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# An Apt Material Model to Predict Creep and Shrinkage Behaviour of HPC Concrete

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## ABSTRACT

Time dependent properties such as creep and shrinkage of concrete play an important role in the long term response of concrete structures and hence the need of a reliable material model to predict the same for the given grade of high performance concrete made from local material, construction practices and environmental condition has increased. In this study creep and shrinkage behaviour has been predicted up to 900 days using four existing popular material models i.e. the ACI 209R-92 model, the CEB FIP Model Code 1990, the B3 model and the GL2000 model and the same are compared with the observed experimental data reported by Karthikeyan et al. (2008). Based upon the comparison of results it has been observed that there is a good match between CEB FIP Model Code 1990 with experimental results.

**Keywords.** High Performance Concrete, Numerical Models, Creep, Shrinkage, Creep Coefficient

## INTRODUTION

Engineering community as a whole is facing twin challenges of developing newer material which is sustainable and durable for concrete structure. Creep and shrinkage effects are sensible contribution in this issue and it can be affecting the longevity of the infrastructure. It is very important sustainability aspects for concrete structure being built such that thereby delaying its replacement and it remains durable. To address this issue, use of high performance concrete (HPC) in infrastructure projects is gradually increasing. Presently world over, most of the infrastructures are constructed using HPC and combined effect of creep and shrinkage in concrete change the internal forces and deflection of concrete infrastructures, due to sustained loads for long time. Therefore, the study of creep and shrinkage effect on long term response of such infrastructures built in HPC is important to ensure that these remain serviceable and durable, all through its anticipated life.
Creep and shrinkage are two important time-dependent properties of HPC. These properties are affected by the local construction material, environment condition and play an important

role on the long term response of concrete structures. There are many factors which affect the magnitude of the time-dependent creep and shrinkage of concrete under the local condition. These factors are: mix proportion of concrete constituent's i.e. ratio of cement, sand, aggregate and admixture; effect of environmental factors like temperature and humidity; effect of construction practices and structural design.

In this study the four existing popular material models: the ACI 209R-92 model (ACI), the CEB FIP Model Code 1990 (CEB), the B3 model (B3) and the GL2000 model (GL) are used for prediction of creep and shrinkage properties of HPC. Earlier Goel et al. (2007) reported experimental results of Russell and Larson (1989) and compared the results with five existing creep and shrinkage prediction models and observed the GL2000 model has performed best for prediction of creep and shrinkage properties in concrete. Brook's (2005) has reported the 30 year creep and shrinkage measured data having different water cement ration of concrete and the reported results are compared with five design methods of creep and shrinkage prediction i.e. CEB, Gardner, Bazant and Baweja, ACI and BS 8110 and observed, the most methods fail to recognize the influence of strength of concrete and type of aggregate on creep coefficient. Gardener and Lockman (2001) have modified and updated GL2000 model describe and explain design procedure to estimate creep and shrinkage for normal-strength concretes, which is defined as concretes with mean compressive strength less than 82 MPa. Huo et al. (2001) reported detailed experimental program to study material properties like creep, shrinkage and modulus of elasticity of HPC made with local materials from Nebraska and compared the results with ACI model and observed that the ACI equation for shrinkage, creep and elastic modulus of concrete do not accurately predict the material properties of HPC.  Al-Manaseer et al. (2005) have statistically evaluated creep and shrinkage prediction models with RILEM experimental data bank and observed that B3 and GL are best performing models for shrinkage and CEB, B3 and GL models performing best for creep prediction in concrete. Mazloom et al. (2004) reported detail experimental result on short and long term mechanical properties of HPC, containing different level of silica fume. Also the measured creep and shrinkage result were compared with ACI and CEB model and observed that both the models at early age underestimate the shrinkage strain and at later age the CEB and ACI modes underestimate and overestimate total shrinkage respectively. Still further both models overestimate creep strain.

As seen in literature review, the creep and shrinkage prediction model for HPC gets affected by local construction material and environment condition. Also since then, some material models have been modified and upgraded. In view of very limited experimental test data available for creep and shrinkage study an indigenous HPC, no attempt has been made to propose any new model for creep and shrinkage prediction. Therefore, in the present study the four existing popular material creep and shrinkage prediction models are studied to determine which one predicts creep and shrinkage behaviour of M50 grade of HPC satisfactorily under the (Indian Environment) local condition.

