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Research Article

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A Technology to Improve the Concrete Structure Prediction in the Civil Engineering

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ABSTRACT

The computational accuracy of concrete prediction models is the key to investigate shrinkage influence on performance of concrete structure. Commonly used concrete prediction models are evaluated for their accuracy by comparing their predicted results against the six groups of test data which were collected from published papers. The results show that prediction models were not coincided very well with the experimental data. The phenomenon of concrete structure is a result of several interacting physical mechanisms and is influenced by many variable factors. The shrinkage deformations invariably exhibit large statistical scatter. The calculated results of prediction models could not agree very well with the test results. In order to improve the calculation accuracy of concrete structure prediction models, updating the prediction models based on short-time tests is an effective technology. And the general technology is not proper because of ill-posed problem. So a new improvement technology was proposed and suggested in this study. Seven groups of concrete structure test data were used to evaluate the suggested technology. It could be found that the suggested technology could match better with the test data.

Key words: concrete; shrinkage; prediction model; analysis; test; improved; evaluate

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INTRODUCTION

During the past few decades, the long-term deflection and cracks of long-span prestressed concrete bridge is getting more and more serious in terms of structure safety [1], many bridges have already been found to exhibit excessive long-time deflections which may lead to the collapse of bridges [2-6].

The time-dependent performance of concrete, governed by creep and shrinkage, is of particular importance. The concrete structure and creep phenomenon has a double effect on prestressed concrete structures as it leads to both long-term deflection of bridge structure and prestress losses. Accuracy of shrinkage and creep prediction models is important in the design of concrete structures. A huge number of prediction models are available in practice, such as ACI 209 model recommended by the American Concrete Institute [2], CEB 90 model recommended by the Euro-international concrete committee [3], GL2000 model developed by Prof. Gardner in Canada [4], and the B3 model from Prof. Bazant at Northwestern University [5].

A fair amount of concrete prediction models were proposed, but there are still a number of problems needed further research. Various researchers have investigated the accuracy of these models for shrinkage and creep prediction and compared with the experimental data [8, 11-13]. But the results show that prediction models were not coincided very well with the experimental data. In order to improve the calculation accuracy of concrete structure prediction models, updating the prediction model based on short-time tests is an effective technology [10, 14-17]. The technology proposed by Prof. Bazant [5] is effective to improve creep prediction model, and is widely acknowledged [6, 7]. Improving shrinkage prediction is more difficult. And the general technology is not proper because of ill-posed problem [5]. So a new technology was proposed and suggested in this study. Examples of improving shrinkage prediction model based on the short-time tests were also presented to verify the suggested technology.

2 Evaluation of concrete structure Prediction Models

In order to evaluate the accuracy of commonly used concrete prediction models, six groups of concrete structure test data were collected from published papers . Commonly used concrete prediction models include B3 prediction model [5], JSCE1996 prediction model [8], JSCE2002 prediction model [8], GL2000 prediction model [4], GZ 1993 prediction model [9] and JTJ D62-2004 prediction model [10]. The predicted shrinkage values of prediction models are compared with the collected test datum, and the CEB Coefficient of Variation technology [3] is used to determine the precision of these predicted values.

Results of the CEB coefficient of variation for shrinkage strain (w_{CEB}) are summarized in Tab.1. It can be observed that their predicted shrinkage values were not coincided very well with experimental values. In al1 shrinkage prediction models, the average w_{CEB} is within the range of 6.1% and 190.7%. Meanwhile, a prediction model presents highly variable w_{CEB} in different data sets. For example，the w_{CEB} of JTJ D62-2004 prediction model is within the range of 17.4% and 81.7%, but the w_{CEB} of a prediction model exhibits large statistical scatter in a data set.

