COMPARISON OF CREEP PREDICTION MODELS FOR SELF-COMPACTING AND CONVENTIONAL CONCRETE

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Abstract

Realistic prediction of concrete creep is of crucial importance for durability and long-term serviceability of concrete structures. To date, research about the behaviour of self-compacting concrete (SCC) members, especially concerning the long-term performance, is rather limited. Hence, the realistic SCC creep strain prediction is an important requirement of the design process of this type of concrete structures. SCC is quite different from conventional concrete (CC) in mixture proportions and applied materials, particularly in the presence of aggregate which is limited. This paper reviews the accuracy of the creep prediction models proposed by six international codes of practice, including: CEB-FIP 1990, ACI 209R (1992), Eurocode 2 (2001), AASHTO (2004), AASHTO (2007) and AS 3600 (2009). The predicted creep strains are compared with actual measured creep strains in 60 mixtures of SCC and 17 mixtures of CC. The affecting parameters on the creep of SCC including: the water to binder ratio, binder to aggregate ratio, sand ratio, and curing age are investigated and discussed.

1. INTRODUCTION

Since deformability of the paste is higher than aggregate, it is generally assumed that the higher the paste volume the higher the concrete deformations (instantaneous and delayed). As a result, SCC could show a rather specific behaviour when dealing with creep or shrinkage, which might lead to hold up the development of SCC for the manufacturing of some precast concrete elements such as prestressed beams [1]. Studying of the creep behaviour of SCC is essential for successful application of this high- performance material in precast, prestressed members. Creep depends on the characteristics of aggregate stiffness and texture, w/c ratio, volume of paste, volume of coarse aggregate, cement type, admixture type, curing method, ratio of volume to surface area, environmental conditions, magnitude of loads and age of first loading. According to Neville [2] mostly the hydrated cement paste experiences creep, while the aggregate is the only portion which resists against creep. Therefore, creep is highly dependent on the stiffness of the chosen aggregate and its proportion within the mixture [2]. As a result, since creep mainly occurs in the cement paste, main concern arises that SCC may exhibit higher creep because of its high paste content. Creep increases with increasing w/c ratio [3], which is an indication that creep decreases with increase in strength of the paste phase of the concrete. Cement type and content, ambient conditions like temperature and humidity, curing duration, and applied stress levels all affect the amount of creep [2-3]. Neville [2] reported that “because of the long-term hydration and increase in strength under sustained load of concrete containing fly ash or ground granulated blast furnace slag, the long-term rate of creep can be reduced.”

Since SCC has high paste volume (or high sand to aggregate ratio) to achieve high workability and high early strength, several researchers reported relatively large creep of SCC for precast, prestressed concrete, resulting in large prestress losses [4-7]. Even though the mechanical properties of SCC are superior to those of CC, creep of SCC is significantly high [4]. Also, Naito et al. [5] found that SCC exhibited higher shrinkage and creep than CC, which is relevant to the high fine aggregate volume in the SCC.

Although many studies on creep in SCC are completed and several empirical formulas are presented, still commonly accepted method to predict creep precisely has not been developed. Since calculation of the time-dependent behaviour of reinforced or prestressed concrete structures constructed with SCC is important for serviceability checks, clear understanding of the creep mechanism is vitally conducting and fulfilling a very extensive long-term experiments. In fact, it is impossible to test the used concrete in the structure in the same real working environment and condition before the structure is constructed. Therefore , the reliable prediction of creep of the concrete in the real environment becomes important when the time-dependent behaviour of the structure is determined [8].

This study reviews the accuracy of the creep prediction models proposed by six international codes of practice, including: CEB-FIP [9], ACI 209R [10], Eurocode 2 [11], AASHTO [12-13] and AS 3600 [14]. The predicted creep strains are compared with the actual measured creep strains in 60 mixtures of SCC and 17 mixtures of CC.

2. DATABASE FOR CREEP EXPERIMENTAL TESTS

The use of a database with experimental results from various published investigations is an important tool for studying the applicability of the various creep estimation models of SCC.

