Department of

CIVIL ENGINEERING

Zakura Campus

GEOTECHNICAL ENGINEERING II LABORATORY MANUAL

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Srinagar, Jammu and Kashmir

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Srinagar, Jammu and Kashmir

Certificate

This is to certify that Mr. / Ms. ____

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____________________________________ laboratory during the academic year ____.

Signature of Coordinator

Signature of Faculty

Signature of Internal Examiner

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EXPERIMENT 1

DIRECT SHEAR TEST

Objective:

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

Standards:

1. Indian Standards : IS: 2720 (Part-13)
2. ASTM: D-3080 (Granular soil)
3. AASHTO: T-236

Need and scope:

In many engineering problems such as design of foundation, retaining walls, slab bridges, pipes, sheet piling, the value of the angle of internal friction and cohesion of the soil involved are required for the design. Direct shear test is used to predict these parameters quickly.

Apparatus:

1. The shear box, grid plates, porous stones, base plates, and loading pad and water jacket shall conform to IS: 11229-19857.
    a. Shear box: Shear box of internal dimension 60 mm x 60 mm x 25 mm. Shear box, divided into two halves by a horizontal plane and fitted with locking and spacing screw.
    b. Base plate having cross grooves on its top surface
    c. Grid plates perforated (2 nos.)
    d. Porous stones 6 mm thick (2 nos.)
    e. Loading yoke, loading pad.
2. Loading frame (motor attached).
3. Dial gauge.
4. Proving ring.
5. Tamper.
6. Straight edge.
7. Balance.
8. Aluminum container.
9. Spatula.

Figure1: Direct shear test setup

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 stone and loading block on top of soil.
8. Measure the thickness of 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 adjustments to see that there is no connection 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 5 kg normal stress 0.5 kg/cm2 and continue the experiment till failure
17. Record carefully all the readings. Set the dial gauges zero, before starting the experiment

Shearing stage

Rate of shearing _________mm/min

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

Date and Time	Displacement Dial Reading	Displacement, δ	Area Correction	Corrected Area	Proving dial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

Normal stress 1.0 kg/cm^2 L.C =.......   P.R.C =........

Date and Time	Displacement Dial Reading	Displacement, δ	Area Correction	Corrected Area	Proving dial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

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

Date and Time	Displacement Dial Reading	Displacement, δ	Area Correction	Corrected Area	Proving dial reading	Shear Force	Shear Stress	Vertical Dial Reading	Vertical Dial Difference	Thickness of Specimen

Plot shear stress- shear displacement curve and find:

a) Maximum shear stress, and
b) Corresponding shear displacement.

Proving Ring constant.......   Least count of the dial........

Calibration factor.......

Leverage factor........

Dimensions of shear box= 60 x 60 mm

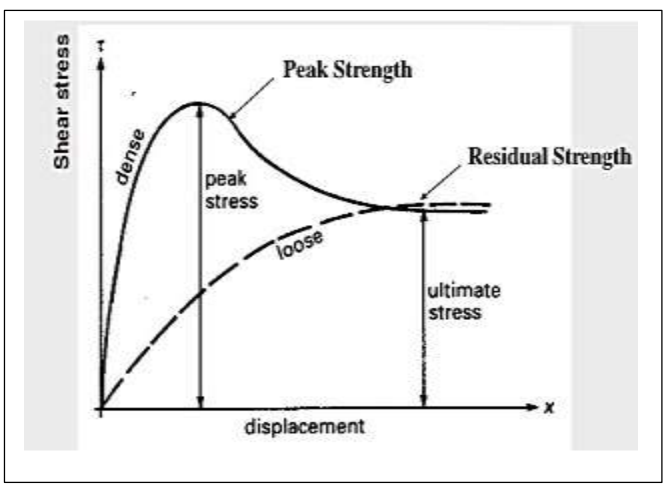
Empty weight of shear box........

Least count of dial gauge.........

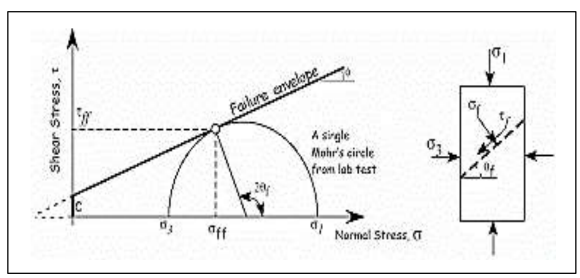
Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)			
	Proving Ring Reading (Division)	Proving Ring Constant	Shear Force (kg)	Shear Stress (kg/cm2)
0.5				
1				
1.5				

Plot shear normal stress displacement curve and find:

a) Cohesion intercept, and
b) Angle of shearing resistance.



Stress-strain plot



Mohr’s circle for direct shear

Figure 1: Sample graphs from test data

Calculations:

1. Shear strength of soil

$$\tau_f = \sigma_n tan\emptyset + c$$

where,

τ_f= Shear strength of soil = shear stress at failure.
C = Cohesion intercepts.
σ_n = Total normal stress on the failure plane
$\emptyset$ = Angle of internal friction

2. Deformation (δ) = elapsed time× strain rate
3. Corrected Area

$$A = A_o\,(1 - \frac{\delta}{3})$$

where,

A = Corrected area (cm^2)
A_o = Initial area of specimen (cm^2)
δ = Displacement

4. Normal load = normal weight added + weight of yoke
5. Normal stress

$$\sigma = \frac{\text{Normal load}}{\text{Initial area of specimen}}$$

6. Shear stress

$$\tau = \frac{\text{Shear load}}{\text{Corrected area}}$$

Result:

Angle of internal friction (Ø):

Cohesion (c):

General Remarks:

1. In the shear box test, the specimen is not failing along its weakest plane but along a predetermined or induced failure plane i.e. horizontal plane separating the two halves of the shear box. This is the main drawback of this test. Moreover, during loading, the state of stress

cannot be evaluated. It can be evaluated only at failure condition i.e Mohr’s circle can be drawn at the failure condition only. Also failure is progressive.

2. Direct shear test is simple and faster to operate. As thinner specimens are used in shear box, they facilitate drainage of pore water from a saturated sample in less time. This test is also useful to study friction between two materials – one material in lower half of box and another material in the upper half of box.
3. The angle of shearing resistance of sands depends on state of compaction, coarseness of grains, particle shape and roughness of grain surface and grading. It varies between 28^o (uniformly graded sands with round grains in very loose state) to 46^o (well graded sand with angular grains in dense state).
4. The volume change in sandy soil is a complex phenomenon depending on gradation, particle shape, state and type of packing, orientation of principal planes, principal stress ratio, stress history, magnitude of minor principal stress, type of apparatus, test procedure, method of preparing specimen etc. In general loose sands expand and dense sands contract in volume on shearing. There is a void ratio at which either expansion contraction in volume takes place. This void ratio is called critical void ratio. Expansion or contraction can be inferred from the movement of vertical dial gauge during shearing.
5. The friction between sand particles is due to sliding and rolling friction and interlocking action.
6. The ultimate values of shear parameter for both loose sand and dense sand approximately attain the same value so, if angle of friction value is calculated at ultimate stage, slight disturbance in density during sampling and preparation of test specimens will not have much effect.

