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RILEM TECHNICAL COMMITTEES

RILEM TC 107-CSP: CREEP AND SHRINKAGE PREDICTION MODELS: PRINCIPLES OF THEIR FORMATION

Recommendation

Measurement of time-dependent strains of concrete

Prepared by Subcommittee 4: Standardized Test Methods for Creep and Shrinkage

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The text presented hereunder is a draft for general consideration. Comments should be sent to the TC Chairman, Prof. Zdeněk P. Bažant, Northwestern University, WP Murphy Professor of Civil Engineering, 2145 Sheridan Road, A131, Evanston, IL 60208, USA, Fax: +1 847 467 1078, e-mail: z-bazant@nwu.edu before April 1, 1999.

ABSTRACT

The present recommendation defines a method for measuring the time-dependent strain in hardened concrete specimens that are either load-free or are subjected to a uniform compressive force kept constant over a long period. It states the definitions of autogenous shrinkage and drying shrinkage, basic creep and drying creep, instantaneous strain at a given age, and recovery. It gives the specifications for testing and measuring devices and describes, in an appendix, three types of apparatus for creep tests. The present recommendation applies to the case of concretes containing light, normal, and heavy aggregates, when the maximum size of these aggregates does not exceed 50 mm.

1. INTRODUCTION

Under constant mechanical loading, the strain of concrete increases significantly with loading duration, the increase often reaching 2 to 3 times the value of the instantaneous strain. This phenomenon, known as creep, requires a precise evaluation, in particular for the design of structures. In the case of prestressed concrete, knowing the creep properties of concrete is at least as important as knowing its instantaneous elastic modulus.

The growing diversification of concrete compositions, in particular with the fast development of high-performance concrete, is accompanied by a diversification of long-term behaviour. At the same time, creep and shrinkage values appear in certain cases to be a material selection criterion.

Shrinkage and creep tests thus have two possible purposes:

• determination of the properties of the concrete of a given mix design, aimed to provide the input data for the time-dependent constitutive law of the material; in this case, the aim is to determine the influence of the main parameters by varying the test conditions (loading age, ambient environment, compression stress magnitude, age at unloading);

• concrete mix design optimization (generally in relation with other mechanical or physical properties, and in particular compressive strength); in this case, it is normally feasible to test only some representative conditions (early age and 28-day loading, with and without drying, for example).

In both situations, the pronounced hereditary behaviour of the material (*i.e.* the fact that the behaviour at a given instant depends on the entire history of preceding stress) calls for a rigorous definition of the creep test, which does not require any correction in the case of non-constant loading. The quality of the test consequently depends primarily on the ability of the device to keep the applied load constant, particularly at the very beginning of the test.

Furthermore, an essential influencing factor is the evaporable water content in the material which, except in very special cases, is not uniform in the structures, owing to the slow rate of the drying process. This problem is complex and goes beyond the scope of this recommendation.

A practical method, yielding data which may be used in structural design, has been widely used and is adopted here. This method consists in conducting tests in two extreme cases: the case without moisture exchange with the environment, obtained by protecting the specimens against desiccation, and the case of drying under conventional conditions. The first case characterizes the core concrete of thick parts. The second case characterizes the concrete of thin parts or of the skin concrete of thick parts. A finer analysis of the drying process can then provide a picture of the actual in-service behaviour of the material.

2. SCOPE

2.1 The present recommendation defines a method for measuring time-dependent strain in hardened concrete specimens subjected to a uniform compressive force kept constant over a long period (creep test) and not subjected (shrinkage test). In the case of creep, the objective of this method is the measurement of the strain per unit applied uniaxial stress.

2.2 It gives the definitions of autogenous shrinkage and drying shrinkage, basic creep and drying creep, instantaneous strain at a given age, and creep recovery.

2.3 It presents specifications for the testing and measuring devices for time-dependent deformation of hardened concrete. The measurement of initial shrinkage starting at concrete setting goes beyond the scope of this recommendation. In an appendix, three types of apparatus for creep testing are proposed.

2.4 It does not deal with safety and health hazards relative to the performance of the tests. Attention, however, is drawn to the risks that may exist in the implementation of these tests, and in particular of creep tests.

3. FIELD OF APPLICATION

The present recommendation applies to the case of concretes containing light, normal, and heavy aggregates, with a maximum size of 50 mm.

