Japanese Geotechnical Society Standard (JGS 0526-2020)
Method for K_0 consolidated-undrained triaxial extension test on soils with pore water pressure measurements

1 Scope

This standard specifies a test method to determine the consolidation properties of soil consolidated in the K_0 condition, and the strength and deformation properties when the soil is subjected to axial extension in an undrained condition following consolidation. The test shall be performed for saturated cohesive soil.

Note: This standard may also be applied mutatis mutandis to sandy 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 soil specimens used for this test shall be prepared and installed in accordance with the following standards.

JGS 0520 Preparation of soil specimens for triaxial tests

When performing this test, the following standards shall be referenced for matters not specified in this standard.

JIS A 1217 Test method for one-dimensional consolidation properties of soils using Incremental loading

JGS 0522 Method for consolidated-undrained triaxial compression test on soils (CU)

JGS 0523 Method for consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($\overline{\text{CU}}$)

JGS 0524 Method for consolidated-drained triaxial compression test on soils

JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\text{CU}}\text{C}$)

3 Terms and definitions

In addition to those specified in JIS A 0207, the main terms and definitions used in this standard are as follows:

Note 1: As axial extension force is applied following K_0 consolidation, the soil specimen will be in an extended state when the axial stress becomes lower than the lateral stress (when the principal stress difference becomes negative).

Note 2: This test may be abbreviated to "$K_0\overline{\text{CU}}\text{E}$ triaxial test".

3.1 K_0 consolidated-undrained triaxial extension ($K_0\overline{\text{CU}}\text{E}$)

Application of axial extension force to achieve shear while simultaneously measuring pore water pressure in the undrained condition after consolidation in the triaxial K_0 condition.

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 Anisotropic stress state

A stress state with different axial stress and lateral stress.

3.6 K_0 condition

An anisotropic stress state in which no displacement is produced in the radial direction of the soil specimen.

3.7 Cell pressure

The pressure applied within a triaxial cell.

3.8 Back pressure

The pressure applied to the pore water within the 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 test specimen while maintaining a constant effective stress.

3.9 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 test specimen and the back pressure during the consolidation process.

3.10 Axial consolidation stress

Consolidation stress in the long axis direction of the specimen.

3.11 Lateral consolidation stress

Consolidation stress in the radial direction of the specimen.

3.12 Undrained extensive strength

The minimum 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 test apparatus

The triaxial test equipment shall consist of a triaxial pressure cell, a system for applying cell pressure and back-pressure, axial loading equipment, and measurement devices for load, displacement, volume change, and pore water pressure. The apparatus shall satisfy the following conditions. Figure 1 in JGS 0525 "Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements $K_0\overline{\mathrm{CU}}\mathrm{C}$" shows an example of the configuration of K_0 consolidated triaxial test equipment that conducts tests through automatic control. A configuration in which the piston and cap are rigidly connected is suitable for the structure of the triaxial cell. A configuration that prevents the triaxial cell from separating from the loading equipment when tensile force is applied to the piston is needed.

a) The apparatus shall have sufficiently high load-bearing strength and load capacity to handle the maximum cell pressure, back pressure and maximum axial load to be applied to the specimen, and shall be capable of applying axial stress and lateral stress independently during consolidation.

b) The apparatus shall be capable of continuously applying the specified cell pressure and back pressure within ±2 kN/m^2 of the target value for pressures up to 200 kN/m^2, and within ±1 % 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 axial displacement continuously at a constant rate up to 15% 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 $(\Delta V/V)/\Delta u < 5\times10^{-6}$ m^2/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 force up to the specimen's maximum axial force within an allowable tolerance of 1 %. As a standard, a load cell shall be provided inside the triaxial cell, and in this case, any effect of cell pressure shall be calibrated, and the axial force measurement shall be corrected. In the case of test equipment in which the load cell is provided outside the triaxial cell, the friction force of the piston and the sliding section of the pressure chamber shall be measured and the axial compression force measurement 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 0.02 %.

g) The apparatus shall be capable of measuring the volume change of the specimen up to its maximum value within an allowable tolerance of 0.05 % of the specimen's initial volume. When measuring lateral displacement and controlling K_0 consolidation, the apparatus shall be capable of conducting measurements with an allowable tolerance of 0.025 % of the initial diameter of the soil specimen.

5 Test method

5.1 Preparation and set-up of test specimen

The preparation and set up of the test specimen shall be in accordance with JGS 0520 Preparation of soil specimens for triaxial tests. The standard height of the specimen shall be 1.5 to 2 times the diameter. The drain filter attached to the soil specimen shall be made of a material that exhibits little compression or expansion when the cell pressure is changed.

Note 1: Correction should be performed when there is a great change in volume of the drain filter.

Note 2: When performing a test for K_0 consolidation only, the height of the soil specimen may be reduced.

5.2 Confirmation of degree of saturation

The pore pressure coefficient B (B value) shall conform to Section 5.2 in JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\mathrm{CU}}\mathrm{C}$).

