EXPERIMENT 1
WATER CONTENT DETERMINATION

Purpose:

This test is performed to determine the water (moisture) content of soils. The water content is the ratio, expressed as a percentage, of the mass of “pore” or “free” water in a given mass of soil to the mass of the dry soil solids.

Standard Reference:

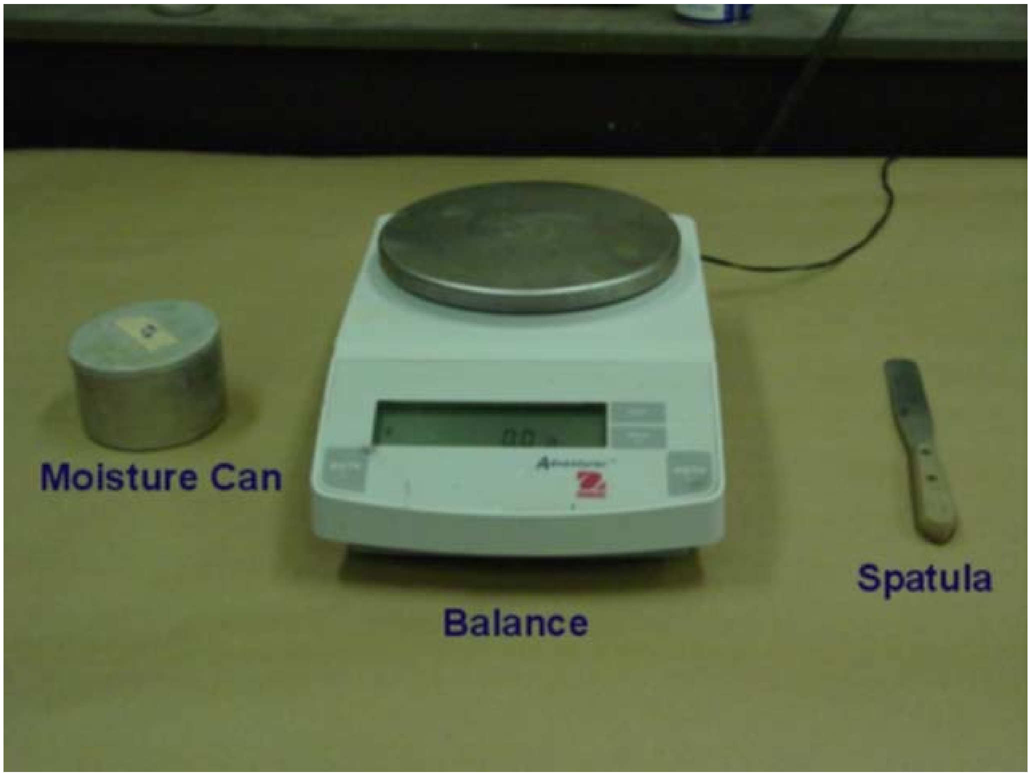
ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

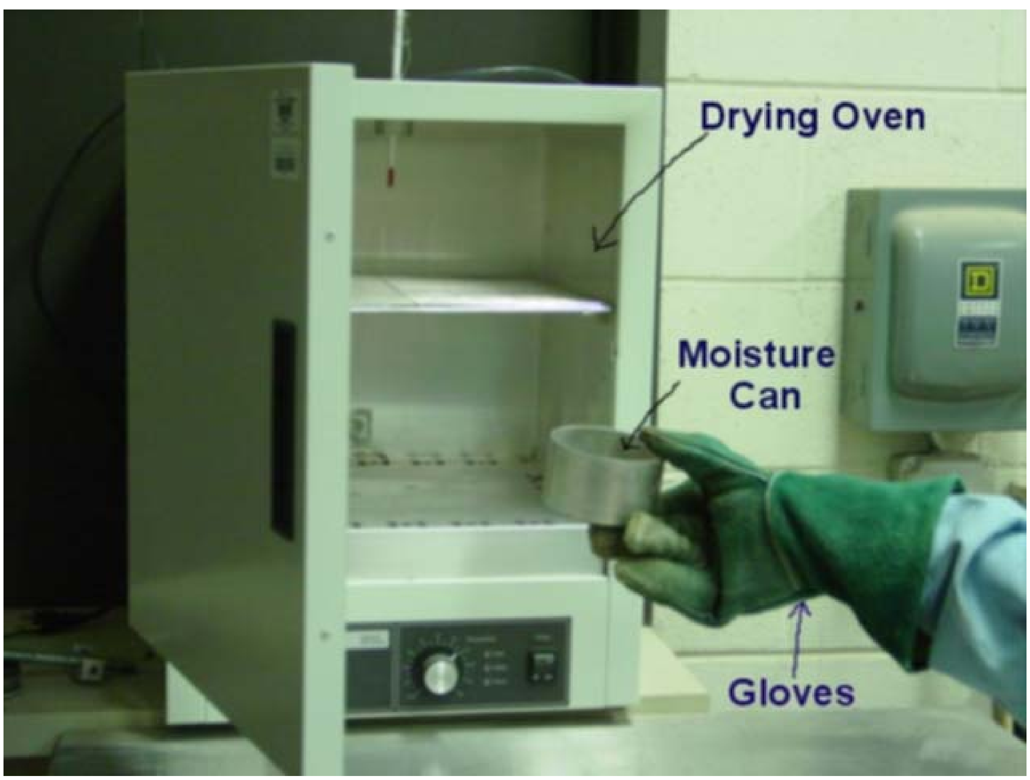
Significance:

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.

Equipment:

Drying oven, Balance, Moisture can, Gloves, Spatula.


Moisture Can
Balance
Spatula


Drying Oven
Moisture Can
Gloves

Test Procedure:

(1) Record the moisture can and lid number. Determine and record the mass of an empty, clean, and dry moisture can with its lid (M_C)

(2) Place the moist soil in the moisture can and secure the lid. Determine and record the mass of the moisture can (now containing the moist soil) with the lid (M_{CMS}).

(3) Remove the lid and place the moisture can (containing the moist soil) in the drying oven that is set at 105 °C. Leave it in the oven overnight.

(4) Remove the moisture can. Carefully but securely, replace the lid on the moisture can using gloves, and allow it to cool to room temperature. Determine and record the mass of the moisture can and lid (containing the dry soil) (M_{CDS}).

(5) Empty the moisture can and clean the can and lid.

Data Analysis:

(1) Determine the mass of soil solids.

$$M_S = M_{CDS} - M_{SC}$$

(2) Determine the mass of pore water.

$$M_W = M_{CMS} - M_{CDS}$$

(3) Determine the water content.

$$w = \frac{Mw}{Ms} x100$$

EXAMPLE DATA

WATER CONTENT DETERMINATION
DATA SHEET

Date Tested: August 30, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1,AU-1, 0'-2'

Sample Description: Gray silty clay

Specimen number	1	2
Moisture can and lid number	12	15
M_C = Mass of empty, clean can + lid (grams)	7.78	7.83
M_{CMS} = Mass of can, lid, and moist soil (grams)	16.39	13.43
M_{CDS} = Mass of can, lid, and dry soil (grams)	15.28	12.69
M_S = Mass of soil solids (grams)	7.5	4.86
M_W = Mass of pore water (grams)	1.11	0.74
w = Water content, w%	14.8	15.2

Example Calculation: $M_C = 7.78g$, $M_{CMS} = 16.39g$, $M_{CDS} = 15.28g$

$M_S = 15.28 - 7.78 = 7.5g$

$M_W = 16.39 - 15.28 = 1.11g$

$$w = \frac{1.11}{7.5} x100 = 14.8\%$$

BLANK DATA SHEETS

WATER CONTENT DETERMINATION
DATA SHEET

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Specimen number	1	2
Moisture can and lid number		
M_C = Mass of empty, clean can + lid (grams)		
M_{CMS} = Mass of can, lid, and moist soil (grams)		
M_{CDS} = Mass of can, lid, and dry soil (grams)		
M_S = Mass of soil solids (grams)		
M_W = Mass of pore water (grams)		
w = Water content, w%		

EXPERIMENT 2
ORGANIC MATTER DETERMINATION

Purpose:

This test is performed to determine the organic content of soils. The organic content is the ratio, expressed as a percentage, of the mass of organic matter in a given mass of soil to the mass of the dry soil solids.

Standard Reference:

ASTM D 2974 – Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Organic Soils

Significance:

Organic matter influences many of the physical, chemical and biological properties of soils. Some of the properties influenced by organic matter include soil structure, soil compressibility and shear strength. In addition, it also affects the water holding capacity, nutrient contributions, biological activity, and water and air infiltration rates.

Equipment:

Muffle furnace, Balance, Porcelain dish, Spatula, Tongs

Test Procedure:

(1) Determine and record the mass of an empty, clean, and dry porcelain dish (M_P).

(2) Place a part of or the entire oven-dried test specimen from the moisture content experiment (Expt.1) in the porcelain dish and determine and record the mass of the dish and soil specimen (M_{PDS}).

(3) Place the dish in a muffle furnace. Gradually increase the temperature in the furnace to 440^{o}C. Leave the specimen in the furnace overnight.

(4) Remove carefully the porcelain dish using the tongs (the dish is very hot), and allow it to cool to room temperature.

Determine and record the mass of the dish containing the ash (burned soil) (M_{PA}).

(5) Empty the dish and clean it.

Data Analysis:

(1) Determine the mass of the dry soil.

$$M_D=M_{PDS}-M_P$$

(2) Determine the mass of the ashed (burned) soil.

$$M_A=M_{PA}-M_P$$

(3) Determine the mass of organic matter

$$M_O = M_D - M_A$$

(4) Determine the organic matter (content).

$$OM = \frac{M_O}{M_D} x100$$

EXAMPLE DATA

ORGANIC MATTER DETERMINATION
DATA SHEET

Date Tested: August 30, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1,AU-1, 0'-2'

Sample Description: Gray silty clay

Specimen number	1	2
Porcelain dish number	5	8
M_P = Mass of empty, clean porcelain dish (grams)	23.20	23.03
M_{PDS} = Mass of dish and dry soil (grams)	35.29	36.66
M_{PA} = Mass of the dish and ash (Burned soil) (grams)	34.06	35.27
M_D = Mass of the dry soil (grams)	12.09	13.63
M_A = Mass of the ash (Burned soil) (grams)	10.86	12.24
M_O = Mass of organic matter (grams)	1.23	1.39
OM = Organic matter, %	10.17	10.20

Example Calculation: $M_P = 23.2g$, $M_{PDS} = 35.29g$, $M_{PA} = 34.06g$

$$M_D = 35.29 - 23.20 = 12.09g$$

$$M_A = 34.06 - 23.20 = 10.86g$$

$$M_O = 12.09 - 10.86 = 1.39g$$

$$OM = \frac{1.39}{12.09} x100 \quad = 10.17\%$$

BLANK DATA SHEETS

ORGANIC MATTER DETERMINATION
DATA SHEET

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Specimen number	1	2
Porcelain dish number		
M_P = Mass of empty, clean porcelain dish (grams)		
M_{PDS} = Mass of dish and dry soil (grams)		
M_{PA} = Mass of the dish and ash (Burned soil) (grams)		
M_D = Mass of the dry soil (grams)		
M_A = Mass of the ash (Burned soil) (grams)		
M_O = Mass of organic matter (grams)		
OM = Organic matter, %		

EXPERIMENT 3

DENSITY (UNIT WEIGHT) DETERMINATIOM

Purpose:

This lab is performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder. The bulk density is the ratio of mass of moist soil to the volume of the soil sample, and the dry density is the ratio of the mass of the dry soil to the volume the soil sample.

Standard Reference:

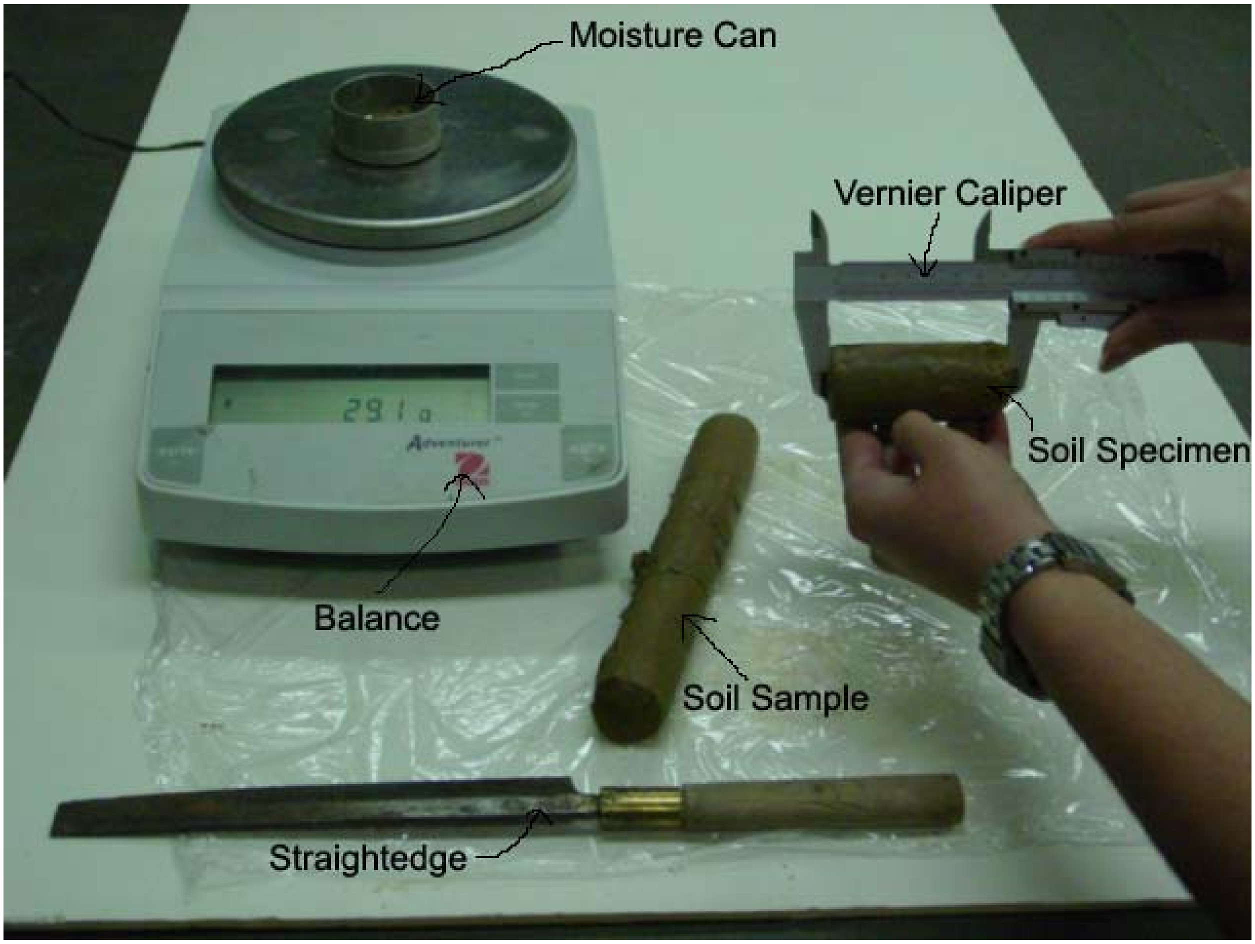
ASTM D 2937-00 – Standard Test for Density of Soil in Place by the Drive-Cylinder Method

Significance:

This test is used to determine the in-place density of soils. This test can also be used to determine density of compacted soils used in the construction of structural fills, highway embankments, or earth dams. This method is not recommended for organic or friable soils.

Equipment:

Straightedge, Balance, Moisture can, Drying oven, Vernier caliper



Test Procedure:

(1) Extrude the soil sample from the cylinder using the extruder.

(2) Cut a representative soil specimen from the extruded sample.

(3) Determine and record the length (L), diameter (D) and mass (M_t) of the soil specimen.

(4) Determine and record the moisture content of the soil (w). (See Experiment 1)

(Note: If the soil is sandy or loose, weigh the cylinder and soil sample together. Measure dimensions of the soil sample within the cylinder. Extrude and weigh the soil sample and determine moisture content)

Data Analysis:

(1) Determine the moisture content as in Experiment 1

(2) Determine the volume of the soil sample

$$V = \frac{\pi D^2 L}{4} \quad cm^3$$

(3) Calculate bulk density (ρ_t) of soil

$$\rho_t = \frac{M_t}{V} \quad \frac{g}{cm^3}$$

or unit weight $\gamma_t = \rho_t g$

(4) Calculate dry density (ρ_d) of soil

$$\rho_d = \frac{\rho_t}{1+w} \quad \frac{g}{cm^3}$$

or dry unit weight $\gamma_d = \rho_d g$

EXAMPLE DATA

DENSITY (UNIT WEIGHT) DETERMINATION
DATA SHEET

Sample number: B-1, ST-1, 10'-12' Date Tested: September 10, 2002

Soil description: Gray silty clay

Mass of the soil sample (M_t): 125.20 grams

Length of the soil sample (L): 7.26 cm

Diameter of the soil sample (D): 3.41 cm

Moisture content determination:

Specimen number	1
Moisture can and lid number	15
M_C = Mass of empty, clean can + lid (grams)	7.83
M_{CMS} = Mass of can, lid, and moist soil (grams)	13.43
M_{CDS} = Mass of can, lid, and dry soil (grams)	12.69
M_S = Mass of soil solids (grams)	4.86
M_W = Mass of pore water (grams)	0.74
w = Water content, w%	15. 2

Example calculations: w=15.2%, M_t=125.2g, L=7.26cm, D=3.41cm

$$V = \frac{\pi(3.41)^2(7.26)}{4} = 66.28 \quad cm^3$$

$$\rho_t = \frac{125.20}{66.28} = 1.89 \quad \frac{g}{cm^3} \quad or \quad \gamma_t = 1.89 \times 62.4 = 118 \quad \frac{lb}{ft^3}$$

$$\rho_d = \frac{1.89}{1 + \left(\frac{15.20}{100}\right)} = 1.64 \quad \frac{g}{cm^3} \quad or \quad \gamma_d = 1.64 \times 62.4 = 102.3 \quad \frac{lb}{ft^3}$$

(Note: 62.4 is the conversion factor to convert density in g/cm³ to unit weight in lb/ft³)

BLANK DATA SHEETS

DENSITY (UNIT WEIGHT) DETERMINATION
DATA SHEET

Sample number: Date Tested:
Soil description:

Mass of the soil sample (M_t):
Length of the soil sample (L):
Diameter of the soil sample (D):

Moisture content determination:

Specimen number	1
Moisture can and lid number	
M_C = Mass of empty, clean can + lid (grams)	
M_{CMS} = Mass of can, lid, and moist soil (grams)	
M_{CDS} = Mass of can, lid, and dry soil (grams)	
M_S = Mass of soil solids (grams)	
M_W = Mass of pore water (grams)	
w = Water content, w%	

Calculations:

EXPERIMENT 4
SPECIFIC GRAVITY DETERMINATION

Purpose:

This lab is performed to determine the specific gravity of soil by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature.

Standard Reference:

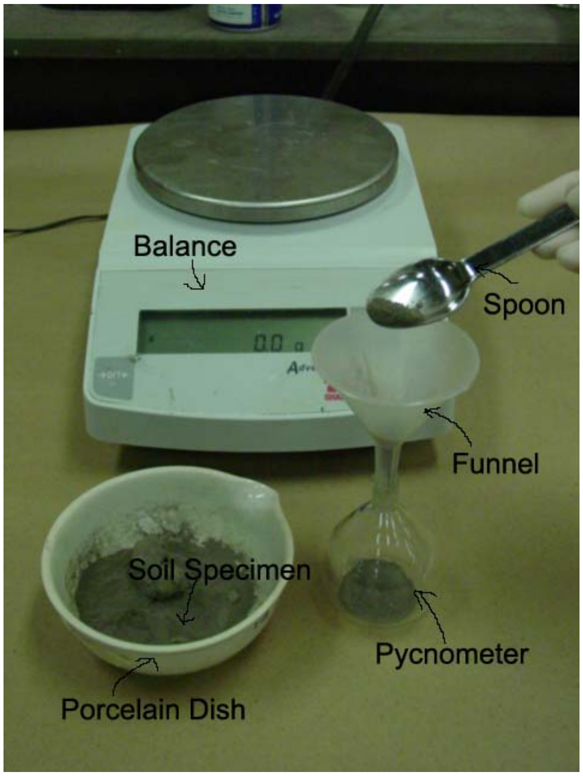
ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by Water Pycnometer.

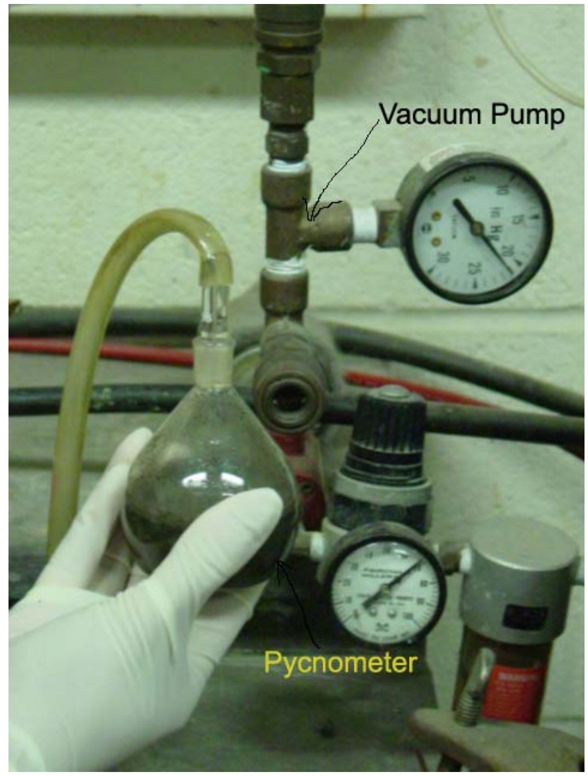
Significance:

The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil.

Equipment:

Pycnometer, Balance, Vacuum pump, Funnel, Spoon.





Test Procedure:

(1) Determine and record the weight of the empty clean and dry pycnometer, W_P.

(2) Place 10g of a dry soil sample (passed through the sieve No. 10) in the pycnometer. Determine and record the weight of the pycnometer containing the dry soil, W_{PS}.

(3) Add distilled water to fill about half to three-fourth of the pycnometer. Soak the sample for 10 minutes.

(4) Apply a partial vacuum to the contents for 10 minutes, to remove the entrapped air.

(5) Stop the vacuum and carefully remove the vacuum line from pycnometer.

(6) Fill the pycnometer with distilled (water to the mark), clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and contents, W_B.

(7) Empty the pycnometer and clean it. Then fill it with distilled water only (to the mark). Clean the exterior surface of the pycnometer with a clean, dry cloth. Determine the weight of the pycnometer and distilled water, W_A.

(8) Empty the pycnometer and clean it.

Data Analysis:

Calculate the specific gravity of the soil solids using the following formula:

$$\text{Specific Gravity}, G_S = \frac{W_0}{W_0 + (W_A - W_B)}$$

Where:

W_0 = weight of sample of oven-dry soil, g = W_{PS} - W_P

W_A = weight of pycnometer filled with water

W_B = weight of pycnometer filled with water and soil

EXAMPLE DATA

SPECIFIC GRAVITY DETERMINATION
DATA SHEET

Date Tested: September 10, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1, SS-1, 2'-3.5'

Sample Description: Gray silty clay

Specimen number	1	2
Pycnometer bottle number	96	37
W_P = Mass of empty, clean pycnometer (grams)	37.40	54.51
W_{PS} = Mass of empty pycnometer + dry soil (grams)	63.49	74.07
W_B = Mass of pycnometer + dry soil + water (grams)	153.61	165.76
W_A = Mass of pycnometer + water (grams)	137.37	153.70
Specific gravity (G_S)	2.65	2.61

Example Calculation: $W_P = 37.40$ g, $W_{PS} = 63.49$ g, $W_B = 153.61$ g,

$W_A = 137.37$ g

$W_O = 63.49 - 37.40 = 26.09$ g

$$G_S = \frac{26.09}{26.09 + (137.37 - 153.61)} = 2.65$$

BLANK DATA SHEETS

SPECIFIC GRAVITY DETERMINATION
DATA SHEET

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Specimen number	1	2
Pycnometer bottle number		
W_P = Mass of empty, clean pycnometer (grams)		
W_{PS} = Mass of empty pycnometer + dry soil (grams)		
W_B = Mass of pycnometer + dry soil + water (grams)		
W_A = Mass of pycnometer + water (grams)		
Specific Gravity (G_S)		

Calculations:

EXPERIMENT 5

RELATIVE DENSITY DETERMINATION

Purpose:

This lab is performed to determine the relative density of cohesionless, free-draining soils using a vibrating table. The relative density of a soil is the ratio, expressed as a percentage, of the difference between the maximum index void ratio and the field void ratio of a cohesionless, free-draining soil; to the difference between its maximum and minimum index void ratios.

Standard References:

ASTM D 4254 – Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density.

ASTM D 4253 – Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table.

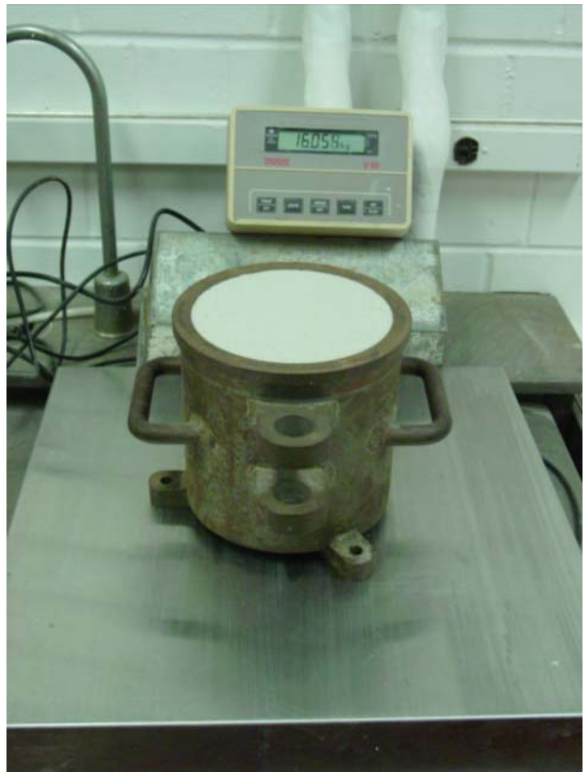
Significance:

Relative density and percent compaction are commonly used for evaluating the state of compactness of a given soil mass. The engineering properties, such as shear strength, compressibility, and permeability, of a given soil depend on the level of compaction.

Equipment:

Vibrating Table, Mold Assembly consisting of standard mold, guide sleeves, surcharge base-plate, surcharge weights, surcharge base-plate handle, and dial-indicator gage, Balance, Scoop, Straightedge.


Surcharge Weight
Dial Indicator Guage
Standard Mold
Guide Sleeves
Vibrating Table
Surcharge Base Plate



Test Procedure:

(1) Fill the mold with the soil (approximately 0.5 inch to 1 inch above the top of the mold) as loosely as possible by pouring the soil using a scoop or pouring device (funnel). Spiraling motion should be just sufficient to minimize particle segregation.

(2) Trim off the excess soil level with the top by carefully trimming the soil surface with a straightedge.

