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INTRODUCTION

Drying shrinkage is regarded as a major cause contributing to the complex cracking issue in concrete. In 2006, the Federal Highway Administration reported that 12% (72,500 out of 599,976) of the country's bridges in the National Highway System were considered structurally deficient, which refers to bridges having major deterioration, cracks, or other deficiencies in their structural components including decks, girders, or foundations[1]. According to a survey conducted by Krauss and Rogalla in 1996, 62% of respondents in the state departments of transportation (DOTs) believed transverse cracking was a significant problem, and more than 100,000 bridges decks had suffered from transverse cracking, which is a pattern indicating the presence of drying shrinkage[2]. However, there are many factors which can lead to cracking in concrete bridge decks, such as dimensional stabilities (shrinkage and creep), environment fluctuations and restraint conditions. Drying shrinkage refers to the volume decrease over time due to moisture loss to the surrounding environment. It is affected by many factors, such as cement properties, quality of aggregate, size and grading of aggregate, water to cement ratio (w/cm) as well as water content, relative humidity, chemical admixtures, duration of curing and the size of the concrete specimen[3]. A comprehensive summary of factors affecting shrinkage of hardened concrete can be found in literature[4].

Research has shown that a greater potential of cracking due to the combination of drying shrinkage, autogenous shrinkage and plastic shrinkage exists in modern high performance concrete (HPC), which is usually comprised of supplementary cementitious materials (SCMs) and has a low w/cm below 0.40[5, 6]. To reduce the effect of shrinkage, internal curing using pre-wetted lightweight fine aggregates (LWFA) has been found effective both in the laboratory research and field applications in the last decade[7-14]. Similarly, shrinkage reducing admixtures (SRAs) have also been found to be successful in reducing cracking potential due to reductions in autogenous and drying shrinkage[5, 10, 15-21]. More information and a list of literatures can be found in ACI SP-256[22], a compilation specifically focused on internal curing of HPC.

Currently there are various models to predict the long-term drying shrinkage of concrete. However, there has not been any previous research done on predicting the efficacy of these models on internally cured HPC. Six existing drying shrinkage prediction models were evaluated in this paper to evaluate their ability to predict the drying shrinkage of internally cured HPC. The models analyzed in this paper were: ACI 209 model[23], CEB90 model [24], AASHTO model [25], B3 model [26], GL2000 model [27], and ALSN model [28].

The ACI 209 model is predominately used in the United States, and has been incorporated into many of the building codes. This model was developed empirically and is based on drying shrinkage data obtained prior to 1968. The equations can be used to predict the drying shrinkage of normal weight, sand lightweight and all lightweight concretes. A detailed description of the method can be found in ACI Committee 209 report [23].

European code specifies the prediction of drying shrinkage using the method developed in 1990 by the Comité Euro-International du Béton (CEB) [24]. The CEB90 model was derived using mathematical functions rather than strictly empirical data, and has been optimized from information from a data bank of normal weight plain structural concrete performance. It is not clearly stated weather the model can be applied to internally cured HPC, however, the A detailed description and guidance for this model can be found in the CEB 1990 code, section 2.1.6.4.4[24].

The AASHTO model of determining shrinkage, specified in AASHTO LRFD Bridge Design Specifications[25] Article 5.4.2.3.3, was developed by Huo et al. [29], All-Omaishi [30] and Tadros et al. [31] based on the ACI 209 model. This model is derived from the study of prestress losses in high strength concrete.

The B3 model developed by Bažant and Baweja is a better theoretically justified model than the rest models. It is based on "a systematic theoretical formulation of the basic physical phenomena involved", and it was "calibrated by a computerized data bank comprising practically all the relevant test data obtained in various laboratories throughout the world" [26]. Bažant and Baweja state the coefficient of variations for the B3 model are much lower than the CEB 90 model and the ACI 209 model.

