Japanese Geotechnical Society Standard (JGS 0543-2020) Method for cyclic torsional shear test on hollow cylindrical specimens to determine deformation properties of soils

1 Scope

This standard specifies a test method to obtain the deformation properties in cyclic loading of soils consolidated under isotropic stress or anisotropic stress conditions, under drained states or undrained states, using cyclic torsional shear equipment. The standard applies to cohesive soils and sandy soils.

Note 1: This standard applies to saturated specimen. Also this standard can be applied to specimen in the air dried state and in the unsaturated state.

Note 2: This standard is also applicable to other geomaterials.

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 specimen to be 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 executing this test, the following standards shall be referred to for matters not prescribed in this standard.

JGS 0541 Method for cyclic undrained triaxial test on soils
JGS 0542 Method for cyclic triaxial test to determine deformation properties of geomaterials
JGS 0551 Method for torsional shear test on hollow cylindrical specimens of 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 Cyclic torsional shear test on hollow cylindrical specimens to determine deformation properties

A test in which a constant-amplitude symmetrical cyclic torque is applied at a constant period to a horizontal plane in a hollow cylindrical specimen that has been isotropically or anisotropically consolidated, under drained or undrained states.

Note: Instead of a constant amplitude cyclic torque, a constant amplitude cyclic torsional displacement may be applied.

3.2 Deformation properties

The equivalent shear modulus obtained from the cyclic shear stress amplitude and the cyclic shear strain amplitude, and the hysteretic damping factor obtained from the shear stress and shear strain hysteresis curve.

3.3 Axial stress

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

3.4 External pressure and internal pressure

The pressure acting on the specimen external lateral surface and hollow part, respectively.

3.5 Lateral stress

When the external pressure and the internal pressure are equal, they are referred to as the lateral stress. The value of the stress is defined at the mid-height of the specimen.

3.6 Back pressure

The pore water pressure applied to a 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 at completion of consolidation.

3.8 Consolidation stress

The stress in a soil element, leading to its 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 axis direction.

3.10 Lateral consolidation stress

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

4 Equipment

The cyclic torsional shear testing equipment is configured from a pressure cell; an external pressure, internal pressure, and back pressure supply device; a torque and axial force loading device; and external pressure, internal pressure, torque, axial force, rotational angle, axial displacement, specimen volumetric change, and pore water pressure measuring and recording equipment, satisfying the following conditions. Figure 1 shows an example of cyclic torsional shear test equipment. It may include capability of measuring volume changes of the hollow part of the specimen.

a) The equipment shall have sufficient load endurance and load capability with respect to the maximum external pressure, internal pressure, and back pressure, and the maximum torque and axial load applied to the specimen. The pressure cell shall be fixed to a loading platform or similar, so that the pressure cell does not rotate when the torque is acting.

b) The specimen shall be covered with a cap, a pedestal, and rubber sleeves, the prescribed external pressure, internal pressure, back pressure, torque, 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 as 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. Also, when the cyclic loading test is carried out in the undrained state, the volumetric change of the pore water pressure measurement path due to changes in water pressure shall be sufficiently small.

Note: The volumetric change properties of the pore water pressure measurement path due to changes in water pressure shall preferably comply with Note of Section 4b) of JGS 0541 Method for cyclic undrained triaxial test on soils.

c) The apparatus shall be capable of continuously applying the prescribed external pressure, internal pressure, back pressure, and axial stress during isotropic or anisotropic consolidation with fluctuations of pressure within ±2 kN/m^2 for less than 200 kN/m^2, and within ±1% for 200 kN/m^2 and higher. Also during consolidation it shall be capable of measuring the axial displacement and volumetric change of the specimen to within an allowable tolerance of 0.02% and 0.05% of the specimen height and volume respectively. The volumetric change of the specimen during isotropic or anisotropic consolidation shall be measured by a burette or a measuring device with equal or better performance.

Note: The burette shall be capable of applying the back pressure, and it is desirable that it has a structure such that the water level within the burette does not change due to changes in back pressure.

d) The torque during cyclic loading shall satisfy the following specifications.

1) After isotropic or anisotropic consolidation, it shall be possible to continuously apply a constant amplitude cyclic torque with a one-sided shear strain $(\gamma)_{SA}$ as defined in Section 5.4 ranging from 0.001% or less to 0.1% or more, with a constant application period under drained or undrained conditions.

