FEDERAL UNIVERSITY OYE-EKITI

FACULTY OF ENGINEERING AND TECHNOLOGY

CIVIL ENGINEERING LABS (CVE 495)

DEPARTMENT OF CIVIL ENGINEERING

400 LEVEL LABORATORY

MANUAL

TABLE OF CONTENTS

PREPARING LABORATORY REPORTS

The following guideline is used to prepare laboratory reports.

i. **Title:** This section contains the title of the test, the nature of the test and the specification number used.

ii. **Scope of the test:** A brief statement of the purpose or aim and significance of the test should be indicated.

iii. **Apparatus:** Equipments used should be briefly described.

iv. **Materials:** The materials used or tested should be described.

v. **Theory:** This section summarizes the test/experiment or it gives us an overview of what the test is all about.

vi. **Definitions and Process Terminology:** This section contains terminology and definition of specific words and test related terms.

vii. **Procedure:** Clearly and concisely list the procedure in the order the test is carried out.

viii. **Raw Data:** This section contains the raw data gotten from the test. All laboratory data shall be submitted in tabular form.

ix. **Observations and Calculations:** Observations relating to the behavior of the materials should be included. All equations or formulas used should be clearly indicated. Calculations should be properly checked.

x. **Result**: This section contains the test results and all finalized answers including graphs. The results of the test may be summarized in tabular or graphical form.

xi. **Figures and Diagrams:** This section contains clear and concise diagrams and/or figures in accordance with the laboratory requirement. Figures including the equipment front and side views, parts and panels can be displayed in this section.

xii. **Discussion:** There should be included a brief discussion in which attention is drawn to the silent facts shown by the tables and diagrams. The test results should be compared with the standard values.

xiii. **Conclusion:** Include modification procedures, calibration procedures and any additional information that will be helpful.

xiv. **References (if applicable):** Include references to any manuals, documents or textbooks used in compiling the reports.

COMPACTION TEST

OBJECTIVE:

To determine the optimum moisture content and maximum dry density of a soil by Standard Proctor test.

APPARATUS:

a. Cylindrical mould of non-corrodible material with 100 mm internal diameter, internal effective height 127.3mm, thus having a capacity of 1000 cc. OR A cylindrical mould of non-corrodible material with 150mm internal diameter, internal effective height 127.3mm, thus having a capacity of 2250 cc.
b. Accessories of the mould.
    i. Detachable base plate and a removable extension collar of approximately 60mm height, both of non-corrodible material.
    ii. Metallic rammer for light compaction-face diameter as 50mm, weight 2.6 Kg equipped with suitable arrangements to give a free drop of 310 mm.
    iii. Steel straight edge of about 300 mm in length with one edge leveled.
    iv. Spatula
    v. Balance (sensitivity 1g, capacity 10kg).
    vi. Balance (sensitivity 0.01g, capacity 200g).
    vii. Over-thermostatically controlled to maintain a temperature of 105^o – 110^oC.
    viii. Drying crucibles
    ix. Graduated jar.
    x. I.S. sieve – 20 mm dia., 4.75 mm.
    xi. Mixing tool – mixing pan, spoon etc. for uniformly mixing the soil sample with water.

THEORY:

Water plays a vital role in soil compaction. When some moisture is added to a dry soil, its grains are surrounded by a film of this absorbed water. If we add more water, the films become thicker and soil particles surrounded by such films slide over each other more easily. On application of pressure, they occupy closer spacing more easily. The water in this process acts as a lubricant and a closer packing of soil grains is obtained by the expulsion of air from the voids.

If we continue to add still more water to this soil, a stage is reached when water starts occupying space that could have been occupied by soil grains under compaction. Therefore, the water at this stage hinders a closer packing of grains. Thus, there must be a most appropriate moisture content which would provide maximum benefit of lubrication without occupying pore space into which the soil grains could have been pushed by the compaction method. Such a moisture content at which the weight of the soil grains in a unit volume of compacted soil mass is maximum is called the optimum moisture content and the corresponding density is called maximum dry density.

The purpose of laboratory compaction test is to determine the proper amount of water at which the weight of the soil gains in a unit volume of the compacted soil mass is maximum. The amount of water, thus calculated is called the "Optimum Moisture Content" (OMC). In the laboratory, the different values of moisture content and the resulting dry densities, obtained after compaction are plotted both to arithmetic scale, the former as abscissa and the latter as ordinate. The points thus obtained are joined as a curve. The maximum dry density and the corresponding optimum moisture content are read from the curve. The wet density (γ_t) of the compacted soil is calculated as below:

$$\gamma_t = \frac{W_1 - W_2}{V}$$

Where,

W_1 = Weight of mould with moist compacted soil

W_2 = Weight of empty mould

V = Volume of the mould

The dry density (γ_d) of the soil shall be computed as follows:

$$\gamma_d = \frac{\gamma_t}{(1 + \omega/100)}$$

Where,

γ_t = Wet density of the compacted soil

ω = Moisture content in percent

The dry density of a soil with a given moisture content at a particular saturation ratio can also be expressed as:

$$\gamma_d = \frac{G\gamma_w}{(1 + G.\omega/S)}$$

Where,

G = Specific gravity of the soil particles

γ_w = Unit weight of water (1.0g/cc, generally)

S = Degree of saturation

For a particular soil, it is possible to obtain the relation between dry density and moisture content at a constant saturation ratio, using the equation above.

Zero Air voids Line

A line which shows the water content-dry density relation for the compacted soil containing a constant percentage air voids is known as air-voids line. The line showing the dry density as a function of water content for soil containing no air voids is called the zero air voids line or the saturation line.

The equation with degree of saturation above can be used to draw zero air voids line. For S = 100%, the equation reduces to

$$\gamma_d = \frac{G\gamma_w}{(1 + \omega G)}$$

For $\gamma_w = 1$, $\gamma_d = \frac{G}{(1 + \omega G)}$

PROCEDURE:

Preparation of Specimen

i. Take about 18kg air dried soil sample for 1000 cc mould (40kg for 2250 cc mould).

ii. Sieve the soil through 20 mm and 4.75 mm I.S. sieves and calculate the ratio of fraction passing 20 mm I.S. sieve and retained on 4.75 I.S. sieve. Use 100 mm diameter mould if percentage of soil retained on 4.75 mm I.S. sieve is less than 20, and 150 mm diameter mould if soil percentage retained on 4.75 mm I.S. sieve is more than 20. Discard the soil retained on 20 mm I.S. sieve.

iii. Mix the soil retained on 4.75 mm I.S. sieve and passing through 4.75 mm I.S. sieve thoroughly and uniformly in its original ratio.

Testing of the Specimen

i. Clean, dry and slightly grease the mould and the base plate. Weigh the empty mould with the base plate but without extension collar. The collar is then attached to the mould. Place the mould on a solid base.

ii. Take about 2.5kg of the soil for 100 mm diameter mould (or 5.6kg for 150 mm diameter mould) for light compaction. For heavy compaction, take about 2.8kg of the soil for 100 mm diameter mould (6kg for 150 mm diameter mould).

iii. Add water to the soil sample to bring the moisture content to about 4-5 percent in sandy soil and 8-9 percent in clayey soils.

iv. Mix the water with soil thoroughly.

v. Keep this soil-water mix in an air tight container for about 5 to 30 minutes for sandy soils and 18 to 20 hours for clayey soils.

vi. Prepare similar six to seven equal parts (each of about 2.5 kg) from the oven-dried (18kg) soil sample at different moisture content.

For light compaction:

a. Compact one part of the wet soil in three equal layers using a rammer of mass 2.6kg and free fall 310 mm with 25 evenly distributed blows in each layer for 100mm diameter mould (56 blows for 150 mm diameter mould).
b. Before putting the second layer of the soil, the top surface of the first compacted layer should be scratched with the help of a sharp edged tool (like steel Nail/Screw driver). The second and third layers are similarly compacted.
c. Rotate the collar to break the bond between it and soil and then remove the collar.
d. Trim off the soil to make it flush with the top of the mould by means of a straight edged tool/knife.
e. Clean all the loose soil from the outside and base of the mould.
f. Weigh the mould with base plate and compacted soil.
g. Now, eject or remove the soil from the mould, take a representative sample from the center of the compacted specimen and keep it in an oven for its water content determination.
h. Repeat the procedure six to seven times using a fresh soil specimen after adding higher water content then, the preceding one till there is either a decrease or no change in the mass of the wet compacted soil in the mould. In case of coarse grained soil, the water contents may be about 9, 12, 16, 19, and 22 percent while for fine grained soil, the water content may be of the order of about 11, 14, 17, 20, 23, and 25 percent.
i. Weigh the crucibles with dry soil samples and empty crucibles.
j. Enter the observations in the table below and plot the graph of dry density versus moisture content (in percentage).

PRECAUTIONS:

1. Ramming should be done continuously taking care of height of 310 mm free fall accurately. The blows should be uniformly distributed over the surface of each layer of soil compaction.
2. Scratch each layer of the compacted soil with a sharp tool before pouring the soil for the next layer.
3. The amount of soil taken for compaction should be in such a way that after compacting the last layer, the soil surface is not more than 5mm above the top rim of the mould.
4. Weighing should be done accurately.
5. During compaction, the mould should be kept over a solid base.

OBSERVATIONS AND CALCULATIONS:

a. Soil sample No.: …………………
b. Specific gravity =
c. Diameter of mould =
d. Height of mould =
e. Volume of mould (V) =
f. Weight of mould =
g. Type of Test =
h. Weight of rammer =
i. No. of layers =
j. No. of blows =
k. Height of free fall =

l. Plot the graph of dry density (g/cc) versus moisture content (%).

Determination No.			1	2	3	4	5	6
1.	Weight of mould + compacted soil (g)	=						
2.	Weight of compacted soil (g)	=						
3.	Wet density – γ_t (g/cc)	=						
4.	Crucible No.	=						
5.	Weight of crucible + wet soil (g)	=						
6.	Weight of crucible + dry soil (g)	=						
7.	Weight of water (5) – (6) (g)	=						
8.	Weight of empty crucible (g)	=						
9.	Weight of dry soil (6) – (8) (g)	=						
10.	Water content w (7)/(9) %	=						
11.	Dry density $\gamma_d = \frac{\gamma_t}{(1 + \omega/100)}$ (g/cc)	=						

RESULTS:

From the curve,

i. Maximum dry density (g/cc) =

ii. Optimum moisture content (%) =

CONSOLIDATION TEST

OBJECTIVE:

The objective of the test is to obtain the compressibility i.e. consolidation characteristics of a soil by one dimensional consolidation using consolidometer apparatus.

APPARATUS:

i. **Consolidation Ring.** The ring of minimum 60 mm diameter and 20 mm height made of non-corrosive material having a smooth and highly polished surface. For convenience in preparation of soil specimen, the ring is provided with a cutting edge.

ii. **Porous Stone (2 Nos.)**
   a. Bottom stone of 65 mm diameter to support consolidation ring and top stone of 59 mm diameter each with 12 mm thickness (floating ring type set up).
   b. Both of 59 mm diameter and thickness as 12 mm (fixed ring type set up).

iii. **Consolidation cell.** It is a container made of non-corrosive material to place the consolidation ring containing soil specimen. A water filling system is attached with the base plate of a cell to saturate the soil specimen. Alternatively, the consolidation test apparatus has been modified to electronic system.

iv. **Dial gauge.** Having a least count (preferably) of 0.002 mm and a minimum travel capacity of 10 mm.

v. **Loading Ram.** Comprises of a counter balanced (lever ratio 1:10) loading beam and a weight hanger. The device should be capable of applying vertical load to the soil specimen through a suitable loading yoke.

vi. **Set of weights.** The weights should be slotted type to give a loading sequence of say 0.125, 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 kg/cm^2 to the test specimen.

vii. **Jack.** To eject the soil from sampling tubes.

viii. **Jig.** For holding the consolidation ring above the sampling tube for direct jacking method.

ix. **Trimming equipment**. Metallic straight edge, trimming knife and wire saw.

x. **Balance.** 0.01g accuracy.

xi. **Density bottle.** 100 cc capacity.

xii. **Vacuum pump**.

xiii. **Dish.** 2Nos.

xiv. **Oven.** Thermostatically controlled between 105° – 110°C.

xv. **Stop watch**.

THEORY:

Consolidation of soil is the process of compression by gradual reduction of pores under a steady applied pressure. The main purpose of the consolidation test is to obtain soil data required for predicting the rate and amount of settlement of structures. The data can also be used to develop void ratio (e) versus pressure (p) curve generally for cohesive soil.

The void ratio (e) of a soil specimen under any applied pressure (p) may be computed using the following relationship:

$$\mathbf{e = H - H_s / H_s}$$

Where,

H = Height of soil specimen at the end of each pressure increment (cm)

H_s = equivalent height of solids (cm), which is determined as follows:

$$\mathbf{H_s = \frac{W_s}{G.\ \gamma_w\ .\ A}}$$

Where,

W_s = dry density of the specimen (g)

G = specific gravity of the solid particles

γ_w = unit weight of water (g/cc)

A = cross-sectional area of the soil specimen (cm^2)

PREPARATION OF TEST SPECIMEN:

Undisturbed Soil Specimen

Clean, dry and lubricated the consolidation ring from inside with silicon grease. Then weigh it. Record it as (W_1)g.

Preparation from a block (Undisturbed) Sample:

i. Sometimes the soil sample from the field is also collected as block en mass. In that case, cut a sample disc with two plain faces parallel to each other having its diameter and thickness each at least 10 mm greater than that of the consolidation ring.
ii. Hold the consolidation ring vertically with cutting edge downwards and place it on the prepared disc of the undisturbed soil sample. Using the ring as a template, trim off the excess soil around the cutting edge.
iii. Gently, press the ring downwards with minimum force required to until the soil sample protrudes into the ring by about 5 mm above its top. Cut the soil at the level of the cutting edge of the cutter of the consolidation ring. Trim the excess soil flush with top and bottom edges of the ring, using straight edge.
iv. Remove the small interfering inclusion if any, during trimming process and fill the cavity completely with the soil from the cuttings. Avoid the excessive remoulding of the soil surfaces. Keep a portion from the trimmings/cuttings for determination of initial moisture content and specific gravity.
v. Weigh the ring with the specimen. Record it as (W_2)g.

Preparation from a tube sample: To push the sample directly into the consolidation ring, hold the ring firmly about 5 mm above the sample tube keeping the cutting face downwards. By means of a hydraulic jack, eject the sample gently and steadily out of the tube so that it intrudes into the ring. During the process, continue trimming the specimen carefully from outside the consolidation ring to reduce friction. Finally, trim and flush the soil sample with the ends of the consolidation ring.