5.3 Consolidation process

The consolidation process shall conform to Section 5.3 in JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\mathrm{CU}}\mathrm{C}$).

5.4 Undrained extension process

The undrained extension process shall be carried out in accordance with the following procedure.

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

b) Close the drainage valve.

c) Start extending 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 force P (N), the axial displacement ΔH (mm) and the pore water pressure u (kN/m^2).

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.

e) Terminate the extension either when an axial strain of more than -3 % has been reached since the minimum 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 State of soil specimen before consolidation

Calculation of the state of the soil specimen before consolidation shall conform to Section 6.1 in JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\mathrm{CU}}\mathrm{C}$).

6.2 Pore pressure coefficient *B*

Calculation of the B value shall conform to Section 6.2 in JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\mathrm{CU}}\mathrm{C}$).

6.3 Consolidation process

Data calculation of the consolidation process shall conform to Section 6.3 in JGS 0525 Method for K_0 consolidated-undrained triaxial compression test on soils with pore water pressure measurements ($K_0\overline{\mathrm{CU}}\mathrm{C}$).

6.4 Undrained extension process

The method used to calculate and organize the undrained extension process shall be as follows.

a) Calculate the axial strain of soil specimen ε_a (%) using the following equation (compression is positive).

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

where

ΔH: Axial displacement of the specimen (mm), where compression is defined to be positive

b) Calculate the principal stress difference ($\sigma_a - \sigma_r$) (kN/m^2) under axial strain ε_a (%) and the increase in pore water pressure resulting from axial extension u_e (kN/m^2), using the following equations.

$$\sigma_a - \sigma_r = \frac{P - P_0}{A_c}\left(1 - \frac{\varepsilon_a}{100}\right) \times 1000$$

$$u_e = u - u_b$$

where

P: Axial compression force (N) acting on the specimen at the axial strain ε_a (%)
u: Pore water pressure (kN/m^2) measured at the axial strain ε_a (%)
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 minimum principal stress difference $(\sigma_a - \sigma_r)_{min}$ in the axial strain range of $0 < \varepsilon_a \le 15$ %, and this value shall be taken as the extension strength (kN/m^2), which shall be rounded to three significant digits. Also, determine the corresponding axial strain ε_f from these figures, which shall be rounded to one digit after the decimal point.

e) Determine the ratio s_u/σ'_{ac} of undrained shear strength $s_u = \left|(\sigma_a - \sigma_r)_{min}/2\right|$ to effective axial consolidation stress σ'_{ac}, which shall be rounded to three significant digits.

f) Calculate the effective principal stress σ'_a (kN/m^2) and σ'_r (kN/m^2) in the undrained extension process from the following equations, and draw an effective stress path diagram with $\sigma_a - \sigma_r$ on the vertical axis and $(\sigma'_a+2\sigma'_r)/3$ on the horizontal axis.

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

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

Note: If necessary, draw an effective stress path diagram with $(\sigma_a - \sigma_r)/2$ on the vertical axis and $(\sigma'_a+\sigma'_r)/2$ on the horizontal axis.

g) Calculate the effective principal stresses at the minimum principal stress difference σ'_{af} (kN/m^2) and σ'_{rf} (kN/m^2), using the following equations, which shall be rounded to three significant digits.

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

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

where

σ_{rf}: Lateral stress at minimum principal stress difference (kN/m^2)
u_f: Pore water pressure at minimum principal stress difference (kN/m^2)

Note: Obtain σ'_a and σ'_r at $(\sigma'_a/\sigma'_r)_{min}$, 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 back pressure (kN/m^2)

d) Time needed for B value and pore water pressure to stabilize (min)

e) Stress loading method at stages in which consolidation is in progress (note the stress in the case of staged loading)

f) Change in volume during consolidation process (mm^3), axial displacement (mm), and relationship of $\sigma_{af} - u_b$ (kN/m^2), $\sigma_{rf} - u_b$ (kN/m^2) and time (min)

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

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

h) Relationship of $(\sigma_{rf} - u_b) / (\sigma_{af} - u_b)$, ε_r (%) and elapsed time (min)

i) Relationship between $(\sigma_{rf} - u_b) / (\sigma_{af} - u_b)$ and $\sigma_{af} - u_b$ (kN/m^2)

j) Axial consolidation stress σ'_{ac} (kN/m^2), lateral consolidation stress σ'_{rc} (kN/m^2) and stress ratio $\sigma'_{rc}/\sigma'_{ac}$ (= K_0)

k) Strain rate of undrained extension process (%/min)

l) Principal stress difference versus axial strain curve, pore water pressure increase versus axial strain curve, and minimum principal stress difference (kN/m^2) and axial strain at that time (%)

m) Effective stress path diagram

n) Failure mode of soil specimen

o) Effective principal stress (kN/m^2) and s_u/σ'_{ac} at minimum principal stress difference

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

p) When testing multiple soil specimens with the same sample, the relationship between undrained shear strength and consolidation stress

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

r) Other reportable matters