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Practical Manual ON SOIL MECHANICS

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PREFACE

Practical manual on SOIL MECHANICS is written to provide a single source of information for Agricultural Engineering under graduate students and to provide them a solid base in engineering practical. The main purpose of teaching soil mechanics to agricultural engineering students is to equip them with understanding of scientific methods so that they may use this knowledge beneficially in their higher pursuits.

The authors are highly thankful to all teachers and scientist for their kind co-operation towards speedy preparation of this practical manual. Authors are also indebted to all friends and colleagues, sources who have helped them at every stage for the preparation of this practical manual.

Though every care has been taken to avoid any misprint, omission and error; yet the same might have left due to oversight. Authors will personally thank the person who brings to his notice shortcoming and the same will be taken care of for the future edition of the practical manual to make it more useful to the readers.

Raipur
February, 2013

Authors

CONTENT

EXPERIMENT NO. 1

Title: Determination of Water Content of Soil.

A) Objective: To determine water content of the soil by oven-drying method.

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

$$w = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100$$

where M_1 = mass of empty container with lid;
M_2= mass of the container with wet soil and lid;
M_3= mass of the container with dry soil and lid;

Equipment: 1. Thermostatically controlled oven, maintained at a temperature of 110^0C; 2. Weighing balance with accuracy of 0.04% of the mass of the soil taken; 3. Desiccator with any suitable desiccating agent; 4. Airtight container made of non-corrodible material with lid; 5. Tongs.

Soil specimen: 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 particles. For more than 90% of the particles passing 425µ IS sieve, the minimum quantity is 25 gm.

Procedure:

1. Clean the container, dry it and weight it with lid M_1.
2. Take the required quantity of the wet specimen in the container and close it with lid. Take the mass M_2.
3. Place the container, with its lid removed, in the oven till its mass becomes constant (normally for 24 hours.)
4. When the soil has dried, remove the container from the oven, using tongs. Replace the lid on the container. Cool it in desiccator.
5. Find the mass (M_3) of the container with lid and dry soil sample.

Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Container No.			
2.	Mass of the empty container (M_1)			
3.	Mass of the container with soils (M_2)			
4.	Mass of container with dry soil (M_3)			
	Calculations			
5.	Mass of water, M_w= (M_2)- (M_3)			
6.	Mass of solids, M_s = (M_3)- (M_1)			
7.	Water content, w = (5)/(6) x 100			

Result: The water content of soil sample is ....%

B) Objective: To determine water content of the soil by pycnometer method.

Theory: A pycnometer is a glass jar of about 1 litre 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.

$$w = \left[\frac{(M_2 - M_1)}{(M_3 - M_4)}\left(\frac{G-1}{G}\right) - 1\right] \times 100$$

where M_1 = mass of empty pycnometer;
M_2= mass of the pycnometer and wet soil;
M_3= mass of the pycnometer and soil filled with water;
M_4= mass of the pycnometer filled with water only;
G= specific gravity of soil.

Equipment: 1. Pycnometer; 2. Weighing balance with accuracy of 1.0 gm; 3. Glass rod.

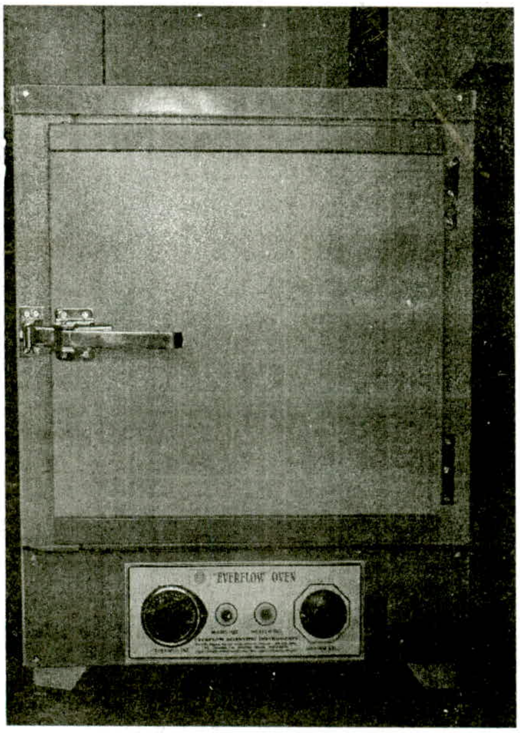
Procedure:

1. Wash and clean the pycnometer and dry it.
2. Determine the mass of the pycnometer, with brass cap and washer *(M_1)*, accurate to 1 gm.
3. Place about 200 to 400 gm of wet soil specimen in the pycnometer and weigh it with its cap and washer *(M_2)*.
4. Fill water in the pycnometer containing the wet soil specimen to about its half height.
5. Mix the contents thoroughly with a glass rod. Add more water and stir it. Fill the pycnometer with water, flush with the hole in the conical cap
6. Dry the pycnometer from outside and take its mass (M_3).
7. Empty the pycnometer. Clean it thoroughly. Fill it with water, flush with the hole in the conical cap and weigh (M_4).

Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Mass of the empty pycnometer (M_1)			
2.	Mass of pycnometer and wet soils (M_2)			
3.	Mass of pycnometer soil, filled with water (M_3)			
4.	Mass of pycnometer filled with water only (M_4)			
5.	**Calculations**			
6.	$(M_2)-(M_1)$			
7.	$(M_3)-(M_4)$			
8.	$(G-1)/G$			
	W = [(5)/(6) x(7)-1]x 100			

RESULT: The water content of soil sample is ....%.

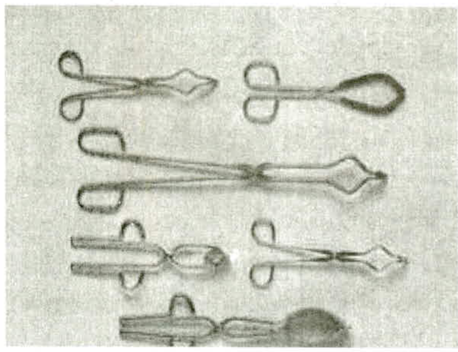


Hot Air Oven

Weighing Balance

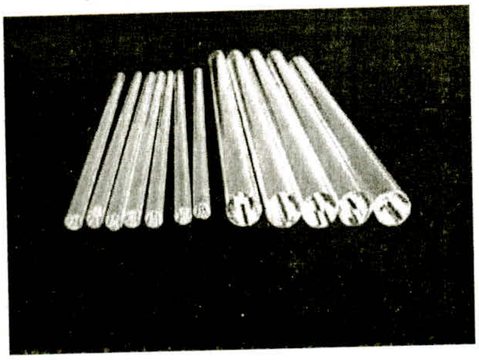
Desiccator

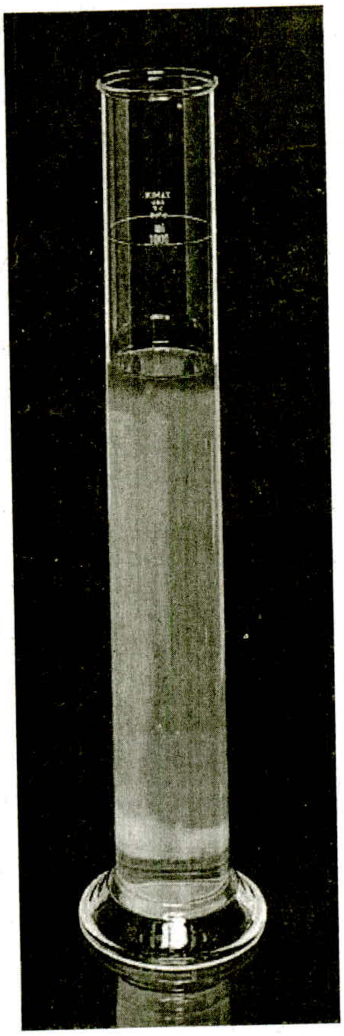
Air-tight container



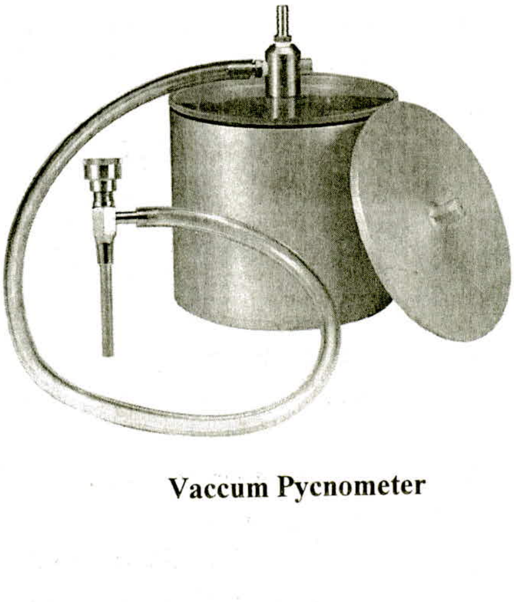
Tongs

Pycnometer





Glass rods



Vaccum Pycnometer

EXPERIMENT NO. 2

Title: Determination of Specific Gravity of Soil.

A) Objective: To determine the specific gravity of soil by the density bottle method.

Theory: The specific gravity of soil particles is the ratio of the mass density of solids to that of water. It is determined in the laboratory using the relation

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

where M_1= mass of empty bottle;

M_2= mass of the bottle and dry soil

M_3= mass of bottle, soil and water

M_4= mass of bottle filled with water only.

Equipment: 1. 50 ml density bottle with stopper; 2. Oven (105^0C to 110^0C); 3. Constant temperature water bath (27^0C); 4. Vaccum desiccators; 6. Weighing balance, accuracy 0.001gm; 7. Spatula.

Procedure:

1. Wash the density bottle and dry it in an oven at 105^0C to 110^0C. Cool it in the desiccators.
2. Weigh the bottle, with stopper, to the nearest 0.001 gm *(M_1)*.
3. Take 5 to 10 gm of the oven dried soil sample and transfer it to the density bottle. Weigh the bottle with the stopper and the dry sample *(M_2)*.
4. Add de-aired distilled water to the density bottle just enough to cover the soil. Shake gently to mix soil and water.
5. Place the bottle containing the soil and water, after removing the stopper, in the vaccum desiccator.
6. Evacuate the desiccators gradually by operating vaccum pump. Reduce the pressure to about 20mm of mercury. Keep the bottle in the desiccators for at least 1 hour or until no further movement of air is noticed.
7. Release the vacccum and remove the lid of the desiccators.

   Stir the soil in the density bottle carefully with the spatula. Before removing the spatula from the bottle, the particles of soil adhering to it should be washed off with a few drops of air-free water.

   Replace the lid of the desiccators and again apply vaccum.

   Repeat the procedure until no more air is evolved from the specimen.
8. Remove the bottle from the desiccators. Add air-free water until the bottle is full. Insert the stopper.
9. Immerse the bottle upto the neck in a constant-temperature bath for approximately 1 hour or until it has attained the constant temperature.

   If there is an apparent decrease in the volume of the liquid- in the bottle, remove the stopper and add more water to the bottle and replace the stopper. Again place the bottle in the water bath. Allow sufficient time to ensure that the bottle and its content attain the constant temperature.

10. Take out the bottle from the water bath. Wipe it clean and dry it from outside. Fill the capillary in the stopper with drops of distilled water, if necessary.
11. Determine the mass of the bottle and its contents (M_3).
12. Empty the bottle and clean it thoroughly. Fill it with distilled water. Insert the stopper.
13. Immerse the bottle in the constant-temperature bath for 1 hour or until it has attained the constant temperature of the bath.
    If there is an apparent decrease in the volume of the liquid, remove the stopper and add more water. Again keep it in the water bath.
14. Take out the bottle from the water bath. Wipe it dry and take the mass (M_4).

Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Density Bottle No.			
2.	Mass of empty density bottle (M_1)			
3.	Mass of the bottle and dry soil (M_2)			
4.	Mass of bottle, soil and water (M_3)			
5.	Mass of bottle filled with water only (M_4)			
	Calculations			
6.	$(M_2 - M_1)$			
7.	$(M_3 - M_4)$			
8.	$G = \frac{(6)}{(6) - (7)}$			

Result: Specific gravity of soil is ....

B) Objective: To determine the specific gravity of soil by pycnometer method.

Theory: The pycnometer method can be used for the determination of the specific gravity of solid particles of both fine-grained and coarse-grained soils. It is determined in the laboratory using the relation

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

where M_1= mass of empty pycnometer;

M_2= mass of the pycnometer and dry soil

M_3= mass of pycnometer, soil and water

M_4= mass of pycnometer filled with water only.

Equipment: 1. Pycnometer of about 1 litre capacity; 2. Weighing balance, accuracy 1gm 3. Glass rod; 4. Vaccum pump.

