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Comprehensive Database on Concrete Creep and Shrinkage

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As a sequel to the first large database created at Northwestern University in 1978, this paper presents a further enlargement of the database, comprising 621 creep tests and 490 shrinkage tests. This database significantly extends the 1993 RILEM database, which contains 518 creep tests and 426 shrinkage tests. This new, conveniently computerized database will make possible more realistic verification and calibration of creep prediction models for design, provided that a proper unbiased statistical technique, compensating for inevitable strong statistical bias in the distribution of data, is employed. The database can be downloaded freely from the Web site http://www.iti.northwestern.edu.

Keywords: calibration; creep; database; model verification; shrinkage; statistics.

INTRODUCTION

A vast number of creep and shrinkage experiments have been carried out around the world since the phenomenon of concrete creep was discovered by W. K. Hatt at Purdue University, West Lafayette, IN, in 1907. The first comprehensive database, comprising approximately 400 creep tests and approximately 300 shrinkage tests, was compiled 30 years ago at Northwestern University,[1-3] Evanston, IL, mostly from American and European sources. In collaboration with CEB, begun at the 1980 Rüsch Workshop,[4] this database was slightly expanded by an ACI 209 subcommittee. A further expansion was undertaken by subcommittee of RILEM Committee TC-107. It led to what became known as the RILEM database,[5-7] which contained 518 creep tests and 426 shrinkage tests.

Presented herein is a significantly enlarged database, named the NU-ITI database,[8] which has recently been assembled in the Infrastructure Technology Institute of Northwestern University. It consists of 621 creep tests and 490 shrinkage tests. The enlargement consists mainly of recent Japanese and Czech data.[9,10]

RESEARCH SIGNIFICANCE

It is generally accepted that a readily accessible database assembling the essential results of the relevant experiments is required for validating and calibrating a prediction model. Compiling such a database is a tedious project, and so its publication will save future researchers from this time-consuming effort. The new database, which is conveniently computerized and can be downloaded freely,[8] will help in the development of more realistic prediction models. It can also be used for reevaluation, recalibration, and mutual comparisons of the existing creep and shrinkage prediction models such as those described in References 1-3, 5, and 11-13.

Information included in the database and its organization

All the creep data in the database have been obtained for sustained uniaxial compressive normal stress less than 40% of the uniaxial compressive strength. In that range, the dependence of creep strain on stress is approximately linear, which means that the creep can be characterized by the compliance function $J(t,t')$, representing the strain at age t caused by sustained uniaxial stress applied at age t'. The database consists of four interlinked tables (computer arrays).

Tables 1 and 2 report the time series of the measured values compliance $J(t,t')$ and shrinkage $\varepsilon_{sh}(t)$ at different times of various concretes and various test conditions. For the data of each time series, Column 0 gives the counter, Column 1 the file name, Column 2 the duration of loading $t - t'$ (labeled tt′) or the duration of drying $t - t_0$ (labeled tt0) in days, and Column 3 the measured values compliance $J(t,t')$ (labelled Jcreep) or shrinkage $\varepsilon_{sh}(t)$ given as microstrains. The table for compliance has 11,821 lines, one for each data point, and the table for shrinkage has 8326 lines.

Table 1—Examples of data points for compliance

ID	File	tt′	Jcreep
1	c_001_01	0	34.4
2	c_001_01	40	57
3	c_001_01	161	83
4	c_001_01	241	92
5	c_001_01	300	96
6	c_001_01	700	111
7	c_001_01	900	112

Table 2—Examples of data points for shrinkage

ID	File	tt0	Shrinkage
1	e_005_01	13	–230
2	e_005_01	25	–395
3	e_005_01	59	–625
4	e_005_01	90	–740
5	e_005_01	577	–920
6	e_005_01	665	–900
7	e_005_01	667	–925

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Table 3 for compliance and the Table 4 for shrinkage give, for each test number, the corresponding information on the type of concrete and the test conditions. The table for creep has 621 lines, one for each creep test, and the table for shrinkage has 490 lines.

The columns of each of these tables (Tables 1 to 4) have the following meanings:

Column 0: ID (number of row).

1. Test number.
2. Name of the experimenter(s), that is, author(s) of the article.
3. The water-cement ratio (wc) by weight.
4. The aggregate-cement ratio (ac) by weight.
5. Cement content (c) without additives, in kg/m^3.
6. Cement type (cCEB) according to CEB Model Code (SL, N, R, RS).
7. Silica fume content (SiO_2) in percent of cement weight.
8. Fly ash content in percent of cement weight.
9. Water reducer (WR) content in percent of cement weight.
10. Retarder (Re) content in percent of cement weight.
11. Content of air-entraining agent (AEA) in percent of cement weight.
12. Mean compressive strength $\bar{f}_c$ (fc28) of concrete at 28 days of age, in MPa (for standard cylinders or converted from cube tests).
13. Modulus of elasticity E (E28) at 28 days of age, in MPa (which generally does not correspond to initial deformation in creep test[11]).
14. Size and shape (Geometry) of specimens: P is a square prism, length times height, in mm; C is a solid cylinder, diameter times height, in mm; HC is a hollow cylinder, diameter1/diameter2 times height, in mm; S is a slab, length times length times height, in mm; and CU is a cube, side in mm.
15. Effective thickness D of specimen (2VS), that is, 2 × (specimen volume)/(surface exposed to environment), in mm.
16. Environmental humidity (H0) of specimen preconditioning, in percent (if unsealed).
17. Age t' at loading, or age t_0 (or t0) at the beginning of environmental exposure, in days.
18. Temperature (T), in °C.
19. Type of heating (Heat), if any.
20. Environmental relative humidity (H) in percent during the test (99 means a sealed specimen, 100 means storage in water).
21. Stress level = stress/(compressive strength) at the beginning of loading (Sigfc).
22. Sustained stress during the test, σ, in MPa (Sigma).
23. Location or geographical region of test.
24. Year of test or year of publication.
25. File name.