The GL 2000 was developed by Gardner and Lockman [27]. Several minor coefficients have been modified in the latest version [32]. This model is effective at predicting shrinkage in normal strength concrete with a 28-day compressive strength less than 11,900 psi (82 MPA) and a w/cm ratio ranging from 0.4 to 0.6. Gardner and Lockman stated that the GL2000 method can be used to accurately predict the shrinkage regardless of which admixtures, mineral by-products, curing regime or casting temperature are employed [27]. This is realized by tracking concrete strength development with time, and measuring modulus of elasticity. Then, the concrete stiffness is taken into account thus the model can be applied to internally cured concretes. However, one assumption in the model is that the shrinkage decreases with the increase of strength and modulus elasticity. This is not true for the incorporation of SRAs, which significantly reduces the shrinkage and can adversely affect the strength slightly.

The ALSN model was proposed by Al-Manaseer and Ristanovic [28]. The model works exactly the same as the GL2000 model, expect that a coefficient was added to take the influence of SRAs into account. Thus these two models are evaluated at the same time for concrete mixtures without SRAs, and mentioned as GL2000/ALSN model in the following figures and tables. The ALSN model is the only model which is designed to predict the shrinkage of concrete containing a SRA dosage between 0 and 2.5% based on mass of total cementitious materials [28]. Due to above-mentioned reason, only data of concrete mixtures with SRAs (Mix 1-SRA and Mix 3C-SRA) are used to evaluate this model.

With all different models at hand, it is critical to choose a proper model to predict shrinkage for concrete using local materials. A major concern for each model is that whether the data source used to develop the model is representative of all concretes, such as concrete mixtures with SRAs. With the presence of SRAs in concrete, the shrinkage is reduced significantly, thus most existing models are unable to predict shrinkage in these types of concretes. Another example would be portland pozzolan cement concrete, which has been widely used in some countries [33]. ACI 209 committee states in the 209.2R-08 report that the average ultimate shrinkage value along with correction factors should be used only in the absence of specific shrinkage data for local aggregates and conditions. The report also recommends that to perform sensitivity analysis in selecting a proper model and to carry out short-term testing to calibrate the models to improve prediction. However, long-term shrinkage data is usually not readily available, especially with novel materials or admixtures. On the other hand, there are no set rules on how to use short-term testing to calibrate the model or to predict long-term performance. Additionally, very little work has been done to deal with this issue.

To solve this dilemma, Videla et al. [33] proposed a methodology to update prediction models when different materials were used compared to those used to develop the current prediction models. They included a correction factor applied to an ultimate shrinkage value, and a correction time function applied to shrinkage development. An experimental program was designed and carried out to derive a modified CEB90 model which enabled an accurate shrinkage prediction for concrete made with locally available materials. This research provided a feasible example on how to modify and utilize an established shrinkage prediction model to fit the local materials. However, they concluded that to achieve an estimation with 30% or less coefficient of variation, the minimum testing time required for 75×75×280 mm (3×3×11.25 in) and 100×100×500 mm (3×3×20 in) sample size are 100 and 170 days, respectively.

A simple alternative procedure based on the ACI 209 model is proposed in this study. It allows the prediction of long-term shrinkage strain using short-term experimental measurements. The reliability of proposed procedure was also discussed. In addition, free shrinkage data collected from 10 different HPC mixtures was compared to calculated shrinkage strains using all six above-mentioned prediction models. The appropriateness of using each model for concrete containing lightweight fine aggregate (LWFA) and/or SRAs was examined.

RESEARCH SIGNIFICANCE

Since concrete durability is closely related to effects of shrinkage, it is important to develop proper prediction models. The ACI 209 model is recommended by American Concrete Institute and widely used in the U.S. for normal strength concretes using conventional aggregates. It recommends to perform short-term testing on concrete to calibrate the model to improve predictions for local materials [23]. However, the calibration procedure is not clearly stated in the document. The significance of this research is to propose a procedure based on the ACI 209 shrinkage model to predict long-term shrinkage strain using short-term experimental measurements. In addition, evaluation of the accuracy of six existing shrinkage models is reported compared to the authors' experimental data. These models are the ACI 209 model, the CEB90 model, the AASHTO model, the B3 model, the GL2000 model, and the ALSN model. The shrinkage values determined by each model are compared against the experimental results from 10 high-performance concrete mixtures with incorporation of LWFAs and/or SRAs.

