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INTERNATIONAL SOCIETY FOR ROCK MECHANICS COMMISSION ON STANDARDIZATION OF LABORATORY AND FIELD TESTS

SUGGESTED METHODS FOR DETERMINING TENSILE STRENGTH OF ROCK MATERIALS

INTRODUCTION

The Commission on Standardization of Laboratory and Field Tests on Rock was appointed in 1967. Subsequent to its first meeting in Madrid in October 1968, the Commission circulated a questionnaire to all the members of the International Society for Rock Mechanics, the answers received clearly showing a general desire for standardized testing procedures. At a further meeting in Oslo in September 1969, tests were categorised and a priority for their standardization was agreed upon, as given in Table 1.

It was also decided that research tests, including many of the rock physics tests, were beyond the scope of standardization. Subsequent meetings were held in Belgrade in September 1970, in Nancy in October 1971, in Lucerne in September 1972, in Katowice in October 1973, in Denver in September 1974, in Minneapolis in September 1975 and in Salzburg in October 1976. At the Lucerne meeting the Commission was subdivided into two committees, one on standardization of laboratory tests and the second on the standardization of field tests.

The present document has been produced by the Committee on Standardization of Laboratory Tests. The present document covers Category II(1) in Table 1.

It should be emphasized that the purpose of these "Suggested Methods" is to specify rock testing procedures and to achieve some degree of standardization without inhibiting the development or improvement of techniques.

Any person interested in these recommendations and wishing to suggest additions or modifications should address his remarks to the Secretary General, International Society for Rock Mechanics, Laboratório Nacional de Engenharia Civil, Avenida do Brasil, Lisboa, Portugal.

Acknowledgements—The following persons contributed in the drafting of these "Suggested Methods": Z. T. Bieniawski (South Africa), I. Hawkes (U.S.A.).

TABLE 1. TEST CATEGORIES FOR STANDARDIZATION

Category I: *Classification and Characterization*

Rock material (*laboratory tests*)

(1) Density, water content, porosity, absorption.*
(2) Strength and deformability in uniaxial compression; point load strength.*
(3) Anisotropy indices.
(4) Hardness, abrasiveness.*
(5) Permeability.*
(6) Swelling and slake-durability.*
(7) Sound velocity.*
(8) Micro-petrographic descriptions.*

Rock mass (*field observations*)

(9) Joint systems: orientation, spacing, openness, roughness, geometry, filling and alteration.*
(10) Core recovery, rock quality designation and fracture spacing.
(11) Seismic tests for mapping and as a rock quality index.
(12) Geophysical logging of boreholes.*

Category II: *Engineering Design Tests*

Laboratory

(1) Determination of strength envelope (triaxial and uniaxial compression and tensile tests).*
(2) Direct shear tests.*
(3) Time-dependent and plastic properties.

In situ

(4) Deformability tests.*
(5) Direct shear tests.*
(6) Field permeability, ground-water pressure and flow monitoring; water sampling.*
(7) Rock stress determination.*
(8) Monitoring of rock movements, support pressures, anchor loads, rock noise and vibrations.
(9) Uniaxial, biaxial and triaxial compressive strength.
(10) Rock anchor testing.*

* Asterisks indicate that final drafts on these tests have been prepared.

Suggested Methods for Determining Tensile Strength of Rock Materials

PART 1: SUGGESTED METHOD FOR DETERMINING DIRECT TENSILE STRENGTH

1. SCOPE

This method of test is intended to measure directly the uniaxial tensile strength of a rock specimen of regular geometry. The test is mainly intended for classification and characterization of intact rock.

2. APPARATUS

(a) A suitable machine shall be used for applying and measuring the axial load to the specimen. It shall be of sufficient capacity and capable of applying load at a rate conforming to the requirements set in section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4, Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1.

(b) Cylindrical metal caps shall be cemented to the specimen ends, providing a means through which the direct uniaxial tensile load can be applied. The diameter of the metal caps shall not be less than that of the test specimen nor shall it exceed the test specimen diameter by more than 2 mm. Caps shall have a thickness of at least 15 mm. Caps shall be provided with a suitable linkage system for load transfer from the loading device to the test specimen. The linkage system shall be so designed that the load will be transmitted through the axis of the test specimen without the application of bending or torsional stresses. The length of the linkages at each end shall be at least twice the diameter of the metal caps.*

3. PROCEDURE

(a) The test specimens shall be right circular cylinders having a height to diameter ratio of 2.5:3.0 and a diameter preferably of not less than NX core size, approximately 54 mm. The diameter of the specimen should be related to the size of the largest grain in rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be generally smooth and flat.† The ends shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.1 mm over the full length of the specimen.

(d) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the mid-height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(e) Samples shall be stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, until the time of specimen preparation. Following their preparation, the specimens shall be stored prior to testing for 5–6 days in an environment of 20°C $\pm$ 2°C and 50% $\pm$ 5% humidity.‡ This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, Committee on Laboratory Tests, Document No. 2, Final Draft, November 1972.

(f) The metal caps should be cemented to the specimen in such a manner as to ensure alignment of the cap axes with the logitudinal axis of the specimen. The thickness of the cement layer should not exceed 1.5 mm at each end. After the cement has hardened sufficiently to exceed the tensile strength of the rock, the test speciment shall be placed in the testing machine in such a way that the load transfer system is properly aligned.

(g) The tensile load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5 min of loading; alternatively the stress rate shall be within the limits of 0.5 MPa/s to 1.0 MPa/s.

(h) The maximum load on the specimen shall be recorded to within 1%.

(i) The number of specimens per sample tested should be determined from practical considerations but at least five are preferred.

4. CALCULATIONS

The tensile strength of the specimen shall be calcu-

* According to the *Annual Book of ASTM Standards*, Test D2936-71, a roller or link chain of suitable capacity has been found to perform quite well in this application. Because roller chain flexes in one plane only, the upper and lower segments are positioned at right angles to each other to reduce bending in the specimen. Ball-and-socket, cable or similar arrangements have been found to be generally unsuitable because their tendency for bending and twisting makes the assembly unable to transmit a purely direct tensile stress to the test specimen.

‡ In direct tension tests, the condition of the specimen ends with regard to the degree of flatness and smoothness is not as critical as in compression tests. End surfaces such as result from sawing with a diamond cut-off wheel are entirely adequate.

† It is recognised that in some cases for some materials (e.g. shale), it may be desired to test specimens in other moisture conditions, for example, saturated or oven dry at 105°C. Such conditions shall be noted in the test report.

lated by dividing the maximum load applied to the specimen by the original cross-sectional area.

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientation, dates of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and/or stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure, e.g. location and orientation of failure surface.

(j) Any other observations or available physical data, such as specific gravity, porosity and permeability, citing the method of determination of each.

(k) The tensile strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample. The pascal (Pa) or kilopascal (kPa) or mega-pascal (MPa) shall be used as the unit of stress and strength.

(l) Should it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

PART 2: SUGGESTED METHOD FOR DETERMINING INDIRECT TENSILE STRENGTH BY THE BRAZIL TEST

1. SCOPE

This test is intended to measure the uniaxial tensile strength of prepared rock specimens indirectly by the Brazil test. The justification for the test is based on the experimental fact that most rocks in biaxial stress fields fail in tension at their unaxial tensile strength when one principal stress is tensile and the other finite principal stress is compressive with a magnitude not exceeding three times that of the tensile principal stress.

2. APPARATUS

(a) Two steel loading jaws designed so as to contact a disc-shaped rock sample at diametrically-opposed surfaces over an arc of contact of approx 10° at failure. The suggested apparatus to achieve this is illustrated in Fig. 1. The critical dimensions of the apparatus are the radius of curvature of the jaws, the clearance and length of the guide pins coupling the two curved jaws and the width of the jaws. These are as follows: Radius of jaws—1.5 × specimen radius; guide pin clearance—permit rotation of one jaw relative to the other by 4×10^{-3} rad out of plane of the apparatus (25 mm penetration of guide pin with 0.1 mm clearance); width of jaws—1.1 × specimen thickness. The remaining dimensions can be scaled from Fig. 1. The upper jaw contains a spherical seating conveniently formed by a 25-mm diameter half-ball bearing.

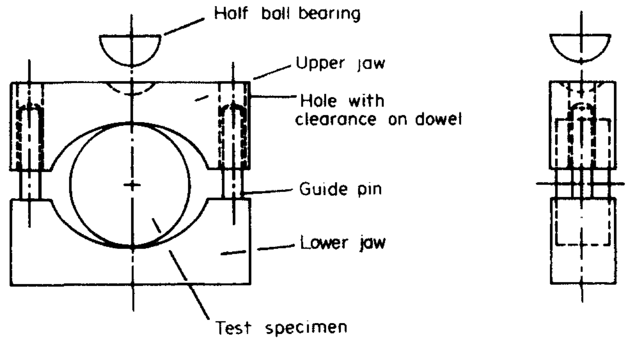

Fig. 1. Apparatus for Brazil test.

(b) Double thickness (0.2–0.4 mm) adhesive paper strip (masking tape) with a width equal to or slightly greater than the specimen thickness.

(c) A suitable machine for applying and measuring compressive loads to the specimen. It shall be of sufficient capacity and be capable of applying load at a rate conforming to the requirements set out in section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4, Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1.

(d) A spherical seat, if any, of the testing machine crosshead shall be placed in a locked position, the two loading surfaces of the machine being parallel to each other.

(e) It is preferable but not obligatory that the testing machine be fitted with a chart recorder to record load against displacement to aid in the measurement of the failure load.

3. PROCEDURE

(a) The test specimens should be cut and prepared using clean water. The cylindrical surfaces should be free from obvious tool marks and any irregularities across the thickness of the specimen should not exceed 0.025 mm. End faces shall be flat to within 0.25 mm and square and parallel to within 0.25°.

(b) Specimen orientation shall be known and the water content controlled or measured and reported in accordance with the "Suggested method for determination of water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, November 1972.

(c) The specimen diameter shall not be less than NX core size, approximately 54 mm, and the thickness should be approximately equal to the specimen radius.

