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Identifying the Significance of Factors Affecting Creep of Concrete: A Probabilistic Analysis of RILEM Database

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Abstract: Modeling creep of concrete has been one of the most challenging problems in concrete. Over the years, research has proven the significance of creep and its ability to influence structural behavior through loss of prestress, violation of serviceability limit states or stress redistribution. Because of this, interest in modeling and simulation of creep has grown significantly. A research program was planned to investigate the significance of different factors affecting creep of concrete. This research investigation is divided into two folds: first, an in-depth study of the RILEM creep database and development of a homogenous database that can be used for blind computational analysis. Second: developing a probabilistic Bayesian screening method that enables identifying the significance of the different factors affecting creep of concrete. The probabilistic analysis revealed a group of interacting parameters that seem to significantly influence creep of concrete.

Keywords: creep, RILEM database, bayesian modeling, probabilistic analysis.

1. Introduction

Concrete is a metastable material that is known to have a significant time-dependent behavior due to its ability to creep under sustained stresses and to shrink because of drying. It is well established in the literature that the time-dependent volume changes of concrete caused by sustained load and moisture loss have a profound influence on concrete structural behavior. The consequences can be summarized in the possibility of excessive long-term deflection of the structural members, wide cracks in the tension members, loss of prestressing force in prestressed concrete elements and redistribution of stresses with time in composite concrete structures. It is therefore necessary for designers and engineers to have accurate methods for predicting creep and shrinkage strains in order to consider them in structural analysis. However, the mechanics of creep and shrinkage in concrete is a complex process that is affected by significant number of variables. This wide variation of creep and shrinkage measurements makes it difficult to develop accurate prediction models. The within-batch coefficient of variation for shrinkage measured on a single mix is about 8%. Therefore, it would be unrealistic to expect any prediction model to be within ±20% for shrinkage. This acceptable variation has to be higher for creep represented by concrete compliance as compliance is not directly measured but calculated by subtracting the shrinkage strain from the total strain, thus creep compliance is prone to further uncertainty propagation. For structures where creep and shrinkage are deemed critical, material testing should be undertaken and long-term behavior can then be extrapolated from experimental observations.[1-8]

Currently, there are many practical and sophisticated models for predicting creep of concrete, most of which are based on tests carried out on normal strength concrete. However, some other models are developed specifically for high strength and high performance concrete.[9-16] Moreover, there were efforts to develop a unified creep and shrinkage prediction model that is valid for both normal and high strength/high performance concrete.[11,17,18] Some researchers used their own data and/or other limited data to develop their prediction models, while others used the whole available database. Most existing models were calibrated using the existing database to improve their performance and accurately simulate creep and shrinkage of concrete.[19-26]

2. Research significance

This paper introduces a new approach using Bayesian analysis to develop a probabilistic screening method to identify the different critical factors affecting creep of concrete and their interaction and to develop a rank order of these factors. The analysis is performed on the RILEM database of concrete creep. The results of the analysis are of great interest for researchers investigating concrete creep and will help them focus on the significant factors in their experimental work. Moreover, the rank order concluded by the analysis provides valuable information for building new robust computational models to predict creep of concrete.

3. RILEM creep database

The time-dependent behavior of reinforced concrete structures

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is influenced by a large number of factors that generally depend upon one or more of the followings: concrete constituent material properties, geometry of the structure, load history and magnitude and the external environmental conditions. The interdependence of these factors creates difficulty in isolating causes and effectively predicting time-dependent behavior of concrete without extensive testing. Therefore, significant amounts of research have been carried out during the last century on examining both creep and shrinkage in concrete laboratories all over the world. These extensive efforts lead to the collection and establishment of a database on the results of available and suitable experimental investigations on creep and shrinkage. This database has been extended and refined under the sponsorship of RILEM and considered as the basis for the derivation and optimization of prediction models.[27] The database provides an insight on investigations by 98 researchers examining different concretes with considerably varying constituent materials, environmental conditions, loading magnitude and time periods. A total of 512 compression creep and 412 shrinkage experimental tests which have been selected to cover the period between 1936 and 1996 are included and reported thereof. The database therefore provides a great opportunity for an overall realization of the time-dependent behavior of concrete. This database is presented in three documents; one document contains background and description of the database followed by an appendix that lists in detail the database on creep and shrinkage testes. The other two documents contain in a tabulated form the full information of creep and shrinkage datasets.

The factors that would affect creep of concrete are generally classified into *extrinsic* and *intrinsic* factors. The extrinsic factors rather than the intrinsic factors are believed to give greater influence on creep of concrete.[28] However, both extrinsic and intrinsic factors have received ample attention in both experimental investigation and modeling.[6] Table 1 provides a list of the most significant factors as reflected in the most widely known existing prediction models.[5,10,11,16] It is worth noting that although some other factors are considerably important, they are not included in most prediction models. These factors include chemical and mineral admixtures, preconditioning relative humidity prior to the beginning of the test (if creep measurements start a few days after drying), compressive strength at testing and creep stress level.

In-depth investigation of the database revealed a few discrepancies and issues that needed to be addressed in order to provide a uniform database that could be used in the subsequent steps of the analysis. To overcome these discrepancies and/or the lack of some reported information, we referred to the original articles reported in the database. However, some information such as concrete composition or material properties was neither reported in the database nor in the original articles. In this case, these datasets were excluded from the current analysis. The following sections provide some insight on some critical issues in the RILEM creep database and how these issues were handled for developing a homogenous database for conducting the probabilistic analysis.

3.1 Concrete strength and modulus of elasticity

Concrete strength is presented in terms of a 28-day mean cylinder strength value for most of the datasets documented in the database. However, occasionally, cube strength instead of cylinder strength was reported. The RILEM database used a conversion factor of 0.836 to transfer cube strength into the equivalent cylinder strength. This conversion factor can obviously be noticed by comparing the strength values given in the separate files provided by RILEM database. Nevertheless, other factors were also used to transfer cube strength for datasets reported by some researchers such as Wischer and Dahms[29] and Brooks and Wainwright.[30] To solve this issue in the current analysis, cube strength was converted into the equivalent cylinder strength using the conversion factors recommended by CEB-FIP MC90.[11]

One more interesting issue in the RILEM database is the absence of reliable data describing the modulus of elasticity of most of creep datasets reported therein.[27] While it is evident from

Table 1 Input factors considered in existing creep prediction models.

