Techno India NJR Institute of Technology

Course File

Geotechnical Engineering Lab (5CE4-22)

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Syllabus

Year - V Semester: B.Tech. (Civil Engineering)

5CE4-22: GEOTECHNICAL ENGINEERDING LAB

Credit: 1.5 | Max. Marks: 100(IA:60, ETE:40)
0L+0T+3P | End Term Exam: 3 Hours

1	Grain size distribution by sieve Analysis and Hydrometer
2	Determination of specific Gravity by Pycnometer.
3	Determination of liquid limit by Casagrande's apparatus and cone penetrometer.
4	Determination of plastic limit and shrinkage limit
5	Determination of field density by core-cutter and sand replacement method
6	Determination of compaction properties by standard Proctor Test Apparatus.
7	Determination of C-Ø values by unconfined compression Test Apparatus, Direct Shear Test Apparatus and Triaxial Test.
8	To determine the differential free swell index of soil and swelling pressure of soil.
9	To determine the CBR of soil.
10	To determine the compressibility parameters of soil by consolidation test.
11	To determine the permeability of soil by constant and falling head methods. Design as per syllabus of theory.

Office of Dean Academic Affairs
Rajasthan Technical University, Kota

Course Overview:

Geotechnical engineering is the branch of civil engineering concerned withthe engineering behavior of earth materials. Geotechnical engineering is important in civil engineering concerned with construction on or in the ground. Geotechnical engineering uses principles of soil mechanics and rock mechanics to investigate subsurface conditions and materials; determine the relevant physical/mechanical and chemical properties of these materials; evaluate; assess risks posed by site conditions; design earthworks andstructure foundations; and monitor site conditions, earthwork and foundation construction.

Course Outcomes:

CO.NO.	Cognitive Level	Course Outcome
1	**Comprehension**	Ability to identify the index properties of soils
2	**Application**	Students are able determine the field density by sand replacement method
3	**Analysis**	Capable to find all consistency limits for soil.
4	**Synthesis**	Able to impart knowledge on the various factors governing the Engineering behavior of soils and the suitability of soils forvarious Geotechnical Engineering applications
5	**Evaluation**	Able to characterize stress-strain behaviour of soils, the failure criteria and to evaluate the shear strength and compressibility Parameters of soils.

Prerequisites:

1. Fundamentals knowledge of Soil Classification.
2. Fundamentals knowledge of Geotech lab Instruments.
3. Fundamentals knowledge of Properties of Soil.

Course Outcome Mapping with Program Outcome:

Geotechnical Engineering Lab															
Course Outcome	**PO 1**	**PO 2**	**PO 3**	**PO 4**	**PO 5**	**PO 6**	**PO 7**	**PO 8**	**PO 9**	**PO1 0**	**PO1 1**	**PO12**	**PSO 1**	**PSO 2**	**PSO 3**
CO422.1	3	2	2	2	2	1	1	1	2	1	1	2	2	1	1
CO422.2	2	2	1	1	1	2	1	1	2	2	2	1	1	1	1
CO422.3	3	2	2	2	2	1	1	1	2	1	1	2	2	1	1
CO422.4	2	2	2	1	2	2	2	2	1	1	2	1	1	1	1
CO422.5	2	2	2	2	1	1	0	0	0	1	0	0	1	1	1
CO422(AVG)	2.4	2	1.8	1.6	1.6	1.4	1	1	1.4	1.2	1.2	1.2	1.4	1	1

Course Coverage Module Wise:

LabNo.	Experiments List According to RTU Syllabus
1	Grain size distribution by sieve Analysis and Hydrometer
2	Determination of specific Gravity by Pycnometer.
3	Determination of liquid limit by Casagrande's apparatus and cone penetrometer.
4	Determination of plastic limit and shrinkage limit
5	Determination of field density by core-cutter and sand replacement method
6	Determination of compaction properties by standard Proctor Test Apparatus
7	Determination of C-Ø values by unconfined compression Test Apparatus, Direct Shear Test Apparatus and Triaxial Test.
8	To determine the differential free swell index of soil and swelling pressure of soil.
9	To determine the CBR of soil.
10	To determine the compressibility parameters of soil by consolidation test.
11	To determine the permeability of soil by constant and falling head methods. Design as per syllabus of theory.

Faculty Lab Manual Link

1. https://drive.google.com/file/d/1btdIhAZkmemodx9S47L1vz6ZVjeUKB15/view?us p=sharing

Viva QUIZ Link

1. https://engineeringinterviewquestions.com/soil-mechanics-lab-viva-questions-answers/
2. https://www.sanfoundry.com/geotechnical-engineering-basic-questions-answers/
3. https://www.scribd.com/doc/213801751/Soil-Lab-Viva-Question
4. https://www.researchgate.net/topic/Geotechnical-Engineering.

Assessment Methodology:

1. Practical exam using Geotech Experiments.
2. Internal exams and Viva Conduct.
3. Final Exam (practical paper) at the end of the semester.

1. SPECIFIC GRAVITY

[A] Aim: To determine the specific gravity of a coarse grained soil sample by Pycnometer method.

Theory: Specific gravity - true specific gravity, apparent specific gravity; significance and uses.

Apparatus

- Pycnometer with a conical cap screwed at its top
- Balance, sensitive to 0.2 g
- Wash bottle with deaired, distilled water
- Glass rod, about 150 mm and 3 mm diameter
- Thermometer with 0 - 50°C range and accurate to 1°C.
- Thermostatically controlled oven.

Procedure

- Clean the Pycnometer, and dry it. Find the mass of the Pycnometer with its cap and washer, accurate to 1.0 g (M_l).
- Introduce about 400 g of oven dried coarse grained soil in to the Pycnometer. Record the mass of the Pycnometer with its cap and washer along with the soil (M_2).
- Fill the Pycnometer with distilled water to half its height, and mix it thoroughly with the soil using the glass rod. Keep the entire system aside for about 4 hrs. At the end of this period, fill the Pycnometer with water up to the top of the conical cap. Dry the Pycnometer from outside and record its mass (M_3).
- Clean the Pycnometer thoroughly. Fill it with distilled water up to the top of conical cap. Dry the Pycnometer from outside and record its mass to the nearest 0.2 g (M_4).
- Repeat the steps (2) and (3) thrice.
- Calculate the specific gravity of the soil at the room temperature as well as at 27°C.

Results and discussions:

Contd......

Observations and Calculations

Soil type: Lab. Temp. = T^0C =

Determination No.		1	2	3
1. Pycnometer No.				
2. Mass of Pycnometer (M_1)	g			
3. Mass of (Pycnometer + soil) (M_2)	g			
4. Mass of (Pycnometer + soil + water) (M_3)	g			
5. Mass of (Pycnometer + water) (M_4)	g			
6. Specific gravity				
7. Average specific gravity at lab temperature (G_T)				
8. Average specific gravity at 27^0C (G_{27})				

Note: Calculate the average of the three determinations and report it to the nearest 0.01. If the results differ by more than 0.03 from the average value, repeat the test.

Specimen calculations

i) $G_T = \dfrac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} =$

ii) Average specific gravity at 27^0C = $G_{27} = G_T \dfrac{(G_{water})_T}{(G_{water})_{27}}$

Relevant BIS Code:
IS: 2720 (Part 3 / Sec. 1) – 1980 (Reaffirmed 1987).

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[B] Aim: To determine the specific gravity of a fine-grained soil sample by density bottle method.

Apparatus

- Density bottle of approximately 50 ml capacity with stopper.
- A vacuum pump
- A vacuum desiccator
- A balance, sensitive to 0.001 g
- Wash bottle with deaired, distilled water
- Rubber tubing to connect the vacuum pump and the desiccator
- A thermometer with 0 - 50°C range and accurate to 1°C.
- A desiccator containing anhydrous silica gel.
- Thermostatically controlled oven.

Procedure

- Clean and dry the density bottle with stopper at 105°C to 110°C. Cool it in a desiccator and determine its mass to the nearest 0.001 g (M_1).
- Take about 10 g of oven dried fine-grained soil and transfer it to the density bottle directly from the desiccator in which it has been cooled. Record the mass of the density bottle with stopper and the soil to the nearest 0.001 g (M_2).
- Add de-aired, distilled water to the density bottle such that the soil is just covered with water. Place the bottle containing the soil and water without stopper in a vacuum desiccator and evacuate gradually. Allow the bottle to remain in the desiccator for at least 1 hour until no further loss of air is apparent.
- Release the vacuum. Take the bottle out of desiccator and fill it up to the calibrated mark with de-aired, distilled water.
- Wipe dry the outside of the bottle. Record the mass of the stoppered bottle containing the soil and water to the nearest 0.001 g (M_3).
- Clean the bottle thoroughly. Fill it with de-aired, distilled water up to the calibrated mark. Wipe dry the outside of the bottle. Record the mass of the stoppered bottle with water to the nearest 0.001 g (M_4).
- Repeat the steps (2) to (5) twice.
- Calculate the specific gravity of the soil sample at the room temperature and at 27°C.

Note: If any liquid other than de-aired, distilled water is used to conduct the test, then calculate the specific gravity of the soil with respect to distilled water using the following equation.

$$G_T = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} G_L \qquad \text{----- (3)}$$

where G_L = Specific gravity of the liquid used at lab temperature.

Contd......

Results and discussions:

Observations and Calculations

Soil type   Lab. Temp. = T^0C =   Liquid used in the test:

Determination No.	**1**	**2**	**3**
Density bottle No.			
Mass of Density bottle (M_1) g			
Mass of (Density bottle + soil) (M_2) g			
Mass of (Density bottle + soil + liquid) (M_3) g			
Mass of (Density bottle +liquid) (M_4) g			
Specific gravity with respect to test liquid (G_l)			
Average specific gravity with respect to test liquid at lab temperature $(G_l)_{av}$			
Average specific gravity with respect to water at lab temperature $(G_{av})_T$			
Average specific gravity at 27^0C (G_{27})			

Note: Calculate the average of the two determinations and report it to the nearest 0.01. If the two results differ by more than 0.03, repeat the tests.

