COLLEGE OF ENGINEERING & TECHNOLOGY

# LABORATORY MANUAL

# GEOTECHNICAL ENGINEERING

## **SUBJECT CODE**: 3130606

## CIVIL ENGINEERING DEPARTMENT

## B.E. 3RD SEM

NAME:________________________________________

ENROLLMENT NO: ________________________________

BATCH NO: ____________________________________

YEAR: ______________________________________


**Amiraj College of Engineering and Technology,**
Nr.Tata Nano Plant, Khoraj, Sanand, Ahmedabad.

COLLEGE OF ENGINEERING & TECHNOLOGY

**Amiraj College of Engineering and Technology,**
Nr.Tata Nano Plant, Khoraj, Sanand, Ahmedabad.

# CERTIFICATE

***This is to certify that Mr. / Ms. ____________________________________________ Of class____________________ Enrolment No ___________________________has Satisfactorily completed the course in ____________________________________as by the Gujarat Technological University for ____ Year (B.E.) semester___ of Civil Engineering in the Academic year____________.***

***Date of Submission:-***

**Faculty Name and Signature**
**(Subject Teacher)**

**Head of Department**
**(Civil Department)**

# AMIRAJ COLLEGE OF ENGINEERING & TECHNOLOGY

| Sr. No. | Date | Title | Date of Assessment | Sign of Faculty |
|---|---|---|---|---|
| 1 | | Moisture Content Test | | |
| 2 | | Sieve Analysis | | |
| 3 | | Atterberg's Limit Test (Liquid Limit and Plastic Limit) | | |
| 4 | | Atterberg's Limit Test ( Shrinkage Limit Test) | | |
| 5 | | Permeability Test by Falling Head Method | | |
| 6 | | Proctor Compaction Test | | |
| 7 | | Consolidation / Oedometer Test | | |
| 8 | | CBR Test | | |

**Date:**

# EXPERIMENT NO. 1
# MOISTURE CONTENT TEST

**OBJECTIVE:**

This test is performed to determine the water (moisture) content by Oven drying method.

**STANDARD REFERENCE:**

IS 2720 (Part-2) - 1973

**MATERIAL:**

Soil Sample

**APPARATUS:**

Drying oven, Balance, Moisture can, Gloves and Spatula.

**THEORY:**

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil.

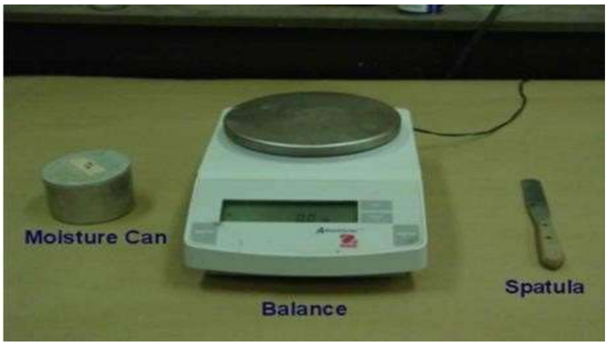
The water content is the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of soil to the mass of the dry soil solids.

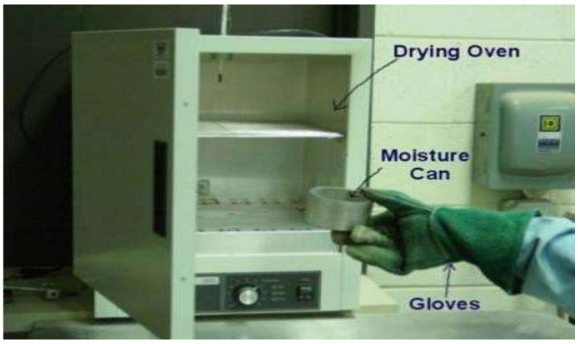
**Methods for finding out Moisture Content:**

1) Oven Drying Method
2) Calcium Carbide Method
3) Sand Bath Method
4) Radiation Method
5) Torsion Balance Method

6) Alcohol Method

**FIGURE:**




**PROCEDURE:**

1. Take clean and dry empty container and weight it (W1).
2. Take about 20 to 30 gms of soil sample if it is fine grained soil and about 250 to 300 gms if it is coarse grained soil in to the container & weight it (W2).
3. Place the container in the oven and dry it for 24 Hours at temperature of 110° ± 5°C.
4. Remove the container from the oven, replace the lid and cool it.
5. After cooling weight the container along with lid (W3).

**DATA ANALYSIS:**

➢ **Determine the water content by Oven Drying Method:-**

$$Water\ Content, w\% = \frac{(W2-W3)}{(W3-W1)} \times 100 w(\%) = \frac{weight\ of\ water}{weight\ of\ solids} X\ 100$$

$$water\ content, w(\%) = \frac{(W2 - W3)}{(W3 - W1)} X\ 100$$

**MOISTURE CONTENT DETERMINATION DATA SHEET:**

**OBSERVATION TABLE:**

| **Specimen Number** | **1** | **2** | **3** |
|---|---|---|---|
| Container and lid number | | | |
| W1 = Mass of clean & empty container + lid (gms) | | | |
| W2 = Mass of container, lid, and wet soil (gms) | | | |
| W3= Mass of container, lid, and dry soil (gms) | | | |
| w = Water content (%) | | | |
| Average Water Content = $w_{avg}$ | | | |

**CALCULATIONS:**

**CONCLUSION:**

| **Signature of Faculty:** | **Date:** |
|---|---|

**Date:**

# EXPERIMENT NO. 2

# SIEVE ANALYSIS

**OBJECTIVE:**

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles.

**MATERIAL:**

Soil Sample

**APPARATUS:**

Balance, Set of sieves, Oven, Cleaning brush and Sieve shaker.

**THEORY:**

Soil contains particles of different sizes and in varying quantities. The distribution of different grain sizes affects the engineering properties of soil. The percentage of different sizes of particles in a given soil sample is found by particle size analysis, also known as mechanical analysis. Grain size analysis provides the grain size distribution, and it is required in classifying the soil. The mechanical analysis is performed in two stages:

1) Sieve analysis

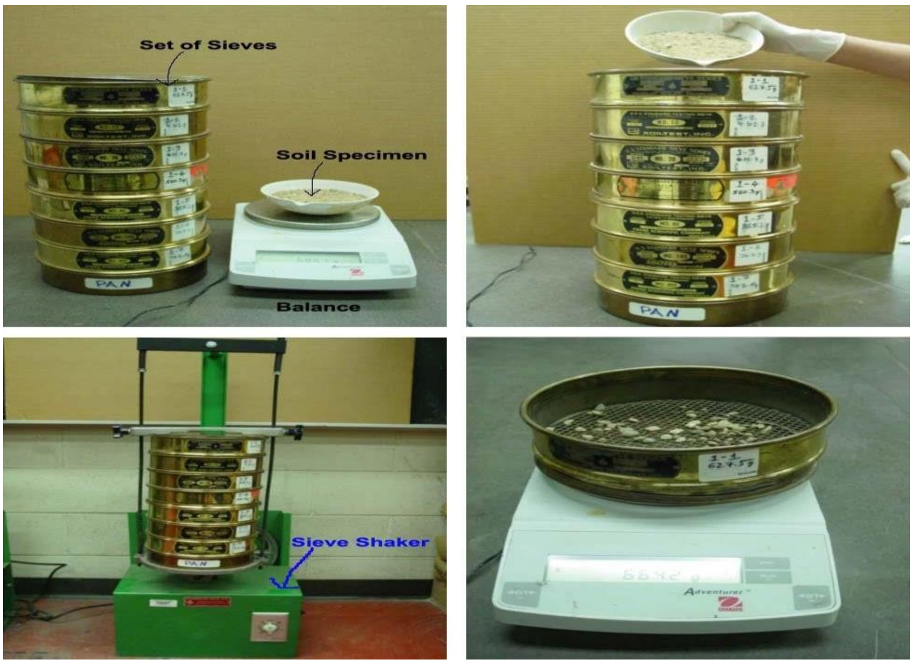
2) Sieve analysis is only for coarse grained soil and sedimentation analysis is for fine grained soil. The results of the mechanical analysis are plotted to get a particle size distribution curve. It gives us an idea about the type and gradation of soil.

