PART 1

Tests on Soil Subgrade

1. Grain Size Analysis
2. Liquid Limit and Plastic Limit
3. Shrinkage Factors of Soil
4. *In Situ* Density
5. Compaction Test
6. Laboratory California Bearing Ratio (CBR) Test
7. Triaxial Test
8. Plate Load Test
9. North Dakota Cone Test

CHAPTER 1

Grain Size Analysis

SIEVE ANALYSIS

1.1 OBJECT

To determine grain size distribution of a soil by sieve analysis.

1.2 THEORY

The grain size analysis is also known as mechanical analysis. In this analysis the percentage of individual grain sizes present is determined by sieving a known weight of soil through successive smaller sieves. Based on grain size the soil is divided into four parts as follows:

Gravel: Fraction of soil >4.75 mm
Sand: Size 0.075–4.75 mm
Silt: Size 0.002–0.075 mm
Clay: <0.002 mm

1.3 APPLICATIONS

The results of grain size distribution are widely used for soil classification, design of filters, construction of earth dams, highway embankments, for construction of building, hydraulic structures and road construction, etc.

Fig. 1.1: Sieve shaker (grain size analysis)
(*Courtesy:* AIMIL Ltd.)

1.4 APPARATUS

- For coarse sieve analysis: IS sieves 100, 63, 20, 10 and 4.75 mm.
- For fine sieve analysis: IS sieves 2, 1, 0.6, 0.425, 0.212, 0.150 and 0.75 mm.
- Oven
- Balance accurate to 0.1 g
- Weights
- Sieve shaker (Fig. 1.1)
- Tray
- Pan

1.5 COARSE SIEVE ANALYSIS

- Take suitable quantity of oven-dry soil.
- Arrange the first set of sieves such that 100 mm sieve is at the top and 4.75 mm sieve is at the bottom.
- Put cover on top sieve and pan at the bottom of 4.75 mm sieve and put the soil on top sieve before covering it.
- Put the sieves in the sieve shaker and clamp it tightly.
- Shake the sieves for 10 minutes.
- Find the weight of soil retained on each sieve.
- Find the weight of soil on pan.

1.6 FINE SIEVE ANALYSIS

- Arrange the second set of sieves such that 2 mm sieve is at the top and 0.075 mm sieve is at the bottom.
- Put pan at the bottom of 0.075 mm sieve.
- Put the soil passing 4.75 mm sieve on the top sieve and then cover it.
- Put the set of sieves with pan and cover in the sieve shaker.
- Shake the sieves for 10 minutes.
- Find the weight of soil retained on each sieve.

1.7 WET SIEVE ANALYSIS

Wet sieve analysis is considered for clayey or cohesive soil:

- Take soil finer than 2 mm size and oven-dry it 105–l10°C.
- Spread the sample in a tray and cover it with water.
- Stir the mix and leave for soaking.
- Put the soaked soil specimen on the top sieve of the set of sieves such that the finest sieve and pan is at the bottom.
- Wash the soaked soil specimen thoroughly. Continue washing till the water passing each sieve is substantially clean.
- Empty the fraction of soil on each sieve carefully. Dry the soil in oven at 105–110°C.
- Weigh the oven dry-soil separately.

Note: The sieve sizes for wet sieve analysis are same as the fine sieve analysis.

For coarse grained analysis, fine grained analysis and wet sieve analysis, find the percentage of soil retained on each sieve; cumulative percentage retained and percentage finer. Particle size distribution curve is obtained by plotting particle size on x-axis on log scale and percentage finer on *y*-axis.

1.8 PRECAUTIONS

- The temperature of oven should be between 105–110°C.
- The soil should not come out while shaking the sieves in the sieve shaker.
- Determine percentage finer with respect to total soil taken.

1.9 OBSERVATIONS AND CALCULATIONS

Table 1.1 shows coarse sieve analysis.

Table 1.1: Coarse sieve analysis

Weight of soil taken for analysis = ... g

1st sieve size (mm)	*Particle size (mm)*	*Weight of soil retained (g)*	*Percentage weight retained*	*Cumulatf-e retained percentage*	*Percentage finer (NJ)*
100					
63					
40					
20					
4.75					

Table 1.2 shows fine sieve analysis and wet sieve analysis.

Table 1.2: Fine sieve analysis and wet sieve analysis

Weight of soil taken for analysis = ... g

Ist Sieve	*Particle Size (mm)*	*Wight of soil retained (g)*	*Percentage weight retained*	*Cumulative Percentage retained*	*Percentage finer (N)*
2					
1					
0.600					
0.425					
0.212					
0.150					
0.0075					

1.10 RESULT

1. Plot curve between percentage finer and grain size on semi log graph
2. Find particle size for 10% finer, D_{10}: Particle size for 30% finer, D_{30}: Particle size for 60% finer, D_{60}.
3. Find uniformity coefficient $Cu = \frac{D_{60}}{D_{10}}$
4. Find coefficient of curvature Cc = $\frac{(D_{30})^2}{(D_{60} \times D_{10})}$

1.11 GRAIN SIZE ANALYSIS FOR SOIL PASSING 0.075 MM SIEVE BY SEDIMENTATION

The following are the methods used to find the grain size distribution of soils smaller than 0.075 mm sieve.

1. Pipet method
2. Hydrometer method

Details of these methods are not included as it is beyond the scope of coverage. For details please refer author's "Laboratory Manual for Soil Testing" and IS 2720 part IV, Indian Standard Methods of Test for Soils, Grain Size Analysis.

QUESTIONS

1. What is the purpose of sieve analysis?
2. Define coefficient of curvature (Cc) and coefficient of uniformity (Cu). What are their applications?
3. What do you understand by uniformly graded and well graded soil?
4. Write the meaning of soils which are GW, GM, GC, SW, SP, SM, SC, SW-SM, GP-GC.
5. Why do you use semilog graph paper for plotting grain-size distribution curve?
6. What are the precautions in sieve analysis?
7. What are the sources of errors in sieve analysis?
8. How do you decide the type of samples to be taken for sieve analysis?
9. What are the poorly graded, well graded and uniformly graded soil?
10. What is the difference between dry sieve analysis and wet sieve analysis?

CHAPTER 2

Liquid Limit and Plastic Limit

2.1 THEORY

The limiting water content when a soil mass passes from liquid to plastic state of consistency is termed liquid limit. Liquid limit is the water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 13 mm under an impact of 25 blows in Casagrande's liquid limit apparatus. The limiting water content when a soil mass passes from plastic to semisolid state of consistency is termed plastic limit. Plastic limit is defined as the water content at which a soil will just begin to crumble when rolled into a thread of 3 mm in diameter.

2.2 APPLICATIONS

Fine grained cohesive soils are classified by knowing liquid limit and plastic limit. From liquid limit and plastic limit we can find flow index, toughness index and plasticity index. These give an idea about plasticity, cohesiveness, compressibility, shear strength and permeability of cohesive soils.

2.3 LIQUID LIMIT TEST

2.3.1 Object

To determine liquid limit of soil.

2.3.2 Apparatus

- Casagrande's liquid limit apparatus (Fig. 2.1)
- Grooving tool
- Spatula
- Mixing dish or bowl
- Containers for water content
- Balance, sensitive to 0.01 g
- Oven
- Sieve 0.425 mm.

Fig. 2.1: Liquid limit test apparatus
(Courtesy: AIMIL Ltd.)

2.3.3 Procedure

- Clean, dry and make oil free the bowl of liquid limit device.
- Keep the height of drop of bowl equal to 10 mm.

- Take about 250 g of dry soil sample passing 0.425 mm sieve.
- Mix the soil with water on a glass plate with a spatula until the mixture is uniform and behaves as a soft paste.
- Place 50 to 80 g of soil paste in the bowl and level it off to a depth of approximately 1 cm, i.e. 10 mm.
- Cut a groove through the sample from back to front dividing the paste in the bowl into two equal halves. Consider Casagrande's tool for a normal fine grained soil and ASTM tool for sandy fine grained soil.
- Turn the handle of Casagrande's device at a steady rate of two revolutions per second. Continue turning until two halves of soil pat come in contact at the bottom of the groove along a distance of 13 mm. Note the number of blows. The groove should come in contact due to flow of soil not due to sliding.
- Take 5 to 10 g of soil from the sample and put it in a small container for water content determination.
- Repeat steps 3 to 8 for four to five times. Note down the number of drops and water content each time. It is recommended that the water content should be varied such that the number of drops are between 15 and 30.

2.3.4 Precautions

- The soil used in liquid limit test should not be oven dried.
- The groove made in the soil in liquid limit test should close 13 mm by flow of soil from either side and not by slippage.
- The lid of container should be made tight immediately after putting the soil in the container.
- Add water in the different soil sample such that the number of blows (drops) range from 15 to 35

2.3.5 Observations and Calculations

Table 2.1 shows liquid limit.

Table 2.1: Liquid limit

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*
1. Number of drops, N			
2. Container number			
3. Weight of container with lid, W_1 (g)			
4. Weight of container + lid + wet soil, W_2 (g)			
5. Weight of container + lid + dry soil, W_3 (g)			
6. Weight of water (W_w) = ($W_2 - W_3$) (g)			
7. Weight of dry soil (W_d) = ($W_3 - W_1$) (g)			
8. Water content $w = \dfrac{W_2 - W_3}{W_3 - W_1} \times 100\%$ $= \dfrac{W_w}{W_d} \times 100\%$			

Plot log N on x-axis and water content, w on y-axis. From plot find the water content for 25 numbers of blows (drops). This gives liquid limit (Fig. 2.2).