Questionnaire:

EXPERIMENT 2

VANE SHEAR TEST

Objective:

To determine the shear strength of a soft clay deposit and to measure the sensitivity

Standards:

1. IS: 2720 (Part-30)
2. ASTM: D-4648

Need and scope:

A difficulty often encountered in determining the shearing resistance of soft, saturated clay deposits in the field is in obtaining undisturbed samples. The shear strength of such sensitive clays may be significantly altered in the process of sampling and handling. Vane shear test offers a method of overcoming this problem. The test can be carried both on undisturbed and remolded specimen, and are used for evaluating the sensitivity of the soft clays, especially marine clays. 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.

Theory:

The shear vane consists of four steel blades called vanes welded at right angles to a steel rod. The vane is gently pushed into the soil up to the required depth or at the bottom of the borehole and torque is applied gradually to the upper end of the torque rod until the soil fails in shear, due to the rotation of the vane. The torque is measured by noting the angle of twist. Shear failure occurs over the surface and the ends of a cylinder having a diameter'd' equal to the diameter of the vane.

If the torque is measured at failure, the undrained shear strength q can be calculated. If, after the initial test, the vane is rotated rapidly several times, the soil becomes remolded or disturbed and the shear strength of the remolded or disturbed clay can be calculated, and thus the sensitivity of the clay soil determined.

Apparatus:

1. One assembled Vane Shear Apparatus with container
2. Four calibrated torsion springs
3. Electronic balance with an accuracy of 1 gm
4. Moisture content tins
5. Steel rule or vernier calipers
6. Spade or pickaxe
7. Straight edge
8. Knife
9. Sample extruder

Figure 1: Vane shear apparatus

- **Sample preparation:**
  - **Undisturbed**

Push the sample out of the sampler by about 6 mm and trim it flush with the cutting edge of the sampler. Force 75 mm length of the sample out and cut it and trim it to 50 mm diameter, and transfer it into sample container.

  - **Remoulded**

Compact the calculated amount of soil either in a proctor mould or in a CBR mould to give a particular dry density at particular moisture content. Force the sample container into the compacted soil mass until the flange of the sample container just touches the top surface of the compacted soil mass. Pull out the container with the sample in it and mount it on the instrument base for test.

Otherwise, mix the predetermined quantity of water in a required quantity of soil mixture with spatula, into the sample container eliminating the formation of the voids. Level the sample surface with the spatula or knife edge and compact it to specific volume through static pressure applied on it by some contrivance.

Experimental procedure:

1. Measure the height (h) and internal diameter (d) of the vane.
2. Clean the apparatus thoroughly. Apply grease to the lead screw and thin oil to support pillar. Apply thin grease to gears.
3. Place the instrument on a firm base.
4. Select a suitable torsion spring and fix it to the apparatus.
5. Mount the specimen container with the specimen on the base of the vane shear apparatus and fix it securely to the base. The specimen in the tube should be at least 37.5 mm in diameter and 75 mm long (L/D ratio 2 or 3).

   (If the specimen container is closed at one end it should be provided at the bottom with a hole of about 1 mm diameter)

6. Move the strain indicating pointer up to its original position on the torque shaft and clamp it tight. Turn the maximum pointer into contact with the strain indicating pointer.
7. Lower the shear vanes into the specimen to their full length gradually with minimum disturbance of the soil specimen so that the top of the vane is at least 10 mm below the top of the specimen.
8. Note the readings of the strain indicators.
9. Rotate the vane at a uniform rate approximately 0.1 degrees per second by suitably operating the torque applicator handle until the specimen fails, which is indicated by the return of the strain indicating pointer.
10. Note the final reading of the torque indicator. The difference between the two readings (initial & final) gives the angle of torque.

11. Just after the determination of the maximum torque, rotate the vane rapidly through a minimum of ten revolutions. The remolded strength should then be determined within 1 minute after completion of the revolution.

Calculations:

1. Torque:
   T = K× θ

where,

T = Torque in kg-cm
K = Torsional constant of spring
θ = Angle of Torque

2. Shear strength (for fully immersed vane):

$$q_u = \frac{T}{\pi(\frac{d^2h}{2} + \frac{d^3}{6})}$$

where,

T = Torque in kg-cm
q_u = Undrained shear strength in kg/cm^2
d = diameter of vane in cm.
h = height of the vane in cm.

3. Sensitivity:

$$S_t = \frac{(q_u)_{undisturbed}}{(q_u)_{remoulded}}$$

where,

S_t = Sensitivity
$(q_u)_{undisturbed}$ = undrained shear strength in undisturbed state
$(q_u)_{remoulded}$ = undrained shear strength in remoulded state

Observation:

Spring No.

Spring Constant:

Diameter of vane: cm

Height of vane : cm

Observation Table: Undisturbed Sample:

SI No.	Initial Reading (degrees)	Final Reading (degrees)	Difference (degrees)	Torque 'T' (kg-cm)	Shear Strength 'S' (kg/cm^2)	Average S (kg/cm^2)

Observation Table: Disturbed Sample:

SI No.	Initial Reading (degrees)	Final Reading (degrees)	Difference (degrees)	Torque 'T' (kg-cm)	Shear Strength 'S' (kg/cm^2)	Average S (kg/cm^2)

Result:

Undisturbed shear strength:

Disturbed or remoulded shear strength:

Sensitivity:

Sensitivity	**Classification**
1	Insensitive
2 – 4	Normal or less sensitive
4 – 8	Sensitive
8 – 15	Extra sensitive
> 16	Quick

General remarks:

This test is useful when the soil is soft and its water content is nearer to liquid limit.

Questionnaire:

1. Can you measure thixotropy using vane shear test?

EXPERIMENT 3

UNCONFINED COMPRESSION TEST

Objective:

To determine the unconfined compressive strength of the given cohesive soil.

Standards:

1. Indian Standards : IS: 2720 (Part-10)
2. ASTM: D-2166
3. AASHTO: T-208

Need and scope of the experiment:

It is not always possible to conduct the bearing capacity test in the field. Sometimes it is cheaper to take the undisturbed soil sample and test its strength in the laboratory. Also to choose the best material for the embankment, one has to conduct strength tests on the samples selected. Under these conditions it is easy to perform the unconfined compression test on undisturbed and remoulded soil sample.

The unconfined compression test is inappropriate for dry sands or crumbly clays because the materials would fall apart without lateral confinement. A cylindrical soil specimen is subjected to gradually increasing axial stress until it fails. Since the test is quick, water is not allowed to drain out of the sample. Hence it is also called undrained or 'quick' test. Since the test produces only one mohr's circle (corresponding to $\sigma_3 = 0$), the test is applicable only to soils for which $\varphi_u = 0$, i.e, fully saturated, non-fissured clay.

For $\sigma_3 = 0$ $\quad\quad\quad \sigma_{1f} = 2c_u\sqrt{\frac{1+\sin\emptyset_u}{1-\sin\emptyset_u}}$

The subscript u is used since the test is an undrained test.

Since $\emptyset_u = 0$ $\quad\quad\quad \sigma_{1f} = 2c_u$

In the unconfined compression test, the major principal stress at failure, σ_{1f} is called the unconfined compressive strength and is usually denoted by the notation q_u.