**PROCEDURE:**

1. Take a sample of soil and dry it in oven.
2. Weigh the required quantity of soil and soak it with water. Depending upon the maximum size of the particles present in the sample, the quantity of soil to be taken for the test is decided.

3. Stir the soil-water solution thoroughly and pass it through 4.75mm sieve which segregate gravel fraction from sand fraction.
4. Place the soil retained on 4.75mm in the oven for drying.
5. Pass then mixture of soil-water, passing through 4.75mm sieve, through 75µ sieve. This will separate silt and clay particles from sand fraction.
6. Place the soil retained on 75µ sieve in the oven for drying.
7. Sieve the dry soil retained on 4.75 mm sieve by passing it through the following set of sieves: 100 mm, 63 mm, 20 mm, and 10 mm.
8. Take the weight of the soil retained on each sieve.
9. Sieve the dried soil retained on 75 µ sieve by using mechanical sieve shaker. The following sets of sieves are used: 2mm, 1mm, 600 µ, 425 µ, 300 µ, 212 µ, 75 µ.
10. Minimum of 10 minutes sieving is required in mechanical sieve shaker in both the sets of sieves.
11. Take the weight of soil retained on each sieve and calculate the cumulative percentage retained in each sieve. Cumulative percentage finer is then calculated.
12. Particle size distribution curve is plotted on a semi-log graph paper with percentage finer on Y-axis and particle diameter on X-axis(log scale).

**FIGURE:**



**DATA ANALYSIS:**

1. Obtain the mass of soil retained on each sieve The sum of these retained masses should be approximately equals the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.
2. Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample mass.
3. Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.
4. Make a semi logarithmic plot of grain size vs. percent finer.
5. Compute Cc and Cu for the soil.

$$Cu = \frac{D_{60}}{D_{10}} Cu = \frac{D_{60}}{D_{10}} \quad \text{and} \quad Cc = \frac{D_{30}^2}{D_{10}D_{60}} Cc = \frac{D_{30}^2}{D_{10}D_{60}}$$

Where,

Cu = Uniformity Coefficient

Cc = Coefficient of curvature and

D designate diameter of IS Sieve number written in subscript.

- Soil Grading according to uniformity coefficient

| **Cu** | **Type of Soil** |
|---|---|
| < 5 | Uniform Size Particle |
| 5 - 15 | Medium Graded Soil |
| >15 | Well Graded Soil |

- Value of Cc lie between 1 – 3 for well graded soil

**OBSERVATIONS:**

Weight of Container : __________gm

Wt. Container + Dry Soil : __________gm

Wt. of Dry Sample : __________gm

| Sieve size | Weight of soil retained on each sieve (gm) | % retained | Cumulative % retained | Cumulative % Finer (N) |
|---|---|---|---|---|
| **4.75 mm** | | | | |
| **2 mm** | | | | |
| **1 mm** | | | | |
| **600µ** | | | | |
| **425 µ** | | | | |
| **300 µ** | | | | |
| **212 µ** | | | | |
| **75 µ** | | | | |
| **PAN** | | | | |

From Grain Size Distribution Curve:

% Gravel = __________ D10 =_________mm

% Sand = __________ D30 =_________mm

% Clay = __________ D60 =_________mm

Cu = __________ Cc = __________

IS or Unified Classification of Soil: __________

**DISCUSSION AND CONCLUSION:**

Discuss the classification of soil according to IS method or Unified Soil Classification and suitability of soil for foundation.

| Signature of Faculty: | Date: |
|---|---|

**Date:**

# EXPERIMENT NO. 3
# ATTERBERG'S LIMIT TEST
# (LIQUID LIMIT AND PLASTIC LIMIT TEST)

**OBJECTIVE:**

To determine the liquid limit and plastic limit of a fine-grained soil.

**STANDARD REFERENCE:**

I.S. 2720 (Part-V) - 1985

**APPARATUS:**

**For Liquid Limit:**

Casagrande Liquid limit device, Grooving tools of both standard tool and ASTM tool, 425 μ IS sieve, Glass plate, Spatula, Aluminum Containers, Weighing Balance, Wash bottle filled with distilled water and Drying oven set at 105°C.

**For Plastic Limit:**

Glass plate, 425 μ IS sieve, Weighing Balance, Aluminum Container, 3mm dia. Metallic rod and Oven.

**THEORY:**

**Liquid Limit:**

Liquid limit (LL) of a soil is the minimum water content at which the soil ceases to be liquid. A soil containing high water content is in a liquid state. It has no shear strength and can flow like liquids. As the water content is reduced, the soil becomes stiffer and starts developing resistance to shear deformation. At some particular water content, the soil becomes plastic. It may also be defined as the water content at which soil changes from the liquid state to the plastic state.

