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PREDICTING CREEP DEFORMATION OF CONCRETE: A COMPARISON OF RESULTS FROM DIFFERENT INVESTIGATIONS

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Abstract

Creep deformation of concrete is often responsible for excessive deflection at service loads which can compromise the performance of elements within a structure. Hence, the realistic prediction of both the magnitude and rate of creep strain is an important requirement of the design process. Although laboratory tests may be undertaken to determine the deformation properties of concrete, these are time-consuming, often expensive and generally not a practical option. Therefore, relatively simple empirically based national design code models are relied upon to predict the magnitude of creep strain.

This paper reviews the accuracy of creep predictions yielded by eight commonly used international “code type” models, all of which do not consider the same material parameters and yield a range of predicted strains, when compared with actual strains measured on a range of concretes in seventeen different investigations.

The models assessed are the: SABS 0100 (1992), BS 8110 (1985), ACI 209 (1992), AS 3600 (1988), CEB-FIP (1970, 1978 and 1990) and the RILEM Model B3 (1995).

The RILEM Model B3 (1995) and CEB-FIP (1978) were found to be the most and least accurate, respectively.

1. Introduction

1.1 The Phenomenon of Creep

Creep is the time dependent increase in strain of a solid body under constant or controlled stress.

Creep strain (at any time) can be divided into a basic creep and a drying creep component. If the concrete is sealed or if there is no moisture exchange between the concrete and the ambient medium, only basic creep occurs. Drying creep is the additional creep experienced when the concrete is allowed to dry while under sustained load. The sum of basic and drying creep is referred to as total creep.

The creep strain at any time, $\varepsilon_c(t)$, is determined as:

$$\varepsilon_c(t) = \varepsilon(t) - \varepsilon_e - \varepsilon_{sh}(t)$$

Where,

$\varepsilon_c(t)$	=	creep strain at any time t;
$\varepsilon(t)$	=	total measured strain at any time t;
ε_e	=	average instantaneous elastic strain recorded immediately after loading;
$\varepsilon_{sh}(t)$	=	drying shrinkage strain at any time t (determined on unloaded specimens).

1.2 The Effects of Creep

Creep of concrete is both a desirable and an undesirable phenomenon. On the one hand it is desirable as it imparts a degree of necessary ductility to the concrete. On the other hand, creep is often responsible for excessive deflections at service loads, which can result in the instability of arch, or shell structures, cracking, creep buckling of long columns and loss of prestress (RILEM Model B3, 1995). Frequently the detrimental results of creep are more damaging to non-load-bearing components associated with the structure, such as window frames, cladding panels and partitions, than they are to the structure itself (Davis and Alexander, 1992). Often, damaged structures are either shut down or undergo extensive repairs long before the end of their intended design life, resulting in significant economic consequences. Creep strain is generally associated with its detrimental effects.

2. The prediction of creep strain

2.1 Accuracy of Estimations

The magnitude of creep, which is required for design purposes, can be estimated at various levels. The choice of level depends on the type of structure and the quality of the data available for the design. In cases where only a rough estimate of the creep is required, which is suitable only for approximate calculations, an estimate can be made on the basis of a few parameters such as relative humidity, age of concrete and member dimensions. On the other extreme, in the case of deformation-sensitive structures, estimates are based on comprehensive laboratory testing and mathematical and computer analyses. Ideally, a compromise has to be sought between the simplicity of the prediction procedure and the accuracy of results obtained.

At the design stage, when often the only information available is the compressive strength of the concrete, the general environmental conditions of exposure and the member sizes, the designer has to rely on a design code model to estimate the extent and rate of creep strains. Given their nature, these models are not able to account for the full range of factors that are known to influence the creep deformation in concrete and simplicity of application is usually demanded by the users of the model. Nevertheless, the users of the model require some confidence as to the accuracy of the predictions as well as the range of error of the prediction.