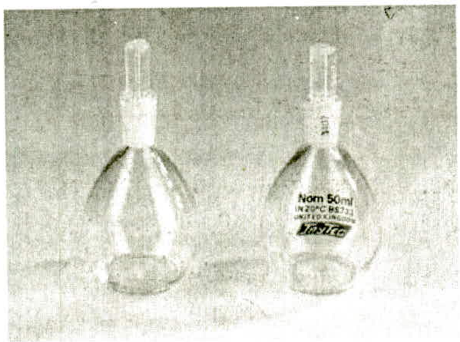
Procedure:

1. Clean and dry the pycnometer. Tightly screw its cap. Take its mass (M_1) to the nearest 0.1 gm.
2. Mark the cap and pycnometer with a vertical line parallel to the axis of the pycnometer to ensure that the cap is screwed to the same and mark each time.
3. Unscrew the cap and place about 200gm of oven-dried soil in the pycnometer.
   Screw the cap. Determine the mass(M_2).
4. Unscrew the cap and add sufficient amount of de-aired water to the pycnometer so as to cover the soil. Screw on the cap.
5. Shake well the contents. Connect the pycnometer to a vaccum pump, to remove the entrapped air, for about 20 minutes for fine-grained soils and for about 10 minutes for coarse-grained soils.
6. Disconnect the vaccum pump. Fill the pycnometer with water, about three fourths full.
   Reapply the vaccum for about 5 minutes, till air bubbles stop appearing on the surface of the water.
7. Fill the pycnometer with water completely, upto the mark. Dry it from outside. Take its mass (M_3).
8. Record the temperature of contents.
9. Empty the pycnometer. Clean it and wipe it dry.
10. Fill the pycnometer with water only. Screw on the cap upto the mark. Wipe it dry. Take its mass (M_4).

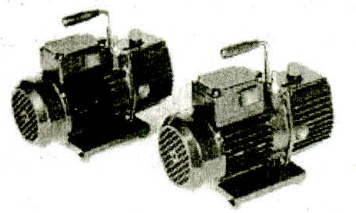
Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No. 1	2	3
	Observations			
1.	Pycnometer No.			
2.	Room Temperature			
3.	Mass of empty pycnometer (M_1)			
4.	Mass of the pycnometer and dry soil (M_2)			
5.	Mass of pycnometer, soil and water (M_3)			
6.	Mass of pycnometer filled with water only (M_4)			
	Calculations			
7.	$(M_2 - M_1)$			
8.	$(M_3 - M_4)$			
	$G=\frac{(7)}{(7)-(8)}$			

Result: Specific gravity of soil at 26^0C is ....

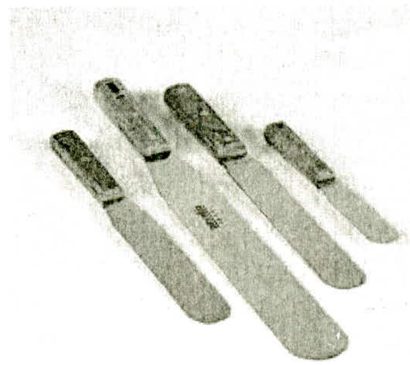


Density bottle (50 ml) with stopper

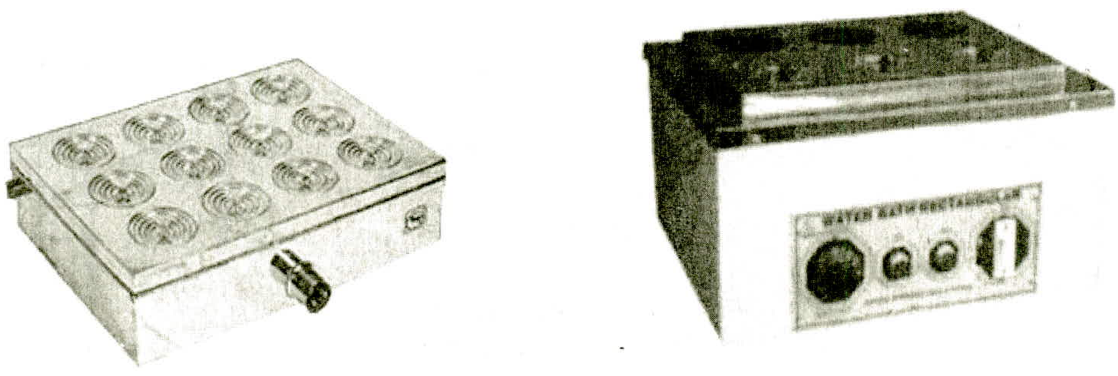


Vaccum Pump

Vaccum Desiccator



Spatula



Water Bath

EXPERIMENT NO. 3

Title: Determination of Field Density of the Soil by Core Cutter Method.
Objective: To determine the dry density of the soil by core cutter method.

Theory: A cylindrical core cutter is a seamless steel tube. For determination of the dry density of the soil, the cutter is pressed into the soil mass so that it is filled with the soil. The cutter filled with the soil is lifted up. The mass of the soil in the cutter is determined. The dry density is obtained as

$$\rho = \frac{\gamma}{1+w} = \frac{M/V}{1+w}$$

where M= mass of the wet soil in the cutter;
V= internal volume of the cutter
w= water content

Equipment: 1. Cylindrical core cutter, 100 mm internal diameter and 130 mm long; 2. Steel rammer, mass 9 kg. Overall length, with the foot and staff about 900mm; 3. Steel dolley, 25 high and 100 mm internal diameter; 4. Weighing balance, accuracy 1 gm; 5. Palette knife; 6. Straight edge, steel rule etc.

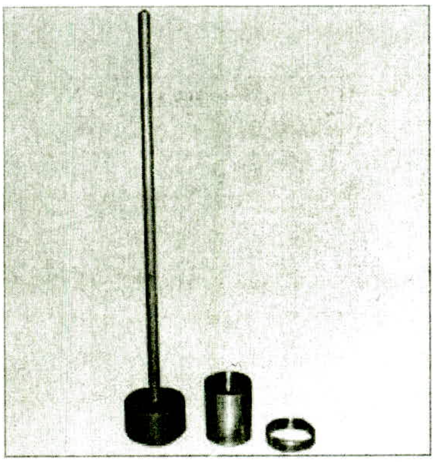
Procedure:

1. Determine the internal diameter and height of the core cutter to the nearest 0.25 mm.
2. Determine the mass (M_1) of the cutter to the nearest gram. Screw the cap.
3. Expose a small area of the soil mass to be tested. Level the surface, about 300 mm square in area.
4. Place the dolley over the top of the core cutter and press the core cutter into the soil mass using the rammer.
   Stop the process of pressing when about 15 mm of the dolley protrudes above the soil surface.
5. Remove the soil surrounding the core cutter, and take out the core cutter. Some soil would project from the lower end of the cutter.
6. Remove the dolley. Trim the top and bottom surface of the core cutter carefully using a straight edge.
7. Weigh the core cutter filled with the soil to the nearest gram (M_2)
8. Remove the core of the soil from the cutter. Take a representative sample for the water content determination.
   Determine the water content, as described in Experiment No. 1.

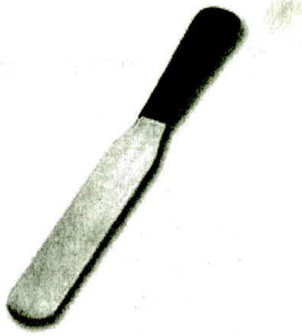
Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Core cutter No			
2.	Internal diameter			
3.	Internal height			
4.	Mass of the empty core cutter (M_1)			
5.	Mass of the core cutter with soils (M_2)			
	Calculations			
6.	Mass of wet soil, $M = (M_2) - (M_1)$			
7.	Volume of cutter, V			
8.	Water content (w)			
9.	Dry density= $\frac{(6)/(7)}{1+(8)}$			

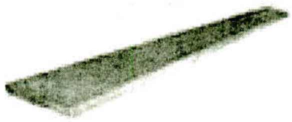
Result: Dry density of soil is ....g/ml.



Core Cutter with steel rammer



Palette Knife



Straight Edge

EXPERIMENT NO. 4

Title: Determination of Field Density by Sand Replacement Method.
Objective: To determine in-situ dry density by sand replacement method.

Theory: A hole of specified dimensions is excavated in the ground. The mass of the excavated soil is determined.

The volume of the hole is determined by filling it with clean, uniform sand whose dry density (ρ_s) is determined separately by calibration. The volume of the hole is equal to the mass of the sand filled in the hole divided by its dry density.

The dry density of the excavated soil is determined as

$$\rho_d = \frac{(M/V)}{1+w}$$

Where M= mass of excavated soil;
V=volume of the hole;
w=water content

Equipment: 1. Sand- pouring cylinder; 2. Calibrating container, 100 mm diameter and 150 mm height; 3. Soil cutting and excavating tool, such as a scraper tool, bent spoon; 4. Glass plate, 459 mm square, 9 mm thick; 5. Metal container to collect excavated soil; 6. Metal tray, 300 mm square and 40 mm deep with a hole of 100 mm in diameter at the centre; 7. Weighing balance; 8. Moisture content cans; 9. Oven; 10. Desiccator.

Clean, uniform sand passing 1mm IS sieve and retained on 600 micron IS sieve in sufficient quantity.

Part-I Calibration
Procedure:

1. Determine the internal volume of the calibrating container by filling it with water and determining the mass of water required. The mass of water in grams is approximately equal to the volume in millimetres. The volume may also be determined from the measured dimensions of the container.
2. Fill the sand-pouring cylinder with sand, within about 10 mm of its top. Determine the mass of the cylinder (M_1) to the nearest gram.
3. Place the sand-pouring cylinder vertically on the calibrating container.
   Open the shutter to allow the sand run out from the cylinder into the calibrating container till it fills the cone of the cylinder and the calibrating container. When there is no further movement of the sand in the cylinder, close the shutter.
4. Lift the pouring cylinder from the calibrating container and weigh it to the nearest gram (M_3).
5. Again fill the pouring cylinder with sand, within 10 mm of its top.
6. Open the shutter and allow the sand to run out of the cylinder. When the volume of the sand let out is equal to the volume of the calibrating container, close the shutter.

7. Place the cylinder over a plane surface, such as a glass plate. Open the shutter. The sand fills the cone of the cylinder. Close the shutter when no further movement of sand takes place.
8. Remove the cylinder. Collect the sand left on the glass plate.
   Determine the mass of sand (M_2) that had filled the cone by weighing the collected sand.
9. Determine the dry density of sand, as shown in observation table, part-I.

Part-II. Dry Density

Procedure:

1. Expose an area of about 450 mm square of the soil mass.
   Trim the surface down to a level surface, using a scraper tool.
2. Place the metal tray on the levelled surface.
3. Excavate the soil through the central hole of the tray, using the hole in the tray as a pattern.
   The depth of the excavated hole should be about 150 mm.
4. Collect all the excavated soil in a metal container, and determine the mass of the soil (M).
5. Remove the metal tray from the excavated hole.
6. Fill the sand-pouring cylinder within 10 mm of its top. Determine its mass (M_1).
7. Place the cylinder directly over the excavated hole. Allow the sand to run out of the cylinder by opening the shutter.
   Close the shutter when the hole is completely filled and no further movement of sand is observed.
8. Remove the cylinder from the filled hole. Determine the mass of the cylinder (M_4).
9. Take a representative sample of the excavated soil. Determine its water content, as explained in the Experiment N0.1.
   Determine the dry density of soil as shown in the observation table, part-II.

Observations and Calculations:

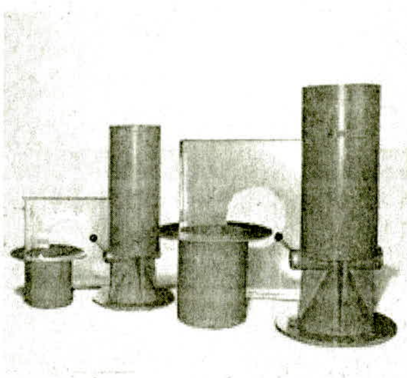
Part-I. Calibration for Dry Density of Sand

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
	Container No.			
1.	Volume of the calibrating cone (V_c)			
2.	Mass of a pouring cylinder (M_1), filled with sand			
3.	Mass of a pouring cylinder after pouring sand into the calibrating container and cone (M_3)			
4.	Mass of sand in cone (M_2)			
	Calculations			
5.	Mass of sand in the calibrating container $M_c = (2) - (3) - (4)$			
6.	Dry density of sand $(\rho_s) = M_c / V_c$			

Part-II. Calibration for Dry Density of Soil

Sr. No.	Observations and Calculations	Determination No. 1	2	3
	Observations			
	Container No.			
1.	Mass of excavated soil (M)			
2.	Mass of a pouring cylinder (M_1), filled with sand			
3.	Mass of a pouring cylinder after pouring into the hole and cone (M_4)			
	Calculations			
4.	Mass of sand in the hole, $M_s = (M_1) - (M_4) - (M_2)$			
5.	Volume of sand in the hole $V = M_s / \rho_s$			
6.	Bulk density, $\rho = M / V$			
7.	Water content, determined as in Experiment No.1			
8.	Dry density $= \frac{\rho}{1+w} = \frac{(M/V)}{1+w}$			

Result: Dry density is.................... gm/ml.