## CREEP AND SHRINKAGE PREDICTION MODELS

### ACI 209R-92 Codal Provisions

The ACI 209R-92 Code reapproved in 2008, has reported the procedure for prediction of time-dependent material behaviour (creep and shrinkage) under standard condition and correction factors for other than standard condition. The recommended expressions for creep and shrinkage strain prediction are:

### Creep

$$J(t, t_0) = \sigma_c(t)\delta_t \quad (1)$$

$$\delta_t = \left[\frac{t^{\Psi}}{d + t^{\Psi}}\right]\left[\frac{\emptyset(t, t_0)_u}{E_{ci}}\right]$$

$$\emptyset(t, t_0)_u = 2.35\gamma_c$$

### Shrinkage

$$\epsilon_{sh}(t, t_s) = \left[\frac{t_s^{\alpha}}{f + t_s^{\alpha}}\right](\epsilon_{sh})_{\mu} \quad (2)$$

$$(\epsilon_{sh})_u = 780\gamma_{sh}$$

Where, $\gamma_c$ and $\gamma_{sh}$ represent applicable correction factors for creep and shrinkage compliance function, in this paper correction factors are considered based on average characteristics of concrete made from local materials and environmental condition as shown in Table 1.

**Table 1. Local Materials and Environmental Condition for Creep and Shrinkage Prediction Using ACI 209R-92 Model (2008)**

| SI number | Affecting factors | Experimental standard condition |
|---|---|---|
| 1 | Type of cement | Type I |
| 2 | Slump, $\gamma_s$ | 110 mm |
| 3 | Air content, $\gamma_\alpha$ | 2 percent |
| 4 | Fine aggregate percentage, $\gamma_\Psi$ | 62 percent |
| 5 | Cement content, c | 434 kg/m$^3$ |
| 6 | Type and period of curing | Moisture curing at 28 days |
| 7 | Relative humidity | 95 percent |
| 8 | Concrete temperature | 23 ± 2 $^o$C |
| 9 | Ambient relative humidity, $\gamma_\lambda$ | 50 ± 6 % |
| 10 | Volume-surface ratio, v/s | v/s = 34 mm |
| 11 | Average thickness, $\gamma_h$ | $\gamma_h$ = 150 mm |
| 12 | Age of concrete at the time of loading | 28 days |
| 13 | Compressive stress | Axial compression stress |
| 14 | Stress/strength ratio | 0.15 |

## CEB FIP Model Code 1990 Provisions

The CEB-FIP Model Code 1990 is valid for ordinary concrete grade, for which mean compressive strength varies between 12 MPa to 80 MPa and having mean relative humidities in the rage of 40 to 100 % at mean temperatures from 5 $^o$C to 30 $^o$C. The recommended expressions for creep and shrinkage strain prediction are:

### Creep

$$J(t, t_0) = \frac{\sigma_c(t_0)}{E_{ci}}\emptyset(t, t_0) \quad (3)$$

$$\emptyset(t,t_0) = \left[1 + \frac{1-RH}{0.46\left(\frac{2A_C}{100\mu}\right)^{1/3}}\right] \times \left[\frac{5.3}{(0.1f_{cm})^{0.5}}\right] \times \left[\frac{1}{0.1+(t)^{0.2}}\right] \times \left[\frac{(t-t_0)}{\beta_H+(t-t_0)}\right]^{0.3}$$

$$\beta_H = 150[1+(1.2RH)^{18}]\left(\frac{2A_c}{100\mu}\right) + 250 \le 1500$$

## Shrinkage

$$\epsilon_{sh}(t,t_0) = [160 + 10\beta_{sc}(9 - 0.1f_{cm})] \times 10^{-6}\beta_{RH}\left[\frac{(t-t_s)}{350\left(\frac{2A_C}{100\mu}\right)^2+(t-t_s)}\right]^{0.5} \quad (4)$$

## B3 Model Provisions

The updated B3 Model is applicable for high-strength concrete and the time-dependent material prediction of creep and shrinkage. This model representing the third major updates β2 of the models β3, β4 and is calibrated by computerized data bank comprising practically all the relevant test data obtained in various laboratories throughout the world. The recommended expressions for creep and shrinkage strain prediction are:

## Creep

Creep strain include instantaneous strain due to unit stress

$$J(t,t_0) = [q_1 + C_0(t,t_0) + C_d(t,t_0,t_s)]\sigma_c(t_0) \quad (5)$$

$$q_1 = \frac{0.6 \times 10^6}{E_{ci}}, \quad q_2 = 185.4\, c^{0.5}(f_{cm})^{-0.9}, \qquad q_3 = 53.766\,(w/c)^4 c^{0.5}(f_{cm})^{-0.9}$$

$$q_4 = 20.3\,(a/c)^{-0.7}, \quad q_5 = 7.57 \times 10^5 (f_{cm})^{-1}|\epsilon_{sh\infty}|^{-0.6}$$

$$C_0(t,t_0) = q_2 Q(t,t_0) + q_3 \ln[1+(t-t_0)^n] + q_4 ln\,(t/t_0)$$

$$Q(t,t_0) = Q_f(t_0)\left[1+\left(\frac{Q_f(t_0)}{Z(t,t_0)}\right)^{r(t_0)}\right]^{-1/r(t_0)}$$

$$m = 0.5, n = 0.1$$

$$r(t_0) = 1.7(t_0)^{0.12} + 8$$

$$Q_f(t_0) = \left[0.086\,(t_0)^{2/9} + 1.21\,(t_0)^{4/9}\right]^{-1}$$

$$Z(t,t_0) = (t_0)^{-m} In\,[1+(t-t_0)^n]$$

$$C_d(t,t_0,t_s) = q_5\sqrt{exp\,[-8H(t)] - exp\,[-8H(t_0)]}$$

## Shrinkage

$$\epsilon_{sh}(t,t_0) = -\epsilon_{sh\infty}k_h S(t) \quad (6)$$

$$\epsilon_{sh\infty} = \propto_1\propto_2 [1.9 \times 10^{-2} w^{2.1}(f_{cm})^{-0.28} + 270]$$

$$S(t) = tanh\sqrt{\frac{t - t_S}{\tau_{sh}}}$$

$$\tau_{sh}(t, t_0) = 8.5\ t_S^{-0.08}(f_{cm})^{-0.25}[k_s 2(v/s)]^2$$

## GL2000 Model Provisions

The GL2000 model is applicable for time-dependent material prediction of creep and shrinkage having compressive strength of concrete less than 82 MPa. Prediction of creep and shrinkage require 28-day concrete strength, the concrete strength at loading, element size, and the relative humidity. This model does not consider effect of any chemical and mineral admixtures or by-products in the concrete, the casting temperature, or the curing regime. The recommended expressions for creep and shrinkage strain prediction are:

## Creep

$$J(t, t_0) = \frac{1}{E_{ci}} + \frac{\emptyset(t, t_0)}{E_{cm}} \tag{7}$$

$$E_{cm} = 3500 + 4300\left[\frac{f_{cm}t_0^{3/4}}{a + bt_0^{3/4}}\right]^{0.5}$$

$$\emptyset_{(t,t_0)} = \Phi(t_c)\Phi(t_{c'})$$

$$\Phi(t_{c'}) = \left(\frac{2(t - t_0)^{0.3}}{(t - t_0)^{0.3} + 14}\right) + \left(\frac{7(t - t_0)}{t_0(t - t_0 + 7)}\right)^{0.5}$$

$$+2.5(1 - 1.08h^2)\left(\frac{(t - t_0)}{(t - t_0 + 0.15\ (V/S)^2)}\right)^{0.5}$$

If $t_0 = t_c$, $\Phi(t_c)$ = 1 when $t_0 > t_c$

$$\Phi(t_c) = \left[1 - \left(\frac{(t_0 - t_c)}{(t_0 - t_c + 0.15\ (V/S)^2)}\right)^{0.5}\right]^{0.5}$$

