Japanese Geotechnical Society Standard (JGS 0523-2020)
Method for consolidated-undrained triaxial compression test on soils with pore water pressure measurements

1 Scope

This standard specifies a test method to determine the strength and the deformation characteristics of a soil specimen when it is subjected to undrained axial compression after isotropic consolidation, and to obtain the effective stresses at the maximum principal stress difference. The test shall be carried out on three or more test specimens prepared from the same test material, under different consolidation stresses within the required consolidation stress range. In this test, the relationship between the volumetric change during the consolidation process (and the axial displacement if possible) and time, and the relationship between the pore water pressure during the axial compression process and the axial strain are obtained. This standard applies mainly to saturated cohesive soils.

Note 1: In this standard, it is assumed that the axial displacement is measured, but if the axial displacement is not measured, provisions relating to axial displacement may be ignored.

Note 2: This standard is also applicable to saturated coarse granular soil.

2 Normative references

The following standards shall constitute a part of this standard by virtue of being referenced in this standard. The latest versions of these standards shall apply (including supplements).

The specimens to be used in this test shall be prepared and installed in accordance with the following standard.

JGS 0520 Preparation of soil specimens for triaxial tests

For coarse-grained soil with a maximum particle size exceeding about 20 mm, the test specimens to be used in this test shall be prepared and installed in accordance with the following standard.

JGS 0530 Preparation of specimens of coarse granular materials for triaxial tests

3 Terms and definitions

The terms and definitions used in this standard are as follows:

Note: The test covered by this standard can be referred to in abbreviated form as $\overline{\mathrm{CU}}$ triaxial test.

3.1 $\overline{\mathrm{CU}}$

Shearing soil under the undrained condition with pore pressure measurement after consolidating it (Consolidated and Undrained: $\overline{\mathrm{CU}}$).

3.2 Axial stress

The stress acting on the specimen in the cylinder axis direction.

3.3 Lateral stress

The stress acting in the radial direction of the specimen.

3.4 Principal stress difference

The difference between the axial stress and the lateral stress. The value of stress shall be defined at the mid-height of the test specimen.

3.5 Isotropic stress state

The stress state when the axial stress is equal to the lateral stress.

3.6 Cell pressure

The pressure applied to the triaxial pressure cell. The lateral stress is equal to the cell pressure.

3.7 Back pressure

The pressure applied to the pore water within the test specimen (JIS A 1227).

Note: In this standard, the back pressure means the pore water pressure applied to the specimen to achieve a higher degree of saturation of the specimen while maintaining a constant effective stress.

3.8 Consolidation stress

The stress of soil element that induces consolidation.

Note: In this standard, the consolidation stress means the difference between the externally applied stress on the specimen and the back pressure during the consolidation process.

3.9 Undrained compressive strength of soil

The maximum principal stress difference that can be applied to the soil specimen when no pore water is allowed to flow in or out of the specimen.

4 Equipment

4.1 Triaxial compression test apparatus

The triaxial compression test apparatus shall consist of a triaxial pressure cell, a system for applying cell pressure and back pressure, a compression device, and measurement devices for load, displacement, volume change, and pore water pressure. The apparatus shall satisfy the following conditions. Figure 1 shows an example of the configuration of triaxial compression test apparatus. Figure 2 shows the schematic structure of the triaxial pressure cell; (a) is an example in which the piston and cap are rigidly connected, while (b) is an example in which the two are not rigidly connected. Both forms must allow for mounting of a specimen having the same diameter as the cap and pedestal between the cap and pedestal, covered with a rubber sleeve, and sealed with an O-ring, etc.

a) The apparatus shall have sufficiently high load-bearing strength and load capacity to handle the maximum cell pressure, back pressure and maximum axial compression load to be applied to the specimen.

b) The apparatus shall be capable of maintaining the cell pressure and back pressure within ±4 kN/m^2 of a target value for pressures up to 200 kN/m^2, and within ±2 % of the target value for pressures of 200 kN/m^2 or greater, for the duration of a single test.

c) The apparatus shall be capable of applying and sustaining axial displacement up to 15% or more of the specimen height.

d) The apparatus shall be capable of measuring the cell pressure, the back pressure and the pore water pressure inside the soil specimen, with an allowable tolerance of 2 kN/m^2 for pressures up to 200 kN/m^2 and 1% for pressures of 200 kN/m^2 or greater.

