Japanese Geotechnical Society Standard (JGS 0560-2020)
Method for consolidated constant volume direct box shear test on soils

1 Scope

This standard specifies a test method to obtain the constant-volume shear strength of a fixed volume of soil that has been one-dimensionally consolidated by causing it to shear across a plane perpendicular to an applied vertical force using a shear box. This standard applies to soils with a maximum particle size not exceeding 0.85 mm for a specimen of 60 mm in diameter and 20 mm in height.

Note: To obtain the relationship between consolidation stress and constant-volume shear strength, the test shall be conducted with several specimens under different consolidation stresses.

2 Normative references

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

JIS A 0207 Technical terms for geotechnical engineering
JIS A 1202 Test method for density of soil particles
JIS A 1203 Test method for water content of soils
JIS A 1204 Test method for particle size distribution of soils
JIS A 1217 Test method for one-dimensional consolidation properties of soils using incremental loading
JIS B 7507 Vernier, dial and digital calipers

Note: The maximum particle size of soils to be tested by this method shall be confirmed in accordance with JIS A 1204 Test method for particle size distribution of soils.

3 Terms and definitions

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

3.1 Direct box shear test

One type of direct shear test in which a soil specimen is subject to shear across a plane perpendicular to an applied vertical force. The vertical force acts on the upper and lower surfaces of a disk-shaped soil specimen.

3.2 Constant volume shear

A shear mode in which the soil specimen is sheared in the direct box shear test while keeping its volume constant.

3.3 Constant volume shear strength

The maximum shear stress applied to a specimen in the constant volume direct box shear test.

3.4 Block sample

A sample retrieved in a block shape directly or by using a sampler. It usually consists of a clayey soil, while a sandy soil may also be included.

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4 Equipment

4.1 Apparatus for direct box shear test

The direct box shear test apparatus shall consist of a shear box, loading plate, reaction plate, shear box guide, vertical force loading device, shear force loading device, load cell to measure the vertical force and the shear force, displacement gauge to measure the vertical displacement and shear displacement, and spacers to create a clearance between the upper and lower parts of the shear box. It shall meet the following requirements. Figure 1 (a) shows an example of the configuration of a direct box shear test apparatus in which the vertical force load cell is positioned on the loading plate, the vertical force is applied from below the specimen, and the upper part of the shear box is movable. An example of an alternative configuration in which the vertical load cell is positioned on the reaction plate is given in section 4.1 of JGS 0561 Method for consolidated constant pressure direct box shear test on soils.

a) Shear box

The shear box shall be a metal box with a smooth inner surface to hold the specimen. It shall contain a specimen of 60 mm in diameter and 20 mm in height. The box shall be divided into upper and lower parts, one fixed and one movable, and shall have a mechanism to allow the movable box to travel parallel to the fixed box. There shall also be a means of creating a suitable clearance between the upper and lower parts of the shear box. Further, there shall be a mechanism for fixing the upper and lower parts of the shear box with taper pins, etc., during preparation of the specimen.

Note: For soils with a maximum particle size greater than 0.85 mm, the standard diameter of the specimen (and therefore the shear box) shall be about 70 times the maximum particle size; however, this requirement may be relaxed for soils that have a wide particle size range. The height of the specimen shall be about one-third of its diameter. The cross-sectional shape of the specimen may be rectangular or square.

b) Loading plate

The loading plate shall be a rigid plate that transfers the vertical force and shear force to the specimen, which shall be secured to the vertical force loading device and be capable of moving up and down in the shear box without friction. It shall be fitted with a porous plate so as to allow water absorption and drainage and shall have a coarse surface finish to ensure application of the shear force to the specimen. The porous plate shall have an area 85 % or greater of the loading plate area and a coefficient of permeability of 10^{-6} m/s or greater.

