LABORATORY MANUAL

Geotechnical Engineering Laboratory
(CEN01312)

DEPARTMENT OF CIVIL ENGINEERING
CENTRAL UNIVERSITY OF JHARKHAND
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List of Experiments

Visual Classification of Soil

Objective: To perform visual examination of soil samples for their field identification.

Theory: The first step in any geotechnical engineering project is to identify and describe the subsoil condition. For example, as soon as a ground is identified as gravel, engineer can immediately form some ideas on the nature of problems that might be encountered in a tunneling project. In contrast, a soft clay ground is expected to lead to other types of design and construction considerations. Therefore, it is useful to have a systematic procedure for identification of soils even in the planning stages of a project.

Soils can be classified into two general categories: (1) coarse grained soils and (2) fine grained soils. Examples of coarse-grained soils are gravels and sands. Examples of fine-grained soils are silts and clays. Procedures for visually identifying these two general types of soils are described in the following sections.

Apparatus: Magnifying glass (optional).

Procedure:

1. Identify the color (e.g. brown, gray, brownish gray), odor (if any) and texture (coarse or fine-grained) of soil.
2. Identify the major soil constituent (>50% by weight) using Table 1 as coarse gravel, fine gravel, coarse sand, medium sand, fine sand, or fines.
3. Estimate percentages of all other soil constituents using Table 1 and the following terms:
   Trace - 0 to 10% by weight
   Little - 10 to 20%
   Some - 20 to 30%
   And - 30 to 50%
   (Examples: trace fine gravel, little silt, some clay)
4. If the major soil constituent is sand or gravel:

Identify particle distribution. Describe as well graded or poorly graded. Well-graded soil consists of particle sizes over a wide range. Poorly graded soil consists of particles which are all about the same size.

Identify particle shape (angular, subangular, rounded, subrounded) using Figure 1 and Table 2.

5. If the major soil constituents are fines, perform the following tests:

   Dry strength test: Mould a sample into 1/8" size ball and let it dry. Test the strength of the dry sample by crushing it between the fingers. Describe the strength as none, low, medium, high or very high depending on the results of the test as shown in Table 3(a).

   Dilatancy Test: Make a sample of soft putty consistency in your palm. Then observe the reaction during shaking, squeezing (by closing hand) and vigorous tapping. The reaction is rapid, slow or none according to the test results given in Table 3(b). During dilatancy test, vibration dandifies the silt and water appears on the surface. Now on squeezing, shear stresses are applied on the densities silt. The dense silt has a tendency for volume increase or dilatancy due to shear stresses. So the water disappears from the surface. Moreover, silty soil has ahigh permeability, so the water moves quickly. In clay, we see no change, no shiny surface, in other words, no reaction.

   Plasticity (or Toughness) Test: Roll the samples into a threadabout 1/8" in diameter. Fold the thread and reroll it repeatedly until the thread crumbles at a diameter of 1/8". Note (a) the pressure required to roll the thread when it is near crumbling, (b)whether it can support its own weight, (c) whether it can be moulded back into a coherent mass, and (d) whether it is tough during kneading. Describe the plasticity and toughness according to the criteria in Tables 3(c) and 3(d). A low to medium toughness and non-plastic to low plasticity is the indication that the soil is silty; otherwise the soil is clayey.

Based on dry strength, dilatancy and toughness, determine soil symbol based on Table 4.

6. Identify moisture condition (dry, moist, wet or saturated) using Table 5.

7. Record visual classification of the soil in the following order: color, major constituent, minor constituents, particle distribution and particle shape (if major constituent is coarse-grained),plasticity (if major constituent is fine-grained), moisture content,soil symbol (if major constituent is fine-grained).

Examples of coarse-grained soils:

Soil 1: Brown fine gravel, some coarse to fine sand, trace silt, trace clay, well graded, angular, dry.

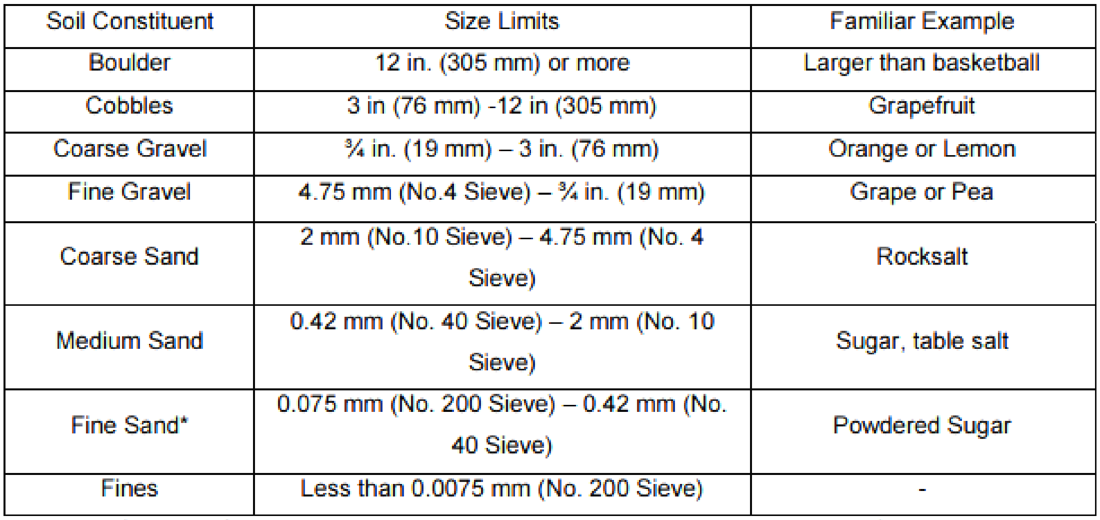
Soil 2: Gray coarse sand, trace medium to fine sand, some silt, trace clay, poorly graded, rounded, saturated.

Examples of fine-grained soils:

Soil A: Brown lean clay, trace coarse to fine sand, medium plasticity, moist, CL.

Soil B: Gray clayey silt, trace fine sand, non-plastic, saturated, ML.

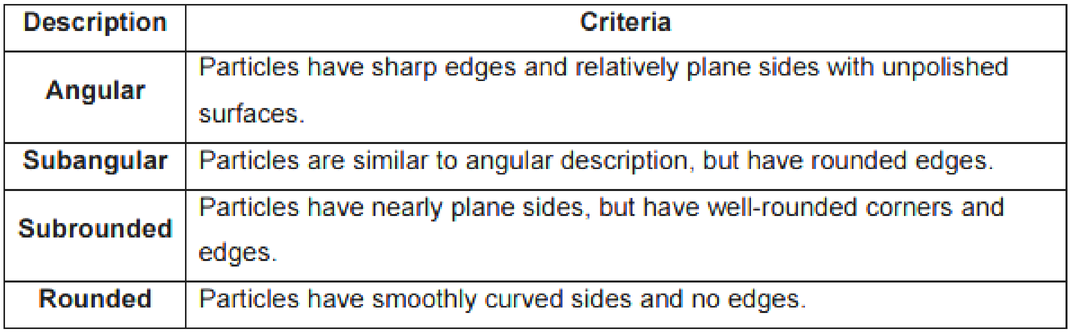
Table 1. Grain Size Distribution



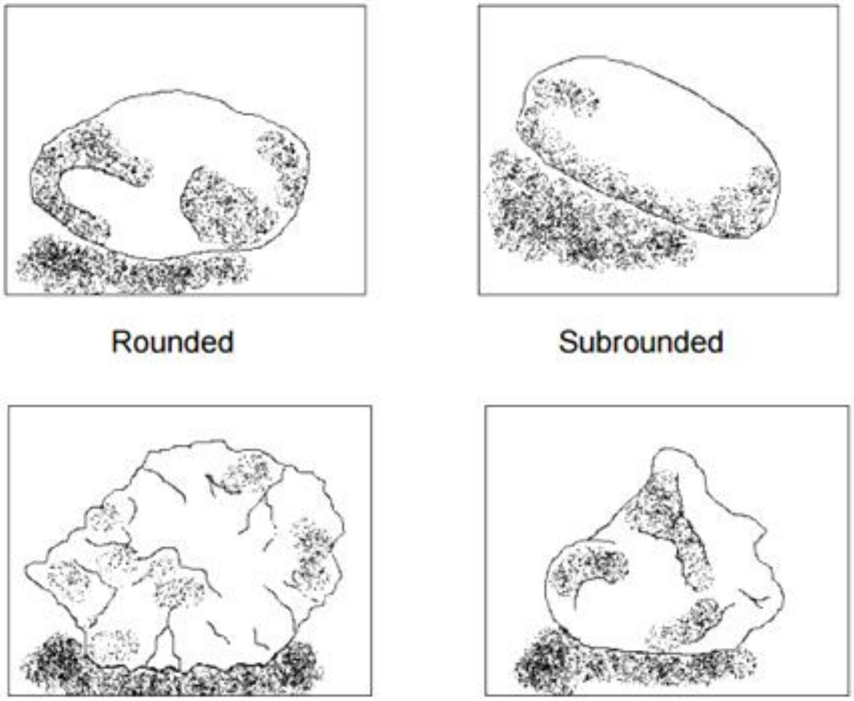
Soil Constituent	Size Limits	Familiar Example
Boulder	12 in. (305 mm) or more	Larger than basketball
Cobbles	3 in (76 mm) -12 in (305 mm)	Grapefruit
Coarse Gravel	¾ in. (19 mm) – 3 in. (76 mm)	Orange or Lemon
Fine Gravel	4.75 mm (No.4 Sieve) – ¾ in. (19 mm)	Grape or Pea
Coarse Sand	2 mm (No.10 Sieve) – 4.75 mm (No. 4 Sieve)	Rocksalt
Medium Sand	0.42 mm (No. 40 Sieve) – 2 mm (No. 10 Sieve)	Sugar, table salt
Fine Sand*	0.075 mm (No. 200 Sieve) – 0.42 mm (No. 40 Sieve)	Powdered Sugar
Fines	Less than 0.0075 mm (No. 200 Sieve)	-

*Particles finer than fine sand cannot be discerned with the naked eye at a distance of 8 in (20 cm).

