

LABORATORY MANUAL



011509P: Soil Mechanics Laboratory

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SYLLABUS**SOIL MECHANICS LABORATORY**

1. Identification of gravel type, sand type, silt type and clay types soils; Tests for determination of Specific gravity (for coarse and fine grained soils) and Water content (Oven drying method).
2. Grain size analysis of soil sample (sieve analysis).
3. In situ density by core cutter and sand replacement methods.
4. Consistency Limits – Liquid Limit (Casagrande and Cone Penetration Methods), plastic limit and shrinkage limit.
5. Standard Proctor Compaction Test and Modified Proctor Compaction Test.
6. Coefficient of permeability by constant head and variable head methods.

Course objectives:

This course will enable students to

1. Determine the type and properties of the soil.
2. Determine the compaction strength of the soil.
3. Determine the strength characteristics of the soil.
4. Determine the permeability of the soils.
5. Determine the amount of consolidation occurring the soil.

Course outcomes:

After a successful completion of the course, the students will be able to

1. Draw the particle size distribution curve and to find the particle size.
2. To find the MDD and OMC.
3. To find the CBR of the soil.
4. To find the SBC of the soil.
5. To find the consistency limits of the soil.

Do's

1. Bring observation note books, lab manuals and other necessary things for the class.
2. Use tools for mixing concrete and water
3. Check the instruments for proper working conditions while taking and returning the same.
4. Thoroughly clean your laboratory work space at the end of the laboratory session.
5. Maintain silence and clean environment in the lab

Don'ts

1. Do not operate the machines without the permission of the staff
2. Do not put hands or head while equipment is in running condition.
3. Do not fix or remove the test specimen while the main is switch on.
4. Do not spill the concrete and aggregates on the floor.

List of Experiments

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EXPERIMENT NO. 1

DATE: _____

DETERMINATION OF SPECIFIC GRAVITY OF SOIL SOLIDS BY PYCNOMETER METHOD

Aim: To determine the specific gravity of soil solids by Pycnometer bottle method.

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.

Specification:

This test is specified in IS: 2720 (Part 4) – 1985. A soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. However, as a general guide, some typical values for specific soil types are as follows:

- The specific gravity of the solid substance of most inorganic soils varies between 2.60 and 2.80.
- Tropical iron-rich laterite, as well as some lateritic soils, usually have a specific gravity of between 2.75 and 3.0 but could be higher.
- Sand particles composed of quartz have a specific gravity ranging from 2.65 to 2.67.
- Inorganic clays generally range from 2.70 to 2.80.
- Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) have specific gravities below 2.60. Some range as low as 2.00.

Equipments Required:

- a) Pycnometer of about 1 litre capacity
- b) Balance accurate to 1 g, glass rod, de-aired distilled water etc.

Theory:

Specific gravity of soil solids is defined as the weight of soil solids to weight of equal volume of water. In effect, it tells how much heavier (or lighter) the material is than water. This test method covers the determination of the specific gravity of soil solids that pass 4.75 mm sieve.

Equation for specific gravity, G:

$$G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$$

Where, W_1 = weight of Pycnometer in grams.

W_2 = weight of Pycnometer + dry soil in grams.

W_3 = weight of Pycnometer + soil + water grams.

W_4 = weight of Pycnometer + water grams.

Precautions:

- Soil grains whose specific gravity is to be determined should be completely dry.
- If on drying soil lumps are formed, they should be broken to its original size.
- Inaccuracies in weighing and failure to completely eliminate the entrapped air are the main sources of error. Both should be avoided.
- While cleaning the glass jar, please be careful as there may be glass grains projecting out and it may tear the skin.
- Make sure, you handle the glass jar and conical cap without falling on your legs or floor. Hence, handle the equipment with care.

Procedure:

- a) Clean and dry the pycnometer and weigh it along with the conical cap (W_1 in gm).
- b) Select about 300 gm of dry soil free of clods and put the same into the pycnometer. Weigh it (W_2 in g) with cap and washer.
- c) Fill the pycnometer with de-aired water up-to half its height and stir the mix with a glass rod. Add more water and stir it. Fit the screw cap and fill the pycnometer flush with the hole in the conical cap and take the weight (W_3 in g).
- d) Remove all the contents from the pycnometer, clean it thoroughly and fill it with distilled water. Weigh it (W_4 in g).
- e) Now use the above equation for determining G.
- f) Repeat the same process for additional tests.

Pre-Viva Questions:

1. Why we need to compute the specific gravity of soil?
2. What is the unit of specific gravity?
3. What is specific gravity of water?
4. Explain the steps required to determine specific gravity by Pycnometer method

5. What are the calculations required in computing specific gravity by Pycnometer method?

OBSERVATION Table:

Table 1: Weights of Pycnometer

Sl. No.	Particulars	Test No 1 (G1)	Test No 2 (G2)	Test No 3 (G3)
1	Weight of Pycnometer bottle (W_1), g			
2	Weight of Pycnometer + dry soil (W_2),g			
3	Weight of Pycnometer + soil + water, (W_3), g			
4	Weight of Pycnomerter + water (W_4), g			
5	Calculation of specific gravity, G			
6	Average G = $(G1+G2+G3)/3$			

Specimen calculations:

$$G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$$

Result:

AVERAGE VALUE OF G =

Verification/ Validation:

The value of specific gravity for the existing soil falls in the range 2.6 to 2.75. If there is any variation, check under the 'specification' provided and re-do the experiment to get accurate results.

Conclusion:

The experiment is conducted as per the procedure laid down. The specific gravity of soil solids obtained is _____. This value falls in the range 2.6 to 2.75. Hence the type of soil is _____.

Post - Viva Questions:

1. What are the standard values of specific gravity?
2. Do we need to conduct this test? Why?

3. What is your inference on the result obtained?
4. Can we use this method for all types of soils?
5. Write phase diagrams for a) Dry soil b) Saturated soil.

EXPERIMENT NO. 2

DATE: _____

DETERMINATION OF SPECIFIC GRAVITY OF SOIL SOLIDS BY DENSITY BOTTLE METHOD

Aim: To determine the specific gravity of soil solids by Density bottle method.

Specific gravity G is defined as the ratio of the weight of an equal volume of distilled water at that temperature, both weights taken in air.

Specification:

IS 2720 (Part III) – 1980 is the standard recommended to determine specific gravity of fine grained soils. The value ranges are same as the previous experiment. The average of the values obtained shall be taken as the specific gravity of the soil particles and shall be reported to the nearest 0.01 precision. If the two results differ by more than 0.03 the tests shall be repeated.

Equipments Required:

1. 50 ml capacity density bottle with stopper
2. A constant temperature water bath (27 ° C)
3. Oven with a range of 105 to 110 °C
4. Vacuum desiccators
5. Vacuum pump
6. Other accessories, such as, weighing balance accurate to 0.001 g, trays, wooden mallet, etc.

Theory:

Specific gravity of soil solids is defined as the weight of soil solids to weight of equal volume of water.

Equation for specific gravity, G :

$$G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$$

Where, W_1 = weight of empty bottle
 W_2 = weight of bottle + dry soil
 W_3 = weight of bottle + soil + water
 W_4 = weight of bottle + water

Precautions:

- Soil grains whose specific gravity is to be determined should be completely dry.
- If on drying soil lumps are formed, they should be broken to its original size.
- Inaccuracies in weighing and failure to completely eliminate the entrapped air are the main sources of error. Both should be avoided.
- While cleaning the density bottle, please be careful as there may be glass grains projecting out and it may tear the skin.
- Make sure, you handle the density bottle without falling on your legs or floor. Hence, handle the equipment with care.

Procedure:

- a) Clean and dry the density bottle and weigh it along with the stopper (W_1 in g).
- b) Select about 25 gm of dry soil free of clods and put the same into the density bottle. Weigh it with brass cap and washer (W_2 in g).
- c) Fill the density bottle with de-aired water upto half its height and stir the mix with a glass rod. Add more water and stir it. Place the stopper on top and take the weight (W_3 in g).
- d) Remove all the contents from the density bottle, clean it thoroughly and fill it with distilled water. Weigh it (W_4).
- e) Use above equation for determining G.
- f) Repeat the same process for additional tests.

Pre-Viva Questions:

1. Which method is accurate in determining specific gravity of soil solids?
2. What are the steps involved in determining specific gravity using density bottle method?
3. How much grams of soil need to be taken for the test?
4. What is the specification required for the test?
5. What is the equation to determine the specific gravity?