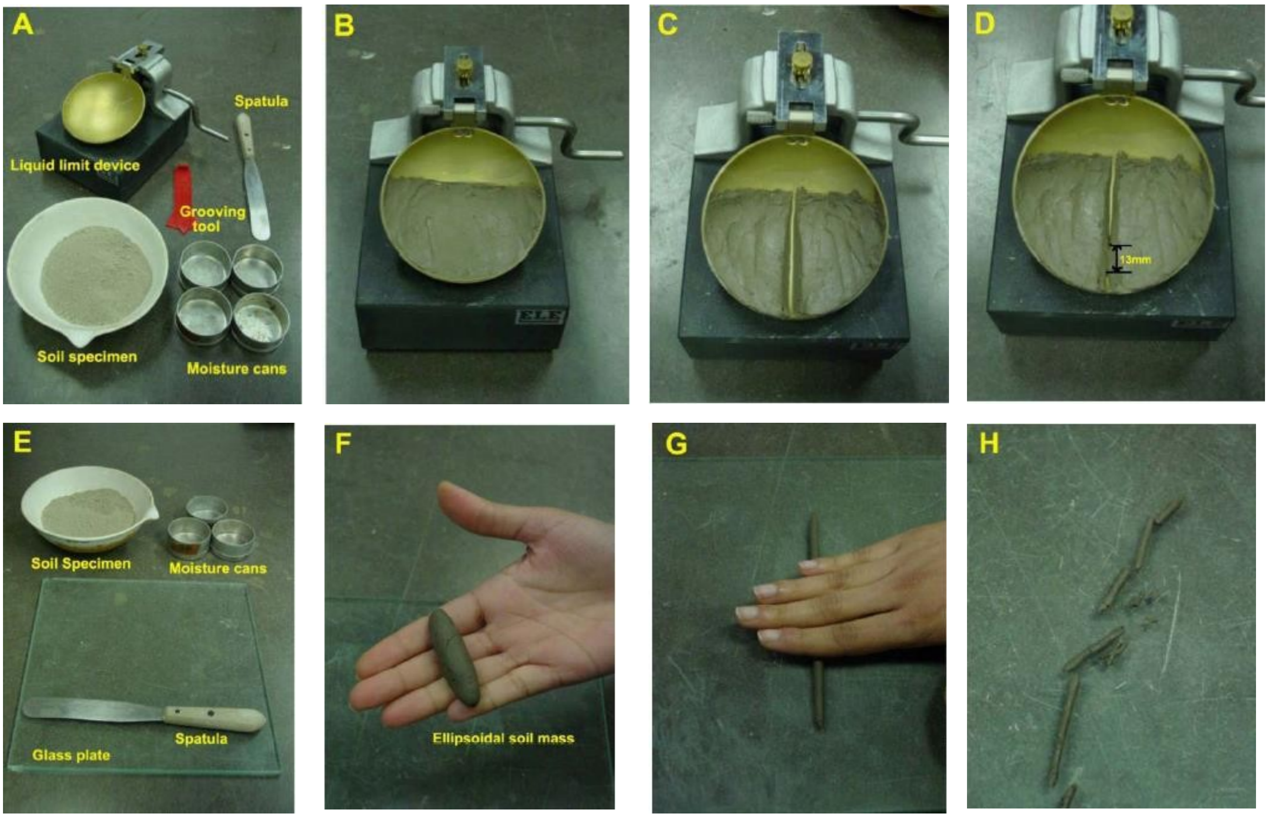
**Plastic Limit:**

The plastic limit (PL) is the minimum water content, in percent, at which a soil will just begin to crumble when rolled into a thread of approximately 3 mm in diameter.

The soil in the plastic state can be moulded into various shapes. As the water content is reduced, the plasticity of the soil decreases. Ultimately, the soil passes from the plastic state to the semi-solid state when it stops behaving as a plastic. It cracks when moulded.

It may also be defined as the water content at which soil changes from plastic state to the semi-solid state.

**FIGURE:**




**PROCEDURE:**

**Liquid Limit:**

1. Take about 120 gm of dry soil passing through the 425 μ IS sieve.
2. Mix the sample thoroughly with distilled water on the glass plate to form a uniform paste. Mixing should be continued for about 15 to 30 minutes, till a uniform mix is obtained.
3. Take a portion of the paste with the spatula and place it in the Centre of the cup so that it is almost half filled. Level off the top surface of the wet soil with the spatula, so that it is parallel to the rubber base and maximum depth of the soil is 1 cm.

4. Cut a groove in the wet soil in the cup by using appropriate grooving tool.
5. Turn the handle of the apparatus at the rate of 2 revolutions per seconds, until the two parts of the soil come in contact with bottom of the groove along a distance of 10 mm. record the number of blows required to cause the groove close for approximate length of 10 mm.
6. Collect a representative slice of soil from cup and put it in an airtight container. Determine water content of that sample.
7. Remove the soil from the cup and mix it with the soil left earlier on the glass plate. Change the consistency of the mix by adding more water or leaving the soil paste to dry. Repeat the above steps 3, 4, 5 and 6. Note the number of blows to close the groove and keep the soil for water content determination.
8. A plot is made between the water content (w) as ordinate and number of blows (N) on log scale as abscissa. The plot is approximately a straight line. The plot is known as flow curve.
9. The liquid limit is obtained, from the plot, corresponding to 25 blows.

**Plastic Limit:**

1. Take about 120 gm of dry soil passing through the 425 μ IS sieve.
2. Mix the soil with distilled water on a glass plate to make it plastic enough to shape into a small ball.
3. Leave the plastic soil mass for some time for maturing.
4. Take about 8 gm of the plastic soil, and roll it with fingers on a glass plate. When the diameter of the thread has decreased to 3mm, the specimen is kneaded together and rolled out again. Continue the process until thread just crumbles at 3 mm diameter.
5. Collect the pieces of the crumbled soil thread in a moisture content container for water content determination.
6. Repeat the procedure at least twice more with fresh samples of plastic soil.
7. The average water content of three soil samples will give plastic limit.

**DATA SHEETS:**

**Liquid Limit Determination**

| Sample No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of blows (N) | | | | |
| Container Number | | | | |
| $W_1$ = Weight of container (gm) | | | | |
| $W_2$= Weight of container + wet soil (gm) | | | | |
| $W_3$ = Weight of container + dry soil (gm) | | | | |
| w = Water content, w% $(W_2-W_3) / (W_3-W_1)$ | | | | |

**CALCULATIONS:**

Plot the flow curve on a semi-log graph paper and read the water content against 25 blows, which is liquid of the sample.

**Liquid limit of given soil sample = %**

**Plastic Limit Determination:**

| Sample No. | **1** | **2** | **3** |
|---|---|---|---|
| Container Number | | | |
| $W_1$ = Weight of container (gm) | | | |
| $W_2$= Weight of container + wet soil (gm) | | | |
| $W_3$ = Weight of container + dry soil (gm) | | | |
| w = Water content, w% $(W_2-W_3) / (W_3-W_1)$ | | | |
| Plastic Limit (PL) = Average w % | | | |

**Plastic limit of given soil sample = ________ %**

**Plasticity Index =**

**CONCLUSION:**

| Signature of Faculty: | Date: |
|---|---|

# EXPERIMENT NO. 4

# ATTERBERG'S LIMIT TEST

# (SHRINKAGE LIMIT TEST)

**OBJECTIVE:**

To determine the shrinkage limit of a soil sample.

**STANDARD REFERENCE:**

I.S 2720 (Part-VI) - 1972

**APPARATUS:**

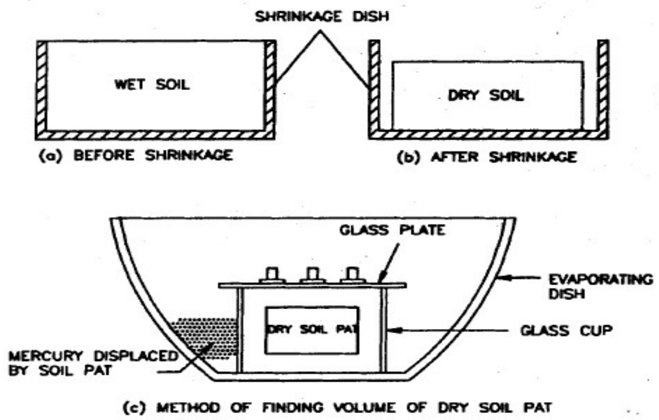
Shrinkage dish, having a flat bottom, 45 mm diameter and 15 mm height; Evaporating dish (2 nos.) of porcelain, about 12 cm in diameter with flat bottom; Glass cup, 50 mm diameter and 25 mm high; One small mercury dish 60 mm diameter; Two glass plates, one plain and one with prongs, 75 mm x 75 mm x 3 mm size; IS sieve 425 μ; Weighing Balance; Drying oven set at 105°C; Spatula; Straight edge and Mercury.

**THEORY:**

When the water content is reduced below the plastic limit, the soil attains a semisolid state. The soil cracks when moulded. In semi-solid state, the volume of soil decreases with a decrease in water content till a stage is reached when further reduction of the water content does not cause any reduction in the volume of the soil. The soil is said to have reached a solid state.

The water content at which the soil changes from the semi-solid state to the solid state is known as Shrinkage Limit.

