K.S. School of Engineering & Management

15, Mallasandra, Off Kanakapura Road
Bangalore 560109

Department of Civil Engineering

V Semester

Geotechnical Engineering Laboratory

(Code: BCV502)

Academic Year: 2024-25

Laboratory Manual/Observation Book

Name of the Student :

University Seat No :

K S SCHOOL OF ENGINEERING AND MANAGEMENT

Holiday Village Road, Vajarahalli Village, Mallasandra, off, Kanakapura Rd, Bengaluru, Karnataka 560109

VISION

To impart quality education in engineering and management to meet technological business and societal needs through holistic education and research.

MISSION

K. S. School of Engineering and Management shall,

- Establish state-of-art infrastructure to facilitate effective dissemination of technical and managerial knowledge.
- Provide comprehensive educational experience through a combination of curricular and experiential learning, strengthened by industry-institute interaction.
- Pursue socially relevant research and disseminate knowledge.
- Inculcate leadership skills and foster entrepreneurial spirit among students.

DEPARTMENT OF CIVIL ENGINEERING

VISION

- To emerge as one of the leading Civil Engineering Department by producing competent and quality ethical engineers with strong foot hold in the areas of Infrastructure development and research.

MISSION

- Provide industry oriented academic training with strong fundamentals and applied skills.
- Engage in research activities in Civil Engineering and allied fields and inculcate the desired perception and value system in the students.

INDEX

Experiment No. 1

Determination of Moisture Content

Objective

Determine the natural water content of the given soil sample.

Need and Scope of Experiment

In almost all soil tests natural moisture content of the soil is to be determined. The knowledge of the natural moisture content is essential in all studies of soil mechanics. To sight a few, natural moisture content is used in determining the bearing capacity and settlement. The natural moisture content will give an idea of the state of soil in the field.

Theory

The natural water content also called the natural moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage.

Apparatus Required

Non-corrodible air-tight containers, electric oven, desiccator and weighing balance.

Procedure

1. Clean the container with lid, dry it and weigh it (M_1).
2. Take a specimen of the sample in the container and weigh with lid (M_2).
3. Keep the container in the oven with lid removed. Dry the specimen to constant weight maintaining the temperature between 105° C to 110°C for a period varying with the type of soil but usually 16 to 24 hours.
4. Record the final constant weight (M_3) of the container with dried soil sample.

Peat and other organic soils are to be dried at a lower temperature (say 60^0 C) possibly for a longer period. Certain soils contain gypsum, which on heating loses its water of crystallization. If it is suspected that gypsum is present in the soil sample used for moisture content determination it shall be dried at not more than 80 °C and possibly for a longer time.

Observations & Calculations

S.No.	Sample No.	1	2	3
1	Weight of container with lid(M_1) g			
2	Weight of container with lid +wet soil (M_2) g			
3	Weight of container with lid +dry soil (M_3)g			
4	Water/Moisture content , $w = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100$			

Result

The natural moisture content of the soil sample is _________

Relevant BIS Code:

IS: 2720 (Part 2/Section 1) – 1973 (Reaffirmed 2010).

Viva Questions

1) Define water content

   It is the ratio of the weight of water to the weight of the solids in a given mass of soil

2) List the various methods of determining water content

- Oven drying method
- Rapid moisture meter method

3) What are the applications of water content in geotechnical engineering?

   - Strength & stability of soils in almost all the cases depend upon its moisture content and hence it is required to find out the moisture content of the soils.
   - It is also used to determine the plasticity and shrinkage limit of fine grained soils, for which moisture content is used as the index

Experiment No. 2

Grain Size Distribution by Sieve Analysis

Objective

The grain size analysis is an attempt to determine the relative proportions of different grain sizes which make up a given soil mass and draw graph between log grain size of soil and % finer.

Need and Scope of Experiment

The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used.

Apparatus Required

Weighing balance, I.S sieves and mechanical sieve shaker

Theory

Effective size (D_{10}) is the particle diameter corresponds to 10% finer in the grain size distribution graph. It means 10% of particle is finer than this diameter.

Uniformity coefficient: $Cu = \frac{D_{60}}{D_{10}}$

Coefficient of Curvature $Cc = \frac{(D_{30})^2}{(D_{60} \times D_{10})}$

Procedure

1. Take a representative sample of soil received from the field and dry it in the oven.
2. Take 1,000 g of dried soil with all the grains properly separated out.

3. Set the sieves one over the other in an ascending order of size of sieves from the bottom with a pan attached to the lowest 75 μ sieve and fit the nest to a mechanical shaker.
4. Place the selected sample of soil on the top 4.75 mm sieve and close it with a cap.
5. The whole nest of sieves is given a horizontal shaking for 10 min. till the soil retained on each sieve reaches a constant value.
6. Determine the mass of soil retained on each sieve including that collected in the pan below.

Observations and Calculations

Mass of dry soil sample (M) = g

I.S sieve size (mm)	Mass retained on each sieve (g)	Percentage retained on each sieve	Cumulative percentage retained on each sieve	Percent finer	Remarks

The percentage of soil retained on each sieve shall be calculated on the basis of total weight of soil sample taken. Cumulative percentage of soil retained on successive sieve is found.

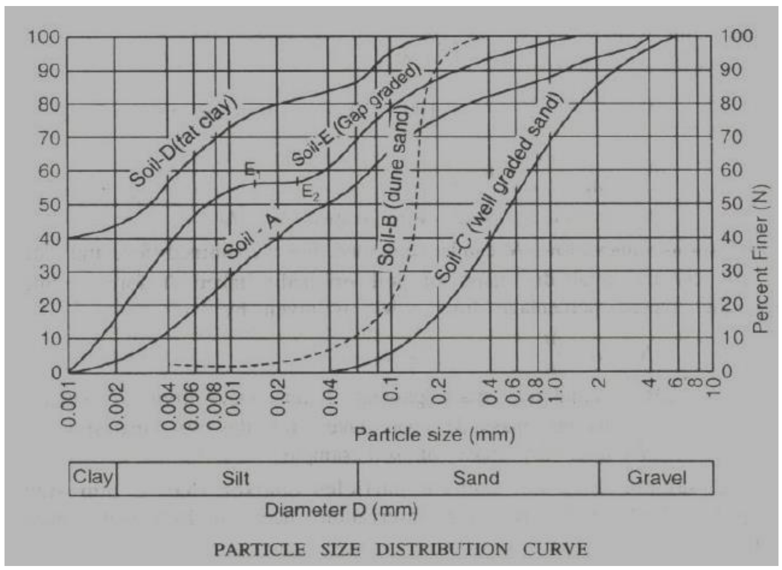
Result:

Draw a graph between log sieve size Vs % finer. The graph is known as gradation curve. Corresponding to 10%, 30% and 60% finer, obtain diameters from the graph and designate them as D_{10}, D_{30}, and D_{60}.

Effective size, D_{10} = mm

Uniformity coefficient: C_u =

Coefficient of Curvature C_c =



(I.S 460-1962) The sieves for soil tests: 4.75 mm to 75 µ.

