Dr. AMBEDKAR INSTITUTE OF TECHNOLOGY

BENGALURU - 560056

DEPARTMENT OF CIVIL ENGINEERING



GEOTECHNICAL ENGINEERING LABORATORY

(For Internal Use Only)

Lab Manual Compiled by
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Asst. Professor

Name	
USN	
Section	
Batch	

DRAFT

Semester: VI		
Course Title: GEOTECHNICAL ENGINEERING LABORATORY		
Course Code: **18CVL67**	Evaluation Procedure:	
Credits: **01**	CIE + Record + SEE = 20 + 30 + 50 = 100	
Teaching Hours: 26 Hrs (L:T:P:S:0:0:2:0)	SEE Duration: 3 Hrs	
Course Learning Objectives:		
1	To perform laboratory tests to determine index properties of soil as per IS code procedures.	
2	To perform tests to determine compaction, permeability, shear strength and consolidation characteristics of soil.	
#	**Syllabus Contents**	**Hours**
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). Tests for determination of Water content (Oven drying method and Rapid moisture meter methods).	04
2	Grain size analysis of soil sample (Wet sieve analysis and Hydrometer test).	02
3	In-situ density by core cutter and sand replacement method.	02
4	Consistency Limits – Liquid Limit (A.Casagrande and Cone Penetration Method), Plastic limit and Shrinkage limit.	04
5	Standard Proctor Compaction Test and Modified Proctor Compaction Test.	02
6	Determination of relative density of sand.	02
7	Coefficient of permeability by constant head and variable head methods.	02
8	Shear Strength Tests: (Undrained conditions) a) Direct Shear Box Test. b) Tri-axial Compression Test. **(Blended learning)** c) Unconfined Compression Test.	06
9	a) Demonstration of miscellaneous equipments such as Augers, Samplers, Rapid Moisture meter, Proctor's needle. b) Demonstration of Free Swell Index, Differential free swell test. c) Demonstration of Consolidation Test - Determination of compression index and coefficient of consolidation. d) Demonstration of Laboratory vane shear test.	02
Course Outcomes: The students will be able to		
1	Classify the soils based on index properties and field identification.	
2	Determine OMC and MDD, plan and assess field compaction program.	
3	Understand shear strength and consolidation parameters to assess shear strength characteristics of the soil samples.	
Reference Books:		
1	Manual of Soil Laboratory Testing - Head K.H., (1986) - Vol. I, II, III, Princeton Press, London.	
2	BIS Codes of Practice: IS: 2720(Part-3/Sec. 1) – 1987; IS: 2720 (Part – 2)- 1973; IS: 2720 (Part – 4) – 1985; IS: 2720 (Part – 5) – 1985; IS: 2720 (Part – 6) – 1972; IS: 2720 (Part – 7) – 1980; IS: 2720 (Part – 8) – 1983; IS: 2720 (Part – 17) – 1986; IS: 2720 (Part - 10) – 1973; IS: 2720 (Part – 13) – 1986; IS: 2720 (Part 11) – 1971; IS: 2720 (Part 15) – 1986; IS: 2720 (Part 30) – 1987; IS: 2720 (Part 14) – 1977; IS: 2720 (Part – 14) – 1983; IS: 2720 (Part – 28) – 1974; IS: 2720 (Part – 29) – 1966, IS: 2720 (Part-60) 1965.	
3	Engineering Properties of Soil and Their Measurements - Bowles J.E. (1988), - McGraw Hill Book Co. New York.	
4	A text book of Soil Mechanics & Foundation Engineering by BC Punmia, KR Arora.	

1. Determination of Water content: IS 2720 (Part 2) - 1973

Aim: To determine the water content or moisture content of the given soil sample by Oven drying method.

Apparatus:

- Non-corrodible air-tight container.
- Electric oven, maintain the temperature between 105^0 C to 110^0 C.
- Weighing balance of sufficient sensitivity to weigh the soil samples to an accuracy of 0.04 percent of the weight of the soil taken for the test.
- Desiccator with any suitable desiccating agent.

Diagram:



Procedure:

- ✓ Clean the container with lid, dry and weigh it ($\mathbf{M_1}$).
- ✓ Take the required quantity of the soil specimen in the container crumbled and placed loosely, and weigh with lid ($\mathbf{M_2}$).
- ✓ Then keep it in an oven with the lid removed, and maintain the temperature of oven at 110 ± 5^0 C.
- ✓ Dry the specimen in the oven for 24 hours.
- ✓ Every time the container is taken out for weighing, replace the lid on the container and cool the container in a desiccator.
- ✓ Record the final mass ($\mathbf{M_3}$) of the container with lid with dried soil sample.

Observations and Tabulations:

Determination No.	1	2	3
Cup number			
Mass of cup (M_1) g			
Mass of cup + Wet soil (M_2) g			
Mass of cup + Dry soil (M_3) g			
Mass of Water (M_W) g = ($M_2 - M_3$)			
Mass of Solids (M_S) g = ($M_3 - M_1$)			
Water Content (ω) % = (M_W / M_S)			
Average Water Content (ω) %			

Result:

The average natural moisture content of the soil sample is ---------- %

Note:

1) The water content (ω) of the soil sample shall be reported to two significant figures.
2) Oven drying at 110 ± 5^0 C does not result in reliable water content values for soil containing gypsum or other minerals having loosely bound water of hydration or for soil containing significant amounts of organic material.
3) Reliable water content values for these soils can be obtained by drying in an oven at approximately 60 to 80^0 C.
4) The soil specimen taken shall be representative of the soil mass.
5) The size of the specimen selected depends on the quantity required for good representation which is influenced by gradation and the maximum size of particles and on the accuracy of weighing.

The following quantities are recommended for laboratory use:

Size of particles more than 90% passing, IS sieve	Minimum quantity of soil specimen to be taken for test, Mass in g
425 µm	25
2 mm	50
4.75 mm	200
9.5 mm	300
19 mm	500

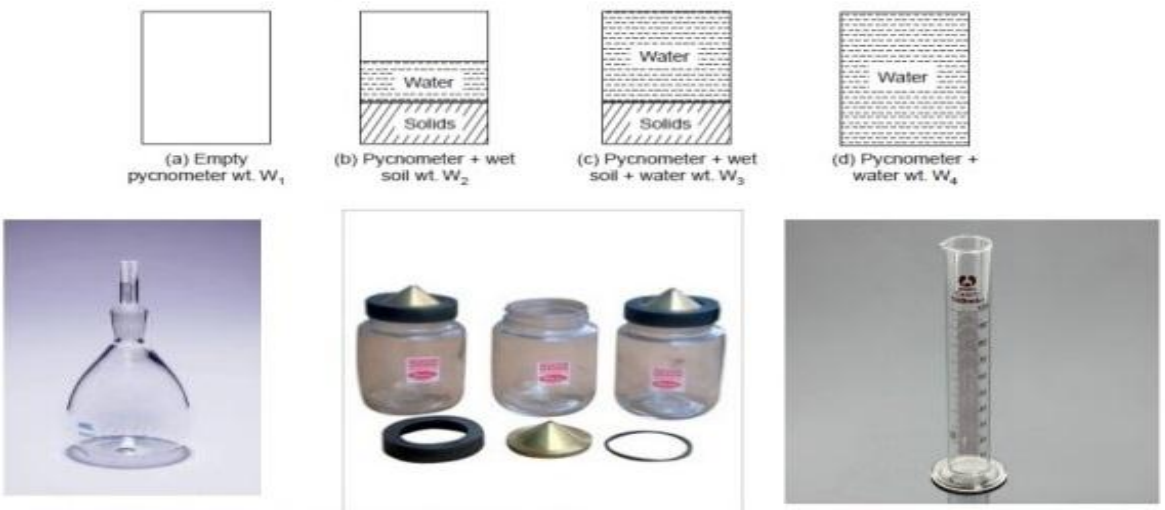
2. Determination of Water content by Pycnometer method: IS: 2720 (Part II) – 1973

Aim: To determine the water content of soil sample by pycnometer. For this determination, the specific gravity (G) of soil solids must be known.

Apparatus:

- Pycnometer bottle with a conical brass cap screwed at its top.
- Balance sensitive to 1 g.
- Glass rod.

Diagram:



Procedure:

- ✓ Clean the pycnometer and dry it. Find the mass (M_1) of the pycnometer, brass cap and the washer, accurate to 1 g.
- ✓ Put about 200 g to 400 g of wet soil sample in the pycnometer and find its mass with its cap and washer (M_2).
- ✓ Fill the pycnometer to half its height and mix it thoroughly with the glass rod. Add more water and stir it. Replace the screw top and fill the pycnometer flush with the hole in the conical cap. Dry the pycnometer from outside and find its mass (M_3).
- ✓ Empty the pycnometer, clean it thoroughly and fill it with clean water to the hole of the conical cap and find its mass (M_4).

Calculations:

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

Observations and tabulations:

Specific gravity of soil solids (G) =

Sl. No.	Determination No.	1	2	3
1	Mass of pycnometer (M_1) g			
2	Mass of pycnometer + Moist soil (M_2) g			
3	Mass of pycnometer + Soil + Water (M_3) g			
4	Mass of pycnometer + Water (M_4) g			
5	Water content (ω) % = $\left[\frac{M_2 - M_1}{M_3 - M_4}\left(\frac{G-1}{G}\right) - 1\right] \times 100$			
6	Average Water Content ($\boldsymbol{\omega}$) %			

Results:

The average natural moisture content of the soil sample is ---------- %

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3. Determination of Specific gravity: IS 2720 (Part 3/Sec 1) - 1980

Aim: Determination of Specific gravity of soil fraction passing 4.75 mm IS sieve by Pycnometer bottle and passing 75µm IS sieve by Density bottle method.

Theory:

The specific gravity of a soil is the ratio of the mass of a given volume of the material at a stated temperature to the mass of an equal volume of de-aired (or) gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water and solids in a given volume of the soil.

Need and Scope:

The specific gravity of a soil is used in relating a weight of soil to its volume and in calculation of phase relationship i.e. the relative volume of solids to water and air in a given volume soil. The specific gravity is used in the computations of most of the laboratory tests and is needed in nearly all pressure, settlement and stability problems in soil engineering.

Apparatus: Pycnometer, Density bottle, Weighing balance, Oven, Distilled water, Thermometer.

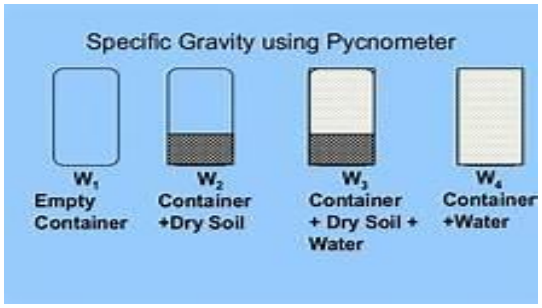
Diagram:



Pycnometer



Density Bottle



Phase Diagram

Calculations:

Specific gravity of soil solids = $\frac{\text{Dry mass of soil}}{\text{Mass of water of equal volume}}$

G_S at 27^0 C $= \frac{(M_2-M_1)}{(M_2-M_1)-(M_3-M_4)} \times \frac{G_w \text{ at } t^0 C}{G_w \text{ at } 27^0 C} =$

Results:

The average specific gravity of soil solids is ……

Procedure: Soil fraction passing 4.75 mm IS sieve by Pycnometer bottle method.

1) Weigh the clean dry pycnometer with lid accurate to 1g (**M_1**).
2) Take about one third height of dry soil passing 4.75 mm IS sieve in the pycnometer and find its mass (**M_2**).
3) Fill the pycnometer half of its height with distilled water and stir it with glass rod, remove the entrapped air by boiling gently for 10 minutes in a water bath or rolling the pycnometer to assist the removal of air.
4) Add distilled water till the pycnometer is full.
5) Clean the outer surface of pycnometer and then determine its mass (**M_3**).
6) Fill the pycnometer with distilled water till the surface of water is flush with the hole in the screw cap and weigh the pycnometer (**M_4**).
7) Repeat the steps **2)** to **6)** for more number of trials by taking fresh sample from representative soil.

Observations and Tabulations:

Determination No.	**1**	**2**	**3**
Test temperature of Water $\mathbf{t^0}$ C			
Specific gravity of Distilled water **(G_W)**			
Mass of the Pycnometer **(M_1)** g			
Mass of Pycnometer + Dry soil **(M_2)** g			
Mass of Pycnometer + Dry soil + Water **(M_3)** g			
Mass of Pycnometer + Water **(M_4)** g			
Specific gravity G_S at t^0 C = $\frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$			
Specific gravity G_S at 27^0 C = G_S at t^0 C $\times \frac{G_W \text{ at } t^0 \text{ C}}{G_W \text{ at } 27^0 \text{ C}}$			

Procedure: Soil fraction passing 75 µm IS sieve by Density bottle method.

1) Weigh the clean dry density bottle with lid accurate to 0.001g (M_1).
2) Take about one third height of dry soil passing 75 µm IS sieve in the density bottle and find its mass (M_2).
3) Fill the density bottle half of its height with distilled water remove the entrapped air by boiling gently for 10 minutes in a water bath to assist the removal of air.
4) Add distilled water till the density bottle is full.
5) Clean the outer surface of density bottle and then determine its mass (M_3).
6) Fill the density bottle with distilled water till the surface of water is flush with the hole in the screw cap and weigh the density bottle (M_4).
7) Repeat the steps **2)** to **6)** for more number of trials by taking fresh sample from representative soil.

Observations and Tabulations:

Determination No.	**1**	**2**	**3**
Test temperature of Water t^0 C			
Specific gravity of Distilled water (G_W)			
Mass of the Pycnometer (M_1) g			
Mass of Pycnometer + Dry soil (M_2) g			
Mass of Pycnometer + Dry soil + Water (M_3) g			
Mass of Pycnometer + Water (M_4) g			
Specific gravity G_S at t^0 C = $\frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$			
Specific gravity G_S at 27^0 C = G_S at t^0 C $\times \frac{G_W \text{ at } t^0 \text{ C}}{G_W \text{ at } 27^0 \text{ C}}$			

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Specific Gravity of Water (G_W)

Temp ^{0} C	0	1	2	3	4	5	6	7	8	9
0	0.9999	1.0000	1.0000	1.0000	**1.0000**	1.0000	1.0000	0.9992	0.9999	0.9998
10	0.9997	0.9996	0.9995	0.9994	0.9991	0.9991	0.9900	0.9988	0.9985	0.9984
20	0.9982	0.9980	0.9978	0.9978	0.9973	0.9971	0.9968	**0.9965**	0.9963	0.9960
30	0.9957	0.9954	0.9951	0.9947	0.9944	0.9941	0.9937	0.9934	0.9930	0.9926
40	0.9922	0.9919	0.9915	0.9911	0.9907	0.9902	0.9898	0.9894	0.9890	0.9885
50	0.9881	0.9876	0.9872	0.9867	0.9862	0.9857	0.9852	0.9848	0.9842	0.9838
60	0.9832	0.9827	0.9822	0.9817	0.9811	0.9806	0.9800	0.9795	0.9789	0.9784
70	0.9778	0.9772	0.9767	0.9761	0.9755	0.9749	0.9743	0.9737	0.9731	0.9724
80	0.9718	0.9712	0.9706	0.9699	0.9693	0.9686	0.9680	0.9673	0.9667	0.9660
90	0.9653	0.9647	0.9640	0.9633	0.9626	0.9612	0.9605	0.9605	0.9598	0.9591

Viscosity of Water (values given in milli poises)

Temp ^{0} C	0	1	2	3	4	5	6	7	8	9
0	17.94	17.32	16.74	16.19	15.68	15.19	14.73	17.29	13.87	13.48
10	13.10	12.74	12.39	12.06	11.75	11.45	11.16	10.88	10.60	10.34
20	10.09	9.84	9.61	9.38	9.16	8.95	8.75	**8.55**	8.36	8.18
30	8.00	7.83	7.67	7.51	7.36	7.21	7.06	6.92	6.79	6.66
40	6.54	6.42	6.30	6.18	6.08	5.97	5.87	5.77	5.68	5.58
50	5.49	5.40	5.32	5.24	5.15	5.07	4.99	4.92	4.84	4.77
60	4.70	4.63	4.56	4.50	4.43	4.37	4.31	4.24	4.19	4.13
70	4.07	4.02	3.96	3.91	3.86	3.81	3.76	3.66	3.66	3.63
80	8.57	3.53	3.48	3.44	3.40	3.36	3.32	3.28	3.24	3.20
90	3.17	3.13	3.10	3.06	3.03	2.99	2.96	2.93	2.90	2.87

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4. FIELD DENSITY METHODS:

I) CORE CUTTER METHOD: IS: 2720 (Part 29) - 1988

Aim: To determine the field density of natural or compacted soil using core cutter method.

Apparatus: Cylindrical core cutter, dolly or collar, rammer of mass 9 kg, weighing balance and containers for water content determination.

Diagram:



Procedure:

- ✓ Measure inside dimensions of the core cutter and calculate its volume (**V**).
- ✓ Find the mass of the core cutter (without dolly) ($\mathbf{M_1}$).
- ✓ In the field, clean the small area about 30 cm^2 to be tested and level it.
- ✓ Place the core cutter at the centre of leveled surface
- ✓ Put the dolly on the core cutter and drive the assembly into the soil with the help of rammer until the top of dolly equal to level surface.
- ✓ Dig out the core cutter from the surrounding soil without disturbing the surface.
- ✓ Trim the lower edge and upper edge with the help of straight edge.
- ✓ Find the mass of core cutter with soil ($\mathbf{M_2}$).
- ✓ Remove the soil from the core cutter and keep some representative soil sample for water content determination.
- ✓ Repeat the test at two or three locations nearby and determine the average density.

