Japanese Geotechnical Society Standard (JGS 0551-2020) Method for torsional shear test on hollow cylindrical specimens of soils

1 Scope

This standard specifies a test method to obtain the torsional shear strength in the drained state and in the undrained state of soils that have been consolidated under isotropic or anisotropic stress conditions, and the relationship between the shear stress on a horizontal plane and the corresponding shear strain, using torsional shear test apparatus. The standard is applicable to saturated cohesive and sandy soils.

Note 1: In this standard the shear stress on a horizontal plane of the specimen and the corresponding shear strain are simply referred to as the “shear stress” and “shear strain”.

Note 2: The scope includes cohesive soils and sandy soils that have been saturated after specimen preparation. Also, this standard can be applied to other soil materials.

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).

JIS A 0207 Technical terms for geotechnical engineering

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

JGS 0550 Practice for preparing hollow cylindrical specimens of soils for torsional shear test

When implementing this test, refer to the following standards for matters that are not prescribed in this standard.

JGS 0523 Method for consolidated-undrained triaxial compression test on soils with pore water pressure measurements

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

3 Terms and definitions

In addition to those specified in JIS A 0207, the main terminology and definitions used in this standard shall be as follows.

3.1 Consolidated-drained (CD) torsional shear test

A shear test in which an axial stress, external pressure, internal pressure, and back pressure are maintained constant on a hollow cylindrical specimen consolidated under an isotropic or specified anisotropic stress ratio, and then a torsional force is applied to the horizontal plane of the specimen under drained states.

3.2 Consolidated-undrained ($\overline{CU}$) torsional shear test

A shear test in which an axial stress, external pressure, internal pressure, and back pressure are maintained constant on a hollow cylindrical specimen consolidated under an isotropic or specified anisotropic stress ratio, and then a torsional force is applied to the horizontal plane of the specimen under undrained states while measuring the pore water pressure.

3.3 Axial stress

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

3.4 External pressure and internal pressure

The pressure that is applied to the external surface of the specimen and the hollow part of the specimen, respectively.

3.5 Lateral stress

The stress corresponding to the external pressure and the internal pressure, when they are equal. The value of stress is defined at the mid-height of the specimen.

3.6 Back pressure

Pore water pressure applied to the specimen (refer to 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

3.7 Anisotropic consolidation stress ratio

The effective lateral stress divided by the effective axial stress when consolidation is completed.

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 Axial consolidation stress

The value of the consolidation stress on the specimen acting in the cylinder axial direction.

3.10 Lateral consolidation stress

The value of the consolidation stress on the specimen acting in the radial direction.

3.11 Torsional shear strength in the drained state

The maximum value of shear stress that can be applied to a horizontal plane of the specimen, based on the effective stress at the time of completion of consolidation.

3.12 Torsional shear strength in the undrained state

The maximum shear stress that can be applied to a horizontal plane of the specimen, when entry or exit of the pore water is not permitted.

4 Equipment

The torsional shear test equipment is configured from a pressure cell; a device for supplying external pressure, internal pressure, and back pressure; a device for applying torsional force and axial force; and a device for measuring external pressure, internal pressure, torque, axial force, rotational angle, axial displacement, specimen volumetric change, and pore water pressure, and shall satisfy the following conditions. An example of the torsional shear test equipment is shown in Figure 1.

Note: It may include capability of measuring volume changes of the hollow part of the specimen.

a) The equipment shall have sufficient durability and load resistance with respect to the maximum external pressure, internal pressure, back pressure, and the maximum torque and axial force on the specimen. The pressure cell shall be fixed to a loading platform, etc., so that the pressure cell does not rotate when the torsional force is acting.

b) The specimen shall be covered with a cap, a pedestal, and a rubber sleeve, the prescribed external pressure, internal pressure, back pressure, torsional force, and axial force shall be capable of being applied to this, and water shall be capable of being supplied to or drained from the top and bottom ends of the specimen. The external diameter and the internal diameter of the cap and the pedestal shall be the same as the external diameter and internal diameter of the specimen as standard. The two surfaces of the cap and the pedestal shall be flat and parallel to each other, and shall be normal to the axial direction of the loading piston. A porous plate with metal ribs and having sufficiently high water permeability shall be used at the drainage surface, and when necessary appropriate filter paper shall be placed there. However, sliding shall not occur between the specimen and the cap or the pedestal, and another format may be used provided excessive disturbance is not caused to the specimen.