2) The wave form shall be a sine wave or a triangular wave, and the frequency shall be 0.05 to 1.0 Hz as standard. The loading frequency need not be in the range 0.05 to 1.0 Hz, provided it has been confirmed that the measurement accuracy prescribed in this standard can be satisfied. A rectangular wave or a trapezoidal wave shall not be used as the cyclic torque load wave form instead of the sine wave or the triangular wave. The following conditions shall always be satisfied during cyclic loading.

3) The cyclic loading should satisfy the following conditions.

3.1) The fluctuation of the sum ($T_R + T_L$) of the one-sided amplitude T_R of the clockwise torque and the one-sided amplitude T_L of the counterclockwise torque T_L defined from the stress state at the start of cyclic loading shall be 10% or less.

3.2) $0.8 \leq T_R / T_L \leq 1.2$

The one-sided amplitude T_R of the torque in the clockwise direction and the one-sided amplitude T_L of the torque in the counterclockwise direction are defined from the stress state prior to cyclic loading as shown in Figure 2. Both have positive values. ΔT ($= T_R + T_L$) is the double-sided amplitude of the cyclic torque.

e) During cyclic loading the apparatus shall be capable of continuously applying the external pressure and the internal pressure within a range of pressure fluctuation of ±2 kN/m^2 for pressures less than 200 kN/m^2, and ±1% for pressures 200 kN/m^2 or higher.

f) During cyclic loading the apparatus shall be capable of continuously measuring the external pressure and the internal pressure (and the pore water pressure also for the undrained cyclic loading test) to within an allowable tolerance of 2 kN/m^2 for pressures less than 200 kN/m^2, and 1% for pressures 200 kN/m^2 or higher.

g) Measurement of the torque during cyclic loading shall satisfy the following specifications.

1) When cyclic loading with a one-sided shear strain $(\gamma)_{SA}$ of 0.01% or more is applied, the apparatus shall be capable of continuously measuring the cyclic torque acting on the specimen to within an allowable tolerance of 1% of the double-sided amplitude of the prescribed torque, using a torque meter whose hysteresis properties can be ignored, installed within the pressure cell.

2) An electrical torque meter installed within the pressure cell shall be used for measurement of the cyclic torque.

3) The torque meter output shall not change due to changes in the external pressure. It shall not be affected by the axial force either. In addition, during cyclic loading for each wave, the measured torque shall not have a drift of 1% or more, and a calibrated value change of 1% or more, of that measured during a cycle with one-sided shear strain $(\gamma)_{SA}$ of 0.01%.

4) The relationship between the torque meter output and the actual torque shall be obtained for loading and unloading and the hysteresis property h_{LC} obtained for cyclic loading shall be obtained by the method shown in Figure 3. It shall be confirmed that the value of h_{LC} is 5% or less of the hysteretic damping factor h of the specimen when the one-sided amplitude shear strain $(\gamma)_{SA}$ is 0.01%. The maximum value of the torque applied to the torque meter shall be the maximum value of the torque applied in the actual test.

Torque meter hysteresis property $h_{LC} = (1/2\pi)\cdot\Delta X/X$

h) The rotation measurement during cyclic loading shall satisfy the following specifications.

1) During cyclic loading with a one-sided amplitude shear strain $(\gamma)_{SA}$ of 0.01% or more, the apparatus shall be capable of continuously measuring the rotational angle to within an allowable tolerance of 1% of the double-sided amplitude of the prescribed rotational angle, using a rotational angle measuring device whose hysteresis properties can be ignored. For one-sided amplitude shear strains $(\gamma)_{SA}$ of less than 0.1%, the rotational angle of the cap can be directly measured by the rotational angle measuring device installed within the pressure cell.

2) If the rotational angle of the specimen during cyclic loading is measured with an electrical rotational angle measuring device installed outside the pressure cell, the deformation of the loading piston, torque meter, etc., located between the rotational angle measuring device and the specimen, and the deformation of the fixing position of the rotational angle measuring device, etc., shall be 1% or less of the rotational angle of the specimen when the one-sided shear strain $(\gamma)_{SA}$ is 0.1%.