Hence, $\quad\quad\quad q_u = 2c_u$

The undrained shear strength of saturated clay is expressed as,

$$\tau_f = c_u = \frac{q_u}{2}$$

Apparatus:

1. Loading frame of capacity of 2t, with constant rate of movement.
2. Proving ring of 0.01 kg sensitivity for soft soils; 0.05 kg for stiff soils.
3. Soil trimmer.
4. Split mould: 38 mm diameter, 76 mm long.
5. Frictionless end plates (Perspex plate with silicon grease coating).
6. Evaporating dish (Aluminum container).
7. Soil sample of 75 mm length.
8. Dial gauge (0.01 mm accuracy).
9. Balance of capacity 200 g and sensitivity to weigh 0.01 g.
10. Oven thermostatically controlled with interior of non-corroding material to maintain the temperature at the desired level.
11. Sample extractor and split sampler.
12. Vernier calipers

Figure 1: Experimental setup for unconfined compression test

Sample preparation:

1. **Specimen size:** The specimen for the test shall have a minimum diameter of 38 mm and the largest particle contained within the test specimen shall be smaller than 1/8 of the specimen diameter. If after completion of test on undisturbed sample, it is found that larger particles than permitted for the particular specimen size tested are present, it shall be noted in the report of test data under remarks. The height to diameter ratio shall be within 2 to 2.5. Measurements of height and diameter shall be made with Vernier calipers or any other suitable measuring device to the nearest 0.1 mm.
2. **Undisturbed specimen**
    1. Note down the sample number, borehole 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 until 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.
3. **Remolded sample**
    1. For the desired water content and the dry density, calculate the weight of the dry soil Ws 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.

       $W_w = (W_S * W/100)$ g
    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 until 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.

Test procedure:

1. Place the sampling soil specimen at the desired water content and density in the large mould.
2. Push the sampling tube into the large mould and remove the sampling tube filled with the soil. For undisturbed samples, push the sampling tube into the clay sample.
3. Saturate the soil sample in the sampling tube by a suitable method.
4. Coat the split mould lightly with a thin layer of grease and weigh the mould.
5. Extrude the sample out of the sampling tube into the split mould, using the sample extractor and the knife.
6. Trim the two ends of the specimen in the split mould. Weigh the mould with the specimen.
7. Remove the specimen from the split mould by splitting the mould into two parts.
8. Measure the length and diameter of the specimen with vernier calipers.
9. Place the specimen on the bottom plate of the compression machine. Adjust the upper plate to make contact with the specimen.
10. Adjust the dial gauge and the proving ring gauge to zero.
11. Apply the compression load to cause an axial strain at the rate of ½ to 2% per minute.
12. Record the dial gauge reading, and the proving ring reading every thirty seconds upto a strain of 6%. The reading may be taken after every 60 seconds for a strain between 6%, 12% and every 2 minutes or so beyond 12%.
13. Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached.
14. Measure the angle between the failure surface and the horizontal, if possible.

15. Take the sample from the failure zone of the specimen for the water content determination.
16. The values of compressive stress σ and strain ϵ obtained are plotted on a natural graph along Y-axis and X-axis respectively.
17. The maximum stress from this plot gives the value of the unconfined compressive strength (q_u).
18. In case no maximum occurs within 20 percent axial strain, the unconfined compressive strength shall be taken as the stress at 20 percent axial strain.

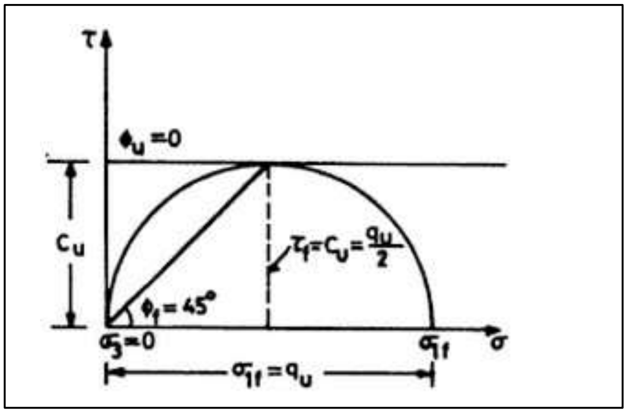


Figure 2: Mohr-Coulomb plot for unconfined compression test

Calculations:

1. Axial Strain (e):

$$\varepsilon = \frac{\text{Change in length } (\Delta L)}{\text{Original length of specimen } (L_0)}$$

2. Average Cross sectional area (A)

$$A = \frac{A_o}{1-\varepsilon}$$

Where, A_o is the original cross-sectional area of the specimen

3. Compressive stress (σc)

$$\sigma_c = \frac{P}{A}$$

Where, P is compressive force.

A is average cross sectional area.

Observations:

Specific gravity (G_S) = Bulk density = kN/m^3

Water content=   Degree of saturation =   %

Diameter (D_o) of the sample =   cm   Area of cross-section = cm^2

Initial length (L_o) of the sample =   cm

Sample 1: Proving ring number/constant:

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain e	Corrected area A (cm^2)	Proving ring dial reading	Axial force P (kg)	Compressive stress (kg/cm^2)

Sample 2:

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain e	Corrected area A (cm^2)	Proving ring dial reading	Axial force P (kg)	Compressive stress (kg/cm^2)

Sample 3:

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain e	Corrected area A (cm^2)	Proving ring dial reading	Axial force P (kg)	Compressive stress (kg/cm^2)

Result:

Unconfined compressive strength (q_u):

Undrained shear strength (τ_f):

Failure pattern:

Water content in specimen at testing:

Sensitivity = (q_u for undisturbed sample)/(q_u for remoulded sample):

Safety and precautions:

1. The specimen shall be handled carefully to prevent disturbance, change in cross section, or loss of water.
2. The specimen shall be of uniform circular cross-section with ends perpendicular to the axis of the specimen.
3. Where the prevention of the possible development of appreciable capillary forces is required, the specimens shall be sealed with rubber membranes, thin plastic coatings, or with coating or grease or sprayed plastic immediately after preparation and during the entire testing cycle.
4. Representative sample cuttings taken from the tested specimen shall be used for the determination of water content.

Questionnaire:

1. What is the difference between uniaxial compression and unconfined compression?
2. Is it suitable to conduct the above test for all types of soil?

EXPERIMENT 4

TRIAXIAL SHEAR TEST: unconsolidated undrained

Objective:

To determine shear strength parameters of the given soil sample by conducting unconsolidated undrained (UU) triaxial shear test.

Standards:

1. Indian Standards : IS: 2720 (Part-11)
2. ASTM: D-2850
3. AASHTO: T-234

Theory:

The triaxial compression test, introduced by Casagrande and Terzaghi's in 1936, is by far the most popular, and extensively used shearing strength test, both for field application and for purposes of research. As the name itself suggests, the soil specimen is subjected to three compressive stresses in mutually perpendicular directions, one of the three stresses being increased until the specimen fails in shear. Usually a cylindrical specimen with a height equal to twice its diameter is used. The desired three-dimensional stress system is achieved by an initial application of all-round fluid pressure or confining pressure through water. While this confining pressure is kept constant throughout the test, axial or vertical loading is increased gradually and at a uniform rate. The axial stress thus constitutes the major principal stress and the confining pressure acts in the other two principal directions, the intermediate and minor principal stresses being equal to the confining pressure.