Observation Table:**Table 2: Weights of density bottle**

Sl No	Particulars	Test No 1 (G1)	Test No 2 (G2)	Test No 3 (G3)
1	Weight of density bottle (W_1), g			
2	Weight of bottle + dry soil (W_2), g			
3	Weight of bottle + soil + water (W_3), g			
4	Weight of bottle + water (W_4), g			
5	Specific Gravity, G			
6	Average G, $(G1+G2+G3)/3$			

Specimen calculations:

$$G = (W_2 - W_1) / ((W_2 - W_1) - (W_3 - W_4))$$

Result:

AVERAGE G =

Verification/ Validation:

The value of specific gravity for the existing soil falls in the range 2.6 to 2.75. If there is any variation, check under the 'specification' provided and re-do the experiment to get accurate results.

Conclusion:

The experiment is conducted as per the procedure laid down. The specific gravity of soil solids = _____. The value falls in the range 2.6 to 2.75. The type of soil is _____ as per the specification.

Post- Viva Questions:

1. Can we use kerosene instead of water to determine specific gravity of soil?
2. Could we do classification of soil based on the specific gravity of soil?
3. Could there be entrapped air in the soil sample?
4. What are the various sources of error in this experiment, if any?
5. What are the applications in geotechnical engineering where the specific gravity is used?

EXPERIMENT NO. 3

DATE: _____

DETERMINATION OF WATER CONTENT OF SOIL SOLIDS BY OVEN DRYING METHOD

Aim: To determine the water content of soil solids by Oven Drying method.

The water content (w) of a soil sample is equal to the mass of water divided by the mass of solids.

Specifications:

This test is done as per IS: 2720 (Part II) – 1973. The soil specimen should be representative of the soil mass. The quantity of the specimen taken would depend upon the gradation and the maximum size of the particles. For more than 90% of the particles passing through 425 micron IS sieve, the minimum quantity is 25g.

Equipments Required:

- a) Non-corrodible airtight containers.
- b) Balance weighting to accuracy of 0.04% of the weight of the soil taken for test.
- c) Desiccators with suitable desiccating agent.
- d) Thermostatically controlled oven to maintain temperature $110\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$.
- e) Other accessories.

Theory:

In almost all soil tests natural moisture content of the soil is to be determined. The knowledge of the natural moisture content is essential in all studies of soil mechanics. To sight a few, natural moisture content is used in determining the bearing capacity and settlement. The natural moisture content will give an idea of the state of soil in the field. Water content, w of a soil mass is defined as the ratio of mass of water in the voids to the mass of solids:

$$W = (W_2 - W_3) / (W_3 - W_1) \times 100 \%$$

Where, W_1 = Weight of empty container in grams

W_2 = Weight of container + wet soil in grams

W_3 = Weight of container + dry soil in grams

Precautions:

- Ensure that soil samples are between 350 to 400g. Larger samples take too long to dry, while smaller samples lead to inaccurate results.
- Ensure that the oven temperature is maintained at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Do not allow the oven door to stay open for too long, as it takes a while for the oven to regain the drying temperature.
- Do not put moist samples in the oven on a shelf below dry samples. Moist samples should be placed on the top shelf and all partially dried samples placed on the lower shelf.
- Do not over-load the oven, as this will create a much longer drying time.
- Do not allow dried samples to pick up moisture after they are removed from the oven. Weigh them immediately after drying.
- Soils and aggregates may contain bacteria and/or organisms which can be harmful for one's health. Wearing dust masks and protective gloves when handling materials is advised. The use of heat resistant gloves/mitts or pot holders to remove samples from the ovens is recommended.
- Prior to handling oven, testing or disposing of any waste materials, students are required to read do's and don'ts of the Geotechnical engineering laboratory.

Procedure:

- a) Clean the container with lid and find the mass (W_1 in g).
- b) Select the required quantity of moist soil sample, place it in the container, place the lid on it, and weigh it (W_2 in g).
- c) Keep the container in the oven with lid removed and dry it for at least 24 hr. at a temperature of 110°C till the mass remains constant.
- d) Remove the container from the oven, replace the lid, and cool it in desiccators. Find the mass (W_3 in g).
- e) Determine the water constant w by using the above equation.
- f) Repeat the experiment with other test samples

Pre-viva Questions:

1. Water content is also called?
2. Which method is mostly used to determine the water content in field?
3. What is water content for clay soil?
4. On which factor water content is depended?
5. Ground Penetrating Radar (GPR) method is also used for measuring water content (True or False?)
- 6 Name different types of soil textures?
7. The percentage of water remaining in an air-dry soil is called _____.

Observation Table:**Table 3: Weights of container**

SI No	Particulars	Test No1 (w ₁)	Test No2 (w ₂)	Test No3 (w ₃)
1	Weight of empty container (W ₁), g			
2	Weight of container + wet soil (W ₂), g			
3	Weight of container + dry soil (W ₃), g			
4	Water content, w			
5	Average water content, $w = (w_1 + w_2 + w_3)/3$			

Specimen calculations:

$$W = (W_2 - W_3) / (W_3 - W_1) \times 100 \%$$

Result:

Average of w =

Verification/ Validation:

Soil mass is generally a three phase system. It consists of solid particles, liquid and gas. The phase system may be expressed in SI units either in terms of mass-volume or weight volume relationships. Water content value is 0% for dry soil and its magnitude can exceed 100%.

Conclusion:

The experiment is conducted as per the procedure laid down. The water content of the soil sample is determined. Water content, w = ____%. The value is verified and the three phase system is sketched.

Post-Viva Questions

1. Draw the schematic diagram of the three phase system based on the result.
2. Is there a possibility of the soil getting burnt? In that case, what will be effect on the water content value?
3. How does air-dry soil differ from oven-dry soil?
4. Is this method the most direct method to compute the water content of soil?
5. To get accurate result, how much gram of soil have you taken to conduct the test?

EXPERIMENT NO. 04

DATE: _____

DETERMINATION OF WATER CONTENT OF SOIL SOLIDS BY PYCNOMETER METHOD

Aim: To determine the water content of soil solids by Pycnometer bottle Method.

To determine water content by this method, the value of G should have been determined prior.

Specifications:

This test is done as per IS: 2720 (Part II) – 1973. This method is suitable for coarse grained soils from which the entrapped air can be easily removed.

Equipments Required:

1. Pycnometer of 1000 ml capacity with a brass conical cap.
2. Balance accurate to 1 g.
3. Glass rod other accessories.

Theory:

A Pycnometer is a glass jar of about 1 liter capacity, fitted with a brass conical cap by means of a screw type cover. The cap has a small hole of about 6mm diameter at its apex. 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.

Water content, w of a soil mass is defined as the ratio of mass of water in the voids to the mass of solids:

$$\text{Water content, } W \text{ (in \%)} = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)} \times \left(\frac{G - 1}{G} \right) - 1 \right] \times 100$$

Where, W_1 = Weight of empty pycnometer in grams

W_2 = Weight of pycnometer + wet soil in grams

W_3 = Weight of pycnometer + dry soil in grams

W_4 = Weight of pycnometer + water in grams

Procedure:

- a) Clean and dry the pycnometer and weigh it (W_1 in g).
- b) Select a mass of wet soil of about 300 gm and place the same in pycnometer and weigh it (W_2 in g).
- c) Fill the pycnometer with distilled water up-to half its height and stir the mix with a glass rod. Keep on adding more water till the mix is flush with the hole in the conical cap. Dry the pycnometer outside and find the mass (W_3 in g).
- d) Remove the contents of PM and clean it. Fill with clean water up-to the top level of the hole in the cap weigh it (W_4 in g).
- e) Now use the above equation for determining water content, where, G value is taken from Experiment No 1 (Determination of specific gravity by pycnometer method) for the given soil.

Pre-Viva Questions:

1. A pycnometer is used to determine?
2. Other than pycnometer, is there any other method to determine water content?
3. Which method is more accurate to determine water content, oven drying method or pycnometer method?
4. If there are lots of clods in the soil, what would happen to the result? Is it advisable to have lots of organic matter in the soil?
5. Explain the procedure to determine the water content using pycnometer?

ObservationTable:**Table 4: Weights of pycnometer**

Sl No	Particulars	Test No1 (w_1)	Test No2 (w_2)	Test No3 (w_3)
1	Weight of empty pycnometer (W_1), g			
2	Weight of pycnometer + wet soil (W_2), g			
3	Weight of pycnometer + soil + water (W_3), g			
4	Weight of pycnometer + water (W_4), g			
5	Water content, w			
6	Average water content, Avg w			

Specimen calculations:

$$W \% = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)} \times \left(\frac{G - 1}{G} \right) - 1 \right] \times 100$$

$$\text{Average water content, } w = \frac{(w_1 + w_2 + w_3)}{3}$$

Result:

Average water content, $w = \text{_____}\%$

Verification/ Validation:

Soil mass is generally a three phase system. It consists of solid particles, liquid and gas. The phase system may be expressed in SI units either in terms of mass-volume or weight volume relationships. Water content value is 0% for dry soil and its magnitude can exceed 100%.