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Observations and Tabulations:

Sl No	Determination No.	1	2	3
1	Internal Diameter of the Core cutter **(D)** cm			
2	Height of the core cutter **(H)** cm			
3	Internal Volume of the core cutter **(V)** cc = $\left(\frac{\pi \times D^2 \times H}{4}\right)$			
4	Mass of the Core cutter (M_1) g			
5	Mass of the Core cutter + soil sample (M_2) g			
6	Mass of the bulk soil sample $(M_b) = (M_2 - M_1)$ g			
7	Bulk Density of soil sample $(\rho_b) = \left(\frac{M_b}{V}\right)$ g/cc			
8	Cup number			
9	Mass of cup (m_1) g			
10	Mass of cup + Wet soil (m_2) g			
11	Mass of cup + Dry soil (m_3) g			
12	Water content (ω) % = $\left(\frac{m_2 - m_3}{m_3 - m_1}\right) \times 100$			
13	Dry Density of soil sample (ρ_d) g/cc = $\left(\frac{\rho b}{1 + (\frac{\omega}{100})}\right)$			

Results:

The average dry density of the soil sample is ---------- g/cc.

Volumetric parameters at field dry density and water content	
Void ratio **(e)**	
Porosity **(n)** %	
Degree of saturation **(S)** %	
Air content **(A_C)** %	
Percentage of air voids **(n_a)** %	

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II) SAND REPLACEMENT METHOD IS: 2720 (Part 28) - 1988

Aim: To determine the field density of natural (or) compacted soils using sand pouring cylinder.

Diagram:





Apparatus:

- Sand pouring cylinder of 3 liter capacity mounted above a pouring cone and separated by a shutter cover plate.
- Cylindrical calibrating container fitted with flange.
- Metal tray with central circular hole of diameter equal to diameter of the pouring cone.
- Tools for excavating hole.
- Balance.
- Containers for water content determination.
- Clean, uniformly graded natural sand passing 600µ IS sieve and retained on 300µ IS sieve.

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Procedure:

Measure inside dimensions of the cylindrical calibrating container and calculate its volume ($\mathbf{V_{CC}}$).

A. CALIBRATION PART:

I. Determination of mass of sand filling the cone ($\mathbf{M_C}$):

- ✓ Fill the sand pouring cylinder with clean sand upto a height 1cm below the top.
- ✓ Determine the initial mass of the pouring cylinder plus sand ($\mathbf{M_1}$) g.
- ✓ Place the sand pouring cylinder on glass plate, open the shutter and allow the sand to run, when there is no further movement of sand in the pouring cylinder, close the shutter.
- ✓ Weigh the sand pouring cylinder ($\mathbf{M_2}$) g.
- ✓ Mass of sand filling the cone ($\mathbf{M_C}$) **g =** $\mathbf{(M_1 - M_2)}$
- ✓ Put the sand back into the sand pouring cylinder, to have same constant mass ($\mathbf{M_1}$).

II. Determination of bulk density of sand $\rho_{b_(sand)}$:

- ✓ Place the sand pouring cylinder concentrically on the top of the calibrating container.
- ✓ Open the shutter and allow the sand to run, when there is no further movement of sand in the pouring cylinder, close the shutter.
- ✓ Remove the sand pouring cylinder and weigh its mass ($\mathbf{M_3}$) g
- ✓ Mass of sand filling calibrating container ($\mathbf{M_4}$) g = $\mathbf{(M_1 - M_3 - M_C)}$
- ✓ Bulk density of sand ($\boldsymbol{\rho_b}$) **sand** g/cc = $\left(\frac{\mathbf{M_4}}{\mathbf{V_{cc}}}\right)$

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B. EXPERIMENTAL PART:

III. Determination of Dry density of soil (ρ_d)$_{soil}$ g/cc:

- ✓ Expose about 45 cm^2 area of the soil to be tested and trim it down to level surface.
- ✓ Keep the metal tray on the level surface and excavate a circular hole of volume equal to that of the calibrating container.
- ✓ Collect all the excavated soil in the metal tray and find its mass ($\mathbf{M_5}$) g.
- ✓ Remove the metal tray and place the sand pouring cylinder, so that base of the cylinder concentrically covers the hole.
- ✓ The sand pouring cylinder should have same constant initial mass ($\mathbf{M_1}$) g.
- ✓ Open the shutter and allow the sand to run, when there is no further movement of sand in the pouring cylinder, close the shutter.
- ✓ Remove the sand pouring cylinder and weigh its mass ($\mathbf{M_6}$) g.
- ✓ Therefore, mass of sand filling excavated hole. ($\mathbf{M_7}$) g = $(\mathbf{M_1 - M_6 - M_C})$
- ✓ Therefore, Volume of the excavated hole ($\mathbf{V_h}$) cc = $\left(\frac{\mathbf{M_7}}{\boldsymbol{\rho_b}(\mathbf{sand})}\right)$
- ✓ Bulk density of soil ($\boldsymbol{\rho_b}$) g/cc = $\left(\frac{\textbf{Mass of the excavated soil from the hole}}{\textbf{Volume of the hole}}\right) = \left(\frac{\mathbf{M_5}}{\mathbf{V_h}}\right)$
- ✓ Keep the representative sample of the excavated soil for water content ($\boldsymbol{\omega}$) determination.
- ✓ Therefore, Dry density of soil ($\boldsymbol{\rho_d}$) g/cc = $\left(\frac{\boldsymbol{\rho b}}{1+(\frac{\omega}{100})}\right)$

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Observations and Tabulations:

Sl No	Determination No.	1	2	3
1	Diameter of the Calibrating Container **(D)** cm			
2	Height of the Calibrating Container **(H)** cm			
3	Volume of the Calibrating Container **(V_{CC})** cm^3			
	A. CALIBRATION PART:			
	I. Determination of mass of sand filling the cone **(M_C)*:***			
1	Mass of the Sand + Sand Pouring Cylinder (**M_1**) g			
2	Mass of the Sand + Sand Pouring Cylinder after pour into glass plate (**M_2**) g			
3	Mass of sand filling Cone (**M_C**) **=** (**$M_1 - M_2$**) g			
	II. Determination of bulk density of sand $\rho_{b\ (sand)}$:			
1	Mass of the Sand + Sand Pouring Cylinder (**M_1**) g			
2	Mass of the Sand + Sand Pouring Cylinder after pour into the Calibrating Container (**M_3**) g			
3	Mass of sand filling Calibrating Container (**M_4**) g **= ($M_1 - M_3 - M_C$)**			
4	Bulk density of sand (**ρ_b**) **sand** g/cc = $\left(\frac{M_4}{V_{cc}}\right)$			
	B. EXPERIMENTAL PART:			
	III. Determination of Dry density of soil (ρ_d) $_{soil}$ g/cc:			
1	Mass of the excavated soil from the hole (**M_5**) g.			
2	Mass of the Sand + Sand Pouring Cylinder (**M_1**) g.			
3	Mass of the sand + Sand Pouring Cylinder after pour into the excavated hole (**M_6**) g.			
4	Mass of sand filling excavated hole (**M_7**) g = (**$M_1 - M_6 - M_C$**)			

5	Volume of the excavated hole ($\mathbf{V_h}$) cc = $\left(\frac{\mathbf{M_7}}{\boldsymbol{\rho}_{\mathbf{b\ Sand}}}\right)$			
6	Bulk density of soil ($\boldsymbol{\rho}_{\mathbf{b}}$) g/cc = $\left(\frac{\textbf{Mass } \boldsymbol{of\ the\ excavated\ soil\ from\ the\ hole}}{\textbf{Volume } \boldsymbol{of\ the\ hole}}\right)$ = $\left(\frac{\mathbf{M_5}}{\mathbf{V_h}}\right)$			
7	Cup number			
8	Mass of cup **(m_1)** g			
9	Mass of cup + Wet soil **(m_2)** g			
10	Mass of cup + Dry soil **(m_3)** g			
11	Water content $(\boldsymbol{\omega})$ % = $\left(\frac{\mathbf{m_2 - m_3}}{\mathbf{m_3 - m_1}}\right) \times \mathbf{100}$			
12	Dry Density of soil sample $(\boldsymbol{\rho_d})$ g/cc= $\left(\frac{\boldsymbol{\rho b}}{\mathbf{1} + \left(\frac{\boldsymbol{\omega}}{\mathbf{100}}\right)}\right)$			

Result:

The average dry density of the soil sample is ---------- g/cc.

Volumetric and gravimetric relations:

Volumetric parameters at field dry density and water content	
Void ratio **(e)**	
Porosity **(n)** %	
Degree of saturation **(S)** %	
Air content **(A_C)** %	
Percentage of air voids **(n_a)** %	

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5. Mechanical Sieve analysis: IS: 2720 (Part 4) - 1985

Aim: To classify the Coarse grained soil sample by Mechanical Sieve analysis as per **IS: 1498-1970**

Theory:

Soil gradation (sieve analysis) is the distribution of particle sizes expressed as a percent of the total dry mass. Gradation is determined by passing the material through a series of sieves stacked with progressively smaller openings from top to bottom and weighing the material retained on each sieve.

Need and scope:

The results of testing will reflect the condition and characteristics of the aggregate from which the sample is obtained. Therefore, when sampling, it is important to obtain a disturbed representative sample that is representative of the source being tested because the distribution of different grain sizes affects the engineering properties of soil.

Apparatus:

I.S. sieves (from 4.75mm to 75μm), Balance sensitive to 0.01g, Sieve brush, Mechanical sieve shaker, Oven.

Diagram:





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Procedure:

Soil passing 4.75mm I.S. Sieve and retained on 75micron I.S. Sieve contains no fines. Those soils can be directly dry sieved rather than wet sieving.

Dry Sieve Analysis:

- ✓ Take 500 g of the oven dried soil sample from disturbed representative sample.
- ✓ Conduct sieve analysis using a set of standard sieves as given in the data sheet.
- ✓ The sieving may be done either by hand or by mechanical sieve shaker for 10 minutes.
- ✓ Weigh the material retained on each sieve.
- ✓ From these results the percentage passing through each of the sieves is calculated.
- ✓ Draw the grain size curve for the soil in the semi-logarithmic graph provided.

Wet Sieve Analysis:

If the soil contains a substantial quantity (say more than 5%) of fine particles, a wet sieve analysis is required. All lumps are broken into individual particles.

- ✓ Take 500 g of oven dried soil sample and soaked in water.
- ✓ For heavy clays if deflocculation is required, 2% calgon solution is used instead of water.
- ✓ The sample is stirred and left for soaking period of at least 10 minutes.
- ✓ The material is sieved through 75μm sieve.
- ✓ The material is washed until the water filtered becomes clear.
- ✓ The soil retained on 75μm sieve is collected and dried in oven.
- ✓ It is then sieved through the sieve shaker for 10 minutes and retained material on each sieve is collected and weighed.
- ✓ The material that would have been retained on pan is equal to the total mass of soil taken for dry sieve analysis minus the sum of the masses of material retained on all sieves.
- ✓ Draw the grain size distribution curve for the soil in a semi-logarithmic graph.

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Observations and Tabulations:

M_d =…….…… g

Equivalent Diameter D (mm)	Mass retained (g)	Cumulative Mass		Cumulative Percent Finer (N) $= \left(\frac{M_d - X}{M_d}\right) \times 100$
		Retained (g) (X)	Passed (g) (M_d - X)	

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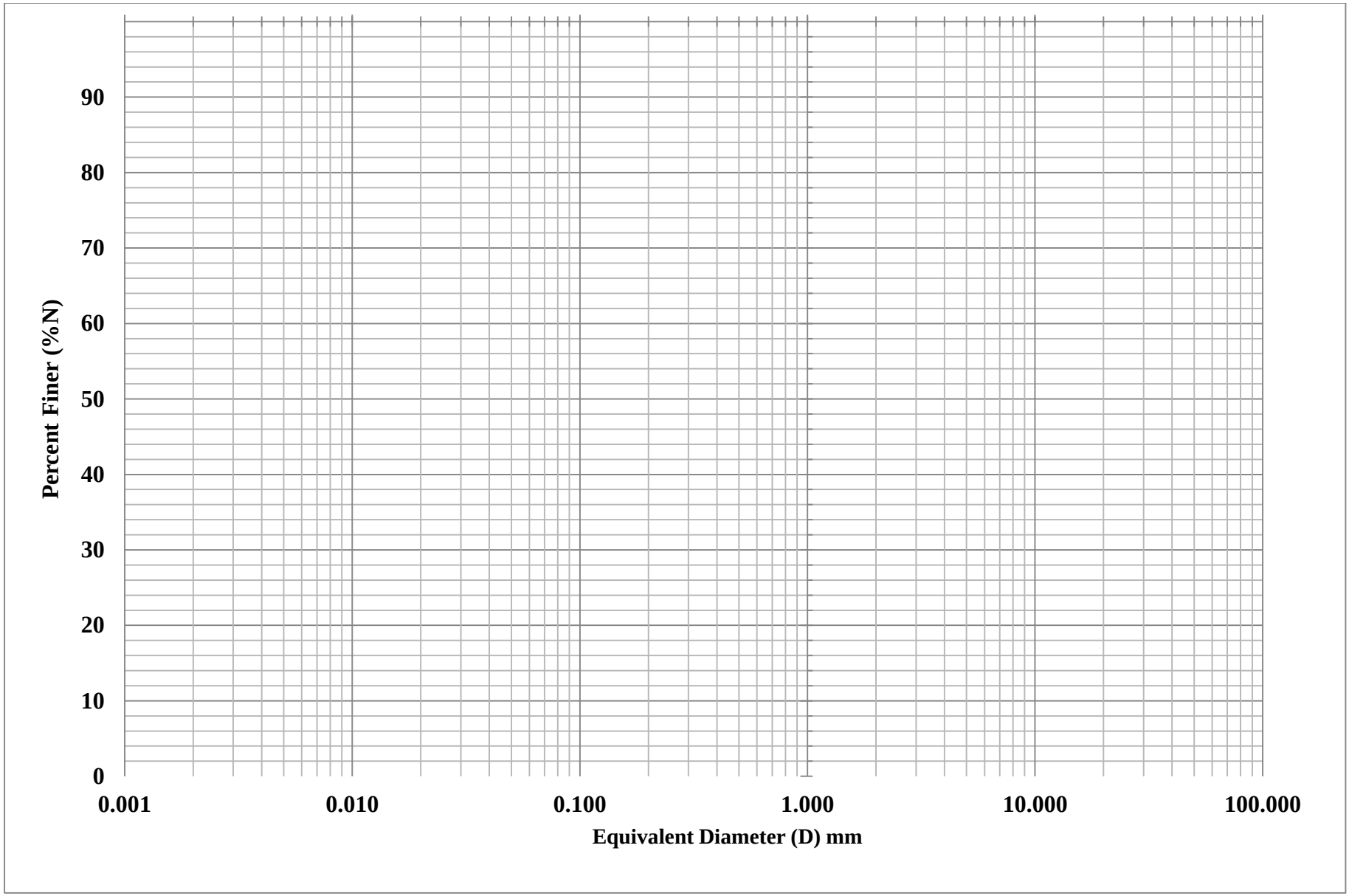
Results:

From the graph:

Percentages of particle size distribution:

- ✓ Gravel = ----------%
  - Coarse Gravel = ----------%
  - Fine Gravel = ----------%
- ✓ Sand = ----------%
  - Coarse Sand = ----------%
  - Medium Sand = ----------%
  - Fine Sand = ----------%
- ✓ Silt and Clay size = ----------%
- ✓ D_{60} = ---------- mm
- ✓ D_{30} = ---------- mm
- ✓ D_{10} = ---------- mm
- ✓ Cu = $\frac{\mathbf{D_{60}}}{\mathbf{D_{10}}}$ = _____ =
- ✓ Cc = $\frac{\mathbf{D_{30}}^{\mathbf{2}}}{\mathbf{D_{60}} \times \mathbf{D_{10}}}$ = _____ =
- ✓ Classification of soil sample as per **IS: (1498 - 1970) = ……**

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90
80
70
60
50
40
30
20
10
0
Percent Finer (%N)
0.001
0.010
0.100
1.000
10.000
100.000
Equivalent Diameter (D) mm

6. Sedimentation Analysis: (Hydrometer method) IS: 2720- Part-IV: 1985

Aim:

To determine the distribution of particle size, finer than 75µ by sedimentation analysis, using density hydrometer and then plot the grain size distribution curve.

Apparatus:

- Density hydrometer.
- Four glass measuring jars of 1000 ml capacity.
- Rubber stopper or bung.
- Thermometer.
- Stirring apparatus.
- 75µ sieve.
- Balance accurate to 0.01 g.
- Stop watch.
- Wash bottles.
- Glass rod.
- Reagents: Sodium carbonate and Sodium hexametaphosphate.
- Measuring cylinder of 100 ml capacity.

Test Procedure:

Calibration of Hydrometer:

✓ Determination of volume of the hydrometer bulb (V_H):

Pour about 800 ml of water in the 1000 ml measuring cylinder and note the reading at the water level. Immerse the hydrometer in water and note the water reading. The difference between the two readings is recorded as the volume of the hydrometer bulb plus the volume of the part of the stem which is submerged.

For practical purposes the error due to inclusion of this stem volume may be neglected.

Alternatively, weight the hydrometer to the nearest 0.2 g. this mass in grams is recorded as the volume of hydrometer in ml. This includes the volume of the bulb plus the volume of the stem.

For practical purposes the error due to inclusion of this stem volume may be neglected.