The apparatus consists of a lucite or Perspex cylindrical cell, called 'triaxial cell' with appropriate arrangements for an inlet of cell fluid and application of pressure by means of a compressor, outlet of pore water from the specimen if it is desired to permit drainage which otherwise may serve as pore pressure connection and axial loading through a piston and loading cap.

The soil sample is placed inside a rubber sheath, which is sealed to a top cap and bottom pedestal by rubber O-rings. For tests with pore pressure measurement, porous discs are placed at the bottom, and sometimes at the top of the specimen. Filter paper drains may be provided around the outside of the specimen in order to speed up the consolidation process. Pore pressure generated inside the specimen during testing can be measured by means of pressure transducers.

The triaxial compression test consists of two stages:

(i) **First stage:** In this, a soil sample is set in the triaxial cell and confining pressure is then applied.

(ii) **Second stage:** In this, additional axial stress (also called deviator stress) is applied which induces shear stresses in the sample. The axial stress is continuously increased until the sample fails.

During both the stages, the applied stresses, axial strain, and pore water pressure or change in sample volume can be measured.

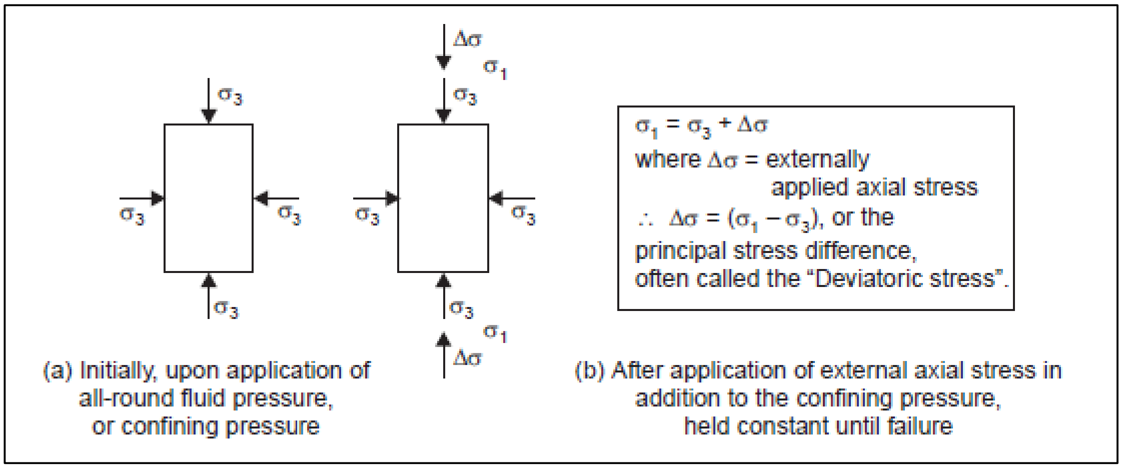
Test types:

There are several test variations, and those used mostly in practice are:

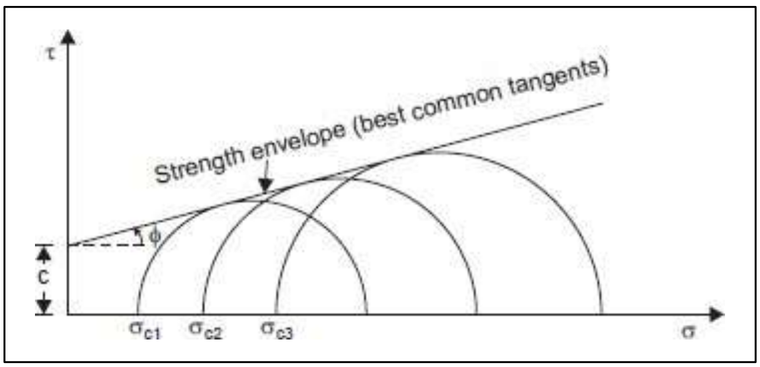
1. **UU (unconsolidated undrained) test:** In this, cell pressure is applied without allowing drainage. Then keeping cell pressure constant, deviator stress is increased to failure without drainage.
2. **CU (consolidated undrained) test:** In this, drainage is allowed during cell pressure application. Then without allowing further drainage, deviator stress is increased keeping cell pressure constant.
3. **CD (consolidated drained) test:** This is similar to CU test except that as deviator stress is increased, drainage is permitted. The rate of loading must be slow enough to ensure no excess pore water pressure develops.

In the UU test, if pore water pressure is measured, the test is designated by $\bar{U}\bar{U}$.

In the CU test, if pore water pressure is measured in the second stage, the test is symbolized as $C\bar{U}$.



Stresses on soil element under triaxial testing



Mohr's circle plot for triaxial compression test

Apparatus:

1. Triaxial testing machine complete with triaxial cell
2. Water pressure unit with hand pump
3. Proving ring
4. Dial gauge
5. Rubber membranes
6. Membrane stretcher
7. Sample trimming apparatus
8. Bins for moisture content determinations
9. Balance and box of weights
10. Drying oven

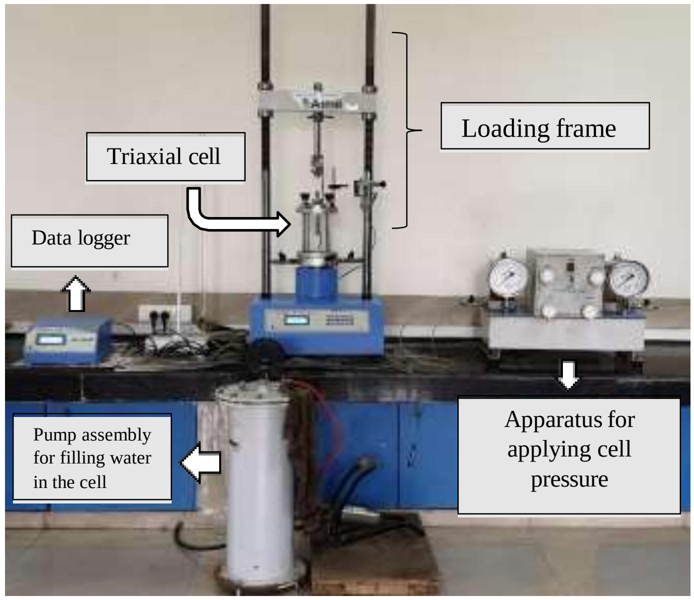


Figure 1: Triaxial test setup

Sample preparation:

Undisturbed specimens:

The object of the specimen preparation is to produce cylindrical specimens of height twice the specimen diameter with plane ends normal to the axis and with the minimum change of the soil structure and moisture content. The method of preparation will depend on whether the sample is received in the laboratory in a tube or as a block sample.

Remolded samples:

Remolded samples prepared at the desired moisture and density by static and dynamic methods of compaction or by any other suitable method, where necessary.

Experimental procedure:

1. Trim the soil specimen (prepared from the sampling tube of an undisturbed sample tube using universal extractor frame or from a compacted soil specimen as per standard proctors method, at optimum moisture content or any other moisture content to suite the field situations).
2. Using the trimming apparatus if necessary the trimmed specimen should be 76.2 mm long and 38.1 mm in diameter. The diameter and the length are measured at not less than 3 places and the average values are used for computation.
3. Note the weight of the specimen (W1).

