TRIAXIAL SHEAR TEST

1. Objective

The tri-axial shear test is most versatile of all the shear test testing methods for getting shear strength of soil i.e. Cohesion (C) and Angle of Internal Friction (Ø), though it is bit complicated. This test can measure the total as well as effective stress parameters both. These two parameters are required for design of slopes, calculation of bearing capacity of any strata, calculation of consolidation parameters and in many other analyses. This test can be conducted on any type of soil, drainage conditions can be controlled, pore water pressure measurements can be made accurately and volume changes can be measured. In this test, the failure plane is not forced, the stress distribution of failure plane is fairly uniform and specimen can fail on any weak plane or can simply bulge.

Depending upon the drainage condition, there can be three types of tri-axial tests:

(i) Unconsolidated Undrained (UU) Test: In this test, drainage is not allowed during application of cell pressure (i.e. sample remains unconsolidated) during the first stage of all round cell pressure application as well as during the second stage of additional axial pressure application.

(ii) Consolidated Undrained (CU) Test: In this test, drainage is allowed during application of cell pressure (i.e. sample gets consolidated) during the first stage of all round cell pressure application but drainage is not allowed during the second stage of additional axial pressure application.

(iii) Consolidated Drained (CD) Test: In this test, drainage is allowed during application of cell pressure (i.e. sample gets consolidated) during the first stage all round cell pressure application as well as during the second stage of additional axial pressure application.

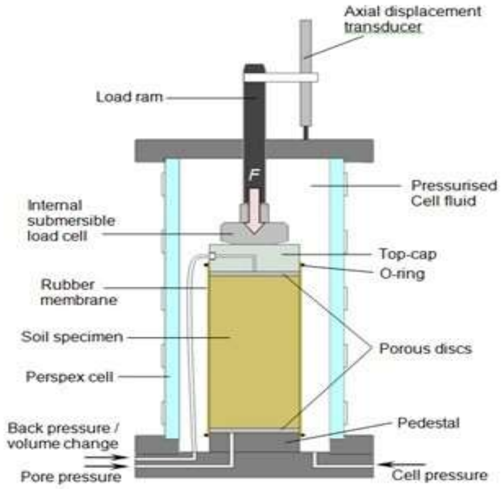

Fig. 1: Tri-axial Shear Test

Fig. 2: Tri-axial Shear Test Setup

2. Reference

1. IS 2720(Part 11):1993 - Determination of the shear strength parameters of a specimen tested in unconsolidated undrained tri-axial compression without the measurement of pore water pressure. Reaffirmed- 2021.
2. IS 2720(Part 12):1981 - Determination of the shear strength parameters of soil from consolidated undrained tri-axial compression with measurement of pore water pressure. Reaffirmed- 2021.

3. Preparation of Sample

3.1 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 sampler tubes.
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, and push the plunger until a sample larger than required length comes out.
5. Cut this sample carefully and hold it on the split sampler so that it does not fall and trim the specimens to required height.
6. Take about 10 to 15 g of soil from the tube for water content determination.
7. Measure the diameter (at top, middle and bottom of the sample and record average of the same), length and weight of the specimen.

3.2 Remoulded Specimen

1. Remoulded samples are prepared at the desired moisture and density by static and dynamic methods of
2. Measure the diameter (at top, middle and bottom of the sample and record average of the same), length and weight of the specimen.

(A) Unconsolidated Undrained (UU) Test

4. Apparatus

Fig. 3: Apparatus for UU test

1. Machine capable of applying and maintaining axial compression to specimen: Capacity of 50 kN, speed of 0.05 to 5 mm per minute and capable of applying axial compression of about one-third of the specimen height.
2. Proving ring of 1 kN capacity with sensitivity of 2 kN for low strength soils and 10 kN capacity with sensitivity of 20 kN for high strength soils.
3. End platen of required diameter made with Perspex glass (diameter of the platen is selected according to the diameter of the sample)
4. Dial gauge of 0.01 mm accuracy
5. Soil specimen of nominal diameter 38, 50, 70 and 100 mm and height approximately equal to twice the nominal diameter. In case of remolded samples, the ratio of diameter of specimen to maximum size of particle in the soil should not be less than 5.
6. O-rings of rubber
7. Seamless Rubber membrane: Open at both ends, with internal diameter equal to specimen diameter, length 50 mm greater than the height of the specimen and thickness of 0.2 to 0.3 mm.
8. Split mould, of length and diameter to suit the test specimen.
9. Trimming knife, piano wire saw, metal scale etc.
10. Non-corrodible metal or Plastic End Caps: Of the same diameter as the test specimen, with thickness of 20 mm for plastic or 12 mm for metal and the upper cap having central spherical seating to receive the loading ram.
11. Apparatus for Moisture Content Determination
12. Balance, with accuracy of 0.5 g.
13. Extruder, Thin-walled Tubes etc., for extruding the sample from sampler tube or from block sample.

