

Processing triaxial tests

Students are requested to analyze the results of a drained and an undrained triaxial compression tests. The word *drained* is used to describe the condition in which the pore water is allowed to flow freely into or out of the soil sample, and thus dissipate any excess pore pressure. In drained test, a *backpressure* is applied throughout the test in order to ensure sample saturation: the pore water pressure is kept constant and equal to a static value p_w . The word *undrained* indicates that pore water is not allowed to move into or out of the specimen, thus the pore water pressure is not constant.

1. Test conditions

Both samples are prepared in triaxial cells at following dimensions: diameter 38 mm, height 76 mm. Conditions for tests:

a) drained triaxial test

- Initial isotropic compression up to a cell pressure $\sigma_c = 250$ kPa.
- Initial pore water pressure $p_w = 50$ kPa.

The sample undergoes a conventional drained triaxial compression test with cell pressure σ_c and pore water pressure p_w held constant.

b) undrained triaxial test

- Initial isotropic compression up to a cell pressure $\sigma_c = 500$ kPa.
- Initial pore water pressure $p_w = 80$ kPa.

An undrained triaxial compression test is carried out at a constant cell pressure σ_c on the sample.

2. Experimental data

a) Drained triaxial test

After the isotropic compression, the shearing phase is performed. During the shearing phase, the following results are obtained, where F is the applied force, δ is the axial displacement (negative means that the sample height is reducing), ΔV_w is the pore water volume variation (*note*: positive ΔV_w implies that water flows out of the sample).

| F (N) | δ (mm) | ΔV_w (mm ³ · 10 ³) |
|----------|------------------|------------------------------------------------------|
| 0 | 0 | 0 |
| 108 | -0.85 | 1.2 |
| 240 | -4.31 | 4.9 |
| 305 | -8.72 | 7.1 |
| 360 | -16.52 | 8.0 |
| 412 | -24.02 | 8.2 |
| 443 | -27.3 | 8.2 |

b) Undrained triaxial test

After the isotropic compression, the shearing phase is performed. The following results are obtained during the shearing phase, where F is the applied force, δ is the axial displacement (negative means that the sample height is reducing) and p_w is the pore water pressure.

| F (N) | δ (mm) | p_w (kPa) |
|------------------|-------------------------------------|-----------------------------------|
| 0 | 0 | 80 |
| 46 | -1.30 | 112 |
| 85 | -3.58 | 150 |
| 120 | -8.39 | 198 |
| 135 | -12.98 | 206 |
| 152 | -18.50 | 211 |
| 156 | -20.50 | 211 |

3. Instructions

Calculate deviatoric stress q , mean effective p' and mean total stress p , axial strain ϵ_a , and volumetric strain ϵ_v for each step of the test. Give the resulting values in a table. Then, plot the experimental results in the following planes (y axis - x axis):

1. $q - \epsilon_a$
2. $q - p (p')$
3. $\epsilon_v - \epsilon_a$
4. $\epsilon_v - p'$
5. $p_w - \epsilon_a$

Represent both the total and effective stress paths in the plane $q - p (p')$, highlighting the difference between the two.

Comment on the difference between the total stress paths and the effective stress path. How is it different from the drained case?

Calculations and results

a) Drained triaxial test:

The following formulae are used to determine the axial and volumetric strain, the deviatoric stress and the mean effective stress. Values at the beginning of the shearing phase are reported with the 0 subscript:

$$\varepsilon_v = -\frac{\Delta V}{V_0} \text{ with } \Delta V = -\Delta V_w$$

For a saturated drained test, the variation in pore water volume correspond to the variation in pore volume, thus in sample volume (assuming incompressible grains and water)

$$V_0 = 76 \cdot \pi \cdot \left(\frac{38^2}{4}\right) = 8.62 \cdot 10^4 \text{ mm}^3$$

$$\varepsilon_a = -\frac{\delta}{H_0}$$

$$A = \frac{V}{H} = \frac{V_0 + \Delta V}{H_0 + \delta} = A_0 \frac{1 - \varepsilon_v}{1 - \varepsilon_a} \text{ with } A_0 = 1134 \text{ mm}^2$$

The area of the sample section is not constant, but varies according to the volume and height variations. It needs to be recalculated at each step.