c) It shall be possible to continuously apply the prescribed external pressure, internal pressure, back pressure, and axial stress to within ±2 kN/m^2 for less than 200 kN/m^2, and within ±1% for 200 kN/m^2 and higher.

d) It shall be possible to apply torsion continuously to the specimen until the shear strain in the horizontal direction exceeds 22.5%.

e) It shall be possible to measure the external pressure, internal pressure, and porewater pressure to an allowable tolerance of 2 kN/m^2 for less than 200 kN/m^2, and 1% for 200 kN/m^2 and higher. The performance of the pore water pressure measuring device shall comply with Section 4.1d) of JGS 0523 Method for consolidated-undrained ($\overline{\text{CU}}$) triaxial compression test on soils.

f) It shall be possible to measure the torque acting on the specimen using a torque meter installed within the pressure cell, to an allowable tolerance of 1% of the maximum torque. The interference with the output of the torque meter due to changes in the external pressure or axial force shall not exceed 1% of the capacity of the torque meter.

g) It shall be possible to measure the axial force acting on the specimen using a load cell installed within the pressure cell, to an allowable tolerance of 1% of the axial force when consolidation is completed. The interference with the output of the load cell due to changes in the external pressure or the torque shall not exceed 1% of the capacity of the load cell.

h) It shall be possible to measure the rotational angle of the specimen using a rotational angle measuring device to an allowable tolerance of 1% of the maximum rotational angle. If the rotational angle of the specimen is measured with a rotational angle measuring device installed outside the pressure cell, then the deformation of the loading piston, torque meter, load cell, etc., located between the rotational angle measuring device and the specimen shall be 1% or less of the rotational angle of the specimen. The interference with the output of the rotational angle measuring device due to changes in the external pressure shall be not more than 1% of the maximum rotational angle, and the change in the calibration value shall be not more than 1%.

i) It shall be possible to measure the axial displacement and the volumetric change of the specimen to an allowable tolerance of 0.02% and 0.05% of the height and volume of the specimen, respectively. The volumetric change of the specimen during isotropic or anisotropic consolidation or during drained torsional shear shall be measured using a burette, or a measuring device having equal or better performance. If the volumetric change of the hollow part of the specimen is measured, it shall be capable of being measured to an allowable tolerance of 0.05% of the hollow part volume.

Note: The burette shall have a structure to enable back pressure to be applied, and it is desirable that it shall have a structure such that the water level within the burette does not vary due to changes in the back pressure.

5 Test method

5.1 Preparation and installation of the specimen

Preparation and installation of the specimen shall be carried out by the method prescribed in JGS 0550 Practice for preparing hollow cylindrical specimens of soils for torsional shear test.

5.2 Checking the specimen saturation

The pore water pressure coefficient *B* (*B* value) shall be measured in the last stage of back pressure application.

a) Close the drainage valve.

b) Apply an increment $\Delta\sigma$ to the lateral stress σ_r for 1 to 2 minutes, while maintaining the isotropic stress state. As standard $\Delta\sigma$ shall be about 10-50 kN/m^2. However, the lateral stress after applying $\Delta\sigma$ shall not exceed the lateral stress when the specified consolidation is completed.

c) Measure the increment of pore water pressure Δu when the pore water pressure has stabilized to a constant value.

d) Open the drainage valve after increasing the back pressure by the same amount as $\Delta\sigma$.

5.3 Consolidation process

Isotropic consolidation or anisotropic consolidation shall be carried out in accordance with the objectives of the test. The axial displacement of the specimen ΔH_c (mm) and the volumetric change of the specimen ΔV_c (mm^3) due to consolidation shall be measured. During consolidation, the back pressure u_b (kN/m^2) shall be constant. Completion of primary consolidation of the specimen shall be confirmed by the method described in Section 5.2 d) of JGS 0522 Method for consolidated-undrained triaxial compression test on soils.

a) Isotropic consolidation process

1) Under drained states, the lateral stress shall be increased by maintaining the isotropic stress state up to the value at completion of the prescribed consolidation.

2) Consolidation shall be continued at least until completion of primary consolidation.

b) Anisotropic consolidation process

Anisotropic consolidation shall be carried out by the following method as standard.

1) An axial stress shall be applied that satisfies the prescribed anisotropic consolidation stress ratio corresponding to the effective lateral stress in the initial isotropic consolidation state.

2) $\Delta\sigma_r$ shall be obtained by dividing the difference in the effective lateral stress between the initial consolidation stress state and the final consolidation stress state into 5 or more equal increments. However, $\Delta\sigma_r$ shall not exceed 20 kN/m^2.

