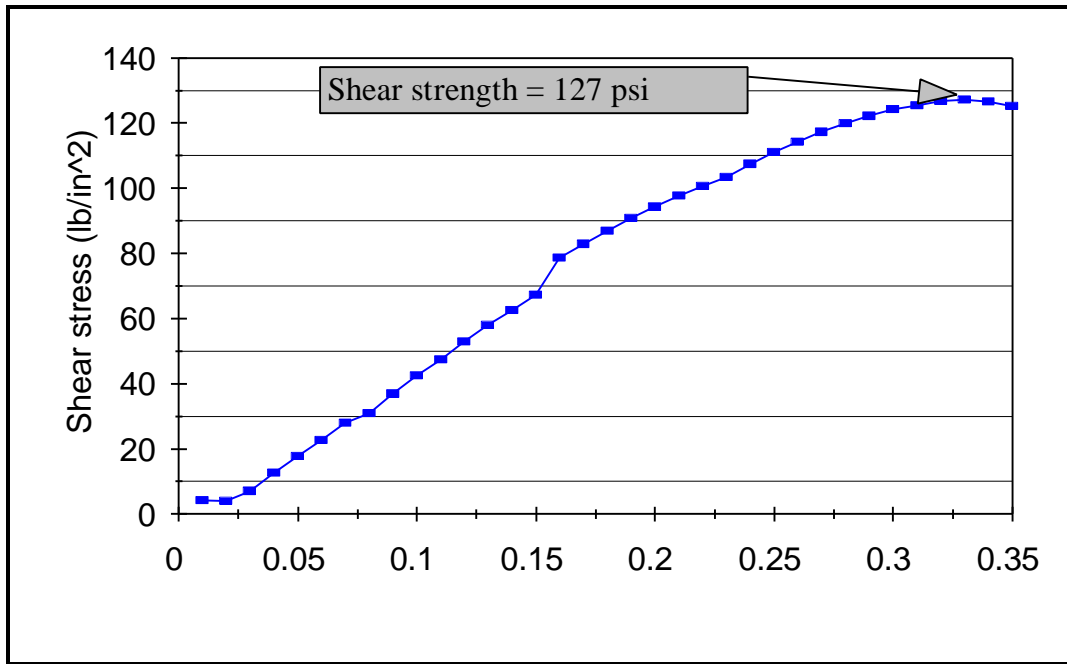
Figure 2: Shear stress-displacement curve and horizontal displacement-vertical displacement curve for Ottawa sand at a load of 20 kg.

Table 3: Direct shear test results for Ottawa sand with a load of 40 kg (88.18 lb) applied.

| | | |
|--------------------|----------|--------------------|
| Area of Specimen = | 6.25 | in ² |
| Normal Load = | 88.184 | kg |
| Normal stress = | 14.10944 | kg/in ² |

| Horizontal Displacement (in.*10 ³) | Horizontal Displacement (in.) | Vertical Displacement (in.*10 ³) | Vertical Displacement (in.) | Dial Reading | Shear force S (lb) | Shear Stress τ (lb/in. ²) |
|--|-------------------------------|--|-----------------------------|--------------|--------------------|--|
| 10 | 0.01 | 0 | 0 | 64 | 26.368 | 4.21888 |
| 20 | 0.02 | 0 | 0 | 61 | 25.132 | 4.02112 |
| 30 | 0.03 | 0 | 0 | 108 | 44.496 | 7.11936 |
| 40 | 0.04 | 0 | 0 | 192 | 79.104 | 12.65664 |
| 50 | 0.05 | 0 | 0 | 270 | 111.24 | 17.7984 |
| 60 | 0.06 | 0 | 0 | 345 | 142.14 | 22.7424 |
| 70 | 0.07 | 0 | 0 | 425 | 175.1 | 28.016 |
| 80 | 0.08 | -15.5 | -0.0155 | 470 | 193.64 | 30.9824 |
| 90 | 0.09 | -15.7 | -0.0157 | 560 | 230.72 | 36.9152 |
| 100 | 0.1 | -15.8 | -0.0158 | 644 | 265.328 | 42.45248 |
| 110 | 0.11 | -15.8 | -0.0158 | 721 | 297.052 | 47.52832 |
| 120 | 0.12 | -15.8 | -0.0158 | 804 | 331.248 | 52.99968 |
| 130 | 0.13 | -15.8 | -0.0158 | 880 | 362.56 | 58.0096 |
| 140 | 0.14 | -15.8 | -0.0158 | 950 | 391.4 | 62.624 |
| 150 | 0.15 | -15.9 | -0.0159 | 1022 | 421.064 | 67.37024 |
| 160 | 0.16 | -16 | -0.016 | 1193 | 491.516 | 78.64256 |
| 170 | 0.17 | -16 | -0.016 | 1257 | 517.884 | 82.86144 |
| 180 | 0.18 | -16 | -0.016 | 1319 | 543.428 | 86.94848 |