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- ✓ To find the cross-sectional area (A) of the measuring cylinder in which the hydrometer is to be used, measure the distance in cm between the two graduations of the cylinder. The cross-sectional area (A) is then equal to the volume included between the two graduations divide by the distance between them.
- ✓ Measure the distance (h) from the neck to the bottom of the bulb and recorded it as the height of the bulb.
- ✓ With the help of an accurate scale measure the height (H) between the neck of the hydrometer to each of the other major calibration marks (R_H).
- ✓ Calculate the effective depth (H_e) corresponding to each of the major calibration marks of hydrometer readings by the following expression:

  $H_e = H + ½ \ (h - \frac{V_H}{A})$
- ✓ Draw a calibration curve between H_e and R_H which may be used for finding the effective depth (He) corresponding to hydrometer readings (RH) obtained during the test.
- ✓ Meniscus correction: Insert the hydrometer in the measuring cylinder containing about 700 ml of water. Take hydrometer readings at the top and bottom of the meniscus. The difference between the two readings is taken as the meniscus correction (CM) which is constant for a hydrometer. During the actual sedimentation test, the readings should be taken at the bottom of the meniscus but since the soil suspension is opaque, readings are taken at the bottom of the meniscus. The hydrometer readings decrease in downward direction. Thus, the observed hydrometer readings is always less than the true one. Hence the meniscus correction is always positive.
- ✓ The stock solution is prepared by dissolving 33 g of sodium hexametaphosphate and 7 g of sodium carbonate in distilled water to make 1 litre of solution. This solution is unstable and should be freshly prepared once in a month.
- ✓ **Composite correction:** in order to determine the composite correction, put 100 ml of stock solution in another 1000 ml measuring jar and make it to 1000 ml by adding distilled water. The jar should be maintained at the same temperature as that of the test jar containing soil specimen. Insert the hydrometer in comparison jar containing distilled water and the dispersing agent and take the reading corresponding to the top of meniscus. The negative of the hydrometer so obtained gives the composite correction (CC). The composite correction is found before the start of the test and also at every timer intervals of 30 minutes, 1 hour, 2 hours and 4 hours after the beginning of the test and after each hydrometer reading is taken in test jar.

- ✓ The temperature of the soil suspension should be observed and recorded once during the first 15 minutes and then after every subsequent reading.

Dispersion of soil:

- ✓ Weigh accurately 50 g of oven dried soil sample (M_d) in the evaporating dish, add 100 ml of stock solution and warm the mixture gently for about 10 minutes. Transfer the mixture to the cup of the mechanical mixer using a jet of distilled water and stir it well for about 15 minutes.
- ✓ Transfer the soil suspension to the 1000 ml measuring jar and add more distilled water to make the volume to exactly 1000 ml in the cylinder.

Sedimentation test with hydrometer:

- ✓ Insert a rubber bung on the top of the 1000 ml measuring jar containing the soil suspension and shake it vigorously end over end. Stop shaking and allow it to stand. Immediately, start the stop watch and remove the top cover from the jar.
- ✓ Immerse the hydrometer gently to a depth slightly below its floating position and then allow it to float freely.
- ✓ Take the hydrometer readings after periods of ½, 1, 2 and 4 minutes.
- ✓ Take out the hydrometer rinse it with distilled water and allow it to stand in a jar containing distilled water at the same temperature as that of the test cylinder.
- ✓ The hydrometer is re-inserted in the suspension and readings are taken after periods of 8, 15minutes, 1, 2 and 4 hours after shaking.
- ✓ The hydrometer should be removed, rinsed and placed in the distilled water after each reading.
- ✓ After the end of 4 hours, readings should be taken once or twice within 24 hours.

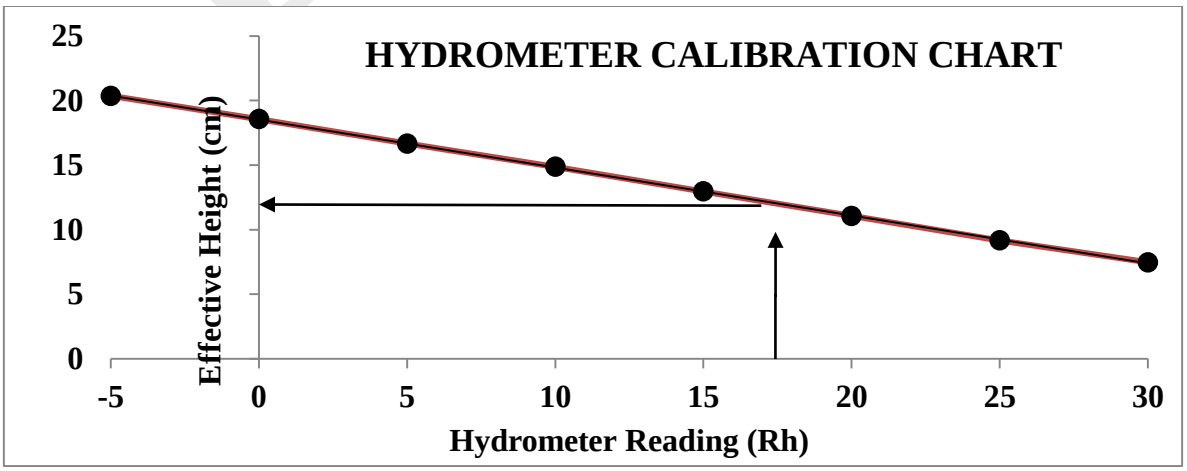
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Observations:

- ✓ Mass of dry soil sample (M) = 1000 g.
- ✓ Mass of soil sample retained on 75 μ after wet washing = 700 g.
- ✓ Mass of soil sample Passed on 75 μ after wet washing = 1000 - 700 = 300 g.
- ✓ Mass of dry soil sample taken for sedimentation test (Md) = 50 g.
- ✓ Specific gravity of soil solids (G) = 2.67
- ✓ Meniscus correction (C_M) = + 0.5
- ✓ Volume of Hydrometer bulb (V_H) = 75.25 cm^3.
- ✓ Cross-sectional area of 1000 ml measuring glass jar (A_J) = 28.57 cm^2.
- ✓ Height of hydrometer bulb (h) = 16.8 cm.
- ✓ Constant term, ½ (h - $\frac{V_H}{A_J}$) = 7.08 cm.

Calibration chart:

Specific gravity of soil suspension (G_{SS})	Hydrometer Reading (R_H) = (G_{SS} - 1) × 1000	Distance between Neck of the Hydrometer to each of the major marks (H) cm	Effective height (He) cm = H + ½ (h - $\frac{V_H}{A_J}$)
0.995	-5	13.7	20.78
1.000	0	11.9	18.98
1.005	5	10	17.08
1.010	10	8.2	15.28
1.015	15	6.3	13.38
1.020	20	4.4	11.48
1.025	25	2.5	9.58
1.030	30	0.8	7.88



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Calculations:

The coordinates of points on the grain size distribution at 4 minutes.

1. **The diameter of particles (D) in suspension at any sampling time (t):**

$$\mathbf{D} = \sqrt{\frac{\mathbf{3000 \times \eta \times H_e}}{\mathbf{(G-1) \times \gamma_\omega \times t}}}$$

Where,

D = Equivalent diameter of grain size (mm).

η = Viscosity of water (kN-s/m^2) = 7.83×10^{-7} kN-s/m^2 at 30^0 C of soil suspension temperature.

G = Specific gravity of soil solids = 2.67.

γ_ω = Unit weight of water (kN/m^3) = 9.81 kN/m^3.

He = Effective depth (cm) from the Calibration chart (R_H1 = (R_H + C_M = 15.5 + 0.5 = 16) V/S H_e = 12.3 cm).

t = Elapsed time (min) = 4 min.

2. **The percentage finer (N^1) based on the mass M_d = 50 g:**

$$\mathbf{N^1} = \frac{G}{(G-1) \times M_d} \times \mathbf{R_C} \times \mathbf{100}$$

Where,

G = Specific gravity of soil solids = 2.67.

Md = Mass of dry soil sample taken for sedimentation test = 50 g.

R_C = Corrected Hydrometer reading (R_H1 - C_C) = 16 – 1 = 15.

3. **The percentage finer (N) based on the mass (M_d = 1000 g):**

$$\mathbf{N} = \mathbf{N^1} \times \left(\frac{M_{-75}}{M_d}\right)$$

Where,

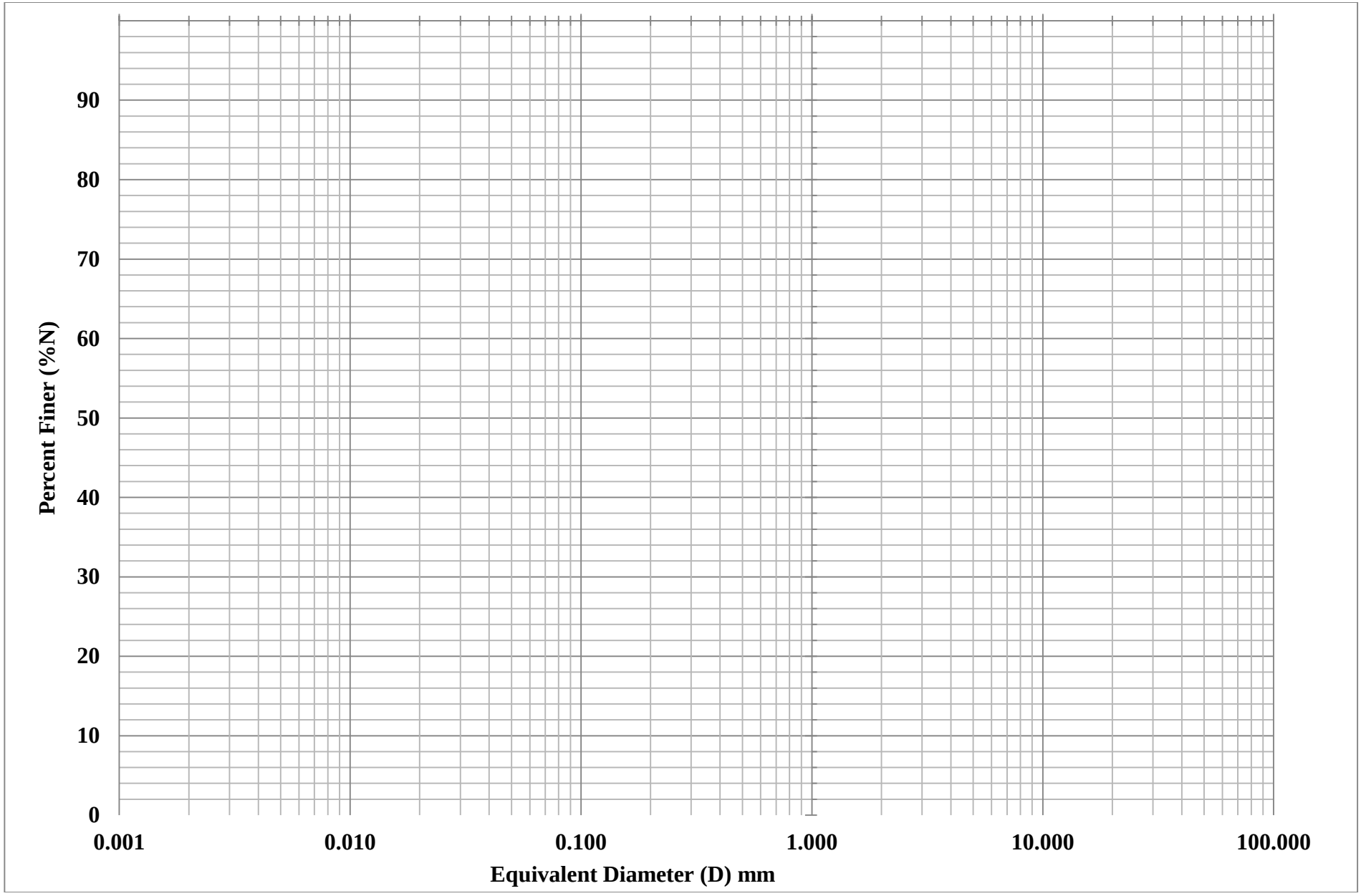
M_{-75} = Mass of soil sample passing 75μ sieve after wet washing = 300 g.

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Tabulations:

Elapsed time (t) min	Hydrometer Reading (R_H)	Temperature of soil suspension (^{0})C	Viscosity of soil suspension η (kN-s/m^2)	Hydrometer Reading (R_C1) = ($R_H + C_M$)	Effective depth (H_e) cm	Grain size (D) mm = $\sqrt{\frac{3000 \times \eta \times H_e}{(G-1) \times \gamma_\omega \times t}}$	Composite correction (C_C)	Corrected Hydrometer Reading (R_C2) = ($R_C2 - C_C$)	Percent Finer (%)	
									$N^1 = \frac{G}{(G-1) \times M_d} \times R_C \times 100$	$N = N^1 \times (\frac{M-75}{M_d})$
0.25	19	29	8.18×10^{-7}	19.5	11.1	0.08155	1	18.5	59.15	17.74
0.5	19	29	8.18	19.5	11.1	0.05766	1	18.5	59.15	17.74
1	17.5	29	8.18	18	11.6	0.04168	1	17	54.36	16.30
2	17	30	8.00	17.5	11.8	0.02939	1	16.5	52.76	15.83
4	15.5	31	7.83	16	12.3	0.02939	1	15	47.96	14.38
8	11.5	32	7.67	12	13.3	0.01528	1	11	35.17	10.55
15	10	33	7.51	10.5	14.1	0.01137	1	9.5	30.37	9.11
30	9.5	33	7.51	10	14.3	0.00809	0.5	9.5	30.37	9.11
60	8	34	7.36	8.5	14.9	0.00578	0.5	8	25.58	7.67
120	7.5	33	7.51	8.0	15	0.00414	0.5	7.5	23.98	7.19
240										
480										
960										
1440										

DRAFT


Percent Finer (%N)
90
80
70
60
50
40
30
20
10
0
0.001
0.010
0.100
1.000
10.000
100.000
Equivalent Diameter (D) mm

COSISTENCY LIMITS (or) ATTERBERG'S LIMITS:

I) LIQUID LIMIT: IS: 2720 (Part 5) - 1985

Aim: To determine the Liquid limit of the soil sample using A. Casagrande liquid limit apparatus.

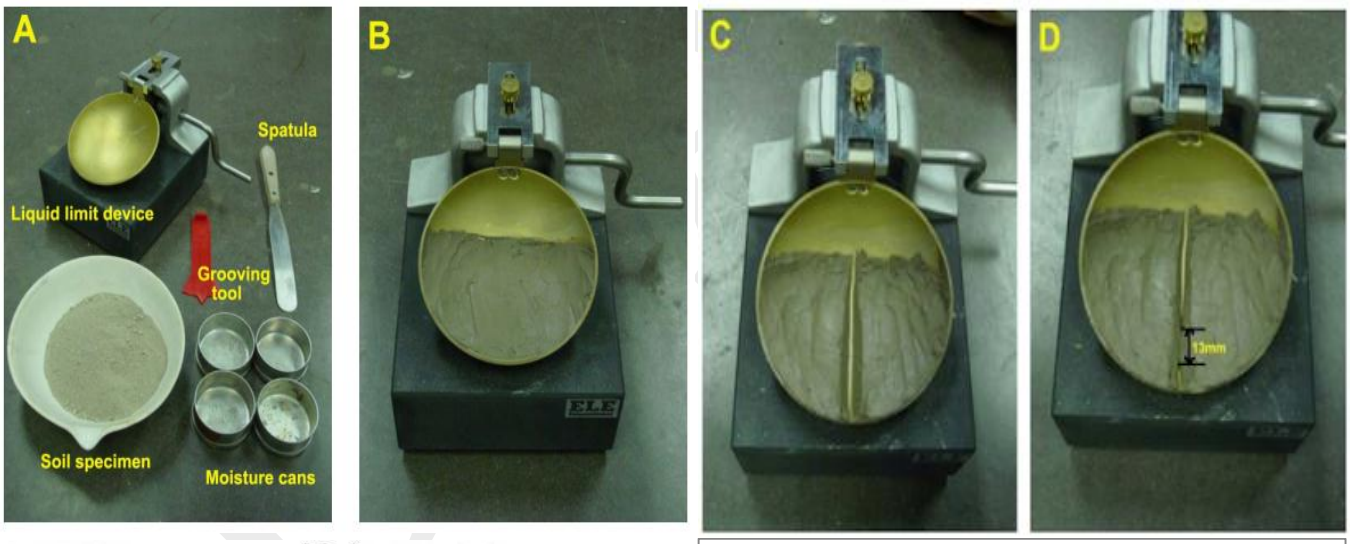
Theory:

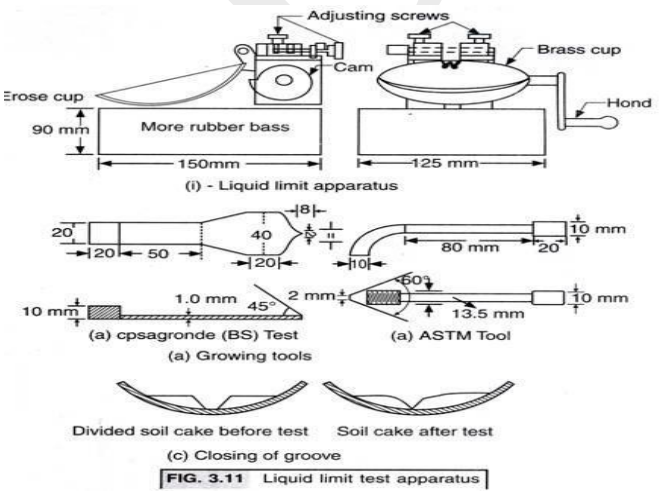
The liquid limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes for 10 mm on being given 25 blows in a standard manner. This is the limiting moisture content at which the cohesive soil passes from liquid state to plastic state.