Note: Normally, a diaphragm type pressure transducer is used as the pore water pressure measurement device. If the volume of the test specimen is V, and the volume change of the measuring system including the pressure transducer is ΔV for a change in pore water pressure Δu, then a proper transducer shall be selected so that its performance satisfies $(\Delta V/V)/\Delta u<5\times10^{-6}$ m²/kN. Also, the measured values of the pore water pressure are affected by temperature changes, so it is desirable that the change in temperature within the measurement room be controlled to within ±2 °C.

e) The apparatus shall be capable of measuring the axial compression force up to the specimen's maximum axial compressive strength within an allowable tolerance of 1 %. If the test apparatus is set up such that the load cell is located outside the triaxial pressure cell, the frictional force at the point of sliding between the piston and the triaxial pressure cell shall be measured. This friction value shall be used to correct the measured value of axial compression force. If the load cell is located inside the triaxial pressure cell, the effect of cell pressure shall be determined and the measured value of axial compression force shall be corrected.

f) The apparatus shall be capable of measuring the axial displacement up to 15 % of the specimen height within an allowable tolerance of 0.1 %.

g) The apparatus shall be capable of measuring the volume change of the specimen up to its maximum value within an allowable tolerance of 0.1 % of the specimen's initial volume. In a standard setup, the volume change of the test specimen shall be determined as the amount of water expelled from the specimen during the test measured by using a burette or other devices with equivalent or higher measurement accuracy. In the sections below, a burette is used as a representative device for measuring the volume change.

5 Test method

5.1 Preparation and set-up of test specimen

Preparation and set up of the test specimen shall be in accordance with JGS 0520 Preparation of soil specimens for triaxial tests. However, the test specimen shall have a height not less than twice its diameter. For coarse-grained soils with a maximum particle diameter greater than 20 mm, the specimen shall be prepared in accordance with JGS 0530 Preparation of specimens of coarse granular materials for triaxial tests.

5.2 Consolidation process

The consolidation procedure of the test shall be in accordance with the following requirements.

a) Make zero adjustments to the displacement transducer and pore water pressure transducer, and confirm that the pore water pressure measurement system is indicating the desired value of back pressure u_b (kN/m²) by opening the valve in the pore water pressure measurement system. At the same time, take the initial reading of the burette.

b) Close the drainage valve connected to the burette. Increase only the isotropic stress so that the difference between the isotropic stress and the back pressure is equal to the desired value of consolidation stress. If the loading piston is not rigidly connected to the cap, set the load measuring device, the piston, and the cap in contact with each other before this process.

c) Open the drainage valve to start consolidation.

d) Record readings of the volume change ΔV_t (mm³) and the axial deformation ΔH_t (mm) of the specimen at appropriate time intervals during consolidation, and plot them. Consolidation shall be continued at least until the end of primary consolidation. Measure the volume change ΔV_c (mm³) (which is equal to the amount of water expelled from the specimen) and the axial deformation ΔH_c (mm) due to consolidation. If the axial displacement cannot be measured during consolidation because the piston is not rigidly connected to the cap, carefully bring the piston into contact with the cap, while observing the load cell reading such that no additional force is applied to the specimen Then take the reading of the displacement transducer. This measured value is to be taken as the axial displacement ΔH_c (mm) due to consolidation.

Note: Refer to Section 5.2(d) of JGS 0522 Method for consolidated-undrained (CU) triaxial compression test on soils for deciding when to stop consolidation.

e) Close the drainage valve connected to the burette, and increase the isotropic stress by the amount $\Delta\sigma$ (kN/m^2). Wait for the change in pore water pressure caused by this to stabilize, and measure the pore pressure increment Δu (kN/m^2) after stabilization and the time required for stabilization. A schematic illustration to explain this process is shown in Figure 3. The standard amount of isotropic stress increment $\Delta\sigma$ shall be 10 to 50 kN/m^2.

f) Return the isotropic stress to its original value, wait for the value of the pore water pressure to stabilize, and open the drainage valve.

5.3 Axial compression process

The axial compression shall be carried out in accordance with the following procedure.

a) Check and adjust the zero reading of the load cell and deformation transducer.

b) Close the drainage valve.

c) Start Compressing the specimen continuously at a constant strain rate keeping the cell pressure constant. To ensure that the pore water pressure is uniformly distributed in the specimen, the standard axial compression rate shall be about 0.1 %/min for silty soils and about 0.05 %/min for clayey soils.

d) Record the axial compression force P (N), the axial deformation ΔH (mm), and the pore water pressure u (kN/m^2) during compression.