Note: The porous plate should ideally comprise a porous stone material that is fine enough to prevent ingress of soil particles into the voids.

c) Reaction plate

The reaction plate shall be a rigid plate that receives the vertical force applied to the opposite face of the specimen by the loading plate. It shall similarly be fitted with a porous plate with a coarse finish in order that it has water supply and drainage functions and imparts the shear force to the specimen. The porous plate shall have an area 85 % or greater of the loading plate area and a coefficient of permeability of 10^{-6} m/s or greater.

Note: The porous plate should ideally comprise a porous stone material that is fine enough to prevent ingress of soil particles into the voids.

d) Shear box guide device

The shear box guide device shall ensure that the movable part of the shear box travels parallel to the fixed part of the box and moves smoothly in the prescribed direction, which shall typically consist of highly rigid rollers.

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e) Vertical force loading device

This loading device shall be capable of transferring a prescribed vertical force to the loading plate. A mechanism shall be provided to prevent any tilting tendency of the loading plate under vertical loading while the shear force is applied to the specimen. There shall also be a means of controlling the vertical force as shearing takes place. The device shall consist of a loading application device, a loading shaft, and guide rollers. The loading application device may be pneumatic, by mechanical weight-and-lever, or other means.

Note: Constant volume shear can be performed also by locking the loading shaft and, in that case, a load cell for measuring the vertical force shall be positioned on the reaction plate.

f) Shear force loading device

The shear force loading device shall cause the movable part of the shear box to travel smoothly at a constant speed. It shall be capable of controlling the shear displacement rate in the range 0.05-0.5 mm/min.

g) Load cell

The load cell shall be capable of measuring the maximum values of vertical force and expected shear force to an accuracy of ±1 % or better. It shall be sufficiently stiff, exhibiting its own deformation of 0.01 mm or less within the range of the loading conditions to be measured. The load cell for measuring the vertical force shall be placed either on the loading plate face or on the reaction plate face.

Note: If a load cell for measuring the vertical force is placed on the loading plate face, its stiffness does not need to meet any requirement.

h) Displacement gauge

The displacement gauge shall be capable of measuring vertical displacement and shear displacement to an accuracy of ±0.01 mm or less, respectively, with a capacity of 10 mm or larger.

i) Spacers for creating clearance

The spacers used to create clearance between the two parts of the shear box shall consist of plates with a thickness of 0.2 to 0.5 mm, which shall not deform under the consolidation pressure. The spacers shall be 0.2 to 0.5 mm thick. An example of a spacer is shown in Figure 1 (b).

Note: An alternative to using spacers is to create clearance by adjusting the screws after consolidation.

4.2 Tools for Specimen Preparation

The tools used to prepare specimens from block samples shall be equivalent to those specified in Section 4.2 in JIS A 1217 Test method for one-dimensional consolidation properties of soils using incremental loading. To prepare specimens from samples that are not in a block shape, the tools described in a) and b) below shall be used. In this standard, the consolidation ring for the consolidation tests shall be replaced with the shar box.

a) Tool for air-pluviation method

This tool shall be used to prepare a specimen by the air-pluviation method. Figure 2 shows an example of the tool for the air-pluviation method.

g) Tool for compaction method

This tool shall be used to prepare a specimen by compacting sample material in the shear box. Figure 3 shows an example of the tool for the compaction method.

Note: This tool shall include a tamping rod with a flat bottom and a disk with a diameter slightly smaller than the specimen, such as shown in Figure 4.

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4.3 Miscellaneous equipment

The equipment used during the preparation and placement of specimens, etc., shall be as follows.

a) Balance

The balance shall have a resolution of 0.01 g.

b) Tool for water content measurement

The tool used to obtain the water content of the soil shall conform with section 4 (Test tool) of JIS A 1203 Test method for water content of soils.

c) Stopwatch or watch

The stopwatch or watch shall have readings to the second.

d) Vernier, dial and digital calipers

Vernier, dial and digital calipers specified in JIS B 7507 shall be used.