Tables 1 to 4 show examples of several lines of each table.

It must be admitted that many of the tests in the database did not use the test procedure that is today considered optimal.[14] Nevertheless, the results of these tests are valuable and there is no better substitute for them. Also, many tests in the present database were conducted on old types of concrete not in use today. These tests, however, still give useful information on the relative increase of creep and shrinkage over long times, and their percentage in the present database is lower than in the previous databases.

Table 3—Examples of information on creep tests—right part

2VS	H0	t'	T	Heat	H	Sigfc	Sigma	Region	Year	File
100	47.5	60	21.5	None	47.5	0.176	5.89	B	1936	c_001_01
100	47.5	60	21.5	None	47.5	0.234	7.85	B	1936	c_001_02
100	100	60	19	None	100	0.176	5.89	B	1936	c_001_03
100	100	60	19	None	100	0.234	7.85	B	1936	c_001_04
100	67.5	60	20.5	None	67.5	0.176	5.89	B	1936	c_001_05
100	100	60	21.5	None	47.5	0.176	5.89	B	1936	c_001_06
76	99	28	21	None	99	0.155	3.45	U.S.	1953	c_002_01
76	99	2	21	None	99	0.031	0.69	U.S.	1953	c_002_02

Unbiased use of database

Were it possible to construct the database according to the proper statistical design of experiment, the data distribution would be completely different. Unfortunately, whereas the main interest for design is the creep loading with a duration of several decades, most of the data are crowded into short load durations, into short drying times, and also into short ages at loading. Likewise, they are crowded into small thicknesses, and those for thicknesses approaching 1 m (3.281 ft) are just a few. Another problem is that the conditional local coefficient of variation of compliance data shows them to be strongly heteroscedastic. Therefore, in its raw form, the database is unsuitable for statistical regression.

Table 3(cont.)—Examples of information on creep tests—left part

ID	Test no.	Author	w/c	a/c	c	cCEB	SiO_2	Fly ash	WR	Re	AEA	fc28	E28	Geometry
1	1	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
2	2	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
3	3	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
4	4	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
5	5	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
6	6	Dutron	0.56	6.46	289	R	0	0	0	0	0	28.4	—	P 100 x 400
7	1	Hanson	0.58	5.624	346	SL	0	0	0	0	0	22.3	—	C 152 x 660
8	2	Hanson	0.56	6.14	320	SL	0	0	0	0	0	34.3	—	C 152 x 406

Table 4—Examples of information on shrinkage tests—left part

ID	Test no.	Author	w/c	a/c	c	cCEB	SiO_2	Fly ash	WR	Re	AEA	fc28	E28	Geometry
1	1	Troxel	0.59	5.669	320	R	0	0	0	0	0	16.5	20,000	C 102 x 356
2	2	Troxel	0.59	5.669	320	R	0	0	0	0	0	16.5	20,000	C 102 x 356
3	3	Troxel	0.59	5.669	320	R	0	0	0	0	0	16.5	20,000	C 102 x 356
4	4	Troxel	0.59	5.669	320	R	0	0	0	0	0	16.5	20,000	C 102 x 356
5	1	England	0.45	6	—	—	—	—	—	—	—	—	—	C 114 x 305
6	2	England	0.45	6	—	—	—	—	—	—	—	—	—	C 114 x 305

Consequently, the statistics of the deviations of some prediction model from the database values must be based on a proper statistical method that compensates for the bias of data. A method of minimized bias, representing a refinement of the method introduced in References 1 through 3, has been presented in References 15 and 16. That study gives examples of using the new database and also illustrates that, if the bias of the database is not compensated for, false conclusions inevitably result.

Table 4(cont.)—Examples of information on shrinkage tests—right part

2VS	H0	t0	T	H	Region	Year	File
51	99	28	21	50	U.S.	1958	e_005_01
51	99	28	21	70	U.S.	1958	e_005_02
51	99	28	21	99	U.S.	1958	e_005_03
51	99	28	21	100	U.S.	1958	e_005_04
57	90	10	20	99	GB	1962	e_009_01
57	90	10	50	99	GB	1962	e_009_02

Fruitful directions for future improvement of the database

To provide the most valuable enhancements of the present database, future testing should strengthen the database regions with little or no data and expand it to provide further kinds of data. In particular:

1. All the future testing of shrinkage and creep at drying should be accompanied by measurements of simultaneous loss of water (that is, weight loss) during the test and also upon heating at the end of test[11] (these simple additional measurements make possible a great improvement of long-time predictions by a simple calculation; refer to the Shrinkage Updating section and Fig. 4 in Reference 11; also the RILEM recommendation,[14] and the confirmation of effectiveness in Reference 10);
2. More tests of modern high-performance concretes and various special concretes are needed;
3. Future tests should extend to longer test durations, and should also include higher ages at loading and thicker specimens;
4. More tests are needed to document the effects of temperature and varying or cyclic environmental conditions; and
5. To reach understanding of the effect of composition, companion tests of the hardened cement paste and of concretes with various aggregate percentages and granulometry are desirable.

CLOSING COMMENT

Accessibility and adoption of a unified database incorporating test data from the entire world may help to unify design codes and standard practices in various countries and to mitigate durability problems.

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