Sand Replacement Cylinder

EXPERIMENT NO. 5

Title: Grain Size Analysis by Sieving (Dry Sieve Analysis)
Objective: To determine the particle size distribution of a soil by sieving.

Theory: The soil is sieved through a set of sieves. The material retained on different sieves is determined. The percentage of material retained on any sieve is given b

$$P_n = \frac{M_n}{M} \times 100$$

Where M_n= mass of soil retained on sieve 'n',
M = total mass of the sample.
The cumulative percentage of the material retained,

$$C_n = p_1 + p_2 + ... + p_a$$

Where, p_1, p_2, etc, are the percentage retained on sieve '1', '2', etc. Which are coarser than sieve 'n'. The percentage finer than the sieve 'n',

$$N_n = 100 - C_n$$

Equipment: 1. Set of fine sieves, 2mm, 1 mm, 600 µ, 425 µ, 212 µ, 150 µ and 75 µ; 2. Set of coarse sieves 100 mm, 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm; 3. Weighing balance, accuracy of 0.1% of the mass of the sample; 4. Oven; 5. Mechanical shaker; 6. Trays; 7. Mortar, with a rubber covered pestle; 8. Brushes; 9. Riffler.

Part-I. Coarse sieve Analysis

Procedure:

1. Take the required quantity of sample. Sieve it through a 4.75 mm IS sieve. Take the soil fraction retained on 4.75 mm IS sieve for the coarse sieve analysis (part I) and that passing through the sieve for the fine sieve analysis (part-II).
2. Sieve the sample through the set of coarse sieves, by hand.
   While sieving through each sieve, the sieve should be agitated such that the sample rolls in irregular motion over the sieve. The material retained on the sieves may be rubbed with the rubber pestle in the mortar, if necessary. Care shall be taken so as not to break the individual particles. The quantity of the material taken for sieving on each sieve shall be such that the maximum mass of material retained on each sieve does not exceed the specified value.
3. Determine the mass of the material retained on each sieve.
4. Calculate the percentage of soil retained on each sieve on the basis of the total mass of the sample, taken in step (1).
5. Determine the percentage passing through each sieve.

Part-II. Fine sieve analysis

6. Take the portion of the soil passing through 4.75 mm IS sieve. Ovens dry it at 105^0 to 100^0C. Weigh it to the 0.1% of the total mass.

7. Sieve the soil through the nest of fine sieves. The sieves should be agitated to that the sample rolls in irrrgular motion over sieves. However, no particles should be pushed through the sieve.
8. Take the material retained on various sieves in a mortar. Rub it with rubber pestle, but do not try to break individual particles.
9. Reseive the material through the nest of sieves.
   A minimum of 10 minutes of shaking is required if a mechanical shaker is used.
10. Collect the soil fraction retained on each sieve in a separate container. Take the mass.
11. Determine the percentage retained, cumulative percentage retained and the percentage finer, based on the total mass taken in step (1).

Observations and Calculations:

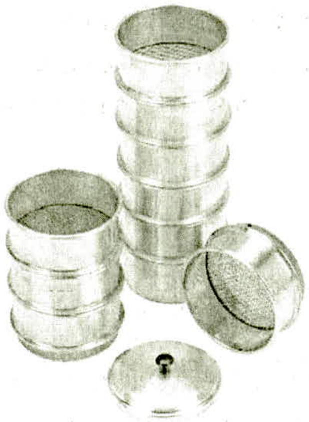
Sr. No.	Observations and Calculations			Calculations		
	IS Sieve	**Size of Opening**	**Mass of soil retained**	**Percentage retained**	**Cumulative % retained**	**% finer**
	Coarse Fraction (Part I)					
1.	100 mm	100 mm				
2.	80 mm	80 mm				
3.	40 mm	40 mm				
4.	20 mm	20 mm				
5.	10 mm	10 mm				
6.	4.75 mm	4.75 mm				
	Fine Fraction (Part II) 100 mm					
7.	2mm	2mm				
8.	1mm	1mm				
9.	600 μ	0.600 mm				
10.	425 μ	0.425 mm				
11.	300 μ	0.300 mm				
12.	212 μ	0.212 mm				
13.	150 μ	0.150 mm				
14.	75 μ	0.075 mm				
15	P_{an}	------				

Result: Percentage finer given in the last column can be used to plot the particle size distribution curve with particle size as abscissa on log scale and the percentage finer as ordinate.

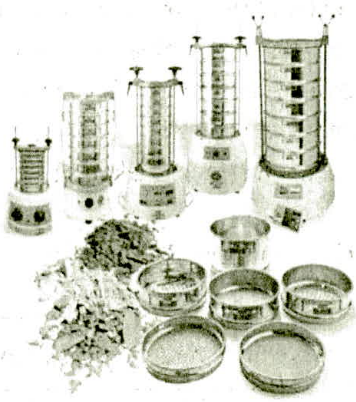
[**Note.** If the fine fraction contains an appreciable amount of clay particles, the wet sieve analysis is required. Alternatively, the following method may be used.

Before continuing step (7), add the water containing sodium hexa-metaphosphate at the rate of 2 gm per liter of water to the soil fraction. Stir the mix thoroughly and leave for soaking. Wash the soaked specimen on a 75 μ IS sieve until the water passing the sieve is clear. Take the fraction retained on the sieve and dry it in an oven. Sieve the oven dried soil through the nest of sieves as discussed in step (7). Perform further steps, as before.

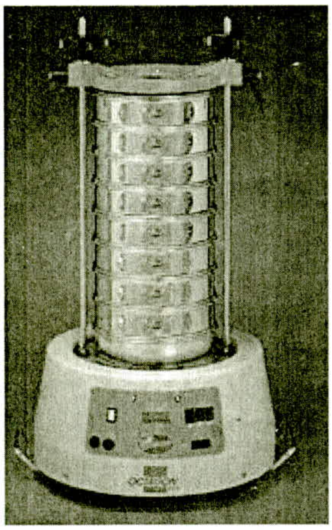
Obviously, the mass of material which would have been retained on pan is equal to the original mass of the soil before washing minus the dry mass of the soil retained on 75 μ IS sieve after washing.]

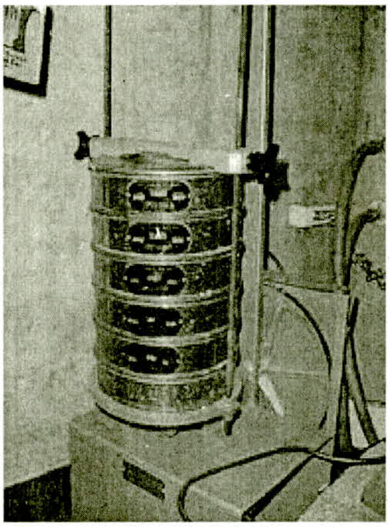


Set of sieves



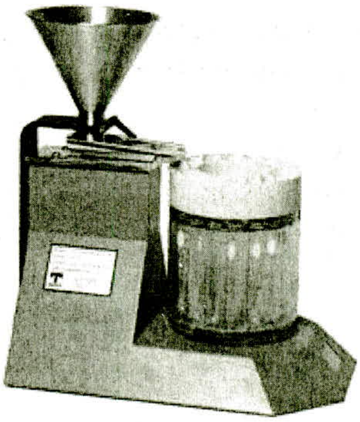
Sieve shakers with sieve





Mechanical Sieve shaker

Mortar with rubber covered Pestle



Riffler

EXPERIMENT NO. 6

Title: Grain Size Analysis by Hydrometer Method.
Objective: To determine the particle size distribution of a soil by hydrometer method.

THEORY: Hydrometer method is used to determine the particle size distribution of fine-grained soils passing 75 μ sieve. The hydrometer measures the specific gravity of the soil suspension at the centre of its bulb. The specific gravity depends upon the mass of solids present, which, in turn, depends on the particle size. The particle size (D) is given by

$$D= M\sqrt{H_e/t}$$

where $M=\left[\frac{0.3\,\eta}{g\,(G-1)\rho_w}\right]^{1/2}$,

in which, η = viscosity of water (poise), G= specific gravity of solids; ρ_w = density of water (gm/ml); g = 981 cm/sec^2 , H_e = effective depth (cm); t = time in minutes at which observation is taken, reckoned with respect to the beginning of sedimentation.

The percentage finer than the size D is given by

$$N=\left(\frac{G}{G-1}\right) \times \frac{R}{M_s} \times 100$$

where, *R*= corrected hydrometer reading; M_S= mass of dry soil in 1000 ml suspension.

Equipment: 1. Hydrometer; 2. Glass measuring cylinder (jar), 1000 ml; 3. Rubber bung for the cylinder (jar); 4. Mechanical stirrer; 5. Weighing balance, accuracy 0.01 gm; 6. Oven; 7. Desiccators;; 8. Evaporating dish; 9. Conical flask of beaker, 1000 ml; 10. Stop watch; 11. Wash bottle; 12. Thermometer; 13. Glass rod; 14. Water bath; 15. 75 μ sieve; 16. Scale; 17. Deflocculating agent.

Procedure:

Part-I. Calibration of hydrometer

1. Take about 800 ml of water in one measuring cylinder. Place the cylinder on a table and observe the initial reading.
2. Immerse the hydrometer in the cylinder. Take the reading after immersion.
3. Determine the volume of the hydrometer (V_H), which is equal to the difference between the final and initial readings.
   Alternatively, weigh the hydrometer to the nearest 0.1 gm. The volume of the hydrometer in ml is approximately equal to its mass in grams.
4. Determine the area of cross-section (*A*) of the cylinder. It is equal to the volume indicated between any two graduations divided by the distance between them. The distance is measured with an accurate scale.
5. Measure the distance between the hydrometer neck and the bottom of the bulb. Record it as the height of the bulb (*h*).

6. Measure the distance (H) between the neck to each of the marks on the hydrometer (R_h).
7. Determine the effective depth (H_e), corresponding to each of the mark (R_h), as

$$H_e = H + \frac{1}{2}\left(h - \frac{V_H}{A}\right)$$

[**Note.** The factor V_H/A should not be considered when the hydrometer is not taken out when taking readings after start of the sedimentation at ½, 1, 2 and 4 minutes.]

8. Draw a calibration curve between H_e and R_h. Alternatively, prepare a table between H_e and R_h.

   The curve may be used for finding the effective depth H_e corresponding to reading R_h.

Part-II. Meniscus Correction

1. Insert the hydrometer in the measuring cylinder containing about 700 ml water.
2. Take the readings of the hydrometer at the top and at the bottom of the meniscus.
3. Determine the meniscus correction, which is equal to the difference between two readings.
4. The meniscus correction (C_m) is positive and is a constant for hydrometer.
5. The observed hydrometer reading (R_h') is corrected to obtain the corrected hydrometer reading R_h as

$$R_h = R_h' + C_m$$

Part-III. Pretreatment and Dispersion

1. Weigh accurately, to nearest 0.01 gm about 50 gm air-dried soil sample passing 2 mm IS sieve, obtained by riffling from the air-dried sample passing 4.75 mm IS sieve.
2. Add about 150 ml of hydrogen peroxide to the soil sample in the flask.

   Stir it gently with a glass rod for a few minutes.
3. Cover the flask with a glass plate, and leave it to stand overnight.
4. Heat the mixture in the conical flask gently after keeping it in an evaporating dish.

   Stir the contents periodically. When vigorous frothing subsides, the reaction is complete. Reduce the volume to 50 ml by boiling. Stop heating and cool the contents.
5. If the soil contains insoluble calcium compounds, add about 50 ml of hydrochloric acid to the cooled mixture.

   Stir the solution with a glass rod for a few minutes. Allow it to stand for one hour or so. The solution would have an acid reaction to litmus when the treatment is complete.
6. Filter the mixture and wash it with warm water until the filtrate shows no acid reaction.
7. Transfer the damp soil on the filter and funnel to an evaporating dish, using a jet of distilled water. Use the minimum quantity of distilled water.
8. Place the evaporating dish and its contents in an oven, and dry it at 105°C to 110°C.

   Transfer the dish to a desiccator, and allow it to cool.
9. Take the mass of the oven dried soil after pretreatment.

10. Add 100 ml of sodium hexa-metaphosphate solution to the oven-dried soil in the evaporating dish after pretreatment.
11. Warm the mixture gently for about 10 minutes.
12. Transfer the mixture to the cup of a mechanical mixture. Use a jet of distilled water to wash all traces of the soil out of the evaporating dish. Use about 150 ml of water. Stir the mixture for about 15 minutes.
13. Transfer the soil suspension passing 75 μ sieve. Dry it in oven. Determine its mass. If required, do the sieve analysis of this fraction.