5 Preparation and set-up of specimen

Set up the clearance between upper and lower parts of the shear box using spacers and then secure the upper and lower parts using taper pins or similar. Apply silicone oil or silicone grease to the inner surface of the shear box parts to reduce surface friction. Measure the inner diameter and the height of the shear box, which shall be set as the diameter, D (mm) and the height H_0 (mm) of the specimen, respectively. For block samples, transfer the specimen from the cutter ring to the shear box. For samples that are not in a block shape, prepare the specimen directly in the shear box.

Note: If there is a risk of soil particle penetrating the porous plates, a non-compressible water-permeable membrane may be used as a filter.

5.1 Block samples

Specimens shall be prepared from block samples using a method that is equivalent to section 5.2 (Trimming of specimen) of JIS A 1217 Test method for one-dimensional consolidation properties of soils using incremental loading.

a) Measure the mass, m_R (g), of the cutter ring.

b) Place a sample 5-10 mm larger in height than the required specimen on the turntable of the trimmer and use a wire saw, knife, etc., to shape it into a circular disk 3-5 mm larger in diameter than the required specimen.

c) Place the cutter ring on the top surface of the sample lying on the trimmer and use a wire saw, knife, etc., to trim the part of the sample outside the blade edge to a size 1-2 mm greater than the inner diameter of the cutter ring. Gently push the upper plate of the trimmer down to insert the cutter ring 2-3 mm into the sample. Repeat this process of trimming and insertion to fill the cutter ring with sample material without leaving voids.

d) Use a wire saw to cut off any sample material projecting from the two faces of the cutter ring and use a straight knife to finish it into a smooth, flat surface.

e) Measure the mass, m_1 (g), of the specimen while held in the cutter ring.

f) Choose a representative sample from the cut waste and measure its initial water content, w_0 (%).

g) Secure the cutter ring in place on top of the shear box and use the insertion tool to transfer the specimen into the shear box.

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5.2 Samples that are not in block shape

Specimens shall be prepared from samples that are not in a block shape as follows.

a) Measure the maximum particle size of the samples in advance, and confirm that the maximum particle size is 0.85 mm or less.

b) Measure the initial water content, w_0 (%), of the sample.

c) Prepare the sample to ensure that the prescribed volume and density can be obtained for the specimen, and measure the mass.

d) Air-pluviation method

Obtain in advance the drop height required to achieve the prescribed density in a preliminary test. Allow the sample material to fall from the nozzle for the pre-determined drop height into the shear box. Level and smooth the upper surface of the sample.

e) Compaction method

Place the sample material in the shear box and use the tool for the compaction method to compact it dynamically or statically to achieve uniform distribution of the local specimen density. Level and smooth the upper surface of the sample.

f) Weigh the remaining part of the sample and subtract it from the total mass of the sample to obtain the mass, m_0 (g), of the specimen.

6 Test procedure

6.1 Preparation

Preparations for the test shall be carried out as follows.

a) Assemble the shear box guide device and mount the displacement gauge for measuring vertical displacement.

b) Arrange for water to be supplied to the porous plate if the degree of saturation of the specimen is to be enhanced.

6.2 Consolidation process

The consolidation process shall be carried out as follows.

a) Adjust the origin on the vertical force load cell and the vertical displacement gauge.

b) Apply a vertical force equivalent to the prescribed consolidation stress, σ_c (kN/m^2) and start consolidation. Incremental loading may be used to the prescribed consolidation stress.

c) Read the vertical displacement as the consolidation amount, ΔH_t (mm), at appropriate elapsed times during consolidation. Plot elapsed time, t (min), on the logarithmic axis to draw a semi-logarithmic time-consolidation curve. The elapsed times at which the consolidation amount is measured shall be equivalent to those specified in section 6.2 (Loading and measurement) of JIS A 1217 Test method for one-dimensional consolidation properties of soils using incremental loading.

d) Continue consolidation until the consolidation rate becomes insignificant after the completion of primary consolidation.

6.3 Creation of clearance between upper and lower parts of shear box

The clearance between the upper and lower parts of the shear box shall be set up as follows.

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a) Remove the clearance spacers.

