modeling of prestress loss in extremely high-performance concrete

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Abstract:

The design of prestressed structural parts relies heavily on the accurate estimate of prestress losses. Even though UHPC shows different creep and shrinkage behaviours, a survey of the literature indicated a dearth of data and a limited number of prediction models for UHPC-class materials' creep and shrinkage behaviours. New equations and data-driven models were devised to solve this shortfall in understanding the creep and shrinkage behaviour of UHPC-class materials. Compressive strength, material maturity, and age all play a role in determining how much ultimate creep and shrinkage UHPCs will experience. Results were compared to commercially available UHPC-class materials that had been assessed for creep and shrinkage. The following were the study's primary goals: For each service condition, develop data-driven models to predict the ultimate creep coefficient and the shrinkage strains of UHPC-class materials; (2) examine the current AASHTO LRFD equations for creep and shrinkage of conventional concrete and determine the applicability of the parameters in the equations for UHPC-class materials; (3) compare the predictive models with measured data, AASHTO LRFD equations, and existing European recommendations for UHPC-class materials; (4)

Introduction

To put it simply, UHPC has better mechanical qualities than ordinary concrete, including high compressive and tensile strength, high tensile strain capacity and low water absorption [10–11], as well as long service life [9–10). UHPC's mechanical qualities set it apart as a construction material, especially for use in precast/prestressed concrete. When employed in pretensioned bridge girders with smaller cross sections and more durable components, UHPC may solve long-standing issues including longer spans, wider girder spacing, and shallower superstructure depth. By virtue of UHPC's better mechanical qualities, more prestressing forces may be used to produce bridge girders with higher structural capabilities than those built from ordinary concrete (e.g., flexure, shear). Because of this, pretensioned UHPC girders may minimise the number of spans (and hence substructures) in multi- span bridges, which can save time and money during construction while providing a stronger structure.

When concrete structures are exposed to long-term compressive stresses, they deform in a time-dependent manner.

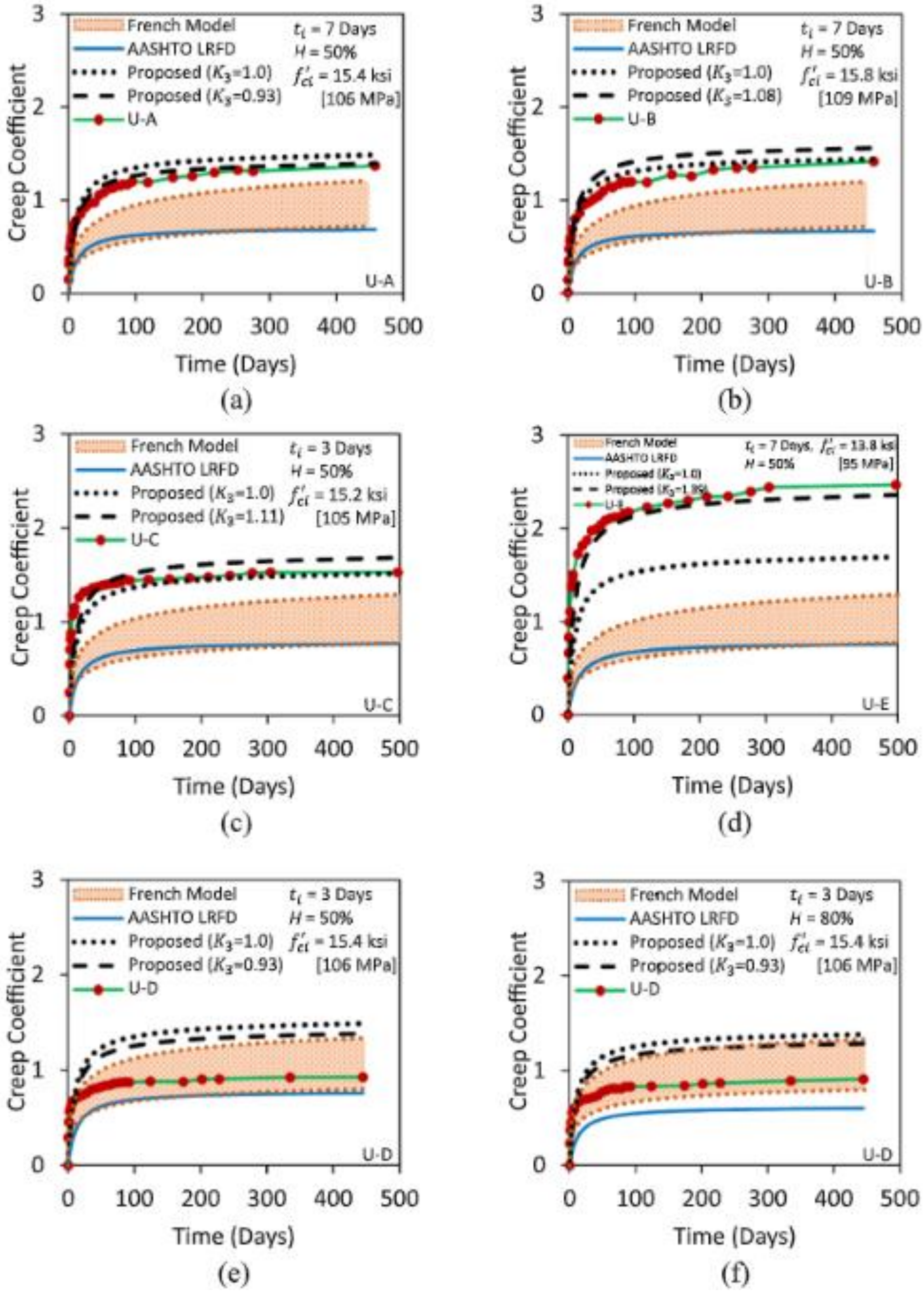
In order to accurately estimate a structure's long-term performance, it is vital to understand how deformations and prestress losses could affect the structure's serviceability. There are two types of deformation: creep and shrinkage. When a constant weight on a piece of concrete causes it to distort over time, this is called creep [2]. Creep coefficient is a measure of how much stress a material can take before it breaks. Hydration in cementitious materials and dehydration in concrete members produce shrinkage [2]. When a prestressed member is subjected to creep and shrinkage deformations, the prestress force gradually decreases and the member deflections increase.

