

# DEPARTMENT OF CIVIL ENGINEERING

Course Code : CEC304

Geotechnical Engineering Laboratory

Bachelor of Technology



Department of Civil Engineering

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## General instructions on safety and Do's and Don'ts

- Before starting laboratory work follow all written and verbal instructions carefully. If you do not understand a direction or part of a procedure, **ASK YOUR CONCERN TEACHER BEFORE PROCEEDING WITH THE ACTIVITY.**
- Before use equipment must be read carefully Labels and instructions. Set up and use the equipment as directed by your teacher.
- Any failure / break-down of equipment must be reported to the teacher.
- Observe good housekeeping practices. Replace the materials in proper place after work to keep the lab area tidy.
- Maintain silence and clean environment in the lab
- Protect yourself from getting electric shock.

## GENERAL NOTES ON WRITING LABORATORY RECORD

All civil engineering projects require some soil exploration work at the very early stages, where soil tests are carried out in the laboratory and in situ. There are several commercial soil testing laboratories, and they have their own reporting styles. The report may be read by engineers who may not have the opportunity to see the soils being tested. Therefore, it is necessary to provide complete information in a simple and concise manner.

### Notes on Plotting:

The following items should be looked into when presenting experimental data in graphical form:

#### 1. Scale:

Choose convenient scales; avoid odd, fractional, or decimal numbers per division. Even if preprinted graph paper is used, it is generally a good idea to put small tic marks at major divisions and indicate numerical values of these divisions. The scales should be chosen to adequately show the range of data i.e., the curves, data, notes, legend etc. should fill the graph.

#### 2. Axes:

Provide arrowheads at the ends. All axes need to be labelled (preferably in words) along with the units. Symbols are acceptable provided they are widely recognised or they are defined in the text. A modern approach is to enclose the graphs in a rectangular box, showing grid lines as necessary. The grid lines should be thinner than the curves or the axes.

#### 3. Experimental & theoretical curves:

If the curve is based on experimental data, show the data points clearly. If more than one set of data is included (e.g., std. proctor & modified Proctor compaction test data), differentiate between them by using different symbols and define them in a legend and/or clearly label the curves.

It is a good idea to use different types of curves (e.g., ----, ....., ———) to distinguish the graphs.

Smooth curves should be drawn with french curve through experimental data points - rarely should individual points be connected by straight lines. When showing variation of field water contents and blow counts with depth, in a bore log, connect the points by straight line segments.

Do not show the data points on theoretical curves, such as those plotted from calculations based on a mathematical formulae (e.g., zero air void curve).

**4. Title & figure number:**

All plots, figures and tables need to be numbered and titled so that they can be referred to in the report.

**5. Data from other sources:**

When you include data from other literature, clearly show them in the figure and give proper references.

The common software such as Excel, Origin, etc. have all the facilities you would need for a professional look. A good quality plot can be made within 30 minutes, with the axes, scales, etc. fixed up nicely. It is worth learning one of them.

# **EXPERIMENT - 1**

## **DETERMINATION OF CONSISTENCY LIMITS OF SOIL**

### **1(a) LIQUID LIMIT TEST**

**Objective:**

To determine the liquid limit of given soil sample by mechanical method.

**Standards:**

1. Indian Standards : IS: 2720 (Part-5)
2. ASTM: D-4318
3. AASHTO: T-89

**Need and scope:**

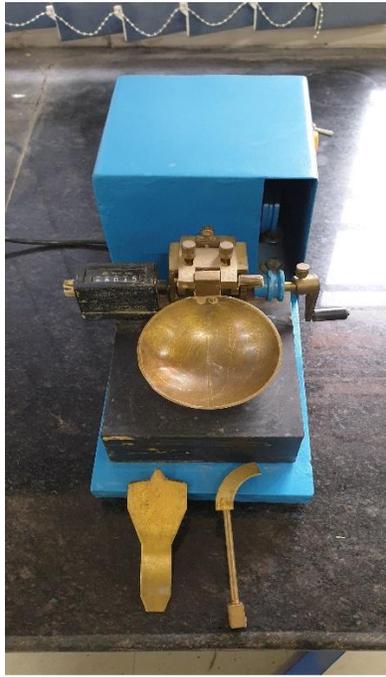
Liquid limit is significant to know the stress history and general properties of the soil met with construction. From the results of liquid limit the compression index may be estimated. The compression index value will help us in settlement analysis. If the natural moisture content of soil is closer to liquid limit, the soil can be considered as soft.

**Definition (As per Casagrande):**

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 12 mm on being given 25 blows in a standard manner. At this limit the soil possess low shear strength.

**Apparatus:**

1. Balance
2. Liquid limit device (Casagrande's)
3. Grooving tool
4. Mixing dishes
5. Spatula
6. Electrical Oven



**Figure 1: Casagrande's liquid limit device**

**Procedure:**

1. About 120 g of air-dried soil from thoroughly mixed portion of material passing 425-micron I.S sieve is to be obtained.
2. Distilled water is mixed to the soil thus obtained in a mixing dish to form uniform paste. The paste shall have a consistency that would require 30 to 35 drops of cup to cause required closer of standard groove for sufficient length.
3. A portion of the paste is placed in the cup of liquid limit device where cup rest on the base and spread into portion with few strokes of spatula.
4. Trim it to a depth of 1 cm at the point of maximum thickness and return excess of soil to the dish.
5. The soil in the cup shall be divided by the firm strokes of the grooving tool along the diameter through the center line of the follower so that clean sharp groove of proper dimension is formed.
6. Lift and drop the cup by turning crank at the rate of two revolutions per second until the two halves of soil cake come in contact with each other for a length of about 12 mm by flow only (should not slip).
7. The number of blows required to cause the groove close for about 12 mm shall be recorded.

8. A representative portion of soil is taken from the cup for water content determination.
9. Repeat the test with different moisture contents at least three more times for blows between 10 and 40.

**Observations:**

Details of the sample: .....

Natural moisture content: ..... Room temperature: .....

**Observation Table:**

Determination Number	1	2	3		4
Container number					
Mass of container , M <sub>1</sub> (g)					
Mass of container + wet soil, M <sub>2</sub> (g)					
Mass of container + dry soil, M <sub>3</sub> (g)					
Mass of water, M <sub>2</sub> – M <sub>3</sub> (g)					
Mass of dry soil, M <sub>3</sub> -M <sub>1</sub> (g)					
Moisture content (%) = $\frac{M_2 - M_3}{M_3 - M_1} \times 100$					
No. of blows					

**Calculation:**

Draw a graph showing the relationship between water content (on y-axis) and number of blows (on x-axis) on semi-log graph. The curve obtained is called flow curve. The moisture content corresponding to 25 drops (blows) as read from the graph represents liquid limit. It is usually expressed to the nearest whole number.

## Interpretation and recording:

### Result:

Flow index,  $I_f = \frac{(W_2 - W_1)}{\left(\log \frac{N_1}{N_2}\right)} = \text{slope of the flow curve} = \underline{\hspace{2cm}}$ .

### Questionnaire:

1. If natural water content of the soil is greater than the liquid limit and consistency index is negative, what is the consistency/ state of the soil?
2. What is the difference in consistency of soil and consistency of cement?

## 1(b) PLASTIC LIMIT TEST

### Objective:

Determination of the plastic limit of soil

### Standards:

1. Indian Standards : IS: 2720 (Part-5)
2. ASTM: D-4318
3. AASHTO: T-90

### Need and scope:

Soil is used for making bricks, tiles, soil cement blocks in addition to its use as foundation for structures.

### Apparatus:

1. Porcelain dish.
2. Glass plate for rolling the specimen.
3. Air tight containers to determine the moisture content.
4. Balance of capacity 200 g and sensitive to 0.01g
5. Oven thermostatically controlled with interior of non-corroding material to maintain the temperature around 105<sup>0</sup> and 110<sup>0</sup>C.



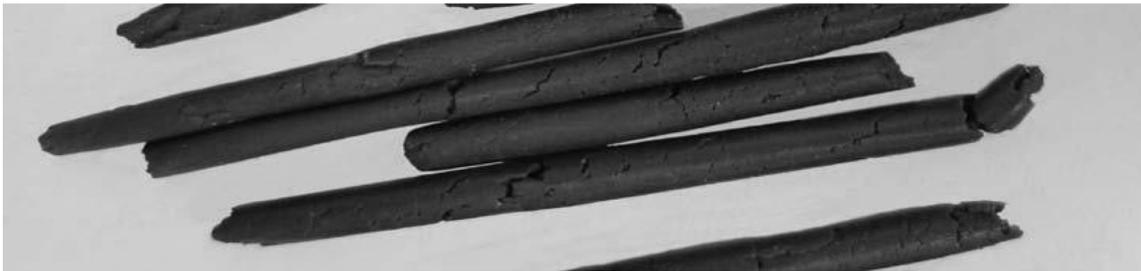
Figure 1: Equipment for Plastic Limit

### Procedure:

1. Take about 20 g of thoroughly mixed portion of the material passing through 425 micron I.S. sieve obtained in accordance with I.S. 2720 (Part 1).
2. Mix it thoroughly with distilled water in the evaporating dish till the soil mass becomes plastic enough to be easily molded with fingers.
3. Allow it to season for sufficient time (for 24 hrs.) to allow water to permeate throughout the soil mass.
4. Take about 8 g of this plastic soil mass and roll it between fingers and glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling shall be between 80 and 90 strokes per minute.
5. Continue rolling till you get a thread of 3 mm diameter.
6. Knead the soil together to a uniform mass and re-roll.
7. Continue the process until the thread crumbles when the diameter is 3 mm.
8. Collect the pieces of the crumbled thread in air tight container for moisture content determination.
9. Repeat the test atleast 3 times and take the average of the results calculated to the nearest whole number.

**Observation:**

Compare the diameter of thread at intervals with the rod. When the diameter reduces to 3 mm, note the surface of the thread for cracks.



**Figure 3: 3 mm thread of soil with cracks**

**Observation Table:**

Determination Number	1	2	3
Container No.			
Mass of container + lid, $W_1$ (g)			
Mass of container + lid + wet sample, $W_2$ (g)			
Mass of container + lid + dry sample, $W_3$ (g)			
Mass of dry sample (soil solids) = $W_3 - W_1$ (g)			
Mass of water in the soil = $W_2 - W_3$ (g)			
Water content, $w$ (%) = $\frac{W_2 - W_3}{W_3 - W_1} \times 100$			

**Results:**

Flow index,  $I_f = \frac{(W_2 - W_1)}{(\log \frac{N_1}{N_2})} = \text{slope of the flow curve} = \text{_____}$ .

Plasticity Index,  $I_p = w_l - w_p = \text{_____}$ .

Toughness Index,  $I_T = \frac{I_p}{I_f} = \text{_____}$ .

Liquidity Index,  $I_L = \frac{w_o - w_p}{I_p} = \text{_____}$ .

Consistency Index,  $I_c = \frac{w_l - w_o}{I_p} = \text{_____}$ .

Where,  $w_o$  = Natural Moisture content of soil

Result Summary						
Liquid limit ( $w_l$ )	Plastic limit ( $w_p$ )	Flow Index ( $I_f$ )	Plasticity Index ( $I_p$ )	Toughness Index ( $I_T$ )	Liquidity Index ( $I_L$ )	Consistency Index ( $I_c$ )

## 1(c) SHRINKAGE LIMIT TEST

### Objective:

To determine the shrinkage limit and calculate the shrinkage ratio for the given soil

### Standards:

1. Indian Standards : IS: 2720 (Part-6)
2. ASTM: D-427
3. AASHTO: T-92

### Theory:

As the soil loses moisture, either in its natural environment, or by artificial means in laboratory it changes from liquid state to plastic state, from plastic state to semi-solid state and then to solid state. Volume changes also occur with changes in water content. But there is particular limit at which any moisture change does not cause soil any volume change.

### Need and scope:

Soils which undergo large volume changes with change in water content may be troublesome. Volume changes may not and usually will not be equal.

A shrinkage limit test should be performed on a soil.

1. To obtain a quantitative indication of how much change in moisture can occur before any appreciable volume changes occurs.
2. To obtain an indication of change in volume.

The shrinkage limit is useful in areas where soils undergo large volume changes when going through wet and dry cycles (as in case of earth dams).

### Apparatus:

1. Evaporating Dish- Porcelain, about 12cm diameter with flat bottom.
2. Spatula
3. Shrinkage Dish- Circular, porcelain or non-corroding metal dish (3 nos) having a flat bottom and 45 mm in diameter and 15 mm in height internally.
4. Straight Edge- Steel, 15 cm in length.

5. Glass cup- 50 to 55 mm in diameter and 25 mm in height, the top rim of which is ground smooth and level.
6. Glass plates- Two, each 75 x 75 mm one plate shall be of plain glass and the other shall have prongs.
7. Sieves- 2mm and 425- micron IS sieves.
8. Oven- thermostatically controlled.
9. Graduate- Glass, having a capacity of 25 ml and graduated to 0.2 ml and 100 cc one –mark flask.
10. Balance- Sensitive to 0.01 g minimum.
11. Mercury- Clean, sufficient to fill the glass cup to over flowing.
12. Wash bottle containing distilled water.
13. Desiccator

**Caution:**

Do not touch the mercury with gold rings.

**Procedure:**

**Preparation of soil paste:**

1. Take about 100 g of soil sample from a thoroughly mixed portion of the material passing through 425-micron I.S. sieve.
2. Place about 30 g the above soil sample in the evaporating dish and thoroughly mix with distilled water and make a creamy paste.

Use water content somewhere around the liquid limit.

**Filling the shrinkage dish:**

3. Coat the inside of the shrinkage dish with a thin layer of Vaseline to prevent the soil sticking to the dish.
4. Fill the dish in three layers by placing approximately 1/3rd of the amount of wet soil with the help of spatula. Tap the dish gently on a firm base until the soil flows over the edges and no apparent air bubbles exist. Repeat this process for 2nd and 3rd layers also till the dish is completely filled with the wet soil. Strike off the excess soil and make the top of the dish smooth. Wipe off all the soil adhering to the outside of the dish.
5. Weigh immediately, the dish with wet soil and record the weight.

6. Air- dry the wet soil cake for 6 to 8hrs, until the colour of the pat turns from dark to light. Then oven-dry up to a constant weight at  $105^{\circ}\text{C}$  to  $110^{\circ}\text{C}$  (say about 12 to 16 hrs).
7. Remove the dried disk of the soil from oven. Cool it in a desiccator. Then obtain the weight of the dish with dry sample.
8. Determine the weight of the empty dish and record.
9. Determine the volume of shrinkage dish which is evidently equal to volume of the wet soil as follows. Place the shrinkage dish in an evaporating dish and fill the dish with mercury till it overflows slightly. Press it with plain glass plate firmly on its top to remove excess mercury. Pour the mercury from the shrinkage dish into a measuring jar and find the volume of the shrinkage dish directly. Record this volume as the volume of the wet soil pat.