2.2 Code Type Models Assessed

This paper assesses the accuracy of eight commonly used international code type models that are used to predict creep strains without the need for creep tests. These empirically based models, which vary widely in their techniques, require certain intrinsic and/or extrinsic variables, such as mix proportions, material properties and age of loading as input. The models considered are listed in Table 1, which also shows the factors accounted for by each model.

With the exception of the RILEM Model B3 (1995), the models considered derive from structural design codes of practice and express creep strain as the product of the elastic deformation of the concrete (at the time of loading) and the creep coefficient.

The creep coefficient accounts for the effect of one or more intrinsic and/or extrinsic variables. The RILEM Model B3 (1995) is, by relative comparison, more complex than the design code models and has a different structure as it enables the calculation of separate compliance functions for the basic creep and drying creep (in excess of the basic creep). All the methods employ one or more monograms and/or algebraic expressions to determine the creep strain.

The SABS 0100 (1992) code has adopted the BS 8110 (1985) method for predicting creep. However, the SABS method uses specific values for the elastic modulus of the aggregate type, as determined by Alexander and Davis (1992).

3. Comparison of results from different investigations

3.1 Data Sources

The accuracy of the abovementioned code type prediction methods was assessed by comparing the accuracy of predictions from separate research projects by Ballim (2000), Fanourakis (1998), Gilbert (1988), McDonald et al., (1988), Rogowsky and Soleymani (2003) and the RILEM Data Bank.

In each of these investigations experimental data was compared to the values predicted at the corresponding ages by the different models.

Ballim (2000) considered the accuracy of the SABS 0100 (1992), CEB-FIP (1998) and RILEM Model B3 when applied to concretes made with aggregates specifically deriving from the Gauteng region of South Africa. This investigation comprised 720 data points.

The work of Fanourakis (1998) comprised the measurement of creep on concretes of different strength grades made with three commonly used South African aggregate types. This investigation, which entailed 540 creep measurements, assessed the accuracy of predictions made by all of the eight code type models listed in Table 1.

The accuracy of predictions made by the ACI 209 (1978), CEB–FIP (1970) and CEB-FIP (1978) was included in the investigation by Gilbert (1988).

McDonald et al. (1988) assessed the accuracy of a number of creep prediction methods including the CEB-FIP (1978) and AS 3600 (1988) methods. This investigation included over 1000 data points from 29 creep tests (conducted on Australian concretes) from five different sources.

The recent research by Rogowsky and Soleymani (2003) assessed the accuracy of two Canadian models as well as the CEB-FIP 1978 and 1990 models when applied to specimens at three different loading ages. This investigation was based on approximately 1000 data points.

In the case of the RILEM Model B3 (1995), comparisons were made between total creep predictions for the RILEM Model B3 (1995), the ACI 209 (1992) and the CEB-FIP (1990) methods (RILEM Model B3, 1995). The data used in these comparisons derived from the RILEM Data Bank, which was compiled by subcommittee 5 of RILEM Committee TC-107 (1995), comprising approximately 15 000 data points from twelve different investigations from laboratories around the world.

Table 1 Summary of Factors Accounted for by Different Prediction Methods

METHOD		SABS 0100 (1992)	BS 8110 (1985)	ACI 209 (1992)	AS 3600 (1988)	CEB – FIP (1970)	CEB - FIP (1978)	CEB – FIP (1990)	RILEM Model B3 (1995)
Intrinsic Factors	Aggregate Type	X							
	A/C Ratio								X
	Air Content			X					
	Cement Content					X			X
	Cement Type					X	X	X	X
	Concrete Density			X	X				
	Fine/Total Aggregate Ratio (Mass)			X					
	Slump			X					
	W/C Ratio					X			X
	Water Content								X
Extrinsic Factors	Age at First Loading	X	X	X	X	X	X	X	X
	Age of Sample								X
	Applied Stress	X	X	X	X	X	X	X	X
	Characteristic Strength at Loading	X	X						
	Cross-section Shape								X
	Curing Conditions								X
	Compressive Strength at 28 Days			X	X	X	X	X	X
	Duration of Load			X	X	X	X	X	X
	Effective Thickness	X	X	X	X	X	X	X	X
	Elastic Modulus at Age of Loading	X	X						X
	Elastic Modulus at 28 Days	X	X	X	X	X	X	X	X
	Relative Humidity	X	X	X	X	X	X	X	X
	Temperature							X	X
	Time Drying Commences								X