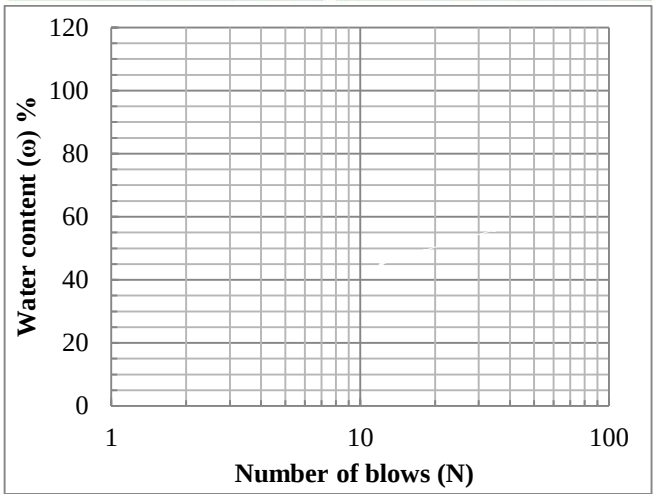
Need and scope:

Liquid limit is significant to know the stress history and general properties of the soil met with construction. From the results of liquid limit the compression index may be estimated. The compression index value will help us in settlement analysis. 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 liquid limit, the soil is brittle and stiffer.

Diagram:







Apparatus:

- Casagrande type mechanical liquid limit apparatus.
- Grooving tools ‘a’ (Casagrande) and ‘b’ (ASTM).
- Marble plate 30 cm square.
- Flexible spatula.
- Balance to weigh to 0.01g.
- Containers to determine water content.
- Electrical Oven to maintain the temp between $110^0 \pm 5^0$ C.
- Wash bottles containing distilled water.
- 425µm IS sieve.

Procedure:

1) With adjustment plate, adjust the height through which the cup is lifted and dropped so that the point on the cup which comes in contact with the base falls through exactly 1 cm when the handle is rotated by one revolution. When the adjustment is complete, secure the adjustment by tightening the screws.
2) Take about 120 g of the specimen, passing through 425 µm IS sieve, and mix it thoroughly with distilled water on the marble plate so that the uniform paste is formed.
3) Take a portion of the paste with the spatula and place it on the centre of the cup so that it is almost half filled. Level off the top of the wet soil symmetrically with spatula, so that it is parallel to the rubber base and maximum depth of the soil is 1 cm.
4) With the help of grooving tool ‘a’, the paste in the cup is divided along the diameter (through the centre line of the cam follower), by holding the tool normal to the surface of the cup and drawing it firmly across.
5) V-shaped gap, 2 mm wide at the bottom and 11 mm at the top and 8 mm deep will be formed. In case of sandy soils tool ‘a’ does not form a neat groove and hence tool ‘b’ is used.
6) Turn the handle of the apparatus at the rate of 2 revolutions per seconds, until the two parts of the soil come in contact with the bottom of the groove along a distance of 10mm.
7) Record the number of blows required to close the groove for approximate length of 10 mm.
8) Collect a representative slice of soil by moving spatula widthwise from one edge to the other edge of the soil cake at right angles to the groove, including the portion of groove in which the soil flowed together and put in the airtight container.
9) Remove the remaining soil from the cup and mix it with the soil left earlier on the marble plate.
10) Change the consistency of the mix by either adding more water or leaving the soil paste to dry.
11) Repeat the steps **3)** to **10)**.

12) Note the number of revolutions to close the groove and keep the soil for water content determination.
13) These operations are repeated for 4 or 5 more additional trials.
14) The soil paste in these operations should be of such consistency that number of blows to close the groove is **25 ± 10**.
15) The test should always proceed from the wetter (less blows) to the dryer (more blows) condition of the soil.

Observations and Tabulations:

Natural Moisture content of the soil sample (ω_{nat}) = ……..%

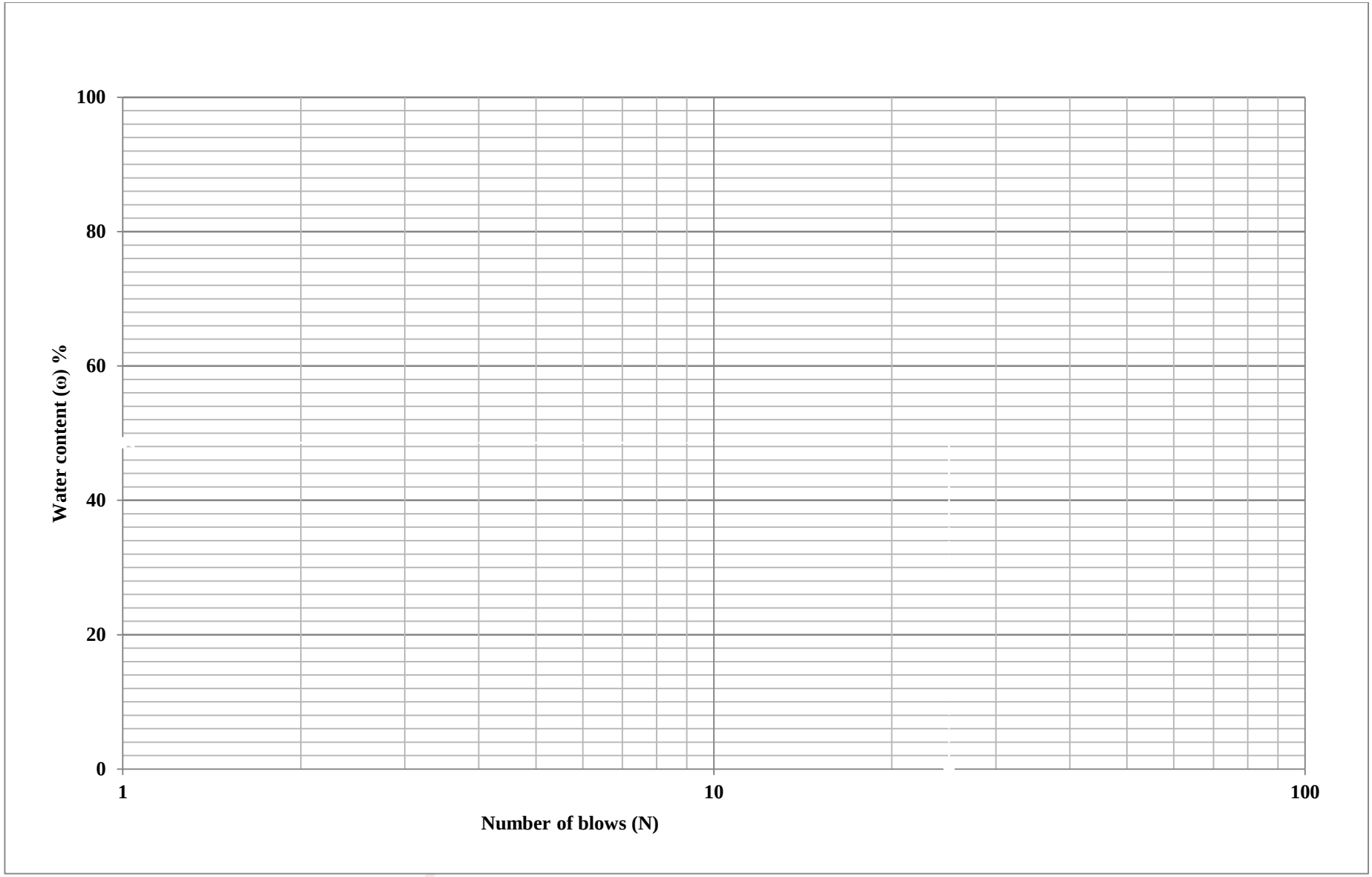
Determination No	1	2	3	4	5
Number of Blows (N)					
Cup No					
Cup Mass (M_1) g					
Cup mass + Wet soil (M_2) g					
Cup mass + Dry soil (M_3) g					
Water Content (ω) % $= \left(\frac{M_2 - M_3}{M_3 - M_1}\right) \times 100$					

Results:

From the graph:

1) Liquid Limit **(LL)** = …… %
2) Flow Index (FI) = $\left(\frac{\omega_1 - \omega_2}{Log_{10}\left(\frac{N_2}{N_1}\right)}\right)$ = …….. = ……..

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100
80
60
40
20
0
Water content (ω) %
1
10
100
Number of blows (N)

II) LIQUID LIMIT: IS: 11196 - 1985

Aim: To determine the liquid limit of the soil sample using cone penetrometer apparatus.

Diagram:



Apparatus:

- Automatic and Manual Cone Pentrometer.
- Balance sensitive to 0.01 g.
- Containers for moisture content determination.
- Oven thermostatically controlled to maintain the temperature between 105 and 110^0 C.
- 425µm IS sieve.
- Flat marble plate.
- Spatula and palette knives.
- Wash bottles.

Procedure:

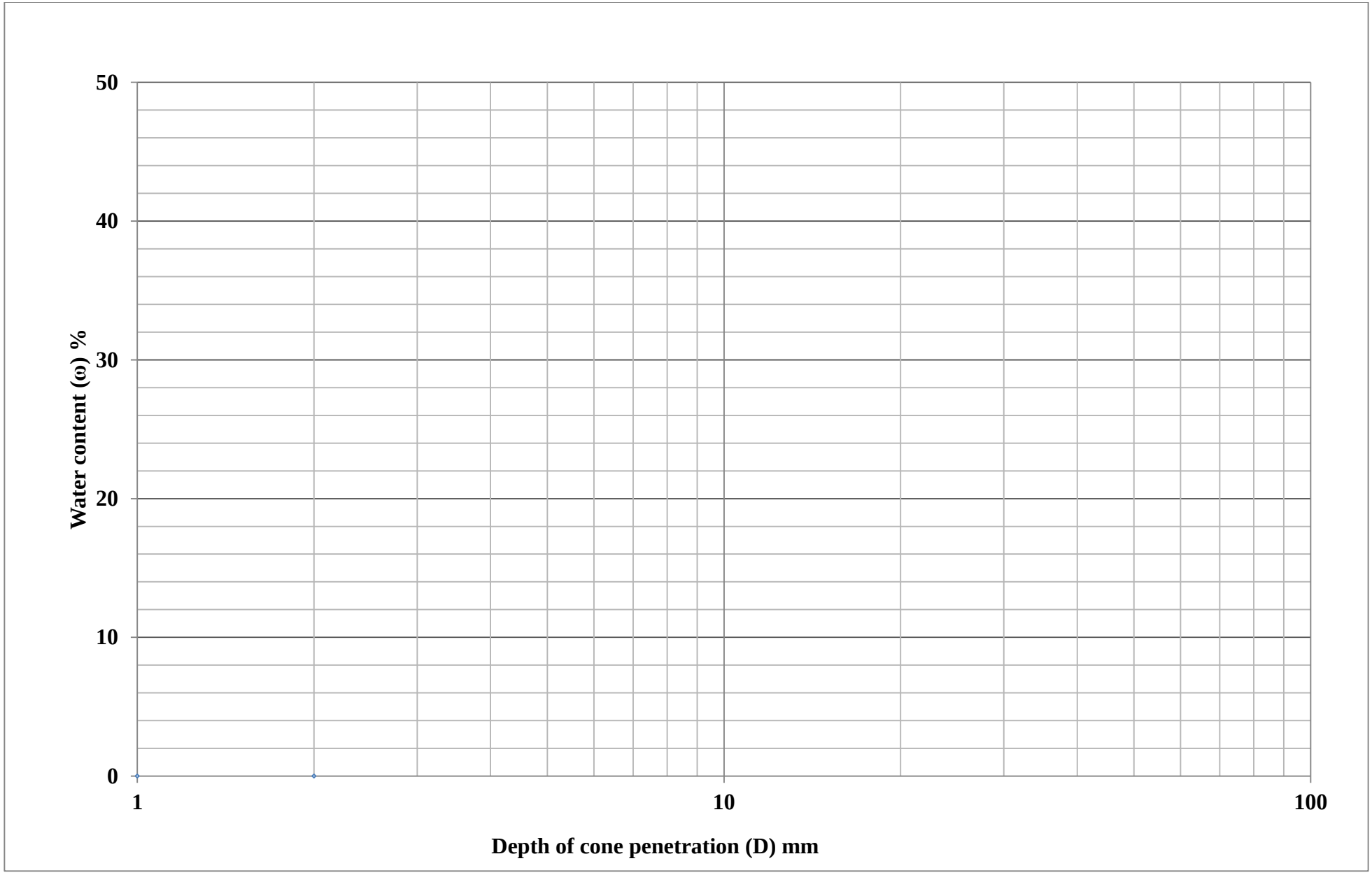
- ✓ Take about 150 g of soil sample from a thoroughly mixed portion of the material passing 425µm IS sieve.
- ✓ Place the above sample in marble plate and mix it thoroughly with distilled water.
- ✓ Water added should be sufficient to fill the voids in the soil completely and make the soil pasty.
- ✓ Place the soil paste, about one-third of the volume of the cylindrical cup of cone penetrometer apparatus with the help of spatula.
- ✓ Tap the cup gently on a firm surface and allow the paste to flow towards the edges.
- ✓ Place another installment of the paste in the cup and make it flow toward the edges by tapping.
- ✓ Tapping should be continued till the paste is compacted and all the entrapped air is brought to the surface.
- ✓ Repeat the process till the cup is completely filled and the excess soil overflows.
- ✓ Strike off the excess soil paste with a spatula. Wipe off the soil adhering to the outside of the cup.
- ✓ The cup is placed on the base of the cone penetrometer apparatus.
- ✓ The penetrometer shall be so adjusted that the cone point just touches the surface of the soil paste in the cup clamped in this position.
- ✓ The initial reading is adjusted to zero as is shown on the graduated scale.
- ✓ The vertical clamp is then released allowing the cone to penetrate into the soil paste under its own weight.
- ✓ The penetration of the cone after 5 seconds shall be noted to the nearest millimeter.
- ✓ If the difference in penetration lies between 14 and 28 mm, the test is repeated with suitable adjustments to moisture either by addition of more water or exposure of the spread paste on a marble plate for reduction in moisture content.
- ✓ The test shall then be repeated at least to have four sets of values of penetration in the range of 14 to 28 mm.
- ✓ The moisture content of each trial shall be determined.
- ✓ A graph representing water content on the y-axis and the cone penetration on the x-axis shall be prepared.
- ✓ The best fitting straight line is then drawn.
- ✓ The moisture content corresponding to cone penetration of 20 mm shall be taken as the liquid limit of the soil.

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Observations and Tabulations:

Determination No	1	2	3	4	5
Depth of cone penetration (D) mm					
Cup No					
Cup Mass **(M_1)** g					
Cup mass + Wet soil **(M_2)** g					
Cup mass + Dry soil **(M_3)** g					
Water content $(\omega)\ \% = \left(\frac{M_2 - M_3}{M_3 - M_1}\right) \times 100$					

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50
40
30
20
10
0
Water content (ω) %
1
10
100
Depth of cone penetration (D) mm

III) PLASTIC LIMIT: IS: 2720 (Part 5) - 1985

Aim: To determine the Plastic limit of the given soil sample by rolling thread method.

Diagram:

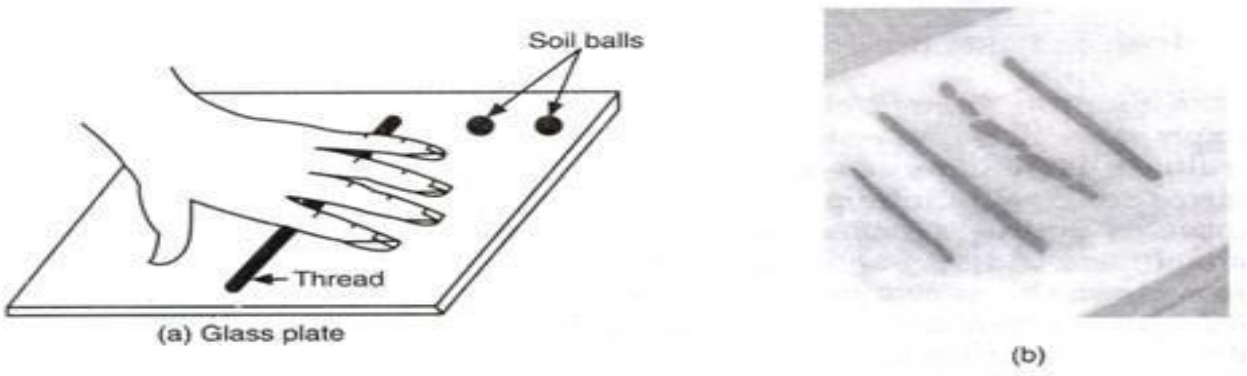


FIG. 3.17 (a) Plastic limit test (b) Cylinder rolling process

Apparatus:

- Rod of 3 mm diameter.
- Marble plate 30 cm square.
- Flexible spatula.
- Balance to weigh to 0.01g.
- Containers to determine water content.
- Electrical Oven to maintain the temp between $110^0 \pm 5^0$ C.
- Wash bottles containing distilled water.
- 425µm IS sieve.