EXPERIMENTAL

The experimental program was designed to investigate the effect of LWFA and/or SRAs on reducing drying shrinkage in HPC. Two different types of LWFAs (one expanded shale and one expanded clay) and one SRA were incorporated into the standard local DOT HPC mixture, which contains 30% class F fly ash and 4% silica fume replacement by weight of cement. Drying shrinkage was monitor using the ASTM C157 test up to 180 days; compressive strength tests (ASTM C39) and modulus of elasticity tests (ASTM C469) were also performed at 28 days.

Materials and Mixture Proportions

The cement and SCMs used in this research were an ASTM C150 type I/II cement, an ASTM C618 class F fly ash, and an ASTM C1240 silica fume containing nearly pure silica dioxide in a noncrystalline form with approximately 1% crystalline silica.

Local siliceous river gravel and natural siliceous river sand were used in all concrete mixtures. The maximum size of the river gravel was 19 mm (3/4 in). The LWFAs used met ASTM C330 specifications. The absorption test (ASTM C128 cone test) was performed and the results showed the absorption capacity of the two LWFAs were 17.5% and 34.1% for expanded shale and clay, respectively. A desorption test (modified ASTM C1498) showed that more than 97% of the LWFA absorbed moisture was released by the point when an external relative humidity (RH) of 84% was obtained. This was true for both LWFA, regardless of their composition. More detailed information about the LWFAs can be found in another reference by one of the authors [34].

Table 1 shows a summary of the 10 mixture proportions investigated in this research. All mixing was conducted according to ASTM C192. The 28-day compressive strength was targeted at 34.5 MPa (5000 psi). A w/cm of 0.37 was used in all mixtures. The mixtures contained 375 kg/m^3 (633 lb/yd^3) of cementitious materials, including cement, fly ash and silica fume. The SRA was added at 2% of the total cementitious materials by mass, as an equal mass replacement of mixing water. A high-range water reducing admixture (HRWR) was adjusted and used to ensure uniform workability with similar slumps of 100 to 150 mm (4 to 6 in) among all mixtures. An air entraining admixture was also used to ensure proper free/thaw resistance specified by the local DOT, and had a target air content of 5% to 7%. The standard LWFA replacement level was determined using a previously published equation [35, 36], which was 164 kg/m^3 (277 lb/yd^3) for the shale LWFA and 77 kg/m^3 (130 lb/yd^3) for the clay LWFA, which would provide the same amount of internally available water in the reservoir of two types of LWFA based on their different absorption capacities, provided above. In addition, two additional replacement levels, approximately 60% and 80% of the standard level, were investigated to determine the effectiveness of the LWFA. A full replacement of normal weight fine aggregate by the shale LWFA was also studied for a maximum effectiveness. The effect of the combination of LWFA and SRA was also studied with the LWFA shale mixture with 2% SRA. All LWFA was pre-wetted at least 24 hours prior to mixing to ensure their absorption capacity was reached.

ASTM C157 Prism Test

Free shrinkage was monitored using the ASTM C157 prism test, which utilizes a 75×75×280 mm (3×3×11.25 in) concrete prism. The curing duration was modified from 28 days as specified in the standard [37] to better represent actual field exposure conditions. For all mixtures, three prisms for each mixture and specified curing duration were cast and cured for 1, 3, 7, 10, or 14 days, except for mixtures 3D and 3C-SRA for which curing time of 1, 7 and 14 days were applied, totaling 138 drying shrinkage prisms. The specimens were cast and sealed in molds using wet burlap and plastic sheeting to protect against moisture loss until demoldling at 24 hours. Then the prisms were transferred to a fog room for curing. Upon reaching their specified curing duration, the prisms were moved to an environmental chamber which maintains a drying environment of 23±2 °C (73±3 °F) and 50±4% relative humidity (RH), and initial length of each prism was recorded. The length change and mass loss were monitored up to 180 days from the initiation of drying. A brief summary of testing results is shown in Table 3. The predicted ultimate shrinkage strains are also given in Table 3 for each model. For simplicity, results of 3 and 10 day curing was not displayed in this table, however all data were included in the evaluation. Generally, longer curing time resulted in lower shrinkage at the early age, but did not significantly affect shrinkage at the later age (180 day). In addition, higher replacement levels of pre-wetted LWFA exhibited more benefit in terms of reducing shrinkage. The incorporation of SRAs was more effective to reduc the shrinkage compared to the LWFA. And the combination of LWFA and SRA further reduced shrinkage. A more detailed discussion on the testing results is beyond the scope of this paper, and can be found in another publication by one of the authors [34].