### **Volume of the Dry Soil Pat:**

10. Determine the volume of 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 a larger one and fill the glass cup to overflowing with mercury. Remove the excess mercury by covering the cup with glass plate with prongs and pressing it. See that no air bubbles are entrapped. Wipe out the outside of the glass cup to remove the adhering mercury. Then, place it in another larger dish, which is, clean and empty carefully.

Place the dry soil pat on the mercury. It floats submerge it with the pronged glass plate which is again made flush with top of the cup. The mercury spills over into the larger plate. Pour the mercury that is displaced by the soil pat into the measuring jar and find the volume of the soil pat directly.

**Calculation:**

**Tabulation and results:**

S.No	Determination	1	2	3
1.	Shrinkage dish No.			
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 oven-dry soil pat ( $W_o$ ), g			
6.	Mass of water, g			
7.	Moisture content (w) of soil pat, %			
8.	Mass of mercury filling shrinkage dish + Mass of evaporating dish			
9.	Mass of evaporating dish			
10.	Mass of mercury filling shrinkage dish, g			
11.	Volume of wet soil pat (V), ml			
12.	Mass of mercury displaced by the dry soil pat, g			
13.	Mass of evaporating dish, g			
14.	Mass of mercury displaced by the dry soil pat, g			
15.	Volume of dry soil pat ( $V_o$ ), g			
16.	Shrinkage limit = $\left(w - \frac{V - V_o}{W_o}\right) \times 100$			
17.	Shrinkage ratio, $R = \frac{W_o}{V_o}$			

**NOTE: This test will not be conducted due to use of hazardous metal, mercury.**

## 1(d) FREE SWELL INDEX

### Objective:

To determine the free swell index of soil as per IS: 2720 (Part XL) – 1977.

### Standard:

1. IS: 2720 (Part XL) -1977

### Need and scope:

Free swell or differential free swell is the increase in volume of soil without any external constraint when subjected to submergence in water.

Swelling soils, which are clayey soils, are also called expansive soils. When these soils are partially saturated, they increase in volume with the addition of water. They shrink greatly on drying and develop cracks on the surface. These soils possess a high plasticity index. Black cotton soils found in many parts of India belong to this category. Expansive soils contain minerals like montmorillonite, which due to large specific surface are capable of absorbing large amount of water. When they absorb water, they increase in volume. The more water they absorb the more their volume increases. Expansions of ten percent or more are not uncommon. This change in volume can exert large force on a building or other structure to cause damage. Cracked foundations, floors and basement walls are typical types of damage done by swelling soils.

Expansive soils will also shrink when they dry out. This shrinkage can remove support from buildings or other structures and result in damaging subsidence. Fissures in the soil can also develop. These fissures can facilitate the deep penetration of water when moist conditions or runoff occurs. This produces a cycle of shrinkage and swelling that places repetitive stress on structures.

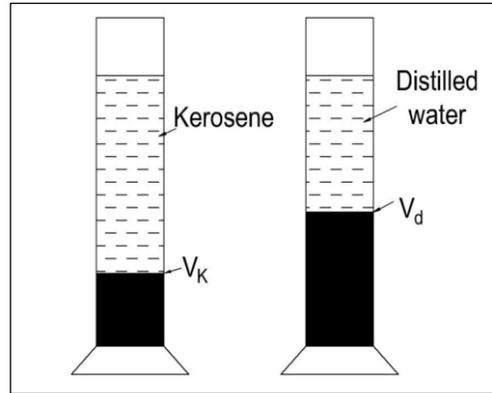
### Apparatus:

1. 425 micron IS sieve
2. Oven
3. Balance, with an accuracy of 0.01g
4. Graduated glass cylinder - 2 nos., each of 100ml capacity
5. Glass rod for stirring

### Procedure:

1. Take two oven dried specimens of 10g each passing through 425micron IS Sieve.
2. Pour each soil specimen into a graduated glass cylinder of 100ml capacity.
3. Pour distilled water in one and kerosene oil in the other cylinder up to 100ml mark.
4. Remove entrapped air by gently shaking or stirring with a glass rod.
5. Allow the suspension to attain the state of equilibrium (for not less than 24hour).

6. Final volume of soil in each of the cylinder should be read out.



**Figure 1: Schematic representation of experimental procedure**

**Calculation:**

$$\text{Free swell index} = \frac{V_d - V_k}{V_k} \times 100$$

where,

$V_d$  = volume of soil specimen read from the graduated cylinder containing distilled water.

$V_k$  = volume of soil specimen read from the graduated cylinder containing kerosene.

FSI in %	Expansiveness
<20	Low
20-35	Moderate
35-50	High
>50	Very high

**Observation Table:**

Trial No.	1	2
Mass of dry soil passing 425micron IS Sieve (g)		
Volume of soil specimen in distilled water after 24h ( $V_d$ ) ml		
Volume of soil specimen in kerosene after 24h ( $V_k$ ) ml		
Free Swell Index (%) = $\frac{V_d - V_k}{V_k} \times 100$		
Average (%)		

**Result:**

The differential free swell index (DFS) of the given soil is \_\_\_\_\_.

### **Safety and precautions:**

1. In the case of highly expansive soils such as sodium bentonites the sample size may be 5 g or alternatively a cylinder of 250 ml capacity for 10 g of sample may be used.
2. Switch off the oven and use hand gloves while removing the soil sample from oven.

### **Questionnaire:**

1. Under what condition DFS value be negative and for what type of soil?

## **EXPERIMENT - 2**

### **FIELD DENSITY TEST 2(a) CORE CUTTER METHOD**

#### **Objective:**

To determine the in-situ dry density of soil by core cutter method

#### **Standard:**

IS: 2720 (Part XXIX) – 1975

#### **Theory:**

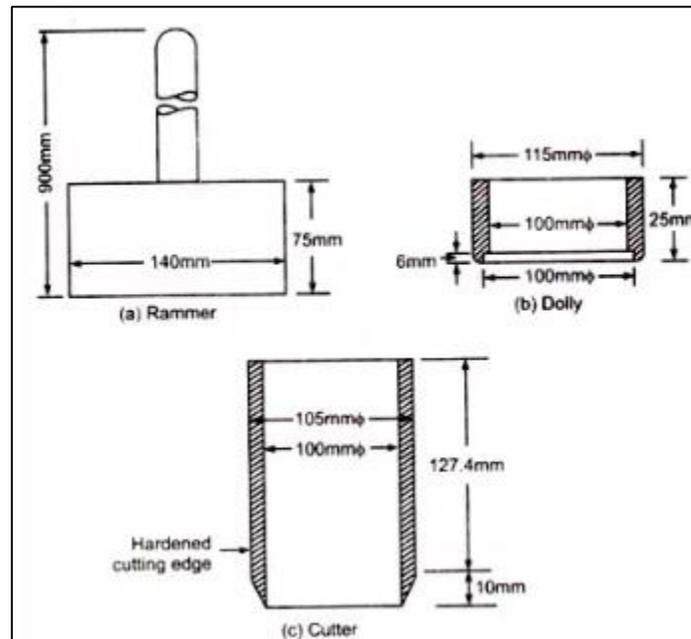
The Core-cutter method consists of driving a core-cutter of known volume into the soil after placing it on the cleaned soil surface. The cutter filled with soil is removed and excess soil is trimmed off. The cutter with the soil is weighed. The volume of the cutter is calculated from the dimensions of the cutter and the in-situ weight is determined by dividing the weight of the soil in the cutter by the volume of the cutter. By determining the water content of the soil in the laboratory, the dry unit weight of the soil can be computed.

The in-situ density of the soil is needed for stability analysis, for the determination of the degree of compaction of compacted soil, etc. The core-cutter method is suitable for fine-grained soils free from aggregations. It is less accurate than the sand-replacement method and is not recommended, unless speed is essential or unless the soil is well compacted.

#### **Apparatus:**

1. Cylindrical core cutter - seamless steel tube, 130 mm long and 10 cm internal diameter, with a wall thickness of 3 mm and beveled at one end.
2. Steel rammer - With solid mild steel foot 140 mm diameter and 75 mm height with a concentrically screwed 25 mm diameter solid mild steel staff. The overall length of the rammer including the foot as well as the staff should be approximately 900 mm. The rammer (foot and staff together) should weigh approximately 9 kg.
3. Steel dolly – 2.5 cm high and 10 cm internal diameter with a wall thickness of 7.5 mm and with a lip to enable it to be fitted on top of the core-cutter
4. Electronic balance with an accuracy of 1 gm.
5. Steel rule
6. Spade or pickaxe
7. Straight edge - A steel strip about 30 cm long, 2.5 cm wide and 3 to 5 mm thick with one bevelled edge.

8. Knife
9. Sample extruder



**Figure 1: Core cutter setup**

#### **Site preparation:**

Clear a small area, approximately 30 cm square and level it. The area should be free from vegetation and should not contain tree roots, rocks and boulders. The ideal site would be cohesive soil.

#### **Test procedure:**

1. Measure the height ( $h$ ) and internal diameter ( $d$ ) of the core cutter. Determine the inner volume of the core-cutter ( $V_c$ )
2. Apply grease to the inside of the core cutter and weigh the empty core cutter ( $W_1$ )
3. Clean and level the place where density is to be determined.
4. Attach the steel dolly on the top of the core cutter. With the help of the steel rammer drive the core cutter vertically into the soil until only about 15 mm of the dolly protrudes above the surface.
5. Excavate the soil around the cutter with a crow bar and gently lift the cutter without disturbing the soil in it.
6. Trim the top and bottom surfaces of the sample and clean the outside surface of the cutter.
7. Weigh the core cutter with soil ( $W_2$ )

8. Remove the soil from the core cutter using a sample ejector and take representative soil sample from it to determine the moisture content.
9. Report the dry density of the soil to second place of decimal in  $\text{g/cm}^3$  and water content of the soil to two decimal figures.

### CALCULATIONS:

#### 1. Bulk unit weight:

$$\gamma_b = \frac{W_2 - W_1}{V_c}$$

where,

$\gamma_b$  = Bulk unit weight in g/cc

$W_1$  = empty weight of the core cutter in grams

$W_2$  = weight of the core cutter with soil in grams

$V_c$  = Volume of the cutter in cc.

#### 2. Dry unit weight:

$$\gamma_d = \frac{100 \gamma_b}{100 + w}$$

where,

$\gamma_d$  = Dry unit weight in g/cc

$\gamma_b$  = Bulk unit weight in g/cc

$w$  = moisture content in percentage

#### 3. In-situ void ratio:

$$e = \frac{G_s - \gamma_w}{\gamma_d}$$

where,

$e$  = in-situ void ratio

$G_s$  = Specific gravity of soil solids

$\gamma_w$  = Unit weight of water in g/cc

$\gamma_d$  = Dry unit weight of soil in g/cc

### Result:

The in-situ dry density of the soil is \_\_\_\_\_.

The in-situ void ratio of soil is \_\_\_\_\_.

### **Safety and precautions:**

1. Care should be taken in excavating the pit, so that it is not enlarged by levering, as this will result in lower density being recorded.
2. No loose material should be left in the pit.
3. There should be no vibrations during this test.

## 2(b) SAND REPLACEMENT METHOD

### Objective:

To determine the in-situ dry density of soil by sand replacement method.

### Standards:

1. IS: 2720 (Part-XXVIII)
2. ASTM: D-1556
3. AASHTO: T-19

### Need and scope:

Determination of field density of cohesionless soil is not possible by core cutter method, because it is not possible to obtain a core sample. In such situation, the sand replacement method is employed to determine the unit weight.

The in-situ density of natural soil is needed for the determination of bearing capacity of soils, for the purpose of stability analysis of natural soils, for the determination of pressures on underlying strata, for calculation of settlement, etc. In compacted soils, the in-situ density is needed to check the amount of compaction that the soil has undergone for comparing with design data. The correct estimation of the in-situ density of both natural and compacted soils is therefore of great importance.

By conducting this test it is possible to determine the bulk density of the soil. The moisture content is likely to vary from time to time and hence the bulk density also. So it is required to report the test result in terms of dry density. It is a quality control test, where compaction is required.

### Apparatus:

1. Sand pouring cylinder of 3L capacity mounted above a pouring cone and separated by a shutter cover plate.
2. Calibrating container: With an internal diameter of 100 mm and an internal depth of 150 mm. Fitted with a flange approximately 50 mm wide and about 5 mm thick surrounding the open end. The volume of the container should be given to an accuracy of 0.25 percent.
3. Metal tray with a central hole: 300 mm square and 40 mm deep with 100 mm hole in the centre.
4. **Dry sand:** Clean, uniformly graded natural sand passing the 1 mm IS Sieve and retained on the 600 micron IS Sieve. It shall be free from organic matter and should be oven dried and

stored for a suitable period to allow its water content to reach equilibrium with atmospheric humidity.

5. Tools for excavating holes; suitable tools such as scraper tool to make a level surface.
6. Balance to weigh unto an accuracy of 1g.
7. Glass plate about 450 mm/600 mm square and 9mm thick.
8. Suitable non-corrodible airtight containers.
9. Thermostatically controlled oven with interior on non-corroding material to maintain the temperature between 105<sup>0</sup>C to 110<sup>0</sup>C.
10. A dessicator with any desiccating agent other than sulphuric acid.



**Figure1: Apparatus for sand replacement method**

**Procedure:**

**Bulk density of sand:**

1. The volume of calibrating container is found.
2. The sand pouring cylinder is filled with sand within about 10mm from top.
3. The sand pouring cylinder with sand is weighed as  $W_1$ .
4. The sand pouring cylinder is kept over the calibrating cylinder. The shutter is opened and sand is allowed to run out into the calibrating container till no further movement of sand is observed.
5. The shutter is closed and again the sand pouring cylinder containing the remaining sand is weighed as  $W_2$ .

6. The sand pouring cylinder is kept on a glass plate.
7. The shutter is opened and the sand is allowed to run out until no further movement of the sand took place in the cylinder. The shutter is closed and the sand pouring cylinder is removed carefully.
8. The sand left on the glass plate is weighed as  $W_3$ .
9. The weight of sand to fill the calibrating container is found.
10. The bulk density of sand is found.
11. The same operations are repeated twice ensuring the same weight of the cylinder with sand before pouring.