3) The output of the rotational angle measuring device shall not change due to changes in the cell pressure. In addition, during cyclic loading for each wave, the measured rotation shall not have a drift of 1% or more, and a calibrated value change of 1% or more, of that measured during a cycle with one-sided shear strain $(\gamma)_{SA}$ of 0.01%.

4) The relationship between the rotational angle measuring device output and the rotational angle applied to the rotational angle measuring device shall be obtained by increasing and decreasing the static rotational angle, and the hysteresis property h_{DT} obtained for cyclic loading shall be obtained by the method shown in Figure 4. It shall be confirmed that the value of h_{DT} is 5% or less of the hysteretic damping factor h of the specimen when the one-sided amplitude shear strain $(\gamma)_{SA}$ is 0.01%. The maximum value of the applied rotational angle shall be the maximum value of the rotational angle applied in the actual test.

Rotational angle measurement device hysteresis property $h_{LC} = (1/2\pi)\cdot\Delta Y/Y$

i) Data recording during cyclic loading shall satisfy the following specifications.

1) The apparatus shall be capable of continuously and simultaneously recording the cyclic torque and the cyclic rotational angle. If necessary it shall be capable of continuously recording the pore water pressure.

2) During cyclic loading the measured values of torque, rotational angle, and if necessary the external pressure, internal pressure, and pore water pressure shall be continuously recorded using an electrical recording device such as a digital data recorder. The number of data points in one cycle shall be 40 or more, so that it is possible to sufficiently interpolate values between two consecutive digital measurement values.

3) It shall be confirmed that the error in the hysteretic damping factor due to phase shift between the measured results of torque and rotational angle is not more than 5% of the hysteretic damping factor of the specimen when the one-sided shear strain $(\gamma)_{SA}$ is 0.01%. If the hysteretic damping factor linearly increases (decreases) as the frequency increases when a non-viscous specimen is tested, there is likely to be a time delay (advance) between the records of torque T and rotational angle $\Delta\theta$ (Figure 5).

5 Test method

5.1 Preparation and installation of the specimen

Preparation and installation of the specimen shall be carried out in accordance with the method specified by 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 prior to consolidation, and if necessary after consolidation. The B value shall be obtained by the method described in Section 5.2 of JGS 0541 Method for cyclic undrained triaxial test on soils. However, if anisotropic consolidation is being carried out, the B value shall be measured during the isotropic consolidation prior to the anisotropic consolidated state.

5.3 Consolidation process

Isotropic consolidation or anisotropic consolidation shall be carried out in accordance with the test objectives. 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 shall be constant.

Note: This shall be carried out in accordance with Section 5.3 of JGS 0551 Method for torsional shear test on hollow cylindrical specimens of soils.

a) Isotropic consolidation process

1) In the drained state, the lateral stress shall be increased while maintaining the isotropic stress state, until the prescribed value at completion of consolidation is reached.

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

b) Anisotropic consolidation process

1) In the drained state, the axial stress shall be increased so as to satisfy the prescribed anisotropic consolidation stress ratio relative to the effective lateral stress in the initial isotropic consolidation stress state.

2) The lateral stress and the axial stress shall be increased in stages in the combination to obtain the prescribed anisotropic consolidation stress ratio, until the final anisotropic consolidation stress state is reached.

3) Consolidation shall continue until completion of primary consolidation at least.

5.4 Cyclic loading process

The cyclic loading process shall be carried out in accordance with the following requirements.

a) Check that the state is the prescribed isotropic or anisotropic stress state.

b) Apply the cyclic torsional load in accordance with the following requirements 1) to 3). The axial stress during the cyclic loading shall be kept constant within an allowable tolerance of 2 kN/m^2 for pressures less than 200 kN/m^2, and ±1% for pressures 200 kN/m^2 or higher.

Note 1: The maximum cyclic torque amplitude may be determined as appropriate in accordance with the state of the specimens and the objectives of the test.

Note 2: Figure 6 shows an example of record of the cyclic torsional shear test.

1) First loading

1.1) For an undrained test, the drainage valve shall be closed.

1.2) Apply 11 cycles of cyclic torque with a sinusoidal or triangular wave form with a constant amplitude and a constant frequency in the range 0.05 to 1.0 Hz, so that the one-sided shear strain $(\gamma)_{SA}$ is 0.001% or less. During loading the cyclic torque, the rotational angle, and if necessary the pore water pressure shall be continuously recorded.