To apply the models to a particular concrete mixture, it is necessary to use only investigations that adequately define the applied testing methodology. The presented experimental results in the database are mainly from papers presented at the various conferences on SCC and other published articles. Using experimental data results from different sources can frequently be problematic for the following reasons: 1. there is often insufficient information regarding the exact composition of the concrete mixtures; 2. the size of the specimen, curing condition, and testing methodology vary between the different investigations and in some cases this information is not fully indicated; 3. in many cases it is difficult to extract the relevant experimental values because the published results are incomplete or are presented in graphical form and the data values have to be extrapolated.

Table 1 presents a general summary of the concrete mixtures included in the database. The database comprises test results from 11 different investigations, with a total of 52 SCC mixtures for creep tests. Table 1 also includes complimentary information regarding the applied stress to the creep specimens, final age of the concrete, relative humidity (R.H.), type of the specimen, type of the cement and filler. Figures 1 and 2 show the CC and SCC experimental results database that summarized in Table 1 (creep coefficient versus time (days)). By considering experimental results of creep in the database following conclusions are observed: (1) by decreasing of water to binder ratio, increment in creep is observed (2) increase in the proportion of the total aggregate in the mixture could cause decrease in the total creep (3) when the content of total aggregate and binder in concrete is held constant, the total creep decreases as coarse aggregate proportion increases.

Table 1: Creep database

No.	Reference	No. of SCC mixtures	No. of CC mixtures	Applied stress to the creep specimens	Final age of concrete (days)	R.H. (%)	Type of specimen (mm)	Type of cement	Type of filler
1	**Chopin et al. [1]**	5	1	40% or 60% of the compressive strength at 28 days	365	50	Cylinder (90 × 280)	CEM I	Limestone
2	**Poppe and De Schutter [15]**	4	0	1/3 of the compressive strength at 28 days	1400	60	Prism (150×150×500)	CEM I 42.5 R, CEM I 52.5	Limestone
3	**Horta [16]**	6	0	40% of the compressive strength at 28 days	70, 200	50	Cylinder (150 × 300)	CEM I , CEM III	Fly ash and GGBFS
4	**Larson [17]**	1	0	40% of the compressive strength at 28 days	520	50	Prism (101.6×101.6×609.6) and Cylinder (114.3×609.6)	CEM III	Limestone
5	**Turcry et al. [18]**	2	2	20% of the compressive strength at 7 days	65, 100	50	Cylinder (110 x 200)	CEM I 52.5, CEM II 42.5	Limestone
6	**Cordoba [19]**	4	1	30% of the compressive strength at 28 days	365	50	Cylinder (101.6 × 203.2), (101.6 × 1057.8)	CEM I/II	Fly ash and GGBFS
7	**Heirman et al. [20]**	7	1	±1/3 of the compressive strength at 28 days	70	60	Cylinder (120 × 300)	CEM I 42.5 R, CEM III/A 42.5 N LA	Limestone
8	**Oliva and Cramer [21]**	11	4	40% of the compressive strength at 28 days	495	50	Cylinder (152.4 × 2133.6)	CEM I	GGBFS
9	**Kim [22]**	4	4	Changeable for each mixture	150	50	Cylinder (100×200)	CEM III	Fly ash and Limestone
10	**Zheng et al. [23]**	7	1	30% of the compressive strength at loading days	150	60	Prism (100×100×400)	CEM I	Fly ash
11	**Loser and Leemann [24]**	1	1	Changeable for each mixture	91	70	Prism (120×120×360)	CEM I 42.5 N, CEM II/A-LL 45.2 N	Fly ash and Limestone
Total of 67 mixtures		52	15						