(d) The test specimen shall be wrapped around its periphery with one layer of the masking tape and mounted squarely in the test apparatus such that the curved platens load the specimen diametrally with the axes of rotation for specimen and apparatus coincident.

(e) Load on the specimen shall be applied continuously at a constant rate such that failure in the weakest rocks occurs within 15–30 s. A loading rate of 200 N/s is recommended.

(f) Where the testing machine is fitted with a force/displacement recorder, a record should be taken during testing—so that the load for primary fracture can be precisely determined (in some cases load continues to increase after primary failure as the split specimen is still bearing load). If a load/displacement recorder is not available on the testing machine, then care must be taken by the operator to detect the load at primary failure. At primary failure there will be a brief pause in the motion of the indicator needle. However, the difference between the load at primary failure and ultimate load bearing capacity is at most only about 5%.

(g) The number of specimens per sample tested should be determined from practical considerations, but normally ten are recommended.

4. CALCULATIONS

The tensile strength of the specimen σ_t, shall be calculated by the following formula:

$$\sigma_t = 0.636\, P/Dt \text{ (MPa)}$$

where P is the load at failure (N), D is the diameter of the test specimen (mm), t is the thickness of the test specimen measured at the center (mm).

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientation, dates and method of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure.

(j) Any other observations or available physical data such as specific gravity, porosity and permeability, citing the method of determination for each.

(k) The tensile strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample.

REFERENCES

Mellor M. & Hawkes I. Measurement of tensile strength by diametral compression of discs and annuli. *Engng Geol.* **5**, 173–225 (1971).

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INTERNATIONAL SOCIETY FOR ROCK MECHANICS

COMMISSION ON STANDARDIZATION OF LABORATORY AND FIELD TESTS

SUGGESTED METHODS FOR DETERMINING THE STRENGTH OF ROCK MATERIALS IN TRIAXIAL COMPRESSION

INTRODUCTION

The Commission on Standardization of Laboratory and Field Tests on Rock was appointed in 1967. Subsequent to its first meeting in Madrid in October 1968, the Commission circulated a questionnaire to all the members of the International Society for Rock Mechanics, the answers received clearly showing a general desire for standardized testing procedures. At a further meeting in Oslo in September 1969, tests were categorized and a priority for their standardization was agreed upon, as given in Table 1.

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Category I: Classification and Characterization

Rock material (laboratory tests)

(1) Density, water content, porosity, absorption.*
(2) Strength and deformability in uniaxial compression; point load strength.*
(3) Anisotropy indices.
(4) Hardness, abrasiveness.*
(5) Permeability.
(6) Swelling and slake-durability.*
(7) Sound velocity.*
(8) Micro-petrographic descriptions.*

Rock mass (field observations)

(9) Joint systems: orientation, spacing, openness, roughness, geometry, filling and alteration.*
(10) Core recovery, rock quality designation and fracture spacing.
(11) Seismic tests for mapping and as a rock quality index.
(12) Geophysical logging of boreholes.*

Category II: Engineering Design Tests

Laboratory

(1) Determination of strength envelope (triaxial and uniaxial compression and tensile tests).*
(2) Direct shear tests.*
(3) Time-dependent and plastic properties.

In situ

(4) Deformability tests.*
(5) Direct shear tests.*
(6) Field permeability, ground-water pressure and flow monitoring; water sampling.
(7) Rock stress determination.*
(8) Monitoring of rock movements, support pressures, anchor loads, rock noise and vibrations.
(9) Uniaxial, biaxial and triaxial compressive strength.
(10) Rock anchor testing.*

* Asterisks indicate that final drafts on these tests have been prepared.

Suggested Methods for Determining the Strength of Rock Materials in Triaxial Compression

1. SCOPE

This test is intended to measure the strength of cylindrical rock specimens subjected to triaxial compression. This provides the values necessary to determine the strength envelope and from this the value of the internal friction angle ϕ and the "apparent" cohesion C may be calculated.*

2. APPARATUS

The apparatus consists essentially of three parts (See Fig. 1): a triaxial cell, a loading device and a device for generating confining pressure.

2.1. *A triaxial cell*

This comprises:

(a) Test specimens shall be right circular cylinders be placed in order to apply the confining pressure. The body of the cell should have an air bleeder hole and a connection for a hydraulic line.

(b) A flexible jacket of suitable material to prevent the hydraulic fluid from entering the specimen, and which shall not significantly extrude into abrupt surface pores.

(c) The triaxial cell shall be filled with hydraulic fluid, than C30 shall be placed at both specimen ends. The diameter of the platens shall be between D and $D + 2$ mm, where D is the diameter of the specimen. The thickness of the platens shall be at least 15 mm or $D/3$. Surfaces of platens should be ground and their flatness should be 0.005 mm.

(d) Spherical seats which are incorporated in each of the platens.† The curvature centre of the seat surfaces should coincide with the centre of the specimen ends.

2.2. *A loading device for applying and controlling axial load*

(a) A suitable machine shall be used for applying, controlling and measuring the axial load on the rock specimen. It shall be of sufficient capacity and capable of applying the load at a rate conforming to the requirements as set out in section 4(e). It shall be verified at certain time intervals‡ and shall comply with the accepted national requirements such as prescribed in either ASTM Methods E 4, Verification of Testing Machines; British Standard 1610, 1964, Grade A or Deutsche Normen DIN 51 220 and DIN 51 223, Klasse 1 and DIN 51 300.

(b) The spherical seat of the loading machine, if any, and if it is not complying with specification 2.1 (d) above, shall be removed or placed in a locked position, the two loading faces of the machine being parallel to each other.

2.3. *Equipment for generating and measuring the confining pressure*

This includes:

(a) A hydraulic pump or pressure intensifier or other system of sufficient capacity and capable of maintaining constant confining pressure within 2% of the desired value.

(b) A pressure indicating device§ (pressure gauges or pressure transducers) which shall be accurate enough to allow the above to be observed or recorded.

3. PREPARATION OF THE TEST SPECIMEN

(a) Test specimens shall be right circular cylinders having a height to diameter ratio of 2.0–3.0 and a diameter preferably of not less than NX core size (approximately 54 mm). The diameter of the specimen should be related to the size of the largest grain in the rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the longi-

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* No provision has been made for drainage of the pore water, nor for the measurement of its pressure. In certain rock types (e.g. shales) and under certain conditions the pore water pressure may influence the results. In such cases it is advisable to conduct tests on specimens with different degrees of saturation, e.g. saturated, oven dried at 105°C or any other. A comparison of the results allows an estimation of the influence of the pore water.

Such conditions shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document 2, Final Draft, November 1972.

† The concave halves of the spherical seats in triaxial machines usually have no freedom of movement in the direction perpendicular to the specimen axis. In order to align itself, the specimen must have two spherical seats. This is contrary to the uniaxial compression test where the top concave seat half has freedom in the lateral direction and where only one spherical seat is thus required.

‡ The procedure for, and time intervals between verifications are usually given in the National Standard specifications, e.g. ASTM E4; DIN 51300 and B.S. 1610.

§ In order to fulfil the requirements of section 2.3. (b) for the accuracy of the pressure indicating device, it may be necessary to use two or more interchangeable pressure indicating devices having different ranges. Their accuracy will generally have to be 4–5 times better than that of the pressure to be maintained.

tudinal axis of the specimen by more than 0.001 radian (about 3.5 minutes) or 0.05 mm in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen.

(d) The use of capping materials or end surface treatments other than machining is not permitted.

(e) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the upper-height, the mid-height and the lower-height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(f) Samples shall be stored for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, until the time of specimen preparation. Following their preparation, the specimens shall be stored prior to testing for 5–6 days in an environment of 20°C ± 2°C and 50% ± 5% humidity.* This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, Final Draft, November 1972.

(a) The number of specimens to be tested as well as the number of different confining pressure values should be determined from practical considerations, but at least five specimens per rock sample are preferred in addition to the uniaxial compressive strength tests conducted according to the relevant specifications.†

4. PROCEDURE

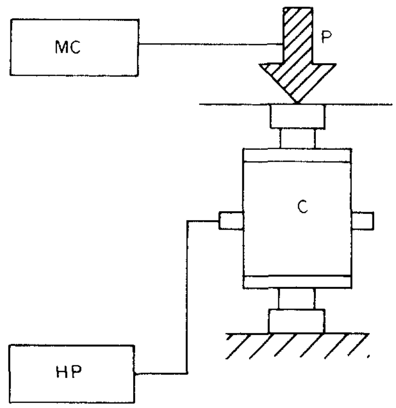
(a) The cell shall be assembled with the specimen aligned between steel platens and surrounded by the jacket.‡ The specimen, the platens and the spherical seats shall be accurately aligned so that each is coaxial with the others.

(b) The spherical seats should be lightly lubricated with mineral oil.

(c) The triaxial cell shall be filled with hydraulic fluid, allowing the air to escape through an air bleeder hole. Close air bleeder hole.

(d) The cell shall be placed into the axial loading device (Fig. 1).

(e) The axial load and the confining pressure must be increased simultaneously and in such a way that axial stress and confining pressure be approximately equal, until the predetermined test level for the confining pressure is reached. Subsequently, the confining pressure shall be maintained to within 2% of the prescribed value.



P Testing machine with: [for applying and controlling axial load]
MC Control unit

C Triaxial cell

HP Equipment for generating and controlling confining pressure

Fig. 1. Block diagram showing test arrangement for determining the triaxial compressive strength.

(f) The axial load on the specimen shall then be increased continuously at a constant stress rate such that failure will occur within 5–15 min of loading. Alternatively the stress rate shall be within the limits of 0.5 to 1.0 MPa/s.

(g) The maximum axial load and the corresponding confining pressure on the specimen shall be recorded.

5. CALCULATIONS

(a) The compressive strength of the specimen shall be calculated by dividing the maximum axial load, applied to the specimen during the test, by the original cross-sectional area.

(b) The confining pressures and the corresponding strength values for the different specimens are plotted with the confining pressures as abscissae and strengths as ordinates (Fig. 2).