		CEB-FIP 90[11]	ACI 209[10]	B3[16]	GL 2000[5]
Intrinsic Factors	Slump, (S)	---	√	---	---
	28-day mean compressive strength, (f_{cm28})	√	---	√	---
	28-day mean modulus of elasticity, (E_{cm28})	√	---	√	√
	Modulus of elasticity at loading, (E_{cmto})	√	---	---	√
	Water-cement ratio, (w/c)	---	---	√	---
	Cement type, (CT)	√	√	√	---
	Cement content, (C)	---	√	√	---
	Aggregate content, (A)	---	√	√	---
Extrinsic Factors	Relative humidity, (RH)	√	√	√	√
	Temperature, (T)	√	√	---	---
	Curing regime, (CR)	---	√	√	---
	Age at the end of moist curing, (t_c)	---	---	√	√
	Age at loading, (t_o)	√	√	√	√
	Specimen size, (2A/u)	√	√	√	√
	Specimen shape, (SS)	---	---	√	---
	Creep stress ratio, (σ/f_{cmto})	√	---	---	---

√ indicates that the factor was considered in the model the literature that a relationship exists between creep and modulus of elasticity,[5,11,31-33] the absence of elastic modulus data hinders analytical realization of the level of correlation between creep and modulus of elasticity. Therefore, in the current analysis, the modulus of elasticity was expressed as a function of the compressive strength using the relationship recommended by CEB-FIP MC90.[11] Moreover, it has been recognized in the literature[34-35] that the modulus of elasticity, in spite of being correlated to compressive strength, is much more sensitive to factors affecting creep and shrinkage such as humidity, curing time and curing periods compared with the compressive strength. Including the modulus of elasticity and compressive strength independently in the analysis is therefore necessary. This approach has been adopted by other prediction models[5,11,16] as presented in Table 1. Although the compressive strength and modulus of elasticity at time of loading are important factors,[34,35] they were not included in the analysis as their values are not available in the RILEM database.[27] Instead, the values of a 28-day compressive strength and corresponding modulus of elasticity were considered.

3.2 Cement type and supplementary cementing materials

Cement was expressed by weight per unit concrete volume. A numerical representation of the cement type is important if its significance on concrete creep is to be examined. Cement type was represented according to ASTM classification. A simple representation of the Portland cement type using the total C_3S and C_3A content in the cement was suggested by Adam et al.[36] and adopted here. The use of this representation might be attributed to the fact that C_3S and C_3A represent the two most active components in Portland cement that might significantly contribute to concrete creep. The adopted numerical values of C_3S and C_3A components are 0.67, 0.52, and 0.70 for cement types I, II, and III respectively.[37] It was noticed that a relatively few data are reported in the RILEM database concerning creep of concrete containing supplementary cementing materials (SCM) such as fly ash and silica fume. In spite of this, the inclusion of SCM was taken into consideration regardless of the type and amount of the SCM. The significance of SCM was achieved through using a binary representation of SCM existence in the concrete mix. The value of 1 was used to express the existence of SCM and 0 was used if there was no SCM in the concrete. Water-cement ratio (w/c), as reported in RILEM database,[27] was considered rather than water-cementitious materials ratio.

3.3 Relative humidity

The ambient relative humidity (RH) of water curing under loading is expressed as $RH = 100$, while the sealed condition is expressed as $RH = 101$. The age of concrete at the end of the moist curing period (t_c) was considered to account for the preconditioning humidity (RH_0) prior to the beginning of the creep test (when the age at the end of moist curing (t_c) differs from the age at loading (t_0)). Hence, the preconditioning humidity (RH_0) was considered only in the case if the age at the end of moist curing was less than the age at the application of load.

3.4 Other factors

The specimen size effect was considered and is expressed in terms of twice the cross section area divided by its perimeter ($2A/u$). Furthermore, the level of creep stress is expressed as the ratio of the initial creep stress to the 28-day compressive strength of concrete (σ/f_{cm28}). Finally, we considered the creep test duration (t-t_0) as a parameter affecting creep. Moreover, only creep under normal ambient temperature (19~23°C) is considered here. Due to the scarcity of information on the chemical admixture type and dose in concrete, chemical admixtures were not considered in the analysis. Table 2 presents factors considered in analysis and their ranges in the RILEM database.

3.5 Discrepancies

An in-depth look at the RILEM database unveiled discrepancies in some of the data reported in the RILEM database.[27] For example, concrete age at the end of moist curing (t_c) was reported similar to concrete age at loading (t_0) by one of the RILEM database documents.[27] However, in another database document[27] it was reported that (t_c) is different from (t_0). This contradiction was solved after referring to the original article by Weil.[38] Moreover, the RH of creep tests by Hummel et al.[39] is missing in one of the database

Table 2 Factors considered in the current analysis and their current range.

#	Factor	Range
1	28-day mean compressive strength, (f_{cm28}) - (MPa)	11 ~ 120
2	28-day mean modulus of elasticity, (E_{cm28}) - (MPa)	22,000 ~ 49,000
3	Water-cement ratio, (w/c)	0.24 ~ 0.80
4	Cement type, (CT)	ASTM types I, II, III
5	Cement content, (C) - (kg/m^3)	247 ~ 725
6	Aggregate-cement ratio, (a/c)	2.08 ~ 8.32
7	Supplementary cementing materials, (SCM)	1: exists & 0: does not exists
8	Relative humidity, (RH) - %	20 ~ 101
9	Age at the end of moist curing, (t_c) - (day)	0.4 ~ 90
10	Age at loading, (t_0) - (day)	0.5 ~ 3,300
11	Specimen size, ($2A/u$) - (mm)	35 ~ 305
12	Preconditioning relative humidity, (RH_0) - %	35 ~ 101
13	Creep stress to strength ratio, (σ/f_{cm28})	0.02 ~ 0.72
14	Duration of loading, (t-t_0) - (day)	90 ~ 8,700

documents[27] but is provided in both the original work[39] and by another document in the database.[27] Likewise, the cement content of mixture L in work by Lambotte and Mommens[40] was given as 400 kg/m^3 in one of the database documents,[27] while the cement content of this same mixture was tabulated as 450 kg/m^3 in another document of RILEM database.[27] This discrepancy was corrected after referring to the original article by Lambotte and Momments.[40] Furthermore, it is mentioned in one database document[27] that Wesche et al.[41] used cement type I for Mixture C, while in the other documents and the original work, it is listed as type III cement.[27,41] Moreover, the cement content is missing in both RILEM database and the original articles by Ngab et al.[42] and Brooks.[43] Data by Ngab et al.[42] and Brook[43] was therefore excluded from the analysis.