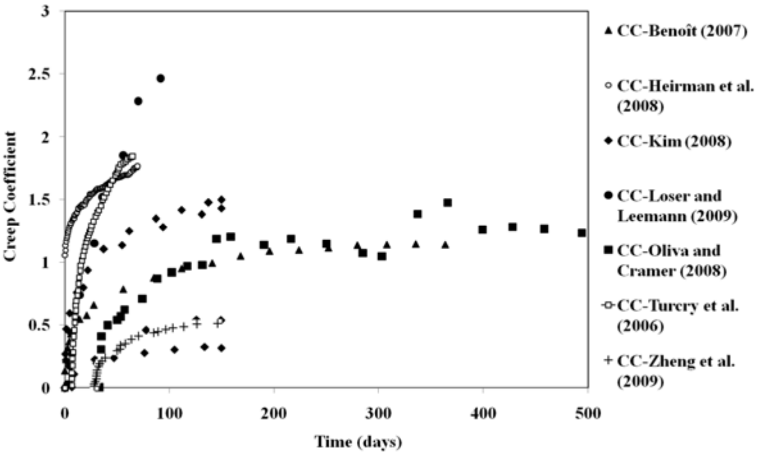

Figure 1: CC experimental results database that summarized in Table 1 (creep coefficient versus time (days))

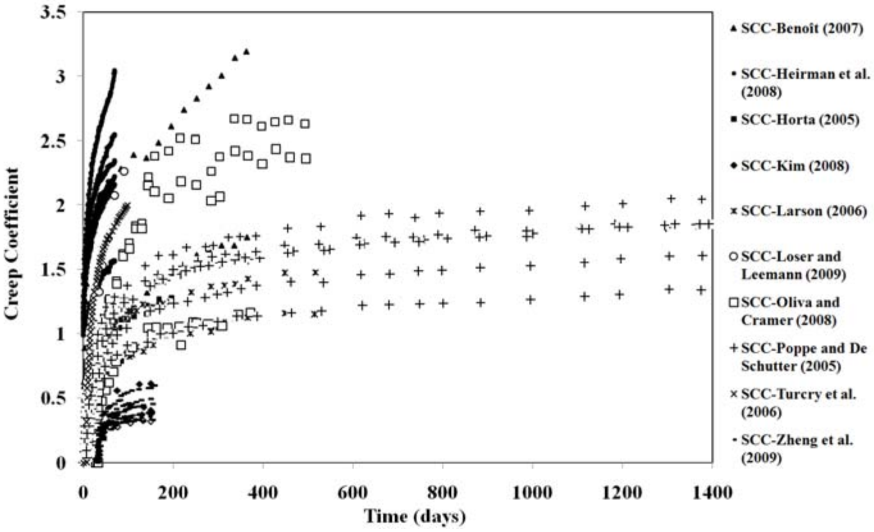

Figure 2: SCC experimental results database that summarized in Table 1 (creep coefficient versus time (days))

3. RESULTS AND DISCUSSION

Figures 3 to 4 show the comparison of the SCC and CC creep coefficient versus time from CEB-FIP [9], ACI 209R [10], Eurocode 2 [11], AASHTO [12-13] and AS 3600 [14] prediction models. Figure 5 shows comparison of the creep coefficient by CEB-FIP [9] with the experimental results available in the literature (Table 1). It can be seen that this model overestimates the creep coefficient of both SCC and CC mixtures. Figures 6 and 8 illustrate comparison of the predicted creep coefficient by ACI 209R [10] and AASHTO [12] with the experimental results (Table 1). According to the Figures 6 and 8, ACI 209R [10] and AASHTO [12] creep models have good prediction for the creep coefficient of both SCC and CC mixtures although AASHTO [12] creep model trend is underestimate slightly. Figures 5 and 9 present the same comparison by using Eurocode 2 [11] and AASHTO [13] models. Based on the presented results Eurocode 2 [11] and AASHTO [13] creep model are more conservative as its trend is to underestimate for the creep coefficient of CC mixtures but these models for SCC creep coefficient are underestimate.