Conclusion:

Pycnometer method is a simple method to determine the water content of a soil. Experiment is carried out using the soil specimen collected from the college itself. All foreign matters are removed, clods broken and water content we got for the soil specimen is _____.

Comparing with the oven drying method, the value is _____.

Post-Viva Questions:

1. Draw the schematic diagram of the three phase system based on the result.
2. Is there a possibility of error by this method? In that case, what need to be done?
3. Which method gives the water content value rapidly, pycnometer method or oven drying method?

EXPERIMENT NO. 5

DATE: _____

DETERMINATION OF IN-SITU DENSITY BY CORE CUTTER METHOD

Aim: To determine the field density or unit weight of soil by Core cutter method.

Field density is used in calculating the stress in the soil due to its overburden pressure. It is needed in estimating the bearing capacity of soil foundation system, settlement of footing, earth pressures behind the retaining walls and embankments. Stability of natural slopes, dams, embankments and cuts is checked with the help of density of soil. It is the density that controls the field compaction of soils. Permeability of soils depends upon its density. Relative density of cohesionless soils is determined by knowing the dry density of soil in natural, loosest and densest states. Void ratio, porosity and degree of saturation need the help of density of soil.

Specifications:

This test is done to determine the in-situ dry density of soil by core cutter method as per IS-2720-Part-29 (1975). Core cutter method in particular, is suitable for soft to medium cohesive soils, in which the cutter can be driven. It is not possible to drive the cutter into hard and boulder soils.

Equipments Required:

- 1) Cylindrical core cutter, 100mm internal diameter and 130mm long.
- 2) Steel dolly, 25mm high and 100mm internal diameter.
- 3) Steel rammer mass 9kg, overall length with the foot and staff about 900mm.
- 4) Balance, with an accuracy of 1g.
- 5) Palette knife, Straight edge, steel rule etc.
- 6) Square metal tray – 300mm x 300mm x 40mm.
- 7) Trowel.

Theory:

Field density is defined as weight per unit volume of soil mass in the field at in-situ conditions. In the spot adjacent to that where the field density by sand replacement method has been determined or planned, drive the core cutter using the dolly over the core cutter. Stop ramming when the dolly is just proud of the surface. Dig out the cutter

containing the soil out of the ground and trim off any solid extruding from its ends, so that the cutter contains a volume of soil equal to its internal volume which is determined from the dimensions of the cutter. The weight of the contained soil is found and its moisture content determined.

Equations are;

$$\gamma_d = \gamma_b / (1+w) \text{ gm/cm}^3$$

OR $\gamma_d = \gamma_b / (1+w) \text{ kN/m}^3$

Where,

γ_d = dry unit weight in g/cm^3 ,

γ_b = field moist unit weight in g/cm^3 ,

w = water content %/100,

γ_w = unit weight of water = 9.81 kN/m^3

Precautions:

1. Core cutter method of determining the field density of soil is only suitable for fine grained soil (Silts and clay). That is, core cutter should not be used for gravels, boulders or any hard surface. This is because collection of undisturbed soil sample from a coarse grained soil is difficult and hence the field properties, including unit weight, cannot be maintained in a core sample.
2. Core cutter should be driven into the ground till the steel dolly penetrates into the ground half way only so as to avoid compaction of the soil in the core.
3. Before lifting the core cutter, soil around the cutter should be removed to minimize the disturbances.
4. While lifting the cutter, no soil should drop down.

Procedure:

- a) Measure the height and internal diameter of the core cutter to the nearest 0.25 mm.
- b) Calculate the internal volume of the core-cutter V_c in cm^3 .
- c) Determine the weight of the clean cutter accurate to 1 g (W_1 in g).
- d) Select the area in the field where the density is required to be found out. Clean and level the ground where the density is to be determined.
- e) Place the dolly over the top of the core cutter and press the core cutter into the soil mass using the rammer. Stop the pressing when about 15mm of the dolly protrudes above the soil surface.

- f) Remove the soil surrounding the core cutter by digging using spade, up to the bottom level of the cutter. Lift up the cutter and remove the dolley and trim both sides of the cutter with knife and straight edge.
- g) Clean the outside surface of the cutter and determine mass of the cutter with the soil (W_2 in g).
- h) Remove the soil core from the cutter and take the representative sample in the water content containers to determine the moisture content
- i) The field test may be repeated at other places if required.
- j) The water content of sample collected is determined in the laboratory as per Experiment no 3 (*Determination of water content of soil solids by Oven Drying Method*).
- k) Use the above equation, given the theory section, for determining density of soil (γ_d OR ρ_d).

Pre-Viva Questions:

1. Out of wet density, dry density, and saturated density, which one of them is maximum and minimum? Explain.
2. What are the main factors which affect in-situ density of soil? Explain.
3. Beside the density, what other properties do you need to calculate the void ratio and degree of saturation of soils?
4. What are the other methods to calculate the field density of soil?
5. Which is the most accurate method to determine the field density?

Observations:

Height of core cutter = ----- cm

Diameter of core cutter (d) = ----- cm

Volume of core cutter (V_c) = ----- cm

Table:

Table 5: Weights of core cutter

Sl.No.	Particulars	Test Nos.		
		1 (γ_{d1})	2 (γ_{d2})	3 (γ_{d3})
1.	Weight of empty cutter (W_1), gms			
2.	Weight of cutter + wet soil (W_2), gms			
3.	Volume of core cutter (V_c) cm^3			
4.	Weight ass of empty container (W_3), gms			
5.	Weight of container + wet soil (W_4), gms			
6.	Weight of container + dry soil (W_5), gms			
7.	Water content (w)= $(W_4-W_5)/(W_5-W_3)$			
8.	Field moist density γ_b (kN/m^3) = $(W_2-W_1)/V_c$			
9.	Dry density γ_d (kN/m^3) = $\rho_t / (1+w)$			
10.	Average density, Avg γ_d			

Specimen calculations:

$$\text{Average } \gamma_d = (\gamma_{d1} + \gamma_{d2} + \gamma_{d3})/3$$

Result:

Average in-situ field dry density: = -----

Verification/ Validation:

The dry density of most soils varies within the range of $1.1-1.6 \text{ g/cm}^3$. In sandy soils, dry density can be as high as 1.6 g/cm^3 ; in clayey soils and aggregated loams, it can be as low as 1.1 g/cm^3 .

Conclusion:

The value of dry density of the soil is _____. The type of soil is _____.

Post-Viva Questions:

1. Can we use core cutter method on stony or non-cohesive soils?

2. Which method is more accurate, sand replacement method or core cutter method?
3. What is the practical application of the current test?
4. Do we get undisturbed sample using core cutter?
5. Why is field density required?
6. Out of wet density, dry density, and saturated density, which one of them is maximum and minimum? Explain

EXPERIMENT NO 6

DATE: _____

DETERMINATION OF IN-SITU DENSITY BY SAND REPLACEMENT METHOD

Aim: To determine in-situ density of natural or compacted soil using Sand replacement method.

The in-situ density of natural soil is needed for the determination of bearing capacity of soils, for the purpose of stability analysis of slopes, for the determination of pressures on underlying strata for the calculation of settlement and the design of underground structures. Moreover, dry density values are relevant both of embankment design as well as pavement design.

Specifications:

This test is done to determine the in-situ dry density of soil by core cutter method as per IS-2720-Part-28 (1975). In order to conduct the test, select uniformly graded clean sand passing through 600 micron IS sieve and retained on 300 micron IS sieve.

Equipments Required:

- a) Sand pouring cylinder of about 3 litre capacity (Small pouring cylinder as per IS 2720 Part 28)
- b) Cylindrical calibrating container 10 cm internal diameter and 15 cm depth
- c) Glass plate, trays, containers for determining water content
- d) Tools for making of a hole of 10 cm diameter and 15 cm deep, knife and other accessories
- e) Metal container to collect excavated soil
- f) Metal tray, 300mm square and 40mm deep with a hole of 100mm in diameter at the centre
- g) Weighing balance
- h) Moisture content cans
- i) Glass plate about 450 mm/600 mm square and 10mm thick
- j) Oven
- k) Dessicator

Theory:

By conducting this test, it is possible to determine the field density of the soil. The moisture content is likely to vary from time and hence the field density also. So it is required to report the test result in terms of dry density. In sand replacement method, a small cylindrical pit is excavated and the weight of the soil excavated from the pit is measured. Sand whose density is known is filled into the pit. By measuring the weight of sand required to fill the pit and knowing its density, the volume of pit is calculated. Knowing the weight of soil excavated from the pit and the volume of pit, the density of soil is calculated. Therefore, in this experiment there are two stages, namely

1. Calibration of sand density
2. Measurement of soil density

Field density is defined as weight per unit volume of soil mass in the field at in-situ conditions. Equations are:

$$\gamma_d = \gamma_b / (1+w)$$

Where,

γ_d = dry unit weight,

γ_b = field moist unit weight,

w = water content,

γ_w = unit weight of water = 9.81 kN/m³

The basic equations in determination of density using sand replacement method are:

$$V_h = W_s / (G \times \rho_w)$$

$$\gamma_b = M / V_h$$

$$\gamma_d = \gamma_b / (1+w)$$

Where, V_h = Volume of hole made in the field.

