Method for Consolidated-Drained (CD) Triaxial Compression Test on Rocks

1. FOREWORD

This official draft standard presented by the Japanese Geotechnical Society is for the Consolidated-Drained (CD) triaxial compression test methods on rocks. The original draft was prepared by the Standardizing Committee of the Consolidated-Drained (CD) Triaxial Compression Test on Rocks (refer to Table I for the committee member composition). Brief history and significance of this standard, and notes are described in the following sections.

2. Brief history of the draft standard

To select laboratory and in-situ test methods to be standardized, the Study Committee for the Rock Testing Methods of the Japanese Geotechnical Society (chaired by Professor Ryunoshin Yoshinaka of Saitama University, founded in 1993), conducted surveys on specifications and guidelines officially used by both domestic and foreign academic societies and organizations. The Committee studied practicability and necessity of the new standards. Two-year study showed that although the uniaxial and triaxial compression tests are widely used and considered important, there are no standards covering rock characteristics varying widely from soft to hard rocks. It was therefore concluded that the establishment of a new standard would be extremely important.

Under these circumstances, the Study Committee for the Uniaxial and Triaxial Compression Test Methods on Rocks (hereafter called the Study Committee), chaired by Professor Yoshinaka, carried out a three-year preliminary investigation since 1995 to collect and classify necessary information for standardization of the test methods. There were five main activities involved: (1) questionnaire survey; (2) nationwide round robin tests; (3) literature research; (4) sorting out of major points for standardization of test methods; and (5) organizing symposiums focusing on the uniaxial and triaxial compression test methods. Taking the results of the study by the aforementioned Study Committee into consideration, standardization of the triaxial compression test has been carried forward ever since.

The Consolidated-Drained (CD) triaxial compression test method on rocks presented here is based on the original plan by the Standardizing Committee of the Consolidated-Drained (CD) Triaxial Compression Test on Rocks (founded in 2000). This draft standard was then finalized, incorporating the decisions reached through in-depth discussions by the Study Committee for Standards Test and Survey Methods on Rocks, and the Standardizing Department.

3. Significance of the specification

This draft standard for Consolidated-Drained (CD) triaxial compression test method is mainly for saturated rocks from soft to hard rocks, and rock like geomaterials. Namely, the draft standard is for test methods where a rock specimen is subjected to a constant cell pressure in a triaxial cell, subsequent to completion of consolidation under applied cell pressure,

Table I: Members of the Standardizing Committee of the Consolidated-Drained (CD) Triaxial Compression Test Method on Rocks

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<thead>
<tr>
<th>Position</th>
<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Chairman</td>
<td>Soich Tanaka</td>
<td>Oyo Corporation</td>
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<tr>
<td>Secretary / Member</td>
<td>Masahiro Seto</td>
<td>National Institute of Advanced Industrial Science and Technology (AIST)</td>
</tr>
<tr>
<td></td>
<td>Takeshi Iwamoto</td>
<td>Oyo Corporation</td>
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<tr>
<td>Members</td>
<td>Kenji Aoki</td>
<td>Kyoto University, Faculty of Engineering</td>
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<td></td>
<td>Arakawa</td>
<td>Dia Consultants Co., Ltd.</td>
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<tr>
<td></td>
<td>Toshiaki Ikeda</td>
<td>Chuo Kaihatsu Corporation</td>
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<tr>
<td></td>
<td>Tamotsu Kiyama</td>
<td>Railway Technical Research Institute (RTRI)</td>
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<tr>
<td></td>
<td>Kenichirou Suzuki</td>
<td>Geosphere Research Institute of Saitama University</td>
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<td></td>
<td>Takayuki Nishino</td>
<td>Mitsui Construction Co., Ltd.</td>
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<td>Kohei Watanabe</td>
<td>Obayashi Corporation</td>
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opening the drainage path for pore water, while the axial stress is monotonically increased until the specimen fails.

The aforementioned Study Committee conducted a nationwide questionnaire to learn what sort of uniaxial and triaxial compression tests on rocks have been conducted for what purposes, and how the test results have been used. Seventy-nine domestic organizations responded (response rate: 65%) and multiple analyses on the survey results were conducted. Main results obtained so far are, as follows:

1) Next to the uniaxial compression test, the triaxial compression test is the second most important and frequently used test method on soft and hard rocks.