Discrepancies on creep test details and conditions were also found. The initial creep stress/strength ratio of creep tests carried out by Brooks and Wainwright[30] is provided as 0.25 of cylinder strength in the database[27] while reported less than 0.25 elsewhere.[30] Discrepancies in reported RH values and the absence of concrete composition of creep tests by Espion and Wastiels[44] necessitated excluding this work from analysis. Significant discrepancy between the compressive strength, curing regime and time and value of creep stress in data by Russel and Larson[45] and that in the RILEM database required fixing this discrepancy. Discrepancies also within the RILEM database documents for the tests by Shritharan[46] in cement content resulted in correcting these discrepancies of the datasets. For creep data by Burg and Ost,[47] the RILEM database documents[27] have inconsistency for the moist curing time period and the level of applied stress. Similar contradictions in the work by Han and Walraven[48] were observed in the RILEM database[27] documents in addition to discrepancies related to RH conditions and concrete composition. The discrepancies of datasets by Burg and Ost[47] and Han and Walraven[48] were solved and corrected after referring to the original articles.[47,48] The preconditioning humidity (RH_0) was reported[27] as sealed condition for experiments by Summer and Scharge,[49] while in another RILEM document[27] $RH_0 = 65\%$. Furthermore, contradiction in moist curing time periods, silica fume content and concrete age at loading in two RILEM database documents dictated correction of that contradiction in the creep dataset by Summer and Scharge.[49] Finally, RILEM database[27] for Chern and Chang[50] reported creep specimens were moist cured and $w/c = 0.311$, but in another RILEM database document[27] $RH_0 = 50\%$ and $w/c = 0.28$. Referring to the original article by Chern and Chang[50], It was found that specimens were cured in a moist room until day of testing and $w/c = 0.311$. This dataset was corrected based on the original research article[50]. Based on the above considerations, some datasets from the RILEM creep database were excluded to avoid inconsistency. Moreover, datasets representing creep under normal ambient temperature (19~23°C) only were considered here. Therefore, the probabilistic analysis considered experimental results of 26 researchers including a total of 271 creep tests and 4700 datasets. The datasets considered in the analysis are listed in Table A1.

4. Analytical method

The probabilistic analysis considered the relationship of concrete compliance function $J(t,t_0)$ defined using Eq. (1) with the 14 factors (Table 2) that cover both intrinsic and extrinsic factors.

$$J(t, t_0) = \frac{1}{\sigma(t_0)}[\varepsilon_{el}(t_0) + \varepsilon_{cr}(t, t_0)] \tag{1}$$

Where $\sigma(t_0)$ is the sustained creep stress, $\varepsilon_{el}(t_0)$ is the instantaneous elastic strain, and $\varepsilon_{cr}(t,t_0)$ is the creep strain between time of load application t_0 and time of evaluating creep t. The method of analysis is based on Bayes Theory of conditional probability. This method is applied to the RILEM database to rank order the fourteen (14) factors identified to affect concrete creep. Equal importance was assumed *a priori* for all factors. The proposed method is a Bayesian model screening process that is performed by identifying the most probable polynomial models to describe a phenomenon and thus utilizes these models to estimate the most important factors that influence the phenomenon of interest.[51] Bayesian model screening is implemented using a Markov Chain Monte Carlo (MCMC) algorithm which steps through the developed polynomial models using Gibbs sampling[52] in a search for the most likely model to relate the data describing the phenomenon of interest. To analyze the RILEM creep database,[27] a polynomial model is used to describe concrete compliance as a function of its main factors having the general form in Eq. (2).

$$J = M(\psi ;x) \tag{2}$$

This model represents a single iteration in the MCMC analysis and it relates concrete compliance J as a function of an unspecified number of coefficients ψ and the creep effects x that are functions of "n" creep factors denoted: f. We define the creep effects x as a linear or linear interaction effect of the creep factors: f where a linear effect describes when $x_i = f_i$ and linear interaction effect is described by $x_i = f_i \times f_j$. The consideration of linear interaction effects is essential to identify the significance of correlated factors on creep. The "$n = 14$" creep factors lead to a total of "$m = 105$" effects incorporating linear and linear interaction effects. The m effects result in $2^m = 2^{105} = 4.06 \times 10^{31}$ possible polynomial models that can be used to describe concrete compliance. As evaluating this very large number of polynomial models is computationally very expensive, we implement MCMC technique and Gibbs sampling method to step through a randomly selected subset of possible polynomial models. At each run the method evaluates the goodness to fit (the likelihood) of one model with $m \le 105$ effects at a time. The selected model can be described by Eq. (3) where the coefficients can be defined using method of least squares[53] to fit the database as in Eq. (4).

$$J = \sum_{k=1\ldots m} x_k \psi_k = x^T \psi \tag{3}$$

$$\psi = (X^T X)^{-1} X^T J \tag{4}$$

J is the vector of N concrete compliance observations and the matrix X consists of the m effects corresponding to the N observations as

$$J = \begin{Bmatrix} J_1 \\ J_2 \\ \vdots \\ J_N \end{Bmatrix}; \quad X = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,m} \\ x_{2,1} & x_{2,2} & & x_{2,m} \\ \vdots & & & \\ x_{N,1} & x_{N,2} & & x_{N,m} \end{bmatrix} \qquad (5)$$

The process is similar to a typical least square analysis for a polynomial fit,[53] however, the objective is not to define the polynomial fit function but to identify the factors contributing to this polynomial function. By considering N datasets the likelihood of the j^{th} model (L_j) to predict concrete compliance is determined by Eq. (6) after Kerschen et al.[54] This likelihood is then used to determine the posterior probability of each coefficient ψ and therefore its associate factor as in Eq. (7) using Bayes theorem.

$$L_j(J|\psi) = e^{\sum_{k=1\ldots N}(J_k - x_k^T\psi)^2} \qquad (6)$$

$$P(\psi|J) = \frac{L(J|\psi)P(\psi)}{P(J)} \qquad (7)$$

The probability of the response data $P(J)$ is assumed constant as all the factors are assumed of equal importance *a priori*. By implementing Gibbs sampling, the process is randomized and a significantly large number of possible models is evaluated and their posterior probabilities are calculated. The model with the highest posterior probability is considered the best model to predict concrete compliance given the selected effects. The whole process is repeated for 10,000 iterations and the marginal probability of the factors contributing to the best model is determined based on the frequency of appearance of these factors across the polynomial models. A threshold probability of 95% was used to establish the limit beyond which a single or dual (linear interaction) effect of factors was assumed significant. The marginal probability of the significant factor(s) is then used to rank order those factors affecting creep of concrete. A flow chart summarizing the method is shown in Fig. 1.