W_s = weight of the sand that fills the hole.

W = weight of moist soil removed from the hole.

w = moisture content of soil removed from the hole.

γ_b = moist soil in-situ density.

γ_d = dry density of the soil.

G = specific gravity of the solids.

γ_w = density of the water.

Precautions:

- If for any reason it is necessary to excavate the pit to a depth other than 12 cm, the standard calibrating can should be replaced by one with an internal height same as the depth of pit to be made in the ground.
- Care should be taken in excavating the pit, so that it is not enlarged by levering, as this will result in lower density being recorded.
- No loose material should be left in the pit.
- There should be no vibrations during this test.
- It should not be forgotten to remove the tray, before placing the SPC over the pit.

Procedures:**Stage1 –Determination of mass of sand that fills the cone**

- a) Measure the internal dimensions (diameter, d and height, h) of the calibrating can and compute its internal volume, $V_c = \frac{\pi d^2 h}{4}$
- b) With the valve closed, fill the cylinder with sand
Weight of sand filled in the cylinder+cylinder $W' = \text{-----gms.}$
- c) Keep the cylinder on a glass plate, which is kept on a horizontal surface.
- d) Open the valve and allow the sand to fill the cone completely. Close the valve. Weight of sand in the cylinder +cylinder $W'' = \text{-----gms}$
- e) Determine the mass of the sand left in the cylinder.
Weight of sand fills the conical portion= $W_1 = W' - W''$
- f) The difference between the mass of sand taken prior to opening of the valve and the weight of sand left in the cylinder after opening the valve gives the weight of sand that fills the cone. Let the mass be W_1 .

Determination of bulk density of sand

- a) Measure the internal dimensions of the calibrating container and find its volume.
Length of calibrating container $l = \text{-----cm}$

Diameter of calibrating container, $d = \text{-----cm}$

Volume of calibrating container, $V_c = \text{-----cm}^3$
- b) Place the pouring cylinder concentrically on the top of the calibrating container with the valve closed. Fill the cylinder with sand up to about 1 cm below the top.
Weight of cylinder $W_1 = \text{----- g}$

Weight of cylinder +sand in the cylinder $W_2 = \text{----- gm}$

Weight of sand filled in the cylinder $W_0 = W_2 - W_1 = \text{----- --gm}$

Let the weight of sand filled be W_0

- c) Open the valve of the cylinder and allow the sand to flow into the container. When no further movement of sand is seen, close the valve. Find the weight of the sand left in the cylinder

Weight of cylinder +sand after filling the calibrating container $W_3 = \text{-----gms.}$

Determine the weight of sand that fills the calibrating container $W_c = W_2 - W_3 = \text{-----}$

- d) The bulk density of sand ρ_s is

$$\gamma_s = W_c / V_c.$$

Stage 2 - Determination of in-situ density:

- a) Level the area where the density is required.

- b) Place the metal plate on the surface, which is having a circular hole of about 10 cm diameter at the center. Dig a hole of this diameter up to about 15 cm depth collect all the excavated soil in a container.

Let the weight of the soil removed = $W_2 = \text{-----g}$

- c) Remove the plate and place the sand-pouring cylinder concentrically on the hole. Fill the cylinder with sand up to a constant level mark with the shutter valve closed. Open the valve and allow the sand to run into the hole till no movement of the sand is noticed. Close the valve and determine the mass of sand that is left in the cylinder

Weight of cylinder+sand after filling the hole completely $W_4 = \text{----g}$

Weight of sand filling only the hole in the field $W_s = W_2 - W_4 - W_c = \text{-----g}$

Volume of the hole, $V_h = W_s / \rho_s$ where $\rho_s =$ bulk density of sand.

- d) Bulk density of soil in-situ, γ_t , is

$$\gamma_t = W / V_h = (W / W_s) \times \rho_s$$

Determination of Water content of soil collected from the hole:

Weight of empty container (W_5) =----- gm

Weight of container + wet soil (W_6) = ----- gm

Weight of container + dry soil (W_7) = ----- gm

Water content (w) = $(W_6 - W_7) / (W_7 - W_5)$

Dry density of sand $\rho_d = \gamma_t / (1 + w) = \text{----- g/cm}^3$

Pre-Viva Questions:

- 1) What is the objective of sand replacement method?
- 2) What is the relationship that can be established between the dry density with known moisture content?
- 3) What are the apparatus that are needed in this test?
- 4) What is the significance of determining the in-situ density of the soil?
- 5) Depth of hole is kept to 15 cm in the field. Why?

Result:

- 1) Weight of wet soil from the hole, $W = \text{----- gm}$
 - 2) Water content of the soil, $w = \text{--- \%}$
 - 3) Weight of sand that fills the hole = ----- gm
 - 4) Volume of the hole $V_h = W_s / \rho_s = \text{----- cm}^3$
 - 5) Bulk density of the soil $\rho_t = W / V_h = \text{----- gm/cm}^3$
 - 6) Dry density $\rho_d = \rho_t / (1 + w) = \text{----- gm/cm}^3$
- a) Dry density of soil = ----- g/cm^3
- b) Water content of the soil = ----- \%

Verification and Validations:

Sand replacement method is an indirect method of finding the density of soil. The basic principle is to measure the in-situ volume of hole from which the material was excavated from the weight of sand with known density filling in the hole. The in-situ density of material is given by the weight of the excavated material divided by the in-situ volume. The dry density of most soils varies within the range of 1.1-1.6 g/cm³. In sandy

Soils, dry density can be as high as 1.6 g/cm^3 ; in clayey soils and aggregated loams, it can be as low as 1.1 g/cm^3 .

Conclusion:

The dry density of the soil is _____g/cc. comparing with the in-situ density by core cutter method; more or less the same value is achieved. The type of soil is silty-clay.

Post-Viva Questions:

1. Why we need to determine the unit weight of sand to determine the unit weight of soil?
2. Which method is the accurate one, core cutter or sand replacement method as per you? And why?
3. How many samples are to be collected and why?
4. What is the advantage of sand replacement method over core cutter method?
5. What is the practical application of the test?

EXPERIMENT NO 7

DATE: _____

DETERMINATION OF PARTICLE SIZE DISTRIBUTION BY SIEVING (GRAIN SIZE ANALYSIS)

Aim: To determine the particle size distribution by sieving (Grain size analysis) and to determine the fineness modulus, effective size and uniformity coefficient.

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. 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.

Specifications:

This test is specified in IS: 2720 (Part 4) – 1985 – Method of test for soil (Part 4- Grain size analysis).

Equipments Required:

- a) Sieves of sizes: 4.75 mm, 2.0 mm, 1.0 mm, 600 μ , 300 μ , 150 μ and 75 μ . That is, I.S 460-1962 is used. The sieves for soil tests: 4.75 mm to 75 microns.
- b) Thermostatically controlled oven.
- c) Trays, sieve brushes, mortar with a rubber covered pestle, etc.
- d) Mechanical sieve shaker etc.

Theory:

The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are generally used. The method is applicable to dry soil passing through 4.75 mm size sieve less than 10 % passing through 75-micron sieve.

Percentage retained on any sieve = (weight of soil retained / total weight) \times 100

Cumulative percentage retained = sum of percentages retained on any sieve on all coarser sieves

Percentage finer than any sieve = 100 percent minus cumulative Size, N
Percentage retained.

Precautions:

- Clean the sieves set so that no soil particles were struck in them
- While weighing put the sieve with soil sample on the balance in a concentric position.
- Check the electric connection of the sieve shaker before conducting the test.
- No particle of soil sample shall be pushed through the sieves.

Procedures:

- a) Take a representative sample of soil received from the field and dry it in the oven.
- b) Use a known mass of dried soil with all the grains properly separated out. The maximum mass of soil taken for analysis may not exceed 500 g.
- c) Prepare a stack of sieves. Set the sieves one over the other with an ascending order (sieves having larger opening sizes i.e., lower numbers are placed above the one with smaller opening sizes i.e., smaller numbers). The very last sieve is #200 (75 μ sieve). A pan is attached to the lowest 75 μ sieve to collect the portions passing #200 sieves and fit the nest to a mechanical shaker.
- d) Make sure sieves are clean. If many soil particles are stuck in the openings try to poke them out using brush.
- e) The whole nest of sieves is given a horizontal shaking for 10 min in sieve shaker till the soil retained on each reaches a constant value.
- f) Determine mass of soil retained on each sieve including that collected in the pan below.