3) The lateral stress shall be increased by $\Delta\sigma_r$ in steps.

4) The axial stress shall be increased until the prescribed anisotropic consolidation stress ratio is reached.

5) Repeat the operation in 3) and 4) until the final consolidation stress state is reached.

6) As a guide the loading rate of the axial stress and the lateral stress during isotropic consolidation should be such that the axial strain rate is 0.1%/min or less, then proceed to the next stage.

7) Consolidation shall be continued at least until completion of primary consolidation.

5.4 Torsional shear process

Either drained torsional shear or undrained torsional shear shall be carried out, in accordance with the purpose of the test.

a) Consolidated-drained (CD) torsional shear

1) Check that the state is the prescribed isotropic or anisotropic consolidation state.

2) Continuously apply torsion to the specimen so that the shear strain rate is constant, maintaining the external pressure, internal pressure, back pressure, and axial stress constant. Instead of controlling the axial stress during torsional shear to be constant, the axial force may be controlled to within a range of variation of ±5% of the axial force when consolidation is completed. If it is possible to predict the shear strain γ_f (%) at the maximum shear stress, the shear strain rate $\dot{\gamma}$ (%/min) shall not exceed the value calculated from the following equation.

$$\dot{\gamma} = \frac{\gamma_f}{15 t_c}$$

where

t_c: Consolidation time (min)

However, the shear strain rate shall not exceed 1% per minute, regardless of the value calculated from the above equation.

3) During torsional shear, the torque T (N･m), the axial force P (N), the rotational angle $\Delta\theta$ (rad), the axial displacement ΔH (mm), and the volumetric change ΔV (mm^3) shall be measured.

4) Shearing shall be continued for an additional 5% or more shear strain after the torque meter reading reaches a maximum, or shearing shall be terminated when the shear strain reaches 22.5%.

Note: If the torque, axial force, rotational angle, axial displacement, and volumetric change are not continuously recorded, their measurement intervals shall be such that it is possible to smoothly draw the shear stress-shear strain curve and the volumetric strain-shear strain curve.

b) Consolidated-undrained ($\overline{\mathrm{CU}}$) torsional shear

1) Check that the state is the prescribed isotropic or anisotropic consolidation state.

2) Close the drainage valve.

3) Continuously apply torsion to the specimen at a constant shear strain rate, maintaining the external pressure, internal pressure, and axial stress constant. As a guide the shear strain rate should be 0.5%/min. for sandy soil, 0.2%/min. for specimens with a large quantity of silt, and 0.1%/min. for specimens with a large quantity of clay, in order that the pore water pressure distribution within the specimen becomes uniform. For controlling the axial stress, the conditions described in Section 5.4a) 2) apply.

4) During torsional shear, the torque T (N･m), the axial force P (N), the rotational angle $\Delta\theta$ (rad), the axial displacement ΔH (mm), and the pore water pressure u (kN/m^2) shall be measured.

Note: If there is no continuous record of the torque, axial force, rotational angle, axial displacement, and pore water pressure, their measurement intervals shall be such that it is possible to smoothly draw the shear stress-shear strain curve and the pore water pressure-shear strain curve.

5) Shearing shall be continued for an additional 5% or more shear strain after the torque meter reading reaches a maximum, or shearing shall be terminated when the shear strain reaches 22.5%.

5.5 State of the specimen after the test

The state of the specimen after testing shall be determined as follows.

a) The deformation and failure state of the specimen, etc., shall be observed and recorded. The deformation and failure state of the specimen after torsional shear shall be observed and recorded from the direction at which their state is most distinct. Also, if a slip plane is evident, it shall be observed from the direction at which the slope is steepest, and recorded so that the angle can be approximately read. Heterogeneity or foreign matter in the specimen shall be observed and recorded.

b) The oven-dried mass m_s (g) of the specimen shall be measured.

6 Processing test results

Note: If the volumetric change of the hollow part of the specimen is measured during the consolidation process and the torsional shear process, the external diameter and the internal diameter of the specimen may be calculated using these values. However, this shall not be carried out for sandy soils if it is not possible to appropriately evaluate the effect of penetration of the rubber sleeve.