$$q = \sigma_1 - \sigma_3 = \frac{F}{A}$$

$$\text{with } \sigma_1 = \sigma_3 + \frac{F}{A} \text{ and } \sigma_3 = \sigma_c$$

$$p' = p - p_w = \frac{\sigma_1 + 2\sigma_3}{3} - p_w = \frac{\frac{F}{A} + 3\sigma_c}{3} - p_w$$

| | F (N) | δ (mm) | ΔV_w (mm ³ ·10 ³) | H (mm) | V (mm ³ ·10 ³) | A (mm ²) | q (kPa) | p (kPa) | ε_a (-) | ε_v (-) | p' (kPa) |
|--------------------------|----------|------------------|-----------------------------------------------------|-----------|------------------------------------------|-------------------------|------------|------------|------------------------|------------------------|-------------|
| <i>Initial condition</i> | 0 | 0 | 0 | 76 | 86.2 | 1134 | 0 | 250 | 0.00 | 0.00 | 200 |
| | 108 | -0.85 | 1.2 | 75.15 | 85.0 | 1131 | 95 | 282 | 0.01 | 0.01 | 232 |
| | 240 | -4.31 | 4.9 | 71.69 | 81.3 | 1134 | 212 | 321 | 0.06 | 0.06 | 271 |
| | 305 | -8.72 | 7.1 | 67.28 | 79.1 | 1176 | 259 | 336 | 0.11 | 0.08 | 286 |
| | 360 | -16.52 | 8 | 59.48 | 78.2 | 1315 | 274 | 341 | 0.22 | 0.09 | 291 |
| | 412 | -24.02 | 8.2 | 51.98 | 78.0 | 1500 | 275 | 342 | 0.32 | 0.10 | 292 |
| | 443 | -27.3 | 8.2 | 48.7 | 78.0 | 1601 | 277 | 342 | 0.36 | 0.10 | 292 |

Remarks:

The sign convention for stresses and strains is that of soil mechanics (compression is positive)

In a drained triaxial compression test the total and effective stress path (TSP and ESP respectively) are parallel, and the difference is equal to the pore pressure value p_w , which is constant.

b) Undrained triaxial test

The following formulae are used to determine the axial strain, the deviatoric stress and the mean effective stress:

$\varepsilon_v = 0$ because the test is undrained

$$\varepsilon_a = -\frac{\delta}{H_0}$$

$$A = \frac{V}{H} = \frac{V_0 + \Delta V}{H_0 + \Delta H} = \frac{A_0 H_0}{H_0(1 - \varepsilon_a)} = A_0(1 - \varepsilon_a)^{-1}$$

with $\Delta V=0$ and $A_0 = 1134 \text{ mm}^2$

The area of the sample section is not constant, but varies according to height variations, at constant volume. It needs to be recalculated at each step.

$$q = \sigma_1 - \sigma_3 = \frac{F}{A}$$

with $\sigma_1 = \sigma_3 + \frac{F}{A}$ and $\sigma_3 = \sigma_c$

$$p' = p - p_w = \frac{\sigma_1 + 2\sigma_3}{3} - p_w = \frac{\frac{F}{A} + 3\sigma_c}{3} - p_w$$

| F (N) | δ (mm) | p_w (kPa) | H (mm) | V (mm³) | A (mm²) | q (kPa) | p (kPa) | ε_a (-) | ε_v (-) | p' (kPa) |
|------------------------|-------------------------------------------|-----------------------------------------|-------------------------|-------------------------------------|-------------------------------------|--------------------------|--------------------------|-------------------------------------------------|-------------------------------------------------|---------------------------|
| 0 | 0 | 80 | 76 | | 1134 | 0 | 500 | 0.00 | | 420 |
| 46 | -1.3 | 112 | 74.7 | | 1154 | 40 | 513 | 0.02 | | 401 |
| 85 | -3.58 | 150 | 72.42 | | 1190 | 71 | 524 | 0.05 | | 374 |
| 120 | -8.39 | 198 | 67.61 | 86.2·10 ³ | 1275 | 94 | 531 | 0.11 | 0 | 333 |
| 135 | -12.98 | 206 | 63.02 | | 1368 | 99 | 533 | 0.17 | | 327 |
| 152 | -18.5 | 211 | 57.5 | | 1499 | 101 | 534 | 0.24 | | 323 |
| 156 | -20.5 | 211 | 55.5 | | 1553 | 100 | 533 | 0.27 | | 322 |

Remarks :