4. The specimen is then enclosed in a 38.1 mm diameter and about 100 mm long rubber membrane, using the membrane stretcher. Spreading back the ends of the membrane over the ends of the stretcher and applying suction between the stretcher and the rubber membranes does by inhalation.
5. The membrane and stretcher are then easily slide over the specimen, the suction is released and membrane is unrolled from the ends of the stretcher.
6. Use non-porous stones on either side of the specimen as neither any pressure is to be measured nor any drainage of air or water is allowed.
7. Remove the porous cylinder from its base removing the bottom fly nuts.
8. The pedestal at the centre of the base of the cylinder on which the specimen is to be placed is cleaned and a 38.1 mm diameter rubber O-ring is rolled over to its bottom.
9. The specimen along with the non-porous plate on either side is centrally placed over the pedestal and the bottom edge of the machine covering the specimen is sealed against the pedestal by rolling back the O-ring over the membrane.
10. The cap is placed over the top plate of the specimen and the top of the rubber membrane is sealed against the cap by carefully rolling over it another O-ring. This arrangement of rubber O-ring forms the effective seal between the specimen with the membrane and the water under pressure.
11. The specimen is checked for its verticality and co-axiality with the cylinder chamber.
12. The chamber along with the loading plunger is carefully placed over its base without disturbing the soil specimen and taking care to see that the plunger rests on the cap of the specimen centrally.
13. The loading frame is then adjusted so that it just touches the plunger top by naked eye. The chamber is then rotated if necessary such that the dial gauge, recording compression, rests centrally over the top of the screw which can be locked at any level and which is attached to the top of the cylinder chamber carrying the specimen.
14. The cylinder is then attached to the base plate tightly by means of tightening the nuts.
15. The valve to drain out the chamber and the valve to drain out the air and water from the sample are closed and the air lock nut at the top of the cylinder is kept open to facilitate the

exit of air as water enters the chamber through another valve which connects the chamber to the water storage cylinder subjected to a pressure by a compressor or by any other means.

16. The water storage cylinder is filled with water completely and its top is then closed by means of a valve. Necessary pressure is built up in the cylinder by working the hand pump and the pressure communicated to the cylinder where the specimen is placed, by opening the connecting valve.
17. The cylindrical chamber is allowed to be filled up completely which is indicated by the emergence of water through the air lock nut at the top of the chamber. Then the airlock nut is closed to develop necessary confining pressure by using compressor and the same is maintained constant.
18. If necessary, bring the loading plunger down until it is in contact with the specimen top cap by means of hand operated loading device. This is indicated by a spurt in the reading of the proving ring dial gauge.
19. For this position, adjust the deformation dial gauge reading to zero.
20. Record the initial reading of the proving ring and compression dial gauge.
21. The vertical load is applied to the specimen by starting the motor at the loading frame. The change in the proving ring dial gauge gives the measure of the applied load.
22. The deformation dial gauge gives the deformation in the soil specimen, which can be used to compute strain in the soil.
23. Take readings of proving ring dial gauge at 0.5, 1.0, 1.5, 2.0% (or any other smaller values) of strain and for every 1.0% strain thereafter up to failure or 20% strain whichever is earlier.
24. Throughout the test, make sure that the chamber, containing pressure is kept constant at the desirable value as indicated by the pressure gauge on the water cylinder. If necessary, the pressure can be made good for any possible losses by working the compressor.
25. After specimen has failed or 20% strain is recorded, as the case may be
    (a) stop application of load
    (b) disconnect the chamber from water storage cylinder by closing the linger valve
    (c) open the air lock knob a little and
    (d) open the valve to drain out the water in the cylinder.
26. After a few seconds open the airlock nut completely to facilitate quick draining out of water, by entry of air at top of the cylinder.

27. After the water is completely drained out, take out the cylinder from loading frame carefully, loosen the nuts and remove the Lucite cylinder from its base, without disturbing the sample.
28. Note the space of the failed specimen, angle of shear plane if any and dimensions of the specimen.
29. Wipe the rubber membrane dry and find its weight W2 that should be same as W1.
30. Remove the membrane from the specimen and take a representative specimen preferably from the sheared zone.
31. Repeat the test with three specimens of the same soil sample subjected to three different lateral pressures (confining) of 0.5, 1.0 and 1.5 kg/cm^2 (5, 10 and 15 psi or 50, 100 and 150 kpa)
32. A graph is drawn between the deviator stress and strain. The deviator stress is the difference between the stresses in axial and radial direction i.e. ($\sigma_1 - \sigma_3$) and is equal to the vertical stress P/A. σ_3 is the lateral confining pressure at any time, which is constant for a test.
33. From the plot, determine the second result at half the ultimate stress, which can be taken as modulus of elasticity.
34. The mohr's circle of stress to define the state of stress at failure is drawn for each sample. The circle has for its centre point ($\sigma_1 + \sigma_3$)/2 and the radius equal to ($\sigma_1 - \sigma_3$)/2.
35. An envelope, which approximates to a straight line, is drawn touching the circle.
36. The intercept made on Y-axis and the slope of the envelope gives the values of strength parameters of the soil C and φ respectively.

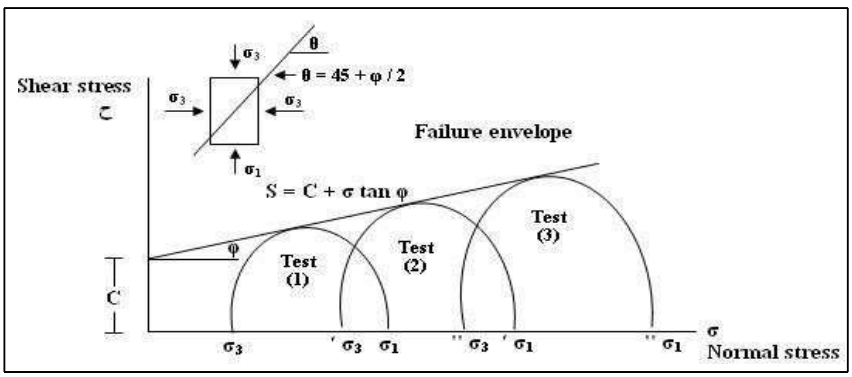


Figure 2: Mohr-coulomb plot for triaxial compression test

Calculations:

1) **Axial Strain (e):**

$$\varepsilon = \frac{\text{Change in length } (\Delta L)}{\text{Original length of specimen } (L_0)}$$

2) **Average Cross sectional area (A)**

$$A = \frac{A_o}{1 - \varepsilon}$$

where,

A_o is the original cross-sectional area of the specimen

3) **Deviator stress (σ_d)**

$$\sigma_d = \frac{P}{A}$$

where,

P is axial load

A is average cross sectional area

4) **Major Principal Stress (σ_1)**

$$\sigma_1 = \sigma_d + \sigma_3$$

where,

σ_d is deviator stress

σ_3 is cell pressure

5) **Correction to allow for the restraining effect of the rubber membrane:**

$$\text{Correction} = 4\text{M}\,\frac{(1 - \varepsilon)}{\text{D}}$$

where,

M is the compression modulus of the rubber membrane in kg/cm^2.