Table:

The test results obtained from a sample of soil are given below.
 Mass of soil taken for analysis $W = \text{--- gm}$

Table 7: Sieve Analysis data sheet

Sl. No.	IS Sieves (mm)	Particle Size (mm)	Mass Retained (gm)	% Mass Retained	Cumulative % Mass Retained	% Finer
1	4.75	4.75				
2	2.00	2.00				
3	1.00	1.00				
4	0.600	0.600				
5	0.300	0.300				
6	0.150	0.150				
7	0.075	0.075				
8	pan					

Cumulative
 mass retained $W' = \text{----- gm}$

Graph (Grain Size in mm vs. Percentage Finer in %):

Draw graph of log sieve size vs. % finer. The graph is known as grading curve. Corresponding to 10%, 30% and 60% finer, obtain diameters from graph these are D_{10} , D_{30} , D_{60} , using these obtain C_c and C_u which further represent how well the soil is graded i.e. whether the soil is well-graded, gap-graded or poorly graded.

Pre-Viva Questions:

- 1) Define the grain size analysis and what is the silt size?
- 2) What is uniformity coefficient? What is the significance on computing the same?
- 3) What is the most basic classification of soil?
- 4) What are the methods of soil gradation or grain size distribution?
- 5) How to compute D_{10} , D_{30} and D_{60} of soil using sieve analysis?
- 6) How to compute C_c and C_u ?
- 7) What is poorly graded, gap graded and well graded soil?

Result:

Uniformity coefficient, C_u =

Coefficient of curvature, C_c =

Percentage gravel =

Percentage sand =

Percentage silt =

Verification/Validations:

For the soil to be well graded the value of coefficient of uniformity C_u has to be greater than 4 and C_c should be in the range of 1 to 3. So higher the value of C_u the larger the range of the particle sizes in the soil. So if the C_u value is high it indicates that the soil mass consists of different ranges of particle sizes.

Conclusion:

The uniformity coefficient, $C_u = \underline{\quad}$ and $C_c = \underline{\quad}$.

The value comes in the range of well graded soil.

Post-Viva Questions:

1. Does grain distribution affect the voids ratio of the soil?
2. Could the quality of concrete enhanced by the grade of the sand?
3. If soil is uniformly graded, voids ratio is high or low?
4. Well graded aggregates require less cement or more?
5. What is the practical significance of Grain Size Distribution Analysis?

EXPERIMENT NO 8

DATE: _____

DETERMINATION OF LIQUID LIMIT OF FINE SOIL

Aim: To determine the liquid limit of fine soil by using Casagrande Apparatus

When water is added to dry soil, it changes its state of consistency from hard to soft. We can define liquid limit as the minimum water content at which the soil is still in the liquid state, but has a small shearing strength against flow. From test point of view we can define liquid limit as the minimum water content at which a pat of soil cut by a groove of standard dimension will flow together for a distance of 12 mm (1/2 inch) under an impact of 25 blows in the device.

Specifications:

This test is done to determine liquid limit of soil as per IS: 2720(Part 5)-1985. After receiving the soil sample it is dried in air or in oven (maintained at a temperature of 60°C). If clods are there in soil sample then it is broken with the help of wooden mallet. The soil passing 425 micron sieve is used in this test.

Equipments Required:

- a) A mechanical liquid limit apparatus (casagrande type) with grooving tools.
- b) Evaporating dishes, wash bottle etc.
- c) Balance accurate to 0.01 g.
- d) Airtight container to determine water content.
- e) Oven to maintain temperature at 105°C to 110°C .
- f) Sieve (425 micron).
- g) Spatula
- h) Desiccator and other accessories.

Theory: Consistency of fine-grained soils may be defined as the relative ease with which a soil can be remoulded. Consistency limits may be categorized into three limits called Atterberg limits. They are 1. Liquid limit 2. Plastic limit and 3. Shrinkage limit

Liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. Other limits will be discussed during corresponding experiments.

Precautions:

- Soil used for liquid limit determination should not be oven dried prior to testing.
- In LL test the groove should be closed by the flow of soil and not by slippage between the soil and the cup
- After mixing the water to the soil sample , sufficient time should be given to permeate the water throughout out the soil mass
- Wet soil taken in the container for moisture content determination should not be left open in the air, the container with soil sample should either be placed in desiccators or immediately be weighed.
- After performing each test the cup and grooving tool must be cleaned.
- The number of blows should be just enough to close the groove.
- The number of blows should be between 10 and 40.

Procedure:

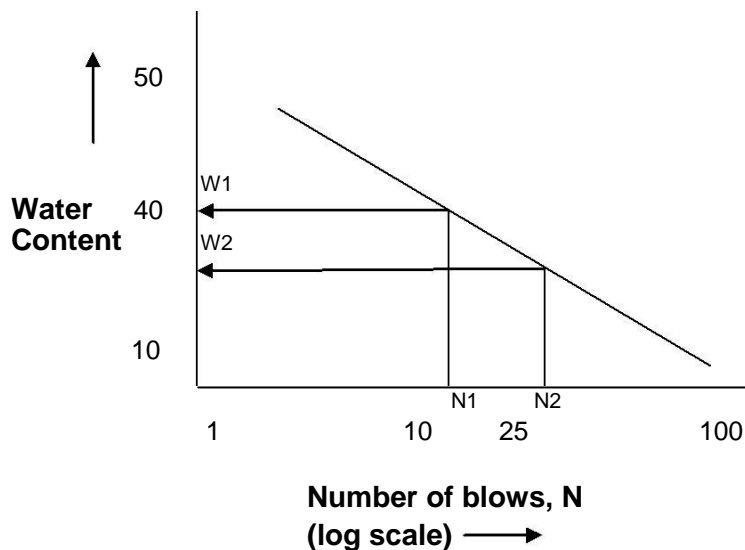
- a) A representative sample of mass of about 120 gm passing through 425 μ IS sieve is taken for the test. Mix the soil in an evaporating dish with distilled water to form a uniform paste.
- b) Adjust the cup of the device so that the fall of the cup on to the hard rubber base is 10 mm.
- c) Transfer the portion of the paste to the cup of liquid limit device. Allow some time for the soil to have uniform distribution of water.
- d) Level the soil topsoil so that the maximum depth of soil is 12 mm. A channel of 11 mm wide at the top, 2 mm at the bottom and 8 mm deep is cut by the grooving tool. The grooving tool is held normal to the cup and the groove is cut through the sample along the symmetrical axis of the top.
- e) The handle of the device is turned at a rate of about 2 revolutions per second and the number of blows necessary to close the groove along the bottom distance of 12 mm is counted. A sample of soil which closes the groove is collected
- f) The soil in the cup is re-mixed thoroughly (adding some more soil if required) Some quantity of water which changes the consistency of soil, repeat the process. At least 4 tests should be conducted by adjusting the water contents of the soil in the cup in such a way that the number of blows required to close the groove may fall within the range of 5 to 40 blows. A plot of water content against the log of blows is made as shown in figure. The water content at 25 blows gives the liquid limit.

Observation Table:**Table 8: Number of blows vs Water Content**

Trial No	1	2	3	4
	(w ₁)	(w ₂)	(w ₃)	(w ₄)
No of blows (N)				
Weight of Container (W ₁)				
Weight of Container + Wet soil (W ₂)				
Weight of Container + dry soil (W ₃)				
Water content $w = (W_2 - W_3) / (W_3 - W_1)$				
Water content, $w = (W_1 + W_2 + W_3 + W_4) / 4$				

Graph:

A semi-log plot of Number of blows Vs water Content is drawn from the table data.

**Pre-Viva Questions:**

- 1) Define consistency of the soil. How is it measured?
- 2) What is liquid limit of soil?
- 3) What is the apparatus used to determine the liquid limit?

- 4) When a soil sample is given, what is the procedure to determine the liquid limit of the sample?
- 5) In a liquid limit test, the moisture content at 10 blows was 70% and that at 100 blows was 20%. The liquid limit of the soil, is?

Result:

From the graph drawn, flow index $I_f = (w_1 - w_2) / \log (N_2 / N_1) = \text{----}$

Liquid Limit =-----%

Verification/Validation:

If the natural moisture content of soil is closer to liquid limit, the soil can be considered as soft if the moisture content is lesser than liquids limit, the soil is brittle and stiffer. Hence if the points on the graph are obtained scattered, we need to draw the linear curve at the mean. Flow index indicates the rate at which the soil loses shearing resistance with an increase in the water content.