14. Soil lathe, Meter Box etc., for preparing the test specimen.

5. Testing Procedure

1. Place the specimen on one of the end caps and put the other end cap on the top of the specimen.
2. Place the rubber membrane around the specimen using the membrane stretcher and seal the membrane to the end caps by means of rubber rings.
3. The specimen is now ready to be placed on the pedestal in the triaxial cell. The pedestal should be either covered with a slid end cap or the drainage valve should be kept closed.
4. Place the specimen on the pedestal of the triaxial cell. The cell must be properly set up and uniformly clamped down to prevent leakage of pressured water during the test.
5. Move down the loading ram and set up it on the circular groove of the top cap. Place a steel ball on the top of plunger. Adjust the center line of the specimen such that the proving ring, the steel ball, loading tram and specimen are in the same line.
6. Fill the cell with the water with inlet valve open and the confining pressure (σ_3) be raised to the desired value (for example, 50 kPa, 100 kPa and 150 kPa or 100kPa, 200 kPa and 300 kPa as per the depth where the sample is brought and the application requirements. Close the inlet valve tightly after filling the cell with water.
7. Adjust the loading machine to bring the loading ram a short distance away from the seat on the top cap. The loading machine shall then be further adjusted to bring the loading ram just in contact with the seat on the top cap and the initial reading of the gauge measuring the axial compression of the specimen shall be recorded.
8. Rate of axial compression shall be selected such that failure is produced within a period of approximately 5 to 15 minutes and readings of the load and compression measuring gauges be taken.
9. The test shall be continued until the maximum value of the stress has been passed or until an axial strain of 20 percent has been reached.
10. The cell shall be drained of fluid and dismantled, and the specimen taken out. The rubber membrane shall be removed from the specimen and the mode of failure shall be noted.
11. The specimen shall be weighed and samples for the determination of the moisture content of the specimen. The most convenient method of recording the mode of failure is by means of sketch indicating the position of the failure planes and the angle of failure plane to the horizontal.
12. At least three specimen should be tested for the UU test.

6. Calculations

1. The difference between the initial reading and any subsequent reading of the load measuring device is the axial load applied to specimen in addition to the cell pressure (σ_3).
2. The corrected area of specimen at any stage of test is given by:
   $A = A_0 / (1 - e)$ and $e = (L_0 - L) / L_0$
   where: A_0 = Initial are of specimen
   L_0 = Initial length of specimen
   L = Length of specimen at the given stage of test
3. The principal stress difference or deviator stress ($\sigma_1 - \sigma_3$) for any stage of test shall be determined by dividing the axial load by the corrected area.
4. A correction to allow for the restraining effect of the rubber membrane shall be deducted from the measured principal stress difference (or deviator stress) to give correct value of maximum principal stress difference (or maximum deviator stress). This correction value shall be calculated as under:
   Correction = $4\,M \times (1 - e) / D$
   where:
   M = Compression modulus of the rubber membrane in kg/cm. This cannot be measure directly but may be assumed to equal to the modules measured in tension, as per the procedure given in Para 6.1.1.4 and Fig. 1 of IS:2720 (Part-11)-1983.
   e = Axial strain at the maximum value of ($\sigma_1 - \sigma_3$)
   D = Initial diameter of the sample

7. Reporting of Results

1. Where required, the stress-strain curve of the test shall be plotted with the axial strain on X-axis and axial stress on Y-axis.
2. The type of sampler and method of sampling shall be reported.
3. The shear parameters shall be obtained from a plot of Mohr circles.

8. Video

Triaxial Shear Test – Unconsolidated Undrained (UU) Test

(B) Consolidated Undrained (CU) Test

4. Apparatus

1. Machine capable of applying and maintaining axial compression to specimen, with Proving ring to measure the axial force being applied and Dial gauge to measure the change in length of the specimen.
2. Triaxial cell
3. Pore water pressure transducer
4. Volume change transducer
5. Data acquisition system
6. Computer with triaxial testing software
7. Specimen preparation holder for remoulded specimen
8. Coarse Porous stone of about 3 mm thickness and made of the material with particle size between 180 to 150 micron.
9. Filter paper. Filter paper strips or a rectangular paper of appropriate size with parallel slits should be provided along the height of the sample at its circumference to induce radial drainage. Filter paper discs should be placed between the sample ends and the coarse porous stones.
10. O-rings of rubber, with unstretched diameter of 31 +/- 1 mm.
11. Seamless Rubber membrane: Open at both ends, with internal diameter equal to specimen diameter, length about 140 mm and thickness of about 0.2 mm.
12. End platen of required diameter made with Perspex glass (diameter of the platen is selected according to the diameter of the sample)
13. Soil specimen of nominal diameter 38, 50, 70 and 100 mm and height approximately equal to twice the nominal diameter. The ratio of diameter of specimen to maximum size of particle in the soil should not be less than 5.
14. Split mould, of length and diameter to suit the test specimen.
15. Extruder, Thin-walled Tubes etc., for extruding the sample from sampler tube or from block sample.
16. Soil lathe, Meter Box etc., for preparing the test specimen.
17. Trimming knife, piano wire saw, metal scale etc.
18. Apparatus for Moisture Content Determination
19. Balance, with accuracy of 0.5 g.