Note: If no spacers are used, adjust the screws to create a clearance of 0.2-0.5 mm using the vertical displacement gauge as an indicator.

b) Remove the taper pins or other devices used to fix the upper and lower parts of the shear box together.

6.4 Shear process

The shear part of the test shall be carried out as follows.

a) Mount the displacement gauge for measuring shear displacement and adjust the origin on the displacement gauge and the shear force load cell.

b) Start the shear process at the prescribed shear displacement rate.

Note: The shear displacement rate shall be 0.05 mm/min for clayey soil specimen, 0.1 mm/min for over-consolidated clay specimen, about 0.2 to 0.5 mm/min for sand specimen.

c) During the shear process, control the vertical force or lock the loading shaft so that no vertical displacement occurs, thereby keeping the volume of the specimen constant. To satisfy the constant volume conditions, in the case of a specimen with a height of 20 mm, maintain control such that fluctuations in vertical displacement fall within ±0.01 mm. If the loading shaft is locked, a vertical force load cell shall be in advance fitted on the reaction plate face.

d) Record the shear displacement δ (mm), shear force S (N), vertical force N (N), and vertical displacement ΔH (mm) at appropriate intervals.

Note: The measurement interval shall be chosen such that a smooth stress-displacement curve can be drawn. It is recommended to measure the shear displacement at a maximum interval of 0.1 mm or less, up to the maximum value of shear force and, thereafter, at a maximum interval of 0.25 mm or less. Pay extra attention not to miss the maximum value of shear force.

e) Continue to apply shear until 7 mm of shear displacement has been applied.

Note: If the purpose is to obtain the constant volume shear strength only, the test may be terminated after confirming the maximum value of shear force.

f) Once shearing has been completed, remove the specimen from the shear box and observe the condition of the sheared surface, etc. For cohesive soil samples, measure the oven-dried specimen mass, m_s (g).

g) For block samples, based on JIS A 1204 Test method for particle size distribution of soils, measure the maximum particle size of the specimen after it has been oven-dried, and confirm that the maximum particle size is 0.85 mm or less.

7 Processing test results

7.1 Initial state of specimen

The initial state of the specimen shall be obtained using the following equations.

a) For cohesive soil samples, calculate the initial water content w_0 (%), wet density ρ_{t0} (Mg/m^3), and actual height H_s (mm) of the specimen before the test using the following equation. The value of the initial water content w_0 (%) shall be rounded to the first decimal place, and the value of the wet density ρ_{t0} (Mg/m^3) shall be rounded to the second decimal place.

$$w_0 = \frac{(m_1 - m_R) - m_s}{m_s} \times 100$$

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$$\rho_{t0} = \frac{m_1 - m_R}{AH_0} \times 1000$$

$$H_s = \frac{m_s}{A\rho_s} \times 1000$$

where

m_1: Mass of specimen with cutter ring (g)
m_R: Mass of cutter ring (g)
m_s: Mass of oven-dried specimen after the test (g)
A: Cross-sectional area of specimen (=$\pi D^2/4$) (mm^2)
D: Diameter of specimen (mm)
H_0: Initial height of specimen (mm)
ρ_s: Density of soil particles (Mg/m^3)

Note: The values of densities that have been expressed conventionally with a unit of g/cm^3 are the same as those expressed with a unit of Mg/m^3.

b) For samples that are not in a block shape, calculate the wet density ρ_{t0} (Mg/m^3) and actual height H_s (mm) of the specimen before the test using the following equation, where the value of the wet density ρ_{t0} (Mg/m^3) shall be rounded to two digits after the decimal point.

$$\rho_{t0} = \frac{m_0}{AH_0} \times 1000$$

$$H_s = \frac{H_0\rho_{t0}}{\rho_s\left(1 + \frac{w_0}{100}\right)}$$

where

m_0: Mass of the specimen before the test (g)

c) Calculate the void ratio e_0, dry density ρ_{d0} (Mg/m^3), and degree of saturation S_{r0} (%) of the specimen before the test using the following equation. The values of the void ratio e_0 and the dry density ρ_{d0} (Mg/m^3) shall be rounded to two digits after the decimal point, and the value of the degree of saturation S_{r0} (%) shall be rounded to one digit after the decimal point.