**FIGURE:**




**PROCEDURE:**

1. Take about 100 gm of soil sample from a thoroughly mixed portion of the material passing 425 micron IS sieve.
2. Take about 30 gm of the soil sample in a large evaporating dish.
3. Mix it thoroughly with distilled water to make a creamy paste which can be readily worked without entrapping the air bubbles. In case of plastic soils, the water content of the paste may exceed its liquid limit by as much as 10 percent.
4. Take a shrinkage dish and determine its mass $M_1$.
5. Coat the inside of the shrinkage dish with a thin layer of silicone grease or vaseline. Place the soil sample in the centre of the shrinkage dish, equal to about one-third the volume of the shrinkage dish. Tap the dish gently on a firm surface (rubber sheet) and allow the paste to flow towards the edges. Place another equal installment of the paste in the dish and make it flow towards the edges by tapping. Add more soil paste and continue taping till the shrinkage dish is completely filled and excess soil overflows. Strike off the excess soil overflows. Strike off the excess soil paste with a straight edge.
6. Determine mass of the shrinkage dish with wet soil as $M_2$.
7. Dry the soil in the shrinkage dish in air until the colour of the pat turns from dark to light. Then dry the pat in the oven at 105' to 110' C temperature for 24 hours.
8. Cool the dry pat in a desiccator. Remove the dry pat from the desiccator after cooling, and weigh the shrinkage dish with the dry soil pat as $M_3$.
9. The mass of dry soil pat = $M_d = M_3 - M_1$.

10. To determine volume of the shrinkage dish, place it in the evaporating dish and fill it to overflowing the mercury. Remove the excess mercury by pressing the plain glass plate firmly on its top, taking care that no air is entrapped. Wipe off, any mercury which may be adhering to the outside of the shrinkage dish.

**11.** Determine mass of mercury and shrinkage dish as $M_4$.

$$\text{Volume of shrinkage dish} = \frac{\text{mass of mercury in shrinkage dish}}{\text{density of mercury}}$$

$$\therefore \; V = \frac{(M_4 - M_1)}{\text{density of mercury}} \qquad \text{density of mercury} = 13.6 \text{ gm/cm}^3$$

12. To determine the volume of the dry soil pat, keep the glass cup in the evaporating dish. Fill the cup to overflowing with mercury. Remove the excess mercury by pressing the glass plate with the three prongs firmly over the top of the cup. Transfer the cup carefully to another evaporating dish. Place the oven dried soil pat on the surface of mercury in the cup and carefully force the pat into the mercury by glass plate with three prongs. Collect carefully the displaced mercury and find its mass.

$$\therefore \quad \text{Volume of dry soil pat } (V_d) = \frac{\text{mass of displaced mercury}}{\text{density of mercury}}$$

$$\text{Water content of soil} = \frac{M_w}{M_d} \times 100$$

$$M_w = (M_2 - M_1) - (M_3 - M_1)$$

$$M_d = (M_3 - M_1)$$

**CALCULATIONS:**

**Shrinkage limit :**

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

where, $w_s$ = shrinkage limit of soil

$w$ = initial water content

$V$ = Initial volume of soil (volume of shrinkage dish)

$M_d$ = Weight of dry soil pat.

**Shrinkage Limit Determination:**

| Description | Results |
|---|---|
| $M_1$ = Mass of shrinkage dish (gm) | |
| $M_2$= Mass of shrinkage dish + wet soil (gm) | |
| $M_3$ = Mass of shrinkage dish + dry soil (gm) | |
| $M_d$ = Mass of dry soil pat , $M_d = M_3 – M_1$ | |
| $M_4$ = Mass of shrinkage dish + Mercury (gm) | |
| V = Volume of shrinkage dish | |
| $V_d$= Volume of dry soil pat | |
| $M_w = (M_2-M_1) - (M_3-M_1)$ | |
| $M_d = (M_3-M_1)$ | |
| w = Water content, w% $(M_w / M_d)$ x 100 | |
| Ws = Shrinkage Limit | |

**Shrinkage limit of given soil sample = ____________ %**

**CONCLUSION:**

| **Signature of Faculty:** | **Date:** |
|---|---|

**DATE:**

# EXPERIMENT NO. 5

# PERMEABILITY (HYDRAULIC CONDUCTIVITY) TEST BY FALLING HEAD METHOD

**OBJECTIVE:**

To determine the co efficient of permeability (hydraulic conductivity) of soil by the falling head test method.

**MATERIAL:**

Cohesive Soil Sample

**APPARATUS:**

Laboratory Permeameter with its accessories and mould 1000 ml capacity, 2.6 kg rammer, 1 gm accuracy Balance, de aired water, Mixing pan, Scoop, 1000 mL Graduated cylinders, Watch (or Stopwatch), Thermometer, Filter paper, IS sieves 4.75 mm and 2 mm, water collecting tank, drainage base 12 mm thick and drainage cap 12 mm thick with an inlet/outlet fitting.

**THEORY:**

The falling head method of determining permeability is used for soil with low discharge.

The passage of water through porous material is called seepage. A material with continuous void called permeable material.

The test result of this experiment is used,

- To estimate underground water flow.
- To calculate seepage through dams.
- To find out rate of consolidation and settlement of structure.
- To plan the method of lowering the ground water table.
- To calculate the uplift pressure and piping.
- To design grouting.
- To design seepage pits for recharge.

The principle behind this test is Darcy's law for laminar flow. The rate of discharge/unit time is proportionalto hydraulic gradient. i.e, q is directly proportional to (i×A)

So, $q = k \times i \times A$

But, $V = q/A$

Hence, $V = k \times i$

Where,

$q$ = Discharge per unit time

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

$I$ = Hydraulic Gradient

$k$ = Darcy's coefficient of permeability

There for dimension of K is the same as that of velocity.

Again, $q = V \times A$

$= V_s \times A_v$

Where,

$A_v$ = Area of voids

$V_s$ = Seepage Velocity Which rate of discharge of percolating water per unit cross sectional of voids perpendicular to the direction of flow.

Therefore, $V_s = V \times A/A_v$ $\qquad V_v/V_s = e$ = void ratio

But, $A/A_v = (1+e)/e$ $\qquad V_v/V = n$ = porosity

Therefore always $V_s > V$

Hence the factors affecting permeability are:

1. Grain size
2. Properties of the pore fluid
3. Voids ratio of soil
4. Arrangements of soil particles
5. Air or other material in the pores
6. Absorbed water in the soil

**PREPARATION OF SPECIMEN FOR TESTING:**

**A. Undisturbed Soil Sample**

Note down the specimen number, borehole number depth of sample.

Remove protective cover from sampling tube.

Extrude the sample for required and trim in required diameter having height equal to that of mould.

The specimen shall be placed centrally over the porous disc to the drainage base.

Angular space shall be made lick proof by filling wax or cement slurry, protect the porous disc when cement slurry is poured.

The drainage cap shall be fixed over the top of the mould.

The specimen is ready for test.

**B. Disturbed Soil Sample**

Disturbed sample can be prepared by static compaction and dynamic compaction.

**a. Preparation of statically compacted sample**

Measure internal dimensions of the mould. Apply a little grease on the inside to the mould.

Take about 2.5 kg of the soil, from a thoroughly mixed wet soil, in the mould. Compact the soil at the required dry density using a suitable compacting device.

Remove the collar and base plate. Trim the excess soil level with the top of the mould.

Clean the outside of the mould. Find the mass of soil in the mould. Take a small specimen of the soil in a container for the water content determination.

Saturate the porous stones.

Place the porous stone on the drainage base and keep a filter paper on the porous stone.

Place the mould with the soil on the drainage base.

Place a filter paper and the porous stone on the top of specimen.

Saturate it. Deaired water is preferred.

Assemble the Permeameter in the bottom tank and fill the tank with water.

Inlet nozzle of the mould is connected to the stand pipe allow some water to flow until steady state of flow is obtained

Note down the time interval ‘t’ for the fall of head in the stand pipe ‘h’.

Repeat above steps 3 times to determine ‘t’ for same falling head ‘h’.

Now coefficient of permeability K is,

**Coefficient of permeability (k) :**

$$k = 2 \cdot 3 \frac{a \cdot L}{A \cdot t} \log_{10} \frac{h_1}{h_2}$$

where, a = c/s area of stand pipe ($cm^2$)

A = c/s area of soil sample = $\frac{\pi}{4} \times D^2$ ($cm^2$)

L = length of soil sample (cm)

t = time interval to fall head from $h_1$ to $h_2$

$h_1$ = initial head (cm)

$h_2$ = final head (cm).

**INTERPRETATION OF THE RESULT:**

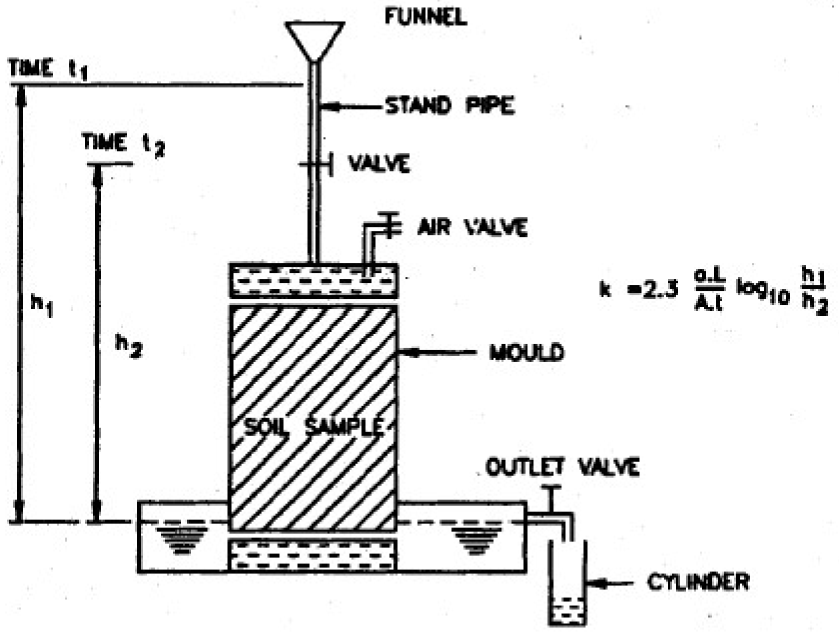
If, $K > 10^{-1}$ cm/sec, the permeability is high.

$K = 10^{-1}$ cm/sec, the permeability is medium.

$K < 10^{-1}$ cm/sec, the permeability is low.

Hence soil with permeability less than 1mm/ sec can be used as core of earth dam.

**FIGURE:**



**OBSERVATION TABLE:**

| | | |
|---|---|---|
| Area of stand pipe(dia 5 cm) | a | = $mm^2$ |
| Diameter of the Soil Specimen (Permeameter), | D | = cm |
| Cross sectional area of soil specimen | A | |
| Length of Soil Specimen, | L | = cm |
| Initial reading of stand pipe, (cm) | $h_1$ | |
| Final reading of stand pipe, (cm) | $h_2$ | |
| Time interval, (sec) | t | |
| Coefficient of permeability (cm/sec) | k | |

**CALCULATIONS:**

**CONCLUSION :**

| Signature of Faculty: | Date: |
|---|---|

**Date:**

# EXPERIMENT NO. 6

# PROCTOR COMPACTION TEST

**OBJECTIVE:**

To establish relationship between optimum moisture content and maximum dry density of a soil for a specified compactive effort.

**STANDARD REFERENCE:**

IS 2720 (Part-7), 1965

**APPARATUS:**

Compaction mould, 1000ml capacity, Rammer, mass 2.6kg, 50 mm dia. And 310 mm free fall, Detachable base plate, Collar 60mm high, IS sieve 4.75mm size, Oven, weighing Balance, Large mixing pan, Straight edge, Spatula, Graduated jars, Mixing tools, Spoons and Trowels.

**THEORY:**

Compaction is the process by which soil particles are packed more closely together by expulsion of air from the pores. Compaction is done by application of mechanical energy such as by tamping, rolling and vibration. It increases the density of soil. The required standard of field compaction can be specified in terms of percent compaction.

$$\text{Percent compaction} = \frac{\text{Field density}}{\text{Lab. Maximum dry density}}$$

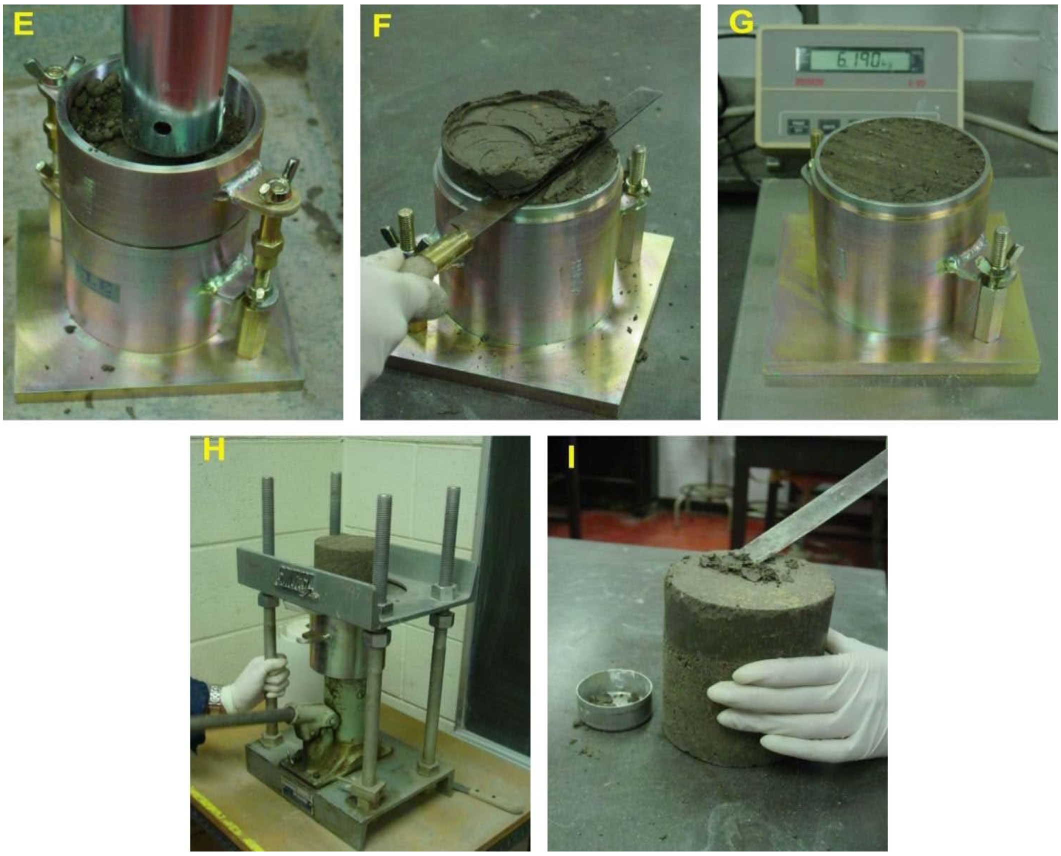
Maximum dry density is determined from standard proctor test.