4. DEFINITIONS

4.1 By definition, shrinkage strain ε_{sh} (t) is the strain measured on load-free specimens. Autogenous shrinkage is the normal strain in a specimen maintained at constant temperature and without any hygral exchange with the surrounding medium. Drying shrinkage is the longitudinal strain in the central portion of the length of a long enough cylindrical specimen (with a distance of each end of the cylinder not smaller than 1.5 diameters) which has been stored (after the stripping of the mould) in a dry atmosphere of controlled relative humidity, conventionally at 20 ± 1°C and 50 ± 5% relative humidity (Europe), or 25 ± 1°C and 65 ± 3% (North America).

4.2 By definition, the viscoelastic strain ε_{ve} (t,t') at a given age t is the strain obtained by subtracting from the total strain ε_t (t,t') measured on a specimen subjected to a constant stress σ_i applied at loading age t' the shrinkage strain ε_{sh} (t) for the same age, measured on a control companion specimen, preserved under the same environmental conditions (see § 6.4). Note that the total strain and shrinkage strain measurements are defined with respect to the same origin of time (see § 7.1.6). The instantaneous strain ε_i (t') is not subtracted, even if measured on the creep specimen itself.

4.3 By definition, the compliance function J (t,t') is the viscoelastic strain ε_{ve} (t,t') at age t caused by a unit uniaxial stress applied since loading age t'. Under constant load, the compliance function J (t,t') and the viscoelastic strain ε_{ve} (t,t') at any stress σ_i are thus related by the formula:

$$\varepsilon_{ve}\,(t,t') = \sigma_i\ J\,(t,t')$$

or by:

$$\varepsilon_{ve}\,(t,t') = \varepsilon_i\,(t')\ [1 + J\,(t,t')]$$

where:

$$J\,(t,t') = \ E\,(t')\ J\,(t,t') - 1$$

The last formula indicates how the creep coefficient φ should be calculated. E (t') is the elastic (or Young's) modulus at the age of loading t', which may be determined in accordance with current standards or recommendations.

4.4 In certain cases, when the apparatus allows a quasi instantaneous load-application (see § 7.3.2), the instantaneous strain ε_i can be measured during the loading of the creep specimen itself, which allows obtaining supplementary information from a creep test, such as related instantaneous mechanical properties (Young's modulus, Poisson's ratio, rapid early creep, etc.) at the loading age t'.

4.5 By definition, the basic creep is the creep observed in the absence of any hygral exchange with the surrounding environment, and drying creep is the (total) creep observed in a drying atmosphere, conventionally at 20 ± 1°C and 50 ± 5% relative humidity, or 25 ± 1°C and 65 ± 3% (the basic creep is not subtracted).

4.6 The creep recovery is the strain recovered after unloading. A distinction is made between the instantaneous recovery, generally very close in absolute value to the instantaneous strain at the same age, and the total recovery, which is defined as the difference between the strain measured after unloading and the strain that would have been recorded at the same age if there had been no unloading.

5. APPARATUS

5.1 The creep test device must apply a centric compressive force and keep it constant with time, with an accuracy of ± 1% around the mean value. This may be achieved by different systems: the hydropneumatic accumulator, the helical spring, and electronic or manual control. These different systems are described in the appendix.

5.2 The apparatus must allow the measurement of the applied force with a known precision (1 % is reasonable), which should be reported. A calibration process ought to be established, applied in the tests and information on it supplied on request.

5.3 The strain must be measured with the same system both in the creep test and in the shrinkage test, in the middle portion of the specimen length and along at least three longitudinal lines along the circumference, and on a base not shorter than one diameter. The distance between the strain measurement base and the ends of the specimen must not be smaller than 1.5 diameters. It is useful, but not required, to measure also the transverse deformation across the central portion of the specimen, in order to determine the creep Poisson's ratio.

6. SPECIMENS

6.1 Form and dimensions

All creep and shrinkage specimens must be cylinders. A sufficient number of specimens (at least six) should have the same diameter, with a slenderness (length/diameter ratio) not less than 4 , in order to allow measuring the deformations on a base not smaller than one diameter and with a distance of each end of the cylinder not smaller than 1.5 diameters (or one if the end faces of the specimens are protected against drying). These specimens are normally cast in moulds but, if necessary, can be cored from concrete blocks that have not lost water before coring (as, for example, in testing of fibre reinforced concrete) or from massive *in situ* structures, from those parts that have not lost water before the coring (*e.g.* for diagnosis of a structure in service).

6.1.1 The specimens cast in moulds require metallic moulds (or moulds lined internally with a metallic foil, or a sheet of an organic material, provided that the total water absorption of the lining remains, after 24 hours, less than 2 grams per liter of capacity of the mould). The diameter must be at least 5 times the size of the largest aggregate.

