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.
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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 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.

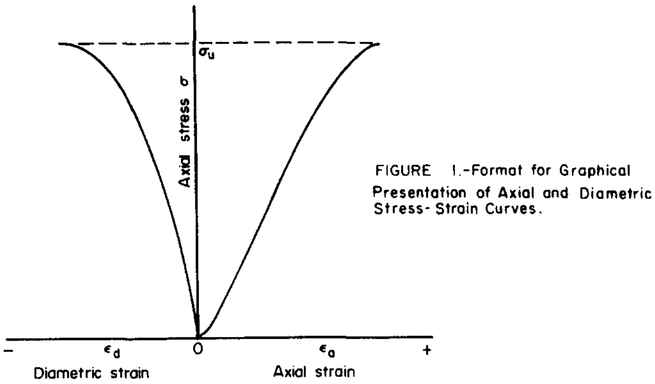

Fig. 1. Format for graphical presentation of axial and diametric stress-strain curves.

(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-

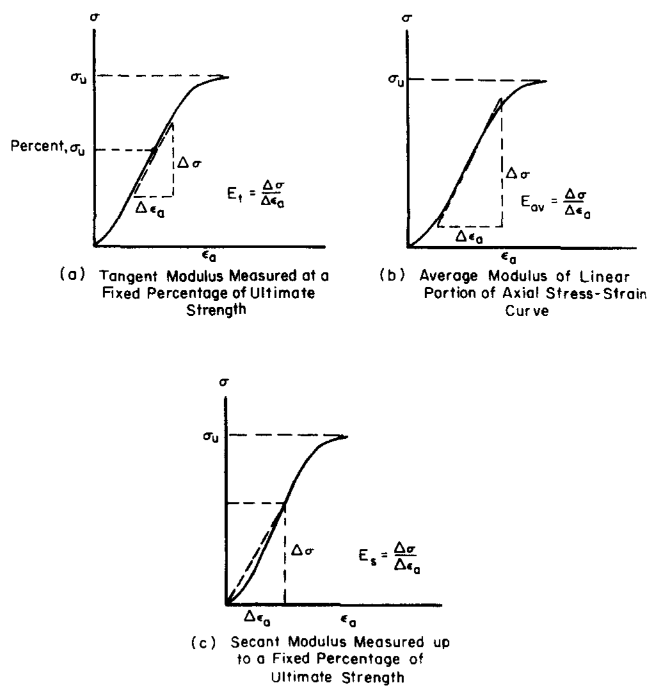

Fig. 2. Methods for calculating Young's modulus from axial stress-strain curve.

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.