Table 2. Criteria for Describing Shape of Coarse-Grained Soil Particles



Description	**Criteria**
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces.
Subangular	Particles are similar to angular description, but have rounded edges.
Subrounded	Particles have nearly plane sides, but have well-rounded corners and edges.
Rounded	Particles have smoothly curved sides and no edges.



Rounded Subrounded

Angular Subangular

Fig. 1 Shape of coarse-grained soil particles

Table (3a). Criteria for Describing Dry Strength

Description	**Criteria**
None	The dry specimen ball crumbles into powder with the slightest handling pressure.
Low	The dry specimen crumbles into powder with some pressure form fingers.
Medium	The dry specimen breaks into pieces or crumbles with moderate finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between the thumb and a hard surface.

Table (3b). Criteria for Describing Dilatancy of a Soil Sample

Description	**Criteria**
None	There is no visible change in the soil samples.
Slow	Water slowly appears and remains on the surface during shaking or water slowly disappears upon squeezing.
Rapid	Water quickly appears on the surface during shaking and quickly disappears upon squeezing.

Table (3c). Criteria for Describing Soil Plasticity

Description	**Criteria**
Non-plastic	A 1/8" (3-mm) thread cannot be rolled at any water content.
Low	The thread is difficult to roll and a cohesive mass cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll and little time is needed to reach the plastic limit. The thread cannot be re-rolled after the plastic limit is reached. The mass crumbles when it is drier than the plastic limit.
High	Considerable time is needed, rolling and kneading the sample, to reach the plastic limit. The thread can be rerolled and reworked several times before reaching the plastic limit. A mass can be formed when the sample is drier than the plastic limit

Note: The plastic limit is the water content at which the soil begins to break apart and crumbles when rolled into threads 1/8" in diameter.

Table (3d). Criteria for Describing Soil Toughness

Description	Criteria
Low	Only slight pressure is needed to roll the thread to the plastic limit. The thread and mass are weak and soft.
Medium	Moderate pressure is needed to roll the thread to near the plastic limit. The thread and mass have moderate stiffness.
High	Substantial pressure is needed to roll the thread to near the plastic limit. The thread and mass are very stiff.

Table 4. Identification of Inorganic Fine-Grained Soils

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None or Low	Slow to Rapid	Low or thread cannot be formed
CL	Medium to High	None to Slow	Medium
MH	Low to Medium	None to Slow	Low to Medium
CH	High to Very High	None	High

Note: ML = Silt; CL = Lean Clay (low plasticity clay); MH = Elastic Soil; CH = Fat Clay (high plasticity clay). The terms 'lean' and 'fat' may not be used in certain geographic regions (midwest).

Table 5. Criteria for Describing Soil Moisture Conditions

Description	Criteria
Dry	Soil is dry to the touch, dusty, a clear absence of moisture
Moist	Soil is damp, slight moisture; soil may begin to retain molded form
Wet	Soil is clearly wet; water is visible when sample is squeezed
Saturated	Water is easily visible and drains freely from the sample

You will be given ten different soil samples. Visually classify these soils. Record all information on the attached sheet.

Results:

Soil Number: ________________

Classified by: _________________

Date: _________________

1. Color __________________
2. Odor __________________
3. Texture ___________________
4. Major soil constituent: ____________
5. Minor soil constituents: ___________

Type	Approx. % by weight
__________	__________
__________	__________
__________	__________

6. For coarse-grained soils:

Gradation: ____________

Particle Shape: ____________

7. For fine-grained soils:

Dry Strength ___________

Dilatancy ___________

Plasticity ___________

Toughness ___________

Soil Symbol ___________

8. Moisture Condition: _____________

Classification:

Precautions:

1. The colour seen by one person will depend on the type of light source, the background, the size of the object and the colours that have been seen immediately before.
2. Tests to be performed should be with precision.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.
2. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.
3. *Basic and Applied Soil Mechanics* ByGopalRanjan, New Age International Publishers, 2000.

Determination of Water Content

(A) Oven Drying Method

Objective: To determine the water content of soil by oven drying method.

Standard: IS: 2720 (Part 2) – 1973, Determination of water content.

Theory: The water content (w) is also called natural water content or natural moisture content is the ratio of the weight of water to the weight of the solids in a given mass of soil. This ratio is usually expressed as percentage. The various methods to determine moisture content of soil are as follows:

1. Oven Dry Method
2. Pycnometer test
3. Sand Bath Method
4. Calcium Carbide Method
5. Rapid Moisture Meter Method

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

For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. The water content is also used in expressing the phase relationships of air, water, and solids in a given volume of soil. Soil mass is generally a three phase system. It consists of solid particles, liquid and gas. For all practical purposes, the liquid may be considered to be water (although in some cases, the water may contain some dissolved salts) and the gas as air. The phase system may be expressed in SI units either in terms of mass-volume or weight volume relationships. The inter relationships of the different phases are important since they help to define the condition or the physical make-up of the soil.

Apparatus:

1. Non-corrodible air-tight container.
2. Electric oven, maintain the temperature between 105 C to 115 C.
3. Desiccators
4. Balance of sufficient sensitivity
5. Gloves
6. Spatula

Procedure:

1. Clean the containers with lid dry it and weigh it (W_1). " Make sure you do this after you have tarred the balance"
2. Take a specimen of the sample in the container and weigh with lid (W_2).
3. Keep the container in the oven with lid removed. Dry the specimen to constant weight maintaining the temperature between 105^0 C to 110^0 C for a period varying with the type of soil but usually 16 to 24 hours.
4. Record the final constant weight (W3) of the container with dried soil sample. Peat and other organic soils are to be dried at lower temperature (say 600 C) possibly for a longer period.

Results:

1. Weight of can, W1 (g) =
2. Weight of can + wet soil W_2 (g) =
3. Weight of can + dry soil W_3 (g)=

	Sample 1	**Sample 2**	**Sample 3**
Weight of can, W1 (g)			
Weight of can + wet soil W2 (g)			
Weight of can + dry soil W3 (g)			
Water/Moisture content W (%) $\frac{W_2-W_3}{W_{3-}w_1}=$			

The Water/Moisture content, w (%) =$\frac{W_2-W_3}{W_{3-W_1}}\ x\ 100$

The natural moisture content of the soil sample is %

Precautions:

1. Weighing oven-dry specimen while still hot. The accuracy of a sensitive balance may be affected by a hot specimen container.
2. Incorrect temperature of oven.
3. Loss of moisture before weighing wet specimen and Cain of moisture before weighing oven-dry specimen.

References:

1. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.
2. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

Objective: To determine the specific gravity of soil fraction passing 4.75 mm I.S sieve by Pycnometer.

Standard: IS: 2720 (Part 3), 1980: Determination of specific gravity of soil.

Theory: The knowledge of specific gravity is needed in calculation of soil properties like void ratio, degree of saturation etc. Specific gravity G is defined as the ratio of the weight of an equal volume of distilled waters at that temperature both weights taken in air.
The Specific gravity of soil solids (Gs) is calculated using the following equation.

$$Specific\ gravity\ (G) = \frac{(w_2 - w_1)}{(w_2 - w_1) - (w_3 - w_4)}$$

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 full
Specific Gravity of given soil =

Apparatus:

1. Pycnometer
2. Balance to weigh the materials (accuracy 10gm).
3. Wash bottle with distilled water.
4. Alcohol and ether.

Procedure:

1. Clean and dry the pycnometer
    a. Wash the pycnometer with water and allow it to drain.
    b. Wash it with alcohol and drain it to remove water.
    c. Wash it with ether, to remove alcohol and drain ether.

2. Weigh the pycnometer (W_1).

3. Take about 200 gm of oven-dried soil sample which is cooled in a desiccators. Transfer it to the pycnometer. Find the weight of the pycnometer and soil (W_2).

4. Put 10ml of distilled water in the pycnometer to allow the soil to soak completely. Leave itfor about 2 hours.

5. Again fill the pycnometer completely with distilled water put the stopper and keep the pycnometer under constant temperature water baths (T ˚C).

6. Take the pycnometer outside and wipe it clean and dry it. Now determine the weight of the pycnometer and the contents (W3).

7. Now empty the pycnometer and thoroughly clean it. Fill the pycnometer with only distilled water and weigh it. Let it be W4 at temperature (T ˚C).

Results:

S. No.	Observations and calculations	1	2	3
1	Pycnometer No.			
2	Mass of empty pycnometer (M_1)			
3	Mass of pycnometer and dry soil (M_2)			
4	Mass of pycnometer, soil and water (M_3)			
5	Mass of pycnometer and water (M_4)			
6	G			

Precautions:

1. Soil grains whose specific gravity is to be determined should be completely dry.
2. If on drying soil lumps are formed, they should be broken to its original size.
3. Inaccuracies in weighing and failure to completely eliminate the entrapped air are the main sources of error. Both should be avoided.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Sieve Analysis

Objective: To perform grain size analysis of given sample of sand and determination of coefficient of uniformity and coefficient of curvature.

Standard: IS: 2720 (Part 4) 1975, Grain size analysis.

Theory: Grain size analysis is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil. The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used.

Soil gradation is a classification of a coarse-grained soil that ranks the soil based on the different particle sizes contained in the soil. Soil gradation is an important aspect of soil mechanics and geotechnical engineering because it is an indicator of other engineering properties such as compressibility, shear strength, and hydraulic conductivity. In a design, the gradation of the in situ or on site soil often controls the design and ground water drainage of the site. A poorly graded soil will have better drainage than a well graded soil. Soil is graded as either well graded or poorly graded.