1.3) The change in the height and the change in the volume of the specimen due to the cyclic loading shall be measured. When undrained conditions are applied during cyclic loading, the drainage valve shall be opened and any excess pore water pressure shall be dissipated. The change in height and the change in volume of the specimen that occurs as a result shall be measured.

2) Second loading

2.1) For an undrained test, the drainage valve shall be closed.

2.2) The cyclic loading shall be carried out in the same way as the first loading, so that the one-sided shear strain $(\gamma)_{SA}$ is about double that in the first loading.

2.3) The change in the height and the change in the volume of the specimen due to the cyclic loading shall be measured. When undrained conditions are applied during cyclic loading, the drainage valve shall be opened and any excess pore water pressure shall be dissipated. The change in height and the change in volume of the specimen that occurs as a result shall be measured.

3) Third and subsequent loadings

The loading shall be applied in the same way as for the second loading. The loading shall repeat this cyclic loading stage as much as possible.

c) The state of deformation of the specimen shall be observed and recorded.

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

6 Processing test results

6.1 Specimen state 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.

$$V_0 = V_i - \mathit{\Delta} V_i$$

where

V_i : Initial volume of the specimen (mm³)

$\mathit{\Delta} V_i$: Volumetric change in the specimen produced from the initial state until prior to consolidation (mm³) (volume reduction is taken positive)

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

$$H_0 = H_i - \mathit{\Delta} H_i$$

where

H_i : Initial height of the specimen (mm)
ΔH_i : Change in height of the specimen produced from the initial state until prior to consolidation (mm) (compression is taken 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_{o0}: Initial external diameter of the specimen (mm)
D_{i0}: Initial internal diameter of the specimen (mm)
ε_{vi}: Volumetric compressive strain (%) produced from the initial state until prior to consolidation ($=\Delta V_i / V_i$)
ε_{ai}: Axial compressive strain (%) produced from the initial state until prior to consolidation ($=\Delta H_i / H_i$)

6.2 Pore water pressure coefficient *B*

The *B* value of the specimen shall be calculated as follows, and the value shall be 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)

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) (volume reduction is taken 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) (compression is taken 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 compressive strain (%) due to consolidation ($=\Delta V_c / V_0$)
ε_{ac}: Axial compressive strain due to consolidation ($=\Delta H_c / H_0$)

e) The dry density ρ_{dc} (Mg/m^3) of the specimen after consolidation shall be calculated from the following equation.

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

where

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

Note: 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 a minimum density test
e_{min}: Void ratio of the sample from a maximum density test

6.4 Cyclic loading process

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

a) The volume V_n (mm), height H_n (mm), cross-sectional area A_n (mm^2), external diameter D_{on} (mm), and internal diameter D_{in} (mm), of the specimen at the start of each loading stage carried out with constant amplitude cyclic torque shall be calculated.

Note: If necessary the void ratio e_n at the start of each loading stage shall be calculated from the following equation. The void ratio e_n at the start of the initial cyclic loading stage is equal to the void ratio e_c after consolidation.

$$e_n = \frac{V_n/1000 \times \rho_s}{m_s} - 1$$

1) The specimen volume V_n (mm^3) at the start of each loading stage shall be calculated from the following equation.

$$V_n = V_c - \Delta V_n$$

where

ΔV_n: Volumetric change in the specimen from completion of consolidation until commencement of each loading stage (mm^3) (volume reduction is taken positive)

2) The specimen height H_n (mm) at the start of each loading stage shall be calculated from the following equation.

$$H_n = H_c - \Delta H_n$$

where

ΔH_n: Axial displacement from completion of consolidation until commencement of each loading stage (mm) (compression is taken positive)

3) The specimen cross-sectional area A_n (mm^2) at the start of each loading stage shall be calculated from the following equation.

$$A_n = \frac{V_n}{H_n}$$

4) The specimen external diameter D_{on} (mm) and internal diameter D_{in} (mm) at the start of each loading stage shall be calculated from the following equation.

$$D_{on} = D_{oc} \times \sqrt{(1 - \varepsilon_{vn}/100)/(1 - \varepsilon_{an}/100)}$$

$$D_{in} = D_{ic} \times \sqrt{(1 - \varepsilon_{vn}/100)/(1 - \varepsilon_{an}/100)}$$

where

ε_{vn}: Volumetric compressive strain (%) from completion of consolidation until the start of each loading stage (=$\Delta V_n / V_c$)

ε_{an}: Axial compressive strain (%) from completion of consolidation until the start of each loading stage (=$\Delta H_n / H_c$)

b) In each cyclic loading stage in which a cyclic torque with a constant amplitude is applied, the one-sided shear stress amplitude τ_d (kN/m^2), the one-sided shear strain amplitude $(\gamma)_{SA}$ (%), the equivalent shear modulus G_{eq} (MN/m^2), and the hysteretic damping factor h (%) shall be calculated for the 5th and 10th loading cycles.