ε is the axial strain at the maximum principal stress.

D is initial diameter of the sample in cm.

The value of the correction calculated as above shall be deducted from the measured maximum principal stress difference to give the corrected value of the maximum principal stress.

Safety and precautions:

1. The most convenient method of recording the mode of failure is by means of sketch indicating the position of the failure planes. The angle of the failure plane to the horizontal may be recorded, if required. These records should be completed without undue delay to avoid loss of moisture from specimen.

2. Comparison with the recorded mass of the specimen before testing provides a check on the impermeability of the rubber membrane if water has been used as the operating fluid in the cell.
3. Precautions shall be taken to prevent adhesion between the soil and the extruder, for example, by interposing oiled paper discs or lightly oiling the face of the extruder.
4. The length, diameter, and mass of the specimen shall be measured to an accuracy enabling the bulk density to be calculated to an accuracy of ± 0.1 percent.

Observation and recording:

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.

Observations:

Sample No:

Date:

Location: Size of specimen:

Length: Proving ring constant:

Diameter: Initial area:

Initial Volume: Strain dial least count:

Sample 1: **Cell Pressure:**

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain ε	Corrected area A (cm^2)	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm^2)

Deviator stress at failure:

Sample 2: **Cell Pressure:**

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain ε	Corrected area A (cm^2)	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm^2)

Deviator stress at failure:

Sample 3: **Cell Pressure:**

Deformation dial gauge reading	Axial deformation ΔL (mm)	Axial strain ε	Corrected area A (cm^2)	Proving ring dial reading	Axial Load P (kgf)	Deviator stress (kg/cm^2)

Deviator stress at failure:

General remarks:

1. It is assumed that the volume of the sample remains constant and that the area of the sample increases uniformly as the length decreases. The calculation of the stress is based on this new area at failure, by direct calculation, using the proving ring constant and the new area of the sample. By constructing a chart relating strains readings, from the proving ring, directly to the corresponding stress.
2. The strain and corresponding stress is plotted with stress abscissa and curve is drawn. The maximum compressive stress at failure and the corresponding strain and cell pressure are found out.
3. The stress results of the series of triaxial tests at increasing cell pressure are plotted on a Mohr stress diagram. In this diagram a semicircle is plotted with normal stress as abscissa shear stress as ordinate.
4. The condition of the failure of the sample is generally approximated to by a straight line drawn as a tangent to the circles, the equation of which is $\tau = c + \sigma \tan\phi$. The value of cohesion, c is read of the shear stress axis, where it is cut by the tangent to the mohr circles, and the angle of shearing resistance (ϕ) is angle between the tangent and a line parallel to the shear stress.

Questionnaire:

1. What is the stress path of the triaxial shear tests?
2. What is the basis of the sample size?

EXPERIMENT 5

STANDARD PENETRATION TEST

Objective:

- **Determine Soil Resistance**: Measure the **N-value** (number of blows required to drive the sampler 300 mm) to assess soil stiffness and relative density.

- **Classify Soil**: Identify soil type and consistency based on penetration resistance and retrieved disturbed samples.

Standards:

3. IS: 2131 (1981)
4. ASTM: D-1586

Need and scope:

Need for Standard Penetration Test (SPT):

The Standard Penetration Test (SPT) is one of the most widely used in-situ tests in geotechnical engineering. It is conducted to evaluate the subsurface soil properties and provide essential input for foundation design. The primary reasons for conducting an SPT include:

1. **Assessment of Soil Strength:**
   - Determines the relative density and strength of granular soils.
   - Provides an indication of soil stiffness and consistency for cohesive soils.
2. **Bearing Capacity Estimation:**
   - Helps estimate the bearing capacity of soils for shallow and deep foundation design.
3. **Liquefaction Potential Analysis:**
   - SPT-N values help assess the potential for soil liquefaction, which is critical in seismic regions.
4. **Soil Stratification and Characterization:**
   - Provides information on the layering of soil and rock, which is essential for site characterization.
5. **Correlation with Soil Properties:**
   - Empirical correlations exist between SPT-N values and key soil parameters like angle of internal friction (ϕ), cohesion (c), and modulus of elasticity (E).
6. **Cost-Effective and Simple Execution:**
   - Compared to other in-situ tests (e.g., CPT, vane shear test), SPT is relatively easy and economical to perform.

Scope of Standard Penetration Test (SPT):

The SPT has a broad scope in geotechnical investigations and foundation engineering, including:

1. **Foundation Design:**
   - Used in designing shallow foundations (spread footings, raft foundations) and deep foundations (piles, drilled shafts).
2. **Geotechnical Site Investigation:**
   - Commonly conducted as part of preliminary site investigations for buildings, bridges, highways, and dams.
3. **Pile Capacity Estimation:**
   - Used in empirical formulas to estimate the load-carrying capacity of piles in different soil conditions.
4. **Highway and Pavement Design:**
   - Helps in subgrade evaluation and pavement design, particularly for flexible and rigid pavements.
5. **Slope Stability Analysis:**
   - Provides soil strength parameters required for stability analysis of slopes and embankments.
6. **Tunneling and Excavation Projects:**
   - Helps assess soil properties for tunnel stability and excavation support system design.
7. **Dams and Earth Retaining Structures:**
   - Used to estimate soil strength parameters necessary for designing earth dams and retaining walls.

Theory of Standard Penetration Test (SPT)

The Standard Penetration Test (SPT) is an in-situ dynamic penetration test widely used in geotechnical engineering to determine the relative density, strength, and load-bearing capacity of soils. It provides valuable empirical correlations with soil properties and is conducted in accordance with **IS 2131:1981**, **ASTM D1586**, and other relevant standards.

Principle of SPT

The test involves driving a **split-spoon sampler** into the soil using a **standardized hammer** and recording the number of blows required to penetrate a specific depth. The resistance to penetration, expressed as the **SPT-N value**, is used to infer soil properties.

Equipment Used

1. **Split-spoon sampler** – A steel tube (50.8 mm outer diameter, 35 mm inner diameter) used for collecting soil samples.
2. **Drop hammer** – A hammer weighing **63.5 kg (140 lb)**, dropped from a height of **760 mm (30 inches)**.
3. **Drilling Rig and Borehole** – The test is conducted in a borehole created using auger or rotary drilling.
4. **Rods and Anvil** – Used to connect the hammer and transmit impact forces.

Test Procedure

1. **Preparation of Borehole:**
   - A borehole is drilled to the desired depth using auger or rotary drilling.
2. **Positioning the Split-Spoon Sampler:**
   - The sampler is placed at the test depth inside the borehole.
3. **Driving the Sampler:**
   - The 63.5 kg hammer is dropped from 760 mm height to drive the sampler into the soil.
   - The penetration is recorded in three stages:
     - **First 150 mm** – Seating drive (ignored).
     - **Second 150 mm** – First penetration.
     - **Third 150 mm** – Second penetration.
4. **Recording the Blow Count (N-value):**
   - The number of hammer blows required to drive the sampler through the **last 300 mm** (second and third stages) is recorded as the **SPT-N value**.
5. **Soil Sample Collection:**
   - The sampler is withdrawn, and the collected soil sample is stored for laboratory analysis.