The moisture content at which dry density is maximum for a given compactive effort is called optimum moisture content. Water content, beyond OMC, tends to keep the soil particles apart without causing an appreciable change in air voids, which results in low dry density and high void ratio. Hence knowledge of OMC is essential to achieve a particular compaction.

**PROCEDURE**:

1. Take about 20 kg of soil passing through 4.75 mm sieve.
2. Add water to it to bring the water content to about 4% if the soil is sandy and to about 8% if the soil is clayey. Keep the soil in an air tight container for about 18 to 20 hours for maturing.
3. Divide the soil in to 6 to 8 parts.
4. Clean and dry the mould and the base plate. Grease them lightly attach the collar to the mould. Determine empty mass of mould as $M_1$.
5. Take about 2.5kg of the processed soil, and place it in the mould in 3 equal layers. Each layer is compacted by standard rammer of 2.6 kg mass and 310mm free fall giving 25 blows.
6. Remove the collar, and trim off the excess soil projecting above the mould using a straight edge.
7. Determine mass of mould with soil as $M_2$.
8. Take the soil samples for the water content determination and determine water content.
9. Add about 3% of the water to a fresh portion of the processed soil and repeat the above steps.
10. Determine bulk density and dry density.

**FIGURE:**



**OBSERVATION:**

**Water Content Determination:**

| Sample No. | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Container Number | | | | | |
| $W_1$ = Weight of container (gm) | | | | | |
| $W_2$= Weight of container + wet soil (gm) | | | | | |
| $W_3$ = Weight of container + dry soil (gm) | | | | | |
| w = Water content, w% $(W_2-W_3) / (W_3-W_1)$ | | | | | |

**Density Determination:**

Diameter of mould=100 mm

Height of mould= 127.3 mm

Volume of mould = 1000 $cm^3$

| Sample No. | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Container Number | | | | | |
| $M_1$ = Mass of empty mould (gm) | | | | | |
| $M_2$= Mass of mould + compacted soil (gm) | | | | | |
| Mass of compacted soil = M= $M_2$ - $M_1$ | | | | | |
| Bulk density, $\rho_b = \frac{M}{V}$ gm/cm$^3$ | | | | | |
| w = Water content, w% | | | | | |
| Dry density, $\rho_d = \frac{\rho_b}{1+w}$ gm/cm$^3$ | | | | | |

Plot a curve between water content as abscissa and dry density as ordinate.

**RESULT:**

From the plot,

Optimum Moisture Content =__________________%

Maximum Dry Density =____________________gm/cm$^3$

**CONCLUSION:**

| Signature of Faculty: | Date: |
|---|---|

**Date:**

# EXPERIMENT NO. 7

# CONSOLIDATION TEST

**OBJECTIVE:**

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

**MATERIAL:**

Soil Sample

**APPARATUS:**

Consolidation device (including ring, porous stones, water reservoir, and load plate), Dial gauge (0.0001 inch = 1.0 on dial), Sample extractor, Sample trimming device, Weighing Balance, Glass Plate, Metal straight edge, Clock, Moisture can and Filter paper.

**THEORY:**

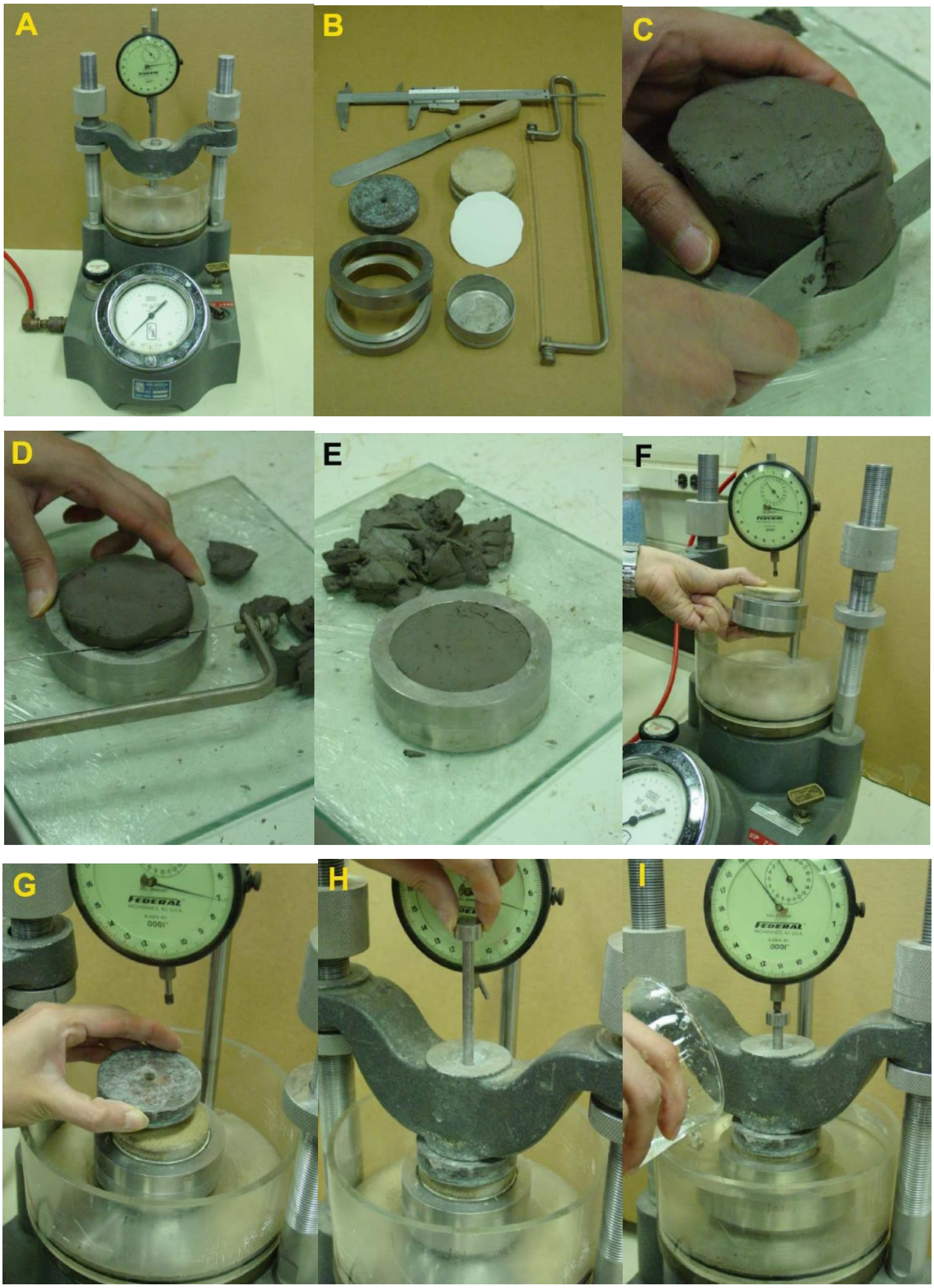
This test is conducted to determine the settlement due to primary consolidation. To determine