(3) Determine and record the mass of the mold and soil. Then empty the mold (M_1). See Photograph on Page 35.

(4) Again fill the mold with soil (do not use the same soil used in step 1) and level the surface of the soil by using a scoop or pouring device (funnel) in order to minimize the soil segregation. The sides of the mold may be struck a few times using a metal bar or rubber hammer to settle the soil so that the surcharge base-plate can be easily placed into position and there is no surge of air from the mold when vibration is initiated.

(5) Place the surcharge base plate on the surface of the soil and twist it slightly several times so that it is placed firmly and uniformly in contact with the surface of the soil. Remove the surcharge base-plate handle.

(6) Attach the mold to the vibrating table.

(7) Determine the initial dial reading by inserting the dial indicator gauge holder in each of the guide brackets with the dial gage stem in contact

with the rim of the mold (at its center) on the both sides of the guide brackets. Obtain six sets of dial indicator readings, three on each side of each guide bracket. The average of these twelve readings is the initial dial gage reading, R_i. Record R_i to the nearest 0.001 in. (0.025 mm). See Photograph on Page 35.

(8) Firmly attach the guide sleeve to the mold and lower the appropriate surcharge weight onto the surcharge base-plate. See Photograph on Page 35.

(9) Vibrate the mold assembly and soil specimen for 8 min.

(10) Determine and record the dial indicator gage readings as in step (7). The average of these readings is the final dial gage reading, $R_{f.}$

(11) Remove the surcharge base-plate from the mold and detach the mold from the vibrating table.

(12) Determine and record the mass of the mold and soil (M_2)

(13) Empty the mold and determine the weight of the mold.

(14) Determine and record the dimensions of the mold (i.e., diameter and height) in order to calculate the calibrated volume of the mold, V_c. Also, determine the thickness of the surcharge base-plate, T_p.

Analysis:

(1) Calculate the minimum index density (ρ_{dmin}) as follows:

$$\rho_{dmin} = \frac{M_{S1}}{V_C}$$

where

M_{s1}= mass of tested-dry soil

= Mass of mold with soil placed loose – mass of mold

V_c= Calibrated volume of the mold

(2) Calculate the maximum index density (ρ_{dmax}) as follows:

$$\rho_{dmax} = \frac{M_{S2}}{V}$$

where

M_{s2} = mass of tested-dry soil

= Mass of mold with soil after vibration – Mass of mold

V = Volume of tested-dry soil

= V_c – (Ac*H)

Where

Ac = the calibrated cross sectional area of the mold

$H = |R_f - R_i| + T_p$

(3) Calculate the maximum and the minimum-index void ratios as follows (use G_s value determined from Experiment 4; ρ_w=1 g/cm^3):

$$e_{min} = \frac{\rho_w G_s}{\rho_{dmin}} - 1$$

$$e_{max} = \frac{\rho_w G_s}{\rho_{dmin}} - 1$$

(4) Calculate the relative density as follows:

$$D_d = \frac{e_{max} - e}{e_{max} - e_{min}}$$

[Calculate the void ratio of the natural state of the soil based on ρ_d (Experiment 3*) and* $\rho_{s=}G_{S*}\rho_w$ (Gs determined from Experiment 4) as follows: $e = \frac{\rho_s}{\rho_d} - 1$]

EXAMPLE DATA

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RELATIVE DENSITY DETERMINATION
DATA SHEET

Date Tested: September 10, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1, ST-1, 2'-3.5'

Sample Description: Brown sand

Mass of empty mold:	9.878 Kg
Diameter of empty mold:	15.45 cm
Height of empty mold:	15.50 cm
Mass of mold and soil (M_1):	14.29 Kg
Average initial dial gauge reading (R_i):	0.88 inches
Average final dial gauge reading (R_f):	0.40 inches
Thickness of surcharge base plate (T_P):	0.123 inches
Mass of mold and soil (M_2):	14.38 Kg

Calculations:

$$M_{s1} = 14.29 - 9.878 = 4.412 \text{ kg} = 4412 \text{ g}, \quad M_{s2} = 14.38 - 9.878 = 4.502 \text{ kg} = 4502 \text{ g}$$

$$A_c = \frac{\pi(15.45)^2}{4} = 187.47 \text{ cm}^2, \quad H = (0.88 - 0.4 + 0.123) \times 2.54 = 1.53 \text{ cm}$$

$$V_c = \frac{\pi(15.45)^2 15.5}{4} = 2905.88 \text{ cm}^3, \quad V = 2905.88 - (187.47 \times 1.53) = 2618.75 \text{ cm}^3$$

$$\rho_{dmin} = \frac{4412}{2905.88} = 1.52 \frac{g}{cm^3}, \quad \rho_{dmax} = \frac{4502}{2618.75} = 1.72 \frac{g}{cm^3}$$

$Gs = 2.65$ (Based on Experiment − 4 conducted using the soil)

$$e_{min} = \frac{1 \times 2.65}{1.72} - 1 = 0.54, \quad e_{max} = \frac{1 \times 2.65}{1.52} - 1 = 0.74$$

$\rho d = 1.65 \frac{g}{cm^3}$ (Based on Experiment − 3 conducted using this soil)

$$e = \frac{2.65}{1.65} - 1 = 0.61$$

$$D_d = \frac{0.74 - 0.61}{0.74 - 0.54} x100 = 65\%$$

BLANK DATA SHEETS

RELATIVE DENSITY DETERMINATION
DATA SHEET

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Mass of empty mold:	____________
Diameter of empty mold:	____________
Height of empty mold:	____________
Mass of mold and soil (M_1):	____________
Average initial dial gauge reading (R_i):	____________
Average final dial gauge reading (R_f):	____________
Thickness of surcharge base plate (T_P):	____________
Mass of mold and soil (M_2):	____________

Calculations:

EXPERIMENT 6

GRAIN SIZE ANALYSIS

(SIEVE AND HYDROMETER ANALYSIS)

Purpose:

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

Standard Reference:

ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils

Significance:

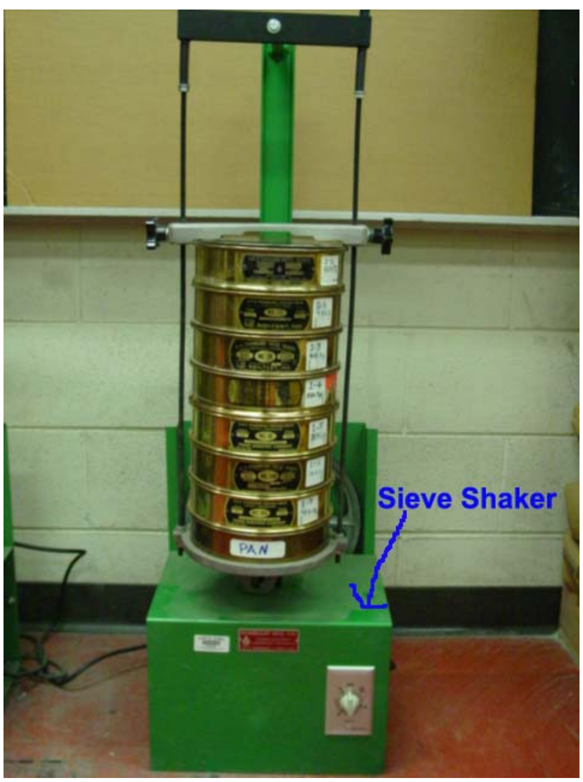
The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

Equipment:

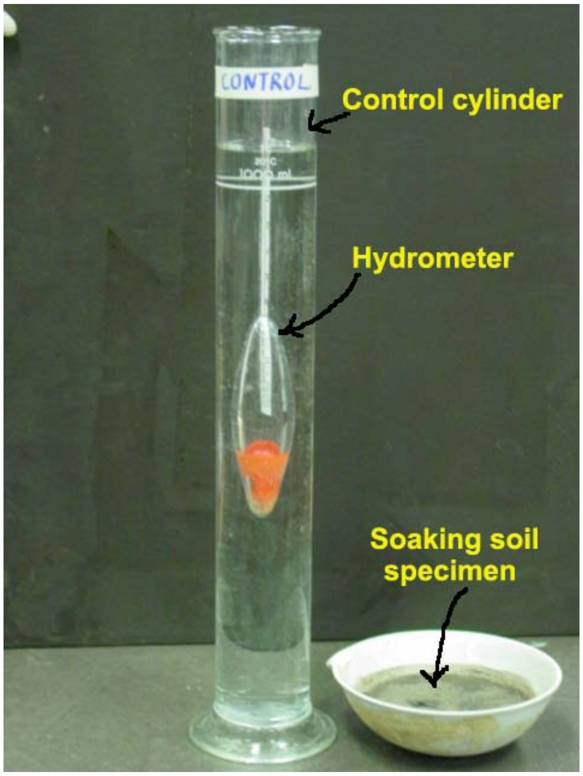
Balance, Set of sieves, Cleaning brush, Sieve shaker, Mixer (blender), 152H Hydrometer, Sedimentation cylinder, Control cylinder, Thermometer, Beaker, Timing device.


Set of Sieves
Soil Specimen
Balance
PAN


PAN

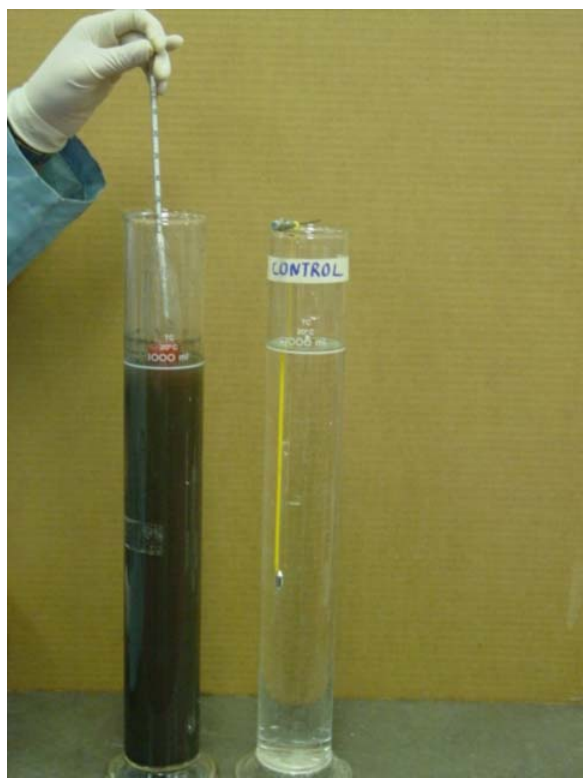

Sieve Shaker
PAN


1-1
627.5g
6642 g
Adventurer


CONTROL
Control cylinder
Hydrometer
Soaking soil specimen


Soaked soil specimen
Blender


Stopper


CONTROL

Test Procedure:

Sieve Analysis:

(1) Write down the weight of each sieve as well as the bottom pan to be used in the analysis.

(2) Record the weight of the given dry soil sample.

(3) Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). Place the pan below #200 sieve. Carefully pour the soil sample into the top sieve and place the cap over it.

(4) Place the sieve stack in the mechanical shaker and shake for 10 minutes.

(5) Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

Hydrometer Analysis:

(1) Take the fine soil from the bottom pan of the sieve set, place it into a beaker, and add 125 mL of the dispersing agent (sodium hexametaphosphate (40 g/L)) solution. Stir the mixture until the soil is thoroughly wet. Let the soil soak for at least ten minutes.

(2) While the soil is soaking, add 125mL of dispersing agent into the control cylinder and fill it with distilled water to the mark. Take the

reading at the top of the meniscus formed by the hydrometer stem and the control solution. A reading less than zero is recorded as a negative (-) correction and a reading between zero and sixty is recorded as a positive (+) correction. This reading is called the zero correction. The meniscus correction is the difference between the top of the meniscus and the level of the solution in the control jar (Usually about +1). Shake the control cylinder in such a way that the contents are mixed thoroughly. Insert the hydrometer and thermometer into the control cylinder and note the zero correction and temperature respectively.

(3) Transfer the soil slurry into a mixer by adding more distilled water, if necessary, until mixing cup is at least half full. Then mix the solution for a period of two minutes.

(4) Immediately transfer the soil slurry into the empty sedimentation cylinder. Add distilled water up to the mark.

(5) Cover the open end of the cylinder with a stopper and secure it with the palm of your hand. Then turn the cylinder upside down and back upright for a period of one minute. (The cylinder should be inverted approximately 30 times during the minute.)

(6) Set the cylinder down and record the time. Remove the stopper from the cylinder. After an elapsed time of one minute and forty seconds, very slowly and carefully insert the hydrometer for the first reading. (Note: It should take about ten seconds to insert or remove the hydrometer to minimize any disturbance, and the release of the

hydrometer should be made as close to the reading depth as possible to avoid excessive bobbing).

(7) The reading is taken by observing the top of the meniscus formed by the suspension and the hydrometer stem. The hydrometer is removed slowly and placed back into the control cylinder. Very gently spin it in control cylinder to remove any particles that may have adhered.

(8) Take hydrometer readings after elapsed time of 2 and 5, 8, 15, 30, 60 minutes and 24 hours

Data Analysis:

<u>Sieve Analysis</u>:

(1) Obtain the mass of soil retained on each sieve by subtracting the weight of the empty sieve from the mass of the sieve + retained soil, and record this mass as the weight retained on the data sheet. The sum of these retained masses should be approximately equals the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.

(2) Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample mass.

(3) Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

For example: Total mass = 500 g

Mass retained on No. 4 sieve = 9.7 g

Mass retained on No. 10 sieve = 39.5 g

For the No.4 sieve:

Quantity passing = Total mass - Mass retained

= 500 - 9.7 = 490.3 g

The percent retained is calculated as;

% retained = Mass retained/Total mass

= (9.7/500) X 100 = 1.9 %

From this, the % passing = 100 - 1.9 = 98.1 %

For the No. 10 sieve:

Quantity passing = Mass arriving - Mass retained

= 490.3 - 39.5 = 450.8 g

% Retained = (39.5/500) X 100 = 7.9 %

% Passing = 100 - 1.9 - 7.9 = 90.2 %

(Alternatively, use % passing = % Arriving - % Retained

For No. 10 sieve = 98.1 - 7.9 = 90.2 %)

(4) Make a semilogarithmic plot of grain size vs. percent finer.

(5) Compute C_c and C_u for the soil.

<u>Hydrometer Analysis</u>:

(1) Apply meniscus correction to the actual hydrometer reading.

(2) From Table 1, obtain the effective hydrometer depth L in cm (for meniscus corrected reading).

(3) For known G_s of the soil (if not known, assume 2.65 for this lab purpose), obtain the value of K from Table 2.

(4) Calculate the equivalent particle diameter by using the following formula:

$$D = K\sqrt{\frac{L}{t}}$$

Where t is in minutes, and D is given in mm.

(5) Determine the temperature correction C_T from Table 3.

(6) Determine correction factor "*a*" from Table 4 using G_s.

(7) Calculate corrected hydrometer reading as follows:

$R_c = R_{ACTUAL}$ - zero correction + C_T

(8) Calculate percent finer as follows:

$$P = \frac{Rc \times a}{w_S} \times 100$$

Where W_S is the weight of the soil sample in grams.

(9) Adjusted percent fines as follows:

$$P_A = \frac{P \times F_{200}}{100}$$

F_{200} = % finer of #200 sieve as a percent

(10) Plot the grain size curve D versus the adjusted percent finer on the semilogarithmic sheet.

Table 1. Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specific Sizes

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L (cm)	Actual Hydrometer Reading	Effective Depth, L (cm)	Actual Hydrometer Reading	Effective Depth, L (cm)
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5	36	10.4
1.006	14.7	6	15.3	37	10.2
1.007	14.4	7	15.2	38	10.1
1.008	14.2	8	15.0	39	9.9
1.009	13.9	9	14.8	40	9.7
1.010	13.7	10	14.7	41	9.6
1.011	13.4	11	14.5	42	9.4
1.012	13.1	12	14.3	43	9.2
1.013	12.9	13	14.2	44	9.1
1.014	12.6	14	14.0	45	8.9
1.015	12.3	15	13.8	46	8.8
1.016	12.1	16	13.7	47	8.6
1.017	11.8	17	13.5	48	8.4
1.018	11.5	18	13.3	49	8.3
1.019	11.3	19	13.2	50	8.1
1.020	11.0	20	13.0	51	7.9
1.021	10.7	21	12.9	52	7.8
1.022	10.5	22	12.7	53	7.6
1.023	10.2	23	12.5	54	7.4
1.024	10.0	24	12.4	55	7.3
1.025	9.7	25	12.2	56	7.1
1.026	9.4	26	12.0	57	7.0
1.027	9.2	27	11.9	58	6.8
1.028	8.9	28	11.7	59	6.6
1.029	8.6	29	11.5	60	6.5
1.030	8.4	30	11.4		
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				
1.039	5.9				

Table 2. Values of **k** for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis

Temperature °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.0394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01269	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Table 3. Temperature Correction Factors C_T

Temperature $^\circ C$	factor C_T
15	1.10
16	-0.90
17	-0.70
18	-0.50
19	-0.30
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Table 4. Correction Factors ***a*** for Unit Weight of Solids

Unit Weight of Soil Solids, g/cm^3	Correction factor a
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

EXAMPLE DATA

Grain Size Analysis

Sieve Analysis

Date Tested: September 15, 2002
Tested By: CEMM315 Class, Group A
Project Name: CEMM315 Lab
Sample Number: B-1, ST-1, 2'-3. 5'
Visual Classification of Soil: Brown Clayey to silty sand, trace fine gravel
Weight of Container: 198.5 gm
Wt. Container+Dry Soil: 722.3 gm
Wt. of Dry Sample: 523.8 gm

Sieve Number	Diameter (mm)	Mass of Empty Sieve (g)	Mass of Sieve+Soil Retained (g)	Soil Retained (g)	Percent Retained	Percent Passing
4	4.75	116.23	166.13	49.9	9.5	90.5
10	2.0	99.27	135.77	36.5	7.0	83.5
20	0.84	97.58	139.68	42.1	8.0	75.5
40	0.425	98.96	138.96	40.0	7.6	67.8
60	0.25	91.46	114.46	23.0	4.4	63.4
140	0.106	93.15	184.15	91.0	17.4	46.1
200	0.075	90.92	101.12	10.2	1.9	44.1
Pan	---	70.19	301.19	231.0	44.1	0.0
			Total Weight=	523.7		

* Percent passing=100-cumulative percent retained.

From Grain Size Distribution Curve:

% Gravel= 9.5 — D_{10}= 0.002 mm
% Sand= 46.4 — D_{30}= 0.017 mm
% Fines= 44.1 — D_{60}= .0.25 mm

$$C_u = \frac{0.25}{0.002} = 125, \quad C_c = \frac{(0.017)^2}{0.25 \times 0.002} = 0.58$$

Unified Classification of Soil: SC/SM

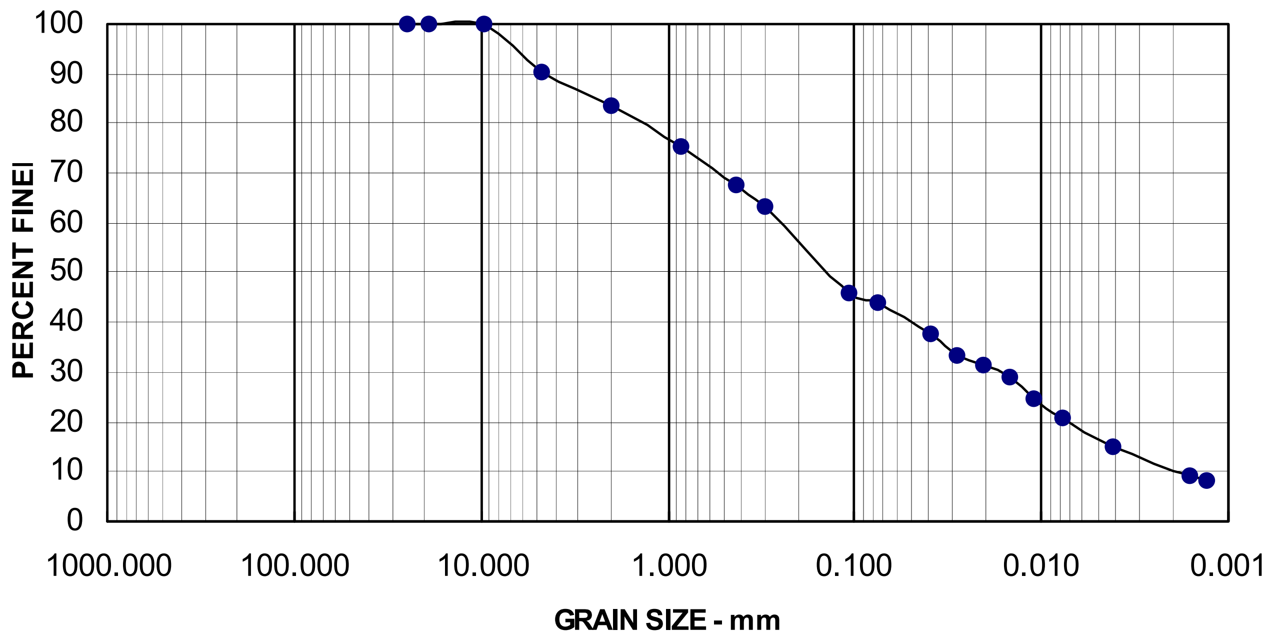
Hydrometer Analysis

Test Date: September 15, 2002
Tested By: CEMM315 Class, Group A
Hydrometer Number (if known): 152 H
Specific Gravity of Solids: 2.56
Dispersing Agent: Sodium Hexametaphosphate
Weight of Soil Sample: 50.0 gm
Zero Correction: +6
Meniscus Correction: +1

Date	Time	Elapsed Time (min)	Temp. ^{o}C	Actual Hydro. Rdg. R_a	Hyd. Corr. for Meniscus	L from Table 1	K from Table 2	D mm	C_T from Table 3	a from Table 4	Corr. Hydr. Rdg. R_c	% Finer P	% Adjusted Finer P_A
09/15	4:06 PM	0	25	55	56	7.1	0.01326	0	+1.3	1.018	-	-	-
	4:07	1	25	47	48	8.6	0.01326	0.03029	+1.3	1.018	42.3	86.1	37.8
	4:08	2	25	42	43	9.2	0.01326	0.02844	+1.3	1.018	37.3	75.9	33.3
	4:10	4	25	40	41	9.6	0.01326	0.02054	+1.3	1.018	35.3	71.9	31.6
	4:14	8	25	37	38	10.1	0.01326	0.01490	+1.3	1.018	32.3	65.8	28.6
	4:22	16	25	32	33	10.9	0.01326	0.01094	+1.3	1.018	27.3	55.6	24.1
	4:40	34	25	28	29	11.5	0.01326	0.00771	+1.3	1.018	23.3	47.4	20.8
	6:22	136	23	22	23	12.5	0.01356	0.00411	+0.7	1.018	16.7	34	14.9
09/16	5:24 PM	1518	22	15	16	13.7	0.01366	0.00130	+0.4	1.018	9.4	19.1	8.4

Unified Classification of Soil: SC/SM

GRAIN SIZE ANALYSIS



BLANK DATA SHEETS

Grain Size Analysis

Sieve Analysis

Date Tested:
Tested By:
Project Name:
Sample Number:
Visual Classification of Soil:

Weight of Container: _____gm
Wt. Container+Dry Soil: _____gm
Wt. of Dry Sample: _____gm

Sieve Number	Diameter (mm)	Mass of Empty Sieve (g)	Mass of Sieve+Soil Retained (g)	Soil Retained (g)	Percent Retained	Percent Passing
4	4.75					
10	2. 0					
20	0.84					
40	0.425					
60	0. 25					
140	0.106					
200	0.075					
Pan	---					
			Total Weight=			

* Percent passing=100-cumulative percent retained.