Procedure:

- ✓ Determine the natural water content of the soil sample obtained from the field.
- ✓ Take about 20 g of air dried soil from the thoroughly mixed portion of the material passing 425 µm IS sieve.
- ✓ Mix it on the marble plate with sufficient distilled water to make it plastic enough to be shaped into a ball.
- ✓ Take about 8 g of the plastic soil, make a ball of it, and roll it on the marble plate with the hand with sufficient pressure to roll the mass into a thread of uniform diameter throughout its length.
- ✓ When the diameter of the thread has decreased to 3 mm, the specimen is kneaded together and rolled out again.
- ✓ Continue the process until thread just crumbles at 3 mm diameter.

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- ✓ Collect the crumbled soil thread in the airtight container and keep it for water content determination.
- ✓ The test is repeated twice more.
- ✓ Thus three readings are obtained for the determination.

Observations and Tabulations:

Determination No.	1	2	3
Cup number			
Mass of cup (M_1) g			
Mass of cup + Wet soil (M_2) g			
Mass of cup + Dry soil (M_3) g			
Water content (ω) % = $\left(\frac{M_2 - M_3}{M_3 - M_1}\right) \times 100$			
Average Water content (ω) %			

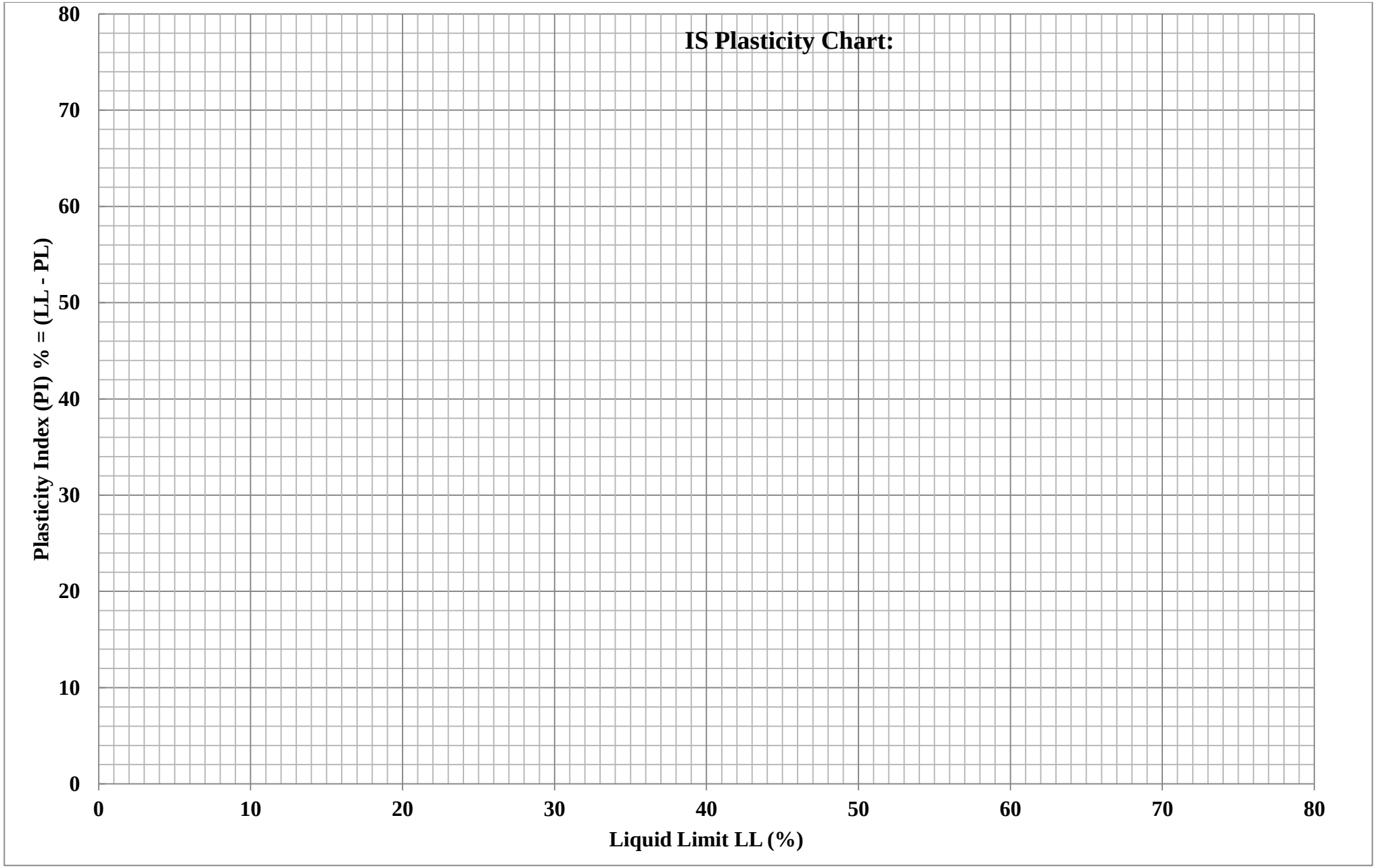
Calculations:

1) Natural water content of the soil sample (ω_{nat}) = …… %
2) Liquid limit **(LL)** = ……. % (From Liquid Limit Experiment).
3) Plastic limit (**PL**) = …… %
4) Plasticity Index **(PI) = LL – PL =** ……. = ……..%
5) Flow Index **(FI)** = …… (From Liquid Limit Experiment).
6) Consistency Index **(CI) =** $\left(\frac{LL - \omega_{nat}}{PI}\right)$ **=** ……. = ……..
7) Liquidity Index **(LI) =** $\left(\frac{\omega_{nat} - PL}{PI}\right)$ **=** ……. = ……..
8) Toughness Index **(TI) =** $\left(\frac{PI}{FI}\right)$ **=** …….. = …….
9) The soil classification as per IS Plasticity chart = ……..

Summary of results:

Liquid limit **(LL)**	Flow Index **(FI)**	Plastic Limit **(PL)**	Plasticity Index **(PI)**	Consistency Index **(CI)**	Liquidity Index **(LI)**	Toughness Index **(TI)**

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IS Plasticity Chart:
Plasticity Index (PI) % = (LL - PL)
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
Liquid Limit LL (%)

IV) SHRINKAGE LIMIT: IS: 2720 (Part 6) - 1972

Aim: To determine the shrinkage limit of the given soil sample.

Diagram:





Apparatus:

- Evaporating porcelain dish.
- Shrinkage dish.
- Glass cup.
- Glass plates, (2 Nos), each 75 × 75 mm. One plate should be of plain glass and the other should have three metal prongs.
- Mercury.
- 425µ IS sieve.
- Marble plate 30 cm square.
- Flexible spatula.
- Balance to weigh to 0.01g.
- Electrical Oven to maintain the temp between $110^0 \pm 5^0$ C.
- Desiccator.
- Wash bottles containing distilled water.

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Procedure:

I. Preparation of soil paste:

- ✓ Take about 100 g of soil sample from a thoroughly mixed portion of the material passing 425µ IS sieve.
- ✓ Place the above sample in marble plate and mix it thoroughly with distilled water.
- ✓ Water added should be sufficient to fill the voids in the soil completely and make the soil pasty.

II. Determination of initial water content (ω_i):

- ✓ Clean a shrinkage dish and determine its mass accurately **(M_1)**.
- ✓ Coat the inside of the shrinkage dish with a thin layer of vaseline to prevent the soil sticking to the dish.
- ✓ Place the soil paste, about one-third of the volume of the dish, with the help of spatula.
- ✓ Tap the dish gently on a firm surface and allow the paste to flow towards the edges.
- ✓ Place another installment of the paste in the dish and make it flow toward the edges by tapping.
- ✓ Tapping should be continued till the paste is compacted and all the entrapped air is brought to the surface.
- ✓ Repeat the process till the dish is completely filled and the excess soil overflows.
- ✓ Strike off the excess soil paste with a spatula.
- ✓ Wipe off the soil adhering to the outside of the dish.
- ✓ Weigh the shrinkage dish with the wet soil pat **(M_2)**.
- ✓ Keep the shrinkage dish open to air until the colour of pat turns from dark to light.
- ✓ Keep the shrinkage dish in the oven and thus dry the pat to constant mass at 105°C to 110°C.
- ✓ Cool the dish in a desiccator and weigh immediately **(M_3)**.
- ✓ Initial water content (ω_i) % $= \left(\frac{M_2 - M_3}{M_3 - M_1}\right) \times 100$

III. Determination of volume of wet soil pat (V_i):

Determine the volume of shrinkage dish which is evidently equal to volume of the wet soil pat.

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- ✓ Place the shrinkage dish in an evaporating and fill the dish with mercury till it overflows slightly.
- ✓ Press it with plain glass plate firmly on its top to remove excess mercury.
- ✓ Carefully transfer the mercury of the shrinkage dish to the other evaporating dish and then determine the mass of mercury **(M_F).**
- ✓ The mass of mercury divided by its density would give the volume of the shrinkage dish, which is also the volume of wet soil pat (**V_i**).

IV. <u>Determination of volume of wet soil pat (V_f):</u>

Determine the volume of the dry soil pat by removing the pat from the shrinkage dish and immersing it in the glass cup full of mercury in the following manner.

- ✓ Place the glass cup in the evaporating dish and fill the glass cup to overflowing with mercury.
- ✓ Remove the excess mercury by pressing the glass plate with the three prongs firmly over the top of the cup.
- ✓ Transfer the cup carefully to another evaporating dish.
- ✓ Place the oven-dried soil pat on the surface of mercury in the cup and carefully force the pat into the mercury by pressing it by the glass plate containing three prongs.
- ✓ Press the plate firmly on the top of the cup.
- ✓ Collect carefully the displaced mercury and find its mass **(M_D)**.
- ✓ The volume of the dry soil pat is then determined by dividing this mass by the density of mercury (**V_f**).

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Observations and Tabulations:

Sl. No.	Determination No.	1	2	3
I	***Initial water content of soil pat (ω_i)***			
1	Shrinkage dish No.			
2	Mass of Shrinkage dish $\mathbf{(M_1)}$ g			
3	Mass of Shrinkage dish + Wet soil pat $\mathbf{(M_2)}$ g			
4	Mass of Shrinkage dish + Dry soil pat $\mathbf{(M_3)}$ g			
5	Mass of water $\mathbf{(M_W)} = (\mathbf{M_2 - M_3})$ g			
6	Mass of solids $\mathbf{(M_S)} = (\mathbf{M_3 - M_1})$ g			
7	Initial water content of soil pat $\mathbf{(\omega_i) = (\frac{M_W}{M_S})}$			
II	***Volume of the wet soil pat (Vi)***			
8	Mass of mercury filling shrinkage dish $\mathbf{(M_F)}$ g			
9	Volume of wet soil pat $\mathbf{(V_i)}$ cm^3 $\mathbf{= (\frac{M_F}{13.6})}$			
III	***Volume of the dry soil pat (V_f)***			
10	Mass of mercury displaced by dry soil pat $\mathbf{(M_D)}$ g			
11	Volume of dry soil pat $\mathbf{(V_f)}$ cm^3 $\mathbf{= (\frac{M_D}{13.6})}$			
12	Shrinkage limit **(SL)** % $\mathbf{= (\omega_i - \frac{(V_i - V_f)\times \rho_\omega}{M_S})\times 100}$			

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Results:

- ✓ Shrinkage limit **(SL or ω_S)** of the soil sample % = $\left(\omega_i - \frac{(V_i - V_f) \times \rho_\omega}{M_S}\right) \times 100 =$ …….
- ✓ Shrinkage index **(SI)** % = **(PL−SL)** = ……. = ……..
- ✓ Initial bulk density of pat (ρ_{bi}) (g/cc) = $\left(\frac{M_b}{V_i}\right)$ = ……. = ……..
- ✓ Initial dry density of pat (ρ_{di}) (g/cc) = $\left(\frac{\rho_{bi}}{1+\frac{\omega_i}{100}}\right)$ = ……. = ……
- ✓ Final dry density of pat (ρ_{df}) (g/cc) = $\left(\frac{M_S}{V_S}\right)$ = ……. = …….
- ✓ Specific gravity **(G_S)** = $\frac{1}{\left(\frac{\rho_\omega}{\rho_{df}} - \frac{SL}{100}\right)}$ = …….. = ……..
- ✓ Initial Void ratio **(e_i) = ($G_S \times \omega_i$) =** ……. = ……
- ✓ Final Void ratio **(e_f) = ($G_S \times \omega_s$) =** ……. = ……..
- ✓ Shrinkage Ratio **(SR)** = $\left(\frac{\left(\frac{V_i - V_f}{V_i}\right) \times 100}{\omega_i - \omega_s}\right)$ = …… = ……..
- ✓ Degree of shrinkage **(DS)** % = $\left(\frac{V_i - V_f}{V_i}\right) \times 100$ = …… = ……
- ✓ Volumetric Shrinkage **(VS)** % = $\left(\frac{V_i - V_f}{V_f}\right) \times 100$ = …….. = ……..
- ✓ Linear shrinkage **(LS)** % = $100 \times \left[1 - \left(\frac{100}{VS + 100}\right)^{\frac{1}{3}}\right]$ = …… = …….

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COMPACTION PROPERTIES:-

I. LIGHT COMPACTION (STANDARD PROCTOR TEST): IS: 2720 (Part 7) - 1987

Aim: To determine the Optimum moisture content and the corresponding Maximum dry density of the given soil sample.

Diagram:



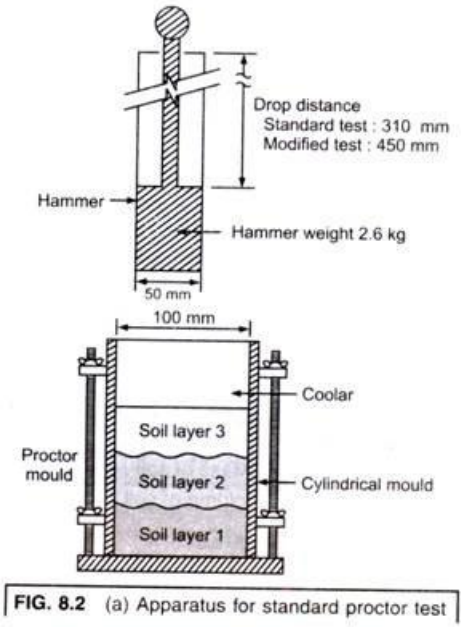


FIG. 8.2 (a) Apparatus for standard proctor test

Apparatus:

- IS compaction mould having a capacity of 1000 cc, with an internal diameter of 10.2 cm and internal effective height of 12.7 cm or mould capacity 2250 cc, with an internal diameter of 15 cm and internal effective height of 12.7 cm.
- The mould shall have a detachable collar assembly and a detachable base plate.
- Rammer, a mechanical operated metal rammer having 5.08 cm diameter face and a weight of 2.6 kg. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free fall of 30 cm.
- Balances, 10 kg capacity sensitive to 1 g, and 200 g capacity sensitive to 0.01g.
- Steel straight edge.
- Thermostatically controlled oven (105 - 110^0 C).
- Water content containers.
- Mixing equipment, such as mixing pan, spoon, trowel, spatula etc.
- Graduated cylindrical jar (100 ml capacity).

Procedure:

1) Take representative oven dried soil sample weighing approximately 3 kg passing 4.75 mm IS sieve.
2) Add enough water to bring its water content to about 7% (Sandy soils) or 10% (Clayey soils).
3) Thoroughly mix the sample with sufficient water.
4) Weigh the proctor mould without base plate and collar **(M_1)**.
5) Fix the collar and base plate to the proctor mould. The inside of the mould greased thoroughly.
6) Take about 2.5 kg of the moist soil sample and compact it in the mould in three equal layers. Each layer being given 25 blows from the rammer weighing 2.6 kg dropping from a height of 31 cm, if 1000 cc mould is used.
7) However, 2250 cc mould is used, take about 5 kg of moist soil sample and compacted in three equal layers. Each layer being given 56 blows from the rammer weighing 2.6 kg dropping from a height of 31 cm.
8) The blows should be uniformly distributed over the surface of each layer.
9) Each layer of compacted soil should be scored with a spatula before putting the soil for the succeeding layer.
10) Remove the collar and base plate, and cut the excess soil with the help of a straight edge.
11) Clean the mould from outside and weigh it **(M_2)**.
12) Remove the sample from the mould, cut in the middle and keep a representative soil specimen for water content determination.
13) Thoroughly break up the remainder of the sample.
14) Repeat the steps 5) to 12) for about increase water content by two to four percentages.