6.1.2 In the case of drilled core specimens, the diameter must be at least 4 times the size of the largest aggregate.

6.2 Manufacture

The specimens must be manufactured according to the requirements for compression tests. Casting in a horizontal position is prohibited for both mechanical and hazardous reasons (transversal heterogeneity increases the risk of *buckling* in compression). The age of the specimen is measured from the moment of the filling of the mould with concrete.

6.3 Curing

Unless specified otherwise (in view of research goals such as the study of curing effects) or industrial applications (whose aim may be to represent as accurately as possible the specific conditions of a construction site), all the specimens must be kept after manufacture in their mould and in a temperature controlled room at 20 ± 1°C or at 25 ± 1°C. If the age at exposure to drying is at least three hours lower than the first age of loading, all the specimens are stripped at the same time in the testing room (which must be temperature and moisture controlled). Immediately after stripping, all the specimens intended for autogenous shrinkage and basic creep are confined by an adhering protective jacket consisting of a metallic (*e.g.* aluminium or copper) foil. The end faces of the drying specimens should be protected against desiccation, immediately after stripping, by the same procedure. If it is desired that the age at exposure to drying would coincide with the first age at loading, all the specimens of the series must be stripped not more than two to three hours before the loading of the first creep test, preferably in a wet room, temperature controlled at 20 ± 1°C or at 25 ± 1°C, and protected, immediately after stripping, against desiccation by an adhering protective jacket consisting of a metallic (*e.g.* aluminium or copper) foil.

6.4 Environmental conditions

Unless specified otherwise (in view of research goals such as the study of mechanical effects of drying) or industrial applications (for which the drying conditions of the concrete are fixed), two types of test are carried out, requiring two series of specimens: tests without drying (autogenous shrinkage and basic creep) and tests under conventional drying (drying shrinkage, including autogenous shrinkage, and creep at drying).

6.4.1 The autogenous shrinkage and basic creep tests are carried out at 20 ± 1°C or at 25 ± 1°C, on specimens confined by an adhering protective jacket consisting of a metallic (*e.g.* aluminium or copper) foil; the specimens are kept in a temperature controlled room at 20 ± 1°C or at 25 ± 1°C, preferably in a wet room. They must be stripped in the same room two hours before the start of the shrinkage measurements (which must start before the first creep test). The surface protection (*e.g.* coating with a resin and application of an aluminium or copper foil, or direct application of a self-adhesive aluminium foil) must be applied immediately after the stripping or coring of each specimen.

6.4.2 The drying shrinkage and drying creep tests must be carried out in a room of controlled temperature and humidity, preferably at 20 ± 1°C and at 50 ± 5% or at 25 ± 1°C and at 65 ±3 % relative humidity. The shrinkage strain measurements must start immediately (within 3 minutes) after stripping of the moisture seal. In any case, the specimens must be kept (before, during and after stripping) in a room in which the temperature is kept constant to within ± 1°C. Except for special cases duly specified, the specimens cored from a structure are always kept sealed according to the conditions of the preceding paragraph.

6.5 Control companion specimens

Control (or companion) specimens that are load-free must be made and tested for each creep test. They are made and kept under the same conditions as those for the creep tests and for Young's modulus tests, at different loading ages, in accordance with the current standards or recommendations.

7. PROCEDURE

7.1 Preparation of the specimens

7.1.1 The specimens intended for shrinkage measurements must be placed in the creep test room at least two hours before the start of the shrinkage measurements. Measurements of drying shrinkage must begin as quickly as possible after stripping of the mould or the moisture seal. Since the placing of a wet surface in contact with a dry atmosphere causes a drop in temperature of the surface (*e.g.* Kovler, 1995), it is useful to measure temperature both in the core and near the surface of the specimen, in order to assess of this thermal effect.

7.1.2 Immediately after the stripping of specimens intended for creep tests, the two end faces of each of the creep specimens should be ground flat, in order to have plane faces perpendicular to the axis of the cylinder, with a precision of 50 microns. In cored specimens, this should be done before, right at coring.

7.1.3 Immediately after the stripping and, for the creep specimens, after the grinding of the end faces, the two end sides of all the specimens must be protected against desiccation. This protection must include a metallic (*e.g.* aluminium or copper) foil and must ensure that there are no air pockets between the concrete and the aluminium. Immediately after that, the specimen must be weighed (see 7.4).

7.1.4 The specimens intended for autogenous shrinkage and for basic creep measurements must be protected immediately after the stripping or grinding, on their entire surface, and must be weighed, by the same procedure.

7.1.5 All the creep specimens must be weighed just before the start of their loading, as well as just after the end of the test.