SPT-N Value Interpretation

The **SPT-N value** indicates soil strength and density:

SPT-N Value	Soil Type	Interpretation
0 – 4	Very Loose	Very soft clay or loose sand
5 – 10	Loose	Soft clay or loose sand
11 – 20	Medium	Medium stiff clay or medium dense sand
21 – 30	Dense	Stiff clay or dense sand
31 – 50	Very Dense	Very stiff clay or very dense sand
>50	Hard	Hard soil or rock

Corrections to SPT-N Value

Several corrections are applied to obtain a more accurate N-value:

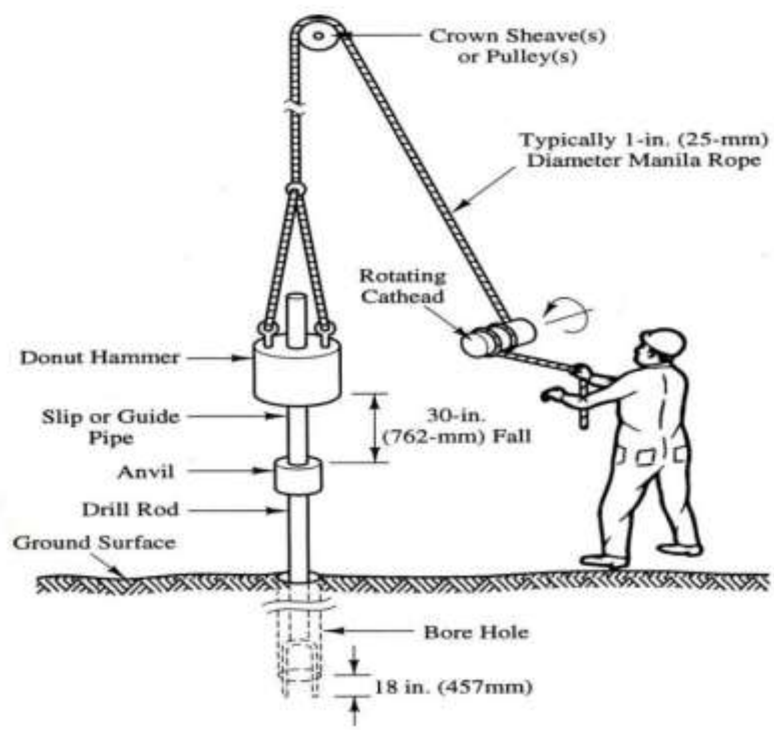
1. **Overburden Pressure Correction:**
   - For granular soils, a correction is applied to account for depth-related stress variations: Nc=CN×NN_c = C_N \times NNc=CN×N where CNC_NCN is the correction factor based on effective overburden stress.
2. **Dilatancy Correction (for silts and fine sands below water table):**
   - If Nc>15N_c > 15Nc>15, a correction is applied: N′=15+(Nc−15)2N' = 15 + \frac{(N_c - 15)}{2}N′=15+2(Nc−15)
3. **Hammer Energy Correction:**
   - Variations in hammer efficiency require a correction factor.

Advantages of SPT

- Simple and cost-effective.
- Provides both **quantitative (N-value)** and **qualitative (soil sample)** data.
- **Used for correlation with various soil properties.**

Limitations of SPT

- High variability due to operator skill and equipment differences.
- Not suitable for very soft clays or gravels.
- Results may be affected by **borehole disturbance** and **energy losses**.



Conclusion

The Standard Penetration Test (SPT) is a fundamental in-situ test for geotechnical site investigations. Despite some limitations, it remains widely used due to its ability to provide valuable empirical correlations with soil properties and its practical applicability in foundation design.

EXPERIMENT 6

PLATE LOAD TEST

Plate Load Test:

The *Plate load test* is a field test, which is performed to determine the ultimate bearing capacity of the soil and the probable settlement under a given load. This test is very popular for the selection and design of the shallow foundation.

For performing this test, the plate is placed at the desired depth, then the load is applied gradually and the settlement for each increment of the load is recorded. At one point a settlement occurs at a rapid rate, the total load up to that point is calculated and divided by the area of the plate to determine the **ultimate bearing capacity** of soil at that depth. The ultimate bearing capacity is then divided by a safety factor (typically 2.5~3) to determine the **safe bearing capacity**.

Plate load test apparatus and equipment:

The following plate load test apparatus is necessary for performing the test:

1. Test plate
2. Hydraulic jack & pump
3. Reaction beam or reaction truss
4. Dial gauges
5. Pressure gauge
6. Loading columns
7. Necessary equipment for the loading platform.
8. Tripod, Plumb bob, spirit level, etc.

Loading arrangement:

The loading to the test plate may be applied with the help of a hydraulic jack. The reaction of the hydraulic jack may be borne by either of the following:

1. ***Gravity Loading method***
2. ***Reaction Truss method***

1. Gravity loading method:

In the gravity loading method, a platform is constructed over a vertical column resting on the test plate, and the loading is done with the help of sand bags, stones or concrete blocks.

Reaction truss method:

The reaction of the jack is borne by a reaction truss. The truss is held to the ground through soil anchors. The reaction truss is made of mild steel section. The guy ropes are used for the lateral stability of the truss.

Test Procedure:

The necessary steps to perform a plate load test is written below-

1. Excavate test pit up to the desired depth. The pit size should be at least 5 times the size of the test plate (B_p).
2. At the centre of the pit, a small hole or depression is created. The size of the hole is the same as the size of the steel plate. The bottom level of the hole should correspond to the level of the actual foundation. The depth of the hole is created such that the ratio of the depth to width of the hole is equal to the ratio of the actual depth to the actual width of the foundation.
3. A mild steel plate is used as a load-bearing plate whose thickness should be at least 25 mm thickness and size may vary from 300 mm to 750 mm. The plate can be square or circular. Generally, a square plate is used for square footing and a circular plate is used for circular footing.
4. A column is placed at the centre of the plate. The load is transferred to the plate through the centrally placed column.
5. The load can be transferred to the column either by gravity loading method or by truss method.
6. For gravity loading method a platform is constructed over the column and load is applied to the platform by means of sandbags or any other dead loads. The hydraulic jack is placed in between column and loading platform for the application of gradual loading. This type of loading is called reaction loading.
7. At least two dial gauges should be placed at diagonal corners of the plate to record the settlement. The gauges are placed on a platform so that it does not settle with the plate.
8. Apply seating load of .7 T/m^2 and release before the actual loading starts.
9. The initial readings are noted.
10. The load is then applied through the hydraulic jack and increased gradually. The increment is generally one-fifth of the expected safe bearing capacity or one-tenth of the ultimate bearing capacity or any other smaller value. The applied load is noted from the pressure gauge.
11. The settlement is observed for each increment and from dial gauge. After increasing the load-settlement should be observed after 1, 4, 10, 20, 40, and 60 minutes and then at hourly intervals until the rate of settlement is less than .02 mm per hour. The readings are noted in tabular form.
12. After completing the collection of data for a particular loading, the next load increment is applied and readings are noted under new load. This increment and data collection is repeated until the maximum load is applied. The maximum load is generally 1.5 times the expected ultimate load or 3 times of the expected allowable bearing pressure.