From Grain Size Distribution Curve:

% Gravel= _______ D_{10}= ______ mm

% Sand= _______ D_{30}= ______ mm

% Fines= _______ D_{60}= ______ mm

C_u= _______________ C_C= _________

Unified Classification of Soil: ________

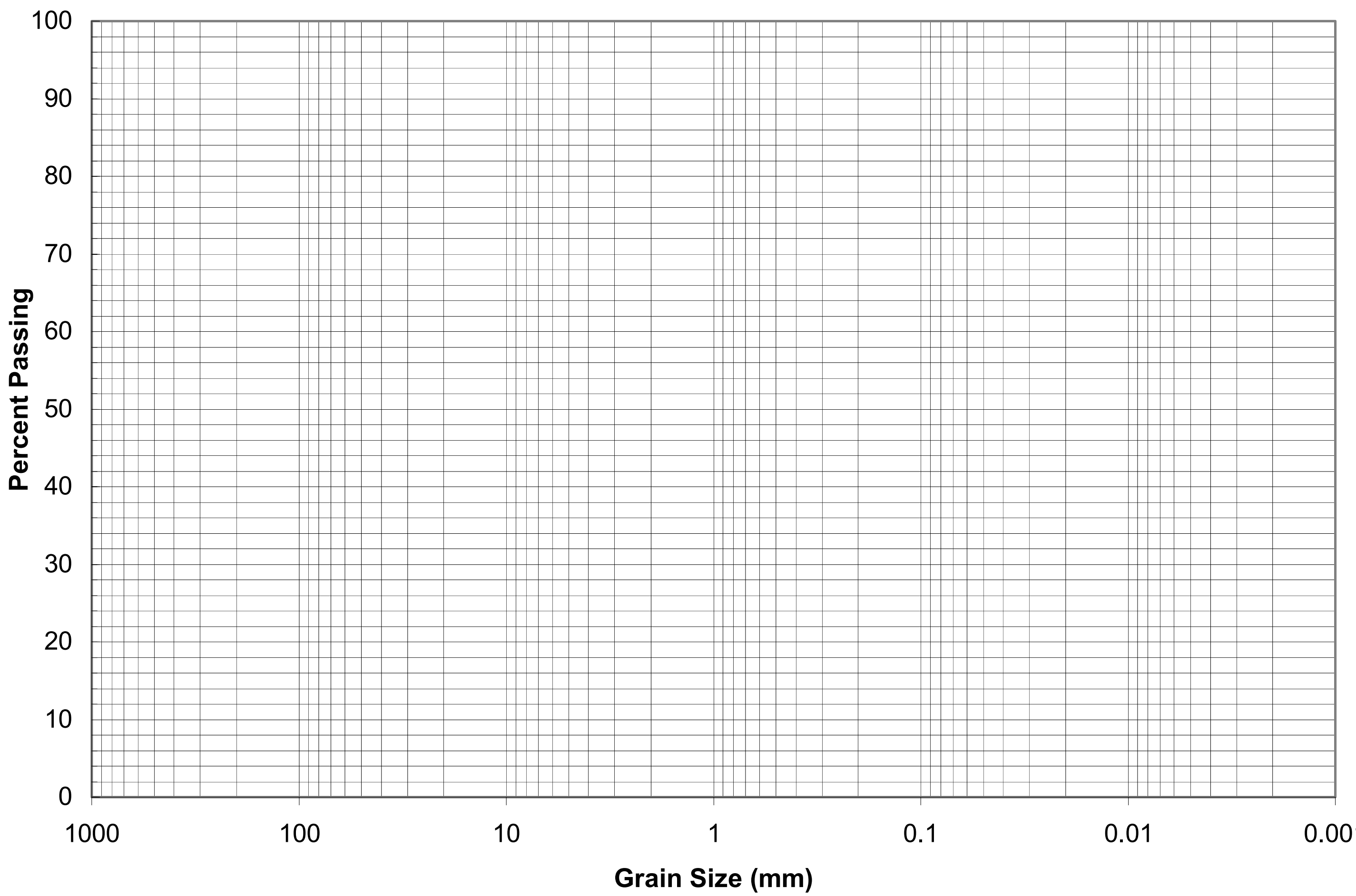
Hydrometer Analysis

Test Date: ___________
Tested By: ___________
Hydrometer Number (if known): __________
Specific Gravity of Solids:__________
Dispersing Agent: __________
Weight of Soil Sample: __________gm

Zero Correction: __________
Meniscus Correction: __________

Date	Time	Elapsed Time (min)	Temp. ^{O}C	Actual Hydro. Rdg. R_a	Hyd. Corr. for Meniscus	L from Table 1	K from Table 2	D mm	C_T from Table 3	a from Table 4	Corr. Hydr. Rdg. R_c	% Finer P	% Adjusted Finer P_A

Unified Classification of Soil:



Note: You can plot your data on this graph or generate similar graph using any graphics program (e.g., excel)

EXPERIMENT 7
ATTERBERG LIMITS

Purpose:

This lab is performed to determine the plastic and liquid limits of a fine-grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

Standard Reference:

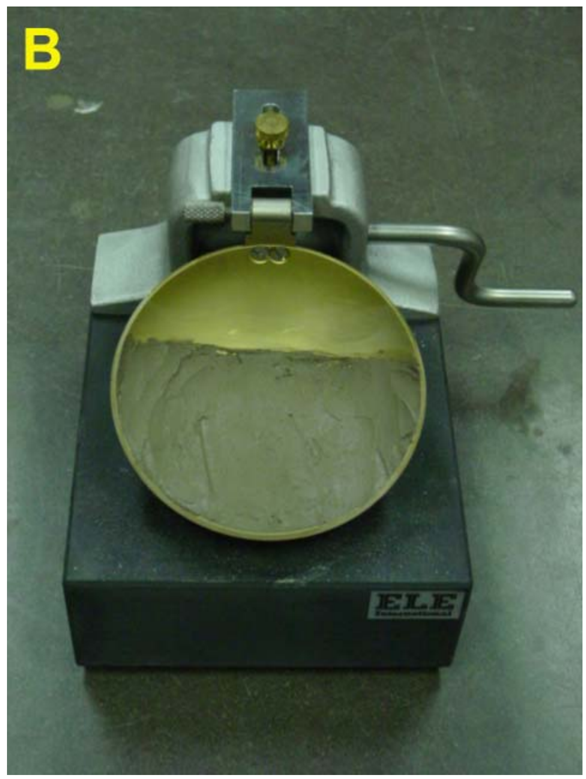
ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

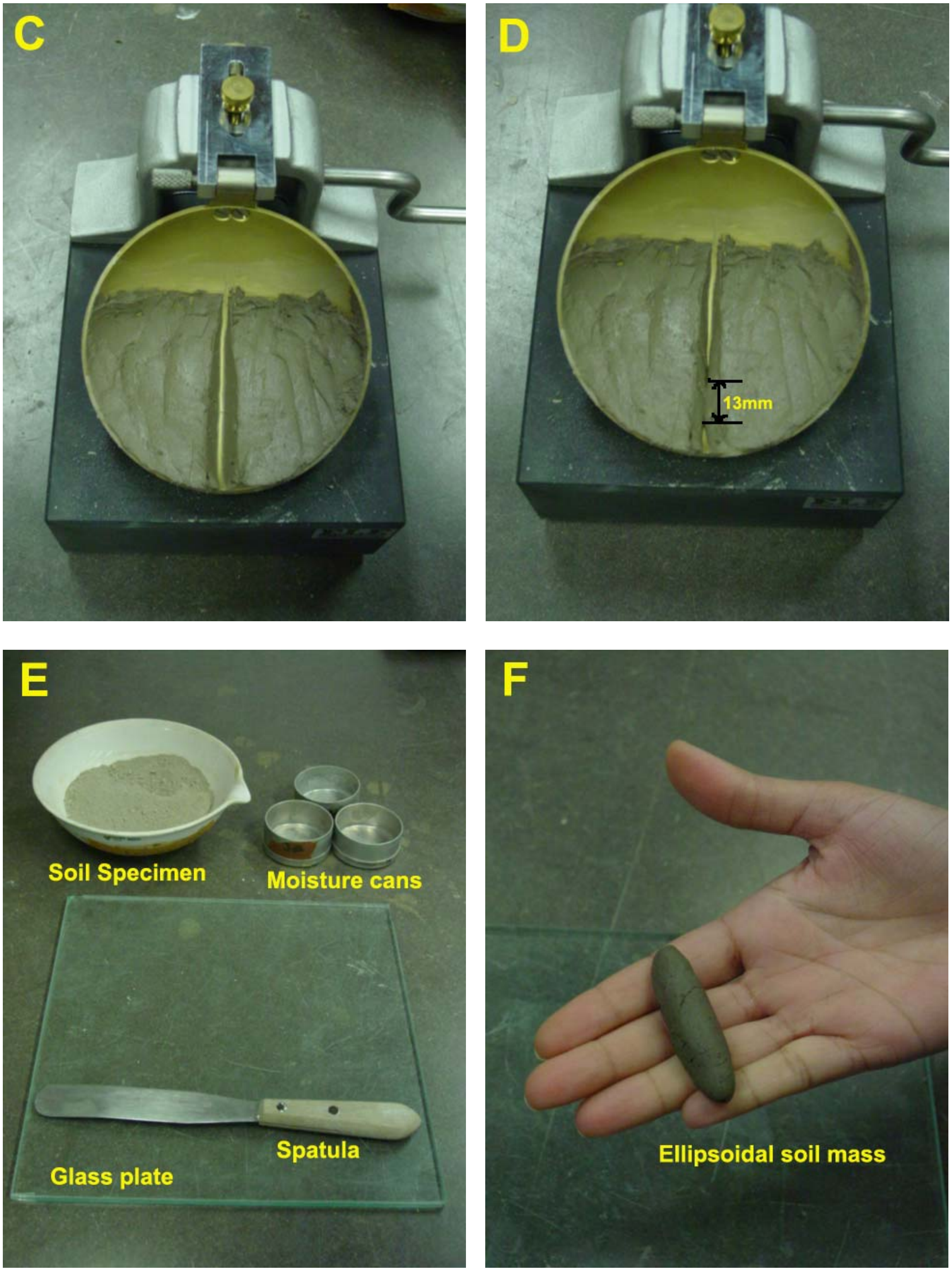
Significance:

The Swedish soil scientist Albert Atterberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally.) The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system or AASHTO system.

Equipment:

Liquid limit device, Porcelain (evaporating) dish, Flat grooving tool with gage, Eight moisture cans, Balance, Glass plate, Spatula, Wash bottle filled with distilled water, Drying oven set at 105°C.




C
D
13mm
E
Soil Specimen
Moisture cans
Spatula
Glass plate
F
Ellipsoidal soil mass

Test Procedure:

Liquid Limit:

(1) Take roughly 3/4 of the soil and place it into the porcelain dish. Assume that the soil was previously passed though a No. 40 sieve, air-dried, and then pulverized. Thoroughly mix the soil with a small amount of distilled water until it appears as a smooth uniform paste. Cover the dish with cellophane to prevent moisture from escaping.

(2) Weigh four of the empty moisture cans with their lids, and record the respective weights and can numbers on the data sheet.

(3) Adjust the liquid limit apparatus by checking the height of drop of the cup. The point on the cup that comes in contact with the base should rise to a height of 10 mm. The block on the end of the grooving tool is

10 mm high and should be used as a gage. Practice using the cup and determine the correct rate to rotate the crank so that the cup drops approximately two times per second.

(4) Place a portion of the previously mixed soil into the cup of the liquid limit apparatus at the point where the cup rests on the base. Squeeze the soil down to eliminate air pockets and spread it into the cup to a depth of about 10 mm at its deepest point. The soil pat should form an approximately horizontal surface (See Photo B).

(5) Use the grooving tool carefully cut a clean straight groove down the center of the cup. The tool should remain perpendicular to the surface of the cup as groove is being made. Use extreme care to prevent sliding the soil relative to the surface of the cup (See Photo C).

(6) Make sure that the base of the apparatus below the cup and the underside of the cup is clean of soil. Turn the crank of the apparatus at a rate of approximately two drops per second and count the number of drops, N, it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.) (See Photo D). If the number of drops exceeds 50, then go directly to step eight and do not record the number of drops, otherwise, record the number of drops on the data sheet.

(7) Take a sample, using the spatula, from edge to edge of the soil pat. The sample should include the soil on both sides of where the groove came into contact. Place the soil into a moisture can cover it. Immediately weigh the moisture can containing the soil, record its

mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours. Place the soil remaining in the cup into the porcelain dish. Clean and dry the cup on the apparatus and the grooving tool.

(8) Remix the entire soil specimen in the porcelain dish. Add a small amount of distilled water to increase the water content so that the number of drops required to close the groove decrease.

(9) Repeat steps six, seven, and eight for at least two additional trials producing successively lower numbers of drops to close the groove. One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring 15 to 25 drops. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Plastic Limit:

(1) Weigh the remaining empty moisture cans with their lids, and record the respective weights and can numbers on the data sheet.

(2) Take the remaining 1/4 of the original soil sample and add distilled water until the soil is at a consistency where it can be rolled without sticking to the hands.

(3) Form the soil into an ellipsoidal mass (See Photo F). Roll the mass between the palm or the fingers and the glass plate (See Photo G). Use sufficient pressure to roll the mass into a thread of uniform

diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position.) The thread shall be deformed so that its diameter reaches 3.2 mm (1/8 in.), taking no more than two minutes.

(4) When the diameter of the thread reaches the correct diameter, break the thread into several pieces. Knead and reform the pieces into ellipsoidal masses and re-roll them. Continue this alternate rolling, gathering together, kneading and re-rolling until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3.2 mm diameter thread (See Photo H).

(5) Gather the portions of the crumbled thread together and place the soil into a moisture can, then cover it. If the can does not contain at least 6 grams of soil, add soil to the can from the next trial (See Step 6). Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours.

(6) Repeat steps three, four, and five at least two more times. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

Analysis:

Liquid Limit:

(1) Calculate the water content of each of the liquid limit moisture cans after they have been in the oven for at least 16 hours.

(2) Plot the number of drops, N, (on the log scale) versus the water content (w). Draw the best-fit straight line through the plotted points and determine the liquid limit (LL) as the water content at 25 drops.

Plastic Limit:

(1) Calculate the water content of each of the plastic limit moisture cans after they have been in the oven for at least 16 hours.

(2) Compute the average of the water contents to determine the plastic limit, PL. Check to see if the difference between the water contents is greater than the acceptable range of two results (2.6 %).

(3) Calculate the plasticity index, PI=LL-PL.
Report the liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation.

EXAMPLE DATA

ATTERBERG LIMITS
DATA SHEETS

Date Tested: September 20, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1, SS-1, 8'-10'

Sample Description: Grayey silty clay

Liquid Limit Determination

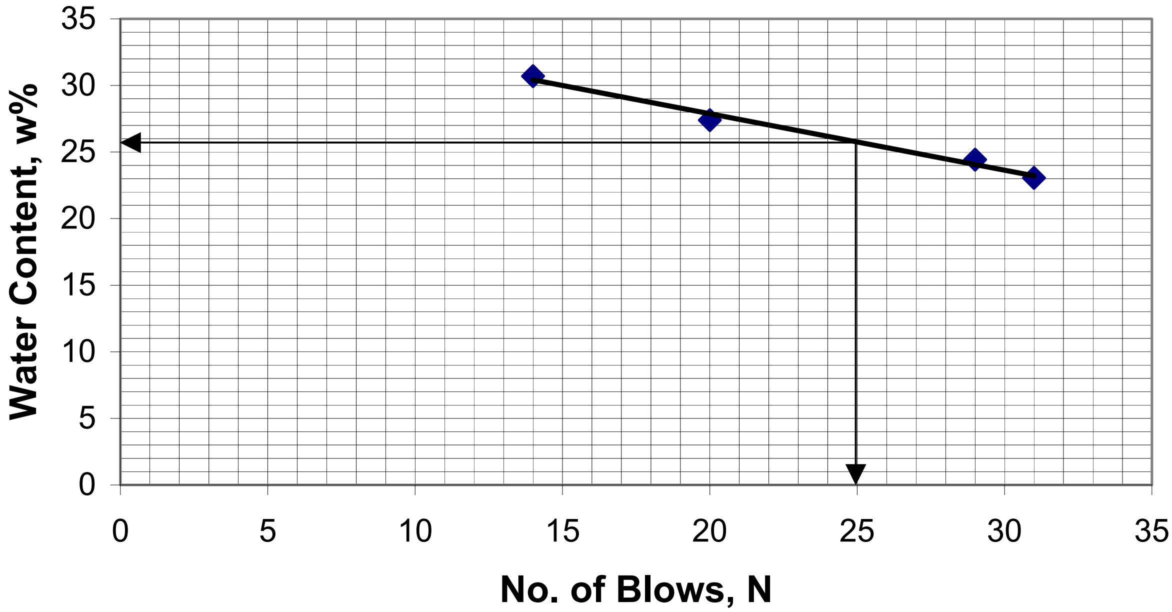
Sample no.	1	2	3	4
Moisture can and lid number	11	1	5	4
M_C = Mass of empty, clean can + lid (grams)	22.23	23.31	21.87	22.58
M_{CMS} = Mass of can, lid, and moist soil (grams)	28.56	29.27	25.73	25.22
M_{CDS} = Mass of can, lid, and dry soil (grams)	27.40	28.10	24.90	24.60
M_S = Mass of soil solids (grams)	5.03	4.79	3.03	2.02
M_W = Mass of pore water (grams)	1.16	1.17	0.83	0.62
w = Water content, w%	23.06	24.43	27.39	30.69
No. of drops (N)	31	29	20	14

Plastic Limit Determination

Sample no.	1	2	3
Moisture can and lid number	7	14	13
M_C = Mass of empty, clean can + lid (grams)	7.78	7.83	15.16
M_{CMS} = Mass of can, lid, and moist soil (grams)	16.39	13.43	21.23
M_{CDS} = Mass of can, lid, and dry soil (grams)	15.28	12 .69	20.43
M_S = Mass of soil solids (grams)	7.5	4.86	5.27
M_W = Mass of pore water (grams)	1. 11	0.74	0.8
w = Water content, w%	14.8	15.2	15.1

Plastic Limit (PL)= Average w % = $\frac{14.8 + 15.2 + 15.1}{3} = 15.0$

LIQUID LIMIT CHART



From the above graph, Liquid Limit = 26

Final Results:

Liquid Limit = 26

Plastic Limit = 15

Plasticity Index =11

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ATTERBERG LIMITS
DATA SHEETS

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Liquid Limit Determination

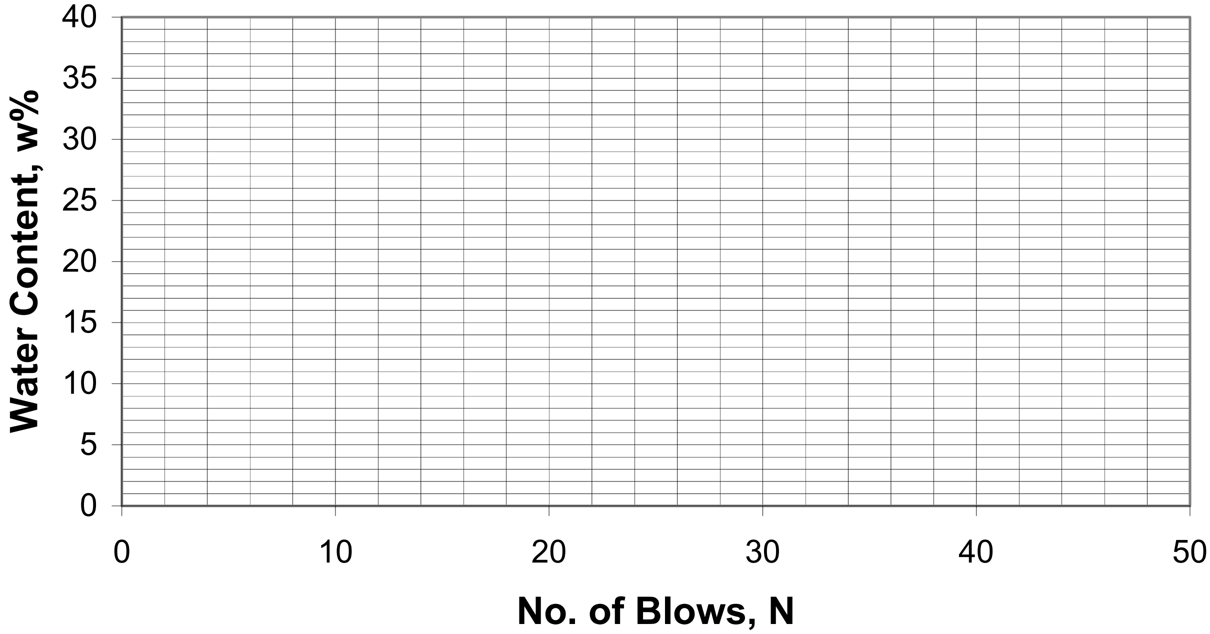
Sample no.	1	2	3	4
Moisture can and lid number				
M_C = Mass of empty, clean can + lid (grams)				
M_{CMS} = Mass of can, lid, and moist soil (grams)				
M_{CDS} = Mass of can, lid, and dry soil (grams)				
M_S = Mass of soil solids (grams)				
M_W = Mass of pore water (grams)				
w = Water content, w%				
No. of drops (N)				

Plastic Limit Determination

Sample no.	1	2	3
Moisture can and lid number			
M_C = Mass of empty, clean can + lid (grams)			
M_{CMS} = Mass of can, lid, and moist soil (grams)			
M_{CDS} = Mass of can, lid, and dry soil (grams)			
M_S = Mass of soil solids (grams)			
M_W = Mass of pore water (grams)			
w = Water content, w%			

Plastic Limit (PL) = Average w % =

LIQUID LIMIT CHART



Final Results:

Liquid Limit =
Plastic Limit =
Plasticity Index =

EXPERIMENT 7

VISUAL CLASSIFICATION OF SOILS

Purpose:

Visually classify the soils.

Standard Reference:

ASTM D 2488 - Standard Practice for Description and Identification of Soils (Visual - Manual Procedure)

Significance:

The first step in any geotechnical engineering project is to identify and describe the subsoil condition. For example, as soon as a ground is identified as gravel, engineer can immediately form some ideas on the nature of problems that might be encountered in a tunneling project. In contrast, a soft clay ground is expected to lead to other types of design and construction considerations. Therefore, it is useful to have a systematic procedure for identification of soils even in the planning stages of a project.

Soils can be classified into two general categories: (1) coarse grained soils and (2) fine grained soils. Examples of coarse-grained soils are gravels and sands. Examples of fine-grained soils are silts and clays. Procedures for visually identifying these two general types of soils are described in the following sections.

Equipment:

Magnifying glass (optional)

Identification Procedure:

a. Identify the color (e.g. brown, gray, brownish gray), odor (if any) and texture (coarse or fine-grained) of soil.

b. Identify the major soil constituent (>50% by weight) using Table 1 as coarse gravel, fine gravel, coarse sand, medium sand, fine sand, or fines.

c. Estimate percentages of all other soil constituents using Table 1 and the following terms:

Trace - 0 to 10% by weight
Little - 10 to 20%
Some - 20 to 30%
And - 30 to 50%

(Examples: trace fine gravel, little silt, some clay)

d. If the major soil constituent is sand or gravel:

Identify particle distribution. Describe as **well graded** or **poorly graded**. Well-graded soil consists of particle sizes over a wide range. Poorly graded soil consists of particles which are all about the same size.

Identify particle shape (angular, subangular, rounded, subrounded) using Figure 1 and Table 2.

e. If the major soil constituents are fines, perform the following tests:

Dry strength test: Mold a sample into 1/8" size ball and let it dry. Test the strength of the dry sample by crushing it between the fingers. Describe the strength as none, low, medium, high or very high depending on the results of the test as shown in Table 3(a).

Dilatancy Test: Make a sample of soft putty consistency in your palm. Then observe the reaction during shaking, squeezing (by closing hand) and vigorous tapping. The reaction is rapid, slow or none according to the test results given in Table 3(b).

During dilatancy test, vibration densifies the silt and water appears on the surface. Now on squeezing, shear stresses are applied on the densified silt. The dense silt has a tendency for volume increase or dilatancy due to shear stresses. So the water disappears from the surface. Moreover, silty soil has a high permeability, so the water moves quickly. In clay, we see no change, no shiny surface, in other words, no reaction.

Plasticity (or Toughness) Test: Roll the samples into a thread about 1/8" in diameter. Fold the thread and reroll it repeatedly until the thread crumbles at a diameter of 1/8". Note (a) the pressure required to roll the thread when it is near crumbling, (b) whether it can support its own weight, (c) whether it can be molded back into a coherent mass, and (d) whether it is tough during kneading. Describe the plasticity and toughness according to the criteria in Tables 3(c) and 3(d). A low to medium toughness and non-plastic to low plasticity is the indication that the soil is silty; otherwise the soil is clayey.

Based on dry strength, dilatancy and toughness, determine soil symbol based on Table 4.

f. Identify moisture condition (dry, moist, wet or saturated) using Table 5.

g. Record visual classification of the soil in the following order: color, major constituent, minor constituents, particle distribution and particle shape (if major constituent is coarse-grained), plasticity (if major constituent is fine-grained), moisture content, soil symbol (if major constituent is fine-grained).

Examples of coarse-grained soils:

Soil 1: Brown fine gravel, some coarse to fine sand, trace silt, trace clay, well graded, angular, dry.

Soil 2: Gray coarse sand, trace medium to fine sand, some silt, trace clay, poorly graded, rounded, saturated.

Examples of fine-grained soils:

Soil A: Brown lean clay, trace coarse to fine sand, medium plasticity, moist, CL.

Soil B: Gray clayey silt, trace fine sand, non-plastic, saturated, ML.

Laboratory Exercise:

You will be given ten different soil samples. Visually classify these soils. Record all information on the attached forms.

Table 1. Grain Size Distribution

Soil Constituent	Size Limits	Familiar Example
Boulder	12 in. (305 mm) or more	Larger than basketball
Cobbles	3 in (76 mm) -12 in (305 mm)	Grapefruit
Coarse Gravel	¾ in. (19 mm) – 3 in. (76 mm)	Orange or Lemon
Fine Gravel	4.75 mm (No.4 Sieve) – ¾ in. (19 mm)	Grape or Pea
Coarse Sand	2 mm (No.10 Sieve) – 4.75 mm (No. 4 Sieve)	Rocksalt
Medium Sand	0.42 mm (No. 40 Sieve) – 2 mm (No. 10 Sieve)	Sugar, table salt
Fine Sand*	0.075 mm (No. 200 Sieve) – 0.42 mm (No. 40 Sieve)	Powdered Sugar
Fines	Less than 0.0075 mm (No. 200 Sieve)	-

*Particles finer than fine sand cannot be discerned with the naked eye at a distance of 8 in (20 cm).

Figure 1. Shape of Coarse-Grained Soil Particles

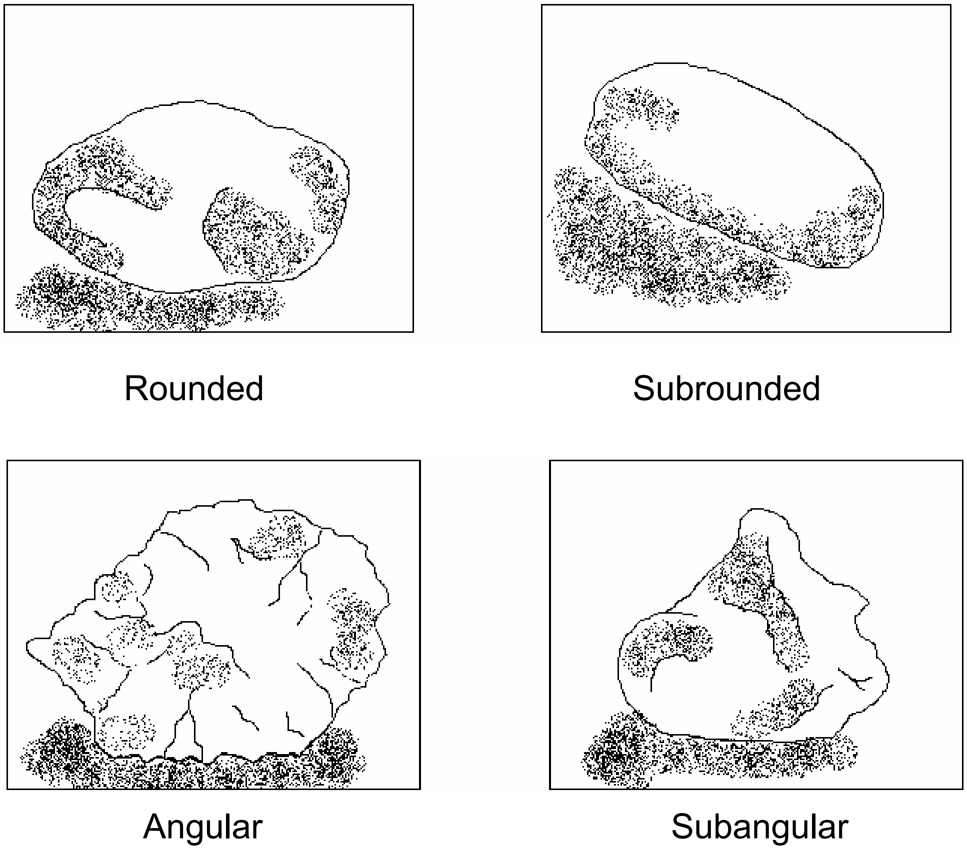


Table 2. Criteria for Describing Shape of Coarse-Grained Soil Particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces.
Subangular	Particles are similar to angular description, but have rounded edges.
Subrounded	Particles have nearly plane sides, but have well-rounded corners and edges.
Rounded	Particles have smoothly curved sides and no edges.

Table (3a). Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen ball crumbles into powder with the slightest handling pressure.
Low	The dry specimen crumbles into powder with some pressure form fingers.
Medium	The dry specimen breaks into pieces or crumbles with moderate finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between the thumb and a hard surface.

Table (3b). Criteria for Describing Dilatancy of a Soil Sample

Description	Criteria
None	There is no visible change in the soil samples.
Slow	Water slowly appears and remains on the surface during shaking or water slowly disappears upon squeezing.
Rapid	Water quickly appears on the surface during shaking and quickly disappears upon squeezing.

Table (3c). Criteria for Describing Soil Plasticity

Description	Criteria
Non-plastic	A 1/8” (3-mm) thread cannot be rolled at any water content.
Low	The thread is difficult to roll and a cohesive mass cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and little time is needed to reach the plastic limit. The thread cannot be re-rolled after the plastic limit is reached. The mass crumbles when it is drier than the plastic limit.
High	Considerable time is needed, rolling and kneading the sample, to reach the plastic limit. The thread can be rerolled and reworked several times before reaching the plastic limit. A mass can be formed when the sample is drier than the plastic limit

Note: The plastic limit is the water content at which the soil begins to break apart and crumbles when rolled into threads 1/8” in diameter.