Note: If the axial compression force, the axial displacement, and the pore water pressure are not recorded continuously, the measurement time intervals should be sufficiently small to enable smooth curves for the principal stress difference - axial strain curve and the pore water pressure – axial strain to be drawn. It is recommended, for example, to measure the axial deformation at a maximum interval of 0.2 mm up to the maximum value of the axial compression force, and thereafter at maximum intervals of 0.5 mm.

e) Terminate the compression either when an axial strain of more than 3 % has been reached since the maximum axial load reading, when the load has fallen to about 2/3 of its peak value, or when an axial strain of 15 % has been reached.

f) Remove the specimen from the triaxial pressure cell, and observe and record its deformed shape, failure mode, and other features. The observation shall be made in the direction that captures the features of failure most clearly. If a slip surface is found, observe it from the direction in which the steepest gradient is determined and record it so that the gradient angle can be approximately read. Any heterogeneity of the specimen and the presence of any foreign materials shall be observed and recorded.

g) Measure the oven-dried mass of the specimen m_s (g).

Note: This step in the process may be omitted if the water content of the specimen is determined from the trimmed waste of the sample.

6 Processing test results

6.1 Initial state of the specimen before consolidation

Refer to Section 6.1 of JGS 0522 Method for consolidated-undrained (CU) triaxial compression test on soils for the initial state of the specimen before consolidation.

6.2 Consolidation process

Refer to Section 6.2 of JGS 0522 Method for consolidated-undrained (CU) triaxial compression test on soils for the method of calculation for the consolidation process.

6.3 Pore pressure coefficient, *B*-value

The *B*-value of the test specimen after consolidation shall be calculated from the following equation and rounded to two significant digits.

$$B = \frac{\Delta u}{\Delta \sigma}$$

where

$\Delta\sigma$: Amount of isotropic stress increment (kN/m^2)
Δu: Amount of pore water pressure increment (kN/m^2) caused by $\Delta\sigma$

6.4 Axial compression process

The method of calculation for the axial compression process shall be as follows.

a) The axial strain of the test specimen ε_a (%) shall be calculated from the following equation, where compression is defined to be positive.

$$\varepsilon_a = \frac{\Delta H}{H_c} \times 100$$

where

ΔH: Axial deformation of the specimen in the axial compression process (mm), where compression is defined to be positive

b) The principal stress difference ($\sigma_a - \sigma_r$) (kN/m^2) and pore water pressure increment u_e (kN/m^2) due to the axial compression at axial strain of ε_a (%) shall be calculated from the following equations.

$$\sigma_a - \sigma_r = \frac{P}{A_c}\left(1 - \frac{\varepsilon_a}{100}\right) \times 1000$$

$$u_e = u - u_b$$

where

P: Axial compression force (N) applied to the specimen at the axial strain ε_a (%), where P=0 in the isotropic stress state
σ_a: Axial stress (kN/m^2) acting on the specimen
σ_r: Lateral stress (kN/m^2) acting on the specimen
u: Pore water pressure in the specimen (kN/m^2)
u_b: Back pressure (kN/m^2)

c) Draw graphs with the principal stress difference and the pore water pressure on the vertical axis versus axial strain on the horizontal axis, to obtain the principal stress difference – axial strain curve and the pore water pressure increment due to axial compression – axial strain curve.

d) Obtain the maximum principal stress difference $(\sigma_a - \sigma_r)_{max}$ in the axial strain range of $0 < \varepsilon_a \leq 15$ % from the graph, and the corresponding value of axial strain shall be taken as the strain at failure (%), which shall be rounded to one digit after the decimal point. The value of this maximum principal stress difference shall be taken as the compressive strength, which shall be rounded to three significant digits.

e) Calculate the effective principal stresses, σ'_a (kN/m^2) and σ'_r (kN/m^2) in the axial compression process from the following equations, and draw an effective stress path diagram with $(\sigma_a - \sigma_r)/2$ on the vertical axis versus $(\sigma'_a + \sigma'_r)/2$ on the horizontal axis.

$$\sigma'_r = \sigma_r - u$$

$\sigma'_a = (\sigma_a - \sigma_r) + \sigma'_r$

f) Calculate the effective axial stress σ'_{af} (kN/m^2) and the effective lateral stress σ'_{rf} (kN/m^2) at the maximum principal stress difference from the following equations, which shall be rounded to three significant digits.