## Shrinkage

$$\epsilon_{sh}(t, t_0) = \epsilon_{shu}\ \beta(h)\beta(t_0) \tag{8}$$

$$\epsilon_{shu} = 1000\ K\ \left(\frac{30}{f_{cm}}\right)^{0.5} \times 10^{-6}$$

$$\beta(h) = (1 - 1.18h^4)$$

$$\beta(t_0) = \left(\frac{t - t_s}{t - t_s + 0.15\ (V/S)^2}\right)^{0.5}$$

## EXPERIMENT STUDY [KARTHIKEYAN, 2008]

Karthikeyan et al. have designed HPC mixes for creep and shrinkage strain study; air content in mix design is considered 2% of total volume of mix design, slump 110 mm. The 28 days, average of three cube compressive strength ($f_{ck}$) and cylinder modulus of elasticity (E) of the mix were found experimentally and it’s reported in Table. 2. The creep and shrinkage studies are carried out on prism specimens (150 mm × 150 mm × 600 mm) according ASTM standard C512 and average results of three identical specimens have been adopted; the demountable mechanical gauge points were attached on the surface of each creep and shrinkage specimen at a spacing of 200 mm at the centre of the specimen in the longitudinal direction; all specimens have been cured at 27 ± 2 °C till the age of 28 days. The creep and shrinkage specimens are kept in controlled environmental condition having temperature 22 ± 3 °C and relative humidity 50 ± 6 %; loading on creep specimens is such that constant stress/strength ratio of 0.15 is maintained, where strength was taken as 28 days average compressive strength of cube (150 mm × 150 mm × 150 mm). A constant stress was maintained on creep specimens till the end of the experiment.

**Table 2. Mix Composition for HPC and Its Physical Properties for Creep and Shrinkage Prediction**

| Mix | Cement (kg/m$^3$) | Silica fume (kg/m$^3$) | Fine aggregate (kg/m$^3$) | Course aggregate (kg/m$^3$) | Water (kg/m$^3$) | Super plasticizer (kg/m$^3$) | Average cube compressive strength 28 days (MPa) | Modulus of elasticity 28 days (MPa) |
|---|---|---|---|---|---|---|---|---|
| HPC M50 | 434 | 32.6 | 685 | 1098 | 158 | 4 | 51.11 | 21900 |

## EVALUATION OF CREEP AND SHRINKAGE PREDICTION MODELS ERROR AND DEVIATIONAL COFFICIENT

Brook's proposed expressions for error coefficient and deviational coefficient to compare experimental results with model prediction.

The error coefficient (*M*, %) expresses the 'goodness of fit' and is given as follow

$$M = \frac{1}{\bar{m}}\sqrt{\frac{\sum(p-m)^2}{n}} \times 100 \tag{9}$$

And, the deviational coefficient (*D*, %) expresses whether the model prediction equation generally overestimates (+) or underestimates (-) the equations

$$D = \frac{\sum(p-m)}{\bar{m}n} \times 100 \tag{10}$$

**Table 3. Comparison of Accuracy of Different Prediction Models of Creep and Shrinkage in Concrete**

| Properties | Error coefficient (M) in % and deviational Coefficient (D) in % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ACI | | CEB | | B3 | | GL2000 | |
| | M | D | M | D | M | D | M | D |
| Creep Strain | 79 | +66 | 14 | -2 | 40 | +31 | 74 | +64 |
| Shrinkage Strain | 49 | -46 | 5 | -2 | 9 | +7 | 97 | -89 |
| Creep Coefficient | 44 | -41 | 8 | +5 | 30 | -28 | 48 | +43 |

## RESULT AND DISCUSSION

For accurate prediction of long-term performance of HPC structures, it is necessary to perform experimental program to determine the creep and shrinkage characteristics under the local material and environmental conditions as far as possible. The Creep and shrinkage behaviour is getting affected by local factors like the material used, construction and design practices as well as environmental and as such experimental studies carried out at a particular region will help in accurate prediction of creep and shrinkage strain. Results of one such experimental study carried out in Indian environment and reported by Karthikeyan et al. are compared with latest updated creep and shrinkage prediction methods available in literatures.

### Creep

The creep result (Fig. 1 and Table 3) shows that the CEB FIP Model Code 1990 is a closer match with experimental data, whereas the ACI 209R-92, B3 and GL2000 models are overestimating deviational coefficient between 31% to 66%, while CEB FIP Model Code 1990 underestimated deviational coefficient by just 2% of creep results. Also, CEB FIP Model Code 1990 under the expression of the goodness of fit in creep, error coefficient observed is 14% and other models gives very high level of error coefficient.

