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Predicting long-term compressive creep of concrete using inverse analysis method

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HIGHLIGHTS

- Prediction of creep was improved using proposed inverse analysis methodology.
- Sample results from different studies were used to verify proposed methodology.
- Various statistical indicators were used to evaluate the accuracy of proposed method.
- Proposed method had lower prediction errors compared to available creep models.
- For certain creep models, the proposed method was too sensitive and thus not appropriate.

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ABSTRACT

Long-term creep prediction has been a major issue of concern in designing concrete structures for some time. Many researchers have developed various models in order to predict uni-axial compressive concrete creep, however a more precise and reliable method of prediction is still required. This investigation introduces an inverse analysis (IA) method that utilizes short-term creep measurements under certain conditions to predict long-term results under the same conditions. The proposed IA method was applied to seven different prediction models and the experimental results of six specimens (from three different studies) were chosen to verify the reliability of this method. It was concluded that the IA method is able to successfully improve the accuracy of prediction and has a comprehensive range of application.

1. Introduction

Concrete creep is a time-dependent deformation of concrete under sustained load that is a complex phenomenon and as shrinkage [1–11] it plays a major role in durability and cracking tendency of concrete structures and repaired systems [12–17]. Concrete creep consists of two components: basic creep, which occurs under conditions of no moisture movement to or from the environment, and drying creep, which is the additional creep caused by drying [12]. Both components depend on various parameters (e.g. ambient moisture, temperature, mix proportions, state and magnitude of stress) which make it difficult to predict the time-dependent creep of concrete. It is worth noting that the creep considered in this study is the total creep (the sum of basic and drying creep) that means that the specimens are in an unsealed state and in contact with the environment so as to allow drying, as are most structures in the field.

Extensive research has been carried out on the long-term compressive creep prediction of concrete during the past few decades and several prediction models have been proposed by various authors [18–27]. Due to the variability and uncertainty attributed to concrete properties and mixture designs, there is no overall reliable model available for creep prediction of different mixture designs. Therefore, proposing the new procedure for predicting the long-term compressive creep of concrete is needed.

In order to provide better predictions of time-dependent deformations, short-term measurements should be obtained from

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List of notations

$\varphi(t)$	creep coefficient at time t
t_0	age of concrete at loading (days)
h	ambient relative humidity (decimals)
V/S	volume to surface ratio (mm^3/mm^2)
$\gamma_{c,d}$	correction factor for the combined effect of age and volume-surface ratio
t	duration of loading (days)
H	ambient relative humidity (percent)
t_i	age of concrete at loading (days)
f'_{ci}	80% of the compressive strength of concrete at 28 days (MPa)
$C(t)$	creep compliance
$J(t_0)$	total elastic compliance after loading
SF	percentage of cement replaced by silica fume
f'_c	compressive strength of concrete at 28 days (MPa)
$K_3, K_4,$ and K_5	correction factors which consider effect of loading age, ambient humidity and concrete strength respectively
$\varphi_{cc,b}$	basic creep coefficient
t_h	hypothetical thickness (mm)
A	cross-sectional area (mm^2)
u_e	cross-sectional perimeter (mm)
$\varphi_{28}(t)$	28-day creep coefficient
E_{cmt_0}	modulus of elasticity of concrete at loading age of specimen
E_{cm28}	modulus of elasticity of concrete due to load applied at 28 days
$\varphi_{RH}(h)$	a coefficient which depends on ambient relative humidity & volume-surface ratio
$\beta(f_{cm28})$	a coefficient that depends on 28 day compressive strength of concrete
$\beta(t_0)$	a coefficient that depends on loading age
β_h	a coefficient that depends on ambient relative humidity, concrete compressive strength and the volume-surface ratio
$\varphi(t_c)$	a correction factor for effect of drying before loading
$\varepsilon_c(t)$	total creep strain
ε_E	initial elastic strain
$\varepsilon_s(t)$	total shrinkage strain
$\varepsilon_T(t)$	total strain of the specimen

samples [12,27]. Afterwards, inverse analysis (IA) can be used to improve the accuracy of creep prediction. IA is used to estimate unknown parameters from available information and provides algorithms that lead to the best fit between experimental measurements and corresponding computed data. Once a representative model is chosen, the parameters of the model can be inversely obtained by calibrating them to short-term measurements under certain conditions. The long-term behavior of concrete (under the same conditions) can be estimated by using the calibrated models [5,27,28]. Studies have proven that the error in predicting long-term results can be significantly reduced by using inverse analysis in various areas of engineering [29–32].

Several authors have modified existing creep prediction models by using shot-term measurements to minimize the errors between the models and experimental data for a long term creep. Ojdrovic and Zarghamee [33] modified two such models (Bažant-Panula (BP-KX) [34] and ACI 209.2R-08 [18]) and concluded that the coefficient of variance of predicted long-term creep values (obtained using modified forms of these two models) compared to experimental values can be significantly reduced. The adjustment is performed by using the measured data at 7 and 28 days to predict the instantaneous strain and creep strain parameter which depends on age at loading, environment, geometry, and material in ACI and BP-KX models. They also mentioned that using creep data for the first few days after exposure will increase the errors of long-term prediction. Brooks and Neville [35] also extrapolated short-term creep results (from concrete specimens) in order to predict long-term creep values. However, the limited creep models and experiments have been investigated in these studies.

In previous research conducted by the authors [36], a particular method which incorporated IA for the prediction of long-term shrinkage was proposed and applied to experimental shrinkage results. The previously proposed method not only modifies models using IA, but also combines the results from the IA modified models. The authors concluded that by applying their proposed method, the overall accuracy of long-term shrinkage predictions can be significantly improved.

In this paper, the aforementioned method [36] is further developed for creep prediction and applied to a variety of experimental results. The validity of the proposed method is examined through comparing the predicted values with the test results and by using suitable statistical indicators. This investigation only aims to demonstrate how inverse analysis can be used to refine and significantly improve the predictions provided by available models. In order to implement the finding of this research in practice and the design of concrete structures, the statistical reliability of the developed IA method should be further investigated.

2. Research significance

Creep is of great importance in all concrete structures and requires constant monitoring and attention. However, if numerical models can be used to accurately predict creep effects, then issues regarding excessive deformation and cracking of structures can potentially be prevented. The available prediction models cannot accurately predict creep for all types of concrete under any condition. Statistical modification of these models is required to improve the effectiveness of these prediction models. This investigation introduces an IA method which utilizes short-term creep measurements under certain conditions to predict long-term results under the same conditions.

3. Methodology

3.1. IA method for prediction of concrete creep

The process of the inverse analysis method (as presented in the flowchart of Fig. 1) begins with the short-term measurements of existing specimens. A number of creep prediction models are then selected and modified using IA. The modified form of each model after applying IA can be expressed as:

$$\varphi(t) = \alpha_1 (A \times F(t))^{\alpha_2} \quad (1)$$

where A is variable coefficient that depends on the properties of the specimens, $F(t)$ is time-function term (different for each model), and α_1 and α_2 = coefficients that are applied to modify the entire equation based on short-term measurements.

To determine the optimized values of α_1 and α_2 for each model and specimen, the CurveExpert [37] software was used. After given