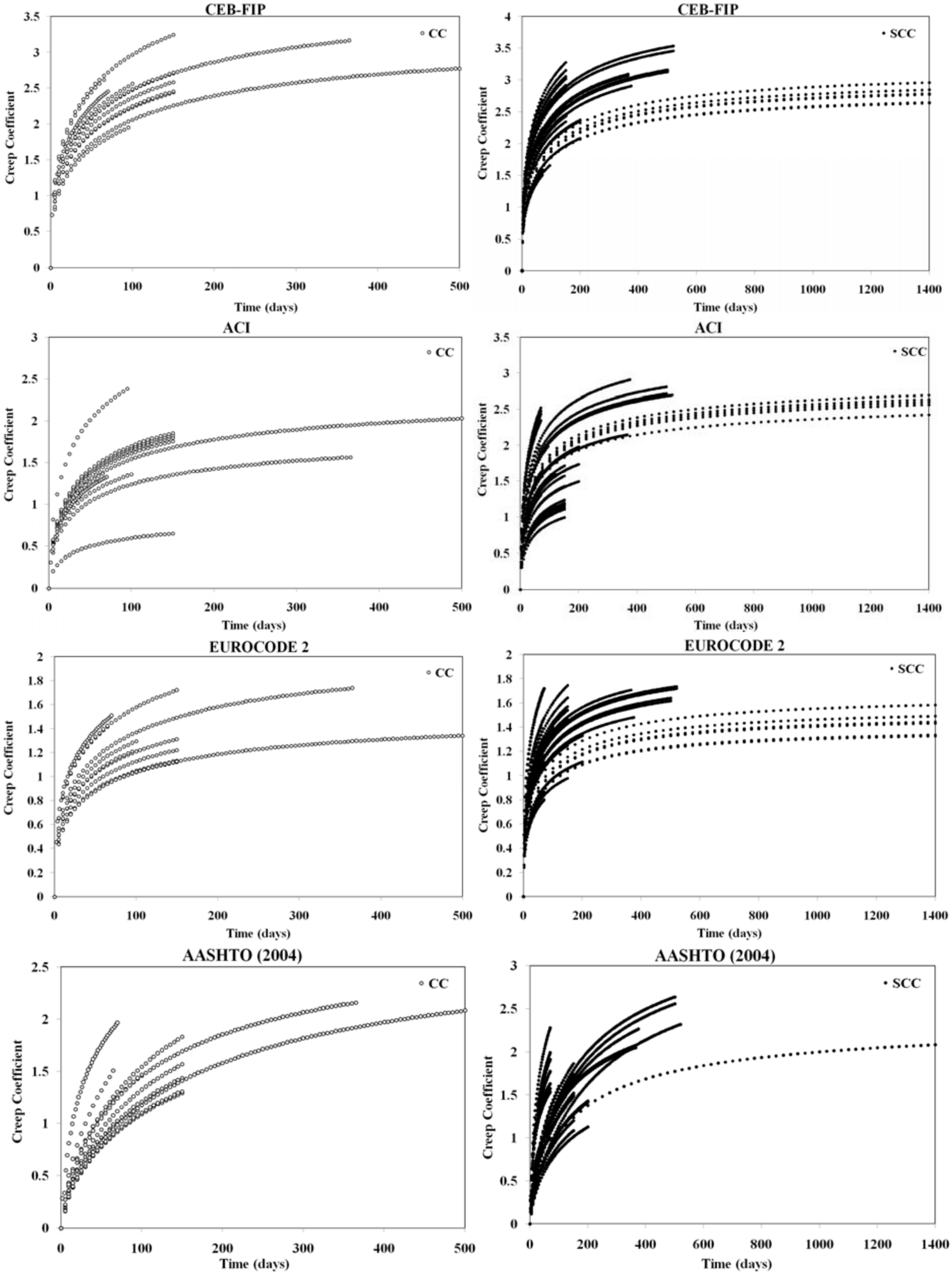

Figure 3: Comparison of the SCC and CC creep coefficient versus time from CEB-FIP [9], ACI [10], Eurocode 2 [11] and AASHTO [12] models