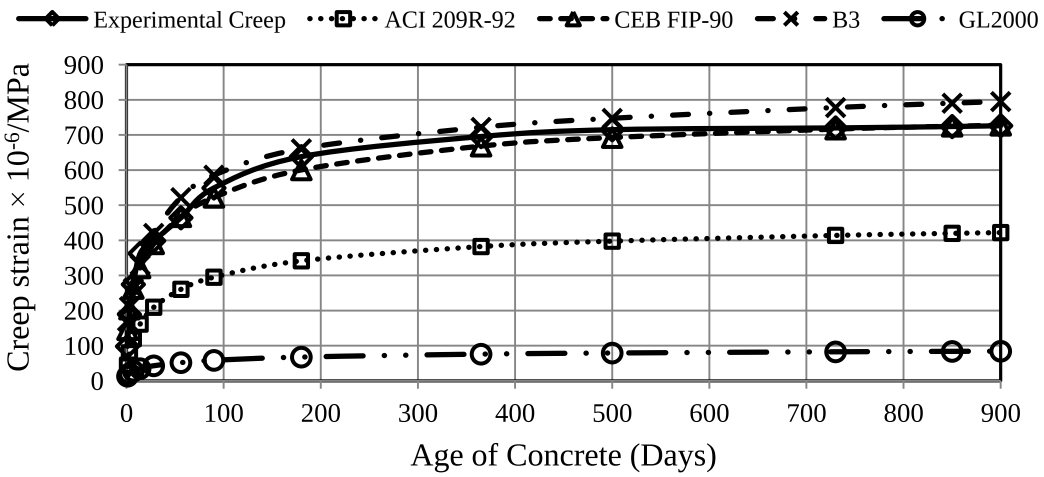


**Figure 1. Time-dependent variation of creep strain in concrete having compressive strength 51.1 MPa at 28 days**

### Shrinkage

The shrinkage result (Fig. 2 and Table 3) shows ACI 209R-92 and GL2000 model gives large deviational coefficient error 46 to 89 % as well as underestimate the shrinkage. The CEB FIP Model Code 1990 and B3 mode gives better match in terms of error coefficient and deviational coefficient. CEB FIP Model Code 1990 underestimated by just 2% and B3 model overestimate by 7%. Also, CEB FIP Model Code 1990 under the expression of the goodness of fit in shrinkage, error coefficient observed is 5% and other models give very high level of error coefficient.

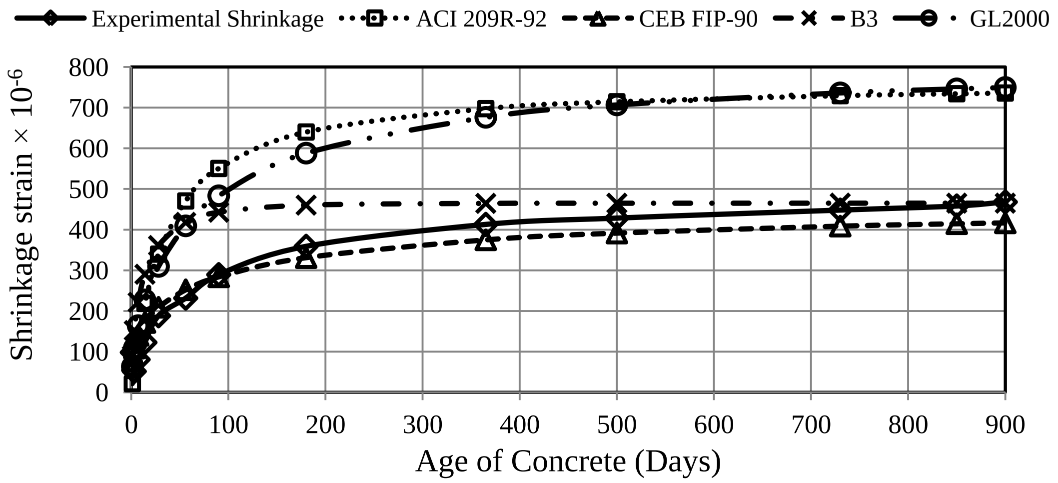


**Figure 2. Time-dependent variation of shrinkage strain in concrete having compressive strength 51.1 MPa at 28 days**

## Creep Coefficient

The creep coefficient result (Fig. 3 and Table 3), it is seen that the ACI 209R-92 and B3 model underestimate deviational coefficient and it varies between 28% to 41% while CEB FIP Model Code 1990 and GL 2000 models underestimated deviational coefficient between 5% to 43%. Also, CEB FIP Model Code 1990 under the expression of the goodness of fit the creep coefficient, error coefficient observed is 8% and other models gives very high level of error coefficient.