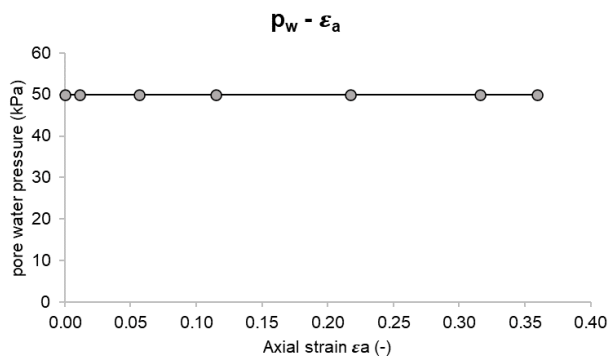
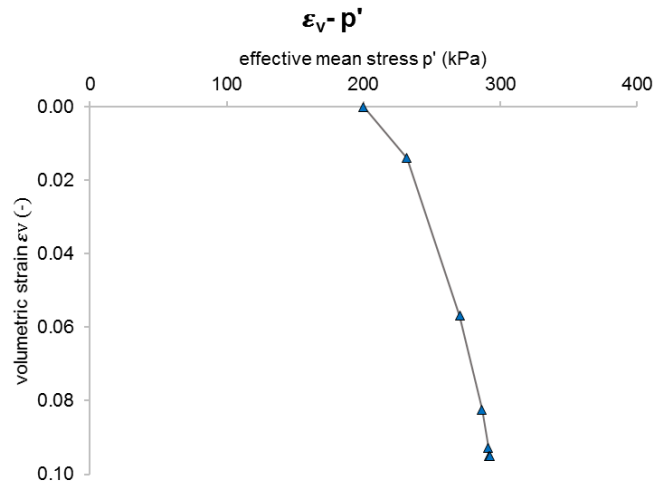
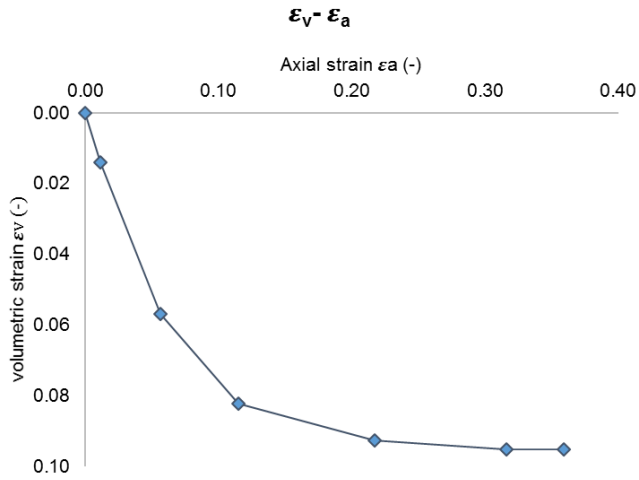
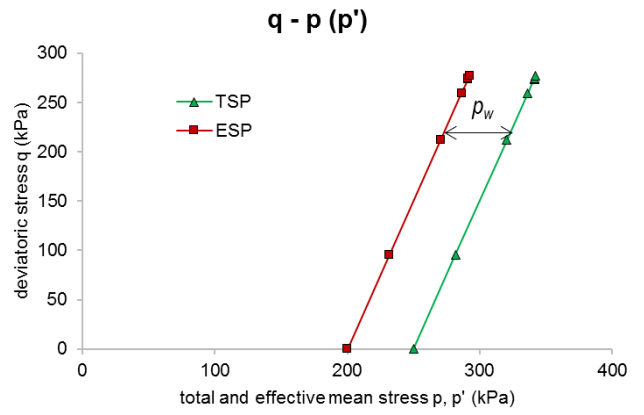
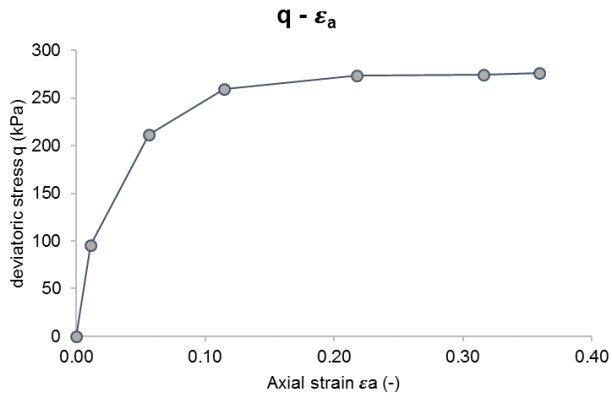
- The sign convention for stresses and strains is that of soil mechanics (compression is positive)
- In undrained conditions, the volume of water flowing into or out of the sample is null, the overall volume change is null.

Difference between the total stress paths and the effective stress paths:

Differently from the drained test, in an undrained test the TSP and EST are not parallel. During the test, water overpressure build up, increasing the difference between the total and effective pressure.

Graphs

a) Drained triaxial test:



b) Undrained triaxial test:

