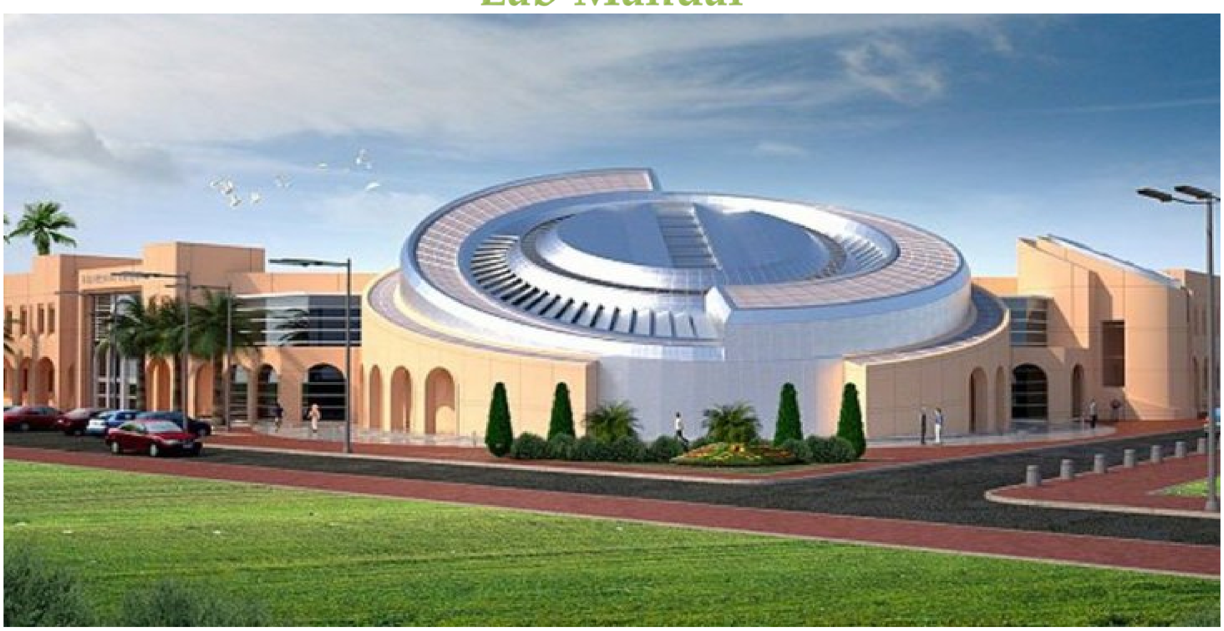
KING FAISAL UNIVERSITY
College Of Engineering

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

CEE361: Geotechnical Engineering

"Lab Manual"



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Major Topics covered and schedule in weeks:

Topic	Week #	Courses Covered
Introduction and Lab safety.	1	CEE360
Determination of Soil Moisture Content.	2	CEE360
Determination of Specific Gravity of a soil sample.	3	CEE360
Grain-Size Analysis of a given soil sample	4	CEE360
Hydrometer Analysis of sample passing Sieve 200.	5	CEE360
Liquid and Plastic Limits.	6	CEE360
Standard Proctor Compaction Test by using Manual and Automatic compactor	7	CEE360
Modified Proctor Compaction Test by using Manual and Automatic compactor	8	CEE360
Field density test	9	CEE360
Constant Head Permeability Test.	10	CEE360
Falling Head Permeability Test.	11	CEE360
Consolidation Test	12	CEE360
Direct Shear Test	13	CEE360
Unconfined Compression Test	14	CEE360
Triaxial Test	15	CEE360

Specific Outcomes of Instruction (Lab Learning Outcomes):

1. Develop knowledge of soil index properties. **(1,5,6)**
2. Develop a thorough understanding of soil compaction, field & laboratory measurements, and factors affecting compaction of soil. **(1,5,6)**
3. Develop a thorough understanding of water flow through soils. **(1,5,6)**
4. Develop a basic understanding of consolidation theory and settlement calculations. **(1,5,6)**
5. Develop a good understanding of shear strength of soils and characteristics of failure planes. **(1,5,6)**

Student Outcomes (SO) Addressed by the Lab:

z	Outcome Description General Engineering Student Outcomes	Contribution
1.	an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	
2.	an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	
3.	an ability to communicate effectively with a range of audiences	
4.	an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	
5.	an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	
6.	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	
7.	an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	

Table of Content

Experiment 1: Determination of Moisture Content of a given soil sample

I. Objective:

To determine the amount of water or moisture present in the given quantity of soil in terms of its dry weight.

II. Test Standard

ASTM D2216 – 19. Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.

III. Theory:

Water content or moisture content determination is a routine laboratory test, the results of which are used in evaluation of different important engineering properties of soil. The determination of moisture content involves removing of soil moisture by oven-drying a soil sample until the weight remains constant. The moisture content is expressed in percentage and is calculated from the sample weight before and after drying.

IV. Apparatus:

1. Moisture cans
2. Weighing balance (Least count of 0.01 g)
3. Drying oven (Temperature control at 110 ±5 ^{0}C)

V. Procedure:

1. Take empty clean moisture can and mark it with an identifying number or code.
2. Weight the container and record the weight as W_1 to the nearest 0.01 g
3. Take representative wet soil sample (not less than 20 g) and place it quickly in the moisture can.
4. Weight the moisture tin with wet soil sample to the nearest 0.01 g and record this weight as W_2
5. Place the moisture can with the wet soil sample in drying oven, at constant temperature of 110 ± 5^0 C for 24 hours.
6. After 24 hours remove the moisture tin from drying oven and weight it to the nearest 0.01 g. Record this weight as W_3

VI. Experimental Work:

Item	Test Number			
Can No	1	2	3	4
Mass of can, W_1(g)				
Mass of can + wet soil, W_2(g)				
Mass of can + dry soil, W_3(g)				
Mass of moisture, w_2- w_3 (g)				
Mass of dry soil, $w_3 - w_1$ (g)				
Moisture content, $w_{(\%)} = \frac{w2-w3}{w3-w1} \times 100$				

Average Moisture Content $w_{(\%)} =$ ____________

Experiment 2: Determination of a Specific Gravity of a given soil sample.

I. Objective:

To familiarize the students with general method of obtaining the specific gravity of a mass of any type or material composed of small particles (especially soil)

II. Test Standard

ASTM D854-02. Standard test method for specific gravity of soil solids by water pycnometer.

III. Theory:

This test method covers the determination of the specific gravity of soil solids that pass the 4.75 mm
(No. 4). The specific gravity of soil solids is used in calculating the phase relationships of soils, such as void ratio and degree of saturation. Also, it used to calculate density of soil solids, this is done by multiplying its specific gravity by the density of water. The specific gravity of soil solids (which is often referred to as the specific gravity of soil) is an important parameter for calculation of the weight-volume relationship. Thus, specific gravity, G" is defined as

$$G_s = \frac{\text{unit weight (or density) of soil solids only}}{\text{unit weight (or density) or water}}$$

$$G_s = \frac{W_s / V_s}{P2} = \frac{W_s}{V_s\, P2}$$

Where:

W_s = mass of soil solids (g).
V_s = volume of soil solids (cm3)
Pw = density of water (glcm3).

IV. Apparatus:

The equipment for determining Specific Gravity of Soil Solids includes:

1- Volumetric flask (500 ml)
2- Thermometer graduated in 0.5°C division scale
3- Balance sensitive up to 0.01 g
4- Distilled water
5- Bunsen burner and a stand (and/or vacuum pump or aspirator)
6- Evaporating dishes
7- Spatula

8- Plastic squeeze bottle
9- Drying oven

V. Procedure:

1. Weigh the dry pycnometer to nearest 0.01 g and record it as W_1
2. Take about 100 g of oven dried soil and put it into the flask. Weigh the flask and dry soil to the nearest 0.01 g. Record this weight as W_2
3. Add water in the Pycnometer, Fig. 2.1 until it is about two-third full. In order to remove the entrapped air from soil and water, heat the mixture at least 2h after soil –water mixture comes to a full boil. Use only enough heat to keep the slurry boiling. Agitate the slurry as necessary to prevent any soil from sticking to or drying on to the glass above the slurry surface
4. Allow the mixture to cool, and then fill the flask with distilled water to above the calibration mark
5. Place the stopper in the bottle while removing the excess water. Be sure the entire exterior of the flask is dry. Weigh the flask to the nearest 0.01 g and record this weight as W_3
6. Empty the flask, wash it thoroughly and fill it completely with water. Dry the exterior of the flask. Weigh the flask and record it as W_4
7. Repeat the procedure three times
8. Record the temperature of soil water mixture

VI. Experimental Work:

Item	Test No			
Sample No.	1	2	3	4
Mass of flask + water filled to mark, w_1 (g)				
Mass of flask +soil+ water filled to mark,w_2 (g)				
Mass of dry soil, w_s (g)				
Mass of equal volume of water as the soil solids, w_w (g) = (w_1 +w_s) - w_2				
$G_{s(T_1\,°C)} = w_S/w_W$				
$G_{S(20\,°C)} = G_{s(T_1\,°C)}$ x A (A=1)				

Average Specific Gravity (Gs) = __________

Experiment 3: Grain-Size Analysis of a given soil sample

I. Objective:

To introduce the students to the method of making a mechanical grain size analysis of a soil and presenting the resulting data

II. Test Standard

ASTM D2216-98. Standard test method for mechanical size analysis of extracted aggregate (mechanical analysis13)

iii. Theory:

In order to classify a soil for engineering purposes, one needs to know the distribution of the size of grains in a given soil mass. Sieve analysis is a method used to deter mine the grain- size distribution of soils. Sieves are made of woven wires with square openings. Note that. As the sieve, number increases the size of the openings decreases. Table 4-1 gives a list of the U.S. standard sieve numbers with their corresponding size of openings. For all practical purposes, the No. 200 sieve is the sieve with the smallest opening that should be used for the test. The sieves that are most commonly used for soil tests have a diameter of 8 in. (203 mm)

IV. Apparatus:

1. Sieves, a bottom pan, and a cover
   <u>*Note:*</u> Sieve numbers 4, 10, 18, 30, 50, 100, and 200 are generally used for most standard sieve analysis work.
2. A balance sensitive up to 0.1 g
3. Mortar and pestle
4. Oven
5. Mechanical sieve shaker

V. Procedure:

1. Collect a representative oven dry soil sample. Samples having largest particles of the size of No. 4 sieve openings (4.75 mm) should be about 500 grams. For soils having largest particles of size greater than 4.75 mm, larger weights are needed
2. Break the soil sample into individual particles using a mortar and a rubber-tipped
3. Determine the mass of the sample accurately to 0.1 g (m).
4. Prepare a stack of sieves. A sieve with larger openings is placed above a sieve with smaller openings.
5. Place the cover on the top of the stack of sieves.
6. Run the stack of sieves through a sieve shaker for about 10 to 15 minutes.
7. Stop the sieve shaker and remove the stack of sieves.
8. Weigh the amount of soil retained on each sieve and the bottom pan.