Soil gradation is determined by analyzing the results of a sieve analysis or a analysis. The process for grading a soil is in accordance with either the **Unified Soil Classification System** or the **AASHTO Soil Classification System**. Gradation of a soil is determined by reading the grain size distribution curve produced from the results of laboratory tests on the soil. Gradation of a soil can also be determined by calculating the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, of the soil and comparing the calculated values with published gradation limits.

Soil gradation is a classification of the particle size distribution of a soil. Coarse-grained soils, mainly gravels or sands, are graded as either well graded or poorly graded. Poorly graded soils are further divided into uniformly-graded or gap-graded soils.

A well graded soil is a soil that contains particles of a wide range of sizes and has a good representation of all sizes from the No. 4 to No. 200 sieves.

A poorly graded soil is a soil that does not have a good representation of all sizes of particles from the No. 4 to No. 200 sieve.

A gap-graded soil is a soil that has an excess or deficiency of certain particle sizes or a soil that has at least one particle size missing.

The coefficient of uniformity, C_u is a crude shape parameter and is calculated using the following equation:

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

Where, D_{60} is the grain diameter at 60% passing, and D_{10} is the grain diameter at 10% passing

The coefficient of curvature, C_c is a shape parameter and is calculated using the following equation:

$$C_c = \frac{{D_{30}}^2}{D_{10} X D_{60}}$$

Where D_{60} is the grain diameter at 60% passing, D_{30} is the grain diameter at 30% passing, and D_{10} is the grain diameter at 10% passing.

Apparatus:

1. Balance
2. Sieves
3. Sieve shaker

The balance to be used must be sensitive to the extent of 0.1% of total weight of sample taken. Also IS 460-1962 are to use the sieves for soil tests: 4.75 mm to 75 microns.

Procedure:

1. Write down the weight of each sieve as well as the bottom pan to beused in the analysis.
2. Record the weight of the given dry soil sample.
3. Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). Place the pan below #200 sieve. Carefully pour the soil sample into the top sieve and place the cap over it.
4. Place the sieve stack in the mechanical shaker and shake for 10minutes.
5. Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

Results:

The percent retained (%), Cumulative retained (%) & percent finer (%) is calculated.

Percent retained on each sieve = Weight of retained sample in each sieve / Total weight of sample

The cumulative percent retained is calculated by adding percent retained on each sieve as a cumulative procedure.

The percent finer is calculated by subtracting the cumulative percent retained from 100 percent.

Draw graph between log sieve sizes vs. % finer. The graph is known as grading curve. Corresponding to 10%, 30% and 60% finer, obtain diameters from graph are designated as D_{10}, D_{30}, D_{60}.

The coefficient of uniformity, C_u and the coefficient of curvature, C_c are hence calculated.

IS Sieve no. or size in mm	Wt. retained on each sieve (gm)	Percentage retained on each sieve	Cumulative percentage retained on each sieve	% Finer	Remarks
4.75 4.00 3.36 2.40 1.46 1.20 0.60 0.30 0.15 0.075					

Precautions:

1. Clean the sieves set so that no soil particles were struck in them
2. While weighing put the sieve with soil sample on the balance in a concentric position.
3. Check the electric connection of the sieve shaker before conducting the test.

References:

1. Soil Mechanics Laboratory Manual by B M Das, Oxford University Press, 2012.

2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Hydrometer Analysis

Objective: To perform grain size analysis of soils by hydrometer analysis test.

Standard: IS: 2720 (Part 4) 1975, Grain size analysis.

Theory: Grain size analysis is performed to determine the percentage of different grain sizes contained within a soil. The hydrometer method is used to determine the distribution of the finer particles. For determining the grain size distribution of soil sample, usually mechanical analysis (sieve analysis) is carried out in which the finer sieve used is 63 micron or the nearer opening. If a soil contains appreciable quantities of fine fractions in (less than 63 micron) wet analysis is done. One form of the analysis is hydrometer analysis. It is very much helpful to classify the soil as per ISI classification. The properties of the soil are very much influenced by the amount of clay and other fractions.

Hydrometer analysis is based on **Stokes law**. According to this law, the velocity at which grains settles out of suspension, all other factors being equal, is dependent upon the shape, weight and size of the grain.

In case of soil, it is assumed that the soil particles are spherical and have the same specific gravity. Therefore we can say that in a soil water suspension the coarser particles will settle more quickly than the finer ones

Apparatus:

1. Hydrometer
2. Dispersion cup with mechanical stirrer with complete accessories
3. Two glass jar of 1 litre capacity
4. Deflocculating agent (sodium Hexametaphosphate solution prepared by dissolving 33g of sodium Hexametaphosphate and 7g of sodium carbonate in distilled water to make one litre solution)
5. Stop watch
6. Thermometer
7. Scale

Procedure:

1. Take about 50g in case of clayey soil 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 the 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 and the temperature T0C 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 tuck to the base of the graduated jar.
8. Immediately after shaking, place the Hydrometer jar on the table and start the stopwatch. Insert the Hydrometer into the suspension carefully and take Hydrometer readings at the total elapsed times of ¼, ½, 1 and 2 minutes.
9. After 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.

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 time elapses, because of the fall of the solid particles the density of the fluid suspension decreases reading, which should be checked as a guard against possible error in readings of the Hydrometer.

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

Results:

If the temperature during the experiment is constant, then the the following formula can be used to calculate the diameter of the soil particles

$$D^2 = KH_R/t$$

Where,

T = time in minutes

D = diameter of soil particle in mm

$$K = \frac{30N}{(G - g_w)}$$

The percentage finer N may be obtained from,

$$N(\%) = \frac{GV\ X\ 100}{(G-1)W(r - r_{w)}}$$

Where,

V = Volume of soil suspension (1000 cc)

W = weight of dry soil taken for the test

r = Hydrometer reading in distilled water

r_w = Hydrometer readings in soil suspension

G = Specific gravity of soil particles

Since V = 1000 cc, the above equation may be conveniently represented as follows:

$$N\ (\%) = K_1(R_{h1} - 1000) * 100$$

Where,

$$K_1 = \frac{G}{G-1} X \frac{100}{W}$$

$$R_{h1} = Hydrometer\ reading = R_h + C_m - C_d \pm C_t$$

Where,

R_h = actually observed hydrometer reading (upper meniscus)

C_m = the meniscus correction (i.e. 0.5)

C_t = Correction for temperature (positive if the test temperature is more than the temperature at which the hydrometer is calibrated and vice versa)

C_d = Correction for dispersing agent. This is determined as mentioned below

The addition of a dispersing agent to the soil suspension results in an increase in density of the liquid and necessitates a correction to the observed hydrometer reading. The correction factor, C_d, is determined by adding to a 1000-ml graduate partially filled with distilled or dematerialized water the amount of dispersing agent to be used for the particular test, adding additional distilled water to the 1000-ml mark, then inserting a hydrometer and observing the reading. The correction factor, C_d is equal to the difference between this reading and the hydrometer reading in pure distilled or dematerialized water.

Precautions:

1. The hydrometer shall be calibrated to determine its true depth in terms of the hydrometer reading.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Determination of Atterberg Limits

Objective: To determine the liquid limit and plastic limit of the given soil sample by Casagrande apparatus and penetrometer method.

Standard: IS: 2720 (Part 5) 1970, Determination of liquid limit and Plastic limits.
IS: 2720 (Part 6) 1972, Determination of shrinkage factors.

Theory: The definitions of the consistency limits proposed by Atterberg are not, by themselves, adequate for the determination of their numerical values in the laboratory, especially in view of the arbitrary nature of these definitions. In view of this, Arthur Casagrande and others suggested more practical definitions with special reference to the laboratory devices and methods developed for the purpose of the determination of the consistency limits. In this sub-section, the laboratory methods for determination of the liquid limit, plastic limit, shrinkage limit, and other related concepts and indices will be studied, as standardized and accepted by the Indian Standard Institution and incorporated in the codes or practice.

Liquid limit: Liquid limit (L_L or w_L) is defined as the arbitrary limit of water content at which the soil is just about to pass from the plastic state into the liquid state. At this limit, the soil possesses a small value of shear strength, losing its ability to flow as a liquid. In other words, the liquid limit is the minimum moisture content at which the soil tends to flow as a liquid.

Plastic limit: The plastic limit (PL or w_P) is the water content where soil starts to exhibit plastic behavior. A thread of soil is at its plastic limit when it is rolled to a diameter of 3 mm or begins to crumble. To improve consistency, a 3 mm diameter rod is often used to gauge the thickness of the thread when conducting the test. (AKA Soil Snake Test).

Plasticity index: Plasticity index (PI or I_P) is the range of water content within which the soil exhibits plastic properties; that is, it is the difference between liquid and plastic limits. $I_p = (LL - PL) = (w_L - w_P)$

When the plastic limit cannot be determined, the material is said to be non-plastic (NP). Plasticity index for sands is zero. For proper evaluation of the plasticity properties of a soil, it has been found desirable to use both the liquid limit and the plasticity index values.

Consistency index: Consistency index or Relative consistency (CI OR IC) is defined as the ratio of the difference between liquid limit and the natural water content to the plasticity index of a soil:

$$I_C = \frac{wL - w}{Ip}$$

Where w = natural water content of the soil (water content of a soil in the undisturbed condition in the ground).

If,

IC= 0, w = LL

IC = 1, w = PL

IC > 1, the soil is in semi-solid state and is stiff.

IC < 0, the natural water content is greater than LL, and the soil behaves like a liquid.

