Designation: C 801 – 98

Standard Test Method for Determining the Mechanical Properties of Hardened Concrete Under Triaxial Loads[1]

This standard is issued under the fixed designation C 801; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the procedures for testing hardened concrete when subjected to triaxial stress conditions. Materials other than concrete, cement paste, or mortar are excluded. When the determination of the strength of concrete under a triaxial state of stress is made according to this test method, two of the three principal stresses are always equal. There is no provision made for the measurement of pore pressures; therefore all strength values are in terms of total stress.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units which are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 512 Test Method for Creep of Concrete in Compression[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

E 4 Practices for Load Verification of Testing Machines[2]

3. Significance and Use

3.1 This test method provides data useful in determining the strength and deformation characteristics of concrete such as shear strength at various lateral pressures, angle of shearing resistance, strength in pure shear, deformation modulus, and creep behavior.

4. Apparatus

4.1 *Loading Device*—A suitable device for applying and measuring axial load to the specimen. It must be of sufficient capacity to apply the required loads at specified rates. It should be verified at suitable time intervals in accordance with the procedures given in Practices E 4, and should comply with the requirements prescribed therein.

4.2 *Triaxial Compression Chamber*—A device in which the test specimen may be enclosed in an impermeable, flexible membrane, placed between two hardened bearing blocks, and subjected to hydraulic pressure and deviator stress. The bearing blocks must be of steel, the bearing faces of which should be hardened to a minimum of 55 HRC, and which should not depart from plane surfaces by more than 0.0005 in. (0.0127 mm) when the blocks are new and should be maintained within a permissible variation of 0.001 in. (0.0254 mm). In order to develop the required hydraulic pressure, the apparatus should consist of a high pressure cylinder with an overflow valve, a base, suitable entry ports for filling the cylinder with hydraulic fluid and applying the lateral pressure, and hoses, gages and valves as needed (**1, 2, 3, 4**).[3] Fig. 1 and Fig. 2 illustrate triaxial chambers which have proved to be satisfactory.

4.3 *Combination Devices*—Alternatively, devices may be used which combine the function of loading device and pressure chamber. Fig. 3 illustrates one such device (**5, 6, 7, 8**).

4.4 *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system of sufficient capacity to maintain the desired pressures in the triaxial compression chamber.

4.5 *Strain-Measuring Devices*—Suitable devices must be provided for the measurement of strain in the specimen. Such devices should be readable to the nearest 0.0001 in. (0.00254 mm) and accurate to within 0.0001 in. (0.00254 mm) in any 0.001-in. (0.0254-mm) range, and within 0.0002 in. (0.00508 mm) in any 0.0100-in. (0.254-mm) range. Such devices may consist of micrometer screws, dial micrometers or linear variable differential transformers securely attached to the high pressure cylinder, and designed to measure bearing block travel (**5, 6, 7, 9**).

4.5.1 Vibrating wire or electrical resistance strain gages may be embedded in the concrete, aligned along the axis of the

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61on Testing for Strength.