(c) A strength envelope is obtained by fitting a mean curve to the above points. From practical considerations it may be advisable to fit a straight line to only the most relevant part of the curve, or to fit several straight lines to different parts of the curve. Each straight line is characterized by calculating its gradient (tangent of the inclination) m and its Y intercept, b. In each case the range in which the respective straight line is valid must be shown on the abscissa.

(d) Using parameters m and b, the internal friction angle Ø and a value for the "apparent" cohesion C (in the sense of Coulomb's failure theory) may be calculated using the formulae:

$$\phi = \arc\sin \frac{m-1}{m+1}; \quad C = b\,\frac{1-\sin\phi}{2\cos\phi}.$$

6. REPORTING OF RESULTS

The report should include the following:

(a) Lithologic description of the rock.

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* See footnote * on p. 48.

† The test programme, i.e. the choice of the confining pressure values, depends on practical considerations regarding the purpose of the tests.

‡ The acceptable triaxial cells in use differ widely. No exact guidelines as how to install the rock specimen or how to assemble the cell can therefore be given.

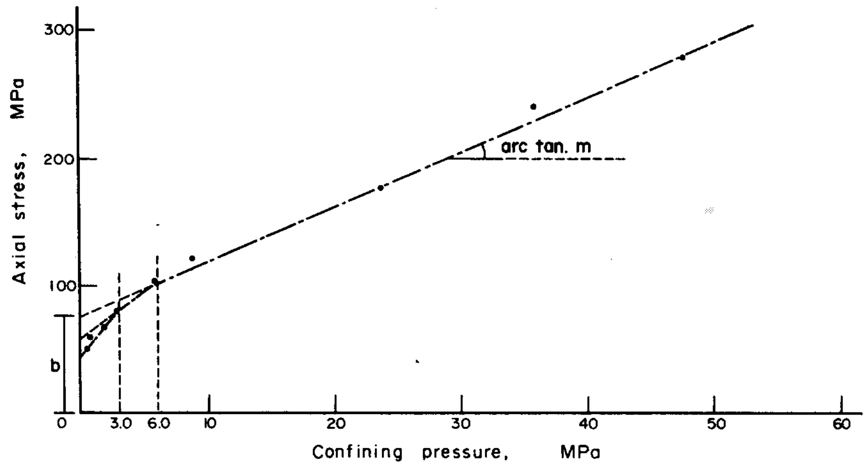

Fig. 2. Strength envelope.

(b) Orientation of the axis of loading of specimen with respect to anisotropy, bedding planes, foliation, etc.

(c) Source of sample including: geographic location, depth and orientation, data and method of sampling and storage history and environment.

(d) Water content and degree of saturation at time of test.

(e) Test duration and/or stress rate.

(f) Date of testing and description of testing machine, triaxial cell and equipment for creating and measuring of confining pressure.

(g) Number of specimens tested.

(h) Any other observations, e.g. mode of failure or available physical data, e.g. specific gravity, porosity, etc., citing the method of determination of each.

(i) A table giving specimen number, specimen height, specimen diameter, confining pressure and the corresponding axial strength to 3 significant figures.

(j) The plot of axial strength vs confining pressure as discussed in section 5(b) (Fig. 2).

(k) A table giving the values of C and ϕ together with the range of confining pressures in which they are valid.

(l) Should it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

REFERENCES

1. International Society for Rock Mechanics. Committee on Laboratory Tests. Suggested method for determining the uniaxial compressive strength of rock material. Document No. 1, first revision (March 1977).
2. ASTM. Standard method of test for triaxial compressive strength of undrained rock core specimens without pore pressure measurements. ASTM Designation D 2664–67.
3. Kovari K. & Tisa A. *Höchstfestigkeit und Restfestigkeit von Gesteinen im Triaxialversuch.* Institut für Strassen- und Untertagbau an der ETH Zürich. Mitteilung Nr. 26.

Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials

PART 1. SUGGESTED METHOD FOR DETERMINATION OF THE UNIAXIAL COMPRESSIVE STRENGTH OF ROCK MATERIALS

1. SCOPE

This method of test is intended to measure the uniaxial compressive strength of a rock sample in the form of specimens of regular geometry. The test is mainly intended for strength classification and characterization of intact rock.

2. APPARATUS

(a) A suitable machine shall be used for applying and measuring axial load to the specimen. It shall be of sufficient capacity and capable of applying load at a rate conforming to the requirements set in Section 3. It shall be verified at suitable time intervals and shall comply with accepted national requirements such as prescribed in either ASTM Methods E4: Verification of Testing Machines or British Standard 1610, Grade A or Deutsche Normen DIN 51 220, DIN 51 223, Klasse 1 and DIN 51 300.

(b) A spherical seat, if any, of the testing machine, if not complying with specification 2(d) below, shall be removed or placed in a locked position, the two loading faces of the machine being parallel to each other.

(c) Steel platens in the form of discs and having a Rockwell hardness of not less than HRC58 shall be placed at the specimen ends. The diameter of the platens shall be between D and D + 2 mm where D is the diameter of the specimen. The thickness of the platens shall be at least 15 mm or D/3. Surfaces of the discs should be ground and their flatness should be better than 0.005 mm.

(d) One of the two platens shall incorporate a spherical seat. The spherical seat should be placed on the upper end of the specimen. It should be lightly lubricated with mineral oil so that it locks after the dead-weight of the cross-head has been picked up. The specimen, the platens and spherical seat shall be accurately centred with respect to one another and to the loading machine. The curvature centre of the seat surface should coincide with the centre of the top end of the specimen.

3. PROCEDURE

(a) Test specimens shall be right circular cylinders having a height to diameter ratio of 2.5–3.0 and a diameter preferably of not less than NX core size, approximately 54 mm. The diameter of the specimen should be related to the size of the largest grain in the rock by the ratio of at least 10:1.

(b) The ends of the specimen shall be flat to 0.02 mm and shall not depart from perpendicularity to the axis of the specimen by more than 0.001 radian (about 3.5 min) or 0.05 mm in 50 mm.

(c) The sides of the specimen shall be smooth and free of abrupt irregularities and straight to within 0.3 mm over the full length of the specimen.

(d) The use of capping materials or end surface treatments other than machining is not permitted.

(e) The diameter of the test specimen shall be measured to the nearest 0.1 mm by averaging two diameters measured at right angles to each other at about the upper-height, the mid-height and the lower height of the specimen. The average diameter shall be used for calculating the cross-sectional area. The height of the specimen shall be determined to the nearest 1.0 mm.

(f) Samples shall be stored, for no longer than 30 days, in such a way as to preserve the natural water content, as far as possible, and tested in that condition.* This moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, First Revision, December 1977.

(g) Load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5–10 min of loading, alternatively the stress rate shall be within the limits of 0.5–1.0 MPa/s.

(h) The maximum load on the specimen shall be

* It is recognized that in some cases for some materials it may be desired to test specimens in other moisture conditions, for example, saturated or oven dry at 105°C. Such conditions shall be noted in the test report.

recorded in newtons (or kilonewtons and meganewtons where appropriate) to within 1%.

(j) The number of specimens tested should be determined from practical considerations but at least five are preferred.

4. CALCULATIONS

(a) The uniaxial compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test, by the original cross-sectional area.

5. REPORTING OF RESULTS

(a) Lithologic description of the rock.

(b) Orientation of the axis of loading with respect to specimen anisotropy, e.g. bedding planes, foliation, etc.

(c) Source of sample, including: geographic location, depth and orientations, dates and method of sampling and storage history and environment.

(d) Number of specimens tested.

(e) Specimen diameter and height.

(f) Water content and degree of saturation at time of test.

(g) Test duration and stress rate.

(h) Date of testing and type of testing machine.

(i) Mode of failure, e.g. shear, axial cleavage, etc.

(j) Any other observations or available physical data such as specific gravity, porosity and permeability citing the method of determination for each.

(k) Uniaxial compressive strength for each specimen in the sample, expressed to three significant figures, together with the average result for the sample. The pascal (Pa) or its multiples shall be used as the unit of stress and strength.

(l) Should it be necessary in some instances to test specimens that do not comply with specifications as stated above these facts shall be noted in the test report.

REFERENCES

1. Obert L., Windes S. L. & Duvall W. I. Standardized tests for determining the physical properties of mine rocks. *U.S. Bureau of Mines Report of Investigations.* No. 3891, 1946, 67 p.
2. International Bureau for Rock Mechanics. Richtlinien zur Durchführung von Druckversuchen an Gesteinen im Bergbau. *Bericht, 5. Ländertreffen des I.B.G.*, Akademie-Verlag, Berlin, 1964, pp. 21–25.
3. U.S. Corps of Engineers. Strength parameters of selected intermediate quality rocks—testing procedures. *Missouri River Division Laboratory Reports.* No. 64/493, July 1966, pp. 1A–6A; 1B–7B.
4. ASTM. Standard method of test for unconfined compressive strength of rock core specimens. *American Society for Testing and Materials.* ASTM Designation D-2938-71a.
5. Hawkes I. & Mellor M. Uniaxial testing in rock mechanics laboratories. *Engng. Geol.* **4**, July 1970, pp. 177–285.

PART 2. SUGGESTED METHOD FOR DETERMINING DEFORMABILITY OF ROCK MATERIALS IN UNIAXIAL COMPRESSION

1. SCOPE

This method of test is intended to determine stress-strain curves and Young's modulus and Poisson's ratio in uniaxial compression of a rock specimen of regular geometry. The test is mainly intended for classification and characterization of intact rock.

2. APPARATUS

(a) to (d)—See Part 1.

(e) Electrical resistance strain gauges, linear variable differential transformers, compressometers, optical devices or other suitable measuring devices. Their design shall be such that the average of two circumferential and two axial strain measurements, equally spaced, can be determined for each increment of load. The devices should be robust and stable, with strain sensitivity of the order of 5×10^{-6}.

Both axial and circumferential strains shall be determined within an accuracy of 2% of the reading and a precision of 0.2 percent of full scale.

If electrical resistance strain gauges are used, the length of the gauges over which axial and circumferential strains are determined shall be at least ten grain diameters in magnitude and the gauges should not encroach within D/2 of the specimen ends, where D is the diameter of the specimen.