Soil Type	Liquid limit
Sand	-
Silt	30-40
Clay	40 -150

Conclusion:

As per the procedure the experiment is carried out. For 25 blows, water content is _____%.

Post-Viva Questions:

1. What is the purpose of computing liquid limit of the soil?
2. With the organic matter in the soil, will the liquid limit increase or decrease?

EXPERIMENT NO. 9

DATE: _____

DETERMINATION OF PLASTIC LIMIT OF THE SOIL

Aim: To determine plastic limit of the soil.

The plastic limit of fine-grained soil is the water content of the soil below which it ceases to be plastic. It begins to crumble when rolled into threads of 3mm dia.

Specifications:

This test is done to determine the plastic limit of soil as per IS: 2720 (Part 5) – 1985. Take out 30g of air-dried soil from a thoroughly mixed sample of the soil passing through 425 μ m IS Sieve. Mix the soil with distilled water in an evaporating dish and leave the soil mass for 24hrs.

Equipments Required:

- a) Porcelain evaporating dish.
- b) Flat glass plate.
- c) Balance accurate to 0.01 g.
- d) Drying oven, maintained at $110 \pm 5^\circ\text{C}$ ($230 \pm 9^\circ\text{F}$).
- e) Weighing dishes, non-absorbent, with lids.
- f) Flexible spatula, blade approximately 102 mm (4 in.) long \times 19 mm (0.75 in.) wide.

Theory:

The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic state. It may also be defined as that water content at which soil starts crumbling when rolled into threads of 3mm diameter. Use the paste from liquid limit test and begin drying. May add dry soil or spread on plate and air dry.

Precautions:

1. Soil used for plastic limit determination should not be oven dried prior to testing.
2. After mixing the water to the soil sample, sufficient time should be given to permeate the water throughout the soil mass

3. Wet soil taken in the container for moisture content determination should not be left open. The container with soil sample should either be placed in desiccators or immediately be weighed.

Procedure:

- a) Select a representative sample of fine-grained soil of about 20 g or more passing through 420 μ IS sieve. Mix it with distilled water thoroughly on a glass plate such that the palm of the soil can be rolled into a thread of 3 mm diameter. Allow some time for the proper distribution mixed with water.
- b) Take about 10 g of this wet soil and roll it into a thread on a glass plate with the palm of the hand. The rolling must be such that it forms a uniform thread of 3 mm diameter. If the thread cracks before attaining 3 mm diameter, and add little more water, knead it and roll again. If the rolling can be done to diameter less than 3 mm, mix some dry soil, knead it to remove some extra moisture in the soil. This process has to continue till the sample crumbles just at about 3 mm diameter. Collect the crumbled soil (at least 6 g) and measure its water content.
- c) Repeat the process to get at least three water content determination (after they have been in the oven at least 16 hours).
- d) The average of water content so obtained is the plastic limit of the soil.

Observation Table:

Table 9: Water content of 3 mm soil

Trail No	1	2	3	4
	(w ₁)	(w ₂)	(w ₃)	(w ₄)
Weight of Container (W ₁), g				
Weight of Container+Wet soil (W ₂), g				
Weight of Container+dry soil (W ₃), g				
Water content $w=(W_2-W_3)/(W_3-W_1)$, g				
Average water content, $w = (w_1+w_2+w_3+w_4)/4$				

Pre-Viva Questions:

- 1) Define plastic limit of soil
- 2) How is plastic limit computed in laboratory?
- 3) What is the practical significance of determining plastic limit of the soil?
- 4) What is plasticity index?
- 5) What is toughness index?

Result:

The Plastic limit of soil (average water content) is _____.

$$\text{Plasticity index} = w_p - w_L$$

Verification/Validations:

Determine the plasticity index I_p , which is the difference between liquid limit and plastic limit. Following table list the standard values:

Soil Type	w_L	w_p	I_p
Sand			Non-Plastic
Silt	30-40	20-25	10-15
Clay	40-150	25-50	15-100

Conclusion:

The plastic limit of the soil = _____ and plasticity index = _____

The type of soil is _____.

Post-Viva Questions:

1. What is meant by unified soil classification?
2. What is A-line and U-line?
3. What is liquidity index and consistency index?

EXPERIMENT NO. 10

DATE: _____

DETERMINATION OF SHRINKAGE LIMIT

Aim: To determine the shrinkage limit of the soil.

The value of shrinkage limit is used for understanding the swelling and shrinkage properties of cohesive soils. It is used for calculating the shrinkage factors which helps in the design problems of the structures made up of the soils or/and resting on soil. It gives an idea about the suitability of the soil as a construction material in foundations, roads, embankments and dams.

Specifications:

The test is specified in IS: 2720(Part 6)-1972. The 30 g soil passing 425 micron sieve is used for the test.

Equipments Required:

- a) 2 numbers of porcelain evaporating dish, about 12 cm in diameter within a flat bottom.
- b) 3 numbers of shrinkage dish made of non-corroding metal, having a flat bottom, 45 mm diameter and 15 mm high.
- c) A glass cup of about 50 mm diameter and 25 mm high.
- d) Two numbers glass plates of size 75□75 mm, one plate of plane glass and the other with three metal prongs.
- e) Spatula balance accurate to 0.01 g, oven etc.
- f) Mercury.
- g) Desiccator and other accessories.

Theory:

As the soil loses moisture, either in its natural environment, or by artificial means in laboratory, it changes from liquid state to plastic state to semi-solid state and then to solid state. The volume is also reduced by the decrease in water content. But, at a particular limit the moisture reduction causes no further volume change. A shrinkage limit test gives a quantitative indication of how much moisture can change before any significant volume change and to also indication of change in volume. The shrinkage limit is useful in areas where soils undergo large volume changes when going through wet and dry cycles (e.g. earth dams).

Shrinkage limits are required to be determined on two types of soils, they are

- i. Remoulded soil.
- ii. Undisturbed soil.

Other shrinkage factors i.e. shrinkage ratio, volumetric shrinkage may also be calculated from the test data of shrinkage limit.

Shrinkage ratio is the ratio of a given volume change expressed as a percentage of dry volume to the corresponding change in water content above the shrinkage limit.

Volumetric Shrinkage is the decrease in volume of a soil mass when the water content is reduced from given percentage to the shrinkage limit and which is expressed as percentage of dry volume of the soil mass.

Precautions:

- **CAUTION : DO NOT TOUCH THE MERCURY WITH GOLD RINGS**
- The water content of the soil taken in shrinkage dish should be above liquid limit but within 10% from liquid limit.
- To prevent the cake from adhering to the shrinkage dish and consequent cracking of the dry soil paste, inside of the shrinkage dish should be greased with vaseline.
- During filling the shrinkage dish with soil paste, sufficient tapping should be done to remove the entrapped air.
- The dry soil paste should be weighed soon after it has been removed from a desiccator otherwise it picks up moisture from the air.
- Test should be repeated at least three times for each sample and the average of the results thus obtained reported.
- No air should be entrapped under the dry soil paste when pressing by the glass with prongs is being carried out.

Procedure:

- a) Select a representative sample of soil of about 100 g passing through 425 μ sieve.
- b) Take 30 g out of it and place the same in an evaporating dish. Mix it thoroughly with distilled water and make it into a thin paste for readily filling into a dish free from air bubbles.

Determination of mass and volume of shrinkage dish:

- a) Take a shrinkage dish, clean it and find its mass correct to 0.1 gm (M3). =-----g
- b) To determine its volume, place it in an evaporating dish. Fill the shrinkage dish with mercury till the excess overflows to the evaporating dish.
- c) Coat the inside of the shrinkage dish with a thin layer of silicon grease or Vaseline. Place a part of the soil paste prepared earlier at the center of the dish so that it may occupy about one-third of its volume.