Table (3d). Criteria for Describing Soil Toughness

Description	Criteria
Low	Only slight pressure is needed to roll the thread to the plastic limit. The thread and mass are weak and soft.
Medium	Moderate pressure is needed to roll the thread to near the plastic limit. The thread and mass have moderate stiffness.
High	Substantial pressure is needed to roll the thread to near the plastic limit. The thread and mass are very stiff.

Table 4. Identification of Inorganic Fine-Grained Soils

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None or Low	Slow to Rapid	Low or thread cannot be formed
CL	Medium to High	None to Slow	Medium
MH	Low to Medium	None to Slow	Low to Medium
CH	High to Very High	None	High

Note: ML = Silt; CL = Lean Clay (low plasticity clay); MH = Elastic Soil; CH = Fat Clay (high plasticity clay). The terms 'lean' and 'fat' may not be used in certain geographic regions (midwest).

Table 5. Criteria for Describing Soil Moisture Conditions

Description	Criteria
Dry	Soil is dry to the touch, dusty, a clear absence of moisture
Moist	Soil is damp, slight moisture; soil may begin to retain molded form
Wet	Soil is clearly wet; water is visible when sample is squeezed
Saturated	Water is easily visible and drains freely from the sample

EXAMPLE DATA

VISUAL SOIL CLASSIFICATION
DATA SHEET

Soil Number: Soil A
Classified by: RES
Date: 09-29-02

1. Color brown
2. Odor none
3. Texture coarse
4. Major soil constituent : gravel
5. Minor soil constituents: sand, fines

Type	Approx. % by weight
gravel	60
sand	30
fines	10

6. For coarse-grained soils:

   Gradation: well graded
   Particle Shape: subrounded

7. For fine-grained soils:
   Dry Strength ______
   Dilatancy ______
   Plasticity ______
   Toughness ______
   Soil Symbol ______

8. Moisture Condition: dry

Classification:

Brown gravel, some sand, trace fines, well graded, subrounded, dry

VISUAL SOIL CLASSIFICATION
DATA SHEET

Soil Number: Soil B
Classified by: RES
Date: 09-27-02

1. Color gray
2. Odor none
3. Texture coarse
4. Major soil constituent: sand
5. Minor soil constituents: gravel, fines

Type	Approx. % by weight
sand	80
fine gravel	15
fines	5

6. For coarse-grained soils:

   Gradation: poorly graded
   Particle Shape: rounded

7. For fine-grained soils:
   Dry Strength ___________
   Dilatancy ___________
   Plasticity ___________
   Toughness ___________
   Soil Symbol ___________

8. Moisture Condition: dry

Classification:

Gray sand, little fine gravel, trace fines, poorly graded, rounded, dry

VISUAL SOIL CLASSIFICATION
DATA SHEET

Soil Number: Soil C
Classified by: RES
Date: 09-29-02

1. Color gray
2. Odor none
3. Texture fine-grained
4. Major soil constituent : fines
5. Minor soil constituents: Fine Sand

Type	Approx. % by weight
Fines	95
Fine Sand	5

6. For coarse-grained soils:

   Gradation: ____________
   Particle Shape: ____________

7. For fine-grained soils:
   - Dry strength high
   - Dilatancy none
   - Plasticity medium
   - Toughness medium
   - Soil Symbol CL

8. Moisture Condition: moist

Classification:

Gray silty clay, trace fine sand, medium plasticity, moist, CL

BLANK DATA SHEETS

VISUAL SOIL CLASSIFICATION
DATA SHEET

Soil Number: ________________
Classified by: _________________
Date: _________________

1. Color __________________
2. Odor __________________
3. Texture ___________________
4. Major soil constituent: ____________
5. Minor soil constituents: ___________

Type	Approx. % by weight
__________	________
__________	________
_________	_________

6. For coarse-grained soils:

   Gradation: ____________
   Particle Shape: ____________

7. For fine-grained soils:
   - Dry Strength ___________
   - Dilatancy ___________
   - Plasticity ___________
   - Toughness ___________
   - Soil Symbol ___________

8. Moisture Condition: _____________

Classification:

EXPERIMENT 9

MOISTURE-DENSITY RELATION (COMPACTION) TEST

Purpose:

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory will employ the tamping or impact compaction method using the type of equipment and methodology developed by R. R. Proctor in 1933, therefore, the test is also known as the Proctor test.

Two types of compaction tests are routinely performed: (1) The Standard Proctor Test, and (2) The Modified Proctor Test. Each of these tests can be performed in three different methods as outlined in the attached Table 1. In the Standard Proctor Test, the soil is compacted by a 5.5 lb hammer falling a distance of one foot into a soil filled mold. The mold is filled with three equal layers of soil, and each layer is subjected to 25 drops of the hammer. The Modified Proctor Test is identical to the Standard Proctor Test except it employs, a 10 lb hammer falling a distance of 18 inches, and uses five equal layers of soil instead of three. There are two types of compaction molds used for testing. The smaller type is 4 inches in diameter and has a volume of about 1/30 ft^3 (944 cm^3), and the larger type is 6 inches in diameter and has a volume of about 1/13.333 ft^3 (2123 cm^3). If the larger mold is used each soil layer must receive 56 blows instead of 25 (See Table 1).

Table 1 Alternative Proctor Test Methods

	Standard Proctor ASTM 698			Modified Proctor ASTM 1557		
	Method A	Method B	Method C	Method A	Method B	Method C
Material	≤20% Retained on No.4 Sieve	>20% Retained on No.4 ≤20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve	≤20% Retained on No.4 Sieve	>20% Retained on No.4 ≤20% Retained on 3/8" Sieve	>20% Retained on No.3/8" <30% Retained on 3/4" Sieve
For test sample, use soil passing	Sieve No.4	3/8" Sieve	¾" Sieve	Sieve No.4	3/8" Sieve	¾" Sieve
Mold	4" DIA	4" DIA	6" DIA	4" DIA	4" DIA	6" DIA
No. of Layers	3	3	3	5	5	5
No. of blows/layer	25	25	56	25	25	56

Note: Volume of 4" diameter mold = 944 cm^3 , Volume of 6" diameter mold = 2123 cm^3
(verify these values prior to testing)

Standard Reference:

ASTM D 698 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbs/ft^3 (600 KN-m/m^3))

ASTM D 1557 - Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbs/ft^3 (2,700 KN-m/m^3))

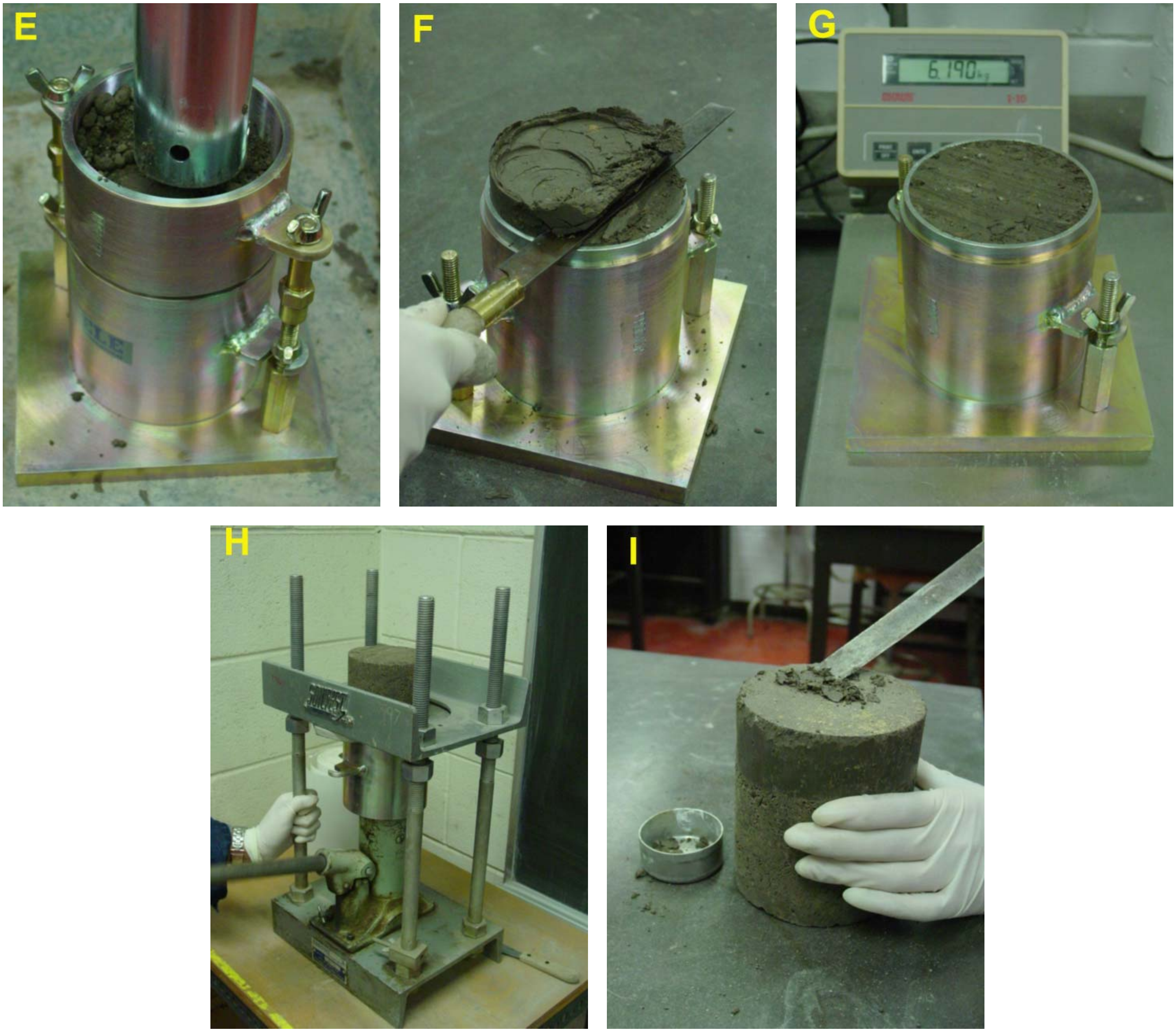
Significance:

Mechanical compaction is one of the most common and cost effective means of stabilizing soils. An extremely important task of geotechnical engineers is the performance and analysis of field control tests to assure that compacted fills are meeting the prescribed design specifications. Design specifications usually state the required density (as a percentage of the "maximum" density measured in a standard laboratory test), and the water content. In general, most engineering properties, such as the strength, stiffness, resistance to shrinkage, and imperviousness of the soil, will improve by increasing the soil density.

The optimum water content is the water content that results in the greatest density for a specified compactive effort. Compacting at water contents higher than (wet of) the optimum water content results in a relatively dispersed soil structure (parallel particle orientations) that is weaker, more ductile, less pervious, softer, more susceptible to shrinking, and less susceptible to swelling than soil compacted dry of optimum to the same density. The soil compacted lower than (dry of) the optimum water content typically results in a flocculated soil structure (random particle orientations) that has the opposite characteristics of the soil compacted wet of the optimum water content to the same density.

Equipment:

Molds, Manual rammer, Extruder, Balance, Drying oven, Mixing pan, Trowel, #4 sieve, Moisture cans, Graduated cylinder, Straight Edge.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Test Procedure:

(1) Depending on the type of mold you are using obtain a sufficient quantity of air-dried soil in large mixing pan. For the 4-inch mold take approximately 10 lbs, and for the 6-inch mold take roughly 15 lbs. Pulverize the soil and run it through the # 4 sieve.

(2) Determine the weight of the soil sample as well as the weight of the compaction mold with its base (without the collar) by using the balance and record the weights.

(3) Compute the amount of initial water to add by the following method:

(a) Assume water content for the first test to be 8 percent.

(b) Compute water to add from the following equation:

$$\text{water to add (in ml)} = \frac{(\text{soil mass in grams})8}{100}$$

Where "water to add" and the "soil mass" are in grams. Remember that a gram of water is equal to approximately one milliliter of water.

(4) Measure out the water, add it to the soil, and then mix it thoroughly into the soil using the trowel until the soil gets a uniform color (See Photos B and C).

(5) Assemble the compaction mold to the base, place some soil in the mold and compact the soil in the number of equal layers specified by the type of compaction method employed (See Photos D and E). The number of drops of the rammer per layer is also dependent upon the type of mold used (See Table 1). The drops should be applied at a uniform rate not exceeding around 1.5 seconds per

drop, and the rammer should provide uniform coverage of the specimen surface. Try to avoid rebound of the rammer from the top of the guide sleeve.

(6) The soil should completely fill the cylinder and the last compacted layer must extend slightly above the collar joint. If the soil is below the collar joint at the completion of the drops, the test point must be repeated. (Note: For the last layer, watch carefully, and add more soil after about 10 drops if it appears that the soil will be compacted below the collar joint.)

(7) Carefully remove the collar and trim off the compacted soil so that it is completely even with the top of the mold using the trowel. Replace small bits of soil that may fall out during the trimming process (See Photo F).

(8) Weigh the compacted soil while it's in the mold and to the base, and record the mass (See Photo G). Determine the wet mass of the soil by subtracting the weight of the mold and base.

(9) Remove the soil from the mold using a mechanical extruder (See Photo H) and take soil moisture content samples from the top and bottom of the specimen (See Photo I). Fill the moisture cans with soil and determine the water content.

(10) Place the soil specimen in the large tray and break up the soil until it appears visually as if it will pass through the # 4 sieve, add 2 percent more water based on the original sample mass, and re-mix as in step 4. Repeat steps 5 through 9 until, based on wet mass, a peak

value is reached followed by two slightly lesser compacted soil masses.

Analysis:

(1) Calculate the moisture content of each compacted soil specimen by using the average of the two water contents.

(2) Compute the wet density in grams per cm^3 of the compacted soil sample by dividing the wet mass by the volume of the mold used.

(3) Compute the dry density using the wet density and the water content determined in step 1. Use the following formula:

$$\rho_d = \frac{\rho}{1+w}$$

where: w = moisture content in percent divided by 100, and ρ = wet density in grams per cm^3.

(4) Plot the dry density values on the y-axis and the moisture contents on the x-axis. Draw a smooth curve connecting the plotted points.

(5) On the same graph draw a curve of complete saturation or "zero air voids curve". The values of dry density and corresponding moisture contents for plotting the curve can be computed from the following equation:

$$w_{sat} = \left(\frac{\rho_w}{\rho_d} - \frac{1}{G_s} \right) \times 100$$

or

$$\rho_d = \frac{\rho_w}{\left(\frac{w}{100} + \frac{1}{Gs} \right)}$$

where:

ρ_d = dry density of soil grams per cm^3

G_s = specific gravity of the soil being tested (assume 2.70 if not given)

ρ_w = density of water in grams per cm^3 (approximately1 g/cm^3)

w_{sat} = moisture content in percent for complete saturation.

Example Calculations:

G_s=2.7 (assumed)

ρ_w=1.0 g/cm^3

Assumed w_{sat}%	Calculated ρ_d (g/cm^3)
8	2.22
10	2.13
12	2.04
14	1.96
16	1.89
18	1.82

(6) Identify and report the optimum moisture content and the maximum dry density. Make sure that you have recorded the method of compaction used (e.g., Standard Proctor, Method A) on data sheet.

EXAMPLE DATA

Moisture-Density (Compaction) Test

Data Sheets

Test Method: Standard Proctor, Method A (ASTM 698)

Date Tested: October 05, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: Bag-1, 2'-6'

Visual Classification of Soil: Gray silty clay, trace fine sand, low plasticity, moist, CL

Water Content Determination:

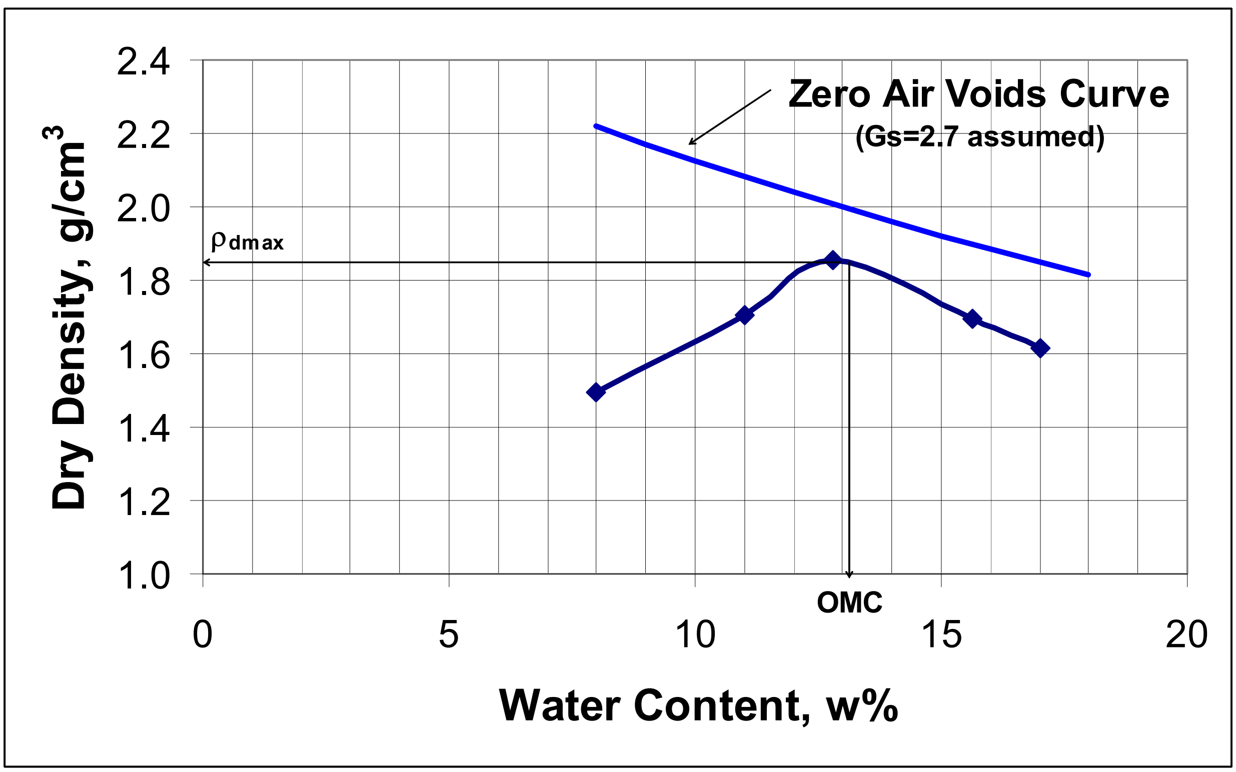
Compacted Soil - Sample no.	1		2		3	
Water content - Sample no.	1A	1B	2A	2B	3A	3B
Moisture can number - Lid number	1	2	3	4	5	6
M_C = Mass of empty, clean can + lid (grams)	7.78	7.83	7.71	7.9	7.5	7.9
M_{CMS} = Mass of can, lid, and moist soil (grams)	11.78	11.05	10.71	11 . 1	10.7	12 .0
M_{CDS} = Mass of can, lid, and dry soil (grams)	11.48	10.81	10.41	10.75	10.3	11.52
M_S = Mass of soil solids (grams)	3.70	2.98	2.7	2.85	2.84	3.62
M_W = Mass of pore water (grams)	0.29	0.24	0.30	0.35	0.40	0.53
w = Water content, w%	7.9	8.1	11 . 1	10.9	12.5	13.1

Compacted Soil - Sample no.	4		5		6	
Water content - Sample no.	4A	4B	5A	5B	6A	6B
Moisture can number - Lid number	7	8	9	10		
M_C = Mass of empty, clean can + lid (grams)	8.1	7.6	7.7	7.65		
M_{CMS} = Mass of can, lid, and moist soil (grams)	11. 1	10.2	10.3	10.33		
M_{CDS} = Mass of can, lid, and dry soil (grams)	10.70	9.84	10.02	9.92		
M_S = Mass of soil solids (grams)	2.60	2.24	2.32	2.27		
M_W = Mass of pore water (grams)	0.40	0.35	0.4	0.39		
w = Water content, w%	15.3	16.0	17. 1	17.6		

Density Determination:

Mold Volume=944 cm^3

Compacted Soil - Sample no.	1	2	3	4	5	6
w = Assumed water content, w%	10	12	14	16	18	
Actual average water content, w%	8.0	11.0	12.8	15.65	17	
Mass of compacted soil and mold (grams)	3457.2	3721.2	3909.0	3782.5	3715.2	
Mass of mold (grams)	1933	1933	1976.0	1849.5	1782.2	
Wet mass of soil in mold (grams)	1524.2	1788.2	2176	2149	2082	
Wet density, ρ , (g/cm^3)	1.615	1.894	2.093	1.959	1.888	
Dry density, ρ_d , (g/cm^3)	1.50	1.71	1.86	1.69	1.61	



Optimum Moisture Content = 13.1 %

Maximum Dry Density = 1.87 g/cm^3

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Moisture-Density (Compaction) Test

Data Sheets

Test Method:

Date Tested:

Tested By:

Project Name:

Sample Number:

Visual Classification of Soil:

Water Content Determination:

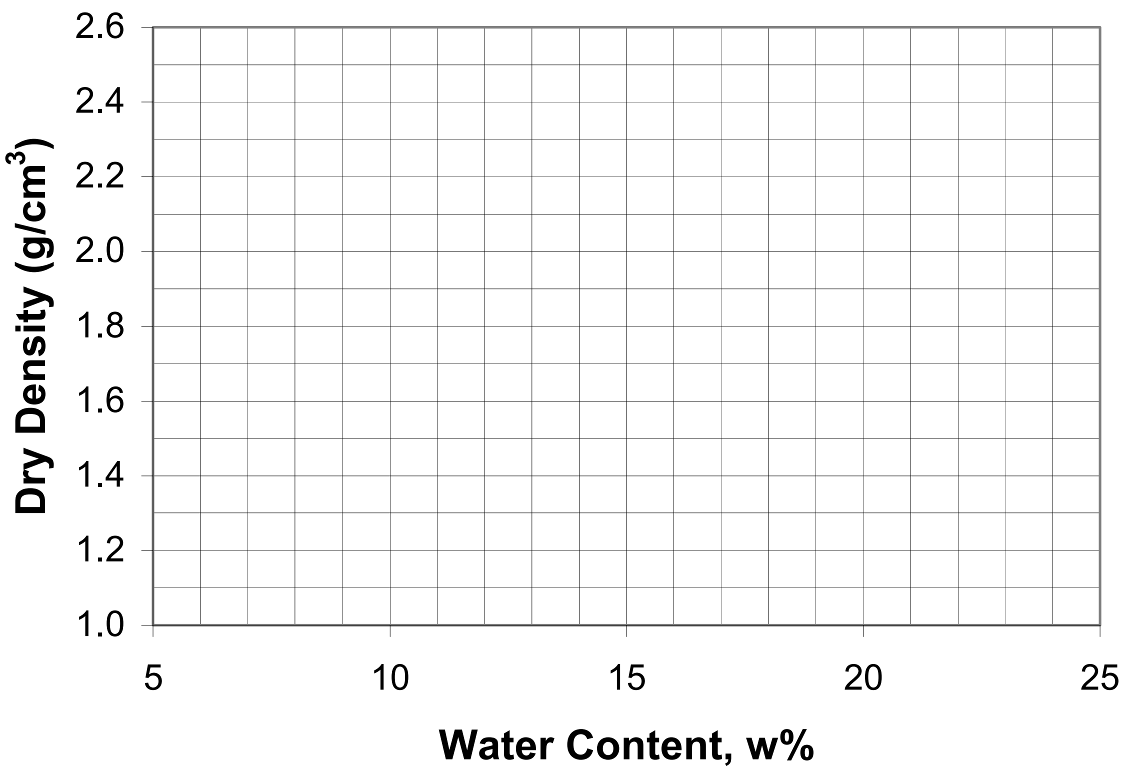
Compacted Soil - Sample no.	1		2		3	
Water content - Sample no.	1A	1B	2A	2B	3A	3B
Moisture can number - Lid number						
M_C = Mass of empty, clean can + lid (grams)						
M_{CMS} = Mass of can, lid, and moist soil (grams)						
M_{CDS} = Mass of can, lid, and dry soil (grams)						
M_S = Mass of soil solids (grams)						
M_W = Mass of pore water (grams)						
W = Water content, w%						

Compacted Soil - Sample no.	4		5		6	
Water content - Sample no.	4A	4B	5A	5B	6A	6B
Moisture can number - Lid number						
M_C = Mass of empty, clean can + lid (grams)						
M_{CMS} = Mass of can, lid, and moist soil (grams)						
M_{CDS} = Mass of can, lid, and dry soil (grams)						
M_S = Mass of soil solids (grams)						
M_W = Mass of pore water (grams)						
W = Water content, w%						

Density Determination:

Volume of mold=

Compacted Soil - Sample no.	1	2	3	4	5	6
w = Assumed water content, w%						
Actual average water content, w%						
Mass of compacted soil and mold (grams)						
Mass of mold (grams)						
Wet mass of soil in mold (grams)						
Wet density, ρ , (kg/m^3)						
Dry density, ρ_d , (kg/m^3)						



Optimum Moisture Content = _________________ %

Maximum Dry Density = ___________________ g/cm^3

EXPERIMENT 10

PERMEABILITY (HYDRAULIC CONDUCTIVITY) TEST

CONSTANT HEAD METHOD

Purpose:

The purpose of this test is to determine the permeability (hydraulic conductivity) of a sandy soil by the constant head test method. There are two general types of permeability test methods that are routinely performed in the laboratory: (1) the constant head test method, and (2) the falling head test method. The constant head test method is used for permeable soils ($k>10^{-4}$ cm/s) and the falling head test is mainly used for less permeable soils ($k<10^{-4}$ cm/s).

Standard Reference:

ASTM D 2434 - Standard Test Method for Permeability of Granular Soils (Constant Head) (Note: The Falling Head Test Method is not standardized)

Significance:

Permeability (or hydraulic conductivity) refers to the ease with which water can flow through a soil. This property is necessary for the calculation of seepage through earth dams or under sheet pile walls, the calculation of the seepage rate from waste storage facilities (landfills, ponds, etc.), and the calculation of the rate of settlement of clayey soil deposits.

Equipment:

Permeameter, Tamper, Balance, Scoop, 1000 mL Graduated cylinders, Watch (or Stopwatch), Thermometer, Filter paper.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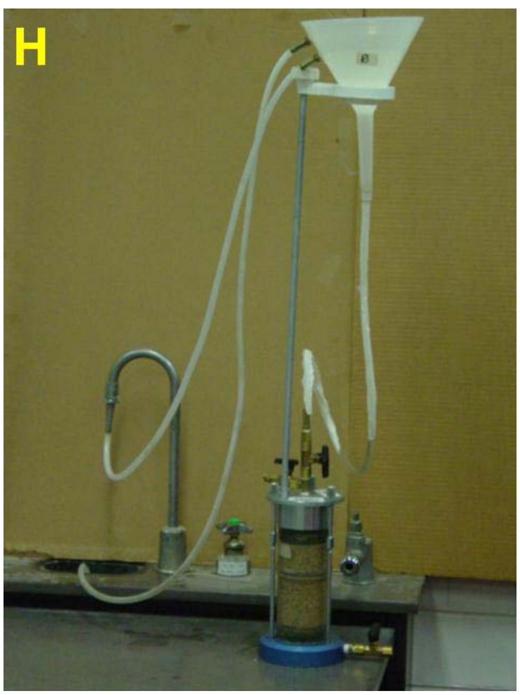
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Test Procedure:

(1) Measure the initial mass of the pan along with the dry soil (M_1).