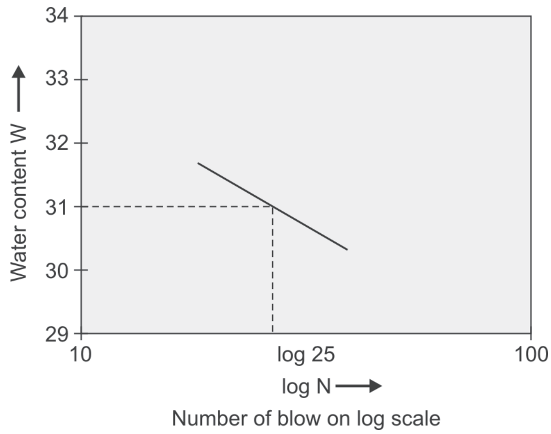

Fig. 2.2: Liquid limit result

QUESTIONS

1. Define liquid limit. What do you understand by it?
2. To determine liquid limit in the laboratory, how is it defined?
3. At liquid limit, what will be the consistency of soil?
4. At liquid limit, what will be the state of soil?
5. At liquid limit, what will be the shear strength of soil?
6. Explain giving reasons as to why liquid limits of 2 samples from two sites are different?
7. Describe in brief the applications of liquid limit.
8. What is the name of liquid limit apparatus? Who invented it?
9. Whether undisturbed or remoulded sample is used to determine liquid limit and why?
10. In order to estimate liquid limit plane graph paper or semilog graph paper is used and why?
11. Define flow curve and flow index.

2.4 PLASTIC LIMIT TEST

2.4.1 Object

To determine plastic limit of soil.

2.4.2 Apparatus

- Glass or plastic plate
- Metal rod of 3 mm diameter
- Spatula
- Containers (small size)
- Balance sensitive to 0.01 g
- Oven.

2.4.3 Procedure

- Take about 20 g of soil for plastic limit test. The soil should pass through 0.425 mm IS sieve.
- Mix the soil with distilled water thoroughly to get soil paste.
- Make the soil paste into a ball of diameter 10–20 mm.
- Convert the ball of soil into a thread by rolling it under the fingures against the glass surface. Roll the thread such that the thread is of 3 mm diameter. Measure the diameter of the thread by metal rod of 3 mm diameter.
- If the thread crumbles when rolled into diameter 3 mm, collect such threads for water content determination. If the thread does not crumble, knead the sample and again make the thread. Repeat this process until the thread crumbles at 3 mm diameter.
- Repeat steps 1–5 with three more fresh samples.

2.4.4 Observations and Calculations

Table 2.2 shows plastic limit.

Table 2.2: Plastic limit

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*
1. Container number			
2. Weight of container with lid, W_1 (g)			
3. Weight of container + lid + wet soil, W_2 (g)			
4. Weight of container + lid + dry soil, W_3 (g)			
5. Weight of dry soil (W_d) = ($W_3 - W_1$) (g)			
6. Weight of water (W_w) = ($W_2 - W_3$) (g)			
7. Plastic limit = $\frac{W_w}{W_d} \times 100\%$ (water content)			

$$\text{Average plastic limit, } W_p = \ldots\ldots (\%)$$

$$\text{Natural water content, } W = \ldots\ldots (\%)$$

$$\text{Plasticity index } (I_p) = \text{Liquid limit} - \text{Plastic limit}$$

$$= (W_L - W_P)\ldots..\% \tag{2.1}$$

$$\text{Consistency index} = \frac{W_L - w}{I_P} \tag{2.2}$$

$$\text{Liquidity index} = \frac{w - W_P}{I_P} \tag{2.3}$$

QUESTIONS

1. Define plastic limit. What do you understand by it?
2. To determine plastic limit in the laboratory how is it defined?
3. At plastic limit, what will be the consistency of soil?

4. At plastic limit, what will be the state of soil?
5. Do different soils have different consistency at their plastic limits?
6. What would be the diameter of soil while determining plastic limit and why?
7. How will the plastic limit be affected if the diameter of thread is >3 mm?
8. Will the two soil samples have the same shear strength at their plastic limits? Explain it.
9. Whether the plastic limit will be same or different for two soils obtained from the same site.

CHAPTER 3

Shrinkage Factors of Soil

3.1 OBJECT

To determine the shrinkage factors, i.e. shrinkage limit, shrinkage ratio, shrinkage index and volumetric shrinkage of soils.

3.2 THEORY

The shrinkage limit is the maximum water content at which a further reduction in water content will not cause a decrease in volume of the soil mass. The shrinkage limit is obtained as

$$W_s = W_s = \left[w - \frac{(V_w - V_d)}{W_d} \times 100 \right] \% \tag{3.1}$$

Where w is the water content

V_w is the internal volume of shrinkage dish

v_d is the volume of dry soil pat

W_d is the weight of dried soil pat

Shrinkage index, $$I_s = (I_p - W_s) \tag{3.2}$$

Shrinkage ration, $$R = \frac{W_d}{V_d} \tag{3.3}$$

Volumetric shrinkage, $$V_s = (W_1 - W_s)R \tag{3.4}$$

$$= (W_1 - W_s)\frac{W_d}{V_d} \tag{3.5}$$

Where W_1 is the given water content in percentage.

3.3 APPLICATIONS

By knowing the shrinkage limit we understand the swelling and shrinkage properties of cohesive soils. From shrinkage limit we find the suitability of soil as a construction material in foundations, roads, embankments and dams.

3.4 APPARATUS

Shrinkage dish 45 mm diameter and 15 mm height (Fig. 3.1).

- Evaporating dish
- Glass cup 50 to 55 mm in diameter and 25 mm in height
- Glass plates, plain and with metal prongs 75 × 75 mm, 3 mm thick
- Spatula
- Straight edge 150 mm length
- Balance of 0.1 g sensitivity
- Mercury
- Drying oven.

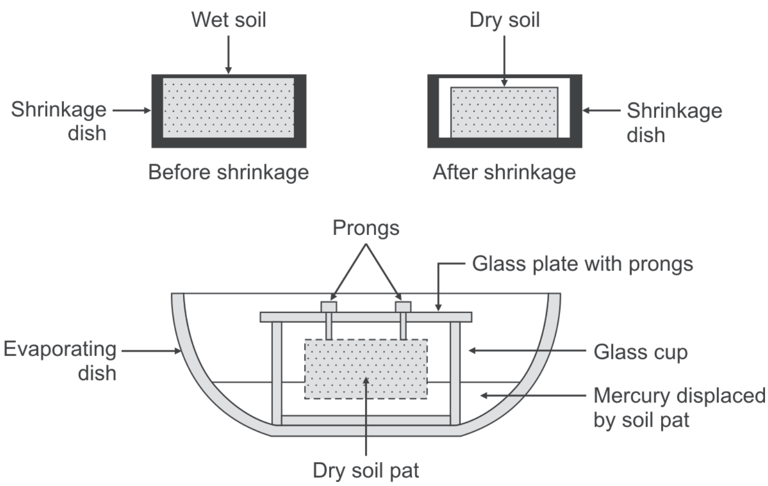

Fig. 3.1: Shows the apparatus for shrinkage limit

3.5 PROCEDURE

1. Weight the shrinkage dish. Let it be W_1. Put the shrinkage dish in an evaporating dish. Fill the shrinkage dish with mercury. Put a glass plate on the top of the shrinkage dish and press it. Find the weight of shrinkage dish with mercury. Then find the weight of mercury in shrinkage dish. Divide the weight of mercury with its unit weight. It gives the internal volume of shrinkage dish. Let it be V_w.
2. Mix 50 gram of soil passing 425 micron, i.e. 0.425 mm sieve with distilled water in an evaporating dish. The water added should be somewhat greater than the liquid limit.
3. Coat the inside of shrinkage dish with a thin layer of grease.
4. Fill the dish by soil paste up to one-third of its height. Tap the dish so that soil paste flow towards end. Repeat this for two more layers and fill the shrinkage dish. Strike off the excess soil paste with straight edge; clean outside surface and find the weight of shrinkage dish with wet soil. Let it be W_2 .
5. Dry the soil in air until the colour of soil pat turns light. Then dry it in a temperature controlled oven at 105–110°C. After drying, cool it in air and then find the weight of shrinkage dish with dry soil pat. Let it be W_3.

6. Fill the glass cup with mercury.
7. Place the glass cup with mercury in a large evaporating dish.
8. Place dry soil pat on the surface of mercury.
9. With the help of glass plate with prongs, press the soil pat such that it is completely submerged in mercury.
10. Find the weight of displaced mercury. Divide it by unit weight of mercury. This gives the volume of dry soil pat. Let it be V_d.

3.6 PRECAUTIONS

1. While filling the shrinkage dish with soil paste, do sufficient taping to remove the entrapped air.
2. Weigh the dry soil pat soon after it has been removed from desiccator.
3. Grease inside of the shrinkage dish with vaseline.
4. Repeat the test at least four times for each soil sample and take the average.