Note: Depending on the objectives of the test, the equivalent shear modulus G_{eq} (MN/m^2) and the hysteretic damping factor h (%) may be calculated at loading cycles other than the 5th and 10th loading cycles.

1) The one-sided amplitude of the cyclic shear stress τ_d (kN/m^2) shall be calculated from the following equation. The calculated value shall be rounded to three significant digits. When it is beyond the precision of the measuring devices, it shall be rounded to two significant digits.

$$\tau_d = \frac{T_R + T_L}{2\pi(r_{on}^2 + r_{in}^2)(r_{on} + r_{in})} \times 10^6$$

where

T_R, T_L: The right and left one-sided cyclic torque amplitude (N·m) in that loading cycle (each having positive values)

r_{on} : Specimen external radius at start of that cyclic loading stage (m) (= $D_{on}/2$)

r_{in} : Specimen internal radius at start of that cyclic loading stage (m) (= $D_{in}/2$)

2) The one-sided shear strain amplitude $(\gamma)_{SA}$ (%) shall be calculated from the following equation and rounded to three significant digits. When it is beyond the precision of the measuring devices, it shall be rounded to two significant digits.

$$(\gamma)_{SA} = \frac{\Delta\theta(r_{on}+r_{in})}{4H_n} \times 100$$

where

$\Delta\theta$: Double-sided amplitude of rotational angle of specimen in that loading cycle (rad)

H_n : Specimen height at the start of that cyclic loading stage (mm)

3) The equivalent shear modulus G_{eq} (MN/m^2) shall be calculated from the following equation and rounded to three significant digits. When it is beyond the precision of the measuring devices, it shall be rounded to two significant digits.

$$G_{eq} = \frac{\tau_d}{(\gamma)_{SA}} \times \frac{1}{10}$$

Note: Figure 7 is an explanatory diagram for the equivalent shear modulus G_{eq} (MN/m^2) showing an example of hysteresis curve drawn from the shear stress and shear strain obtained using the specimen height, external diameter, and internal diameter at the start of that loading cycle.

4) The hysteretic damping factor h (%) shall be calculated from the following equation and rounded to three significant digits. When it is beyond the precision of the measuring devices, it shall be rounded to two significant digits.

$$h = \frac{1}{2\pi} \cdot \frac{\Delta W}{W} \times 100$$

where

ΔW: The damping energy in that loading cycle, given by the area (N·m) of the hysteresis curve produced with the torque T and the rotational angle $\Delta\theta$

W: The equivalent elastic energy in that loading cycle, calculated from the following equation

$$W = \frac{(T_R + T_L)\Delta\theta}{4} \quad (\text{N·m})$$

Note 1: Figure 8 is a diagram explaining the hysteretic damping factor $h=(1/2\pi)\cdot\Delta W/W$.

Note 2: When the hysteresis curve does not close, as shown in Figure 9, ΔW (N·m) shall be taken to be the sum of the area of the hysteresis curve gbh and the area of the hysteresis curve hdf.

7 Reporting

The following items of the test results shall be reported.

a) Method of preparation of the specimen

b) Specimen dimensions prior to consolidation

c) B value and its method of measurement

d) Volumetric change (mm^3) and axial displacement (mm) due to consolidation

Note: 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 (mm^3) shall also be reported.

