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CREEP AND SHRINKAGE BEHAVIOR OF HIGH-STRENGTH SELF-CONSOLIDATING-CONCRETE (HS-SCC) AND NORMAL STRENGTH SELF-CONSOLIDATING-CONCRETE (NS-SCC) COMPARED TO CODE MODELS

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ABSTRACT

Creep and shrinkage can be critical factors for design of structural members due to the length change by time dependent deformation. In this paper, four high strength self-consolidation concrete specimens (HS-SCC) and other four normal strength self-consolidation specimens (NS-SCC) were developed and tested to measured creep and shrinkage for each mixture. The samples of these mixtures were taken from a multiple-spans Bridge A7957- Route 50 in Osage County, Missouri, USA where construction has been completed. Span No. two of the bridge was cast with HS-SCC and span No. three with NS-SCC. The specimens were beam cured (Steam cured) at 120 ℉ (49 ℃). This study shows that HS-SCC developed 13% higher creep at 120 days than NS-SCC and also HS-SCC exhibited 12% higher drying shrinkage at 180 days than NS-SCC. The results of this study were compared to different prediction models used to predict creep and shrinkage. Correction factors are presented to account for adequate prediction of creep and shrinkage for HS-SCC and NS-SCC.

KEYWORDS

High strength- self consolidation concrete, prediction models, creep coefficient, shrinkage.

INTRODUCTION

Self-consolidation concrete (SCC) is an innovation concrete material used successfully throughout the world. It can be consolidated into every corner of a formwork, purely by means of its own weight and without the need for mechanical consolidation as traditional vibration concrete. It is composed of Portland cement, fine and coarse aggregates, water, chemical admixture, and typically supplementary commentating material (Daczko 2012).

Throughout time, improvements and developments have been made by civil engineers to the material used in the design and construction of bridges, buildings, and roads of the infrastructure of the nation to lowered costs, reduced construction time, and increased the service life of the structures. Recently, high-strength self-consolidating concrete (HS-SCC) has been developed and utilized in structural applications. HS-SCC has all of the benefits of SCC with the added addition of increased strength.

Creep and shrinkage are one of critical factors for design of structural members due to the length change over time. Since SCC has high paste or sand content, this led to concerns about properties such as shrinkage and creep. Questions regarding hardened properties of SCC were raised to better understand these concerns. For example, is it always the case that SCC will have higher shrinkage and creep than conventional concrete? Will HS-SCC behave the same as that of NS-SCC?

Creep and shrinkage are two important time-dependent properties of concrete. These properties are affected by the local construction material, environment condition and play an important role on the long term response of concrete structures. There are many factors which affect the magnitude of the time-dependent creep and shrinkage of concrete under the local condition. Table 1 illustrates these factors that are taken into account by different code models.

Table 1. Factors adopted in different prediction models

Factor	AASHTO LRFD (2007)		ACI 209 (2008)		AS 3600 (2009)		Eurocode 2 (2004)	
	Shrinkage	Creep	Shrinkage	Creep	Shrinkage	Creep	Shrinkage	Creep
Cement Content			✸	✸				
Cement Type			✸	✸			✸	✸
Aggregate Type					✸			
Fine/ Total Aggregate Ratio			✸	✸				
Slump			✸	✸				
Air Content			✸	✸				
Curing Regime			✸	✸				
Volume/ Surface Area	✸	✸	✸	✸				
Compressive strength at 28	✸	✸		✸	✸	✸	✸	✸
Relative humidity	✸	✸	✸	✸	✸	✸	✸	✸
Applied Stress (Creep only)						✸		✸
Effective Thickness	✸				✸	✸		✸
Age at loading		✸		✸		✸		✸
Age at Drying	✸		✸			✸	✸	
Duration of Loading		✸		✸		✸		✸

The purpose of this paper is to understand the creep and shrinkage behavior of HS-SCC and NS-SCC. An experimental study has been conducted to determine the amount of creep and shrinkage strain. The measuring data has been compared with predictive equations from ACI 209R-08, AASHTO LRFD 2007, AS3600, and Eurocode 2 to determine whether these typical Equations used by design engineers can be applied to HS-SCC and NS-SCC under condition of construction local materials and curing condition of concrete plants.

CREEP AND SHRINKAGE CODE MODELS

Overtime, several models have been proposed to predict creep and shrinkage in concrete structure. Since creep and shrinkage are influenced by many factors, as mentioned above, the ability to obtain an accurate prediction is not an easy one. In this study, the measured data were compared to typical code models from ACI 209R-08, AASHTO LRFD 2007, AS3600, and Eurocode 2 to determine whether these equations used by design engineer can be applied to HS-SCC and NS-SCC. A brief discussion is presented below. For specific details of the code models, the specific reference should be sought out for review.

ACI 209R (2009)

The ACI 209 model was developed for conventional concrete in 1973 and modified by ACI committee 209 to predict creep and shrinkage at a given age under standard condition and correction factors for other than standard condition. This ACI model considers numerous factors including cement content and type, the aggregate ratio, slump, air content, curing regime and others as listed in Table 1.