3.7 OBSERVATIONS AND CALCULATIONS

$$\text{Weight of wet soil} = (W_2 - W_1)\ (g)$$

$$\text{Weight of dry soil } (W_d) = (W_3 - W_1)\ (g)$$

$$\text{Water content of soil, } w = \frac{\text{Weight of water}}{\text{Weight of dry soil}} \times 100\%$$

$$= \frac{(W_2 - W_1) - (W_3 - W_1)}{(W_3 - W_1)} \times 100\% \qquad (3.6)$$

Shrinkage limit (remoulded soil)

$$W_s = \left[w - \frac{(V_w - V_d)}{W_d} \times 100 \right] \%$$

$$\text{Shrinkage index, } Is = Ip - Ws$$

$$\text{Shrinkage ratio, } R = \frac{W_d}{V_d}$$

$$\text{Volumetric shrinkage, } V_s = (W_8 - W_s)\ R$$

$$= (W_8 - W_s)\ \frac{W_d}{V_d}$$

Where W_8 is the given water content in percentage.

Table 3.1 shows shrinkage limit.

Table 3.1: Shrinkage limit

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*	*4*
1. Weight of shrinkage dish, W_1 (g)				
2. Weight of shrinkage dish with wet soil pat, W_2 (g)				
3. Weight of shrinkage dish with dry soil pat, W_3 (g)				
4. Weight of dry soil pat, $W_d = (W_3 - W_1)$ (g)				
5. Weight of wet soil pat, $(W_{wet}) = (W_2 - W_1)$ (g)				
6. Volume of shrinkage dish = Volume of wet soil, V_w (*cc*)				
7. Volume of dry soil = V_d (*cc*)				
8. Water content, $w = \frac{[(W_2 - W_1) - (W_3 - W_1)]}{W_3 - W_1} \times 100\%$				
9. Shinkage Limit, $= \left[w - \frac{(V_w - V_d)}{W_d} \times 100 \right] \%$				

QUESTIONS

1. What do you understand by shrinkage limit?
2. If water content is reduced at shrinkage limit what is the reason for no decrease of volume of soil?
3. Write the factors which affect the value of shrinkage limit.
4. Write the practical application of shrinkage factors.
5. At shrinkage limit, what is the consistency of soil?
6. At shrinkage limit, what is the degree of saturation?
7. If water is added to the soil sample at shrinkage limit, what will be its effect on volume of soil?
8. What is the importance of coating inside the shrinkage dish with grease?
9. Three prongs are provided on the glass plate, what is the reason for this?
10. Whether undisturbed or remoulded sample is used in the shrinkage limit test?

CHAPTER 4

In Situ Density (Core Cutter Method and Sand Replacement Method)

4.1 THEORY

Density is defined as mass per unit volume of soil. The density can be expressed in g/cm^3, kg/m^3, etc.

Density of Soil

$$r = \frac{W}{V}$$

where r is density of soil, V is the volume of soil, W is mass of soil.

Wet Density of Soil

Wet density of soil is the mass of wet soil per unit volume of soil, i.e.

$$r_b = \frac{W_{wet}}{V}$$

Where r_b is the wet density (bulk density) of soil and V is the volume of soil.

Dry Density of Soil

Dry density of soil, $r_d = \dfrac{r_b}{1 + w}$

where w is water content.

Void Ratio

Void ratio is the ratio of volume of voids to volume of soil solids.

$$\text{Void ratio, } e = \frac{V_v}{V_s} \times 100$$

where V_v is the volume of void and V_s is the volume of soil solids.

Degree of Saturation

Degree of saturation is defined as the ratio of volume of water to volume of voids.

i.e., Degree of saturation, $S = \dfrac{V_W}{V_V} \times 100$

where V_w = Volume of water and V_v is the volume of void.

4.2 APPLICATIONS

With the help of density of soil we can find bearing capacity of soil foundation system, settlement of footings, earth pressure behind retaining walls, dams and embankments. The density also helps in checking the stability of dams, natural slopes and embankments. It helps in determining the relative density of soil.

4.3 CORE CUTTER METHOD

4.3.1 Object

To determine the field density by core cutter method.

4.3.2 Apparatus

- Cylindrical core cutter of diameter 10 cm and height 12.74 cm
- Steel dolly
- Balance
- Straight edge
- Knife
- Water content cans
- Oven
- Steel rammer.

4.3.3 Procedure

1. Find the weight of the core cutter; Let it be W_1.
2. Measure internal diameter and height of the core cutter. Find internal volume of core cutter. Let it be V_0.
3. In the field, clean and level the ground where density is to be determined.
4. Push the cylindrical core cutter into the soil to its complete depth by gently ramming it by rammer.
5. Excavate the soil around the core cutter and remove the excavated soil.
6. Lift the core cutter up carefully so that no soil comes out of the core cutter. The soil must be projected up and down of the core cutter.
7. Trim the bottom and top surface of the sample very carefully.
8. After cleaning the outside of the core cutter, determine the weight of core cutter with soil. Let it be W_2.
9. Take the empty weight of can. Let it be W_3.
10. After removing the soil from core cutter put some soil in the can for water content determination. Let the weight of can with soil be W_4.
11. Put the can with wet soil in oven at 105–110°C for 24 hours for drying.
12. Find the weight of dry soil with can. Let it be W_5.

4.3.4 Precautions

1. The core cutter should be removed gently by putting steel dooly on the core cutter.
2. Excavate the soil all around the core cutter before lifting the cutter.
3. Take care that no soil drops down while taking out the cutter from soil.

4. The soil for water content determination should be kept in oven at temperature 105–110°C.

4.3.5 Observations and Calculations

$$\text{Weight of core cutter, } W_1 = \text{......}(g)$$

$$\text{Weight of core cutter with soil, } W_2 = \text{......}(g)$$

$$\text{Weight of wet soil, } W_{wet} = W_2 - W_1 = \text{...........}(g)$$

$$\text{Volume of soil} = \text{Internal volume of core cutter}$$

$$= V_0 = \text{...........}(\text{cm}^3)$$

$$\text{Bulk density of soil } (r_b) = \frac{W_{wet}}{V_0}$$

$$= \frac{W_2 - W_1}{V_0} \text{.........}(\text{g/cm}^3)$$

$$\text{Weight of can} = W_3 = \text{...........(g)}$$

$$\text{Weight of can + wet soil} = W_4 = \text{......(g)}$$

$$\text{Weight of can + dry soil} = W_5 = \text{......(g)}$$

$$\text{Weight of water } (W_w) = W_4 - W_5 = \text{......(g)}$$

$$\text{Weight of dry soil} = W_d = W_5 - W_3 = \text{......(g)}$$

$$\text{Water content, } w = \frac{\text{Weight of water}}{\text{Weight of dry soil}} \times 100$$

$$= \frac{W_w}{W_d} \times 100\% \quad (4.1)$$

$$\text{Dry density of soil, } r_d = \frac{r_b}{1 + w} = \text{........}(\text{g/cm}^3) \quad (4.2)$$

Repeat the above steps for 3 to 4 samples for the same levelled ground.

4.4 SAND REPLACEMENT METHOD

4.4.1 Object

To determine field density of soil by sand replacement method.

4.4.2 Apparatus

- Sand pouring cylinder
- 30 cm^2 metal tray with 10 cm hole in the centre.
- Cylindrical calibration container
- Balance
- Cans

- Oven
- Glass plate
- Clean oven dried sand passing 600 micron sieve, i.e. 0.600 mm sieve.

Figure 4.1 shows the sand pouring cylinder, calibrating container and metal tray with hole in the centre.

Fig. 4.1: *In situ* density by sand replacement method (*Courtesy:* AIMIL Ltd.)

4.4.3 Produce

I. Determination of Density of Sand in Laboratory

1. Measure the internal diameter and height of the calibrating container and find its volume. Let it be V_c.
2. Find the weight of sand pouring cylinder filled with sand. Let it be W_1.
3. Place the sand pouring cylinder on glass plate and open its shutter. The sand falls and fills the cone of sand pouring cylinder. Close the shutter when cone is completely filled by sand. Find the weight of sand pouring cylinder with remaining sand. Let it be W_2.
4. Put the sand pouring cylinder concentrically on the top of the calibrating container. Open the shutter. Sand falls and fills the calibrating container and cone completely. Close the shutter. Find the weight of sand pouring cylinder with remaining sand. Let it be W_3.
5. Find the density of sand.

II. Determination of Water Content

1. Weigh the metal tray having central hole. Let the weight be W_1.
2. Place the metal tray with central hole on levelled ground.
3. Excavate soil of diameter equal to the diameter of hole and depth approximately 15 cm.
4. Put the excavated soil in tray and find its weight. Let the weight of tray and soil be W_2.
5. Put the tray with soil in oven. Find the weight of tray with dry soil. Let it be W_3.
6. Determine water content.

III. Density of Soil in the Field

1. Fill the sand pouring cylinder by sand and weigh it. Let the weight be W_1.
2. Put the pouring cylinder over the hole, and open the shutter until the sand fills completely the hole and cone. Close the shutter. Find the weight of sand pouring cylinder with remaining sand. Let it be W_2.
3. Subtract the weight of sand in cone to $W_1 – W_2$. It gives the weight of sand filled in the hole. Let it be W_{hole}.

4. Find the volume of hole by dividing the weight of sand filled in the hole by density of sand. Let this volume be V_{hole}.
5. Find density of soil, dividing the weight of soil excavated from hole by volume of hole. It gives the density of soil in field. Let the density by r_b.