Mechanical Properties

In addition to the free drying shrinkage test, the compressive strength and modulus of elasticity were also measured at 28 days. Concrete cylinders measuring Φ75×150 mm (Φ3×6 in) were cast, cured and tested according to ASTM C39 and C469. The summary of the test results is listed in **Table 2**. The measured compressive strengths were used in all shrinkage prediction models.

EVALUATION OF PREDICTION MODELS

For each prediction model, certain criteria apply as well as different input factors. For the ACI 209 model, the CEB90 model, the B3 model and the GL2000 model, a thorough summary of criterion and input factors with a numeric example can be found in an ACI Committee 209 report [23]. More details about AASHTO model is outlined in literature [25] and as for the ALSN model [28].

To evaluate the accuracy of the prediction models, five methods can be used, including the residual method, the B3 coefficient of variation method, the CEB coefficient of variation method, the CEB mean square error method, and the CEB mean deviation method. Detailed descriptions of these methods have been summarized by Al-Manaseer and Lam [38] and ACI Committee 209[23] . The CEB mean square error (F_{CEB}%) method was arbitrarily selected in this study:

$$f_j = \frac{(Cal\ X_{ij} - Obs\ X_{ij})}{Obs\ X_{ij}} \times 100 \tag{1}$$

$$F_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n} f_j^2} \tag{2}$$

$$F_{CEB} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} F_i^2} \tag{3}$$

Where $Cal\ X_{ij}$ = predicted shrinkage strain at time j of experiment i; $Obs\ X_{ij}$ = experimental shrinkage strain at time j of experiment i; f_j = percent difference between calculated and observed data point j; F_i = mean square of residuals, %; F_{CEB} = mean square error, %; n = total number of values j of experiment i considered at a fixed time; and N = total number of data sets considered.

Figure 1 through **6** show the comparisons between the experimental data and the calculated data from each prediction model. The solid diagonal line in each figure represents perfect correlation between the measured value and calculated value for each model respectively. Two other reference lines (±40% of measured value) are added in all the figures to show the relative accuracy of each prediction models. All models, except theGL2000, underestimate the shrinkage strain, especially at the later age. In addition, a summary of calculated mean square error is given in **Table 4**. For concrete without SRAs, the results show that the GL2000 model (F_{CEB} = 20%) performed best in this research, followed by the CEB90 model (F_{CEB} = 38%) and the ACI 209 model (F_{CEB} = 42%), while the B3 model (F_{CEB} = 50%) and AASHTO model (F_{CEB} = 49%) show the largest variation. All models show similar performance among HPC control mixtures and HPC with LWFA mixtures, except the GL2000 model which gives a better prediction for HPC control mixtures (F_{CEB} = 13%) than HPC with LWFA (F_{CEB} = 20%).

There are noticeable slope changes in **Figure 1, and Figure 3**, in a similar pattern. This occurred in the ACI 209 model and AASHTO model. These trends occurred because these three models work better to calculate long-term shrinkage strains, and share a similar time function "f(t)= t/(t+a)". Meanwhile the B3 model (**Figure 4**) uses a different time function "f(t) = tanh (t/a)", and the CEB90 model (**Figure 2**), the GL2000 model (**Figure 5**) and the ALSN model (**Figure 6**) use "f(t)= sqrt((t/t/+a))". To some extent, the B3 and the GL2000 model describe the time dependence better since the slopes in those figures remain quite constant. The errors of these three models mostly come from the discrepancy between estimated ultimate shrinkage strain and measured shrinkage strain.