- Rate of consolidation
- Degree of consolidation at any time
- Pressure void ratio relation
- Coefficient of consolidation at various pressures
- Compression Index

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

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

**FIGURE:**



**PROCEDURE**:

1. Weigh the empty consolidation ring together with glass plate.
2. Measure the height (h) of the ring and it's inside diameter (d).
3. Extrude the soil sample from the sampler, generally thin-walled Shelby tube. Determine the initial moisture content and the specific gravity of the soil as per Experiments water content and specific gravity, respectively (Use the data sheets from these experiments to record all of the data).
4. Cut approximately a three-inch long sample. Place the sample on the consolidation ring and cut the sides of the sample to be approximately the same as the outside diameter of the ring. Rotate the ring and pare off the excess soil by means of the cutting tool so that the sample is reduced to the same inside diameter of the ring. It is important to keep the cutting tool in the correct horizontal position during this process.
5. As the trimming progresses, press the sample gently into the ring and continue until the sample protrudes a short distance through the bottom of the ring. Be careful throughout the trimming process to insure that there is no void space between the sample and the ring.
6. Turn the ring over carefully and remove the portion of the soil protruding above the ring. Using the metal straight edge cut the soil surface flush with the surface of the ring. Remove the final portion with extreme care.
7. Place the previously weighed Saran-covered glass plate on the freshly cut surface, turn the ring over again, and carefully cut the other end in a similar manner.
8. Weigh the specimen plus ring plus glass plate.
9. Carefully remove the ring with specimen from the Saran-covered glass plate and peel the Saran from the specimen surface. Centre the porous stones that have been soaking, on the top and bottom surfaces of the test specimen. Place the filter papers between porous stones and soil specimen. Press very lightly to make sure that the stones adhere to the sample. Lower the assembly carefully into the base of the water reservoir. Fill the water reservoir with water until the specimen is completely covered and saturated.
10. Being careful to prevent movement of the ring and porous stones, place the load plate centrally on the upper porous stone and adjust the loading device.
11. Adjust the dial gauge to a zero reading.

12. With the toggle switch in the down (closed) position, set the pressure gauge dial (based on calibration curve) to result in an applied pressure of 0.5 tsf (tons per square foot) or 50 $kg/cm^2$.
13. Simultaneously, open the valve (by quickly lifting the toggle switch to the up (open) position) and start the timing clock.
14. Record the consolidation dial readings at the elapsed times given on the data sheet.
15. Repeat Steps 11 to 13 for different preselected pressures (generally includes loading pressures of 10, 20, 40, 80, and 160 $kg/cm^2$ and unloading pressures of 80, 40, 20, 10 and 5 $kg/cm^2$
16. At the last elapsed time reading, record the final consolidation dial reading and time, release the load, and quickly disassemble the consolidation device and remove the specimen. Quickly but carefully blot the surfaces dry with paper toweling. (The specimen will tend to absorb water after the load is released.)
17. Place the specimen and ring on the Saran-covered glass plate and, once again, weigh them together.
18. Weigh an empty large moisture can and lid.
19. Carefully remove the specimen from the consolidation ring, being sure not to lose too much soil, and place the specimen in the previously weighed moisture can. Place the moisture can containing the specimen in the oven and let it dry for 12 to 18 hours.
20. Weigh the dry specimen in the moisture can.

**ANALYSIS**:

1. Calculate the initial water content and specific gravity of the soil.
2. For each pressure increment, construct a semi log plot of the consolidation dial readings versus the log time (in minutes). Determine D0, D50, D100, and the coefficient of consolidation (cv) using Casagrande's logarithm of time fitting method. See example data. Also calculate the coefficient of secondary compression based onthese plots.
3. Calculate the void ratio at the end of primary consolidation for each pressure increment (see example data). Plot log pressure versus void ratio. Based on this plot, calculate compression index, recompression index and preconsolidation pressure (maximum past pressure).
4. Summarize and discuss the results.

**PRECAUTIONS**:

1. While preparing the soil sample, attempt has to be made to have the soil strata oriented in the same direction in the consolidation apparatus.
2. During trimming care should be taken in handling the soil specimen with least pressure.
3. A smaller increment of sequential loading has to be adopted for soft soil.

**OBSERVATIONS:**

Date Tested :
Tested By :
Project Name :
Sample Number :
Sample Description :

| | |
|---|---|
| **Before Test:** | |
| Consolidation type | = |
| Mass of the ring + glass plate | = |
| Inside diameter of the ring | = |
| Height of specimen, Hi | = |
| Area of specimen, A | = |
| Mass of specimen + ring | = |
| Initial moisture content of specimen, wi (%) | = |
| Specific gravity of solids, Gs | = |
| | |
| **After Test:** | |
| Mass of wet sample + ring + glass plate | = |
| Mass of can | = |
| Mass of can + wet soil | = |
| Mass of wet specimen | = |
| Mass of can + dry soil | = |
| Mass of dry specimen, Ms | = |
| Final moisture content of specimen, wf | = |

**CALCULATIONS:**

Mass of solids in specimen, Ms =

(Mass of dry specimen after test)

Mass of water in specimen before test, Mwi = wi× Ms=

Mass of water in specimen after test, Mwf (g) = wf× Ms=

Height of solids, Hs = $\frac{Ms}{A\times Gs\times \rho w} = \frac{Ms}{A\times Gs\times \rho w} =$

(same before and after test and note ρw = 1 g/cm$^3$)

Height of water before test, Hwi = $\frac{Mwi\ \ Mwi}{A\times \rho w A\times \rho w}$ =

Height of water after test, Hwf = $\frac{}{A\times \rho w A\times \rho w}$ =

Change in height of specimen after test, ΣΔH =

(ΣΔH for all pressures – see t vs Dial reading plot)

Height of specimen after test, Hf = Hi - ΣΔH =

Void ratio before test, eo = $\frac{Hi-Hs\,Hi-Hs}{Hs\quad Hs}$ =

Void ratio after test, $e_f$= $\frac{Hf-Hs\,Hf-Hs}{Hs\quad Hs}$ =

Degree of saturation before test, $S_i$ = $\frac{Hwi\quad Hwi}{Hi-Hs\,Hi-Hs}$ =

Degree of saturation after test, $S_f$= $\frac{Hwf\quad Hwf}{Hf-Hs\,Hf-Hs}$ =

Dry density before test, ρd = $\frac{Ms\quad Ms}{A\times Hi\,A\times Hi}$ =

**Time - Settlement Data:**

Conversion: 0.0001 inch = 1.0 on dial reading (confirm this before using)

| Pressure intensity (kg/cm$^2$) | | 0.1 | 0.2 | 0.5 | 1 | 2 | 4 | 8 | 16 |
|---|---|---|---|---|---|---|---|---|---|
| Elapsed time, min | $\sqrt{t}$ | Dial Reading | | | | | | | |
| 0 | 0 | | | | | | | | |
| 0.25 | 0.5 | | | | | | | | |
| 1 | 1 | | | | | | | | |
| 2 | 1.5 | | | | | | | | |
| 4 | 2.0 | | | | | | | | |
| 6.25 | 2.5 | | | | | | | | |
| 9 | 3 | | | | | | | | |
| 12.25 | 3.5 | | | | | | | | |
| 16 | 4 | | | | | | | | |
| 20.25 | 4.5 | | | | | | | | |
| 25 | 5 | | | | | | | | |
| 30.25 | 5.5 | | | | | | | | |
| 36 | 6 | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 42.25 | 6.5 | | | | | | | | |
| 49 | 7 | | | | | | | | |
| 56.25 | 7.5 | | | | | | | | |
| 64 | 8 | | | | | | | | |
| 72.25 | 8.5 | | | | | | | | |
| 81 | 9 | | | | | | | | |
| 90.25 | 9.5 | | | | | | | | |
| 100 | 10 | | | | | | | | |
| 121 | 11 | | | | | | | | |
| 144 | 12 | | | | | | | | |
| 169 | 13 | | | | | | | | |
| 196 | 14 | | | | | | | | |
| 225 | 15 | | | | | | | | |
| 256 | 16 | | | | | | | | |
| 24 hr | | | | | | | | | |
| unloading | | | | | | | | | |
| 0- loading | | | | | | | | | |