4.4.4 Precautions

1. Do not leave loose material in the hole.
2. There should be no vibration.
3. Take average value of density as density varies from point to point.
4. In no case the side of hole should cave in.

4.4.5 Observations and Calculations

Table 4.1 shows determination of density of sand in laboratory.

Table 4.1: Determination of density of sand in laboratory

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*
1. Volume of calibrating container, V_c (cm^3)			
2. Weight of pouring cylinder + sand, W_1 (g)			
3. Weight of pouring cylinder with remaining sand, W_2(g) (after filling the cone)			
4. Weight of pouring cylinder with remaining sand, W_3(g) (after filling the calibrating container and cone)			
5. Weight of sand filled in cone = $(W_1 - W_2)$ (g)			
6. Weight of sand filled in cylinder and cone = $(W_2 - W_3)$ (g)			
7. Weight of sand in calibrating container $Wc = [(W_2 - W_3) - (W_1 - W_2)]$(g)			
8. Hence, density of sand $r_d = \frac{W_c}{V_c}$ (g/cm$_3$)			

Table 4.2 shows water content determination.

Table 4.2: Water content determination

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*	*4*
1. Tray No.				
2. Weight of tray = W'_1 (g)				
3. Weight of tray with excavated wet soil = W'_2(g)				
4. Weight of tray with dry soil = W'_3(g)				
5. Weight of water $(W_w) = (W'_2 - W'_3)$ (g)				
6. Weight of dry soil $(W_d) = (W'_3 - W'_1)$ (g)				
7. Water content, $w = \frac{W_w}{W_d} \times 100\%$				

Table 4.3 shows field density of soil.

Table 4.3: Field density of soil

Soil sample No.:............................ Date : ....

Observation No.	*1*	*2*	*3*	*4*
1. Weight of pouring cylinder filled with sand = W_1 (g)				
2. Weight of pouring cylinder with sand after filling the hole and cone = W_2(g)				
3. Weight of sand filled in cone = W_{cone} (Refer Table 4.1)				
4. Weight of sand filled in hole (W_{hole}) = $[(W_1 - W_2) - W_{cone}]$ (g)				
5. Volume of hole V_{hole} (cm^3) = $\frac{W_{hole}}{r_d}$ where r_d is density of sand (refer Table 4.1)				
6. Hence, density of soil, r_b (g / cm^3) = $\frac{\text{Weight of excavated soil}}{\text{Volume of hole}} = \frac{W_2 - W_1}{V_{hole}}$ (Refer Table 4.2)				

QUESTIONS

1. What are dry density, wet density and saturated densities of a soil?
2. Define submerged density.
3. Out of dry density, wet density and saturated densities, which density is maximum and which one is minimum?
4. Compare density, relative density and specific gravity of a soil.
5. Describe in brief the precautions to be taken in core cutter method.
6. Describe in brief the precautions to be taken in sand replacement method.
7. Differentiate between core cutter method and sand replacement method.
8. How the density of soil gets affected when the core cutter is inserted in the soil?

CHAPTER 5

Compaction Test

5.1 OBJECT

To determine the optimum moisture content and maximum dry density of a soil by standard and modified proctor tests.

5.2 THEORY

In compaction the soil gets densified due to the reduction of air voids. The degree of compaction of a soil is measured in terms of its dry density. The degree of compaction mainly depends upon its moisture content, compaction energy and type of soil. Compaction energy remaining the same each soil attains the maximum dry density at a particular water content. This water content is known as optimum water content.

5.3 APPLICATIONS

Due to compaction, the density, shear strength and bearing capacity of soil increase. The result of compaction is to reduce void ratio, porosity, permeability and settlements. The stability of earthen dams, embankments, roads, etc. are achieved from results of compaction tests. The laboratory results are useful for field problems.

5.4 APPARATUS

Cylindrical mould of capacity 1000 ml having internal diameter 100 mm and height 127.3 mm or cylindrical mould of capacity 2250 ml having internal diameter 150 mm and height 127.3 mm (Fig. 5.1).

The cylindrical mould is having base plate and removable extension collar:

- Rammer for light compaction, weight 2.6 kg and free drop 310 mm.
- Rammer for heavy compaction, weight 4.89 kg and free drop 450 mm.
- IS sieves: 20 mm and 4.75 mm.
- Oven to maintain a temperature of 105 to 110°C.
- Balance 10 kg capacity with 1 g accuracy.
- Balance 200 g capacity with accuracy 0.01 g.
- Spatula.
- Steel straight edge.

Fig. 5.1: Shows the apparatus for compaction test
(Courtesy: AIMIL Ltd.)

5.5 PROCEDURE

1. Take about 20 kg air dried soil sample for 1000 ml mould or about 40 kg for 2250 ml mould. Sieve the soil through 20 mm and 4.75 mm IS sieve. If the percentage of soil retained on 4.75 mm sieve is less than 20, take 1000 ml mould and if percentage retained on 4.75 mm IS sieve is greater than 20, take 2250 ml mould.
2. Mix the soil passing 4.75 mm IS sieve and retained on 4.75 mm IS sieve.
3. Take about 2.5 kg of soil for 1000 ml mould and 5.6 kg for 2250 ml mould for light compaction. Similarly take 2.8 kg of soil for 1000 ml mould and 6 kg for 2250 ml mould for heavy compaction.
4. Add water about 4% for coarse grained soil and 8% for fine grained soil. Keep this soil water mix in an airtight container for about 5 to 30 minutes for sandy soil and 18–20 hours for clayey soils.
5. Find the weight of mould with base plate. Let it be W_1.
6. Fix the collar on the mould and apply grease inside of the mould and collar.
7. For light compaction, use 2.6 kg rammer with height of fall 310 mm with 25 number of blows for a layer of soil. Scratch the compacted soil on top and put the second layer and compact it as the first layer. Similarly scratch the top of second layer and put the soil on it and compact it as the first layer. In case of 2250 ml mould compaction will be similar to mould of 1000 ml except that the number of blows now will be 56.
8. For heavy compaction, the compaction is done using 4.89 kg hammer with free fall of 450 mm in five layers. Each layer is compacted by 25 blows for 1000 ml mould and 56 blows for 2250 ml mould.
9. Remove the collar and carefully level off the top of the mould by means of straight edge. find the weight of mould plus base plate plus wet soil. Let it be W_2 .
10. Eject the soil from the mould and cut at the middle and take samples for water content determination.

11. Repeat steps 6–10 for 4–5 times, using a fresh part of soil specimen each time. Add water to the specimen such that the water content increases each time.

5.6 PRECAUTIONS

1. During compaction, the mould should be placed on a solid base.
2. The compaction blows should be uniformly distributed over the surface of each layer.
3. Scratch each layer of compacted soil and then put the next layer and compact.
4. After compacting the last layer the soil should project about 5 mm above the top rim of the mould.

5.7 OBSERVATIONS AND CALCULATIONS

Table 5.1 shows standard proctor test.

Table 5.1: Standard proctor test

Soil sample No.:............................ Date : ....

Volume of mould (V) = 945 cc Weight of rammer = 2.5 kg

Number of layers = 3 Number of blows = 25

Observation No.	*1*	*2*	*3*	*4*	*5*
Determination of bulk density of soil, r_b					
1. Weight of mould + base plate, W_1 (g)					
2. Weight of mould + base plate + compacted soil, W_2 (g)					
3. Weight of compacted soil (w), = ($W_2 - W_1$) (g)					
4. Bulk density $r_b = \frac{W}{V}$ g/cm^3					

Table 5.2 shows standard proctor test determination of dry density.

Table 5.2: Standard proctor test (determination of dry density)

Observation No.	*1*	*2*	*3*	*4*	*5*
Determination of water content					
1. Can no.					
2. Weight of can + lid, W_1 (g)					
3. Weight of can + lid + wet soil, W_2 (g)					
4. Weight of can + lid + dry soil, W_3 (g)					
5. Weight of water = ($W_2 - W_3$) (g)					
6. Weight of dry soil W_d = ($W_3 - W_1$) (g)					
7. Water content $w = \frac{W_w}{W_d} \times 100\%$					
8. Dry density $= \frac{r_b}{1+w}$ g/cm^3					

Table 5.3 shows modified proctor compaction

Table 5.3: Modified proctor compaction

Soil sample No.:............................ Date : ....
Volume of mould (V) = 945 cc Weight of rammer = 4.5 kg
Number of layers = 5 Number of blows = 25

Observation No.	*1*	*2*	*3*	*4*	*5*
Determination of bulk density of soil, r_b					
1. Weight of mould + base plate, W_1 (g)					
2. Weight of mould + base plate + compacted soil, W_2 (g)					
3. Weight of compacted soil (w)=($W_2 - W_1$) (g)					
4. Bulk Density $r_b = \frac{W}{V}$ g/cm^3					

Table 5.4 shows modified proctor test (determination of dry density).