2) Some of the commonly used triaxial compression test methods for rocks are UU, CU, and CD methods. For soft rocks UU, CU, and CD tests are used with a similar frequency, whereas UU tests are much more frequently used for hard rocks than CU, and CD tests.

Upon this investigation the standardizing Committee was founded in the 1998-1999 year, of UU test, the most frequently used and essential method for both soft and hard rocks, and Method for Unconsolidated-Undrained (UU) Triaxial Compression Test on Rocks (JGS 2531-2000) was finalized. Standardizations have been carried forward continuously, of the methods for consolidated-undrained triaxial compression test and the test methods under consolidated-drained condition.

In planning of social-capital of our country, the importance of underground space use is appealed. There are many construction enterprises for soft rocks in various areas, and it is important to understand that stability over a long period of time beforehand as the important dynamics characteristic peculiar to soft rocks. Moreover, it is important to get to know the dynamics characteristic in connection with the long-term behavior of hard rocks in large depth underground use. However, there are no specific standards in the triaxial compression test methods on rock in connection with such long-term stability evaluation also including movement of pore water, and the treatment by each organization, such as applying correspondingly the test method on the soil, is not necessarily unified in the present situation.

Under these circumstances, the standardizing committee decided to arrange the factors which give influence to an test result, such as preparation of specimens, test apparatus, test procedure and method and measurement of displacement, on the Consolidated-Drained (CD) triaxial compression test methods on rocks, and establish the standard to understand the dynamics characteristic under consolidated-drained conditions.

In addition, for the Consolidated-Undrained (CU, CU) triaxial compression test methods on rock, standardization is carried forward separately.

4. Outline of the draft standard

This draft standard comprises seven sections: 1. General rules to 7. Reporting. Fundamentally this has the same structure and standard text contents as the UU test method and the CU and CU test method, however, on 5. Test Method, as test environment, determination of consolidation time, and loading rate, that is especially important in case of conducting the test, the draft standard was prepared after analyzing the examples and repeating deliberations carefully. It is difficult to state these in detail in the standard texts or notes, and judgment is also needed, it is made to give facilities when conducting the tests by being substantial in description and showing the examples.

4.1 General

This draft standard is "as a principle" applied to saturated rocks and rock like geomaterials. When the tests are conducted for hard rocks, it is assumed when the saturation of the specimen is difficult for the initial water state of the specimen, the hardness of a frame, the form of pores, the hydraulic conductivity, and the stress state at the time of the test. This is why the phrase "as a principle" is used.

Here, consolidation is defined as the phenomenon in which pore waters is drained by isotropic stress in the exterior of the specimen. Consolidated-drained compressive strength is defined as the maximum principal stress difference applicable to the specimen under consolidated-drained condition.

The number of the specimens which are needed in order to evaluate strength and deformation characteristics is defined as "use of more than four specimens is recommended" according to the unconsolidated-undrained (UU) triaxial compression test method on rocks (JGS 2531-2000)

4.2 Test Apparatus

The CD triaxial compression test requires back pressure supply device and volume change measurement device. Here, especially, capacity and accuracy of cell pressure and back pressure are referred. Accuracy required in the measurement of longitudinal displacements is set to be ±0.01% of the specimen height. Volume change of the specimen is set to be
measured with an accuracy of ±0.03 % of the initial volume of the specimen. Although various methods are applied for volume change measurement, here, representative five methods are referred to in the notes.

4.3 Preparation of specimens and measurement

The standard diameter of a specimen is set at 5.0cm and the height is double the diameter. This is based on the results of the aforementioned questionnaire, in which most organizations responded with these dimensions. The notes with respect to specimen dimensions state that “for coarse-grained or brecciated rocks, or conglomerate, it is desirable that the specimen be greater than 5 times the largest compositional grain.”

Concerning preparation of specimens, for this standard is applied to rocks on the whole, usually used recoring method and trimming method are referred.

4.4 Setting of specimens and saturation

As increasing the degree of saturation of the specimen is important process, four methods are presented as ones that should be adopted according to kind and state of rock. Concerning method of adding back pressure, procedure is referred to in the notes, in consideration that “when applying pressure to specimen, the cell pressure and the back pressure shall be applied as gradually in order not to cause fluctuations in the effective stress of the specimen.”