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Observations:

- ✓ Mass of rammer $\mathbf{(M_R)}$ kg = …….
- ✓ Falling height of rammer $\mathbf{(H_R)}$ cm = …….
- ✓ Number of layers $\mathbf{(N_L)}$ = …….
- ✓ Number of blows $\mathbf{(N_B)}$ = ……
- ✓ Internal Diameter of the IS compaction mould **(D)** cm = …….
- ✓ Internal Height of the IS compaction mould **(H)** cm = …….
- ✓ Volume of the IS compaction mould **(V)** cc = $\left(\frac{\pi}{4} \times D^2 \times H\right)$ = …….
- ✓ Compactive Energy **(E)** kg-cm/cm^3 = $\left(\frac{M_R \times H_R \times N_L \times N_B}{V}\right)$ = ……

  =……
- ✓ Specific gravity of soil solids $\mathbf{(G_{S\ -4.75\ mm})}$ = …….
- ✓ Specific gravity of oversized soil particles $\mathbf{(G_{S\ +4.75\ mm})}$ = …….
- ✓ Density of oversize gravel particles $\mathbf{(\rho_d)_{Gravel}}$ g/cc = $\mathbf{(G_{S\ +4.75\ mm}) \times \rho_\omega}$ =

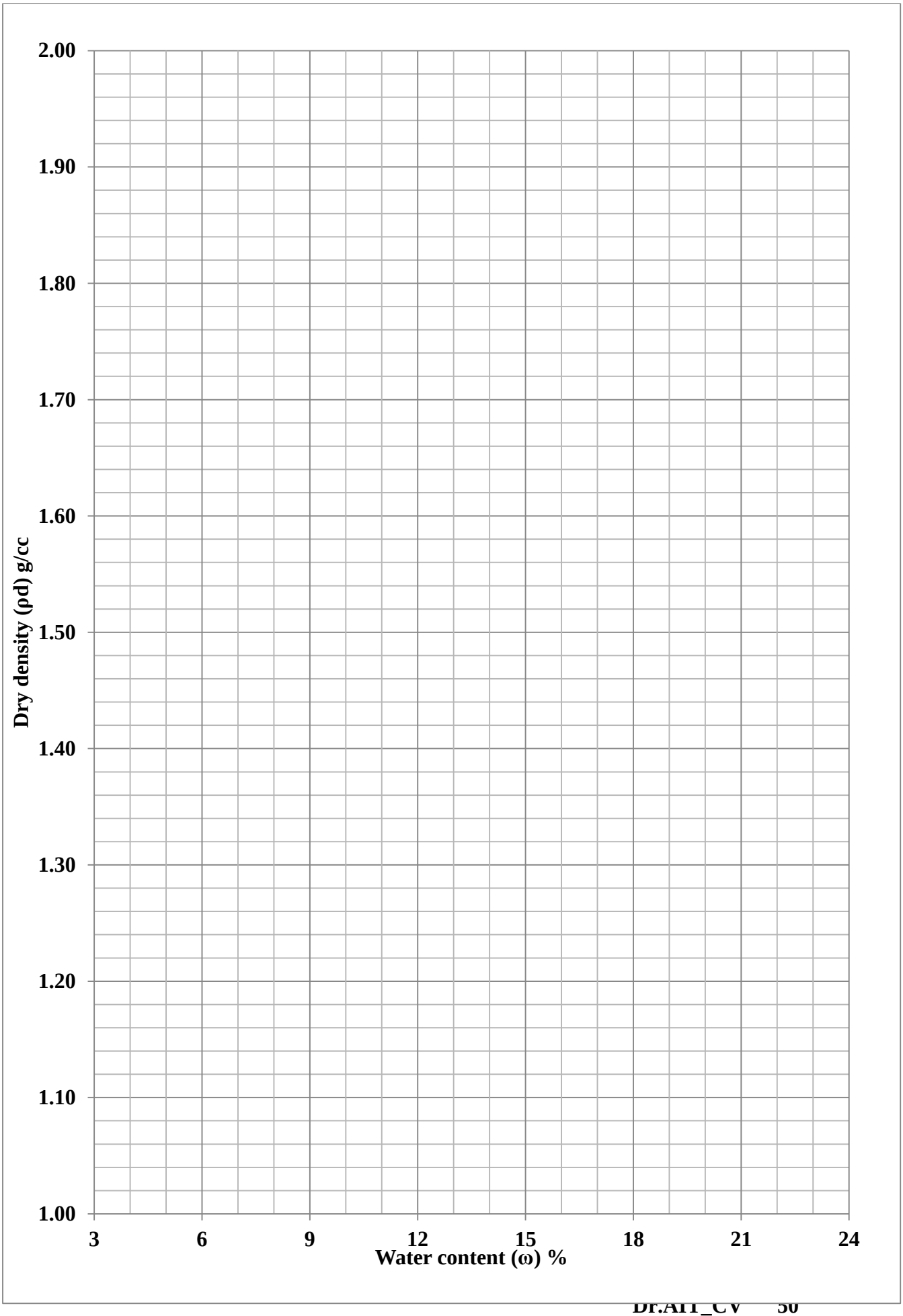
  ……..
- ✓ Percentages of fraction retained on IS 4.75 mm sieve $\mathbf{(n_1)}$ % = ……
- ✓ Percentages of fraction passed on IS 4.75 mm sieve $\mathbf{(n_2)}$ % = ……
- ✓ Percentages of water absorbed $\mathbf{(A_0)}$ % = …….
- ✓ Mass of the IS compaction mould $\mathbf{(M_1)}$ g = ……

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Tabulations:

Sl. No	Determination No.	1	2	3	4	5
1	Percentage of water to be added **(%)**					
2	Mass of mould + compacted soil **(M_2)** g					
3	Mass of compacted soil **($M_b = M_2 - M_1$)** g					
4	Bulk density **(ρ_b)** = ($\frac{M_b}{V}$) g/cc					
5	Container No.					
6	Mass of container **(m_1)** g					
7	Mass of container + wet soil **(m_2)** g					
8	Mass of container + wet soil **(m_3)** g					
9	Water content **(ω)** % = ($\frac{m_2 - m_3}{m_3 - m_1}$) ×100					
10	Dry density **(ρ_d)** = ($\frac{\rho_b}{1+\frac{\omega}{100}}$) g/cc					
11	Zero air voids density **(ρ_{ZAV})** = ($\frac{G\times\rho_\omega}{1+(G\times\omega)}$) g/cc					
12	Saturated density **(ρ_{sat})** = ($\frac{G\times\rho_\omega}{1+(\frac{G\times\omega}{S_r})}$) g/cc					
13	Percentage of Air voids density **(ρ_{n_a})** = ($\frac{(1-n_a)\times(G\times\rho_\omega)}{1+(G\times\omega)}$) g/cc					

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2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
Dry density (ρd) g/cc
3
6
9
12
15
18
21
24
Water content (ω) %

Results:

From the graph:

1) Optimum moisture content $(\omega)_0$ = ... **%.**

2) Maximum dry density $(\rho)_{d\ max}$ = …… **g/cc.**

Volumetric and gravimetric relations:

Sl. No	Volumetric ratios at OMC and MDD	
1	Void ratio **(e)**	
2	Porosity **(n)** %	
3	Degree of saturation (S_r) %	
4	Air content (A_C) %	
5	Percentage of air voids (n_a) %	

Correction for oversize fraction:

1) Corrected Optimum moisture content

$$(\omega)_{C0} = (n_1 \times A_0 + n_2 \times \omega_0) = \text{…..} \%.$$

2) Corrected Maximum dry density

$$(\rho)_{d\ C\ max} = \left(\frac{(\rho_d)\ \mathbf{max} \times (\rho_d)\ \mathbf{Gravel})}{(n_1 \times (\rho_d)\ \mathbf{max}) + (n_2 \times (\rho_d)\ \mathbf{Gravel}))}\right) = \text{……} \text{g/cc.}$$

HEAVY COMPACTION (MODIFIED PROCTOR TEST): IS: 2720 (Part 7) - 1987

- ✓ The equipment required for the heavy compaction test is the same as that required for the light compaction except that the rammer has a falling mass of **4.9 kg** and has a drop of **45 cm**.
- ✓ The soil is compacted in **five** layers, instead of three.
- ✓ Each layer is given **25** blows of the rammer if the **1000 cc** mould is used and **55** blows if the **2250 cc** mould is used.

Relative Density (IS: 2720 (Part XIV) - 1983

Aim: To determine relative density of a given sand.

Diagram:



Apparatus:

- Cushioned steel vibrating desk.
- 3000 cc and 15000 cc, 10 mm thick surcharge base plate with handle separately for each mould.
- Surcharge weights.
- Pouring devices, consisting of funnels with cylindrical spouts.
- Weighing balance 100 kg capacity.

Sample preparation:

- ✓ Dry the soil sample in a thermostatically controlled oven.
- ✓ Cool in the sample in a desiccator.
- ✓ Segregate soil lumps without breaking individual particles and sieve through the required sieve size.

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Procedure:

The volume of the mould (V) should be determined by measure inside diameter and inside height of mould.

(i) Minimum Density:

- ✓ The empty mould is weighed accurately (M_1).
- ✓ Pour the dry pulverized soil into the mould through a funnel in a steady stream.
- ✓ The spout should be adjusted so that the height of free fall of the soil is always 25 mm. while pouring soil, the spout must have a spiral motion from the rim to the center. The process is continued to fill up the mould with soil up to about 25 mm above the top. It is then levelled, with the soil and weight is recorded (M_2).

(ii) Maximum density:

- ✓ The empty mould is weighed accurately (M_1).
- ✓ Put the collar on top of the mould and clamp it. Fill the mould with the oven dried soil sample till ½ or 2/3 of the collar is filled.
- ✓ Place the mould on the vibrating desk and fix it with nuts and bolts. Then place a surcharge weight on it. The vibrator is allowed to run for 8 minutes.
- ✓ Remove the surcharge weight and guide sleeves from the mould. Obtain the dial gauge readings on two opposite sides of the surcharge base plate and take the average.
- ✓ Weigh the mould with the soil (M_3).

(iii) Natural Density:

- ✓ Weigh the mould with dry soil.
- ✓ Knowing the volume of the mould and weight of dry soil

Calculations:

$$\mathbf{R_D = \frac{e_{max} - e_{nat}}{e_{max} - e_{min}} \times 100 \text{ (or) } R_D = \left(\frac{\gamma_{d\,max}}{\gamma_d}\right) \times \left(\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}\right) \times 100}$$

Where,

e_{max} = void ratio of the soil in the loosest state obtained in the laboratory.

e_{min} = void ratio of the soil in the densest state obtained in the laboratory.

e_{nat} = void ratio of the soil in the field.

Observations:

- ✓ Specific gravity of soil solids (G) =
- ✓ Internal diameter of the mould (Di) cm =
- ✓ Internal height of the mould (H) cm =
- ✓ Cross-sectional area of the mould (A) $cm^2 = \frac{\pi}{4} \times D^2$ =
- ✓ Calibrated volume of mould (V) $cm^3 = A \times H$ =
- ✓ Mass of empty mould (M_1) g =
- ✓ Mass of mould + Dry soil in the minimum density test (M_2) g =
- ✓ Dry soil in the minimum density test (M_3) g = ($M_2 - M_1$) =
- ✓ Minimum Density ($\rho_{d_{min}}$) g/cc = $\frac{M_3}{V}$ =
- ✓ Mass of mould + Dry soil in the maximum density test (M_4) g =
- ✓ Dry soil in the maximum density test (M_5) g = ($M_4 - M_1$) =
- ✓ Volume of the soil in the maximum density test (V_f) $cm^3 = V - A \times (D_i - D_f)$ =
- ✓ Maximum Density ($\rho_{d_{max}}$) g/cc = $\frac{M_5}{V_f}$ =

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COEFFICIENT OF PERMEABILITY:

- The knowledge of the permeability is essential in the solution of many engineering problems involving flow of water through soils such as:
  - ✓ Dewatering and drainage of excavations, back-fills and subgrades.
  - ✓ Determining yield of water bearing strata.
  - ✓ Assessing seepage through the body of earth dams
  - ✓ Computing losses from canals.
- The permeability test is recommended for soils with coefficient of permeability in the range 10^{-3} to 10^{-7} cm/s and maximum particle size of 9.5 mm.

I. CONSTANT HEAD METHOD: IS: 2720 (Part 36) - 1987

Aim: To determine the coefficient of permeability of coarse grained soil by constant head method using IS Permeameter.

Diagram:







Apparatus:

- IS permeameter mould assembly (including drainage base and drainage cap)
- Stand pipes
- De-aired water
- Balance to weigh to 1 g
- 4.75 mm and 2 mm IS sieves
- Mixing pan
- Stop watch
- Graduated measuring cylinder
- Meter scale
- Beaker
- Thermometer
- Containers for water content determination
- Straight edge or trimming knife

Procedure:

- ✓ Take 2.5 kg of representative soil sample and raise its water content to the optimum moisture content.
- ✓ The permeameter mould shall be weighed empty to the nearest gram **(M_1)**.
- ✓ After greasing lightly the inside of the mould, it shall be clamped between the compaction base plate and the extension collar.
- ✓ Compact the wet soil mix in two layers, with 15 blows of the 2.5 kg rammer given to each layer.
- ✓ Remove the collar and excess soil trimmed level with the top of the mould.
- ✓ The base shall be detached and the mould full of the compacted specimen shall be weighed **(M_2)**.
- ✓ The difference of the two masses taken in steps 2) and 6) would give the mass **(M_b)** of soil compacted.
- ✓ Place the filter paper on the top of soil specimen and fix the perforated base plate on to it.
- ✓ Turn the assembly upside down and remove the compaction base plate. Place the filter paper on the top of soil specimen and fix the perforated base plate on to it.

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- ✓ The specimen shall be connected through the inlet nozzle of the permeameter to the outlet tube of constant head tank.
- ✓ Adjust the hydraulic head by adjusting the relative heights of the permeameter mould and the constant head tank
- ✓ The bottom outlet shall be opened and when the steady state of flow for a convenient time interval shall be collected and measured
- ✓ The collection of the quantity of flow for the same time interval shall be repeated thrice under the same head.

Observations:

- ✓ Mass of the IS permeameter mould $\mathbf{(M_1)}$ g = ……..
- ✓ Moulding water content $\mathbf{(\omega)}$ % = ……..
- ✓ Mass of the IS permeameter mould **+** Compacted soil $\mathbf{(M_2)}$ g = …….
- ✓ Mass of compacted soil in the IS permeameter mould $\mathbf{(M_b)} = \mathbf{(M_2 - M_1)}$ g =…….
- ✓ Specific gravity of soil solids **(G)** = …….
- ✓ Diameter of the soil specimen **(D)** cm = …….
- ✓ Cross-sectional area of the soil specimen **(A)** cm^2 = …….
- ✓ Length of the soil specimen **(L)** cm = ……
- ✓ Volume of the soil specimen **(V)** cc = $\mathbf{(\frac{\pi \times D^2 \times H}{4}) =}$ …….
- ✓ Hydraulic head **(h)** cm = ……..
- ✓ Hydraulic gradient $\mathbf{(i)} = \mathbf{(\frac{h}{L})}$ = ……..
- ✓ Bulk density of soil specimen $\mathbf{(\rho_b)}$ g/cc = $\mathbf{(\frac{M_b}{V})}$ = ……..
- ✓ Dry density of soil specimen $\mathbf{(\rho_d)}$ g/cc = $\mathbf{(\frac{\rho_b}{1+(\frac{\omega}{100})})}$ = ……
- ✓ Void ratio $\mathbf{(e)} = (\frac{G \times \rho_w}{\rho_d}) \mathbf{- 1 =}$ …….
- ✓ Porosity $\mathbf{(n)} = (\frac{e}{1+e}) \times 100$ = …….

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Tabulations:

Sl No.	Determination No.		
1	Time interval **(t)** s		
2	Quantity of flow **(Q)** m^3/s	(i) I test	
		(ii) II test	
		(iii) III test	
		Average	
3	Coefficient of permeability **($k_{t^0 C}$)** cm/s		
4	Test temperature **(^{0} C)**		
5	Viscosity of water **(η)** kN-s/m^2		
6	Coefficient of permeability at 27^0 C **($k_{27^0 C}$)** cm/s		
7	Coefficient of percolation **(k_P)** cm/s		
8	Coefficient of absolute permeability **(K)** cm/s		

Calculations:

- ✓ Discharge velocity **(V_d)** m/s = $\frac{Q}{A}$ = ……
- ✓ Seepage velocity **(V_S)** m/s = $\frac{V_d}{n}$ = ……..
- ✓ The coefficient of permeability at test temperature **(k_{t^oC})** cm/s = $\frac{Q}{t} \times \frac{L}{h} \times \frac{1}{A}$ = ……
- ✓ The coefficient of permeability at 27^0 C **($k_{27^0 C}$)** cm/s = $k_{t^oC} \times \frac{\eta_{t^oC}}{\eta_{27^oC}}$ = ……
- ✓ The coefficient of percolation **(k_P)** cm/s = $\frac{k}{n}$ = ……
- ✓ The coefficient of absolute permeability **(K)** cm/s = $k \times \frac{\eta}{\gamma_\omega}$ = ……

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II. FALLING HEAD METHOD: IS: 2720 (Part 17) - 1986

Aim: To determine the coefficient of permeability of fine grained soil by falling head method using IS Permeameter.

Diagram:







Apparatus: same as in experiment: Constant head method.

Procedure:

- ✓ Prepare the remoulded soil specimen in the permeameter and saturate it as explained in experiment: Constant head method.
- ✓ Keep the permeameter mould assembly in the bottom tank and fill the bottom tank with water upon its outlet.
- ✓ Connect the water inlet nozzle of the mould to the selected stand pipe filled with water. The bottom outlet shall be opened.
- ✓ Permit water to flow for some time till steady of flow is reached.

- ✓ Time interval required for the water level to fall from a known initial head to a known final head as measured above the centre of the outlet shall be recorded.
- ✓ The stand pipe shall be refilled with water and the test repeated till three successive observations give nearly same time interval.

After selecting the suitable initial and final heads h_1 and h_2 respectively, the time intervals shall be noted for the head to fall from h_1 to $\sqrt{h_1 \times h_2}$ and similarly from $\sqrt{h_1 \times h_2}$ to h_2. The time intervals should be the same, otherwise the observation shall be repeated after refilling the stand pipe.

