Comprehensive Database on Concrete Creep and Shrinkage

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Abstract: As a sequel to the first large database created at Northwestern University in 1978, the 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 contained 518 creep tests and 426 shrinkage tests. The new 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 website *http://iti.northwestern.edu*.

Evolution of Databases

A vast number of creep and shrinkage experiments have been carried out around the world since the phenomenon of concrete creep has been discovered by W.K. Hatt at Purdue University in 1907. The first comprehensive database, comprising about 400 creep tests and about 300 shrinkage tests, was compiled 30 years ago at Northwestern University [1], mostly from American and European sources. In collaboration with CEB, begun at the 1980 Rüsch Workshop [2], this database was slightly expanded by an ACI-209 subcommittee chaired by L. Panula. A further expansion was undertaken by H. Müller in RILEM committee TC-107 chaired by Bažant. It led to what became known as the RILEM database [3, 4, 5], which contained 518 creep tests and 426 shrinkage tests.

Presented here is a significantly enlarged database, named NU-ITI database [6], 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 [7, 8]. The sources of all the data are given in references [1, 7, 8, 9, 10, 14–103].

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 can be downloaded freely [6], will help development of more realistic prediction models. It can also be used for reevaluation, recalibration and mutual comparisons and of the existing creep and shrinkage prediction models, e.g. [1, 3, 9, 10, 11].

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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 is on stress is approximately linear, which means that the creep can be characterized by the compliance function $J(t, t_0)$, representing the strain at age t caused by sustained uniaxial stress applied at age t_0. The database consists of four interlinked tables (computer arrays).

The first two tables report the time series of the measured values compliance $J(t, t')$ and shrinkage $\epsilon_{sh}(t)$ at different times, for various concretes and various test conditions (Fig. 1). For the data of each time series, column 0 gives the counter, column 1 the file name, column 2 the duration of loading $t - t'$ (labelled tt') or the duration of drying $t - t_0$ (labelled tt0) in days, and column 3 the measured values compliance $J(t, t')$ (labelled Jcreep) or shrinkage $\epsilon_{sh}(t)$. The table for compliance has 11821 lines, one for each data point, and the table for shrinkage has 8326 lines.

The third table for compliance, and the fourth table for shrinkage, give, for each test number, the corresponding information on the type of concrete and the test conditions (Fig. 1). 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 (Fig. 1) have the following meanings:

Column 0: ID (number of row).
1: Test number (TestNo).
2: Name of the experimenter(s), i.e., 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 % of cement weight.
8: Fly ash content in % of cement weight.
9: Water reducer (WR) content in % of cement weight.
10: Retarder (Re) content in % of cement weight.
11: Content of air entraining agent (AEA) in % 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 [9]).
14: Size and shape (Geometry) of specimens: P = square prism, length × height, in mm; C = solid cylinder, diameter × height in mm; HC = hollow cylinder, diameter1/ diameter2 × height in mm; S = slab, length × length × height in mm; CU = cube, side in mm.
15: Effective thickness D of specimen (2VS), i.e. 2 × (specimen volume)/(surface exposed to environment), in mm.
16: Environmental humidity (H0) of specimen preconditioning, in % (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 % 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.

Fig. 1 shows 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 [12]. 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. However, these tests 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.

Unbiased Use of the Database

Were it possible to construct the database according to the proper statistical design of experiment, the data distribution would be completely different. Unfortunately, while the main interest for design is the creep loading with a duration of several decades of years, 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 are just a few. In its raw form, the database is unsuitable for statistical regression because the conditional coefficient of variation of compliance data shows them to be strongly heteroscedastic. Therefore, 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. Such an unbiased method, representing a refinement of the method introduced in [1], has been presented in [13]. In that study it is also illustrated that, if the bias of the database is not compensated for, false conclusions inevitably result.

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 lead to mitigation of durability problems.

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List of Figures

Table 1. Data Points for Compliance

ID	File	tt'	Jcreep
1	c_001_0	0	34.4
2	c_001_0	40	57
3	c_001_0	161	83
4	c_001_0	241	92
5	c_001_0	300	96
6	c_001_0	700	111
7	c_001_0	900	112

Table 2. Data Points for Shrinkage

ID	File	tt0	shrinkage
1	e_005_0	13	-230
2	e_005_0	25	-395
3	e_005_0	59	-625
4	e_005_0	90	-740
5	e_005_0	577	-920
6	e_005_0	665	-900
7	e_005_0	667	-925

Table 3. Information on Creep Tests – Left Part

ID	TestNo	Author	wc	ac	c	cCEB	SiO2	FlyAsh	WR	Re	AEA	fc28	E28	Geometry
1	1	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
2	2	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
3	3	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
4	4	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
5	5	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
6	6	Dutron [1]	0.6	6.46	289	R	0	0	0	0	0	28.4		P 100x400
7	1	Hanson [2]	0.6	5.624	346	SL	0	0	0	0	0	22.3		C 152x660
8	2	Hanson [2]	0.6	6.14	320	SL	0	0	0	0	0	34.3		C 152x406

Continued – 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_0
100	47.5	60	21.5	none	47.5	0.234	7.85	B	1936	c_001_0
100	100	60	19	none	100	0.176	5.89	B	1936	c_001_0
100	100	60	19	none	100	0.234	7.85	B	1936	c_001_0
100	67.5	60	20.5	none	67.5	0.176	5.89	B	1936	c_001_0
100	100	60	21.5	none	47.5	0.176	5.89	B	1936	c_001_0
76	99	28	21	none	99	0.155	3.45	USA	1953	c_002_0
76	99	2	21	none	99	0.031	0.69	USA	1953	c_002_0

Table 4. Information on Shrinkage Tests – Left Part

ID	TestNo	Author	wc	ac	c	cCEB	SiO2	FlyAsh	WR	Re	AEA	fc28	E28	Geometry
1	1	Troxel [5]	0.6	5.669	320	R	0	0	0	0	0	16.5	20000	C 102x35
2	2	Troxel [5]	0.6	5.669	320	R	0	0	0	0	0	16.5	20000	C 102x35
3	3	Troxel [5]	0.6	5.669	320	R	0	0	0	0	0	16.5	20000	C 102x35
4	4	Troxel [5]	0.6	5.669	320	R	0	0	0	0	0	16.5	20000	C 102x35
5	1	England [9]	0.5	6										C 114x30
6	2	England [9]	0.5	6										C 114x30

Continued – Right Part

2VS	H0	t0	T	H	Region	Year	File
51	99	28	21	50	USA	1958	e_005_0
51	99	28	21	70	USA	1958	e_005_0
51	99	28	21	99	USA	1958	e_005_0
51	99	28	21	100	USA	1958	e_005_0
57	90	10	20	99	GB	1962	e_009_0
57	90	10	50	99	GB	1962	e_009_0

Fig.1

Creep and shrinkage prediction model for analysis and design of concrete structures: Model B3. RILEM Recommendation, Materials and Structures, 28, p.357â€“367 (Errata, 29, p.126). DOI: https://doi.org/10.1007/bf02473152.Â Statistical Justification of Model B4 for Drying and Autogenous Shrinkage of Concrete and Comparisons to Other Models. RILEM Materials and Structures, 48: 797-814. DOI: https://doi.org/10.1617/s11527-014-0516-z. [7] Wendner, R., Hubler, M.H., and BaÅ¾ant, Z. P. (2015). Statistical Justification of Model B4 for Multi-Decade Concrete Creep and Comparisons to Other Models Using Laboratory and Bridge Databases. RILEM Materials and Structures, 48: 815-833. DOI: https://doi.org/10.1617/s11527-014-0486-1.