PROPOSED PROCEDURE BASED ON ACI 209 MODEL

Closer attention was given to the ACI 209 model in this paper. Although directly applying the model did not yield the most favorable accuracy according to the experimental data in this research, the authors believed that this model has a potential to capture any given hyperbolic-like drying shrinkage curve, regardless of the properties of constituents and admixtures. The current ACI 209 model is given as:

$$\varepsilon_{sh}(t, t_c) = \frac{(t-t_c)^{\alpha}}{f+(t-t_c)^{\alpha}} \cdot \varepsilon_{shu} \tag{4}$$

$$\varepsilon_{shu} = 780\gamma_{sh} \times 10^{-6} mm/mm\ (in/in) \tag{5}$$

Where $\varepsilon_{sh}(t,\ t_c)$ = shrinkage strain at concrete age t since the start of drying at age $t_{c,}$ mm/mm (in/in); ε_{shu} = ultimate shrinkage strain, mm/mm (in/in); α, f = constants defining the shape of time-dependent curve; γ_{sh} = the cumulative product of the applicable correction factors including initial moist curing duration, ambient relative humidity, size of the drying specimen in terms of the volume-surface ratio, and fresh concrete properties (i.e. slump, fine aggregate factor, cement content, and air content).

It is noted that for simplification an average value of 1.0 was suggested for constant α, representing a flatter hyperbolic form. However, the specific mathematical form of Eq.(4) is able to capture the time-dependent characteristic of a drying shrinkage curve, which starts from the origin and converages at an asymptote. To manipulate (curve fitting) three parameters (ε_{sh} , α, and f), Eq.(4) is able to describe any "drying-shrinkage-like" hyperbolic-like curves with high accuracy ($R^2 > 0.99$). A non-linear Levenberg-Marquardt least squares fitting tool was used in curve fitting. In most cases, the curve fitting tool is applied to a set of drying shrinkage data, and then the three curve fitting parameters are stable after 10 to 20 iterations. A similar procedure has been successfully used in predicting long-term chemical shrinkage[36, 39, 40].

To determine the minimum required testing duration, a sensitivity study was conducted using the proposed prediction model. **Table 5** shows a summary of the predicted ultimate drying shrinkage strain using experimental measurements. The sensitivity study was performed to determine a minimum testing period for different concrete mixtures in order for the prediction model to be valid. It should be noted that for concrete without SRA, after approximately 50 days from initiation of drying, the predicted ultimate values are stable. Also, there is an assumption that the prediction from data recorded from a longer testing period would yield a more accurate ultimate shrinkage strain value. Most ultimate values (except Mix 3A-3 day cure) derived from data up to 50 day are around 5% when comparing to the ultimate value derived from 180 day data. This is acceptable and within the coefficient of variation of other testing parameters. For concrete with the incorporation of SRA, it was observed that a longer measurement period was needed due to delayed shrinkage development. A testing period of 84 day was selected as a cut-off date for Mix 1-SRA and Mix 3C-SRA.

Figure 7 shows the comparison between experimental measurements, the improved ACI 209 model, and the GL2000/ALSN model. One mixture and curing regime was randomly selected to represent a group of test, which are the control HPC, HPC with LWFA, HPC with SRA, and HPC with SRA and LWFA. It showed that the proposed procedure better predicts the shrinkage for all of the concrete mixtures when compared to the GL2000 model. Therefore, the conclusion can be drawn that it is possible to obtain a stable and more accurate ultimate shrinkage stain. The minimum 50 day testing duration works well for the control HPC and the internally cured HPC with pre-wetted LWFA. A longer testing duration of 84 days was selected to predict shrinkage strain of concrete with the incorporation of SRA. To apply this method to local or novel concrete, it is recommended that an individual cut-off date should be chosen. The proposed procedure is briefly summarized as follow:

- Perform ASTM C157 test, track the length change in a weekly basis (daily basis for the first week of drying);
- After each measurement starting from 28 days of drying, perform curve fitting to all data at hand using Eq. (4), determine the three parameters (ε_{sh} α, and f);
- Keep tracking the shrinkage development till the fitted ε_{sh} is stable at certain drying period (cut-off date), take the last fitted ε_{sh} as the ultimate shrinkage value;
- For the HPC studied in this research, a cut-off date of 50 day is reliable for the control HPC and the HPC internally cured by pre-wetted LWFA.A longer cur-off date of 84 day is selected for the HPC incorporated with 2% SRA.