There is a paucity of data on the creep and shrinkage behaviour of UHPC-class materials, as shown by a literature study. Specificall

Models for estimating long-term deformation and prestress losses owing to UHPC creep and shrinkage aren't accessible within the framework of US-based structural design guidelines or requirements. Many numerical models and design recommendations have been established outside the United States, such as in France and Switzerland [16,17], where the models were mostly based on the European goods and standards that were readily accessible. To date, the body of information available has been sufficient for a preliminary assessment of creep behaviour, but the depth required to construct a prediction model to assess various service situations is lacking.. For this purpose, the study collects additional data and then builds on the existing conventional concrete creep and shrinkage predictive models that are currently used to design bridges in accordance with the American Association of State Highway and Transportation Officials Load and Resistance Factor Design Bridge Design Specifications (2020), hereafter referred to as AASHTO LRFDS..

2. The importance of the research

This work examined the long-term deformations and prestress losses of UHPC-class materials, and created prediction models for creep and shrinkage.. Mohebbi et al. [14] laid the groundwork for this study. The following were the goals of this study: For each service condition, develop data-driven models to predict the ultimate creep coefficient and shrinkage strain of UHPC-class materials; (2) examine the current AASHTO LRFD [1] equations for creep and shrinkage of conventional concrete and determine the applicability of parameters in the equations for UHPC-class materials; and (3) compare the predictive models with measured data, AASHTO LRFD [1] equations, and existing European recommendations for UHPC-class mater. A



ig. 1. Creep coefficient of UHPC-class materials loaded at early age: (a) U-A with 50% H, (b) U-B with 50% H, (c) U-C with 50% H, (d) U-E with 50% H, (e) U-D with50% H, (f) U-D with 80% H, (g) U-G with 50% H, (h) U-G with 80% H, (i) U-H with 50% H, (j) U-H with 80% H, (k) U-J with 50% H, and (l) U-J with 80% H.

3. Experimentation

Both creep and shrinkage testing and full-scale testing of pretensioned UHPC girders were carried out as part of this study's experimental programme.

Using eight distinct, commercially available UHPCs, ASTM C1856 [6], which refers to ASTM C512 [5], tests were performed on the compressive creep behaviour of UHPC-class materials. This publication referred to these materials as U-A through U-E, U-G, U-H, and U-J. Loading age, sustained stress level, relative humidity (H), and UHPC product were among the experimental factors. Using the ASTM C1856 [6] changes, the identical UHPC materials that were employed in the creep investigation were put through their paces according to ASTM C157 [3]. Detailed information on the creep and shrinkage studies, as well as the testing process, is included in a separate paper [14]. Detailed findings for creep and shrinkage tests may be seen in Tables 1 and 2 correspondingly. Measurements of the creep of all of the UHPC-class materials were taken up to 386 days after loading. After demolding the samples, shrinkage measurements were taken between 270 and 365 days. You should keep in mind, however, that these measures don't take into account any shrinking that occurs between casting and de-molding. The modulus of elas material correction factors K1, K3, and K4 are shown in Tables 1 and 2.