Relevant BIS Code: IS 2720-Part 4, 1985

Viva Questions

1) What is grain size analysis and name its two stages of the test.
   - Grain size analysis or Gradation analysis is used for classification of soils and it is conducted in two stages
   - (i) *Dry analysis:* It involves shaking the representative soil sample in a set of sieves of varying apertures. This test is conducted for coarse grain soils.
     (ii) *Wet analysis*: It meant for fine grained soils (fractions passing through 75μ carried out with the use of hydrometer or a pippete. The basis for wet analysis is Stoke's Law of sedimentation

2) What are the applications/uses of grain size analysis?
   - Useful for classification of soils
   - In the case of coarse grained soils, sieve analysis can give a fair idea about the probable density, shear strength and permeability that would be achieved in the field
   - In the case of clean sands certain relationships correlating the effective size (D_{10}) and permeability have been developed ($K=CD_{10}^2$, where, $C=100$)
   - To find out clay content which enables us to get the value of activity. Activity indicates the potential plasticity of clay particles from which a rough idea about clay minerals can be obtained
   - For design of filter in earth dams or design of relief wells. The following formula is used

     (a) $$\frac{D_{15}\text{ (filter material)}}{D_{85}\text{ (protected soil)}} < 4 \text{ to } 5$$

     (b) $$\frac{D_{15}\text{ (filter material)}}{D_{15}\text{ (protected soil)}} > 4 \text{ to } 5$$

   - Certain fine sands especially in foundations are susceptible to quick sand condition in earthquakes. Terzaghi and others have fixed approximate range of grain-size distribution in which the sands are susceptible to liquefaction. i.e. $D_{10} < 0.1$, $Cu < 5$, $I_D < 50\%$, $n > 44\%$

3) Define Uniformity Coefficient (Cu) and Coefficient of Curvature (Cc). What is its significance

- **Coefficient of uniformity (C_U)**

  It is a measure of particle size range and is calculated as follows:

$$C_U = \frac{D_{60}}{D_{10}}$$

Where, D_{60} = 60% of total mass are finer than D_{60} size (mm)

D_{10} = 10% of total mass are finer than D_{10} size (mm)

D_{10} is also known as effective size

For well graded soils, $C_U > 4$ for Gravels,
$C_U > 6$ for Sands,

- **Coefficient of curvature (C_C)**

  The shape of the particle size curve is represented by coefficient of curvature.

$$\mathbf{C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}}$$

For well graded soil, C_C is between 1-3

(Note: Even if either of the two conditions is not satisfied, the sample is poorly graded)

4) Why is a logarithmic plot is used instead of an ordinary plot for representing diameter of the grain-size

- Because the range of particle size is very wide (i.e. 1 μ to 100 mm)

5) What are the characteristics of grain size distribution curve?

- Particle size distribution curve clearly indicates whether the soil is predominantly coarse grained or fine grained
- The curve shows whether the soil is uniformly graded or well graded
- In the case of uniformly graded soil, the curve is almost vertical
- In the case of well graded soil, the curve is "S" shape

6) Distinguish between cohesive soils and cohesionless soils with respect to engineering properties

Cohesive soils (Fine grained)	**Cohesionless soils (coarse grained)**
Particle size < 75 μ (clay & silt)	Particle size > 75 μ (sand & gravel)
Plastic	Non-plastic
Less Void ratio	More void ratio
Density higher	Density less than cohesive soils
Permeability is less	Permeability is higher
Shear strength derived from cohesion	Shear strength derived from friction

7) How do you distinguish between sand, silts & clays in the field?

Sedimentation test

- Make a soil suspension in water about 100 mm depth.
- Sand will settle within half a minute
- Silt will settle in about 5-60 minutes
- Clay will remain in suspension for at least several hours or may remain even for several days

Rubbing test

- Rub a small quantity of soil between fingers immersed in water.
- Highly cohesive soils will give a distinct greasy feel and does not wash off readily. Clay dries slowly and may shrink on drying or crack may appear
- Silts will give rough feel but not gritty. Silts will wash away easily or can be brushed off fingers if dry
- Sands will give gritty feel and large number of sand particles stick to fingers

8) List the different systems of soil classification.

- Particle Size Classification System
- MIT Classification System
- Indian Standard System of Classification System (ISCS)
- Textural Classification System
- Highway Research Board Classification System (HRBS)
- Unified Soil Classification System (USCS)

Experiment No. 3

In situ Density of Soil by Core-Cutter Method

Objective

Determination of field density of soil by core-cutter method

Theory

Field density is defined as weight per unit volume of soil mass in the field at insitu conditions.

$$\gamma_d = \frac{\gamma_t}{(1 + w)}$$

Where, ρ_d = dry density, γ_d = dry unit weight, ρ_t = field moist density, γ_t =field moist unit weight, w =water content, γ_w = unit weight of water = 9.81 kN/m³

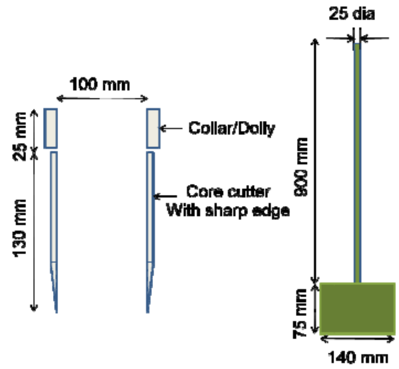
Apparatus

Core cutter, dolly and rammer and weighing balance.

Procedure

1. Determine the internal volume of the core-cutter Vc in cm³and weigh the cutter accurate to 1 g. (M_1).
2. Select the area in the field where the density is required to be found out and level it.
3. Place the cutter over the ground with the dolly and drive the cutter with the hammer until top of the cutter is just below the ground level.
4. Remove the soil outside the cutter by digging up to the bottom level of the cutter. Take out the cutter with sample inside. Remove the dolly and trim both sides of the cutter with a knife and straight edge.
5. Determine mass of the cutter with the soil (M_2).
6. Take a small sample of soil from the site for water content determination and seal it properly.
7. The field test may be repeated at other places if required.

The water content of sample collected is determined in the laboratory (as per the procedure explained earlier). Use the above equation for determining γ_d or ρ_d.



Observations & Calculations

Length of core cutter, L = ...cm

Diameter of core cutter, d = ...cm

Volume of core cutter, V_c = ...cm^3

Sl. No	Particulars	Test nos.		
		1	2	3
01	Mass of empty cutter (M_1), g			
02	Mass of cutter + wet soil (M_2), g			
03	Volume of core cutter (V_c) cm^3			
04	Mass of empty container (M_3), g			
05	Mass of container + wet soil (M_4), g			
06	Mass of container + dry soil (M_5), g			
07	Water content (w) $= \frac{(M_4-M_5)}{(M_5-M_3)} \times 100$			
08	Field moist density $\rho = \frac{(M_2-M_1)}{V_c}$ (g/cm³)			
09	Dry density $\rho_d = \frac{\rho_t}{(1 + w)}$ (g/cm³)			

Result:

In-situ field dry density =

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

Viva questions

1) Define insitu density

- In-situ (field) density is defined as weight per unit volume of soil mass in the field at insitu conditions.

2) What are the methods of determining insitu density? Indicate their suitability.

- Core cutter method: for cohesive and c-φ soils
- Sand replacement method: for non-cohesive soils (granular soils)

3) What are the applications/uses of insitu density?

- for the determination of bearing capacity of soils
- for the purpose of stability analysis of natural slopes
- for the determination of pressures on underlying strata
- for the calculation of settlement

In compacted soils, the in-situ density is needed to check the amount of compaction that the soil has undergone for the comparison with design data.

4) What is the effect of density on void ratio, permeability, shear strength, deformation?

   As the density increases void ratio, permeability and deformation decreases but shear strength increases

Experiment No 4

In situ Density by Sand Replacement Method

Objective

Determine the in situ density of natural or compacted soils using sand pouring cylinders.

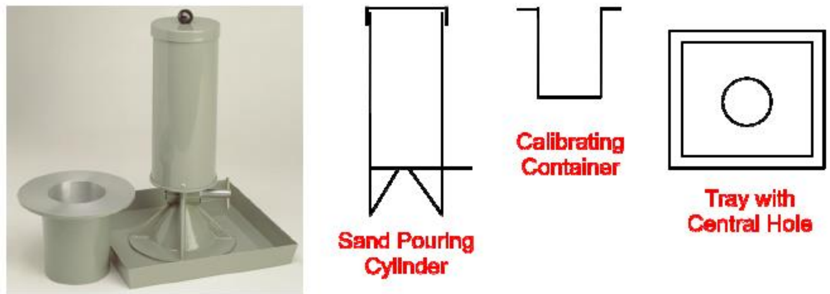
Need and Scope

The in situ density of natural soil is needed for the determination of bearing capacity of soils, for the purpose of stability analysis of slopes, for the determination of pressures on underlying strata for the calculation of settlement and the design of underground structures.