Specimen calculations

i) $G_{TL} = \dfrac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$ =

ii) Specific gravity with respect to water at room temperature = G_T = G_{TL} x Specific gravity of test liquid =

iii) Average specific gravity at 27^0C = G_{27} = $G_T \dfrac{(G_{water})_T}{(G_{water})_{27}}$ =

Relevant BIS Code:
IS: 2720 (Part 3 / Sec. 1) – 1980 (Reaffirmed 1987)

2. SIEVE ANALYSIS

Aim: To determine the grain size distribution of the given soil by dry sieving.

Theory: Particle size classification of soils: IS system, MIT system, Differentiation: clay size fraction and clays; particle size distribution curves, characteristic sizes, well graded and poorly graded soils; gradation characteristics.

Apparatus

1. Set of IS sieves: 4.75mm, 2mm, 1mm, 600 micron, 425 micron, 300 micron, 212 micron, 150 micron, 106 micron, 75 micron.
2. Brushes to clean the sieves
3. Mechanical sieve shaker
4. Balance
5. Trays
6. Thermostatically controlled hot air oven

Procedure

1. Oven dry the given soil sample passing 4.75 mm IS sieve.
2. Take 200 g of oven dried soil sample. Mix the sample with distilled water to form a slurry and allow it for soaking.
3. Wash the soaked soil sample through 75 micron sieve until the water passing through the sieve is substantially clear.
4. Dry the fraction of the soil retained on 75 micron sieve in oven.
5. Arrange the remaining sieves one above the other such that 2mm sieve is at the top and 75 micron sieve is at the bottom. Place a cover at the top and receiver at the bottom.
6. Fix the set of sieves to the mechanical sieve shaker. Operate the sieve shaker for a minimum of 10 minutes.
7. Carefully collect and record the mass of the soil fraction retained on each sieve and also in the receiver.
8. Calculate the cumulative mass of soil fraction retained on each sieve. Calculate the percentage finer.
9. Plot a graph of percentage finer (along y-axis) Vs equivalent particle diameter in mm (along x-axis in log scale). Draw a smooth curve encompassing the plotted points.
10. Record the values of percentage sand, percentage silt and percentage clay size fractions from the graph.
11. Record D_{10}, D_{30} and D_{60} from the graph.
12. Calculate coefficient of curvature (C_C) and coefficient of uniformity (C_U).
13. Classify the soil based on gradation.

Results and Discussions:

Contd......

Observation and Calculations

Total mass of soil taken for analysis = M = --------------------------- g.

IS Sieve	Practical size D, mm	Mass retained m′, g	Corrected mass retained m, g	% retained	Cumulative % retained	% finer (N)
4.75mm	4.75mm					
2mm	2 mm					
1mm	1mm					
600 micron	0.6mm					
425 micron	0.425mm					
300 micron	0.3mm					
212 micron	0.212mm					
150 micron	0.15mm					
106 micron	0.106mm					
75 micron	0.075mm					
Receiver	0.075mm					
		M′ =				

Specimen Calculations

Corrected mass retained = m = m′ x $\frac{M}{M'}$ =

From the graph

1) The given soil is ____________________ grained.
2) (i) % sand = (ii) % silt = (iii) % clay size =
3) (i) D_{10} = (ii) D_{30} = (iii) D_{60} =
4) (i) Coefficient of uniformity = $C_U = D_{60} / D_{10}$ = _____________________

   (ii) Coefficient of curvature = $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ = _____________________
5) Particle size and gradation classification of the given soil: _____________________
   (reason: ____)

Relevant BIS Code:
IS 2720-Part 4, 1985

3. HYDROMETER ANALYSIS

Aim: To determine percentage silt size and clay size fractions of the given soil by hydrometer analysis.

Theory: Sedimentation analysis: Principle and assumptions made; Hydrometer analysis; Calibration of hydrometer, corrections to hydrometer readings.

Apparatus

1. Three 1000 ml capacity measuring jars
2. Hydrometer
3. Mechanical stirrer
4. Balance
5. Dispersion agents- Sodium hexa meta phosphate and sodium carbonate
6. Thermostatically controlled hot air oven
7. Stop watch

Procedure

1. Calibrate the hydrometer to be used in the test.
2. Determine the meniscus correction.
3. Take about 50 g of oven dried soil sample passing 75 μ IS sieve.
4. Subject the soil to pre-treatment to remove soluble salts or organic matter or calcium compounds, if necessary.
5. Dissolve 3.3 g of sodium hexa meta phosphate and 0.7 g of sodium carbonate in 100 ml distilled water. Transfer the solution to 1000 ml capacity jar and add distilled water to make the volume of the solution to 1000 ml (This dispersion agent solution is required for getting the composite correction).
6. Take the measured quantity of soil in a beaker. Add 100 ml of solution prepared by dissolving 3.3 g of sodium hexa meta phosphate and 0.7 g of sodium carbonate in distilled water to the beaker.
7. Warm the soil suspension gently for about 10 minutes.
8. Transfer the soil suspension to the cup of a mechanical stirrer using about 100 ml of distilled water. Stir the suspension for about 15 minutes.
9. Transfer the stirred soil suspension to another 1000 ml capacity measuring jar. Add distilled water to the suspension to make its volume to 1000 ml.
10. Place suitable covers on the top of the two 1000 ml measuring jars – one containing the dispersion agent solution and the other containing the soil suspension. Shake the contents in the two jars vigorously and place them slowly on a level platform. Start a stop watch immediately.
11. Insert the hydrometer in to the jar containing the soil suspension slowly and allow it to float freely.

Contd….

12. Note down the hydrometer readings corresponding to upper meniscus after suitable time intervals or note down the time intervals corresponding to well defined hydrometer readings.
13. After 4 minutes reading, take out the hydrometer from the jar, rinse it with distilled water and allow it to stand in another 1000 ml jar containing distilled water.
14. Insert the hydrometer in to the jar containing soil suspension from time to time and note down the hydrometer readings and corresponding time intervals. After removing the hydrometer from the jar each time, rinse it with distilled water and store it in the jar containing distilled water.
15. Record the temperature of the soil suspension and the composite correction in the beginning of the test and also after each time the hydrometer reading is taken beyond 15 minutes period

Note: Recording of composite correction: Insert the hydrometer in to the 1000 ml jar containing the dispersion agent solution; allow it to float freely; note down the hydrometer reading corresponding to upper meniscus. Record the negative of this reading as the composite correction.

16. Calculate the equivalent diameter of the soil particles corresponding to the noted time intervals (D) and also the corresponding values of percentage finer based on the dry mass of the soil sample taken for the test (N') and based on the total mass of the dry soil sample taken for the grain size analysis(N).
17. Carry out the test till the equivalent diameter of the particles is less than 2 μm.
18. Using the values of equivalent diameter of the particles (D) and the values of corresponding percentage finer (N), plot the grain size distribution curve. From the plotted curve, note down the percentage of silt size and clay size fractions present in the soil.

Results and Discussions:

Specimen Calculations

1. $D = 17.487\sqrt{\frac{\mu}{(G-1)}}\sqrt{\frac{H_e}{t}}$ = --------------------------- mm

   Note: In the above equation, substitute H_e in cm, t in minutes and μ in kPa-s.

2. $N' = \frac{100G}{M_d(G-1)}R$ = --------------------------- %
3. $N = N' \times \frac{M'}{M}$ = --------------------------- %

Relevant BIS Code:
IS 2720-Part 4, 1985

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Observations and Tabulation

1. Soil:
2. Mass of total dry soil taken for the analysis (M) = --------------------------- g
3. Mass of the dry soil fraction passing 75 μ sieve (M') = --------------------------- g
4. Mass of the dry soil sample taken for the test (M_d) = --------------------------- g
5. Specific gravity of soil solids passing 75 μ sieve (G) = ---------------------------
6. Hydrometer No.:
7. Meniscus correction (C_m) = ---------------------------
8.

Date	Time	Elapsed time (t)	Hydrometer reading (R_h')	Temperature	Composite correction (C)	$R_h = R_h' + C_m$	Effective depth (H_R)	D	$R = R_h'+C$	% finer based on M'	% finer based on M
		Minutes		°C			cm	Mm			

4. ATTERBERG LIMITS OF FINE-GRAINED SOIL

A) Aim: To determine the liquid limit of the soil using Casagrande liquid limit apparatus with soft base.

Theory: Definitions: Liquid limit, Plastic limit, Shrinkage limit, Plasticity index, Consistency index, Liquidity index, Toughness index, Flow index; Applications of Atterberg limits.

Apparatus

1. Casagrande liquid limit apparatus
2. Casagrande grooving tool of standard dimensions (Type A)
3. Glass plate, 10 mm thick and about 45 cm square
4. Spatula
5. Balance, sensitive to 0.01 g
6. Thermostatically controlled hot air oven
7. Airtight and non-corrodible containers for moisture content determination.
8. Wash bottle containing distilled water.
9. 425 micron IS sieve.

Procedure

1. Using the gauge on the handle of the grooving tool or a separate gauge, adjust the height through which the cup of the Casagrande apparatus is lifted and dropped so that the point on the cup which comes in content with the base falls through exactly one centimeter for one revolution of the handle. Then, tighten the adjustment screws.
2. Take about 120 g of soil sample passing through 425 micron IS sieve and mix it thoroughly with distilled water on the glass plate to form uniform paste. Allow sufficient time to ensure uniform moisture distribution throughout the soil mass.
3. Remix the soil thoroughly. Take a portion of the soil paste with the spatula and place it in the central portion of the cup and spread it into position with the spatula so that the soil surface is parallel to the rubber base with the maximum depth of the soil as 1.0 cm at the centre.
4. With the help of the grooving tool, divide the soil paste in the cup along the diameter of the cup (through the centre line of the cam follower) to get a clean, sharp groove of proper dimensions.
5. Turn the handle of the apparatus at a rate of 2 revolutions per second until the two parts of the soil paste come in contact at the bottom of the groove for a distance of about 12 mm and record the number of revolutions to achieve this.
6. Collect a representative sample of the soil by moving the spatula normal to the groove, width wise from the portion of the groove where the soil flowed together and put it in a container and determine its water content by oven drying method.