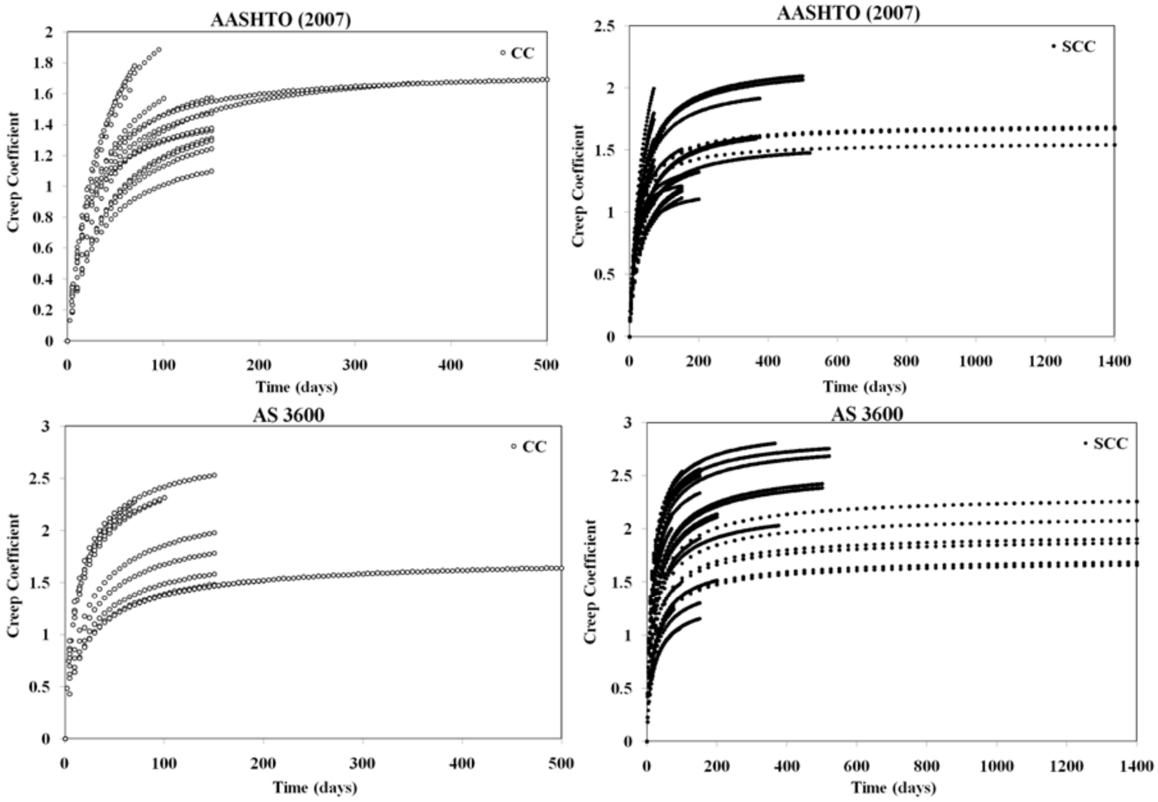

Figure 4: Comparison of the SCC and CC creep coefficient versus time from AASHTO [13] and AS 3600 [14] models

Figure 10 shows comparison of the creep coefficient by AS 3600 [14] with the experimental results creep coefficient available in the literature (Table 1). It can be seen that this model overestimates the creep coefficient of CC mixtures.

As shown in the Table 2 for CC, the AASHTO 2007 [13], Eurocode 2 [11] and AASHTO 2004 [12] models provided a better prediction of creep data with a coefficient of correlation factor (R^2) of 0.90, 0.89 and 0.86 compared to 0.41 for the CEB-FIP [9], 0.70 for the AS 3600 [14] and 0.79 for the ACI 209R [10] models. Also, as shown in the Table 2 for SCC, AASHTO 2004 [12] and ACI 209R [10] models provided a better prediction of creep data with a coefficient of correlation factor (R^2) of 0.87 and 0.84 compared to 0.58 for the CEB-FIP [9], 0.80 for the Eurocode 2 [11], 0.80 for the AASHTO 2007 [13] and 0.75 for the AS 3600 [14] models.