Viscosity of Water (values given in milli poises)

Temp^0 c	0	1	2	3	4	5	6	7	8	9
0	17.94	17.32	16.74	16.19	15.68	15.19	14.73	17.29	13.87	13.48
10	13.10	12.74	12.39	12.06	11.75	11.45	11.16	10.88	10.60	10.34
20	10.09	9.84	9.61	9.38	9.16	8.95	8.75	**8.55**	8.36	8.18
30	8.00	7.83	7.67	7.51	7.36	7.21	7.06	6.92	6.79	6.66
40	6.54	6.42	6.30	6.18	6.08	5.97	5.87	5.77	5.68	5.58
50	5.49	5.40	5.32	5.24	5.15	5.07	4.99	4.92	4.84	4.77
60	4.70	4.63	4.56	4.50	4.43	4.37	4.31	4.24	4.19	4.13
70	4.07	4.02	3.96	3.91	3.86	3.81	3.76	3.66	3.66	3.63
80	8.57	3.53	3.48	3.44	3.40	3.36	3.32	3.28	3.24	3.20
90	3.17	3.13	3.10	3.06	3.03	2.99	2.96	2.93	2.90	2.87
100	2.84	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.62	2.59

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Observations:

- ✓ Mass of the IS permeameter mould **(M_1)** g = ……..
- ✓ Moulding water content **(ω)** % = ……..
- ✓ Mass of the IS permeameter mould **+** Compacted soil **(M_2)** g = …….
- ✓ Mass of compacted soil in the IS permeameter mould **(M_b)** = **($M_2 - M_1$)** g =…….
- ✓ Specific gravity of soil solids **(G)** = ……
- ✓ Diameter of the stand pipe **(d)** cm = …….
- ✓ Cross-sectional area of the stand pipe **(a)** cm^2 = …….
- ✓ Diameter of the soil specimen **(D)** cm = …….
- ✓ Cross-sectional area of the soil specimen **(A)** cm^2 = …….
- ✓ Length of the soil specimen **(L)** cm = ……
- ✓ Volume of the soil specimen **(V)** cc = $\left(\frac{\pi \times D^2 \times H}{4}\right)$ **=** …….
- ✓ Bulk density of soil specimen **(ρ_b)** g/cc = $\left(\frac{M_b}{V}\right)$ = ……..
- ✓ Dry density of soil specimen **(ρ_d)** g/cc = $\left(\frac{\rho_b}{1+(\frac{\omega}{100})}\right)$ = ……
- ✓ Void ratio **(e)** = $\left(\frac{G \times \rho_w}{\rho_d}\right)$ **– 1 =** …….
- ✓ Porosity **(n)** = $\left(\frac{e}{1+e}\right) \times 100$ = …….

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Tabulations:

Sl No.	Determination no.		
1	Initial head (h_1) cm		
2	Final head (h_2) cm		
3	Time interval (t) s	(i) I test	
		(ii) II test	
		(iii) III test	
		Average	
4	Coefficient of permeability $(k_{t^o C})$ cm/s		
5	Test temperature $(^0 C)$		
6	Viscosity at test temperature (η) kN-s/m^2		
7	Coefficient of permeability at 27^0 C $(k_{27^o C})$ cm/s		
8	Coefficient of percolation (k_P) cm/s		
9	Coefficient of absolute permeability (K) cm/s		

Calculations:

- ✓ The coefficient of permeability at test temperature $(k_{t^o C})$ cm/s = $2.303 \frac{a \times L}{A \times t} \log_{10} (\frac{h1}{h2})$ = ……..
- ✓ The coefficient of permeability at 27^0 C $(k_{27^o C})$ cm/s = $k_{t^o C} \times \frac{\eta_{t^o C}}{\eta_{27^o C}}$ = ……
- ✓ The coefficient of percolation (k_P) cm/s = $\frac{k}{n}$ = ……
- ✓ The coefficient of absolute permeability (K) cm/s = $k \times \frac{\eta}{\gamma_\omega}$ = ……

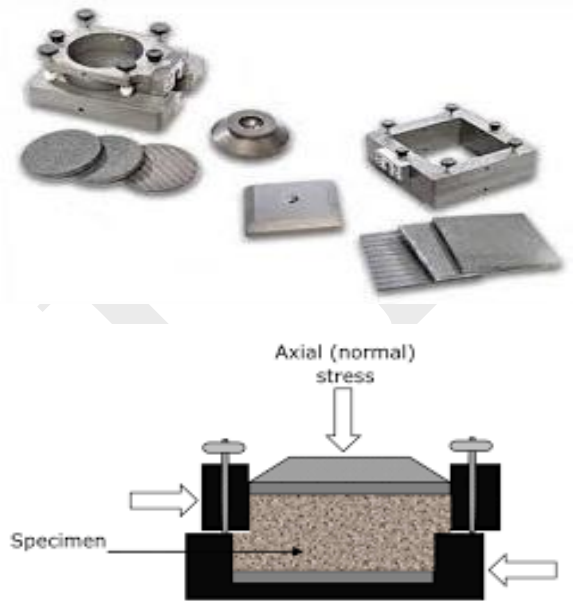
SHEAR STRENGTH TESTS:

I. DIRECT SHEAR TEST: IS: 2720 (Part 39/Sec 1) – 1986.

Aim: Determination of shear strength of the soil with a maximum particle size of 4.75 mm in undrained conditions.

Diagram:





Apparatus:

- Upper and lower parts of shear box coupled together with two shear keys (pins)
- Grid plates – two pairs
- Stone plates
- Base plate
- Loading pad
- Loading ball
- Loading frame
- Loading yoke
- Weights
- Proving ring – Force measuring of suitable capacity, fitted with a dial gauge accurate to 0.002 mm to measure the shear force.
- Micrometer Dial gauges – Accurate to 0.01 mm. suitably mounted to measure the horizontal movement.

- Sample trimmer
- Balance – Balance of 1 kg capacity sensitive to 0.1 g.
- Spatula and a Straight edge

➢ Preparation of Remoulded Specimens:

- Cohesive soils may be compacted to the required density and moisture content, the sample extracted and then trimmed to required size.
- The cut specimen shall be weighed and trimmings obtained during shall be used to obtain the moisture content.
- Using this information, the bulk density of the specimen in the shear box shall be determined.
- Alternatively, the soil may be compacted to the required density and moisture content directly into the shear box after fixing the halves of the shear box together by means of the fixing screws.
- Cohesionless soils may be tamped in the shear box itself with the base plate and grid plate or porous stone as required in place at the bottom of the box.

Procedure: (UU test)

- ✓ The shear box with the specimen, plain grid plate over the base plate at the bottom of the specimen and plain grid plate at the top of the specimen should be fitted into position in the loading frame.
- ✓ The serrations of the grid plates should be at right angles to the direction of shear.
- ✓ Plain plates of equal thickness should be substituted in porous stones place so as to maintain the shear plane in the sample middle of its thickness.
- ✓ The loading pad should be placed on the top grid plate.
- ✓ The water jacket should be provided so that the sample does not get dried during the test.
- ✓ Mount the shear box assembly on the loading frame.
- ✓ Set the lower part of the shear box to bear against the load jack and the upper part of the box to bear against the proving ring.
- ✓ Set the dial of the proving ring to zero.
- ✓ Put the loading yoke on the top of the loading pad, and adjust the dial gauge to zero to measure the vertical displacement in the soil sample.
- ✓ Put proper normal weight on the hanger of the loading yoke, so that this weight plus the weight of the hanger equals the required normal load.

- ✓ Note the reading of the vertical displacement dial gauge.
- ✓ Remove the shear keys so that the parts are freed to move against each other.
- ✓ By turning the spacing keys, raise the upper part slightly above the lower part s by about 1 mm.
- ✓ The test may now be conducted by applying horizontal shear load to failure **or** to 20 % longitudinal displacement, whichever occurs first.
- ✓ The rate of strain may vary from 1 to 2.5 mm per minute.
- ✓ Take the readings of proving ring dial gauge, longitudinal displacement gauge and vertical displacement gauge should be noted at regular intervals.
- ✓ At the end of the test, the specimen should be removed from the box and the final moisture content measured.
- ✓ A minimum of three (preferably four) tests shall be made on separate specimens of the same density.
- ✓ The loads so obtained divided by the corrected cross-sectional area of the specimen gives the shear stress in the sample.
- ✓ The corrected cross-sectional area shall be calculated from the following equation:

  Corrected area $\mathbf{A_C = A_0\ (1-\frac{\Delta L}{3})}$

  Where, A_0 = initial cross-sectional area of the specimen in cm^2, and ΔL = displacement in cm
- ✓ The stress-longitudinal displacement readings should be plotted and the maximum shear stress and corresponding longitudinal displacement and applied normal stress should be recorded for each test.
- ✓ The results should be presented in the form of a graph in which the applied normal stress is plotted as abscissa and the maximum shearing stress is plotted as ordinate to the same scale.
- ✓ The angle which the resulting straight line makes with the horizontal axis and the intercept which the straight line makes with the vertical axis shall be reported as the angle of shearing resistance and cohesion intercept respectively.

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Observations:

- ✓ Length of specimen **(L)** cm = …….
- ✓ Breadth of specimen **(B)** cm = …….
- ✓ Thickness of specimen **(H)** cm = …….
- ✓ Area of specimen **(A_0)** cm^2 = **(L×B)** = …….
- ✓ Volume of specimen **(V)** cm^3 = **(L×B×H)** = …….
- ✓ Initial mass of specimen **(M)** g = …….
- ✓ Initial water content **(ω)** % = …….
- ✓ Bulk density **(ρ_b)** g/cc = $(\frac{M}{V})$ = …….
- ✓ Dry density **(ρ_d)** g/cc = $(\frac{\rho_b}{1+\omega})$ = …….
- ✓ Least count of the strain dial gauge **(LC_{DG})** = …….
- ✓ Least count of the load dial gauge (or) proving ring **(LC_{PRR})** = …….
- ✓ Strain controlled rate = …….
- ✓ Hanger load (kg) = …….
- ✓ Applied load (kg) = …….
- ✓ Normal stress **(σ_N)** = 0.5 kg/cm^2, 1.0 kg/cm^2, 1.5 kg/cm^2

Calculations:

- ✓ The horizontal strain ε is determined by the following equation: $\boldsymbol{\varepsilon = \frac{\Delta L}{L_0}}$

  Where, ΔL = change in length of specimen, as read from strain dial gauge.

  L_0 = initial length of the specimen.

- ✓ The corrected cross-sectional area, $\boldsymbol{A_C = A_0 \times (1 - \frac{\Delta L}{3})}$

  Where, A_0 = initial cross-sectional area of the specimen.

- ✓ The horizontal shear stress, $\boldsymbol{\tau_H = \frac{P_H}{A_C}}$

  Where, P = Horizontal shear force.

Results:

The shear strength parameters are determined to be from the Mohr's – Coulomb's plot:

C_U = …… kg/cm^2 and **$\emptyset_U$ = ……**

<u>Tabulations:</u> 1) Normal stress (σ_N) = 0.5 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L} \times 100$	$A_C = A_0 \times (1-\frac{\Delta L}{3})$ **cm^2**	PRR	$P_H = PRR \times LC_{PR}$ **(kg)**	$\tau_H = \frac{P_H}{A_C}$ **(kg/cm^2)**
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2) Normal stress (σ_N) = 1.0 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L} \times 100$	$A_C = A_0 \times (1 - \frac{\Delta L}{3})$ **cm^2**	PRR	$P_H = PRR \times LC_{PR}$ **(kg)**	$\tau_H = \frac{P_H}{A_C}$ **(kg/cm^2)**
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3) Normal stress (σ_N) = 1.5 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L} \times 100$	$A_C = A_0 \times (1 - \frac{\Delta L}{3})$ **cm^2**	PRR	$P_H = PRR \times LC_{PR}$ **(kg)**	$\tau_H = \frac{P_H}{A_C}$ **(kg/cm^2)**
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II. UNCONFINED COMPRESSIVE STRENGTH TEST:
IS: 2720 (Part 10) – 1973

Aim: To determine the Unconfined Compressive Strength of clay soil

Diagram:













Apparatus:

- Compression device
- Sample ejector
- Dial gauge with 0.01 mm graduations
- Loading gauge with 0.002 kg graduations

Procedure:

- ✓ Remoulded sample may be prepared by compacting the soil at the desired water content and dry density directly in the split mould.
- ✓ Measure the initial diameter and length of the specimen.
- ✓ Put the specimen on the bottom plate of the loading device.
- ✓ Adjust the upper plate to make contact with the specimen.
- ✓ Set the load dial gauge and the strain dial gauge to zero.

- ✓ Compress the specimen until cracks have definitely developed or the stress strain curve is well past its peak or until a vertical deformation of 20 % is reached.
- ✓ Take the load dial readings approximately at every 1 mm deformation of the specimen.
- ✓ Sketch the failure pattern, measure the angle between cracks and the horizontal, if possible.
- ✓ A plot is made between σ and ε.
- ✓ The maximum stress from this curve gives the values of the unconfined compressive strength q_u.
- ✓ Where no maximum occurs, the unconfined compressive strength is taken as the stress at 20 percent axial strain.

Observations:

- ✓ Initial Length of specimen **(L_0)** cm = …….
- ✓ Initial diameter of specimen **(D_0)** cm = …….
- ✓ Initial cross-sectional area of specimen **(A_0)** cm^2 = $\left(\frac{\pi}{4} \times D_0^2\right)$ = …….
- ✓ Volume of specimen **(V)** cm^3 = **($A_0 \times L$)** = …….
- ✓ Initial mass of specimen **(M_b)** g = …….
- ✓ Initial water content **(ω)** % = …….
- ✓ Bulk density **(ρ_b)** g/cc = $\left(\frac{M_b}{V}\right)$ = …….
- ✓ Dry density **(ρ_d)** g/cc = $\left(\frac{\rho_b}{1+\omega}\right)$ = …….
- ✓ Least count of the strain dial gauge **(LC_{DG})** = …….
- ✓ Least count of the load dial gauge (or) proving ring **(LC_{PR})** = …….
- ✓ Strain controlled rate = …….

Calculations:

- The axial strain ε is determined by the following equation: $\boldsymbol{\varepsilon = \frac{\Delta L}{L_0}}$

  Where, ΔL = Change in length of specimen, as read from strain dial gauge.

  L_0 = Initial length of the specimen.

- The corrected cross-sectional area, $\boldsymbol{A_C = \frac{A_0}{1-\varepsilon}}$

  Where, A_0 = Initial cross-sectional area of the specimen.

- The compressive stress, $\boldsymbol{\sigma = \frac{P}{A_C}}$, Where, P = Compressive force.

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Results:

The shear strength parameters are determined to be from the Mohr's – Coulomb's plot:

C_U = …… kg/cm^2 and **$\emptyset_U$ = ……**

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Tabulations:

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L_0}$	$A_C = \frac{A_0}{1-\varepsilon}$ **(cm^2)**	PRR	$P = PRR \times LC_{PR}$ **(kg)**	$\sigma = \frac{P}{A_C}$ **(kg/cm^2)**
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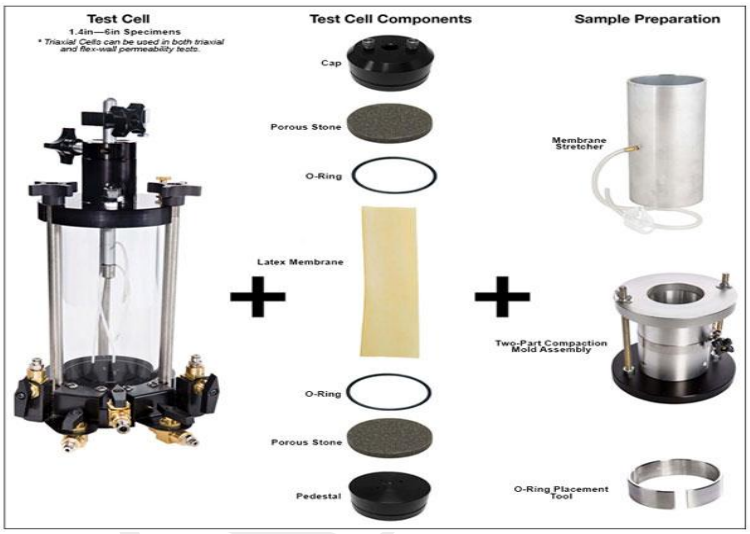
Tri-axial shear test (IS: 2720 (Part 11) : 1993)

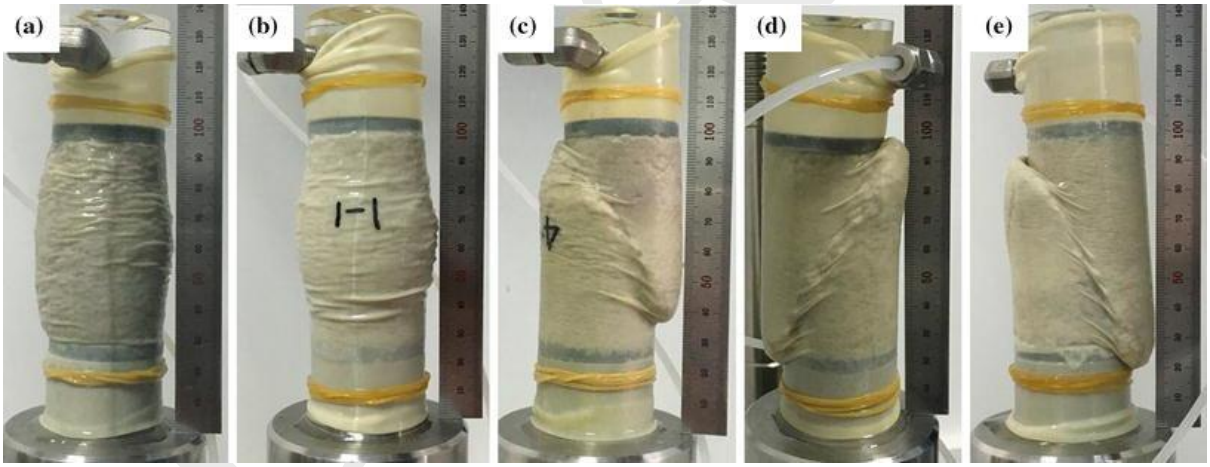
Aim:

To determine shear strength parameters of remoulded soil specimen in the tri-axial compression apparatus by unconsolidated undrained test without the measurement of pore pressure.