6.1 State of the specimen prior to consolidation

The state of the specimen prior to consolidation shall be obtained from the following equations.

a) The volume of the specimen prior to consolidation V_0 (mm³) shall be calculated from the following equation.

$$V_0 = V_i - \Delta V_i$$

where

V_i: Initial volume of the specimen (mm³)
ΔV_i: Volumetric change in the specimen produced from the initial state until prior to consolidation (mm³), where compression is defined to be positive

b) The height of the specimen H_0 (mm) prior to consolidation shall be calculated from the following equation.

$$H_0 = H_i - \Delta H_i$$

where

H_i: Initial height of the specimen (mm)
ΔH_i: Axial displacement of the specimen produced from the initial state until prior to consolidation (mm), where compression is defined to be positive

c) The external diameter D_{o0} (mm) and the internal diameter D_{i0} (mm) of the specimen prior to consolidation shall be calculated from the following equations.

$$D_{o0} = D_{oi} \times \sqrt{(1 - \varepsilon_{vi}/100)/(1 - \varepsilon_{ai}/100)}$$

$$D_{i0} = D_{ii} \times \sqrt{(1 - \varepsilon_{vi}/100)/(1 - \varepsilon_{ai}/100)}$$

where

D_{oi}: Initial external diameter of the specimen (mm)
D_{ii}: Initial internal diameter of the specimen (mm)
ε_{vi}: Volumetric strain (%) produced from the initial state until prior to consolidation ($=\Delta V_i / V_i$), where compression is defined to be positive
ε_{ai}: Axial strain (%) produced from the initial state until prior to consolidation ($=\Delta H_i / H_i$), where compression is defined to be positive

6.2 Pore water pressure coefficient *B*

The *B* value of the specimen shall be calculated as follows and rounded to two significant digits.

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

where

$\Delta\sigma$: Increment of isotropic stress (kN/m^2)

Δu: Increment of pore water pressure associated with $\Delta\sigma$ (kN/m^2)

Note: The *B* value need not be calculated for consolidated drained torsional shear tests.

6.3 Consolidation process

The method of calculating and analyzing the consolidation process shall be as follows.

a) The volume of the specimen V_c (mm^3) after consolidation shall be calculated from the following equation.

$$V_c = V_0 - \Delta V_c$$

where

ΔV_c: Volumetric change due to consolidation (mm^3), where compression is defined to be positive

b) The specimen height H_c (mm) after consolidation shall be calculated from the following equation.

$$H_c = H_0 - \Delta H_c$$

where

ΔH_c: Axial displacement due to consolidation (mm), where compression is defined to be positive

c) The specimen cross-sectional area A_c (mm^2) after consolidation shall be calculated from the following equation.

$$A_C = \frac{V_C}{H_C}$$

d) The specimen external diameter D_{oc} (mm) and internal diameter D_{ic} (mm) after consolidation shall be calculated from the following equations.

$$D_{oc} = D_{o0} \times \sqrt{(1 - \varepsilon_{vc}/100)/(1 - \varepsilon_{ac}/100)}$$

$$D_{ic} = D_{i0} \times \sqrt{(1 - \varepsilon_{vc}/100)/(1 - \varepsilon_{ac}/100)}$$

where

ε_{vc}: Volumetric strain (%) due to consolidation ($=\Delta V_c / V_0$), where compression is defined to be positive

ε_{ac}: Axial strain (%) due to consolidation ($=\Delta H_c / H_0$), where compression is defined to be positive

e) The dry density ρ_{dc} (Mg/mm^3) of the specimen after consolidation shall be calculated from the following equation, and rounded to two digits after the decimal point.

$$\rho_{dc} = \frac{m_s}{V_c} \times 1000$$

where

m_s: Oven-dried mass of the specimen (g)

Note 1: If necessary, the void ratio e_c and the relative density D_{rc} of the specimen after consolidation shall be calculated from the following equations.

$$e_c = \frac{V_c/1000 \times \rho_s}{m_s} - 1$$

$$D_{rc} = \frac{e_{max} - e_c}{e_{max} - e_{min}} \times 100$$

where

ρ_s: Soil particle density (Mg/m^3)
e_{max}: Void ratio of the sample from the minimum density test
e_{min}: Void ratio of the sample from the maximum density test

6.4 Torsional shear process

The method of calculation and analysis of the torsional shear process shall be as follows.

a) Consolidated drained (CD) torsional shear

1) The axial strain ε_a (%) of the specimen shall be calculated from the following equation.