It is a very good quality control test, in the embankment and pavement construction, where controlled compaction is required.

Apparatus Required

1. Sand pouring cylinder with pouring cone, separated by a shutter cover plate.
2. Tools for excavating holes.
3. Cylindrical calibrating container.
4. Balance to weigh to an accuracy of 1g.
5. Metal containers to collect excavated soil.
6. Metal tray with hole in the centre.
7. Glass plate about 450 mm square and 10 mm thick.
8. Suitable non-corrodible airtight containers.
9. Thermostatically controlled oven with interior made of non-corroding material to maintain the temperature between 105^0C to 110^0C.
10. Desiccators with any desiccating agent other than sulphuric acid.



Materials Required

Clean, uniformly graded natural sand passing through 600 μ, I.S.sieves and retained on the 300 μ, I.S.sieves. It shall be free from organic matter and shall be oven dried and exposed to atmospheric humidity.

Theory

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

$$\gamma_d = \frac{\gamma_t}{(1+w)}$$

Void ratio is defined as volume of voids to volume of solids in a soil mass.

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

Where, ρ_d = dry density, γ_d = dry unit weight, ρ_t = field moist density, γ_t =field moist unit weight, w =water constant, γ_w = unit weight of water = 9.81 kN/m³

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

$$\rho_t = \frac{M_s}{V_h}$$

$$\rho_d = \frac{\rho_t}{(1+w)}$$

Where, V_h = Volume of hole made in the field.
M_s = mass of moist soil removed from the hole.
w = moisture content of soil removed from the hole.
ρ_t = in-situ bulk density.

ρ_d = dry density of the soil.
G = specific gravity of the solids.
ρ_w = density of water.
e = void ratio

Procedure

(I) ***Determination of mass of sand that fills the cone.***

1. With the valve closed, fill the cylinder with sand and weight it (M_1).
2. Keep the cylinder on a glass plate, which is kept on a horizontal surface. Open the valve and allow the sand to fill the cone completely. Close the valve and weigh the cylinder + balance sand (M_2)
3. Mass of sand that fills the conical portion, $M_3 = M_1 - M_2$

(II) Determination of bulk density of sand (Calibration of the container)

1. Measure the internal dimensions of the calibrating container and find its volume (V_c).
2. With the valve closed, fill the cylinder with sand upto about 1 cm below the top and weight it (M_4).
3. Place the cylinder over the container, open the valve and allow the sand to flow into the container. When no further movement of sand is seen close the valve. Find the mass of the cylinder and sand left in the cylinder (M_5).
4. The bulk density of sand ρs is: $$\rho_s = \frac{(M_4-M_5-M_3)}{V_c}$$

(III) Determination of in-situ density:

1. Level the area where the density is required to be found out.
2. Place the metal plate on the surface, which is having a circular hole of about 10 cm diameter at the centre. Dig a hole of this diameter up to about 15 cm depth. Collect all the excavated soil in a container.

   Let the mass of the soil removed = (M_s)
3. With the valve closed, fill the cylinder with sand upto about 1 cm below the top and weight it (M_6).

4. Remove the plate and place the sand-pouring cylinder concentrically on the hole. Open the valve and allow the sand to run into the hole till no movement of the sand is noticed. Close the valve and determine the mass of cylinder and balance sand that is left in the cylinder (M_7)
5. Volume of hole, $V_h = \dfrac{(M_6 - M_7 - M_3)}{\rho_s}$

Observations and Calculations

Determination of mass of sand that fills the cone

Mass of sand pouring cylinder + sand, (M_1) = g

Mass of sand pouring cylinder + balance sand after filling cone (M_2) = g

Mass of sand filling cone (M_3) = (M_1 – M_2) = g

Determination of bulk density of sand (Calibration of the container)

Length of calibrating container (L) = ____________cm

Diameter of calibrating container (d) = __________cm

Volume of calibrating container (V_c) = _________cc

Mass of sand pouring cylinder + sand (M_4) = g

Mass of sand pouring cylinder + balance sand after filling calibrating container and cone (M_5) = g

The bulk density of sand ρ_s is: $\rho_s = \dfrac{(M_4 - M_5 - M_3)}{V_c.}$ = g/cc

Determination of in-situ density

Mass of the soil removed from the hole (M_s) = g

Mass of sand pouring cylinder + sand (M_6) = g

Mass of sand pouring cylinder +balance sand after filling hole and cone (M_7) = g

Volume of hole $(V_h) = \frac{(M_6 - M_7 - M_3)}{\rho_s}$ = cc

Bulk density of soil in-situ, $\rho_t = \frac{(M_s)}{V_h}$ = g/cc

Water content

Mass of empty container (W_1) = g

Mass of container + wet soil (W_2) = g

Mass of container + dry soil (W_3) = g

Water content (w) = $\frac{(W_2 - W_3)}{(W_3 - W_1)} \times 100$ =

Dry density of soil $(\rho_d) = \frac{\rho_t}{(1+w)}$ = g/cc

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

Result

1) Bulk density of the soil (ρ_t) =
2) Dry density (ρ_d) =
3) Voids ratio (e) =

General Remarks

1. The excavated hole must be equal to the volume of the calibrating container.

2. Weight of sand that filled the cylinder should be maintained constant.

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

Experiment No 5

Liquid Limit Test by Casagrande Method

Objective

Draw the flow curve and find out liquid limit.

Need and scope

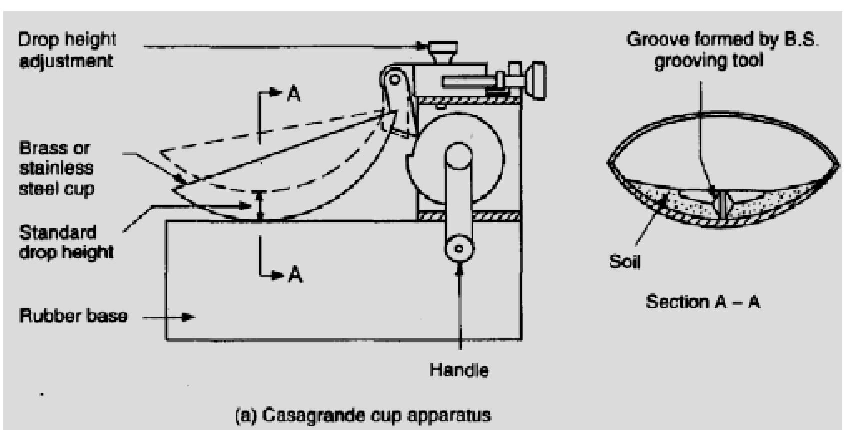
Liquid limit is significant, to know the stress history and general properties of the soil, met with during construction. From the liquid limit value, the compression index may be estimated. The compression index value will be useful for the settlement analysis. If the natural moisture content of soil is closer to the liquid limit, the soil can be considered as soft. If the moisture content is lesser than liquids limit, the soil can be considered as brittle and stiffer.

Theory

The liquid limit is the moisture content at which the groove, formed by a standard tool into the sample of soil taken in the standard cup, closes by 12 mm on being given 25 blows in a standard manner. At this limit the soil possess low shear strength.

Apparatus Required

Balance, Liquid limit device (Casagrande's), grooving tool, mixing dishes, spatula, oven



(a) Casagrande cup apparatus

Procedure

1. About 120 g of air-dried soil from thoroughly mixed portion of material passing 425 μ I.S sieve is to be obtained.

2. Distilled water is added, to the soil in a mixing dish to form a uniform paste.

3. A portion of the paste is placed in the cup of Liquid Limit device and spread with few strokes of spatula.

4. Trim it to a depth of about 1cm 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 grooving tool along the diameter through the centre line, so that clean sharp groove of proper dimension is formed.