Table 5.4: Modified proctor test (determination of dry density)

Observation No.	*1*	*2*	*3*	*4*	*5*
Determination of water content					
1. Can no.					
2. Weight of can + lid, W_1 (g)					
3. Weight of can + lid + wet soil, W_2 (g)					
4. Weight of can + lid + dry soil, W_3 (g)					
5. Weight of water = ($W_2 - W_3$) (g)					
6. Weight of dry soil Wd = ($W_3 - W_1$) (g)					
7. Water content $w = \frac{W_w}{W_d} \times 100\%$					
8. Dry density = $\frac{r_b}{1+w}$ g/cm^3					

QUESTIONS

1. What do you mean by compaction of soil?
2. What do you mean by optimum water content? Explain.
3. What are the factors which affect compaction?
4. What do you mean by wet side of optimum and dry side of optimum? Which side will you consider for field compaction?
5. What is difference between compaction and consolidation of soil?
6. Describe in brief the field applications of compaction test.
7. What are the different methods of compaction of soil in the laboratory?
8. What is the maximum dry density of soil?
9. What will be the dry density of soil at optimum water (moisture) content?
10. Write the field methods of compaction of soil.
11. Explain zero air void line.
12. Compare standard proctor compaction test with modified proctor compaction test.

CHAPTER 6

Laboratory California Bearing Ratio (CBR) Test

6.1 OBJECT

To determine California bearing ratio (CBR) of soil in laboratory.

6.2 THEORY

The CBR test was developed by the California division of highway as a method of classifying and evaluating soil-subgrade and base course material for flexible pavements and in designing base course for airfield pavements. The CBR is defined as the ratio of load corresponding to the chosen penetration to the standard load for same penetration expressed in percentage. The CBR test may be conducted in undisturbed specimen or remolded specimen in the laboratory. In this method a cylindrical plunger of 50 mm diameter is caused to penetrate a pavement component material at 1.25 mm / minute. The loads for 2.5 mm and 5 mm penetration are recorded. This load is expressed as a percentage of standard load. The standard load values are obtained from the Table 6.1.

Table 6.1: Standard load values on crushed stones for different penetration values

Penetration, mm	*Standard load, kg*
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

6.3 APPARATUS

Refer IS 2720 (Part 16): 1987

- Loading machine
- Compaction rammer
- Perforated plate, tripod and dial gauge
- Annular weight
- Coarse filter paper
- Sieves 4.75 and 20 mm
- Oven

- Balance
- CBR mould, 150 mm diameter and 175 mm high
- Spacer disc
- Penetration plunger: 50 mm diameter
- Surcharge weights
- Rammer 2.6 kg with 310 mm drop and 4.89 kg with 450 mm drop
- Penetration measuring dial gauge
- Straight edge
- Filter paper
- Soaking tank.

6.4 PREPARATION OF SOIL SPECIMEN

Undisturbed Specimen

The undisturbed soil specimens are obtained by fitting a cutting edge to the mould. The mould with cutting edge is pushed into the ground until the mould is full of soil. The soil around the mould is excavated and then the mould with soil is taken out.

The excess soil from top and bottom surface is trimmed with straight edge.

Remoulded Specimen

About 45 kg of dried material is sieved through 20 mm IS sieve. If there is no sufficient material retained on 20 mm sieve, take equal amount of material passing 20 mm sieve and retained on 4.75 mm sieve and then add it to the material which has already passed through 20 mm IS sieve and retained on 4.75 mm sieve. For remoulded soil optimum water content and dry density are required which are determined by IS light compaction or IS heavy compaction. 5.5 kg weight for granular soils and 4.5–5.0 kg for fine grained soil are taken and mixed with water up to the optimum water content or the field water content. The spacer disc is placed at the bottom of the mould over the base plate. A coarse filter paper is placed over the spacer disc. The wet soil is kept in the mould and then compacted either by IS light compaction or by IS heavy compaction. In IS light compaction or standard proctor compaction the soil is compacted in three equal layers by applying 56 blows of 2.6 kg rammer. The blows should be evenly distributed. In IS heavy compaction or the modified proctor compaction, the· soil is compacted in five equal layers by applying blows of the 4.89 kg rammer. In static compaction, the correct ‘weight of wet soil to obtain the desired density is placed in the mould. The filter paper is placed on the top of soil and then spacer disc is placed on the filter paper. The compaction is attained by pressing in the spacer disk using a compaction machine or jack.

6.5 PROCEDURE

Refer IS 2720 (Part 16): 1987

1. Remove the clamps and lift the mould with compacted soil. Remove the perforated base plate and the spacer disk. Weight the mould with compacted soil.
2. Invert the mould with compacted soil and place it on the filter placed over the base plate. Tighten the clamps of base plate.
3. Place filter paper on the top surface of the sample and place the perforated plate over it.

4. Place the surcharge weights 2.5 or 5.0 kg weight over perforated plate. Keep the mould in water tank for soaking. Let the water enter the specimen both from top and bottom.
5. The tripod and the dial gauge are placed on the top edge of mould to measure swell. Take the initial dial gauge reading. The test set-up is kept in water tank for four days or 96 hours for soaking and then final dial gauge reading is recorded to measure the expension or swelling of the specimen.
6. At the end of soaking, take out the mould and allow it to drain downwards for 15 minutes. Remove the surcharge weight, the perforated top plate and filter paper. Remove the mould with soil from base plate and then weigh the mould with soil. From this weight, water absorbed is obtained.
7. Clamp the mould with specimen over the base plate. Place surcharge weights on specimen sufficient to produce an intensity of loading equal to the weight of the base material (in field) and pavement.
8. To prevent upheaval of soil into the hole of surcharge, place a 2.5 kg annular weight on the soil surface.
9. Place the mould with specimen and base plate under the penetration plunger of the loading machine. In order to make full contact between the surface of specimen and the plunger, place the plunger under a load of about 4 kg.
10. Set the penetration dial gauge and proving ring dial gauge to zero. Apply load to the penetration plunger at the rate of penetration equal to 1.25 mm per minute.
11. Note the load reading at penetration of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5.

6.6 PRECAUTIONS

1. Cutting edge must be fitted to the mould while obtaining undisturbed soil sample.
2. The spacer disc must be placed at the bottom of the mould over the base plate.
3. Coarse filter paper must be placed over spacer disc.
4. The blows of the hammer should be evenly distributed.
5. Keep the test set up in water for soaking for four days or 96 hours.
6. Place a 2.5 kg annular weight on soil surface to prevent upheaval of soil into the hole of surcharge.
7. Apply load to the penetration plunger at the rate of penetration equal to 1.25 mm per minute.

6.7 OBSERVATIONS AND CALCULATIONS

The swelling or expansion ratio is calculated as swelling or expansion ratio

$$\frac{H_f - H_i}{H} \times 100\% \tag{6.1}$$

where H_f = Final dial gauge after soaking, mm
H_i = Initial dial gauge reading before soaking, mm
H = Initial height of specimen, mm.

Plot graph between load (in kg) and penetration (in mm).

Figure 6.1 shows a load penetration curve drawn.

Curve is concave upward in the initial portion and hence correction is required. A correction is applied by drawing a tangent to the upper curve at the steepest point on the curve, i.e.

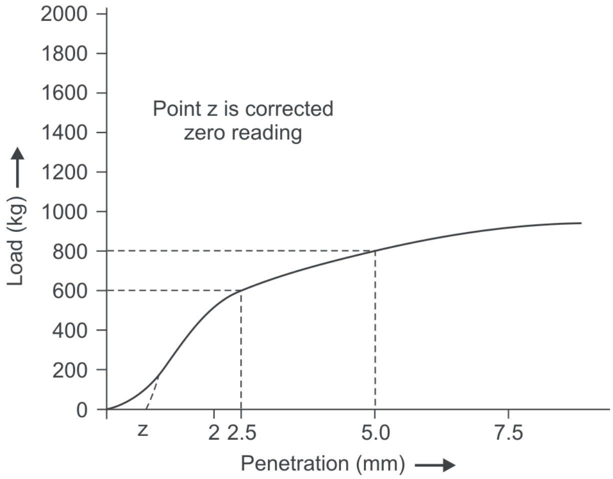

Fig. 6.1: CBR test, load-penetration curve

at point of contraflexure. It intersects the abscissa at point *z*. This point is the corrected origin and penetration of plunger shall be read from this shifted zero point instead of original zero. The corrected load is read from the corrected penetration value.

The CBR is determined as follows:

$$CBR = \frac{F_c}{F_s} \times 100\% \qquad (6.2)$$

where *Fc* is corrected test load corresponding to selected penetration from the load penetration curve. *Fs* is standard load for the same penetration as for corrected load.

The California bearing ratio values are generally calculated at 2.5 mm and 5.0 mm penetration. The CBR value at 2.5 mm penetration is generally greater than at 5.0 mm penetration .

If CBR value corresponding to 5 mm penetration is greater than that for 2.5 mm penetration, the test must be repeated. If same result is obtained then the CBR value corresponding to 5 mm penetration should be taken for design. Table 6.2 shows load penetration values.