CONCLUSIONS AND RECOMMENDATIONS

Ten different HPC concrete mixtures with LWFA or/and SRA were cast and drying shrinkage was monitored by the ASTM C157 test. Data collected was used to evaluate six existing shrinkage prediction models, including the ACI 209 model, the CEB90 model, the AASHTO model, the B3 model, the GL2000 model and the ALSN model. Several conclusions can be drawn as follows:

- All models, except the GL2000 model, underestimated shrinkage compared to experimental measurements in this research;
- The GL2000 is the best model to predict shrinkage, especially for the HPC control mixture, at the later ages, followed by the CEB90 model. The GL2000 model also gave an acceptable performance predicting HPC internally cured by pre-wetted LWFA; and,
- Although developed to predict shrinkage for concrete with SRA, the ALSN model did not perform satisfactorily as expected in this research.

A procedure to predict long-term shrinkage stain using short-term experimental measurements was proposed based on current ACI 209 model. The comparison results indicated that the prediction using the proposed procedure outperformed all existing shrinkage models. A 50 day test period was recommended for HPC and internally cured HPC with pre-wetted LWFA. A longer test period of 84 day was recommended for concrete with SRA.

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Table 1 - Concrete mixture proportions

Mixture	Note	Cement (kg/m^3)	Fly Ash (kg/m^3)	Silica Fume (kg/m^3)	Water (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	LWFA (kg/m^3)	SRA (kg/m^3)	AE (mL/m^3)	HRWR (mL/m^3)
1	Control	248	112	14.8	139	1074	659	0	0	61	905
1-SRA	w/ SRA	248	112	14.8	131	1074	659	0	7.53	451	1030
2A	Low Clay	248	112	14.8	139	1074	556	45	0	61	900
2B	Medium Clay	248	112	14.8	139	1074	518	62	0	56	880
2C	Standard Clay	248	112	14.8	139	1074	482	77	0	41	900
3A	Low Shale	248	112	14.8	139	1074	512	93	0	56	800
3B	Medium Shale	248	112	14.8	139	1074	452	131	0	54	900
3C	Standard Shale	248	112	14.8	139	1074	400	164	0	52	860
3D	Full Shale	248	112	14.8	139	1074	0	466	0	104	920
3C-SRA	Standard Shale w/ SRA	248	112	14.8	131	1074	400	164	7.53	133	945

*1 kg/m^3=1.69 lb/yd^3, 100 mL/m^3= 2.58 fl oz/ yd^3

Table 2 - Mechanical properties of concrete cylinders at 28 day

Mixture	1	1-SRA	2A	2B	2C	3A	3B	3C	3D	3C-SRA
Compressive Strength (Mpa)	36.8	33.245	23.84	28.65	38.1	41.35	31.67	36.64	46.77	35.01
Modulus of Elasticity (Gpa)	37.3	31.5	28.2	28.7	28.8	32.7	24.5	27.2	-	-

* 1 MPa=145 psi, 1 GPa=145 ksi

Table 3 – Summary of free shrinkage testing results (up to 180 days) and ultimate shrinkage strain predicted using each model. Environmental chamber condition: 23±2 °C (73±3°F), 50% RH