6. Lift and drop the cup by turning the 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.

7. The number of blows required to cause the groove to close for about 12 mm shall be recorded.

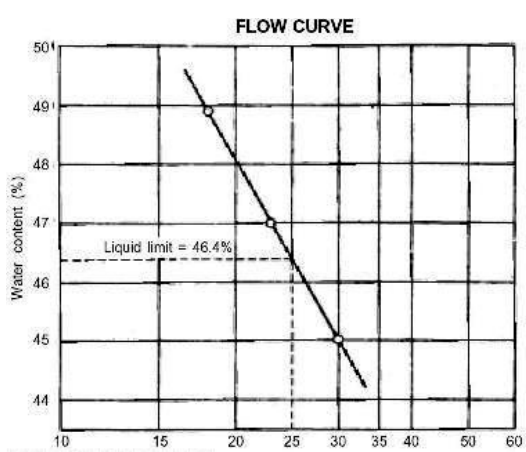
8. A representative portion of soil is taken from the cup for water content determination.

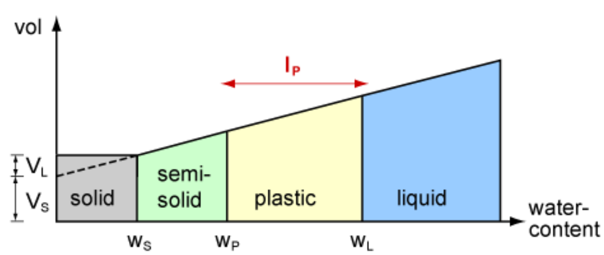
9. Repeat the test with different moisture contents at least three more times to get blows between 10 and 40.

Observations and Calculations

Sl. Number	1	2	3	4
Container number				
Mass of container M_1 g				
Mass of container + wet soil M_2 g				
Mass of container + dry soil M_3 g				
Moisture content (%) $w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$				
No. of blows (N)				

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 the liquid limit. It is usually expressed to the nearest whole number.





Result

Liquid limit of the given soil =

Flow index (slope of the flow curve), $I_f = \frac{(w_2 - w_1)}{(\log N_1/N_2)}$ = .

Relevant BIS Code: IS: 2720, Part-5, 1985

Viva questions

1) Define Consistency (Atterberg) Limits, Plasticity Index, Consistency Index, Flow Index, and Toughness Index. What is its significance?

2) List the methods to determine liquid limit

- Casagrande method
- Cone penetration method

3) What are the applications/uses of Consistency Limits?

- Liquid Limit and Plasticity Index are the important properties for the identification and classification of fine grained soils. Classification of silty and clayey soils by HRB and USCS systems are based on Liquid Limit and Plasticity Index
- The Liquid Limit of clay indicates its compressibility. Higher the liquid limit, higher is the compressibility. The compression index of the normally consolidated clay is found to be dependent on the liquid limit. The plastic limit of a soils depends both on the amount and type of clay in the soil
- Plasticity index gives the idea about the clay content in a soil. Plasticity Index increases with clay content
- Plastic limit indicates the moisture content above which moulding of soil or its compaction in the field can be done without cracking.
- In standard compaction test, the plastic limit can be taken as a rough guide for the value of OMC
- Shrinkage Limit gives the idea about shrinkage or swelling which is likely to takes place after being compacted at specified moisture content. If a soil is compacted at its OMC which happens to be higher than its shrinkage limit, the compacted soil mass is likely to shrink on drying after

compaction. If such clay is compacted at about shrinkage limit (lower than OMC) it is likely to swell on soaking subsequently.

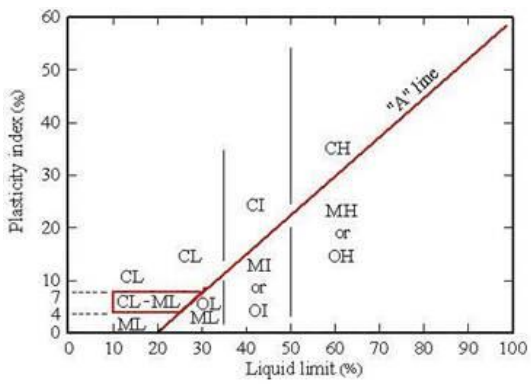
- Higher the value of liquid limit and plasticity index are considered as indication of poor subgrade soils

4) Differentiate between Consistency Limits and Relative Density

Consistency limits	Relative Density
Applicable for cohesive soils	Applicable for cohesionless soils
Denotes degree of firmness	Denotes degree of compaction
Function of water content (w)	Function of void ratio (e)

5) Explain plasticity chart

Plasticity chart is used to classify the fine grain (<75 µ) soils into silt, clay and organic. The plasticity chart is based on the values of liquid limit (W_L) and plasticity index (I_P). The 'A' line in this chart is expressed as $I_P = 0.73 (W_L - 20)$.



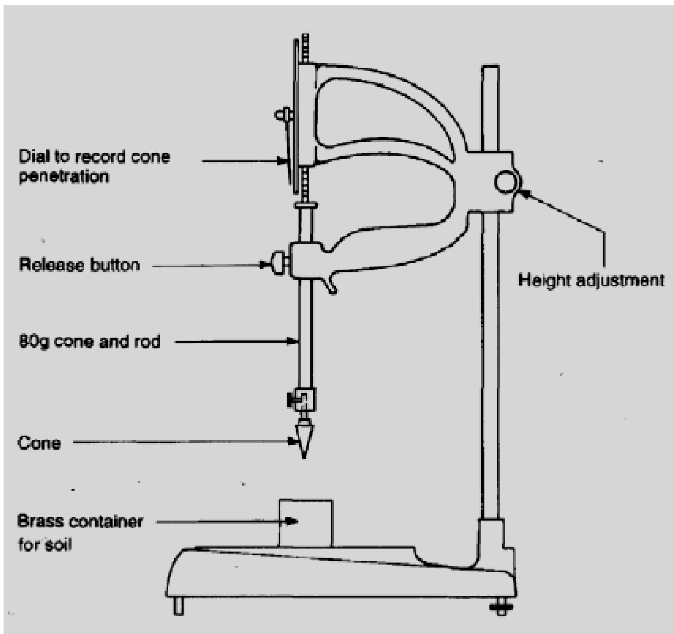
Liquid Limit Test by Cone Penetration Method

Objective

To find out liquid limit.

Apparatus

Cone Penetrometer

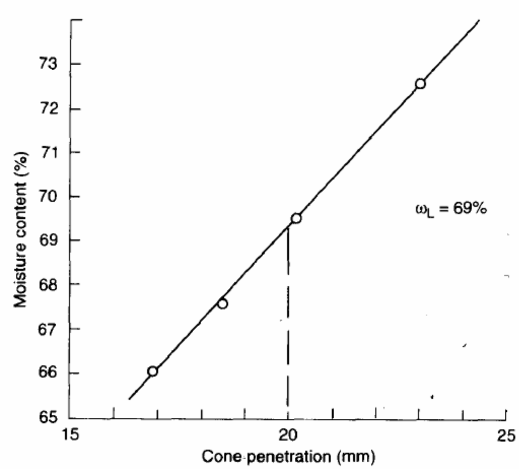


This method is based on the principle of static penetration.

Procedure

- A 31^0 cone of stainless steel is made to penetrate the soil pat under a mass of 80 g inclusive of mass of cone.
- The soil pat is kept in a cylindrical mould/container (5 cm dia, 5 cm height) below the cone. The cone is allowed fall freely into the container.
- The depth of penetration of cone is measured.
- Procedure is repeated for soil pats at different moisture content and depth of penetration for each point is noted.

- A graph is plotted representing water content (w) on y-axis and cone penetration on x-axis. The best fitting straight line drawn. The water content corresponds to cone penetration of 20 mm is taken as Liquid Limit.



Sl. Number	1	2	3	4
Container number				
Mass of container M_1 g				
Mass of container + wet soil M_2 g				
Mass of container + dry soil M_3 g				
Moisture content (%) $w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$				
Cone penetration (mm)				

Result

Liquid Limit =

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

Experiment No 7

Plastic Limit Test

Objective

To find the plastic limit of soil

Need and Scope

Soil is used for making bricks, tiles, soil cement blocks in addition to its use as foundation for structures. Plastic limit indicates the moisture content above which moulding of soil or its compaction in the field can be done without cracking.