If dial micrometers of LVDT's are used for measuring axial deformation due to loading, these devices should be graduated to read in 0.002 mm units and accurate within 0.002 mm in any 0.02 mm range and within 0.005 mm in any 0.25 mm range. The dial micrometer or LVDT's should not encroach within D/2 of the specimen ends.

(f) An apparatus for recording the loads and deformations; preferably an X–Y recorder capable of direct plotting of load-deformation curves.

3. PROCEDURE

(a) to (e)—See Part 1.

(f) Moisture can have a significant effect on the deformability of the test specimen. When possible, *in situ* moisture conditions should be preserved until the time of the test. When the characteristic of the rock material under conditions varying from saturation to dry is required, proper note shall be made of moisture conditions so that correlation between deformability and moisture content can be made. Excess moisture can create a problem of adhesion of strain gauges which may require making a change in moisture content of the sample. The moisture condition shall be reported in accordance with "Suggested method for determination of the water content of a rock sample", Method 1, ISRM Committee on Laboratory Tests, Document No. 2, December 1977.

(g) Load on the specimen shall be applied continuously at a constant stress rate such that failure will occur within 5–10 min of loading, alternatively the stress rate shall be within the limits of 0.5–1.0 MPa/s.

(h) Load and axial and circumferential strains or deformations shall be recorded at evenly spaced load intervals during the test, if not continually recorded. At least ten readings should be taken over the load range to define the axial and diametric stress-strain curves.

(i) It is sometimes advisable for a few cycles of loading and unloading to be performed.

(j) The number of specimens instrumented and tested under a specified set of conditions shall be governed by practical considerations but at least five are preferred.

4. CALCULATIONS

(a) Axial strain, ϵ_a, and diametric strain, ϵ_d, may be recorded directly from strain indicating equipment or may be calculated from deformation readings depending upon the type of instrumentation such as discussed in paragraph 2(e).

(b) Axial strain is calculated from the equation

$$\epsilon_a = \frac{\Delta l}{l_0}$$

where

l_0 = original measured axial length

Δl = change in measured axial length (defined to be positive for a decrease in length)

(c) Diametric strain may be determined either by measuring the changes in specimen diameter or by measuring the circumferential strain. In the case of measuring the changes in diameter, the diametric strain is calculated from the equation

$$\epsilon_d = \frac{\Delta d}{d_0}$$

where

d_0 = original undeformed diameter of the specimen

Δd = change in diameter (defined to be negative for an increase in diameter)

In the case of measuring the circumferential strain ϵ_d, the circumference is $C = \pi d$, thus the change in circumference is $\Delta C = \pi \Delta d$. Consequently, the circumferential strain, ϵ_c, is related to diametric strain, ϵ_d, by

$$\epsilon_c = \frac{\Delta C}{C_0} = \frac{\Delta d}{d_0},$$

so that

$$\epsilon_c = \epsilon_d$$

where C_0 and d_0 are original specimen circumference and diameter, respectively.

(d) The compressive stress in the test specimen, σ, is calculated by dividing the compressive load P on

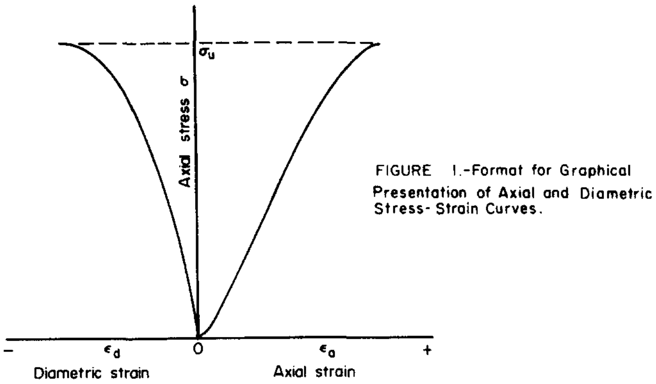

Fig. 1. Format for graphical presentation of axial and diametric stress-strain curves.

the specimen by the initial cross-sectional area, A_0. Thus

$$\sigma = \frac{P}{A_0}$$

where in this test procedure, compressive stresses and strains are considered positive.

(e) Fig. 1 illustrates typical plot of axial stress versus axial and diametric strains. These curves show typical behaviour of rock materials from zero stress up to ultimate strength, σ_u. The complete curves give the best description of the deformation behaviour of rocks having non-linear stress-strain behaviour at low and high stress levels.

(f) Axial Young's modulus, E (defined as the ratio of the axial stress change to axial strain produced by the stress change) of the specimen may be calculated using any one of several methods employed in accepted engineering practice. The most common methods, listed in Fig. 2, are as follows:

(1) Tangent Young's modulus, E_t, is measured at a stress level which is some fixed percentage of the ulti-

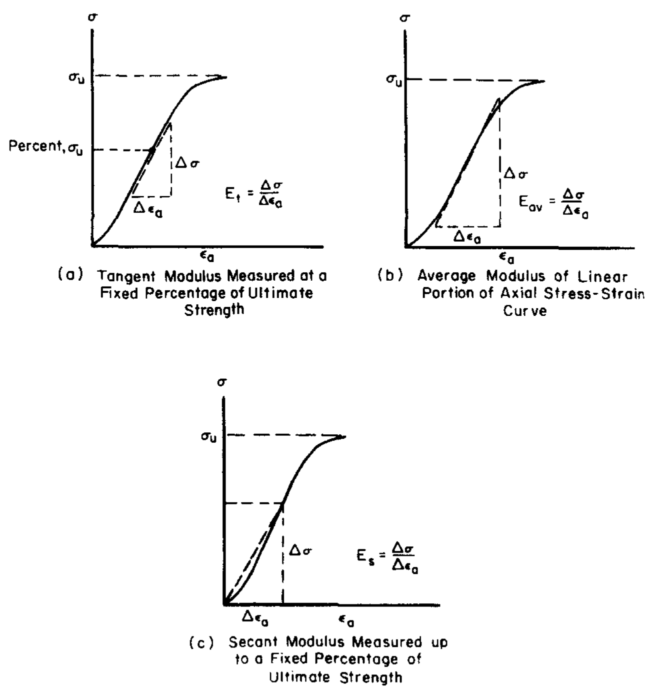

Fig. 2. Methods for calculating Young's modulus from axial stress-strain curve.

mate strength (Fig. 2a). It is generally taken at a stress level equal to 50% of the ultimate uniaxial compressive strength.

(2) Average Young's modulus, E_{av}, is determined from the average slopes of the more-or-less straight line portion of the axial stress-axial strain curve (Fig. 2b).

(3) Secant Young's modulus, E_s, is usually measured from zero stress to some fixed percentage of the ultimate strength (Fig. 2c), generally at 50%.

Axial Young's modulus E is expressed in units of stress i.e. pascal (Pa) but the most appropriate multiple is the gigapascal (GPa = 10^9 Pa).

(g) Poisson's ratio, v, may be calculated from the equation

$$v = -\frac{\text{slope of axial stress–strain curve}}{\text{slope of diametric stress–strain curve}} = -\frac{E}{\text{slope of diametric curve}}$$

where the slope of the diametric curve is calculated in the same manner for either of the three ways discussed for Young's modulus in paragraph 4(f). Note that Poisson's ratio in this equation has a positive value, since the slope of the diametric curve is negative by the conventions used in this procedure.

(h) The volumetric strain, ϵ_v, for a given stress level is calculated from the equation

$$\epsilon_v = \epsilon_a + 2\epsilon_d.$$

5. REPORTING OF RESULTS

The report should include the following:

(a) to (j)—See Part 1.

(k) Values of applied load, stress and strain as tabulated results or as recorded on a chart.

(1) Young's modulus and Poisson's ratio for each specimen in the sample, expressed to three significant figures, together with the average result for the sample.

(m) Method of determination of Young's modulus and at what axial stress level or levels determined.

(n) Sould it be necessary in some instances to test specimens that do not comply with the above specifications, these facts shall be noted in the test report.

REFERENCE

Standard method of test for elastic moduli of rock core specimens in uniaxial compression. *American Society for Testing and Materials*, ASTM Designation D 3148-72.

INTERNATIONAL SOCIETY FOR ROCK MECHANICS
COMMISSION ON
STANDARDIZATION OF LABORATORY AND FIELD TESTS

Suggested Methods for Determining Shear Strength

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COMMITTEE ON FIELD TESTS
DOCUMENT No. 1

FINAL DRAFT: FEBRUARY 1974

Suggested Methods for Determining Shear Strength

PART 1. SUGGESTED METHOD FOR *IN SITU* DETERMINATION OF DIRECT SHEAR STRENGTH

SCOPE

1. (a) This test measures peak and residual direct shear strength as a function of stress normal to the sheared plane. Results are usually employed in limiting equilibrium analysis of slope stability problems or for the stability analysis of dam foundations [1–3*].

(b) The inclination of the test block and system of applied loads is usually selected so that the sheared plane coincides with a plane of weakness in the rock, for example a joint, plane of bedding, schistosity or cleavage, or with the interface between soil and rock or concrete and rock [4].

(c) A shear strength determination should preferably comprise at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

(d) In applying the results of the test, the pore water pressure conditions and the possibility of progressive failure must be assessed for the design case as they may differ from the test conditions.

* Numbers refer to Notes at the end of the text.

APPARATUS

2. (a) Equipment for cutting and encapsulating the test block, rock saws, drills, hammer and chisels, formwork of appropriate dimensions and rigidity, expanded polystyrene sheeting or weak filler, and materials for reinforced concrete encapsulation.

3. Equipment for applying the normal load (i.e. Fig. 1) including:

(a) Flat jacks, hydraulic rams or dead load of sufficient capacity to apply the required normal loads [5].

(b) A hydraulic pump if used should be capable of maintaining normal load to within 2% of a selected value throughout the test.