(2) Remove the cap and upper chamber of the permeameter by unscrewing the knurled cap nuts and lifting them off the tie rods. Measure the inside diameter of upper and lower chambers. Calculate the average inside diameter of the permeameter (D).

(3) Place one porous stone on the inner support ring in the base of the chamber then place a filter paper on top of the porous stone (see Photo C).

(4) Mix the soil with a sufficient quantity of distilled water to prevent the segregation of particle sizes during placement into the permeameter. Enough water should be added so that the mixture may flow freely (see Photo B).

(5) Using a scoop, pour the prepared soil into the lower chamber using a circular motion to fill it to a depth of 1.5 cm. A uniform layer should be formed.

(6) Use the tamping device to compact the layer of soil. Use approximately ten rams of the tamper per layer and provide uniform coverage of the soil surface. Repeat the compaction procedure until the soil is within 2 cm. of the top of the lower chamber section (see Photo D).

(7) Replace the upper chamber section, and don't forget the rubber gasket that goes between the chamber sections. Be careful not to disturb the soil that has already been compacted. Continue the placement operation until the level of the soil is about 2 cm. below the rim of the upper chamber. Level the top surface of the soil and place a filter paper and then the upper porous stone on it (see Photo E).

(8) Place the compression spring on the porous stone and replace the chamber cap and its sealing gasket. Secure the cap firmly with the cap nuts (see Photo F).

(9) Measure the sample length at four locations around the circumference of the permeameter and compute the average length. Record it as the sample length.

(10) Keep the pan with remaining soil in the drying oven.

(11) Adjust the level of the funnel to allow the constant water level in it to remain a few inches above the top of the soil.

(12) Connect the flexible tube from the tail of the funnel to the bottom outlet of the permeameter and keep the valves on the top of the permeameter open (see Photo G).

(13) Place tubing from the top outlet to the sink to collect any water that may come out (see Photo G).

(14) Open the bottom valve and allow the water to flow into the permeameter.

(15) As soon as the water begins to flow out of the top control (deairing) valve, close the control valve, letting water flow out of the outlet for some time.

(16) Close the bottom outlet valve and disconnect the tubing at the bottom. Connect the funnel tubing to the top side port (see Photo H).

(17) Open the bottom outlet valve and raise the funnel to a convenient height to get a reasonable steady flow of water.

(18) Allow adequate time for the flow pattern to stabilize (see Photo I).

(19) Measure the time it takes to fill a volume of 750 - 1000 mL using the graduated cylinder, and then measure the temperature of the water. Repeat this process three times and compute the average time, average volume, and average temperature. Record the values as t, Q, and T, respectively (see Photo I).

(20) Measure the vertical distance between the funnel head level and the chamber outflow level, and record the distance as h.

(21) Repeat step 17 and 18 with different vertical distances.

(22) Remove the pan from the drying oven and measure the final mass of the pan along with the dry soil (M_2).

Analysis:

(1) Calculate the permeability, using the following equation:

$$K_T = \frac{QL}{Ath}$$

Where:

K_T = coefficient of permeability at temperature T, cm/sec.

L = length of specimen in centimeters

t = time for discharge in seconds

Q = volume of discharge in cm^3 (assume 1 mL = 1 cm^3)

A = cross-sectional area of permeameter (= $\frac{\pi}{4}D^2$, D= inside diameter of the permeameter)

h = hydraulic head difference across length L, in cm of water; or it is equal to the vertical distance between the constant funnel head level and the chamber overflow level.

(2) The viscosity of the water changes with temperature. As temperature increases viscosity decreases and the permeability increases. The coefficient of permeability is standardized at 20°C, and the permeability at any temperature T is related to K_{20} by the following ratio:

$$K_{20} = K_T \frac{\eta_T}{\eta_{20}}$$

Where:

η_T and η_{20} are the viscosities at the temperature T of the test and at 20°C, respectively. From Table 1 obtain the viscosities and compute K_{20}.

(3) Compute the volume of soil used from: $V = LA$.

(4) Compute the mass of dry soil used in permeameter (M) = initial mass - final mass:

$$M = M_1 - M_2$$

(5) Compute the dry density (ρ_d) of soil

$$\rho_d = \frac{M}{V}$$

Table 1. Properties of Distilled Water (η = absolute)

Temperature $^{\circ}C$	Density (g/cm^3)	Viscosity (Poise*)
4	1.00000	0.01567
16	0.99897	0.01111
17	0.99880	0.01083
18	0.99862	0.01056
19	0.99844	0.01030
20	0.99823	0.01005
21	0.99802	0.00981
22	0.99780	0.00958
23	0.99757	0.00936
24	0.99733	0.00914
25	0.99708	0.00894
26	0.99682	0.00874
27	0.99655	0.00855
28	0.99627	0.00836
29	0. 99598	0.00818
30	0. 99568	0.00801

$$\text{*Poise} = \frac{\text{dyne} \cdot \text{s}}{\text{cm}^2} = \frac{\text{g}}{\text{cm} \cdot \text{s}}$$

EXAMPLE DATA

HYDRAULIC CONDUCTIVITY TEST
CONSTANT HEAD METHOD
DATA SHEET

Date Tested: October 10, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: B-1, ST-10, 8'-10'

Visual Classification: Brown medium to fine sand, poorly graded, subrounded, dry.

Initial Dry Mass of Soil + Pan (M_1) = 1675.0 g
Length of Soil Specimen, L = 17 cm
Diameter of the Soil Specimen (Permeameter), D = 6.4 cm
Final Dry Mass of Soil + Pan (M_2) = 865.6 g
Dry Mass of Soil Specimen (M) = 809.4 g
Volume of Soil Specimen (V) = 846.9 cm^3
Dry Density of Soil (ρ_d) = 1.48 g/cm^3

Trial Number	Constant Head, h (cm)	Elapsed Time, t (seconds)	Outflow Volume, Q (cm^3)	Water Temp., T (°C)	K_T cm/sec	K_{20} cm/sec
1	30	84	750	22	0.157	0.149
2	50	55	750	22	0.144	0.137
3	60	48	750	22	0.137	0.130
4	70	38	750	22	0.149	0.142

Average K_{20}= 0.139 cm/sec

BLANK DATA SHEETS

HYDRAULIC CONDUCTIVITY TEST
CONSTANT HEAD METHOD
DATA SHEET

Date Tested:
Tested By:
Project Name:
Sample Number:
Visual Classification:

Initial Dry Mass of Soil + Pan (M_1) = ___________________ g
Length of Soil Specimen, L = __________________ cm
Diameter of the Soil Specimen (Permeameter), D = ______________ cm
Final Dry Mass of Soil + Pan (M_2) = __________________ g
Dry Mass of Soil Specimen (M) = ______________________ g
Volume of Soil Specimen (V) = ____________________ cm^3
Dry Density of Soil (ρ_d) = ___________________ g/cm^3

Trial Number	Constant Head, h (cm)	Elapsed Time, t (seconds)	Outflow Volume, Q (cm^3)	Water Temp., T (°C)	K_T	K_{20}
1						
2						
3						
4						

Average K_{20}= _______________________ cm/sec

EXPERIMENT 11

CONSOLIDATION TEST

Purpose:

This test is performed to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the preconsolidation pressure (or maximum past pressure) of the soi. In addition, the data obtained can also be used to determine the coefficient of consolidation and the coefficient of secondary compression of the soil.

Standard Reference:

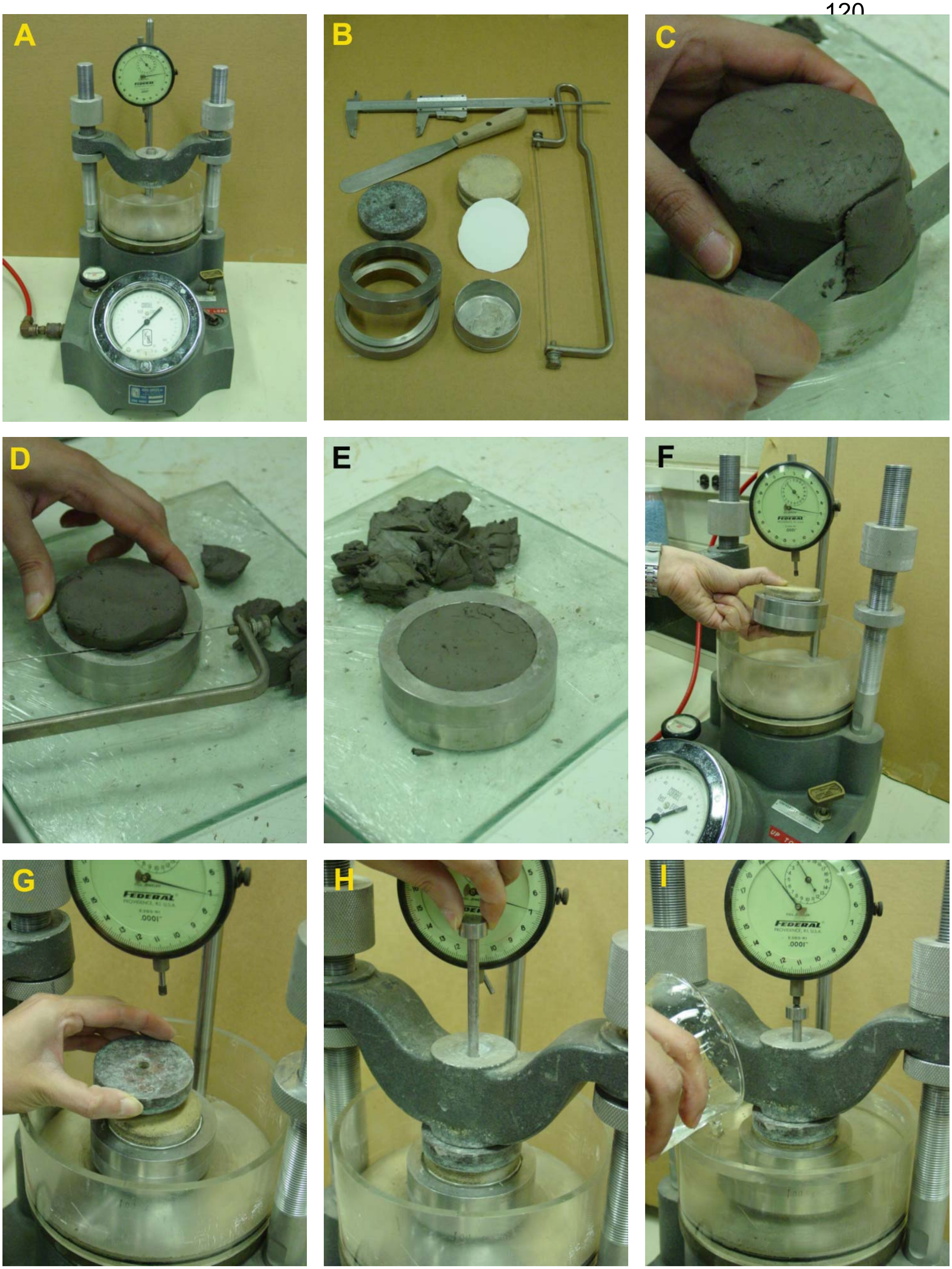
ASTM D 2435 - Standard Test Method for One-Dimensional Consolidation Properties of Soils.

Significance:

The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earthfill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

Equipment:

Consolidation device (including ring, porous stones, water reservoir, and load plate), Dial gauge (0.0001 inch = 1.0 on dial), Sample trimming device, glass plate, Metal straight edge, Clock, Moisture can, Filter paper.


A
B
C
D
E
F
G
H
I
FEDERAL

Test Procedure:

(1) Weigh the empty consolidation ring together with glass plate.

(2) Measure the height (h) of the ring and its inside diameter (d).

(3) Extrude the soil sample from the sampler, generally thin-walled Shelby tube. Determine the initial moisture content and the specific gravity of the soil as per Experiments 1 and 4, respectively (Use the data sheets from these experiments to record all of the data).

(4) Cut approximately a three-inch long sample. Place the sample on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring. Rotate the ring and pare off the excess soil by means of the cutting tool so that the sample is reduced to the same inside diameter of the ring. It is important to keep the cutting tool in the correct horizontal position during this process.

(5) As the trimming progresses, press the sample gently into the ring and continue until the sample protrudes a short distance through the bottom of the ring. Be careful throughout the trimming process to insure that there is no void space between the sample and the ring.

(6) Turn the ring over carefully and remove the portion of the soil protruding above the ring. Using the metal straight edge, cut the soil surface flush with the surface of the ring. Remove the final portion with extreme care.

(7) Place the previously weighed Saran-covered glass plate on the freshly cut surface, turn the ring over again, and carefully cut the other end in a similar manner.

(8) Weigh the specimen plus ring plus glass plate.

(9) Carefully remove the ring with specimen from the Saran-covered glass plate and peel the Saran from the specimen surface. Center the porous stones that have been soaking, on the top and bottom surfaces of the test specimen. Place the filter papers between porous stones and soil specimen. Press very lightly to make sure that the stones adhere to the sample. Lower the assembly carefully into the base of the water reservoir. Fill the water reservoir with water until the specimen is completely covered and saturated.

(10) Being careful to prevent movement of the ring and porous stones, place the load plate centrally on the upper porous stone and adjust the loading device.

(11) Adjust the dial gauge to a zero reading.

(12) With the toggle switch in the down (closed) position, set the pressure gauge dial (based on calibration curve) to result in an applied pressure of 0.5 tsf (tons per square foot).

(13) Simultaneously, open the valve (by quickly lifting the toggle switch to the up (open) position) and start the timing clock.

(14) Record the consolidation dial readings at the elapsed times given on the data sheet.

(15) Repeat Steps 11 to 13 for different preselected pressures (generally includes loading pressures of 1.0, 2.0, 4.0, 8.0, and 16.0 tsf and unloading pressures of 8.0, 4.0, 2.0, 1.0 and 0.5 tsf)

(16) At the last elapsed time reading, record the final consolidation dial reading and time, release the load, and quickly disassemble the consolidation device and remove the specimen. Quickly but carefully blot the surfaces dry with paper toweling. (The specimen will tend to absorb water after the load is released.)

(17) Place the specimen and ring on the Saran-covered glass plate and, once again, weigh them together.

(18) Weigh an empty large moisture can and lid.

(19) Carefully remove the specimen from the consolidation ring, being sure not to lose too much soil, and place the specimen in the previously weighed moisture can. Place the moisture can containing the specimen in the oven and let it dry for 12 to 18 hours.

(20) Weigh the dry specimen in the moisture can.

Analysis:

(1) Calculate the initial water content and specific gravity of the soil.

(2) For each pressure increment, construct a semilog plot of the consolidation dial readings versus the log time (in minutes). Determine D_0, D_{50}, D_{100}, and the coefficient of consolidation (c_v) using Casagrande's logarithm of time fitting method. See example data. Also calculate the coefficient of secondary compression based on these plots.

(3) Calculate the void ratio at the end of primary consolidation for each pressure increment (see example data). Plot log pressure versus void ratio. Based on this plot, calculate compression index, recompression index and preconsolidation pressure (maximum past pressure).

(4) Summarize and discuss the results.

EXAMPLE DATA

Consolidation Test

Data Sheets

Date Tested: October 05, 2002

Tested By: CEMM315 Class, Group A

Project Name: CEMM315 Lab

Sample Number: GB-08-ST-13'-15'

Visual Classification: Gray silty clay

Before test

Consolidation type	= Floating type
Mass of the ring + glass plate	= 465.9 g
Inside diameter of the ring	= 6.3 cm
Height of specimen, H_i	= 2.7 cm
Area of specimen, A	= 31.172 cm^2
Mass of specimen + ring	= 646.4 g
Initial moisture content of specimen, w_i (%)	= 19.5 %
Specific gravity of solids, G_s	= 2.67

After test

Mass of wet sample + ring + glass plate	= 636.5 g
Mass of can	= 59.3 g
Mass of can + wet soil	= 229.8 g
Mass of wet specimen	= 170.50 g
Mass of can + dry soil	= 208.5 g
Mass of dry specimen, M_s	= 149.2 g
Final moisture content of specimen, w_f	= 14.27 %

<u>Calculations</u>

Mass of solids in specimen, M_s =149.2 g
(Mass of dry specimen after test)

Mass of water in specimen before test, M_{wi} = w_i x M_s
= 0.195*149.2 = 29.094 g

Mass of water in specimen after test, M_{wf} (g) = w_f x M_s
= 0.1427*149.2 = 21.29 g

Height of solids, H_s = $\frac{M_s}{A \times G_s \times \rho_w} = \frac{149.2}{31.172 \times 2.67 \times 1}$ = 1.792 cm
(same before and after test and note ρ_w = 1 g/cm^3)

Height of water before test, H_{wi} = $\frac{M_{wi}}{A \times \rho_w} = \frac{29.09}{31.172 \times 1}$ = 0.933 cm

Height of water after test, H_{wf} = $\frac{M_{wf}}{A \times \rho_w} = \frac{21.29}{31.172 \times 1}$ = 0.683 cm

Change in height of specimen after test, $\Sigma\Delta H$ =0.257 cm
($\Sigma\Delta H$ for all pressures – see t vs Dial Reading plots)

Height of specimen after test, H_f = H_i - $\Sigma\Delta H$ = 2.7-0.257 = 2.443 cm

Void ratio before test, e_o = $\frac{H_i - H_s}{H_s} = \frac{2.7 - 1.792}{1.792}$ = 0.506

Void ratio after test, e_f = $\frac{H_f - H_s}{H_s} = \frac{2.443 - 1.792}{1.792}$ = 0.3617

Degree of saturation before test, S_i = $\frac{H_{wi}}{H_i - H_s} = \frac{0.933}{2.7 - 1.792} \times 100$
=102.7 %

Degree of saturation after test, $S_f = \frac{H_{wf}}{H_f - H_s} = \frac{0.683}{2.443 - 1.792} \times 100$

$= 105.08\%$

Dry density before test, $\rho_d = \frac{M_s}{H_i \times A} = \frac{149.2}{2.7 \times 31.172} = 1.77 \text{ g/cm}^3$

$= (110.6 \text{ pcf})$

Table 1: Time - Settlement Data (1 unit on dial guage = 0.0001 inches)

loading= ¼ tsf	
time	dail reading
0	0
0.1	0
0.25	0
0.5	0
1	
2	
4	
8	
15	
30	
60	
120	

loading=1/8 tsf	
time	dail reading
0	0
0.1	0
0.25	0
0.5	0
1	
2	
4	
8	
15	
30	
60	
120	

loading=1/2 tsf	
time	dail reading
0	0
0.1	13
0.25	18
0.5	25
1	34
2	40
4	54
8	77
15	90
30	126
60	144.5
130	160
300	162
1380	169

loading=1 tsf	
time	dail reading
0	0
0.1	6
0.25	8
0.5	11.5
1	15
2	20.5
4	27
10	42
15	46
31	58
60	79
121	81
240	85
562	86

loading=2 tsf	
time	dail reading
0	255
0.1	255.5
0.25	256
0.5	256.5
1	257
2	257.5
4	258
8	258.5
15	262.5
30	283
60	286
128	292.5
240	297
335	299
390	300
678	303
1380	303.5
1520	304

loading=4 tsf	
time	dail reading
0	313
0.06	319
0.15	328
0.3	336
1	357
2	375
4	398
8	428
15	453
30	464
60	472.5
120	479.5
290	486
395	488
1230	496

loading=2 tsf (unloading)	
time	dail reading
0	496
0.1	496
0.25	496
0.5	495.5
1	495
2	494
4	493.5
8	493
15	492.5
30	492.5
70	492.5
140	492.5
215	492.5

loading=1 tsf (unloading)	
time	dail reading
0	492.5
0.1	492.5
0.25	492.5
0.5	492
1	490.5
2	486.5
4	481.5
8	477.5
15	474.5
44	472.5
60	471.5
218	470.5

loading=1/2 tsf (unloading)	
time	dail reading
0	470.5
0.06	469.5
0.5	466
1	464.5
2	461.5
4	458.5
8	454
15	450.5
30	447
60	444.5
110	443.5
930	440.5

loading=1 tsf (reloading)	
time	dail reading
0	440.5
0.1	440.7
0.25	441
0.5	441.2
1	441.5
2	441.6
4	441.8
8	442
15	442.1
30	442.4
60	442.4
120	442.4

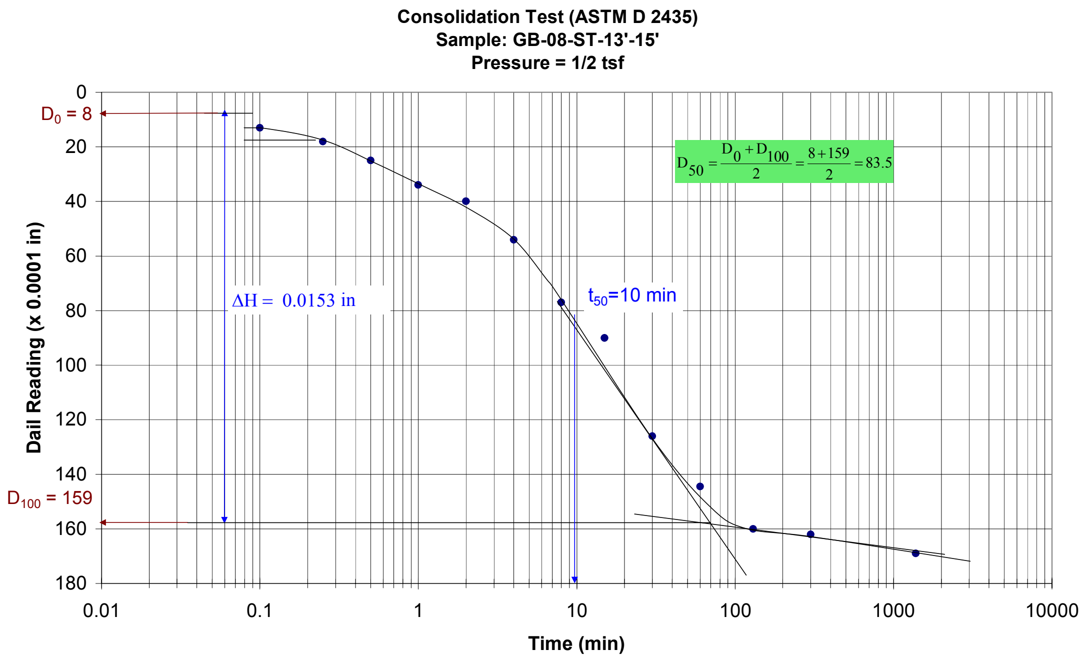
loading=2 tsf (reloading)	
time	dail reading
0	442.4
0.1	442.9
0.25	443.4
0.5	444.4
1	445.1
2	445.3
4	445.4
8	445.9
15	446.3
30	446.4
60	446.5
120	446.5

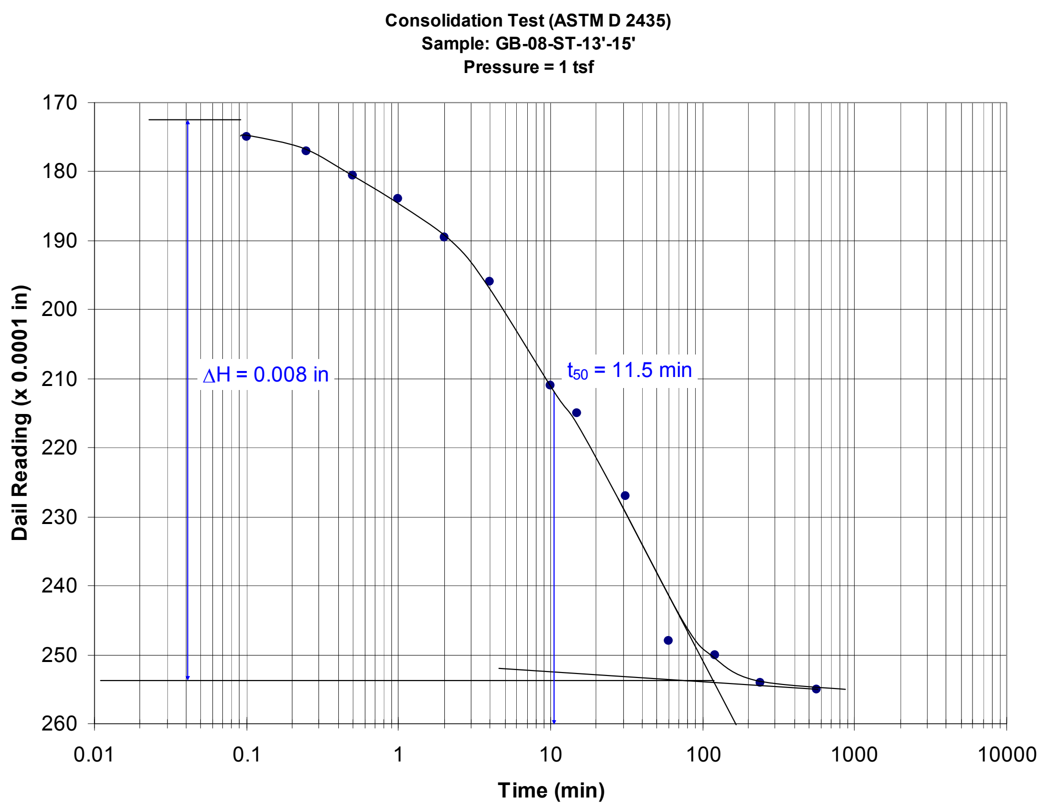
loading=4 tsf (reloading)	
time	dail reading
0	446.5
0.1	446.5
0.25	446.6
0.5	449.5
1	456.5
2	465.5
4	473.5
8	481
17	485.5
30	488
108	490.5
947	500