Apparatus Required

Porcelain dish, glass plate, air tight containers, balance, oven etc.

Procedure

1. Take about 20 g of thoroughly mixed portion of the material passing through 425 μ 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 moulded with fingers.

3. Allow it to season for sufficient time to allow water to permeate throughout the soil mass

4. Take about 10 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 60 and 90 strokes per minute.

5. Continue rolling till you get a thread of 3 mm diameter.

6. Kneed 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 an air tight container for moisture content determination.

9. Repeat the test for at least 3 times and take the average of the results calculated to the nearest whole number.

Observations and Calculations

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.

Container No.		
Mass. of container + lid, M_1 (g)		
Mass of container + lid + wet sample, M_2 (g)		
Mass of container + lid + dry sample, M_3 (g)		
Mass of dry sample = $M_3 - M_1$ (g)		
Mass of water in the soil = $M_3 - M_2$ (g)		
Water content, $w = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100$		

Result

Average Plastic Limit, PL =

Plasticity Index, Ip = (LL - PL) =

Toughness Index, $I_t = \frac{I_p}{I_f} =$

Relevant IS Code: IS: 2720, Part-5, 1985

Experiment No 8

Standard Proctor Compaction Test

Objective

To find the optimum moisture content and maximum dry density

Apparatus Required

1. Proctor mould having a capacity of 1000 cc with an internal diameter of 100 mm and a height of 127.3 mm. The mould shall have a detachable collar assembly and a detachable base plate.
2. Rammer of weight 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. Straight edge.
6. Graduated cylinder.
7. Mixing tools such as mixing pan, spoon, towel, spatula etc.
8. Moisture tins.

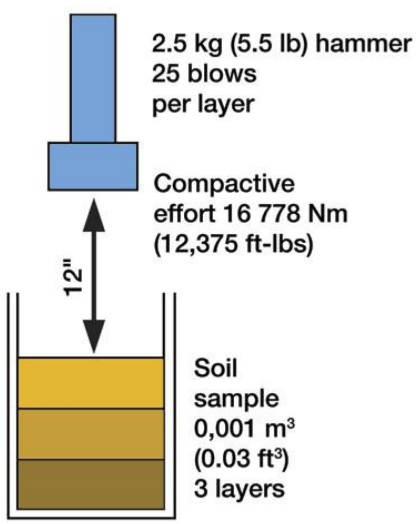
Theory

1. Bulk density $\rho_t = \frac{(M_2 - M_1)}{V} =$
2. Dry density $\rho_d = \frac{\rho_t}{(1 + w)} =$
3. Dry density ρ_d for zero air voids line: $\rho_d = \frac{G\rho_w}{(1 + (wG/S))}$

where, M_1 = mass of mould used for proctor test
M_2 = mass of mould + compacted soil.
M = mass of wet soil.
V = volume of mould.
ρ_w = density of water.
G = Specific gravity of soils.
W = water content.
S = degree of saturation.

Procedure

1. Take a representative air dry soil sample of about 3 kg.
2. Add sufficient water to the sample (about 7 % for sandy soils and 10 % for clay soils), which will be less than the estimated optimum moisture content and mix it thoroughly.
3. Fix the mould to the base plate after cleaning its inside surface. Find the mass of the mould with the base plate (M_1).
4. Attach the extension collar to the mould.
5. Place the soil in the mould, in three equal layers (approximately 6 cm). Each layer is compacted by giving 25 blows by the rammer weighing 2.6 kg and dropping from a height of 310 mm. The compaction must be uniform over the whole area, and a spatula scratches each layer before adding another layer. The filling must be such that the last layer projects into the collar by about 5 mm. After the completion of compaction, remove the collar and remove the excess soil with the help of a straight edge.
6. Find the mass of the mould with the base plate and the soil (M_2).
7. Remove the soil from the mould by making use of an ejector and take a representative sample for water content determination.
8. Repeat the tests 4 times for different water contents (increments of 3%), such that at least one value of dry density is showing decreasing trend.



Observations and Calculations

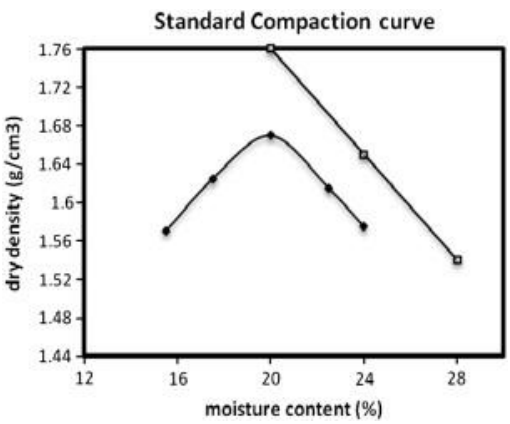
The following observations were made on the compaction of a soil by standard proctor test. Six tests were carried out on the selected samples of soil by varying the water content. Water contents of samples of each test were found out by the procedure explained earlier.

Sl. No	Test No	1	2	3	4	5	6
01	Mass of empty mould M_1 g						
02	Volume of mould, cm^3						
03	Mass of mould + sample, M_2, g						
04	Mass of wet soil, M, g						
05	Wet density, ρ_t g/cm^3						
06	Water content, w%						
07	Dry density, ρ_d, g/cm^3						
08	Water content for saturation line						
09	ρ_d, g/cm^3 for S=100% (zero air void line)						
10	ρ_d, g/cm^3 for S=90%						

Result

Maximum dry density ρ_d = ___________ g/cm^3

Optimum moisture content, w = ______________ %



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

Viva questions

1. What are the factors that affect the compaction of a soil?
   - Water content
   - Compactive effort
   - Method of compaction
   - Type of soils

2. What are the applications/uses of compaction?

   - To determine the design values of density and moisture content in the field
   - For field control, to check whether the design values (MDD & OMC) are achieved in the field

3. Explain the characteristics of compaction curve
4. What is the difference between compaction and consolidation? Discuss the effect of increased compactive effort on OMC and dry density.

COMPACTION	**CONSOLIDATION**
Man made	Natural
Expulsion of air	Expulsion of pore water
Fast process	Gradual process
Possible in dry or partially saturated soil	Possible in saturated soil
Results in increased density	Results in dense packing

As the compactive effort increases OMC decreases and MDD increases

Experiment No 9

Coefficient of Permeability by Constant Head Method

Objective

To determine the coefficient of permeability of soils, using constant head permeameter, as per IS: 2720 (Part XVII)-1966

Apparatus

Constant head permeameter setup, stop watch. Volume measuring beaker, etc.

Procedure

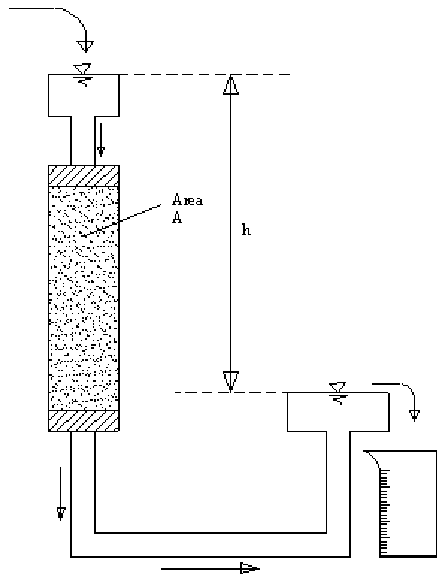
1. Take the dimensions of permeameter mould, such as length and diameter.

2. Fix the mould to the bottom perforated base plate and plate the filter paper on it. Fill the soil sample into the mould. Place the filter paper on top perforated plate and fix the top cap on it.