5. Testing Procedure

1. Place the saturated porous stone disc, of diameter same as the sample, on top of the pedestal of triaxial testing machine and place the circular filter paper of same size over this disc. Then place the specimen on top of the filter paper.

2. Stretch the rubber membrane, using membrane stretcher, and placed it on the soil specimen. Place the O rubber rings on top and bottom of platens of the soil specimen.
3. Place the triaxial cell over the base and tighten with the screws. Fill up the cell with water and apply a small confining pressure of about 10 kPa to hold the specimen in place.
4. The soil specimen needs to be completely saturated before consolidation phase. For this first of all water saturation is done by supplying water from bottom of the specimen and allowing it to go out of the specimen from the top. The water used needs to be distilled & de-aired water.
5. The forced saturation is performed by applying cell pressure and the back pressure at constant increments with constant difference between these two pressures. The sample is allowed to saturate for some time (10-20 min) after each increment of cell pressure and the back pressure. This increase should be followed by a check for saturation value (B), also known as Skempton's pore pressure parameter. B is the ratio of pore pressure change due to the change in cell stress ($B = \Delta u / \Delta\sigma_{cell}$). It is important to note that cell pressure always is higher than back pressure. The sample is said to be fully saturated if the B value greater than 0.95 can be acquired.
6. The consolidation stage is started by applying confining pressure. During this stage, drainage valve is kept open and the volume change is measured until no change in volume is observed (when primary consolidation is over).
7. The machine is set in motion at an appropriate strain rate based on the soil type. The fine grained soils require to be sheared at much lower strain rate (0.05% per min – 0.2% per min) as compared to the coarse grained soils (0.5% per min – 1% per min). Fine grained soil has lower permeability (lower void space), thus pore water pressure distribution will not be uniform at higher strain in such soils (clay, silt).
8. Data acquisition system (DAQ) is attached with the computer & various transducers of triaxial system, which records the data with the help of triaxial CU software. The experiment is stopped at around 15% axial strain.
9. No drainage is allowed during shearing stage and pore pressure is measured throughout the test using the pore pressure transducer.
10. The three CU tests need to be performed at three different chosen confining pressures (σ_3).

6. Calculations

1. Deviator stress versus Axial strain curve and Excess pore pressure versus axial strain curves are plotted for all three CU triaxial tests.
2. The failure point of soil specimen can be defined as the point of peak stress in stress-strain relationship of each test.
3. The axial strain during consolidation is calculated by dividing the axial deformation by post-consolidation length.
4. By subtracting each reading of pore water pressure from the initial reading of pore water pressure, change in pore water pressure is obtained.
5. By subtracting the value of load on proving ring when the loading frame was operated without the loading ram touching the sample from each value of load on proving ring, obtain the values of axial loads during shearing.
6. By dividing post-consolidation area A, by (1 - e) where "e" is the axial strain, obtain for each e the value of the area of the sample A_I at that strain.
7. By dividing each value of axial load, during shearing, by corresponding value of area of the sample A_I obtain values of deviator stress ($\sigma_1 - \sigma_3$).
8. Obtain values of initial cell pressure, that is cell pressure minus back pressure, which will be minor principal effective stress (σ_3).
9. By adding values of deviator stress and minor principal stress, obtain values of major principal stress (σ_1).
10. The values of effective stresses (for both minor as well as principal stress) can be obtained by subtracting the value of measured pore water pressure from values of measured stresses.

7. Reporting of Results

1. The type of sampler and method of sampling shall be reported.
2. The shear parameters (total or effective) shall be obtained from a plot of Mohr circles.

(C) Consolidated Drained (CD) Test

4. Apparatus

Same as for the CU test above.

5. Testing Procedure

Same as for the CU test above except the changes:

1. Item No. 7: The CD tests are performed at much slower strain rate as compared to CU tests for the same soil. The strain rate for CD test can be chosen approx. 8-10 times lower than the CU test. It is important to have no pore water pressure generation throughout the shearing phase of CD test or in other words strain rate must be so small that pore water pressure must get dissipated quickly when specimen is subjected to compression loading in CD test.
2. Item No. 9: Drainage valves are kept open during shearing stage and volume change is measured throughout the test using the volume change transducer.

6. Calculations

1. Deviator stress versus Axial strain curve and Volumetric strain versus axial strain curves are plotted for all three CU triaxial tests.
2. Volumetric strain = (ΔVs / Vc) x 100
   where, ΔV = Volume change due to deviator stress during shearing stage
   Vc = volume of specimen after the isotropic consolidation or before shearing stage
3. Volume of soil specimen after isotropic consolidation (Vc) can be obtained by following equation:
   $Vc = V0 - \Delta Vc$
   where, ΔVc = volume change during isotropic consolidation and $V0$ is initial volume of the soil specimen
4. The failure point of soil specimen can be defined as the point of peak stress in stress-strain relationship of each CD triaxial test.
5. Effective stress analysis is performed in CD triaxial tests as pore pressure is zero as drainage valves kept open throughout the test. Total stress is the same as the effective stress during this test.

7. Reporting of Results

1. The type of sampler and method of sampling shall be reported.
2. The shear parameters (total or effective) shall be obtained from a plot of Mohr circles.

8. Download

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