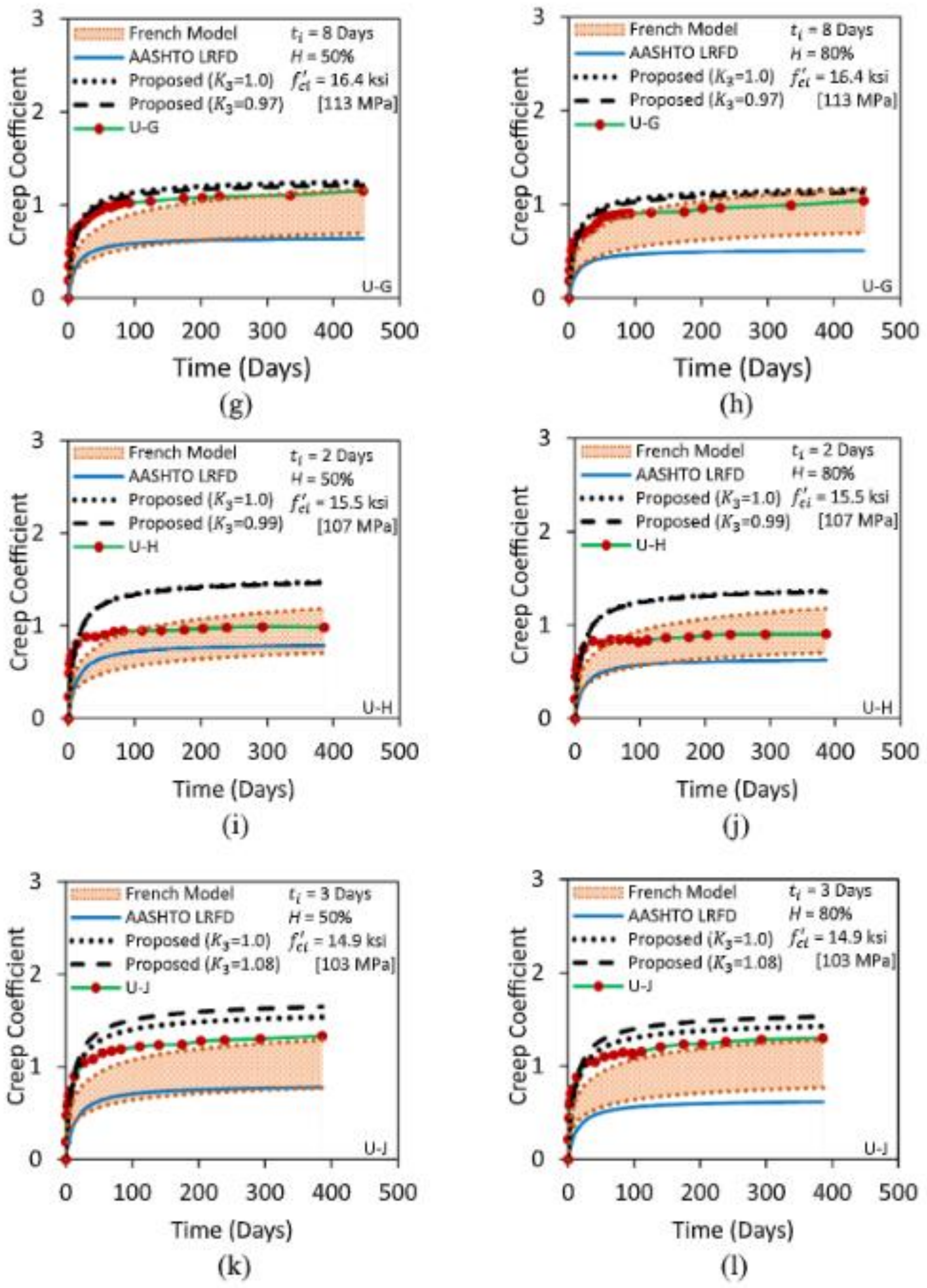


Fig1 (continued)