AASHTO LRFD (2007)

The AASHTO LRFD model was based upon work undertaken by Tadros et al. (2003). The research work undertaken by Tadros specifically investigated creep and shrinkage of high-strength concrete since earlier creep and shrinkage models were developed based upon conventional concrete data. The 2007 AASHTO LRFD model, based upon the 2003 study considers volume to surface ratio, relative humidity, and various age and loading aspects respectively.

AS 3600 – 2009

The AS 3600 creep and shrinkage models include correction factors for the type of environment, maturity of hardened concrete, and time. The environmental factor considers climates ranging from arid to tropical / near-coastal. Concrete strength is also considered through a basic creep coefficient and calibration factors.

Eurocode 2 (2004)

Eurocode 2 takes into account the ambient humidity, the dimensions of the element and composition of the concrete to estimate the amount of creep and shrinkage. Creep is also influenced by the maturity of the concrete when the load is first applied and depends on the duration and magnitude of the loading.

EXPERIMENT STUDY

A modified version of ASTM C512 (2010) "Standard Test Method for Creep of Concrete in Compression" was performed to determine the creep of 4x24 in. (100x600 mm) cylinders loaded to 40 percent of the design strength of 10,000 psi and 8000 psi (68.9 MPa and 55.1 MPa). In addition, the same cylinders were used to determine the shrinkage of the specimens using a modified version of ASTM C157 (2008) "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete." Each specimen was placed in 4 x 24 in. (100x600 mm) polyvinyl chloride (PVC) pipes. Within 24-48 hours of placement, the specimens were de-molded and DEMEC points were outfitted with five-minute quick set epoxy on the specimens and preliminary readings were taken. Nine locations on each cylinder could be read to determine the change in strain over that length. The average of all of the readings was computed to be the total strain of the specimen. The creep and shrinkage specimens are kept in controlled environmental condition having temperature 73 ± 6 ℉ (23±1.0 ℃) and relative humidity 45 ± 5 %. The samples of these mixtures were taken from girders' mix of multiple-spans Bridge A7957-Route 50 in Osage County- Missouri, which is already completed. Span No. two of bridge was cast with HS-SCC and span No. three with NS-SCC. The HS-SCC and NS-SCC specimens were steam cured prior to strand released. Figure 1 illustrates the shrinkage and creep specimens under laboratory study. Tables 2 and 3 report the mix compositions and concrete properties for the HS-SCC and NS-SCC respectively.

a) Shrinkage specimens b) Creep specimens

Figure 1. Shrinkage and Creep specimens

Table 2. Mix composition of HS-SCC and NS-SCC

Type	Material	Weight (lb/yd^3)	
		HS-SCC	NS-SCC
Coarse Aggregate	Leadbelt 1/2" Dolomite	1340	1476
Fine Aggregate	Mississippi River Sand	1433	1433
Cementitious Material	Portland Cement Type I	850	750
Chemical Admixtures	Air Entraining Agent	17 oz/yd^3	17 oz/yd^3
	High Range Water Reducer	76.5 oz/yd^3	67.5 oz/yd^3
	Retarder	25.5 oz/yd^3	25.5 oz/yd^3
Water	--	280	260
W/Cm	--	0.329	0.346

Table 3. Properties of concrete

Mixture	Compressive Strength, psi (MPa) at 28 days		Duration of Steam Curing at 120 ℉ (49 ℃), hours prior to strand release
	Target	Tested	
HS-SCC	10000 (69)	11238 (77.54)	36
NS-SCC	8000 (55.2)	9966 (68.76)	18

RESULT AND DISCUSSION

Since the creep and shrinkage are susceptible to local material, environmental condition , and curing condition, it important to preform experimental study to determine the creep and shrinkage strain under these condition. Results of this study carried out for Bridge A7957 girders are compared with latest updated creep and shrinkage code models.

Creep

As shown in Table 4, the creep coefficient, which is total creep strain to elastic creep strain, shows that the HS-SCC developed 13% higher creep at 120 days than NS-SCC because HS-SCC has higher paste content. The comparisons with code models show that ACI 209 and Eurocode 2 underestimated the creep coefficient for both mixtures. AASHTO 2007 prediction model overestimated the creep for both HS-SCC and NS-SCC. The AS 3600 prediction model underestimated the Creep of HS-SCC; however, it overestimated the creep of NS-SCC.

Table 4. Measured and predicted creep coefficient at 120 days

Material	HS-SCC	NS-SCC
Measured	1.68	1.49
AASHTO LRFD 2007	1.8	1.95
ACI 209-08	0.82	0.73
AS 3600-2009	1.301	1.529
Eurocode 2 -2004	0.864	0.926

Shrinkage

Shrinkage results, as shown in Figures 2 and 3, illustrate that HS-SCC exhibited 12% higher drying shrinkage at 180 days than NS-SCC. The comparisons with code models ACI 209, AASHTO 2007, and AS 3600 show that these models are more conservative to predict the amount of shrinkage strain for both HS-SCC and NS-SCC; however, the Eurocode 2 yields a better prediction than the other models.