$$e_0 = \frac{H_0}{H_s} - 1$$

$$\rho_{d0} = \frac{\rho_s H_s}{H_0}$$

$$S_{r0} = \frac{w_0\rho_s}{e_0\rho_w}$$

where

ρ_w: Density of water (Mg/m^3)

7.2 Consolidation process

The calculation and analysis of results for the consolidation process shall be made as follows.

a) Plot a log t versus ΔH_t curve with the logarithm of time t (min) on the horizontal axis and consolidation amount ΔH_t (mm) on the vertical axis.

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b) Calculate the height H_c (mm), void ratio e_c, and dry density ρ_{dc} (Mg/m³) of the specimen after consolidation using the following equation, where the values of the void ratio e_c, and the dry density ρ_{dc} (Mg/m³) shall be rounded to two digits after the decimal point.

$$H_c = H_0 - \Delta H_c$$

$$e_c = \frac{H_c}{H_s} - 1$$

$$\rho_{dc} = \frac{\rho_s H_s}{H_c}$$

where

ΔH_c: Final consolidation amount (mm), where compression is defined to be positive

7.3 Shear process

The calculation and analysis of results for the shear process shall be made as follows.

a) Calculate the shear stress τ (kN/m²) and vertical stress σ (kN/m²) relative to each shear displacement δ (mm) using the following equation.

$$\tau = \frac{S}{A} \times 1000$$

$$\sigma = \frac{N}{A} \times 1000$$

where

S: Shear force (N)
N: Vertical force (N)

Note: No correction for the cross-sectional area of the specimen during shearing shall be made.

b) Plot a shear stress versus shear displacement ($\tau - \delta$) curve with shear stress, τ, on the vertical axis and shear displacement, δ, on the horizontal axis.

c) Using the same horizontal axis as in b) above, plot a vertical stress versus shear displacement ($\sigma - \delta$) curve with vertical stress, σ, on the vertical axis.

d) Plot a stress path ($\tau - \sigma$ relationship) with shear stress, τ, on the vertical axis and vertical stress, σ, on the horizontal axis.

e) The constant-volume shear strength (kN/m²) shall be determined as the maximum value of τ before the ultimate shear displacement, which shall be rounded to three significant digits.

8 Reporting

The following results of the test shall be reported.

a) Dimensions of the specimen (mm)

b) Details of the apparatus used for the test (location of the vertical force load cell, force application system and location of the vertical force loading device, whether the upper or lower part of the box is movable, and method of setting up the clearance)

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c) Type and the maximum particle size of the specimen (mm)

d) Specimen preparation method

e) Initial state of the specimen (water content (%), void ratio, wet density (Mg/m^3), dry density (Mg/m^3), and degree of saturation (%))

f) Consolidation stress and the time-consolidation curve

g) State of the specimen after consolidation (height (mm), void ratio, and dry density (Mg/m^3))

h) Shear displacement rate (mm/min) and size of clearance between the upper and lower parts of the shear box (mm)

i) Maximum fluctuation in vertical displacement during shear (mm)

j) Shear stress versus shear displacement curve, vertical stress versus shear displacement curve, stress path, and constant volume shear strength

k) Relationship between the constant volume shear strength and consolidation stress if the test was conducted under different consolidation stresses for several specimens taken from the same sample

Note: This relationship may be superimposed on the stress path diagram.