Table 2: Coefficient of correlation factor (R^2) creep prediction models for CC and SCC

Creep prediction models	**CC**	**SCC**
	R^2	R^2
CEB-FIP [9]	0.41	0.58
ACI 209R [10]	0.79	0.84
Eurocode 2 [11]	0.89	0.80
AASHTO 2004 [12]	0.86	0.87
AASHTO 2007 [13]	0.90	0.80
AS 3600 [14]	0.70	0.75

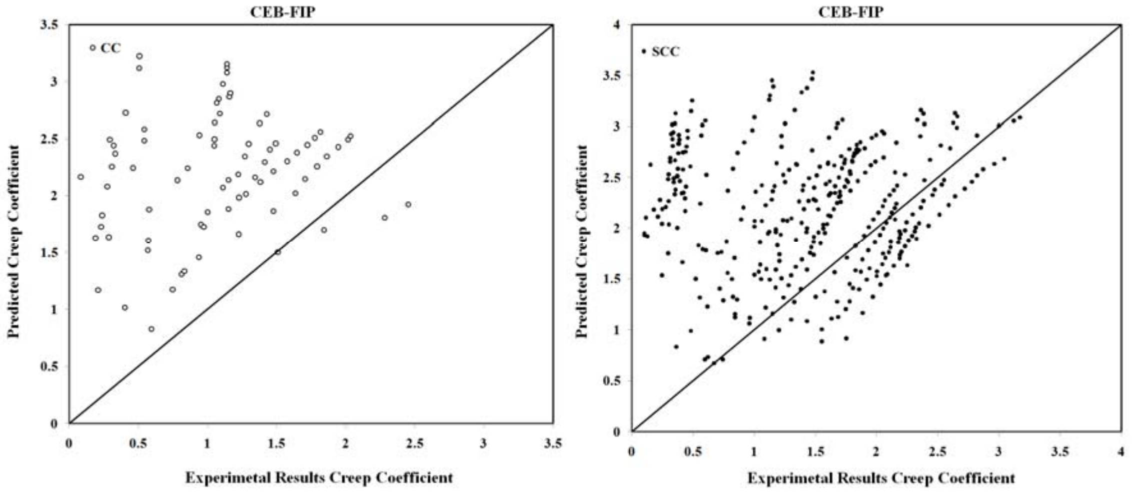

Figure 5: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from CEB-FIP [9] model

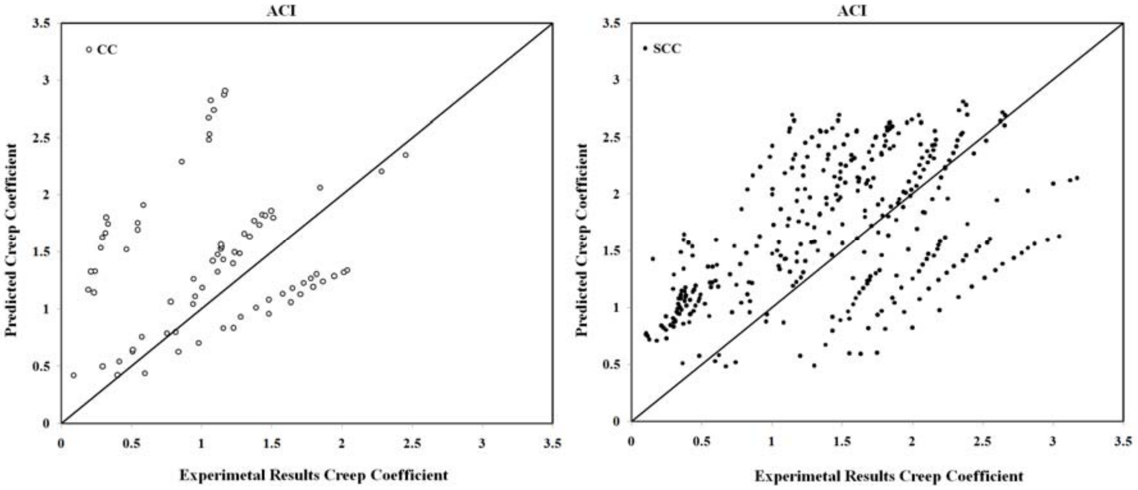

Figure 6: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from ACI [10] model