(c) A reaction system to transfer normal loads uniformly to the test block, including rollers or a similar

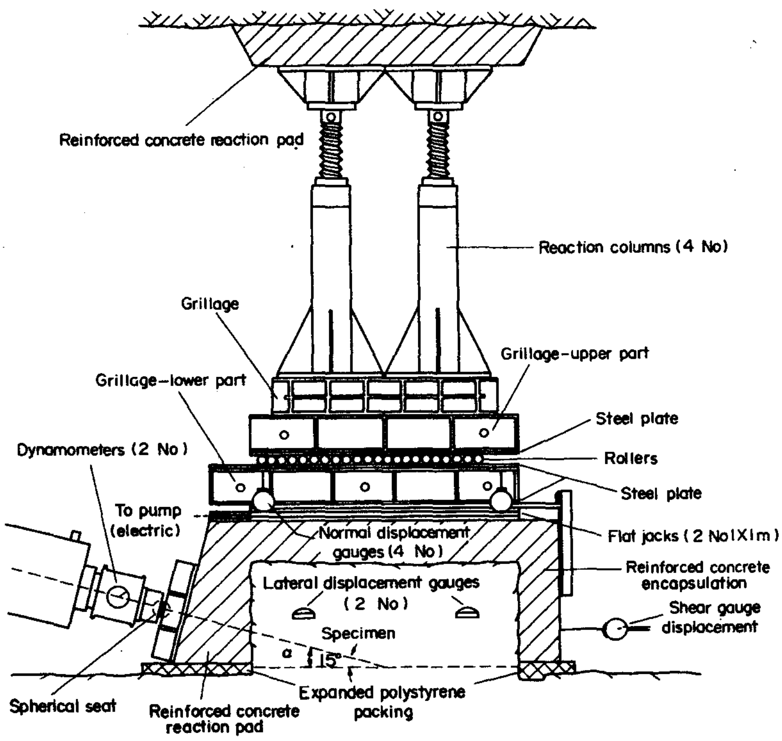


Fig. 1. Typical arrangement of equipment for *in situ* direct shear test.

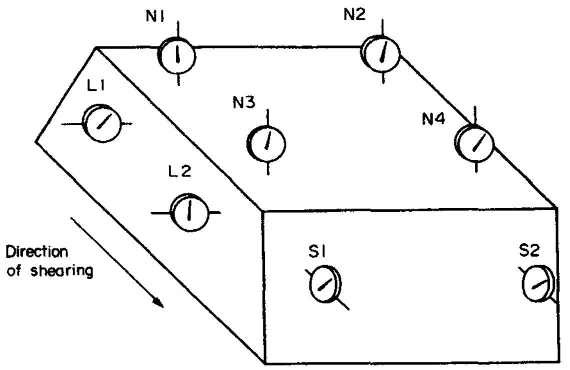


Fig. 2. Arrangement of displacement gauges: S1 and S2 for shear displacement, L1 and L2 for lateral displacement, N1–N4 for normal displacement.

low-friction device to ensure that at any given normal load the resistance to shear displacement is less than 1% of the maximum shear force applied in the test. Rock anchors, wire ties and turnbuckles are usually required to install and secure the equipment.

4. Equipment for applying the shear force (i.e. Fig. 1) including:

(a) One or more hydraulic rams [5] or flat jacks of adequate total capacity with at least 70 mm travel.

(b) A hydraulic pump to pressurize the shear force system.

(c) A reaction system to transmit the shear force to the test block. The shear force should be distributed uniformly along one face of the specimen. The resultant line of applied shear forces should pass through the centre of the base of the shear plane [6], with an angular tolerance of $\pm 5°$.

5. Equipment for measuring the applied forces including:

(a) One system for measuring normal force and another for measuring applied shearing force with an accuracy better than $\pm 2\%$ of the maximum forces reached in the test. Load cells (dynamometers) or flat jack pressure measurements may be used. Recent calibration data applicable to the range of testing should be appended to the test report. If possible the gauges should be calibrated both before and after testing.

6. Equipment for measuring shear, normal and lateral displacements:

(a) Displacements should be measured (for example using micrometer dial gauges [7]) at eight locations on the specimen block or encapsulating material, as shown in Fig. 2.

(b) The shear displacement measuring system should have a travel of at least 70 mm and an accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel of at least 20 mm and an accuracy better than 0.05 mm. The measuring reference system (beams, anchors and clamps) should, when assembled, be sufficiently rigid to meet these requirements. Resetting of gauges during the test should if possible be avoided.

PROCEDURE

7. Preparation:

(a) The test block is cut to the required dimensions (usually 700 × 700 × 350 mm) using methods that avoid disturbance or loosening of the block [8,9]. The base of the test block should coincide with the plane to be sheared and the direction of shearing should correspond if possible to the direction of anticipated shearing in the full-scale structure to be analysed using the test results. The block and particularly the shear plane should unless otherwise specified be retained as close as possible to its natural *in situ* water content during preparation and testing, for example by covering with saturated cloth. A channel approximately 20 mm deep by 80 mm wide should be cut around the base of the block to allow freedom of shear and lateral displacements.

(b) A layer at least 20 mm thick of weak material (e.g. foamed polystyrene) is applied around the base of the test block, and the remainder of the block is then encapsulated in reinforced concrete or similar material of sufficient strength and rigidity to prevent collapse or significant distortion of the block during testing. The encapsulation formwork should be designed to ensure that the load-bearing faces of the encapsulated block are flat (tolerance ± 1 mm) and at the correct inclination to the shear plane (tolerance $\pm 2°$).

(c) Reaction pads, anchors, etc., if required to carry the thrust from normal and shear load systems to adjacent sound rock, must be carefully positioned and aligned. All concrete must be allowed time to gain adequate strength prior to testing.

8. Consolidation:

(a) The consolidation stage of testing is to allow pore water pressures in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Behaviour of the specimen during consolidation may also impose a limit on permissible rate of shearing (see paragraph 9(c)).

(b) All displacement gauges are checked for rigidity, adequate travel and freedom of movement, and a preliminary set of load and displacement readings is recorded.

(c) Normal load is then raised to the full value specified for the test, recording the consequent normal displacements (consolidation) of the test block as a function of time and applied loads (Figs 3 and 4).

(d) The consolidation stage may be considered complete when the rate of change of normal displacement recorded at each of the four gauges is less than 0.05 mm in 10 minutes. Shear loading may then be applied.

9. Shearing:

(a) The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test horizon [2]. Corrections to the applied normal load may be required to hold the normal stress constant; these are defined in paragraph 10(c).

(b) The shear force is applied either in increments or continuously in such a way as to control the rate of shear displacement.

DIRECT SHEAR TEST DATA SHEET

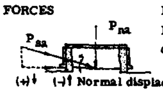
Client: Project: Concrete Dam Location: Alcântara Loc. No.: Block No.:

TEST BLOCK SPECIFICATION See drawings & photographs Nos.:

General rock description, index properties and water conditions
Phyllite, sound to moderately weathered Normal conditions

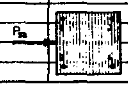
Description and index properties of surface to be sheared Type;
Dip; Dip direction; Roughness; Filling & alteration;
Persistance; Spacing of set; Surface dimensions; 0.70 x 0.70 Initial area A; 0.490 m^2

FORCES



$P_n = P_{na} + P_{sa} \sin \alpha$
$P_s = P_{sa} \cos \alpha$
$\sigma_n = P_n/A$
$\tau = P_s/A$
$\alpha = 15^{\circ}$ σ_n (nominal)

1 Time elapsed (min)	2 Applied normal force P_n Reading	2 Force (kN)	3 Normal displacement Δ_n Reading 1	Reading 2	Reading 3	Reading 4	Average (mm)	4 Applied shear force P_s Reading	Force (kN)	5 Shear displacement Δ_s Reading 1	Reading 2	Average (mm)	6 Contact area A (corrected) m^2	7 P_{na} (kN)	8 σ_n (MP_a)	9 P_{sa} (kN)	10 τ (MP_a)
10		196	0.100	0.070	0.130	0.070			0	0	0	-	0.490	196		0	
35		233	0.130	0.085	0.140	0.090			137	0.05	0.05	0.05		"		142	
48		270	0.050	0.065	0.285	0.290			275	0.55	0.35	0.45		"		284	
64		306	-0.200	0.010	0.435	0.495			412	1.35	1.10	1.22		"		426	
87		343	-0.710	-0.205	0.600	0.720			549	2.55	2.30	2.42		"		568	
109		380	-1.165	-0.445	0.680	0.850			686	3.90	3.50	3.70		"		710	
131		417	-1.675	-0.615	0.710	0.970			824	5.15	4.60	4.88		"		853	
154		453	-1.965	-0.745	0.720	1.050			961	6.10	5.50	5.80		"		995	
172		490	-2.245	-0.880	0.720	1.105			1098	7.20	6.50	6.85		"		1137	
189		527	-2.480	-1.055	0.695	1.165			1235	8.20	7.40	7.80		"		1279	
206		504	-2.750	-1.205	0.640	1.165			1373	9.45	8.45	8.95		"		1421	
234		601	-3.075	-1.505	0.465	1.100			1510	11.00	10.00	10.50		"		1563	
252		637	-3.350	-1.830	0.280	0.910			1647	12.45	11.40	11.92		"		1705	
264		674	-3.675	-2.185	0.050	0.720			1784	14.00	12.80	13.40		"		1847	
276		711	-4.005	-2.665	-0.290	0.360			1922	15.55	14.40	14.98		"		1989	
289		748	-4.585	-3.125	-0.890	-0.020			2059	17.60	16.45	17.02		"		2132	
293	Rupture	784	-4.975	-3.375	-1.250	-0.290			2196	20.00	19.55	19.78		"		2274	



Calibration data Remarks Tested by; Dates; Checked by; Date;

Fig. 3. Example layout of direct shear test data sheet.

(c) Approximately 10 sets of readings should be taken before reaching peak strength (Figs 3 and 5). The rate of shear displacement should be less than 0.1 mm/min in the 10-minute period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings provided that the peak strength itself is adequately recorded. For a 'drained' test, particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed $6\,t_{100}$ as determined from the consolidation curve (see paragraph 10(a) and Fig. 4). If necessary the rate of shear should be reduced or the application of later shear force increments delayed to meet this requirement.

