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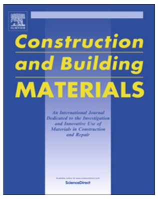

Improvement of concrete creep prediction with probabilistic forecasting method under model uncertainty

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HIGHLIGHTS

- Concrete creep is one of the important considerations for field and construction engineering.
- Various prediction models for concrete creep exist from different model codes and literature.
- A novel predictive modeling method for creep is proposed using competing prediction models.
- The proposed method provides reliable and better predictions than using a single creep prediction.

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ABSTRACT

Concrete creep has much to do with structural integrity and durability. Therefore, it is important to estimate long-term creep prediction based on actual mix composition and operating conditions. There are various creep models from different organizations and literature. Consequently, model uncertainty inevitably arises. This study proposes a novel predictive modeling method with short-term creep tests to address the model uncertainty in the creep prediction. The proposed method introduces various creep models and combines them by optimal weights to complement each other by sharing their strengths. Two creep tests were performed and used to compare the proposed method with individual creep models. Depending on different mix compositions and stress levels, individual models provide different predictions over long-term behavior. The proposed method only provides the consistent and reliable predictions over long-term behaviors.

1. Introduction

When concrete is subjected to a permanent load (e.g., self-weight and pre-stressing) for a considerable period of time, concrete undergoes additional deformations even without any increase of the applying load. This time-dependent deformation is referred to as creep. Creep effects on concrete structures are one of the important considerations for design, construction and maintenance. Creep increases the deflection with time in reinforced concrete beams. Especially in pre-stressed concrete structures, creep may result in loss of pre-stressing. The loss of pre-stressing significantly affects the strength of the structural members and the member's serviceability [1]. In mass concrete structures such as dams and nuclear power plants, creep relieves the initial thermal stresses due to thermal gradient. However, cooling produces a reversible stress at the later age (creep relief). As a result of the creep relief, creep may be a cause of cracking in the interior of mass concrete [2]. Creep has much to do with durability of concrete structures [3].

Creep should be reliably predicted to reduce negative impacts on both structural integrity and durability. Based on the reliable creep prediction, proper counter measures of creep effects can be made. In practice, several model codes and literature provide the creep models to estimate the creep and shrinkage based on actual mix compositions, strength of concrete and operating conditions. Such creep models include American Concrete Institute (ACI) model [4], International Federation for Structural Concrete (*fib*) model [5], Korean Concrete Institute (KCI) model [6], Model B3 (RILEM) [7], American Association of State Highway and Transportation Officials (AASHTO) model [8], and so on. These creep models have own model parameters to determine a rate of creep progress and its ultimate creep coefficient. These parameters reflect variability of the creep progress caused by inherent heterogeneity of the concrete materials. In practice, short-term creep

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tests are performed to estimate the model parameters (calibration of creep model). Based on a calibrated model, creep prediction is estimated for long-term behavior.

Although various creep models are available, no one can guarantee that a certain creep model is always best. Stated differently, model uncertainty inherently arises from various creep models. In addition, different predictions are sometimes estimated from the different creep models. Model selection method is generally used to select a best model by scoring each creep model. To select a best model, model selection criteria compute the score by balancing the predictive accuracy and model complexity. Such model selection criteria include Akaike Information Criteria (AIC) [9], Bayesian Information Criteria (BIC) [10], and so on. However, a best creep model varies depending on actual mix compositions, strength of concrete, operating conditions, and calibration data. Especially, different creep predictions are sometimes obtained over extrapolation regions (i.e., forecasting). Using a single creep model ignores predictive capabilities of alternative creep models, so that predictive uncertainty may be underestimated.

To address the abovementioned difficulties, this study proposes a novel predictive modeling method to introduce various creep models and combine them by optimal weights. The idea of the proposed method is that some of creep models are useful and they can be complemented each other by sharing their strengths to improve the predictive capability [11]. Benefits of combining predictions are well appreciated in statistics [12], meteorological forecasting [13,14] and econometrics [15,16]. Especially in econometrics, the density forecast combination method is referred to as optimal pooling method [16–18]. The optimal pooling method is one of the predictive modeling methods to make better predictions under incomplete creep models. Based on our best knowledge, this predictive modeling method has not been considered in the previous studies. To investigate the influence of the calibration periods, three different calibration periods were considered. The results of both proposed method and individual models were compared over both calibration data and evaluation data. In addition, this study shows misleading results from model selection method using AIC and BIC [19].