Contd......

7. Transfer the remaining soil in the cup back on to the glass plate. Dry the soil by kneading the wet soil using spatula.
8. Repeat the steps 3 to 6 to get a minimum of 5 trials. The trials are conducted such that the number of blows is in the range 25 ± 10.
9. Plot a "flow curve" on a semi-log sheet with water content on y-axis (arithmetic scale) and number of blows on x-axis (log scale). Draw a well defined straight line through the points. Record the moisture content corresponding to 25 blows and round off to the nearest whole number and report it as the liquid limit of the soil. Measure the slope of the line, which represents the flow index (I_f).

Observations and Calculations

Soil: Period of soaking before the test:

Determination No.		1	2	3	4	5
Number of blows						
Container No.						
Mass of the (container + wet soil)	g					
Mass of the (container + dry soil)	g					
Mass of water	g					
Mass of container	g					
Mass to dry soil	g					
Moisture content (w)	%					

From the flow curve:

i) Liquid limit of the soil = w_L = ________________

ii) Flow index = $I_f = \dfrac{(w_2 - w_1)}{\log_{10}\left(N_2/N_1\right)}$ = ________________

Relevant BIS Code:

IS: 2720, Part-5, 1985

Contd......

B) Aim: To determine the plastic limit of the soil sample and to calculate plasticity index, Toughness index of fine-grained soil.

Apparatus

1. Flat glass plate, 10 mm thick and about 45 cm square.
2. Spatula
3. Balance, sensitive to 0.01 g
4. Thermostatically controlled oven
5. Airtight and non-corrodible containers for moisture content determination.
6. Wash bottle containing distilled water
7. 425 mircon IS sieve
8. 3 mm diameter rod of about 10 cm length.

Procedure

1. Take about 20 g of soil sample, passing 425 micron IS sieve. Mix it on the glass plate with sufficient distilled water to make it plastic enough to be shaped into a ball. Allow the soil to stand for sufficient time to ensure uniform distribution of moisture throughout the soil mass.
2. With about 8 g of soil so prepared, make a ball and roll it on the glass plate with hand, with pressure just sufficient to roll the soil mass into a thread of uniform diameter throughout its length. When the diameter of the thread reaches 3 mm, kneed the soil together to a uniform mass and once again roll it. Continue the process until the soil thread just crumbles at 3mm diameter.
3. Collect the crumbled soil threads in a container and determine the corresponding water content by oven drying method.
4. Repeat the test to have three trials.
5. Report the average water content rounded off to the nearest whole number as the plastic limit of the soil.

Observations and Calculations

Determination No.		1	2	3
Container No.				
Mass of (container + wet soil)	g			
Mass of (container + dry soil)	g			
Mass of water	g			
Mass of container	g			
Mass of dry soil	g			
Water content (w)	%			
Plastic limit (w_P)	%			

Contd......

Calculations

Plasticity index = Ip = w_L - w_p

Toughness index = $I_T = I_p / I_f$ =

Soil classification:

Relevant IS Code:

IS: 2720, Part-5, 1985

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C) Aim: To determine the shrinkage characteristics of fine-grained soil.

Apparatus

1. Evaporating dish of porcelain, about 12 cm in dia with a pour out and flat bottom.
2. Shrinkage dish with a flat bottom, 45 mm in dia and 15 mm height internally.
3. Glass cup of 50 mm dia and 24 mm height.
4. Plain glass plate of dimensions 75 mm x 75 mm x 3 mm.
5. Pronged glass plate of dimensions 75 mm x 75 mm x 3 mm with three prongs fixed to the plate at 120^0 from each other and spacing of 30 mm center to center.
6. spatula
7. straight edge
8. 425 micron IS sieve
9. Balance, sensitive to 0.1 g to 0.01 g.
10. Thermostatically controlled hot air oven
11. Wash bottle containing distilled water
12. Desiccator
13. Mercury

Note: Instead of glass instruments, instruments made of Perspex may be used to avoid damage to the glass instruments.

Procedure

1. Determine the mass of the clean, empty shrinkage dish. Fill the shrinkage dish to overflowing with mercury. Remove the excess by pressing the plain glass plate firmly over the top of the dish. Record the mass of the mercury in the shrinkage dish. This mass when divided by the unit mass of mercury gives the volume of the dish which itself represents the volume of the wet soil mass to be placed in the shrinkage dish.
2. Take about 100 gm of soil sample passing 425 micron IS sieve.
3. Place about 30 g of soil in evaporating dish and mix it thoroughly with distilled water such that all the soil voids are completely filled and the soil becomes pasty enough to be readily worked into the shrinkage dish without entrapping air bubbles. The water content of the soil paste shall be approximately equal to the liquid limit of the soil.
4. Coat the inside surface of the shrinkage dish with a thin layer of silicon grease to prevent the adhesion of the soil to the dish. Fill the shrinkage dish by well mixed soil paste to one third its volume and tap it on a firm cushioned surface. Place some more soil and repeat this process until the paste is thoroughly compacted and all included air has been removed. When the dish is completely filled up, strike off the excess soil paste with a straight edge and wipe off all the soil paste adhering to the outside surface of the shrinkage dish.

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5. Record the mass of the shrinkage dish with the wet soil mass in it. Allow the soil pat to dry in air until the colour of the pat turns from dark to light, which may take one day to about a week depending upon the type of soil. Then, dry the pat in an oven to constant mass. Cool it in a desiccator and record the mass of the shrinkage dish with the dry soil pat immediately.
6. Fill the glass cup to overflowing with mercury and remove the excess by pressing the glass with three prongs. Place the cup with mercury in the evaporating dish without spilling any mercury from the cup. Place the oven dried soil pat on the surface of the mercury in the cup. Then, carefully force the pat into the mercury by means of glas plate with prongs. Collect the displaced mercury and record its mass. Determine its volume, which itself represents the volume of the dry soil pat.
7. Conduct three trials for each soil and report the average value of the shrinkage limit. If any individual value varies from the average by ± 2 %, discarded the test results and repeat the test.

Results and Discussions

Soil:

Liquid Limit (w_L)	Plastic limit (w_p)	Plasticity index (I_p)	Flow index (I_f)	Toughness index (I_T)	Shrinkage limit (w_s)	Shrinkage ratio (R)	Volumetric shrinkage (V_s)

Observations and Calculations:

Soil:

Determination No.			**1**	**2**
(a) Determination of water content of wet soil pat:				
1.	Shrinkage dish number			
2.	Mass of Shrinkage dish	g		
3.	Mass of (Shrinkage dish + wet soil pat)	g		
4.	Mass of (Shrinkage dish + dry soil pat)	g		
5.	Mass of dry soil pat (M_d)	g		
6.	Mass of water (M_w)	g		
7.	Water content of the soil (w)	Ratio		

Contd......

(b) Determination of volume of wet soil pat:			
1.	Glass cup number		
2.	Mass of glass cup with the mercury filling the shrinkage dish g		
3.	Mass of the glass cup g		
4.	Mass of the mercury filling the shrinkage dish (M_1) g		
5.	Volume of the wet soil mass (V) cm^3		
(c) Determination of volume of the dry soil pat:			
1.	Mass of the glass cup with mercury displaced by the dry soil pat. g		
2.	Mass of mercury displaced by the dry soil pat (M_2) g		
3.	Volume of dry soil pat (V_d) cm^3		
(d) Results:			
1.	Shrinkage limit (w_s) %		
2.	Shrinkage ratio (R) g/cm^3		
3.	Volumetric shrinkage (V_s)		

Calculations

i) Water content of the soil = $w = \frac{\text{Mass of water}}{\text{Mass of dry soil pat}} = \frac{M_w}{M_d} =$ ________________

ii) Volume of wet soil mass = $V = \frac{\text{Mass of the mercury filling the shrinkage dish}}{13.6} = \frac{M_1}{13.6} =$

iii) Volume of dry soil mass = $V_d = \frac{\text{Mass of the mercury displaced by dry soil pat}}{13.6} = \frac{M_2}{13.6} =$

iv) Shrinkage limit = $w_s = \left[w - \left(\frac{V - V_d}{M_d} \right) \rho_w \right] 100 =$

v) Shrinkage ratio = $R = \frac{M_d}{V_d} =$

vi) Volumetric shrinkage = $V_s = (w - w_s)R =$

Relevant BIS Code:
IS: 2720, Part-6, 1972 (Reaffirmed 1978).

5. LIQUID LIMIT OF SOIL

Aim: To determine the liquid limit of fine-grained soil using cone penetrometer (i.e., fall cone apparatus).

Apparatus
1. Cone penetrometer
2. Marble plate or glass plate
3. Spatula
4. Balance
5. Thermostatically controlled hot air oven
6. Containers for moisture content determination.
7. Wash bottle containing distilled water.
8. 425 micron IS sieve.