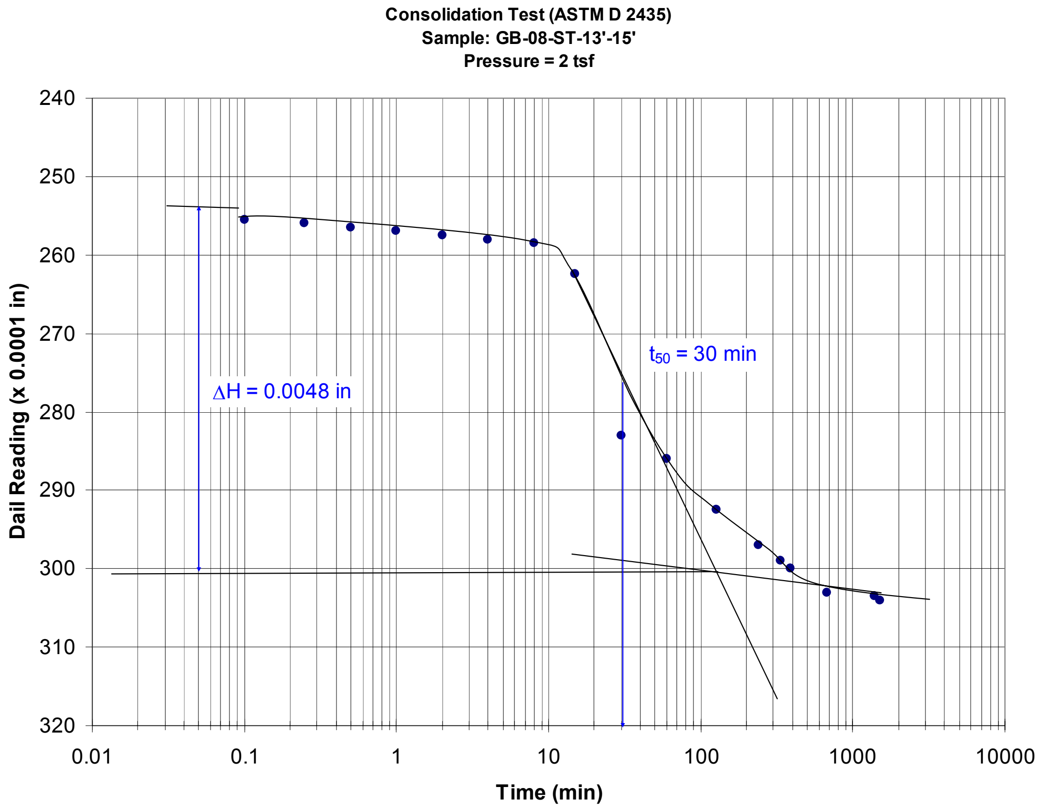
loading=8 tsf	
time	dail reading
0	500
0.1	510
0.25	518
0.5	528
1	542
2	561.5
4	580
8	604
15	619.5
30	631.8
60	640
127	642
205	651
228	652

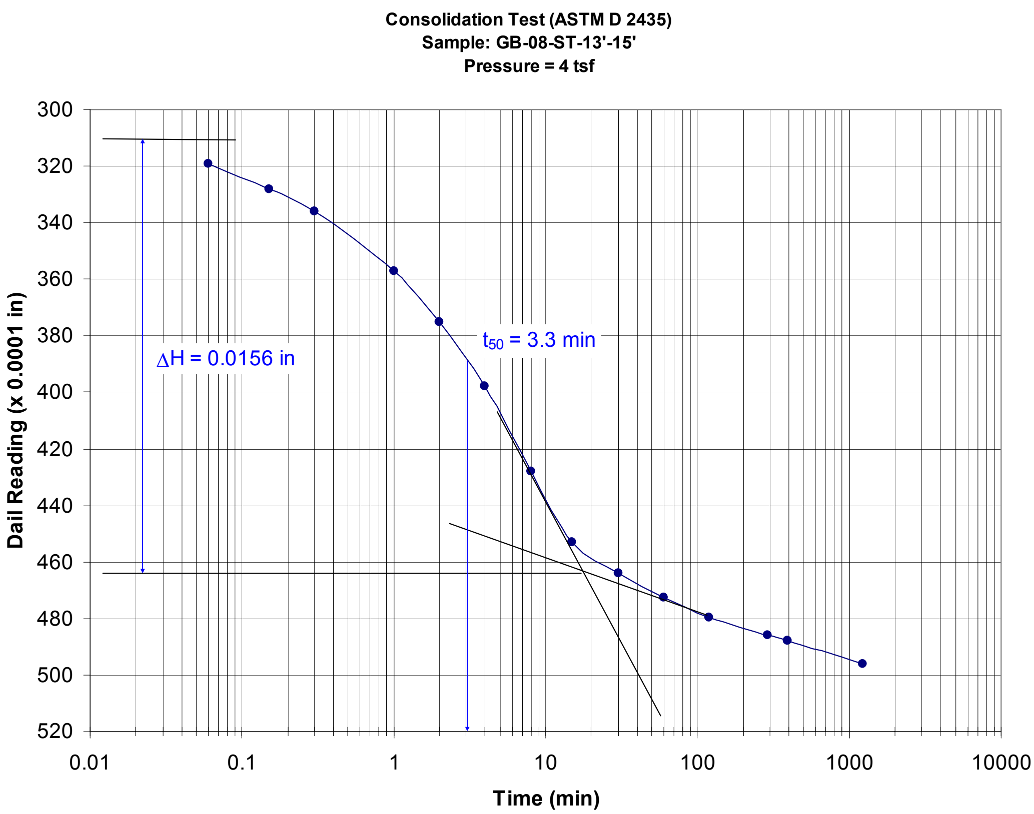
loading=16 tsf	
time	dail reading
0	652
0.1	672
0.25	687
0.5	702
1	727
2	754
4	800.5
8	816
15	836.5
30	850
60	860
115	867

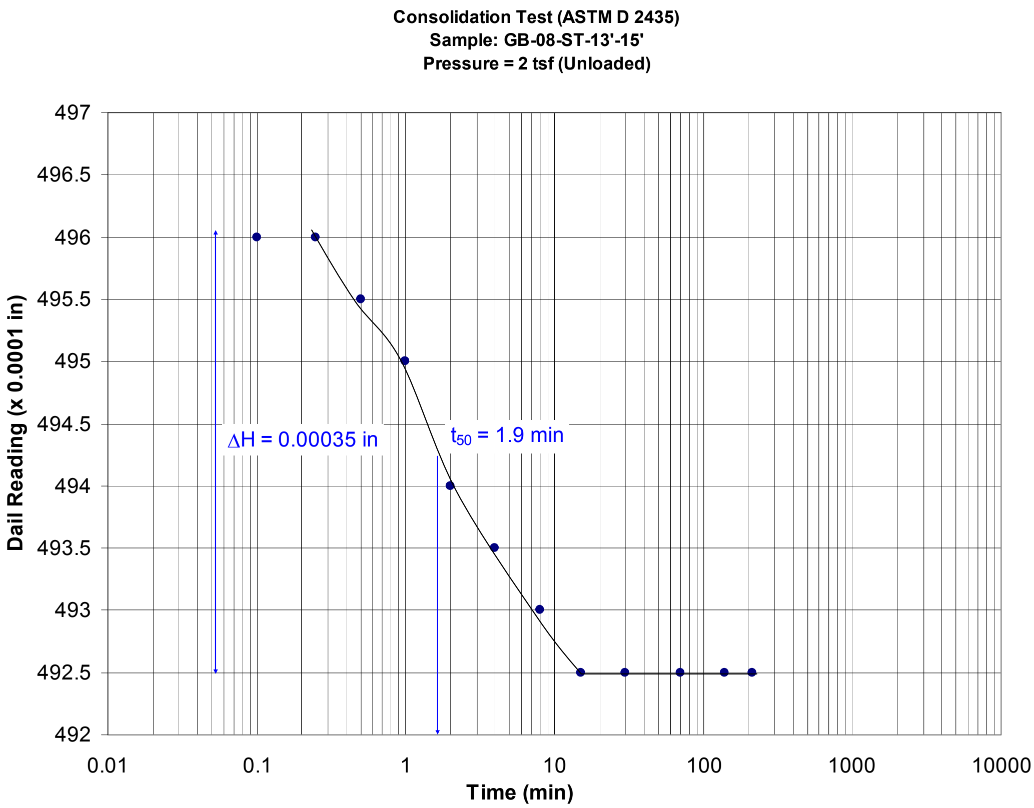
loading=32 tsf	
time	dail reading
0	867
0.1	877
0.25	893
0.5	908
1	928
2	953
4	983
8	1012
15	1027
30	1040
50	1047.5
76	1052.5
138	1060
240	1063


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1/2 tsf
D0 = 8
D100 = 159
D50 = (D0 + D100)/2 = (8+159)/2 = 83.5
ΔH = 0.0153 in
t50=10 min
Dail Reading (x 0.0001 in)
Time (min)

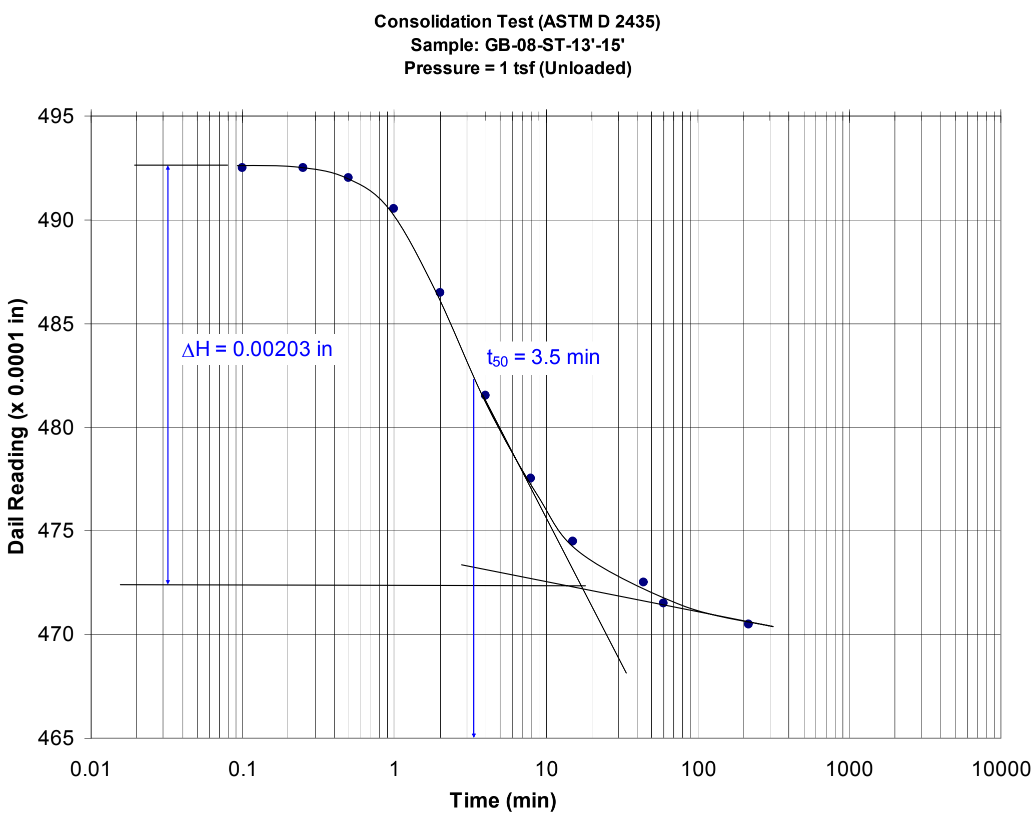

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf
ΔH = 0.008 in
t50 = 11.5 min
Dail Reading (x 0.0001 in)
Time (min)


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0048 in
t50 = 30 min
240
250
260
270
280
290
300
310
320
0.01
0.1
1
10
100
1000
10000

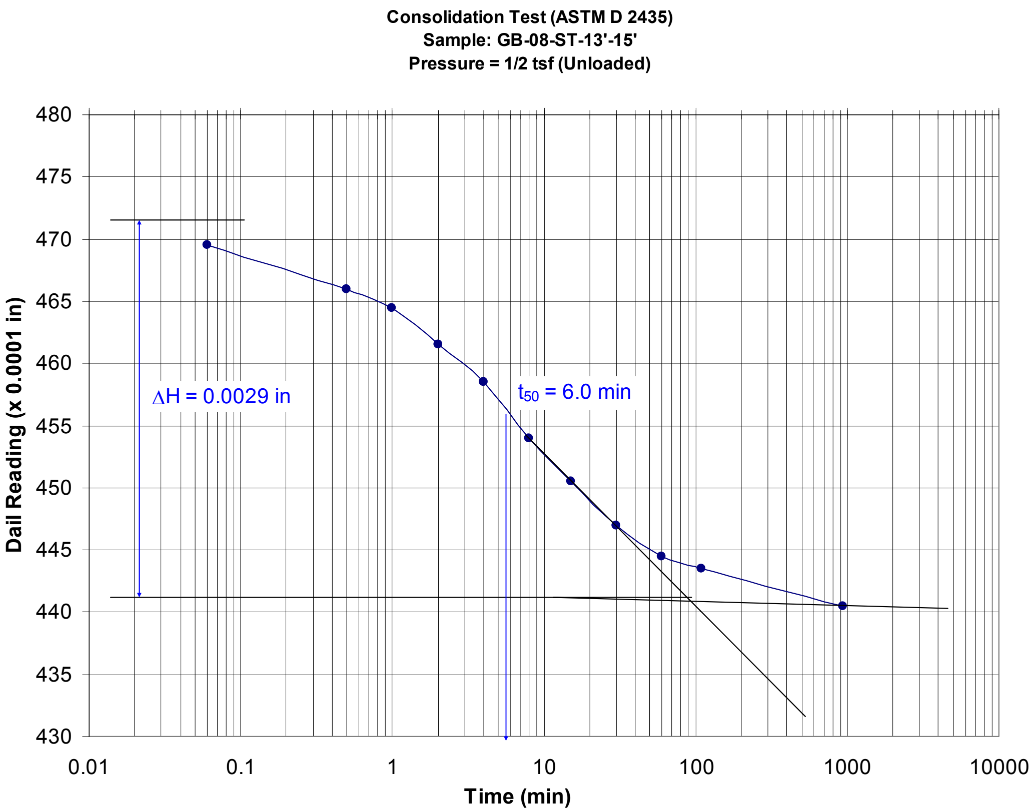

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 4 tsf
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0156 in
t50 = 3.3 min
300
320
340
360
380
400
420
440
460
480
500
520
0.01
0.1
1
10
100
1000
10000

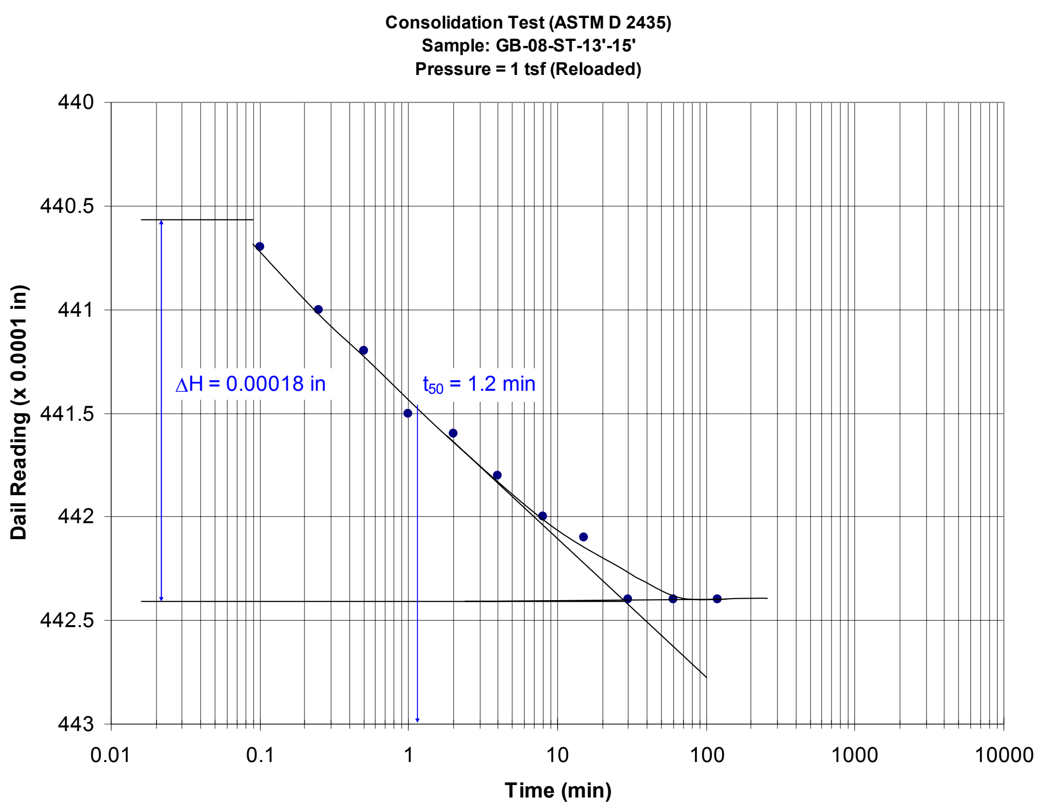


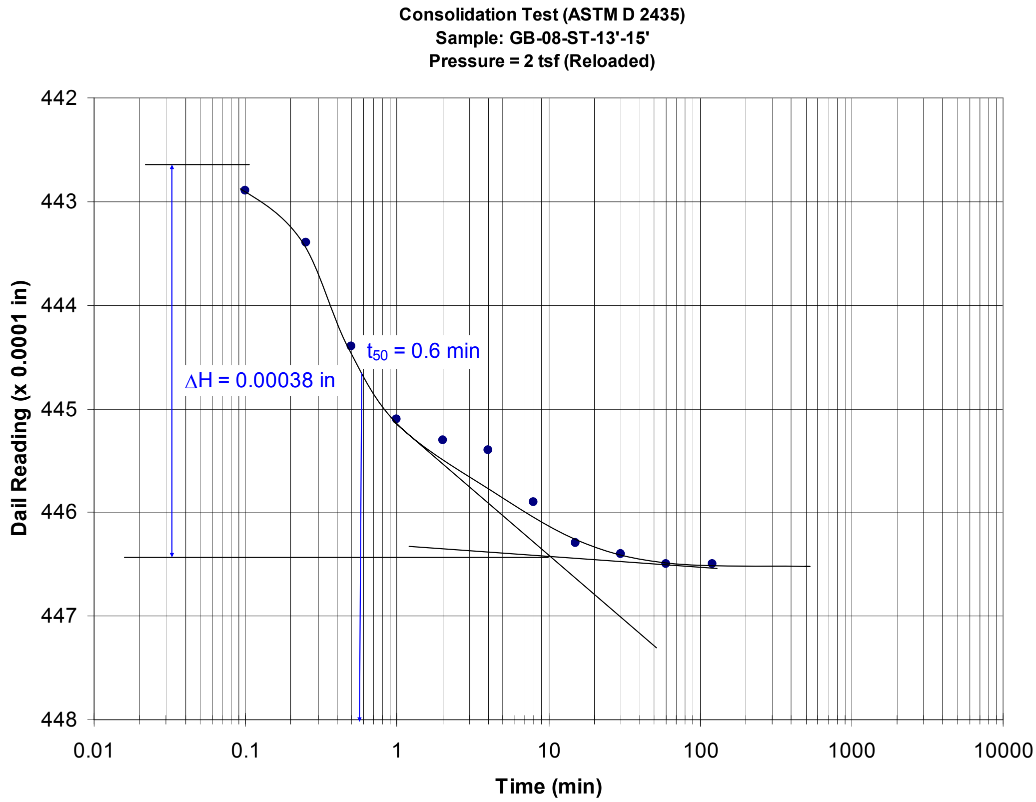
Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf (Unloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.00035 in
t50 = 1.9 min
497
496.5
496
495.5
495
494.5
494
493.5
493
492.5
492
0.01
0.1
1
10
100
1000
10000

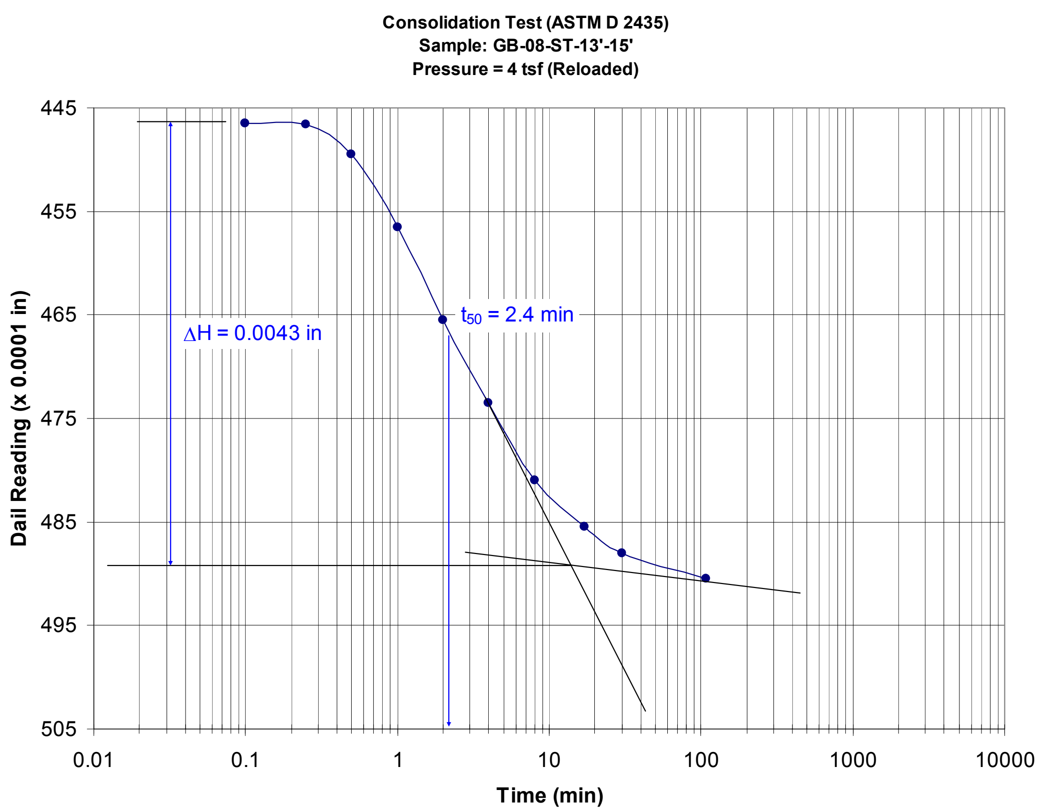


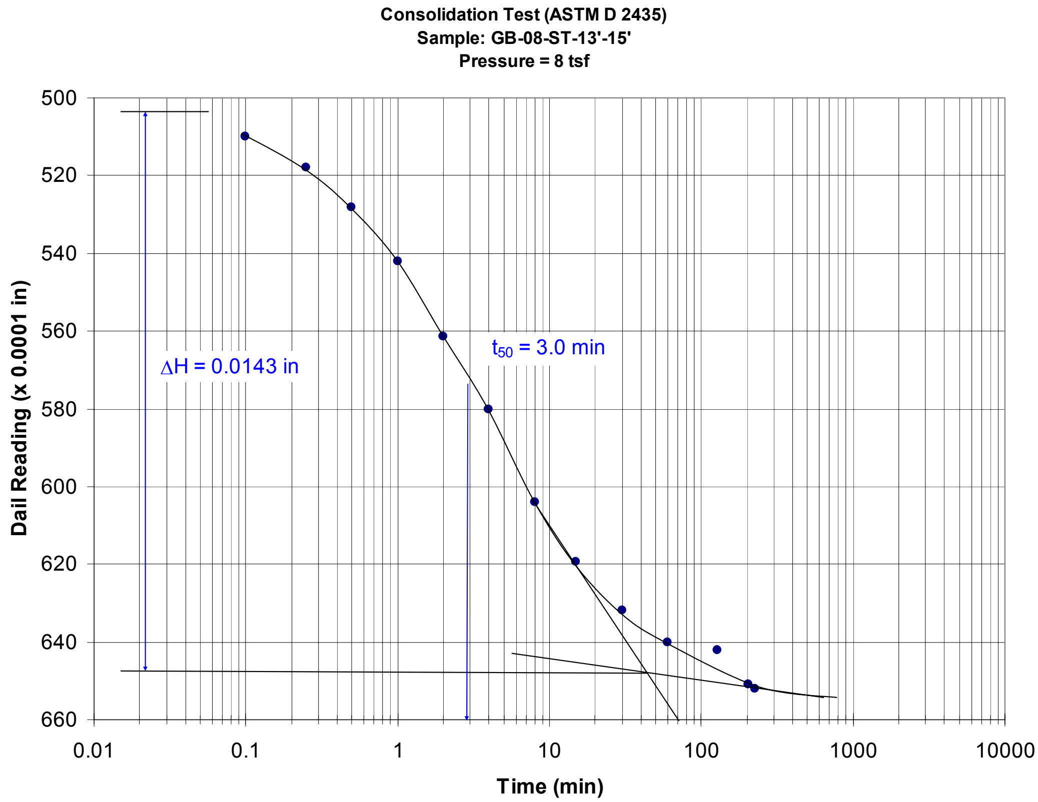
Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf (Unloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.00203 in
t50 = 3.5 min
495
490
485
480
475
470
465
0.01
0.1
1
10
100
1000
10000

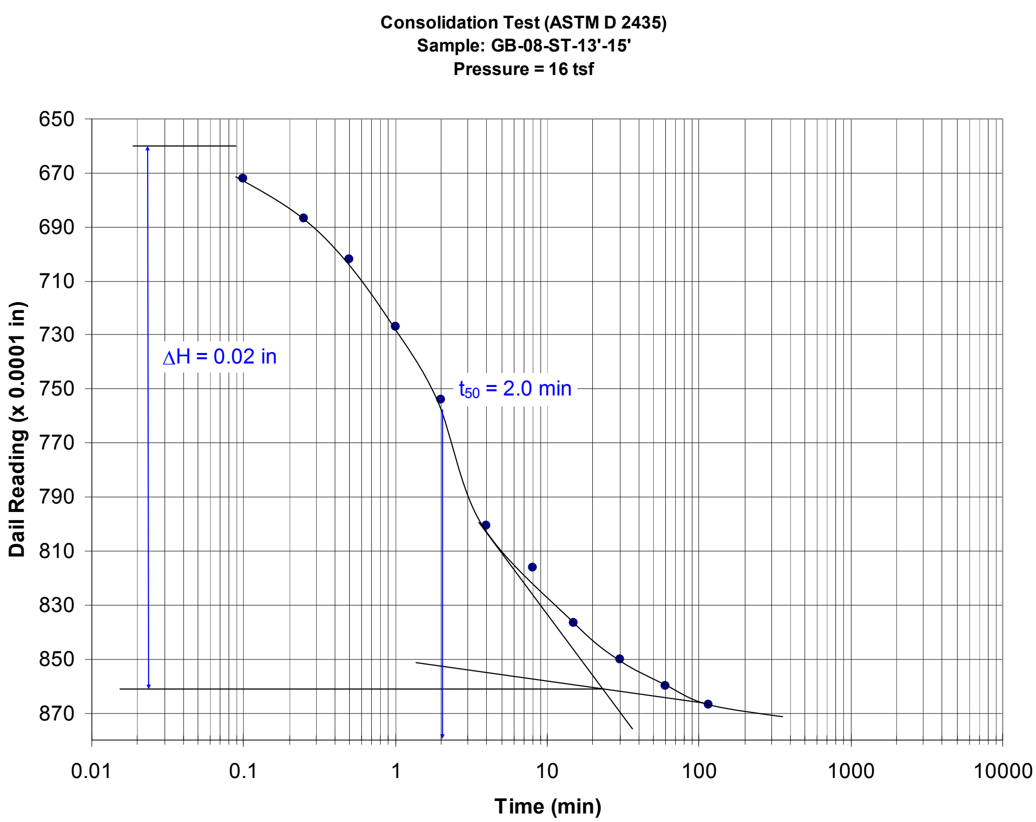

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1/2 tsf (Unloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.0029 in
t50 = 6.0 min
480
475
470
465
460
455
450
445
440
435
430
0.01
0.1
1
10
100
1000
10000


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 1 tsf (Reloaded)
Dail Reading (x 0.0001 in)
Time (min)
ΔH = 0.00018 in
t50 = 1.2 min
440
440.5
441
441.5
442
442.5
443
0.01
0.1
1
10
100
1000
10000