Remoulded Specimen

i. Prepare the soil sample after sieving through 2 mm aperture size sieve (as particle size should be one tenth of height of specimen) by compaction method in a compaction mould. The compaction efforts (number of blows required for each layer) may be determined by trial and error if the test it to be performed at desired moisture content and density, other than optimum moisture content and maximum dry density.

   Place the consolidation ring on a glass plate with the cutting edge upwards. Press the remoulded soil into the ring by suitable means.

   Flush the soil specimen with the top end of the ring and weigh. Alternatively, the soil specimen may also be intruded into the consolidation ring as explained above.

ii. **Dynamically compacted specimen.** Weigh the consolidation ring. Attach extension collar to the ring and place it on the base plate. Prepare about 300 g wet soil for desired water content and density. Calculate the volume of the ring including collar thickness (for a 60 mm diameter 30 mm total height (including 20 mm soil sample height), volume = 84.86 cm^3) and the required quantity of soil.

   Place this soil in the ring and compact by 2.6kg rammer or by any suitable tool to the total thickness including that of collar (30 mm).

   Detach the extension collar and trim the excess soil flushing with the ring ends to make the thickness of the specimen as 20 mm. Weigh the ring with compacted soil.

iii. **Statically compacted specimen.** Prepare the soil specimen by mixing required quantity of water to about 300g dry soil. Leave the mix for about 5-6hours. Keep a small quantity of this mix for moisture content determination.

Place the ring on the base plate and attach the extension collar to it. Weigh the required quantity of the processed mix of wet soil to obtain the desired test density when compressed to 84.86 cm^3 volume.

Place gently the soil into the consolidation ring. Compress this apparatus by means of a suitable pressing device. Detach the extension collar and trim the soil flushing with the edge of the ring.

PROCEDURE:

i. Soak the porous stones in water and place the bottom of the porous stone on the base of the consolidation cell. Keep filter paper over the stone. Attach guide ring to one or both ends of the consolidation ring containing soil specimen (as required) and place it gently on the porous stone. Place another filter paper on the top of the specimen and keep upper porous stone and loading cap on it. Adjust a steel ball in the groove of the loading cap to provide uniform loading on the specimen.

ii. Place this whole arrangement properly in position in the loading device. Check and adjust the loading beam and the counter balancing system. Level the loading beam with the help of a spirit level. Clamp the dial gauges in position for recording the compression/swelling of the soil specimen. Read the initial dial reading and place a 0.05 kg/cm^2 seating pressure on the pan of weight hanger. Connect the base plate of the consolidation cell to water reservoir by means of rubber/plastic tubing for saturating the soil specimen. Allow the saturation of the specimen for 24 hours or more to attain an almost constant dial gauge reading.

iii. Select appropriate sequence of pressures to be applied. It is customary that the pressure applied at any loading stage is twice that of the preceding stage pressure. The test, therefore may be carried out for loading sequence, to apply pressure on the soil specimen in the range of 0.125, 0.25, 0.5, 1.0, 2.0, 4.0, 8.0 and 16.0 kg/cm^2. However, some other combination of loads may also be taken. The maximum pressure to be applied should be more than the effective vertical pressure envisaged due to insitu over burden and the proposed structure to be constructed on that soil.

iv. Take the dial gauge readings after application of each load according to a time sequence (i.e. total elapsed) such as 0.25, 1.00, 2.25, 4, 6.25, 9, 12.25, 16, 20.25, 25, 36, 49, 64, 100, 144, 196, 225, 256 minutes and thereafter, 24 hours. A period of 24 hours is generally sufficient for completion of primary consolidation of the soil specimen for a particular load. A longer time may be required in case of hard soil (i.e. soil containing clay particles 25% or (N) SPT values ≥or unconfined compressive strength > 4.0 kg/cm^2).

With the help of the above time sequence, it is easy to plot the specimen’s thickness against square root of time or logarithmic of time. If the object of the study is to obtain pressure-void ratio relationship only, the time versus dial gauge readings may be avoided and record only the final dial gauge reading for each load increment after 24 hours.

v. After completing the dial gauge observations at maximum pressure, release the applied pressure to zero (0.05 kg/cm^2 seating pressure) and leave the soil specimen to swell by water for 24 hours. Record the final reading of the dial gauge. If required, the loads may be reduced in stages and time-swelling readings may also be taken accordingly.

vi. Remove the seating load (0.05 kg/cm^2) and dismantle the consolidation ring. Wipe off water from the ring and remove filter papers from both the ends of the specimen. Weigh the ring and record it as (W')g with the specimen and then, place it in a container and dry in an oven (105^o – 110^oC). Alternatively, push the soil specimen out of the ring carefully so that no soil particle is lost, weigh the specimen dry. After drying, weigh the ring with the specimen and record it as (W_3)g. Determine the specific gravity of the soil from the dried specimen. Place the porous stones in a container filled with water and boil for about 20-30 minutes and then clean to remove any soil particle therein for their further use.

PRECAUTIONS:

i. The diameter to weight ratio of the ring should be about 3.0 and the maximum soil particle size in the soil specimen should be one tenth of the height of the specimen/ring. For remoulded soil specimen, the dry soil sample should be sieved through 2 mm size sieve. Then, add moisture equivalent to Optimum Moisture Content (OMC) in the sample.
ii. Inside surface of the consolidation ring should be coated with silicon grease for stiff and medium soil and by thick oil for testing very soft soils (i.e. containing clay particles 8-9% or (N) SPT values as 0-2 or $q_u < 0.25$ $kg.cm^2$).
iii. The porous stones should allow the free drainage throughout the test. A sheet of Whatman No. 54 filter paper of diameter equal to that of the porous stones should be placed between the stone and the soil specimen to prevent any intrusion of the soil particles.
iv. The loading ram/device should be placed on a firm base, free from vibrations and disturbances. It is better if constant temperature conditions are also maintained.
v. Care should be taken while preparing test specimen especially from undisturbed soil sample and ensure that the specimen is subjected to loads in the direction of applied force in the field.
vi. Avoid the excessive remoulding of the specimen surfaces by straight edge.

vii. Use the water in reservoir for saturation of the soil specimen of the same ionic content as the specimen pore water. Alternatively, use distilled water.

viii. In case the initial pressure applied on the specimen indicates swelling (especially in case of black cotton soils) on addition of water, increase the pressure immediately to higher value to counteract swelling. As a guide, the initial pressure for stiff soils should be equivalent or somewhat less than the estimated existing overburden pressure. For soft soils, this pressure should be less than the existing overburden pressure.

ix. Make the loading lever to a level position (check the horizontality by spirit level) each time before noting the final dial gauge reading.

x. Place the load increment on the pan of the weight hanger very gently causing no jerk to the consolidation ring.

xi. While dismantling, see that no soil particle remains attached to the surface of the filter papers.

xii. Dismantle the apparatus only when all the swelling of the soil specimen is complete. It is essential to determine the final water content accurately.

xiii. After dismantling the apparatus, the bulk density and dry density of the specimen may also be determined.

OBSERVATIONS AND CALCULATIONS:

i. Determine void ratio (e) and plot the graph of e versus log p to obtain the e-log p curve.

ii. Compute the coefficient of volume change (m_v) and Compression Index (C_c) as follows:

Determination of m_v between any two selected pressures;

$$\mathbf{m_v = \frac{\Delta H}{H_i} \times \frac{1}{\Delta \sigma}}$$

Where,

H_i = Initial thickness of the sample

ΔH = Change in thickness of the sample

$\Delta\sigma$ = change in pressure

The Cc is the slope of the straight line portion of the e-log p curve which is determined below:

$$\mathbf{Cc = \frac{e_i - e_f}{\text{Log } 10\ (\sigma_f/\sigma_i)}}$$

Where,

e_i = void ratio at initial pressure

e_f = void ratio at final pressure

σ_i = Initial pressure

σ_f = Final pressure

iii. Determine settlement. The settlement for cohesive soil may be computed using the formula below.

$$\mathbf{S = \left(\frac{Cc\ H}{1 + e_o}\right) \log_{10} \left(\frac{P_o + \Delta P}{P_o}\right)}$$

Where,

H = Thickness of compressible layer (cm)

e_o = Initial void ratio

P_o = Existing overburden pressure (kg/cm^2)

ΔP = Pressure increment (kg/cm^2)

OBSERVATION SHEET

Pressure increment (p) = ……………………………………………….. (kg/cm^2)

Time of starting as per users watch

Elapsed time in minutes	√t	**DIAL GAUGE READINGS (mm)**					
0							
0.25							
1							
2.25							
4							
6.25							
9							
12.25							
16							
20.25							
25							
36							
49							
64							
100							
144							
196							
225							
256							
1440							

e_o = Initial void ratio = $\frac{G \cdot \gamma_w}{\gamma_d} - 1$

In case of pre-compressed clays, the compressibility of the stratum being lower than that of normally consolidated clay, the settlement may be computed as below:

$$S = \Delta P \, m_v \, H$$

COMPUTATION SHEET

Measurement of container ring:

Diameter (interior) of container ring = ……………………………………… cm

Area of container = ……………………………………… cm^2

Initial thickness of soil sample H = ……………………………………… cm

Specific gravity of soils G = 2.67

Equivalent height of solid, $H_s = \dfrac{Ws}{G\gamma w \cdot A}$ = ……………………………………… cm.

Least count of Dial gauge = ……………………………………… cm

Moisture content:

Wt. of container ring, W_1 = ……………………………………… g

Wt. of container ring + Wet Soil = W_2 = ……………………………………… g

Wt. of container ring + Dry Soil = W_3 = ……………………………………… g

Wt. of Dry Soil = W_s = ……………………………………… g

Wt. of water = ……………………………………… g

Moisture content = ……………………………………… %

Degree of saturation (S = wG / e) = ……………………………………… %

Applied pressure (kg/cm^2) (p)	**Final dial gauge reading taken from the table above**	**Change in dial gauge reading**	**Thickness of soil sample H (cm) (2) – (3) x L.C. of dial gauge**	**Equivalent height of voids $H - H_s$ (cm)**	**Void ratio $e = \frac{H - H_s}{H_s}$**
(1)	(2)	(3)	(4)	(5)	(6)
0.0					
0.125					
0.25					
0.5					
1.0					
2.0					
4.0					
8.0					
16.0					

DIRECT SHEAR TEST

OBJECTIVE:

To determine:

- i. The shear stress-strain characteristics of soils and
- ii. The shear parameters, i.e., cohesion and angle of internal friction.

APPARATUS:

1. Shear box of non-corrosive material, size 60 mm x 60 mm x 25 mm (large size box e.g. 300 mm x 300 mm x 200 mm are also used in special test containing gravel up to 25 mm size) open at the top and bottom, divided horizontally into two halves. The shear box is equipped with computer where proving ring (with dial gauge) and strain dial gauge are replaced by the computer which records the shear stress and strain. In other instruments where computer is not equipped, the shear force is recorded by proving ring (with dial gauge) and strain by a dial gauge.

2. Container for shear box. It holds the bottom of the shear box and filled up with water surrounding the shear box when sample is tested at saturated condition.

3. Grid plates. Two plain, two perforated and two perforated with serrations of 1.5 mm depth.

4. Porous stones. Two nos each 6 mm thick, 60 mm x 60 mm in size.

5. Base plate. Non-corrosive metal containing cross grooves on its top face.

6. Loading pad. Non-corrosive metal to be fitted in the shear box.

7. Loading frame. The important requirement of the frame is that the normal load is applied uniformly on the soil specimen in the shear box, without any eccentricity.

8. Proving ring with dial gauge. Capacity 250kg and least count of dial gauge as 0.002 mm.

9. Other Accessories. Weights, strain dial gauge (least count as 0.002 mm), two fixing screws, two spacing screws, spatula, a straight edge, compaction device for remoulded specimen, oven, balance and crucibles.

THEORY:

The shear strength of a soil mass is its property against sliding along internal planes within itself. The stability of slope in an earth dam or hills and the foundations of structures built on different types of soil depend upon the shearing resistance offered by the soil along the possible slippage surface. Shear parameters are also used in computing the safe bearing capacity of the foundation soils and the earth pressure behind retaining walls.

The shear strength is determined as below (after Coulomb)

$$S = c + \sigma \tan \Phi$$

Where,

S = Shear strength of soil (kg/cm^2)
c = Cohesion (kg/cm^2)
σ = Normal stress (kg/cm^2)
Φ = Angle of shearing resistance (Degrees)

The parameters c and Φ for a particular soil depend upon its degree of saturation, density and the condition of laboratory testing.

In a Direct Shear test, the sample is sheared along a horizontal plane. This indicates that the failure plane is horizontal. The normal stress (σ) on this plane is the external vertical load divided by the area of the soil sample. The shear stress at failure is the external lateral load divided by the corrected area of soil sample.

The main advantage of direct shear apparatus is its simplicity and smoothness of operation and the rapidity with which testing programmes can be carried out. But this test has the disadvantage that lateral pressure and stresses on planes other than the plane of shear are not known during the test.

TYPE OF LABORATORY TESTS

i. Unconsolidated undrained (Quick) test: The sample is tested in its natural state without applying any pressure from outside (prior to test) and also not letting pore water from the specimen to come out during the test. This test can be performed both on disturbed and undisturbed soil samples.

ii. Consolidated undrained or consolidated Quick test: Here the initial normal pressure (equivalent to the pressure to be applied during the test) is applied on the specimen after putting the same in shear box so that it gets consolidated. For consolidation, perforated grids are kept at the top and bottom of the specimen to let the pore water come out of the specimen for consolidation. After the consolidation of the specimen is complete, the perforated grids are carefully replaced by plain grids and test is carried out under undrained conditions. The test can be performed both on disturbed and undisturbed soil samples.

iii. Drained test: In this test, the pore water within the specimen (if any) is allowed to come out throughout the test both during applying normal and shear stress. The specimen is sheared at a slow strain rate so that no pore pressure within the specimen develops throughout the test. This test can be performed both on disturbed and undisturbed soil samples.

PROCEDURE:

For Undisturbed Specimen:

Specimen of required size (6 cm x 6 cm x 2.5 cm) shall be prepared from a natural undisturbed chunk. Weigh the mould empty and with the specimen also.

For Remoulded Specimen/Disturbed Sample:
The dried soil passing through 2.36 mm sieve size is compacted at the desired density (add desired moisture content, if soil is to be tested in moist conditions) into the shear box after keeping both the halves of the shear box together by means of the fixing screws.