Diagram:







Apparatus:

- Tri-axial cell with transparent chamber.
- Apparatus for applying and maintaining desired fluid pressure in the cell.
- Compression machine.
- Dial gauge to measure axial compression.
- Seamless rubber membrane.
- Membrane stretcher.
- Rubber rings.
- Split mould.

Procedure:

(i) Sample Preparation:

- ✓ 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.
- ✓ The specimen is then taken out carefully and its length, diameter and weight should be measured to an accuracy enabling the bulk density to be calculated.
- ✓ A portion of the soil trimmings is placed for water content determination.
- ✓ The specimen is 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 tri-axial cell.

(ii) Undrained tri-axial compression test:

- ✓ Cover the pedestal in the tri-axial cell with a solid end cap or keep drainage valve closed.
- ✓ Place the specimen assembly centrally on the pedestal.
- ✓ Assemble the cell with the loading arm initially clear of the top of the specimen and place it in the loading machine.
- ✓ Admit the operating fluid in the cell and rise its pressure to the desired value.
- ✓ Adjust the loading machine further so that the loading arm comes in contact with the seat on the top of the specimen.
- ✓ Note the initial reading of the dial measuring axial compression.
- ✓ Apply the compressive force at constant rate of axial compression such that failure is produced in period of 5 to 15 minutes.
- ✓ Take the simultaneous reading of the load and deformation dials, to draw the stress – strain curve.
- ✓ Continue the test until the maximum value of stress has been passed or until an axial strain of 20 % has been passed.
- ✓ Unload the specimen and drain off the cell fluid. Dismantle the cell and taken out the specimen.
- ✓ Remove the rubber membrane and note down the mode of failure.
- ✓ Repeat the test on three or more identical specimens under different cell pressure.

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Observations:

- ✓ Initial Length of specimen **(L_0)** cm = …….
- ✓ Initial diameter of specimen **(D_0)** cm = …….
- ✓ Initial cross-sectional area of specimen **(A_0)** cm^2 = **$(\frac{\pi}{4} \times D_0^2)$** = …….
- ✓ Volume of specimen **(V)** cm^3 = **$(A_0 \times L)$** = …….
- ✓ Initial mass of specimen **(M_b)** g = …….
- ✓ Initial water content **(ω)** % = …….
- ✓ Bulk density **(ρ_b)** g/cc = $(\frac{M_b}{V})$ = …….
- ✓ Dry density **(ρ_d)** g/cc = $(\frac{\rho_b}{1+\omega})$ = …….
- ✓ Least count of the strain dial gauge **(LC_{DG})** = …….
- ✓ Least count of the load dial gauge (or) proving ring **(LC_{PR})** = …….
- ✓ Strain controlled rate = …….

Calculations:

- The difference between the initial pressure and the subsequent reading of the load measuring device is the axial load applied to the specimen in addition to that due to cell pressure.
- The axial strain ε is determined by the following equation: $\boldsymbol{\varepsilon = \frac{\Delta L}{L_0}}$

  Where, ΔL = Change in length of specimen, as read from strain dial gauge.

  L_0 = Initial length of the specimen.
- The corrected cross-sectional area, $\boldsymbol{A_C = \frac{A_0}{1-\varepsilon}}$

  Where, A_0 = Initial cross-sectional area of the specimen.
- The deviator stress, $\sigma_d = (\sigma_1 - \sigma_3)$ or the principal stress difference at any stage of the test is determined by dividing the additional axial load by the corrected cross-sectional area (A_C)

  The deviator stress, $\sigma_d = (\sigma_1 - \sigma_3) = \boldsymbol{\frac{P_d}{A_C}}$

  Where, P_d = Compressive deviator force.
- For each test, a plot may be made between $(\sigma_1 - \sigma_3)$ and ε.
- The shear strength parameters are obtained from a plot of Mohr's circles for which purpose peak value of principal stress difference $(\sigma_1 - \sigma_3)$ or ultimate value as desired may be used.

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Results:

Test No.	Cell pressure (σ_3) kN/m^2	Deviator stress at failure (σ_d) kN/m^2 = (σ_1 - σ_3)	Maximum Principal Stress at failure (σ_1) kN/m^2 = (σ_d + σ_3)
1			
2			
3			

- ✓ The shear strength parameters are determined to be from the Conventional Mohr's – Coulomb's plot:

  C_U = …… kg/cm^2 and **$\emptyset_U$ = ……**

- ✓ The shear strength parameters are determined to be from the Modified Failure Envelope plot:

  C_U = …… kg/cm^2 and **$\emptyset_U$ = ……**

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Tabulations:

(i) Cell pressure (σ_3) = 0.5 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L_0}$	$A_C = \frac{A_0}{1-\varepsilon}$ **(cm^2)**	PRR	$P_d = PRR \times LC_{PR}$ **(kg)**	$\sigma_d = \frac{P_d}{A_C}$ **(kg/cm^2)**
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(ii) Cell pressure (σ_3) = 1.0 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L_0}$	$A_C = \frac{A_0}{1-\varepsilon}$ **(cm^2)**	PRR	$P_d = PRR \times LC_{PR}$ **(kg)**	$\sigma_d = \frac{P_d}{A_C}$ **(kg/cm^2)**
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(iii) Cell pressure (σ_3) = 1.5 kg/cm^2

Sl. No	DGR	$\Delta L = DGR \times LC_{DG}$ **(cm)**	$\varepsilon = \frac{\Delta L}{L_0}$	$A_C = \frac{A_0}{1-\varepsilon}$ **(cm^2)**	PRR	$P_d = PRR \times LC_{PR}$ **(kg)**	$\sigma_d = \frac{P_d}{A_C}$ **(kg/cm^2)**
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CONSOLIDATION TEST (IS: 2720-Part XV-1965)

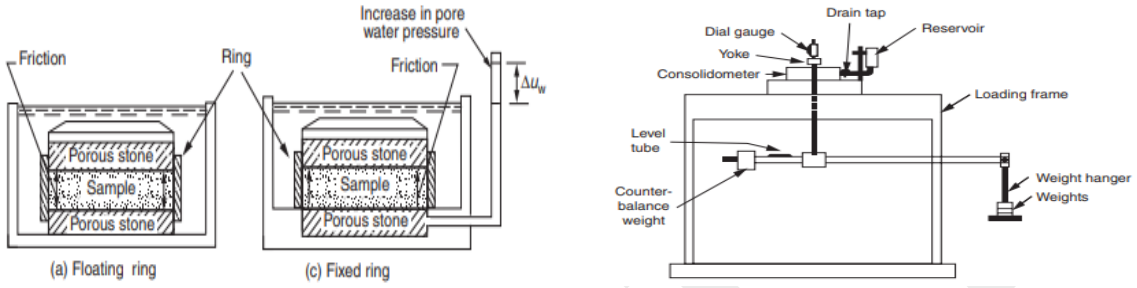
Scope

To determine the consolidation properties of soil

Apparatus

Consolidation ring, Porous stone, Consolidation cell, loading device, Balance of 0.01 g sensitivity, Stopwatch.

Figure:



Procedure:

- ✓ Find the mass of the empty consolidation ring (M_1).
- ✓ Coat the inside surface with silicone grease or oil. Trim a sample carefully to fit the consolidation ring and weigh the mass along with the ring (M_2). Keep a small quantity of the soil from the trimmings for water content determination.
- ✓ Record the thickness of the specimen. In case of difficulties in measuring the thickness, take the thickness of the ring as the initial thickness.
- ✓ Depending on the type of ring (fixed or floating), choose the correct size of the porous stone. Place the ring and the specimen centrally on the saturated bottom porous stone and place the upper saturated porous stone, followed by the loading cap.
- ✓ Place the consolidometer in the loading device and attach the dial gauge. Fill the consolidometer with water, apply a seating load of 6.25 kN/m^2, and allow it to reach moisture equilibrium in 24 hours.
- ✓ Apply the first load increment and simultaneously take deformation readings at elapsed times of 0.25, 0.50, 1, 2, 4, 8, 15, 30, and 60 minutes and 2, 4, 8, and 24 hours.
- ✓ After 24 hours apply the increment load, keeping mind the fact that the applied pressure at any loading stage should be double that at the preceding stage. Apply the following loading sequence: 12.5, 50, 100, 200, 400, 800 & 1600 kN/m^2. Each time repeat Step 6.
- ✓ On completion of the final loading, unload the specimen with pressure decrements which decrease the load to one-fourth the previous load. Take dial gauge readings during each stage of unloading. If desired, the same time interval as adopted during loading may be

adopted. Keep the last unloading at a pressure of 6.25 kN/m^2 for 24 hours to minimize the swelling during disassembly.

- ✓ Remove the ring, wipe the water on the outside of the ring, and find the mass (M_3).
- ✓ After drying, weigh the specimen with the ring and find the mass (M_4).

Computations:

(a) Coefficient of consolidation

Plot dial gauge reading versus $\sqrt{t}$ or versus log t for each load increment, and find the coefficient of consolidation from the following expressions.

(i) Square root of time method: $C_V = \frac{0.848\ (H_{avg}/2)^2}{t_{90}}$

(ii) Logarithm of time method: $C_V = \frac{0.197\ (H_{avg}/2)^2}{t_{50}}$

Where, H_{avg} is the average thickness of the specimen for that load increment.

(b) **Coefficient of compressibility**

Volume of solids, $V_S = \frac{M_S}{G\ \rho_\omega}$

Where, $M_S = M_4 - M_1$

The equivalent height, $H_S = \frac{V_S}{A}$

Where, A is the area of specimen.

The void ratio e, at the end of each pressure increment, is given as, $e = \frac{H}{H_S} - 1$

Where, H is the height of specimen at the end of each pressure increment.

The coefficient of compressibility av, with units inverse of those for stress is given as, $av = \frac{\Delta e}{\Delta P}$

(c) **Compression index**

Plot the void ratio e versus log p. The slope of the straight line portion of the curve is the compression index Cc which is given as, $C_C = \frac{\Delta e}{\log_{10}(\frac{P_2}{P_1})}$

Where, P_2 and P_1 are the successive values of pressure and Δe is the change in the void ratio over the above range of pressures.

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Results:

The consolidation test results are presented in the form of the following curves:

- ✓ e versus log P
- ✓ Dial reading versus log t for different stress ranges
- ✓ Dial reading versus t for different stress ranges
- ✓ av versus log P
- ✓ C_V versus log P

Observations:

Specimen No.	**1**	**2**	**3**
Height of consolidation ring			
Diameter of consolidation ring			
Area of cross-section of consolidation ring (A)			
Mass of empty consolidation ring (M_1)			
Mass of wet soil + ring (M_2)			
Initial thickness of sample			
Initial water content			
Specific gravity of soil solids (G)			
Initial void ratio (e_0 = w G)			
Mass of wet soil + ring (after completion of consolidation) (M_3)			
Mass of dry soil + ring (M_4)			
Mass of dry soil ($Ms = M_4 - M_1$)			
Volume of soil solids ($V_S = \frac{M_S}{G\,\rho_\omega}$)			
Final water content			

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Tabular Column: Specimen – 1.

Elapsed time (min)	$\sqrt{\text{Time}}$ (min)	Dial Gauge Reading (Least count = 0.01 mm)												
		Pressure Loading (kN/m^2)									Pressure Unloading (kN/m^2)			
		6.25	12.5	25	50	100	200	400	800	1600	400	100	25	6.25
0	0.00													
0.25	0.50													
0.50	0.71													
1.00	1.00													
2.00	1.41													
4.00	2.00													
8.00	2.83													
15.00	3.87													
30.00	5.48													
60.00	7.75													
120.00	10.96													
180.00	13.42													
1440.00	37.95													

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Tabular Column: Specimen – 2.

Elapsed time (min)	$\sqrt{\text{Time}}$ (min)	Dial Gauge Reading (Least count = 0.01 mm)												
		Pressure Loading (kN/m^2)									Pressure Unloading (kN/m^2)			
		6.25	12.5	25	50	100	200	400	800	1600	400	100	25	6.25
0	0.00													
0.25	0.50													
0.50	0.71													
1.00	1.00													
2.00	1.41													
4.00	2.00													
8.00	2.83													
15.00	3.87													
30.00	5.48													
60.00	7.75													
120.00	10.96													
180.00	13.42													
1440.00	37.95													

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Tabular Column: Specimen – 3.

Elapsed time (min)	$\sqrt{\text{Time}}$ (min)	Dial Gauge Reading (Least count = 0.01 mm)												
		Pressure Loading (kN/m^2)									Pressure Unloading (kN/m^2)			
		6.25	12.5	25	50	100	200	400	800	1600	400	100	25	6.25
0	0.00													
0.25	0.50													
0.50	0.71													
1.00	1.00													
2.00	1.41													
4.00	2.00													
8.00	2.83													
15.00	3.87													
30.00	5.48													
60.00	7.75													
120.00	10.96													
180.00	13.42													
1440.00	37.95													

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Geotechnical Engineering Laboratory Viva Questions

1) What are the Residual and Transported soils?
2) Define: (i) Alluvial soils (ii) Lacustrine soils (iii) Marine soils (iv) Aeolian soils (v) Glacial soils
3) What are Volumetric ratios and Gravimetric ratio?
4) Define the following:
   (i) Void ratio, Porosity, Air content, Degree of saturation and Percentage of air voids.
   (ii) Water content or Moisture content.
   (iii) Dry density, Bulk density, Saturated density, Submerged density and soil solid density.
   (iv) Specific gravity and Mass specific gravity.
   (v) Relative density and Relative compaction.
5) Explain the various field identification tests carried out to identity the soils?
   (i) Visual examination.
   (ii) Dilatancy test.
   (iii) Toughness test.
   (iv) Dry strength.
   (v) Organic content and Colour.
6) List the Index and Engineering properties of soils? Explain their significance in soil engineering practice.
7) Explain the following with neat sketch:
   (i) Coarse grained soil and Fine grained soil.
   (ii) Well graded soil and Poorly graded soil.
   (iii) Uniformly graded soil and Gap graded soil.
   (iv) Coefficient of Uniformity and Coefficient of Curvature.
8) What is the significance of plotting the sieve analysis result on a semi-logarithmic sheet? What are the uses of grading curves?
9) Distinguish between Dry and Wet sieve analysis?
10) What is effective size? Discuss its importance?

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11) Explain the tests you conduct to distinguish between clay and silt?

12) What is Stoke's law? What are the assumptions and limitations of Stoke's law?

13) List the Atterberg's indices of soil? What their uses in soil engineering practice?

14) Define: Liquid limit, Plastic limit, Shrinkage limit, Plasticity index, Shrinkage index, Consistency index, Liquidity index, Flow index and Toughness index.

15) Define shrinkage limit. Can its value greater than liquid limit? Explain the shrinkage limit in soil engineering?

16) How do you classify the soil as per IS?

17) Explain briefly IS Plasticity chart?

18) Classification of soils:

    (i) The Unified Soil Classification System.

    (ii) AASHTO Soil Classification System.

    (iii) Textural Soil Classification System.

    (iv) Indian Standard Soil Classification System.

19) What are the methods of determining the in-situ density of soil? Discuss for what type of soil they are suitable?

20) What are Sensitivity, Activity and Thixotropy?

21) Differentiate between the following:

    (i) Compaction and Consolidation.

    (ii) Standard Proctor test and Modified Proctor test.

    (iii) Dry of optimum and Wet of optimum.

22) What is compactive effort? How does it influence the strength behaviour of soils?

23) What type of compaction equipments you adopt for compacting the following type of soils?

    (i) Clay

    (ii) Silt

    (iii) Sand

24) What are the factors influence the compaction characteristics of soil?

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25) Explain the terms: (i) Optimum moisture content (ii) Maximum dry density (iii) ZAV line (iv) Relative compaction

26) List the important uses of permeability of soil?

27) You are given a sample of clay and silt. Which one do you consider is more permeable?

28) List the various factors affecting the permeability?

29) Comment on the behaviour of the silt and clay soils on the Permeability, Shear strength and Compressibility?

30) Define the following terms:

(i) Total stress.

(ii) Effective stress.

(iii) Pore water pressure.

31) What is the effect of effective stress on strength behaviour of soils?

32) State Darcy's law for permeability of soils and mention its assumptions and limitations?

33) Define critical hydraulic gradient?

34) What boiling condition is as referred to sand?

35) What is Pre-consolidation pressure? How do you determine in the laboratory?

36) Define the following terms:

(i) Compression index.

(ii) Coefficient of compressibility.

(iii) Coefficient of volume change.

(iv) Degree of consolidation.

(v) Time rate of consolidation.

(vi) Primary consolidation settlement.

(vii) Secondary consolidation settlement.

(viii) Immediate settlement.

37) What are the assumptions made in Mohr's theory and Mohr's-Coulomb's theory?

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38) What are the shear strength parameters of soils? What are the methods of determining the shear parameters of soil in the laboratory? Mention the merits and demerits of the methods used?

39) Which are the three drainage conditions under which a shear test is conducted? When do you use this particular type of tests?

40) Explain the principle of direct shear box test?

41) What is confining pressure? What is its effect on the test results?

42) What is deviator stress? How is it affected by cell pressure?

43) Where do you use the shear strength parameters of soil in soil engineering practice?

44) What are the effective shear strength parameters of soil?

45) Differences between:

(i) Undisturbed and Disturbed soil sample.

(ii) Sample and Specimen.

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