Calculation of Bearing Capacity from Plate Load Test:

After the collection of field data, the load-settlement curve is drawn. It is a logarithmic graph where the load applied is plotted on X-axis and settlement on Y-axis. From the graph, the ultimate load for the plate is obtained which is the corresponding load for settlement of one-fifth of the plate width.

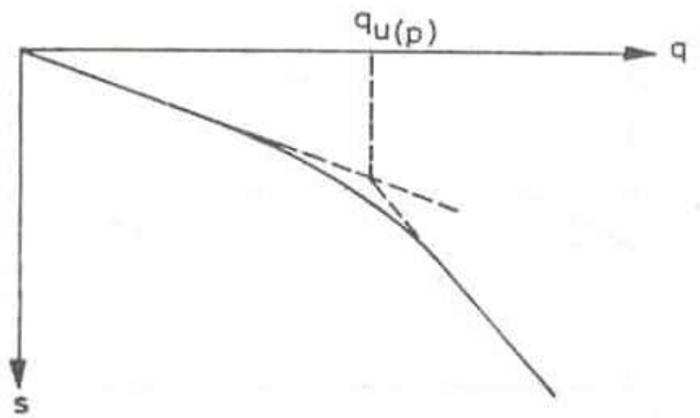


Figure: Load-settlement graph

When the points are plotted on the graph, the curve is broken at one point. The corresponding load to that breakpoint is considered to be the ultimate load on the plate. The ultimate bearing capacity can be calculated from the ultimate load from the plate. The ultimate bearing capacity is then divided by a suitable factor of safety to determine the safe bearing capacity of soil from the foundation.

Bearing Capacity Calculation for Clayey Soils

Ultimate bearing capacity = ultimate load for plate

i.e. $\mathbf{q_u(f) = q_u(p)}$

Bearing Capacity Calculation for Sandy Soils

Ultimate bearing capacity = ultimate load for plate x {Width of pit (B_f) / Size of Plate (B_p)}

$$\mathbf{q_u(f) = q_u(p) \times B_f / B_p}$$

Finally, safe bearing capacity = ultimate bearing capacity / factor of safety

The factor of safety ranges from 2 to 3.

Calculation of Foundation Settlement from Plate Load Test:

We can also calculate settlement for given load from plate load test as follows

Foundation Settlement Calculation on Clayey Soils

$$\textbf{Settlement of foundation } (s_f) = s_p \times B_f/B_p$$

Foundation Settlement Calculation on Sandy Soils

$$\textbf{Settlement of foundation } (s_f) = s_p\,[\{B_f(B_p + 0.3)\}/\{B_p(B_f + 0.3)\}]^2$$

Where B_f and B_p are widths of foundation and plate.

Advantages of Plate load test:

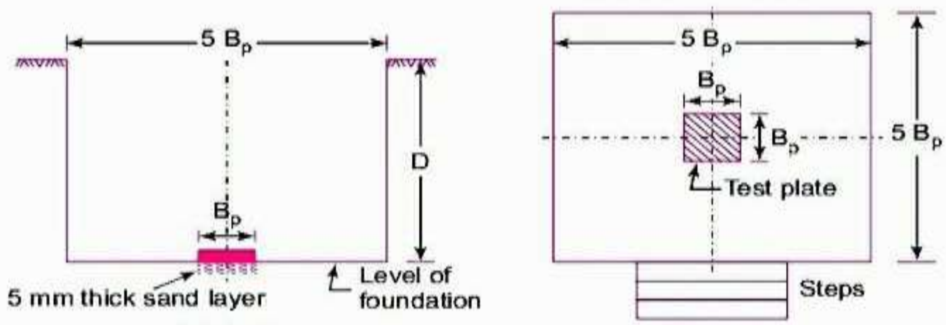
The advantages of Plate Load Test are discussed below:

- Being able to understand the foundation behaviour under loading conditions.
- Evaluation of bearing capacity of soil at a certain depth and prediction of settlement for a certain load.
- Shallow foundation can be calculated considering the allowable bearing capacity, which can be predicted from the plate load test.
- Time and cost-efficient.
- Easy to perform.
- Reliable.

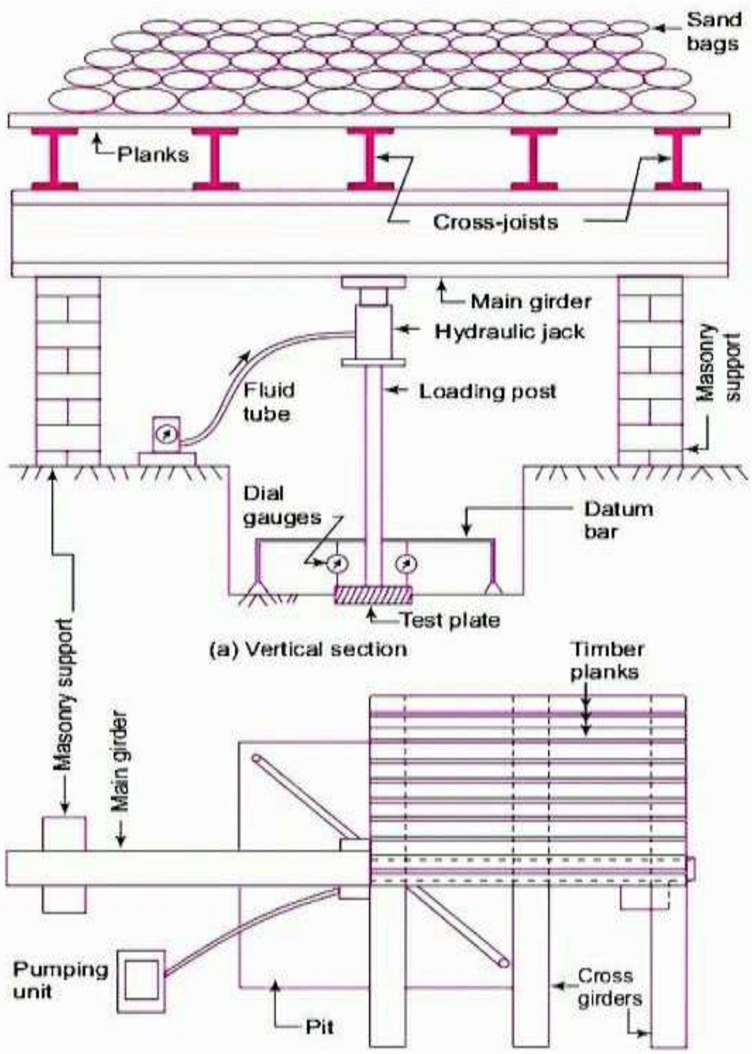
Limitations of Plate load test:

It has the following limitations:

- The test predicts the behaviour of soil located at a depth less than twice the depth of the width of the bearing plate. But in practical condition, the influence zone of a foundation is up to a much greater depth.
- The plate load test is performed for a short time period, so it cannot predict the settlement for a longer period, especially for cohesive soil.
- The bearing capacity for clayey soil is almost similar to the bearing capacity obtained from the plate load test, but in the case of dense sandy soil, the plate load test provides a conservative value. The actual capacity obtained for dense sandy soil is higher than the results from the plate load test.
- The settlement for losing sandy soil is usually greater than the settlement indicated by the plate bearing test.



(a) Section (b) Plan



(b) Plan