### **Dry density of soil:**

1. An area of about  $450\text{mm}^2$  is exposed on the soil surface where test is to be performed.
2. The surface is trimmed and levelled.
3. The metal tray with the central hole is kept on the prepared surface.
4. A hole is excavated in the soil using an excavating tool.
5. The hole in the metal tray is used as a pattern while excavating.
6. The excavation is done upto a depth of 150 mm.
7. The excavated soil is weighed as  $W_w$ .
8. The sand pouring cylinder is filled with standard sand to the weight as recorded earlier.
9. The sand pouring cylinder is placed concentrically over the excavated hole.
10. The shutter is opened and sand is allowed to run out into the hole until no further movement of sand took place in the cylinder. Then, the shutter is closed.
11. The cylinder is removed from the excavated hole. Then, the pouring cylinder is weighed with the remaining sand as  $W_4$ .
12. The weight of the sand in the hole is found as  $W_1 - W_4 - W_2$ .
13. The volume of the hole is found.
14. The bulk density is found.
15. A small soil specimen is taken for moisture content determination.
16. The dry density is found.
17. The field operations are repeated in the same area at different locations to get average results.
18. The average dry density of the field soil is found.

**Observation Table:**

**Table 1: Bulk density of sand.**

Sl. No.	Sample Details Calibration	1	2	3
1.	Volume of calibrating container (V) in cc			
2.	Weight of cylinder + sand (before pouring), $W_1$ g			
3.	Mean weight of cylinder + sand (after pouring), $W_2$ g			
4.	Mean weight of sand in cone (of pouring cylinder), $W_3$ g			
5.	Weight of sand to fill calibrating container $W_a = (W_1 - W_2 - W_3)$ g			
6.	Bulk density of sand $\gamma_s = \frac{W_a}{V}$ g/cc			

**Table 2: Dry density of soil.**

Sl. No.	Measurement of soil density	1	2	3
1.	Weight of wet soil from hole, $W_w$ g			
2.	Weight of cylinder + sand (before pouring), $W_1$ g			
3.	Weight of cylinder + sand (after pouring), $W_4$ g			
4.	Weight of sand in hole, $W_b = (W_1 - W_4 - W_3)$ g			
5.	Volume of hole, $V_b = \frac{W_b}{\gamma_s}$ cc			
6.	Bulk density $\gamma_b = \frac{W_w}{W_b} \times \gamma_s$ g/cc			
7.	Water content (%)			
8.	Dry density $\gamma_d = \frac{\gamma_b}{1+w}$ g/cc			
9.	Average dry density of soil			

**Result:**

The dry density of soil is \_\_\_\_\_.

**General remarks:**

1. While calibrating for the bulk density of sand great care has to be taken.
2. The excavated hole must be equal to the volume of the calibrating container.

**Questionnaire:**

1. How to decide the type of test if you have a mixture of fine and coarse grained soil?

## **EXPERIMENT - 3**

### **COMPACTION TEST 3(a) LIGHT COMPACTION TEST**

#### **Objective:**

To determine the maximum dry density (M.D.D.) and optimum moisture content (O.M.C.) of a given soil sample using light compaction test.

#### **Standards:**

- 1 Indian Standards : IS: 2720 (Part-7)
- 2 ASTM: D-698 - 12e2
- 3 AASHTO: T-99

#### **Need and scope:**

Compaction can be defined as a simple ground improvement technique, where the soil is densified through external compactive effort.

This method covers the determination of the relationship between the moisture content and density of soils compacted in a mould of a given size with a 2.6 kg rammer dropped from a height of 310 mm.

#### **Apparatus:**

1. Proctor mould having a capacity of 944 cc with an internal diameter of 10.2 cm and a height of 11.6 cm. The mould shall have a detachable collar assembly and a detachable base plate.
2. Rammer: A mechanically operated metal rammer having a 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 310 mm.
3. Sample extruder.
4. A balance of 15 kg capacity.
5. Sensitive balance.
6. Straight edge.
7. Graduated cylinder.

8. Mixing tools such as mixing pan, spoon, towel, spatula etc.
9. Containers.



**Figure 1: Rammer and mould for compaction test**

**Procedure:**

1. Take a representative oven-dried sample, approximately 5 kg in the given pan. Thoroughly mix the sample with sufficient water to dampen it to approximately four to six percent below optimum moisture content.
2. Weigh the proctor mould without base plate and collar. Fix the collar and base plate. Place the soil in the Proctor mould and compact it in 3 layers giving 25 blows per layer with the 2.6 kg rammer falling through 310 mm height.
3. Remove the collar, trim the compacted soil even with the top of the mould by means of the straight edge and weigh.
4. Divide the weight of the compacted specimen by 944 cc and record the result as the bulk weight in gram per cubic centimeter of the compacted soil.
5. Remove the sample from the mould and slice vertically through and obtain a small sample for moisture determination.
6. Thoroughly break the remaining material until it passes through 4.75mm sieve as per eye judgment. Add water in sufficient amount to increase the moisture content of the soil sample by one or two percent and repeat the above procedure for each increment of water added. Continue this series of determination until there is either a decrease or no change in the bulk unit weight of the compacted soil.

**Calculation:**

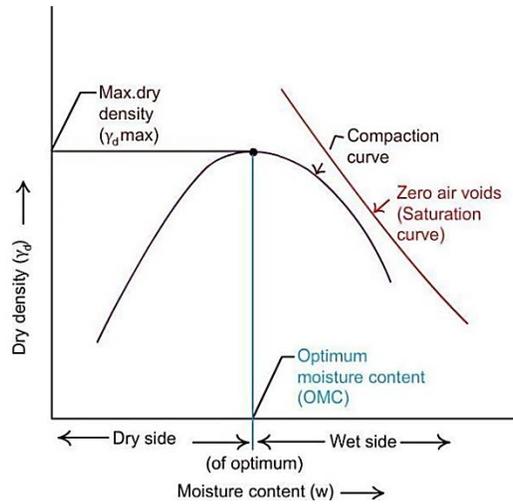
$$\text{Bulk density} = \frac{\text{weight of compacted soil}}{\text{Volume of Mould}}$$

$$\text{Dry density} = \frac{\text{bulk density}}{(1 + w)}$$

where,

‘w’ is the moisture content of the soil.

Plot the dry density against moisture content and find out the maximum dry density and optimum moisture content for the soil.



**Figure 2: Compaction Curve**

**Observations:**

Cylinder (mould)

- a) height = cm
- b) dia = cm
- c) volume = cc

**Observation Table:**

Test No.	1	2	3	4	5	6	7
Mass of empty mould, $W_m$ g							
Assumed water content, w%							
Mass of mould + compacted soil, $W_1$ g							
Mass of compacted soil, g							
Bulk density, $\gamma_t$ (g/cc)							
Container No.							
Mass of container (empty), $X_1$ g							
Mass of container + wet soil, $X_2$ g							
Mass of container + dry soil, $X_3$ g							
Mass of water, $(X_2 - X_3)$ g							
Mass of dry soil, $(X_3 - X_1)$ g.							
Actual water content, w (%)							

Dry density = $\gamma_t / (1+w)$ g/cc							
$\gamma_d$ (ZAV), g/cc							

**Calculation of Zero Air Void Line:**

Zero air void line gives the relationship between dry density and moisture content when the degree of saturation is assumed to be 100%. It can be calculated by using the following formula

$$\gamma_{d(100\% \text{ sat})} = \frac{G\gamma_w}{1 + wG}$$

where,

$\gamma_{d(100\% \text{ sat})}$  = dry density corresponding to 100% saturation ( g/cc).

G = specific gravity of soil solids.

w = water content of soil

$\gamma_w$  = unit weight of water (g/cc)

### **3(b) HEAVY COMPACTION TEST**

#### **Objective:**

To determine the maximum dry density (M.D.D.) and optimum moisture content (O.M.C.) of a given soil sample using heavy compaction test.

#### **Standards:**

1. Indian Standards : IS: 2720 (Part-8)
2. ASTM: D-1557 - 12e1
3. AASHTO: T-180

#### **Need and scope:**

Compaction can be defined as a simple ground improvement technique, where the soil is densified through external compactive effort.

This method covers the determination of the relationship between the moisture content and density of soils compacted in a mould of a given size with a 4.9 kg rammer dropped from a height of 450 mm.

#### **Apparatus:**

1. Proctor mould having a capacity of 944 cc with an internal diameter of 10.2 cm and a height of 11.6 cm. The mould shall have a detachable collar assembly and a detachable base plate.
2. Rammer: A mechanical operated metal rammer having a 5.08 cm diameter face and a weight of 4.9 kg. The rammer shall be equipped with a suitable arrangement to control the height of drop to a free fall of 450 mm.
3. Sample extruder.
4. A balance of 15 kg capacity.
5. Sensitive balance.
6. Straight edge.
7. Graduated cylinder.
8. Mixing tools such as mixing pan, spoon, towel, spatula etc.

## 9. Containers.

### Procedure:

1. Take a representative oven-dried sample, approximately 5 kg in the given pan. Thoroughly mix the sample with sufficient water to dampen it to approximately four to six percentage points below optimum moisture content.
2. Weigh the proctor mould without base plate and collar. Fix the collar and base plate. Place the soil in the Proctor mould and compact it in 5 layers giving 25 blows per layer with the 4.9 kg rammer falling through 450 mm height.
3. Remove the collar, trim the compacted soil even with the top of the mould by means of the straight edge and weigh.
4. Divide the weight of the compacted specimen by 944 cc and record the result as the bulk weight in gram per cubic centimeter of the compacted soil.
5. Remove the sample from the mould and slice vertically through and obtain a small sample for moisture determination.
6. Thoroughly break the remaining material until it passes through 4.75mm sieve as per eye judgment. Add water in sufficient amount to increase the moisture content of the soil sample by one or two percent and repeat the above procedure for each increment of water added. Continue this series of determination until there is either a decrease or no change in the bulk unit weight of the compacted soil.

### Calculation:

$$\text{Bulk density} = \frac{\text{weight of compacted soil}}{\text{Volume of Mould}}$$

$$\text{Dry density} = \frac{\text{bulk density}}{(1 + w)}$$

where,

w is the moisture content of the soil.

### Observations:

Cylinder (mould)

- |           |   |    |
|-----------|---|----|
| a) height | = | cm |
| b) dia    | = | cm |
| c) volume | = | cc |

Test No.	1	2	3	4	5	6	7
Mass of empty mould, $W_m$ g							
Mass of cylinder + compacted soil, $W_1$ g							
Mass of compacted soil, g							
Bulk density, $\gamma_t$ (g/cc)							
Container No.							
Mass of container (empty), $X_1$ g							
Mass of container + wet soil, $X_2$ g							
Mass of container + dry soil, $X_3$ g							
Mass of water, $(X_2 - X_3)$ g							
Mass of dry soil, $(X_3 - X_1)$ g.							
Water content, $w$ (%)							
Dry density = $\gamma_t / (1+w)$ , g/cc							
$\gamma_d$ (ZAV), g/cc							

### Calculation of Zero Air Void Line:

Zero air void line gives the relationship between dry density and moisture content when the degree of saturation is assumed to be 100%. It can be calculated by using the following formula

$$\gamma_{d(100\% \text{ sat})} = \frac{G\gamma_w}{1 + wG}$$

where,

$\gamma_{d(100\% \text{ sat})}$  = Dry density corresponding to 100% saturation ( g/cc).

$G$  = Specific gravity of soil solids.

$w$  = Water content of soil

$\gamma_w$  = Unit weight of water (g/cc)

### Questionnaire:

1. For a particular soil what will happen to OMC and MDD with increase in compactive effort.

2. What type of structure of soil at dry of optimum and wet of optimum?
3. Will above compaction tests will be effective for clayey soil?

# EXPERIMENT - 4

## PERMEABILITY TEST

### 4(a) CONSTANT HEAD METHOD

#### Objective:

To determine the coefficient of permeability of a soil using constant head method.

#### Standards:

1. Indian Standards : IS: 2720 (Part-36)
2. ASTM: D-2434
3. AASHTO: T-215

#### Need and scope:

The knowledge of this property is much useful in solving problems involving yield of water bearing strata, seepage through earthen dams, stability of earthen dams, and embankments of canal bank affected by seepage, settlement etc.

#### Planning and organization:

1. Preparation of the soil sample for the test.
2. Finding the discharge through the specimen under a particular head of water.

#### Definition of coefficient of permeability:

The rate of flow under laminar flow conditions through a unit cross sectional area of porous medium under unit hydraulic gradient is defined as coefficient of permeability.

#### Equipment:

1. Permeameter of non-corrodible material having a capacity of 1000 ml, with an internal diameter of  $100 \pm 0.1$  mm and internal effective height of  $127.3 \pm 0.1$  mm.
2. The mould shall be fitted with a detachable base plate and removable extension counter.
3. **Compacting equipment:** 50 mm diameter circular face, weight 2.6 kg and height of fall 310 mm as specified in I.S 2720 part VII 1980.
4. **Drainage bade:** A bade with a porous disc, 12 mm thick which has the permeability 10 times the expected permeability of soil.
5. **Drainage cap:** A porous disc of 12 mm thick having a fitting for connection to water inlet or outlet.

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



**Figure 1: Experimental setup for constant head permeability test**

## **Preparation of specimen for testing:**

- **Undisturbed soil sample**

1. Note down the sample number, bore hole number and its depth at which the sample was taken.
2. Remove the protective cover (paraffin wax) from the sampling tube.
3. Place the sampling tube in the sample extraction frame, and push the plunger to get a cylindrical form sample not longer than 35 mm in diameter and having height equal to that of mould.
4. The specimen shall be placed centrally over the porous disc to the drainage base.
5. The angular space shall be filled with an impervious material such as cement slurry or wax, to provide sealing between the soil specimen and the mould against leakage from the sides.
6. The drainage cap shall then be fixed over the top of the mould.
7. Now the specimen is ready for the test.

- **Disturbed soil sample:**

1. A 2.5 kg sample shall be taken from a thoroughly mixed air dried or oven dried material.
2. The initial moisture content of the sample shall be determined. Then the soil shall be placed in the air tight container.
3. Add required quantity of water to get the desired moisture content.
4. Mix the soil thoroughly.
5. Weigh the empty permeameter mould.
6. After greasing the inside slightly, clamp it between the compaction base plate and extension collar.
7. Place the assembly on a solid base and fill it with sample and compact it.
8. After completion of a compaction the collar and excess soil are removed.
9. Find the weight of mould with sample.
10. Place the mould with sample in the permeameter, with drainage base and cap having discs that are properly saturated.

### **Test procedure:**

1. For the constant head arrangement, the specimen shall be connected through the top inlet to the constant head reservoir.
2. Open the bottom outlet.
3. Establish steady flow of water.
4. The quantity of flow for a convenient time interval may be collected.
5. Repeat three times for the same interval.