3. Connect the outlet tube of the constant head tank to the inlet nozzle of the permeameter, after removing the air in the flexible rubber tubing connecting the tube. Adjust the hydraulic head by controlling the inflow to the constant head tank. A constant water level in the supply reservoir is maintained by always having a small overflow taking at its top.

4. Start the stop watch, and at the same time put a beaker under the outlet of the Permeameter. Run the test for some convenient time interval. Measure the quantity of water collected in the beaker during that time.

5. Repeat the test twice more, under the same interval.



Tabulation

Diameter of the soil sample, d (cm) =

C/s area of the soil sample, $A = \pi d^2/4$ (cm^2) =

Length of the soil Sample, L (cm) =

Hydraulic head, H (cm) =

Sl.No	1	2	3
Time Interval t (sec) Quantity of flow Q (cm^3) i) l Test ii) ll Test iii) lll Test Average Coefficient of Permeability K (cm/sec)			
Average Coefficient of Permeability K (cm/sec)			

Specimen Calculation:

Sl.No. of the reading =

Diameter of the soil sample d (cm) =

C/s area of the soil sample $A = \pi d^2/4$ (cm^2) =

Length of soil sample L (cm) =

Hydraulic head h (cm) =

Time interval t (sec) =

Quantity of flow (Average) Q (cm^3) =

Coefficient of permeability = $K = \frac{QL}{tHA}$ = (cm/sec)

1. Use distilled water (desired) so that the permeability measured is constant with time.
2. Allow enough time to attain steady state of flow. Make sure that the soil is fully saturated.

Result:

The coefficient of permeability soil K (cm/sec) =

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

Experiment No 10

Coefficient of Permeability by Variable Head Method

Aim

To determine coefficient of permeability by variable head method for fine grained soils

Theory

The below equation can be used:

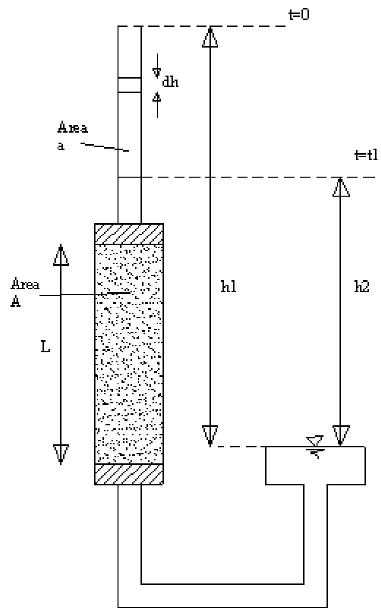
$$K = 2.3 \frac{aL}{At} \times \log_{10} \frac{h_1}{h_2}$$

Apparatus

The test setup for a falling-head assembly is as shown in the figure. All other accessories remain the same as for a constant-head test.

Procedure:

1. Open the valves in the standpipe and the bottom outlet. Ensure that the soil sample is fully saturated without any entrapping of air bubble before starting the test.
2. Fill the standpipe with water keeping the valves V_1 and V_2 open and allow the water to flow out through the outlet pipe for some time and then close the valves.
3. Select in advance the heights h_1 and h_2 for the water to fall and determine the height $\sqrt{h_1 h_2}$ and mark this height on the stand pipe.
4. Open the valves and fill the standpipe with water up to height h_1 and start the stopwatch.
5. Record the time intervals for water to fall from height h_1 to $\sqrt{h_1 h_2}$ and from $\sqrt{h_1 h_2}$ to h_2. These two time intervals will be equal if a stead flow condition has been established.
6. Repeat the step (e) at least after changing the heights h_1 and h_2.
7. Stop the test and disconnect all the parts.
8. Take a small quantity of the sample for water content determination.



Observations: Length of Soil sample L = cm

Diameter of Soil sample D = cm

Area of soil sample A =

Area of Sand Pipe a =

l. No	Initial Head (h_1) cm	Final Head (h_2) cm	Time t (seconds)	$K = 2.3 \frac{aL}{At} \times \log_{10} \frac{h_1}{h_2}$
01				
02				
03				
04				
05				

Specimen calculation:

Result: Coefficient of Permeability of soil k = cm/sec

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

Viva Questions

1) List types of permeability tests and indicate their suitability
   - **constant head:** cohesion-less soils, because void ration is higher for cohesion-less soils and hence permeability is also higher

   - **Variable head:** cohesive soils, because void ration is less for cohesion-less soils and hence permeability is also less
2) List the factors that affect the permeability of soils
   - Soil characteristics (grain size, void ratio, composition, soil structure, degree of saturation, Presence of entrapped air and other foreign matter)
   - Permeant fluid properties (Viscosity, density and concentration of permeant)

3) What are the applications/uses of permeability tests?

   - with the permeability values of soils, the soils can be classified as free draining, semi-pervious or impervious which enables selection of materials for different zones of a dam
   - for estimating the quantity of seepage through the foundation and body of the dam
   - to fix the c/c distance of relief wells, approximate thickness of filter beds and size and spacing of longitudinal cross drains

4) List the assumptions of Darcy's law
   - The flow is laminar that is, flow of fluids is described as laminar if a fluid particles flow follows a definite path and does not cross the path of other particles.
   - Water & soil are incompressible that is, continuity equation is assumed to be valid
   - The soil is saturated
   - The flow is steady state that is, flow condition do not change with time.

Experiment No 11

Unconfined Compression Test

Objective

To determine the unconfined compressive strength and the undrained shear strength of a clayey soil with $\varphi = 0$.

Introduction

This is a special case of a triaxial shear test in which the minor principal stress is equal to zero, that is $\sigma_3 = 0$. The specimen is sheared under a vertical or axial stress. The tests are carried out only on saturated sample which can stand without any lateral support. The test is applicable for only cohesive soils. The test is an undrained test and it is based on the assumption that there is no moisture loss during the test. The UCC test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils. In undrained tests on saturated or nearly saturated cohesive soils, the contribution of friction is negligible and the strength is almost entirely due to cohesion.

Apparatus

Sampling tube, 3.75 cm in internal diameter 4 cm in outside dia and 15 to 20 cm in length. Split mould, 3.75 cm internal diameter, and 7.5 cm long, Sample extractor, trimming knife, unconfined compression tester with arrangement for the autographic recording of the load/deformation characteristic of the specimen by a pencil moving across a chart on the drawing plate.

Procedure

1. Obtain a sample by the sampling tube. Samples can be undisturbed or remoulded.

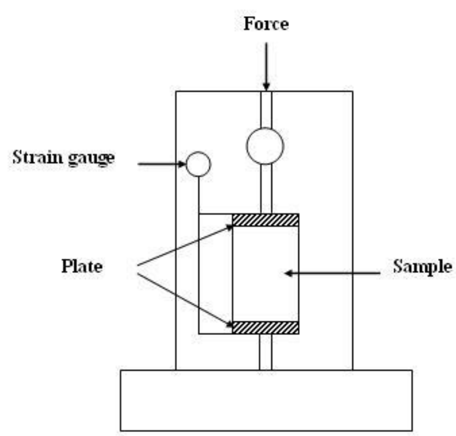
2. Lightly oil the inside of the split mould and weigh. Push the sample out of tube into the split mould. Cut off flush with the ends and weigh the mould with

specimen. Keep the cutting for water content determination. Open the mould and take out the specimen.

3. Oil the flat upper and lower platens of the machine lightly and place the specimen centrally on the lower platens. Turn the handle until the upper platen is just in contact with the specimen.

4. By adjusting top on which the fulcrum rests, the pencil is set to right hand vertical line of the chart. Apply the load to the specimen by turning the handle uniformly at a rate of half a revolution per second until the failure occurs. In some cases plastic failure occurs. For such soils carry the operation of applying the load until 20% strain has been obtained, by which time the specimen will become noticeably barrel-shaped.

5. Take out the chart and fix in another chart and duplicate the test. Determine the moisture content. Super-impose the mark over the chart and note down the reading where the failure occurred.