Table 6.2: Load penetration values

Penetration (mm)	*Proving ring dial gauge reading (divisions)*	*Load on plunger (kg)*	*Corrected load (kg)*	*Standard load (kg)*	*CBR in %*
0.0					
0.5					
1.0					
1.5					
2.0					
2.5					
3.0					
4.0					
5.0					
7.5					
10.0					
12.5					

Result

$$\text{CBR at 2.5 mm penetration} = \frac{\text{Corrected load at 2.5 mm}}{1370} \times 100\%$$

$$\text{CBR at 5.0 mm penetration} = \frac{\text{Corrected load at 5.0 mm}}{2035} \times 100\%$$

Hence, final CBR value for penetration = ... %

QUESTIONS

1. What is the California bearing ratio?
2. Generally, the CBR value is taken for what penetration?
3. If CBR value for 5.0 mm penetration is greater than CBR value at 2.5 mm penetration then what should be done?
4. If after repeating the test, the CBR value for 5.0 mm penetration is greater than CBR value at 2.5 mm penetration what should be done?
5. How do you get swell or expansion ratio?
6. What is expression for CBR?
7. Write the applications of CBR.
8. How the correct load is obtained from load - penetration curve?
9. What do you mean by soaking of CBR sample?
10. Why annual load is kept on the sample?

CHAPTER 7

Triaxial Test

7.1 OBJECT

To determine cohesion and angle of shearing resistance for *c*-Ø soil and stress-strain curve for *c*-Ø and cohesionless soil.

7.2 THEORY

The triaxial test is the most versatile test to measure the shear strength of soil. In triaxial test a cylindrical specimen is stressed in vertical and lateral directions and the shear parameters cohesion (*C*) and angle of shear resistance (Ø) are obtained, from which the shear strength of soil is determined. In this test the plane of shear failure is not pre-determined. The triaxial tests are superior where confining stress is to be applied. It is superior than direct shear test. In order to determine cohesion (*C*) and angle of shearing resistance (Ø) of soil, Mohr's circles are drawn. The tangent line is drawn on the Mohr's circles. It is called the strength envelope. The intercept with ordinate gives cohesion and slope of the line (envelope) gives angle of shearing resistance.

7.3 APPLICATIONS

The *C* and Ø values obtained from laboratory triaxial test are useful to evaluate the ultimate bearing capacity of soil and also for evaluating the stability of embankment, foundations and slopes. The modulus of elasticity (*E*) is obtained from triaxial test which is used for designing the flexible pavement in the triaxial method of flexible pavement design.

7.4 TRIAXIAL TEST FOR c-Ø SOIL

7.4.1 Preparation of Specimen

Undisturbed Specimen

Collect the undisturbed sample in a tube of same diameter as the split mould. Transfer the sample to split mould with the help of sample extractor. The sample is then taken out carefully from split mould. If the undisturbed sample obtained from field is of larger diameter, then trim it to desired size.

Remoulded Sample

Prepare the remoulded sample by compacting the soil statically or dynamically at required density and water content in a big size mould. Then trim the sample to desired size, i.e. equal to the diameter of the split mould.

7.4.2 Types of Test

Undrained Test

In this test the outlet valve, i.e. the drainage valve is closed. No drainage is allowed from time of application of lateral pressure (σ_3) till specimen fails. The specimen fails under gradually increasing vertical load.

Consolidated Undrained Test

In this test, the drainage valve is kept open until the sample is fully consolidated under the applied lateral pressure σ_3. After consolidation the drainage valve is closed, and no further drainage is allowed till failure under the application of vertical load.

Consolidated Drained Test

In this test the drainage is allowed during the consolidation of the sample due to lateral pressure σ_3. Then drainage is again allowed under the duration of the application of vertical load.

7.4.3 Procedure (Fig. 7.1)

1. In undrained test put non-porous cap on the bottom pedestal. Put the sample on lower cap then surround the sample by cylindrical rubber membrane which is fixed at lower end, i.e. at pedestal by o-ring. Put non-porous cap on the top of sample and then tie the rubber membrane in the upper cap by o-ring.
2. If in undrained case pore water pressure is to be measured then put the porous stone on the lower pedestal.

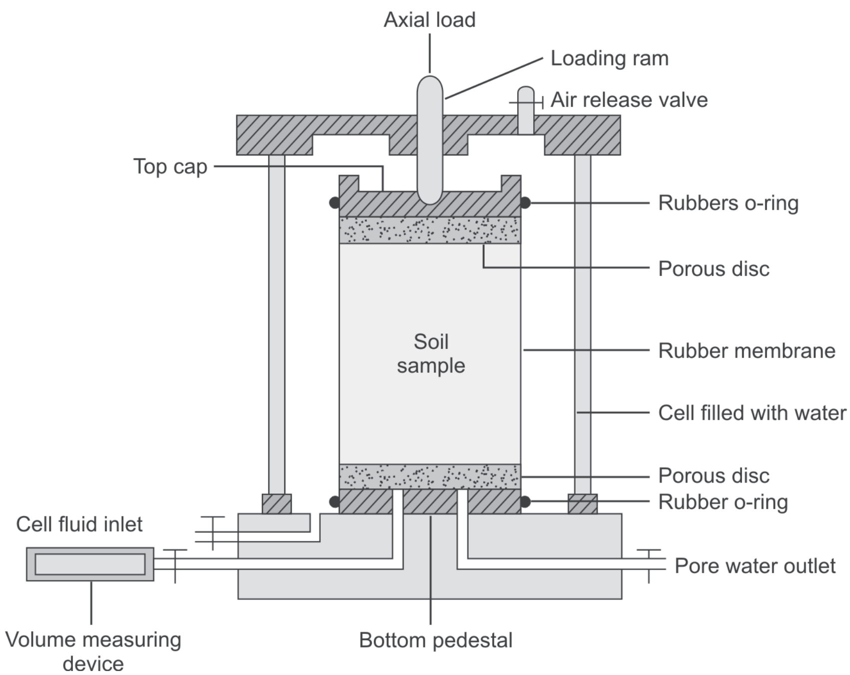

Fig. 7.1: Triaxial apparatus

3. In consolidated undrained and drained test put a porous stone on the lower pedestal, then put sample on it. Then surround the sample by cylindrical rubber membrane which is tied on lower pedestal by o-ring. Tie the sample in top non-porous cap.
4. In order to measure pore water pressure in undrained condition connect the drainage pipe to Bishop's pore pressure apparatus.
5. Apply lateral pressure. Set the proving ring dial gauge and vertical deformation dial gauge to zero. Then apply vertical load and increase gradually until the specimen fails. Take vertical dial gauge reading and proving ring dial gauge reading.
6. Repeat the experiment for various other values of lateral pressure which help in finding the cohesion and angle of internal friction of the soil. Test the soil with lateral pressure of 0, 0.75 and 1.5 kg / cm^2.

7.5 TRIAXIAL TEST FOR COHESIONLESS SOIL

7.5.1 Dry Sample

I. Preparation of Sample

Put a non-porous cap on the bottom pedestal. Fix the cylindrical rubber membrane at the lower pedestal by o-ring. Put the split mould over the base and the rubber membrane taking it through inside and stretch over it at the top. In order to make a sample of required density, weigh the soil on pan. The soil samples may be in loose dry condition or under dense dry condition. To prepare a sample in loose dry condition, pour the soil inside through funnel. Put non-porous cap on it at the top and then seal it by o-ring. Then take out the split mould. To prepare the sample in dry dense condition, pour the soil in layers and compact each layer by tamping. Then put non-porous cap on it and seal the rubber membrane on it by o-ring. Then take out the split mould.

II. Procedure

1. Put the cylindrical cell properly then fill it with water at required lateral (confining) pressure equal to 0.5 kg / cm^2.
2. Raise the loading platform such that the loading cap comes in contact with the ram.
3. Set the proving ring (load measuring device) dial gauge and vertical deformation measuring dial gauge to zero.
4. Start the test and take readings of proving ring dial gauge and vertical deformation dial gauge till the sample fails or 20% deformation is achieved.
5. Draw the sketch of the failure pattern of the sample.
6. Repeat the test for fresh sample at the same density as achieved in the first sample for higher cell pressures such as 1.0, 1.5, 2.0, 3.0 and 4.0 kg / cm^2.

7.5.2 Saturated Sample

I. Preparation of Sample

In order to prepare a sample under saturated condition, put a porous stone (cap) on the pedestal and then seal the rubber membrane to the pedestal by o-ring. Then put the split mould such that the rubber membrane is inside the split mould. Stretch the top portion of the rubber membrane and fold to the split mould. Fill desired water in the membrane. Weigh necessary amount of sand and then pour into the water. When necessary fill sand, level the top surface and then put a non-porous cap on the top and seal it by o-ring. Take out the split mould. Then measure length and diameter of the sample.

II. Procedure

Assemble the cell and then fill it with water. Record the initial readings of burette. Apply confining pressure.

1. Again record the burette readings.
2. Raise the loading platform such that the loading cap comes in contact with the ram.
3. Set the proving ring dial gauge and vertical deformation measuring dial gauge to zero.
4. Start the machine and take the proving ring dial gauge and burette reading and corresponding vertical dial gauge reading till the sample fails or 20% vertical deformation has reached.
5. Draw the sketch of the sample after it has failed.
6. Repeat the test for higher confining pressure for fresh sample at the same density as the first sample.

7.6 OBSERVATIONS AND CALCULATIONS

Correction for area of cross-section.

The normal load applied is the deviatoric load.

The deviatoric stress is load divided by area.

i.e.
$$\sigma_d = \frac{F}{A_0} (\text{kg/cm}^2) \tag{7.1}$$

But the area of cross-section changes with the deformation of the sample. Hence, correct deviatoric stress is load divided by corrected area.

i.e.
$$\sigma_d = \frac{F}{A_c}$$

$$= \frac{F}{A_0}\left(1 - \frac{\Delta L}{L_0}\right) (\text{kg/cm}^2) \tag{7.2}$$

where F is applied load.