To ensure the correct density of sample, take the weight of sample as multiplication of volume of soil (90 cm^3, if shear box size is 6 cm x 6 cm x 2.5 cm) and desired density. Divide the sample into two equal parts. One half of sample should be fully consumed into lower half of the box and other half should be fully consumed in upper half of the box. Gentle tamping to the soil sample should be done while filling in the shear box.

Keep the base plate, grid plate or porous stone before compacting the soil specimen in the shear box.

For undrained test, place the plain grid plate (non-perforated) below the porous stone. Care should be taken to see that serrations of the grid are at right angle to the direction of shear.

For consolidation of specimen and testing at drained condition, keep the perforated grid instead of plain grid to enable the pore water of specimen to pass through. Weigh the box with soil specimen to determine the density of specimen. Keep the porous stone, upper grid and loading pad on the soil specimen. Place the shear box inside container and keep it on the loading frame. Make adjustment that the upper half of the box is in proper contact with the proving ring assembly. Fill the container with water if the test is to be carried out at saturated condition.

Place a ball on the loading pad and mount the loading yoke on it. Adjust one no. dial gauge on the loading pad to record the vertical movement, (if required), and other dial gauge on container to observe the shear movement. Put the weight on the loading yoke to apply the normal stress of desired density.

For consolidated undrained and drained tests, the full consolidation of the soil specimen should be permitted under this normal load.

For unconsolidated undrained test, the consolidation step is avoided.

Remove the fixing screws from the box and raise the upper half of the shear box by about 1 mm, with the help of the spacing screws. The spacing screws pass only through the upper part of the box, abutting against the top of the lower part. Now, adjust all the three dial gauges to zero and apply the shear load at a constant rate of strain by a motorized gearing arrangement. Record the readings of proving dial gauge and shear and vertical movement dial gauges at every minute or so. Continue the test till specimen fails or at arrival of shear displacement of approximately 20 percent (1.2 cm in case of 6 cm x 6 cm shear box. This can be noted by shear dial gauge) of the specimen length.

Repeat the test observations on identical specimen under increasing normal stress corresponding to the field conditions and design requirements. Measure the moisture content of soil before and after the test, if the test was conducted on wet/moist sample. At least three tests should be conducted on different normal loads.

PRECAUTIONS:

i. The dimensions of the shear box should be measured accurately.
ii. Before allowing the sample to shear, the screw joining the two halves of the box should be taken out.
iii. Rate of strain or shear displacement rate should be constant throughout the test.
iv. The spacing screws after creating required spacing between two halves of the shear box should be turned back to make them clear of the lower part.
v. For drained tests, the porous stones should be saturated by boiling in water.

vi. Add the self weight of the loading yoke in the vertical load.

vii. Failure of the soil specimen is assumed when the proving ring dial gauge reading begins to recede after reaching its maximum or at a 20% shear displacement of the specimen length.

viii. One soil specimen should be tested with not more than three normal loading conditions as beyond this, the particle size of soil sample may change due to application of shear and normal loads.

OBSERVATIONS AND CALCULATIONS

a. Stress-strain characteristics

Soil specimen measurements

Dimensions (L x B) = ………………………………… cm
Thickness = ………………………………… cm
Moisture content = ………………………………… %
Area of specimen (A_o) = ………………………………… cm^2
Volume of specimen = ………………………………… cm^3
Bulk density = ………………………………… g/cc
Normal Stress = ………………………………… kg/cm^2

Multiplying factor for proving ring (k) = ………………………………… kg (i.e. 1 division of proving ring dial gauge)

Shearing Stage - Table

S.No.	Time elapsed (min)	Shearing displacement δ (cm)	Corrected Area $A_c = A_o (1-\delta/3)$ (cm^2)	Stress dial gauge reading	Shear force (k)x(5) (kg)	Shear stress = (6)/(4) (kg/cm^2)	Axial strain (%) δcm/L(cm) x 100
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.							
2.							
3.							

4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							

b. Shear parameters determination

S. No.	Normal stress applied (kg/cm2)	Stress dial gauge observations at failure	Shear force (kg)	Corrected area (A_c) (cm^2)	Shear stress (4)/(5) (kg/cm^2)	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.						
2.						
3.						
4.						

Plot the stress-strain graph and the graph of Shear stress against Normal stress using the values above.

RESULTS:

c = ………………………………………… kg/cm^2

Φ = ………………………………………… ^{o}

Note: The effective internal friction angle is essentially the same both in the completely dry as well as in submerged state.

Representative values of angle of friction (Φ) of sands and silts are generally as below:

Soil Type	**Φ (degrees)**	
	Loose	**Dense**
Sands, round grains, uniform	27.5	34
Sands, angular grains, well graded	33	45
Sandy gravels	35	50
Silty sand	27-33	30-34
Inorganic silts	27-30	30-35

DETERMINATION OF SPECIFIC GRAVITY OF SOIL

OBJECTIVE: To determine the specific gravity of soil.

APPARATUS:

1. Pycnometer
2. 4.75 mm sieve
3. Weighing balance
4. Oven
5. Glass rod
6. Distilled water

THEORY:

Specific gravity of soil is the ratio of weight, in air of a given volume; of dry soil to the weight of equal volume of water at 4ºC. Specific gravity of soil grains gives the property of the formation of soil mass and is independent of particle size. Specific gravity of soil grains is used in calculating void ratio, porosity and degree of saturation, by knowing moisture content and density.

The value of specific gravity helps in identifying and classifying the soil type.

PROCEDURE:

1. Dry the pycnometer and weigh it with its cap. (W_1)
2. Put about 200gm of oven dried soil passing through 4.75mm sieve into the pycnometer and weigh again (W_2).
3. Add sufficient distilled water to cover the soil and screw on the cap.
4. Shake the pycnometer well and remove entrapped air if any.
5. After the air has been removed, fill the pycnometer with water completely.

6. Thoroughly dry the pycnometer from outside and weigh it (W_3).
7. Clean the pycnometer by washing thoroughly.
8. Fill the cleaned pycnometer completely with water up to its top with cap screw on.
9. Weigh the pycnometer after drying it on the outside thoroughly (W_4).
10. Repeat the procedure for three samples and obtain the average value of specific gravity.

OBSERVATIONS AND CALCULATIONS

Determine the specific gravity of soil grains (G) using the following equation

$$G = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)}$$

Where,

W_1 = Empty weight of pycnometer.

W_2 = Weight of pycnometer + oven dry soil

W_3 = Weight of pycnometer + oven dry soil+ water

W_4 = Weight of pycnometer + water

OBSERVATION FOR SPECIFIC GRAVITY DETERMINATION

Sample Number	**W_1 in gms**	**W_2 in gms**	**W_3 in gms**	**W_4 in gms**	**Specific Gravity (G)**
1					
2					
3					

RESULT:

Average specific gravity of soil, **G** =

DETERMINATION OF PERMEABILITY OF SOIL BY CONSTANT HEAD METHOD

OBJECTIVE: To determine the coefficient of permeability of the soil by conducting constant head method.

APPARATUS:

1. Permeability apparatus with accessories
2. Stop watch
3. Measuring jar

THEORY:

The property of the soil which permits water to percolate through its continuously connected voids is called its permeability .Water flowing through the soil exerts considerable seepage forces which has direct effect on the safety of hydraulic structures. The quantity of water escaping through and beneath and earthen dam depends on the permeability of the embankment and the foundation soil respectively. The rate of settlement of foundation depends on the permeability properties of the foundation soil.

PROCEDURE:

1. Compact the soil into the mould at a given dry density and moisture content by a suitable device. Place the specimen centrally over the bottom porous disc and filter paper.
2. Place a filter paper, porous stone and washer on top of the soil sample and fix the top collar.
3. Connect the stand pipe to the inlet of the top plate.Fill the stand pipe with water.

4. Connect the reservoir with water to the outlet at the bottom of the mould and allow the water to flow through and ensure complete saturation of the sample.
5. Open the air valve at the top and allow the water to flow out so that the air in the cylinder is removed.
6. When steady flow is reached, collect the water in a measuring flask for a convenient time intervals by keeping the head constant. The constant head of flow is provided with the help of constant head reservoir
7. Repeat the for three more different time intervals

OBSERVATIONS AND CALCULATIONS

Calculate the coefficient of permeability of soil using the equation

$K = Q.L / A.t.h$

Where

K = Coefficient of permeability

Q = Quantity of water collected in time t sec (cc)

t = Time required (sec)

A = Cross sectional area of the soil sample (sq.cm)

h = Constant hydraulic head (cm)

L = Length of soil sample (cm)

(i) Length of soil sample (cm) =

(ii) Area of soil sample (sq.cm) =

S.No.	**Hydraulic Head h in cm**	**Time interval T (sec)**	**Quantity of Water collected(cc)**	**Coefficient of Permeability(cm/sec)**

RESULT:

Coefficient of permeability of the given soil sample =

DETERMINATION OF PERMEABILITY OF SOIL BY VARIABLE HEAD METHOD

OBJECTIVE: To determine the coefficient of permeability of a given soil sample by conducting Variable head test.

THEORY:

The property of the soil which permits water to percolate through its continuously connected voids is called its permeability .Water flowing through the soil exerts considerable seepage forces which has direct effect on the safety of hydraulic structures. The quantity of water escaping through and beneath and earthen dam depends on the permeability of the embankment and the foundation soil respectively. The rate of settlement of foundation depends on the permeability properties of the foundation soil.

APPARATUS:

2. Permeability apparatus with accessories
3. Stop watch
4. Measuring jar
5. Funnel

PROCEDURE:

1. Compact the soil into the mould at a given dry density and moisture content by a suitable device. Place the specimen centrally over the bottom porous disc and filter paper.

2. Place a filter paper, porous stone and washer on top of the soil sample and fix the top collar.
3. Connect the stand pipe to the inlet of the top plate. Fill the stand pipe with water.
4. Connect the reservoir with water to the outlet at the bottom of the mould and allow the water to flow through and ensure complete saturation of the sample.
5. Open the air valve at the top and allow the water to flow out so that the air in the cylinder is removed.
6. Fix the height h1 and h2 on the pipe from the top of water level in the reservoir
7. When all the air has escaped, close the air valve and allow the water from the pipe to flow through the soil and establish a steady flow.
8. Record the time required for the water head to fall from h1 to h2.
9. Change the height h1 and h2 and record the time required for the fall of head.

OBSERVATIONS AND CALCULATIONS:

Calculate the coefficient of permeability of soil using the equation.

K = 2.303 Al / At $\text{Log}_{10}(h_1/h_2)$

K = Coefficient of permeability

a = Area of stand pipe (sq.cm)

t = Time required for the head to fall from h1 to h2 (sec)

A = Cross sectional area of the soil sample (sq.cm)

L = Length of soil sample (cm)

h1 = Initial head of water in the stand pipe above the water level in the reservoir (cm)

h2 = final head of water in the stand pipe above the water level in the reservoir (cm)

(i) Diameter of the stand pipe (cm) =

(ii) Cross sectional area of stand pipe (sq.cm) =

(iii) Length of soil sample (cm) =

(iv) Area of soil sample (sq.cm) =

S. No.	**Initial head h_1 in cm**	**Final head h_2 in cm**	**Time interval t (sec)**	**Coefficient of Permeability(cm/sec)**

RESULT:

Coefficient of permeability of the given soil sample =

DETERMINATION OF LIQUID LIMIT AND PLASTIC LIMIT OF SOIL

OBJECTIVE:

To determine liquid limit and plastic limit of the given soil sample and to find the flow index and toughness index of the soil.

APPARATUS:

1. Casagrande Liquid limit device
2. Grooving tool
3. Glass plate
4. 425 micron sieve
5. Spatula
6. Mixing bowl
7. Wash bottle
8. Moisture content containers
9. Drying oven
10. Sensitive balance

THEORY:

Liquid limit is the water content expressed in percentage at which the soil passes from zero strength to an infinitesimal strength, hence the true value of liquid limit cannot be determined. For determination purpose liquid limit is that water content at which a part of soil, cut by a groove of standard dimensions, will flow together for a distance of 12.5mm under an impact of 5 blows in a standard liquid limit apparatus with a height of fall of 1cm.

The moisture content expressed in percentage at which the soil has the smallest plasticity is called the plastic limit. Just after plastic limit the soil displays the properties of a semi solid

For determination purposes the plastic limit it is defined as the water content at which a soil just begins to crumble when rolled into a thread of 3mm in diameter.

The values of liquid limit and plastic limit are directly used for classifying the fine grained soils. Once the soil is classified it helps in understanding the behaviour of soils and selecting the suitable method of design construction and maintenance of the structures made-up or and resting on soils.

PROCEDURE:

LIQUID LIMIT

1. Adjust the cup of liquid limit apparatus with the help of grooving tool gauge and the adjustment plate to give a drop of exactly 1cm on the point of contact on the base.
2. Take about 120gm of an air dried soil sample passing 425µ sieve.
3. Mix the soil thoroughly with some distilled water to form a uniform paste.

4. Place a portion of the paste in the cup of the liquid limit device; smooth the surface with spatula to a maximum depth of 1 cm. Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.
5. Turn the handle at a rate of 2 revolutions per second and count the blows until the two parts of the soil sample come in contact with each other, at the bottom of the groove, along a distance of 10mm.
6. Transfer about 15 gm of the soil sample forming the wedge of the groove that flowed together to a water content bin, and determine the water content by oven drying.
7. Transfer the remaining soil in the cup to the main soil sample in the bowl and mix thoroughly after adding a small amount of water.
8. Repeat steps 4 – 7 .Obtain at least five sets of readings in the range of 10 – 40 blows.
9. Record the observations in the Table.

PLASTIC LIMIT

1. Take about 30g of air dried soil sample passing through 425µ sieve.
2. Mix thoroughly with distilled water on the glass plate until it is plastic enough to be shaped into a small ball.

3. Take about 10g of the plastic soil mass and roll it between the hand and the glass plate to form the soil mass into a thread of as small diameter as possible. If the diameter of the thread becomes less than 3 mm without cracks, it indicates that the water added to the soil is more than its plastic limit hence the soil is kneaded further and rolled into thread again.
4. Repeat this rolling and remoulding process until the thread start just crumbling at a diameter of 3mm.
5. If the soil sample start crumbling before the diameter of thread reaches 3mm (i.e when the diameter is more than 3mm) in step 3, it shows that water added in step 2 is less than the plastic limit of the soil. Hence, some more water should be added and mixed to a uniform mass and rolled again, until the thread starts just crumbling at a diameter of 3mm.
6. Collect the piece of crumbled soil thread at 3mm diameter in an airtight container and determine moisture content.
7. Repeat this procedure on the remaining masses of 10g.
8. Record the observations in Table and obtain the average value of plastic limit.

OBSERVATION AND CALCULATIONS

1. Use the table for recording number of blows and calculating the moisture content. Use semi-log graph paper. Take number of blows on log scale (X – Axis) and water content on nominal scale (Y – axis). Plot all the points.
2. Read the water content at 25 blows which is the value of liquid limit.

TABLE - Observation for Liquid limit

S.No.	Description	1	2	3	4	5
1	No. of blows					
2	Container number					
3	Weight of container + wet soil					
4	Weight of container + dry soil					
5	Weight of water (3) – (4)					
6	Weight of container					
7	Weigh t of dry soil (4) – (6)					

8	Moisture content (w) (5) / (7)					
9	Moisture content in percentage					

TABLE - Observation for Plastic limit

S.No.	Description	1	2	3	4	5
1	Container number					
2	Weight of container + wet soil					
3	Weight of container +dry soil					
4	Weight of water (2) – (3)					
5	Weight of container					
6	Weigh t of dry soil (3) – (5)					
7	Moisture content (w)					

	(4) / (6)					
8	Moisture content in percentage					

Average plastic limit of the soil:

Flow Index, $I_f = (W_1 – W_2) / \log_{10} (N_2 – N_1)$

Where,

W_1 = Water content in % at N_1 blows

W_2 = Water content in % at N_2 blows

Toughness Index, I_T = Plasticity index / Flow index

RESULT:

1. Liquid limit of the soil =
2. Plastic limit of the soil =
3. Flow Index of the soil =
4. Toughness Index of the soil =

DETERMINATION OF SHRINKAGE LIMIT OF SOILS

OBJECTIVE: To determine shrinkage limit of the soil

APPARATUS:

- i. Shrinkage dish
- ii. Porcelain evaporated dish
- iii. Mercury
- iv. Balance

PROCEDURE:

1. About 30 g of soil passing through 425 micron sieve is taken with distilled water.
2. The shrinkage dish is coated with a thin layer of Vaseline .The soil sample is placed in the dish by giving gentle taps. The top surface is surfaced with a straight edge.
3. The shrinkage dish with wet soil is weighed. The dish is dried first in air and then in oven.
4. The shrinkage dish is weighed with dry soil. After cleaning the shrinkage dish its empty weight is taken.
5. An empty porcelain dish which will be useful for weighing mercury is weighed.

6. The shrinkage dish is kept inside a large porcelain dish it is filled with mercury and the excess is removed by pressing the plain glass plate firmly over the top of the dish. The contents of the shrinkage dish are transferred to the mercury weighing dish and weighed.
7. The glass cup is kept in a large dish, filled with over flowing mercury, the excess is removed by pressing the glass plate with three prongs firmly over the top of the cup.
8. It is placed in another large dish. The dry soil is placed on the surface of the mercury and submerges it under the mercury by pressing with the glass plate with prongs.
9. The mercury displaced by the dry soil pat is transferred to the mercury weighing dish and weighed.

OBSERVATION AND CALCULATIONS:

Sl.No	Description	Trial 1	Trial 2	Trial 3
1	Weight of dish + wet soil pat in gms			
2	Weight of dish + dry soil pat in gms			
3	Weight of water present (2-3)			
4	Weight of shrinkage dish , empty (gms)			

5	Weight of dry soil pat W_s = (2 – 4)			
6	Initial water content (W1) = (4) / (6) x100			
7	Weight of weighing dish + Mercury			
8	Weight of weighing dish empty			
9	Weight of mercury (7 – 8)			
10	Volume of wet soil pat			
11	Weight of weighing dish + displaced mercury			
12	Weight of mercury displaced			
13	Volume of dry soi pat			
14	Shrinkage limit			
15	Shrinkage ratio			
16	Volumetric shrinkage			
17	Linear shrinkage			

RESULT:

1. Shrinkage limit =

2. Shrinkage ratio =

3. Volumetric shrinkage =

DETERMINATION OF PARTICLE SIZE DISTRIBUTION BY SIEVING (SIEVE ANALYSIS)

OBJECTIVE: To determine the percentage of various particle sizes in a soil sample.

Grain size analysis of a soil is generally carried out by two methods:

i. Dry sieving
ii. Wet sieving

APPARATUS:

i. A complete set of I.S. sieves of sizes generally 4.75 mm, 2.00 mm, 1.18 mm, 425 µm, 300 µm, 150 µm, 75 µm with lid and pan.
ii. Oven
iii. Balance of 0.1g sensitivity
iv. Weights and weight box

THEORY:

The knowledge of grain size analysis of soil is very useful in the present geotechnical world. The results of this analysis are widely used for soil classification, design of filters, construction of earth dams, highway embankments and determining the mode of bearing capacity computations and for construction of building, hydraulic structures and road constructions etc. Hence, grain size analysis tests are conducted on almost every soil investigation project.

Dry sieving consists of shaking the soil by a mechanical device through sieves of known aperture size. The particle size, therefore, is defined by the dimension of the square hole of the sieve. The soil particles are generally flaky in shape and in this analysis the width of the flake is measured.

DRY SIEVING

PROCEDURE:

i. Weigh accurately about 200g of oven dried (at 105-110^{o}C) representative soil mass passing through 4.75 mm size sieve (if the soil sample has too much of material larger than 4.75 mm size i.e. $\geq$50 percent, a more weight of sample, about 0.5kg should be taken). For soil containing some particles > 4.75 mm size, the weight of soil sample for grain size analysis should be taken as 0.5kg to 1.0kg. The percentage of such particles should also be accounted for in the analysis.

ii. Clean the sieves and pan with brush and weigh them up to 0.1g accuracy.

iii. Arrange the sieve of sizes 4.75 mm, 2 mm, 1.18 mm, 425 µm, 300 µm, 150 µm and 75 µm in order, keeping the sieve of 4.75 mm at the top and 75 µm at the bottom followed by the pan.

iv. Then, keep the sample in the top (4.75 mm size) sieve and shake the set using a mechanical sieve shaker for 10 minutes. Care should be taken to tightly fit the lid cover on the top sieve (4.75 mm).

v. After shaking the soil on the sieve shaker, weigh each sieve and pan with soil retained on each of them. Then, weigh each of them without soil. Thus, weight of soil retained on each sieve can be calculated by subtracting the second value from the first one. The sum of the retained soil weights must tally with the original weight of soil taken.

OBSERVATIONS AND CALCULATIONS:

Sieve No.	**Sieve Opening i.e. sieve diameter (mm)**	**Wt. of sieve + Soil (g)**	**Wt. of sieve (g)**	**Wt. of soil retained (g) = (3) – (4)**	**% Retained**	**Cumulative percentage retained (%)**	**% Passing =100 – (7)**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
4.75 mm							
2.00 mm							
1.18 mm							
425 µm							
300 µm							
150 µm							
75 µm							
Pan							

RESULTS:

Plot the graph of percentage passing (%) against sieve diameter (mm).

WET SIEVING

In case of soils containing silty and also clayey particles, the wet sieving shall be carried out.

PROCEDURE:

i. Take 200 g of oven-dried soil passing 4.75 mm I.S > sieve. Put this soil in a tray containing water for a period of about 4-6 hours. Then, wash the soil on 75 μm I.S. sieve.

ii. The method of washing is to place the sieve (75 μm) with soil over a bucket. Next, pour clean water on the sieve.

iii. Stir the soil on the sieve with a glass rod. Continue to pour water till water passing the sieve is substantially clear.

iv. Allow the suspension in the bucket to settle for 24 hours. Remove the clear water (After about 24 hours) gently so that the soil settled in the bucket does not flow with water.

v. Dry this soil in oven ($105^{o}C – 110^{o}C$) and keep it for hydrometer analysis. Meanwhile, also dry the soil (in oven) retained on 75 μm sieve during the washing process and perform sieve analysis test on it as detailed above and record the observation in the table below.

PRECAUTIONS:

i. While drying the soil, the temperature of the oven should be about 105 to 110°C, because higher temperature may lead to some organic changes in the material finer than 75 µm.

ii. While removing clear water from the bucket, care should be taken so that no soil particle flows with water out of the bucket.

iii. If the soil is highly flocculated, simply submerging of soil in water shall not be sufficient. In such a case, two grams of Sodium hexametaphosphate or one gram of Sodium hydroxide mixed with one gram of Sodium carbonate per litre of water should be added to the soil. The mix should be thoroughly stirred with glass rod and left for submergence for about 1.5 – 2 hours before washing.

OBSERVATIONS AND CALCULATIONS:

Sieve No.	Sieve Opening i.e. sieve diameter (mm)	Wt. of sieve + Soil (g)	Wt. of sieve (g)	Wt. of soil retained (g) = (3) – (4)	% Retained	Cumulative percentage retained (%)	% Passing =100 – (7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
4.75 mm							
2.00 mm							
1.18 mm							
425 µm							
300 µm							
150 µm							
75 µm							
Pan							

RESULTS:

Plot the graph of percentage passing (%) against sieve diameter (mm).

DETERMINATION OF GRAIN SIZE DISTRIBUTION OF SOILS BY HYDROMETER ANALYSIS

OBJECTIVE: To conduct Hydrometer analysis of soil to study the grain size distribution of the fine grained soil.

APPARATUS:

i. Hydrometer
ii. Dispersion cup with mechanical stirrer with complete accessories
iii. Glass jar 1 litre capacity
iv. Deflocculating agent
v. Stop watch
vi. Thermometer

PROCEDURE:

A. For soils containing considerable amount of fines

1. Take about 50g in case of clayey soils and 100g in case of sandy soil and weigh it correctly to 0.1g.

2. In case the soil contains considerable amount of organic matter or calcium compounds, pre–treatment of the soil with Hydrogen peroxide or hydrochloric acid may be necessary. In case of soils containing less than 20 percent of the above substances pre-treatment shall be avoided.

3. To the soil thus treated, add 100 cc of Sodium hexametaphosphate solution and warm it gently for 10 minutes and transfer the contents to the cup of the mechanical mixer using a jet of distilled water to wash all traces of the soil.

4. Stir the soil suspension for about 15 minutes.

5. Transfer the suspension to the Hydrometer jar and make up the volume exactly to 1000 cc, by adding distilled water.

6. Take another Hydrometer jar with 1000cc distilled water to store the hydrometer in between consecutive readings of the soil suspension to be recorded. Note the specific gravity readings (r_w) and the temperature TºC of the water occasionally.

7. Mix the soil suspension roughly, by placing the palm of the right hand over the open end and holding the bottom of the jar with the left hand turning the jar upside down and back. When the jar is upside down be sure no soil is stuck to the base of the graduated jar.

8. Immediately after shaking, place the hydrometer jar on the table and start the stop watch. Insert the Hydrometer into the suspension carefully (avoiding circular or vertical oscillations to facilitate quick and accurate reading of the Hydrometer) and take hydrometer readings at the total elapsed times of ¼ ½, 1 and 2 minutes.

9. After the 2 minutes reading, remove the hydrometer and transfer it to the distilled water jar and repeat step no 8.Normally a pair of the same readings should be obtained before proceeding further.

10. Take the subsequent hydrometer readings at elapsed timings of 4, 9, 16, 25,36,49,60 minutes and every one hour thereafter. Each time a reading is taken remove the hydrometer from the suspension and keep it in the jar containing distilled water. Care should be taken when the hydrometer recorded to see that the hydrometer is at rest without any movement. As the time elapses, because of the fall of the solid particles the density of the fluid suspension decreases readings, which should be checked as a guard against possible error in readings of the hydrometer.

11. Continue recording operation of the hydrometer readings until the hydrometer reads 1000 approximately.

B. When the soil contains a small portion of fines.

1. Conduct sieve analysis on the soil.

2. Take 50g of the soil passing 75µ sieve and run the hydrometer analysis as explained above

C. Calibration of the hydrometer

1. Note the mid length of the bulb.

2. Note the distance Z_r cm from the first and the last readings and any intermediate readings also on the stem of the hydrometer to find the mid length of the bulb.

3. Plot a curve (A) of hydrometer reading R_h against depth Z_r. This curve is applicable for readings obtained from the first two minutes with the hydrometer continuously kept inside the hydrometer jar. For all subsequent readings of the hydrometer a correction has to be applied by subtracting the volume effect of the hydrometer from the observed values Z_r. The value of this correction is V_r is the volume of the hydrometer, which can be obtained from the volume it displaces when immersed in water (g).The area of cross section of the jar may be obtained by dividing the volume of the jar between two marks by the distance between them.

4. After determining the correction factor, plot the graph ordinate of curve A. This curve is used for all the readings beyond the first two minutes.

RESULT:

Plot the graph of hydrometer R_h against depth Z_r

DETERMINATION OF COEFFICIENT OF CONSOLIDATION

OBJECTIVE: To determine the coefficient of consolidation of a given clay soil.

APPARATUS:

1. Consolidometer consisting of specimen ring.
2. Guide ring
3. Porous stones
4. Dial gauges
5. Stop watch

THEORY:

When a load is applied on a saturated soil, the load will initially be transferred to the water in pores of the soil .This results in development of pressure in pore water which results in the escape of water from voids and brings the soil particles together. The process of escape of water under applied load, leads to reduction in volume of voids and hence the volume of soil. The process of reduction of volume of voids due to expulsion of water under sustained static load is known as consolidation. The magnitude of consolidation depends on the amount of voids or void ratio of the soil. The rate of consolidation depends on the permeability properties of soil. The two important consolidation properties of soil are (i) co-efficient of consolidation (C_v) and

(ii) Compression index (Cc). The coefficient of consolidation reflects the behaviour of soil with respect to time under a given load intensity. Compression index explains the behaviour of soils under increased loads.

APPLICATIONS:

Consolidation properties are required in estimating the settlement of a foundation. They provide the maximum amount of settlements under a given load and the time required for it to occur. Many times the design of foundations is carried out based on the limiting settlements. The amount of consolidation will be more in clay soils. Further due to low permeability, the rate of settlement in clay soil is very low. That means the time required for the total settlement in clay soils is very high. Hence the study of consolidation properties is important for foundation resting on clay soil.

PROCEDURE:

Preparation of specimen

Sufficient thickness of the soil specimen is cut from undisturbed sample. The consolidation ring is gradually inserted into the sample. The consolidation ring is gradually inserted into the sample by pressing and carefully removing the material around it. The specimen should be trimmed smooth and flush to the ends of the ring. Any voids in the specimen caused due to removal of gravel or limestone pieces should be filled back by pressing completely the loose soil in the voids. The ring should be wiped clean and weighed again with the soil. Place wet filter paper on top and bottom faces of the sample and two porous stones covering it should be in place. Place this whole assembly in the loading frame. Over the porous stone a perforated plate with loading ball is placed as shown in the figure.