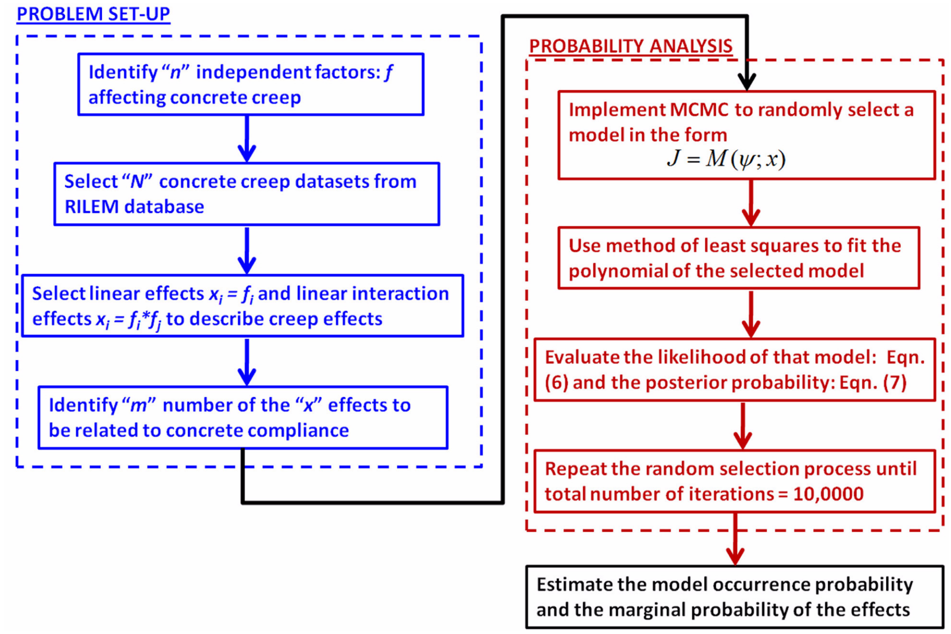

Fig. 1 Flow chart describing the analytical method to evaluate the significance of factors affecting creep.

5. Results and discussion

The screening analysis examined fourteen (14) factors affecting concrete compliance leading to one hundred and five (105) single and dual combinations of factors. The analysis identified twenty six single and dual combinations as significant factors influencing concrete compliance**.** Fig. 2 shows the rank order of the fourteen (14) individual factors affecting creep of concrete. The top five individual factors affecting creep of concrete and their associated coefficients are presented in Table 3. These top five individual factors include the existence of supplementary cementing materials, the duration of loading, the curing time period, the RH and the 28-day compressive strength of concrete. The five individual factors had marginal probabilities above 95%. Four of the five main single parameters (second to fifth) have been identified by many researchers from experimental investigations before as the most significant factors affecting creep.[6]

The analysis also identified twenty one (21) possible dual combinations of factors to also be significant. The dual combinations of factors are listed in Table 4. The twenty one (21) dual combinations of parameters reveal a few interesting relationships in the concrete creep database and how concrete compliance is related to these factors. Nine of the top ten dual combinations have marginal probabilities of 100% indicating their major significance on creep of concrete. The top ten combinations include combinations between cement type, size effect, curing period, duration of loading, supplementary cementing materials existence, age of loading, RH, modulus of elasticity and stress-to-strength ratio.

The analysis confirms the findings of other investigations with the superior role of the duration of loading, the curing time period, the RH and concrete compressive strength on creep of concrete. However, it was surprising that the supplementary cementing materials (SCM) existence showed as a significant individual factor with a very high marginal probability ($\approx$ 100%). The existence

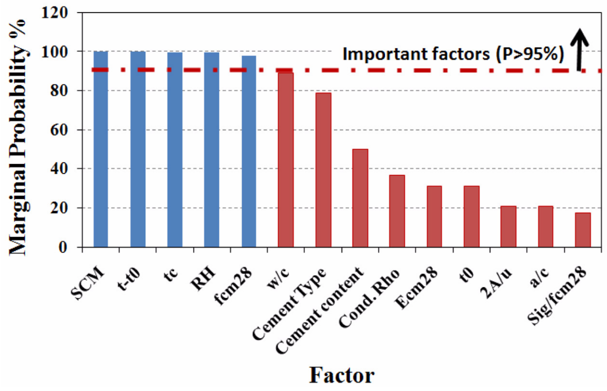

Fig. 2 Rank order of the fourteen (14) individual factors affecting creep of concrete.

Table 3 Five (5) single factors identified as probabilistically significant in affecting concrete compliance based on analysis of RILEM creep database.

Factor	Coefficient	Probability
Supplementary cementing materials	−57.0	100.0
Duration of loading	36.5	99.9
Curing period	−38.0	99.7
Relative Humidity	−39.0	99.6
28 day compressive strength	−35.0	98.0

of SCM also showed to be a significant factor in the dual combinations with duration of loading and curing periods. This implies that within the group of data in the RILEM database that has SCM incorporated in concrete mixtures, it is evident that concrete compliance and thus concrete creep cannot accurately be predicted if the effect of SCM is neglected. It is also interesting to note that both the individual factors and the dual combination factors did not show the aggregate content to have a significant effect on creep of concrete. These results contradict with the ACI 209R-92 model[10] which considers aggregate content to predict concrete creep. However, it agrees with the CEB-FIP MC90[11]-model which does not consider the aggregate content to predict concrete compliance.[9]

Finally, the analysis revealed interesting and controversial results showing that some major factors used in many creep prediction models to be insignificant for predicting concrete compliance. For instance, the model showed that *w/c* ratio, cement type, cement content, the drying condition prior to loading, Young's modulus of elasticity, age at loading, the surface/volume ratio and the stress level to be individually important in modeling creep. This means these factors might affect creep but in the co-existence of other factors. This became apparent when the dual factors were analyzed. For example, cement type showed to make a major creep effect when considered with the curing period, the size effect and duration of loading. Furthermore, the age of loading apparently becomes important when combined with the size effect (Table 4, Comb 5) which can be interpreted as the significance of high drying due to size effect on increasing creep due to loading at young age. Moreover, the stress to strength ratio also seems important when the concrete has a relatively low modulus of elasticity (Table 4, Comb 10). It is interesting that all top 10 dual combinations of factors showed to be highly significant with very high marginal probability (≈ 100%) which indicates their significant effect on concrete creep when combined. It is evident from the analysis that there are many factors affecting concrete creep and accurate predictions require careful understanding of all these individual fac-

Table 4 Twenty one (21) dual factor combinations identified as probabilistically significant in affecting concrete compliance based on analysis of RILEM database.