3.2 *Analysis*

In order to provide a basis for comparing the creep strains of concretes with different strengths and different applied loads, the results are presented in the form of specific creep (C_c), which is defined as creep strain per unit stress ($C_c = \varepsilon_c(t)/\sigma$).

All comparisons were on the basis of total creep (basic plus drying creep). As this investigation was of a general nature, the specific intrinsic and extrinsic factors and differences in experimental techniques, pertaining to the different investigations, were not compared.

The coefficient of variation of errors (ω_j), as defined by Bazant and Baweja (1995), was used to quantify the extent to which predicted specific creep values at different ages after loading (determined by applying a particular model) deviated from the values measured at the relevant ages on the specimens of a particular concrete mix. The more accurate the prediction, the lower the value of ω_j.

3.3 *Results and Discussion*

The coefficients of variation resulting from the different investigations, for the code type model considered, are given in Table 2. The statistics of the comparisons are summarized in Fig. 1.

The BS 8110 (1985) method was excluded from Fig. 1 as comparative predictions were not found. Referring to Table 2 and Fig. 1, it is evident that the RILEM Model B3, which yielded an overall coefficient (ω_{all}) of 25.9, is the most accurate of the prediction models. Although the AS 3600 (1988) model was, for all intents and purposes, almost as accurate (ω_{all} = 26), the latter analysis was based on the results of two data sources as opposed to fourteen in the former case.

The CEB-FIP (1978) was the least accurate method (ω_{all} = 67.4).