Procedure
1. Take about 250 g of soil sample, passing through 425 micron IS sieve and mix it thoroughly with distilled water on the glass plate to form uniform paste. Allow sufficient time for soaking of the soil so as to ensure uniform distribution of moisture throughout the soil mass.
2. Remix the soil thoroughly. Transfer the wet soil into the cylindrical cup of the cone penetrometer apparatus, ensuring that no air is entrapped within the soil mass during this process. The top surface of the wet soil mass is levelled off corresponding to the top of the cup.
3. Place the cup filled with soil on the base of the cone penetrometer apparatus. Adjust the penetrometer such that the tip of the cone just touches the top surface of the soil in the cup. The initial reading of the dial is adjusted to zero.
4. Release the cone allowing it to penetrate into the soil past under its own weight for five seconds. Note down the penetrometer reading to the nearest first decimal of a millimeter.
5. Collect a representative sample of the soil from the cup and determine its moisture content by the oven drying method.
6. Repeat the steps 2-5 to get at least 4 to 5 sets of penetrometer values in the range 14 mm – 28 mm.
7. Plot a graph of water content along y-axis and cone penetration along x-axis. Draw a the best fit straight line through the points plotted. Record the moisture content corresponding to a cone penetration of 20 mm as the liquid limit water content. Report the value to nearest first decimal place of a millimeter.

Results and Discussions

Contd…..

Observations and calculations

Soil: Period of soaking before the test:

Determination No.	1	2	3	4	5
Depth of Penetration mm					
Container No.					
Mass of the container + wet soil g					
Mass of the container + dry soil g					
Mass of container g					
Mass of water g					
Mass of dry soil g					
Moisture content %					
From the graph:	Liquid limit = w_L =				

Relevant BIS Code:
IS: 2720 (Part–5) – 1985

6. *In situ* DRY DENSITY

A) Aim: To determine the dry density of the soil *in-situ* by core cutter method.

Theory: Field dry density and field moisture content – practical significance; methods of determining them. Core cutter method – practical significance.

Apparatus

1. Cylindrical core cutter of steel, 127.4 mm long and 100 mm internal diameter with a wall thickness of 3 mm, bevelled at one end.
2. Steel dolly, 25 mm high and 100 mm internal diameter with a wall thickness of 7.5 mm, with a lip to enable it to be fitted on the top of the core-cutter.
3. Steel rammer
4. Knife
5. Grafting tool or pickaxe or spade
6. Straight edge
7. Balance accurate to 1g
8. Containers for water content determination.
9. Thermostatically controlled hot air oven.

Procedure

1. Measure the inner dimensions of the core cutter and calculate its volume. Determine the mass of the core cutter (without dolly) accurate to 1 g. Oil the inside surfaces of the core cutter and the dolly.
2. Level the area where the in-situ density of the soil is required to be measured. Keep the dolly on the top of the core cutter and drive the assembly in to the soil with the help of the rammer until the top of the dolly protrudes about 1.5 cm above the surface.
3. Dig out the core cutter along with the dolly from the surrounding soil such that some soil projects from the lower end of the core cutter. Take out the dolly, and trim the soil mass at both the ends of the core cutter.
4. Determine the mass of the core cutter with the soil.
5. Determine the water content of the soil by oven drying method.
6. Repeat the test at two or three locations nearby for the average result.

Results and Discussions

Contd......

Observations and Calculations

(a) Determination of in-situ bulk density of the soil:

Determination No.			
1. Inside diameter of the core cutter (d)	cm		
2. Inside height of the core cutter (h)	cm		
3. Volume of the core cutter (V)	cm^3		
4. Mass of the core cutter	g		
5. Mass of the (core cutter + wet soil)	g		
6. Mass of the wet soil (M)	g		
7. Bulk density of the soil (ρ_b)	g/cm^3		

(b) Determination of filed water content:

1. Container No.			
2. Mass of the container	g		
3. Mass of the (container + wet soil)	g		
4. Mass of the (container + dry soil)	g		
5. Mass of the dry soil (M_d)	g		
6. Mass of water (M_w)	g		
7. Water content (w)	(Ratio)		

(c) Determination of in-situ dry density of the soil:

1. Dry density (ρ_d)	g/cm^3		
2. Average dry density $(\rho_d)_{av}$	g/cm^3		

Specimen Calculations

1. Volume of the core cutter = V = $\frac{\pi}{4} d^2 h$ =
2. In-situ bulk density of the soil = $\rho_b = M / V$
3. In-situ water content of the soil = $w = M_w / M_d$ =
4. In-situ dry density = $\rho_d = \frac{\rho_b}{(1 + w)}$ =

Relevant BIS Code:
IS: 2720-Part 27, 1975

Contd......

B) Aim: To determine the dry density of the soil *in-situ* by sand replacement method:

Theory: Sand replacement method of determining *in situ* dry density - practical significance.

Apparatus

1. Sand pouring cylinder with a pouring cone at its bottom separated from it by a shutter.
2. Cylindrical calibrating container, 100 mm internal diameter and 150 mm internal depth, with a flange.
3. Glass plate, about 45cm square and 1cm thick.
4. Metal tray with a central circular hole of diameter equal to the diameter of the sand pouring cone at its outlet.
5. Tools for excavating the hole.
6. Balance accurate to 1g.
7. Containers for water content determination.
8. Thermostatically controlled hot air oven.
9. Clean, uniformly graded natural sand passing the 600 micron IS sieve and retained on the 300 micron IS sieve.

Procedure

(a) Determination of the Bulk density of the sand:

1. Fill the sand in the sand pouring cylinder up to a height 1cm below the top. Determine the total initial mass of the cylinder with the sand (M_1), which is to be maintained constant throughout the test.
2. Keep the cylinder on a glass plate. Open the shutter and allow the sand to run out. Close the shutter when no movement of sand is observed. Remove the cylinder and record the mass of the sand collected on the glass plate (M_2). This represents the mass of the sand filling the cone portion of the sand pouring cylinder. Place the sand back into the cylinder to maintain the constant mass M_1.
3. Measure the inner diameter and height of the calibrating container and hence, determine the volume of the calibrating container.
4. Place the cylinder with sand concentrically on the top of the container. Open the shutter, and allow the sand to the run into the container. Close the shutter when no further movement of sand is observed. Remove the cylinder and record its mass along with the remaining sand (M_3). Put the sand back into the container to maintain the constant mass M_1.
5. Calculate the density of sand in the cylinder.

Contd......

(b) Determination of the dry density of the soil in-situ:

1. Level the surface where the in-situ density of the soil is required to be determined. Keep the metal tray on the level surface and excavate a circular hole of about 15 cm deep. Collect the excavated soil in the tray. Immediately record the mass of the excavated soil (M), and keep some soil for moisture content determination.
2. Remove the tray and place the cylinder with sand on the excavated hole. Open the shutter, and allow the sand to run into the hole. When the no further movement of the sand is seen, close the shutter. Determine the mass of the cylinder with the remaining sand in it (M_4).
3. Determine the bulk density, field water content and field dry density of the soil.

Results and Discussions

Observations and Calculations

(a) Determination of the bulk density of sand:

1.	Inside diameter of the calibrating container (d)	cm	=
2.	Inside height of the calibrating container (h)	cm	=
3.	Volume of the calibrating container (V_c)	cm^3	=
4.	Mass of the (sand + cylinder) before pouring (M_1)	g.	=
5.	Mass of the sand in the cone (M_2)	g.	=
6.	Mass of the (sand + cylinder), after pouring into the calibrating container (M_3)	g.	=
7.	Mass of the sand, filling the calibrating container (M_{sand}) = ($M_1 - M_3 - M_2$)	g.	=
8.	Bulk density of the sand (ρ_s) = (M_{sand} / V_c)	g/cm^3	=

(b) Determination of the bulk density of the soil in-situ:

1.	Mass of the wet soil excavated from the hole (M)	g.	=
2.	Mass of (sand + cylinder) after pouring into the hole (M_4)	g.	=
3.	Mass of sand in the hole (M_h) = (M_1- M_4 - M_2)	g.	=
4.	Volume of the hole (V)	cm^3	=
5.	Bulk density of the soil in-situ (ρ_b)	g/cm^3	=

Contd......

(c) Determination of the field water content and in-situ dry density of the soil:

1. Container No.			
2. Mass of the container	g		
3. Mass of the (container + wet soil)	g		
4. Mass of the (container + dry soil)	g		
5. Mass of the dry soil (M_d)	g		
6. Mass of water (M_w)	g		
7. Water content (w)	(Ratio)		
8. Dry density (ρ_d)	g/cm^3		

Specimen Calculations

1. Bulk density of sand $= \rho_{sand} = \frac{M_{sand}}{V_C} =$
2. Volume of the hole $= V = \frac{\text{Mass of the sand in the hole}}{\rho_{sand}} =$
3. Bulk density of soil in-situ $= \rho_b = M / V =$
4. Water content $= w = M_w / M_d =$
5. In-situ dry density of the soil $= \rho_d = \frac{\rho_b}{(1 + w)} =$

Relevant BIS Code:
IS: 2720-Part 28, 1974

7. FREE SWELL TESTS

Aim: To determine the **swell potential** of fine-grained soil and its dominant clay mineralogical composition.

Theory: Free swell tests: Free swell index, Free swell ratio of fine-grained soils – definitions and their significance.

Useful Information

Table 1: Expansive soil classification based on IS: 1498 (1970)

Degree of expansivity / Swell Potential	FSI (%)
Low	< 50
Medium/Marginal	50 – 100
High	100 – 200
Very High	> 200

Table 1: Expansive soil classification based on FSR (Sridharan and Prakash 2000)

Free swell ratio	Clay type	Degree of soil expansivity	Dominant clay mineral type
≤ 1.0	Non-swelling	Negligible	Kaolinitic
1.0 – 1.5	Mixture of swelling and non-swelling	Low	Mixture of Kaolinitic and Montmorillonitic
1.5 – 2.0	Swelling	Moderate	Montmorillonitic
2.0 – 4.0	Swelling	High	Montmorillonitic
> 4.0	Swelling	Very High	Montmorillonitic

Apparatus

1. 425 μm IS sieve
2. Measuring jars of capacity 100 ml (2 nos.)
3. Distilled water and kerosene

Procedure

- Take two samples of 10 g each of oven dried soil passing 425 μm IS sieve in two 100 ml measuring jars separately.
- Add distilled water to one of these two jars to make up the volume to 100 ml and add kerosene to the other jar to make up the volume 100 ml.
- Mix the contents in the two jars separately & thoroughly and keep them undisturbed for the soil samples in them to settle freely.
- After 24 hours, note down the equilibrium sediment volumes of the soils in the jars containing distilled water (V_d) and kerosene (V_k).
- Calculate the free swell index and free swell ratio of the given fine-grained soil.
- Classify the swell potential of the given fine-grained soil and predict its dominant clay mineralogical composition.