(d) After reaching peak strength, readings should be taken at increments of from 0.5 to 5 mm shear displacement as required to adequately define the force–displacement curves (Fig. 5). The rate of shear displacement should be 0.02–0.2 mm/min in the 10-minute

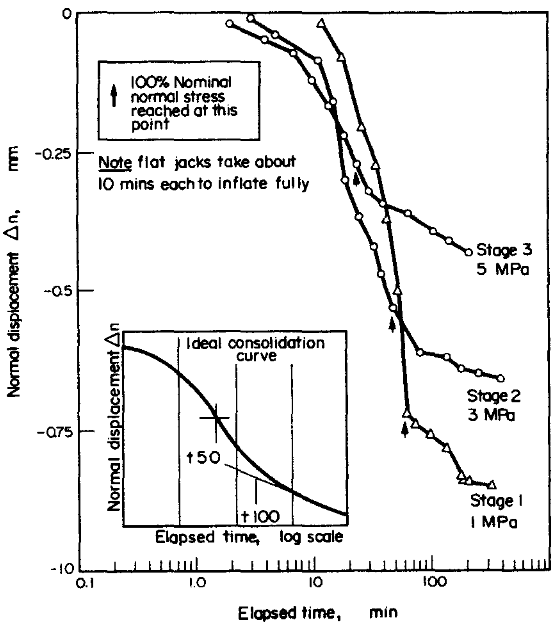


Fig. 4. Consolidation curves for a three-stage direct shear test, showing the construction used to estimate t_{100}.

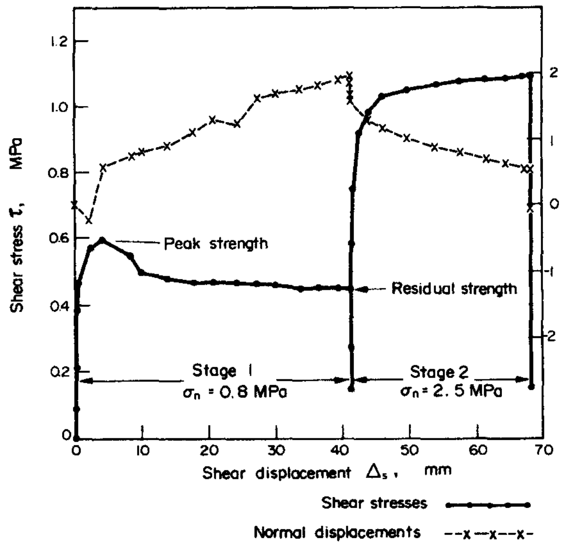


Fig. 5. Shear stress–displacement graphs.

period before a set of readings is taken, and may be increased to not more than 1 mm/min between sets of readings.

(e) It may be possible to establish a residual strength value when the sample is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5% variation in shear stress over a shear displacement of 1 cm [11].

(f) Having established a residual strength the normal stress may be increased or reduced [12] and shearing continued to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress (see paragraph 8(d)) and shearing continued according to criteria given in paragraphs 9(c)–9(e) above.

(g) After the test the block should be inverted, photographed in colour and fully described (see paragraph 11). Measurements of the area, roughness, dip and dip direction of the sheared surface are required, and samples of rock, infilling and shear debris should be taken for index testing.

CALCULATIONS

10. (a) A consolidation curve (Fig. 4) is plotted during the consolidation stage of testing. The time t_{100} for completion of "primary consolidation" is determined by constructing tangents to the curve as shown. The time to reach peak strength from the start of shear loading should be greater than $6\,t_{100}$ to allow pore pressure dissipation [10].

(b) Displacement readings are averaged to obtain values of mean shear and normal displacements Δ_s and Δ_n. Lateral displacements are recorded only to evaluate specimen behaviour during the test, although if appreciable they should be taken into account when computing corrected contact area.

(c) Shear and normal stress are computed as follows:

$$\text{Shear stress } \tau = \frac{P_s}{A} = \frac{P_{sa}\cos\alpha}{A}$$

$$\text{Normal stress } \sigma_n = \frac{P_n}{A} = \frac{P_{na} + P_{sa}\sin\alpha}{A}$$

where

P_s = total shear force; P_n = total normal force,
P_{sa} = applied shear force; P_{na} = applied normal force,
α = inclination of the applied shear force to the shear plane (if $\alpha = 0$, $\cos\alpha = 1$ and $\sin\alpha = 0$),
A = area of shear surface overlap (corrected to account for shear displacement).

If α is greater than zero the applied normal force should be reduced after each increase in shear force by an amount $P_{sa}\sin\alpha$ in order to maintain the normal stress approximately constant. The applied normal force may be further reduced during the test by an amount

$$\frac{\Delta_s(\text{mm}) \times P_n}{700} \text{ to compensate for area changes.}$$

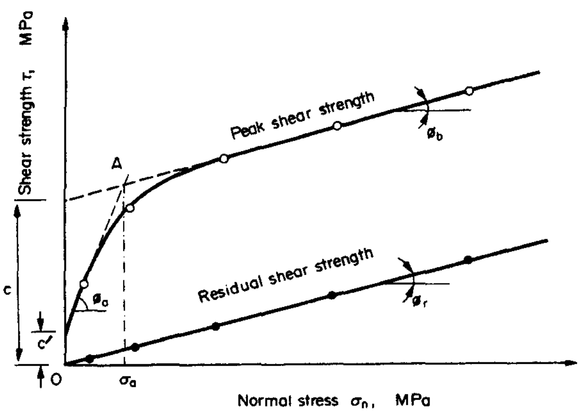
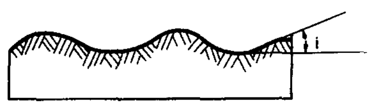


Fig. 6. Shear strength–normal stress graph.

(d) For each test specimen graphs of shear stress (or shear force) and normal displacement vs. shear displacement are plotted (Fig. 5), annotated to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strength and the normal stresses, shear and normal displacements at which these occur are abstracted from these graphs [2].

(e) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters ϕ_a, ϕ_b, ϕ_r, c' and c are abstracted from these graphs as shown in Fig. 6.

ϕ_r = residual friction angle,
ϕ_a = apparent friction angle below stress σ_a; point A is a break in the peak shear strength curve resulting from the shearing off of major irregularities on the shear surface. Between points 0 and A, ϕ_a will vary somewhat; measure at stress level of interest. Note also $\phi_a = \phi_u + i$, where ϕ_u is the friction angle obtained for smooth surfaces of rock on rock and angle i is the inclination of surface asperities.



ϕ_b = apparent friction angle above stress level σ_a (point A); note that ϕ_a will usually be equal to or slightly greater than ϕ_r and will vary somewhat with stress level; measure at the stress level of interest.
c' = cohesion intercept of peak shear strength curve; it may be zero.
c = apparent cohesion at a stress level corresponding to ϕ_b.

REPORTING OF RESULTS

11. The report should include the following:

(a) A diagram, photograph and detailed description of test equipment and a description of methods used for specimen preparation and testing. (Reference may be made to this ISRM "suggested method" stating only departures from the prescribed techniques.)

(b) For each specimen a full geological description of the intact rock, sheared surface, filling and debris preferably accompanied by relevant index test data (e.g. roughness profiles; Atterberg limits, water content and grain size distribution of filling materials).

(c) Photographs of each sheared surface together with diagrams giving the location, dimensions, area, dip and dip direction and showing the directions of shearing and any peculiarities of the blocks.

(d) For each test block a set of data tables, a consolidation graph and graphs of shear stress and normal displacement vs. shear displacement (e.g. Figs 3, 4 and 5). Abstracted values of peak and residual shear strength should be tabulated with the corresponding values of normal stress, shear and normal displacement.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength vs. normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

PART 2. SUGGESTED METHOD FOR LABORATORY DETERMINATION OF DIRECT SHEAR STRENGTH

SCOPE

1. (a) This test measures peak and residual direct shear strength as a function of stress normal to the sheared plane. Results are employed, for example, in the limiting equilibrium analysis of slope stability problems or for the stability analysis of dam foundations [1–3*].

(b) The inclination of the test specimen with respect to the rock mass, and its direction of mounting in the testing machine are usually selected so that the sheared plane coincides with a plane of weakness in the rock, for example a joint, plane of bedding, schistosity or cleavage, or with the interface between soil and rock or concrete and rock [4].

(c) A shear strength determination should preferably comprise at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

(d) In applying the results of the test, the pore-water pressure conditions and the possibility of progressive failure must be assessed for the design case as they may differ from the test conditions.

APPARATUS

2. Equipment for taking specimens of rock, including:

(a) Equipment for cutting the specimen; for example a large-diameter core drill, percussive drills, rock saws or hammers and chisels, also equipment for measuring the dip, dip direction, roughness and other characteristic features of the test horizon.

* Numbers refer to Notes at the end of the text.

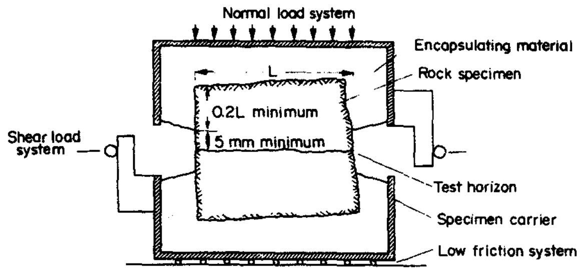


Fig. 7. Arrangement for laboratory direct shear test.

(b) Materials for holding the specimen together, for example binding wire or metal bands.

(c) Materials to protect the specimen against mechanical damage and changes in water content both during cutting and transit to the laboratory, for example protective packing and wax or similar waterproofing material.

3. Equipment for mounting the specimen including:

(a) Specimen carriers, forming a dismountable part of the test equipment.

(b) Cement, plaster, resin or similar strong encapsulating materials together with appropriate mixing utensils.

4. Testing equipment (a shear box, for example Fig. 7) incorporating:

(a) A means of applying the normal load, typically a hydraulic, pneumatic or dead-weight mechanical system, designed to ensure that the load is uniformly distributed over the plane to be tested. The resultant force should act normal to the shear plane, passing through its centre of area. The system should have a travel greater than the amount of dilation or consolidation to be expected, and should be capable of maintaining normal load to within 2% of a selected value throughout the test [5].