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

where

ΔH : Axial strain in the torsional shear process (mm), where compression is defined to be positive

2) The volumetric strain ε_v (%) of the specimen shall be calculated from the following equation.

$$\varepsilon_v = \frac{\Delta V}{V_0} \times 100$$

where

ΔV : Volumetric change in the torsional shear process (mm^3), where compression is defined to be positive

3) The external diameter D_o (mm) and the internal diameter D_i (mm) of the specimen shall be calculated from the following equations.

$$D_o = D_{oc} \times \sqrt{(1 - \varepsilon_v/100)/(1 - \varepsilon_a/100)}$$

$$D_i = D_{ic} \times \sqrt{(1 - \varepsilon_v/100)/(1 - \varepsilon_a/100)}$$

4) The shear strain γ (%) of the specimen shall be calculated from the following equation.

$$\gamma = \frac{\Delta\theta(r_o + r_i)}{2H} \times 100$$

where

$\Delta\theta$: Rotational angle of the specimen (rad)
r_o: External radius of the specimen (mm) ($=D_o/2$)
r_i: Internal radius of the specimen (mm) ($=D_i/2$)
H: Specimen height (mm) ($=H_c-\Delta H$)

Note: The shear strain γ (%) may be alternatively calculated by the following equation.

$$\gamma = \frac{2\Delta\theta(r_o^3 - r_i^3)}{3H(r_o^2 - r_i^2)} \times 100$$

5) The amount of correction (amount of reduction) in the shear stress due to the tension in the rubber sleeve $\Delta\tau_m$ (kN/m^2) shall be calculated from the following equation.

$$\Delta\tau_m = \frac{2E_m t_m (r_o^3 + r_i^3)}{(r_o^3 - r_i^3)(r_o + r_i)} \times \frac{r}{100}$$

where

E_m: Young's modulus of the rubber sleeve (kN/m^2)
t_m: Thickness of the rubber sleeve (mm)

6) The shear stress τ (kN/m^2) shall be calculated from the following equation.

$$\tau = \frac{3T}{2\pi(r_o^3 - r_i^3)} \times 10^6 - \Delta\tau_m$$

where

T: Torque (N·mm)

7) The axial stress σ_a (kN/m^2), the maximum principal stress σ_1 (kN/m^2), and the minimum principal stress σ_3 (kN/m^2) shall be calculated from the following equations.

$$\sigma_a = \frac{P}{A_c} \times \frac{1 - \varepsilon_a/100}{1 - \varepsilon_v/100} \times 1000$$

$$\sigma_1 = \frac{\sigma_a + \sigma_r}{2} + \frac{\sqrt{(\sigma_a - \sigma_r)^2 + 4\tau^2}}{2}$$

$$\sigma_3 = \frac{\sigma_a + \sigma_r}{2} - \frac{\sqrt{(\sigma_a - \sigma_r)^2 + 4\tau^2}}{2}$$

where

P: Axial force acting on the specimen (N)
σ_r: Lateral stress acting on the specimen (kN/m^2)

8) The shear stress-shear strain curve and the volumetric strain-shear stress curve shall be drawn with the shear strain on the horizontal axis.

Note 1: If necessary the major effective principal stress σ'_1 (kN/m^2) and the minor effective principal stress σ'_3 (kN/m^2) shall be calculated from the following equations, and the effective principal stress ratio (σ'_1/σ'_3) – shear strain curve shall be drawn, with the shear strain on the horizontal axis.

$$\sigma'_1 = \sigma_1 - u$$

$$\sigma'_3 = \sigma_3 - u$$

Note 2: If necessary, the axial stress – shear strain curve and the axial strain – shear strain curve shall be drawn with the shear strain on the horizontal axis.

9) Obtain the maximum value of the shear stress within the range $0 < \gamma \leq 22.5\%$ from the above curves, and rounded to three significant digits to obtain the drained torsional shear strength τ_d (kN/m^2). The shear strain at this time shall be rounded to one digit after the decimal point and taken to be γ_f (%).