4.5 Test Method

For it becomes a comparatively long-term test by the relation with strain rate, it is referred to in the notes that temperature’s condition in the laboratory shall be paid attention to.

Measurement of the volume change of the specimen during consolidation, which is one of the essential processes of the CD test, is referred. Also, judgment of the period to stop consolidation is referred in the notes as method for CU test.

The aforementioned questionnaire revealed that most organizations are using either stroke-controlled or strain-controlled test method. This is why this draft standard requires a compression process where the specimen shall be continuously compressed in the axial direction at a constant displacement rate or a constant axial strain rate. Axial strain rate, which is referred in the notes and in the commentary section, ranging between 0.001 and 0.01% per minute is set to be standard, taking affairs as the results of questionnaire into consideration although the test at slow speed is desired.

4.6 Evaluation of Test Results

Equations for calculating values at the consolidation stage and the axial compression stage are similar to those defined by the Consolidated-Drained (CD) triaxial compression test methods on soils (JGS 0524-2000). In addition to these equations, an equation for calculating the Poisson's ratio is given in the notes and in the commentary section.

4.7 Reporting

Considering the fact that tests are often conducted to obtain deformation characteristics of rocks along with strength characteristics, the notes refer to the evaluation of deformation characteristics. This is similar to those of the UU test method and the CU and CU test method on rocks.

References


Designation: JGS 2534-200*
Method for Consolidated-Drained Triaxial Compression Test on Rocks

1. GENERAL

1.1 Purpose of Test
The purpose of this test method is intended to obtain strength and deformation properties of rocks, when subjected to consolidated and drained triaxial compression.

1.2 Range of Application
This standard is mainly applicable to saturated rocks and rock-like geomaterials.

1.3 Definition of Terms
(1) CD means shearing rock specimens under drained condition, with consolidating them (isotropically) prior to shear.
(2) Axial stress is applied in the longitudinal direction, while lateral stress is applied in the radial direction of the specimen. They are defined at mid-height of the specimen. The difference between the two stresses is termed principal stress difference. Cell pressure is the pressure applied in a triaxial cell. Lateral stress is equal to cell pressure.
(3) Isotropic stress state is defined as a stress state in which axial stress is identical to lateral stress.
(4) Drained condition is a state in which pore water moves freely in and out of the specimen.
(5) Back Pressure is the pore water pressure applied in the specimen under the condition that the effective stress is held constant.
(6) Consolidation stress is the pressure obtaining by subtracting the back pressure from the cell pressure in an isotropic consolidation.
(7) Consolidated-drained compressive strength of rock is the maximum principal stress difference applicable to the specimen under consolidated-drained condition.

[Notes]
1. a. In case the method employed is partially different from this standard, details shall be clearly stated in the report.
b. Refer to the following specifications and standards for the issues not defined in this standard:
JGS 2521: Method for Unconfined Compression Test on Rocks
JGS 0542: Method for Undrained Cyclic Triaxial Test to Determine Deformation Properties of Geomaterials.
c. This test can be written as “the CD triaxial test on rocks.”

1.1 a. Tests shall be performed at different isotropic stresses in the required stress range, on as many specimens obtained from the same material as required, usually not fewer than four, to evaluate strength characteristics.
1.2 a. Rock-like geomaterials mean the geomaterials to be improved or man-made, such as concretes and artificial soft rocks.
1.3 a. Consolidation described in this standard means a phenomenon that pore water or pore air discharges out of the specimen irrespective of the degree of saturation, when the specimen is subjected to an isotropic stress.

2. APPARATUS

2.1 Triaxial Compression Apparatus
Triaxial compression test apparatus consists of a triaxial pressure chamber, cell supply system, loading system, together with load, displacement and volume change measurement devices. Is shall satisfy the following conditions:
(1) Triaxial apparatus should be able to sufficiently sustain both the maximum axial compression load of the specimen and the maximum cell pressures.
(2) The apparatus should be able to continuously apply pressures to a specimen till the end of a test, with an accuracy of ±4 kN/m² for pressures less than 200 kN/m², and of ±2 % for pressures greater than 200 kN/m².
(3) Axial displacement or axial load should be continuously applied at a constant rate of feed.
(4) Cell pressures should be measured with an accuracy of ±2 kN/m² for pressures less than 200 kN/m², and of ±1 % for pressures greater than 200 kN/m².
(5) Axial compression load should be measured with an accuracy of ±1 % of the maximum axial compression load of the specimen.
Axial displacement should be measured with an accuracy of $\pm 0.01\%$ of the height of the specimen.