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 2 tsf (Reloaded)
442
443
444
445
446
447
448
Dail Reading (x 0.0001 in)
0.01
0.1
1
10
100
1000
10000
Time (min)
t_{50} = 0.6 min
ΔH = 0.00038 in


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 4 tsf (Reloaded)
445
455
465
475
485
495
505
Dail Reading (x 0.0001 in)
0.01
0.1
1
10
100
1000
10000
Time (min)
t_{50} = 2.4 min
ΔH = 0.0043 in


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 8 tsf
Dail Reading (x 0.0001 in)
500
520
540
560
580
600
620
640
660
0.01
0.1
1
10
100
1000
10000
Time (min)
ΔH = 0.0143 in
t50 = 3.0 min


Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 16 tsf
Dail Reading (x 0.0001 in)
650
670
690
710
730
750
770
790
810
830
850
870
0.01
0.1
1
10
100
1000
10000
Time (min)
ΔH = 0.02 in
t50 = 2.0 min

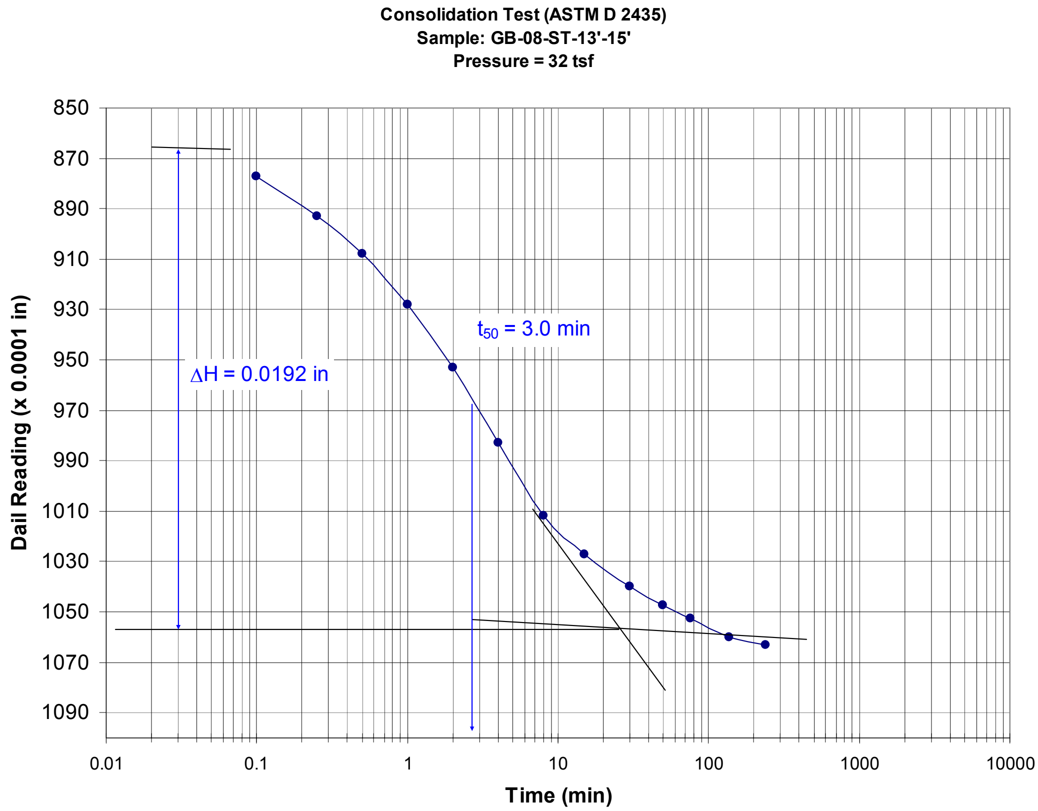

Consolidation Test (ASTM D 2435)
Sample: GB-08-ST-13'-15'
Pressure = 32 tsf
Dail Reading (x 0.0001 in)
850
870
890
910
930
950
970
990
1010
1030
1050
1070
1090
t50 = 3.0 min
ΔH = 0.0192 in
0.01
0.1
1
10
100
1000
10000
Time (min)

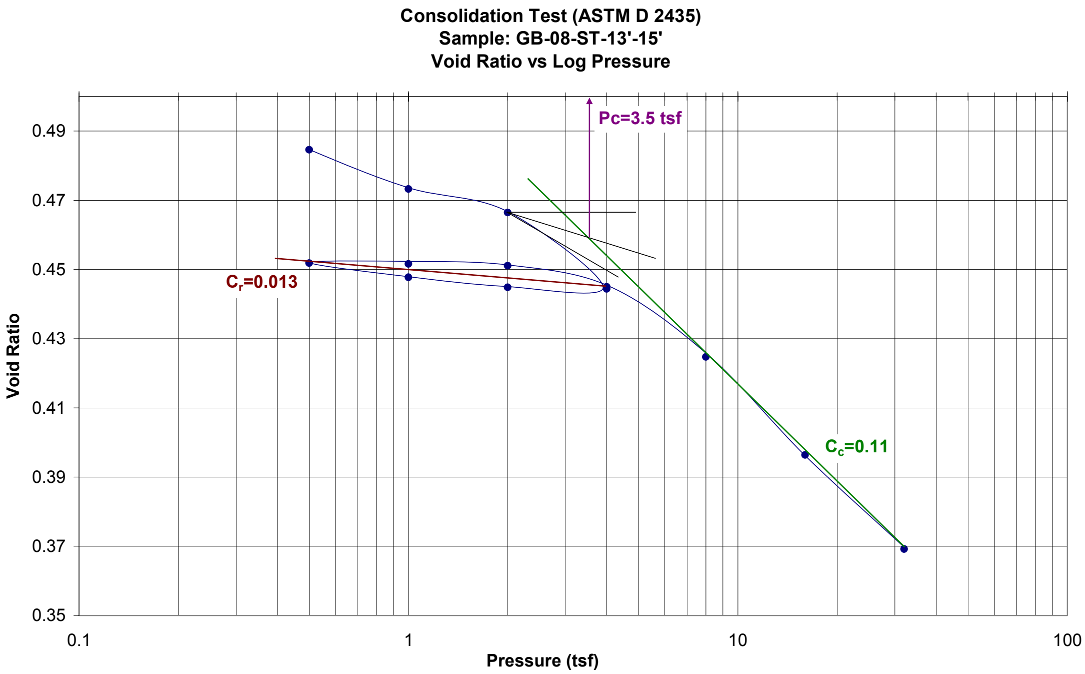
Table 2: Analysis of Consolidation Test Data

Pressure (tsf)	Time for 50% consolidation t_{50} (min)	D_0 (from graph)	D_{100} (from graph)	$D_{50} = (D_0+D_{100})*0.5$	$H_j = D_{50}$ * 0.0001	ΔH (from graph)	Σ ΔH*	H**	H_d**	Coefficient of consolidation C_v (in^2/min)***	H_v***	e***
0								1.06299				
0.5	10	8	159	83.5	0.00835	0.0153	0.0153	1.04769	0.52593	5.45E-03	0.34	0.48
1	11.5	173	254	213.5	0.02135	0.008	0.0233	1.03969	0.52518	4.72E-03	0.33	0.47
2	30	254	301	277.5	0.02775	0.0048	0.0281	1.03489	0.52438	1.81E-03	0.33	0.47
4	3.3	310	362	336	0.03360	0.0156	0.0437	1.01929	0.51805	1.60E-02	0.31	0.44
2	1.9	496	492.5	494.25	0.04943	0.0004	0.04335	1.01964	0.52218	2.83E-02	0.31	0.44
1	3.5	493	472.5	482.5	0.04825	0.002	0.04132	1.02167	0.52290	1.54E-02	0.32	0.45
0.5	6	472	442	457	0.04570	0.0029	0.03842	1.02457	0.52371	9.01E-03	0.32	0.45
1	1.2	441	442.4	441.5	0.04415	0.0002	0.0386	1.02439	0.52323	4.49E-02	0.32	0.45
2	0.6	443	446.5	444.55	0.04446	0.0004	0.03898	1.02401	0.52312	8.98E-02	0.32	0.45
4	2.4	446	489	467.5	0.04675	0.0043	0.04328	1.01971	0.52154	2.23E-02	0.31	0.44
8	3	504	650	577	0.05770	0.0143	0.05758	1.00541	0.51713	1.76E-02	0.30	0.42
16	2	660	861	760.5	0.07605	0.02	0.07758	0.98541	0.51172	2.58E-02	0.28	0.40
32	3	869	1060	964.5	0.09645	0.0192	0.09678	0.96621	0.50722	1.69E-02	0.26	0.37

* ΣΔH for applied pressure = ΣΔH of all previous pressures + ΔH under applied pressure

** $H_{dj} = \frac{H_j}{2} \pm \frac{\Delta H_j}{4}$ and $H_j = H_i \pm \Delta H_{j-1}$ (- for Loading and + for Unloading)

*** $C_v = 0.197 \times \frac{H_d^2}{t_{50}}$, $H_v = (H_i - H_s) - \Sigma\Delta H$ and $e = \frac{H_v}{H_s}$



Final Results:

Compression Index (C_c) = 0.11

Recompression Index (C_r) = 0.013

Preconsolidation pressure (P_c) or Maximum past pressure (σ_{vmax}) = 3.5 tsf

Coefficient of consolidation (C_v)= 1.54×10^{-2} to 9.01×10^{-3} in^2/min
(depends on the pressure)

Coefficient of secondary compression ($C\alpha$) = 0.001
(It is the slope of time vs settlement curve beyond the end of primary consolidation)

BLANK DATA SHEETS

Consolidation Test

Data Sheets

Date Tested:

Tested By:

Project Name:

Sample Number:

Sample Description:

Before test

Consolidation type =
Mass of the ring + glass plate =
Inside diameter of the ring =
Height of specimen, H_i =
Area of specimen, A =
Mass of specimen + ring =
Initial moisture content of specimen, w_i (%) =
Specific gravity of solids, G_s =

After test

Mass of wet sample + ring + glass plate =
Mass of can =
Mass of can + wet soil =
Mass of wet specimen =
Mass of can + dry soil =
Mass of dry specimen, M_s =
Final moisture content of specimen, w_f =

Calculations

Mass of solids in specimen, M_s =
(Mass of dry specimen after test)

Mass of water in specimen before test, M_{wi} = w_i x M_s=

Mass of water in specimen after test, M_{wf} (g) = w_f x M_s=

Height of solids, $H_s = \frac{M_s}{A \times G_s \times \rho_w} =$
(same before and after test and note ρ_w = 1 g/cm^3)

Height of water before test, $H_{wi} = \frac{M_{wi}}{A \times \rho_w} =$

Height of water after test, $H_{wf} = \frac{M_{wf}}{A \times \rho_w} = =$

Change in height of specimen after test, $\Sigma\Delta H$ =
($\Sigma\Delta H$ for all pressures – see t vs Dial reading plot)

Height of specimen after test, $H_f = H_i - \Sigma\Delta H$ =

Void ratio before test, $e_o = \frac{H_i - H_s}{H_s} =$

Void ratio after test, $e_f = \frac{H_f - H_s}{H_s} =$

Degree of saturation before test, $S_i = \frac{H_{wi}}{H_i - H_s} =$

Degree of saturation after test, $S_f = \frac{H_{wf}}{H_f - H_s} =$

Dry density before test, $\rho_d = \frac{M_s}{H_i \times A} =$

Time - Settlement Data

Conversion: 0.0001 inch = 1.0 on dial reading (confirm this before using)

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
120	
240	

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
121	
240	

LOADING = _____ tsf	
ELAPSED TIME, min	**DIAL READING**
0	
0.1	
0.25	
0.5	
1	
2	
4	
10	
15	
30	
60	
120	
240	

Analysis of Consolidation Test Data

Pressure (tsf)	Time for 50% consolidation t_{50} (min)	D_0 (from graph)	D_{100} (from graph)	$D_{50} = (D_0+D_{100})*0.5$	$H_j = D_{50} * 0.0001$	ΔH (from graph)	$\Sigma \Delta H^*$	H^{**}	H_d^{**}	Coefficient of consolidation C_v (in^2/min)	H_v^{***}	e^{***}

* $\Sigma\Delta H$ for applied pressure = $\Sigma\Delta H$ of all previous pressures + ΔH under applied pressure

** $H_{dj} = \frac{H_j}{2} \pm \frac{\Delta H_j}{4}$ and $H_j = H_i \pm \Delta H_{j-1}$ (- for Loading and + for Unloading)

*** $C_v = 0.197 \times \frac{H_d^2}{t_{50}}$, $H_v = (H_i - H_s) - \Sigma\Delta H$ and $e = \frac{H_v}{H_s}$

EXPERIMENT 13

DIRECT SHEAR TEST

Purpose:

This test is performed to determine the consolidated-drained shear strength of a sandy to silty soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall.

Standard Reference:

ASTM D 3080 - Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

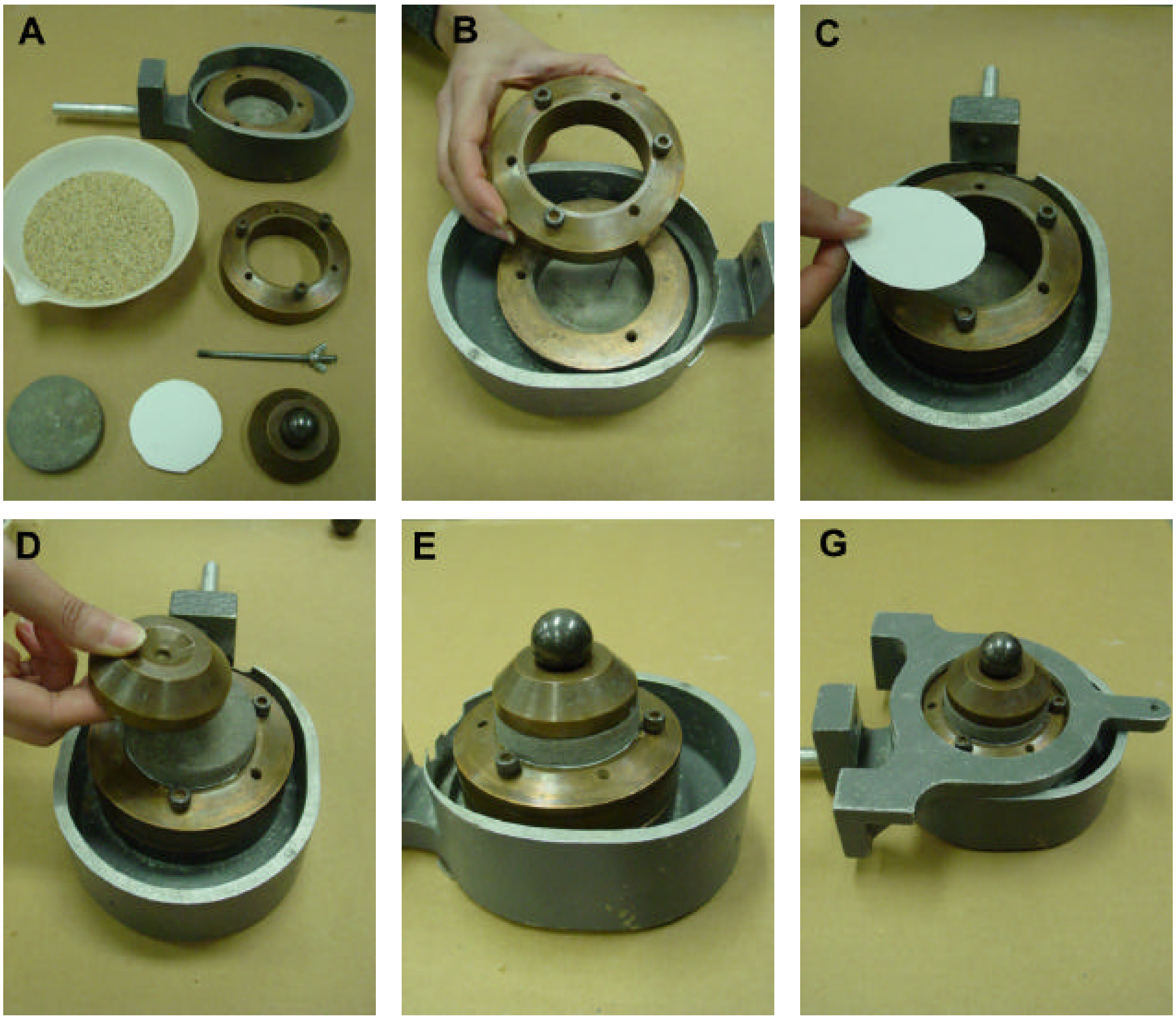
Significance:

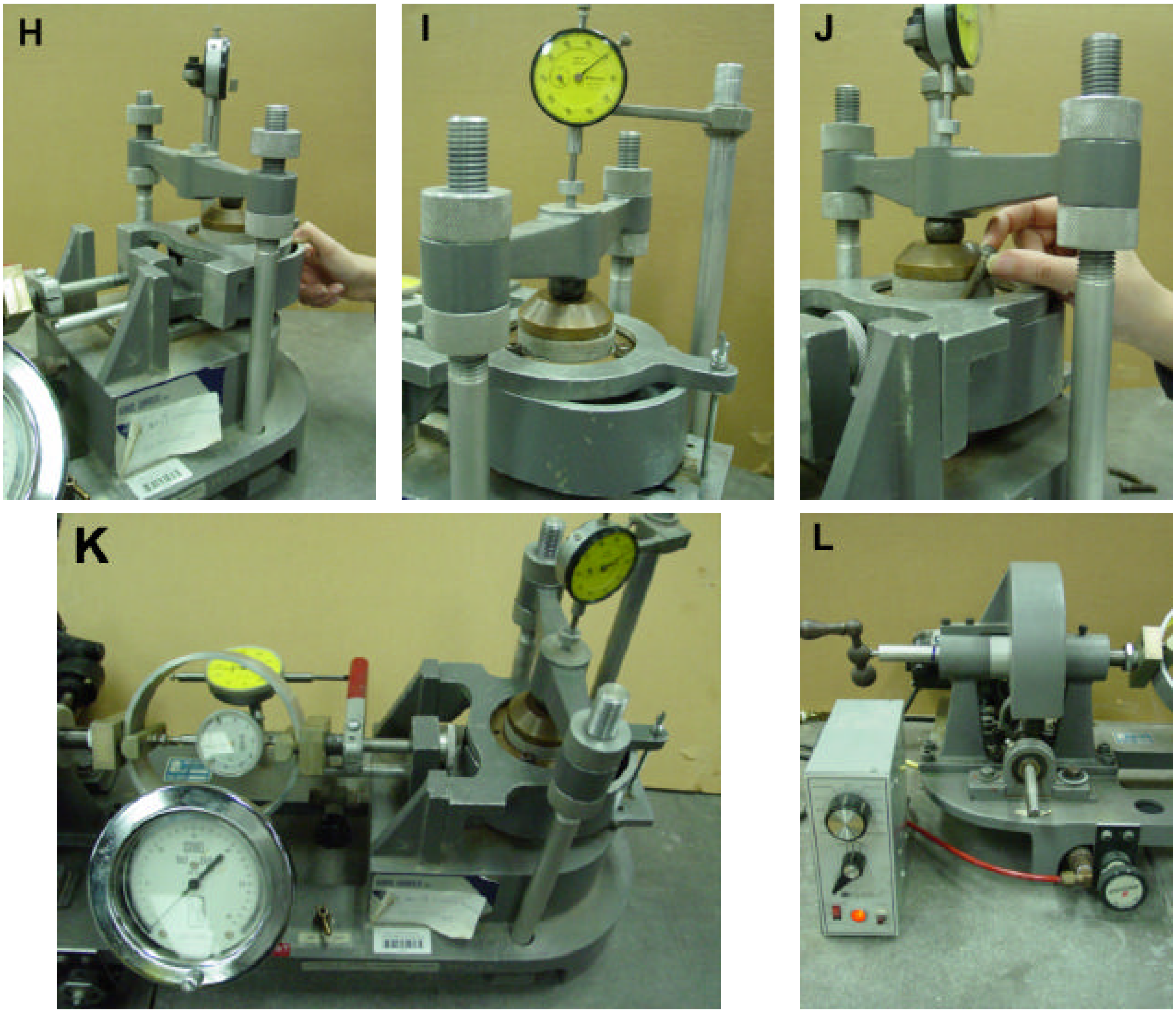
The direct shear test is one of the oldest strength tests for soils. In this laboratory, a direct shear device will be used to determine the shear strength of a cohesionless soil (i.e. angle of internal friction (ϕ)). From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stress. After the experiment is run several times for various vertical-confining stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests is produced. From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, ϕ may be determined, and, for cohesionless soils (c = 0), the shear strength can be computed from the following equation:

$$\tau = \sigma \tan \phi$$

Equipment:

Direct shear device, Load and deformation dial gauges, Balance.




H
I
J
K
L

Test Procedure:

(1) Weigh the initial mass of soil in the pan.

(2) Measure the diameter and height of the shear box. Compute 15% of the diameter in millimeters.

(3) Carefully assemble the shear box and place it in the direct shear device. Then place a porous stone and a filter paper in the shear box.

(4) Place the sand into the shear box and level off the top. Place a filter paper, a porous stone, and a top plate (with ball) on top of the sand

(5) <u>Remove the large alignment screws from the shear box!</u> Open the gap between the shear box halves to approximately 0.025 in. using the gap screws, and then back out the gap screws.

(6) Weigh the pan of soil again and compute the mass of soil used.

(7) Complete the assembly of the direct shear device and initialize the three gauges (Horizontal displacement gage, vertical displacement gage and shear load gage) to zero.

(8) Set the vertical load (or pressure) to a predetermined value, and then close bleeder valve and apply the load to the soil specimen by raising the toggle switch.

(9) Start the motor with selected speed so that the rate of shearing is at a selected constant rate, and take the horizontal displacement gauge, vertical

displacement gage and shear load gage readings. Record the readings on the data sheet. (Note: Record the vertical displacement gage readings, if needed).

(10) Continue taking readings until the horizontal shear load peaks and then falls, or the horizontal displacement reaches 15% of the diameter.

Analysis:

(1) Calculate the density of the soil sample from the mass of soil and volume of the shear box.

(2) Convert the dial readings to the appropriate length and load units and enter the values on the data sheet in the correct locations. Compute the sample area A, and the vertical (Normal) stress s_v.

$$s_v = \frac{N_v}{A}$$

Where: N_v = normal vertical force, and s_v = normal vertical stress

(3) Calculate shear stress (τ) using $t = \frac{F_h}{A}$

Where F_h= shear stress (measured with shear load gage)

(4) Plot the horizontal shear stress (τ) versus horizontal (lateral) displacement ?H.

(5) Calculate the maximum shear stress for each test.

(6) Plot the value of the maximum shear stress versus the corresponding vertical stress for each test, and determine the angle of internal friction (f) from the slope of the approximated Mohr-Coulomb failure envelope.

DIRECT SHEAR TEST
DATA SHEET

Date Tested: **August 30, 2002**

Tested By: **CEMM315 Class, Group A**

Project Name: **CEMM315 Lab**

Sample Number: **K-3,AU-10, 2'-4'**

Visual Classification: **Brown uniform sand**

Shear Box Inside Diameter: **6.3 cm**
Area (A): **31.17 cm^2 = 4.83 in^2**
Shear Box Height: **4.9 cm**
Soil Volume: **119.9 cm^3**
Initial mass of soil and pan: **1000. g**
Final mass of soil and pan: **720.82 cm**
Mass of soil: **279.18 g**
Density of soil (?) **:** **1.65 g/cm^3**

Direct Shear Test Data

Displacement rate: ______
Normal stress: **2.27 psi**

Horizontal Dial Reading (0.001 in)	Horizontal Displacement (in)	Load Dial Reading	Horizontal Shear Force (lb)	Shear Stress (psi)
0	0	0	0	0
10	0.01	4	5.142	1.064
19	0.019	4.3	5.231	1.082
29	0.029	4.8	5.379	1.113
36	0.036	5	5.439	1.126
44	0.044	7	6.033	1.248
51	0.051	8	6.33	1.31
57	0.057	13.5	7.963	1.648
63	0.063	15	8.409	1.740
70	0.07	17	9.002	1.863
76	0.076	19	9.597	1.986
84	0.084	20	9.893	2.047
91	0.091	22	10.488	2.170
100	0.1	22.5	10.636	2.201
107	0.107	23	10.785	2.232
114	0.144	23.5	10.933	2.262
121.5	0.1215	25	11.379	2.355
129	0.129	25.5	11.527	2.385
137	0.137	26	11.675	2.416
145	0.145	27	11.973	2.478
152	0.152	27.5	12.121	2.508
160	0.16	28	12.270	2.539
179	0.179	25	11.379	2.355