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

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

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) The loading frequency, loading wave form, and drainage states during cyclic loading

i) Method of measurement of the torque and rotational angle during cyclic loading

Note: The position of the torque meter and rotational angle measuring device within the pressure cell shall be reported.

j) Dimensions of the specimen at the start of each of the second to final cyclic loading stages

Note: If necessary, the void ratio at the start of each loading stage shall also be reported.

k) Torque and rotational angle time history in each loading stage, and the hysteresis curve for the torque and rotational angle in the 5th and 10th loading cycles

Note: The time history and hysteresis curve for the shear stress and the shear strain may also be reported. The 10th loading cycle can be taken to be the representative value, and the 5th to be a reference value.

l) The equivalent shear modulus G_{eq} (MN/m^2), the hysteretic damping factor h (%), and the corresponding one-sided shear strain amplitude $(\gamma)_{SA}$ (%) at the 5th and 10th loading cycles in each cyclic loading stage

Note: If necessary, the equivalent shear modulus G_{eq} (MN/m^2), the hysteretic damping factor h (%), and the corresponding one-sided shear strain amplitude $(\gamma)_{SA}$ (%) at all the 2nd to 10th loading cycles shall be reported.

m) Relationship between the equivalent shear modulus G_{eq} (MN/m^2), the hysteretic damping factor h (%), and the logarithm of the one-sided shear strain amplitude $(\gamma)_{SA}$ (%) in the 5th and 10th loading cycles

Note: Figure 10 shows a standard example of a summary of a series of test results.

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 outline of the test equipment, the method of saturating the specimen, the hysteresis properties of the torque meter and the rotational angle measuring device, and the material and thickness 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.

3) The state of alternation of strata in the specimen, the state of deformation, such as necking, etc.