Contd......

Results and Discussions

Observations and Calculations

1. Soil:
2. Dry weight of the soil taken =
3. Equilibrium sediment volume in distilled water (V_d) =
4. Equilibrium sediment volume in kerosene (V_k) =
5. Free swell index = $FSI = \frac{V_d - V_k}{V_k}$ =
6. Free swell ratio = $FSR = \frac{V_d}{V_k} =$
7.

	Based on FSI	Based on FSR
Swell potential		
Dominant soil clay mineralogy	–	

References

- IS: 1498 (1970)
- IS: 2720 – Part 40 (1977)
- Sridharan, A., and Prakash K. (2000), "Classification procedures for expansive soils", *Proceedings of ICE: Geotechnical Engineering,* 143, pp. 235-240.

8. PERMEABILITY TESTS

A) Aim: To determine the coefficient of permeability of the given soil sample by constant head permeability test.

Theory: Permeability; Darcy's law; Coefficient of permeability; Laboratory methods of determining the coefficient of permeability – merits and limitations; Practical applications of coefficient of permeability.

Apparatus
1. Permeameter with all accessories
2. De-aired water
3. Balance, sensitive to l g.
4. Mixing pan
5. Stop watch
6. Graduated measuring cylinder
7. Thermometer with 0^o – 50^oC range and accurate to 1^oC.
8. Trimming knife
9. 4.75mm and 2mm IS sieves.

Procedure
1. Measure the inner diameter (D) and inner height (H) of the permeameter.
2. Note down the temperature of water.
3. Place the permeameter assembly containing the soil specimen in the bottom tank, and fill the tank with water up to its outlet.
4. Connect the outlet tube of constant head tank to the inlet nozzle of the permeameter. Remove the air-bubbles in the system, if any.
5. Maintain a constant water head in the constant head tank. Allow the water to flow through the soil sample till a steady state of flow is reached.
6. Once the discharge through the permeameter becomes steady, collect the discharge for a convenient time interval and measure the quantity of water collected.
7. Repeat the test thrice, with the same constant head and time interval.
8. Calculate and report the value of coefficient of permeability at T^oC and 27^oC.

Results and Discussions:

Contd......

Observations and Calculations

Types of Soil: ____

1. Constant hydraulic head (H) = ----------------------cm
2. Length of the specimen (L) = ----------------------cm
3. Hydraulic gradient (i) = H/L = ----------------------
4. Diameter of the specimen (D) = ----------------------cm
5. Cross sectional area of the specimen (A) = ----------------------cm^2
6. Time interval (t) = ----------------------s
7. Quantity of flow (V): --------------ml (Trial 1)
   (in time interval t) --------------ml (Trial 2)
   --------------ml (Trial 3)

   V_{av} = --------------ml.
8. Test temperature (T) = --------------^{0}C.
9. Coefficient of permeability (K_{27}) = --------------cm/s.

Calculations

i) Coefficient of permeability at test temperature (k_T) = $\frac{V_{av} L}{HAt}$ = --------------------cm/s

= -------------------- mm/s

ii) Coefficient of permeability at 27°C (k_{27}) = $k_T \frac{\mu_T}{\mu_{27}}$ = --------------------mm/s

where, μ_T = Viscosity of water at test temperature

μ_{27} = Viscosity of water at 27^0C

Relevant BIS Code:

IS: 3720, Part-17, 1986

Contd......

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

Procedure

1. Measure the inner diameter (D) and inner height (H) of the permeameter.
2. Measure the area of cross section of the stand pipe.
3. Note down the temperature of water.
4. Place the permeameter assembly in the bottom tank, and fill the tank with water upto its outlet.
5. Connect the water inlet nozzle of the mould to the stand pipe filled with water. Allow the water to flow through the soil sample for some time till a steady state of flow is reached.
6. With the help of stop watch, note the time interval required for the water level in the stand pipe to fall from a convenient initial head (h_1) to a convenient final head (h_2).
7. Repeat the test thrice with the same initial and final heads.
8. Calculate and report the value of coefficient of permeability at T^{o}C and at 27^{o}C.

Results and Discussions

Observations and Calculations

Types of Soil: ____

1. Diameter of the stand pipe (d) = ----------------------cm
2. Area of cross section of the stand pipe (a) = ----------------------cm^2
3. Diameter of the soil specimen (D) = ----------------------cm
4. Length of the soil specimen (L) = ----------------------cm
5. Area of cross section of the soil specimen (A) = ----------------------cm^2
6. Initial Head (h_1) = ----------------------cm
7. Final Head (h_2) = ----------------------cm
8. Time interval (t): -------------- s (Trial 1)
   -------------- s (Trial 2)
   -------------- s (Trial 3)
   Average time interval = t_{av} = ------------ s
9. Test Temperature (T) = ----------------------^{o}C
10. Coefficient of permeability at test temperature (k_T) = ----------------------cm^2
11. Coefficient of permeability (k_{27}) = ----------------------cm/s

Contd......

Specimen Calculations

i) Coefficient of permeability at test temperature (k_T) = $\frac{aL}{At_{av}} \log_e\left(\frac{h_1}{h_2}\right)$

= ---------------------cm/s

= ---------------------mm/s

ii) Coefficient of permeability at 27°C (k_{27}) = $k_T \frac{\mu_T}{\mu_{27}}$ = --------------------mm/s

where, μ_T = Viscosity of water at test temperature

μ_{27} = Viscosity of water at 27^0C

Relevant BIS Code:
IS: 3720, Part-17, 1986

9. COMPACTION TESTS

A) Aim: To determine the water content – dry density relationship for a given soil by Indian Standard light compaction test and hence, to obtain optimum moisture content and maximum dry density for the given soil.

Theory: Definition of compaction; necessity of compacting the soil in the field; standard Proctor and modified Proctor compaction tests (and their Indian Standard versions); compaction curves; optimum moisture content and maximum dry density; zero air voids line; line of optimum; factors affecting compaction.

Apparatus

1. A cylindrical metal mould of capacity 1000 cm^3, with an internal diameter of 100 mm and an internal affective height of 127.3 mm. The mould is fitted with a detachable base plate and a removable extension collar approximately 60 mm high.
2. A metal rammer of 50 mm diameter with a circular face and mass 2.6 kg with a free fall of 310 mm.
3. A steel straight edge about 30 cm in length and with one beveled edge.
4. 4.75 mm I.S. sieve
5. Balance – (a) with a capacity of 10 kg and accuracy of 1 g
   (b) with a capacity of 200 g and accuracy of 0.01 g
6. Thermostatically controlled hot air oven.
7. Airtight and non-corrodible containers for water content determination
8. Mixing tools like tray, trowel and spatula.

Procedure

1. Measure the inner diameter and inner height of the cylindrical mould and hence, calculate the volume of the mould. Compare them with standard values.
2. Take about 3 kg of air dried soil passing 4.75mm IS sieve and mix it with a suitable amount of water depending on the soil type (For sandy and gravelly soils, an initial moisture content of 4 to 6% and for cohesive soils, an initial moisture content of (w_P-10)% to (w_P-8)% would be suitable, where w_P is the plastic limit of the soil). Keep the soil in a sealed container for saturation for a minimum period of about 16 hrs.
3. Clean the mould with the base plate and record its mass. Attach the collar to the mould. Place it on a solid base such as concrete floor.

Contd......

4. Remix the soil thoroughly. Compact the moist soil in to the mould, with the collar attached, in three equal layers, each layer being given 25 blows from a 2.6 kg rammer dropped from a height to 310mm above the soil surface. The blows should be uniformly distributed over the surface of each layer. The surface of each layer of the compacted soil shall be roughened with a spatula before laying the next layers. The final layer shall project not more than 6 mm above the top of the mould after the collar is removed.
5. Remove the collar and level off the compacted soil surface to the top of the mould carefully. Then, record the mass of the mould with the base plate and compacted soil.
6. Remove the compacted soil specimen from the mould and place it on the mixing tray. Keep a representative soil sample of the specimen for water content determination.
7. Mix the remaining soil with the reminder of the originally mixed soil in the tray. Add water in suitable increments to the soil sample and mix the soil thoroughly and repeat the above procedure.
8. Conduct a minimum of 5 determinations such that the optimum moisture content lies within this range.
9. Plot the Indian Standard light compaction curve (w % along x-axis and ρ_d along y-axis). Obtain OMC and $\rho_{d\,max}$ from the plotted curve. Plot also the ZAV line.

Results and Discussions

Observations and Calculations

1. Type of soil:
2. Specific gravity of the soil:
3. Diameter of the mould (D) = -- cm
4. Height of the mould (H) = -- cm
5. Volume of the mould (V) = -- cm
6. Mass of the rammer = 2.6 kg
7. Free fall of the rammer = 310 mm

Contd......