(b) A means of applying the shear force, typically a hydraulic jack or a mechanical gear-drive system, designed so that the load is distributed uniformly along one half-face of the specimen with the resultant applied shear force acting in the plane of shearing. The equipment should be designed for a shear travel greater than 10% of the specimen length. It should include rollers, cables or a similar low friction device to ensure that resistance of the equipment to shear displacement is less than 1% of the maximum shear force applied in the test.

(c) Equipment for independent measurement of the applied shear and normal forces, with an accuracy better than $\pm 2\%$ of the maximum forces reached in the test. Recent calibration data applicable to the range of testing should be appended to the test report.

(d) Equipment for measuring shear, normal and lateral displacement, for example micrometer dial gauges or electric transducers. Gauges may be mounted as shown in Fig. 2, or the four normal displacement gauges may be replaced by a single gauge mounted centrally. The shear displacement measuring system should have a travel greater than 10% of the specimen length and an accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel greater than 20 mm and an accuracy better than 0.05 mm. Resetting of gauges during the test should if possible be avoided. If electric transducers or an automatic recording system is used a recent calibration should be included in the report.

PROCEDURE

5. Preparation:

(a) The test horizon is selected and dip, dip direction and other relevant geological characteristics are recorded. Block or core specimens containing the test horizon are collected using methods selected to minimize disturbance, if possible in such a way as to retain natural water content. The specimen dimensions and the location of the test horizon within the block or core should if possible allow mounting without further trimming in the laboratory, and with sufficient clearance for adequate encapsulation [8]. The test plane should preferably be square with a minimum area of 2500 mm [2]. The mechanical integrity of the specimens should be preserved by binding tightly with wire or tape which is to be left in position until immediately before testing.

(b) Specimens that are not encapsulated immediately for testing should be given a waterproof coating, labelled and packaged to avoid damage in transit to the laboratory. Fragile specimens require special treatment, for example packaging in polyurethane foam (Stimpson, B., Metcalfe, F. G., and Walton, G., 1970. *Q. J. Engng Geol.* **3**, No. 2, p. 127).

(c) The protective packaging, with the exception of the steel wire, is removed and the block supported in one of the carriers so that the horizon to be tested is secured in the correct position and orientation. The encapsulating material is poured and, after this has set, the other half-specimen is encapsulated in a similar manner. A zone at least 5 mm either side of the shear horizon should be free from encapsulating material.

6. Consolidation:

(a) The consolidation stage of testing is to allow pore water pressures in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Behaviour of the specimen during consolidation may also impose a limit on permissible rate of shearing (see paragraph 7(e)).

(b) Having mounted the specimen in the shear box, all gauges are checked and a preliminary set of load and displacement readings is recorded.

(c) Normal load is raised to the full value specified for the test, recording the consequent normal displacement (consolidation) of the specimen as a function of time and applied loads (Figs 3 and 4).

(d) The consolidation stage may be considered complete when the rate of change of normal displacement is less than 0.05 mm in 10 minutes. Shear loading may then be applied.

7. Shearing:

(a) The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test horizon [2].

(b) The shear force may be applied in increments but is usually applied continuously in such a way as to control the rate of shear displacement.

(c) Approximately 10 sets of readings should be taken before reaching peak strength (Figs 3 and 5). The rate of shear displacement should be less than 0.1 mm/min in the 10-minute period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings provided that the peak strength itself is adequately recorded. For a "drained" test [10] particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed $6\,t_{100}$ as determined from the consolidation curve (see paragraph 8(a) and Fig. 4). If necessary the rate of shear should be reduced or the application of later shear force increments delayed to meet this requirement.

(d) After reaching peak strength, readings should be taken at increments of from 0.5 to 5 mm shear displacement as required to adequately define the force–displacement curves (Fig. 5). The rate of shear displacement should be 0.02–0.2 mm/min in the 10-minute period before a set of readings is taken, and may be increased to not more than 1 mm/min between sets of readings.

(e) It may be possible to establish a residual strength value when the sample is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5% variation in shear stress over a shear displacement of 1 cm [11].

(f) Having established a residual strength the normal stress may be increased or reduced [12] and shearing contined to obtain additional residual strength values. The specimen should be reconsolidated under each new normal stress (see paragraph 6), and shearing continued according to criteria given in paragraphs 7(c) to 7(e) above.

(g) After the test the shear plane should be exposed and fully described (see paragraph 9). The area of the shear surface is measured and photographs may also be required. Samples of rock, infilling and shear debris should be taken for index testing.

CALCULATIONS

8. (a) A consolidation curve (Fig. 4) is plotted during the consolidation stage of testing. The time t_{100} for completion of "primary consolidation" is determined by constructing tangents to the curve as shown. The time to reach peak strength from the start of shear loading should be greater than $6\,t_{100}$ to allow pore pressure dissipation [10].

(b) Displacement readings are averaged to obtain values of mean shear and normal displacements Δ_s and Δ_n. Lateral displacements are recorded only to evaluate specimen behaviour during the test, although if appreciable they should be taken into account when computing corrected contact area.

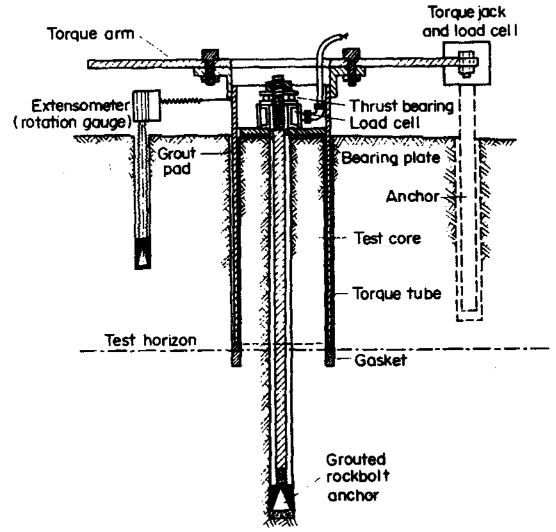


Fig. 8. Torsional shear test equipment.

(c) Shear and normal stress are computed as follows:

$$\text{Normal stress } \tau = \frac{P_s}{A}$$

$$\text{Shear stress } \sigma_n = \frac{P_n}{A}$$

where

P_s = total shear force; P_n = total normal force;
A = area of shear surface overlap (corrected to account for shear displacement).

(d) For each test specimen graphs of shear stress (or shear force) and normal displacement vs. shear displacement are plotted (Fig. 5), annotated to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strength and the normal stresses, shear and normal displacements at which these occur are abstracted from these graphs [2].

(e) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters ϕ_a, ϕ_b, ϕ_r, c' and c are abstracted from these graphs as shown in Fig. 6.

REPORTING OF RESULTS

9. The report should include the following:

(a) A diagram and description of the test equipment and a description of the methods used for taking, packaging, transporting, storing, mounting and testing the specimen. (Reference may be made to this ISRM "suggested method" stating only departures from the prescribed techniques.)

(b) For each specimen a full geological description of the intact rock, sheared surface, filling and debris preferably accompanied by relevant index test data (e.g. roughness profiles; Atterberg limits, water content and grain size distribution of filling materials).

(c) Diagrams and preferably photographs showing the sampling location, dip and dip direction of the tested horizon, also the dimensions and any peculiarities of the specimens.

(d) For each test block a set of data tables, a consolidation graph and graphs of shear stress and normal displacement vs. shear displacement (e.g. Figs 3, 4 and 5). Abstracted values of peak and residual shear strength should be tabulated with the corresponding values of normal stress, shear and normal displacement.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength vs. normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

PART 3. SUGGESTED METHOD FOR *IN SITU* DETERMINATION OF SHEAR STRENGTH USING A TORSIONAL SHEAR TEST

SCOPE

1. (a) This test measures the shear strength of the base of a rock core which is rotated in its drillhole.

(b) The results may be used as an approximation to the direct shear strengths measured by the *in situ* or laboratory methods given in Parts 1 and 2 of this document [13*].

APPARATUS

2. Drilling equipment, including:

(a) A diamond core drill, water or air flush to suit the rock, capable of coring at diameters of approximately 50 mm and 300 mm to a depth greater than the core length required (usually 0.5–3 m).

3. Equipment for applying and measuring the normal load (Fig. 8) including:

(a) A rockbolt at least 1 m longer than the required core length, with grouted anchor at one end and a nut, thread and washer at the other.

(b) A bearing plate with external diameter equal to that of the test core, and a central hole allowing the plate to pass freely over the rockbolt.

(c) A hollow centre load cell fitting over the rockbolt, measuring tension in the bolt to ±2%.

(d) A thrust bearing, concentric with the rockbolt and load cell, to prevent transmission of torque from the rockbolt to the core.

4. Equipment for applying and measuring the torque (Fig. 8) including:

(a) A torque tube to hold the rock core, fitting in the annular space around the core with an external clearance not less than 3 mm and an internal clearance sufficient to allow grouting between the tube and the core.

(b) A torque arm fixed rigidly across a diameter of the torque tube, perpendicular to the core axis and extending equally either side.

* Numbers refer to Notes at the end of the text.

(c) Two identical hydraulic jacks for applying the torque, pressurized by a single hydraulic pump, anchored rigidly to rockbolts equidistant from the core axis connected to the torque arm in such a way as to apply equal forces in opposite directions tangential to the core. Each jack is fitted with a load cell to measure to ±2% the applied force.

5. Equipment for measuring the rotation of the core, for example a dial gauge micrometer fixed to a rigid anchor and connected to the circumference of the torque tube by a wire and pulley system. The system should measure rotation within ±0.001 radian and should have a travel greater than 0.1 radian.