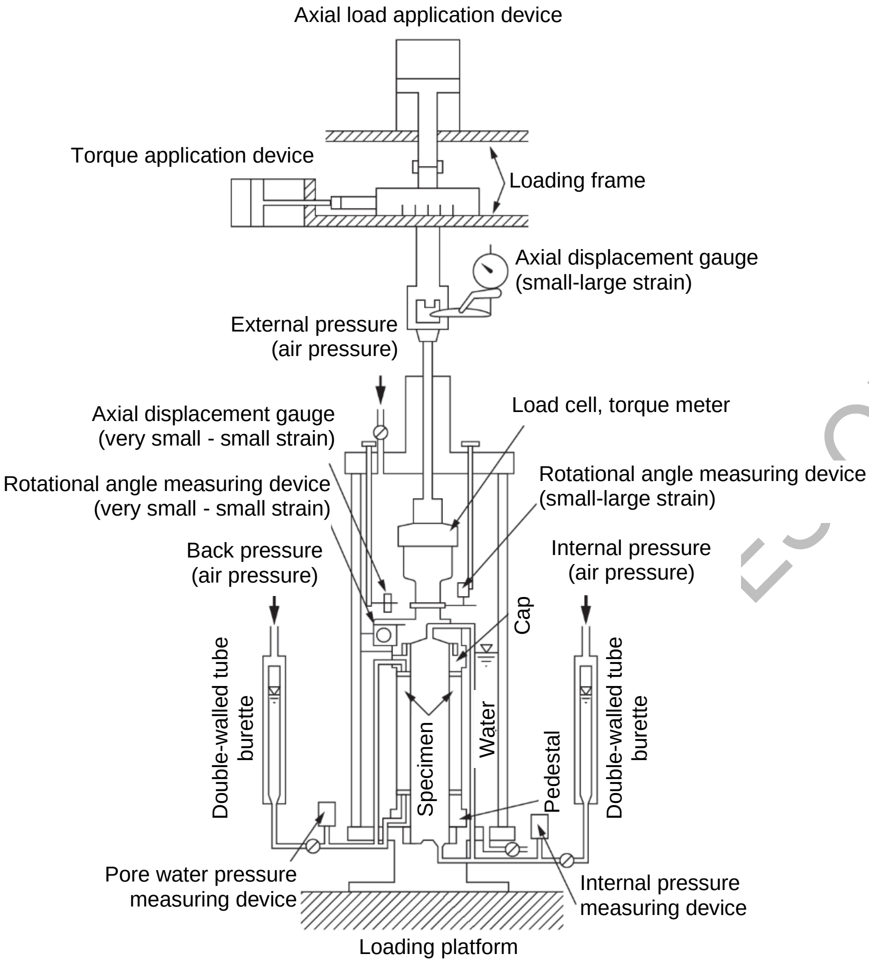

Figure 1 Example of cyclic torsional shear test equipment

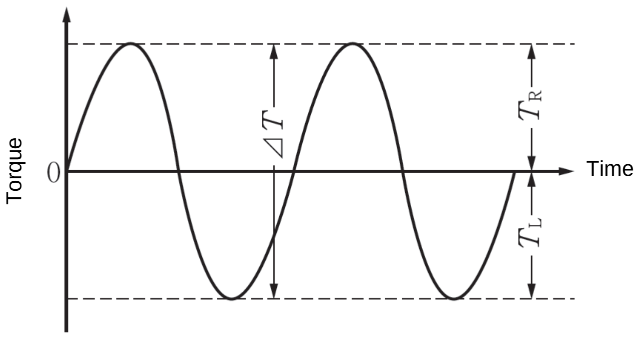

Figure 2 Definition of clockwise one-sided torque amplitude T_R and counterclockwise one-sided torque amplitude T_L for sinusoidal cyclical torque

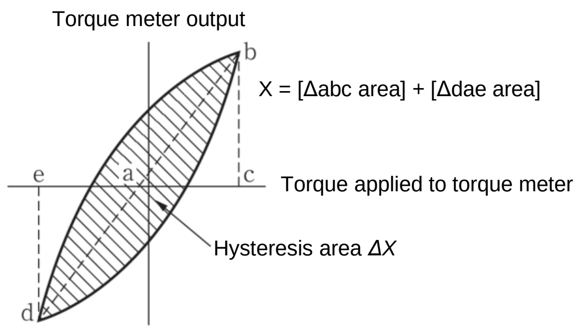

Figure 3 Definition of torque meter hysteresis properties

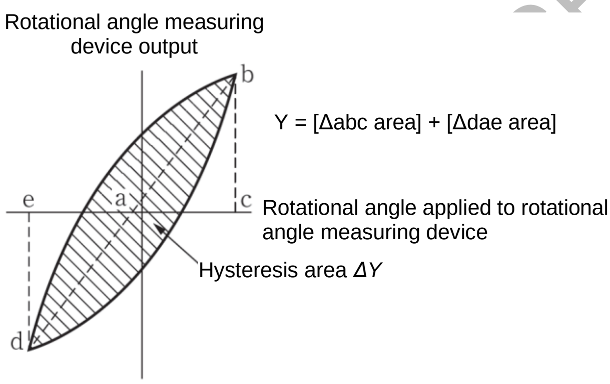

Figure 4 Definition of rotational angle measuring device hysteresis properties

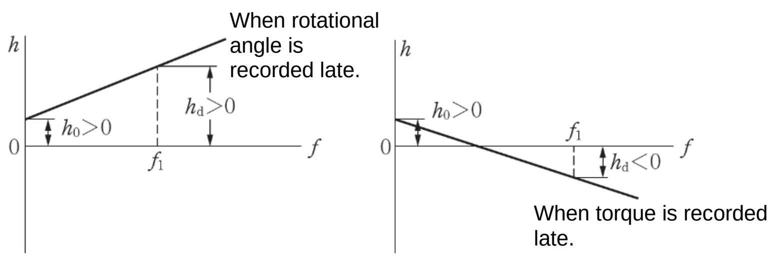

Figure 5 Apparent dependence on loading frequency *f* of *h* measured from the phase shift between the measured results for the torque and the rotational angle when *h* has no frequency dependence (h_0 is the correct value, h_d is the apparent value at f_1)

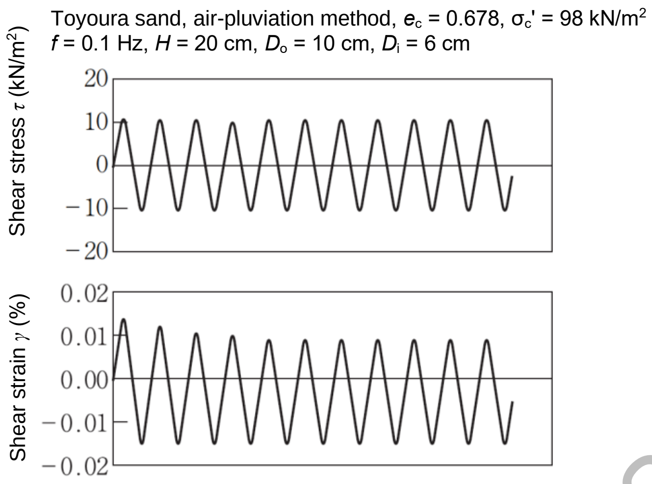

Figure 6 Example of cyclic torsional shear test record when wave form is a sine wave