The sample is put for saturation both from top and bottom. After allowing time for saturation the load is applied through the loading frame. The settlement in sample is measured using a dial gauge. The stepwise procedure for observing reading is as follows:

1. Apply the required load intensity (stress) at which Cv is to be determined.
2. As the loading is applied, the stop watch should be started.
3. Take the readings of the dial gauge at different time interval from the time of loading and record them in the table.

OBSERVATION AND CALCULATIONS:

(a) Square root method

1. Record the dial gauge readings at different time interval from the point of loading in Table.

2. Plot a graph between √t on X-axis and dial gauge reading on Y axis .Where t is time in minutes.
3. The curve drawn reflects three components of settlement (i) Immediate settlement or elastic compression. This will be reflected in the form of steep settlements in a small time interval and a nearly vertical line at the initial portion of the curve represents it. This is followed by (ii) Primary consolidation curve, which will be nearly a straight line with a reduced sloe. The majority of consolidation will be in this zone. After primary consolidation (iii) Secondary consolidation takes place that is marked by a curve nearly parallel to time axis.
4. Draw a straight line through a primary consolidation zone. Identification of primary consolidation zone depends on experience and eye judgement. Extent the straight line to meet Y- axis at Oc. Oc is the corrected zero.
5. Draw another straight line through Oc , with a slope equal to 1.15 times the slope of the earlier straight line.
6. The Straight line so drawn (with 1.15 times the slope of primary consolidation line) will intersect the originally plotted curve at a point. The X co ordinate of this point will give $\sqrt{t_{90}}$. Where t_{90} is the time required for 90% consolidation (in minutes)

7. The coefficient of consolidation is calculated as follows

   $Cv = 0.848\ H^2 / (t_{90} \times 60)$ $cm^2/sec.$

   Where H = length of drainage path (cm)

   H = half thickness of soil sample for double drainage and

   H = thickness of soil sample for single drainage

   t_{90} = time required for 90% consolidation in minutes.

(b) Log - method

1. The compression dial readings should be plotted against the log of time and a smooth curve drawn to pass through the points.
2. The two straight portions of the curve should be extended to intersect at a point , the ordinate of which gives d_{100} corresponding to 100% primary compression.
3. The corrected zero point ds shall be located by the laying of above point in the neighbourhood of 0.1 minute a distance equal to the vertical distance between this point and one at a time which is four times this value
4. The 50% compression point which is halfway between the corrected zero point and the 100% compression point, shall be marked on the curve and the readings on the time axis corresponding to this point t_{50}, time to 50%

primary compression, shall be noted. The readings on the dial gauge reading axis, corresponding to 100% compression gives

d_{100}.

5. Coefficient of consolidation is calculated as follows

   $Cv = 0.197\ H^2/\ t_{50}$.

Dimensions of sample:

Diameter = Thickness = Unit weight of soil =

Elapsed time In minutes, t	**√t**	**Dial gauge reading**
1		
0		
0.25		
2.25		
4.00		
6.25		
9.00		

12.25		
16.00		
20.25		
25.00		
36.00		
49.00		
64.00		
81.00		
100.00		
121.00		
144.00		
169.00		
225.00		
256.00		

RESULT:

Coefficient of Consolidation of the given soil sample, C_v =

DETERMINATION OF TOTAL SOLIDS, DISSOLVED SOLIDS AND SUSPENDED SOLIDS IN WATER

OBJECTIVE: To determine total solids, dissolved solids and suspended solid in water.

APPARATUS:

1. Beaker
2. Measuring Cylinder
3. Filter paper
4. Balance

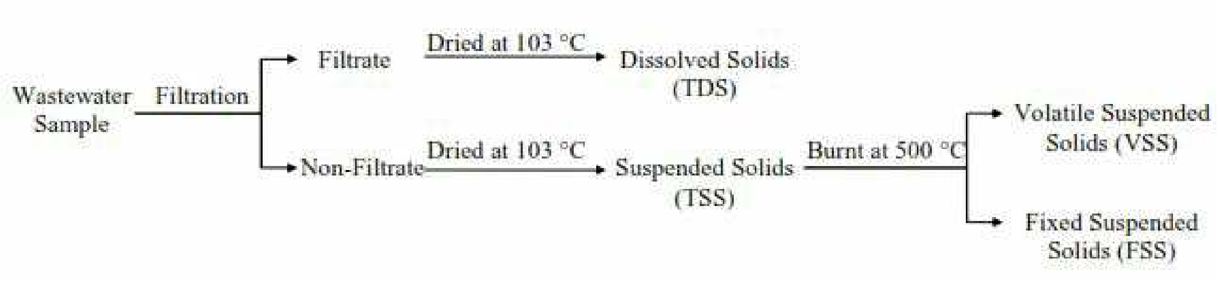
MATERIALS

1. Salt
2. Water

THEORY:

Definition:

Environmental engineering is concerned with the solid material in a wide range of natural waters and wastewaters. The usual definition of solids (referred to as "total solids") is the matter that remains as residue upon evaporation at 103~105°C. The various components of "total solids" can be simplified as follows:



Total Solids (TS) are the total of all solids in a water sample. They include the total suspended solids and total dissolved solids. Total Suspended Solids (TSS) are the amount of filterable solids in a water sample.

Samples are filtered through a glass fiber filter. The filters are dried and weighed to determine the amount of total suspended solids in mg/l of sample.

Total Dissolved Solids (TDS) are those solids that pass through a filter with a pore size of 2.0 micron. or smaller. They are said to be non-filterable. After filtration the filtrate (liquid) is dried and the remaining residue is weighed and calculated as mg/l of Total Dissolved Solids.

Environmental Significance:

The total solids (TS) contents of wastewater are used in the design and process control of wastewater treatment facilities. Total dissolved solids (TDS) are used to evaluate the suitability of water for both domestic supplies and industrial purposes. The total suspended solids (TSS), including the volatile fraction (VSS), are commonly monitored to evaluate the degree of pollution in natural waters and serves as a key process control parameter for wastewater treatment operation.

Most of the impurities in potable waters are in the dissolved state, principally as inorganic salts. Thus, the parameters, "total solids" and especially "total dissolved solids" are of primary importance here.

Waters containing high concentrations of inorganic salts are not suitable as sources of drinking water, because such materials are often difficult to remove during treatment. Finished drinking waters containing more than 1000 mg/L TDS are generally considered unacceptable. Waters of this type may also be unsuitable for agricultural purposes due to the harmful effects of high ionic concentrations on plants. Total solids also affect water clarity. Higher solids decrease the passage of light through water, thereby slowing photosynthesis by aquatic plants. Water will heat up more rapidly and hold more heat; this, in turn, might adversely affect aquatic life that has adapted to a lower temperature regime.

In the realm of municipal wastewater, suspended solids analysis is by far the most important gravimetric method. It is used to evaluate the strength of the raw wastewater as well as the overall efficiency of treatment. Furthermore, most WWTP's have effluent standards of 10 to 30 mg/L suspended solids which may be legally enforceable. As was the case with municipal wastewater, suspended solids analysis is useful as a means of assessing the strength of industrial wastewaters and the efficiency of industrial wastewater treatment.

Water Standards for TS, TDS and TSS

According to Bangladesh Environment Conservation Rules (1997), potable water should not contain more than 1000 mg/l of total dissolved solids (TDS)

Measurement of TS, TDS and TSS

The measurement of solids is by means of the gravimetric procedure. The various forms of solids are determined by weighing after the appropriate handling procedures. The total solids concentration of a sample can be found directly by weighing the sample before and after drying at $103^{o}C$. However, the remaining forms, TDS and TSS require filtration of the sample. For liquid samples, all these solids levels are reported in mg/L.

PROCEDURE:

Total Solids

(1) Take a clear dry glass beaker (which was kept at 103^O C in an oven for 1 hour) of 150ml. capacity and put appropriate identification mark on it. Weigh the beaker and note the weight.

(2) Mix 10g of salt in 150ml of water.

(2) Pour 100ml. of the thoroughly mixed sample, measured by the measuring cylinder in the beaker.

(3) Place the beaker in an oven maintained at 103^O C for 24hours. After 24 hours, cool the beaker and weight. Find out the weight of solids in the beaker by subtracting the weight of the clean beaker determined in step (1)

(4) Calculate total solids (TS) as follows:

Total solids, TS (mg/l) = mg of solids in the beaker x 1000 / (volume of sample)

Dissolved Solids

(1) Same as above (step 1 of total solids).

(2) Take a 100 ml. of sample and filter it through a double layered filter paper and collect the filtrate in a beaker.

(3) Repeat the same procedure as in steps (3) and (4) of the total solids determination and determine the dissolved solids contents as follows:

Total Dissolved Solids, TDS (mg/l) = mg of solids in the beaker x 1000 (volume of sample)

Suspended Solids

Total Suspended Solids, TSS (mg/l) = TS (mg/l) – TDS (mg/l)

OBSERVATIONS AND CALCULATIONS:

DETERMINATION	**VOLUME OF SAMPLE**	**INITIAL WEIGHT (A)**	**FINAL WEIGHT (B)**	**DIFFERENCE (B – A)**
TSS				
TDS				
TS				

QUESTIONS:

1. Discuss possible sources of solids in ground water and surface water.

2. “Groundwater usually has higher dissolved solids and surface water usually has higher suspended solids”- Explain.

3. Why is water evaporated at 103°C instead of 100 °C in assessment of solids of water?

RESULT:

The Total Solids (TS) in a given sample are found to be ……………………….. mg/l

The Suspended Solids (SS) in a given sample are found to be …………………… mg/l

The Total Dissolved Solids (TDS) in a given sample are found to be …………….. mg/l

JAR TEST

OBJECTIVE:

The objectives of the jar test experiment are to estimate the optimum concentration of aluminum sulfate for the removal of suspended matter and to investigate the change in alkalinity as a result of aluminum sulfate addition.

APPARATUS:

i. Phipps & Bird Six-Place Stirrer
ii. 1 or 2-liter beakers
iii. Aluminum sulfate (alum) solution
iv. Hach turbidimeter
v. Pipettes/syringes
vi. Burettes
vii. Erlenmeyer Flasks
viii. 0.02 N H_2SO4
ix. Water sample (River water)
x. Volumetric flasks
xi. Methyl orange (MO) indicator

THEORY:

Coagulation and flocculation are important unit processes in water and waste water treatment plants. The purpose of coagulation/flocculation is to remove suspended matter, turbidity, color, microorganisms, and odor producing substances. Coagulation involves the addition of chemicals to destabilize [allow them to agglomerate] the suspended particles, colloidal materials, and macromolecules.

Some common coagulants used are aluminum sulfate (alum) and ferric sulfate. Flocculation is usually defined as the aggregation of destabilized particles into larger flocs under slow mixing conditions. The flocs formed are subsequently removed by sedimentation and/or filtration (see pages 172 - 178, Davis and Cornwell).

A useful laboratory experiment for the evaluation of coagulation/flocculation of untreated water is the jar test. This test provides information on the effects of the concentrations of the coagulants mixing of the raw water, and the water quality parameters such as pH and alkalinity on the coagulation process. The jar test is often used for the design of treatment facilities and in the routine operation of treatment plants.

PROCEDURE:

1. Determine the turbidity and pH of the raw water sample. Also determine the alkalinity of raw water sample using the procedure below.
2. Place 1 or 2 liters of raw water in each of the six beakers of the laboratory stirrer. Immerse blades and stir the raw water samples at about 100 rpm.
3. Add alum solution into each of the beaker to obtain the desired concentrations in the raw water samples.
4. Let the samples mix at approx. 100 rpm for 1minute, then decrease the speed to approx. 30 rpm. Allow the sample to mix for a period of 10 minutes. Observe any changes in the suspended matter in the sample.
5. At the end of the mixing period, turn off the stirrer, let the flocs settle (at least 20 minutes) and carefully remove the supernatant from each beaker and determine the turbidity in each of the samples. Determine the pH of each treated water sample.
6. Measure the alkalinity of the sample with the largest alum concentration.

ALKALINITY MEASUREMENT

1. Add 50 mL of water sample (V_s) to an erlenmeyer flask
2. Add 2 to 3 drops of methyl orange indicator
3. Read the starting volume of standard 0.02 N H2SO4 on the burette. Titrate water sample with standard 0.02 N H2SO4 until color changes from yellow-orange to red.
4. Read the final volume of the acid in the burette. Record volume used (V_a).
5. Compute alkalinity as follows:

Alkalinity (in mg/L CaCO3) = [mL acid (V_a) x Normality of acid x 50,000] / [mL sample (V_s)]

RESULT:

Beaker No.	1	2	3	4	5	6
Dosage						
Turbidity						
pH						
Alkalinity						

DISSOLVED OXYGEN (DO)

OBJECTIVE: To determine the Dissolved Oxygen present in water.

APPARATUS:

a. BOD bottles, capacity 300mL
b. Sampling device for collection of samples

Reagents

a. Manganese sulphate: Dissolve 480g $MnSO_4.4H_2O$ or 400g $MnSO_4.2H_2O$ in distilled to 1000mL. Filter if necessary. This solution should not give colour with starch when added to an acidified solution of KI.

b. Alkali iodide-azide reagent.

1. For saturated or less than saturated samples: Dissolve 500g NaOH (or 700g KOH) and 150g KI (or 135g NaI) in distilled water and dilute to 1000mL. Add 10g sodium azide, NaN_3 dissolved in 40mL distilled water. This solution should not give colour with starch solution when diluted and acidified.
2. For supersaturated samples: Dissolve 10g NaN_3 in 500mL distilled water. Add 480g NaOH and 750g NaI and stir to dissolve the contents.

Cautions: Do not acidify this solution because toxic hydrozoic acid fumes may be produced.

c. Sulphuric acid: H_2SO_4, conc., 1mL is equivalent to about 3mL alkali-iodide-azide reagent.

d. Starch indicator: Prepare paste or solution of 2.0g of soluble starch powder and 0.2g salicylic acid as preservative in distilled water. Pour this solution in 100mL boiling distilled water. Continue boiling for a few minutes, cool and then use.

e. Stock sodium thiosulphate, 0.1N: Dissolve 24.82g $Na_2S_2O_3.5H_2O$ in distilled water. Preserve by adding 0.4g solid NaOH or 1.5mL of 6N NaOH and dilute to 1000mL.

f. Standard sodium thiosulphate, 0.025N: Dilute 250mL stock $Na_2S_2O_3$ solution to 1000mL with freshly boiled and cooled distilled water. Add preservative before making up the volume. (This should be standardized with standard dichromate solution for each set of titrations).