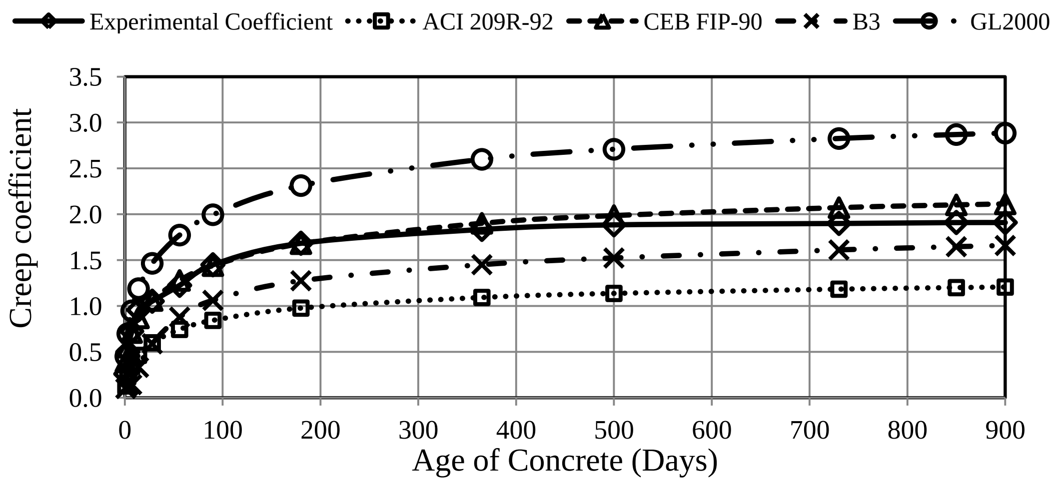


**Figure 3. Time-dependent variation of creep coefficient in concrete having compressive strength 51.1 MPa a at 28 days**

## CONCLUSION

The effects of the creep and shrinkage strain have major impact in prediction of long-term behaviour of concrete structure. In this regard, the available experimental results of HPC are compared with four popular creep and shrinkage models (the ACI 209R-92 model, the CEB FIP Model Code 1990, the B3 model and the GL2000 model) and based on the comparison following conclusion are drawn:

(1) The comparatively study of the results show that the CEB-FIP Model Code 1990 predictions are good for creep, shrinkage and creep coefficient for HPC; difference with experimentally measured test data vary between 4 to 15 percentage while for other prediction models the differences are much higher.
(2) The CEB-FIP Model Code 1990 underestimate creep strain slightly between 100 to 750 days. The B3 model overestimates slightly; however, the error increases with time.
(3) The CEB-FIP Model Code 1990 underestimate shrinkage strain and B3 model overestimates with higher error initially. However, after 750 days B3 model's prediction is much better than any other prediction models.
(4) The GL2000 and ACI 209R-92 models give large creep and shrinkage prediction error under Indian Environmental condition.

Based upon the study presented it is concluded that the CEB-FIP Model Code 1990 model is most apt prediction model for locally produced HPC.

## NOTATION

The following symbols are used in this paper:

$A_c$ : cross-section area ($mm^2$)
$a, b$ : factor depends on type of cement
$C_d(t, t_0, t_s)$ : additional compliance function due to simultaneous drying
$C_0(t, t_0)$ : compliance function for basic creep (creep at constant moisture content and no moisture movement through the material)
$c$ : cement contain in concrete ($kg/m^3$)
$d$ : constant, 10 days for standard condition and 6 to 30 days for other than standard condition
$E_{cm}$ : modulus of elasticity of concrete at the time of 28 days (MPa)
$E_{ci}$ : modulus of elasticity of concrete at the time of $t_0$ initial load (MPa)
$f$ : constant, depends on type of curing, 7 days for moist cured concrete and 1-3 days for steam cured concrete under the standard condition for other than standard condition 20 to 130 days
$f_{cm}$ : mean compressive strength of concrete at the age of $t_0$ days (MPa)
$h$ : relative humidity of the ambient environment, decimal
$J(t, t_0)$ : creep strain in microstrains per unit MPa
$k$ : correction factor depends on type of cement
$k_h$ : factor depends on relative humidity
$k_s$ : shape factor depends on cross section
$m$ : measured value
$\bar{m}$ : average measured value
$n$ : number of observation
$p$ : predicted value
$RH$ : relative humidity of the ambient environment, percentage
$t$ : age of concrete at the time of observation (days)
$t_0$ : age of concrete at the time of loading (days)
$t_s$ : age of concrete at which drying is commenced (days)