Part-IV. Sedimentation Test

1. Place the rubber bung on the open end of the measuring cylinder containing the soil suspension. Shake it vigorously end-over-end to mix the suspension thoroughly.
2. Remove the bung after shaking is complete. Place the measuring cylinder on the table and start the stop watch.
3. Immerse the hydrometer gently to a depth slightly below the floating depth, and then allow it to float freely.
4. Take hydrometer reading (R_h') after ½, 1, 2 and 4 minutes, without removing the hydrometer from the cylinder.
5. Take out the hydrometer from the cylinder, rinse it with distilled water.
6. Float the hydrometer in another cylinder containing only distilled water at the same temperature as that of the test cylinder.
7. Take out the hydrometer from the distilled water cylinder and clean its stem. Insert it in the cylinder containing suspension to take the reading at the total elapsed time interval of 8 minutes. About 10 seconds should be taken while taking the reading. Remove the hydrometer, rinse it and place it in the distilled water cylinder after reading.
8. Repeat the step (7) to take readings at 15, 30, 60, 120 and 240 minutes elapsed time interval.
9. After 240 minutes (4 hours) reading, take readings twice within 24 hours. Exact time of each reading should be noted.
10. Record the temperature of the suspension once during the first 15 minutes, and thereafter at the time of every subsequent reading.
11. After the final reading, pour the suspension in an evaporating dish. Dry it in oven and find its dry mass.
12. Determine the composite correction before the start of the test, and also at 30 minutes, 1, 2 and 4 hours. Thereafter, just after each reading, composite correction is determined.
13. For the determination of the composite corrections (C), insert the hydrometer in the comparison cylinder containing 100 ml of dispersing agent solution in 1000ml of distilled water at the same temperature. Take the reading corresponding to the top of meniscus. The negative of the reading is the composite correction.

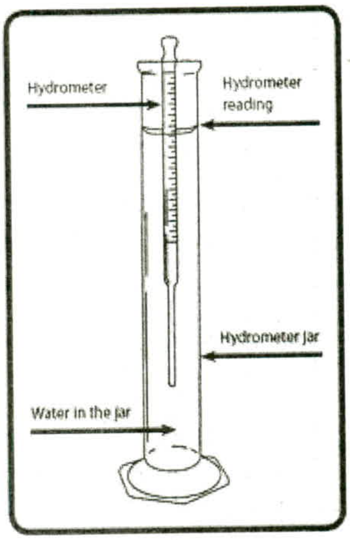
RESULT: Particle size distribution curves can be plotted using the last two columns.

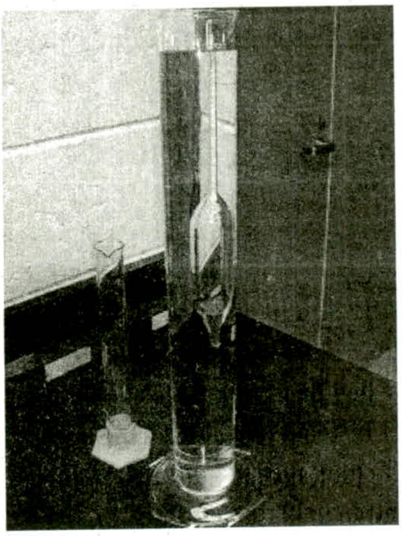
Observations and Calculations:

Mass of dry soil (M_s) = ...gm, Meniscus correction (C_m) = ...

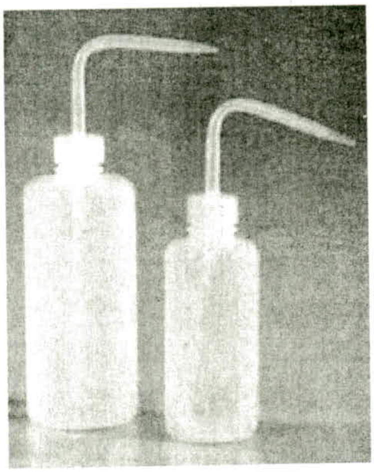
Specific gravity of solids (G) = 2.67

S. No.	Observations				Calculations					
	Elapsed Time (t)	Hydrometer Reading (R_h')	Temperature	Composite Correction (C)	Corrected Reading $R=(R_h')+C_m$	Height H_e (cm)	Reading $R=(R_h')+C$	Factor M	Particle size $D=M\sqrt{H_e/t}$	Percentage finer (N)
1.	½ minutes									
2.	1 minutes									
3.	2 minutes									
4.	4 minutes									
5.	8 minutes									
6.	15 minutes									
7.	30 minutes									
8.	1 hr									
9.	2 hr									
10.	4 hr									
11.	8 hr									
12.	12 hr									
13.	24 hr									

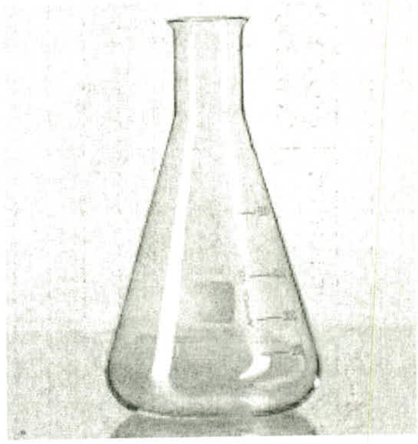




Hydrometer



Wash Bottle



Conical Flask

EXPERIMENT NO. 7

Title: Determination of Liquid Limit by Casagrande's Method.
Objective: To determine the liquid limit of the soil.

Theory: The liquid limit of a soil is the water content at which the soil behaves practically like a liquid, but has a small shear strength. It flows to close the groove in just 25 blows in Casagrande's liquid limit device.

As it is difficult to get exactly 25 blows in a test, 3 to 4 tests are conducted, and the number of blows (N) required in each test is determined. A semi-log plot is drawn between log N and the water content (w). The liquid limit is the water content corresponding to N = 25, as obtained from the plot.

Equipment: 1. Casagrande's liquid limit devices; 2. Grooving tools of both Standard and ASTM types; 3. Oven; 4. Evaporating dish or glass sheet; 5. Spatula; 6. 425 μ IS sieve; 7. Weighing balance, accuracy 0.01 gm; 8. Wash bottle.

Procedure:

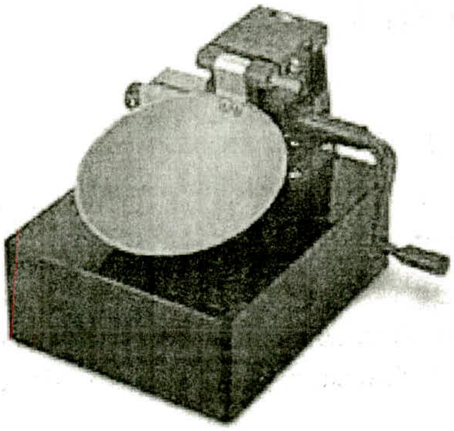
1. Adjust the drop of the cup of the liquid limit device by releasing the two screws at the top and by using the handle of the grooving tool or a gauge.
2. Take about 120 gm of the air-dried soil sample passing 425 μ IS sieve.
3. Mix the sample thoroughly with distilled water in an evaporating dish or a glass plate to form a uniform paste. Mixing should be continued for about 15 to 30 minutes, till a uniform mix is obtained.
4. Keep the mix under humid conditions for obtaining uniform moisture distribution for sufficient period. For some fat clays, this maturing time may be upto 24 hours.
5. Take a portion of the matured paste and remix it thoroughly. Place it in the cup of the device by a spatula and level it by a spatula or a straight edge to have a maximum depth of the soil as 1 cm at the point of the maximum thickness.
   The excess soil, if any, should be transferred to the evaporating dish.
6. Cut a groove in the sample in the cup by using the appropriate tool. Draw the grooving tool through the paste in the cup along the symmetrical axis, along the diameter through the center line of the cam. Hold the tool perpendicular to the cup.
7. Turn the handle of the device at a rate of 2 revolutions per second.
   Count the number of blows until the two halves of the soil specimen come in contact at the bottom of the groove along a distance of 12 mm due to flow and not by sliding.
8. Collect a representative specimen of the soil by moving spatula width-wise from one edge to the other edge of the soil cake, at right-angles to the groove. This should include the portion of the groove in which the soil flowed to close the groove.
   Place the specimen in an air-tight container for the water content determination. Determine the water content.
9. Remove the remaining soil from the cup. Mix it with the soil left in the evaporating dish.

10. Change the water content of the mix in the evaporating dish, either by adding more water if the water content is to be increased, or by kneading the soil, if the water content is to be decreased.
    In no case, the dry soil should be added to reduce water content.
11. Repeat steps 4 to 10 and determine the number of blows (N) and the water content in each case.
12. Draw the flow curve between log N and w, and determine the liquid limit corresponding to $N = 25$.

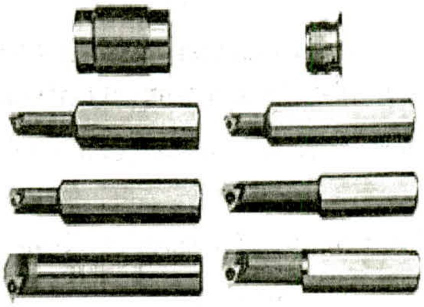
Observations and Calculations:

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	No of blows (N)			
2.	Water content can No.			
3.	Mass of the empty can (M_1)			
4.	Mass of the can with wet soils (M_2)			
5.	Mass of the can with dry soils (M_3)			
	Calculations			
6.	Mass of water = $M_2 - M_3$			
7.	Mass of dry soil = $M_3 - M_1$			
8.	Water content (w) = (6)/(7) x 100			

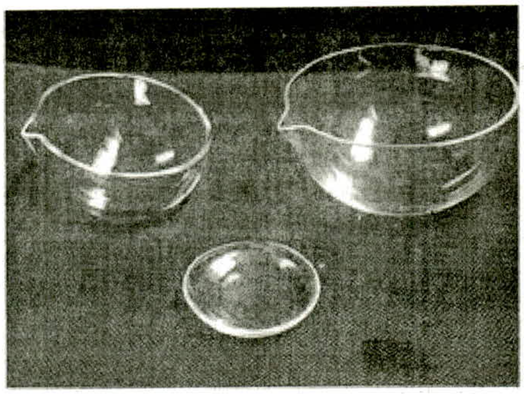
RESULT: Draw a flow curve between log N and w. Liquid limit (for N=........) is................



Casagrande's Liquid Limit Device



Grooving Tools



Evaporating Dish

EXPERIMENT NO. 8

Title: Determination of Plastic Limit.

Objective: To determine the plastic limit of the soil.

Theory: The plastic limit of a soil is the water content of the soil below which it ceases to be plastic. It begins to crumble when rolled into threads of 3 mm diameter.

Equipment: 1. Porcelain evaporating dish, about 120 mm diameter or a flat glass plate, 450 mm square and 10 mm thick; 2. Ground glass plate, about 200 mm x 150 mm; 3. Metallic rod, 3 mm diameter and 100 mm long; 4. Oven; 5. Spatula or palette knife; 6. Moisture content can.

Procedure:

1. Take about 30 gm of air-dried soil from a thoroughly mixed sample of the soil passing 425 μ IS sieve.
2. Mix the soil with distilled water in an evaporating dish or on a glass plate to make it plastic enough to shape into a small ball.
3. Leave the plastic soil mass for some time for maturing. For some fat clays, this period may be even upto 25 hours.
4. Take about 8 gm of the plastic soil, and roll it with fingers on a glass plate. The rate of the rolling should be about 80 to 90 strokes per minute to form a thread of 3 mm diameter, counting one stroke when the hand moves forward and backward to the starting point.
5. If the diameter of the thread becomes less than 3 mm without cracks, it shows that the water content is more than the plastic limit. Knead the soil to reduce the water content, and roll it again into thread.

   Repeat the process of alternate rolling and kneading until the thread crumbles, and the soil can no longer be rolled into thread.

   [**Note.** If the crumbling occurs when the thread has a diameter slightly greater than 3mm, it may be taken as the plastic limit, provided that soil had been rolled into a thread of 3 mm diameter immediately before kneading. Do not attempt to produce failure exactly at 3 mm diameter.]

   The excess soil, if any, should be transferred to the evaporating dish.
6. Collect the pieces of the crumbled soil thread in a moisture content container.
7. Repeat the procedure at least twice more with fresh samples of plastic soil each time.