Combination #	Dual factors	Coefficient	Probability
Comb 1	Cement type & size effect	24.9	100.0
Comb 2	Cement type & curing period	32.8	100.0
Comb 3	Cement type & duration of loading	−30.5	100.0
Comb 4	Supplementary cementing materials & duration of loading	−56.0	100.0
Comb 5	Size effect & age of loading	59.2	100.0
Comb 6	Curing period & duration of loading	−37.0	100.0
Comb 7	Age of loading & duration of loading	−42.0	100.0
Comb 8	Relative humidity & duration of loading	−27.0	100.0
Comb 9	Modulus of elasticity & duration of loading	44.4	100.0
Comb 10	Modulus of elasticity & stress/strength ratio	−40.0	99.9
Comb 11	Curing period & relative humidity	−27.0	99.7
Comb 12	Water/cement ratio & size effect	−28.0	99.4
Comb 13	Aggregate cement ratio & age of loading	35.4	99.3
Comb 14	Size effect & curing period	−33.0	99.2
Comb 15	Curing period & age of loading	34.3	99.0
Comb 16	Supplementary cementing materials & curing period	22.2	98.8
Comb 17	Modulus of elasticity & size effect	−36.0	98.5
Comb 18	Aggregate cement ratio & cement content	24.6	98.4
Comb 19	Modulus of elasticity & preconditioning relative humidity	28.1	97.6
Comb 20	Modulus of elasticity & curing period	−33.0	97.1
Comb 21	Cement content & compressive strength	31.1	96.3

tors and their interaction. The results of this analysis can be used to establish accurate holistic models for predicting creep of concrete by considering all individual and dual factors. Further research is warranted to examine the minimum factors needed to produce acceptable creep models with limited computational expense.

6. Conclusions

A Bayesian screening model was applied using Markov Chain Monte Carlo analysis to examine the most significant factors affecting creep of concrete. The probabilistic analysis considered experimental results of 26 researchers including a total of 271 creep tests and 4700 datasets. The analysis examined fourteen (14) factors affecting concrete compliance and thus concrete creep leading to one hundred and five (105) single and dual combinations of factors. The analysis identified twenty six single and dual combinations as significant factors influencing concrete creep. The top five individual factors include the existence of supplementary cementing materials, the duration of loading, the curing time period, the RH and the 28-day compressive strength of concrete. Moreover, the analysis also identified twenty one (21) possible dual combinations of factors to also be significant. Ten of the twenty one dual combinations have marginal probabilities of approximately 100% indicating their major significance on creep of concrete. The analysis also showed a major effect of cement type, duration of loading and modulus of elasticity on creep of concrete for being common factors in many of the dual interaction combinations. The results of this analysis can be used to build accurate computational models to predict creep of concrete by considering the major factors identified in the analysis.

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Appendix

Table A1: Details of the selected datasets used in the current analysis.

No.	Author**	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
1	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	1	47.5	60	47.5
2	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	1	47.5	60	47.5
3	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	1	100	60	100
4	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	1	100	60	100
5	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	1	67.5	60	67.5
6	Dutron [1]	0.56	6.460	289	R	0	28.4	k.A.	50	60	100	60	47.5
7	Hanson [2]	0.58	5.624	346	SL	0	22.3	k.A.	76	1	101	28	101
8	Hanson [2]	0.56	6.140	320	SL	0	34.3	k.A.	76	1	101	2	101
9	Hanson [2]	0.56	6.140	320	SL	0	34.3	k.A.	76	1	101	7	101
10	Hanson [2]	0.56	6.140	320	SL	0	34.3	k.A.	76	1	101	28	101
11	Hanson [2]	0.56	6.140	320	SL	0	34.3	k.A.	76	1	101	90	101
12	Hanson [2]	0.56	6.140	320	SL	0	34.3	k.A.	76	1	101	365	101
13	Troxel [5]	0.59	5.669	320	R	0	16.5	k.A.	51	28	99	28	100
14	Troxel [5]	0.59	5.669	320	R	0	16.5	k.A.	51	28	99	28	99
15	Troxel [5]	0.59	5.669	320	R	0	16.5	k.A.	51	28	99	28	70
16	Troxel [5]	0.59	5.669	320	R	0	16.5	k.A.	51	28	99	28	50
17	Weil [6] A	0.52	5.385	338	SL	0	25.4	k.A.	50	7	65	28	65
18	Weil [6] A	0.52	5.385	338	SL	0	25.4	k.A.	100	7	65	28	65
19	Weil [6] A	0.52	5.385	338	SL	0	25.4	k.A.	150	7	65	28	65
20	Weil [6] A	0.52	5.385	338	SL	0	25.4	k.A.	300	7	65	28	65
21	Weil [6] B	0.54	5.400	337	SL	0	28	k.A.	50	7	65	28	65
22	Weil [6] B	0.54	5.400	337	SL	0	28	k.A.	50	7	65	28	65
23	Weil [6] C	0.52	5.031	358	R	0	46.9	k.A.	50	7	65	28	65
24	Weil [6] C	0.52	5.031	358	R	0	46.9	k.A.	50	7	65	28	65
25	Weil [6] B	0.54	5.400	337	SL	0	28	k.A.	50	7	65	28	65
26	Weil [6] B	0.54	5.400	337	SL	0	28	k.A.	50	7	65	28	65
27	Weil [6] C	0.52	5.031	358	R	0	46.9	k.A.	50	7	65	28	65
28	Weil [6] C	0.52	5.031	358	R	0	46.9	k.A.	50	7	65	28	65
29	Hummel [11]	0.55	5.396	334	SL	0	26.9	k.A.	100	3	99	3	65
30	Hummel [11]	0.55	5.396	334	SL	0	26.9	k.A.	100	7	65	28	65
31	Hummel [11]	0.55	5.396	334	SL	0	26.9	k.A.	100	7	65	90	65
32	Hummel [11]	0.55	5.396	334	R	0	41.9	k.A.	100	3	65	3	65
33	Hummel [11]	0.55	5.396	334	R	0	41.9	k.A.	100	7	65	28	65
34	Hummel [11]	0.55	5.396	334	R	0	41.9	k.A.	100	7	65	90	65
35	Hummel [11]	0.38	5.391	350	SL	0	43.1	k.A.	100	7	65	28	65
36	Hummel [11]	0.45	5.392	345	SL	0	35.3	k.A.	100	7	65	28	65
37	Hummel [11]	0.65	5.393	328	SL	0	19	k.A.	100	7	65	28	65
38	Rüsch [14]	0.55	5.394	337	SL	0	24.4	20620	100	7	65	28	65
39	Rüsch [14]	0.55	5.469	337	SL	0	25.8	32790	100	7	65	28	65
40	Rüsch [14]	0.55	5.397	337	SL	0	26.4	26670	100	7	65	27	65
41	Rüsch [14]	0.55	5.588	337	SL	0	23.4	17860	100	7	65	28	65
42	Rüsch [14]	0.55	5.504	337	SL	0	27.8	22370	100	7	65	28	65
43	Rüsch [14]	0.55	6.261	337	SL	0	28.4	30310	100	7	65	28	65
44	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	38	8	99	8	99
45	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	38	8	99	8	75
46	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	38	8	99	8	50

Table A1: Continued.