VI. Experimental Work:

Calculate the percent of soil retained on the *nth* sieve (counting from the top)

$$= \frac{\text{mass retained, } W_n}{\text{total mass, } W \text{ (Step 3)}} \times 100 = R_n \quad (4.1)$$

2. Calculate the cumulative percent of soil retained on the *nth* sieve

$$= \sum_{i=1}^{i=n} R_n \quad (4.2)$$

3. Calculate the cumulative percent passing through the nth sieve

$$= \text{percent finer} = 100 - \sum_{i=1}^{i=n} R_n \quad (4.3)$$

4. compute both of the Coefficient of Uniformity and Coefficient of Curvature after finding the D10, D30 and D60 from the graph.

$$C_u = \frac{D_{60}}{D_{10}} \quad (4.4)$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \quad (4.5)$$

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, Wn (g)	Percent of mass retained on each sieves Ra %	Cumulative percent retained ∑ Ra	Percent finer 100-∑ Ra
4	4.75				
10	2.00				
16	1.18				
30	0.60				
50	0.30				
100	0.15				
200	0.075				
Pan	--		--	--	--

Experiment 4: Hydrometer Analysis of sample passing Sieve 200

I. Objective:

The hydrometer method is used to approximate the particle size distribution for particles that passes sieve No.200. The hydrometer test is held as an extension to the sieve analysis to make us able to classify the soil.

II. Test Standard

ASTM D7928 – 17. Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis

III. Theory:

Hydrometer analysis is the procedure generally adopted for determination of the particles size distribution in a soil for fraction that is finer that No.200 sieve size (0.075). The lower limit of the particle size determined by this procedure is about 0.001 mm.
Hydrometer analysis is a widely used method of obtaining an estimate of the distribution of soil particle sizes from the No. 200 (0.075 mm) sieve to around 0.01 mm. The data are presented on a semi-log plot of percent finer vs. particle diameters and may be combined with the data from a sieve analysis of the material retained (+) on the No.200 sieve.

IV. Apparatus:

The equipment for determining Hydrometer test includes:

1- ASTM 152-H hydrometer
2- Mixer
3- Two 1000-cc graduated cylinder
4- Thermometer
5- Deflocculating agent
6- Spatula
7- Beaker
8- Balance
9- Plastic squeeze bottle
10- Distilled water
11- Rubber stopper.

V. Procedure:

1- Take 50 g of oven dry, well pulverized soil in a beaker.

2- Prepare a deflocculating agent. Usually a 4% solution of sodium hex metaphosphate (cogon) is used. This can be prepared by adding 40 g of cologne in 1000 cm^3 of distilled water and mixing it thoroughly.
3- Mix soil sample with 125 cm^3 water solution and keep it for 8 – 12 hours.
4- Take a 1000 cm^3 graduated cylinder and add 875 cm^3 of distilled water plus 125 cm^3 of deflocculating agent in it. Mix the solution well.
5- Put the hydrometer in the cylinder. Record the reading. (note: the top of the meniscus should be read.) This is the zero correction (Fz), which can be +ve or –ve. Also observe the meniscus correction (Fm).
6- By using a spatula, mix the prepared soil in step3. Then pour it into the mixer cup.
7- Add distilled water to the cup to make it about two- thirds full. Mix it for about two minutes using the mixer.
8- Pour the mix into the second graduated 100 cm^3 cylinder.
9- Secure a No. 12 rubber stopper on the top of cylinder.
10- Take hydrometer readings at cumulative times t=0.25 min, t=0.5 min, t= 1min,and 2 min.
11- Take the hydrometer out after two minutes and put it into the cylinder next to it.
12- Hydrometer readings are taken at times t=4 min, 8 min, 15 min, 30 min, 1 hour, 2 hr., 4 hr., 8 hr., 24 hr. and 48 hr.

VI. Experimental Work:

Column 2—These are observed hydrometer readings (R) corresponding to times given in Column 1.

Column 3—R_{cp} = corrected hydrometer reading for calculation of percent finer

$$= R + F_T - F_z \quad (5.7)$$

Column 4—*Percent finer* = $\frac{a R_{cp}}{W_s}(100)$

where W_s = dry weight of soil used for the hydrometer analysis
a = correction for specific gravity (since the hydrometer is calibrated for $G_s = 2.65$)

$$= \frac{G_s\,(1.65)}{(G_s - 1)2.65} \quad \text{(See Table 5-3)} \quad (5.8)$$

Table 5–3. Variation of a with G_s [Eq. 5.8]

G_s	a
2.50	1.04
2.55	1.02
2.60	1.01
2.65	1.00
2.70	0.99
2.75	0.98
2.80	0.97

Column 5—R_{cL} = corrected reading for determination of effective length = $R + F_m$ (5.9)

Column 6—Determine L (effective length) corresponding to the values of R_{cL} (Col. 5) given in Table 5–1.

Column 7—Determine A from Table 5–2.

Column 8— Determine $D\,(\text{mm}) = A\sqrt{\frac{L\,(\text{cm})}{t\,(\text{min})}}$

Elapsed time min	Temp C°	Actual Hydro	R_c	% finer	R	L	L/t	K	D, mm
0.25									
0.5									
1									
2									
4									
8									
15									
30									
60									
120									
240									
1260									
1440									
2880									

Experiment 5: Determination of Liquid and Plastic limits of fine grain soil.