- d) Find the mass of the wet soil with the dish immediately after filling (M_1)=-----g
- e) Keep the dish with soil exposed to air until the colour of the pat turns from black to light.
- f) Select a glass cup with a flat bottom and keep it on an evaporating dish. Fill the cup with mercury and remove the excess mercury by pressing the glass plate with three prongs firmly over the top of the cup.
- g) Remove the split over the mercury, take out the glass plate with the prongs, place the dry soil pat on the surface of the mercury.
- h) Force the soil pat into the mercury by pressing with the same glass plate with the prongs. Collect carefully the split over mercury and find its mass (M_m)=-----g

The volume of the dry soil pat V_d is

$$V_d = M_m / 13.6.$$

Where, 13.6 is the density of mercury in g/cm^3

Calculation of shrinkage limit, W_s

$$\text{Mass of wet soil} = M_o = (M - M_3) = \text{-----g}$$

$$\text{Mass of dry soil} = M_s = (M_2 - M_3) = \text{-----g}$$

$$\text{Volume of shrinkage dish} = \text{Volume of wet soil} = V_o = \text{-----}$$

$$\text{Volume of dry soil} = V_d = \text{-----}$$

$$V_d = M_m / 13.6 \text{ where, } 13.6 \text{ g/cm}^3 \text{ is the density of mercury.}$$

\therefore Shrinkage limit, W_s is

$$W_s = ((M_o - M_s) - (V_o - V_d) \times \rho_w) / M_s$$

$$\text{Shrinkage ratio, } SR = ((V_o - V_d) / V_o) \times 100$$

Shrinkage limit of undistributed soil

In this case G is known in advance. The equation to be used for determining W_s is $[(V_d / M_s) - (1/G)] \times 100$

For the undistributed soil we need to know only the volume of an undistributed dry pot of soil sample of diameter 45 mm and thickness 15 mm. Round off its edges to prevent the entrapment of air during mercury displacement. Air dries the sample initially

and then dry over the same. Find its mass (M_s) after cooling it in a desiccator, and then its volume V_d by mercury displacement method. W_s may now be found out by use of equation

$$W_s = [(V_d/M_s) - (1/G)] \times 100.$$

Pre-Viva Questions:

1. How to measure shrinkage limit of soil?
2. Why is mercury used to determine the shrinkage limit of soil?
3. What is the density of mercury?
4. What is the difference between undisturbed and remoulded soil?
5. Is the dry unit and unit weight of soil the same?
6. What is meant by Thixotropy?

Result:

The shrinkage limit W_s = -----

Verification/Validations:

Value of shrinkage limit varies from 13 to 26.

Conclusion:

The shrinkage limit of soil is _____.

Post-Viva Question:

1. What is shrinkage limit of soil?
2. If water content is increased above shrinkage limit, what is the effect?
3. Instead of Mercury can we use any other substance as mercury may cause health hazard.

EXPERIMENT NO. 11

DATE: _____

DETERMINATION OF MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT BY STANDARD PROCTOR COMPACTION METHOD

Aim: To determine optimum moisture content and maximum dry density of a soil by standard proctor test.

Compaction is the application of mechanical energy to a soil so as to rearrange its particles and reduce the void ratio. It is applied to improve the properties of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, runways, earth dams, and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings. There is usually no change in the water content and in the size of the individual soil particles.

Specifications:

The experiment is conducted as per IS 2720-7(1980).

Equipment Required:

- a) Typical equipment for proctor test is given in figure.
- b) Other accessories are: Balance, oven, straight edge, sieves, metal hammer, etc.

Theory:

The objectives of compaction are:

- a) To increase soil shear strength and therefore its bearing capacity.
- b) To reduce subsequent settlement under working loads.
- c) To reduce soil permeability making it more difficult for water to flow through

To assess the degree of compaction, it is necessary to use the dry unit weight, which is an indicator of compactness of solid soil particles in a given volume. The laboratory testing is meant to establish the maximum dry density that can be attained for a given soil with a standard amount of compactive effort.

1. Bulk density $\gamma_b = (M_2 - M_1)/V$
2. Dry density $\gamma_s = \gamma_b / (1 + w)$

3. Dry density ρ_d for zero air voids line.

$$\gamma_d = G \cdot \gamma_w / (1 + (w \cdot G/S))$$

Where, M_1 = mass of mould used for proctor test

M_2 = mass of mould + compacted soil.

M = mass of wet soil.

V = volume of mould.

γ_w = density of water.

G = Specific gravity of soils.

W = water content.

S = degree of saturation.

Precautions:

1. Thoroughly breakup the sample by running it through the screen before compacting it in the mould.
3. Pound within a moisture range from optimum to 4 percent below optimum. The closer to optimum the moisture content is, the more accurate the test will be.
4. Make sure the clamp on each mold section is tight.
5. Make sure the wing nuts on the base plate are secured with equal tension.
- 6 Place the mould on a solid block that is supported on firm soil or pavement.
- 7 Hold the rammer vertically so that it will fall freely.
- 8 Drop the 25 kg rammer weight freely
- 9 Use exactly 25 blows on each layer.
- 10 Place 3 equal layers in the mold

Procedure

- a) Select a representative soil sample of about 25 kg. The material used for the test must be finer than 20 mm sieve. Air-dry sample.
- b) Add sufficient water to the sample (about 7 % for sandy soils and 10 % for clay soils), which will be less than the estimated optimum moisture content. Mix the soil thoroughly and keep this in an airtight container for a period of 20 hours.
- c) Fix the mould to the base plate after cleaning its inside surface. Find the mass of the mould with the base plate (M_1).
- d) Attach the extension collar to the mould.
- e) Take about 2.5 kg of soil in an air tight container and compact it in the mould in three equal layers each layer is compacted by giving 25 blows by the hammer weighing 2.6 kg and dropping from a height of 310 mm. The compaction must be

Uniform over the whole area, and a spatula scratches each layer before adding another layer. The filling must be such that the last layer projects into the collar by about 5 mm. After the completion of compaction, remove the collar and remove the excess soil with the help of a straight edge. Find the mass of the mould with the base plate and the soil (M_2). Remove the soil from the mould by making use of an ejector and take a representative sample for water content determination.

- f) Carry out the tests 3 to 4 times by repeating the steps from (e) onwards. Each time use a fresh soil sample.

Observations and tabulation:

The following observations were made on the compaction of a soil by standard proctor test. Six tests were carried out on the selected samples of soil by varying the water content. Water contents of samples of each test were found out by the procedure explained earlier.

Table 15: Weight of Soil for varying water content

Test No.	1	2	3	4	5	6
Mass of empty mould M_1 gm						
Volume of mould, cm^3						
Mass of mould + Sample, M_2 gm						
Mass of wet soil, M , gm						
Wet density, γ_b g/cm^3						
Water content, $w\%$						
Dry density, γ_d , gm/cm^3						
W1 for calculation of saturation line %						
γ_d , gm/cm^3 for $S=100\%$						
γ_d , gm/cm^3 for $S=80\%$						

Pre-Viva Questions:

1. What is the difference between standard proctor test and modified proctor test?
2. What is relative density of soil?
3. What is voids ratio? What is zero air voids line?
4. What is the practical implication of conducting standard proctor test?
5. How to determine OMC of soil? Explain.

Result:

Maximum dry density $\gamma_d = \text{_____ g/cm}^3$

Optimum moisture content, $w = \text{_____ \%}$

Verification and Validations:

The peak point of the compaction curve - The peak point of the compaction curve is the point with the maximum dry density. Corresponding to the maximum dry density γ_{dmax} is a water content known as the optimum water content. 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 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.

Zero air voids curve:

The curve represents the fully saturated condition ($S = 100 \%$). (It cannot be reached by compaction)

Conclusion:

The maximum density of the soil is _____ with an OMC of _____. This indicates, after $w\%$, any additional water addition, there is no gain in strength of soil.

Post-Viva Question:

1. How is compaction different from consolidation?
2. Did you watch any civil engineering construction compaction is carried out? Explain.
3. Is there any other method other than standard proctor test to determine maximum density?

EXPERIMENT NO. 12

DATE: _____

DETERMINATION OF PERMEABILITY OF A SOIL SAMPLE BY CONSTANT HEAD METHOD

Aim: To determine the permeability of soil by constant-head method.

The rate of flow under laminar flow conditions through a unit cross sectional area of porous medium under unit hydraulic gradient is defined as coefficient of permeability. Water flowing through soil exerts considerable seepage force which has direct effect on the safety of hydraulic structures. The rate of settlement of compressible clay layer under load depends on its permeability. The quantity of water escaping through and beneath the earthen dam depends on the permeability of the embankments and its foundations respectively. The rate of discharge through wells and excavated foundation pits depends on the coefficient of permeability of the soils. Shear strength of soils also depends indirectly on permeability of soil, as dissipation of pore pressure is controlled by its permeability.

Specifications:

IS 2720-17 (1986): Methods of test for soils, Part 17. This test is used to determine the permeability of granular soils like sands and gravels containing little or no silt.

Equipments Required:

1. Permeameter mould of non-corrodible material having a capacity of 1000 ml
2. The mould shall be fitted with a detachable base plate and removable extension counter.
3. Compacting equipment: 50 mm diameter circular face, weight 2.76 kg and height of fall 310 mm as specified in I.S 2720 part VII 1965.
4. Drainage bade: A bade with a porous disc, 12 mm thick which has the permeability 10 times the expected permeability of soil.
5. Drainage cap: A porous disc of 12 mm thick having a fitting for connection to water inlet or outlet.

6. Constant head tank: A suitable water reservoir capable of supplying water to the permeameter under constant head.
7. Graduated glass cylinder to receive the discharge.
8. Stop watch to note the time.
9. A meter scale to measure the head differences and length of specimen.