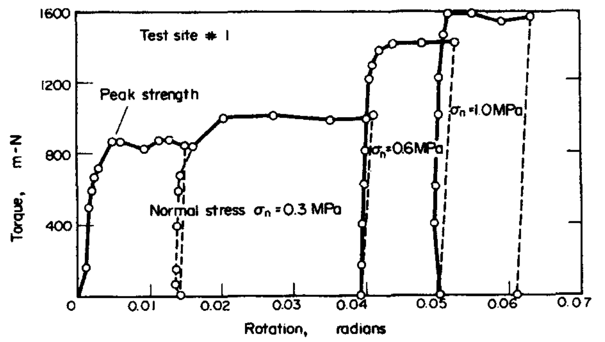


Fig. 9. Torque–rotation graph for the torsional shear test.

PROCEDURE

6. Preparation:

(a) The test site is selected and a firm flat surface prepared perpendicular to the test horizon, usually 0.5–3 m above it. The test horizon is usually a plane of weakness in the rock such as a joint, plane of bedding or schistosity or the junction between concrete and rock.

(b) A small-diameter core (e.g. 50 mm) is drilled perpendicular to the anticipated test horizon and at least 1 m beyond it. This core is logged in detail, the test horizon selected and its depth measured to ±10 mm. Additional small-diameter holes are drilled to take anchors for the torque jacks and rotation-measuring equipment.

(c) The normal load anchor is installed, with the anchor grout entirely below the test horizon. The bearing plate is installed over the bolt on a bed of grout, the load cell and thrust bearing placed in position and a normal load sufficient to rigidly hold the test core during drilling is applied.

(d) The test core is drilled to a depth 20 mm ± 5 mm beneath the test horizon using the bearing plate to centralize the core barrel. The drilling method and drill fluid should be selected to minimize damage to the core.

(e) The annular space surrounding the test core is cleaned and filled with a weak material (e.g. sponge rubber gaskets) to a depth of 5–10 mm above the test horizon. The torque tube is greased on the outside, inserted to rest on the weak filler, and grouted to the core using resin or cement. The grout is left to gain strength and then the remaining apparatus is assembled and checked.

7. Testing:

(a) A selected normal load is applied by tightening the central rockbolt.

(b) The torque is gradually increased taking incremental readings of the torque and normal load cells and of the rotation gauge (e.g. Fig. 9). The rate of torque application should be such that 5–10 sets of readings are taken before reaching peak strength [2].

(c) Torsional loading is continued taking sets of readings at approximately 0.05 radian increments of rotation as shown in Fig. 9, until at least four sets of torque readings differing by less than 5% are obtained.

(d) The torsional loading is then removed, taking a further set of readings. The procedure 7(a) to 7(c) may then be repeated one or more times at successively greater normal loads depending on the maximum rotation permitted by the apparatus [12].

(e) The test core is removed and the sheared surface examined and described in detail. Samples of rock, filling material and shear debris may be taken for index testing.

CALCULATIONS

8. (a) Torque values are calculated using the load cell calibration curves to obtain the loads (kN) then multiplying by the torque radius (mm) to obtain the torque (m–N). The total torque T is the sum of the two applied torques.

(b) Normal loads are calculated from the load cell calibration curve, and converted into normal stresses σ_n using the equation:

$$\sigma_n = \frac{4P_n}{\pi(D^2 - d^2)}$$

where

P_n = applied normal load,
D = outer diameter of test core,
d = inner diameter of test core.

(c) Shear strengths τ corresponding to the peak and residual portions of the torque–displacement graph (Fig. 9, Notes 2 and 3) may be calculated using one of two assumptions:

(i) In strong, elastic rock assuming maximum stress at the outer circumference of the test core

$$\tau = \frac{0.5TD}{J}$$

(ii) In softer rock, assuming constant tangential stress at every radius across the failure plane

$$\tau = \frac{0.365TD}{J}$$

where

$$J = \frac{\pi(D^4 - d^4)}{32}$$

The latter assumption gives a more conservative estimate and should always be used for calculating residual shear strength, usually also for peak strength calculation.

(d) Graphs of peak and residual shear strength vs. normal stress are plotted from the combined results for all test specimens. Shear strength parameters may be abstracted from these graphs as shown in Fig. 6.

REPORTING OF RESULTS

9. The report should include the following:

(a) A diagram and detailed description of the test equipment and methods used for drilling and testing. (Reference may be made to this ISRM method stating only departures from the prescribed techniques.)

(b) For each test a full geological description of the test horizon, filling and shear debris preferably accompanied by relevant index test data.

(c) Photographs of the sheared surface together with diagrams giving the location, depth, dip and dip direction of the surface, the internal and external diameters and any peculiarities of the test core.

(d) For each test a set of data tables, graphs of shear stress and normal stress versus rotational displacement; abstracted values for peak and residual shear strengths and corresponding normal stresses with the assumptions made in their calculation.

(e) For the shear strength determination as a whole, graphs and tabulated values of peak and residual shear strength versus normal stress, together with derived values for the shear strength parameters (e.g. Fig. 6).

NOTES

1. Direct shear strength can be determined in the laboratory (using the method described in Part 2) if the plane to be tested is smooth and flat in comparison with the size of specimen, and if the specimen can be cut and transported without disturbance.

2. Definitions (clarified in Figs. 5 and 6):

Peak shear strength—the maximum shear stress in the complete shear stress–displacement curve.

Residual shear strength—the shear stress at which no further rise or fall in shear strength is observed with increasing shear displacement. A true residual strength may only be reached after considerably greater shear displacement than can be achieved in testing. The test value should be regarded as approximate and should be assessed in relation to the complete shear stress–displacement curve.

Shear strength parameters c and ϕ—respectively the intercept and angle to the normal stress axis of a tangent to the shear strength–normal stress curve at a normal stress that is relevant to design (see Fig. 6).

3. The measured peak strength can be applied directly to full-scale stability calculations only if the same type and size of roughness irregularities are present on the tested plane as on a larger scale. If this is not the case, the true peak strength should be obtained from the test data using appropriate calculations (for example, Patton, F. D., 1966, *Proc. 1st Int. Cong. Rock Mech. ISRM*, Lisbon, Vol. 1, pp. 509–512; Ladanyi, B. and Archambault, G., 1970. In *Rock Mechanics—Theory and Practice* (W. H. Somerton, ed.), AIME, New York, pp. 105–125; Barton, N. R., 1971, *Proc. Symp. ISRM*, Nancy, Paper 1–8).

4. Tests on intact rock (free from planes of weakness) are usually carried out using laboratory triaxial testing. Intact rock can, however, be tested in direct shear if the rock is weak and if the specimen block encapsulation is sufficiently strong.

5. If a dead load is used for normal loading precautions are required to ensure accurate centring and stability. If two or more hydraulic rams are used either for normal or shear loading care is needed to ensure that they are identically matched and are in exact parallel alignment. Each ram should be provided with a spherical seat. The travel of rams and particularly of flat jacks should be sufficient to accommodate the full anticipated specimen displacement. A normal displacement of ± 5–10 mm may be expected, depending on the clay content and roughness of the shear surface.

6. The applied shear force may act in the plane of shearing so that the angle α is 0 (Fig. 1). This requires a cantilever bearing member to carry the thrust from the shear jacks to the specimen. If a method is used where the shear force acts at some distance above the shear plane, the line of action of the shear jacks should be inclined to pass through the centre of area of the shear plane. The angle α for a specimen $700 \times 700 \times 350$ mm approximates to 15° depending on the thickness of encapsulation. Tests where both shear and normal forces are provided by a single set of jacks inclined at greater angles to the shear plane are not recommended, as it is then impossible to control shear and normal stresses independently.

7. The surface of encapsulating material is usually insufficiently smooth and flat to provide adequate reference for displacement gauges, and glass plates may be cemented to the specimen block for this purpose. These plates should be of adequate size to accommodate movement of the specimen. Alternatively a tensioned wire and pulley system with gauges remote from the specimen can be used. The system as a whole must be reliable and conform with specified accuracy requirements. Particular care is needed in this respect when employing electric transducers or automatic recording equipment.

8. A test block size of $700 \times 700 \times 350$ mm is suggested as standard for *in situ* testing. Smaller blocks may be permissible, for example, if the surface to be tested is relatively smooth; larger blocks may be needed when testing very irregular surfaces. The size and shape of the test block may for convenience be adjusted so that faces of the block coincide with natural joints or fissures; this minimizes block disturbance during preparation. Irregularities that would limit the thickness or emplacement of encapsulation material or reinforcement should be removed.

9. It is advisable particularly if the test horizon is

inclined at more than 10°–20° to the horizontal to apply a small normal load to the upper face of the test specimen while the sides are cut, to prevent premature sliding and also to inhibit relaxation and swelling. The load, approximately 5–10% of that to be applied in the test, may, for example, be provided by screw props or a system of rock bolts and cross-beams, and should be maintained until the test equipment is in position.

10. The requirement that total time to reach peak strength should exceed $6\,t_{100}$ is derived from conventional soil mechanics consolidation theory (for example, Gibson and Henkel, *Geotechnique* **4**, pp. 10–11, 1954) assuming a requirement of 90% pore water pressure dissipation. This requirement is most important when testing a clay-filled discontinuity. In other cases it may be difficult to define t_{100} with any precision because a significant proportion of the observed "consolidation" may be due to rock creep and other mechanisms unrelated to pore pressure dissipation. Provided the rates of shear specified in the text are followed, the shear strength parameters may be regarded as having been measured under conditions of effective stress ("drained conditions").

11. An independent check on the residual friction angle should be made by testing in the laboratory two prepared flat surfaces of the representative rock. The prepared surfaces should be saw-cut and then ground flat with No. 80 silicon carbide grit.

12. The normal load should when possible be applied in increasing rather than decreasing stages. Reversals of shear direction or resetting of the specimen block between normal load stages, sometimes used to allow a greater total shear displacement than would otherwise be possible, are not recommended because the shear surface is likely to be disturbed and subsequent results may be misleading. It is generally advisable, although more expensive, to use a different specimen block for each residual strength determination.

13. The torsional shear test is inexpensive and has the advantage of causing a minimum of disturbance to the test horizon. However, shear stress and displacement gradients generally exist from the inner to the outer radius of the core so that the shear strength values obtained must be regarded as approximate. The test should not be used for testing horizons that have a pronounced directional roughness. There is generally no provision for monitoring normal displacements or consolidation of the specimen.