## Analysis of Consolidation Test Data

| Pressure (tsf) | Time for 50% consolidation $t_{50}$ (min) | $D_0$ (from graph) | $D_{100}$ (from graph) | $D_{50} = (D_0+D_{100})*0.5$ | $H_j = D_{50}$ * 0.0001 | $\Delta H$ (from graph) | $\Sigma \Delta H^{*}$ | $H^{**}$ | $H_d^{**}$ | Coefficient of consolidation $C_v$ ($in^2$/min) | $H_v^{***}$ | $e^{***}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
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* $\Sigma\Delta H$ for applied pressure = $\Sigma\Delta H$ of all previous pressures + $\Delta H$ under applied pressure

** $H_{dj} = \frac{H_j}{2} \pm \frac{\Delta H_j}{4}$ and $H_j = H_i \pm \Delta H_{j-1}$ (- for Loading and + for Unloading)

*** $C_v = 0.197 \times \frac{H_d^2}{t_{50}}$, $H_v = (H_i - H_s) - \Sigma\Delta H$ and $e = \frac{H_v}{H_s}$

**CONCLUSION:**

| Signature of Faculty: | Date: |
|---|---|

**DATE:**

# EXPERIMENT NO. 7

# CALIFORNIA BEARING RATIO TEST

## OBJECTIVE

To determine the California bearing ratio by conducting a load penetration test in the laboratory.

## NEED AND SCOPE

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

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

## PLANNING AND ORGANIZATION

Equipments and tool required.

1. Cylindrical mould with inside dia 150 mm and height 175 mm, provided with a detachable extension collar 50 mm height and a detachable perforated base plate 10 mm thick.

2. Spacer disc 148 mm in dia and 47.7 mm in height along with handle.

3. **Metal rammers.** Weight 2.6 kg with a drop of 310 mm (or) weight 4.89 kg a drop 450 mm.

4. **Weights.** One annular metal weight and several slotted weights weighing 2.5 kg each, 147 mm in dia, with a central hole 53 mm in diameter.

5. **Loading machine.** With a capacity of atleast 5000 kg and equipped with a movable head or base that travels at an uniform rate of 1.25 mm/min. Complete with load indicating device.

6. Metal penetration piston 50 mm dia and minimum of 100 mm in length.

7. Two dial gauges reading to 0.01 mm.

8. **Sieves.** 4.75 mm and 20 mm I.S. Sieves.

9. Miscellaneous apparatus, such as a mixing bowl, straight edge, scales soaking tank or pan, drying oven, filter paper and containers.

**DEFINITION OF C.B.R.**

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

C.B.R. = Test load/Standard load ⦚ 100

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

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

The test may be performed on undisturbed specimens and on remoulded specimens which may be compacted either statically or dynamically.

## PREPARATION OF TEST SPECIMEN

**Undisturbed specimen**

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

**Determine the density**

## Remoulded specimen

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

## Dynamic Compaction

Take about 4.5 to 5.5 kg of soil and mix thoroughly with the required water.

Fix the extension collar and the base plate to the mould. Insert the spacer disc over the base (See Fig.38). Place the filter paper on the top of the spacer disc.

Compact the mix soil in the mould using either light compaction or heavy compaction. For light compaction, compact the soil in 3 equal layers, each layer being given 55 blows by the 2.6 kg rammer. For heavy compaction compact the soil in 5 layers, 56 blows to each layer by the 4.89 kg rammer.

Remove the collar and trim off soil.

Turn the mould upside down and remove the base plate and the displacer disc.

Weigh the mould with compacted soil and determine the bulk density and dry density.

Put filter paper on the top of the compacted soil (collar side) and clamp the perforated base plate on to it.

## Static compaction

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

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

Where W = Weight of the wet soil

w = desired water content

V = volume of the specimen in the mould = 2250 $cm^3$ (as per the mould available in laboratory)

Take the weight W (calculated as above) of the mix soil and place it in the mould.

Place a filter paper and the displacer disc on the top of soil.

Keep the mould assembly in static loading frame and compact by pressing the displacer disc till the level of disc reaches the top of the mould.

Keep the load for some time and then release the load. Remove the displacer disc.

The test may be conducted for both soaked as well as unsoaked conditions.

If the sample is to be soaked, in both cases of compaction, put a filter paper on the top of the soil and place the adjustable stem and perforated plate on the top of filter paper.

Put annular weights to produce a surcharge equal to weight of base material and pavement expected in actual construction. Each 2.5 kg weight is equivalent to 7 cm construction. A minimum of two weights should be put.

Immerse the mould assembly and weights in a tank of water and soak it for 96 hours. Remove the mould from tank.

Note the consolidation of the specimen.

## Procedure for Penetration Test

Place the mould assembly with the surcharge weights on the penetration test machine. (Fig.39).

Seat the penetration piston at the center of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the piston on the sample is established.

Set the stress and strain dial gauge to read zero. Apply the load on the piston so that the penetration rate is about 1.25 mm/min.

Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm. Note the maximum load and corresponding penetration if it occurs for a penetration less than 12.5 mm.

Detach the mould from the loading equipment. Take about 20 to 50 g of soil from the top 3 cm layer and determine the moisture content.

## Observation and Recording

## For Dynamic Compaction

Optimum water content (%)

Weight of mould + compacted specimen g

Weight of empty mould g

Weight of compacted specimen g

Volume of specimen $cm^3$

Bulk density g/cc

Dry density g/cc

## For static compaction

Dry density g/cc

Moulding water content %

Wet weight of the compacted soil, (W)g

Period of soaking 96 hrs. (4days).

## For penetration Test

Calibration factor of the proving ring 1 Div. = 1.176 kg

Surcharge weight used (kg) 2.0 kg per 6 cm construction

Water content after penetration test %

Least count of penetration dial 1 Div. = 0.01 mm

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

$$C.B.R. = P_T / P_S \times 100$$

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

$P_S$ = Standard load for the same penetration taken from the table I.

| Penetration Dial | | Load Dial | | Corrected Load |
|---|---|---|---|---|
| Readings | Penetration (mm) | proving ring reading | Load (kg) | |
| | | | | |

## Interpretation and recording

C.B.R. of specimen at 2.5 mm penetration

C.B.R. of specimen at 5.0 mm penetration

C.B.R. of specimen at 2.5 mm penetration

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

**CONCLUSION:**

| Signature of Faculty: | Date: |
| --- | --- |