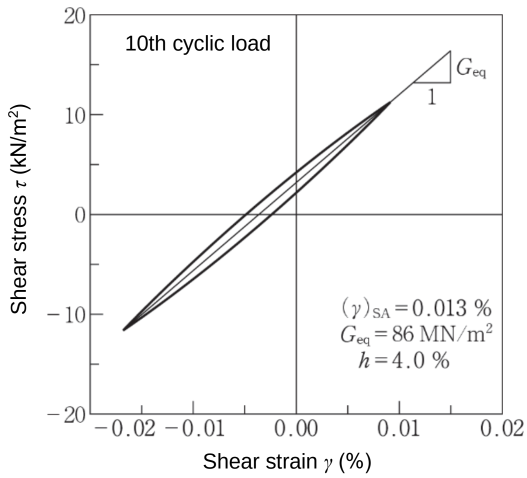

Figure 7 Example of typical hysteresis curve

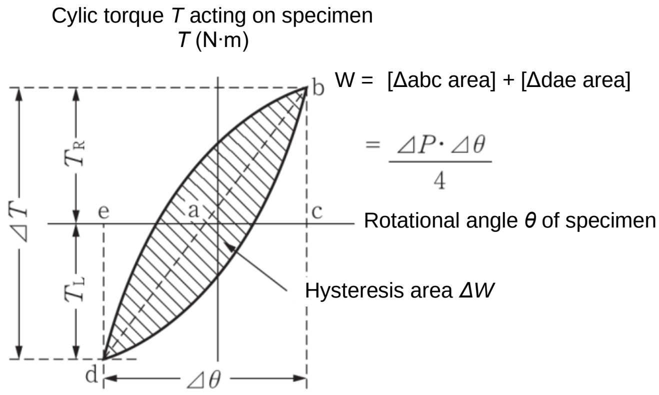

Figure 8 Explanatory diagram for the hysteretic damping factor *h*

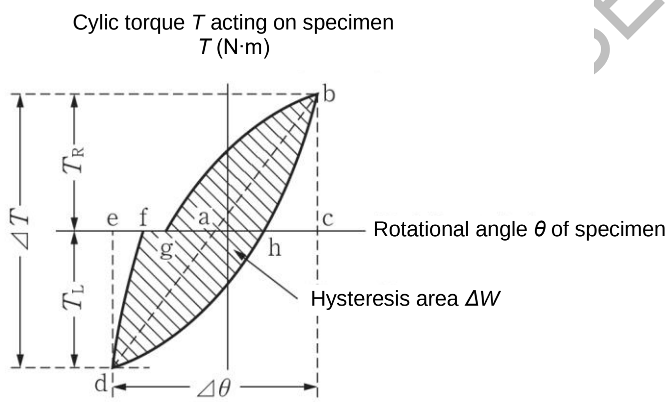

Figure 9 Explanatory diagram for the hysteretic damping factor *h* when the hysteresis curve does not close

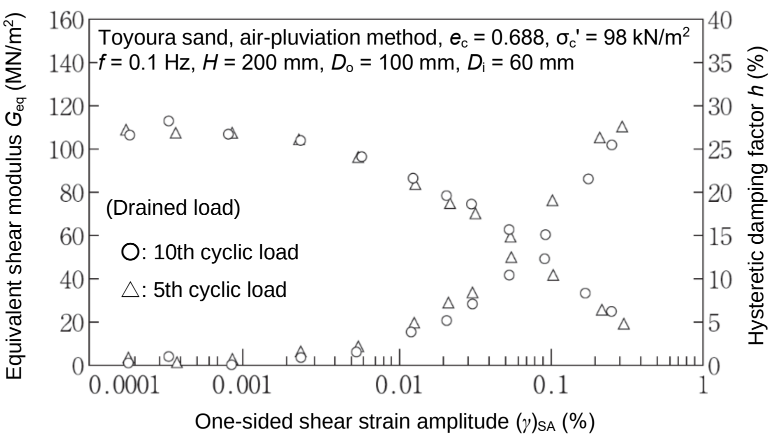

Figure 10 Example of summary of series of test results