I. Objective:

To introduce the students to the procedure for determining the liquid and plastic limit of a given fine grained soil

II. Test Standard

ASTM D4318 - 17 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

III. Theory:

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, 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 of a soil is the percentage of the weight of the oven-dry soil. It is between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a (3 mm) in diameter using a ground glass plate or other acceptable surface.

IV. Apparatus:

1. Liquid limit device with Cassagrande grooving tool (cuts a groove of size 2 mm wide at the bottom, 11 mm wide at the top and 8 mm high)
2. No.40 ASTM sieve
3. Water content equipment
4. Spatula
5. Glass plate
6. 1/8 inch diameter brass rod
7. containers

V. Procedure:

Liquid Limit:

1. Put air-dry soil sample passed through No. 200 sieve, into a porcelain dish.
2. Add water from the plastic squeeze bottle to the soil and mix carefully until it appears as a smooth uniform paste.

3. 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. The soil pat should form an approximately horizontal surface
4. Use the grooving tool carefully cut a clean straight groove down the centre of the cup.
5. 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.
6. Take a sample, using the spatula, from edge to edge of the soil pat.
7. Do the same procedure until the number of blows less than 25.

Plastic Limit:

1. Take a sample from sieved soil.
2. Add water from the plastic squeeze bottle to the soil and mix carefully.
3. Determine the mass of a moisture can in grams and record it on the data sheet (W1)
4. Form a prepare several ellipsoidal-shaped soil masses by squeezing the soil with your fingers
5. Take one of the ellipsoidal-shaped soil masses and roll it on a ground table until it gets 3 mm in diameter.
6. Once a small crack appears, put the part that the cracks appears in the moisture can.
7. Determine the weight of the moist soil + the moisture can (W2)
8. Put the can in the oven for 12-24 h.

VI. Experimental Work:

Sample No.	1	2	3	4
W1 = mass of empty can(g)				
W2= mass of can+ moist soil(g)				
W3= mass of can+ dry soil(g)				
W%= [(W2- W3)/ (W3- W1)] *100				
No. of blows (N)				

Liquid Limit: ____ %

Sample No.	1	2	**3**
W1 = mass of empty can(g)			
W2= mass of can+ moist soil(g)			
W3= mass of can+ dry soil(g)			
PL= [(W2- W3)/ (W3- W1)] *100			

Plastic Limit: ________ %

Plasticity Index: ____________

Experiment 6: Permeability of sandy sample by constant head test

I. Objective:

To determine the co-efficient of permeability of a coarse grain soil by constant head permeameter.

II. Test Standard

ASTM D2434 – 19. Standard Test Method for Permeability of Granular Soils (Constant Head)

III. Theory:

This test method covers the determination of the coefficient of permeability by a constant-head method for the laminar flow of water through granular soils. The procedure is to establish representative values of the coefficient of permeability of granular soils that may occur in natural deposits as placed in embankments, or when used as base courses under pavements. The rate of flow of water through a soil specimen of gross cross-sectional area, A, can be expressed as: $q = kiA$

For coarse sands, the value of the coefficient of permeability may vary from 1 to 0.01 cm/s and, for fine sand, it may be in the range of 0.01 to 0.001 cm/s. The coefficient of permeability of sands can be determined in the laboratory by the constant head test.

IV. Apparatus:

1. Constant head permeameter
2. Graduated cylinder (250 mL or 500 mL)
3. Balance, sensitive up to 0.1g
4. Reservoir of water
5. Stopwatch.
6. Tubes and rubber stoppers.

V. Procedure:

1. Measure the length and diameter of Constant head permeameter.
2. Clean the Constant head permeameter then put the filter and fill it with the specimen.
3. Connect the tubes and rubber from source of water to the reservoir of water to Constant head permeameter.
4. Make the rate of water into reservoir of water equals the rate of water out.

5. Start the stopwatch and collect the water in Graduated cylinder (250 mL or 500 mL) within a certain time in order to get (Q) and (t).
6. During step 5, note down the head difference h = h1 – h2.

VI. Experimental Work:

Parameter	Trial 1	Trial 2	Trial 3
Average flow, Q (cm^3)			
Time of collection, t (s)			
Head 1(cm)			
Head2(cm)			
Head difference h (cm)			
Diameter of the specimen D(cm)			
Length of specimen L (cm)			
Area A ($\frac{\pi * Di^2}{4}$)(cm^2)			
k = $\frac{Q\ L}{t\ h\ A}$ (cm/s)			

$$\text{Average (k)} = \frac{\boldsymbol{Q\ L}}{\boldsymbol{t\ h\ A}} \text{ (cm/s)}$$

Experiment 7: Permeability of fine grain soil by falling head test.

I. Objective:

To determine the co-efficient of permeability of a fine grain soil by falling head permeameter.

II. Test Standard

ASTM D5084 – 03. Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

III. Theory:

This consists of a specimen tube essentially the same as that used in the constant head test. The top of the specimen tube is connected to a burette by plastic tubing. Clamps hold the specimen tube and the burette vertically from a stand. The bottom of the specimen tube is connected to a plastic funnel by a plastic tube. A clamp holds the funnel vertically from another stand. A scale is also fixed vertically to this stand.