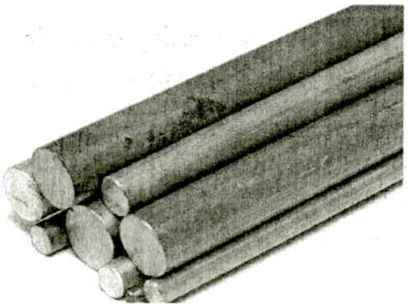
Observations and Calculations:

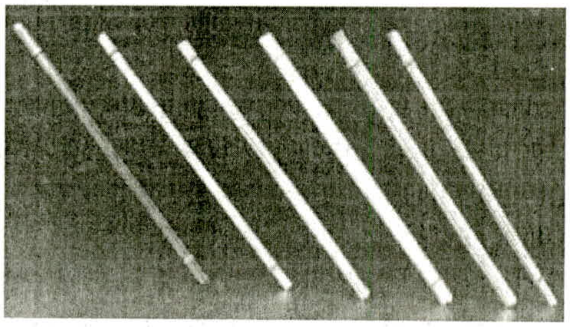
Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Moisture content container No.			
2.	Mass of the empty container (M_1)			
3.	Mass of the container with wet soil (M_2)			

4. 5.	Mass of the container with dry soil (M_3) **Calculations** Mass of water = $M_2 - M_3$			
6.	Mass of dry soil = M_3 - M_1			
7.	Water content (w) = (5)/(6) x 100			

RESULT: Plastic limit of soil is.................%

Porcelain Evaporating Dish





Metallic Rods

EXPERIMENT NO. 9

Title: Determination of Shrinkage Limit.

Objective: To determine the shrinkage limit of the soil.

THEORY: The shrinkage limit of a soil is the water content of the soil when the water content is just sufficient to fill all the pores of the soil, and the soil is just saturated. The volume of the soil does not decrease when the water content is reduced below the shrinkage limit. It can be determined from the relation

$$w_s = \frac{(M_1 - M_s) - (V_1 - V_2)\,\rho_w}{M_s} \times 100$$

where M_1 = initial wet mass;

V_1 = initial volume;

M_2 = dry mass;

V_2 = volume after drying.

Equipment: 1. Shrinkage dish, having a flat bottom, 45 mm diameter and 15 mm height; 2. Two large evaporating dishes about 120 mm diameter, with a pour out and flat bottom; 3. One small mercury dish, 60 mm diameter; 4. Two glass plates, one plain and one with prongs, 75 mm x 75 mm x 3 mm size; 5. Glass cup, 50 mm diameter and 25 mm high; 6. IS sieve 425 µ; 7. Oven; 8. Desiccator; 9. Weighing balance, accuracy 0.01 gm; 10. Spatula; 11. Straight edge; 12. Mercury.

Procedure:

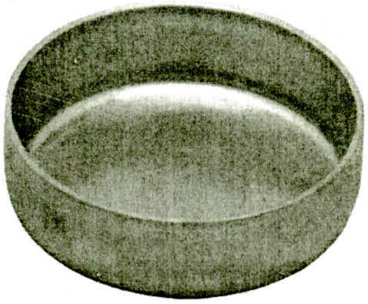
1. Take a sample mass about 100 gm from a thoroughly mixed soil passing 425 µ sieve.
2. Take about 30 gm of the soil sample in a large evaporating dish. Mix it with distilled water to make a creamy paste which can be readily worked without entrapping the air bubbles.
3. Take the shrinkage dish. Clean it and determine its mass.
4. Fill mercury in the shrinkage dish. Remove the excess mercury by pressing the plain glass plate over the top of the shrinkage dish. The plate should be flush with the top of the dish, and no air should be entrapped.
5. Transfer the mercury of the shrinkage dish to a mercury weighing dish and determine the mass of the mercury to an accuracy of 0.1 gm. The volume of the shrinkage dish is equal to the mass of mercury in grams divided by the specific gravity of mercury (*viz.* 13.6)
6. Coat the inside of the shrinkage dish with a thin layer of silicon grease or Vaseline.
   Place the soil specimen in the centre of the shrinkage dish, equal to about one-third the volume of the shrinkage dish.
   Tap the shrinkage dish on a firm, cushioned surface and allow the paste to flow to the edges.
7. Add more soil paste, approximately equal to the first portion and tap the shrinkage dish as before, until the soil is thoroughly compacted.
   Add more soil and continue the tapping till the shrinkage dish is completely filled and excess soil paste projects out about its edge.
   Strike out the top surface of the paste with a straight edge. Wipe off all soil adhering to the outside of the shrinkage dish. Determine the mass of the wet soil (M_1)

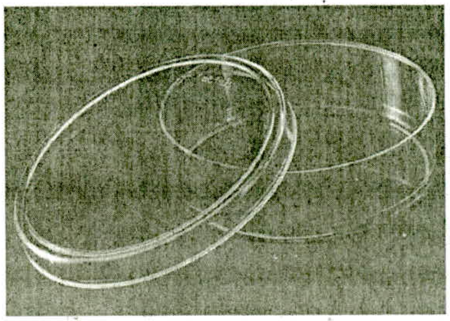
8. Dry the soil in the shrinkage dish in air until the colour of the pat turns from dark to light. Then dry the pat in the oven at 105^{0}C to 110^{0}C to constant mass.
9. Cool the dry pat in a desiccator. Remove the dry pat from the desiccator after cooling, and weigh the shrinkage dish with the dry pat to determine the dry mass of the soil (M_s).
10. Place a glass cup in a large evaporating dish and fill it with mercury. Remove the excess mercury by pressing the glass plate with prongs firmly over the top of the cup. Wipe off any mercury adhering to the outside of the cup.
    Remove the glass cup full of mercury and place it in another evaporating dish, taking care not to spill any mercury from the glass cup.
11. Take out the dry pat of the soil from the shrinkage dish and immerse it in the glass cup full of mercury. Take care not to entrap air under the pat. Press the plate with prongs on the top of the cup firmly.
12. Collect the mercury displaced by the dry pat in the evaporating dish and transfer it to the mercury weighing dish. Determine the mass of the mercury to an accuracy of 0.1 gm. The volume of the dry pat (V_2) is equal to the mass of the mercury divided by the specific gravity of mercury.
13. Repeat the test at least 3 times.

Observations and Calculations:

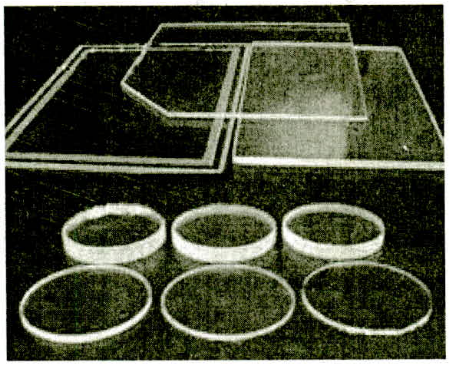
Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Mass of the empty mercury dish			
2.	Mass of the mercury dish, with mercury equal to volume of the shrinkage dish			
3.	Mass of the mercury = (2) – (1)			
4.	Volume of shrinkage dish, V_1= (3)/13.6			
5.	Mass of empty shrinkage dish			
6.	Mass of shrinkage dish with wet soil			
7.	Mass of wet soil, M_1 = (6) – (5)			
8.	Mass of shrinkage dish with dry soil			
9.	Mass of dry soil, M_s = (8) – (5)			
10.	Mass of the mercury dish and mercury equal in volume of dry pat			
11.	Mass of mercury displaced by dry pat = (10) – (1)			
12.	Volume of dry pat, V_2 = (11)/ 13.6			
	Calculations			
13.	Shrinkage limit, $w_s = \frac{(M_1 - M_s) - (V_1 - V_2)\rho_w}{M_s}$			
14.	Shrinkage ratio, $SR = \frac{M_s}{V_2 \rho_w}$			
15.	Volumetric shrinkage, $VS = \left(\frac{V_1 - V_2}{V_2}\right) \times 100$			

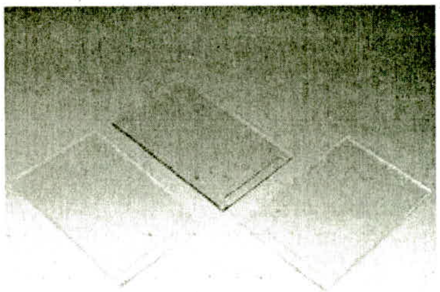
Result: Shrinkage limit of soil is................%.



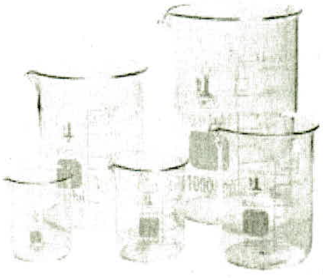


Shrinkage Device **Mercury Dish**





Glass Plates



Glass Cups

EXPERIMENT NO. 10

Title: Determination of Permeability by Constant Head Method.

Objective: To determine the permeability of a soil by constant head permeameter.

Theory: The coefficient of permeability is equal to the rate of flow of water through a unit cross-sectional area under a unit hydraulic gradient. In the constant head permeameter, the head causing flow through the specimen remains constant throughout the test. The coefficient of permeability (k) is obtained from the relation

$$k = \frac{qL}{Ah} = \frac{QL}{Aht}$$

where, q = discharge ; Q= total volume of water; t time period; h = length of specimen; A= cross-sectional area.

Equipment: 1. Permeameter mould, internal diameter= 100 mm, effective height = 127.3 mm, capacity = 1000 ml; 2. Detachable collar, 100 mm diameter, 60 mm high; 3. Dummy plate, 108 mm diameter, 12 mm thick; 4. Drainage base, having a porous disc; 5. Drainage cap, having porous disc with a spring attached to the top; 6. Compaction equipment, such as Proctor's rammer or a static compaction equipment; 7. Constant- head water-supply reservoir; 8. Vaccum pump; 9. Constant head collecting chamber; 10. Stop watch; 11. Large funnel; 12. Thermometer; 13.Weighing balance, accuracy 0.01 gm; 11. Filter paper.

Procedure:

1. Remove the collar of the mould. Measure the internal dimensions of the mould. Weigh the mould, with dummy plate, to the nearest gram.
2. Apply a little grease on the inside to the mould.
   Clamp the mould between the base plate and the extension collar and place the assembly on a soild base.
3. Take about 2.5 kg of the soil sample, from a thoroughly mixed wet soil, in the mould. Compact the soil at the required dry density, using a suitable compacting device.
4. Remove the collar and base plate. Trim the excess soil level with the top of the mould.
5. Clean the outside of the mould and the dummy plate. Find the mass of the soil in the mould.
6. Take a small specimen of the soil in a container for the water content determination.
7. Saturate the porous discs (stones).
8. Place a porous disc on the drainage base and keep a filter paper on the porous disc.
9. Remove the dummy plate and place the mould with soil on the drainage base, after inserting a washer in between.
10. Clean the edges of the mould. Apply grease in the grooves around them.
11. Place a filter paper, a porous disc and fix the drainage cap using washers.
12. Connect the water reservoir to the outlet at the base and allow the water to flow upwards till it has saturated the sample. Let the free water collect for a depth about 100 mm on the top of the sample.
    [Alternatively, the soil of permeability can be saturated by subjecting the specimen to a gradually increasing vaccum with bottom outlet closed so as to remove air from the

voids. Increase the vaccum gradually to 700 mm of mercury and maintain it for 15 minutes or depending upon the type of soil. Follow the evacuation by a process of slow saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both the top and bottom outlets.]

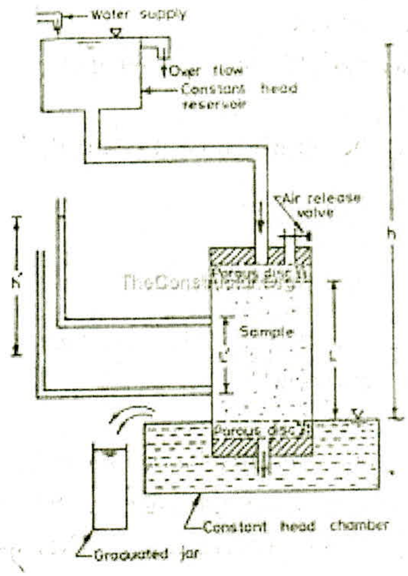
13. Fill the empty portion of the mould with deaired water, without disturbing the soil.
14. Disconnect the reservoir from the outlet at the bottom.
15. Connect the constant-head reservoir to the drainage cap inlet.
16. Open the stop cock and allow the water to the flow downward so that all the air is removed.
17. Close the stop watch and allow the water to flow through the soil till a steady state is attained.
18. Start the stop watch and collect the water flowing out of the base in a measuring flask for some convenient time interval.
19. Repeat this thrice, keeping the interval the same. Check that the quantity of water collected is approximately the same each time.
20. Measure the difference of head (h) in levels between the constant head reservoir and the outlet in the base.
21. Repeat the test for at least 2 more different intervals.