### **Observation and recording:**

The flow is very low at the beginning, gradually increases and then stands constant. Constant head permeability test is suitable for cohesionless soils. For cohesive soils falling head method is suitable.

### **Calculation:**

The test is based Darcy's law for laminar flow.  $q = kiA$

where,

$q$  = Discharge per unit time.

$A$  = Total area of c/s of soil perpendicular to the direction of flow.

$i$  = hydraulic gradient.

$k$  = Darcy's coefficient of permeability

Coefficient of permeability for a constant head test is given by

$$k = \frac{QL}{Ath}$$

where,

$k$  = coefficient of permeability in cm/sec

$Q$  = volume of discharge in  $\text{cm}^3$

$L$  = Length of specimen in cm

$A$  = Cross-sectional area of specimen in  $\text{cm}^2$

$h$  = Head causing flow in cm

The viscosity of the water changes with temperature. As temperature increases viscosity decreases and the permeability increases. The coefficient of permeability is standardized at  $27^\circ\text{C}$ , and the permeability at any temperature  $T$  is related to  $K_{27}$  by the following ratio:

$$K_{27} = K_T \frac{\eta_T}{\eta_{27}}$$

where,

$\eta_T$  and  $\eta_{27}$  are the viscosities at the temperature T of the test and at 27° C, respectively.

**Table 1:** Properties of Distilled Water ( $\eta$  = absolute)

Temperature °C	Density (g/cc)	Viscosity (Poise)
4	1.0000	0.01567
16	0.99897	0.01111
17	0.99880	0.01083
18	0.99862	0.01056
19	0.99844	0.01030
20	0.99823	0.01005
21	0.99802	0.00981
22	0.99780	0.00958
23	0.99757	0.00936
24	0.99733	0.00914
25	0.99708	0.00994
26	0.99682	0.00874
27	0.99655	0.00855
28	0.99627	0.00836
29	0.99598	0.00818
30	0.99568	0.00801

**Presentation of data:**

The coefficient of permeability is reported in cm/sec at 27° C. The dry density, the void ratio and the degree of saturation shall be reported. The test results should be tabulated as below:

**Observation:**

**Permeability Test Record:**

Project: .....

Tested By: .....

Location: .....

Boring No. : .....

Depth: .....

**Details of sample**

Diameter of specimen .....cm

Length of specimen(L) .....cm

Area of specimen (A) .....cm<sup>2</sup>

Specific gravity of soil G<sub>s</sub> .....

Volume of specimen (V) .....cm<sup>3</sup>

Weight of dry specimen (W<sub>s</sub>) .....g

Moisture content ..... %

**Observation Table:**

Experiment No.		1	2	3	4
Length of specimen	L(cm)				
Area of specimen	A(cm <sup>2</sup> )				
Height of water (head)	h(cm)				
Volume	V(cm <sup>3</sup> )				
Time	t(sec)				
Temperature	T(°C)				
Permeability K <sub>T</sub>	K <sub>T</sub> (cm/sec)				
Permeability K <sub>20</sub>	K <sub>20</sub> (cm/sec)				

**Interpretation and Reporting:**

Compare the results with the empirical relationships

$K = CD_{10}^2$  and compare the constants

**Questionnaire:**

1. The flow inside the soil sample is laminar or turbulent?
2. What type of head loss you expect in the soil sampler?

## 4(b) FALLING HEAD METHOD

### **Objective:**

To determine the coefficient of permeability of the given soil sample using falling head method

### **Standards:**

1. Indian Standards : IS: 2720 (Part-17)
2. ASTM: D- D5084
3. AASHTO: T-215
4. BS: 1377-5

### **Need and scope:**

The test results of the permeability experiments are used:

1. To estimate ground water flow.
2. To calculate seepage through dams.
3. To find out the rate of consolidation and settlement of structures.
4. To plan the method of lowering the ground water table.
5. To calculate the uplift pressure and piping.
6. To design the grouting.
7. For soil freezing tests.
8. To design pits for recharging.

Thus, the study of seepage of water through soil is very important with wide field applications.

The falling head method of determining permeability is used for soil with low discharge, whereas the constant head permeability test is used for coarse-grained soils with a reasonable discharge in a given time. For very fine-grained soil, capillarity permeability test is recommended.

### **Principle of the experiment:**

The passage of water through porous material is called seepage. A material with continuous voids is called a permeable material. Hence, permeability is a property of a porous material which permits passage of fluids through inter connecting voids.

Hence, permeability is defined as the rate of flow of water under laminar conditions through a unit cross-sectional area perpendicular to the direction of flow through a porous medium under unit hydraulic gradient and under standard temperature conditions.

The principle behind the test is Darcy's law for laminar flow. The rate of discharge is proportional to ( $i * A$ )

$$q = kiA$$

where,

$q$  = discharge per unit time.

$A$  = total area of c/s of soil perpendicular to the direction of flow.

$i$  = hydraulic gradient.

$k$  = Darcy's coefficient of permeability = the mean velocity of flow that will occur through the cross-sectional area under unit hydraulic gradient.

The coefficient of permeability,  $k$ ,

$$k = \frac{2.303aL}{A(t_1 - t_o)} \log_{10} \left( \frac{h_o}{h_1} \right)$$

where,

$a$  = area of cross-section of standpipe

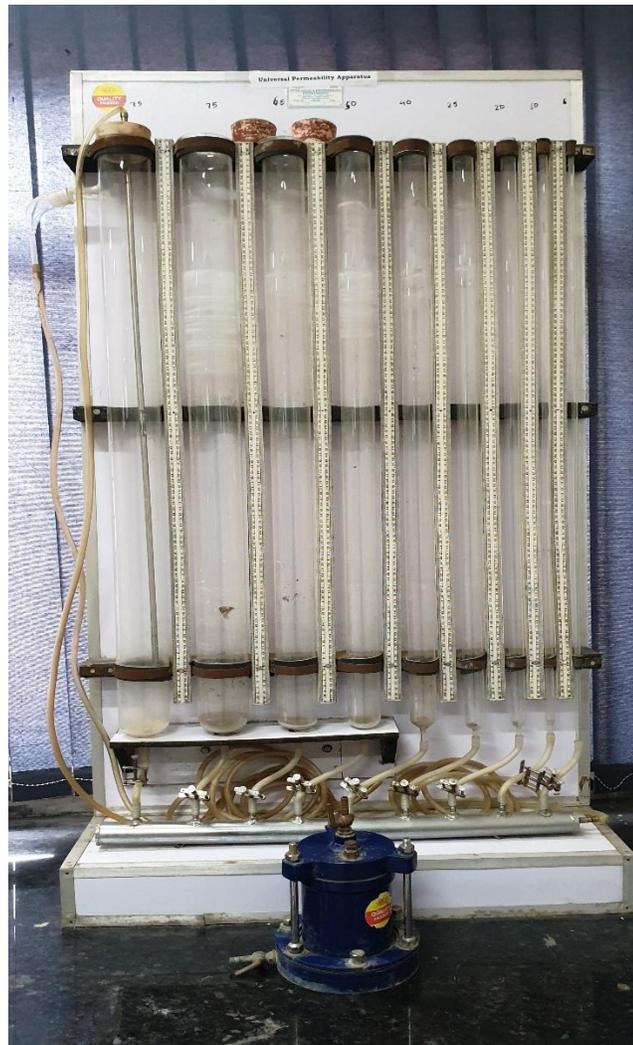
$L$  and  $A$  = length and area of cross-section of the soil sample

### **Planning and organization:**

The tools and accessories needed for the test are:

1. Permeameter with its accessories.
2. Standard soil specimen.
3. Deaired water.
4. Balance to weigh up to 1 g.
5. I.S sieves 4.75 mm and 2 mm.
6. Mixing pan.
7. Stop watch.
8. Measuring jar.
9. Meter scale.
10. Thermometer.
11. Container for water.

## 12. Trimming knife etc.



**Figure1: Experimental setup for falling head permeability test**

### **Knowledge of equipment:**

1. The permeameter is made of non-corrodible material with a capacity of 1000 ml, with an internal diameter of  $100 \pm 0.1$  mm and effective height of  $127.3 \pm 0.1$  mm.
2. The mould has a detachable base plate and a removable exterior collar.
3. The compacting equipment has a circular face with 50 mm diameter and a length of 310 mm with a weight of 2.6 kg.
4. The drainage base is a porous disc, 12 mm thick with a permeability 10 times that of soil.
5. The drainage cap is also a porous disc of 12 mm thickness with an inlet/outlet fitting.
6. The container tank has an overflow valve. There is also a graduated jar to collect discharge.

7. The stand pipe arrangements are done on a board with 2 or 3 glass pipes of different diameters.

### **Preparation of the specimen:**

The preparation of the specimen for this test is important. There are two types of specimen, the undisturbed soil sample and the disturbed or made up soil sample.

#### **A. Undisturbed soil specimen:**

It is prepared as follows:

1. Note down-sample no., borehole no., depth at which sample is taken.
2. Remove the protective cover (wax) from the sampling tube.
3. Place the sampling tube in the sample extractor and push the plunger to get a cylindrical shaped specimen not larger than 85 mm diameter and height equal to that of the mould.
4. This specimen is placed centrally over the drainage disc of base plate.
5. The annular space in between the mould and specimen is filled with an impervious material like cement slurry to block the side leakage of the specimen.
6. Protect the porous disc when cement slurry is poured.
7. Compact the slurry with a small tamper.
8. The drainage cap is also fixed over the top of the mould.
9. The specimen is now ready for test.

#### **B. Disturbed specimen:**

The disturbed specimen can be prepared by static compaction or by dynamic compaction.

##### **(a) Preparation of statically compacted (disturbed) specimen.**

1. Take 800 to 1000 g of representative soil and mix with water to O.M.C determined by I.S Light Compaction test. Then leave the mix for 24 hours in an airtight container.
2. Find weight 'W' of soil mix for the given volume of the mould and hence find the dry density.

3. Now, assemble the permeameter for static compaction. Attach the 3 cm collar to the bottom end of 0.3 litre mould and the 2 cm collar to the top end. Support the mould assembly over 2.5 cm end plug with 2.5 cm collar resting on the split collar kept around the 2.5 cm end plug. The inside of the 0.3 litre mould is lightly greased.
4. Put the weighed soil into the mould. Insert the top 3 cm end plug into the top collar, tamping the soil with hand.
5. Keep now the entire assembly on a compressive machine and remove the split collar. Apply the compressive force till the flange of both end plugs touch the corresponding collars. Maintain this load for 1 minute and then release it.
6. Then, remove the top 3 cm plug and collar. Place a filter paper on fine wire mesh on the top of the specimen and fix the perforated base plate.
7. Turn the mould assembly upside down and remove the 2.5 cm end plug and collar. Place the top perforated plate on the top of the soil specimen and fix the top cap on it, after inserting the seating gasket.
8. Now the specimen is ready for test.

**(B) Preparation of dynamically compacted disturbed sample:**

1. Take 800 to 1000 g of representative soil and mix it with water to get the optimum moisture content (desired density). Leave the mix in airtight container for 24 hours.
2. Assemble the permeameter for dynamic compaction. Grease the inside of the mould and place it upside down on the dynamic compaction base. Weigh the assembly correct to 0.1 g ( $W_1$ ). Put the 3 cm collar to the other end.
3. Now, compact the wet soil in 2 layers with 15 blows to each layer with a 2.5 kg dynamic tool. Remove the collar and then trim off the excess. Weigh the mould assembly with the soil ( $W_2$ ).
4. Place the filter paper or fine wire mesh on the top of the soil specimen and fix the perforated base plate on it.
5. Turn the assembly upside down and remove the compaction plate. Insert the sealing gasket and place the top perforated plate on the top of soil specimen and fix the top cap.
6. Now, the specimen is ready for test.

### Experimental procedure:

1. Prepare the soil specimen as specified.
2. Saturate it. De-aired water is preferred.
3. Assemble the permeameter in the bottom tank and fill the tank with water.
4. Inlet nozzle of the mould is connected to the stand pipe. Allow some water to flow until steady flow is obtained.
5. Note down the time interval 't' for a fall of head in the stand pipe 'h'.
6. Repeat step 5 three times to determine 't' for the same head.
7. Find 'a' by collecting 'q' for the stand pipe. weigh it correct to 1 g and find 'a' from  $q/h=a$ .

Therefore, the coefficient of permeability is \_\_\_\_\_ cm/s

### Observation Table:

		1st set	2nd set	3rd set
Area of stand pipe	a (cm <sup>2</sup> )			
Cross sectional area of soil specimen	A (cm <sup>2</sup> )			
Length of soil specimen	L (cm)			
Initial reading of stand pipe	h <sub>0</sub> (cm)			
Final reading of stand pipe	h <sub>1</sub> (cm)			
Time	t (sec)			
Test temperature	T (°C)			
Coefficient of permeability at T	k <sub>T</sub> (cm/sec)			
Coefficient of permeability at 27° C	k <sub>27</sub> (cm/sec)			

### General remarks:

1. During test there should be no volume change in the soil, there should be no compressible air present in the voids of soil i.e. soil should be completely saturated. The flow should be laminar and in a steady state condition.
2. Coefficient of permeability is used to assess drainage characteristics of soil, to predict rate of settlement founded on soil bed etc.

### Questionnaire:

1. Is there any effect of capillarity on the reading of stand pipe?
2. What is the type of flow inside the soil sample?

# **EXPERIMENT - 5**

## **CONSOLIDATION TEST**

### **Objective:**

To determine the settlements due to primary consolidation of soil by conducting one dimensional test

### **Standards:**

1. Indian Standards : IS: 2720 (Part-15)
2. ASTM: D-2435
3. AASHTO: T-216

### **Need and scope:**

The test is conducted to determine the settlement due to primary consolidation. To determine :

1. Rate of consolidation under normal load.
2. Degree of consolidation at any time.
3. Pressure-void ratio relationship.
4. Coefficient of consolidation at various pressures.
5. Compression index.

From the above information, it will be possible for us to predict the time rate and extent of settlement of structures founded on fine-grained soils. It is also helpful in analyzing the stress history of soil. Since the settlement analysis of the foundation depends mainly on the values determined by the test, this test is very important for foundation design.

### **Planning and organization:**

1. Consolidometer consisting essentially of
  - a) A ring of diameter 60mm and height 20mm
  - b) Two porous plates or stones of silicon carbide, aluminum oxide or porous metal.
  - c) Guide ring.
  - d) Outer ring.
  - e) Water jacket with base.
  - f) Pressure pad.
  - g) Rubber basket.