TABLE - I

Determination No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
(a) Determination of Bulk Density:										
1. Mass of the (mould + Compacted soil) g										
2. Mass of mould g										
3. Mass of compacted soil (M) g										
4. Bulk density (ρ_b) g/cm^3										

(b) Determination of water content and dry density of the soil:										
1. Container No.										
2. Mass of (container + wet soil) g										
3. Mass of (container + dry soil) g										
4. Mass of water g										
5. Mass of container g										
6. Mass of the dry soil g										
7. Water content (w) Ratio										
8. Dry density (ρ_d) g/cm^3										

Specimen Calculations

1. Bulk density = $\rho_b = \dfrac{\text{Mass of compacted wet soil}}{\text{Volume of the mould}} = \dfrac{M}{V}$ = ---------------------------- g/cm^3
2. Water content = w = $\dfrac{\text{Mass of water}}{\text{Mass of dry soil}}$ = ------------------------------------ %
3. Dry density = $\rho_d = \dfrac{\rho_b}{(1+w)}$ = ---------------------------------- g/cm^3

To plot ZAV line

$(w)_{ZAV}$ Ratio						
$(\rho_d)_{ZAV}$ g/cm^3						

Specimen Calculation

$(\rho_d)_{ZAV} = \dfrac{G\rho_w}{\{1+(w)_{ZAV}\,G\}}$ = ---------------------------------- g/cm^3

Relevant BIS Code:

- IS: 2720, Part-7, 1980 (Reaffirmed 1987)
- IS: 9198, 1979 (Reaffirmed 1987)
- IS: 10074, 1982

Contd......

B) Aim: To determine the water content – dry density relationship for a given soil by Indian Standard heavy compaction test and hence, to obtain optimum moisture content and maximum dry density for the given soil.

Apparatus

1. A cylindrical metal mould of capacity 1000 cm^3, with an internal diameter of 100 mm and an internal affective height of 127.3 mm. The mould is fitted with a detachable base plate and a removable extension collar approximately 60 mm high.
2. A metal rammer of 50 mm diameter with a circular face and mass 4.9 kg with a free fall of 450 mm.
3. Steel straight edge about 30 cm in length and with one beveled edge.
4. 4.75 mm I.S. sieve
5. Balance – (a) with a capacity of 10 kg and accuracy of 1 g
   (b) with a capacity of 200 g and accuracy of 0.01 g
6. Thermostatically controlled hot air oven.
7. Airtight and non-corrodible containers for water content determination
8. Mixing tools like tray, trowel and spatula.

Procedure

1. Measure the inner diameter and inner height of the cylindrical mould and hence, calculate the volume of the mould. Compare them with standard values.
2. Take about 3 kg of air dried soil passing 4.75mm IS sieve and mix it with a suitable amount of water depending on the soil type (For sandy and gravelly soils, an initial moisture content of 4 to 6% and for cohesive soils, an initial moisture content of (w_p-10)% to (w_p-8)% would be suitable, where w_p is the plastic limit of the soil). Keep the soil in a sealed container for saturation for a minimum period of about 16 hrs.
3. Clean the mould with the base plate and record its mass. Attach the collar to the mould. Place it on a solid base such as concrete floor.
4. Remix the soil thoroughly. Compact the moist soil in to the mould, with the collar attached, in five equal layers, each layer being given 25 blows from a 4.9 kg rammer dropped from a height to 450 mm above the soil surface. The blows should be uniformly distributed over the surface of each layer. The surface of each layer of the compacted soil shall be roughened with a spatula before laying the next layers. The final layer shall project not more than 6 mm above the top of the mould after the collar is removed.
5. Remove the collar and level off the compacted soil surface to the top of the mould carefully. Then, record the mass of the mould with the base plate and compacted soil.
6. Remove the compacted soil specimen from the mould and place it on the mixing tray. Keep a representative soil sample of the specimen for water content determination.
7. Mix the remaining soil with the reminder of the originally mixed soil in the tray. Add water in suitable increments to the soil sample and mix the soil thoroughly and repeat the above procedure.

Contd…..

8. Conduct a minimum of 5 determinations such that the optimum moisture content lies within this range.
9. Plot Indian Standard heavy compaction curve (w % along x-axis and ρ_d along y-axis). Obtain OMC and $\rho_{d\,max}$ from the plotted curve. Plot also the ZAV line.

Results and Discussions

Observations and Calculations

1. Type of soil:
2. Specific gravity of the soil:
3. Diameter of the mould (D) = --------------------------------------- cm
4. Height of the mould (H) = --------------------------------------- cm
5. Volume of the mould (V) = --------------------------------------- cm
6. Mass of the rammer = 4.9 kg
7. Free fall of the rammer = 450 mm

TABLE - I

Determination No.		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
(a) Determination of Bulk Density:											
1. Mass of the (mould + Compacted soil)	g										
2. Mass of mould	g										
3. Mass of compacted soil (M)	g										
4. Bulk density (ρ_b)	g/cm^3										

(b) Determination of water content and dry density of the soil:											
1. Container No.											
2. Mass of (container + wet soil)	g										
3. Mass of (container + dry soil)	g										
4. Mass of water	g										
5. Mass of container	g										
6. Mass of the dry soil	g										
7. Water content (w)	Ratio										
8. Dry density (ρ_d)	g/cm^3										

Contd….

Specimen Calculations

1. Bulk density = $\rho_b = \dfrac{\text{Mass of compacted wet soil}}{\text{Volume of the mould}} = \dfrac{M}{V}$ = ---------------------------- g/cm^3
2. Water content = w = $\dfrac{\text{Mass of water}}{\text{Mass of dry soil}}$ = ---------------------------- %
3. Dry density = $= \rho_d = \dfrac{\rho_b}{(1+w)}$ = ---------------------------- g/cm^3

To plot ZAV line

$(w)_{ZAV}$ Ratio						
$(\rho_d)_{ZAV}$ g/cm^3						

Specimen Calculation

$(\rho_d)_{ZAV} = \dfrac{G\rho_w}{\{1+(w)_{ZAV}G\}}$ = ---------------------------- g/cm^3

Relevant BIS Code:

- IS: 2720, Part-8, 1983
- IS: 9198, 1979 (Reaffirmed 1987)
- IS: 10074, 1982

10. LABORATORY VANE SHEAR TEST

Aim: To determine the undrained shear strength, of a given cohesive soil using laboratory vane shear apparatus.

Theory: undrained shear strength, vane shear test and its advantages, sensitivity of soils.

Apparatus

1. Laboratory vane shear apparatus.
2. Marble plate or glass plate
3. Spatula
4. Balance
5. Thermostatically controlled hot air oven
6. Containers for moisture content determination.
7. Wash bottle containing distilled water.
8. 425 micron IS sieve.

Procedure

1. Mix the soil at a known water content and transfer it into the test mould.
2. Mount the mould containing the soil specimen on the base of the vane shear apparatus and fix it securely to the base.
3. Lower the vanes into the specimen to their full length gradually with minimum disturbance to the specimen so that the top of the vane is at least 10 mm below the top of the specimen and note down the initial reading of the torque indicator.
4. Rotate the vane at an uniform rate till the specimen fails. Note down the final reading of torque indicator.
5. Calculate the undrained shear strength of the given soil and report it.

Results and Discussions

Observations and Calculations

1. Diameter of the vane (d) = ……………………… cm
2. Height of the vane (H) = ……………………… cm
3. Spring constant (K) = ……………………… kgf-cm
4. Type of soil = ………………………
5. Water content determination:

Container No.		1	2
Mass of (container + wet soil)	g		
Mass of (container + dry soil)	g		
Mass of dry soil	g		
Mass of container	g		
Mass of water	g		
Water content (w_i)	%		

Contd….

6. Initial reading of torque indicator (R1) = ………………………
7. Final reading of the torque indicator (R2) = ………………………
8. Torque (T) = $\frac{(R1-R2)K}{180}$ = ……………………… kgf-cm
9. Undrained shear strength = $\tau_f = \frac{T}{\pi d^2\left[\frac{H}{2}+\frac{d}{6}\right]}$ = ……………………… kgf/cm^2

Relevant BIS Code:
IS: 2720 (Part–30) – 1980 (Reaffirmed 1987)

11. DIRECT SHEAR TEST

Aim: To determine the shear strength parameters of a soil (i.e. Cohesion intercept and angle of internal friction) by direct shear test.

Theory: Direct shear test – description, merits and limitations.

Apparatus

1. Shear box assembly consisting of
    - Upper and lower parts of shear box coupled together with two pins or clamping screws.
    - Container for shear box
    - Grid plates – two pairs
    - Base plate with cross grooves on its top face to fit into the shear box.
    - Loading pad with a steel ball on its top which distributes the load over the specimen, normal to the shear plane.
2. Loading frame
3. Calibrated weights
4. Proving ring with dial gauge to measure shear force
5. Balance with weights.
6. Dial gauge
7. Spatula, straight edge, sample trimmer.

Preparation of the specimen

Remoulded specimens: Cohesive soils may be compacted to the required density and moisture content in a separate mould. The sample is extracted and trimmed to the required size.

OR

The soil may be compacted to the required density and moisture content directly into the shear box after fixing the two halves of the shear box together by means of fixing screws.

* Non Cohesive soils may be tamped in the shear box for required density with the base plate and the grid plate at the bottom of the box.

Procedure: (Undrained Test)

1. Assemble the shear box with the base plate at the bottom and a grid plate over it, the two halves of the box being connected by the locking screws. The serrations of the grid plate should be at right angles to the direction of shear.
2. Place the specimen over the bottom grid plate. Place another grid plate at the top of the specimen such that the serrations of the plate or in contact with the specimen and at right angles to the direction of shear. Place the loading pad on the top of the grid plate.

Contd......

3. Place the shear box inside the container of the shear box. The container can move over roller supports at its bottom.
4. Set the lower part of the shear box to bear against the load jack, the upper part of the box against the proving ring. Set the gauge of the proving ring to read zero.
5. Apply the required normal stress on the specimen inside the shear box through a lever arrangement.
6. Remove the locking screws or pins so that both the parts of the shear box are free to move relative to each other.
7. Conduct the test by applying a horizontal shear load to failure or to 20% longitudinal displacement, whichever occurs first. Take the proving ring dial readings corresponding to known displacement dial readings.
8. At the end of the test, remove the specimen from the box and determine its final water content (for cohesive soil only).
9. Repeat the test on identical specimens, under different normal stresses (0.25 kgf/cm^2, 0.5 kgf/cm^2, 1 kgf/cm^2, 1.5 kgf/cm^2, 2 kgf/cm^2, and 2.5 kgf/cm^2 etc.). A minimum of three (preferably four) tests shall be made on separate specimens of the same density.