Sample collection, preservation and storage

Sampling for dissolved oxygen depends upon the source and method of analysis. While sampling, sample should not remain in contact with air or should not be agitated. These conditions can cause severe change in gaseous content. Sampling from any depth in streams, lakes or reservoir needs special precautions to eliminate changes in pressure and temperature. There are specific procedures and equipment developed for sampling water under pressure and unconfined water.

Sample should be collected in narrow mouth glass BOD bottles of 300mL capacity. Let the bottle overflow for some time and then stopper the bottle so that no air bubbles could form.

The DO determination should be carried out immediately after sampling.

THEORY:

All living organisms are dependent upon oxygen in one form or the other to maintain the metabolic processes that produce energy for growth and reproduction. Aerobic processes are of great interest, which need free oxygen for wastewater treatment. Dissolved Oxygen (DO) is also important in precipitation and dissolution of inorganic substances in water.

DO levels in natural waters and wastewaters depend on physical, chemical and biological activities in water body. The solubility of atmospheric oxygen in fresh water ranges from 14.6mg/L at 0°C to about 7.0mg/L at 35°C under normal atmospheric pressure. Since it is poorly soluble gas, its solubility directly varies with the atmospheric pressure at any given temperature.

Analysis of DO is a key test in water pollution control and wastewater treatment processes. The following illustrations reveal importance of DO as a parameter:

- It is necessary to know DO levels to assess quality of raw water and to keep a check on stream pollution.
- In wastewaters, dissolved oxygen is the factor that determines whether the biological changes are brought out by aerobic or anaerobic organisms.
- DO test is the basis of BOD test which is an important parameter to evaluate pollution potential of wastes.
- DO is necessary for all aerobic biological wastewater treatment processes.
- Oxygen is an important factor in corrosion. DO test is used to control the amount of oxygen in boiler feed waters either by chemical or physical methods.

a. The Winkler method with azide modification

Principle:
Oxygen present in sample rapidly oxidizes the dispersed divalent manganous hydroxide to its higher valency, which is precipitated as a brown hydrated oxide after the addition of NaOH/KOH and KI.

Upon acidification, manganese reverts to divalent state and liberates iodine from KI equivalent to the original DO content. The liberated iodine is titrated against $Na_2S_2O_3$ (N/40) using starch as an indicator. The chemical reactions involved in the method are given below:

1. $MnSO_4 + 2KOH$ ® $Mn(OH)_2 + K_2SO_4$ (white ppt)
2. $2\ Mn(OH)_2 + O_2$ ® $2\ MnO(OH)_2$ (Brown ppt)
3. $MnO(OH)_2 + 2H_2SO_4)_2 + 3H_2O$
4. $Mn(SO_4)_2 + 2\ KI$ ® $MnSO_4 + K_2SO_4 + I_2$
5. $2Na_2S_2O_3.5H_2O + I_2$ ® $Na_2S_4O_6 + 2NaCl + 10H_2O$
6. $2NaN_3 + H_2SO_4$ ® $2HN_3 + Na_2SO_4$
7. $HNO_2 + HN_3$ ® $N_2 + N_2O + H_2O$

PROCEDURE:

1. Collect sample in a BOD bottle using Do sampler.
2. Add 1mL $MnSO_4$ followed by 1mL of alkali-iodide-azide reagent to a sample collected in 250 to 300mL bottle up to the brim. The tip of the pipette should be below the liquid level while adding these reagents. Stopper immediately. Rinse the pipettes before putting them to reagent bottles.
3. Mix well by inverting the bottle 2-3 times and allow the precipitate to settle leaving 150mL clear supernatant. The precipitate is white if the sample is devoid of oxygen, and becomes increasingly brown with rising oxygen content.
4. At this stage, add 1mL conc. H_2SO_4. Replace the stopper and mix well till precipitate goes into solution.
5. Take 201mL of this solution in a conical flask and titrate against standard $Na_2S_2O_3$ solution using starch (2mL) as an indicator. When 1mL $MnSO_4$ followed by 1mL alkali-iodide-azide reagent is added to the samples as in (2) above, 2mL of original sample is lost. Therefore 201mL is taken for titration which will correspond to 200mL of original sample.

200 x 300/ (300-1) = 201mL

CALCULATION:

1mL of 0.025N $Na_2S_2O_3$ = 0.2mg of O_2

DO in mg/L = (0.2 x 1000) x (0.025N) ml of thiosulphate / 200

Modification in Winkler method

Following modifications are suggested to compensate for various interferences.

I. Alsterberg azide modification: The method outlined earlier is known as Azide Modification of Winkler method and also as Alstererg Azide modification. The reagent NaOH + Kl + NaN_3 can be used in the method to eliminate interference caused by NO_2. This also reduces interference due to higher concentration of ferric ions.

II. Redeal Stewart Modification: This modification is used when the samples contain ferrous ions.
Add 0.7mL conc. H_2SO_4 followed by 1mL 0.63% $KMnO_4$ immediately after sample collection in the BOD bottle. If ferric ions are present in large concentration, add 1mL of 40% KF solution. Remove excess $KMnO_4$ as excess oxalate produced negative error.

III. Alum flocculation Modification: Samples containing high suspended matter consume appreciable amount of iodine in acidic condition. Therefore, the samples are treated as follows:

Add 10mL of 10% alum solution followed by 1-2mL NH_4OH to 1000mL of the sample. Allow to settle for 10 minutes and siphon the clear supernatant for DO estimation.

IV. Copper sulphate-sulphamic acid flocculation modification: Activated sludge contains biological flocs having high demand for O_2. Samples from such treatment plants are fixed by adding 10mL copper sulphate-sulphamic acid reagent to 1000mL of the sample. The reagent is prepared by adding 32g $CuSO_4$ in 500mL distilled water + 25mL acetic acid.

V. Alkaline Hypochlorite Modification: To overcome interference of complex sulphur compounds (wastewater from sulphite pulp industry), this modification is used. Pre-treatment with alkaline hypochlorite solution converts polythionates to sulphates and free sulphur. Excess of hypochlorite is destroyed by addition of KI and sodium sulphite.

Calibration: Select the test is titrimetric, the calibration of standard is not relevant.

Precision and Bias:

The minimum detectable limit is 0.1mg/L for reproducible and accurate results. It is better to repeat the test. Check the quality of reagents. Use AR Grade chemicals. Analyze the samples in duplicate for quality assurance.

Interferences:

Ferrous ion, ferric ion, nitrite, microbial mass and high suspended solids constitutes the main sources of interferences. Modifications to reduce these interferences are described in the procedure.

Pollution prevention and waste management:

The acidic liquid samples after titration of dissolved oxygen should be flushed with sufficient water for adequate dilution.

b. Membrane electrode method:

Various modifications for the iodometric method have been developed to eliminate or minimize effects of interferences; nevertheless, the method is still not applicable to a variety of industrial and domestic wastewaters. Moreover, the iodometric method is not suited for field testing and cannot be adopted easily for continuous monitoring or for DO determinations in-situ. With membrane covered electrode systems, these problems are minimized, because the sensing element is protected by an oxygen permeable plastic membrane that serves as a diffusion barrier against impurities.

These electrodes are especially useful for taking dissolved oxygen profiles of reservoirs and streams. The electrodes can be lowered to micrometer located at the surface. They can also be suspended in biological waste treatment tanks to monitor DO level at any point. In laboratory investigations, membrane electrodes have been used for continuous DO analysis in bacterial cultures, including the BOD test. These electrodes provide an excellent method for DO analysis in polluted wastes, highly coloured waters, and strong waste effluents.

Oxygen sensitive membrane electrode of the polarographic or galvanic type are composed of two solid metal electrodes in contact with supporting electrolyte separated from the test solution by a sensitive membrane (polyethylene and fluorocarbon membranes are commonly used).

Membrane electrodes are commercially available in some variety. In all these instruments, the 'diffusion current' is linearly proportional to the concentration of molecular oxygen. The current can be converted to concentration units easily by a number of calibration procedures.

For calibration of the instrument, follow manufacturer's procedure exactly to obtain designed precision and accuracy. Usually these electrodes are calibrated by reading against air or a sample of known Do concentration (determined by iodometric method) as well as sample with zero DO (add excess of Na2S2O3 and a trace of CoCl2 to bring DO to zero). Preferably calibrate with samples of water under test. Avoid an iodometric where interfering substances are suspected.

Membrane electrodes exhibit a relatively high temperature coefficient largely due to changes in the membrane – permeability. Thus, either accurate temperature measurements may be made along with DO measurements so that a correction can be applied or instruments which are equipped with a thermistor or other device to compensate automatically for temperature changes must be used.

To use the Do membrane electrode in estuaries waters or in wastewater with varying ionic strength, correction should be made for effect of salting out on electrode sensitivity. This effect is particularly significant for large changes in salt content. Calibrate with a sample of clean water containing the same salt content as the sample. Add concentrated solution of KCl to produce the sample specific conductance as that in the sample.

REYNOLDS EXPERIMENT

OBJECTIVE: To perform the Reynolds experiment for determination of different regimes of flow.

APPARATUS: A stop watch, a graduated cylinder, and Reynolds apparatus test rig which consists of water tank having a glass tube leading out of it. The glass tube has a bell mouth at entrance and a regulating valve at outlet, a dye container with an arrangement for injecting a fine filament of dye (Potassium permanganate (to give brightly reddish color streak)) at the entrance of the glass tube, thermometer measuring tank.

THEORY:

The purpose of this experiment is to illustrate the influence of Reynolds number on pipe flows. Reynolds number is a very useful dimensionless quantity (the ratio of dynamic forces to viscous forces) that aids in classifying certain flows.

For incompressible flow in a pipe Reynolds number based on the pipe diameter, $Re_D = V_{ave}D\rho/\mu$, serves well. Generally, laminar flows correspond to $Re_D < 2100$, transitional flows occur in the range $2100 < Re_D < 4000$, and turbulent flows exist for $Re_D > 4000$. However, disturbances in the flow from various sources may cause the flow to deviate from this pattern. This experiment will illustrate laminar, transitional, and turbulent flows in a pipe.

The flow of real fluids can basically occur under two very different regimes namely laminar and turbulent flow. The laminar flow is characterized by fluid particles moving in the form of lamina sliding over each other, such that at any instant the velocity at all the points in particular lamina is the same. The laminar near the flow boundary move at a slower rate as compared to those near the center of the flow passage. This type of flow occurs in viscous fluids, fluids moving at slow velocity and fluids flowing through narrow passages.

The turbulent flow is characterized by constant agitation and intermixing of fluid particles such that their velocity changes from point to point and even at the same point from time to time. This type of flow occurs in low density Fluids flow through wide passage and in high velocity flows.

Laminar Flow: A flow is said to be laminar when the various fluid particles moves in layer with one layer of fluid living smoothly over on adjacent layer. A laminar flow is one in which the fluid particles moves in layers or laminar with one layer sliding over the other. Therefore there is no exchange of fluid particles from one layer to the other and hence no transfer of later of momentum to be adjacent layers. The particles, in the layer having lower velocity, obstruct the fluid particles in the layer with higher velocity.
This obstruction force is called viscous resistance or viscosity. The laminar flow is one in which fluid layers glide over each another. It has low velocity and high viscous resistance.

Turbulent Flow: There is a continuous transfer of momentum to adjacent layers. Fluid particles occupy different relative position at different places. It is one in which, the particles get thoroughly mixed on (called turbulence). The turbulent flow has higher velocity. The flow in canals, pipes and rivers is usually turbulent flow.

Transition Flow: The transition flow has intermediate properties between the laminar and turbulent flow. In laminar the forces should be considered to calculate the friction loss and in the turbulent flow only the internal forces are considered because the effect of viscous force is negligible as compared to internal forces. Reynolds carried out experiments to decide limiting values of Reynolds number to quantifiably decide whether the flow is laminar, turbulent or transition. These limits are shown in the table below.

Reynolds conducted an experiment for observation and determination of these regimes of flow. By introducing a fine filament of dye in to the flow of water through the glass tube, at its entrance he studied the different types of flow. At low velocities the dye filament appeared as straight line through the length of the tube and parallel to its axis, characterizing laminar flow. As the velocity is increased the dye filament becomes wavy throughout indicating transition flow. On further increasing the velocity the filament breaks up and diffuses completely in the water in the glass tube indicating the turbulent flow.

After conducting his experiment with pipes different diameters and with water at different temperatures Reynolds concluded that the various parameters on which the regimes of flow depend can be grouped together in a single non dimensional parameter called Reynolds number.

Reynolds number is defined as, the ratio of inertia force to the viscous force. Where, viscous force is shear stress multiplied area and inertia force is mass multiplied acceleration.

$$\mathbf{Re = VD\rho/ \mu = VD/v \qquad (v = \mu\rho)}$$

Where,
Re - Reynolds number
V - Velocity of flow
D - Characteristic length=diameter in case of pipe flow
ρ - Mass density of fluid =1000
μ - dynamic viscosity of fluid = 0.55x 103
v - Kinematic viscosity of fluid

Reynolds observed that in case of flow through pipe for values of Re<2000 the flow is laminar while offer Re>40000 it is turbulent and for 2000<Re<4000 it is transition flow.

Type of flow	Reynolds Number	
	Pipe flow	Canal flow
Laminar flow	< 2000	< 500
Transition flow	2000 to 4000	500 to 2000
Turbulent flow	>4000	>2000

PROCEDURE:

Start the experiment by pressing start button with default values of temperature of water and time taken and diameter of pipe. Then pass the experiment with few cycles and note the observation.

Observation1:

1) Start the experiment and allow the water to flow in to the tank of the apparatus. Water level in the pyrometer is slightly rising along with rise in tank. Control valve of the glass tube should be slightly opened for removing air bubbles.
2) After the tank is filled outlet valve of the glass tube and inlet valve of the tank should be closed, so that water should be at rest.

Observation2:

1) Keeping the velocity of flow very small and inlet of the die injector is slightly opened, so that the die stream moves at a straight line throughout the tube showing the flow is laminar.
2) Again measure the discharge and increase the velocity of flow.

Observation3:

5) Note the observations till the die stream in the glass tube breaks up and gets diffused in water.
6) Repeat the experiment by decreasing the rate of flow (i.e. for different discharges) and by changing the temperature and diameter of pipe.

OBSERVATIONS AND CALCULATIONS:

Inner diameter of glass tube, D =
Cross - sectional area of glass tube, A = (π/ 4) x D^2
Mean temperature of water – t - =
Kinematic viscosity of water-ν- =

Sl. No.	H_1 (cm)	H_2 (cm)	**ΔH** (cm)	Time taken for discharge 't' in sec	Discharge 'Q' in (cm^3/sec)	Velocity 'V' (cm/sec)	Reynold's Number 'Re'	Type of flow
1.								
2.								
3.								
4.								