$\sigma'_{rf} = \sigma_{rf} - u_f$

$\sigma'_{af} = (\sigma_a - \sigma_r)_{max} + \sigma'_{rf}$

where

u_f: Pore water pressure at the maximum principal stress difference (kN/m^2)

Note: Obtain σ'_a and σ'_r at $(\sigma'_a/\sigma'_r)_{max}$, if necessary.

7 Reporting

The following test results and other items shall be reported.

a) Method of specimen preparation

b) Dimensions of the specimen before the consolidation

c) Magnitude of the cell pressure (kN/m^2) and the back pressure (kN/m^2)

d) Relationship between the volume change (mm^3) and time (min) in the consolidation process

Note: Report the relationship between the axial displacement and time in the consolidation process, if necessary.

e) Oven-dried mass(g) of the test specimen and the dry density (Mg/m^3) after consolidation

Note: Report the void ratio of the specimen after consolidation, if necessary.

f) *B*-value and time (min) required for the stabilization of the pore water pressure

g) Strain rate (%/mm) in the axial compression process

h) Compressive strength (kN/m^2) and strain at failure (%)

i) Principal stress difference versus axial strain curve and pore water pressure increment versus axial strain curve

j) Effective stress path diagram

k) Failure condition of the specimen

l) Effective principal stresses (kN/m^2) at the maximum principal stress difference

Note: Report the values of σ'_a and σ'_r at $(\sigma'_a/\sigma'_r)_{max}$, if necessary.

m) Relationship between compressive strength and consolidation stress

n) If the method used deviates in any way from this standard, give details of the method used