Liquidity index: Liquidity index (LI OR IL) or Water-plasticity ratio is the ratio of the difference between the natural water content and the plastic limit to the plasticity index:

$$I_L = \frac{w - wP}{Ip}$$

Apparatus:

1. Casagrande's liquid limit device and grooving tool
2. Spatula
3. Balance
4. Glass plate
5. Hot air oven maintained at 105 ± 10 ^{o}C
6. Moisture Containers

Procedure:

(a) For determination of liquid limit:

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

2. Distilled water is mixed to the soil thus obtained in a mixing disc to form uniform paste. The paste shall have a consistency that would require 30 to 35 drops of cup to cause closer of standard groove for sufficient length.

3. A portion of the paste is placed in the cup of Casagrande apparatus and spread into portion with few strokes of spatula.

4. Trim it to a depth of 1cm at the point of maximum thickness and return excess of soil to the dish.

5. The soil in the cup shall be divided by the firm strokes of the grooving tool along the diameter through the centre line of the follower so that clean sharp groove of proper dimension is formed.

6. Lift and drop the cup by turning crank at the rate of two revolutions per second until the two halves of soil cake come in contact with each other for a length of about 1 cm by flow only.

7. The number of blows required to cause the groove close for about 1 cm shall be recorded.

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

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

(b) For determination of plastic limit:

1. Take about 20gm of thoroughly mixed portion of the material passing through 425 micron I.S. sieve obtained in accordance with I.S. 2720 (part 1).

2. Mix it thoroughly with distilled water in the evaporating dish till the soil mass becomes plastic enough to be easily moulded with fingers.

3. Allow it to season for sufficient time (for 24 hrs) to allow water to permeate throughout the soil mass

4. Take about 10gms of this plastic soil mass and roll it between fingers and glass plate with just sufficient pressure to roll the mass into a threaded of uniform diameter throughout its length. The rate of rolling shall be between 60 and 90 strokes per minute.

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

6. Kneed the soil together to a uniform mass and re-roll.

7. Continue the process until the thread crumbles when the diameter is 3 mm.

8. Collect the pieces of the crumbled thread in air tight container for moisture content determination.

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

Results:

Natural water content of given soil =

Liquid Limit Determination

	Sample 1	**Sample 2**	**Sample 3**
Mass of can (g)			
Mass of wet soil + can (g)			
Mass of dry soil + can (g)			
Mass of dry soil (g)			
Mass of water (g)			
Water content, (%)			
No. of blows			

- A '**flow curve**' is to be plotted on a semi-logarithmic graph representing water content in arithmetic scale and the number of drops on logarithmic scale.
- The flow curve is a straight line drawn as nearly as possible through four points
- The moisture content corresponding to 25 blows as read from curve is the liquid limit of that soil.

Plastic Limit Determination

	Sample 1	**Sample 2**	**Sample 3**
Mass of can (g)			
Mass of wet soil + can (g)			
Mass of dry soil + can (g)			
Mass of dry soil (g)			
Mass of water (g)			
Water content, (%)			
No. of blows (N)			

For given soil:

1. Liquid limit =

2. Plastic limit =

Precautions:

For Liquid Limit Determination:

1. Soil used for liquid limit determination should not be oven dried prior to testing.
2. In LL test the groove should be closed by the flow of soil and not by slippage between the soil and the cup
3. After mixing the water to the soil sample , sufficient time should be given to permeate the water throughout out the soil mass
4. Wet soil taken in the container for moisture content determination should not be left open in the air, the container with soil sample should either be placed in desiccators or immediately be weighed.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Relative Density test

Objective: To determine the in situ density of natural or compacted soils using sand pouring cylinders.

Standard: IS: 2720 (part 14) 1983, Determination of density index of cohesionless soils.

Theory: Porosity of a soil depends on the shape of grain, uniformity of grain size and condition of sedimentation. Hence porosity itself does not indicate whether a soil is in loose or dense state. This information can only be obtained by comparing the porosity or void ratio of the given soil with that of the same soil in its loosest and densest possible state and hence the term, relative density (D_r) is introduced. Relative density or density index is the ratio of the difference between the void ratios of a cohesionless soil in its loosest state and existing natural state to the difference between its void ratio in the loosest and densest states.

$$D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}}$$

$$e = \frac{V_v}{V_s}$$

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow e = \frac{G\gamma_w}{\gamma_d} - 1$$

$$D_r = \frac{\dfrac{1}{\gamma_{d,min}} - \dfrac{1}{\gamma_d}}{\dfrac{1}{\gamma_{d,\min}} - \dfrac{1}{\gamma_{d,\max}}}$$

Relative density is an arbitrary character of sandy deposit. In real sense, relative density expresses the ratio of actual decrease in volume of voids in a sandy soil to the maximum possible decrease in the volume of voids i.e how far the sand under investigation can be capable to the further densification beyond its natural state. Determination of relative density is helpful in compaction of coarse grained soils and in evaluating safe bearing capacity in case of sandy soils.

Apparatus:

1. Cushioned steel vibrating deck 75 X 75 cm size, R.P.M : 3600 ; under a 115 kg load.
2. 440V, 3 phase supply.
3. Two cylindrical metallic moulds, 3000 cc and 15000 cc.
4. 10 mm thick surcharge base plate with handle separately for each mould.
5. Surcharge weights, one for each size having a weight equal to 140 gms / sq.cm.
6. Dial gauge and dial gauge holder, which can be slipped into the eyelets on the moulds sides.
7. Guide sleeves with clamps for each mould separately.
8. Balance.
9. Calibration bar 75 x 300 x 3 mm

Procedure:

Calibration of the Cylinder

1. Measure the internal dimensions (diameter, d and height, h) of the mould and compute its internal volume, $V_c = \pi d^2 h/4$.
2. Fill the mould with distilled water till over flowing takes place.
3. Slid thick glass plate over the top surface of mould.
4. Weigh the water filling the mould.
5. Calculate the volume of the mould (V) which is weight of water filling the mould /density of water.

Preparation of the Cohesionless Sample

1. Dry the soil sample in a thermostatically controlled electric oven.
2. Cool in the sample in a desicator.
3. Segregate soil lumps without breaking individual particles and sieve through the required sieve size..

Determination of Minimum Density of Soil

1. Take the weight of empty mould accurately (W).
2. Pour the dry pulverized soil into the mould through a funnel in a steady stream. The spout is adjusted so that the free fall of soil particle is always 25 mm. While pouring soil the spout must have a spiral motion from the rim to the center.

3. The process is continued to fill up the mould with soil up to about 25mm above the top. It is then leveled, with the soil and weight is recorded (W_1).

Determination of Maximum Density of Soil

1. Put the collar on top of the mould and clamp it.
2. Fill the mould with the oven dried soil sample till 1/2 or 2/3 of the collar is filled.
3. Place the mould on the vibrating deck and fix it with nuts and bolts.
4. Place the surcharge weight on it.
5. Run the vibrator for 8 minutes.
6. Weight the mould with the soil (W_2).

CALCULATION

Minimum Relative Density:

Mass of dry soil (M_s) = (W_1 – W) gm

$$\gamma_{d,\min} = \frac{V}{M_s}$$

Maximum Relative Density:

Mass of dry soil (M_s) = (W_2 – W) gm

$$\gamma_{d,\max} = \frac{V}{M_s}$$

Determination of Field Density

(A) Sand Replacement Method

Objective: To determine the in situ density of natural or compacted soils using sand replacement method

Standard: IS: 2720 (part 28) 1974, Determination of dry density of soil in-place-by sand-replacement method.

IS: 2720 (Part 29) 1975, Determination of dry density of soil in place-by the core cutter method.

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

It is very quality control test, where compaction is required, in the cases like embankment and pavement construction.

By conducting this test it is possible to determine the field density of the soil. The moisture content is likely to vary from time and hence the field density also. So it is required to report the test result in terms of dry density.

Apparatus:

10. Sand pouring cylinder
11. Calibrating can
12. Metal tray with a central hole
13. Dry sand (passing through 600 micron sieve)
14. Balance
15. Moisture content bins
16. Glass plate
17. Metal tray
18. Scraper tool

Procedure:

Calibration of the Cylinder

6. Measure the internal dimensions (diameter, d and height, h) of the calibrating can and compute its internal volume, $V_c = \pi d2h/4$.
7. Fill the sand pouring cylinder (SPC) with sand with 1 cm top clearance (to avoid any spillover during operation) and find its weight (W_1)
8. Place the SPC (sand pouring cylinder) on a glass plate, open the slit above the cone by operating the valve and allow the sand to run down. The sand will freely run down till it fills the conical portion. When there is no further downward movement of sand in the SPC, close the slit. Measure the weight of the sand required to fill the cone. Let it be W2.
9. Place back this W_2 amount of sand into the SPC, so that its weight becomes equal to W_1 (As mentioned in point-2). Place the SPC concentrically on top of the calibrating can. Open the slit to allow the sand to run down until the sand flow stops by it. This operation will fill the calibrating can and the conical portion of the SPC. Now close the slit and find the weight of the SPC with the remaining sand (W_3)**.**

Determination of Bulk Density of Soil

4. Clean and level the ground surface where the field density is to be determined
5. Place the tray with a central hole over the portion of the soil to be tested.
6. Excavate a pit into the ground, through the hole in the plate, approximately 12 cm deep (same as the height of the calibrating can). The hole in the tray will guide the diameter of the pit to be made in the ground.
7. Collect the excavated soil into the tray and weigh the soil (W)
8. Determine the moisture content of the excavated soil.
9. Place the SPC, with sand having the latest weight of W_1, over the pit so that the base of the cylinder covers the pit concentrically.
10. Open the slit of the SPC and allow the sand to run into the pit freely, till there is no downward movement of sand level in the SPC and then close the slit.
11. Find the weight of the SPC with the remaining sand (W_4).

Results:

Calibration of Unit Weight of Sand:

	Sample 1	**Sample 2**	**Sample 3**
Volume of the calibrating container, V (cm^3)			
Weight of SPC + sand, $\mathbf{W_1}$ (g)			
Weight of sand required to fill the conical portion on a flat surface, $\mathbf{W_2}$(g)			
Weight of SPC + sand (after filling calibrating can), $\mathbf{W_3}$ (g)			
Weight of sand required to fill the calibrating container, $W_c = (W_1 - W_2 - W_3)$ (g)			
Unit weight of sand, $\gamma_{sand} = (W_c)/V$ (g/cm^3)			

Determination of Density of Soil:

	Sample 1	**Sample 2**	**Sample 3**
Weight of the excavated from the pit (**W**) (g			
Weight of sand + SPC, before pouring, $\mathbf{W_1}$ (g)			
Weight of SPC after filling the hole & conical portion, $\mathbf{W_4}$ (g)			
Weight of sand in the pit$W_p = (W_1 - W_4 - W_2)$ (g)			
Volume of sand required to fill the pit$V_p = W_p/\gamma_{sand}$ (cm^3)			
Wet unit weight of the soil$\gamma_{wet} = W/V_p$ (g/cm^3)			
Dry unit weight of the soil $\gamma_{dry} = \gamma_{wet}/(1+m)$ (g/cm^3) (where '**m**' is the moisture content of soil)			

1. Bulk Density of soil:

By Sand Replacement method =

2. Dry Density of soil:

By Sand Replacement method =

Precautions:

1. If for any reason it is necessary to excavate the pit to a depth other than 12 cm, the standard calibrating can should be replaced by one with an internal height same as the depth of pit to be made in the ground.
2. Care should be taken in excavating the pit, so that it is not enlarged by levering, as this will result in lower density being recorded.
3. No loose material should be left in the pit.
4. There should be no vibrations during this test.
5. It should not be forgotten to remove the tray, before placing the SPC over the pit.

(B) Core Cutter Method

Objective: To determine the field or in-situ density or unit weight of soil by core cutter method

Theory: Field density is defined as weight of unit volume of soil present in site. That is

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

Where, γ= Density of soil, W = Total weight of soil, V = Total volume of soil

The soil weight consists of three phase system that is solids, water and air. The voids may be filled up with both water and air, or only with air, or only with water. Consequently the soil maybe dry, saturated or partially saturated. In soils, mass of air is considered to be negligible, and therefore the saturated density is maximum, dry density is minimum and wet density is in between the two.

Dry density of the soil is calculated by using equation,

$$\gamma_d = \frac{\gamma b}{1+w}$$

Where, γ_d=dry density of soil, γ_b=Wet density of soil,w = moisture content of soil.

Apparatus:

1. Cylindrical core cutter
2. Steel rammer
3. Steel dolly
4. Balance of capacity 5 Kg and sensitivity 1 gm.
5. Balance of capacity 200 gms and sensitivity 0.01 gms.
6. Scale
7. Spade or pickaxe or crowbar
8. Trimming Knife
9. Oven
10. Water content containers
11. Desiccators.

Procedure:

1. Measure the height and internal diameter of the core cutter.
2. Weight the clean core cutter.
3. Clean and level the ground where the density is to be determined.
4. Press the cylindrical cutter into the soil to its full depth with the help of steel rammer.
5. Remove the soil around the cutter by spade.
6. Lift up the cutter.
7. Trim the top and bottom surfaces of the sample carefully.
8. Clean the outside surface of the cutter.
9. Weight the core cutter with the soil.
10. Remove the soil core from the cutter and take the representative sample in the water content containers to determine the moisture content.

Results:

Determination of Unit Weight of Soil:

	Sample 1	Sample 2	Sample 3
Mass of Core Cutter, W_1 (gm)			
Mass of Cutter+soil from field W_2 (gm)			
Wet Density (gm/cm3) $\gamma_b=\frac{W_2-W_1}{V}$			
Dry Density (gm/cm3) $\gamma_d=\frac{\gamma_b}{1+w}$			

Water Content Determination:

	Type 1	Type 2	Type 3
Weight of can, W_1 (g)			
Weight of can + wet soil W_2 (g)			
Weight of can + dry soil W_3 (g)			
Water/Moisture content, w (%) $\frac{W_2-W_3}{W_{3-W_1}}$			

Internal diameter of cutter (cm): __________

Height of the cutter (cm): __________

Cross sectional area of the cutter (cm^2): __________

Volume of the cutter, V (cm^3): __________

1. Bulk Density of soil:

By Core Cutter Method =

2. Dry Density of soil:

By Core Cutter Method =

Precautions:

1. Steel dolly should be placed on the top of the cutter before ramming it down into the ground.
2. Core cutter should not be used for gravels, boulders or any hard ground.
3. Before removing the cutter, soil should be removed around the cutter to minimize the disturbances.
4. While lifting the cutter, no soil should drop down.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.
2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Proctor Test

Objective: To determine the compaction characteristics of a soil specimen by Proctor's test.

Standards: IS: 2720 (Part 7) 1983, Determination of water content-Dry density relation using light compaction

IS: 2720 (Part 8) 1983, Determination of water content-Dry density relation using heavy compaction.

Theory: Compaction is the process of densification of soil by reducing air voids. The degree of compaction of a given soil is measured in terms of its dry density. The dry density is maximum at the optimum water content. A curve is drawn between the water content and the dry density to obtain the maximum dry density and the optimum water content.

$$Dry\ density = \frac{M/V}{1+w}$$

Where M = total mass of soil; V = volume of soil; and w = water content

Two types of compaction tests are routinely performed: (1) Standard proctor test (2) Modified proctor test. IS: 2720 (Part 7) recommends the mould size of 100 mm diameter and 127.3 mm height. The rammer recommended is of 2.6 kg mass with a free drop of 310 mm and a face diameter of 50 mm. The soil is compacted in three layers. The mould is fixed to detachable base plate. The collar is of 60 mm height. If the percentage of soil retained on 4.75 mm sieve is more than 20%, a large mould of internal diameter 150 mm, effective height of 127.3 mm and capacity 2250 ml is recommended. In case of standard compaction test, soil is compacted by 25 blows of the rammer, with a free fall of 310 mm. in the modified proctor test the rammer used is much heavier and has greater drop than that in the standard proctor test. Its mass is 4.89 kg and free drop is 450 mm.

Apparatus: compaction mould, Rammer, Detachable base plate, collar, Is sieve 4.75 mm, Oven, Desiccators, Weighing balance, Large mixing pan, Straight edge, Spatula, Graduated jar, Mixing spoons, Trowels.

Procedure:

1. Take a representative oven-dried sample, approximately 5 kg in the given pan. Thoroughly mix the sample with sufficient water to dampen it to approximately four to six percentage points below optimum moisture content.
2. Weigh the proctor mould without base plate and collar. Fix the collar and base plate. Place the soil in the Proctor mould and compact it in 3 layers giving 25 blows per layer with the 2.5 kg rammer falling through in case of standard proctor test. In case of modified proctor test rammer of weight 4.89 kg should be used and free drop should be 450 mm. The soil is compacted in five equal layers, each layer is given 25 blows.
3. Remove the collar, trim the compacted soil even with the top of the mould by means of the straight edge and weigh.
4. Divide the weight of the compacted specimen by 1000 cc and record the result as the wet weight γ_{wet} in grams per cubic centimeter of the compacted soil.
5. Remove the sample from the mould and slice vertically through and obtain a small sample for moisture determination.
6. Thoroughly break up the remainder of the material until it will pass a no.4 sieve as judged by the eye. Add water in sufficient amounts to increase the moisture content of the soil sample by one or two percentage points and repeat the above procedure for each increment of water added. Continue this series of determination until there is either a decrease or no change in the wet unit weight of the compacted soil.

Results:

Diameter of mould =

Height of mould =

Volume of mould =

Specific gravity of solids =

S. No.	Observations	1	2	3	4	5
1	Mass of empty mould + base plate					
2	Mass of mould + base plate + compacted soils					

3	Mass of compacted soil					
4	Bulk density, ρ					
5	Water content, w					
6	Dry density, ρ_d					
7	Void ratio, e					
8	Dry density at 100% saturation					
9	Degree of saturation, S					

- Maximum dry density (From compaction curve) =
- Optimum moisture content (%) =

Precautions:

1. Carefully handle instruments, especially rammer.
2. Oven dry soil sample should be used. Otherwise initial water content should be measured.

References:

1. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.
2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.
3. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

Unconfined Compression Test

Objective: To determine the unconfined compressive strength of cohesive soil.

Standard: IS: 2720 (Part 10) 1973, Determination of Unconfined compressive Strength.

Theory: The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (q_u) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test.

For soils, the undrained shear strength (s) is necessary for the determination of the bearing capacity of foundations, dams, etc. The undrained shear strength (s) of clays is commonly determined from an unconfined compression test. The undrained shear strength (s) of a cohesive soil is equal to one-half the unconfined compressive strength (q_u) when the soil is under the Ø = 0 condition (Ø = the angle of internal friction). The most critical condition for the soil usually occurs immediately after construction, which represents undrained conditions, when the undrained shear strength is basically equal to the cohesion (c).This is expressed as:

$$S = c = 2q_u$$

Apparatus: Compression device, Load and deformation dial gauges, Sample trimming equipment, Balance, Moisture can

Sample Preparation

A. Undisturbed specimen

1. Note down the sample number, bore hole number and the depth at which the sample was taken.
2. Remove the protective cover (paraffin wax) from the sampling tube.
3. Place the sampling tube extractor and push the plunger till a small length of sample moves out.