2. Loading device consisting of frame, lever system, loading yoke dial gauge fixing device and weights.
3. Dial gauge to read to an accuracy of at least 0.01mm.
4. Thermostatically controlled oven.
5. Stopwatch to read seconds.
6. Sample extractor.
7. Miscellaneous items like balance, soil trimming tools, spatula, filter papers, sample containers.



**Figure 1: Consolidation test setup**

### **Principle involved:**

When a compressive load is applied to soil mass, a decrease in its volume takes place. The decrease in volume of soil mass under stress is known as compression and the property of soil mass pertaining to its tendency to decrease in volume under pressure is known as compressibility. In a saturated soil mass having its void filled with incompressible water, decrease in volume or compression can take place when water is expelled out of the voids. Such a compression resulting from a long time static load and the consequent escape of pore water is termed as consolidation.

When the load is applied on the saturated soil mass, the entire load is carried by pore water in the beginning. As the water starts escaping from the voids, the hydrostatic pressure in water gets gradually dissipated and the load is shifted to the soil solids which increases effective stress on them, as a result the soil mass decrease in volume. The rate of escape of water depends on the permeability of the soil.

#### **1. Undisturbed sample:**

From the sample tube, eject the sample into the consolidation ring. The sample should project about one cm from outer ring. Trim the sample smooth and flush with top and bottom of the ring by using a knife. Clean the ring from outside and keep it ready from weighing.

#### **2. Remoulded sample :**

- a. Choose the density and water content at which sample has to be compacted from the moisture density relationship.
- b. Calculate the quantity of soil and water required to mix and compact.
- c. Compact the specimen in compaction mould in three layers using the standard rammers.
- d. Eject the specimen from the mould using the sample extractor.

### **Procedure:**

1. Saturate two porous stones either by boiling in distilled water about 15 minute or by keeping them submerged in the distilled water for 4 to 8 hrs. Wipe away excess water. Fittings of the consolidometer, which is to be enclosed.
2. Assemble the consolidometer with the soil specimen and porous stones at top and bottom of specimen, providing a filter paper between the soil specimen and porous stone. Position the pressure pad centrally on the top porous stone.

3. Mount the mould assembly on the loading frame, and center it such that the load applied is axial.
4. Position the dial gauge to measure the vertical compression of the specimen. The dial gauge holder should be set so that the dial gauge is in the begging of its releases run, allowing sufficient margin for the swelling of the soil, if any.
5. Connect the mould assembly to the water reservoir and the sample is allowed to saturate. The level of the water in the reservoir should be at about the same level as the soil specimen.
6. Apply an initial load to the assembly. The magnitude of this load should be chosen by trial, such that there is no swelling. It should be not less than  $50 \text{ g/cm}^2$  for ordinary soils &  $25 \text{ g/cm}^2$  for very soft soils. The load should be allowed to stand until there is no change in dial gauge readings for two consecutive hours or for a maximum of 24 hours.
7. Note the final dial reading under the initial load. Apply first load of intensity  $0.1 \text{ kgf/cm}^2$  start the stopwatch simultaneously. Record the dial gauge readings at various time intervals. The dial gauge readings are taken until 90% consolidation is reached. Primary consolidation is gradually reached within 24 hrs.
8. At the end of the period, specified above take the dial reading and time reading. Double the load intensity and take the dial readings at various time intervals. Repeat this procedure for successive load increments. The usual loading intensity are as follows :  
 $0.1, 0.2, 0.5, 1, 2, 4, 8 \text{ kgf/cm}^2$ .
9. After the last loading is completed, reduce the load to  $\frac{1}{4}$  of the value of the last load and allow it to stand for 24 hrs. Reduce the load further in steps of  $\frac{1}{4}$  the previous intensity till an intensity of  $0.1 \text{ kg/cm}^2$  is reached. Take the final reading of the dial gauge.
10. Reduce the load to the initial load, keep it for 24 hrs and note the final readings of the dial gauge.
11. Quickly dismantle the specimen assembly and remove the excess water on the soil specimen in oven, note the dry weight of it.

**Observation and reading:**

Name of the project

Borehole no.: 1

Depth of the sample :

Description of soil :

Empty weight of ring :

Area of ring :

Diameter of ring :

Volume of ring :

Height of ring :

Specific gravity of soil sample No:

Dial Gauge =      mm (least count)

**Data and observation sheet for consolidation test pressure, compression and time**

Pressure Intensity (kg/cm <sup>2</sup> )	0.1	0.2	0.5	1	2	4	8
Elapsed Time							
0.25							
1							
2.5							
4							
6.25							
9							
16							
25							
30							
1 hr							
2 hrs							
4 hrs							
8 hrs							
24 hrs							

**Observation Sheet for Consolidation Test : Pressure and voids ratio:**

Applied pressure	Final dial reading	Dial change	Specimen height	Height solids	Height of voids	Void ratio
0						
0.1						
0.2						
0.5						
1.0						
2.0						
4.0						
8.0						
4.0						
2.0						
1.0						
0.5						
0.2						
0.1						

**Calculations:**

1. **Height of solids:** ( $H_s$ ) is calculated from the equation

$$H_s = \frac{W_s}{(G \times A)}$$

2. **Void ratio:** Voids ratio at the end of various pressures are calculated from equation

$$e = \frac{(H - H_s)}{H_s}$$

3. **Coefficient of consolidation:** The Coefficient of consolidation at each pressures increment is calculated by using the following equations:

- i.  $C_v = 0.197 d^2/t_{50}$  (Log fitting method)
- ii.  $C_v = 0.848 d^2/t_{90}$  (Square fitting method)

In the log fitting method, a plot is made between dial readings and logarithmic of time, the time corresponding to 50% consolidation is determined.

In the square root fitting method, a plot is made between dial readings and square root of time and the time corresponding to 90% consolidation is determined.

**4. Compression Index:** To determine the compression index, a plot of voids ratio ( $e$ )  $V_s \log t$  is made. The initial compression curve would be a straight line and the slope of this line would give the compression index  $C_c$ .

**5. Coefficient of compressibility:** It is calculated as follows

$$a_v = \frac{0.435 \times C_c}{\text{Average pressure for the increment}}$$

where,

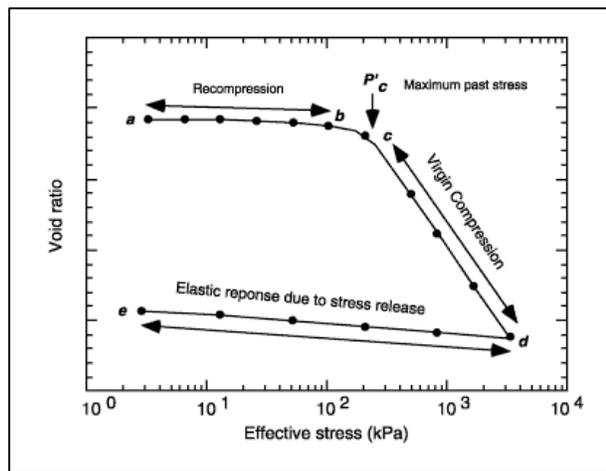
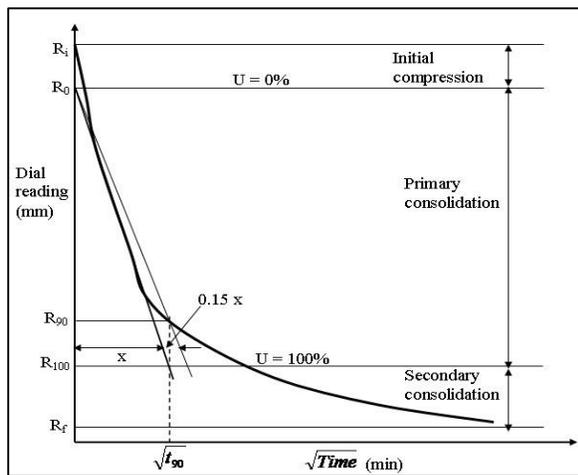
$C_c$  = Coefficient of compressibility

**6. Coefficient of permeability:** It is calculated as follows

$$k = \frac{c_v \times m_v \times \gamma_w}{(1 + e)}$$

**Graphs:**

1. Dial reading  $V_s \log$  of time, or
2. Dial reading  $V_s$  square root of time.
3. Voids ratio  $V_s \log \sigma$  (average pressure for the increment).



**Figure 2: Sample graphs**

**General remarks:**

1. While preparing the specimen, attempts has to be made to have the soil strata orientated in the same direction in the consolidation apparatus.
2. During trimming care should be taken in handling the soil specimen with least pressure.
3. Smaller increments of sequential loading have to be adopted for soft soils.

**Questionnaire:**

1. What will happen if the sample height or diameter is changed in the oedometer test?
2. The soil with higher over consolidation ratio is good or bad for an engineering back fill?
3. For what type of soil, oedometer tests is preferred to determine the coefficient of permeability?

## EXPERIMENT 6

### 6(a) DIRECT SHEAR TEST

#### Objective:

To determine the shearing strength of the soil using the direct shear apparatus.

#### Standards:

1. Indian Standards : IS: 2720 (Part-13)
2. ASTM: D-3080 (Granular soil)
3. AASHTO: T-236

#### Need and scope:

In many engineering problems such as design of foundation, retaining walls, slab bridges, pipes, sheet piling, the value of the angle of internal friction and cohesion of the soil involved are required for the design. Direct shear test is used to predict these parameters quickly.

#### Apparatus:

1. The shear box, grid plates, porous stones, base plates, and loading pad and water jacket shall conform to IS: 11229-19857.
  - a. Shear box: Shear box of internal dimension 60 mm x 60 mm x 25 mm. Shear box, divided into two halves by a horizontal plane and fitted with locking and spacing screw.
  - b. Base plate having cross grooves on its top surface
  - c. Grid plates perforated (2 nos.)
  - d. Porous stones 6 mm thick (2 nos.)
  - e. Loading yoke, loading pad.
2. Loading frame (motor attached).
3. Dial gauge.
4. Proving ring.
5. Tamper.
6. Straight edge.
7. Balance.
8. Aluminum container.
9. Spatula.



**Figure1: Direct shear test setup**

**Procedure:**

1. Check the inner dimension of the soil container.
2. Put the parts of the soil container together.
3. Calculate the volume of the container. Weigh the container.
4. Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil.
5. Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
6. Make the surface of the soil plane.
7. Put the upper grating on stone and loading block on top of soil.
8. Measure the thickness of soil specimen.
9. Apply the desired normal load.
10. Remove the shear pin.
11. Attach the dial gauge which measures the change of volume.
12. Record the initial reading of the dial gauge and calibration values.

13. Before proceeding to test check all adjustments to see that there is no connection between two parts except sand/soil.
14. Start the motor. Take the reading of the shear force and record the reading.
15. Take volume change readings till failure.
16. Add 5 kg normal stress 0.5 kg/cm<sup>2</sup> and continue the experiment till failure
17. Record carefully all the readings. Set the dial gauges zero, before starting the experiment

### Shearing stage

Rate of shearing \_\_\_\_\_ mm/min

Normal stress 0.5 kg/cm<sup>2</sup> L.C =..... P.R.C =.....

Date and Time	Displacement Dial Reading	Displacement, $\delta$	Area Correction	Corrected Area	Proving dial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

Normal stress 1.0 kg/cm<sup>2</sup> L.C =..... P.R.C =.....

Date and Time	Displacement Dial Reading	Displacement, $\delta$	Area Correction	Corrected Area	Proving dial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

Normal stress  $1.5 \text{ kg/cm}^2$  L.C=..... P.R.C=.....

Date and Time	Displacement Dial Reading	Displacement, $\delta$	Area Correction	Corrected Area	Provincial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

Plot shear stress- shear displacement curve and find:

- a) Maximum shear stress, and
- b) Corresponding shear displacement.

Proving Ring constant.....

Least count of the dial.....

Calibration factor.....

Leverage factor.....

Dimensions of shear box= 60 x 60 mm

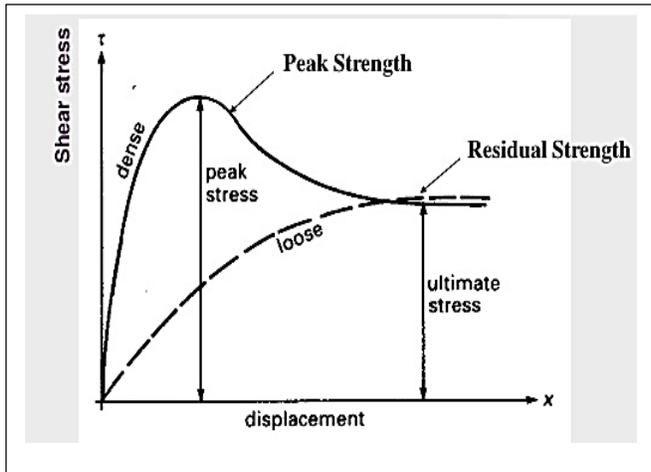
Empty weight of shear box.....

Least count of dial gauge.....

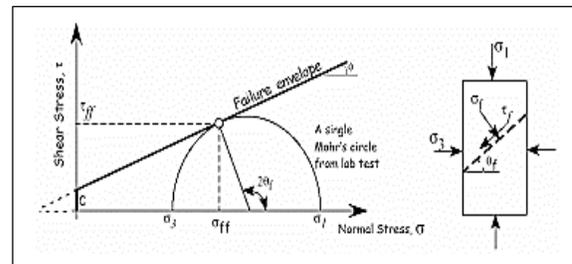
Normal Stress (kg/cm <sup>2</sup> )	Shear Stress (kg/cm <sup>2</sup> )			
	Proving Ring Reading (Division)	Proving Ring Constant	Shear Force (kg)	Shear Stress (kg/cm <sup>2</sup> )
0.5				
1				
1.5				

Plot shear normal stress displacement curve and find:

- a) Cohesion intercept, and
- b) Angle of shearing resistance.



Stress-strain plot



Mohr's circle for direct shear

Figure 1: Sample graphs from test data

## Calculations:

1. Shear strength of soil

$$\tau_f = \sigma_n \tan \phi + c$$

where,

$\tau_f$  = Shear strength of soil = shear stress at failure.

C = Cohesion intercepts.

$\sigma_n$  = Total normal stress on the failure plane

$\phi$  = Angle of internal friction

2. Deformation ( $\delta$ ) = elapsed time  $\times$  strain rate

3. Corrected Area

$$A = A_o \left(1 - \frac{\delta}{3}\right)$$

where,

A = Corrected area (cm<sup>2</sup>)

A<sub>o</sub> = Initial area of specimen (cm<sup>2</sup>)

$\delta$  = Displacement

4. Normal load = normal weight added + weight of yoke

5. Normal stress

$$\sigma = \frac{\text{Normal load}}{\text{Initial area of specimen}}$$

6. Shear stress

$$\tau = \frac{\text{Shear load}}{\text{Corrected area}}$$

## Result:

Angle of internal friction ( $\phi$ ):

Cohesion (c):

## General Remarks:

1. In the shear box test, the specimen is not failing along its weakest plane but along a predetermined or induced failure plane i.e. horizontal plane separating the two halves of the shear box. This is the main drawback of this test. Moreover, during loading, the state of stress

cannot be evaluated. It can be evaluated only at failure condition i.e Mohr's circle can be drawn at the failure condition only. Also failure is progressive.