No.	Author**	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
47	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	38	8	99	8	20
48	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	76	8	99	8	99
49	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	76	8	99	8	75
50	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	76	8	99	8	50
51	Keeton [15]	0.46	3.732	452	RS	0	45.2	25860	76	8	99	8	20
52	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	7	50
53	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	21	50
54	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	90	50
55	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	365	50
56	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	7	50
57	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	21	50
58	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	28	50
59	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	90	50
60	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	365	50
61	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	720	50
62	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	7	100
63	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	21	100
64	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	28	100
65	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	365	100
66	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	730	100
67	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	7	100
68	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	14	100
69	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	21	100
70	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	28	100
71	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	365	100
72	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	730	100
73	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	7	100
74	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	28	100
75	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	365	100
76	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	730	100
77	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	35	28	35
78	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	50	28	50
79	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	75	28	75
80	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	99	28	99
81	L'Hermite [17]	0.49	4.814	350	R	0	33.9	k.A.	35	1	100	28	100
82	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	51	8	99	8	50
83	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	76	8	99	8	50
84	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	101.5	8	99	8	50
85	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	152.5	8	99	8	50
86	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	203	8	99	8	50
87	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	254	8	99	8	50
88	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	305	8	99	8	50
89	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	203	8	99	8	50
90	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	102	8	99	8	50
91	Hanson [20]	0.71	6.000	303	RS	0	41.3	27700	51	8	99	8	50
92	Rüsch [30]	0.49	5.343	344	RS	0	48.6	k.A.	60	7	65	29	65
93	Rüsch [30]	0.45	5.406	350	RS	0	48.4	k.A.	60	8	65	466	65
94	Rostasy [43]	0.56	7.098	275	R	0	41.4	k.A.	100	7	65	28	65

Table A1: Continued.

No.	Author**	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
95	Rostasy [43]	0.41	5.587	332	R	0	40.9	k.A.	100	7	65	28	65
96	Rostasy [43]	0.41	5.587	332	R	0	40.9	k.A.	100	7	99	28	99
97	Lambotte [58]	0.5	6.300	300	R	0	29.2	k.A.	75	1	60	28	60
98	Lambotte [58]	0.44	5.266	360	R	0	41.9	k.A.	75	1	60	15	60
99	Lambotte [58]	0.44	5.266	360	R	0	37.8	k.A.	75	1	60	7	60
100	Lambotte [58]	0.47	5.232	375	R	0	39	k.A.	75	1	60	17	60
101	Lambotte [58]	0.47	5.235	362	R	0	k.A.	k.A.	50	35	95	35	60
102	Lambotte [58]	0.52	5.571	350	R	0	30.8	k.A.	50	1	60	60	60
103	Lambotte [58]	0.5	6.300	300	R	0	29.2	k.A.	75	1	60	28	60
104	Lambotte [58]	0.5	5.314	350	R	0	33.6	k.A.	75	1	60	28	60
105	Lambotte [58]	0.47	5.232	375	R	0	39.4	k.A.	75	1	60	7	60
106	Lambotte [58]	0.35	4.657	400	R	0	45.3	k.A.	75	1	60	28	60
107	Lambotte [58]	0.575	4.835	400	R	0	46.2	k.A.	75	1	60	7	60
108	Lambotte [58]	0.4	4.525	450	R	0	38.9	k.A.	75	1	60	28	60
109	Lambotte [58]	0.43	3.911	450	RS	0	43.2	k.A.	75	1	60	28	60
110	Lambotte [58]	0.48	5.571	350	R	0	k.A.	k.A.	50	42	95	42	60
111	Lambotte [58]	0.49	5.300	350	R	0	k.A.	k.A.	50	49	95	49	60
112	Lambotte [58]	0.52	5.571	350	R	0	34.1	k.A.	50	17	95	17	60
113	Lambotte [58]	0.57	5.969	325	R	0	36.6	k.A.	50	4	95	4	60
114	Lambotte [58]	0.57	5.969	325	R	0	36.6	k.A.	50	28	95	28	60
115	Wischers [61]	0.48	5.862	325	R	0	54	k.A.	75	4.5	100	4.5	65
116	Wischers [61]	0.48	5.862	325	R	0	54	k.A.	75	8	100	8	65
117	Wischers [61]	0.48	5.862	325	R	0	54	k.A.	75	28	100	28	65
118	Wischers [61]	0.48	4.239	410	R	0	46.4	k.A.	75	5	100	5	65
119	Wischers [61]	0.48	4.239	410	R	0	46.4	k.A.	75	10	100	10	65
120	Wischers [61]	0.48	4.239	410	R	0	46.4	k.A.	75	28	100	28	65
121	Wischers [61]	0.48	5.862	325	RS	0	60.4	k.A.	75	0.8	100	0.9	65
122	Wischers [61]	0.48	5.862	325	RS	0	60.4	k.A.	75	2.9	100	3	65
123	Wischers [61]	0.48	5.862	325	RS	0	60.4	k.A.	75	28	100	28	65
124	Wischers [61]	0.48	4.239	410	RS	0	54.5	k.A.	75	1.4	100	1.5	65
125	Wischers [61]	0.48	4.239	410	RS	0	54.5	k.A.	75	2.9	100	23	65
126	Wischers [61]	0.48	4.239	410	RS	0	54.5	k.A.	75	28	100	28	65
127	Wischers [61]	0.4	4.533	400	RS	0	64.6	k.A.	75	0.4	100	0.5	65
128	Wischers [61]	0.4	4.533	400	RS	0	64.6	k.A.	75	1.5	100	1.6	65
129	Wischers [61]	0.4	4.533	400	RS	0	64.6	k.A.	75	28	100	28	65
130	Wesche [63] A	0.55	5.387	336	R	0	33.2	32200	100	3	65	3	65
131	Wesche [63] A	0.55	5.387	336	R	0	33.2	32200	100	7	65	7	65
132	Wesche [63] A	0.55	5.387	336	R	0	33.2	32200	100	7	65	28	65
133	Wesche [63] A	0.55	5.387	336	R	0	33.2	32200	100	7	65	2470	65
134	Wesche [63] A	0.55	5.387	336	R	0	33.2	32200	100	7	65	3055	65
135	Wesche [63] B	0.55	5.406	335	R	0	33.2	k.A.	100	7	65	28	65
136	Wesche [63] B	0.55	5.406	335	R	0	33.2	k.A.	100	7	65	2430	65
137	Wesche [63] B	0.55	5.406	335	R	0	33.2	k.A.	100	7	65	3300	65
138	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	1	65	1	65
139	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	3	65	3	65
140	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	7	65	7	65
141	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	7	65	28	65
142	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	7	65	2700	65

Table A1: Continued.