7.1.6 The first measurement of drying shrinkage is carried out within 3 minutes after exposure. It should be emphasized that a part of shrinkage (the autogenous shrinkage, as well as a part of the drying shrinkage itself, which starts immediately after stripping, with a maximal rate) inevitably remains unrecorded. For a complete assessment of shrinkage, special gages embedded in concrete should be used, in order to obtain the complete shrinkage curves. Furthermore, if the loading age of the first creep test coincides with the age at exposure to drying, a procedure in which the temperature is measured both in the core and near the surface of the specimen should be used in order to be able to take into account the surface cooling due to evaporation.

7.2 Measurements prior to loading

Three specimens are used for determining the compressive strength and the conventional (static) elastic modulus of concrete at the age at which the creep test begin, in accordance with current standards or recommendations.

7.3 Measurement of total strain under load

7.3.1 The loading must be applied as quickly as possible. Preference should be given to reducing the time during which the load is raised (to approach a Heaviside step function), rather than to obtaining right away exactly the required load value (a continuous recording, graphic or digital, of the applied load allows taking into account in calculations the actual loading history, in particular, its difference from the Heaviside function). The strain readings ought to be taken at constant intervals in the logarithmic time scale (for instance 0.5, 1, 2, 4 min., ..., 1, 2, 4, ..., 2^n days), *i.e.* in a geometric progression of reading times.

7.3.2 In the case of an apparatus with a hydropneumatic accumulator, the loading must be applied instantaneously, such that precise measurements of the instantaneous strain and of the initial rapid creep be obtained. Such measurement ought to begin immediately after loading (no later than one second), followed again by a sequence of strain readings taken at constant intervals in the logarithmic time scale (for instance $t_i = 2^{i-18}$ d, with $t_1 \cong 0.66$ s). At the end of the loading and for a period of at least one hour, the pressure in the accumulator, or in the cylinder, must be checked and adjusted (as the nitrogen cooled by adiabatic expansion returns to ambient temperature).

7.4 Measurement of water losses

Simultaneous measurements of water loss by weighing are required for all the tests of shrinkage and creep at drying. Also, the total evaporable water content at the end of test must be determined by measuring the water loss in an oven at 110°C.[1]

7.5 Recommended parameters

The purpose of the recommended values that follow is to make the measurements from different laboratories easier to compare.

7.5.1 Cylinder diameters: d = 7.5, 10, **15**, 20, 25 cm and corresponding length: L = 30, 40, **60**, 80, 100 cm.

7.5.2 Ages at exposure to drying: t_o = 1, 3, **7**, 14 days (t_o must be lower than the lower age of loading of the series).

7.5.3 Ages at loading: t' = 1, 3, 7, **28**, 90 days, 1 year and, if possible, 3 years.

7.5.4 Compressive stress: $\sigma = k \cdot f_c(t')$, where $f_c(t')$ is the strength at the age t' of loading, and k = 0.20; **0.40**; 0.60.

7.6 Test duration

7.6.1 For comparative tests: 6 months for sealed conditions, n years for drying conditions, where $n = (d / 0.16)^2$, with d the diameter in meter.

7.6.2 For extrapolation to the final or long-term (50 year) values: 1 year for sealed conditions, 2 n years for drying conditions.

8. CALCULATION AND PRESENTATION OF RESULTS

8.1 The results should be given in the form of tables indicating, for each specimen, the age of the measurements counted from the end of the casting of concrete into the mould, and the total strains measured (shrinkage *plus* elastic deformation *plus* creep). In the case of drying, adequate data on water loss should also be tabulated.

8.2 The results must be reported in a form making it possible to deduce, without any ambiguity, the difference between the measurements carried out on specimens of different boundary conditions (drying *versus* sealed, loaded *versus* load-free).

8.3 The results of the creep tests may also (but not alternatively) be furnished in the form of a table giving, as a function of the time $(t - t')$ elapsed since the loading, the compliance function $J(t,t')$, obtained according to definition Sec. 4.3. In this case, the shrinkage strains (but not the elastic strains) are subtracted from the total strains, and the difference is divided by the stress applied. In this calculation, the shrinkage value is obtained by linear interpolation in the logarithmic time scale between two successive measurements (provided that the time interval between these two measurements does not exceed one-third of the age of the specimen).

9. TEST REPORT

The test report must make reference to the present recommendation and indicate, for each specimen :

- the preparation mode, including mix composition, environmental conditions and specimen conservation conditions (type of sealing);
- the loading age, the value of the applied stress, stress history during loading (σ *versus* time t), and the compressive strength at loading;
- the strain measurement method, the position and length of the measurement bases;
- the strain measurement results in table form, in accordance with the preceding paragraph;
- the results of weight loss measurements;
- supplementary results, if available, such as Young's modulus, Poisson's ratio, etc.