A_0 is original area of cross-section (cm^2).

ΔL is the deformation of sample (cm).

L_0 is the original length of specimen (cm).

Hence,
$$C = \text{............ kg/cm}^2$$
$$\phi = \text{............ degrees}$$

All round pressure = σ_3 = ... (kg/cm^2)

The applied vertical stress or deviatoric stress.

$$= \sigma_d$$

Total vertical stress = $\sigma_1 = (\sigma_d + \sigma_3)$ (kg/cm^2)

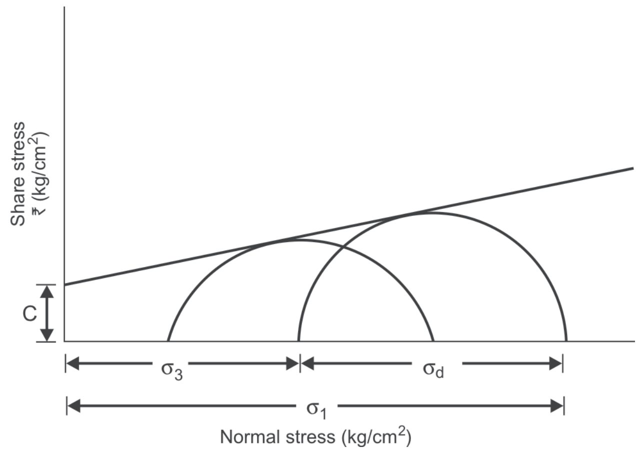

Fig. 7.2: Triaxial text result

Mohr circles arc drawn for various values of σ_3 and corresponding σ_1. The Mohr rupture envelope is then obtained by drawing a tangent to the circles. The intercept of this line with *y*-axis represents cohesion and the inclination with x-axis represents the angle of internal friction (ϕ) of the soils (Fig. 7.2). Table 7.1 shows triaxial test for c-ϕ soil.

Table 7.1: Triaxial test for c-ϕ soil

Soil type: Type of test: Undrained/consolidated undrained/consolidated drained

Water content = ...% Proving ring dial gauge constant, 1 div = ... kg

Size of sample = ...cm Initial length, L_0 = ... cm

Deformation dial gauge constant, 1 div = ...cm Initial area, A_0 = ... cm^2

S. No.	*Lateral pressure* σ_3 *(kg/cm²)*	*Deformation dial reading*	*Deformation* $\Delta L, (cm)$	*Strain* $\in = \Delta L / L_0$	*Proving ring dial reading*	*Vertical Load (kg)*	*Deviatoric stress* $\sigma_d = F / A_c = \frac{F}{A_0}\left(1 - \frac{\Delta L}{L}\right)$ *(kg/cm²)*	*Pore Pressure (kg/cm²)*
1.								
2.								
3.								
4.								
5.								

Table 7.2 shows triaxial test on dry sand.

Table 7.2: Triaxial test on dry sand

Mass of soil taken, Md = ….. (g)
Dry unit weight, rd = ….. (g/cm³)
Proving ring dial gauge constant, 1 div = ….. (kg)
Least count of dial gauge 1 div = ….. (mm)
Confining Pressure, σ_3 = ….. (kg/cm²)
Length of sample (L_0) = ….. (cm)
Diameter of sample (d_0) = ….. (cm)
Initial area of sample (A_0) = ….. (cm²)

S. No.	*Lateral pressure* σ_3 *(kg/cm²)*	*Deformation dial reading*	*Deformation* ΔL, *(cm)*	*Strain* $\in = \Delta L / L_0$	*Proving ring reading*	*Vertical load F (kg)*	*Deviatoric stress* $(\sigma_1 - \sigma_3) = F/A_c$ $\frac{F}{A_0}\left(1 - \frac{\Delta L}{L}\right)$ *(kg/cm²)*	*Pore pressure (kg/cm²)*
1.								
2.								
3.								
4.								
5.								

Table 7.3 shows triaxial test on saturated sand.

Table 7.3: Triaxial test on saturated sand

Mass of soil taken, *Md* = ….. (g)
Dry unit weight, r_d = ….. (g/cm³)
Length of sample (L_0) = ….. (cm)
Diameter of sample (d_0) = ….. (cm)
Initial volume of sample, V_0 = ….. (cm³)
Proving ring dial gauge constant, 1 div = ….. (kg)
Least count of dial gauge 1 div = ….. (mm)
Confining pressure, σ_3 = ….. (kg/cm²)
Initial area of sample (A_0) = ….. (cm²)

S. No.	*Deformation dial reading*	*Deformation* ΔL, *(cm)*	*Strain* $\in = \Delta L / L_0$	*Burette reading*	*Change in volume* ΔV *(cm³)*	*New length* $L - \Delta L$ *(cm)*	*New volume* $V - \Delta V$ *(cm³)*	*Corrected area, Ac* $\frac{V - \Delta V}{L - \Delta L}$ *(cm²)*	*Proving ring reading*	*Load, F (kg)*	$\sigma_3 = \sigma_{3} - \sigma_3$ $= F/Ac$ *(kg/cm²)*
1.											
2.											
3.											
4.											
5.											

QUESTIONS

1. The triaxial test is most versatile for what?
2. In which directions the cylindrical specimen is stressed?
3. What are the shear parameters?
4. Is the plane of shear failure predetermined?
5. Triaxial test is superior with respect to which test?
6. What is strength envelope?
7. How are the cohesion and angle of shearing resistance determined?
8. What are the applications of triaxial test?
9. How are the undisturbed and remoulded soil sample obtained?
10. What are the different types of triaxial test?
11. How the specimen (soil sample) is arranged in a triaxial test?
12. What apparatus is used to measure pore water pressure?
13. Up to what time the vertical load should be applied?
14. How is the sample prepared for triaxial test for cohesionless soil?
15. What should be the maximum vertical deformation?
16. Up to what time the load is applied?

CHAPTER 8

Plate Load Test

8.1 OBJECT

To determine allowable soil pressure of soil foundation system by vertical plate load test.

8.2 THEORY

In plate load test a test plate, square or circular in shape is used. The plate is placed at the bottom level of the foundation. The plate is then subjected to incremental loading. A load settlement curve is then plotted by measuring the settlement corresponding to each increment of load. The load settlement curve plotted provides the bearing capacity and settlement of the foundation (Fig. 8.1).

8.3 APPLICATIONS

The plate load provides data which is utilised in evaluating allowable soil pressure for shallow foundations. The data obtained from plate load test is also used to determine the coefficient of modulus of subgrade reaction. From plate load test the bearing capacity and settlement of foundation can be determined.

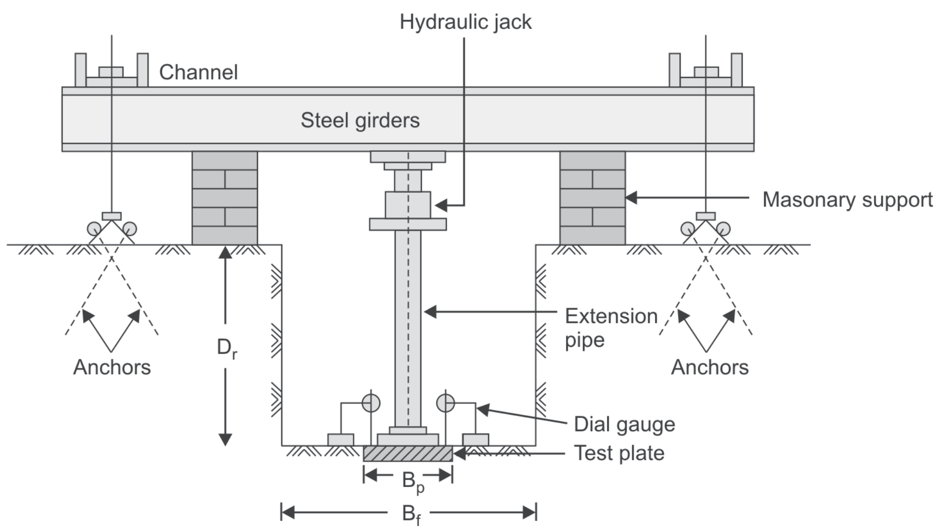

Fig. 8.1: Plate load test set-up

8.4 APPARATUS

- Square or circular mild steel plates of size 30, 45 and 60 cm and thickness 2.5 cm with chaquered or grooved bottom.
- Reaction loading equipment and equipment for gravity loading.
- Remote control type hydraulic jack.
- Proving ring with capacity varying from 10 to 30 tonnes.
- Four dial gauges to measure vertical deflection of 25 to 50 mm range and 0.01 mm sensitivity, datum bars.