	Author	w/c	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
143	Wesche [63] C	0.55	5.395	337	RS	0	46.5	37500	100	7	65	3290	65
144	Wesche [63] D	0.515	5.413	332	R	0	34.9	k.A.	100	7	65	28	65
145	Wesche [63] E	0.545	5.858	312	R	0	34.9	k.A.	100	7	65	28	65
146	Wesche [63] F	0.485	5.413	332	R	0	39.9	k.A.	100	7	65	28	65
147	Wesche [63] G	0.5	5.398	335	R	0	39.1	k.A.	100	7	65	28	65
148	Wesche [63] D	0.515	5.413	332	R	0	34.9	k.A.	100	7	65	2460	65
149	Wesche [63] E	0.545	5.858	312	R	0	34.9	k.A.	100	7	65	2450	65
150	Wesche [63] F	0.485	5.413	332	R	0	39.9	k.A.	100	7	65	2475	65
151	Wesche [63] G	0.5	5.398	335	R	0	39.1	k.A.	100	7	65	2445	65
152	Wesche [63] H	0.55	5.386	336	SL	0	34.1	27800	100	3	65	3	65
153	Wesche [63] H	0.55	5.386	336	SL	0	34.1	27800	100	7	65	7	65
154	Wesche [63] H	0.55	5.386	336	SL	0	34.1	27800	100	7	65	28	65
155	Wesche [63] H	0.55	5.386	336	SL	0	34.1	27800	100	7	65	2735	65
156	Wesche [63] I	0.55	5.386	336	SL	0	33.2	35400	100	7	65	7	65
157	Wesche [63] I	0.55	5.386	336	SL	0	33.2	35400	100	7	65	28	65
158	Wesche [63] I	0.55	5.386	336	SL	0	33.2	35400	100	7	65	3295	65
159	Wesche [63] J	0.55	5.386	336	SL	0	30.8	28400	100	7	65	7	65
160	Wesche [63] J	0.55	5.386	336	SL	0	30.8	28400	100	7	65	28	65
161	Wesche [63] J	0.55	5.386	336	SL	0	30.8	28400	100	7	65	2705	65
162	Aschl [67]	0.52	5.066	351	SL	0	53.1	k.A.	75	30	65	112	65
163	Aschl [67]	0.52	5.066	351	SL	0	53.1	k.A.	75	7	101	112	101
164	Stöckl [69]	0.601	5.020	358	SL	0	17.7	k.A.	75	7	65	28	65
165	Stöckl [69]	0.601	5.020	358	SL	0	17.7	k.A.	75	7	65	28	65
166	Stöckl [69]	0.599	8.320	247	SL	0	19	k.A.	75	7	65	28	65
167	Stöckl [69]	0.599	8.320	247	SL	0	19	k.A.	75	7	65	28	65
168	Stöckl [69]	0.45	5.405	353	SL	0	23.9	k.A.	75	7	65	28	65
169	Stöckl [69]	0.45	5.405	353	SL	0	23.9	k.A.	75	7	65	28	65
170	Stöckl [69]	0.8	7.760	250	SL	0	10.8	k.A.	75	7	65	28	65
171	Stöckl [69]	0.8	7.760	250	SL	0	10.8	k.A.	75	7	65	28	65
172	Brooks [72]	0.36	3.300	520	R	0	70.9	k.A.	38	28	100	28	100
173	Brooks [72]	0.27	3.300	535	R	0	85.5	k.A.	38	28	100	28	100
174	Brooks [72]	0.34	2.600	608	R	0	69.1	k.A.	38	28	100	28	100
175	Brooks [72]	0.27	2.600	628	R	0	80.9	k.A.	38	28	100	28	100
176	Brooks [72]	0.3	2.080	725	R	0	67.3	k.A.	38	28	100	28	100
177	Brooks [72]	0.36	3.300	520	R	0	70.9	k.A.	38	28	100	28	65
178	Brooks [72]	0.27	3.300	535	R	0	85.5	k.A.	38	28	100	28	65
179	Brooks [72]	0.34	2.600	608	R	0	69.1	k.A.	38	28	100	28	65
180	Brooks [72]	0.27	2.600	628	R	0	80.9	k.A.	38	28	100	28	65
181	Brooks [72]	0.3	2.08	725	R	0	67.3	k.A.	38	28	100	28	65
182	Stöckl [73]	0.55	5.354	336	R	0	30.3	k.A.	60	7	65	57	65
183	Stöckl [73]	0.55	5.354	336	R	0	30.3	k.A.	60	7	65	57	65
184	Russel [78]	0.432	4.040	432	R	0	52.4	31556	76	1	98	28	101
185	Russel [78]	0.432	4.040	432	R	0	52.4	31556	76	7	98	28	50
186	Russel [78]	0.432	4.040	432	R	0	52.4	31556	76	7	98	182	50
187	Russel [78]	0.432	4.040	432	R	0	52.4	31556	76	7	98	361	50
188	Russel [78]	0.39	3.340	502	R	0	63	36241	76	1	98	28	101
189	Russel [78]	0.39	3.340	502	R	0	63	36241	76	7	98	28	50

Table A1: Continued.