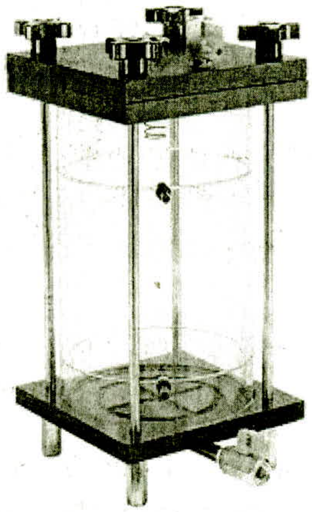
Observations and Calculations:

Diameter = 100 mm; Length = 10 mm; Volume = 942.48 ml; $G = 2.67$; Area = 7854 m^2

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Mass of the empty mould with base plate			
2.	Mass of the mould, soil and base plate			
3.	Hydraulic head (h)			
4.	Time interval (t)			
5.	Quantity of flow (Q)			
	a. First time in period t			
	b. Second time in period t			
	c. Third time in period t			
	Average Q			
	Calculations			
6.	Mass of soil = (2) – (1)			
7.	Bulk density, ρ = Mass / Volume			
8.	Water content, w (determined as in Expt. No. 1)			
9.	Dry density, $\rho_d = \frac{\rho}{1+w}$			
10.	Void Ratio, $e = \frac{\rho_w G}{\rho_d} - 1$			
11.	$k = \frac{QL}{Aht}$			

Result: Coefficient of permeability of soil is...............mm/sec.





Constant Head Permeameter

EXPERIMENT NO. 11

Title: Determination of Permeability by Variable-Head Method.
Objective: To determine the permeability of a soil by the variable-head permeameter.

Theory: The variable head permeameter is used to measure the permeability of relatively less pervious soils. The coefficient of permeability is given by

$$k = \frac{2.30\, a\, L}{A\, t} \log_{10} (h_1 / h_2)$$

where, h_1 = initial head; h_2 = final head; t = time interval; a = cross-sectional area of the stand pipe; A= cross-sectional area of the specimen; L = length of specimen.

Equipment: 1. Permeameter mould, internal diameter= 100 mm, effective height = 127.3 mm, capacity = 1000 ml; 2. Detachable collar, 100 mm diameter, 60 mm high; 3. Dummy plate, 108 mm diameter, 12 mm thick; 4. Drainage base, having a porous disc; 5. Drainage cap, having porous disc with a spring attached to the top; 6. Compaction equipment, such as Proctor's rammer or a static compaction equipment; 7. Constant- head water-supply reservoir; 8. Vaccum pump; 9. Constant head collecting chamber; 10. Stop watch; 11. Large funnel; 12. Thermometer; 13.Weighing balance, accuracy 0.01 gm; 14. Filter paper; 15. Graduated glass stand pipe, 5 to 20 mm diameter; 16. Supporting frame for the stand pipe, and the clamp.

Procedure:

1. Remove the collar of the mould. Measure the internal dimensions of the mould. Weigh the mould, with dummy plate, to the nearest gram.
2. Apply a little grease on the inside to the mould.
   Clamp the mould between the base plate and the extension collar and place the assembly on a solid base.
3. Take about 2.5 kg of the soil sample, from a thoroughly mixed wet soil, in the mould. Compact the soil at the required dry density, using a suitable compacting device.
4. Remove the collar and base plate. Trim the excess soil level with the top of the mould.
5. Clean the outside of the mould and the dummy plate. Find the mass of the soil in the mould.
6. Take a small specimen of the soil in a container for the water content determination.
7. Saturate the porous discs (stones).
8. Place a porous disc on the drainage base and keep a filter paper on the porous disc.
9. Remove the dummy plate and place the mould with soil on the drainage base, after inserting a washer in between.
10. Clean the edges of the mould. Apply grease in the grooves around them.
11. Place a filter paper, a porous disc and fix the drainage cap using washers.
12. Connect the water reservoir to the outlet at the base and allow the water to flow upwards till it has saturated the sample. Let the free water collect for a depth about 100 mm on the top of the sample.

[Alternatively, the soil of permeability can be saturated by subjecting the specimen to a gradually increasing vaccum with bottom outlet closed so as to remove air from the voids. Increase the vaccum gradually to 700 mm of mercury and maintain it for 15 minutes or depending upon the type of soil. Follow the evacuation by a process of slow saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both the top and bottom outlets.]

13. Fill the empty portion of the mould with deaired water, without disturbing the soil.
14. Disconnect the reservoir from the outlet at the bottom.
15. Connect the stand pipe of suitable diameter to the inlet at the top. Fill the stand pipe with water.
16. Open the stop cock at the top and allow the water to the flow out till all the air in the mould is removed.
17. Close the stop cock and allow the water from the stand pipe to flow through the soil specimen.
18. Select the heights h_1 and h_2 measured above the centre of the outlet such that their difference is about 300 to 400 mm.

    Mark the level corresponding to a height $\sqrt{h_1 h_2}$.
19. Open the valve and start the stop watch. Record the time interval for the head to fall from h_1 to $\sqrt{h_1 h_2}$ and also from $\sqrt{h_1 h_2}$ to h_2. These two time intervals will be equal if the steady conditions have established.
20. Repeat the step (19) atleast twice, after changing the heights h_1 and h_2.
21. Take a small quantity of the soil specimen for the water content determination.

Observations and Calculations:

Length of specimen	= 120 mm; Diameter = 100 mm;
Area of specimen	= 7854 mm^2
Volume of specimen	= 942.48 ml;
Diameter of the stand pipe	= 10 mm;
Area of stand pipe	= 78.54 mm^2
$G = 2.67$;	

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Mass of the mould with base plate			
2.	Mass of the mould, soil and base plate			
3.	Initial head (h_1)			
4.	Final head (h_2)			
5.	Head $\sqrt{h_1 h_2}$			

6.	Time interval h_1 to $\sqrt{h_1 h_2}$ $\sqrt{h_1 h_2}$ to h_2 h_1 to h_2			
	Calculations			
7.	Mass of soil = (2) – (1)			
8.	Bulk density, ρ = Mass / Volume			
9.	Water content, w (determined as in Expt. No. 1)			
10.	Dry density, $\rho_d = \frac{\rho}{1+w}$			
11.	Void Ratio, $e = \frac{\rho_w G}{\rho_d} - 1$			
12.	$k = \frac{2.30\, a L}{A t} \log_{10}(h_1/h_2)$			

Result: Coefficient of permeability of soil is...............mm/sec.

EXPERIMENT NO. 12

Title: Determination of Compaction by Standard Proctor's Test.

Objective: To determine the compaction characteristics of a soil by Standard Proctor's Test.

Theory: Compaction is the process of densification of dry reducing air voids. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is maximum at the optimum water content. A curve is drawn between the water content and the dry density to obtain the maximum dry density and the optimum water content.

$$\text{Dry density} = \frac{M/V}{1+w}$$

where, M = total mass of soil; V= volume of soil; w= water content.

Equipment: 1. Compaction mould, capacity 1000 ml; 2. Rammer, mass 2.6 kg; 3. Detachable base plate; 4. Collar, 60 mm high; 5. IS sieve 4.75 mm; 6. Oven; 7. Desiccator; 8. Weighing balance, accuracy 0.01 gm; 9. Large mixing pan; 10. Straight edge; 11. Spatula; 12. Graduated Jar; 13. Mixing tools, spoons, trowels etc.

Procedure:

1. Take about 20 kg of air-dried soil. Sieve it through 20 mm and 4.75 mm IS sieves.
2. Calculate the percentage retained on 20 mm sieve, and 4.75 mm sieve and the percentage passing through 4.75 mm sieve. Do not use the soil retained on 20 mm sieve. Determine the ratio of fraction retained and that passing 4.75 mm sieve.
3. If percentage retained on 4.75 mm sieve is greater than 20, use the larger mould of 150 mm diameter. If it is less than 20 %, the standard mould of 100 mm diameter can be used. The following procedure is for the standard mould.
4. Mix the soil retained on 4.75 mm sieve and that passing 4.75 mm sieve in the proportions determined in step 2 to obtain about 16 to 18 kg of soil specimen.
5. Clean and dry the mould and the base plate. Grease them lightly.
6. Weigh the mould with the base plate to the nearest 1 gram.
7. Take about 16-18 kg of soil specimen. Add water to it to bring the water content to about 4% if the soil is sandy and to about 8% if the soil is clayey.
8. Keep the soil in an air-tight container for about 18 to 20 hours for maturing. Mix the matured soil thoroughly. Divide the processed soil into 6 to 8 parts.
9. Attach the collar to the mould. Place the mould on a solid base.
10. Take about $2\frac{1}{2}$ kg of the processed soil, and place it in the mould in 3 equal layers.

    Take about one-third the quantity first, and compact it by giving 25 blows of the rammer. The blows should be uniformly distributed over the surface of each layer.
    The top surface of the first layer should be scratched with a spatula placing the second layer. The second layer should also be compacted by 25 blows of rammer. Likewise, place the third layer and compact it.
    The amount of the soil used should be just sufficient to fill the mould and leaving about 5 mm above the top of the mould to be struck off when the collar is removed.

11. Remove the collar, and trim off the Clean the outside of the mould and the dummy plate. Find the mass of the soil in the mould.
12. Take a small specimen of the soil in a container for the water content determination.
13. Saturate the porous discs (stones).
14. Place a porous disc on the drainage base and keep a filter paper on the porous disc.
15. Remove the dummy plate and place the mould with soil on the drainage base, after inserting a washer in between.
16. Clean the edges of the mould. Apply grease in the grooves around them.
17. Place a filter paper, a porous disc and fix the drainage cap using washers.
18. Connect the water reservoir to the outlet at the base and allow the water to flow upwards till it has saturated the sample. Let the free water collect for a depth about 100 mm on the top of the sample.

    [Alternatively, the soil of permeability can be saturated by subjecting the specimen to a gradually increasing vaccum with bottom outlet closed so as to remove air from the voids. Increase the vaccum gradually to 700 mm of mercury and maintain it for 15 minutes or depending upon the type of soil. Follow the evacuation by a process of slow saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both saturation of the sample from the bottom upward under full vaccum. When the sample is saturated, close both the top and bottom outlets.]
19. Fill the empty portion of the mould with deaired water, without disturbing the soil.
20. Disconnect the reservoir from the outlet at the bottom.
21. Connect the stand pipe of suitable diameter to the inlet at the top. Fill the stand pipe with water.
22. Open the stop cock at the top and allow the water to the flow out till all the air in the mould is removed.
23. Close the stop cock and allow the water from the stand pipe to flow through the soil specimen.
24. Select the heights h_1 and h_2 measured above the centre of the outlet such that their difference is about 300 to 400 mm.

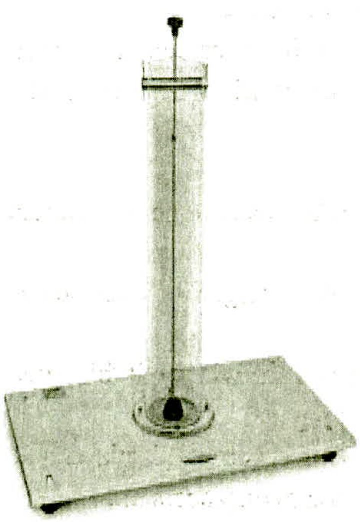
    Mark the level corresponding to a height $\sqrt{h_1 h_2}$.
25. Open the valve and start the stop watch. Record the time interval for the head to fall from h_1 to $\sqrt{h_1 h_2}$ and also from $\sqrt{h_1 h_2}$ to h_2. These two time intervals will be equal if the steady conditions have established.
26. Repeat the step (19) atleast twice, after changing the heights h_1 and h_2.
27. Take a small quantity of the soil specimen for the water content determination.

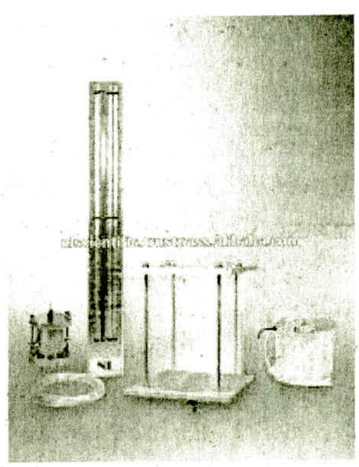
Observations and Calculations:

Length of specimen = 120 mm; Diameter = 100 mm;
Area of specimen = 7854 mm^2
Volume of specimen = 942.48 ml;
Diameter of the stand pipe = 10 mm;
Area of stand pipe = 78.54 mm^2
G = 2.67;

Sr. No.	Observations and Calculations	Determination No.		
		1	2	3
	Observations			
1.	Mass of the mould with base plate			
2.	Mass of the mould, soil and base plate			
3.	Initial head (h_1)			
4.	Final head (h_2)			
5.	Head $\sqrt{h_1 h_2}$			
6.	Time interval			
	h_1 to $\sqrt{h_1 h_2}$			
	$\sqrt{h_1 h_2}$ to h_2			
	h_1 to h_2			
	Calculations			
7.	Mass of soil = (2) – (1)			
8.	Bulk density, ρ = Mass / Volume			
9.	Water content, w (determined as in Expt. No. 1)			
10.	Dry density, $\rho_d = \frac{\rho}{1+w}$			
11.	Void Ratio, $e = \frac{\rho_w G}{\rho_d} - 1$			
12.	$k = \frac{2.30\, a L}{A t} \log_{10} (h_1/h_2)$			

Result: Coefficient of permeability of soil is...............mm/sec.