Perform the following calculations for each set of readings
Discharge –Q = A x ht
Velocity of flow – V = 4 x Qπ x D^2

RESULT:

1) Reynolds number – Re = VD/ ν = …………………………..
2) Regime of flow =………………………………
3) Velocity of flow in glass tube = ……………………………..
4) Discharge = ……………………………
5) Depth of water collected in receiving tank = **ΔH** = ……………………………

DETERMINATION OF CALIFORNIA BEARING RATIO

OBJECTIVE: To determine the California Bearing Ratio (CBR) of soil in the laboratory.

APPARATUS:

i. CBR mould 150 mm diameter and 175 mm high with detachable perforated base plate. Spacer (displacer) disc with a removable handle (with spacer disc placed inside the mould, the effective height remaining only 127.3 mm and the net capacity is 2250 ml).
ii. Collar 50 mm high.
iii. Penetration plunger – 50 mm diameter.
iv. One annular and a few slotted surcharge masses 2.5 kg each.
v. Rammer 2.6 kg with 310 mm drop and 4.89 kg with 450 mm drop.
vi. Steel rod 15 – 20 mm in diameter, 400 mm long.
vii. Cutting edge.
viii. Loading machine of approximately 5t(50 kN) capacity, fitted with a calibrated proving ring to which the standard plunger is attached capable of giving a constant rate of penetration of about 1.25mm/min. Alternatively, an electronic CBR apparatus has been developed which replaces use of proving ring. In this apparatus, a personal computer is attached to the apparatus which records all the stresses.
ix. Penetration measuring dial gauge 25 mm travel, accurate to 0.01 mm. in electronic type apparatus, these dial gauges are not required.
x. Soaking tank.
xi. Swelling gauge consisting of a perforated plate with an adjustable extension stem.
xii. I.S. sieves 4.75 mm.
xiii. Straight edge.
xiv. Mixing basin.
xv. Filter paper.
xvi. Balance accurate to 5g.
xvii. Compression machine (30t) for static compaction.

THEORY:

California Bearing Ratio (CBR) is defined as the ratio of the force per unit area required to penetrate a soil mass with a circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration of a standard material. The ratio is usually determined for penetrations of 2.5 and 5 mm. Where the ratio at 5 mm is consistently higher than that as 2.5 mm, the ratio at 5 mm is used.

For the requirements of pavement design one of the simple strength tests would be a plate bearing test on the sub grade using the plate area and loading approximately equal to the anticipated contact area and the wheel load. Field tests require heavy equipments and considerable time. The California Bearing Ratio method provides a good substitute for heavy field tests. Thus, it is the simple test, internationally accepted for design of flexible pavements.

PREPARATION OF SPECIMEN:

The test may be conducted on undisturbed sample as well as disturbed (remoulded sample) which may be compacted either statically or dynamically. An undisturbed sample is tested when the sub-grade is to be used in natural condition without artificial compaction and a remoulded sample is to be used when the sub-grade is to be used.

Undisturbed specimen

Undisturbed specimen shall be obtained from the field in its natural condition. For this, use 127.3 mm high mould and attach a steel cutting edge to its one end. Push the mould gently into the ground. This process may be facilitated by digging away the soul from outside of mould as it is pushed in. When the mould is full of soil, it shall be taken out carefully. The top and bottom surfaces are then trimmed flat so as to achieve the correct length of specimen for testing. If the mould cannot be pressed in, the sample may be collected by digging at a circumference greater than that of the mould and thus bringing out a whole undisturbed lump of soil. The required size of the sample to fit into the test mould shall then be carefully trimmed from this lump.

Give wax coating and transport to the laboratory. During testing, wax coating is removed. The density of sample is determined by usual method of determining the density of soil.

Remoulded Specimen (Disturbed Sample)

Firstly, the dry density of the remoulded (disturbed) sample shall be determined. It can either be field density of the maximum dry density determined by compaction test. The test can be conducted at any other density also if CBR is to be determined at a particular density.

The water content used for compaction should be the optimum water content or the field moisture as the case may be.

Remoulded specimens are prepared in the laboratory by either static or dynamic compaction. The test material should pass 20 mm sieve and retained on 4.75 mm sieve. If coarser material is retained on 20 mm sieve, it should be discarded and an equal amount of material (retained on 4.75 mm sieve passing through 20 mm sieve) should be replaced. However, the test can be performed on almost all types of soils, ranging from clay to gravel.

Static Compaction (for Remoulded Specimen)

The mass (M) of the wet soil at the required moisture content (w) to give the desired density (γ_d) shall be calculated by the formula;

$$M = \gamma_d (1 + w) V$$

A batch of soil shall be thoroughly mixed with water to give the required moisture content. Now, fix the mould on the base plate. Place the filter paper inside. Pour the weighed amount of soil in the mould. Tamp the soil by the steel rod during the process of pouring and make the top surface roughly level. The amount of tamping should be such that the top surface remains about 35-40 mm below the top of the mould. Place a filter paper on top of soil and insert the spacer disc. Keep the mould assembly in a compression machine and press the disc down in level with the top of the mould. Release the pressure after a while. Remove the disc. The specimen is then ready for penetration test (if soaking is required then firstly, soak the specimen and then subject it to penetration test).

For penetration, the disc should be left in place and the mould covered to prevent evaporation. If 127.3 mm high mould is used for static compaction, fix the collar on top before pouring the soil in the mould.

Dynamic Compaction (for Remoulded Specimen)

Weigh the mould with base plate and collar. Keep the spacer disc on the base plate (not required if it is 127.3 mm high mould) and a filter paper over a disc. Fix the mould to the base plate with the disc inside the mould. Compact the wet soil in 3 equal layers by giving 56 blows to each layer by 2.6 kg rammer. For heavy compaction, compact the soil in 5 layers by giving 56 blows by 4.89 kg rammer to each layer. Remove the collar. Trim off excess soil in level with the top of the mould. Detach the base plate and remove the spacer disc also. Determine the dry density of sample. Place the filter paper on the perforated base plate. Fix the mould upside down to the base plate so that surface of the specimen which was downwards in contact with spacer disc during compaction is now turned upwards on which the penetration test is performed. The specimen is now ready for soaking and penetration test.

Soaking of Specimen

Weigh the mould with base plate and specimen. Keep the filter paper on the specimen and place the perforated top plate with adjustable stem over the specimen. Keep the mould in a tank in which water will be filled for soaking. Apply a surcharge in multiples of 2.5 kg (each 2.5 kg mass is equivalent to 70 mm of construction) equivalent to the expected pavement thickness over the material of which CBR is being determined.

The minim surcharge should be 5 kg. Now, fill the water in the tank to immerse the mould, test specimen and surcharge masses, allowing free access of water to top and bottom of specimen. Mount the dial gauge tripod and set the dial gauge to read zero in contact with the stem of the perforated plate. Allow the specimen to soak under constant water level for 4 days or until the rate of swelling has reduced to almost zero. Record the swell every 24 hours. At the end of soaking, take out the mould and allow it to drain downwards for 15 minutes (tilt the specimen to remove free water). Remove the surcharge masses, the perforated top plate and the filter paper. Weigh the specimen to know the mass of water absorbed.

The expansion ratio is calculated from the following relationship:

$$\mathbf{E = \frac{R_f - R_i}{H_i} \times 100}$$

Where,

R_f = Final dial gauge reading (mm)
R_i = Initial dial gauge reading (mm)
H_i = Initial height of specimen (mm)
E = Expansion ratio

PROCEDURE:

i. The mould containing the test specimen is placed on the lower plate of the testing machine with the base plate in position and the top surface exposed.
ii. Surcharge masses, sufficient to produce and intensity of loading equal to the weight of the base material (in field) and pavement is placed on the specimen (if the soaking had been done earlier, the surcharge then shall be equal to that used during the soaking). To prevent upheaval of the soil into the hole of the surcharge weights, 2.5 kg annular mass is placed on the soil surface prior to seating the penetration plunger after which the remainder of surcharge weights shall be placed. The plunger shall be

placed under a load of about 4 kg so that full contact is ensured between the surface of the specimen and the plunger.

iii. The stress and strain dial gauges are set to initial zero reading. The initial load applied to the plunger is termed as zero load while determining the load-penetration relation.

iv. Load is applied to the penetration plunger at the rate of penetration equal to 1.25 mm per minute. The load is recorded at penetration of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. The maximum load and penetration is recorded for a penetration of less than 12.5 mm.

v. The plunger after the completion of test is raised and the mould is detached from the loading equipment. About 50-100 g of soil is taken immediately below the plunger for water content determination.

The undisturbed test specimen should be examined carefully after the test is completed. For the presence of any oversize particles as it could affect the results. The CBR value increases with the increase on surcharge and confining pressures. However, in partly cohsensionless soils, the CBR values increase with the surcharge weight only up to a particular point beyond which the CBR value almost remains constant. Hence, CBR should not be considered meaningful for application for purely cohensionless soils like sands.

LOAD-PENETRATION CURVE

The load-penetration curve is drawn. The curve is generally convex upwards, although the initial portion of the curve may be concave upwards due to surface irregularities. A correction shall then be applied by drawing a tangent to the upper curve at the point of contraflexure. The corrected curve shall be taken to be this tangent plus the convex portion of the original curve with the origin of strains shifted to the point where the tangent cuts the horizontal strain axis. Thus, the penetration of plunger shall be read from this shifted zero point instead of the original zero. Accordingly, the corrected load shall be read corresponding to this penetration value.

DETERMINATION OF CBR

Corrected load value shall be taken from the load-penetration curve corresponding to the penetration value at which CBR is desired. CBR is reported to the nearest one percent. The CBR is then determined as follows:

$$\mathbf{CBR = P_t / P_s \times 100}$$

Where,

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

P_s = Standard load for the same depth of penetration as for P_s

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

TABLE - STANDARD LOADS FOR CBR TEST

Penetration Depth (mm) (for plunger of 50 mm diameter)	Total Standard Load (kg)	Unit Standard Load (kg/cm^2)
2.5	1370	70
5.0	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

CALCULATIONS AND RESULT:

a. Proving ring constant (a): 1 Div of dial gauge = …………………………….. kg
b. Surcharge weight: ………………………………. kg
c. Diameter of plunger: ……………………………. kg

Penetration (mm)	**Proving Ring Dial gauge reading (Divisions)**	**Load on Plunger (kg)**	**Corrected Load (kg) From the load-penetration curve (values are for 2.5 and 5.0 mm penetration)**	**Standard Load (kg) from the standard loads for CBR tests table**	**CBR (%) determined by P_t / P_s x 100**
(1)	**(2)**	**(3) = (2) x (a)**	**(4)**	**(5)**	**(6)**
0.0					
0.5					
1.0					
1.5					
2.0					
2.5				1370	
3.0					
4.0					
5.0				2055	
7.5					
10.0					
12.5					

Plot the graph of Load on plunger versus Penetration to obtain the load-penetration curve. On the graph, mark off the corrected point for 2.5 mm penetration and the corrected point for 5 mm penetration.

TEST OBSERVATION FOR CALIFORNIA BEARING RATIO

Type of compaction used: ……………………….
Period of soaking: ……………………….
Dry density of specimen before soaking: ……………………….
Bulk density of specimen before soaking: ……………………….
Bulk density of specimen after soaking: ……………………….
CBR of specimen at 2.5 mm penetration: ……………………….
CBR of specimen at 5 mm penetration: ……………………….

MOISTURE CONTENT DETERMINATION

OBJECTIVE: To determine the moisture content of soil by: -

1. Oven-drying method
2. Sand bath method
3. Calcium carbide method and
4. Pycnometer method

APPARATUS:

For Oven Drying Method

- i. Metal container with lid (air tight, non-corrodible).
- ii. Balance (0.01g sensitivity for fine grained soils and 0.1g sensitivity for medium grained soils).
- iii. Oven (interior for non-corrodible material, controlled at $105^{o} - 110^{o}C$ temperature).
- iv. Desiccator
- v. Tong (one pair).

For sand Bath Method

- i. Sand bath (heat resistant containing clean sand up to a depth of about 30 – 45 mm).
- ii. Metal container or enameled tray with proper cover.
- iii. Heating equipment e.g., a kerosene stove or a gas burner.
- iv. Spatula

For Calcium Carbide Method

- i. Rapid moisture meter using Calcium Carbide based on the principle that a gas is released when Calcium Carbide reacts with soil water. It is a metallic pressure chamber fitted with a calibrated gauge at one end and a removable cup at the other end. The gauge reads the water content (percent) based on the wet mass of the soil.

ii. A counterpoised balance to weigh 6g mass of wet soil sample. This is generally provided with apparatus.
iii. Calcium Carbide (reagent).
iv. Scoop for measuring reagent. This is also provided with the apparatus.
v. Steel balls (for cohesive soils), three balls each of 10 mm diameter and one of 20 mm diameter.

For Pycnometer Method

i. Pycnometer made of glass (500 milliliter/1 liter capacity).
ii. 4.75 mm I.S. sieve.
iii. Balance accurate to 0.5g.
iv. Vacuum pump.

THEORY:

Moisture content of a soil is the ratio of the weight of water present to the weight of dry soil in a given soil mass. It is usually expressed as percentage of the dry mass e.g.

$$\mathbf{w = \frac{W_r}{W_s} \times 100}$$

Where,

W_r = Weight of wet soil minus dry soil
W_s = Weight of dry soil
w = Moisture content (%)

PROCEDURE (FOR MOISTURE CONTENT):

OVEN DRYING METHOD

i. Clean, dry the metal container and weigh with lid.

ii. Take about 30 g of soil sample (in natural state) of fine grained soil or 250 g specimen if the soil is medium grained. Place the soil specimen loosely in the container and weigh with lid.

iii. Remove the lid of the container and place the container in the oven. Maintain the oven temperature at 105^{o} – 110^{o}C for normal soils and 60^{o} – 80^{o}C for soils having organic content.

iv. Dry the soil specimen in the oven till its mass is constant. Drying is deemed complete when the difference in the successive mass of the cooled specimen is about 0.1 percent of the original mass of the sample. The drying period of the soil specimen is usually 16-24 hours in normal conditions.

v. After drying, take the container out of the oven, keep the lid on it and place it in desiccator for cooling.

vi. Weigh the container with dry soil and the lid.

vii. Record the observations in the moisture content (oven-drying method) table below.