creep, and shrinkage of UHPC-class materials, respectively, which areexplained in the UHPC material correction factors section 4.5 of thispaper.Figs. 1 and 2 present the measured creep behavior of UHPC-classmaterials loaded at early age and mature age, respectively. Results ofthe creep and shrinkage tests were used to develop predictive models forcreep coefficient and shrinkage strain of UHPC-class materials. TheUHPC models were then incorporated into an overarching prestress lossmodel, allowing comparison with measured prestress losses recordedduring full-scale pretensioned girder fabrication and testing. Seven full-scale pretensioned UHPC girders with 0.7-inch (17.8-mm) diameterstrands and different depths, web thicknesses, and lengths were con-structed using two commercially available UHPC products. Details onthe design and fabrication of these girders can be found elsewhere [7,8].The initial prestress loss due to elastic shortening and the time-dependent losses due to creep, shrinkage, and strand relaxation of thegirders were measured.4. Creep and shrinkage model developmentThe AASHTO LRFD [1] section 5.4.2.3 provides equations to esti-mate the creep coefficient and shrinkage strain of conventional concreteup to compressive strengths of 15 ksi (103.4 MPa). Table 3 summarizesthese equations (Eqs. (1)–(8)). Mohebbi et al. [15] examined theAASHTO equations for creep and shrinkage of UHPC-class materials anddiscussed the applicability of the parameters in the equations. The au-thors reported that, according to the available experimental data, thecurrent AASHTO LRFD [1] equations do not accurately estimate thecreep coefficient and shrinkage strain of UHPC-class materials. There-fore, some parameters may require recalibration. This paper discusseseach parameter and introduces recalibrated, data-driven predictivemodels relevant to UHPC-class materials. Some of these parameterswere investigated elsewhere [14] and are summarized here, whileothers are fully investigated herein.A. Mohebbi and B. Graybeal

Fig. 3. Girder construction and instrumentation at midspan. Source: FHW

4.2. Factor for adjusting for size

Size and form of a concrete part affects the pace at which moisture enters or exits the concrete, which in turn affects the rate of creep and shrinkage. In Eq., the typical concrete ks size adjustment factor is presented (3). Due to the thick microstructure of UHPC, the rate at which moisture enters or exits UHPC is significantly decreased, compared to normal concrete. Due of the size and form effect, UHPC members aren't likely to be greatly affected.

It was found that drying out UHPC-class materials had a negative impact on them. Table 1 shows the results of creep testing in a 50 percent H and sealed state. Sealing specimens represents fundamental creep, which is defined as the passage of moisture through the material and is hence irrespective of specimen size and form. The final creep coefficient of UHPC was not affected by the drying condition, as shown by a comparison of the U-D, U-G, U-H, and U-J findings. Drying had only a tiny influence on UHPC creep, as seen by the 0.1 difference between the final creep coefficients in 50% H and sealed state

Table 2 shows the drying shrinkage of UHPC specimens in 50 percent H, as well. By subtracting the total shrinkage of the sealed specimens from the shrinkage of the specimens in 50% H, the drying shrinkage was computed. It was found that drying shrinkage for UHPC-class materials in 50% H ranged from 3% to 36% of total shrinkage for U-C and U-B. Some of the UHPC-class materials evaluated in this research revealed a relatively low moisture exchange between the material and the environment, suggesting that drying had a modest influence on shrinkage.

As a result, six separate creep coefficient data points were recorded on various days in 50% H for each of the four types of material examined in the appendix and shown in Fig. A1.

Tested samples had a volume-to-surface area ratio of 1.0-inch (25.4 mm), which was related with 4-by-8-inch cylin-ders (102-by 203 mm). Also shown in Fig. A-1 are the creep coefficients corresponding to the sealed state of the chosen data points. A volume-to-surface area ratio of 1.0 in. (25.4 mm) showed that the UHPC creep coefficient was almost identical to the basic creep coefficient. As the volume-to-surface area ratio increases, the creep coefficient lowers dramatically, from 1.0 in. (25.4 mm) to 6 in. (152.4 mm), until it reaches the basic creep [2]. The creep of UHPC is less likely to be impacted by the size and shape effect since there is a modest difference between the UHPC basic creep and that of the volume-to-surface area ratio of 1.0 in. (25.4 mm). Hence, the size correction factor ks for UHPC-class materials is recommended to be one in Eq. 1 based on the findings of creep and shrinkage tests (11).

Humidity, strength, and loading-age correction variables are included in this section.

Humidity, compressive strength, loading age, and maturity affect creep and shrinkage behaviour in UHPC-class materials. A detailed discussion on findings and model development is provided in a separate paper [14], and only major results are mentioned here.

According to the service condition of concrete members, the humidity correction variables khc in Equation (4) and khs in Equation (5) vary the ultimate creep and shrinkage of conventional concrete. Humidity correction parameters for UHPC-class materials were determined via studies examining compressive creep and uncontrolled shrinkage in 50% H and 80% H. Regression analysis of the collected data was then used to construct a linear connection. In Eq. (4), creep testing results were compared to the AASHTO LRFD relationship, and the results showed that the slope of the line of best fit of UHPC-class materials was lower than the AASHTO equation. That's why we came up with this new equation for the UHPC's humidity factor (Eq (12).