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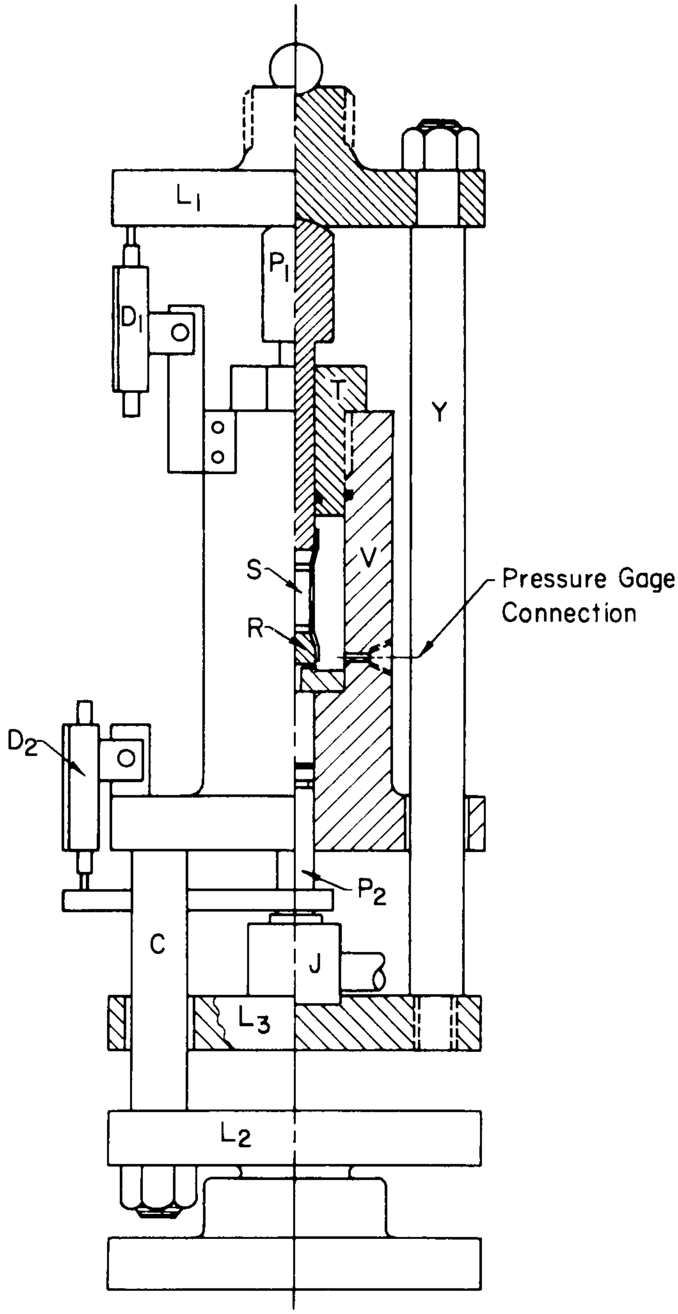
[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] The boldface numbers in parentheses refer to the list of references at the end of this test method.



S—Specimen
V—Pressure vessel
C—Columns (3)
L_1—Plate bearing on upper piston, P_1
L_2—Plate bearing on platen of testing machine
L_3—Plate suspended by columns Y
J—Hydraulic jack
P_2—Piston
R—Stopper
T—Threaded plug
D_1,D_2—Dial gages

FIG. 1 Section Through Test Cell (8)

specimen for measuring axial deformation, or they may be affixed to the surface of the specimen, in which case they should be placed at two diametrically opposite locations and at midlength of the specimen. The effective gage length should be at least three times the nominal maximum size of the aggregate, and at least half the specimen length.

4.5.2 Electrical resistance or vibrating wire strain gages may be applied circumferentially or embedded in the concrete at midlength to measure lateral strains. Gage length and numbers of gages should be such as to provide average values

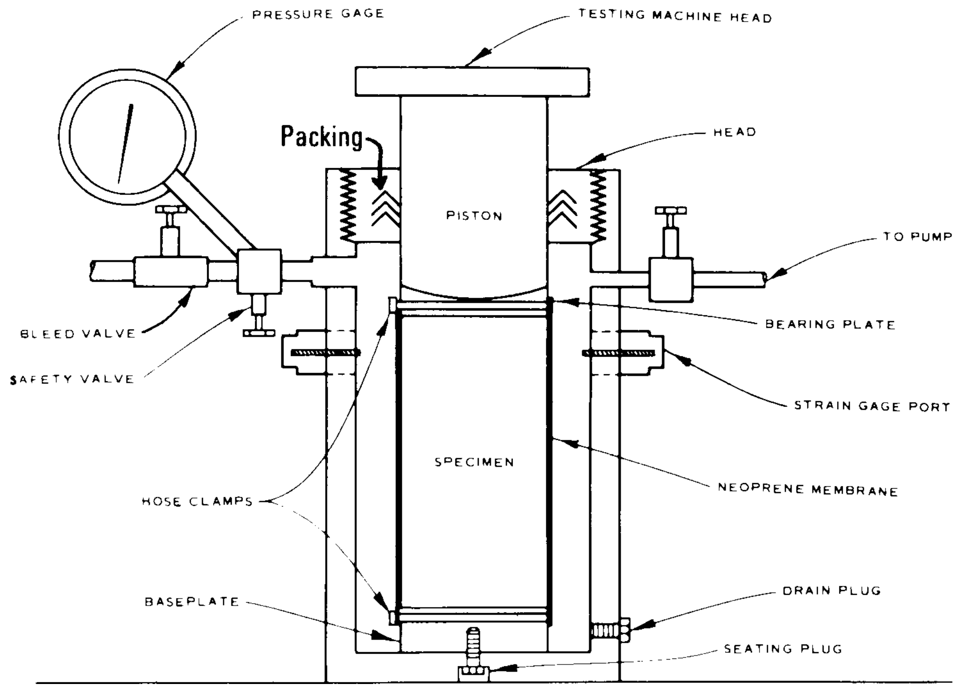


FIG. 2 Diagram of Triaxial Apparatus (1)