Tab.1 The CEB Coefficient of Variation for Shrinkage Strain (w_{CEB} %)

Test Number	B3	GL2000	JTJD62 2004	JSCE 2002	JSCE 1996	GZ1993
I	73.5	31.7	—	25.4	32.7	25.1
II	—	82.9	17.4	—	—	62.8
III	—	61.9	24.0	—	—	36.0
IV	—	190.7	81.7	—	—	116.4
V	68.2	34.5	70.4	17.6	6.1	35.0
VI	48.0	22.1	65.2	37.1	44.6	22.5
Average	63.24	70.63	51.74	26.70	27.80	49.63

Note: in the cause of data sets without complete experimental parameters needed by prediction models, the results are presented by "—" instead

An accurate prediction model of concrete structure is crucial for durability and long-time serviceability of concrete structure. But it is an extremely difficult problem, because the phenomenon is a result of several interacting physical mechanisms and is influenced by many variable factors such as mixture proportion, mechanical properties including strength and modulus of elasticity, ambient relative humidity, duration of drying, and duration of loading. And specimen size also has some influence on the shrinkage development of concrete. The largest source of uncertainty of shrinkage prediction model is from the dependence of model parameters stemming from the composition and strength of concrete. This uncertainty can be greatly reduced by improving prediction models based on short-time tests.

3 The technology of Improving the concrete structure Prediction Based on Short-Time Tests

Problems in the General technology of Updating Shrinkage Prediction Models by Using Short-Time Tests

The performance of creep and shrinkage prediction models can be increased by carrying out short-time measurements on the given concrete and adjusting the values of empirical parameters in prediction models accordingly. The general technology of updating creep and shrinkage prediction models can be explained by taking B3 prediction model as an example [5].

As for updating the creep prediction model, according to the B3 prediction model, the creep could be calculated by Eq.1:

$$J(t,t') = q_1 + C_0(t,t') + C_d(t,t') \tag{1}$$

in which the creep compliance function $J(t,t')$ is strain (creep plus elastic) at time t caused by a unit uniaxial constant stress applied at age t' , q_1 = instantaneous strain due to unit stress, $C_0(t,t')$ is creep compliance function for basic creep, and $C_d(t,t')$ is additional creep compliance function due to simultaneous drying. These parameters and expression were described in details by Bazant in his paper [5]. The updated creep compliance function can be described in Eq.2:

$$J(t,t') = p_1 q_1 + p_2 (C_0(t,t') + C_\mathrm{d}(t,t',t_0)) \tag{2}$$

in which p_1 and p_2 were two updated parameters which play the role of updating empirical constitutive parameters, the values of which could be obtained by least-square regression based on tests.

As far as updating the shrinkage prediction model is concerned, according to the B3 prediction model, values of the shrinkage strain should be calculated by Eq.3:

$$e_{sh}(t,t) = e_{s,¥} \frac{E(607)}{E(t + t_{sh})} k_h \tanh[(t - t)/t_{sh}]^{1/2} \tag{3}$$

in which $e_{sh}(t,t)$ is the concrete structure strain at time t, t is the age of concrete drying commenced, $e_{s,¥}$, k_h, t_{sh}, $E(607)$, and $E(t + t_{sh})$ constants depend on concrete component, test environment, and etc., which are not related to the shrinkage duration. $E(607)$ = modulus of elasticity at 607 days, while $E(t + t_{sh})$ = modulus of elasticity at time $t + t_{sh}$. $\tanh[(t - t)/t_{sh}]^{1/2}$ is the equation to describe the development of shrinkage with time.

The updated shrinkage prediction model could be usually expressed as in Eq. 4:

$$e_{sh}(t,t) = p_1 e_{s,¥} \frac{E(607)}{E(t + t_{sh})} k_h \tanh[(t - t)/(p_2 t_{sh})]^{1/2} \tag{4}$$

in which p_1 and p_2 were used to update empirical constitutive parameters based on tests.

If k(k>2) data points are obtained by carrying out short-time tests, therefore t_{i} and $e_{sh}(t_{\mathrm{i}},t)$ are known (for i=1，2,…k).

$$e_{sh}(t_{\mathrm{i}},t) = p_1 e_{s,¥} \frac{E(607)}{E(t + t_{sh})} k_h \tanh[(t_{\mathrm{i}} - t)/(p_2 t_{sh})]^{1/2} (\mathrm{i} = 1,2,¼\ \mathrm{k}) \tag{5}$$

Eq. 5 includes equalities, but only p_1 and p_2 is unknown quantity. And the values of them can be obtained by regression.