PRECAUTIONS:

i. The wet soil specimen should be kept loosely in the metal container.

ii. Care should be taken to avoid over heating of the soil specimen by maintaining the oven temperature at 105^{o} – 110^{o}C.

iii. Dry soil specimen in the container, should not be left uncovered before weighing as it is likely to catch moisture from the surrounding atmosphere.

OBSERVATIONS AND CALCULATIONS:

Table – Moisture Content (oven-drying method)

Sl. No.	**Particulars**	**1**	**2**	**3**	**4**
1.	Container No.				
2.	Weight of the container with lid W_1 (g)				
3.	Weight of the container + wet soil W_2 (g)				
4.	Weight of the container + dry soil W_3 (g)				
5.	Weight of moisture W_w (g)				
6.	Weight of dry soil W_s (g)				
7.	Moisture content w (%)				

The moisture content (w) is calculated by;

$$\mathbf{w = \frac{W_2 - W_3}{W_3 - W_1} \times 100}$$

SAND BATH METHOD

i. Clean the container and weigh with its lid accurately.

ii. Keep loosely the wet soil in the container so as to have at least 30 g of fine grained soil and 250 g of medium grained soil.

iii. Weigh the container with lid and the soil. Place the sand bath on a stove or an electric heater.

iv. Keep the container on the sand bath. Go on stirring and disturbing the soil specimen frequently during heating with a spatula or a glass rod. A drying period of about 1 – 1.5 hours is sufficient.

v. After the drying of the specimen is complete, remove the container from the sand bath, place the lid on the container and keep it in a desiccator for cooling. Take the container out of the desiccator and weigh.

The method of calculations and recording of observations are as shown in the oven-drying method.

CALCIUM CARBIDE METHOD

i. Clean the cup, chamber of the moisture meter and the balance.
ii. Weigh 6 g wet soil sample in the pan of the balance.
iii. Keep the sample in the chamber and a scoop filled with the reagent (Calcium Carbide) in the cup. For clayey soils, put steel balls in the chamber along with the soil specimen.
iv. Hold the chamber and the cup horizontal and see that the reagent does not move out of the cup. Clamp and tightly fit the cup with the chamber.
v. Turn the moisture meter with gauge downwards so that the reagent in the cup falls into the chamber. Vigorously shake the moisture meter up and down and horizontally for sometimes. Then, rest a while.
vi. Repeat this shaking and resting process for about 5 to 10 minutes. Now, turn the moisture meter so that the gauge is upwards.
vii. Record the gauge reading which gives the percentage of moisture content (w_1 %) on the wet mass basis.
viii. Release the gas slowly by opening the clamp screw, remove the cup and clean the apparatus.

OBSERVATIONS AND CALCULATIONS:

The moisture content (w) at dry mass is calculated as below:

Where, w_1 = Water content at wet mass basis

PRECAUTIONS:

i. Calcium carbide is a good water absorber and therefore should not be kept open to the surrounding atmosphere.
ii. The reagent should be replaced if it is deteriorated, or after a period of about one month.

PYCNOMETER METHOD

i. Weigh the pycnometer with its cap screwed on. While weighing, it should be clean and completely dry.
ii. Take about 350 g of wet soil, unscrew the cap, put the wet soil in the pycnometer and weigh correctly with its cap screwed over it.
iii. Add sufficient quantity of water to cover the soil and screw the cap tightly on the pycnometer.
iv. Stir well and connect the pycnometer with vacuum pump for about 10 0 15 minutes. Add more water in the pycnometer and re-apply the vacuum for at least 5 minutes. After this, fill the pycnometer completely with water.
v. Thoroughly dry the pycnometer from outside and weigh it.
vi. Remove the soil sample and clean the pycnometer thoroughly. Then, fill it completely with water and weigh it after screwing the cap and drying from outside.
vii. Take minimum two such observations and record them in the table below.

OBSERVATIONS AND CALCULATIONS:

The observations should be recorded in the table below and calculations (for known value of specific gravity of the soil) be made using the following relationship:

$$w = \frac{(G - 1) W_5 - G (W_3 - W_4) \times 100}{G (W_3 - W_4)}$$

Specific gravity (G) of the soil = 2.68

Table – Moisture Content Determination (Pycnometer Method)

Sl. No.	Particulars	1	2	3	4
1.	Container No.				
2.	Weight of Pycnometer W_1 (g)				
3.	Weight of Pycnometer + wet natural soil W_2 (g)				
4.	Weight of Pycnometer + Soil + Water W_3 (g)				
5.	Weight of Pycnometer full of water W_4 (g)				
6.	Weight of wet soil = $W_2 – W_1 = W_5$ (g)				
7.	Water content w (%)				

PRECAUTIONS:

i. Washer of the cap of pycnometer should be well set so that there is no leakage while evacuating the entrapped air.
ii. The vacuum should be gradually applied to avoid any violent bubbling of the entrapped air.
iii. Weighing should be done with utmost care.

UNCONFINED COMPRESSION TEST

OBJECTIVE: To determine the compressive strength of a cohesive soil sample in an unconfined compression state.

APPARATUS:

- i. Unconfined compression apparatus comprising of hydraulic loading devices or screw jack with a proving ring and a deformation dial gauge.
- ii. Vernier caliper.
- iii. Sample extractor.
- iv. Coning tool.
- v. Sampling tube.
- vi. Split mould.

THEORY:

The unconfined compressive strength (q_u) of a soil specimen is the ratio of failure load and cross-sectional area of the specimen (at failure) when it is not subjected to any confining pressure. It is the simplest and quickest laboratory method commonly used to measure the shear strength of cohesive soils, collected in natural state (in undisturbed form) from the field. Since a cohensionless soil does not form an unsupported cylinder, the method is mainly used for cohesive soils. It is normally employed as a measure of insitu strength to check the short term stability of foundations and slopes. As during the laboratory test, the rate of loading on the specimen is fast and no pore water is allowed to drain or dissipate, this test is essentially an undrained test.

By unconfined compressive strength test, the sensitivity (reduction of strength due to remoulding. Marine soils are most sensitive with sensitivity as 100, i.e. marine soils suffer the maximum reduction of strength when remoulded) of a soil may also be determined.

Sensitivity measures the effect of remoulding of soil on its strength without any change in its moisture content. Numerically, sensitivity (S) is defined below:

$$S = \frac{\textbf{unconfined compressive strength (undisturbed)}}{\textbf{unconfined compressive strength (remoulded)}}$$

if sensitivity is 1 to 4, the soil is classified as Normal, if 4 to 8, it is termed as Sensitive, if 8 to 15 it is Extra Sensitive and for more than 15, it is termed as Quick Soil.

In the test, a circular soil specimen is compressed axially without any confining pressure. The cross-section of the specimen increases with decrease in length. Assuming that the volume V at any time is almost equal to the initial volume V_0, the corrected area

$$A_0 = \frac{A_0}{1 - \varepsilon}$$

Where,

A_0 = Initial area
ε = strain = $\Delta L/L$
ΔL = change in length and,
L = initial length of the specimen.

Unconfined compressive strength, $\mathbf{q_u = P/A_c}$

Where,

P = axial load at failure for ordinary soils. If φ is the angle of shearing resistance,

$$q_u = 2c \tan (45 + \varphi/2)$$

For clayey soils, φ = zero (for saturated soil when drainage is not permitted during the test)

Thus, $\mathbf{q_u = 2c \cdot 1 = 2c = P/A_c}$

Shear strength, $\mathbf{S = c + \sigma_f \tan \varphi}$

For $\mathbf{\varphi = 0, \quad S = c = q_u/2}$

Category of soils in terms of unconfined compressive strength values are given below:

Unconfined compressive strength q_u (kg/cm^2)	**Consistency of Soil**
< 0.25	Very Soft
0.25 – 0.50	Soft
0.50 – 1.00	Medium
1.00 – 2.00	Stiff
2.00 – 4.00	Very Stiff
>4.00	Hard

PROCEDURE:

A. **For undisturbed sample.** The test specimen shall have a diameter of 38 mm. the height to diameter ratio should be in between 2 to 2.5.

i. Collect the soil sample into sampling tube from large undisturbed sample or directly from bore holes, test pits or open excavation.
ii. Push the sample out of the tube into the split mould with negligible disturbance of the specimen.
iii. Remove the excess soil to flush with the end of the split mould.
iv. Open the split mould and use the coning tool to form cones on two ends of the specimen.
v. Measure the length of specimen and weigh it.
vi. Place the specimen in the compression apparatus.

vii. Apply the compressive load till the sample fails.
viii. Take a representative soil sample from the place near the failure plane and keep it in an oven for water content determination.

B. **For Remoulded Specimen**.

i. Wrap the failed specimen and thoroughly remould it with fingers, taking care to evacuate as little air as possible.
ii. Fill the remoulded sample into 38 mm diameter mould with a spatula, extrude the specimen from the mould gently by means of piston. For soft clays, more than one attempt may be required to mould an acceptable specimen.
iii. Measure the dimensions of specimen and test it as was done for the undisturbed specimen. However, reading may be taken less often (i.e. start with readings at every 0.5 mm axial compression, changing later to every 1 mm).
iv. Compress until the failure surface has definitely developed in the sample. If no definite failure is reached stop the test at a strain of 20%.
v. After the test has run, quickly place the specimen in a dish and weigh.
vi. After it has dried and cooled re-weigh it to determine the moisture content of the entire remoulded specimen.

PRECAUTIONS:

i. The sample should be kept properly between the upper and lower plates.
ii. The remoulded specimen should have (to as much extent as possible) a uniform density and the same void ratio as that of the undisturbed specimen, if consistency of soil is to be determined.
iii. The loading of the sample should be at a constant rate, the strain rate should be approximately 2% per minute.

iv. The maximum particle size in the test specimen should not be more than 1/8 th of diameter of specimen.
v. Lightly oil or grease the inside surface of the mould prior to insertion of soil specimen in it.
vi. The loading direction of the specimen should be similar to that in the field. To ensure this, the sampling tube containing the undisturbed soil sample should be arrow marked showing the direction of sample collection.
vii. The degree of saturation of test specimen should also be calculated from the test results.

OBSERVATIONS AND CALCULATIONS:

Table – Soil Sample Details

S. No.	Description	Undisturbed	Remoulded / disturbed (to be filled by user)
1.	Initial weight of specimen (g)		
2.	Initial diameter of soil sample d_0 (cm)		
3.	Initial area of specimen A_0 (cm^2)		
4.	Initial length of specimen L (cm)		
5.	Bulk density of soil γ_t (g/cc)		
6.	Moisture content (%)		
7.	Dry density of specimen γ_d (g/cc)		
8.	Degree of saturation (%)		

Table – Rate of Strain: 1.5 mm/minute (generally adopted)

S. No.	**Strain dial reading (L_c = 0.01 mm)**	**Stress dial reading (1 div. = 1 kg)**	**Force (kg)**	**Length of specimen (cm)**	**Corrected area A_c (cm^2)**	**Stress (kg/cm^2)**	**Strain (%)**	**Remarks**
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								

RESULT:

The maximum stress from the above observations gives the value of the unconfined compressive strength (q_u).

DETERMINATION OF TOTAL SOLUBLE SOLIDS (BY GRAVIMETRIC METHOD)

OBJECTIVE: To determine the total soluble solids in water.

APPARATUS:

i. Evaporating Dish – 2 Nos. each of 100 ml capacity made of silica, porcelain or glass.
ii. Steam bath.
iii. Buchner funnel or filter candle.
iv. Electric stirrer i.e. shaking machine
v. Filtering flask (750 ml capacity)
vi. Vacuum pump
vii. Pipette 100 ml
viii. Balance accurate to 0.0002g
ix. Desiccator
x. Electric oven, fitted with thermostatic control to maintain the temperature up to 180 ± 2°C.

THEORY:

The presence of water soluble solids in soil greatly influences the engineering properties of soil. The total soluble solids of soil can be determined by (i) Gravimetric and (ii) Conductivity method. The gravimetric method is reliable and dependable which estimates the soluble salts contents accurately and in absolute quantity while the results provided by the conductivity method are approximate and with reference to a standard solution of Potassium Chloride.

For an extract of Soil-water mix (1:10 ratio), the soluble solids are determined as below:

$$\textbf{Total soluble salts } M_1 \text{ (\%)} = \frac{M2}{10} \times 100 = 10\,M_2$$

Where,

M_1 = Total soluble solids (%)

M_2 = Mass of residue (g) after evaporation of 100 cc of extract containing 10g of soil solids.

PROCEDURE (1:10 soil-water extract):

a. Put the clean evaporating dish in electric oven and heat it up to 180 degree C for 1 hour. Cool in the desiccator, weigh and keep in desiccator for ready use.
b. Keep about 50g of soil collected from the field for oven drying at 103 degree – 105 degree C temperature for about 14 hours. After taking the soil out of the oven, cool it and then sieve it through 2 mm sieve. Transfer 50g of (-) 2mm soil to the dispression cup fit it with the electric stirrer. Pour 500 ml distilled water in the cup containing the soil sample.
c. Agitate the soil – water mixture with the help of electric stirrer for about 1 hour. All soluble salts, present in the soil thus get dissolved in 1:10 solution.
d. Allow the solution in the dispression cup to settle for about 10-12 hours. Decant thereafter, the supernatant liquid into a tall 750 ml glass cylinder. Insert a filter candle in the cylinder and connect it with a one liter flask through a rubber tube and start filtering by applying suction to the flask. Discard the first 25-30 ml of filtrate collected in suction flask by stopping suction process. Reconnect the suction system with the flask and collect the remaining filtrate and preserve the same for analysis. The soil extract may also be filtered through a Buchner funnel. Reject the first 20-25 ml of the filtrate and collect the rest into a dry flask. Take out the evaporating dish from the desiccator.
e. Fill (up to the mark) the 100 ml pipette with filtrate (collected in the suction flask) and transfer the same into the evaporating dish. Now keep this dish over a steam bath very carefully. Evaporate the filtrate in the dish to dryness. Alternatively, evaporation can also be done in a drying oven. The temperature in that case should be kept at about 98 degree C to avoid boiling of the sample. After completer evaporation of water, transfer the dish to the oven and dry it for about 1 to 2 hours.
f. Take the dish out of the oven and cool the residue and weigh.

g. Calculate the percentage of the soluble salts using the Total Soluble salts equation above.

PRECAUTIONS:

a. Due to constant use, fine dispersed clay particles stick on the outside of the candle filter. To remove it, take the candle out of the suspension and gently blow air into the filter candle by means of rubber tube connection. The surface of the candle can be cleaned by rubbing with sand paper lightly.
b. During drying of filtrate in the evaporating dish the temperature of the oven should not be kept above 98 degree C in order to avoid boiling of the sample.