4. Trim the projected sample using a wire saw.
5. Again push the plunger of the extractor till a 75 mm long sample comes out.
6. Cutout this sample carefully and hold it on the split sampler so that it does not fall.
7. Take about 10 to 15 g of soil from the tube for water content determination.
8. Note the container number and take the net weight of the sample and the container.
9. Measure the diameter at the top, middle, and the bottom of the sample and find the average and record the same.
10. Measure the length of the sample and record.
11. Find the weight of the sample and record.

B. Moulded specimen

1. For the desired water content and the dry density, calculate the weight of the dry soil W_s required for preparing a specimen of 3.8 cm diameter and 7.5 cm long.
2. Add required quantity of water W_w to this soil.
3. Mix the soil thoroughly with water.
4. Place the wet soil in a tight thick polythene bag in a humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
5. After 24 hours take the soil from the humidity chamber and place the soil in a constant volume mould, having an internal height of 7.5 cm and internal diameter of 3.8 cm.
6. Place the lubricated moulded with plungers in position in the load frame.
7. Apply the compressive load till the specimen is compacted to a height of 7.5 cm.
8. Eject the specimen from the constant volume mould.
9. Record the correct height, weight and diameter of the specimen

Procedure:

1. Take two frictionless bearing plates of 75 mm diameter.
2. Place the specimen on the base plate of the load frame (sandwiched between the end plates).
3. Place a hardened steel ball on the bearing plate.
4. Adjust the center line of the specimen such that the proving ring and the steel ball are in the same line.

5. Fix a dial gauge to measure the vertical compression of the specimen.
6. Adjust the gear position on the load frame to give suitable vertical displacement.
7. Start applying the load and record the readings of the proving ring dial and compression dial for every 5 mm compression.
8. Continue loading till failure is complete.
9. Draw the sketch of the failure pattern in the specimen.

Results:

Initial length of the specimen, L_o =

Initial diameter of the specimen, D_o =

Initial area of the specimen, A_o =

Initial volume of the specimen, V_o =

Mass of split mould + specimen =

Mass of empty split mould =

Mass of the specimen, M =

Water content, w =

Specific gravity, G =

Bulk density, ρ =

Dry density, ρ_d=

Void ratio, e =

Degree of saturation, S =

S. No.	Elapsed time	Dial gauge reading	Deformation (ΔL)	Proving ring reading	Load (P)	Strain (ε)	Corrected area (A)	Compressive stress (σ)

- Plot curve between the compressive stress as ordinate and axial strain as abscissa.

- Shear strength, $s = q_u/2$

Precautions:

1. Minimum three samples should be tested.
2. Strain rate should be selected in such a manner that undrained condition should be achieved.

References:

1. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.
2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.

Direct Shear Test

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

Standard: IS: 2720 (Part 39) 1977, Direct Shear Test for Soils containing gravel, laboratory Test.

Theory: The direct shear test is one of the oldest strength tests for soils. In this laboratory, a direct shear device will be used to determine the shear strength of a cohsionless soil (i.e. angle of internal friction (Ø). From the plot of the shear stress versus the horizontal displacement, the maximum shear stress is obtained for a specific vertical confining stress. After the experiment is run several times for various vertical-confining stresses a plot of the maximum shear stress versus the vertical (normal) confining stresses for each of the tests is produced. From the plot a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, Ø may be determined and for cohesionless soils (c = 0), the shear strength can be computed from the following equation:

$$S = \sigma \tan \text{Ø}$$

Here, S = shear strength of soil

σ = normal shear strength

Ø = angle of internal friction

Schematic diagram of test setup for the direct shear test is shown in Fig. 1. It consists of the two shear box. It can be connected with loading pad to apply normal load. Proving ring should be attached with the upper shear box to measure the searing load. Dial gauge should be attached with the lower shear box to measure the horizontal displacement. At the top one additional dial gauge should be attached to measure the vertical displacement.

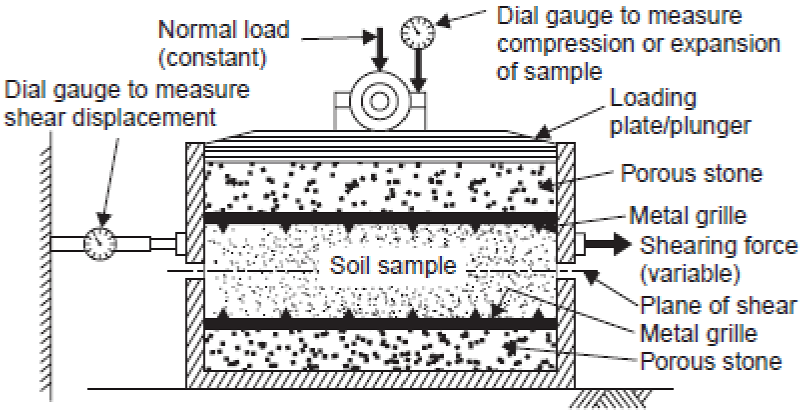


Fig. 1 Test setup of the direct shear test

Apparatus: Direct shear device, Load and deformation dial gauges, Balance

Procedure:

1. Check the inner dimension of the soil container.
2. Put the parts of the soil container together
3. Calculate the volume of the container. Weigh the container.
4. Place the soil in smooth layers (Approximately 10 mm thick). If a dense sample is desired tamp the soil.
5. Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
6. Make the surface of the soil plane.
7. Put the upper grating on the stone and loading block on the top of soil.
8. Measure the thickness of the soil specimen.
9. Apply the desired normal load.
10. Remove the shear pin.
11. Attach the dial gauge which measures the change of volume.
12. Record the initial reading of the dial gauge and calibration values.
13. Before proceeding to test check all adjustment to see that there is no correction between two parts except sand/ soil.
14. Start the motor. Take the reading of the shear force and record the reading.

15. Take volume change readings till failure.
16. Add normal stress 0.5 kg/cm^2 and continue the experiment till failure.
17. Record carefully all the readings. Set the dial gauges zero, before starting the experiment.

Results:

Normal stress = 0.5 kg/cm^2, L.C. = ……., P.R.C. = ……..

Horizontal Gauge Reading (1)	Vertical Gauge Reading (2)	Proving Ring Reading (3)	Horizontal Dial Gauge Reading Initial Reading Div. Gauge (4)	Shear deformation col. (4) x Least count of dial gauge (5)	Vertical Gauge Reading Initial Reading (6)	Vertical Deformation = Div. in Col. (6) (7)	Proving reading initial reading (8)	Shear stress = div.col.(8)x proving ring constant Area of the specimen(kg/cm^2) (9)

Normal stress = 1 kg/cm^2, L.C. = ……., P.R.C. = ……..

Horizontal Gauge Reading (1)	Vertical Gauge Reading (2)	Proving Ring Reading (3)	Horizontal Dial Gauge Reading Initial Reading Div. Gauge (4)	Shear deformation col. (4) x Least count of dial gauge (5)	Vertical Gauge Reading Initial Reading (6)	Vertical Deformation = Div. in Col. (6) (7)	Proving reading initial reading (8)	Shear stress = div.col.(8)x proving ring constant Area of the specimen(kg/cm^2) (9)

Normal stress = 1.5 kg/cm^2, L.C. = ……., P.R.C. = ……..

Horizontal Gauge Reading (1)	Vertical Gauge Reading (2)	Proving Ring Reading (3)	Horizontal Dial Gauge Reading Initial Reading Div. Gauge (4)	Shear deformation col. (4) x Least count of dial gauge (5)	Vertical Gauge Reading Initial Reading (6)	Vertical Deformation = Div. in Col. (6) (7)	Proving reading initial reading (8)	Shear stress = div.col.(8)x proving ring constant Area of the specimen(kg/cm^2) (9)

Calculation:

Proving Ring Constant…..

Least count of the dial…..

Dimension of shear box 60 mm x 60 mm

Empty weight of shear box….

Least count of dial gauge…..

Volume change…..

S.No.	Normal Load (kg)	Normal stress (kg/cm^2) Load x Area	Shear stress proving Ring reading x calibration area of container
1 2 3			

Precautions:

1. To achieve particular density of soil, vibration or tamping method should be used.
2. Pin connect upper shear box and lower shear box should carefully removed.
3. The direction of the groove of the upper and lower plate should be perpendicular to the direction of shearing.

References:

4. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.
5. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006

Triaxial Shear Test

Objective: To find out shear strength parameters of soil through Undrained Triaxial Test.

Standard: IS: 2720 (Part 11), Determination of shear strength parameters of soils from unconsolidated-undrained triaxial compression test without measurement of pore water pressure.

Theory: A. Casagrande developed the triaxial test in the course of his research aimed at removing the disadvantages of the direct shear test. The triaxial test is most versatile of all the shear testing methods. Drainage condition can be controlled, whatever be the type of soil. For example, even while pervious soils can be tested under undrained conditions; saturated soils of low permeability can be tested under drained conditions. In the triaxial test, pore water pressure measurements can be mad accurately. Volume changes can also be measured. There is no rotation of the principal stresses during the test. The stress distribution on the failure plane is fairly uniform. The test is carried out on a cylindrical specimen of soil, usually having length to diameter ratio of 2. The usual sizes are 76 mm x 38 mm and 100 mm x 50 mm. The triaxial test is carried out in two stages. In the first stage, a cell pressure is applied to the sample, sucjecting it only to normal stresses. As soon as the cell pressure is applied, a pore water pressure of equal magnitude builds up in a saturated soil. The drainage line valve can be kept either open or closed. If it is kept open, pore water will drain out of the soil, pore water pressure dissipation shall occur and soil will eventually be consolidated under an effective stress equal to the applied cell pressure. If the drainage line is closed, the soil remains unconsolidated and no volume change takes place. During the second stage of the test, when the additional axial stress is applied, shear stress is induced in soil. The resulting pore water pressure is not equal to the applied additional axial stress and may even be negative, under certain conditions. Again in the second stage, the test can be conducted under two conditions of drainage. The sample tested failure without allowing pore water pressure to dissipate, which is under undrained conditions. Alternatively, water may be allowed to drain out of the sample or to flow into the sample with the dissipation of pore water pressure that is drained conditions.