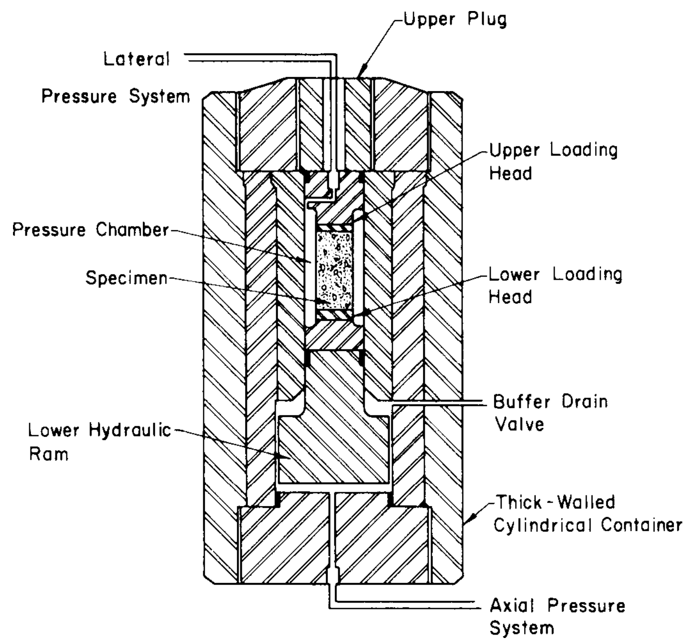


FIG. 3 Section Through Triaxial Testing Machine (7)

of lateral strain, reducing the effect of localized strains (**10**).

4.6 *Flexible Membrane*—A flexible membrane of suitable material to exclude the confining fluid from the specimen, and which does not significantly extrude into abrupt surface pores. It should be sufficiently long to extend well onto the bearing blocks and when slightly stretched be of the same diameter as the specimen (**2, 9, 10**)

NOTE 1—Neoprene rubber tubing of 1⁄16-in. (1.588-mm) wall thickness and of 40 to 60 Durometer hardness. Shore, Type A, has been found generally suitable for this purpose.

5. Test Specimens

5.1 Test specimens must be right circular cylinders within the tolerances specified herein, prepared in accordance with Practice C 192. The relationship of aggregate size to specimen size shall be in accordance with that required in Practice C 192.

5.1.1 The sides of the specimen must be generally smooth and free of abrupt irregularities with all elements straight to within 0.005 in. (0.1270 mm) over the full length of the specimen. Surface voids which are excessive in size and number should be filled with mortar or cement paste to preclude puncturing of the flexible membrane. Ends of the specimen that are not plane within 0.001 in. (0.0254 mm) must be lapped, ground, or capped. Capping compression specimens must be done in accordance with Practice C 617.

5.1.2 Planeness should be checked by means of a straightedge and feeler gage, making a minimum of three measurements on different diameters. Ends should be parallel to each other as indicated by the agreement with 0.002 in. (0.0508 mm) of five equally distributed measurements of the length of the specimen taken by means of a dial comparator. Ends should not depart from perpendicularity to the axis of the specimen by more than 0.25° (approximately 0.01 in. in 2 in. or 0.25 mm in 50.80 mm). Specimens should have a length to diameter ratio (L/D) of 2.0 ± 0.2 and a diameter of not less than 2 in. (50.8 mm).

5.2 The diameter of the test specimen should be determined to the nearest 0.01 in. (0.254 mm) by averaging two diameters measured at right angles to each other at about midlength of the specimen. The length of the test specimen shall be that determined by means of the dial comparator in accordance with 5.1.

5.3 Tests in the moist condition of moist cured specimens shall be made as soon as practicable after removal from the curing room. Specimens tested in a saturated condition shall be kept moist by a wet burlap or blanket covering during the period between their removal from moist storage and testing. Specimens may be tested in a condition other than saturated and other than moist-cured at the discretion of the investigator.

5.4 *Number of Specimens*—Make no fewer than two specimens from each batch of concrete for each test condition or type of loading.