Volume change of the specimen should be measured with an accuracy of $\pm 0.03\%$ of the initial volume of the specimen up to the maximum change of the volume.

### 2.2 Miscellaneous Accessories

1. Specimen covering material
2. Specimen size measurement tools, which should be able to measure the specimen height and diameter with an accuracy of 0.1 mm and better.
3. Balance, which should be able to weigh the specimen with an accuracy of 0.01 g and better.
4. Sample trimming devices

### Notes

#### 2.1a
When back pressure is loaded, the back pressure supply device and the back pressure gauge are prepared. At this time, be the same of the condition of which the device should be full as 2.1(2) and (4).

b. A typical triaxial test apparatus is illustrated in Figure 1. However, when back pressure is used, the back pressure regulator, the back pressure gauge, and the double-walled burette for back pressure shown in Figure 1 with dashed lines are necessary. Schematic views of two different triaxial pressure chambers are shown in Figure 2 and 3: loading piston and cap are rigidly connected (Figure 2); and are separated (Figure 3). In each type of the triaxial cells, the specimen can be mounted between cap and pedestal with the same diameter as that of the specimen. They are covered with a rubber membrane, and sealed with O-rings.

c. As a method of measuring the volume change, 1) Method of using burette. 2) Method of differential pressure transducer (Figure 1(a), 3). 3) Method of strain gage (Figure 3(a)). 4) Method of measuring axle and circumferential direction displacement. 5) Method of using double cell (Figure 1(b)). Being enumerated. Apply correspondingly to 2.1(7) about the condition of which the device should be full though it is necessary to select the measurement method according to the expected displacement.

(1) Capacity of the cell pressure should be selected according to the purpose of the test. In case that the maximum axial force is expected to become large, a loading frame with high rigidity should be used, so that the frame deformation will not affect the axial displacement measurement.

(5) When a load cell is mounted outside the triaxial cell, the measured axial force should be corrected for frictional force between loading piston and bushing. In case that a load cell is installed inside the triaxial cell, the effect of cell pressure on the load cell reading should be calibrated, and correction should be made for measured axial force.

(6) When the main objective of the test is to obtain the deformation properties of rocks, the axial displacement should be measured at the lateral surface of the specimen by a proper technique. (Figure 2 and Figure 3 references)

(7) Intended for a rock not saturated. Whether the specimen of the volume change should be measured at the lateral surface of the specimen

#### 2.2

1. Rubber membrane, heat shrinkage tubing, or silicone rubber may be used as specimen covering material. When the specimen covering material is tightened against the loading cap and pedestal, with O-ring, elastic, and a steel-made ring, etc.

a. When the rubber membrane is used, Membrane stretcher should be cylindrical, and its length and inner diameter should be 5 to 10 % larger than the height and the diameter of the specimen. The stretcher should have a stretcher such that rubber membrane can be stretched snugly against the inner side of the stretcher when vacuum is applied. If the cap is rigidly connected to the loading piston, it is desirable to use a membrane stretcher that can be split longitudinally into two pieces. In such cases, the two pieces of the stretcher should be air-tight when assembled.

b. Filter should be sufficiently permeable in comparison with the permeability of the specimen. In case that filters are installed in the cap and pedestal for the sake of the longitudinal drainage along the specimen side, it is desirable that the filters be sufficiently incompressible and sufficiently little frictional. It is preferable that the filter rolled on the specimen side by the purpose of shortening the consolidation time is shape that the shearing deformation is not restrained as much as possible as the slit is put and is.

(2) Specimen diameter is measured by sliding calipers or by
Pi tape.

(4) Miter box, sample trimmer, straight edge, surface grinder, diamond slab saw, and recoring devices are used for sample trimming.

from the trimmed-off portions, and water content shall be measured. Measured water content shall be assigned as initial water content \( w_0(\%) \).