Note: If necessary the major effective principal stress σ'_{1f} (kN/m^2) and the minor effective principal stress σ'_{3f} (kN/m^2) when the shear stress is maximum are calculated from the following equations.

$$\sigma'_{1f} = \sigma_{1f} - u_f$$

$$\sigma'_{3f} = \sigma_{3f} - u_f$$

where

σ_{1f}: Major principal stress when the shear stress is maximum (kN/m^2)
σ_{3f}: Minor principal stress when the shear stress is maximum (kN/m^2)
u_f: Porewater pressure when the shear stress is maximum (kN/m^2)

10) The ratio of the drained torsional shear strength τ_d and the axial consolidation stress σ'_{ac} shall be obtained as τ_d/σ'_{ac} after being rounded to three significant digits. The axial consolidation stress σ'_{ac} (kN/m^2) shall be obtained from the following equation, and rounded to three significant digits.

$$\sigma'_{ac} = \sigma_{ac} - u_b$$

where

σ'_{ac}: Axial stress when consolidation is completed (kN/m^2)
u_b: Back pressure

b) Consolidated-undrained ($\overline{CU}$) torsional shear

1) The axial strain ε_a (%) of the specimen shall be obtained from the following equation.

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

where

ΔH: Axial displacement in the torsional shear process (mm), where compression is defined to be positive

2) The external diameter D_o (mm) and the internal diameter D_i (mm) of the specimen shall be calculated from the following equation.

$$D_o = D_{oc} \times \sqrt{1/(1 - \varepsilon_a/100)}$$

$$D_i = D_{ic} \times \sqrt{1/(1 - \varepsilon_a/100)}$$

3) The shear strain γ (%) of the specimen shall be calculated from the following equation.

$$\gamma = \frac{\Delta\theta(r_o + r_i)}{2H} \times 100$$

where

$\Delta\theta$: Rotational angle of the specimen (rad)
r_o: External radius of the specimen (mm) ($=D_o/2$)
r_i: Internal radius of the specimen (mm) ($=D_i/2$)
H: Specimen height (mm) ($=H_c - \Delta H$)

Note: The shear strain γ (%) may be alternatively calculated by the following equation.

$$\gamma = \frac{2\Delta\theta(r_o^3 - r_i^3)}{3H(r_o^2 - r_i^2)} \times 100$$

4) The amount of correction (amount of reduction) of the shear stress due to the tension in the rubber sleeve $\Delta\tau_m$ (kN/m²) shall be calculated from the following equation.

$$\Delta\tau_m = \frac{2E_m t_m (r_o^3 + r_i^3)}{(r_o^3 - r_i^3)(r_o + r_i)} \times \frac{\gamma}{100}$$

where

E_m: Young's modulus of the rubber sleeve (kN/m²)
t_m: Thickness of the rubber sleeve (mm)

5) The shear stress τ (kN/m²) shall be calculated from the following equation.

$$\tau = \frac{3T}{2\pi(r_o^3 - r_i^3)} \times 10^6 - \Delta\tau_m$$

where

T: Torque (N·m)

6) The axial stress σ_a (kN/m²), the maximum principal stress σ_1 (kN/m²), the minimum principal stress σ_3 (kN/m²), and the increment of porewater pressure u_e (kN/m²) associated with the torsional shear shall be calculated from the following equations.

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

$$\sigma_1 = \frac{\sigma_a + \sigma_r}{2} + \frac{\sqrt{(\sigma_a - \sigma_r)^2 + 4\tau^2}}{2}$$

$$\sigma_3 = \frac{\sigma_a + \sigma_r}{2} - \frac{\sqrt{(\sigma_a - \sigma_r)^2 + 4\tau^2}}{2}$$

$$u_e = u - u_b$$

where

P: Axial load acting on the specimen (N)
σ_r: Lateral stress acting on the specimen (kN/m²)
u: Pore water pressure acting on the specimen (kN/m²)
u_b: Back pressure (kN/m²)

7) The shear stress – shear strain curve and the porewater pressure increment – shear strain curve shall be drawn with the shear strain on the horizontal axis.

Note 1: When necessary the major effective principal stress σ'_1 (kN/m²) and the minor effective principal stress σ'_3 (kN/m²) shall be calculated by the following equations, and the effective principal stress ratio (σ'_1/σ'_3) – shear strain curve shall be drawn with the shear strain on the horizontal axis.

$$\sigma'_1 = \sigma_1 - u$$

$$\sigma'_3 = \sigma_3 - u$$

Note 2: Note 2 in Section 6.4a) 8) applies.

8) Obtain the maximum value of the shear stress within the range $0< \gamma \leq 22.5\%$ from the above curves, and rounded to three significant digits to obtain the undrained torsional shear strength τ_u (kN/m²). The shear strain at this time shall be rounded to one digit after the decimal point and taken to be γ_f (%).