	Author	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
190	Russel [78]	0.39	3.340	502	R	0	63	36241	76	7	98	181	50
191	Russel [78]	0.39	3.340	502	R	0	63	36241	76	7	98	730	50
192	Shritharan [79]	0.47	5.090	390	R	0	50.1	29800	75	3	95	8	60
193	Shritharan [79]	0.47	5.090	391	R	0	50.1	29800	75	3	95	14	60
194	Shritharan [79]	0.47	5.090	392	R	0	50.1	29800	75	3	95	21	60
195	Shritharan [79]	0.47	5.090	393	R	0	50.1	29800	75	3	95	28	60
196	Shritharan [79]	0.47	5.090	394	R	0	50.1	29800	75	3	95	84	60
197	Shritharan [79]	0.47	5.090	395	R	0	50.1	29800	75	3	95	182	60
198	Shritharan [79]	0.47	5.090	396	R	0	50.1	29800	75	3	95	8	101
199	Shritharan [79]	0.47	5.090	397	R	0	50.1	29800	75	3	95	14	101
200	Shritharan [79]	0.47	5.090	398	R	0	50.1	29800	75	3	95	21	101
201	Shritharan [79]	0.47	5.090	399	R	0	50.1	29800	75	3	95	28	101
202	Shritharan [79]	0.47	5.090	400	R	0	50.1	29800	75	3	95	84	101
203	Shritharan [79]	0.47	5.090	401	R	0	50.1	29800	75	3	95	182	101
204	Shritharan [79]	0.47	5.090	402	R	0	50.1	29800	50	3	95	8	60
205	Shritharan [79]	0.47	5.090	403	R	0	50.1	29800	100	3	95	8	60
206	Shritharan [79]	0.47	5.090	404	R	0	50.1	29800	150	3	95	8	60
207	Shritharan [79]	0.47	5.090	405	R	0	50.1	29800	200	3	95	8	60
208	Burg [85]	0.281	3.041	564	R	0	78.6	43200	76	0	100	28	50
209	Burg [85]	0.32	3.581	487	R	9.651	91.9	45500	76	0	100	28	50
210	Burg [85]	0.255	2.945	564	R	15.78	118.9	50800	76	0	100	28	50
211	Burg [85]	0.318	3.496	475	R	15.58	107	48400	76	0	100	28	50
212	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	101	30	101
213	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	65	30	65
214	Summer [91]	0.3	3.625	500	R	0	75.6	k.A.	50	1	101	30	101
215	Summer [91]	0.3	3.625	500	R	0	75.6	k.A.	50	1	65	30	65
216	Summer [91]	0.271	4.375	432	R	4.167	82.9	k.A.	50	1	101	29	101
217	Summer [91]	0.271	4.375	432	R	4.167	82.9	k.A.	50	1	65	29	65
218	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	29	101
219	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	65	29	65
220	Summer [91]	0.239	3.920	460	R	8.696	96.6	k.A.	50	1	101	29	101
221	Summer [91]	0.38	3.994	450	R	0.000	57.7	k.A.	50	1	101	32	101
222	Summer [91]	0.38	3.994	450	R	0.000	57.7	k.A.	50	1	65	32	65
223	Summer [91]	0.3	4.193	450	SL	0.000	55.9	k.A.	50	1	101	30	101
224	Summer [91]	0.3	4.193	450	SL	0.000	55.9	k.A.	50	1	65	30	65
225	Summer [91]	0.239	4.535	414	SL	8.696	67.6	k.A.	50	1	101	28	101
226	Summer [91]	0.3	4.166	450	R	0.000	75.92	k.A.	50	1	101	29	101
227	Summer [91]	0.239	4.504	414	R	8.696	75	k.A.	50	1	101	29	101
228	Summer [91]	0.3	4.213	450	R	0.000	75	k.A.	50	1	101	29	101
229	Summer [91]	0.239	4.553	414	R	8.696	99.5	k.A.	50	1	101	29	101
230	Summer [91]	0.3	3.151	550	R	0.000	83.4	k.A.	50	1	101	29	101
231	Summer [91]	0.239	4.175	460	R	8.696	104.7	k.A.	50	1	101	29	101
232	Summer [91]	0.239	4.175	460	R	8.696	104.7	k.A.	50	1	65	29	65
233	Summer [91]	0.271	4.017	480	R	0	89.1	k.A.	50	1	65	29	65
234	Summer [91]	0.239	4.186	460	R	8.696	104.6	k.A.	50	1	101	29	101
235	Summer [91]	0.3	3.845	500	SL	0	61.9	k.A.	50	1	101	29	101
236	Summer [91]	0.239	4.156	460	SL	8.696	71.1	k.A.	50	1	101	30	101

Table A1: Continued.

	Author	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
237	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	7	101
238	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	7	65
239	Summer [91]	0.239	4.535	414	SL	8.696	67.6	k.A.	50	1	101	7	101
240	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	101	1	101
241	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	1	101
242	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	101	28	65
243	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	28	65
244	Summer [91]	0.271	4.017	480	R	0	89.1	k.A.	50	1	101	29	101
245	Summer [91]	0.48	3.723	450	R	0	48.7	k.A.	50	1	101	28	101
246	Summer [91]	0.48	3.723	450	R	0	48.7	k.A.	50	1	101	28	65
247	Yue [92]	0.323	4.875	400	RS	0	80.5	k.A.	75	1	60	28	60
248	Yue [92]	0.323	4.875	400	RS	0	80.5	k.A.	75	1	60	28	60
249	Yue [92]	0.657	6.383	300	R	0	36.5	k.A.	75	1	60	28	60
250	Chern [93]	0.28	3.331	505	R	11.09	53.5	k.A.	50	1	50	28	50
251	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
252	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
253	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
254	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
255	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
256	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
257	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
258	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
237	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	7	101
238	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	7	65
239	Summer [91]	0.239	4.535	414	SL	8.696	67.6	k.A.	50	1	101	7	101
240	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	101	1	101
241	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	1	101
242	Summer [91]	0.3	4.217	450	R	0	70.9	k.A.	50	1	101	28	65
243	Summer [91]	0.239	4.559	414	R	8.696	97	k.A.	50	1	101	28	65
244	Summer [91]	0.271	4.017	480	R	0	89.1	k.A.	50	1	101	29	101
245	Summer [91]	0.48	3.723	450	R	0	48.7	k.A.	50	1	101	28	101
246	Summer [91]	0.48	3.723	450	R	0	48.7	k.A.	50	1	101	28	65
247	Yue [92]	0.323	4.875	400	RS	0	80.5	k.A.	75	1	60	28	60
248	Yue [92]	0.323	4.875	400	RS	0	80.5	k.A.	75	1	60	28	60
249	Yue [92]	0.657	6.383	300	R	0	36.5	k.A.	75	1	60	28	60
250	Chern [93]	0.28	3.331	505	R	11.09	53.5	k.A.	50	1	50	28	50
251	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
252	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
253	Han [95]	0.316	3.780	475	R	5.263	106.2	k.A.	50	0.67	101	28	65
254	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
255	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
256	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
257	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
258	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
259	Han [95]	0.316	3.779	475	R	5.263	100.3	k.A.	50	0.67	101	0.67	50
260	Han [95]	0.316	3.783	475	R	5.263	92.8	k.A.	50	0.67	101	0.67	50
261	Han [95]	0.316	3.783	475	R	5.263	92.8	k.A.	50	0.67	101	0.67	50

Table A1: Continued.

	Author	*w/c*	a/c	c	CEB Cem. Typ	SCM	f_c(MPa)	E_c(28)	2A/u	tc	RHo	to	RH
262	Han [95]	0.316	3.783	475	R	5.263	92.8	k.A.	50	0.67	101	0.67	50
263	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	1	99	1	65
264	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	1	65	3	65
265	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	1	65	7	65
266	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	1	65	28	65
267	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	1	65	90	65
268	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	3	99	3	65
269	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	7	99	7	65
270	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	28	99	28	65
271	Hilsdorf [98]	0.55	5.401	337	RS	0	40.3	30200	100	90	99	90	65

** Reference numbers listed in Appendix are based on reference numbers in RILEM database [27]