(5) Initial conditions of the specimen shall be observed and recorded.

3. SAMPLE PREPARATION AND SIZE MEASUREMENTS

3.1 Sample Shape and Sample Size

(1) Test specimens shall be right circular cylinders.

(2) Standard specimen diameter shall be set as 5cm.

(3) Standard specimen height shall be set as twice the diameter.

3.2 Sample Preparation

(1) Without finishing lateral surface of the specimen

In case the borehole core diameter is the same as the diameter of the test specimen, the borehole core shall be cut to a desired length by a cutting machine. A surface grinder if required shall finish the specimen ends.

(2) Trimming method

① Test specimen shall be trimmed to a desired diameter using reamer, straight edge etc.

② Ends shall be finished using miter box, straight edge etc.

(3) Recoring method

① Test specimen shall be recored from block samples into a desired diameter.

② Ends of test specimen shall be trimmed by a cutting machine, and finished by a grinder if necessary.

3.3 Specimen Size Measurement

(1) Specimen diameter shall be measured in the vicinity of both ends and at mid-height to less than 0.1mm, and the average value of the 3 measurements shall be assigned as initial diameter \( D_0(\text{cm}) \).

(2) Specimen height shall be measured at more than 3 locations to less than 0.1mm, and the average value of the 3 measurements shall be assigned as initial height \( H_0(\text{cm}) \).

(3) Mass of the specimen, \( m_0(\text{g}) \) shall be measured to less than 0.01g.

(4) If necessary a representative piece shall be selected

\[ \text{[Notes]} \]

3.1

(2) a. This standard shall be suitable to specimens of the specimen diameter range being 2-10cm.

b. For coarse-grained or brecciated rocks, or conglomerate, it is desirable that the specimen be greater than 5 times the largest compositional grain.

(3) It is desirable size that specimen height be two times that of diameter, but rate of specimen height and diameter shall be adjusted in a range of 1.8-2.5.

3.2

a. It is desirable that the test specimen of soft rocks be made and tested immediately after sampling. In case there is duration between sampling and testing, care shall be taken so as not to damage samples, to change water content, or to change sample condition in-situ.

b. When preparing test specimens, portions of material, which are obviously disturbed during sampling, shall be excluded.

c. Specimen shall be prepared within a reasonable duration of time so as not change water content of material. Care shall be taken so as not to disturb material.

d. When preparing specimens, material orientation shall be recorded for clarity.

e. In principle, material longer than the finished specimen height shall be used.

f. Lateral side of the specimen shall be smooth and free of irregularities. It shall be straight over the full length of the specimen.

(1) If material is affected by wetting, it shall be wrapped with plastic film and trimmed by a cutting machine using a small amount of water or oil.

(2) a. If samples are sensitive to wetting, trimming method should be applied to borehole cores and sample blocks larger than the specimen diameter.

b. If using lower end of sample as standard plane, the maximum deviation of the specimen height shall be within 0.1%, and the angle of the specimen top surface
relative to the contact surface top cap shall be less than 0.5 degree.

3. Specimen ends shall be finished flat to an accuracy of 0.02mm, and square to the specimen axis. The squareness shall not deviate from its perpendicularity by more than 0.001 radians or 0.05mm for 50mm diameter specimen.

3.3 If necessary initial wet density, \( \rho_{w}(g/cm^3) \), initial dry density, \( \rho_{d}(g/cm^3) \), initial void ratio \( e_0 \), initial effective porosity \( n_{eo}(\%) \), and degree of saturation \( S_{ro}(\%) \), may be calculated using the following equations. But, for calculating the \( n_{eo} \), the specimen shall be submerged into water longer than 72 hours.

\[
\begin{align*}
\rho_{i0} &= \frac{m_0}{V_0} \\
\rho_{d0} &= \frac{m_z}{V_0} \\
e_0 &= \frac{V_0 \rho_z - 1}{m_z} \\
n_{eo} &= \frac{m_{ow} - m_z}{m_{ow} - m_v} \times 100 \\
S_{ro} &= \frac{m_z - m_s}{V_0 \rho_v - m_0} \times 100
\end{align*}
\]

Where

\( V_0 (cm^3) \): initial specimen volume \( V = \frac{\pi}{4} D^2 H \)

\( \rho_{w}(g/cm^3) \): grain density of rock composition

\( \rho_{d}(g/cm^3) \): density of water

\( m_s(g) \): dry mass of specimen

\( m_{ow}(g) \): mass after submerging specimen into water longer than 72 hours, and

\( m_w(g) \): apparent mass in water after submerging specimen into water longer than 72 hours

4. When water content is determined on the tested specimen subsequent to the test, water content measurement on a cutoff piece may be omitted.