Hyperbolic tangent function or Ross' hyperbola function [2]is used to describe the development of shrinkage with time in usual shrinkage prediction models, which cause an ill-posed problem in general technologies of updating shrinkage prediction models [5]. The problem can be explained by taking B3 prediction model as an example. The updated B3 shrinkage prediction model can be written as Eq. 2, and it can be simplified as in Eq. 6:

$$e_{sh}(t,t) = E \times \tanh[(t - t)/F]^{1/2} \tag{6}$$

in which E and F are constants which are not related to the shrinkage duration depending on concrete component, test environment, and etc.. Fig.1 shows that different values of parameters E and F fits well with the short-time data. If only short-time data are known, different shrinkage curves according to Eq. 6, corresponding to very different parameter values, can accord with these short-time data points for a long period of time. In other words, if the data points beyond reach the time at which the two curves shown in Fig.1 beg into significantly diverge, there is no way to determine the parameters E and F unambiguously. According to the mentioned phenomenon above, improved prediction model based on short-time tests accords with initial test results quite well, as shown in Fig.2 and fig 2, but the curve may beg into significantly diverge from tests after a period of time. （This is true not only for the formulae of B3 prediction model but also for all other shrinkage formulae, including the Ross' hyperbola used in ACI209-92 prediction model [5].）

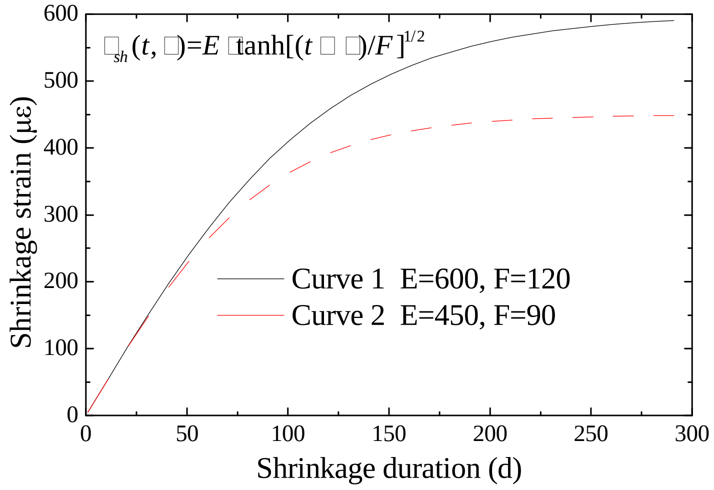

Fig.1 An example of shrinkage-time curves giving nearly the same initial shrinkage strain but very different final values

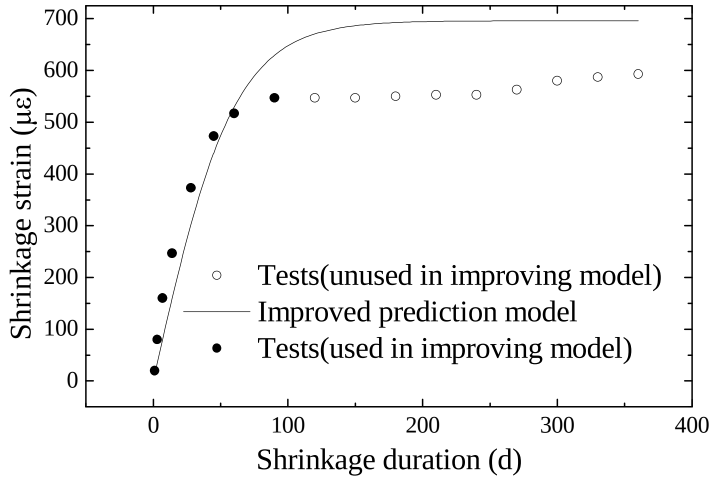

Fig.2 An example of problems in improving prediction model

CONCLUSION

(1) Comparing the results of predicted shrinkage values of commonly used concrete prediction models with the test data，it could be found that the predicted shrinkage values were not coincided very well with experimental data.

(2) An accurate prediction model of concrete structure is of crucial importance for durability and long-time serviceability of concrete structure. But it would be difficult to formulate without short-time tests，because of the effects of the great variety of additives and different combinations used on the model parameters.

(3) Seven groups of concrete structure test data were used to evaluate the suggested technology. It could be found that the suggested technology could match better with the test data.

(4) Updating the prediction model based on short-time tests is an effective technology to improve the calculation accuracy of concrete prediction models, which is thus worthy of further promotion and exploration.

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