Results and Discussions:

Observations and Calculations

1. Type of soil:
2. Are of the specimen (A_o) = --cm^2
3. Volume of the specimen (V) = -- cm^3
4. Bulk density (ρ_b) = --g/cm^3
5. Moisture content (w) = -- %
6. Rate of strain = --
7. Proving ring constant = --
8.

Trial No.	Normal stress (σ) kgf/cm^2	Displacement dial reading Div.	Displacement (δ) cm	Corrected Area (A)	Proving ring reading Div.	Shear force (P) kgf	Shear Stress (τ) kgf/cm^2
1.							

Contd......

Specimen Calculation

Corrected area = A = A_o x (1 – δ / 3) = -- cm^2

Shear load = P = Proving ring reading x Proving ring constant = --------------------- kgf

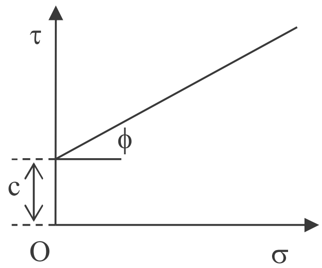
Shear stress = τ = P/A = --

* Conduct the test for different normal stresses (at least four normal stresses). For each test, plot shear stress vs displacement curve to obtain maximum shear stress at failure.

9.

Trial No.					
Normal stress (σ)	kg/cm^2				
Shear stress at failure (τ_f)	kgf/cm^2				

Plot the graph of normal stress (x – axis) vs. maximum shear stress (y-axis). Adopt same scale to plot both normal stress and maximum shear stress.



i) Cohesion intercept = c = ………… kgf/cm^2

ii) Angle of shearing resistance = ϕ =

Relevant BIS Code:
IS: 2720, Part-13, 1986

12. UNCONFIED COMPRESSION TEST

Aim: To determine the unconfined compressive strength of clayey soil.

Theory: Unconfined compressive strength; UCC test and its limitations.

Apparatus
1. Compression device of suitable type
2. Sample ejector
3. Deformation measuring dial gauge
4. Remoulding apparatus – for specimen preparation
5. Thermostatically controlled oven
6. Balance with weights
7. Vernier callipers.
8. Air tight, non-corrodible containers for water content determination.

Preparation of the Specimen
The specimen for the test shall have a minimum diameter of 38 mm and a height to diameter ratio of 2. The largest particle contained within the test specimen should be smaller than $1/8^{th}$ the specimen diameter.

The remoulded specimen may be prepared by compacting the soil at the considered water content and dry density in a bigger mould, and then extracted using sampling tube.

OR

The remoulded specimen may be prepared directly using a split mould.

Procedure
1. Measure the initial length, diameter and mass of the specimen.
2. Place 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 (i.e. proving ring dial) and the compression dial gauge to zero.
3. Apply axial compressive load so as to produce axial strain at a rate of 0.5 to 2 percent per minute. Take the proving ring dial readings corresponding to compression dial readings at suitable intervals.
4. Compress the specimen until failure surfaces have definitely developed or the stress-strain curve is well past its peak or until an axial strain of 20% is reached, whichever occurs first.
5. Stop loading; Remove the failed specimen; Sketch the failure pattern; Keep the soil sample taken from the failure zone for moisture content determination.

Results and Discussions:

Contd......

Observations and Calculations

1. Type of soil:
2. Specimen preparation procedure: Undisturbed / remoulded / compacted
3. Initial dia of the specimen (D_0) = …………………………………… cm.
4. Initial length of the specimen (L_0) = …………………………………… cm
5. Initial area of the cross section of the specimen (A_0) = …………………………………… cm^2
6. Rate of strain = ……………………………………
7. Water content determination (initial)

Container No.		1	2
Mass of (container + wet soil)	g		
Mass of (container + dry soil)	g		
Mass of dry soil	g		
Mass of container	g		
Mass of water	g		
Water content (w_i)	%		

8.

Specimen No.	**Initial mass (m), g**	**ρ_b, g/cm^3**	**(w_i), %**	**ρ_d, g/cm^3**
1.				
2.				
3.				

9.

Specimen No.:

Compression dial reading	**Axial compression of the specimen (ΔL)**	**Proving ring reading**	**Axial load (P)**	**Axial strain (ε)**	**Corrected area (A)**	**Axial stress (σ)**	**Remarks**
div	Cm	div	kgf	Ratio	cm^2	kgf/cm^2	

* Conduct tests on three identical specimens.

Contd......

10. After the test:

Specimen No.	Failure Pattern	Sketch of the failed specimen
1.		
2.		
3.		

11. Water content determination (final)

Container No.		**1**	**2**	**3**
Mass of (container + wet soil)	g			
Mass of (container + dry soil)	g			
Mass of dry soil	g			
Mass of container	g			
Mass of water	g			
Water content	%			

12. Plot the graph of axial stress Vs. Axial strain.
From the graph:

Unconfined compressive strength = q_u =……………………………….. kgf/cm^2

SPECIMEN CALCUALTIONS;

- Axial load (P) = Proving ring constant x proving ring reading = …….. kgf
- Axial strain (ε) = $\Delta L/L_o$ = ………………………………………
- Corrected area (A) = $A_o/(1 - \varepsilon)$ = ……………………………………… cm^2
- Axial stress (σ) = P/A = ………………………………………kgf/cm^2

Relevant BIS Code:
IS: 2720, Part-10, 1973

13.UNCONSOLIDATED, UNDRAINED TRIAXIAL COMPRESSION TEST

Aim: To determine the shear strength parameters of soil by unconsolidated, undrained triaxial compression test without the measurement of pore water pressure.

Theory: Shear strength of soil; Components of shear strength; Total stress, Pore water pressure and Effective stress; Types of shear tests; Total and effective stress shear strength parameters; Conventional failure envelope; Modified failure envelope; Significance of shear strength of soils.

Apparatus

1. Triaxial cell with transparent chamber, capable of with-standing internal fluid pressure up to 10 kgf/cm^2 (i.e., 100 kPa), with all accessories.
2. Apparatus for applying and maintaining the desired fluid pressure within the cell, to an accuracy of 0.1 kgf/cm^2 (i.e., 10 kPa).
3. Compression machine capable of applying axial compression on the specimen at convenient speeds.
4. Dial gauge to measure axial compression.
5. Proving ring to measure the additional axial load
6. Seamless rubber membranes.
7. Membrane stretcher
8. Rubber rings.
9. Air tight, non-corrodible containers for moisture content determination.
10. Balance with weights.
11. Apparatus for sample preparation such as split mould, trimming knife, wire saw, metal straight edge, metal scale etc.
12. Thermostatically controlled hot air oven.

Sample Preparation

The specimens shall be in the form of right cylinders of nominal diameters 38 mm with a height to diameter ratio two.

(a) Undisturbed Specimens

The undisturbed sample in a thin walled tube having the same internal diameter as that of the specimen required for testing shall be extruded out of the tube with the help of a sample extruder and pushed into a split mould. The ends of the specimen shall be trimmed flat and normal to its axis. Then, the specimen shall be taken out of the split mould.

Contd......

(b) Remoulded Specimens

The remoulded specimens may be obtained by compacting the soil at required dry density and water content in a big size mould and then, may be extracted with the help of sampling tubes.

Procedure

1. Measure the length, diameter and the mass of the specimen accurately.
2. Cover the pedestal of the triaxial cell with a solid end cap or keep the drainage valve closed. Place the specimen on the solid end cap, on the pedestal of the triaxial cell and place the other end cap on the top of the specimen. Place a rubber membrane around the specimen using membrane stretcher and seal the membrane to the end caps by means of rubber rings.
3. Assemble the cell with the loading ram initially clear of the top of the specimen and place it on the loading machine.
4. Admit the operating fluid into the cell and bring its pressure to the desired value.
5. Adjust the loading machine such that the loading ram comes just in contact with the seat on the top of the specimen. Note the initial reading on the dial measuring axial compression (or adjust it to read zero). Also, adjust the proving ring dial reading to zero.
6. Apply an axial compressive force at a constant rate such that the failure occurs within a period of approximately 5 to 15 minutes. Note down the proving ring readings corresponding to known compression gauge readings. Continue the loading until the maximum value of the stress has passed (i.e. until the failure of the specimen is observed) or an axial strain of 20% has been reached, whichever occurs first.
7. Unload the specimen and drain off the cell fluid. Dismantle the cell and take out the specimen. Remove the rubber membrane and note down the mode of failure. Weigh the specimen and keep it for moisture content determination.
8. Repeat the test on three or more identical specimens under different cell pressures.

Results and Discussions:

Observations and Calculations

1. Type of soil:
2. Specimen preparation procedure: Undisturbed / remoulded / compacted
3. Initial length of the specimen (L_0) = ……………………………… cm
4. Initial diameter of the specimen (D_0) = ……………………………….
5. Area of cross section (A_0) = ……………………………….. cm^2
6. Volume of specimen (V_0) = ……………………………... cm^3
7. Proving ring constant = …………………………………
8. Rate of strain = ……………………………………

Contd......

9. Water content determination (initial)

Container No.		1	2
Mass of (container + wet soil)	g		
Mass of (container + dry soil)	g		
Mass of dry soil	g		
Mass of container	g		
Mass of water	g		
Water content (w_i)	%		

10.

Specimen No.	Initial mass (m), g	ρ_b, g/cm^3	(w_i), %	ρ_d, g/cm^3
1.				
2.				
3.				

11. Cell pressure:

Compression dial reading	Axial compression of the specimen (ΔL)	Proving ring reading	Axial load (P)	Axial Strain (ε)	Corrected area (A)	Deviator stress (σ_d)
div	cm	div	kgf	Ratio	cm^2	kgf/cm^2

* Conduct tests on three identical specimens with different cell pressures.

12. After the test:

Specimen No.	Failure Pattern	Sketch of the failed specimen
1.		
2.		
3.		