5. Lithology of the trimmed specimen shall be observed, together with properties of bedding planes, lamina, and fissures, and the degree of weathering and alteration. Offset angles of the bedding planes, lamina, and fissures from the specimen axis shall also be measured.

4. SPECIMEN SET UP AND SATURATION

4.1 Specimen set up

(1) The side of the specimen shall be sealed with a covering material.

(2) Specimen shall be placed on the pedestal, onto which a loading cap is placed.

(3) After triaxial pressure chamber is assembled, confining fluid shall be introduced into the chamber.

4.2 Saturation of Specimen

(1) When necessary, attempts shall be made to increase the degree of saturation of the specimen by an appropriate combination of available saturation techniques.

(2) In case of adding back pressure to specimen, the back pressure \( u_b(MN/m^2) \) and isotropic pressure to specimen shall be applied on condition of keeping the back pressure and isotropic in constant at the same time.

[Notes]

4. After placing a loading cap on top of the specimen, excessive seating load shall not be applied in the axial direction of the specimen, until cell pressure is applied to the specimen. Especially when the compressive strength of the specimen is expected small, the seating pressure shall not exceed 10kN/m².

4.1

a. The sequence of 4.1(1) and (2) may be changed according to the covering method of specimen.

(1) In case strain gage and other measuring equipments are set up or drain filter is used to the specimen, the following step shall be done.

(2) a. If the condition specified in Notes 3.2(2),(3) cannot be met, the specimen ends shall be capped with material like gypsum. Capping thickness shall be in the order of 1 to 3mm. The capping material should be stronger and more rigid than the specimen.

b. If necessary, the drainage filter paper shall be set up to upper or lower ends of specimen and side of the specimen.

(3) a. Water or oil is generally used as confining fluid. For some case, e.g., at low cell pressure, gas may be used as a substitute.

b. Testing apparatus shall be assembled together following procedure to the structure of the testing machine.
4.2

(1) In case of increasing saturation degree of specimen, following 4 methods may be combined to use according to kind and state of rock.
   a. Method of passing deaerated water through specimen in which applied cell pressure.
   b. Method of applying back pressure to specimen enough.
   c. Method of using above method a or method b after substituting carbonic acid gas for pore air specimen in which applied cell pressure.
   d. Method of sucking out the air from specimen on the condition of applying partial vacuum to triaxial chamber, and keeping isotropic effective pressure in constant. If necessary, passing deaerated water through the specimen when applying the partial vacuum.

(2) When applying pressure to specimen, following procedure is recommended that the cell pressure and the back pressure shall be applied as gradually in order not to cause fluctuations in the effective stress of the specimen.
   Closing the drainage valve of volume change meter, and applying isotropic pressure increments corresponding to a quart to a half of the value of final back pressure to the specimen. Finally, opening the valve while applying back pressure of the same magnitude. This operation shall be repeated until the back pressure reaches the specified values, whilst ensuring that the difference between the isotropic stress and back pressure being applied to the specimen shall always remains at the preset value.

5. METHOD OF TESTING

5.1 Isotropic Stress Application
(1) Check the set-up of measuring devices. Make the initial readings if necessary.
(2) Close the drainage valve connected to the burette. Raise only the isotropic stress up to a desired initial isotropic stress.
(3) Open the valve to start consolidation.
(4) During consolidation, the volume change of the specimen \( \Delta V_e \) (cm\(^3\)) and if possible axial displacement \( \Delta H_e \) (cm) shall be measured at appropriate intervals of elapsed time \( t \). Additionally, these shall be illustrated in appropriate chart on a semi-logarithmic scale.

(5) Consolidation shall be continued until the appropriate time is elapsed, and the volume change \( \Delta V_e \) (cm\(^3\)) and if possible axial displacement \( \Delta H_e \) (cm) of the specimen during consolidation are to be measured.