Note: If necessary the major effective principal stress σ'_{1f} (kN/m²) and the minor effective principal stress σ'_{3f} (kN/m²) when the shear stress is maximum are calculated from the following equations.

$$\sigma'_{1f} = \sigma_{1f} - u_f$$

$$\sigma'_{3f} = \sigma_{3f} - u_f$$

where

σ_{1f}: Major principal stress when the shear stress is maximum (kN/m²)
σ_{3f}: Minor principal stress when the shear stress is maximum (kN/m²)
u_f: Pore water pressure when the shear stress is maximum (kN/m²)

9) The ratio τ_u/σ'_{ac} of the undrained torsional shear strength τ_u and the axial consolidation stress σ'_{ac} shall be obtained after being rounded to three significant digits.

Note: The axial consolidation stress σ'_{ac} (kN/m²) shall be obtained according to Section 6.4 a) 10).

10) The effective axial stress σ'_a (kN/m²) in the undrained torsional shear process shall be calculated from the following equation, and a diagram of the effective stress path shall be drawn with τ on the vertical axis and σ'_a on the horizontal axis.

$$\sigma'_a = \sigma_a - u$$

7 Reporting

The following items of the test results shall be reported.

7.1 Consolidated-drained (CD) torsional shear test

For the consolidated-drained (CD) torsional shear test, the following items of the test results shall be reported.

a) Method of preparation of specimens

b) Specimen dimensions prior to consolidation

c) If measured, the *B* value and its measurement method

d) Volumetric change (mm³) and axial displacement (mm) due to consolidation. If consolidation required a long period of time, such as for cohesive soils, etc., the relationship between time (min) and the axial displacement (mm) or the volumetric change (mm³) shall also be reported.

e) Oven-dried mass (g) of the specimen and dry density (Mg/m³) after consolidation

Note: If necessary, the void ratio and relative density (%) after consolidation shall be reported.

f) The magnitude of the axial stress (kN/m²), external pressure (kN/m²), internal pressure (kN/m²), and back pressure (kN/m²) after consolidation

g) The axial consolidation stress σ'_{ac} (kN/m²), the lateral consolidation stress σ'_{rc} (kN/m²), and if necessary the anisotropic consolidation stress ratio $\sigma'_{rc}/\sigma'_{ac}(=K)$

h) Shear strain rate (%/min) during the torsional shear process

i) Method of measurement of torque, axial load, and rotational angle during torsional shear, and the positions of the torque meter, load cell, and rotational angle measurement device within the pressure cell.

j) Shear stress versus shear strain curve, and volumetric strain versus shear strain curve

Note: When necessary, the effective principal strain ratio (σ'_1/σ'_3) – shear strain curve, the axial stress – shear strain curve, and the axial strain – shear strain curve shall be reported.

k) The drained torsional shear strength τ_d (kN/m^2), the shear strain γ_f (%) at the maximum shear stress, the major and minor effective principal stresses at the maximum shear stress, and τ_d/σ'_{ac}.

l) Failure state of the specimen

m) When tests have been carried out on multiple specimens of the same material, the drained torsional shear strength – axial consolidated stress relationship. Draw either a graph with the drained torsional shear strength (kN/m^2) on the vertical axis, and the axial consolidation stress (kN/m^2) on the horizontal axis, or, a Mohr circle for σ'_{1f} and σ'_{3f} at τ_d.

n) If a method that partially differs from this standard was used, give details of the points of difference.

o) Other reportable matters, including the following.

  1) An overview of the testing equipment, the method of saturating the specimen, and the material, thickness, and Young's modulus of the rubber sleeve.

  2) The dimensions, positions, and number of the metal ribs embedded in the porous plate, or the status of the slip prevention used instead of the metal ribs.

7.2 Consolidated-undrained ($\overline{\text{CU}}$) torsional shear test

For the consolidated-undrained ($\overline{\text{CU}}$) torsional shear test, the following items of the test results shall be reported.

a) Method of preparation of specimens

b) Specimen dimensions prior to consolidation

c) The *B* value and its measurement method

d) Volumetric change (mm^3) and axial displacement (mm) due to consolidation. The instructions of Section 7.1d) applies.

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

Note: The Note at Section 7.1e) applies.

f) The magnitude of the axial stress (kN/m^2), external pressure (kN/m^2), internal pressure (kN/m^2), and back pressure (kN/m^2) after consolidation

g) The axial consolidation stress σ'_{ac} (kN/m^2), the lateral consolidation stress σ'_{rc} (kN/m^2), and if necessary the anisotropic consolidation stress ratio $\sigma'_{rc}/\sigma'_{ac}(= K)$

h) Shear strain rate (%/min.) during the torsional shear process

i) Method of measurement of torque, axial load, and rotational angle during torsional shear. The instruction of Section 7.1i) applies.

j) Shear stress versus shear strain curve, and pore water pressure increment versus shear strain curve.