o) Other reportable matters

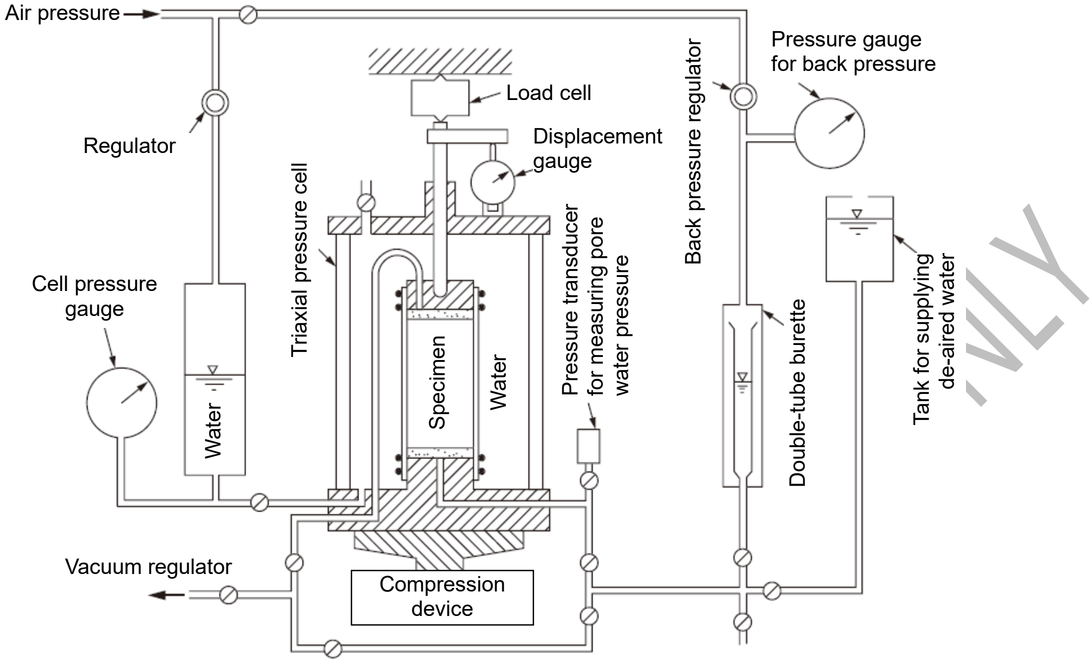

Figure 1 Example of the configuration of CU triaxial test apparatus

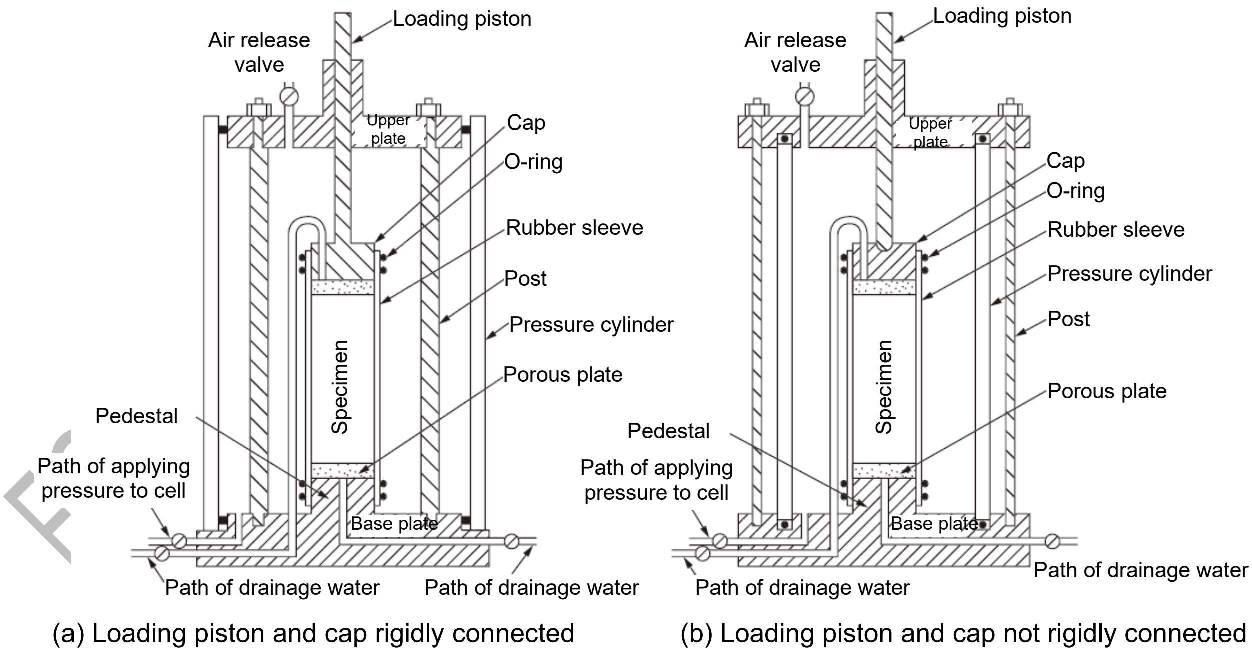

Figure 2 Schematic structure of the triaxial pressure chamber

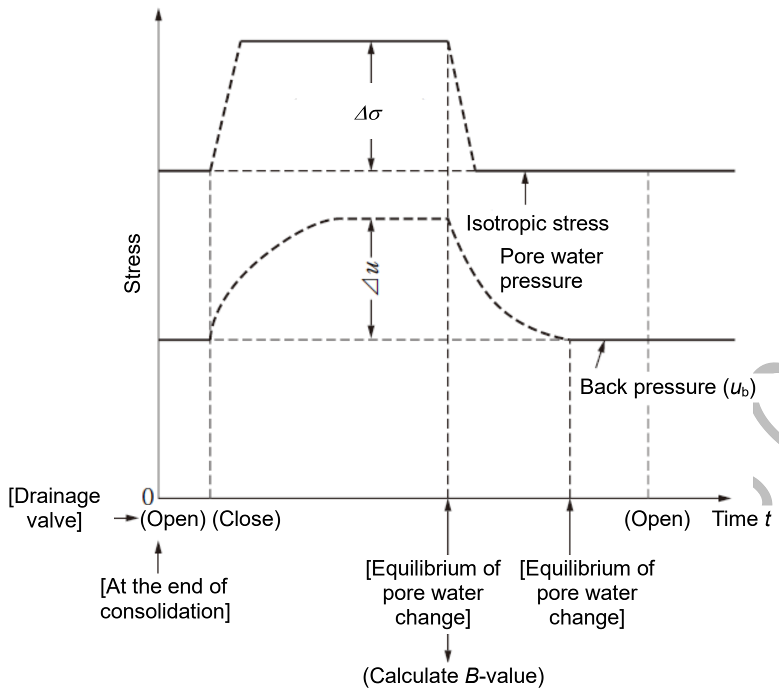

Figure 3 Method of measuring *B*-values