IV. Apparatus:

1. Falling head permeameter.
2. Balance sensitive to 0.1 g
3. Reservoir of water
4. Stopwatch
5. Tubes and rubber stoppers.
6. Graduated cylinder (250 mL)

V. Procedure:

1. Measure the length (L) of the specimen.
2. Measure the diameter (D) of the specimen.
3. Assemble the permeameter near a sink, Clean the Constant head permeameter then put the filter and fill it with the specimen.
4. Supply water using a plastic tube from the water inlet to the burette.
5. Allow the water to flow for some time in order to saturate the specimen.
6. Using the pinch cock, close the flow of water through. The specimen.
7. Measure the head difference, h1 & h2
8. Open the pinchcock. Water will flow through the burette to the specimen and then out of the funnel. Record time (t)
9. Determine the volume (Vw) of water that is drained from burette in cm^3.

VI. Experimental Work:

Test No.	**1**	**2**	**3**
Diameter of specimen, *D* (cm)			
Length of specimen, *L* (cm)			
Area of specimen, *A* (cm2)			
Beginning head difference, h1 (cm)			
Ending head difference, *h2* (cm)			
Test duration, *t* (sec)			
Volume of water flow through the specimen, *V* w (cm^3)			
K = (2.303) (al/At) log (h_1/ h_2)			

The relation can express the coefficient of permeability

$$k = 2.303\frac{aL}{At}\log\frac{h_1}{h_2}$$

Where a = inside cross-sectional area of the burette

Therefore:

$$a = \frac{V_w}{(h_1 - h_2)}$$

$$k = \frac{2.303V_wL}{(h_1 - h_2)tA}\log\frac{h_1}{h_2}$$

Experiment 8: Standard Proctor test.

I. Objective:

Determination of the relationship between water content and dry density of soil using Standard Proctor Test

II. Test Standard

ASTM D698 – 07. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3))

III. Theory:

It is required to compact the in-situ soil to produce a strong, settlement free, water-resistant mass. This test serves as a guide and a basis of comparison for field compaction.

These test methods covers laboratory compaction methods used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4 or 6-in. (101.6 or 152.4 mm) diameter mold with a 5.5-lbf (24.4-N) rammer dropped from a height of 12 in. (305 mm) producing a compacting effort of 12,400 ft-lbf/ft^3 (600 kN-m/m^3).

Dry density of soil (or dry unit weight) is defined as the weight of oven dry soil per unit volume of soil mass. Water content (or moisture content) is expressed as percentage of weight of water in a given soil mass to the weight of solid particles under a specified testing condition. Optimum water content is the water content of which a soil can be compacted to the maximum dry unit weight by a given compacting effort.

IV. Apparatus:

1. Proctor mould with a detachable collar assembly and base plate.
2. Manual rammer weighing 2.5 kg and equipped to provide a height of drop to a free fall of 30 cm.
3. Sample Extruder.
4. A balance accurate to 0.01 g.
5. Straight edge.
6. Squeeze bottle
7. Mixing tools such as mixing pan, spoon, trowel, spatula etc.

8. Moisture cans.

9. Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 $\pm$ 5°C throughout the drying chamber.

V. Procedure:

1. Obtain approximately 10 lb. (4.5 kg) of air-dried soil in the mixing pan, break all the lumps so that it passes No. 4 sieve.
2. Add approximate amount of water to increase the moisture content by about 5%.
3. Determine the weight of empty proctor mould without the base plate and the collar. M4 (g).
4. Fix the collar and base plate.
5. Place the first portion of the soil in the Proctor mould, Fig. 6.1 as explained in the class and compact the layer applying 25 blows.
6. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. Place the second layer, apply 25 blows, place the last portion and apply 25 blows.
7. The final layer should ensure that the compacted soil is just above the rim of the compaction mould when the collar is still attached.
8. Detach the collar carefully without disturbing the compacted soil inside the mould and using a straight edge trim the excess soil leveling to the mould.
9. Determine the weight of the mould with the moist soil M5 (g). Extrude the sample and break it to collect the sample for water content determination preferably from the middle of the specimen.
10. Weigh an empty moisture can, M1 (g) and weigh again with the moist soil obtained from the extruded sample in step9, M2 (g). Keep this can in the oven for water content determination.
11. Break the rest of the compacted soil with hand (visually ensure that it passes US Sieve No.4). Add more water to increase the moisture content by 2%.
12. Repeat steps 4 to 11. During this process the weight W2 increases for some time with the increase in moisture and drops suddenly. Take two moisture increments after the weights starts reducing. Obtain at least 4 points to plot the dry unit weight, moisture content variation.
13. After 24 hrs recover the sample in the oven and determine the weight M3 (g).

VI. Experimental Work:

Test	1	2	3	4
Moisture can number				
Mass of moisture can, M_1, (g)				
Mass of can + moist soil, M_2, (g)				
Mass of can + dry soil, M_3, (g)				
Moisture content: w (%) = $[(M_2-M_3)/(M_3-M_1)] \times 100$				
Mass of the mold without the base and collar, M_4, (g)				
Mass of the mold + moist soil, M_5 (g)				
Mass of the compacted soil, $M=M_5-M_4$, (g)				
Wet Density, $\gamma = [(M_5-M_4)/V]$, (kN/m^3)				
Dry unit weight of compaction: γ_d (lb/ft^3) = $\gamma/[1+(w/100)]$				

Experiment 9: Modified proctor test.

I. Objective:

Determination of the relationship between water content and dry density of soil using Modified Proctor Test

II. Test Standard

ASTM D1557 - 12e[1]. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))

III. Theory:

Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

These test methods cover laboratory compaction methods used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4- or 6-in. (101.6 or 152.4

mm) Diameter mold with a 10-lbf. (44.5-N) rammer dropped from a height of 18 in. (457 mm) producing a compacting effort of 56,000 ft-lbf/ft^3 (2,700 kN-m/m^3).

IV. Apparatus:

1. Proctor mold with a detachable collar assembly and base plate.
2. Manual rammer weighing 4.5 kg and equipped to provide a height of drop to a free fall of 45.7 cm.
3. Sample Extruder.
4. A balance accurate to 0.01 g.
5. Straight edge.
6. Squeeze bottle
7. Mixing tools such as mixing pan, spoon, trowel, spatula etc.

8. Moisture cans.
9. Thermostatically controlled oven, capable of maintaining a uniform temperature of 110 $\pm$ 5°C throughout the drying chamber.

V. Procedure:

1. Obtain approximately 10 lb. (4.5 kg) of air-dried soil in the mixing pan, break all the lumps so that it passes No. 4 sieve.
1. Add approximate amount of water to increase the moisture content by about 5%.
2. Determine the weight of empty proctor mold without the base plate and the collar. M4 (g).
3. Fix the collar and base plate.
4. Place the first portion of the soil in the Proctor mold as explained in the class and compact the layer applying 25 blows.
5. Scratch the layer with a spatula forming a grid to ensure uniformity in distribution of compaction energy to the subsequent layer. Place the second layer, apply 25 blows, place the last portion and apply 25 blows.
6. The final layer should ensure that the compacted soil is just above the rim of the compaction mold when the collar is still attached.
7. Detach the collar carefully without disturbing the compacted soil inside the mold and using a straight edge trim the excess soil leveling to the mold.
8. Determine the weight of the mold with the moist soil M_5 (g). Extrude the sample and break it to collect the sample for water content determination preferably from the middle of the specimen.
9. Weigh an empty moisture can, M_1 (g) and weigh again with the moist soil obtained from the extruded sample in step9, M_2 (g). Keep this can in the oven for water content determination.
10. Break the rest of the compacted soil with hand (visually ensure that it passes US Sieve No.4). Add more water to increase the moisture content by 2%.
11. Repeat steps 4 to 11. During this process the weight W_2 increases for some time with the increase in moisture and drops suddenly. Take two moisture increments after the weights starts reducing. Obtain at least 4 points to plot the dry unit weight, moisture content variation.
12. After 24 hrs. recover the sample in the oven and determine the weight M_3 (g).

VI. Experimental Work:

Test	1	2	3	4
Moisture can number				
Mass of moisture can, M_1, (g)				
Mass of can + moist soil, M_2, (g)				
Mass of can + dry soil, M_3, (g)				
Moisture content: w (%) = $[(M_2-M_3)/(M_3-M_1)] \times 100$				
Mass of the mold without the base and collar, M_4, (g)				
Mass of the mold + moist soil, M_5 (g)				
Mass of the compacted soil, $M=M_5-M_4$, (g)				
Wet Density, $\gamma = [(M_5-M_4)/V]$, (kN/m^3)				
Dry unit weight of compaction: γ_d (lb/ft^3) = $\gamma/[1+(w/100)]$				

Experiment 10: Determination of Density of Soil In place By the Sand Cone Method

I. Objective:

To find the density of the soil compacted on site for road or building foundation.

II. Test Standard

ASTM D1556 / D1556M - 15e1. Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method

III. Theory:

This test method is used to determine the density and water content of compacted soils placed during the construction of earth embankments, road fill, and structural backfill. It often is used as a basis of acceptance for soils compacted to a specified density or percentage of a maximum density determined by a test method, such as Test Methods D698 or D1557.

IV. Apparatus:

The equipment for determining Density of Soil In place Test includes:

1. Sand cone apparatus consisting of a one-gallon glass or plastic bottle with a metal cone attached to it
2. Base plate
3. One gallon can with cap
4. Tools to dig a small hole in the field
5. Balance
6. 20 -30 Ottawa sand
7. Proctor compaction mold without attached extension
8. Steel straightedge

V. Procedure:

1. Determine the weight of the Proctor compaction mold, M1.
2. Using a spoon, fill the compaction mold with 20-30 Ottawa sand. When the mold is full, strike off the top of the mold with the steel straightedge. Determine the weight of the mold and sand, M2.
3. Determine the weight of the Ottawa sand that is required to fill the cone. This can be done by filling the one-gallon bottle with Ottawa sand. Determine the weight of the bottle + cone + sand, M3. Close the valve of the cone, which is attached to the bottle.

Place the base plate on a flat surface. Turn the bottle with the cone attached to it upside down and place the open mouth of the cone in the center hole of the base plate. Open the cone valve. Sand will flow out of the bottle and gradually fill the cone. When the cone is filled with sand, the flow of sand from the bottle will stop. Close the cone valve. Remove the bottle and cone combination from the base plate and determine its weight, M4. M5 = M3 – M4. (The weight of a cone full of sand).

4. For preparation of fieldwork. Fill the one-gallon bottle (with sand cone attached to it) with sand. Close the valve of the cone. Determine the weight of the bottle + cone + sand, M5 (before use).
5. Now proceed to the field with the bottle and the cone attached to it and is filled with Ottawa sand, with the base plate, the digging tools, and the one gallon-can with its cap.
6. Place the base plate on a level ground in the field. Under the center hole of the base plate, dig a hole in the ground using the digging tools. The volume of the hole should be smaller than the volume of the sand in the bottle minus the volume of the cone.
7. Remove all the loose soil from the hole and put it in the gallon can. Close the cap tightly so as not to lose any moisture. Be careful not to move the base plate.
8. Turn the gallon bottle filled with sand, with the cone attached to it, upside down and place it on the center of the base plate. Open the valve of the cone. Sand will flow from the bottle to fill the hole in the ground and the cone. When the flow of sand from the bottle stops, close the valve of the cone and remove it.
9. Bring all the equipment back to the laboratory. Determine the weight of the gallon can + moist soil from the field, M7. Also, determine the weight of the bottle + can + sand, M6 (after use).

VI. Experimental Work:

Item	Quantity
Calibration of unit weight of Ottawa Sand	
Weight of Proctor mold, M1	
Weight of Proctor mold and Sand, M2	
Volume of mold, V1	
Dry unit weight, $\gamma_d = \frac{M2-M1}{V1} \times 9.81$ (N/ cm3)	
Calibration of Cone	
Weight of Bottle + cone + sand (before use), M3	
Weight of Bottle + cone + sand (after use), M4	
Weight of sand to fill cone, M5=M3 – M4	
Weight of Bottle + cone + sand (before use), M6 = M4	
Weight of Bottle + cone + sand (after use), M7	
Volume of hole, V2 = $\frac{M6-M7-M5}{\gamma d}$	
weight of soil from filed, M8	
Density of soil in the field	

Experiment 11: Determination of direct shear strength of a given soil sample

I. Objective:

To familiarize the students with the procedure of evaluating the direct shear strength of a molded or undisturbed soil sample.

II. Test Standard

ASTM D3080 – 04. Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

III. Theory:

The shear strength, s, of a granular soil may be expressed by the equation: $S = \sigma' * \tan(\varphi\mu)$
The angle of friction is a function of the relative density, of compaction of sand, grain size, shape and distribution in a given soil mass. For a given sand, an increase in the void ratio (i.e., a decrease in the relative density of compaction) will result in a decrease of the magnitude of φ. However, for a given void ratio, an increase in the angularity of the soil particles will give a higher value of the soil friction angle

IV. Apparatus:

1. Direct shear test machine (strain controlled)
2. Large porcelain evaporating dish
3. Tamper (for compacting sand in the direct shear box)"

V. Procedure:

- Remove the shear box assembly
2 - Fill the shear box with sand in small layers.
3 - Determine the dimensions of the soil specimen
4 - Slip the loading head down from the top of the shear box to rest on the soil specimen.
5 - Put the shear box assembly in place in the direct shear machine
6 - Apply the desired normal load. *N*
7 - Remove the two vertical pines
8 - Advance the three vertical screws that are located on the side walls of the top half of
the shear boxes.

9 - Set the loading head by tightening the two horizontal screws located at the top half
of the shear box

10 - Attach the horizontal and vertical dial gauges

11 - Apply horizontal load, S, to the top half of the shear box.

VI. Experimental Work:

Sample NO.	Normal Load (N)	Shear Load (N)	Normal Stress (KPa)	Shear Stress (KPa)
1				
2				
3				

Shear stress at failure can be found by $\tau_f = C + (\emptyset)$ where C is the cohesion and angle of friction. From the graph we can get the Cohesion where C is the y intercept in the graph.

Experiment 12: Determination of unconfined compressive shear strength of a given soil sample

I. Objective:

To familiarize the students with the procedure of evaluating the indirect shear strength of a cohesive soil sample.

II. Test Standard

ASTM D2166 / D2166M – 16. Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

III. Theory:

Shear strength of a soil can be given by the Mohr-Coulomb failure criteria as

$$s = c + \sigma + \tan^{\phi}$$

The unconfined compression test is a quick method of determining the value of C_u for a clayey soil. The unconfined strength is given by the relation [for further discussion see any soil mechanics text

$$q_u = \frac{c_u}{2}$$

IV. Apparatus:

1. Unconfined compression testing device
2. Specimen trimmer and accessories (if undisturbed field specimen is used)
3. Harvard miniature compaction device and accessories (if a specimen is to be molded for classroom work)
4. Scale
5. Balance sensitive to 0.01 g
6. Oven
7. Porcelain evaporating dish

V. Procedure:

1 - Prepare a soil specimen for the test
2 - Measure the diameter *(D)* and length *(L)* of the specimen and determine the mass of the specimen.
3 - Place the specimen centrally between the two loading plates of the unconfined compression-testing machine
4 - Turn the machine on. Record loads
5 - Continue taking readings until
  a - Load reaches a peak and then decreases; or

b - Load reaches a maximum value
d - Deformation of the specimen is past 20%

6 - Unload the specimen by lowering the bottom loading plate
7 - Remove the specimen from between the two loading plates
8 - Draw a free-hand sketch of the specimen after failure
9 - Put the specimen in a porcelain-evaporating dish and determine the moisture content

VI. Experimental Work:

Axial Deformation (ΔL)	**Axial Load (P)**	**Axial Strain ($\varepsilon = L/L_o$)**	**Corrected Area ($A = A_o/(1-\varepsilon)$)**	**Deviator Stress ($\Delta\sigma = P/A$)**

Experiment 13: Determination of amount and rate of consolidation of a given soil sample

I. Objective:

To familiarize the students with the procedure of evaluating the amount and rate of consolidation with time for a given soil sample

II. Test Standard

ASTM D2435 / D2435M - 11(2020). Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading.

III. Theory:

All soils are compressible so deformation will occur whenever stress is applied to soils. Soil minerals and water are both incompressible. Therefore, when saturated soils are loaded, the load first acts on the pore water causing pore water pressures that are in excess of the hydrostatic pressures. The excess pore water pressures are largest near the application of load and decrease with distance from the loading. The variations in excess pore water pressure cause total head gradients in the soil which, according to Darcy's Law, will induce water to flow from locations of high total head to low total head. The excess pore water pressures dissipate as water flows from the soil and, to compensate for the applied stress, the stress is transferred to the soil minerals resulting in higher effective soil stress. The flow of water from the soil also causes reductions in the soil volume and settlements at the ground surface. Fine-grained soils have very low permeability so they can require substantial periods of time before the excess pore water pressures fully dissipate. This process of time-dependent settlement is referred to as consolidation. Terzaghi's theory for one-dimensional consolidation provided the means to calculate the total amount of consolidation settlement and the consolidation settlement rate. In practice, engineers obtain representative soil samples, conduct consolidation tests and use Terzaghi's consolidation theory to predict the total settlement and time rate of settlement for embankments and foundations.

IV. Apparatus:

1. Consolidation device (including ring, porous stones, water reservoir, and load plate)
2. Dial gauge (0.0001 inch = 1.0 on dial)
3. Sample trimming device
4. Glass plate
5. Metal straight edge
6. Clock
7. Moisture can
8. Filter paper

V. Procedure:

1) - Apply increments of total stress to the soil specimen. The duration of each increment should be sufficient to define the characteristic curve obtained by a graph of deformation versus either the square root of time or the log of time.

2) The standard loading schedule is determined using a load increment ratio (LIR) of one, obtained by doubling the total stress on the soil. The load values should be 17.1, 34.2, 68.3, 136.7, 273.3, 546.7 kPa.

3) For each load increment, record the dial readings at time intervals of approximately 0.09, 0.25, 0.49, 1, 4, 9, 16, 25, 36, 49, 64, 81 and 100 minutes to obtain the deformations, d.

4) After completion of all load increments, remove the soil from the consolidometer and determine the final water content.

VI. Experimental Work:

Time after load application, t (min.)	$\sqrt{t}$ (min.)$^{0.5}$	Vertical dial reading (in.)	Time after load application, t (min.)	$\sqrt{t}$ (min.)$^{0.5}$	Vertical dial reading (in.)

Experiment 14: Determination of triaxial shear strength of a given soil sample

I. Objective:

To determine the triaxial shear strength of a given soil sample.

II. Test Standard

ASTM D2850 – 15. Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils.

III. Theory:

Conventional triaxial test involves subjecting a cylindrical soil sample to radial stresses (confining pressure) and controlled increases in axial stresses or axial displacements. The cylindrical soil specimen is usually of the dimension of 100 mm diameter and 200 mm height. The specimen in vertically enclosed in a thin rubber membrane. The specimen preparation depends on the type of the soil. Samples of cohesive soils are often prepared directly from saturated compacted samples, either undisturbed or remolded. For cohesion-less soils, however, the specimen is prepared with the help of a mold that maintains the required shape of the specimen.

The specimen is vertically enclosed with a thin rubber membrane and placed between two rigid ends inside a pressure chamber. The upper plate can move vertically and apply vertical stresses to the specimen. The axial strain/stress of the sample is controlled through the movement of this vertical axis. In addition, the water pressure surrounding the sample in the pressure chamber controls the confining pressure. The volume change of the sample is also controlled by measuring the exact volume of moving water.

Depending on the combination of loading and drainage condition, three main types of triaxial tests can be carried out:

Consolidated – Drained (CD)
Consolidated – Undrained (CU)
Unconsolidated - Undrained (UU)

IV. Apparatus:

The triaxial test apparatus consist of the following parts as shown in figures;

1- Triaxial cell

2- Upper Drainage Valve

3- Lower Drainage Valve

4- Cell pressure Control Valve

5- Proving ring

6- Pressure controller

7- Pressure Gauge

8- Bladder for water pressure control

V. Procedure:

1- Place the triaxial cell Fig. 8.1 (with the specimen inside it) on the platform of the compression machine.

2- Make proper adjustments so that the piston of the triaxial cell just rests on the top platen of the specimen

3- Fill the chamber of the triaxial cell with water. Apply a hydrostatic pressure, σ3 to the specimen through the chamber fluid.

4- All drainage valves should be closed so that drainage from the specimen does not occur.

5- Check for proper contact between the piston and the top platen on the specimen. Zero the dial gauge of the proving ring and the gauge used for measurement of the vertical compression of the specimen. Set the compression machine for a strain rate of about 0.5% per minute, and tum the switch on.

6- Take initial proving ring dial readings for vertical compression intervals of 0.01 in. This interval can be increase to 0.02 in. or more later when the rate of increase of load on the specimen decreases. The proving ring readings will increase to a peak value and then may decrease or remain approximately constant. Take about four to five readings after the peak point.

7- After completion of the test, reverse the compression machine; lower the triaxial cell, and then tum off the machine. Release the chamber pressure and drain the water in the triaxial cell. Then remove the specimen and determine its moisture content.

VI. Experimental Work:

Axial Deformation (ΔL)	Axial Load (P)	Axial Strain ($\varepsilon = L/ L_o$)	Corrected Area ($A = A_o/(1- \varepsilon)$)	Deviator Stress ($\Delta\sigma = P/A$)