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

m) Other reportable matters

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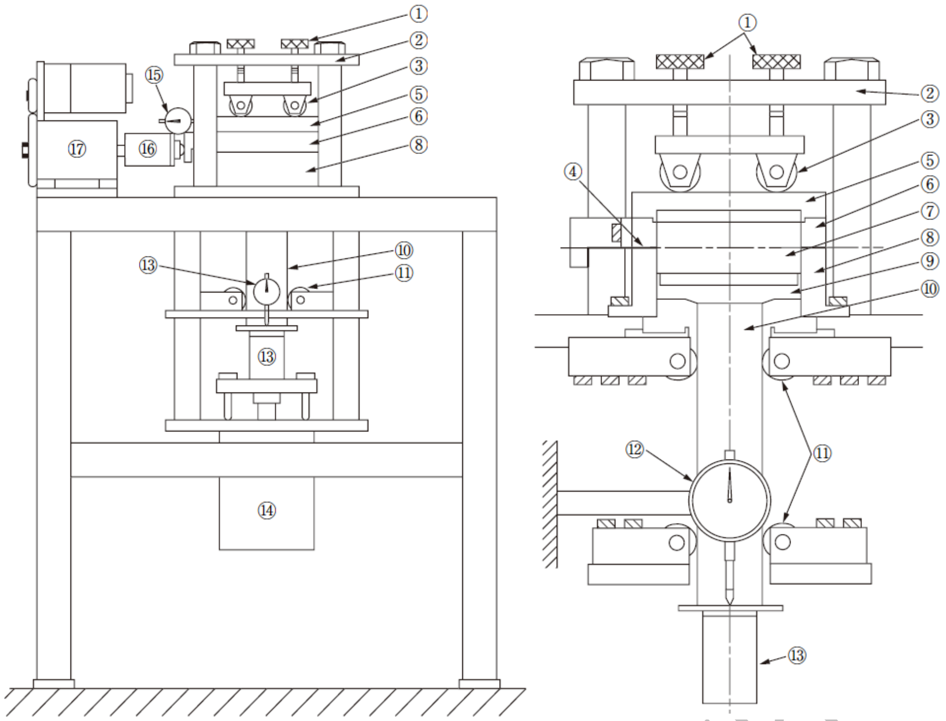

① Screw for creating clearance
② Reaction frame
③ Shear box guide device
④ Spacer for creating clearance
⑤ Reaction plate
⑥ Upper part of shear box (movable)
⑦ Specimen
⑧ Lower part of shear box (fixed)
⑨ Loading plate
⑩ Loading shaft
⑪ Guide roller
⑫ Displacement gauge (for measuring vertical displacement)
⑬ Load cell (for measuring vertical force)
⑭ Lading application device
⑮ Displacement gauge (for measuring shear displacement)
⑯ Load cell (for measuring shear force)
⑰ Shear force loading device

Figure 1 (a) Example of an apparatus configuration for consolidated constant-volume direct box shear test

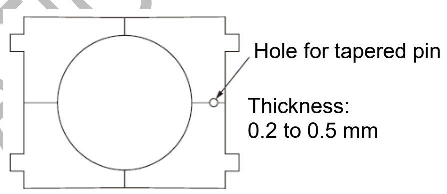

Figure 1 (b) Example of spacer for creating clearance

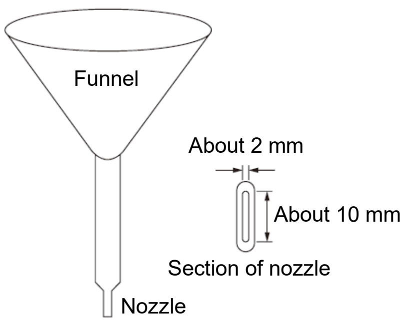

Figure 2 Example of tool for the air-pluviation method

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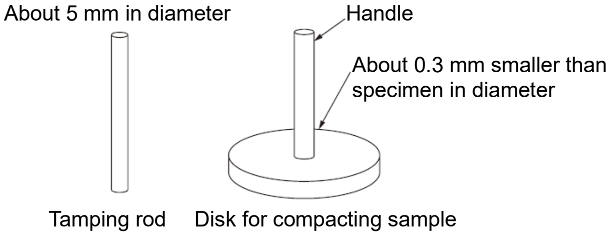

Figure 3 Example of tool for the compaction method

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