SHORT-TIME BEHAVIOR

6. Procedure

6.1 In general, three types of loading can be followed when conducting a triaxial test:

6.1.1 *Type I*—Hydrostatic pressure is increased to a predetermined level, and held constant while the axial stress is increased until failure occurs.

6.1.2 *Type 2*—Hydrostatic pressure is increased to a predetermined level, then the axial stress is held constant while the lateral stress is increased until failure occurs.

6.1.3 *Type 3*—The ratio of axial to lateral stresses is held constant and the stresses are increased until failure occurs.

6.1.4 When a specimen is to be tested under triaxial compression, a loading sequence whereby the lateral stresses are kept zero while the axial stress is increased or vise versa should be avoided since premature failure may occur under uniaxial or biaxial compression, respectively (**11**).

6.2 Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen, and place the test specimen on the lower bearing block. Place the upper bearing block on the specimen and properly align. Fit the flexible membrane over the specimen and bearing blocks and install rubber or neoprene O-rings to seal the specimen from the confining fluid. Enclose the specimen and bearing blocks in the pressure vessel, ensuring proper seal at points of connecting parts. Connect the hydraulic pressure lines. Position any deformation measurement devices required and fill the chamber with hydraulic fluid. Apply a slight axial load, approximately 25 lbf (111 N) to the triaxial compression chamber by means of the loading device in order to properly seat the bearing parts of the apparatus. Take an initial reading on the deformation device. Slowly raise the fluid pressure or the axial load, or both, to the predetermined test level as required by the type of loading adopted for the test.

6.3 Load the specimen in the desired direction(s) continuously and without shock until the load becomes constant or reduces, or a predetermined amount of strain is achieved. Apply the load at an initial rate of 35 ± 15 psi (241 ± 103 kPa)/s. Make no adjustment in the controls of the testing machine while a specimen is yielding rapidly immediately before failure. Maintain the predetermined confining pressure(s) throughout the test and observe and record readings of deformation as required.

7. Presentation of Data

7.1 The presentation of data obtained from triaxial tests may take one or more of the following forms:

7.1.1 Graphical plots of the following equation:

$$f_1 = f'_c + K(f_3)^a \tag{1}$$

or, for the strength increase beyond the uniaxial strength:

$$f_1 - f'_c = K(f_3)^a \tag{2}$$

where:

f_1 = largest principal stress,
f_3 = smallest principal stress,
f'_c = unconfined compressive strength, and
K, a = empirical coefficients (**3, 4, 7, 12**).

7.1.2 A graphical plot of the stress difference versus axial strain. Stress difference is defined as the maximum principal axis stress minus the minimum principal stress. The value of the minimum principal stress should be indicated on the curve.

7.1.3 A graphical plot of axial stress versus axial strain for different confining pressures.

7.1.4 Mohr stress circles constructed on an arithmetic plot with shear stresses as ordinates and normal stresses as abscissas. At least three triaxial compression tests, each at a different confining pressure, should be made on the same material to define the envelope to the Mohr stress circles (**1**).

7.1.4.1 "Best-fit" smooth curve (the Mohr envelope) should then be drawn tangent to the Mohr circles, as shown in Fig. 4. If a straight line can be drawn tangent to all stress circles, draw such a line and indicate the angle of internal friction, ϕ, and the cohesion, c, as shown in Fig. 4. The figure should also include a brief note indicating whether or not a pronounced failure plane was developed during the test, and the inclination of this plane with reference to the plane of major principal stress.

7.1.4.2 If the stress circle envelope can be accurately described by a straight line, fit the data with a straight line using the theory of least squares (**1**). Express the envelope in the following form:

$$Y = c + X \tan \phi \tag{3}$$

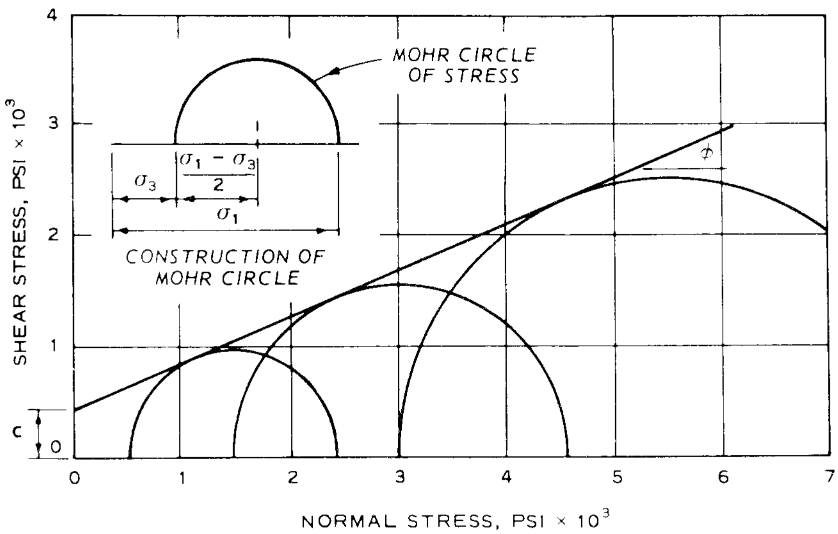


FIG. 4 Determination of Shear Strength Parameters (1)

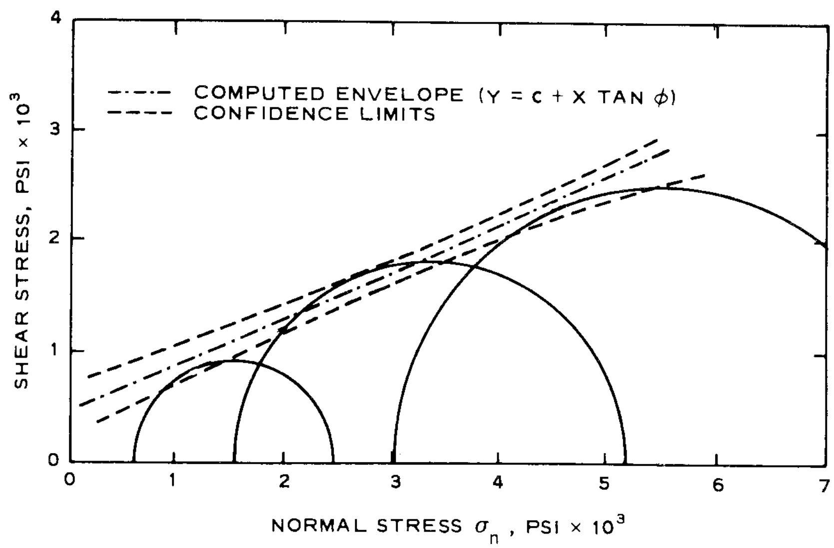


FIG. 5 Mohr's Diagram (1)

where:

Y = shearing stress at failure, and
X = normal stress at failure.

Determine the parameters c and $\tan \phi$ using the following equations:

$$c = \frac{\Sigma f_1 - A\,\Sigma f_3}{2n\sqrt{A}} \quad (4)$$

$$\tan \phi = \frac{A-1}{2\sqrt{A}} \quad (5)$$

where:

$$A = \left(\frac{n\Sigma f_1{}^2 - (\Sigma f_1)^2}{n\Sigma f_3{}^2 - (\Sigma f_3)^2} \right)^{1/2}, \text{ and} \quad (6)$$

n = number of tests.

7.1.4.3 If the data are fitted using the theory of least squares as described above, compute and plot the 95 % confidence limits for Eq 3 using the following equation:

$$2s\,Y'_{yx} = \left(\frac{A - B^2}{n-2} \left[2f_{s_3}{}^2 + \frac{(A+1)^2}{A(A+B^2)} x^2 \right] \right)^{1/2} \quad (7)$$

where:

sY'_{yx} = standard error of the estimated shearing strength for the regression line of Y on X, psi (or MPa),

$$B^2 = \frac{n\Sigma f_1 f_3 - \Sigma f_1 \Sigma f_3}{n\Sigma f_3{}^2 - (\Sigma f_3)^2} \quad (8)$$

$$f_{s_3}{}^2 = \frac{n\Sigma f_3{}^2 - (\Sigma f_3)^2}{n^2} \quad (9)$$

x = $X - M_x$ (Pick x at a convenient interval from lowest to highest stress circle), and

$$M_x = \frac{1}{n(A + 1)} \times (\Sigma f_1 + A\Sigma f_3) \quad (10)$$

See Fig. 5 for Mohr's diagram with 95 % confidence limits about Eq 3.

NOTE 2—Different envelopes may be obtained for different types of loading as described in 6.1. A unique envelope may be obtained only for materials which obey the Mohr-Coulomb theory of failure.