Direct Shear Test Data

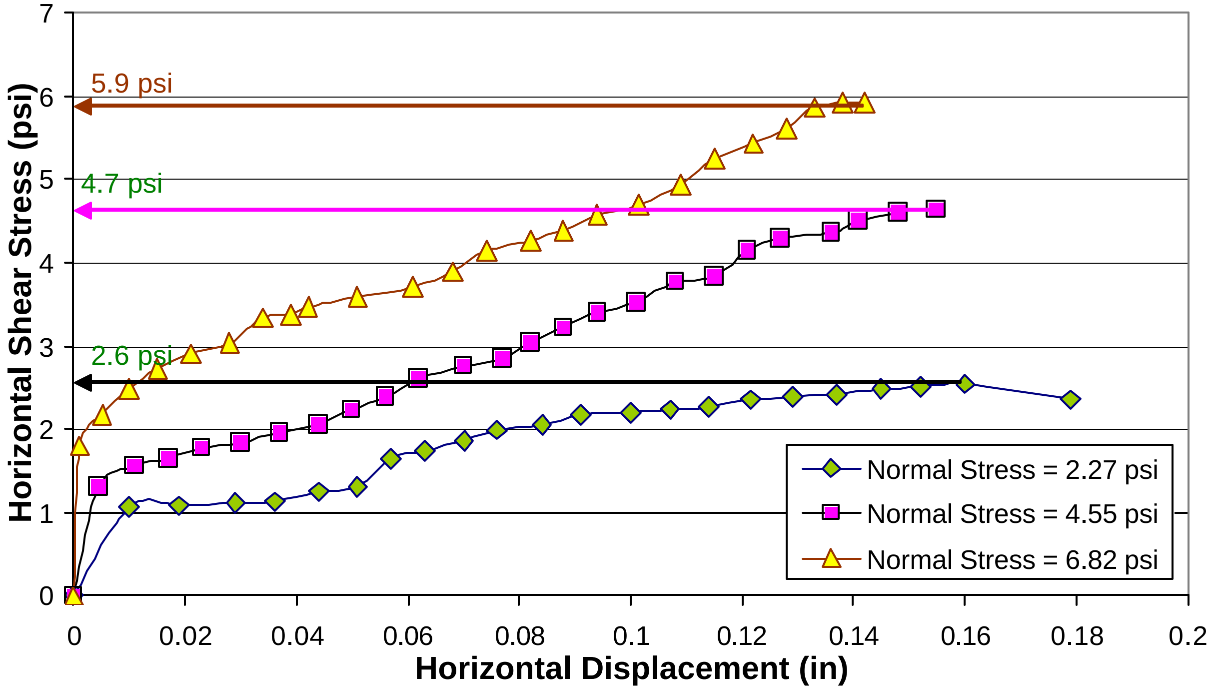
Normal stress: **4.55 psi**

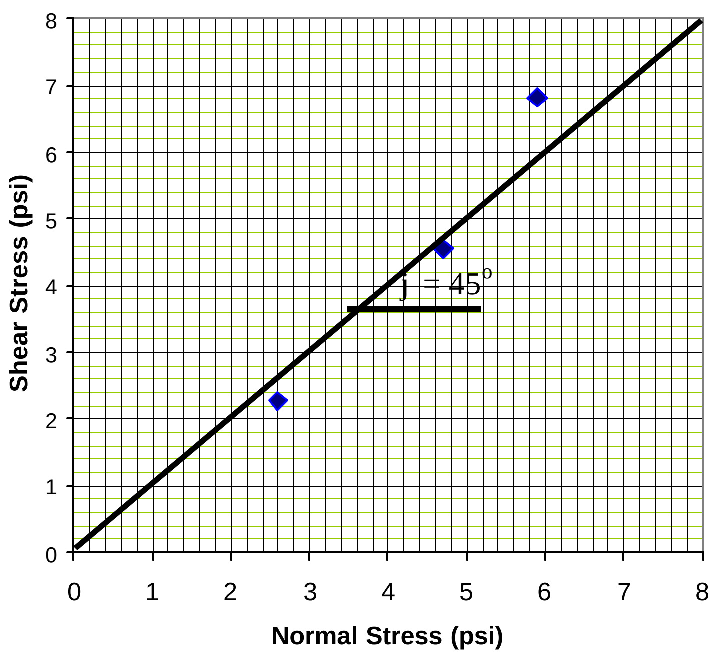
Horizontal Dial Reading (0.001 in)	Horizontal Displacement (in)	Load Dial Reading	Horizontal Shear Force (lb)	Shear Stress (psi)
0	0	0	0	0
4.5	0.0045	8	6.330	1.31
11	0.011	12	7.517	1.556
17	0.017	13.5	7.963	1.648
23	0.023	15.5	8.557	1.77
30	0.030	16.5	8.854	1.832
37	0.037	18.5	9.448	1.955
44	0.044	20	9.894	2.047
50	0.05	23	10.785	2.232
56	0.056	25.5	11.527	2.385
62	0.062	29	12.567	2.60
70	0.07	31.5	13.309	2.754
77	0.077	33	13.755	2.846
82	0.082	36	14.646	3.031
88	0.088	39	15.537	3.215
94	0.094	42	16.428	3.4
101	0.101	44	17.022	3.522
108	0.108	48	18.210	3.768
115	0.115	49	18.507	3.83
121	0.121	54	19.991	4.13
127	0.127	56.5	20.734	4.291
136	0.136	57.5	21.031	4.352
141	0.141	60	21.774	4.506
148	0.148	61.5	22.219	4.599
155	0.155	62	22.368	4.62

Direct Shear Test Data

Normal stress: **6.82 psi**

Horizontal Dial Reading (0.001 in)	Horizontal Displacement (in)	Load dial Reading	Horizontal Shear Force (lb)	Shear Stress (psi)
0	0	0	0	0
1	0.001	16	8.706	1.801
5	0.005	22	10.488	2.170
10	0.01	27	11.972	2.478
15	0.015	31	13.16	2.723
21	0.021	34	14.052	2.908
28	0.028	36	14.646	3.031
34	0.034	41	16.131	3.338
39	0.039	41.5	16.279	3.37
42	0.042	43	16.725	3.461
51	0.051	45	17.319	3.584
61	0.061	47	17.913	3.707
68	0.068	50	18.804	3.891
74	0.074	54	19.99	4.13
82	0.082	56	20.586	4.26
88	0.088	58	21.18	4.383
94	0.094	61	22.071	4.568
101.5	0.1015	63	22.665	4.690
109	0.109	67	23.85	4.937
115	0.115	72	25.337	5.244
122	0.122	75	26.228	5.428
128	0.128	78	27.119	5.612
133	0.133	82	28.307	5.858
138	0.138	83	28.605	5.92
142	0.142	83	28.60	5.92


5.9 psi
4.7 psi
2.6 psi
Horizontal Shear Stress (psi)
Horizontal Displacement (in)
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
0 1 2 3 4 5 6 7
Normal Stress = 2.27 psi
Normal Stress = 4.55 psi
Normal Stress = 6.82 psi


j = 45°
Shear Stress (psi)
Normal Stress (psi)
0 1 2 3 4 5 6 7 8

BLANK DATA SHEETS

DIRECT SHEAR TEST
DATA SHEET

Date Tested:

Tested By:

Project Name:

Sample Number:

Visual Classification:

Shear Box Inside Diameter:
Area (A):
Shear Box Height:
Soil Volume:
Initial mass of soil and pan:
Final mass of soil and pan:
Mass of soil:
Density of soil (?) **:**

Direct Shear Test Data

Displacement rate: ______
Normal stress: ________psi

Horizontal Dial Reading (0.001 in)	Horizontal Displacement (in)	Load Dial Reading	Horizontal Shear Force (lb)	Shear Stress (psi)

Direct Shear Test Data

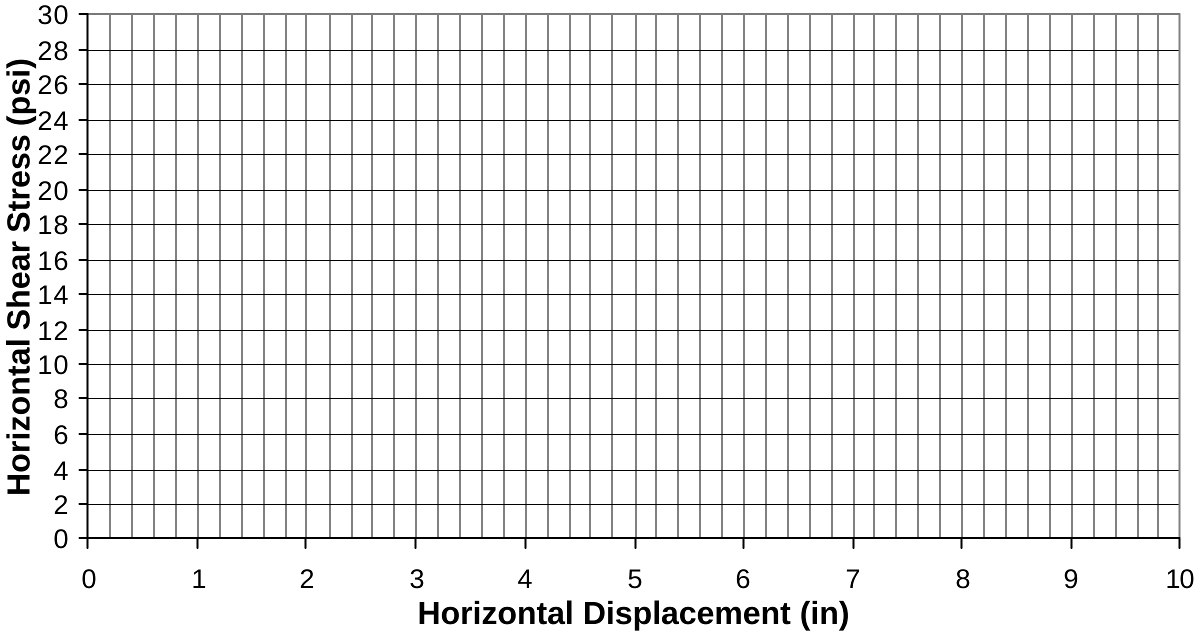
Normal stress: ________ psi

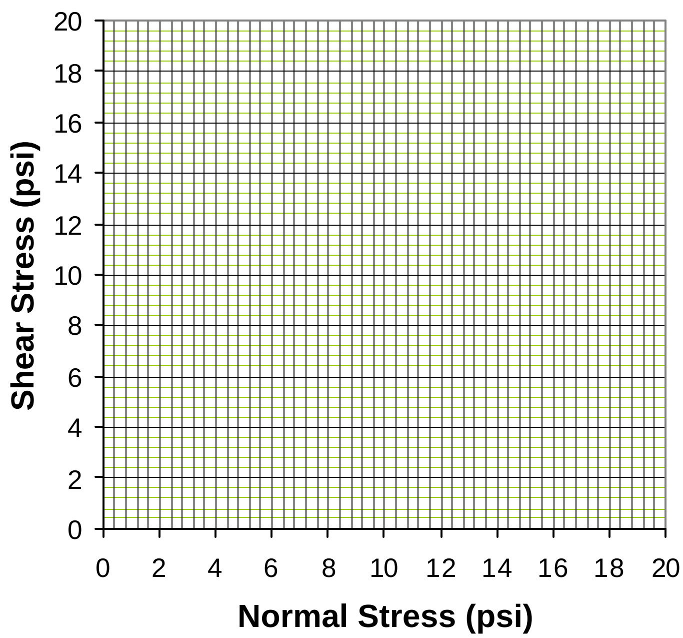
Horizontal Dial Reading (0.001 in)	Horizontal Displacement (in)	Load Dial Reading	Horizontal Shear Force (lb)	Shear Stress (psi)

Direct Shear Test Data

Normal stress: _______**psi**

Horizontal Dial Reading (0.001 in)	**Horizontal Displacement (in)**	**Load dial Reading**	**Horizontal Shear Force (lb)**	**Shear Stress (psi)**


Horizontal Shear Stress (psi)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
Horizontal Displacement (in)


Shear Stress (psi)
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
Normal Stress (psi)

EXPERIMENT 12

UNCONFINED COMPRESSION (UC) TEST

Purpose:

The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test.

Standard Reference:

ASTM D 2166 - Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

Significance:

For soils, the undrained shear strength (s_u) is necessary for the determination of the bearing capacity of foundations, dams, etc. The undrained shear strength (s_u) of clays is commonly determined from an unconfined compression test. The undrained shear strength (s_u) of a cohesive soil is equal to one-half the unconfined compressive strength (q_u) when the soil is under the f = 0 condition (f = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion (c). This is expressed as:

$$s_u = c = \frac{q_u}{2}$$

Then, as time passes, the pore water in the soil slowly dissipates, and the intergranular stress increases, so that the drained shear strength (s), given by s = c + s'tan f , must be used. Where s' = intergranular pressure acting perpendicular to the shear plane; and s' = (s - u), s = total pressure, and u = pore water pressure; c' and φ' are drained shear strength parameters. The determination of drained shear strength parameters is given in Experiment 14

Equipment:

Compression device, Load and deformation dial gauges, Sample trimming equipment, Balance, Moisture can.

Test Procedure:

(1) Extrude the soil sample from Shelby tube sampler. Cut a soil specimen so that the ratio (L/d) is approximately between 2 and 2.5.
Where L and d are the length and diameter of soil specimen, respectively.

(2) Measure the exact diameter of the top of the specimen at three locations 120° apart, and then make the same measurements on the bottom of the specimen. Average the measurements and record the average as the diameter on the data sheet.

(3) Measure the exact length of the specimen at three locations 120° apart, and then average the measurements and record the average as the length on the data sheet.

(4) Weigh the sample and record the mass on the data sheet.

(5) Calculate the deformation (ΔL) corresponding to 15% strain (ε).

$$\text{Strain (e)} = \frac{\Delta L}{L_o}$$

Where L_0 = Original specimen length (as measured in step 3).

(6) Carefully place the specimen in the compression device and center it on the bottom plate. Adjust the device so that the upper plate just makes contact with the specimen and set the load and deformation dials to zero.

(7) Apply the load so that the device produces an axial strain at a rate of 0.5% to 2.0% per minute, and then record the load and deformation dial readings on the data sheet at every 20 to 50 divisions on deformation the dial.

(8) Keep applying the load until (1) the load (load dial) decreases on the specimen significantly, (2) the load holds constant for at least four deformation dial readings, or (3) the deformation is significantly past the 15% strain that was determined in step 5.

(9) Draw a sketch to depict the sample failure.

(10) Remove the sample from the compression device and obtain a sample for water content determination. Determine the water content as in Experiment 1.

Analysis:

(1) Convert the dial readings to the appropriate load and length units, and enter these values on the data sheet in the deformation and total load columns. (Confirm that the conversion is done correctly, particularly proving dial gage readings conversion into load)

(2) Compute the sample cross-sectional area $A_0 = \frac{\pi}{4} \times (d)^2$

(3) Compute the strain, $e = \frac{?L}{L_0}$

(4) Computed the corrected area, $A' = \frac{A_0}{1-e}$

(5) Using A', compute the specimen stress, $s_c = \frac{P}{A'}$

(Be careful with unit conversions and use constant units).

(6) Compute the water content, w%.

(7) Plot the stress versus strain. Show q_u as the peak stress (or at 15% strain) of the test. Be sure that the strain is plotted on the abscissa. See example data.

(8) Draw Mohr's circle using q_u from the last step and show the undrained shear strength, s_u = c (or cohesion) = $q_u/2$. See the example data.

EXAMPLE DATA

UNCONFINED COMPRESSION TEST
DATA SHEET

Date Tested: **August 30, 2002**

Tested By: **CEMM315 Class, Group A**

Project Name: **CEMM315 Lab**

Sample Number: **ST-1, 8'-10'**

Visual Classification: **Brown silty clay, medium plasticity, moist CL.**

Sample data:

Diameter (d) = **7.29 cm**
Length (L_0) = **14.78 cm**
Mass = **1221.4 g**

Table 1: Moisture Content determination

Sample no.	ST-1, 8-10
Moisture can number - Lid number	A
M_C = Mass of empty, clean can + lid (grams)	15.6
M_{CMS} = Mass of can, lid, and moist soil (grams)	45.7
M_{CDS} = Mass of can, lid, and dry soil (grams)	39.5
M_S = Mass of soil solids (grams)	23.9
M_W = Mass of pore water (grams)	6.2
W = Water content, w%	25.94

Area (A_0) = $\frac{p}{4}\times(7.29)$ = **41..74 cm²**

Volume = $\frac{p}{4}\times(7.29)^2\times 14.78$ = **616.9 cm³**

Wet density = $\frac{1221.4}{616.9}$ = **1.98 g/cm³**

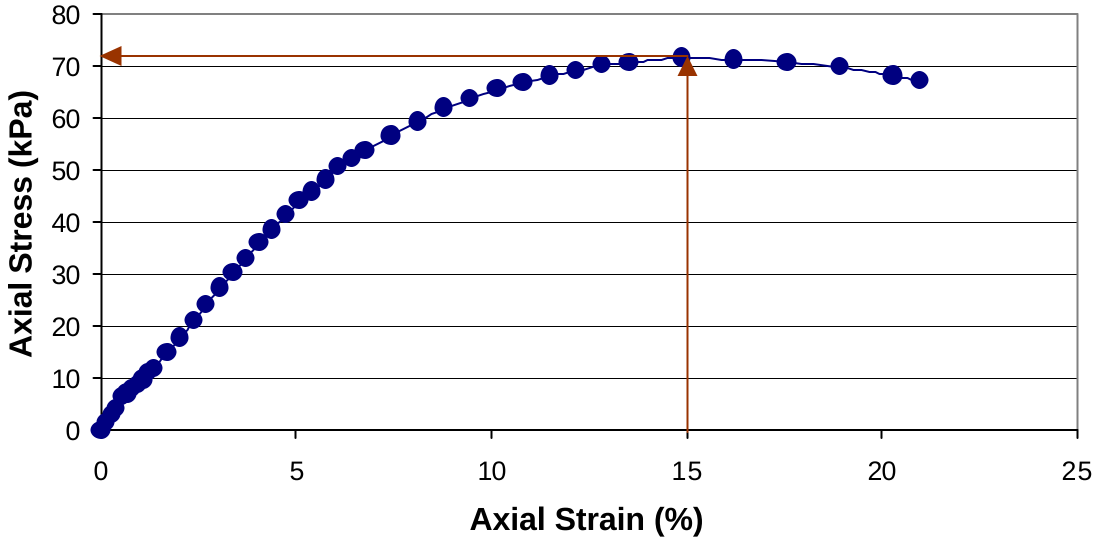
Water content (w%) = **25.9 %**

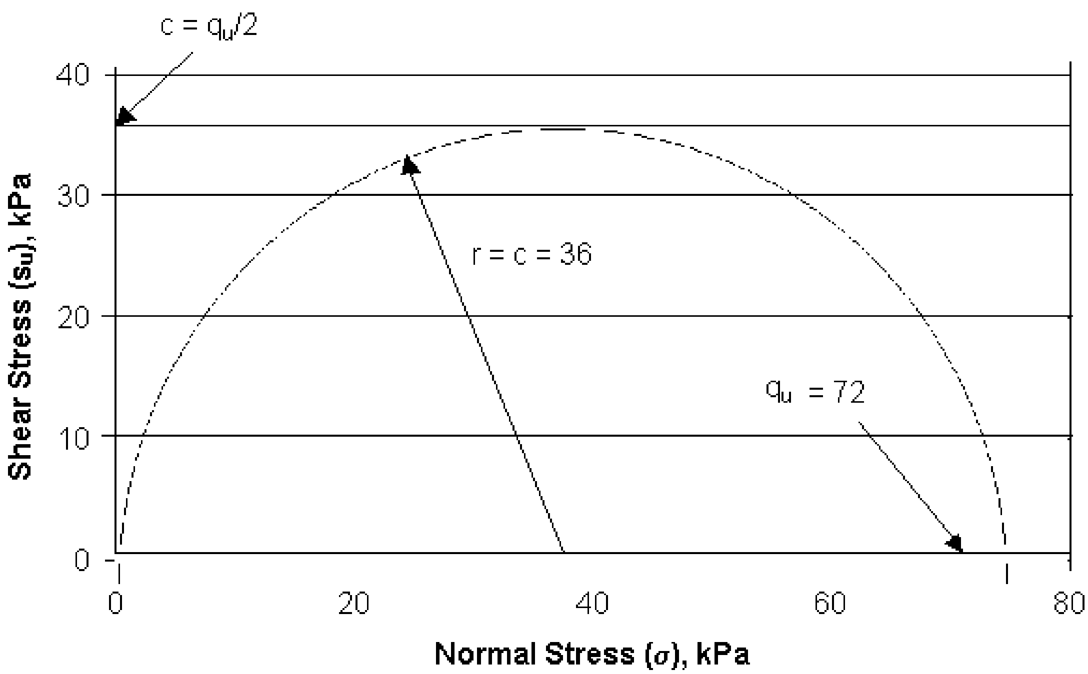
Dry density (?$_d$) = $\frac{1.98}{\left(1+\frac{25.9}{100}\right)}$ = **1.57 g/cm³**

Table 2: Unconfined Compression Test Data (Deformation Dial: 1 unit = 0.10mm; Proving Ring No: 24691; Load Dial: 1 unit = 0.3154 lb)

Deformation Dial Reading	Load Dial Reading	Sample Deformation DL (mm)	Strain (e)	% Strain	Corrected Area A'	Load (lb)	Load (KN)	Stress (kPa)
0	0	0	0.000	0.000	41.739	0.000	0.000	0.000
20	4	0.2	0.001	0.135	41.796	1.262	56.131	1.343
40	9	0.4	0.003	0.271	41.853	2.839	126.295	3.018
60	12	0.6	0.004	0.406	41.909	3.785	168.393	4.018
80	19	0.8	0.005	0.541	41.966	5.994	266.622	6.353
100	21	1	0.007	0.677	42.024	6.625	294.687	7.012
120	24	1.2	0.008	0.812	42.081	7.571	336.786	8.003
140	26	1.4	0.009	0.947	42.138	8.202	364.851	8.658
160	29	1.6	0.011	1.083	42.196	9.148	406.949	9.644
180	33	1.8	0.012	1.218	42.254	10.410	463.080	10.959
200	36	2	0.014	1.353	42.312	11.356	505.178	11.939
250	45	2.5	0.017	1.691	42.457	14.196	631.473	14.873
300	54	3	0.020	2.030	42.604	17.035	757.768	17.786
350	64	3.5	0.024	2.368	42.752	20.189	898.095	21.007
400	74	4	0.027	2.706	42.900	23.344	1038.422	24.205
450	84	4.5	0.030	3.045	43.050	26.498	1178.750	27.381
500	93	5	0.034	3.383	43.201	29.338	1305.044	30.209
550	102	5.5	0.037	3.721	43.353	32.177	1431.339	33.016
600	112	6	0.041	4.060	43.505	35.331	1571.666	36.126
650	120	6.5	0.044	4.398	43.659	37.855	1683.928	38.570
700	129	7	0.047	4.736	43.814	40.694	1810.223	41.316
750	138	7.5	0.051	5.074	43.971	43.533	1936.517	44.041
800	144	8	0.054	5.413	44.128	45.426	2020.714	45.792
850	152	8.5	0.058	5.751	44.286	47.950	2132.976	48.163
900	160	9	0.061	6.089	44.446	50.473	2245.237	50.516
950	166	9.5	0.064	6.428	44.606	52.366	2329.434	52.222
1000	171	10	0.068	6.766	44.768	53.943	2399.598	53.600
1100	182	11	0.074	7.442	45.096	57.413	2553.958	56.634
1200	192	12	0.081	8.119	45.428	60.568	2694.285	59.309
1300	202	13	0.088	8.796	45.765	63.722	2834.612	61.939
1400	209	14	0.095	9.472	46.107	65.931	2932.841	63.610
1500	217	15	0.101	10.149	46.454	68.454	3045.103	65.551
1600	223	16	0.108	10.825	46.806	70.347	3129.300	66.856
1700	229	17	0.115	11.502	47.164	72.240	3213.496	68.134
1800	234	18	0.122	12.179	47.527	73.817	3283.660	69.090
1900	240	19	0.129	12.855	47.896	75.710	3367.856	70.315
2000	243	20	0.135	13.532	48.271	76.656	3409.954	70.642
2200	250	22	0.149	14.885	49.039	78.864	3508.184	71.539
2400	253	24	0.162	16.238	49.831	79.811	3550.282	71.247
2600	255	26	0.176	17.591	50.649	80.442	3578.347	70.650
2800	256	28	0.189	18.945	51.495	80.757	3592.380	69.762
3000	254	30	0.203	20.298	52.369	80.126	3564.314	68.062

SAMPLE: ST-1, 8'-10'





From the stress-strain curve and Mohr's circle:

Unconfined compressive strength (q_u) = **72.0 KPa**

Cohesion (c) = **36.0 KPa**

BLANK DATA SHEETS

UNCONFINED COMPRESSION TEST
DATA SHEET

Date Tested:
Tested By:
Project Name:
Sample Number:
Visual Classification:

Sample data:

Diameter (d) =
Length (L_0) =
Mass =

Table 1: Moisture Content determination

Sample no.	
Moisture can number - Lid number	
M_C = Mass of empty, clean can + lid (grams)	
M_{CMS} = Mass of can, lid, and moist soil (grams)	
M_{CDS} = Mass of can, lid, and dry soil (grams)	
M_S = Mass of soil solids (grams)	
M_W = Mass of pore water (grams)	
W = Water content, w%	

Area (A_0) =
Volume =
Wet density =
Water content (w%) =
Dry density ($?_d$) =

Table 2: Unconfined Compression Test Data (Deformation Dial: 1 unit = 0.10mm; Proving Ring No: 24691; Load Dial: 1 unit = 0.3154 lb)

Deformation Dial Reading	Load Dial Reading	Sample Deformation DL (mm)	Strain (e)	% Strain	Corrected Area A'	Load (lb)	Load (KN)	Stress (kPa)
0								
20								
40								
60								
80								
100								
120								
140								
160								
180								
200								
250								
300								
350								
400								
450								
500								
550								
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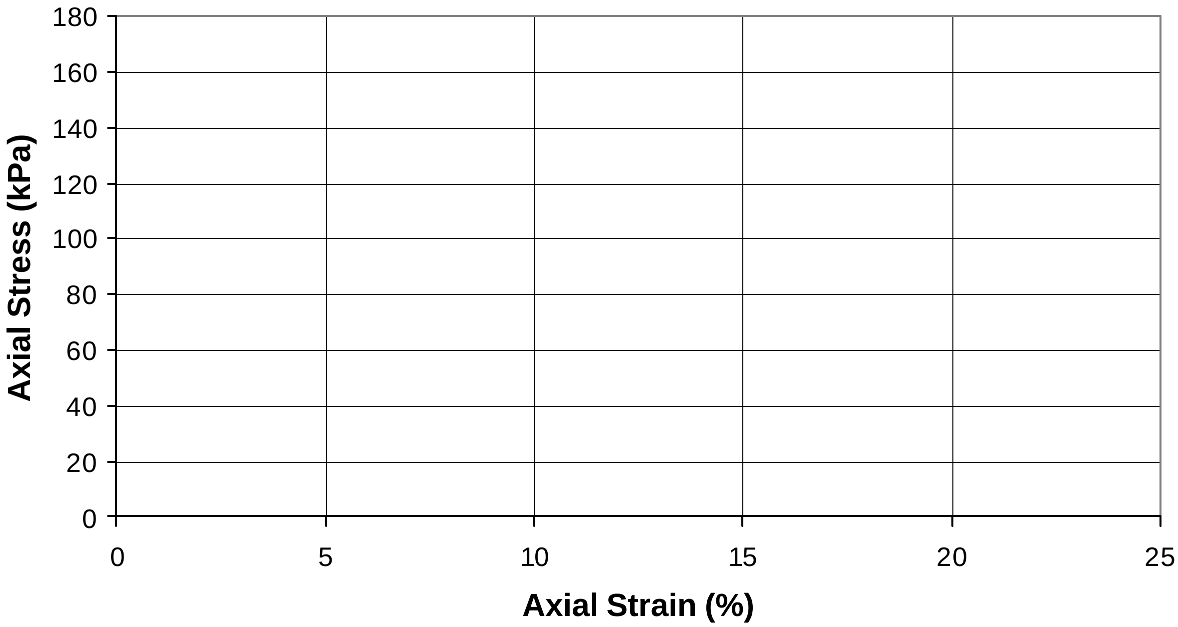
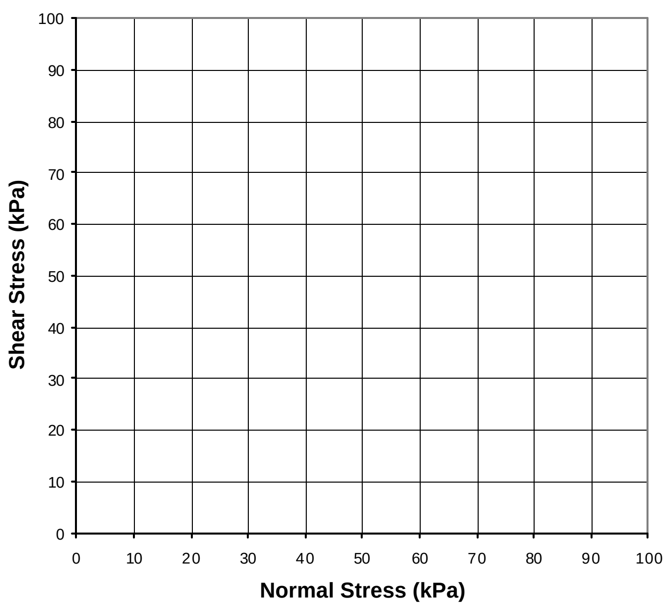
2600								
2800								
3000								





From the stress-strain curve and Mohr's circle:

Unconfined compressive strength (q_u) =

Cohesion (c) =