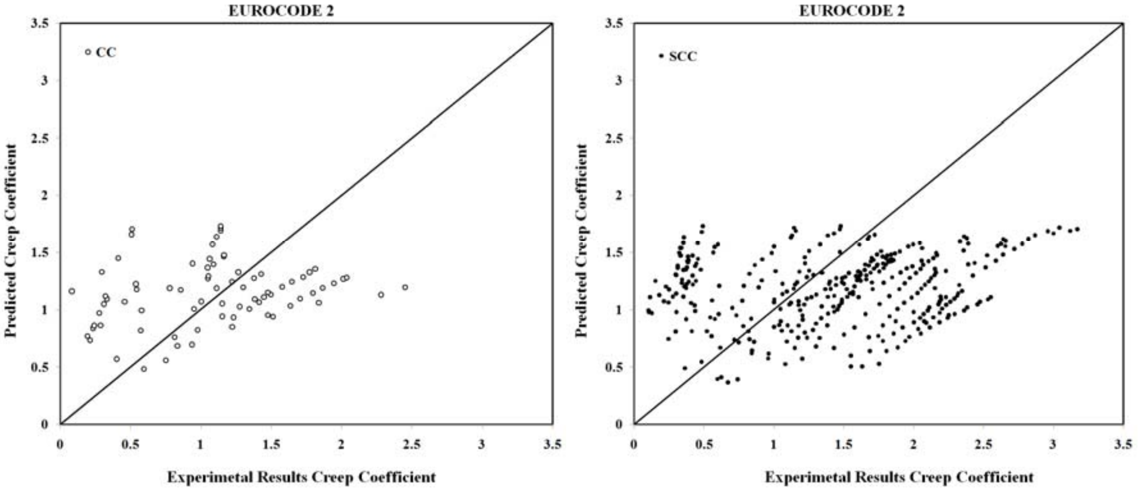

Figure 7: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from Eurocode 2 [11] model

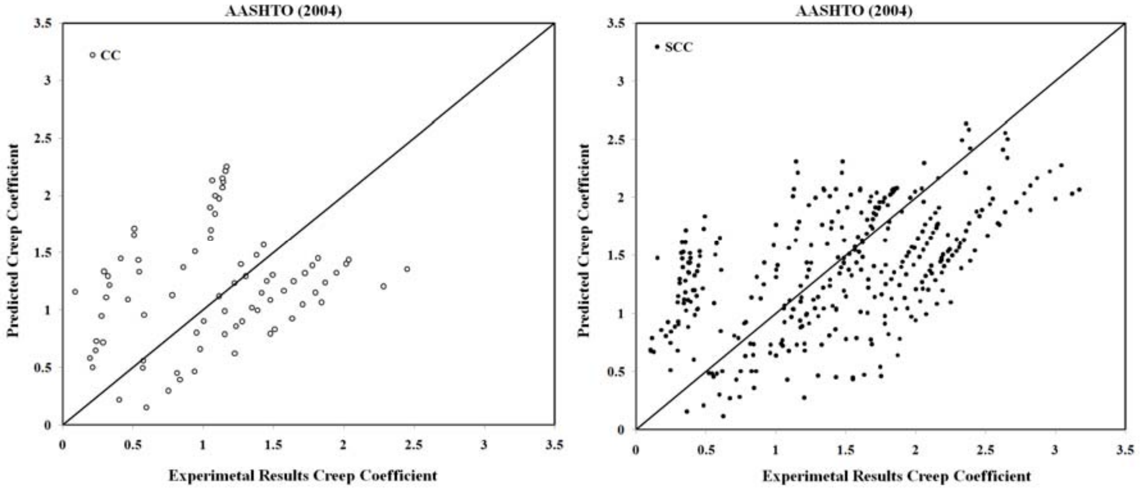

Figure 8: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from AASHTO [12] model