For the shrinkage humidity correction factor (Eq. (5)), the same technique was used to estimate the AASHTO equation (Eq. (5)). An AASHTO equation's slope was found to be quite near to the line of best fit for UHPC materials. Accordingly, it was determined that shrinkage behaviour of UHPC-class materials could be accounted for using the conventional AASHTO concrete humidity correction factor. The AASHTO formulae for humidity, on the other hand, assume a humidity level of 70% H as the default. Linear regression equation (5) was normalised to the baseline circumstances with 50% H. in order to be consistent with the other parameters and model development in this research. Eq. illustrates the link (13).

According to the compressive strength during loading, the strength correction factor (kf) in Eq. (6) affects the ultimate creep and shrinkage strain of typical concrete. Figure 3 is an example of what I mean. Girder building and instrumentation near the middle of the span. The FHWA is the source of this information.

5.2. Loss forecasting model

Total prestress losses and revised estimations of time-dependent losses of pre-tensioned girders are provided by AASHTO [1] LRFD section 5.9.3. Table 5 summarises the equations. It was determined that prestress transfer to deck installation was the period for comparison between the AASHTO model and measured data. NCHRP Report 496 [18] presents the equations for the losses caused by elastic shortening, shrinkage, and creep. The strain compatibility assumption in each calculation is that the concrete and strands have a complete connection. This means that as time passes, both concrete and its strands are subjected to the same degree of strain variation. AASHTO's prestress loss theory is expected to apply to UHPC-class materials, hence the same general model framework is employed to simulate UHPC behaviour here. When it comes to effectively predicting prestress losses, however, the creep and shrinkage formulae must be modified.

Equations (9)– (16) established in this work for creep coefficient and shrinkage were put into the AASHTO loss model in Equations (19) and (21). According to the manufacturer's guideline for 0.7-inch (17.8-mm) strands, 1.5 percent of the jacking stress (3 ksi (21 MPa) was assumed for strand relaxation. Based on the AASHTO LRFD

[1] and the location of the girders that were kept for testing, an average annual relative humidity map of 75% was estimated for the girders.

Table 4 shows the estimated total loss for each girder for the final measurement day, as well as the estimated starting loss from elastic shortening. The discrepancy between the measured and projected initial prestress loss for all girders was less than 4%. As can be seen in Figure 4, the seven full-scale pretensioned girders evaluated in this work had their effective stress recorded in strands and a prediction model developed. Figure 4 depicts the prediction model that incorporates the UHPC material correction coefficients K3 and K4. Tables 1 and 2 of this work were used to compute the UHPC material correction factors for U-H and U-J materials. UHPC's K3 correction factor was derived using the physical creep testing technique described previously and is defined as a ratio between the observed ultimate creep coefficient and Eq (9). Fig. 4 shows the effects of the K3 and K4 correction factors. Predictive models with and without material correction factors adequately predicted the strands' effective prestress force with time. For U-H girders (Fig. 4a–d), the model overestimated the total prestress loss, whereas for U-J girders, the model underestimated the total prestress loss. The accuracy of the prestress loss prediction for U-H material girders was enhanced by using material correction factors in the creep and shrinkage computation.

The following are some last thoughts:

UHPC-class materials' deformations and prestress losses were examined in this work. UHPC-class materials in the U.S. highway sector are the subject of this study as part of a broader effort to provide structural design guidelines and material performance criteria. Materials of several UHPC-class commercially available options have been assessed Creep and shrinkage models are being developed to assess prestress losses in tensioned UHPC girders, building on previous research [14] that has shown that both phenomena occur. This study's findings led to the following conclusions:

The present AASHTO LRFD [1] prediction models for conventional concrete creep and shrinkage do not effectively forecast the creep and shrinkage of UHPC, underestimating the ultimate creep coefficient and shrinkage strain for the UHPC-class materials examined in this work.

2. The creep coefficient and shrinkage strain of UHPC-class materials were predicted using data-driven models. Table 3's Eqs. (9)–(16) indicate the creep and shrinkage behaviour predictions based on a wide range of initial loading and service conditions, respectively.

Eight commercially available UHPC-class materials with varying experimentally observed creep and shrinkage characteristics are well represented by the suggested models.

For pretensioned element design and practise in the U.S., the models provided herein are more widely applicable and include a larger sustained compressive stress than those recommended in Europe. A comparison was made between the observed UHPC creep and the previously developed European forecasting models. The test data and European models were found to be in reasonable agreement; expected behaviours from A. Mohebbi and B. Graybeal were also seen.

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