5.2 Axial Compression Stage
(1) Check the original point of the measuring devices and if necessary read the initial values.
(2) Keeping the cell pressure constant, the specimen shall be continuously compressed in the axial direction, at a constant displacement rate or a constant axial strain rate.
(3) Axial force, \( P \) (kN), and axial displacement, \( \Delta H \) (cm) and volumetric change \( \Delta V \) (cm\(^3\)) shall be measured during compression.
(4) The specimen shall be compressed even after the maximum load cell reading is reached. Compression may however be terminated in principle when a residual stress state (no further principal stress difference) is reached.
(5) The specimen tested shall be taken out of the triaxial cell, and conditions of deformation and failure shall be observed and recorded.

[Notes]
5a. Temperature's condition in the laboratory where the test shall be conducted, may affect the test result. Therefore note the temperature's condition shall be kept constant at a normal condition during the process of testing.

5.1
(2a) When the cap is rigidly connected to the loading piston, the axial force is applied to the specimen through the loading piston, simultaneously with cell pressure application to obtain an isotropic stress state for the specimen. Since the relationship between axial force and cell pressure may vary, depending upon the diameter and self-weight of the loading piston, it is necessary to know their relationship in advance.

b. If the loading piston and the cap are separated from each other, load cell, loading piston and the cap shall be connected to each other before these processes.

(4a) The recording time intervals shall be frequent enough to allow a smooth drawing of a \( \Delta V - \log t \) curve (Refer to JIS A 1217 “Test Method for One-dimensional Consolidation Properties of Soils”).

b. The value of strain gages mounted on the lateral surface of
the specimen $e_a$ (%) can be used in spite of the axial displacement $\Delta H_e$ (cm).

c. If no axial displacement can be measured because the piston is not connected to the cap rigidly, measure the displacement of the piston, which is in contact with the cap, taking care not to apply any additional load to the specimen, by checking the reading of load cell. This displacement is regarded as the axial displacement, $\Delta H_e$ (cm), caused by consolidation.

d. When the volume change measuring device is used on unsaturated rock, measured volume change during consolidation shall be corrected for the expansion of the triaxial chamber and the displacement of the loading piston. Corrected volume change shall be regarded as the volume change during consolidation $AV$ (cm$^3$).

(5) A period to stop consolidation has close relationships with the specimen's permeability characteristic and the stiffness of skeleton structure and so on. On the $AV - \log t$ curve, with drawing a time-domain curve followed by a consolidation theory, judge the period to stop consolidation by the $3t$ method (Refer to JGS 2532-2001 "Method for Consolidated-Undrained Triaxial Compression Test on Soft Rocks". If no primary consolidation can be identified clearly, judge the period with checking whether the present change of measured values closely connected with the change of void ratio is small, represented by the volume change, the excessive pore water pressure, the strain at the surface of the specimen etc.

5.2

a. Oven-dried mass of the specimen, $m_e$ (g), may be measured if required. This procedure may be omitted, provided the water content has been determined using a piece of trimmed-off portions of the specimen prior to the test.

(2)a. If it is difficult to keep the axial displacement rate or axial strain rate constant, the specimen may be compressed at an axial stress rate equivalent to the above-mentioned strain rate.

b. A nominal axial strain rate ranging between 0.001 and 0.01% per minute shall be standard.

(3) In case the axial compression force and axial displacement are not continuously recorded, an adequate sampling interval should be adopted, so as to draw a smooth curve of the principal stress difference vs. axial strain relationship.

(4) Continue the test until an axial strain of 15% has been reached when a peak stress state is not observed. In case of hard rocks, if necessary continue the test until the stroke of the piston is reached the maximum range. For load control tests, compression shall be terminated when the axial displacement begins to increase abruptly.

(5) After compression test, the conditions of deformation and failure shall be observed and sketched from the direction where the state of the specimen can be seen most clearly. When a distinct shear plane is formed, the observation is made from an angle at which the shear plane becomes steepest. The shear plane shall be sketched such that its inclination can be directly read in the drawing. Observations are made to evaluate whether the specimen tested is homogeneous, and what condition impurities are in. The observation results are then recorded.