Note: The instruction of Note at Section 7.1 j) applies.

k) The undrained torsional shear strength τ_u (kN/m^2), the shear strain γ_f (%) at the maximum shear stress, the major and minor effective principal stresses at the maximum shear stress, and τ_u/σ'_{ac}.

Note: When necessary the values of σ'_1 and σ'_3 when the effective principal stress ratio is the maximum shall be reported.

l) The effective stress path diagram

m) The failure state of the specimen

n) When tests have been carried out on multiple specimens of the same material, the undrained torsional shear strength – axial consolidated stress relationship. Draw either a graph with the undrained torsional shear strength (kN/m^2) on the vertical axis, and the axial consolidation stress (kN/m^2) on the horizontal axis, or, a Mohr's stress circle for σ'_{1f} and σ'_{3f} at τ_u.

o) If a method that partially differs from this standard was used, give details of the points of difference.

p) Other reportable matters

Note: The instructions at Section 7.1o) apply.

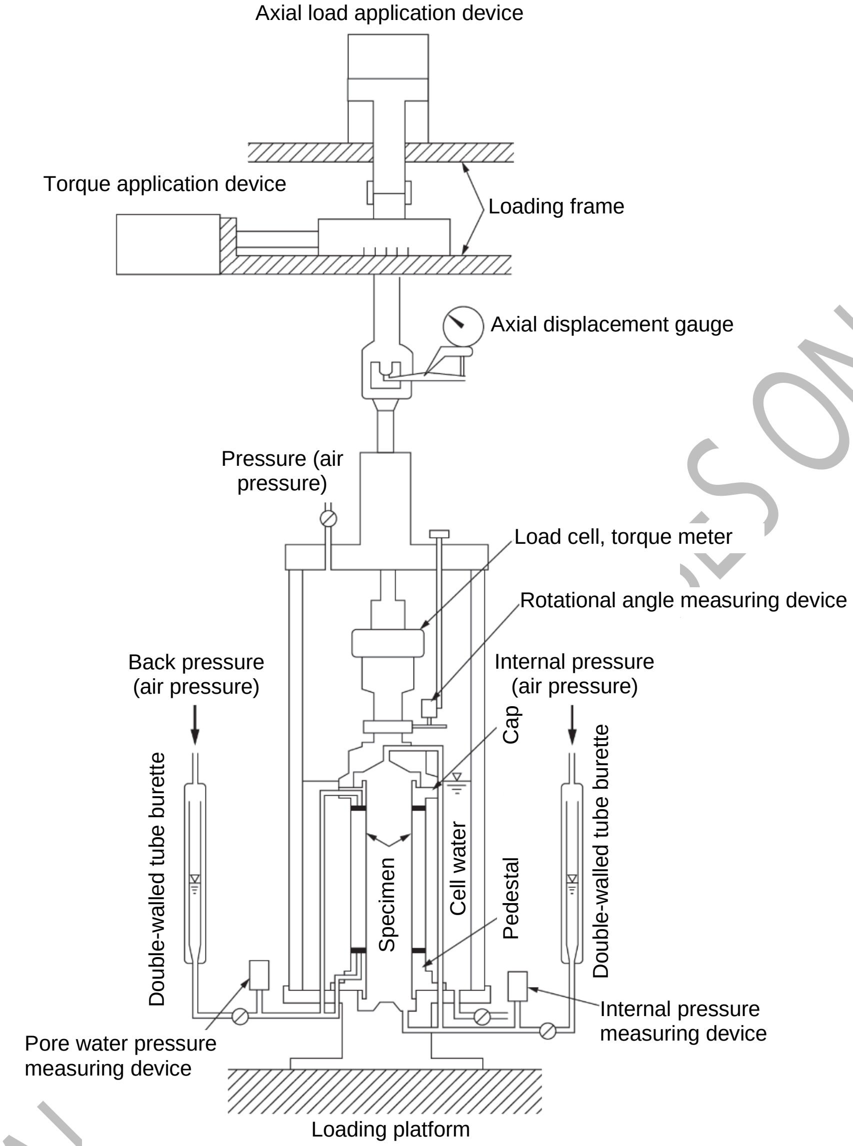

Figure 1 Example of torsional shear test equipment