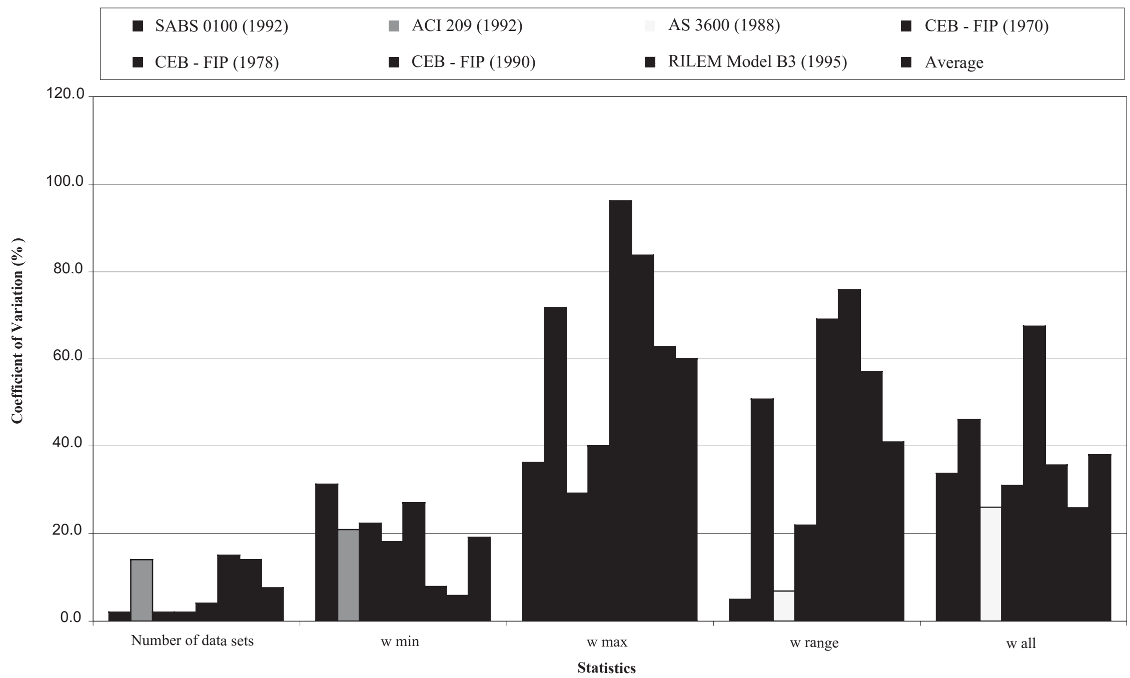

Fig.1 Statistics pertaining to coefficients of variation

Table 2 Coefficients of Variation from Different Investigations

Data Source	SABS 0100 (1992)	BS 8110 (1985)	ACI 209 (1992)	AS 3600 (1988)	CEB - FIP (1970)	CEB - FIP (1978)	CEB - FIP (1990)	RILEM B3 (1995)
Ballim (2000)	36.2							42.5
Fanourakis (1998)	31.3	23.6	50.5	29.2	18.1	96.1	32.2	35.6
Gilbert (1988			32.2		40	27.1		
Hansen and Mattock (1966)*			32.1				11.9	5.8
Hummel et al., (1962)*			46.2				24.6	15.3
Keeton (1965)*			46.3				37.9	31.4
L`Hermite and Mamillan (1970)*			62.5				15.2	20.6
L`Hermite et al., (1965)*			55.8				25.5	14
Maity and Meyers ~~(1970)*~~			45.9				83.7	62.8
McDonald (1975)*			40.4				38.9	10.9
McDonald et al., (1988)			70.4	22.4		72.1		
Mossiossian and Gamble (1972)*			71.7				30.8	11.3
Rogowsky and Soleymani (2003)						54.8	46.2	
Rostasy et al., (1972)*			20.9				14.8	6.5
Russel and Burg (1993)*			41.2				19.1	10.7
Troxell et al., (1958)*			33				7.9	5.9
York et al., (1970)*			42.1				45.1	5.8
Number of data sets	2.0	1.0	14.0	2.0	2.0	4.0	15.0	14.0
ω_{all}	33.8	23.6	48.1	26	31	67.4	36.2	25.9

* Indicates RILEM Data Bank sources

In addition, the lowest coefficient of variation (ω_j = 5.8) was yielded by the RILEM Model B3 in two different investigations.

In view of the fact that at least fourteen data sets were used in the comparisons in the case the RILEM Model B3 (1995), CEB-FIP (1990) and ACI 209 (1992) models, further emphasis is justifiably placed on the accuracy of these models. The overall coefficients of variation (ω_{all}) and minimum coefficient of variations (ω_{min}) increase in the order RILEM Model B3 (1995), CEB-FIP (1990) and ACI 209 (1992).

Furthermore, it is evident from Fig. 1 that the CEB-FIP (1990) model is more accurate than its predecessor, the CEB-FIP (1978) model. However, the CEB-FIP (1970), that is relatively simple in comparison with the 1978 and 1990 models, yields the lowest coefficient of variation. This trend was also evident in the work of Fanourakis (1998).

Further investigation on the accuracy of predictions using the AS 3600 (1988), CEB-FIP (1970) and BS 8110 (1985) methods is proposed in order to determine the accuracy of these methods when applied to more data sets than in the above comparison. This proposed investigation is warranted by the fact that all three of these methods are relatively simple when compared to the RILEM Model B3. This exercise would determine whether the accuracy of the RILEM Model B3 is justified by its relative complexity.

4. Conclusions

This paper considered the accuracy of eight code type creep prediction models.

The RILEM Model B3 appears to provide the most accurate predictions, with an overall coefficient of variation of 25.9. The CEB-FIP (1978) was the least accurate method, yielding an overall coefficient of variation of 67.4.

Further assessment of the accuracy of the AS 3600 (1988), CEB-FIP (1970) and BS 8110 (1985) models, which are significantly simpler in comparison to the RILEM Model B3, is recommended.

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