2. Direct shear test is simple and faster to operate. As thinner specimens are used in shear box, they facilitate drainage of pore water from a saturated sample in less time. This test is also useful to study friction between two materials – one material in lower half of box and another material in the upper half of box.
3. The angle of shearing resistance of sands depends on state of compaction, coarseness of grains, particle shape and roughness of grain surface and grading. It varies between  $28^\circ$  (uniformly graded sands with round grains in very loose state) to  $46^\circ$  (well graded sand with angular grains in dense state).
4. The volume change in sandy soil is a complex phenomenon depending on gradation, particle shape, state and type of packing, orientation of principal planes, principal stress ratio, stress history, magnitude of minor principal stress, type of apparatus, test procedure, method of preparing specimen etc. In general loose sands expand and dense sands contract in volume on shearing. There is a void ratio at which either expansion contraction in volume takes place. This void ratio is called critical void ratio. Expansion or contraction can be inferred from the movement of vertical dial gauge during shearing.
5. The friction between sand particles is due to sliding and rolling friction and interlocking action.
6. The ultimate values of shear parameter for both loose sand and dense sand approximately attain the same value so, if angle of friction value is calculated at ultimate stage, slight disturbance in density during sampling and preparation of test specimens will not have much effect.

### **Questionnaire:**

## 6(b) LABORATORY VANE SHEAR TEST

### Objective:

To determine the shear strength of a soft clay deposit and to measure the sensitivity

### Standards:

1. IS: 2720 (Part-30)
2. ASTM: D-4648

### Need and scope:

A difficulty often encountered in determining the shearing resistance of soft, saturated clay deposits in the field is in obtaining undisturbed samples. The shear strength of such sensitive clays may be significantly altered in the process of sampling and handling. Vane shear test offers a method of overcoming this problem. The test can be carried both on undisturbed and remoulded specimen, and are used for evaluating the sensitivity of the soft clays, especially marine clays. It is a cheaper and quicker method. The test can also be conducted in the laboratory. The laboratory vane shear test for the measurement of shear strength of cohesive soils is useful for soils of low shear strength (less than  $0.3 \text{ kg/cm}^2$ ) for which triaxial or unconfined tests cannot be performed. The test gives the undrained strength of the soil.

### Theory:

The shear vane consists of four steel blades called vanes welded at right angles to a steel rod. The vane is gently pushed into the soil up to the required depth or at the bottom of the borehole and torque is applied gradually to the upper end of the torque rod until the soil fails in shear, due to the rotation of the vane. The torque is measured by noting the angle of twist. Shear failure occurs over the surface and the ends of a cylinder having a diameter ' $d$ ' equal to the diameter of the vane.

If the torque is measured at failure, the undrained shear strength  $q$  can be calculated. If, after the initial test, the vane is rotated rapidly several times, the soil becomes remolded or disturbed and the shear strength of the remolded or disturbed clay can be calculated, and thus the sensitivity of the clay soil determined.

## Apparatus:

1. One assembled Vane Shear Apparatus with container
2. Four calibrated torsion springs
3. Electronic balance with an accuracy of 1 gm
4. Moisture content tins
5. Steel rule or vernier calipers
6. Spade or pickaxe
7. Straight edge
8. Knife
9. Sample extruder



**Figure 1: Vane shear apparatus**

- **Sample preparation:**

- **Undisturbed**

Push the sample out of the sampler by about 6 mm and trim it flush with the cutting edge of the sampler. Force 75 mm length of the sample out and cut it and trim it to 50 mm diameter, and transfer it into sample container.

- **Remoulded**

Compact the calculated amount of soil either in a proctor mould or in a CBR mould to give a particular dry density at particular moisture content. Force the sample container into the compacted soil mass until the flange of the sample container just touches the top surface of the

compacted soil mass. Pull out the container with the sample in it and mount it on the instrument base for test.

Otherwise, mix the predetermined quantity of water in a required quantity of soil mixture with spatula, into the sample container eliminating the formation of the voids. Level the sample surface with the spatula or knife edge and compact it to specific volume through static pressure applied on it by some contrivance.

### **Experimental procedure:**

1. Measure the height (h) and internal diameter (d) of the vane.
2. Clean the apparatus thoroughly. Apply grease to the lead screw and thin oil to support pillar. Apply thin grease to gears.
3. Place the instrument on a firm base.
4. Select a suitable torsion spring and fix it to the apparatus.
5. Mount the specimen container with the specimen on the base of the vane shear apparatus and fix it securely to the base. The specimen in the tube should be at least 37.5 mm in diameter and 75 mm long (L/D ratio 2 or 3).

(If the specimen container is closed at one end it should be provided at the bottom with a hole of about 1 mm diameter)

6. Move the strain indicating pointer up to its original position on the torque shaft and clamp it tight. Turn the maximum pointer into contact with the strain indicating pointer.
7. Lower the shear vanes into the specimen to their full length gradually with minimum disturbance of the soil specimen so that the top of the vane is at least 10 mm below the top of the specimen.
8. Note the readings of the strain indicators.
9. Rotate the vane at a uniform rate approximately 0.1 degrees per second by suitably operating the torque applicator handle until the specimen fails, which is indicated by the return of the strain indicating pointer.
10. Note the final reading of the torque indicator. The difference between the two readings (initial & final) gives the angle of torque.

11. Just after the determination of the maximum torque, rotate the vane rapidly through a minimum of ten revolutions. The remoulded strength should then be determined within 1 minute after completion of the revolution.

### Calculations:

1. Torque:

$$T = K \times \theta$$

where,

T = Torque in kg-cm

K = Torsional constant of spring

$\theta$  = Angle of Torque

2. Shear strength (for fully immersed vane):

$$q_u = \frac{T}{\pi \left( \frac{d^2 h}{2} + \frac{d^3}{6} \right)}$$

where,

T = Torque in kg-cm

$q_u$  = Undrained shear strength in kg/cm<sup>2</sup>

d = diameter of vane in cm.

h = height of the vane in cm.

3. Sensitivity:

$$S_t = \frac{(q_u)_{undisturbed}}{(q_u)_{remoulded}}$$

where,

$S_t$  = Sensitivity

$(q_u)_{undisturbed}$  = undrained shear strength in undisturbed state

$(q_u)_{remoulded}$  = undrained shear strength in remoulded state

### Observation:

Spring No.

Spring Constant:

Diameter of vane:        cm

Height of vane    :        cm

**Observation Table: Undisturbed Sample:**

SI No.	Initial Reading (degrees)	Final Reading (degrees)	Difference (degrees)	Torque 'T' (kg-cm)	Shear Strength 'S' (kg/cm <sup>2</sup> )	Average S (kg/cm <sup>2</sup> )

**Observation Table: Disturbed Sample:**

SI No.	Initial Reading (degrees)	Final Reading (degrees)	Difference (degrees)	Torque 'T' (kg-cm)	Shear Strength 'S' (kg/cm <sup>2</sup> )	Average S (kg/cm <sup>2</sup> )

**Result:**

Undisturbed shear strength:

Disturbed or remoulded shear strength:

Sensitivity:

Sensitivity	Classification
1	Insensitive
2 – 4	Normal or less sensitive
4 – 8	Sensitive
8 – 15	Extra sensitive
> 16	Quick

**General remarks:**

This test is useful when the soil is soft and its water content is nearer to liquid limit.

**Questionnaire:**

1. Can you measure thixotropy using vane shear test?

## EXPERIMENT - 7

### UNCONFINED COMPRESSION TEST

#### Objective:

To determine the unconfined compressive strength of the given cohesive soil.

#### Standards:

1. Indian Standards : IS: 2720 (Part-10)
2. ASTM: D-2166
3. AASHTO: T-208

#### Need and scope of the experiment:

It is not always possible to conduct the bearing capacity test in the field. Sometimes it is cheaper to take the undisturbed soil sample and test its strength in the laboratory. Also to choose the best material for the embankment, one has to conduct strength tests on the samples selected. Under these conditions it is easy to perform the unconfined compression test on undisturbed and remoulded soil sample.

The unconfined compression test is inappropriate for dry sands or crumbly clays because the materials would fall apart without lateral confinement. A cylindrical soil specimen is subjected to gradually increasing axial stress until it fails. Since the test is quick, water is not allowed to drain out of the sample. Hence it is also called undrained or 'quick' test. Since the test produces only one mohr's circle (corresponding to  $\sigma_3 = 0$ ), the test is applicable only to soils for which  $\phi_u = 0$ , i.e, fully saturated, non-fissured clay.

$$\text{For } \sigma_3 = 0 \quad \sigma_{1f} = 2c_u \sqrt{\frac{1+\sin\phi_u}{1-\sin\phi_u}}$$

The subscript u is used since the test is an undrained test.

$$\text{Since } \phi_u = 0 \quad \sigma_{1f} = 2c_u$$

In the unconfined compression test, the major principal stress at failure,  $\sigma_{1f}$  is called the unconfined compressive strength and is usually denoted by the notation  $q_u$ .

$$\text{Hence,} \quad q_u = 2c_u$$

The undrained shear strength of saturated clay is expressed as,

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

#### Apparatus:

1. Loading frame of capacity of 2t, with constant rate of movement.
2. Proving ring of 0.01 kg sensitivity for soft soils; 0.05 kg for stiff soils.
3. Soil trimmer.
4. Split mould: 38 mm diameter, 76 mm long.
5. Frictionless end plates (Perspex plate with silicon grease coating).
6. Evaporating dish (Aluminum container).
7. Soil sample of 75 mm length.
8. Dial gauge (0.01 mm accuracy).
9. Balance of capacity 200 g and sensitivity to weigh 0.01 g.
10. Oven thermostatically controlled with interior of non-corroding material to maintain the temperature at the desired level.
11. Sample extractor and split sampler.
12. Vernier calipers



**Figure 1: Experimental setup for unconfined compression test**

## Sample preparation:

1. **Specimen size:** The specimen for the test shall have a minimum diameter of 38 mm and the largest particle contained within the test specimen shall be smaller than 1/8 of the specimen diameter. If after completion of test on undisturbed sample, it is found that larger particles than permitted for the particular specimen size tested are present, it shall be noted in the report of test data under remarks. The height to diameter ratio shall be within 2 to 2.5.

Measurements of height and diameter shall be made with vernier calipers or any other suitable measuring device to the nearest 0.1 mm.

### 2. Undisturbed specimen

1. Note down the sample number, borehole number and the depth at which the sample was taken.
2. Remove the protective cover (paraffin wax) from the sampling tube.
3. Place the sampling tube extractor and push the plunger till a small length of sample moves out.
4. Trim the projected sample using a wire saw.
5. Again, push the plunger of the extractor until a 75 mm long sample comes out.
6. Cutout this sample carefully and hold it on the split sampler so that it does not fall.
7. Take about 10 to 15 g of soil from the tube for water content determination.
8. Note the container number and take the net weight of the sample and the container.
9. Measure the diameter at the top, middle, and the bottom of the sample and find the average and record the same.
10. Measure the length of the sample and record.
11. Find the weight of the sample and record.

### 3. Remoulded sample

1. For the desired water content and the dry density, calculate the weight of the dry soil  $W_s$  required for preparing a specimen of 3.8 cm diameter and 7.5 cm long.
2. Add required quantity of water  $W_w$  to this soil.

$$W_w = (W_s * W/100) \text{ g}$$

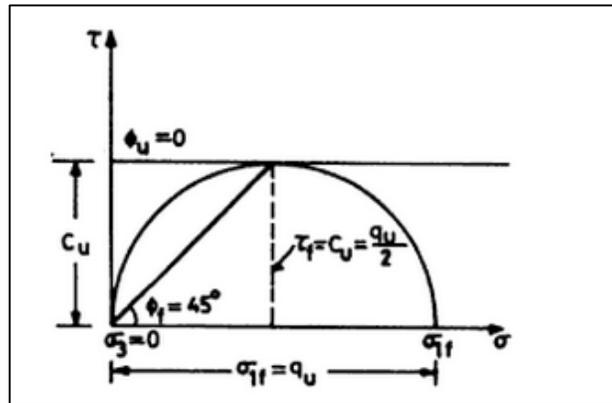
3. Mix the soil thoroughly with water.

4. Place the wet soil in a tight thick polythene bag in a humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
5. After 24 hours take the soil from the humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
6. Place the lubricated moulded with plungers in position in the load frame.
7. Apply the compressive load until the specimen is compacted to a height of 7.5 cm.
8. Eject the specimen from the constant volume mould.
9. Record the correct height, weight and diameter of the specimen.

### **Test procedure:**

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

15. Take the sample from the failure zone of the specimen for the water content determination.
16. The values of compressive stress  $\sigma$  and strain  $\epsilon$  obtained are plotted on a natural graph along Y-axis and X-axis respectively.
17. The maximum stress from this plot gives the value of the unconfined compressive strength ( $q_u$ ).
18. In case no maximum occurs within 20 percent axial strain, the unconfined compressive strength shall be taken as the stress at 20 percent axial strain.



**Figure 2: Mohr-Coulomb plot for unconfined compression test**

### Calculations:

1. Axial Strain ( $\epsilon$ ):

$$\epsilon = \frac{\text{Change in length } (\Delta L)}{\text{Original length of specimen } (L_0)}$$

2. Average Cross sectional area (A)

$$A = \frac{A_0}{1 - \epsilon}$$

Where,  $A_0$  is the original cross-sectional area of the specimen

3. Compressive stress ( $\sigma_c$ )

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

Where, P is compressive force.

A is average cross sectional area.