UCC Test setup

Observation:

Diameter of specimen, d (mm) =

Length of specimen, L (mm) =

Initial c/s area of specimen, A_0 (mm^2) = $\frac{\pi d^2}{4}$ =

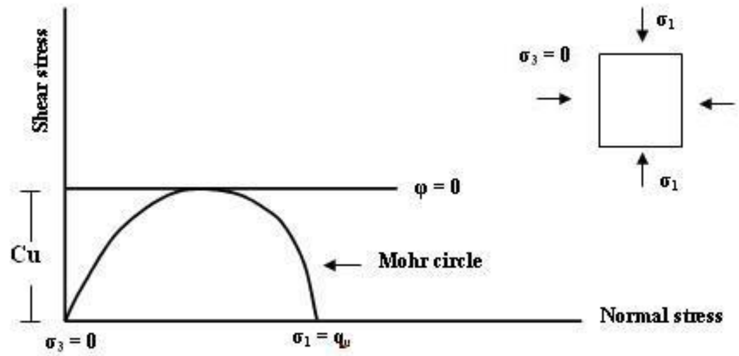
Proving ring constant (PRC) =

Least count of dial gauge (LC) =

Sl No.	Dial gauge reading (DGR) (Divisions)	Deformation (mm) δ = DGR x LC	Proving ring reading(PRR) (div)	Axial load (P) PRR x PRC	Strain, $\Sigma = \frac{\Delta L}{L}$	Area, A = $\frac{A_0}{1 - \Sigma}$	Stress $\sigma = \frac{P}{A}$

Result

The unconfined compressive strength of the given soil sample (U.C.S). Kg/cm^2 =



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

Applications

The unconfined compression test has an advantage over the direct shear test because of the more uniform stresses and strains imposed. Also the soil tends to fail on the weakest plane in contrast to the predetermined horizontal plane as in the direct shear test. This method can be used to find the sensitivity of a clay sample.

Viva Questions

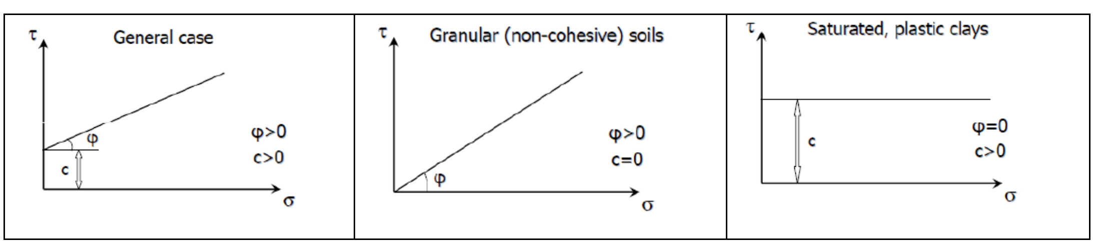
1) What is shear strength? List the tests for determining shear strength
   - Shear strength is defined as capacity of a material to resist internal and external forces which slide past each other
   - Direct shear, UCC, Triaxial and Vane shear tests

2) What are the applications/uses of shear tests?
   - Stability analysis of dam
   - Design of footings, well foundations & pile foundations
   - Design of retaining walls wherein the calculations of earth pressure requires values of cohesion and angle of internal friction
   - Estimating the loads on buried structures like conduits

3) What are the parameters of shear strength?
   - Cohesion & angle of internal friction

4) When do you prefer unconfined compression test and why?
   - UCC test is preferred for pure cohesive soils. Because the cylindrical test specimen can stand without any lateral support

5) Draw failure envelope for different soils



Experiment No 12

Direct Shear Test

Introduction

The direct shear test provides the simplest method of determining the angle of internal friction of cohesionless soil. India standard give the procedure for conducting undrained, direct shear test. There are two types of direct shear apparatus, namely, ‘Stress Control Type’ and Strain Control Type. In stress control type, the rate of shear stress applied is constant, that is, increase in shear stress for a given interval of time is constant. In strain control type, rate of shear strain is constant, that is, the deformation of the soil sample for a given interval of tie is constant.

Theory

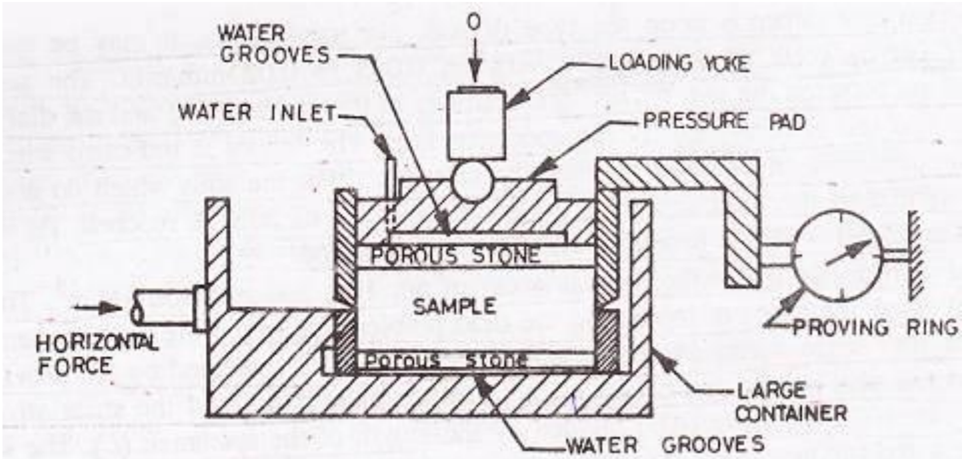
In direct shear test only the normal and shear stresses on the horizontal plane of shear are known. It is not possible to construct Mohr’s circle for stresses before failure. At failure, if it is assumed that the measured stresses are in the ratio $\tau = \sigma \tan\varphi$ then it is possible to construct the Mohr’s circle. Σ and τ are shear and normal stresses on the failure plane at failure.

Objective

To determine the shear strength parameters (c, φ) of soil, by box shear test, as per IS: 2720 (Part XII) - 1972.

Apparatus

Square shear box 6 cm square and with two porous stones, plain grids (2 nos.) and pressure pad. Shearing machine fitted with a geared jack to give constant rate of strain, proving ring, loading yoke, and set of weights.



Direct Shear Test Setup

Procedure

1. Fix the upper part of the box to the lower part by tightening the locking screws. Place a porous stone in the box and a plain grid on the stone, keeping the serrations of the grid at right angles to the direction of shear. Place the specimen (soil sample) carefully in the box. Place the upper porous stone on the grid and pressure pad on the stone.

2. Mount the shear box with specimen inside on the shearing machine and adjust so that the upper part touches the proving ring. Bring toward the jack to bear up against the box which will be indicated by a slight movement of the proving ring dial gauge. Adjust the dial gauge to read ‘zero’.

3. Set the loading yoke over a steel ball placed centrally on the pressure pad and apply the desired normal load.

4. Remove the locking screws. Shear the specimen at a suitable constant rate of strain. (1 to 2.5 mm per minute.) Record reading when specimen fails.

5. Repeat the test on identical specimen under increasing normal load. At least three tests should be carried out.

6. Plot shear stress versus normal stress 'Y' intercept gives 'C' (cohesion) and the angle made by the strength envelope with the horizontal gives (angle of internal friction).

Then, shear strength of the soil, $\tau = c + \sigma \tan \varphi$

Observation:

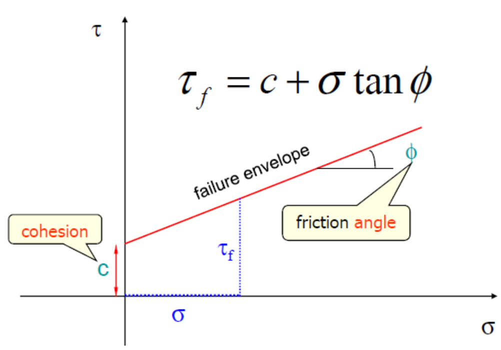
C/s. area of the soil specimen, A =

S.N	Normal load (N)	Shear force (N)	Normal stress (σ = N/A)	Shear stress (τ = F/A)

Result

The angle of internal friction, φ =

Cohesion, C =



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

Application of Shear Tests:

Shear test results play an important role in the following cases.