Theory:

The knowledge of this property is much useful in solving problems involving yield of water bearing strata, seepage through earthen dams, stability of earthen dams, and embankments of canal bank affected by seepage, settlement etc. Permeability of soil can be determined from Darcy's Law. The equation to determine the permeability of soil using constant head permeability test is given by:

$$k = (Q \times L) / (A \times h \times t) \text{ Where, } k = \text{coefficient of permeability}$$

Q = volume of water collected in time t

h = head causing flow

A = cross sectional area of sample

L = length of sample

- A constant head permeameter shown schematically in the figure.
- For a typical setup the following dimensions are used
 - i. Internal diameter of the mould = 100 mm.
 - ii. Effective height of the mould = 127.3 mm.
 - iii. Detachable collar: 100 mm diameter and 60 mm height.
 - iv. Drainage base, having a porous disc.
- Weighing balance, and other accessories.

Precautions:

1. All possible leakage of joints must be eliminated.
2. Porous stones must be saturated before being put to use.
3. De-aired and distilled water should be used to prevent choking of flowing water.
4. Soil sample must be carefully saturated before taking the observations.
5. Use of high heads, which result in turbulent flows, should be avoided.

Procedure:

- a) A constant-head test assembly is as given in below figure.
- b) Select a representative soil mass of about 2.5 kg properly mixed.
- c) Fill the soil into the mould and compact it to the required dry density by making use of a suitable compacting device.
- d) Set the assembly as shown in figure after saturating the porous stones.

- e) The water supply is properly adjusted to maintain constant head.
- f) Open the valve and saturate the sample by allowing water to flow through for a sufficiently long time to remove all air-bubbles.
- g) When the whole setup is ready for the test, open the valve, allow the water to flow through the sample collect water in a graduated jar starting simultaneously a stopwatch. Note the time to collect a certain quantity of water Q.
- h) Repeat the test three times and determine the average of Q for the same time interval t.
- i) Measure the head h, length of sample L, and calculate the cross sectional area A of the sample.
- j) Calculate k by making use of equation

Observation:

Length of Soil sample L= -----cm

Diameter of Soil sample D=----- cm

Area of soil sample A = -----

Constant head h=----- cm

Sl.No.	Quantity of water (ml)	Time t in sec	$k=(QL)/(A.th)$ (cm/sec)
1			
2			
3			
4			

Pre-Viva Questions:

1. What is Darcy's law of flow velocity through soils? What are its Limitations?
2. What are the steady and unsteady flows of water? What type of flow is assumed to occur in soils?
3. What are the laboratory methods of determination of coefficient of permeability of soil? State their suitability.
4. What is the effect of entrapped air on the coefficient of permeability of soil?

5. Constant head method is suitable for what type of soils?
6. Soil with largest void ratio has lesser or more permeability?
7. Coefficient of permeability is also called as?

Result:

Coefficient of Permeability of soil k = -----cm/sec

Verification/Validation:

The table below gives rough values of the coefficient of permeability of various soils:

Type of soil	Value of permeability (cm/sec)
Gravel	10^3 to 1.0
Sand	1.0 to 10^{-3}
Silt	10^{-3} to 10^{-6}
Clay	less than 10^{-3}

Conclusion:

The type of soil tested is ___ as the permeability falls in the range as shown in the above table.

Post-Viva Questions:

1. Will the permeability of soil cause seepage of water through earth dams?
2. In the above case, what can we do to reduce seepage?
3. What does Darcy's law state?

EXPERIMENT NO 13

DATE: _____

FALLING HEAD PERMEABILITY TEST FOR FINE GRAINED SOILS

Aim: To determine the coefficient of permeability of a given soil sample by Variable head permeability test.

The passage of water through porous material is called seepage. A material with continuous voids is called a permeable material. Hence permeability is a property of a porous material which permits passage of fluids through interconnecting conditions. Hence permeability is defined as the rate of flow of water under laminar conditions through a unit cross-sectional area perpendicular to the direction of flow through a porous medium under unit hydraulic gradient and under standard temperature conditions.

Specifications:

IS 2720-17 (1986): Methods of test for soils, Part 17. This test is used for fine grained soils with intermediate and low permeability such as silts and clays. This testing method can be applied to an undisturbed sample.

Equipments Required:

All the accessories are the same as the constant head test and the following:

1. Graduated glass stand pipe and the clamp
2. Supporting frame for the stand pipe and the clamp

Theory:

The falling head permeability test involves flow of water through a relatively short soil sample connected to a standpipe which provides the water head and also allows measuring the volume of water passing through the sample. The diameter of the standpipe depends on the permeability of the tested soil. The test is carried out in falling head permeameter cell.

Before starting the flow measurements, the soil sample is saturated and the standpipes are filled with de-aired water to a given level. The test then starts by allowing water to flow through the sample until the water in the standpipe reaches a given lower limit. The time required for the water in the standpipe to drop from the upper to the lower level is recorded. Often, the standpipe is refilled and the test is repeated for couple of times. The recorded time should be the same for each tests within an allowable variation of about 10% (Head 1982) otherwise the test is failed.

The below equation can be used:

$$k = ((2.3 \times a \times L)/(A \times (t_2 - t_1))) \times \log_{10}(h_1/h_2)$$

Where, L = length of soil sample column

A = Sample cross-section

a = the cross-section of the standpipe

$(t_2 - t_1)$ = the recorded time for the water column to flow through the sample

h_1 and h_2 = the upper and lower water level in the standpipe measured using the same water head reference

Precautions:

1. All possible leakage of joints must be eliminated.
2. Porous stones must be saturated before being put to use.
3. De-aired and distilled water should be used to prevent choking of flowing water.
4. Soil sample must be carefully saturated before taking the observations.
5. Use of high heads, which result in turbulent flows, should be avoided.

Procedure:

- a) Open the valves in the standpipe and the bottom outlet. Ensure that the soil sample is fully saturated without any entrapping of air bubble before starting the test.
- b) Fill the standpipe with water keeping the valves V1 and V2 open and allow the water to flow out through the outlet pipe for some time and then close the valves.
- c) Select in advance the heights h_1 and h_2 for the water to fall and determine the height $\sqrt{h_1 h_2}$ and mark this height on the stand pipe.
- d) Open the valves and fill the standpipe with water up to height h_1 and start the stopwatch.
- e) Record the time intervals for water to fall from height h_1 to $\sqrt{h_1 h_2}$ and from $\sqrt{h_1 h_2}$ to h_2 . These two time intervals will be equal if a steady flow condition has been established.
- f) Repeat the step (e) at least after changing the heights h_1 and h_2 .
- g) Stop the test and disconnect all the parts.
- h) Take a small quantity of the sample for water content determination.

Observation Tables:**Table 12 (a): Observations**

Length of Soil sample L	cm
Diameter of Soil sample D	cm
Area of soil sample A	cm ²
Area of stand pipe a	cm ²

Table 12(b): Computation of coefficient of permeability

Sl.No	Initial Head (h ₁) cm	Final Head (h ₂) cm	Time t In seconds	$k = \frac{2.3 \times a \times L}{A \times t} \times \log_{10}(h_1/h_2)$
1				
2				
3				
4				

Pre-Viva Questions:

1. A fully saturated soil is said to be in which phase?
2. Valid range of degree of saturation of soil in percentage is?
3. If the voids of a soil mass are full of air only, the soil is termed as?
4. Which method is the most suitable to determine the permeability of the clayey soil?
5. Is there any connection between permeability of soil and temperature? If temperature increases, will permeability increase?
6. In the case of natural deposits, permeability is higher parallel to stratification or perpendicular to stratification?

Result:

Coefficient of Permeability of soil k= -----cm/sec

Verification/Validations:

The coefficient of permeability of a soil describes how easily a liquid will move through a soil. It is also commonly referred to as the hydraulic conductivity of a soil. This factor can be affected by the viscosity, or thickness (fluidity) of a liquid and its density. The number can also be affected by the void size, or region of non-soil, void continuity, and soil particle shape and surface roughness. It is an important factor when determining the rate at which a fluid will actually flow through a particular type of soil.

Table 12(C): Typical permeability coefficients for different soils

Soil Type	Typical Permeability, k (cm/sec)
Gravels and Coarse Sands	$> 10^{-1}$
Fine Sands	10^{-1} to 10^{-3}
Silty Sands	10^{-3} to 10^{-5}
Silts	10^{-5} to 10^{-7}
Clays	$< 10^{-7}$

Conclusion:

As per the value of coefficient of permeability (_____), type of soil from the above table is _____.

Post-Viva Questions:

1. Why is variable head method required to find permeability?
2. What are the important steps in the experiment?
3. What is the time gap taken to take the readings?