13. Water content determination (final)

Container No.		1	2	3
Mass of (container + wet soil)	g			
Mass of (container + dry soil)	g			
Mass of dry soil	g			
Mass of container	g			
Mass of water	g			
Water content	%			

Contd......

14. Plot a graph of deviator stress vs axial strain to get deviator stress at failure.

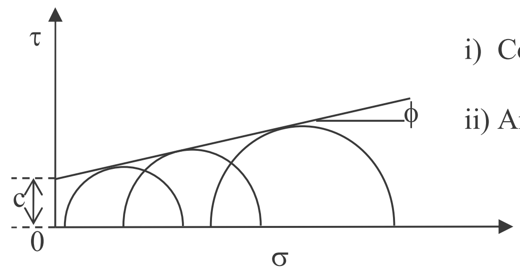
Specimen Calculations

- Axial load (P) = Proving ring constant x proving ring reading = …………. kgf
- Axial strain (ε) = $\Delta L/L_o$ = ………………………………………
- Corrected area (A) = $A_o/(1 - \varepsilon)$ = ……………………………………… cm^2
- Axial stress (σ) = P/A = ………………………………………kgf/cm^2

15.

Test No.	Cell pressure (σ_3) kgf/cm^2	Deviator stress at failure $(\sigma_d)_f = (\sigma_1 - \sigma_3)$ kgf/cm^2	σ_1 kgf/cm^2
1.			
2.			
3.			

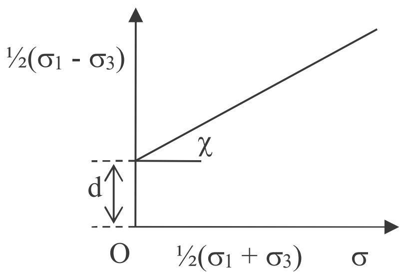
16. Plot (a) Conventional failure envelope (by drawing Mohr's circles) and obtain the shear strength parameters.



i) Cohesion intercept = c = …… kgf/cm^2

ii) Angle of shearing resistance = ϕ =

(b) Modified failure envelope and calculate shear strength parameters.



i) Sin ϕ = tan χ

$\therefore \phi$ = ………………………………..

ii) $c = \dfrac{d}{\text{Cos}\phi}$ = ………………… kgf/cm^2

Relevant BIS Code:

IS: 2720, Part-11, 1971 (Reaffirmed 1978).

14.CONSOLIDATION TEST

Aim: To determine the consolidation properties of given soil.

Theory: Definition of the terms consolidation, compression index, coefficient of volume change; pre-consolidated, normally consolidated and under-consolidated sediments; pre-consolidation pressure and its determination; over-consolidation ratio; fixed ring and floating ring type consolidometers; drainage path; listing of methods to determine the coefficient of consolidation.

Apparatus

1. Fixed ring type consolidometer cell assembly consisting of specimen ring of height not less than 20 mm with a height to diameter ratio of about 3, two porous stones, guide ring, outer ring, pressure pad, steel ball, rubber gasket.
2. Loading frame
3. Dial gauge with an accuracy of 0.002 mm.
4. Balance
5. Thermostatically controlled hot air oven
6. Containers for moisture content determination
7. Mixing basin
8. Soil trimming tools
9. Spatula
10. Ground glass plate/ plate made of Perspex material
11. Whatman No.54 filter papers
12. Stop watch
13. Water reservoir
14. Flexible rubber tube

Procedure

1. Saturate the porous stones either by boiling the porous stones in distilled water for 15 minutes or by submerging them in distilled water for about 5-6 hours. Wipe away the excess water.
2. Assemble the consolidometer cell with one porous stone at the base and one at the top of the specimen ring containing the specimen (undisturbed or remoulded). Provide the filter papers between the porous stones and the specimen.

Note: i) For testing the over consolidated soil or soils sensitive to moisture content, porous stones shall be placed dry. ii) For testing normally consolidated soils, porous stones shall be wet. iii) For testing stiffer soils and moisture sensitive soils, no filter papers shall be used.

3. Place the consolidometer cell assembly in position on the loading frame and suitably adjust its position.

Contd….

4. Clamp the dial gauge in position to measure the vertical deformation of the specimen such that it has a sufficient margin to measure the swell, if any. Note down the initial reading of the dial gauge.
5. Apply a seating stress of 0.05 kgf / cm^2 on the specimen.
6. Fill the consolidation cell with distilled water and connect the cell to the water reservoir such that the level of water in the reservoir and that in the cell are the same.
7. Allow the specimen to reach equilibrium for 24 h.
8. Note down the final dial gauge reading under the seating stress.
9. Apply the next load of intensity such that the stress increment ratio is unity and start the stop watch simultaneously. Record the dial gauge reading at various time intervals.

Note: i) The recommended loading sequence is 0.05 kgf / cm^2, 0.1 kgf / cm^2, 0.2 kgf / cm^2, 0.4 kgf / cm^2, 0.8 kgf / cm^2, 1.6 kgf / cm^2, 3.2 kgf / cm^2 etc.,. However, a loading sequence of 0.05 kgf / cm^2, 0.1 kgf / cm^2, 0.2 kgf / cm^2, 0.5 kgf / cm^2, 1 kgf / cm^2, 2 kgf / cm^2, 4 kgf / cm^2 etc., may also be used. ii) The time sequence for taking the dial gauge readings is such as to facilitate the plotting of time – compression curve

10. After reaching a near equilibrium state (which can be judged by the changes in the dial gauge readings), note down the final dial gauge reading corresponding to the existing stress on the specimen, increment the stress on the specimen to its next value.

Note: Normal equilibrium loading period is 24 h. For some soils, it may be more than 24 h. However, same equilibrium loading period shall be used for all stress increments during the test.

11. On completion of the final loading stage, start unloading the sample by reducing the stress by following a stress decrement ratio of 0.25. Allow sufficient time between successive load decrements and reach the seating stress of 0.05 kgf / cm^2.
12. Maintain the stress for 24 h.
13. After recording the final dial gauge reading, siphon out the water from the cell. Quickly dismantle the specimen from the cell assembly. Remove the excess water on the specimen by using blotting paper.
14. Record the final mass and height of the specimen.
15. Determine the final water content of the specimen by oven drying method.
16. From the equilibrium dial gauge readings recorded under each effective consolidation stress on the specimen, calculate the equilibrium void ratios corresponding to each effective consolidation stress by either the height of solids method or change in void ratio method.
17. Draw void ratio (e) versus log σ' curve and calculate the values of pre-consolidation stress (σ') (if the tested soil is over consolidated) by either Casagrande's method or log-log method, coefficient of volume change (m_v) and compression index (C_c).
18. Calculate the value of coefficient of consolidation (c_v) for each stress range by any of the methods such as square root of time fitting method (Taylor's method), logarithm of time fitting method (Casagrande's method), rectangular hyperbola method and one point method.

Contd….

Results and Discussions:

Observations and Calculations

1. Soil: …………………………………………
2. Specific gravity of soil (G_S) = ………………………………………
3. Specimen preparation: Undisturbed / remoulded / compacted
4. Height of the consolidation ring = ……………………………………… cm
5. Diameter of the consolidation ring = ……………………………………… cm
6. Area of cross section of consolidation ring (A) = ……………………………cm^2
7. **Stress – void ratio data:**

Applied stress (σ'), kgf/cm^2								
Final dial reading, div.								

Calculation of equilibrium void ratio:

8. **Height of solids method:**

Applied stress (σ'),	**Final dial reading,**	**Change in dial (ΔH)**		**Specimen height (H)**	**Void ratio €**	**Remarks**
kgf/cm^2	**div**	**div.**	**mm**	**mm**	**ratio**	
0.0						
0.05						
0.1						

OR

Change in void ratio method:

Applied stress (σ'),	**Final dial reading,**	**Change in dial (ΔH)**		**Specimen height (H)**	**Change in void ratio (Δe)**	**Void ratio €**	**Remarks**
kgf/cm^2	**div**	**div.**	**mm**	**mm**	**ratio**	**ratio**	
0.0							
0.05							
0.1							

Contd….

9. Time – compression data:

Stress range:

Elapsed time, minutes						
Dial reading, div.						

Note: For each of the stress range, the above table shall be recorded, and corresponding values of coefficient of consolidation shall be calculated.

Specimen Calculations

- Effective consolidation stress range: ……………………………
- Average effective drainage path = d_{av} = ……………………………cm

1. **Square root of time fitting method**

- δ_i = …………………… div
- t_{90} = …………………… minutes
- $(c_v)_{90} = \dfrac{0.848\,(d_{av}/2)^2}{t_{90}}$ = …………………… cm^2/min

2. **Logarithm of time fitting method**

- δ_i = …………………… div
- δ_{100} = …………………… div
- δ_{50} = …………………… div
- t_{50} = …………………… minutes
- $(c_v)_{50} = \dfrac{0.196\,(d_{av}/2)^2}{t_{50}}$ = …………………… cm^2/min

3. **Rectangular hyperbola method**

- m = ……………….
- c = ……………….
- $c_v = \dfrac{0.24\,m\,(d_{av}/2)^2}{c}$ = …………………… cm^2/min

4. **One point method**

- δ_f = …………………… div
- δ_{50} = …………………… div
- t_{50} = …………………… minutes
- $(c_v)_{50} = \dfrac{0.196\,(d_{av}/2)^2}{t_{50}}$ = …………………… cm^2/min

Results

- Coefficient of consolidation:
  a) From square root of time fitting method: $(c_v)_{90}$ = ………….. cm^2/min
  b) From log time fitting method: $(c_v)_{50}$ = ………….. cm^2/min
  c) From rectangular hyperbola method: c_v = ……………….. cm^2/min
  d) From one point method: $(c_v)_{50}$ = ………….. cm^2/min

Relevant BIS Code:

IS: 2720, Part-15, 1986

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