1. Stability analysis of dam.
2. Design of footings, well-foundations and pile foundations.
3. Design of retaining walls wherein the calculation of earth pressure requires values of cohesion and angle of internal friction.
4. Estimating loads on buried structures like conduits.

References

Methods of test for soils, Direct Shear Test, IS: 2720 (Part XIII) – 1972

Viva Questions

1. What are the advantages and limitations of direct shear test

Advantages

- Test is simple
- Suitable for cohesionless soils

Limitations

- Failure plane is pre-determined
- Measurements of pore pressure and volume change not possible
- Test can be performed only for drained condition
- Stress distribution on the failure plane is not uniform
- Not possible to determine state of stress during the test

Experiment No 13

Triaxial Compression Test (undrained)

Introduction

Shear tests are generally carried out on small samples in the laboratory to evaluate the strength propertied of the element in the soil mass. The strength propertied, namely the cohesion and angle of shearing resistance are usually found from these tests. The two methods of shear tests commonly used are the direct shear test and triaxial shear test. In triaxial test a cylindrical specimen is stressed in lateral and vertical directions and the shear strength of the soil is evaluated. The plane of shear failure is not pre-determined. The triaxial test is considered as a much superior strength test than the direct shear test.

Types of Triaxial Compression Tests

	Drainage conditions during the two stages of triaxial testing		
Sl.No	1st stage (Application of cell pressure only	2nd stage (Application of additional axial stress at constant cell pressure)	Types of test
1	Drainage allowed Therefore consolidated	Drainage allowed Therefore Drained	Consolidated Drained - CD
2	Drainage allowed Therefore consolidated	Drainage not allowed Therefore undrained	Consolidated Undrained - CU
3	Drainage not allowed Therefore consolidated	Drainage not allowed Therefore undrained	Unconsolidated Undrained - UU

Objective

To determine the shear strength parameters (c,) by triaxial compression test, as per the IS 2720 (Part XI) – 1971.

Apparatus

Triaxial cell, solid end caps and pressure cap for specimen, rubber membrane, sealing rings. Constant rate of strain compression machine fitted with a proving ring and dial gauge. Dial gauge accurate to 0.01 mm for measuring axial deformation. Apparatus for building cell pressure consisting of a water reservoir, pump, pressure gauge and connecting tube for the cell.

Procedure

1. Obtain an undisturbed or remoulded soil specimen. Undisturbed samples are sued when it is required to find the shear strength of the in – situ soil accurately for the purpose of determining the Bearing capacity, earth pressure and slope stability of the soil. Remoulded soil samples are used in the laboratory for research and other purposes. Remoulded specimens may be prepared by compacting the soil, at required water content. Enclose the specimen with the rubber membrane. Mount it on the base of the triaxial cell with solid end cap. Placed on either side of the specimen. Place also the pressure cap on top. Seal the membrane on to the caps with rubber rings. Carefully assemble the cell with piston of the top cap raised in the upward position.

2. Place the triaxial cell in the compression machine. Admit water in the cell with air release valve open until water escapes from the valve, which is then closed. Raise the cell pressure to required amount and keep it constant till the end of test. Record the magnitude of the cell pressure (σ_3)

3. by hand operation of the compression machine, lower the proving ring to rest on the cell piston. Set the proving ring dial gauge and deformation ring dial gauge to read zero.

4. the axial load is applied at a constant rate of strain of approximately 1.25 mm per minute. Take the readings of the proving ring and strain dial gauges for every 0.5 mm deformation until the soil fails by shear. The experiment is done for three more specimens by changing the soil pressure.

Observation:

Diameter of the soil specimen d (cm) =

C/s. area of the soil specimen A = $\pi d^2/4$ = cm^2

S.N	Cell pressure (σ_3)	Axial load	Deviator stress ($\sigma_d = P/A$)	Principal stress ($\sigma_1 = \sigma_3 + \sigma_d$)

Plot graph σ on x axis and τ on y axis to obtain C & ø.

Result

Angle of internal friction φ =

Cohesion C (kg/cm^2) =

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

Viva Questions

1. What are the advantages and limitations of triaxial test?

Advantages of triaxial shear test

- The shear tests under all three conditions (undrained, consolidated undrained, drained) can be performed with complete control
- precise measurements of the pore pressure and volume change during the test is possible
- stress distribution on the failure plain is uniform.
- the state of stress within the specimen during any stage of the test, as well as at failure is completely determined.

Limitations of triaxial shear test

- The triaxial test is more complicated than the direct shear test.
- Samples of cohesionless soil such as sand are difficult to prepare and are perhaps more conveniently tested in a shear box.

2. Distinguish between Direct shear test and Triaxial compression test

Direct Shear Test	Triaxial Compression Test
Test is simple	Complicated
Stress distribution on the failure plane is not uniform	Uniform
Failure plane is pre-determined	Failure plane occurs at maximum stress zone
Not possible to determine state of stress during the test	Possible
Suitable for cohesionless soils	Suitable for all types of soils but samples of cohesionless soils are difficult to prepare
Measurements of pore pressure and volume change NOT possible	Possible
Test can be performed only for drained condition	Tests can be performed under all 3 conditions of drainage

Experiment No 14

Vane Shear Test

Introduction

Vane shear tests are coming into wider use for determining the in-situ strength of cohesive soils. The vane shear apparatus consists of thin blade vanes than can be pushed into soil with a minimum of disturbance. A torque applied to rotate the vanes is related to the shear strength of the soil. A vane shear apparatus can be attached to a long vertical rod and inserted into borings, so that the in-situ strength of soil can be determined without removing the soil from its natural state in the ground.

Aim

To determine the undrained shear strength of soft clayey soils using vane shear apparatus, as per IS (Part XXX)-1968

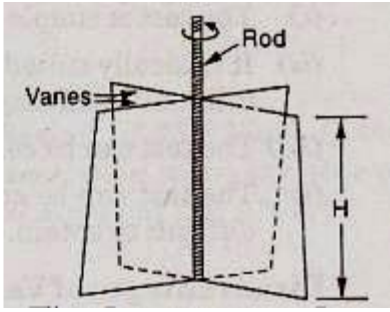
Apparatus

Vane shear apparatus consists of four thin stainless steel rectangular plates, welded orthogonally to a high tensile steel rod. A torque measuring arrangement, such as a calibrated torsion spring is attached to the rod which is rotated by some arrangement from the top

.

Procedure

Prepare remoulded soil sample in a mould and the vane shear tester is then pushed carefully into the soil to a depth somewhat greater than the length of the vane. The torque rod is now rotated at a uniform speed (usually one degree per minute). The rotation of vane shears the soil along a cylindrical surface. The rotation is continued till the soil fails, which will be indicated by a sudden decrease of torque without any back movement of torque-wheel. The maximum torque given, till failure is measured and recorded, sometimes it is directly indicated in kg-cm, and sometimes only the rotation angle ‘θ’ is indicated, which has to be multiplied by ‘spring factor’ and divided by 180 to obtain the applied torque.



Applications

The laboratory vane shear test for the measurement of shear strength of cohesive soils is useful for soils of low shear strength, less than about 0.3kg/cm^2 for which triaxial or unconfined compression tests cannot be performed. The test gives the undrained strength of the soil and the undisturbed and remoulded strengths obtained are used for evaluating the sensitivity of the soil.

Tabulation

Diameter of the vane, d (cm) =

Height of the vane, h (cm) =

Spring factor =

Sl no.	1	2	3
Initial reading on the circular graduated scale			
Final reading on the circular graduated scale			
Angle of torque of the spring			
Torque applied, T			
Shear strength of soil kg/cm^2= $\tau = \dfrac{T}{\pi \left(\dfrac{d^2 h}{2} + \dfrac{d^3}{6}\right)}$			

Result

The shear strength of the given soil sample =

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