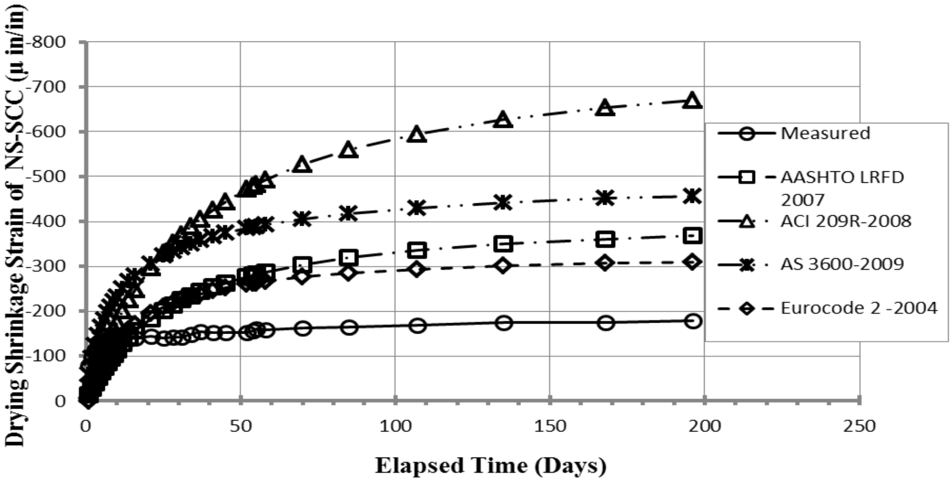

Figure 2. Drying shrinkage strain of NS-SCC

Based upon results of this study, correction factors are suggested for accelerated curing of self-consolidation concrete which can be applied to code models from ACI, AS, and Eurocode. Correction factors can be used for both NS-SCC and HS-SCC after ignoring the effect of compressive strength. Table 5 shows suggested correction factors.

It may be noted that the correction factors suggested by author are developed based on the steam cured specimens data obtained from Bridge A7957 girders and to refine the correction factor to be applied to wide range of SCC mix design additional data is needed, since the investigation beyond this type of SCC is still limited.

Table 5. Suggested correction factors

Code Model	Creep Coefficient	Shrinkage
ACI 209R	1.8	0.5
AS 3600	1.1	0.7
Eurocode 2	1.5	…

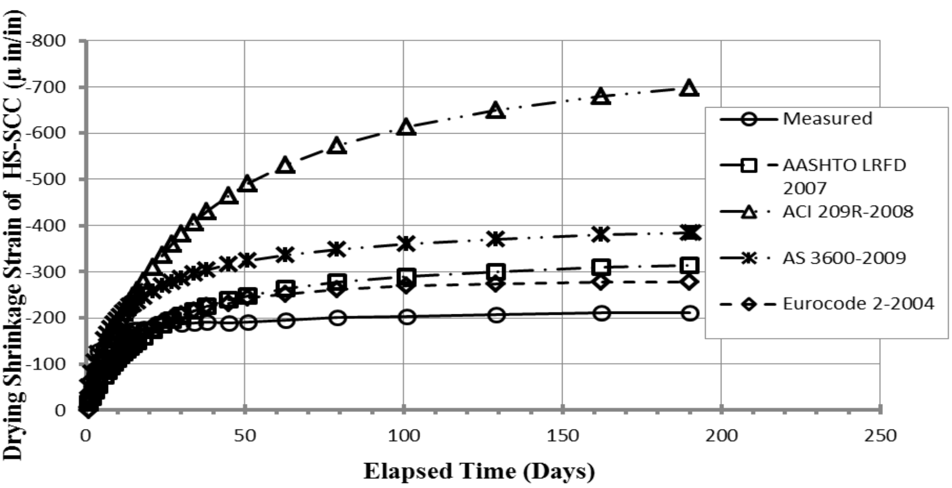

Figure 3. Drying shrinkage strain of HS-SCC

CONCLUSIONS

From this study, the following conclusions can be drawn:

1) In this study, both the HS-SCC and NS-SCC exhibited a low level of shrinkage and creep due to the effect of steam curing which was used in the concrete precast plant (commonly used in the production of prestressed bridge girders in the US during cooler production days). This limited shrinkage and creep are due to accelerated hydration of the cement and the moisture loss that occur when specimens are transferred to cooler condition (Neville 1970).
2) HS-SCC developed 13% higher creep strain at 120 days than that of NS-SCC, also HS-SCC exhibited 12% higher drying shrinkage at 180 days than that of NS-SCC.
3) Code Models from AASHTO LRFD 2007, ACI 209, AS 3600, and Eurocode 2 are more conservative to estimate the drying shrinkage.
4) Code Models from AASHTO LRFD 2007, ACI 209, AS 3600, and Eurocode 2 are wavering to predict creep coefficients.

Based upon this study presented it is concluded that AASHTO LRFD 2007 has a good average correlation for creep and shrinkage than other code models.

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