| | | | | | | |
|-----|------|-------|---------|------|---------|-----------|
| 190 | 0.19 | -16 | -0.016 | 1378 | 567.736 | 90.83776 |
| 200 | 0.2 | -16 | -0.016 | 1431 | 589.572 | 94.33152 |
| 210 | 0.21 | -15.9 | -0.0159 | 1482 | 610.584 | 97.69344 |
| 220 | 0.22 | -15.8 | -0.0158 | 1527 | 629.124 | 100.65984 |
| 230 | 0.23 | -15.6 | -0.0156 | 1570 | 646.84 | 103.4944 |
| 240 | 0.24 | -16.2 | -0.0162 | 1630 | 671.56 | 107.4496 |
| 250 | 0.25 | -17.6 | -0.0176 | 1685 | 694.22 | 111.0752 |
| 260 | 0.26 | -20.2 | -0.0202 | 1734 | 714.408 | 114.30528 |
| 270 | 0.27 | -23 | -0.023 | 1779 | 732.948 | 117.27168 |
| 280 | 0.28 | -26 | -0.026 | 1819 | 749.428 | 119.90848 |
| 290 | 0.29 | -28.7 | -0.0287 | 1854 | 763.848 | 122.21568 |
| 300 | 0.3 | -30.7 | -0.0307 | 1885 | 776.62 | 124.2592 |
| 310 | 0.31 | -31.2 | -0.0312 | 1903 | 784.036 | 125.44576 |
| 320 | 0.32 | -32.6 | -0.0326 | 1923 | 792.276 | 126.76416 |
| 330 | 0.33 | -32.6 | -0.0326 | 1930 | 795.16 | 127.2256 |
| 340 | 0.34 | -32.2 | -0.0322 | 1921 | 791.452 | 126.63232 |
| 350 | 0.35 | -30.8 | -0.0308 | 1901 | 783.212 | 125.31392 |



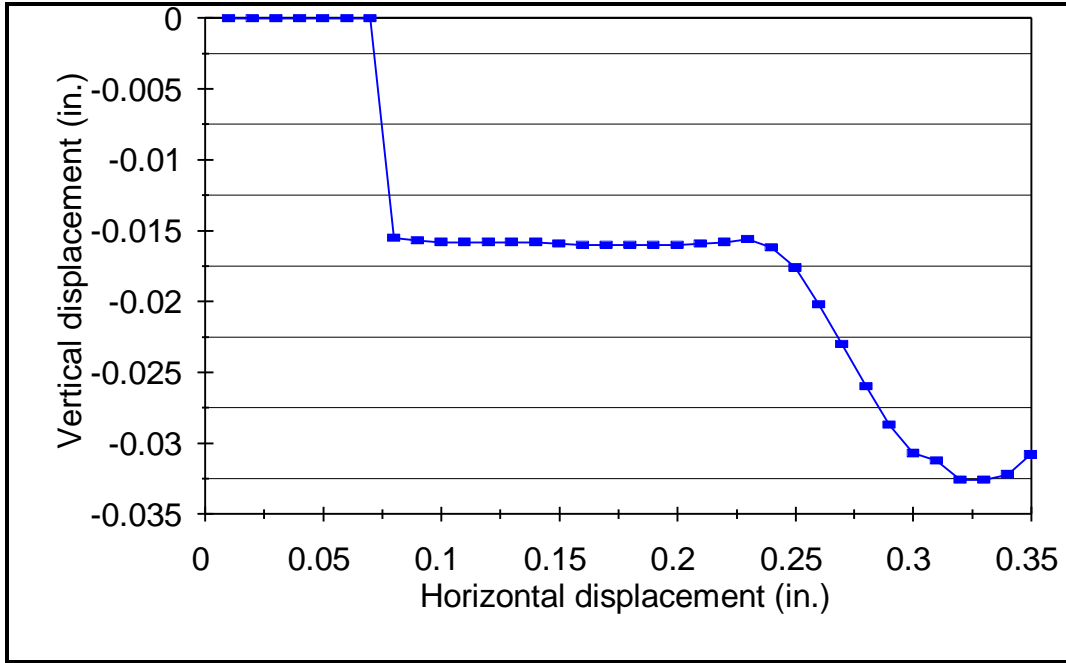


Figure 3: Shear stress-displacement curve and horizontal displacement-vertical displacement curve for Ottawa sand at a load of 40 kg.