Test in which drainage is not permitted during any stage is known as Unconsolidated-Undrained test (UU test). It is also quick test. Schematic diagram of triaxial test setup is shown in Fig. 1. The apparatus consists of a Lucite or Perspex cylindrical cell, called triaxial cell.

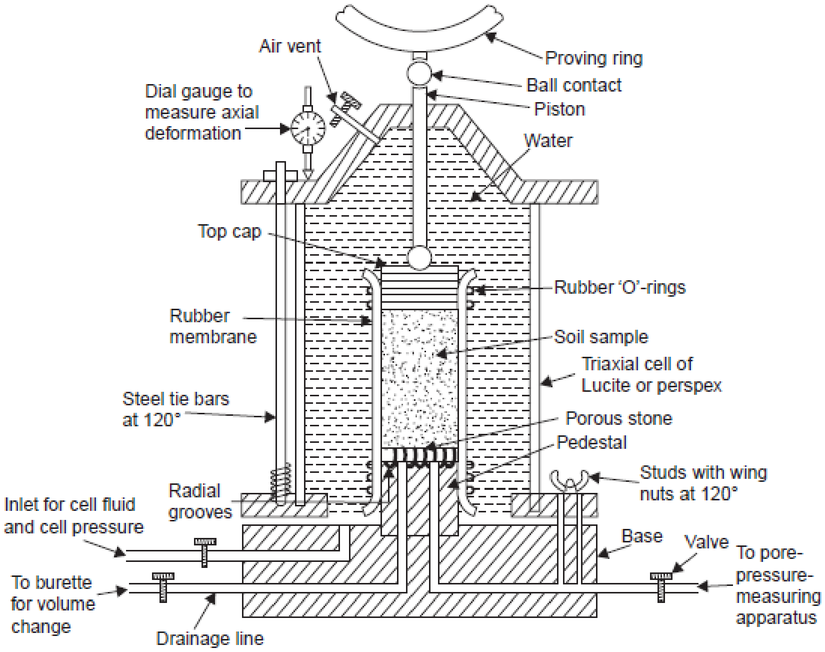


Fig.1 Schematic diagram of Triaxial Test Cell.

Apparatus: Triaxial test setup, Sample tube, Rubber membrane, O-rings, Moisture content test apparatus, stop clock, balance, Proving ring and dial gauges

Procedure:

1. The sample is placed in the compression machine and a pressure plate is placed on the top. Care must be taken to prevent any part of the machine or cell from jogging the sample while it is being setup, for example, by knocking against this bottom of the loading piston. The probable strength of the sample is estimated and a suitable proving ring selected and fitted to the machine.
2. The cell must be properly set up and uniformly clamped down to prevent leakage of pressure during the test, making sure first that the sample is properly sealed with its end

caps and rings (rubber) in position and that the sealing rings for the cell are also correctly placed.

3. When the sample is setup water is admitted and the cell is fitted under water escapes from the beed valve, at the top, which is closed. If the sample is to be tested at zero lateral pressure water is not required.
4. The air pressure in the reservoir is then increased to raise the hydrostatic pressure in the required amount. The pressure gauge must be watched during the test and any necessary adjustments must be made to keep the pressure constant.
5. The handle wheel of the screw jack is rotated until the underside of the hemispherical seating of the proving ring, through which the loading is applied, just touches the cell piston.
6. The piston is then removed down by handle until it is just in touch with the pressure plate on the top of the sample, and the proving ring seating is again brought into contact for the begging of the test.

Results:

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

Operator:	Sample No:
Date :	Job :
Location :	Size of specimen :
Length :	Proving ring constant :
Diameter : 3.81 cm	Initial area L:
Initial Volume :	Strain dial least count (const) :

Cell Pressure (kg/cm^2)	Dial gauge reading	Strain (%)	Proving ring reading	Load on sample (Kg)	Corrected area (A)	Stress (kPa)
0.5						
1						
1.5						

- Draw stress-strain curve to obtained stress at failure
- Also draw failure envelope and Mohr's circle by the help of σ_1 and σ_3.

Sample No.	Cell pressure, σ_3(kPa)	Deviator stress, σ_d(kPa)	Strain at failure (%)	Shear strength (kPa)
1 2 3				

Cohesion intercept = ……..

Precautions:

1. For fully saturated soil in case of UU test failure envelope will be parallel to the normal stress axis.
2. Sample should be properly sealed to prevent form the water present in the cell of triaxial.
3. For undrained test no need of measurement of volume changes and pore water pressure.

References:

1. *Basic and Applied Soil Mechanics* ByGopalRanjan, New Age International Publishers, 2000.
2. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.

Vane Shear Test

Objective: To find shear strength of a given soil specimen by laboratory Vane Shear Test.

Standard Reference: IS: 2720 (Part 30) 1980, Laboratory Vane Shear Test.

Theory: The structural strength of soil is basically a problem of shear strength. Vane shear test is a useful method of measuring the shear strength of clay. It is a cheaper and quicker method. The test can also be conducted in the laboratory. The laboratory vane shear test for the measurement of shear strength of cohesive soils is useful for soils of low shear strength (less than 0.3 kg/cm^2) for which triaxial or unconfined tests cannot be performed. The test gives the undrained strength of the soil. The undisturbed and remoulded strength obtained are useful for evaluating the sensitivity of soil. The vane shear test apparatus consists of a vertical steel rod having four thin stainless steel blades fixed at its bottom end (Fig. 1). The diameter and length of rod is recommended as 2.5 mm and 60 mm respectively. In this test it is assumed that shear strength (s) of the soil is constant on cylindrical sheared surface and at the top and bottom faces of the sheared cylinder. The torque applied (T) must be equal to the sum of the resisting torque at the sides (T1) and at the top and bottom (T2). Shear strength of the soil can be written as below.

$$s = \frac{T}{\pi(\frac{D^2H}{2} + \frac{D^3}{6})}$$

The shear strength of soil under undrained conditions is equal to the apparent cohesion c_u.

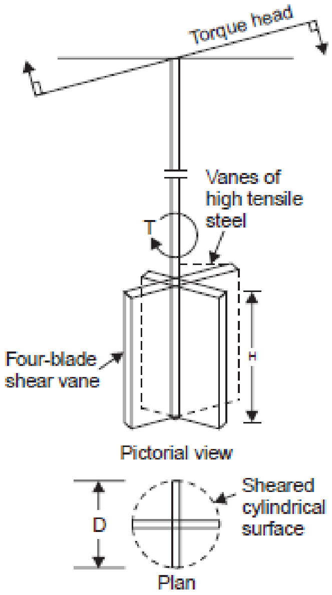


Fig. 1 vane shear apparatus

Apparatus: Vane shear apparatus, Specimen container, Callipers

Procedure:

1. Prepare two or three specimens of the soil sample of dimensions of at least 37.5 mm diameter and 75 mm length in specimen.(L/D ratio 2 or 3).
2. Mount the specimen container with the specimen on the base of the vane shear apparatus. If the specimen container is closed at one end, it should be provided with a hole of about 1 mm diameter at the bottom.
3. Gently lower the shear vanes into the specimen to their full length without disturbing the soil specimen. The top of the vanes should be atleast 10 mm below the top of the specimen. Note the readings of the angle of twist.
4. Rotate the vanes at an uniform rate say 0.1^o/s by suitable operating the torque application handle until the specimen fails.
5. Note the final reading of the angle of twist.
6. Find the value of blade height in cm.
7. Find the value of blade width in cm.

Results:

Height of blade =

Width of blade =

Spring constant =

S. No.	Initial Reading (Deg)	Final Reading (Deg.)	Difference (Deg.)	T=Spring Constant/180x Difference Kg-cm	Shear strength (S)

Average shear strength of soil = …….

Precautions:

1. This test is useful when the soil is soft and its water content is nearer to liquid limit.
2. To get cohesion of soil test should be conducted in undrained condition.

References:

1. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.
2. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

Permeability Test

A. Constant-Head Permeability Test

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

Standards: IS: 2720 (Part 36), 1975, Laboratory Determination of Permeability of Granular Soils (Constant Head).

Theory: The coefficient of permeability is equal to the rate of flow of water through a unit cross-sectional area under a unit hydraulic gradient. In the constant head permeameter, the head causing flow through the specimen remains constant throughout the test. The coefficient of permeability (k) is obtained from the relation

$$k = \frac{qL}{Ah} = \frac{QL}{Aht}$$

Where q = discharge; Q = total volume of water; t = time period; h = head causing flow; L = length of specimen; A = cross-sectional area.

Apparatus: Permeameter mould, Detachable collar, Dummy plate, drainage base, drainage cap, compaction equipment, vaccum pump, constant-head collecting chamber, stop watch, large funnel, Thermometer, Weighing balance, Filter paper.

Preparation of specimen for testing

A. Undisturbed soil sample

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

B. Disturbed soil sample

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

8. After completion of a compaction the collar and excess soil are removed.
9. Find the weight of mould with sample.
10. Place the mould with sample in the permeameter, with drainage base and cap having discs that are properly saturated.

Procedure:

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

Results:

Details of sample

Diameter of specimen =

Length of specimen (L) =

Area of specimen (A) =

Specific gravity of soil G_s =

Volume of specimen (V) =

Weight of dry specimen (W_s) =

Moisture content =

Experiment No**.**	1	2	3	4

Length of specimen, L(cm)				
Area of specimen, A (cm^2)				
Time t (s)				
Discharge(cm^3)				
Height of water (cm)				
Temperature (^{o}c)				
Coefficient of permeability (cm/s)				

Average coefficient of permeability =

B Falling-Head Permeability Test

Objective: To determine the coefficient of permeability of the given soil sample, using falling head method.