6. CALCULATIONS

6.1 Consolidation State

(1) Specimen volume after consolidation, $V_e$ (cm$^3$), is calculated from the following equation:

\[ V_e = V_0 - AV \]

Where

$AV$ (cm$^3$) : volume change during consolidation

(2) Specimen height after consolidation, $H_e$ (cm), is calculated from the following equation:

\[ H_e = H_0 - \Delta H_e \]

Where

$\Delta H_e$ (cm) : axial displacement during consolidation

(3) Cross-sectional area of the specimen after consolidation, $A_e$ (cm$^2$), is calculated from the following equation:

\[ A_e = V_e / H_e \]

6.2 Axial Compression Stage

(1) Axial strain of the specimen, $e_a$ (%), is calculated using the following equation:

\[ e_a = \frac{\Delta H}{H_e} \times 100 \]

Where

$\Delta H$ (cm) : axial displacement of the specimen during axial compression

(2) Volume strain of the specimen, $e_v$ (%) (compression with plus number), at an axial strain of $e_a$ (%) is calculated, as
follows:
\[ \epsilon_v = \frac{\Delta V}{V_o} \times 100 \]

Where
\( \Delta V \) (cm\(^3\)) : volume change of the specimen during axial compression

(3) \((\sigma_a - \sigma_r)\) (MN/m\(^2\)), at an axial strain of \( \epsilon_a \) (%) is calculated, as follows:
\[ \sigma_a - \sigma_r = \frac{P}{A_o} \times \frac{1 - \frac{\epsilon_a}{100} \times 10}{1 - \frac{\epsilon_v}{100}} \]

Where
\( P \) (kN) : axial compression force exerted to the specimen at an axial strain of \( \epsilon_a \) (%) ; \( P = 0 \) in the isotropic consolidation stage.
\( \sigma_a \) (MN/m\(^2\)) : stress acting in the direction of specimen axis, and
\( \sigma_r \) (MN/m\(^2\)) : stress acting in the radial direction of the specimen.

(4) The relationship between principal stress difference and axial strain, and the relationship between volume strain and axial strain is plotted in a graphical form.

(5) Maximum value of the principal stress difference is directly read within the limits of measured axial strain on the figure described in (3) above, and is assigned as the compressive strength of the material tested.

[Notes]

6.2

(1) In case circumferential displacement is measured, lateral strain, \( \epsilon_r \), and Poisson's ratio, \( \nu \), are calculated using the following equations:
\[ \epsilon_r = \frac{\Delta l}{\pi D_o} \times 100, \quad \nu = \frac{\Delta \epsilon_r}{\Delta \epsilon_a} \]

Where \( \Delta l \) (cm) : circumferential displacement of the specimen.

(2) In case the loading cap is not rigidly connected with the piston, when measurement of axial displacement during consolidation, \( \Delta H_e \), is judged to be uncertain, it is assumed that it is what an isotropic strain produced in the specimen, specimen height after consolidation, \( H_e \) (cm), is calculated using the following equations. When \( H_e \) is calculated using this equation, it writes in a report matter clearly.
\[ H_e = \left( 1 - \frac{\Delta V}{3V_o} \right) \times H_o \]
bedding planes, laminae, and fissures from the longitudinal axis of the specimen.

7.3

(5) When circumferential displacement is monitored, principal stress difference vs. lateral stain relationship shall be reported, if required, together with lateral strain vs. axial strain relationship and Poisson's ratio.

(7) If necessary, angle of internal friction, $\phi_m$, and the intercept at the vertical axis, $c_m$, obtained from the Mohr's failure envelope shall be reported. If the envelope is nonlinear, the stress range at which $\phi_m$ and $c_m$ are determined shall be clearly stated.

7.4 a. If required, residual strength of the material tested shall be reported along with the angle of internal friction at this state, $\phi_r$, and the intercept at the vertical axis, $c_r$, determined from the Mohr's circles for the residual stress state.

b. If required, the secant modulus, $E_{50}$, and the tangent modulus, $E_{150}$, for each applied isotropic stress shall be determined from the initial portion of the principal stress difference vs. axial strain curve at 50% of the maximum strength of the material. The relationship between deformation moduli and isotropic stress shall then be reported.