Table 4: Shear strengths of soils tested at different values of normal stress.

| Shear strength (psi) | Normal stress (psi) |
|----------------------|---------------------|
| 55 | 3.52736 |
| 57 | 7.05742 |
| 127 | 14.10944 |

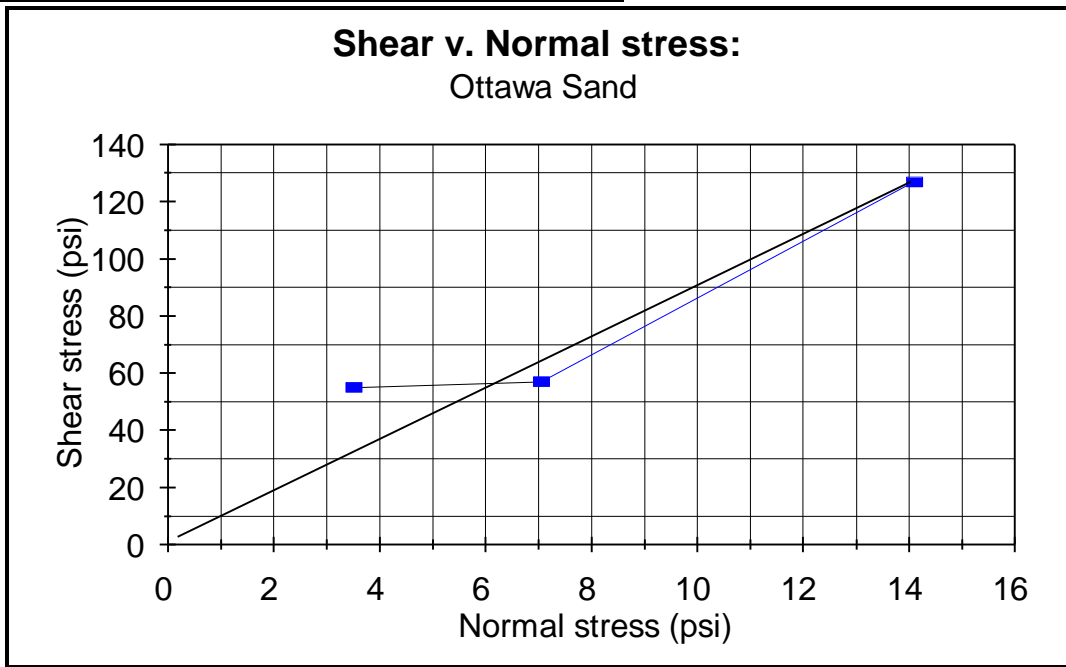


Figure 4: Normal stress-Shear stress curve for Ottawa sand tested by the direct shear test. ($f=83.66$ degrees)

Results From the Direct Shear Test

The results from the direct shear test are located in tables 1-4 and figures 1-4. From the graph in figure 4 (the normal stress-shear stress curve), you can see that the test gave an angle of friction of 83.66 degrees. This value for the angle of friction was quite a bit off from the expected value. The expected value for the angle of friction of Ottawa sand is about 35 degrees.

Determination of the Normal Effective Stress on the specimen

Normal effective stress applied to the specimen was found according to the equation:

$$s' = \frac{N}{L \times B}$$

Where N is the normal load applied to the specimen, L is the length of the specimen, and B is the width of the specimen. The normal stresses applied to each specimen are shown with the respective shear strengths of the soil specimens in figure 4.

Determination of the Shear Force on the Specimens

The shear force on each specimen was determined by:

$$S = D \times 0.412$$

Where D is the number of divisions on the proving ring dial gage and 0.412 is the calibration factor.

Determination of the Shear Stress on the Specimens

The shear force on the Ottawa sand specimens was calculated according to the equation:

Summary of Test Results

A good summary of the test results can be found in table two. On this table, you can see that as the pressure head of the specimen increased, the permeability decreased. The average permeability of the specimen was found to be 0.0014 cm/sec.