8. Report

8.1 In addition to the provisions of the Sections on Presentation of Data and Presentation of Creep Data, report the following:

8.1.1 Specimen identification number,

8.1.2 Specimen dimensions in inches (or millimetres),

8.1.3 Cross-sectional area,

8.1.4 Concrete batching data,

8.1.5 Moisture condition of specimen, and

8.1.6 Curing history.

9. Precision and Bias

9.1 *Precision*[4]—The repeatability coefficient of variation has been found to be 5.0 %[5] for the estimated shear strength at failure at the mean value of normal stress. Therefore, results of two properly conducted tests by the same operator should not differ from weach other by more than 14.0 %[5]

9.1.1 The repeatability coefficient of variation for cohesion and tan ϕ has been found to be 10.8 %[5] and 7.3 %[5], respectively. Therefore, results of two properly conducted tests by the same operator should not differ from each other by more than 30.5 %[5] for strength in pure shear, and 20.6 %[5] for angle of internal friction.

9.1.2 The reproducibility standard deviation is being determined and will be available on or before December 2005.

9.2 *Bias*—This test method has no bias because the values determined can only be defined in terms of the test method.

10. Keywords

10.1 angle of internal friction; compressive strength; concrete; creep; Mohr's diagram; shear strength; strain; triaxial testing

[4] Supporting data have been filed at ASTM Headquarters and may be obtained by requesting Research Report RR: C09-1020.

[5] These numbers represent, respectively, the (ls %) and (d2 %), as described in ASTM C 670.

APPENDIX

(Nonmandatory Information)

X1. LONG-TIME BEHAVIOR (CREEP) (13, 14)

X1.1 Apparatus

X1.1.1 Devices for loading and for development of hydrostatic pressure on cylinder specimens conforming generally to the provisions of Section 4 must be provided. In addition, due to the nature of the test, any loading or hydrostatic pressure devices must be capable of maintaining specified loads or pressure levels for long periods of time. Hydraulic devices must have provision for automatically maintaining the specified pressure. Mechanical devices must be able to follow any long-time strain and still maintain the specified load. The application of load through heavy coil springs has been found to be generally useful for this purpose. However, periodic checking and possibly adjustment of the compression in the spring is required.

X1.1.2 *Strain-Measuring Devices*

Strain gages must conform in general to the provisions of 4.5.

NOTE X1.1—Caution should be exercised in the use of bonded electrical resistance gages, since some cements attaching the gage to the specimen tend to creep, in which event the gages do not follow completely the strain experienced by the specimen.

X1.2 Test Specimens

X1.2.1 Test specimens should be prepared in accordance with the provisions of Section 4.

X1.2.2 *Number of Specimens*

No fewer than six specimens should be made from a given batch of concrete for each test condition: two tested for compressive strength, two loaded and observed for total deformation, and two kept unloaded for use as controls to indicate deformations due to causes other than load. Each strength and control specimen should undergo the same curing and storage treatment as the loaded specimen.

X1.3 Procedure

X1.3.1 Prepare the testing apparatus and position the specimen therein in accordance with Section 6. Immediately before loading the creep specimens, determine the compressive strength of the strength specimens in accordance with Test Method C 39. Seal the unloaded control cylinders, or otherwise protect them in a fashion that simulates the environmental conditions to which the test specimens are subjected.

X1.3.2 Load the specimens at the rates specified in Section 6 until the predetermined stress levels are reached. Take strain readings immediately before and after loading, 2 to 6 h later, then daily for one week, then weekly until the end of one month, and finally monthly until the end of one year. Take strain readings on the control specimens on the same schedule as the loaded specimens.

X1.4 Presentation of Creep Data

X1.4.1 Determine the creep strain due to load by subtracting the strain observed in the control cylinders from the strain observed under load.

X1.4.2 Express the total creep strain, $e_{1c\ c}$, observed in the direction of the maximum principal stress, f_1, as follows:

$$e_{1cc} = e_{1c} - (m_{2c}e_{2c} + m_{3c}e_{3c}) \tag{X1.1}$$

where:

e_{1c}, e_{2c}, e_{3c} = creep strains occurring in the principal stress directions 1, 2 or 3 and caused by the principal stresses f_1, f_2 or f_3, and

m_{1c}, m_{2c}, m_{3c} = Poisson's ratio for creep (**15**).

This equation is used for the general case and is based upon the assumption that the principle of superposition is valid.

X1.4.3 Plot the total creep strain (linear scale) against time (logarithmic scale) and determine the time function of creep. For procedure to be followed in this determination, see Test Method C 512.

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