### Observations:

Specific gravity ( $G_s$ ) =

Bulk density =  $\text{kN/m}^3$

Water content=

Degree of saturation = %

Diameter ( $D_0$ ) of the sample = cm

Area of cross-section =  $\text{cm}^2$

Initial length ( $L_0$ ) of the sample = cm

**Sample 1: Proving ring number/constant:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $e$	Corrected area $A$ ( $\text{cm}^2$ )	Proving ring dial reading	Axial force $P$ (kg)	Compressive stress ( $\text{kg}/\text{cm}^2$ )

**Sample 2:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $e$	Corrected area $A$ (cm <sup>2</sup> )	Proving ring dial reading	Axial force $P$ (kg)	Compressive stress (kg/cm <sup>2</sup> )

**Sample 3:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $e$	Corrected area $A$ (cm <sup>2</sup> )	Proving ring dial reading	Axial force $P$ (kg)	Compressive stress (kg/cm <sup>2</sup> )

**Result:**

Unconfined compressive strength ( $q_u$ ):

Undrained shear strength ( $\tau_f$ ):

Failure pattern:

Water content in specimen at testing:

Sensitivity = ( $q_u$  for undisturbed sample)/( $q_u$  for remoulded sample):

**Safety and precautions:**

1. The specimen shall be handled carefully to prevent disturbance, change in cross section, or loss of water.
2. The specimen shall be of uniform circular cross-section with ends perpendicular to the axis of the specimen.
3. Where the prevention of the possible development of appreciable capillary forces is required, the specimens shall be sealed with rubber membranes, thin plastic coatings, or with coating or grease or sprayed plastic immediately after preparation and during the entire testing cycle.
4. Representative sample cuttings taken from the tested specimen shall be used for the determination of water content.

**Questionnaire:**

1. What is the difference between uniaxial compression and unconfined compression?
2. Is it suitable to conduct the above test for all types of soil?

# EXPERIMENT - 8

## TRIAXIAL SHEAR TEST

### **Objective:**

To determine shear strength parameters of the given soil sample by conducting unconsolidated undrained (UU) triaxial shear test.

### **Standards:**

1. Indian Standards : IS: 2720 (Part-11)
2. ASTM: D-2850
3. AASHTO: T-234

### **Theory:**

The triaxial compression test, introduced by Casagrande and Terzaghi in 1936, is by far the most popular and extensively used shearing strength test, both for field application and for purposes of research. As the name itself suggests, the soil specimen is subjected to three compressive stresses in mutually perpendicular directions, one of the three stresses being increased until the specimen fails in shear. Usually a cylindrical specimen with a height equal to twice its diameter is used. The desired three-dimensional stress system is achieved by an initial application of all-round fluid pressure or confining pressure through water. While this confining pressure is kept constant throughout the test, axial or vertical loading is increased gradually and at a uniform rate. The axial stress thus constitutes the major principal stress and the confining pressure acts in the other two principal directions, the intermediate and minor principal stresses being equal to the confining pressure.

The apparatus consists of a lucite or perspex cylindrical cell, called 'triaxial cell' with appropriate arrangements for an inlet of cell fluid and application of pressure by means of a compressor, outlet of pore water from the specimen if it is desired to permit drainage which otherwise may serve as pore pressure connection and axial loading through a piston and loading cap.

The soil sample is placed inside a rubber sheath, which is sealed to a top cap and bottom pedestal by rubber O-rings. For tests with pore pressure measurement, porous discs are placed at the bottom, and sometimes at the top of the specimen. Filter paper drains may be provided around the outside of the specimen in order to speed up the consolidation process. Pore pressure generated inside the specimen during testing can be measured by means of pressure transducers.

The triaxial compression test consists of two stages:

- (i) **First stage:** In this, a soil sample is set in the triaxial cell and confining pressure is then applied.
- (ii) **Second stage:** In this, additional axial stress (also called deviator stress) is applied which induces shear stresses in the sample. The axial stress is continuously increased until the sample fails.

During both the stages, the applied stresses, axial strain, and pore water pressure or change in sample volume can be measured.

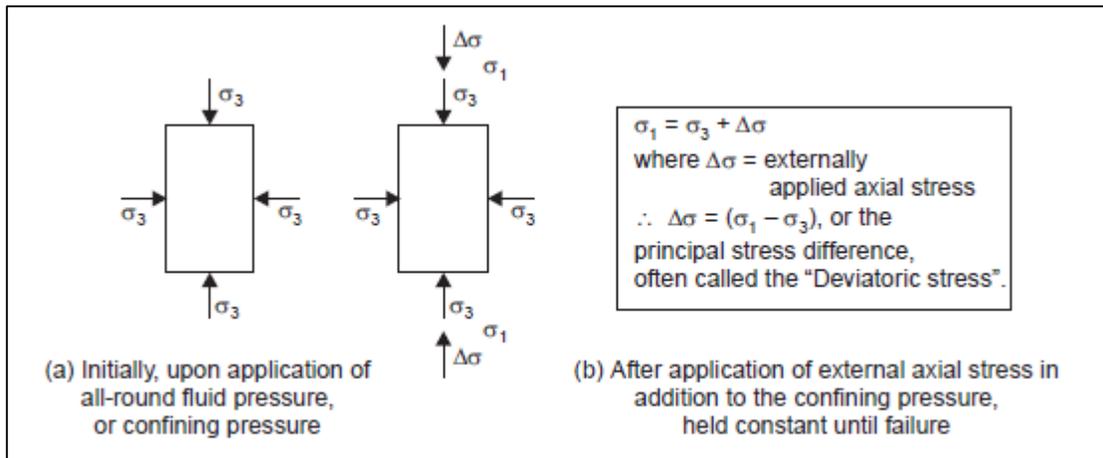
### Test types:

There are several test variations, and those used mostly in practice are:

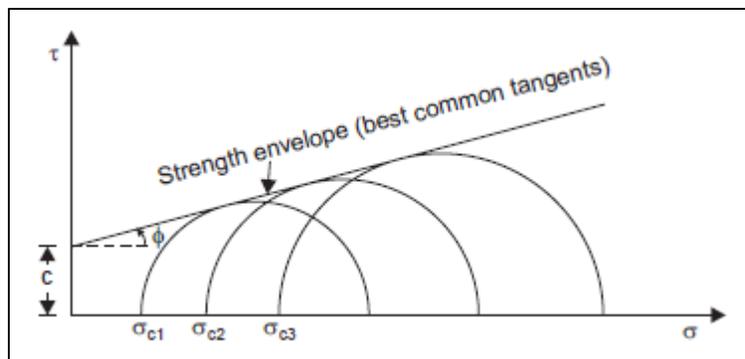
1. **UU (unconsolidated undrained) test:** In this, cell pressure is applied without allowing drainage. Then keeping cell pressure constant, deviator stress is increased to failure without drainage.
2. **CU (consolidated undrained) test:** In this, drainage is allowed during cell pressure application. Then without allowing further drainage, deviator stress is increased keeping cell pressure constant.
3. **CD (consolidated drained) test:** This is similar to CU test except that as deviator stress is increased, drainage is permitted. The rate of loading must be slow enough to ensure no excess pore water pressure develops.

In the UU test, if pore water pressure is measured, the test is designated by  $\overline{UU}$ .

In the CU test, if pore water pressure is measured in the second stage, the test is symbolized as  $\overline{CU}$ .



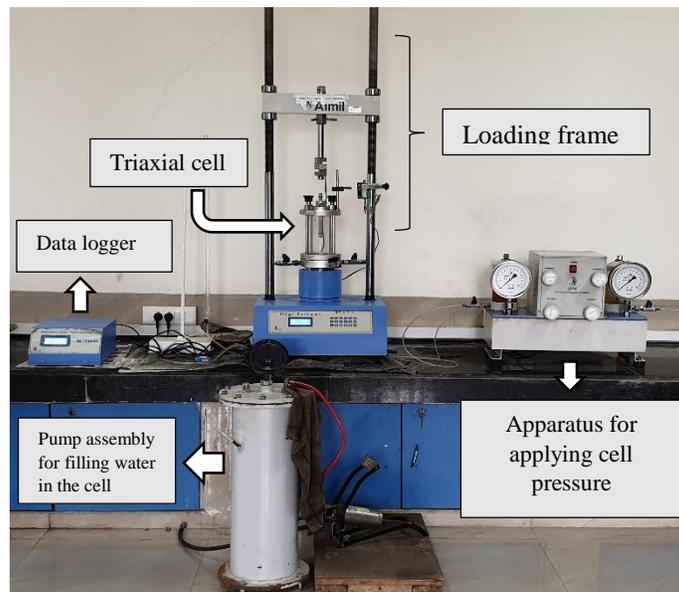
**Stresses on soil element under triaxial testing**



**Mohr's circle plot for triaxial compression test**

**Apparatus:**

1. Triaxial testing machine complete with triaxial cell
2. Water pressure unit with hand pump
3. Proving ring
4. Dial gauge
5. Rubber membranes
6. Membrane stretcher
7. Sample trimming apparatus
8. Bins for moisture content determinations
9. Balance and box of weights
10. Drying oven



**Figure 1: Triaxial test setup**

**Sample preparation:**

**Undisturbed specimens:**

The object of the specimen preparation is to produce cylindrical specimens of height twice the specimen diameter with plane ends normal to the axis and with the minimum change of the soil structure and moisture content. The method of preparation will depend on whether the sample is received in the laboratory in a tube or as a block sample.

**Remoulded samples:**

Remoulded samples prepared at the desired moisture and density by static and dynamic methods of compaction or by any other suitable method, where necessary.

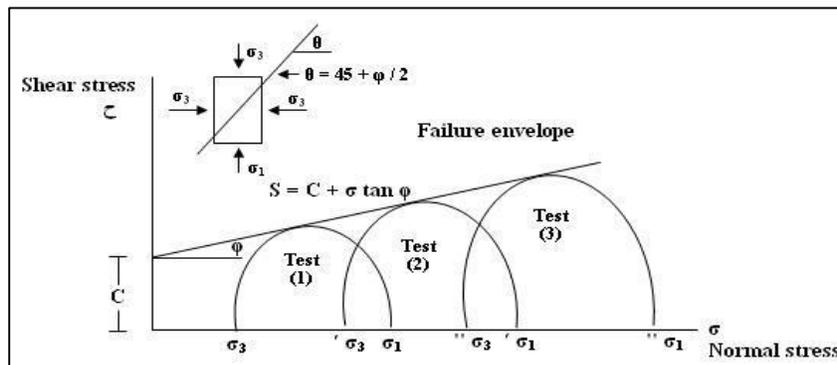
**Experimental procedure:**

1. Trim the soil specimen (prepared from the sampling tube of an undisturbed sample tube using universal extractor frame or from a compacted soil specimen as per standard proctors method, at optimum moisture content or any other moisture content to suite the field situations).
2. Using the trimming apparatus if necessary the trimmed specimen should be 76.2 mm long and 38.1 mm in diameter. The diameter and the length are measured at not less than 3 places and the average values are used for computation.
3. Note the weight of the specimen (W1).

4. The specimen is then enclosed in a 38.1 mm diameter and about 100 mm long rubber membrane, using the membrane stretcher. Spreading back the ends of the membrane over the ends of the stretcher and applying suction between the stretcher and the rubber membranes does by inhalation.
5. The membrane and stretcher are then easily slide over the specimen, the suction is released and membrane is unrolled from the ends of the stretcher.
6. Use non-porous stones on either side of the specimen as neither any pressure is to be measured nor any drainage of air or water is allowed.
7. Remove the porous cylinder from its base removing the bottom fly nuts.
8. The pedestal at the centre of the base of the cylinder on which the specimen is to be placed is cleaned and a 38.1 mm diameter rubber O-ring is rolled over to its bottom.
9. The specimen along with the non-porous plate on either side is centrally placed over the pedestal and the bottom edge of the machine covering the specimen is sealed against the pedestal by rolling back the O-ring over the membrane.
10. The cap is placed over the top plate of the specimen and the top of the rubber membrane is sealed against the cap by carefully rolling over it another O-ring. This arrangement of rubber O-ring forms the effective seal between the specimen with the membrane and the water under pressure.
11. The specimen is checked for its verticality and co-axiality with the cylinder chamber.
12. The chamber along with the loading plunger is carefully placed over its base without disturbing the soil specimen and taking care to see that the plunger rests on the cap of the specimen centrally.
13. The loading frame is then adjusted so that it just touches the plunger top by naked eye. The chamber is then rotated if necessary such that the dial gauge, recording compression, rests centrally over the top of the screw which can be locked at any level and which is attached to the top of the cylinder chamber carrying the specimen.
14. The cylinder is then attached to the base plate tightly by means of tightening the nuts.
15. The valve to drain out the chamber and the valve to drain out the air and water from the sample are closed and the air lock nut at the top of the cylinder is kept open to facilitate the

- exit of air as water enters the chamber through another valve which connects the chamber to the water storage cylinder subjected to a pressure by a compressor or by any other means.
16. The water storage cylinder is filled with water completely and its top is then closed by means of a valve. Necessary pressure is built up in the cylinder by working the hand pump and the pressure communicated to the cylinder where the specimen is placed, by opening the connecting valve.
  17. The cylindrical chamber is allowed to be filled up completely which is indicated by the emergence of water through the air lock nut at the top of the chamber. Then the airlock nut is closed to develop necessary confining pressure by using compressor and the same is maintained constant.
  18. If necessary, bring the loading plunger down until it is in contact with the specimen top cap by means of hand operated loading device. This is indicated by a spurt in the reading of the proving ring dial gauge.
  19. For this position, adjust the deformation dial gauge reading to zero.
  20. Record the initial reading of the proving ring and compression dial gauge.
  21. The vertical load is applied to the specimen by starting the motor at the loading frame. The change in the proving ring dial gauge gives the measure of the applied load.
  22. The deformation dial gauge gives the deformation in the soil specimen, which can be used to compute strain in the soil.
  23. Take readings of proving ring dial gauge at 0.5, 1.0, 1.5, 2.0% (or any other smaller values) of strain and for every 1.0% strain thereafter up to failure or 20% strain whichever is earlier.
  24. Throughout the test, make sure that the chamber, containing pressure is kept constant at the desirable value as indicated by the pressure gauge on the water cylinder. If necessary, the pressure can be made good for any possible losses by working the compressor.
  25. After specimen has failed or 20% strain is recorded, as the case may be
    - (a) stop application of load
    - (b) disconnect the chamber from water storage cylinder by closing the linger valve
    - (c) open the air lock knob a little and
    - (d) open the valve to drain out the water in the cylinder.
  26. After a few seconds open the airlock nut completely to facilitate quick draining out of water, by entry of air at top of the cylinder.