| | | |
|---|---|---|
| $v/s$ | : | volume to surface area ratio (mm) |
| $w$ | : | water contain in concrete (kg/m$^3$) |
| $w/c$ | : | water cement ratio in concrete |
| $\alpha$ | : | constant coefficient, 1 for standard condition and 0.90 to 1.10 for other than standard condition |
| $\alpha_1$ | : | factor depends on type of cement |
| $\alpha_2$ | : | factor depends on type of curing |
| $\beta_{RH}$ | : | constant, depends on relative humidity |
| $\beta_{sc}$ | : | constant coefficient, depends on the type of cement |
| $\epsilon_{sh}(t, t_s)$ | : | shrinkage stain in microstrains |
| $(\epsilon_{sh})_u$ | : | ultimate shrinkage strain in microstrains |
| $\epsilon_{sh\infty}$ | : | time-dependence of ultimate shrinkage ($10^{-6}$) |
| $\mu$ | : | perimeter of the member in contact with the atmosphere (mm) |
| $\emptyset(t, t_0)$ | : | creep coefficient as ratio of creep strain to initial strain |
| $\Psi$ | : | constant coefficient, 0.60 for standard condition and normally rage between 0.40 to 0.80 for other than standard condition |
| $\sigma_c(t_0)$ | : | uniaxial constant stress at an age of loading $t_0$(MPa) |

## REFERENCES


ACI 209-R92. (2008). Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures. *ACI Special Publication.*

Al-Manaseer, A. A., Bazant, Z. P., Brooks, J. J., Burg, R. G., Carreira, D. J., Chiorino, M. A., Daye, M. A., Dilger, W. H., Gardner, N. J. & Hansen, W. (2005). "Report on Factors Affecting Shrinkage and Creep of Hardened Concrete. *Concrete international***,** 21.

Al-Manaseer, A. and Lam, J. P. "Static Evaluation of Shrinkage and Creep Models," ACI Materials Journal, Vol.102, (2005),pp. 170-176.

Bazant, Z. P. & Baweja, S. (2000). Creep and shrinkage prediction model for analysis and design of concrete structures: Model B3. *ACI SPECIAL PUBLICATIONS,* 194**,** 1-84.

Brooks, J. J. (2005). 30-year creep and shrinkage of concrete. *Magazine of concrete research,* 57**,** 545-556.

CEB-FIP, M. 1993. 90 (1993): Design of concrete structures. CEB-FIP-Model-Code 1990. *British Standard Institution, London, UK*.

Gardner, N. & Lockman, M. (2001). Design provisions for drying shrinkage and creep of normal-strength concrete. *ACI Materials Journal,* 98.

Gardner, N. & Zhao, J. W. (1993). Creep and shrinkage revisited. *ACI Materials Journal,* 90.

Goel, R., Kumar, R. & Paul, D. K. (2007). Comparative study of various creep and shrinkage prediction models for concrete. *Journal of materials in civil engineering,* 19**,** 249.

Huo, X. S., Al-Omaishi, N. & Tadros, M. K. (2001). Creep, shrinkage, and modulus of elasticity of high-performance concrete. *ACI Materials Journal,* 98.

Karthikeyan, J., Upadhyay, A. & Bhandari, N. M. (2008). Artificial neural network for predicting creep and shrinkage of high performance concrete. *Journal of Advanced Concrete Technology,* 6**,** 135-142.

Mazloom, M. (2008). Estimating long-term creep and shrinkage of high-strength concrete. *Cement and Concrete Composites,* 30**,** 316-326.

Mazloom, M., Ramezanianpour, A. & Brooks, J. (2004). Effect of silica fume on mechanical properties of high-strength concrete. *Cement and Concrete Composites,* 26**,** 347-357.