Table 2: A Summary of the Test Results.

| Permeability at 141 cm Head | Permeability at 352 cm head | Permeability at 492 cm head | Average Permeability |
|--------------------------------|--------------------------------|--------------------------------|----------------------|
| 0.0017 cm/sec | 0.0014 cm/sec | 0.0012 cm/sec | 0.0014 cm/sec |

IV. Discussion

What do the Results Mean?

The purpose in running the constant head permeability test was to determine the permeability of the soil. After calculating the permeability, you can use the permeability obtained to make calculations which involve flow of the fluid through the soil. The discharge velocity, as stated by Darcy's law, is directly proportional to the hydraulic gradient. The constant of proportionality for a given soil is the coefficient of permeability.

For example, since the average permeability of the Ottawa sand used in this experiment was found to be 0.0014 cm/sec, you could use this value of k in $v=ki$ to compute the discharge velocity in the soil.

How Can the Soil be Classified?

Although the constant head permeability test is not used to classify the soil, we can compare the values obtained from this test with typical values of the coefficient of permeability. Typical values of permeability coefficients for different types of soils are located in table 3.

Table 3: Typical Values of Permeability Coefficients. (from Das, 1993).

| Type of Soil | Permeability Coefficient (cm/sec) |
|--------------------------------|-----------------------------------|
| Clean Gravel | 1.0-100 |
| Coarse Sand | 1.0-0.01 |
| Fine Sand | 0.01-0.001 |
| Silty Clay | 0.001-0.00001 |
| Clay | less than 0.000001 |
| Ottawa Sand (our test results) | 0.0014 |

The permeability coefficient for the Ottawa sand we tested was found to be 0.0014. This permeability coefficient falls in the range of a fine sand, which is what we expected.

What Were the Sources of Error?

The following were possible sources of error in the permeability test:

1. The weight of the sand may have been slightly different than what was read because of inaccuracy in the scale.
2. The measurements of the length and diameter of the specimen were slightly off. It was impossible to get a completely accurate measurement of the length and diameter of the sand specimen.
3. The time of collection for each test was not completely accurate, as the timer attempted to time the "walking velocity" of people passing by throughout the test.
4. The temperature of the water may not have remained at 20 degrees C throughout the test, causing a slight change in the value of the permeability coefficient for the specimen.

5. All of the air bubbles in the specimen may not have been released before performing the test. The water which would normally flow through the soil would then fill these air bubbles and the flow value would be incorrect.

The values of permeability at a head difference of 5 psi (352 cm) were quite a bit different from each other (see figure 1 and table 1). This may have been due to initial air bubbles in the specimen or some other unknown cause. Performing the test another time at this pressure would have given us a surer value for the permeability at this pressure.

What Could be done to Reduce the Error?

To reduce the error in the constant head permeability test, we could simply reverse the effects of the errors above by:

1. Insuring that the scale is correct and the weight of the soil obtained is accurate.
2. Attempting to get an exact value for the length and diameter of the specimen.
3. Insuring that the time of collection of the water is accurately measured for each test.
4. Getting an accurate measurement of the temperature of the water at the beginning of the test and trying to keep the water at a constant temperature throughout the test.
5. Insuring that all or most of the air bubbles are released from the specimen before beginning the test.
6. Insuring that each test is performed correctly and exactly according to ASTM standards.

V. Conclusion

From performing the constant head permeability test on the "permeability board", I have learned the proper method for determination of the void ratio and permeability for a coarse-grained soil.

The permeabilities of the Ottawa sand at different pressures are repeated below, in table 4. The average permeability of 0.0014 appears to be accurate since the permeability of a fine sand is normally between 0.01 and 0.001, as in table 3.

After determining the average value of the permeability coefficient by constant head permeability test, you can use this value in computer seepage analysis programs to perform flow analyses under dams and through soils. You can also use the coefficient of permeability to make calculations by hand. Seepage under dams is highly important, as seepage was one of the main causes of the failure of the Teton dam.

Table 4: A Summary of the Test Results.

| Permeability at 141 cm Head | Permeability at 352 cm head | Permeability at 492 cm head | Average Permeability |
|--------------------------------|--------------------------------|--------------------------------|----------------------|
| 0.0017 cm/sec | 0.0014 cm/sec | 0.0012 cm/sec | 0.0014 cm/sec |

VI. Appendix

References

Das, B. M. (1993). Principles of geotechnical engineering, PWS Publishing Company, Boston.

Das, B. M. (1992). Soil Mechanics Laboratory Manual, Engineering Press, Inc., San Jose, California.

Data and Calculations

**Raw data and calculations are located on the following pages.