27. After the water is completely drained out, take out the cylinder from loading frame carefully, loosen the nuts and remove the Lucite cylinder from its base, without disturbing the sample.
28. Note the space of the failed specimen, angle of shear plane if any and dimensions of the specimen.
29. Wipe the rubber membrane dry and find its weight  $W_2$  that should be same as  $W_1$ .
30. Remove the membrane from the specimen and take a representative specimen preferably from the sheared zone.
31. Repeat the test with three specimens of the same soil sample subjected to three different lateral pressures (confining) of 0.5, 1.0 and 1.5 kg/cm<sup>2</sup> (5, 10 and 15 psi or 50, 100 and 150 kpa)
32. A graph is drawn between the deviator stress and strain. The deviator stress is the difference between the stresses in axial and radial direction i.e.  $(\sigma_1 - \sigma_3)$  and is equal to the vertical stress  $P/A$ .  $\sigma_3$  is the lateral confining pressure at any time, which is constant for a test.
33. From the plot, determine the second result at half the ultimate stress, which can be taken as modulus of elasticity.
34. The mohr's circle of stress to define the state of stress at failure is drawn for each sample. The circle has for its centre point  $(\sigma_1 + \sigma_3)/2$  and the radius equal to  $(\sigma_1 - \sigma_3)/2$ .
35. An envelope, which approximates to a straight line, is drawn touching the circle.
36. The intercept made on Y-axis and the slope of the envelope gives the values of strength parameters of the soil  $C$  and  $\phi$  respectively.



**Figure 2: Mohr-coulomb plot for triaxial compression test**

**Calculations:**

1) **Axial Strain ( $\epsilon$ ):**

$$\epsilon = \frac{\text{Change in length } (\Delta L)}{\text{Original length of specimen } (L_0)}$$

2) **Average Cross sectional area (A)**

$$A = \frac{A_0}{1 - \epsilon}$$

where,

$A_0$  is the original cross-sectional area of the specimen

3) **Deviator stress ( $\sigma_d$ )**

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

where,

P is axial load

A is average cross sectional area

4) **Major Principal Stress ( $\sigma_1$ )**

$$\sigma_1 = \sigma_d + \sigma_3$$

where,

$\sigma_d$  is deviator stress

$\sigma_3$  is cell pressure

5) **Correction to allow for the restraining effect of the rubber membrane:**

$$\text{Correction} = 4M \frac{(1 - \epsilon)}{D}$$

where,

M is the compression modulus of the rubber membrane in  $\text{kg/cm}^2$ .

$\epsilon$  is the axial strain at the maximum principal stress.

D is initial diameter of the sample in cm.

The value of the correction calculated as above shall be deducted from the measured maximum principal stress difference to give the corrected value of the maximum principal stress.

**Safety and precautions:**

1. The most convenient method of recording the mode of failure is by means of sketch indicating the position of the failure planes. The angle of the failure plane to the horizontal may be recorded, if required. These records should be completed without undue delay to avoid loss of moisture from specimen.

2. Comparison with the recorded mass of the specimen before testing provides a check on the impermeability of the rubber membrane if water has been used as the operating fluid in the cell.
3. Precautions shall be taken to prevent adhesion between the soil and the extruder, for example, by interposing oiled paper discs or lightly oiling the face of the extruder.
4. The length, diameter and mass of the specimen shall be measured to an accuracy enabling the bulk density to be calculated to an accuracy of  $\pm 0.1$  percent.

**Observation and recording:**

The machine is set in motion (or if hand operated the hand wheel is turned at a constant rate) to give a rate of strain 2% per minute. The strain dial gauge reading is then taken and the corresponding proving ring reading is taken the corresponding proving ring chart. The load applied is known. The experiment is stopped at the strain dial gauge reading for 15% length of the sample or 15% strain.

**Observations:**

Sample No:

Date:

Location:

Length:

Diameter:

Initial Volume:

Size of specimen:

Proving ring constant:

Initial area:

Strain dial least count:

**Sample 1:**

**Cell Pressure:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $\epsilon$	Corrected area A (cm <sup>2</sup> )	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm <sup>2</sup> )

Deviator stress at failure:

**Sample 2:**

**Cell Pressure:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $\epsilon$	Corrected area A (cm <sup>2</sup> )	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm <sup>2</sup> )

Deviator stress at failure:

**Sample 3:**

**Cell Pressure:**

Deformation dial gauge reading	Axial deformation $\Delta L$ (mm)	Axial strain $\epsilon$	Corrected area A (cm <sup>2</sup> )	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm <sup>2</sup> )

Deviator stress at failure:

## General remarks:

1. It is assumed that the volume of the sample remains constant and that the area of the sample increases uniformly as the length decreases. The calculation of the stress is based on this new area at failure, by direct calculation, using the proving ring constant and the new area of the sample. By constructing a chart relating strain readings, from the proving ring, directly to the corresponding stress.
2. The strain and corresponding stress is plotted with stress abscissa and curve is drawn. The maximum compressive stress at failure and the corresponding strain and cell pressure are found out.
3. The stress results of the series of triaxial tests at increasing cell pressure are plotted on a mohr stress diagram. In this diagram a semicircle is plotted with normal stress as abscissa shear stress as ordinate.
4. The condition of the failure of the sample is generally approximated to by a straight line drawn as a tangent to the circles, the equation of which is  $\tau = c + \sigma \tan\phi$ . The value of cohesion,  $c$  is read of the shear stress axis, where it is cut by the tangent to the mohr circles, and the angle of shearing resistance ( $\phi$ ) is angle between the tangent and a line parallel to the shear stress.

## Questionnaire:

1. What is the stress path of the triaxial shear tests?
2. What is the basis of the sample size?

## EXPERIMENT 9

### CALIFORNIA BEARING RATIO TEST

#### Objective:

To determine the California bearing ratio (C.B.R.) by conducting a load penetration test in the laboratory.

#### Standards:

1. Indian Standards : IS: 2720 (Part-16)
2. ASTM: D-1883 -05

#### Definition of C.B.R.

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston (50 mm diameter) at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

$$\text{C.B.R.} = \frac{\text{Test load}}{\text{Standard load}} \times 100$$

The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%

Table 1: Standard load vs penetration data

Penetration of plunger (mm)	Standard load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

## Need and scope:

The California bearing ratio test is penetration test meant for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

This instruction sheet covers the laboratory method for the determination of C.B.R. of undisturbed and remoulded / compacted soil specimens, both in soaked as well as unsoaked state.

## Apparatus:

1. Cylindrical mould with inside diameter 150 mm and height 175 mm, provided with a detachable extension collar 50 mm height and a detachable perforated base plate 10 mm thick.
2. Spacer disc 148 mm in diameter and 47.7 mm in height along with handle.
3. **Metal rammers:** Weight 2.6 kg with a drop of 310 mm (or) weight 4.89 kg a drop 450 mm.
4. **Weights:** One annular metal weight and several slotted weights weighing 2.5 kg each, 147 mm in dia, with a central hole 53 mm in diameter.
5. **Loading machine:** With a capacity of at least 5000 kg and equipped with a movable head or base that travels at a uniform rate of 1.25 mm/min. Complete with load indicating device.
6. Metal penetration piston 50 mm dia and minimum of 100 mm in length.
7. Two dial gauges reading to 0.01 mm.
8. **Sieves.** 4.75 mm and 20 mm I.S. Sieves.
9. Miscellaneous apparatus, such as a mixing bowl, straight edge, scales soaking tank or pan, drying oven, filter paper and containers.



## Figure 1: CBR mould

### Preparation of test specimen:

- **Undisturbed specimen:**

Attach the cutting edge to the mould and push it gently into the ground. Remove the soil from the outside of the mould which is pushed in. When the mould is full of soil, remove it from weighing the soil with the mould or by any field method near the spot.

### Determine the density:

- **Remoulded specimen :**

Prepare the remoulded specimen at Proctor's maximum dry density or any other density at which C.B.R is desired. Maintain the specimen at optimum moisture content or the field moisture as required. The material used should pass 20 mm I.S. sieve but it should be retained on 4.75 mm I.S. sieve. Prepare the specimen either by dynamic compaction or by static compaction.

### Dynamic Compaction:

1. Take about 4.5 to 5.5 kg of soil and mix thoroughly with the required water. Fix the extension collar and the base plate to the mould. Insert the spacer disc over the base. Place the filter paper on the top of the spacer disc.
2. Compact the mix soil in the mould using either light compaction or heavy compaction. For light compaction, compact the soil in 3 equal layers, each layer being given 55 blows by the 2.6 kg rammer dropped from height of 310 mm. For heavy compaction compact the soil in 5 layers, 56 blows to each layer by the 4.89 kg rammer.
3. Remove the collar and trim off soil.
4. Turn the mould upside down and remove the base plate and the displacer disc.
5. Weigh the mould with compacted soil and determine the bulk density and dry density.
6. Put filter paper on the top of the compacted soil (collar side) and clamp the perforated base plate on to it.

### Static compaction:

1. Calculate the weight of the wet soil at the required water content to give the desired density when occupying the standard specimen volume in the mould from the expression.

$$W = \text{desired dry density} \times (1 + w) \times V$$

where,

W = Weight of the wet soil

w = desired water content

V = volume of the specimen in the mould = 2250 cm<sup>3</sup> (as per the mould available in laboratory)

2. Take the weight W (calculated as above) of the mix soil and place it in the mould.
3. Place a filter paper and the displacer disc on the top of soil.
4. Keep the mould assembly in static loading frame and compact by pressing the displacer disc till the level of disc reaches the top of the mould.
5. Keep the load for some time and then release the load. Remove the displacer disc.
6. The test may be conducted for both soaked as well as unsoaked conditions.
7. If the sample is to be soaked, in both cases of compaction, put a filter paper on the top of the soil and place the adjustable stem and perforated plate on the top of filter paper.
8. Put annular weights to produce a surcharge equal to weight of base material and pavement expected in actual construction. Each 2.5 kg weight is equivalent to 7 cm construction. A minimum of two weights should be put.
9. Immerse the mould assembly and weights in a tank of water and soak it for 96 hours.  
Remove the mould from tank.

Note the consolidation of the specimen.

#### **Procedure for Penetration Test:**

1. Place the mould assembly with the surcharge weights on the penetration test machine.
2. Seat the penetration piston at the center of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the piston on the sample is established.
3. Set the stress and strain dial gauge to read zero. Apply the load on the piston so that the penetration rate is about 1.25 mm/min.
4. Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm. Note the maximum load and corresponding penetration if it occurs for a penetration less than 12.5 mm.
5. Detach the mould from the loading equipment. Take about 20 to 50 g of soil from the top 3 cm layer and determine the moisture content.

#### **Observation and recording:**

## For Dynamic Compaction

Optimum water content (%)

Weight of mould + compacted specimen = g

Weight of empty mould = g

Weight of compacted specimen = g

Volume of specimen = cm<sup>3</sup>

Bulk density = g/cc

Dry density = g/cc

For static compaction:

Dry density = g/cc

Moulding water content = %

Wet weight of the compacted soil, (W) = g

Period of soaking 96 hrs. (4 days).

## For penetration Test:

Calibration factor of the proving ring =

Surcharge weight used = (kg)

Water content after penetration test = (%)

Least count of penetration dial =

If the initial portion of the curve is concave upwards, apply correction by drawing a tangent to the curve at the point of greatest slope and shift the origin (Fig. 40). Find and record the correct load reading corresponding to each penetration.

$$C.B.R. = \frac{P_T}{P_S} \times 100$$

where

$P_T$  = Corrected test load corresponding to the chosen penetration from the load penetration curve.

$P_S$  = Standard load for the same penetration taken from the Table 1.

**Observations:**

**Penetration Test:**

Loading rate:

Proving Ring No:

Calibration factor:

Least count of Dial gauge:

**TEST TYPE: UNSOAKED**

<b>Deformation dial gauge reading</b>	<b>Penetration (mm)</b>	<b>Proving ring reading</b>	<b>Load (kg)</b>	<b>Corrected Load (kg)</b>

**CBR VALUE:**

**TEST TYPE: SOAKED**

<b>Deformation dial gauge reading</b>	<b>Penetration (mm)</b>	<b>Proving ring reading</b>	<b>Load (kg)</b>	<b>Corrected Load (kg)</b>
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**CBR VALUE:**

**Interpretation and recording:**

	<b>Soaked</b>	<b>Unsoaked</b>
C.B.R. of specimen at 2.5 mm penetration		
C.B.R. of specimen at 5.0 mm penetration		

The C.B.R. values are usually calculated for penetration of 2.5 mm and 5 mm. Generally the C.B.R. value at 2.5 mm will be greater than that at 5 mm and in such a case the former shall be taken as C.B.R. for design purpose. If C.B.R. for 5 mm exceeds that for 2.5 mm, the test should be repeated. If identical results follow, the C.B.R. corresponding to 5 mm penetration should be taken for design.

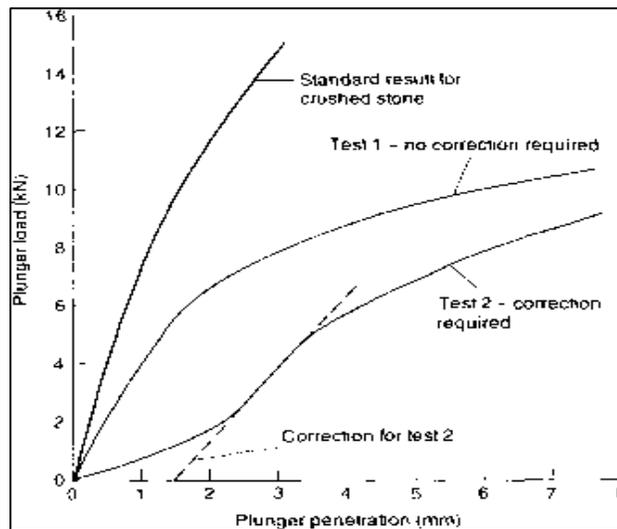
### Variation in CBR:

1. At least three samples should be tested on each type of soil at the same density and moisture content to take care of the variation in the values.
2. This will enable a reliable average value to be obtained in most cases.
3. Where variation with in CBR values is more than the permissible maximum variation the design CBR value should be the average of six samples and not three

CBR (%)	Maximum variation in CBR value
5	$\pm 1$
5-10	$\pm 2$
11-30	$\pm 3$
31 and above	$\pm 5$

### Initial Concavity

- The load – penetration curve may show initial concavity due to the following reasons:
    - The top layer of the sample might have become too soft due to soaking in water
    - The surface of the plunger or the surface of the sample might not be horizontal
1. Draw a tangent to the load-penetration curve where it changes concavity to convexity
  2. The point of intersection of this tangent line with the x-axis is taken as the new origin
  3. Shift the origin to this point (new origin) and correct all the penetration values.



**Figure 1: Load-penetration curve**

**Result:**

Unsoaked CBR value:

Soaked CBR value:

**Safety and precautions:**

1. Align the surcharge weight with the plunger so that the plunger penetrates freely into the soil.
2. After soaking the free water collected in the mould shall be removed and the specimen allowed to drain downwards for 15 minutes. Care shall be taken not to disturb the surface of the specimen during the removal of water.

**Questionnaire:**

1. The CBR is a static or dynamic property of soil.
2. What is the basis of providing surcharge weight?