Practical prediction of creep and shrinkage of high strength concrete

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Model for practical prediction of creep and shrinkage of normal strength concrete, developed previously, is extended to high strength concrete. It is found that only a minor adjustment for the concrete strength effect is needed in the formulas for drying creep. The formulas for basic creep and shrinkage need no adjustment. The prediction model is compared with test data for creep and shrinkage obtained recently by Ngab, Nilson and Slate, and by Collepardi, Corradi and Valente, and a satisfactory agreement is demonstrated. The coefficient of variation of the deviations from test data is not larger than that for the normal strength range. However, the existing data are rather limited and further testing is desirable.

INTRODUCTION

A comprehensive prediction model for creep and shrinkage of concrete applicable over a very wide range of conditions has been recently developed ([1], [2], [3]). This model is more involved than some other previous prediction models, but shows a distinctly better agreement with the existing test data ([1], [2], [4]) and is to a greater extent based on physical considerations [3]. This model, briefly known as the BP Model, has been developed for normal strength portland cement concretes of cylindrical strengths ranging from 3,000 to 7,500 psi. Due to the current increased use of high strength concretes, an extension of this model to strengths exceeding 10,000 psi is needed. Such an extension has now been made possible by the test data of Ngab, Nilson and Slate ([5], [6]) and Collepardi, Corradi and Valente [7], and is attempted here. However, since the presently available data are rather limited, this extension must be considered tentative.

SHRINKAGE

The data base for the previously developed formulas [1] included some data for normal concretes of a relatively high strength and rather low water-cement ratios (McDonald's data, up to strength 7,300 psi). Therefore, it is not too surprising that the previously developed BP formulas (equations 1-10 in reference [1]) are found to yield reasonable agreement with the new measurements by Ngab et al.; see the solid line in figure 1. In the description of these tests it was stated that the specimens were exposed to laboratory air, the relative humidity of which is, in the present calculations, considered to be 60%. The data points in the figure, as well as the specimen strengths shown, represent averages of values from different batches (see Appendix A). However, the last few readings were not reported for all the three batches, and so the last few points shown do not represent the same averages as the preceding points.

Shrinkage data were also reported by Collepardi [7]. In their data, the shrinkage strains for 100 days drying duration were quite high compared to other data for the same type of mixture composition and specimen size. Also, in these tests the specimens were exposed to a drying environment (of relative humidity 65 ± 5%) after a longer than usual curing period of 28 days at a 95% relative humidity.

![Fig. 1. — Comparison of theory (solid line) with Ngab, Nilson and Slate's test data for shrinkage.](image-url)
BASIC CREEP

For basic creep, i.e. the creep at constant moisture content, the previously developed formulas (equations (11)-(19) of reference [1]) are also found to agree with the new test data reasonably well, with errors that are not larger than those previously determined within the normal strength range. This is demonstrated in comparison with the data of Ngab et al. in figure 2, in which the BP Model predictions are again shown by solid lines. Note that, in the reported measurements, the creep strain for the age of 56 days at loadings is higher at some creep durations than the creep strain reported for the age of 30 days at loading, which is contrary to the generally accepted aging effect. This is, however, explicable by normal scatter of measurements.

Drying Creep

The previously reported formulas (eqs. (25)-(33) of reference [1]) need a minor adjustment. Equations (26) and (28) of reference [1] need to be generalized as:

\[ \varphi_d = \left( \frac{1 + t' - t_0}{a_d \tau_{sh}} \right)^{-1/2} \varphi_d \]

where:

\[ a_d = 10 \] for \( f'_c \leq 6,000 \) psi;
\[ a_d = 1 \] for \( f'_c \geq 10,000 \) psi;

\[ S_d(t, t') = \left(1 + b_d \frac{\tau_{sh}}{t - t'_0}\right)^{n} \]

where:

\[ b_d = 10 \] for \( f'_c \leq 6,000 \) psi;
\[ b_d = 100 \] for \( f'_c \geq 10,000 \) psi.

Linear interpolation may be used for \( a_d \) and \( b_d \) between \( f'_c = 6,000 \) and 10,000 psi. In these formulas, \( t_0 = \) age at the start of drying, \( t' = \) age when constant stress is applied, \( n \) is the exponent of double power law, \( c_d \) is a correction coefficient given in Reference [1], \( \tau_{sh} \) is the shrinkage-square half-time, proportional to the square of thickness of concrete, as indicated by diffusion theory; and \( f'_c = \) standard cylindrical strength at age of 28 days.

Drying creep calculated with these formulas is shown as the solid lines in figure 3 in comparison with the data of Ngab et al. and Collepardi et al. The data points from Ngab et al. represent again averages of their measurements (test series A-1, B-1, B-2).

Coefficient \( \varphi_d \) adjusts the final drying creep value as a function of the delay of the start of loading after the start of drying, and function \( S_d(t, t') \) gives the shape of drying creep curve. The adjustment in equations (1)-(4) means that, for high strength concretes as compared to normal strength concretes, the final drying creep value becomes smaller and the drying creep evolves slower. This trend is entirely reasonable if we assume that the mechanism of creep consists of some sort of diffusion or migration within the microstructure of the cement gel. In concretes of higher strengths, the pores are generally smaller and the passages between the larger (capillary) pores become longer. This suggests that diffusion phenomena should be slower and less pronounced.

The values of the conventional creep coefficient \( \varphi(t, t') \), determined as indicated in reference [1] below equation (13), are calculated from prediction formula for creep compliance in table I for concrete of Ngab et al. It may be noted that the trend of the creep coefficient is similar to that shown in table II on p. 258 of reference [6].

STATISTICAL EVALUATION

Statistical characteristics of the deviations of the presently used data from the prediction formulas have