Falling Head Permeameter

EXPERIMENT NO. 13

Title: Determination of Shear Parameters by Direct Shear Test.

Objective: To determine the shear parameters of a soil specimen by Direct Shear Test.

Theory: Shear strength of a soil is its maximum resistance to shearing stresses. The shear strength is expressed as

$$s = c' + \bar{\sigma} \tan \phi'$$

where, c' = effective cohesion; $\bar{\sigma}$ = effective stress; ϕ' = effective angle of shearing resistance.

The shear tests can be conducted under three different drainage conditions. The direct shear test is generally conducted on sandy soils as a consolidated-drained test.

Equipment: 1. Shear box, divided into two halves by a horizontal plane, and fitted with locking and spacing screws; 2. Box container to hold the shear box; 3. Base plate having cross grooves on its top surface; 4. Grid plates, perforated, 2 nos; 5. Porous stones, 6mm thick, 2 nos; 6. Loading pad, 7. Loading frame; 8. Loading yoke; 9. Proving ring, capacity 2 kN; 10. Dial gauges, accuracy 0.01 mm, 2 nos; 11. Static or dynamic compaction device; 12. Spatula.

Procedure:

1. Measure the internal dimensions of the shear box. Also determine the average thickness of the grid plates.
2. Fix the upper part of the box to the lower part using the locking screws. Attach the base plate to the lower part.
3. Place the grid plate in the shear box keeping the serrations of the grid at right angles to the direction of shear. Place a porous stone over the grid plate.
4. Weigh the shear box with base plate, grid plate and porous stone.
5. Place the soil specimen in the box. Tamp it directly in the shear box at the required density. When the soil in the top half of the shear box is filled upto 10 to 15 mm depth, level the soils surface.
6. Weigh the box with the soil specimen.
7. Place the box inside the box container, and fix the loading pad on the box. Mount the box container on the loading frame.
8. Bring the upper half of the box in contact with the proving ring. Check the contact by giving a slight movement.
9. Fill the container with water if the soil is to be saturated; otherwise omit this step.
10. Mount the loading yoke on the ball placed on the loading pad.
11. Mount one dial gauge on the loading yoke to record the vertical displacement and another dial gauge on the container to record the horizontal displacement.
12. Place the weights on the loading yoke to apply a normal stress of 25 kN/m^2.

Allow the sample to consolidate under the applied normal stress. Note the reading of the vertical displacement dial gauge.

13. Remove locking screws. Using the spacing screws, raise the upper part slightly above the lower part such that the gap is slightly larger than the maximum particle size.

Remove the spacing screws.

14. Adjust all the dial gauges to read zero. The proving ring should also read zero.
15. Apply the horizontal shear load at a constant rate of strain of 0.2 mm/minute.
16. Record readings of the proving ring, the vertical displacement dial gauge and the horizontal displacement dial gauge at regular time intervals. Take the first few readings at closer intervals.
17. Continue the test till the specimen fails or till a strain of 20% is reached.
18. At the end of the test, remove the specimens from the door, and take a representative sample for the water content determination.
19. Repeat the test on identical speceimen under the normal stresses of 50, 100, 200, 400 kN/m^2, etc.

    (The range of stresses selected should correspond to the actual field conditions).

Observations and Calculations:

Size of box=

Area of box=

Thickness of specimen=

Volume of specimen=

Mass of soil specimen=

Bulk density=

Water content=

Dry density=

Void ratio=

Tare mass of hanger=

Mass on hanger=

Total mass=

Normal stress=

Mass of box + base plate + porous stones + grid plate =

Mass of box + base plate + porous stones + grid plate + soil specimen =

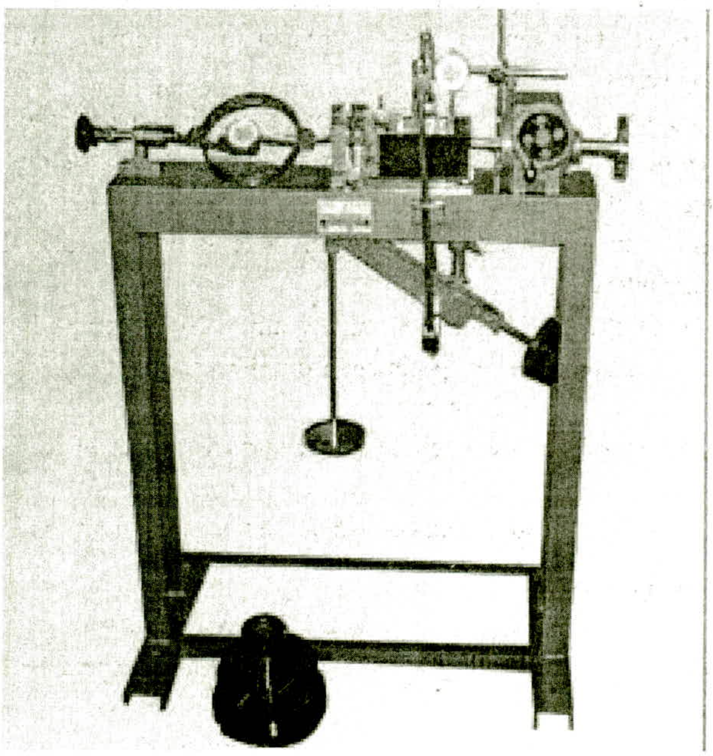
S No	Observations				Calculations			
	Elapsed time	Horizontal dial gauge	Vertical dial gauge	Proving ring	Shear Displacement	Vertical displacement	Shear force	Shear stress

Use separate data sheet for tests under different normal stresses. Determine the shear stress at failure in each case. Summarise the results as follows.

Test No.	Normal stress	Shear stress at failure	Shear displacement at failure	Initial water content	Final water content
1.	25 kN/m^2				
2.	50				
3.	100				
4.	200				
5.	400				

Plot the Coulomb envelope between the normal stress as abscissa and shear stress at failure as ordinate.

Result: From the plot, c' =............................ ; ϕ'=..............................



Direct Shear Apparatus

EXPERIMENT NO. 14

Title: Determination of Unconfined Compressive Strength of soil.

Objective: To determine the unconfined compressive strength of a cohesive soil.

Theory: The unconfined compressive strength (q_u) is load per unit area at which the cylindrical specimen of a cohesive soil fails in compression.

$$q_u = \frac{P}{A}$$

Where P = axial load at failure; A= corrected area = $\frac{A_0}{1-\varepsilon}$, where A_0 initial area of the specimen; ε = axial strain = change in length / original length.

The undrained shear strength (s) of the soil is equal to one half of the unconfined compressive strength, $s = q_u/2$.

Equipment: 1. Unconfined compression apparatus, proving ring type; 2. Proving ring, capacity 1 kN, accuracy 1 N; 3. Dial guage, accuracy 0.01 mm; 4. Weighing balance; 5. Oven; 6. Stop watch; 7. Sampling tube; 8. Split mould, 38 mm diameter, 76 mm long; 9. Sample extractor; 10. Knife; 11. Vernier caliper; 12. Large mould.

Procedure:

1. Prepare the soil specimen at the desired water content and density in the large mould.
2. Push the sampling tube into the large mould, and remove the sampling tube filled with the soil. For undisturbed samples, push the sampling tube into clay sample.
3. Saturate the soil sample in the sampling tube by a suitable method.
4. Coat the split mould lightly with a thin layer of grease. Weigh the mould.
5. Extrude the sample out of the sampling tube into the split mould, using the sample extractor and the knife.
6. Trim the two ends of the specimen in the split mould.
   Weigh the mould with the specimen.
7. Remove the specimen from the split mould by splitting the mould into two parts.
8. Measure the length and diameter of the specimen with a vernier calipers.
9. Place the specimen on the bottom plate of the compression machine.
10. Adjust the dial gauge and the proving-ring gauge to zero.
11. Apply the compression load to cause an axial strain at the rate of ½ to 2% per minute.
12. Record the dial gauge reading, and the proving ring reading every thirty seconds upto a strain of 6%. The reading may be taken after every 60 seconds for a strain between 6% to 12% and every 2 minutes or so beyond 12%.
13. Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached.
14. Measure the angle between the failure surface and the horizontal, if possible.
15. Take the sample from the failure zone of the specimen for the water content determination.

Observations and Calculations:

Initial length of the specimen, L_0 = 		Initial diameter of the specimen, D_0 =

Initial area of the specimen, A_0 =

Initial volume of the specimen, V_0 =

Mass of empty split mould=

Mass of empty split mould + specimen=

Mass of specimen, M =

Bulk density, $\rho = M / V_0$

Water content, w =

Dry density, ρ_d =

Specific gravity of solids, G=

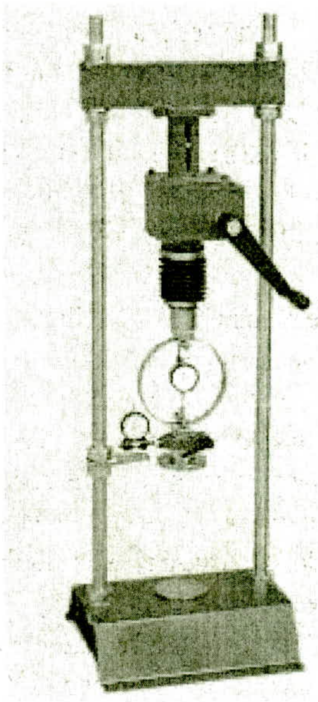
Void ratio, $e = \frac{G\rho_w}{\rho_d} - 1$

Degree of saturation, $S = \frac{wG}{e} \times 100$

S No	Observations					Calculations		
	Elapsed time	Dial gauge		Proving ring		Strain	Corrected area	Compressive stress
		Reading	Deformation (ΔL)	Reading	Load (P)	$\varepsilon = \Delta L / L_0$	$A = \frac{A_0}{1-\varepsilon}$	$p = P/A$

Plot a curve between the compressive stress as ordinate and axial strain as abscissa.

Result: From the plot, unconfined compressive strength, q_u =................. and Shear strength, $s = q_u / 2$ =..........................



Unconfined Compression Apparatus

EXPERIMENT NO. 15

Title: Determination of shear parameters by Triaxial test.

Objective: To determine shear parameters of undisturbed (or remoulded) soil specimen in the triaxial compression apparatus by unconsolidated undrained test without the measurement of pore pressure.

Theory: The difference between the initial pressure and subsequent reading of the load measuring device is the axial load applied to the specimen in addition to that due to cell pressure.

The area of the specimen at any stage of the test is determined by

$$A = \frac{A_0}{1-\varepsilon} = \frac{A_0 L_0}{L}$$

where, A_0 = initial area of specimen;

$$\varepsilon = \frac{L_0 - L}{L_0}$$

L_0= initial length of specimen

L= length of specimen at the stage of the test at which area A is to be determined.

Equipments: 1. Triaxial cell without transparent chamber capable of resisting internal fluid pressure of 1000 kN/m^2 complete with all accessories, 2. Apparatus for applying and maintaining the desired fluid pressure in the cell, to an accuracy of 10 or 5 kN/m^2, 3. Compression machine, capable of applying axial compression to the specimen at convenient speeds to cover the range 0.05 to 7.5 mm/minute, 4. Dial gauge to measure axial compression, accurate to 0.01 mm, 5.seamless rubber membranes, 6. Membrane stretcher, 7. Rubber rings, 8. Split mould, trimmimg knife, wire saw-meter straight-edge, sample extruder, thin walled tubes, soil lathe, meter box etc. 9. Water content determination tins, 10. Balance, 11. Stop watch

Procedure:

Sample preparation:

1. ***Undisturbed specimen:*** If the undisturbed sample has been collected in a thin walled tube having the same internal diameter as that of the specimen required for testing, the sampl may be extruded out with the help of sample extruder, and pushed into the split mould. The sample should be extruded from the tube pusing from the cutting edge side. The ends of the specimen are trimmed flat and normal to its axis. The split mould should be lightly oiled from inside. The specimen is then taken out, carefully, from the split mould, and its length, diameter, weight should be measured to an accuracy enabling the bulk density to be calculated to an accuracy of ± 1.0 per cent. A portion of the soil trimmings is placed for water content determination. The specimen is then placed on one of the end caps and the other end cap is put on the top of the specimen. The rubber membrane is then placed around the specimen using the membrane stretcher. The membrane is sealed to the end

caps by means of rubber rings. The specimen is then ready to be placed on the pedestal in the triaxial cell.