Theory: The variable-held permeameter is used to measure the permeability of relatively less pervious soils. The coefficient of permeability is given by

$$k = \frac{2.303aL}{At} log_{10}^{(\frac{h_1}{h_2})}$$

Where h_1 = initial head; h_2 = final head; t = time interval; a = cross sectional area of the stand pipe, A = cross-sectional area of the specimen, L = length of specimen.

Apparatus: Permeameter with its accessories, Balance to weigh up to 1 gm, Stop watch, Meter scale, Trimming knife.

Preparation of specimen for testing

A. Undisturbed soil sample

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

B. Disturbed soil sample

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

Preparation of statically compacted (disturbed) specimen.

1. Take 800 to 1000 gms of representative soil and mix with water to O.M.C determined by I.S Light Compaction test. Then leave the mix for 24 hours in an airtight container.
2. Take desire weight of soil.
3. Now, assemble the permeameter for static compaction. Attach the 3 cm collar to the bottom end of 0.3 liters mould and the 2 cm collar to the top end. Support the mould assembly over 2.5 cm end plug, with 2.5 cm collar resting on the split collar kept around the 2.5 cm- end plug. The inside of the 0.3 lit. Mould is lightly greased.

4. Put the weighed soil into the mould. Insert the top 3 cm end plug into the top collar, tamping the soil with hand.
5. Keep, now the entire assembly on a compressive machine and remove the split collar. Apply the compressive force till the flange of both end plugs touches the corresponding collars. Maintain this load for 1 mt and then release it.
6. Then remove the top 3 cm plug and collar place a filter paper on fine wire mesh on the top of the specimen and fix the perforated base plate.
7. Turn the mould assembly upside down and remove the 2.5 cm end plug and collar. Place the top perforated plate on the top of the soil specimen and fix the top cap on it, after inserting the seating gasket.
8. Now the specimen is ready for test.

Preparation of Dynamically Compacted Disturbed sample

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

Procedure:

1. Prepare the soil specimen as specified.
2. Saturate it. Desired water is preferred.
3. Assemble the permeameter in the bottom tank and fill the tank with water.

4. Inlet nozzle of the mould is connected to the stand pipe. Allow some water to flow until steady flow is obtained.
5. Note down the time interval t for a fall of head in the stand pipe h.
6. Repeat step 5 three times to determine t for the same head.
7. Find a by collecting q for the stand pipe. Weigh it correct to 1 gm and find a from q/h=a.

Results:

Details of sample

Diameter of specimen =

Length of specimen(L) =

Area of specimen (A) =

Specific gravity of soil G_s =

Volume of specimen (V) =

Weight of dry specimen (W_s) =

Moisture content =

Area of stand pipe = Experiment No.	1	2
Initial reading of stand pipe Final reading of stand pipe Time Test temperature Coefficient of permeability at T		

Coefficient of permeability at 27^o C		

Coefficient of permeability = …..

Precaution:

1. During test there should be no volume change in the soil, there should be no compressible air present in the voids of soil i.e. soil should be completely saturated. The flow should be laminar and in a steady state condition.

References:

1. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.

2. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.

Consolidation Test

Objective: To determine the consolidation characteristics of a soil sample.

Standards: IS: 2720 (Part 15) 1986, Determination of Consolidation Properties.

Theory: Consolidation of a saturated soil occurs due to expulsion of water under static, sustained load. The consolidation characteristics of soils are required to predict the magnitude and the rate of settlement. The following characteristics are obtained from the consolidation test. The consolidation is required to determine the magnitude and rate of volume decrease that a laterally confined soil specimen undergoes when subject to different vertical pressures. From the measured data, the consolidation curve (pressure-void ratio relationship) can be plotted. This data is useful in determining the compression index, the recompression index and the pre-consolidation pressure (or maximum past pressure) of the soil. In addition, the data obtained can also be used to determine the coefficient of consolidation and coefficient of secondary compression of the soil. The consolidation properties determined from the consolidation test are used to estimate the magnitude and the rate of both primary and secondary consolidation settlement of a structure or an earth fill. Estimates of this type are of key importance in the design of engineered structures and the evaluation of their performance.

Coefficient of compressibility, a_v =
Coefficient of volume change m_v =
Compression index, C_c =
Coefficient of consolidation C_v=

Apparatus: Consolidation device (including ring, porous stones, water reservoir and load plate), dial gauge, sample trimming device, glass plate, metal straight edge, clock moisture can, filter paper.

Preparation of sample:

1. For undisturbed sample the sample from the sample tube should be ejected in to the consolidation ring. The sample should project about one cm from outer ring. Trim the sample smooth and flush with top and bottom of the ring by using a knife. Clean the ring from outside and keep it ready from weighting.
2. Remoulded sample:
    a. Choose the density and water content at which has to be compacted from the moisture density relationship.
    b. Calculate the quantity of soil and water required to mix and comp act
    c. Compact the specimen in compaction mould in three layers using the standard rammers.
    d. Eject the specimen from the mould using the sample extractor.

Procedure:

1. Saturate two porous stones either by boiling in distilled water about 15 minute or by keeping them submerged in the distilled water for 4 to 8 hrs. Wipe away excess water. Fittings of the consolidometer which is to be enclosed shall be moistened.

2. Assemble the consolidometer, with the soil specimen and porous stones at top and bottom of specimen, providing a filter paper between the soil specimen and porous stone. Position the pressure pad centrally on the top porous stone.
3. Mount the mould assembly on the loading frame, and center it such that the load applied is axial.
4. Position the dial gauge to measure the vertical compression of the specimen. The dial gauge holder should be set so that the dial gauge is in the begging of its releases run, allowing sufficient margin for the swelling of the soil, if any.
5. Connect the mould assembly to the water reservoir and the sample is allowed to saturate. The level of the water in the reservoir should be at about the same level as the soil specimen.
6. Apply an initial load to the assembly. The magnitude of this load should be chosen by trial, such that there is no swelling. It should be not less than 50 g/cm^3 for ordinary soils & 25 g/cm^2 for very soft soils. The load should be allowed to stand until there is no change in dial gauge readings for two consecutive hours or for a maximum of 24 hours.
7. Note the final dial reading under the initial load. Apply first load of intensity 0.1 kg/cm^2 start the stop watch simultaneously. Record the dial gauge readings at various time intervals. The dial gauge readings are taken until 90% consolidation is reached. Primary consolidation is gradually reached within 24 hrs.
8. At the end of the period, specified above take the dial reading and time reading. Double the load intensity and take the dial readings at various time intervals. Repeat this procedure fir successive load increments. The usual loading intensity are as follows :

    a. 0.1, 0.2, 0.5, 1, 2, 4 and 8 kg/cm^2

9. After the last loading is completed, reduce the load to of the value of the last load and allow it to stand for 24 hrs. Reduce the load further in steps of the previous intensity till an intensity of 0.1 kg/cm^2 is reached. Take the final reading of the dial gauge.
10. Reduce the load to the initial load, keep it for 24 hrs and note the final readings of the dial gauge.
11. Quickly dismantle the specimen assembly and remove the excess water on the soil specimen in oven, note the dry weight of it.

Results:

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

Project : Name of the project

Borehole no. :

Depth of the sample : 2m

Description of soil :

Empty weight of ring : 635 gm

Area of ring : 4560 mm^2 (45.60 cm^2)

Diameter of ring : 76.2 mm (7.62 cm)

Volume of ring : 115.82 cm^3

Height of ring : 25.4 (2.54 cm)

Specific gravity of soil sample No:

Dial Gauge = 0.0127 mm (least count)

Pressure intensity (kg/cm^2)	0.1	0.2	0.5	1	2	4	8
Elapsed time 0.25 1 2.5 4 6.25 9 16 25 30 1 hr							

2 hr							
4 hr							
8 hr							
24 hr							

Observation Sheet for Consolidation Test: Pressure Voids Ratio

Applied pressure	Final dial reading	Dial change	Specimen height	Height of solids	Height of voids	Void ratio
0						
0.1						
0.2						
0.5						
1						
2						
4						
8						
4						
2						
1						
0.5						
0.2						
0.1						

Height of solids (H_S) is calculated from the equation

$$H_s = \frac{W_s}{GA}$$

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

$$e = \frac{H-H_S}{H_S}$$

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

i. $C_V = 0.197\frac{d^2}{t_{50}}$ (Log fitting method)

ii. $C_V = 0.848\frac{d^2}{t_{90}}$ (Square fitting method)

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

In the square root fitting method, a plot is made between dial readings and square root of time and the time corresponding to 90% consolidation is determined. The values of C_v are recorded in table.

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

5. Coefficient of compressibility. It is calculated as follows

$$a_v = 0.435\frac{C_c}{avg. pressure\ for\ the\ increment}$$

where C_c = Coefficient of compressibility

7. **Coefficient of permeability.** It is calculated as follows

$$K = \frac{C_v a_v (unit\ weight\ of\ water)}{1 + e}$$

Graphs

1. Dial reading Vs log of time or

Dial reading Vs square root of time.

2. Voids ratio Vs logσ (average pressure for the increment).

Precautions:

1. Soil should be saturated before application of load.
2. To minimize the friction resistance between the rmould wall and soil, oil should be applied.

References:

1. *Geotechnical Engineering* by C Venkatramaiah, New Age International Publishers, 2006.
2. *Soil Mechanics and Foundation Engineering* by K.R. Arora, Standard Publishers Distributors, 2011.
3. *Soil Mechanics Laboratory Manual* by B M Das, Oxford University Press, 2012.