Mixture	Curing period (day)	Measured shrinkage strain (μm/m, 10^{-6} in/in) at time (number of days) from initiation of drying							Predicted ultimate shrinkage (μm/m, 10^{-6} in/in)					
		7 day	14 day	28 day	56 day	90 day	120 day	180 day	ACI209	CEB90	AASHTO	B3	GL2000 /ALSN	ALSN (SRA only)
	1	-344	-484	-637	-764	-811	-832	-868	-912					
1	7	-307	-444	-564	-660	-724	-750	-779	-725	-578	-673	-431	-753	-
	14	-300	-427	-540	-660	-725	-745	-776	-668					
	1	-210	-327	-467	-577	-631	-658	-707						
1-SRA	7	-160	-244	-400	-530	-578	-622	-654	-	-	-	-	-	-437
	14	-160	-260	-384	-494	-507	-613	-660						
	1	-420	-574	-717	-800	-847	-871	-894	-912					
2A	7	-307	-457	-610	-744	-773	-798	-837	-725	-666	-956	-456	-936	-
	14	-297	-454	-627	-730	-772	-792	-834	-668					
	1	-317	-477	-610	-690	-730	-751	-807	-912					
2B	7	-240	-400	-557	-647	-700	-731	-770	-725	-634	-827	-445	-854	-
	14	-207	-350	-514	-620	-680	-705	-751	-668					
	1	-317	-454	-560	-637	-696	-706	-757	-912					
2C	7	-254	-394	-530	-630	-692	-729	-743	-725	-569	-653	-429	-740	-
	14	-237	-370	-510	-620	-674	-716	-729	-668					
	1	-277	-394	-527	-600	-639	-660	-750	-912					
3A	7	-271	-417	-550	-654	-693	-726	-744	-725	-547	-609	-425	-711	-
	14	-244	-377	-520	-617	-676	-703	-760	-668					
	1	-327	-484	-600	-681	-723	-741	-784	-912					
3B	7	-264	-400	-580	-660	-713	-738	-799	-725	-613	-762	-440	-812	-
	14	-260	-394	-544	-654	-707	-750	-790	-668					
	1	-304	-440	-567	-651	-690	-713	-757	-912					
3C	7	-247	-397	-534	-647	-714	-745	-798	-725	-579	-675	-431	-775	-
	14	-251	-384	-544	-644	-702	-756	-791	-668					
	1	-250	-420	-517	-618	-667	-686	-697	-912					
3D	7	-207	-317	-454	-580	-654	-678	-703	-725	-511	-548	-419	-668	-
	14	-147	-230	-370	-514	-594	-630	-663	-668					
	1	-167	-267	-387	-507	-527	-563	-620						
3C-SRA	7	-130	-210	-357	-477	-522	-553	-590	-	-	-	-	-	-426
	14	-107	-197	-320	-447	-499	-527	-577						

Table 4 – Summary of mean square error (F_{CEB}%) of different models

Model	ACI 209			CEB90			AASHTO			B3			GL2000/ALSN			ALSN (SRA only)	
Mixture	HPC	Clay	Shale	HPC	Clay	Shale	HPC	Clay	Shale	HPC	Clay	Shale	HPC	Clay	Shale	SRA	SRA+Shale
F_{CEB}% for each group	46	42	40	38	40	35	55	45	50	53	51	47	13	20	21	31	27
F_{CEB}% overall	42			38			49			50			20			29	

Table 5 – Sensitivity study using measurement up to different age to predict ultimate shrinkage
(Blocked area indicates selected cut-off date, NC-non converging)