2. ***Undisturbed specimen:*** If the undisturbed soil sample brought from the field is of large diameter than the specimen diameter, the sample may be cut to size either by means of thin walled tube or hand trimming or by a soil lathe. If a block sample has been obtained from the field, a rectangular prism slightly larger than the required final dimensions of the specimen is cut from the block sample. The ends of prism are made plane and parallel using meter box. The prism is then placed in the soil lathe, and excess soil is cut off in thin layers. The trimming operation, rotating the sample between end cutting operation, is continued until a cylindrical specimen results. The rest of the procedure for enclosing the specimen in the membrane etc., is the same as described in step 1.
3. ***Remoulded specimen:*** Remoulded specimens may be prepared by compacting the soil, at required water content and dry density, in a big size mould by static or dynamic method, and then preparing the cylindrical specimen of required dimensions by the method in step 2 above.

Undrained triaxial compression test

1. Cover the pedestal in the triaxial cell with a solid end cap or keep drainage valve closed. Place the specimen assembly centrally on the pedestal. Assemble the cell, with the holding ram initially clear of the top of the specimen, and place it in the loading machine.
2. Admit the operating fluid in the cell, and raise its pressure to the desired value. Adjust the loading machine to bring the loading ram a short distance away from the set on the top cap of the specimen. Read the initial reading to the load measuring gauge. Adjust the loading machine further so that the loading ram comes just in contact with the seat on the top of the specimen. Note the initial reading of the dial measuring axial compression.
3. Apply the compressive force at constant rate of axial compression, such that failure is produced in a period of approximately 5 to 15 minutes. Take the simultaneous reading of load and deformation dials, define the stress-strain curve. Continue the test until the maximum value of stress has been passed or until an axial strain of 20 percent has been passed.
4. Unload the specimen and drain off the cell fluid. Dismantle the cell and take out the specimen. Remove the rubber membrane and note down the mode of failure. Weigh the specimen. Keep samples for water content determination.
5. Repeat the test on three or more identical specimens under different cell pressure.

Observation and Calculations:

1. **Soil specimen measurement:**

Height:	Area:
Diameter:	Volume:
Initial mass:	Water content:
Final mass:	Final water content:

2. Undrained triaxial test:

Cell pressure (σ_3)

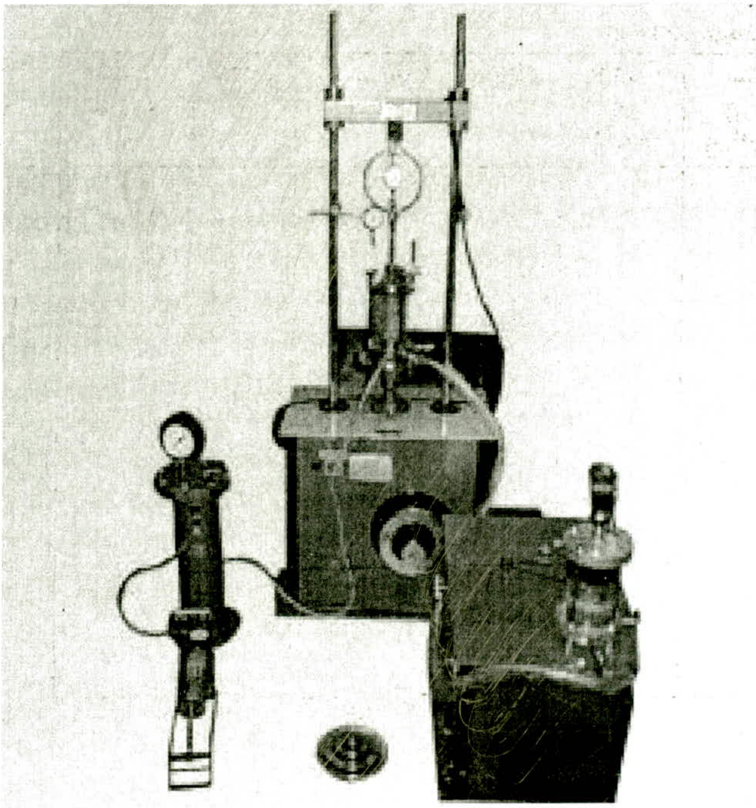
Load gauge constant:

Comp. dial reading	Load gauge reading	Comp. of sample	Strain	Corrected area	Load	Vertical stress σ_1	Deviator stress σ_3	Stress ratio σ_1 / σ_3

Results:

Test no.	Cell pressure σ_3	Deviatoe stress at failure $(\sigma_1 - \sigma_3)$	σ_1 at failure	σ_1 / σ_3 at failure
1. 2. 3. 4.				

1. The deviator stress ($\sigma_1 - \sigma_3$) or the principal stress difference at any stage of the test is determined by dividing the additional axial load by the area A.
2. For each stress, a plot may be made between ($\sigma_1 - \sigma_3$) and ε.
3. The shear parameters are obtained from a plot of Mohr circles for which purpose peak value of principal stress difference ($\sigma_1 - \sigma_3$) or principal stress-ratio σ_1 / σ_3 or the ultimate value as desired may be used.



Triaxial Shear Apparatus

EXPERIMENT NO. 16

Title: Determination of Consolidation Properties of soils.

Objective: To determine the consolidation properties of soil specimen.

Theory: Consolidation of a saturated soil occurs due to expulsion of water under a static, sustained load. The consolidation characteristics of soils are required to predict the magnitude and the rate of settlement. The following characteristics are obtained from the consolidation test.

Coefficient of compressibility, $a_v = -\Delta e / \Delta\bar{\sigma}$

Coefficient of volume change, $m_v = \frac{-\Delta e}{1+e}\left(\frac{1}{\Delta\bar{\sigma}}\right)$

Compressive index, $C_c = \frac{-\Delta e}{\log_{10}\frac{(\bar{\sigma}_0 + \Delta\bar{\sigma})}{\bar{\sigma}_0}}$

Coefficient of consolidation, $C_v = T_v d^2 / t$

Equipment: 1. Consolidometer, with a loading device; 2. Specimen rig, made of a non-corroding material; 3. Water reservoir to saturate the sample; 4. Porous stones; 5. Soil trimming tools, like fine wire saw, knife, spatula, etc.; 6. Weighing balance, accuracy 0.01 gm; 7. Oven; 8. Desiccator; 9. Pressure pad; 10. Steel ball 11. Dial gauge, accuracy 0.002 mm; 12. Water content cans; 13. Large container.

Procedure:

1. Clean and dry the metal ring. Measure its diameter and height. Take the mass of the empty ring.
2. Press the ring into the soil sample contained in a large container at the desired density and the water content. The ring is to be pressed with hands.
3. Remove the soil around the ring. The soil specimen should project about 10 mm on either side of the ring.
   Any voids in the specimen due to the removal of large size particles should be filled back by pressing the soil lightly.
4. Trim the specimen flush with the top and bottom of the ring.
5. Remove any soil particles sticking to the outside of the ring. Weigh the ring with the specimen.
6. Take a small quantity of the soil removed during trimming for the water content determination.
7. Saturate the porous stones by boiling them in distilled water for about 15 minutes.

8. Assemble the consolidometer. Place the bottom porous stone, bottom filter paper, specimen, top filter paper and the top porous stone, one by one.
9. Position the loading block centrally on the top porous stone.
   Mount the mould assembly on the loading frame. Center it such that the load the load applied is axial. In the case of the lever-loading system, counterbalance the system.
10. Set the dial gauge in position. Allow sufficient margin for the swelling of the soil.
11. Connect the mould assembly to the water reservoir having the water-level at about the same level as the soil specimen.
    Allow the water to flow into the specimen till it is fully saturated.
12. Take the initial reading of the dial gauge.
13. Apply the first load increment to apply a pressure of 5 kN/m^2 (2.5 kN/m^2 for very soft soils) to the assembly so that there is no swelling.
    Allow the setting load to stand till there is no change in the dial gauge reading or for 24 hours.
14. Take the final gauge reading under the initial setting load.
15. Apply the first load increment to apply a pressure of 10 kN/m^2, and start the stp watch.
    Record the dial gauge readings at 0, 0.25, 1.0, 2.25, 4.0, 6.25, 9.00, 12.25, 16.00, 20.25, 25.00, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225, 256, 289, 324, 361, 400, 500, 600 and 1440 minutes.
16. Increase the load to apply a pressure of 20 kN/m2 and repeat the step (15). Likewise, increase the load to apply a pressure of 40, 80, 160, 320 and 640 kN/m^2 or upto the desired pressure.
17. After the last load increment had been applied and the readings taken, decrease the load to ¼ of the last load and allow it to stand for 24 hours. Take the dial gauge reading after 24 hours.
    Further reduce the load to ¼ of the previous load and repeat the above procedure. Likewise, further reduce the load ¼ of the previous load and repeat the procedure. Finally, reduce the load to the initial setting load, and keep it for 24 hours, and take the final dial gauge reading.
18. Dismantle the assembly. Tale out the ring with the specimen. Wipe out the excess surface water using a blotting paper.
19. Take the mass of the ring with the specimen.
20. Dry the specimen in the oven for 24 hours, and determine the dry mass of specimen.

Observations and Calculations:

Specific gravity of solids, G =

Area of ring (A) =

Mass of water =

Water content before test =

Height of solids, $H_s = \frac{M_s}{G\,A\,\rho_w}$

Diameter of ring =

Volume of ring =

Initial height, H_0 =

Mass of dry soil (M_s) =

Initial void ratio, $e_0 = \frac{H_0}{H_s} - 1$

Height of ring =

Mass of ring =

Degree of saturation $S = \frac{w\,G}{e}$

Water content after test =

(a) Coefficient of Compressibility

$\bar{\sigma}$ (kN/m^2)	Initial dial reading	Final dial reading	Change in height (ΔH)	Height $H = H_0 \pm \Delta H$	Height of voids $(H - H_s)$	Final void ratio $e = (H - H_s)/H_s$
10						
20						
40						
80						
160						
320						
640						

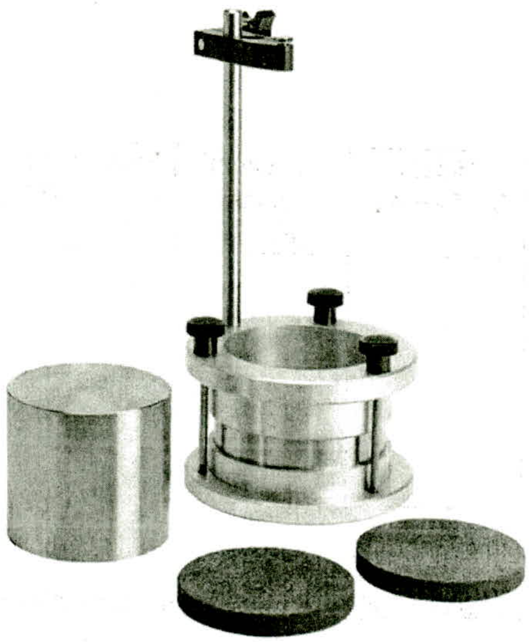
Plot a curve between $\bar{\sigma}$ as abscissa and final void ratio (e) as ordinate for determination of a_v and m_v. Plot a graph between log $\bar{\sigma}$ as abscissa and final void ratio as ordinate for determination of C_c.

(b) Coefficient of consolidation

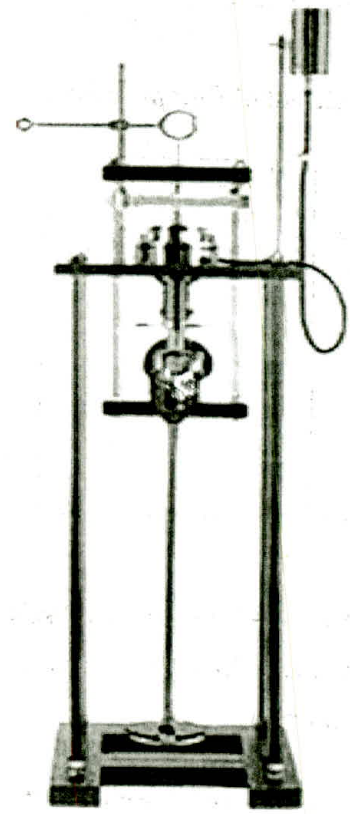
t \ $\bar{\sigma}$	10 (kN/m^2)	20	40	80	160	320	640
	(R)						
0.0 min	-----						
0.25	-----						
1.0	-----						
.	.						
.	.						
.	.						
1440	-----						

For each load increment, plot $\sqrt{t}$ as abscissa and the dial gauge reading (R) as ordinate. Determine the value of t_{90} from the plot.

Now $$C_v = 0.848 d^2 / t_{90}$$



Consolidometer



Consolidation Apparatus

Chhattisagarh Samvad