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APPENDIX: THREE EXAMPLES OF APPROPRIATE CREEP APPARATUS

A.1 Helical spring

The helical spring (Fig. 1) also allows a constant load application. A specimen or a stack of specimens 1 meter long requires a spring whose stiffness is of the order of 5.10^6 N/m; this is a simpler test device, but requires a centric point pressure and, consequently, a thicker pressure plate (thickness of the order of the specimen diameter). [ASTM Standard C 512]

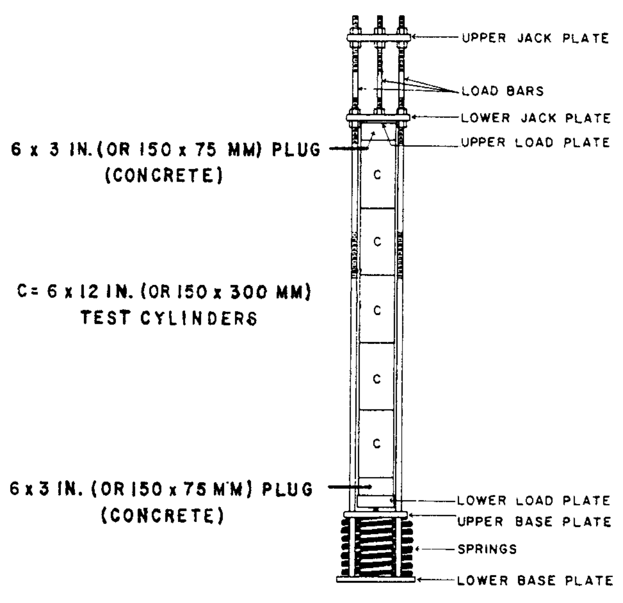

Fig. 1 – Helical spring.
Reprinted with the permission of the ASTM, Fig. 1, p. 276, Vol. 04.02 Concrete and Aggregates, Annual Book of ASTM Standards.

A.2 The hydropneumatic accumulator

The hydropneumatic accumulator consists of a flat, oil-filled cylinder located at the base of the frame, under the specimen, and connected to a nitrogen bottle under pressure (see Fig. 2). In operation, the oil fills the cylinder and the lower part of the nitrogen bottle. A membrane prevents the two fluids from mixing. This system also makes it possible, if completed by a valve between the flat cylinder and the accumulator, to ensure almost instantaneous loading of the specimen and, consequently, of measuring the instantaneous strain of the specimen. For a specimen or a stack of specimens one meter long, a 5-litre nitrogen bottle generally ensures constant load application with a precision of less than 1%; however, the oil pressure must be controlled and adjusted during the first hour of loading, owing to temperature variations induced in the nitrogen during loading (adiabatic expansion). [French Standard]

A.3 Loading control

A constant load may be maintained by means of a hydraulic cylinder and a pump controlled by hand or by means of a control system. In the case of manual control, a digital or analogic recording of the applied force (or, failing this, of the pressure in the cylinder) and of the specimen strain must be carried out continuously during the loading and during at least the first hour of the test.

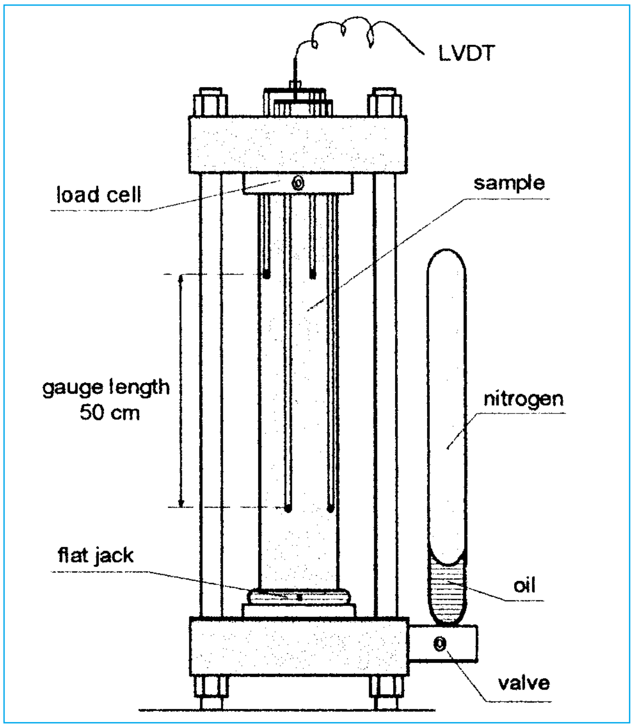

Fig. 2 – The hydropneumatic accumulator.