8.5 PROCEDURE

1. Mild steel plates having rough bottom and of size 30, 45, 60 cm size and of square shape are used in plate load test.
2. To conduct a plate load test a pit of size 5 $B_P \times 5\ B_P$ (where B_P is the size of plate), is excavated up to the depth equal to depth of foundation. A central hole of size $B_P \times B_P$ is made in the pit. The depth of central hole can be obtained as

$$D_p = \left(\frac{B_p}{B_f}\right) \times D_f \tag{8.1}$$

   where B_f is the width of pit, i.e. foundation and D_f the depth of foundation.
3. The plate is seated at the centre over a fine sand layer of maximum thickness equal to 5 mm. The load on the plate is applied through a proving ring and hydraulic jack by taking reaction against a fixed support. The reaction to the jack is transferred by means of a reaction beam, trusses and a loaded platform. The loading on the platform is done by placing sand bags.
4. Initially a seating load equal to 7 kN / m^2 is first applied then it is released after sometime. The load is then applied in increments of about one-fifth the estimated safe load or one-tenth of the ultimate load up to failure or at least until a settlement of 25 mm has taken place, whichever is earlier.
5. For each load the settlement is recorded after 1, 5, 10, 20, 40, 60 minutes and thereafter at interval of one hour. For clayey soil the observations are continued until the rate of settlement is less than 0.2 mm per hour. Settlements are recorded through four-dial gauges mounted on independent datum and resting on plate.

8.6 LIMITATIONS OF PLATE LOAD TEST

1. The pressure bulb for the plate is at smaller depth than that of the pressure bulb corresponding to foundation. Hence, if soil is not homogeneous and isotropic up to 1½ to 2 B_f the plate load test does not truely represent the actual condition.
2. There is no effect of the size of the plate on the bearing capacity of saturated clay. But the bearing capacity of cohesionless soils increases with the size of plate. To reduce this scale effect it is suggested to repeat the plate load test for two or three different sizes of the plate. Then find the bearing capacity of foundation for each size of plate and then take average of the values obtained.
3. A plate load test is conducted in short duration. It gives total settlement for cohesionless soils. But for clayey soils, it does not give the total (ultimate) settlement.

4. The failure load is well-defined only for general shear failure not for other failures like local shear failure and punching shear failure.
5. As it is not possible to provide reaction more than 250 kN, the plate load test cannot be conducted on a plate larger than 60 cm size of plate.
6. The bearing capacity of soil is affected by the level of water table. Hence, if the water table is above the level of footing, it must be lowered up to the level of foundation.

8.7 OBSERVATIONS AND CALCULATIONS

The load-settlement curve for the test plate is plotted from test data. The load intensity q and settlement plot is made on log-log plot. If the plot shows a break, the pressure corresponding to break is ultimate beating capacity $q_u(p)$. If break is not seen on the plot, the ultimate beating capacity is taken as that corresponding to a settlement one-fifth of the plate width (B_p). If the pressure (q) vs settlement plot is on natural scale, the ultimate bearing capacity is obtained from the intersection of tangents drawn as shown in Fig. 8.2 and Table 8.1.

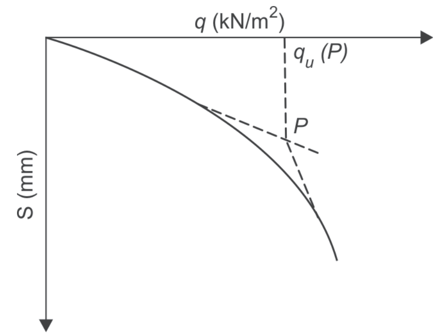

Fig. 8.2: Plate load test result (load settlement curve)

Ultimate Bearing Capacity

(a) For clayey soils

$$q_u(f) = q_u(p)\ (\text{kN/m}^2) \tag{8.2}$$

(b) For sandy soils

$$q_u(f) = q_u(p)\ \frac{B_f}{B_p}\ (\text{kM/m}^2) \tag{8.3}$$

Settlement

(a) For clayey soil

$$S_f = S_p \times \frac{B_f}{B_p}\ (\text{mm}) \tag{8.4}$$

(b) For sandy soil

$$S_f = S_p \times \left[\frac{B_f(B_p + 30)}{B_p(B_f + 30)}\right]^2 \tag{8.5}$$

Where B_f and B_p are in cm.
S_f and S_p are in mm.

Table 8.1: Plate load test

Size of plate = ... (cm)
Depth of plate = ... (cm)
Size of pit = ... (cm)
Depth of pit = ... (cm)

Date:
Name of site:
Least count of dial gauge=
Proving ring constant =

S. No.	*Load proving ring reading*	*Load (kN)*	*Pressure (kN/m²)*	*Dial gauge 1*		*Dial gauge 2*		*Dial gauge 3*		*Dial gauge 4*	
				R	*S (mm)*	*R*	*S (mm)*	*R*	*S (mm)*	*R*	*S (mm)*

Where *R* = Dial gauge reading
S = Corresponding Settlement

QUESTIONS

1. Write the different sizes of plates used in plate load test.
2. What are the shapes of plates used in plate load test?
3. How will you decide the size of plate to be used in plate load test?
4. What should be the size of the pit, i.e. the foundation?
5. What should be the depth of foundation?
6. Proving ring and hydraulic jack are used for what purpose?
7. How will you decide the load increment in plate load test? What should be the maximum load applied on the plate?
8. Write applications of plate load test.
9. How the allowable bearing pressure of soil-foundation system is obtained in plate load test?
10. How the settlement of foundation is obtained in plate load test?
11. How will you obtain modulus of subgrade reaction from plate load test?

CHAPTER 9

North Dakota Cone Test

9.1 OBJECT

To find out the bearing power of subgrade or *in situ* soil by means of a cone penetrometer of the North Dakota Cone apparatus.

9.2 THEORY

The North Dakota Cone (NDC) test is a penetration test developed by North Dakota State Highway Department of the USA for use in flexible pavement design. This test can be performed *in situ* as well as in laboratory. This equipment being portable and simple can easily be used in field control test of soils, soil-bitumen, etc. for soil which is free from coarse particles. The load carried by the shaft, during penetration into the soil, divided by the area of the cone at the surface level is termed the cone bearing value, q_c.

$$q_c = \frac{Q}{\pi(P_c \tan 7°45')^2} = \frac{Q}{0.58Pc^2}$$

where q_c = bearing value (kg/cm^2)

Q = load on cone (kg)

P_c = Penetration (corrected) of cone

9.3 APPLICATIONS

This test is made use of in flexible pavement design method. An empirical design chart, equation correlating the North Dakota Cone bearing value and pavement thickness have been made available.

9.4 APPARATUS

The North Dakota Cone apparatus consists of a shaft with a sharp cone (angle 15°30') attached to one end. The movement of the shaft into the soil is measured with the help of a graduated scale. The shaft can be locked or unlocked when necessary. A plate remains fixed to the top of the shaft. Weights can be put on the plate (Fig. 9.1).

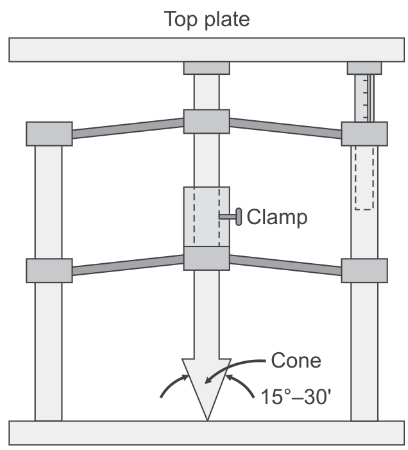

Fig. 9.1: North Dakota Cone test apparatus

9.5 PROCEDURE

1. Level properly the subgrade or *in situ* soil.
2. Keep the apparatus in position and allow the cone to move down such that the tip just touches the surface of soil.
3. Take the initial reading of penetration by locking the shaft.
4. Unlock the shaft and simultaneously start the watch. Allow the penetration for one minute.
5. Lock the shaft and take the reading.
6. Find the difference of penetration readings of step 5 and 3. It gives the penetration of cone under load of 5 kg. The load 5 kg is that of shaft plus cone.
7. Increase the load by 10 kg, i.e. put 5 kg weight on top plate. Note down the penetration reading after unlocking the shaft for one minute.
8. Repeat the procedure for total loads of 20 and 40 kg. This includes the weight of cone and shaft.

9.6 OBSERVATIONS AND CALCULATIONS

If the cone has a true point, for equal bearing pressure, the penetration at 10 kg load should be half that for 40 kg load. Hence correction ‘C’ due to the rounded point is given by

$$C = P_{40} - 2P_{10}$$

where P_{10} is penetration for 10 kg and

P_{40} is penetration for 40 kg.

The corrected penetration reading.

The corrected penetration reading = Observed penetration reading + correction (C).

Table 9.1 shows bearing value kg/cm^2.

Table 9.1: Bearing value kg/cm^2

Soil type:

Test type:

Correction ‘C’ = $P_{40} - 2P_{10}$

Load (kg)	*Penetration reading P, mm*	*Corrected penetration, PC, cm*	*Bearing value Kg/cm^2*
0			
5			
10			
20			
40			

Mean NDC Bearing value =

Result

The result is obtained by taking average bearing value excluding the first reading with 5 kg total load. This gives the North Dakota Cone bearing value of the soil.

Limitations

The use of North Dakota Cone test is limited to fine grained soils (silts and clays) free from coarse particles.

QUESTIONS

1. What is the objective of North Dakota Cone test?
2. Who developed North Dakota Cone test?
3. Where the North Dakota test is performed?
4. Define cone bearing value.
5. Write applications of North Dakota Cone test.
6. Write the apparatus for North Dakota Cone test.
7. Write the procedure of performing North Dakota test.
8. What is corrected penetration reading?
9. Write expression for correction due to the rounded point.
10. Write the limitation of use of North Dakota test.