Mixture	Curing period (day)	Number of days from initiation of drying										Difference between selected cut-off date and 180 day
		28	35	42	49	56	70	84	98	120	180	
1	1	-0.00095	-0.00092	-0.00094	-0.00094	-0.00096	-0.00095	-0.00094	-0.00096	-0.00095	-0.00095	-1.1%
	7	-0.00106	-0.00097	-0.00093	-0.00089	-0.00087	-0.00087	-0.00087	-0.00089	-0.00088	-0.00087	2.3%
	14	-0.00109	-0.00105	-0.00100	-0.00095	-0.00097	-0.00098	-0.00099	-0.00095	-0.00093	-0.00091	4.4%
1-SRA	1	NC	-0.00166	-0.00113	-0.00102	-0.00096	-0.00086	-0.00082	-0.00079	-0.00079	-0.00080	-1.3%
	7	NC	-0.00346	-0.00152	-0.00128	-0.00115	-0.00096	-0.00083	-0.00078	-0.00079	-0.00076	2.6%
	14	NC	-0.00285	-0.00168	-0.00130	-	-0.00086	-0.00078	-0.00078	-0.00079	-0.00079	-1.3%
2A	1	-0.00116	-0.00107	-0.00101	-0.00100	-0.00097	-0.00097	-0.00095	-0.00095	-0.00095	-0.00095	5.3%
	7	-0.00093	-0.00093	-0.00094	-0.00092	-0.00094	-0.00091	-0.00089	-0.00086	-0.00095	-0.00087	5.7%
	14	-0.00091	-0.00098	-0.00091	-0.00089	-0.00087	-0.00086	-	-	-0.00084	-0.00086	3.5%
2B	1	-0.00084	-0.00083	-0.00083	-0.00082	-0.00081	-0.00079	-0.00078	-0.00079	-0.00079	-0.00082	0.0%
	7	-0.00091	-0.00083	-0.00080	-0.00076	-0.00076	-0.00075	-0.00076	-	-0.00078	-0.00080	-5.0%
	14	-0.00076	-0.00073	-0.00073	-0.00072	-0.00071	-0.00072	-0.00074	-0.00074	-0.00075	-0.00078	-7.7%
2C	1	-0.00084	-0.00082	-0.00082	-0.00080	-0.00079	-0.00080	-0.00078	-0.00079	-0.00078	-0.00082	-2.4%
	7	-0.00091	-0.00085	-0.00080	-0.00079	-0.00078	-0.00078	-0.00078	-0.00079	-0.00081	-0.00080	-1.3%
	14	-0.00073	-0.00075	-0.00074	-0.00075	-0.00075	-0.00077	-0.00076	-0.00077	-0.00077	-0.00078	-3.8%
3A	1	-0.00068	-0.00070	-0.00069	-0.00069	-0.00069	-	-0.00069	-0.00069	-0.00069	-0.00076	-9.2%
	7	-0.00089	-0.00086	-0.00082	-0.00080	-0.00081	-0.00079	-0.00078	-0.00079	-0.00076	-0.00079	1.3%
	14	-0.00088	-0.00082	-0.00081	-0.00080	-0.00078	-0.00078	-0.00078	-0.00078	-0.00078	-0.00082	-2.4%
3B	1	-0.00080	-0.00081	-0.00081	-0.00081	-0.00081	-0.00079	-0.00079	-0.00078	-0.00078	-0.00081	0.0%
	7	-0.00137	-0.00097	-0.00088	-0.00084	-0.00082	-0.00081	-0.00081	-0.00080	-0.00080	-0.00083	1.2%
	14	-0.00092	-0.00090	-0.00086	-0.00085	-0.00084	-0.00084	-0.00084	-0.00084	-0.00085	-0.00086	-1.2%
3C	1	-0.00084	-0.00080	-0.00078	-0.00077	-0.00077	-0.00076	-0.00076	-0.00076	-0.00076	-0.00079	-2.5%
	7	-0.00090	-0.00090	-0.00090	-0.00085	-0.00083	-0.00081	-0.00081	-0.00082	-0.00083	-0.00086	-1.2%
	14	-0.00087	-0.00088	-0.00084	-0.00084	-0.00083	-0.00083	-0.00083	-0.00083	-0.00087	-0.00088	-4.5%
3D	1	-0.00116	-0.00107	-0.00101	-0.00100	-0.00097	-0.00097	-0.00095	-0.00095	-	-0.00095	5.3%
	7	-0.00093	-0.00093	-0.00094	-0.00092	-0.00094	-0.00091	-0.00089	-0.00086	-	-0.00087	5.7%
	14	-0.00091	-0.00098	-0.00091	-0.00089	-0.00087	-0.00086	-	-	-	-0.00086	3.5%
3C-SRA	1	-0.00117	-0.00117	-0.00094	-0.00080	-0.00085	-	-0.00069	-0.00065	-0.00065	-0.00069	0.0%
	7	NC	-0.00157	-	-0.00079	-0.00077	-	-0.00067	-0.00066	-0.00065	-0.00065	3.1%
	14	NC	-	-	-	-0.00082	-	-0.00067	-0.00067	-0.00064	-0.00066	1.5%