Based on the experimental results, it is shown that (1) all creep models provides similar creep prediction over calibration periods (i.e., calibration data for parameter estimation); (2) they provide different creep predictions over evaluation periods (i.e., validation data for forecasting); and (3) the proposed method only provide reliable and better predictions over both calibration and evaluation periods.

2. Research background and motivation

2.1. Concrete creep and creep model

Creep and shrinkage effects on concrete structures are one of the important considerations for design, construction and maintenance [20]. Creep is related to the stress level, but it also has a relationship with moisture migration in the porous structure of concrete. The rate of creep increases with the change rate of pore humidity due to the hygro-mechanical coupling between strain and pore humidity changes. In this context, creep and shrinkage are dependent on each other. However, they are considered to be additive in practice, as shown in Fig. 1. The additive assumption has the merit of simplicity for development of the creep model [2].

Based on the additive assumption, the time-dependent deformation of the concrete $\varepsilon(t)$ is formulated by

$$\varepsilon(t) = \varepsilon_{el}(t_0) + \varepsilon_{sh}(t) + \varepsilon_{cr}(t, t_0) \tag{1}$$

where $\varepsilon_{el}(t_0)$ is the instantaneous elastic strain due to applied load at time t_0; $\varepsilon_{sh}(t)$ is the shrinkage strain along with time; $\varepsilon_{cr}(t, t_0)$ is the creep strain as from the time t_0; and t_0 is the time of applying stress. Fig. 2 shows the time-dependent deformations of the concrete under a sustained stress at time t_0. A creep strain can be obtained by subtracting the nominal elastic strain and shrinkage strain from a measured strain.

Since the proposed method is employed for predictive modeling on concrete creep, the creep is described hereafter and the details on the shrinkage can be found in Neville, Dilger and Brooks [2].

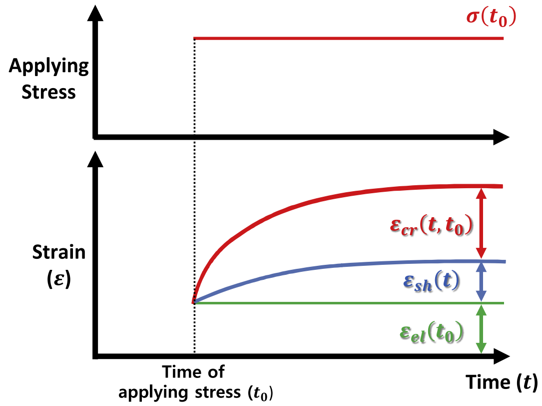

Fig. 2. Time-dependent deformation of concrete under sustained loads.

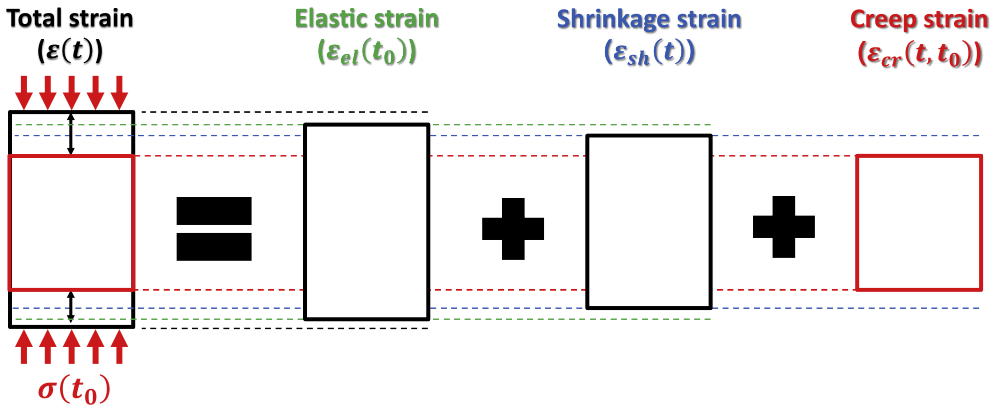

Fig. 1. Components in time-dependent deformation of concrete.