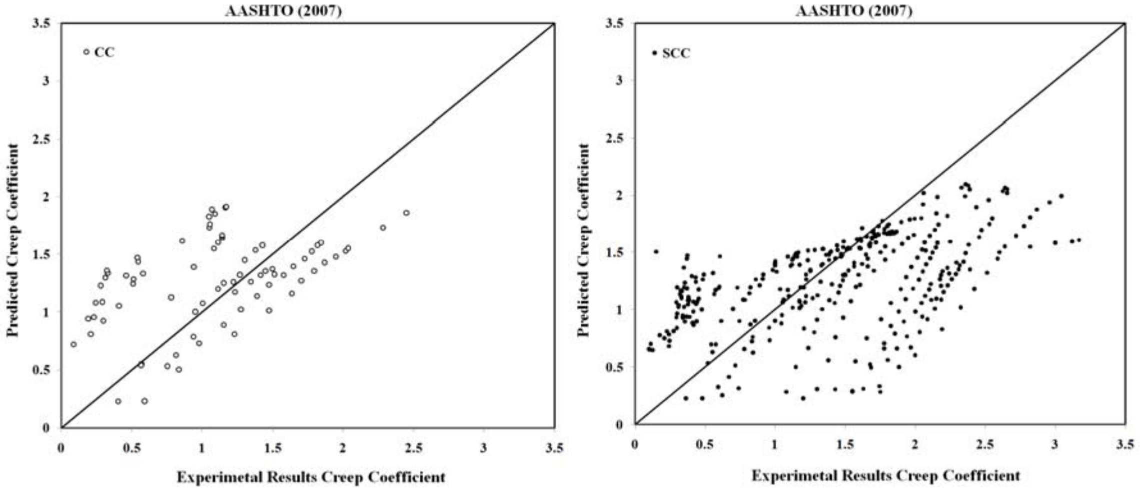

Figure 9: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from AASHTO [13] model

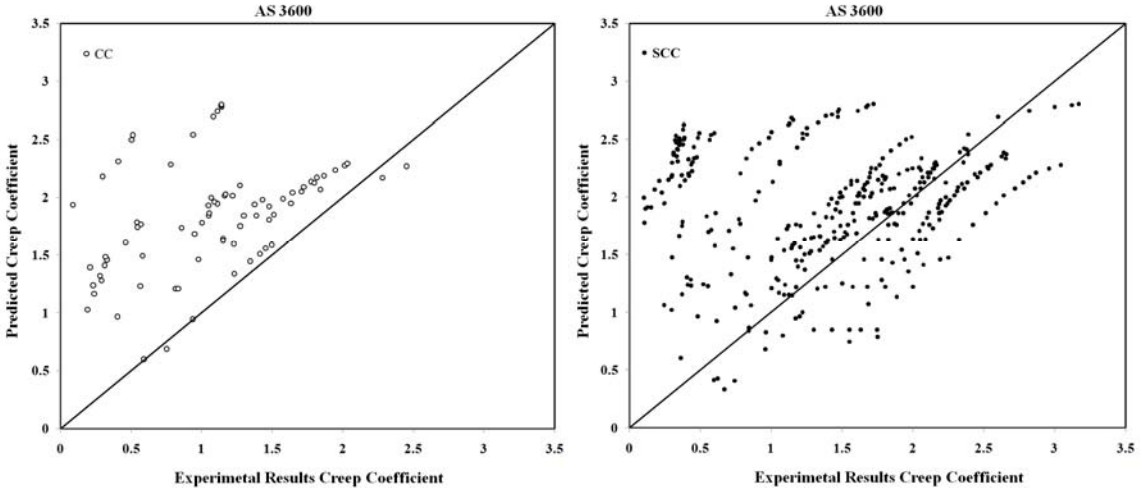

Figure 10: Comparison of the SCC and CC creep coefficient from experimental results versus calculated values from AS 3600 [14] model

4. CONCLUSIONS

This study presents an extensive database of creep experimental results for SCC and CC which evaluates six CC creep models and their applicability. The following conclusions can be drawn from this research:

- The AASHTO 2007 [13], Eurocode 2 [11] and AASHTO 2004 [12] models provided better prediction of CC creep data. Moreover, the CEB-FIP [9], AS 3600 [14], and ACI 209R [10] creep models overestimate CC creep values.
- The AASHTO 2004 [12] and ACI 209R [10] models provided better prediction of SCC creep data. Moreover, the CEB-FIP [9] and AS 3600 [14] creep models overestimate SCC creep values and Eurocode 2 [11] and AASHTO 2007 [13] models are underestimated.

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