ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

MULTISCALE MODELING OF CONCRETE FOR DETERMINING CONCRETE CREEP COMPLIANCE

C. Divyapriya[*1], S.Lalitha.[2] & M.Alaguraj [3]
[*1, 2,&3]Assistant Professor, Department of Civil Engineering, Er. Perumal Manimekalai College of Engineering, India

DOI: 10.5281/zenodo.1050256

ABSTRACT

Estimation of creep of concrete and the resulting long-term deflections and prestress losses are important factors in the design of Reinforced and Prestressed concrete structural elements. Rational modeling of creep is required to ensure the safety and serviceability of structural elements during their service life, while a number of models have been proposed for estimation of creep of concrete for design purposes, a satisfactory model is yet to evolve due to the complexity exhibited by concrete creep. Recent investigation has shown that the knowledge about the nanoscale properties of C-S-H phases can be used along with multiscale modeling of concrete to determine creep properties of concrete. This paper presents the investigations carried out on determination of creep of concrete based on creep properties of nanogranular C-S-H phases. The upscaling of the viscoelastic properties of concrete have been done by using the formulation given by Pichler and Lackner[1]. This model links creep compliance of concrete at a macroscale, to the composition of concrete at microscale, which has been validated by comparing with experimental results available in open literature

KEYWORDS: Creep, Concrete, Multi-scale modeling, Nanoscale, CSH

I. INTRODUCTION

Concrete is one of the most-used construction materials on earth. Under sustained loads, concrete creep leading to excessive deformations. The creepof concrete is a non-elastic deformation of concrete under sustained stress. Estimation of creep of concrete and theresulting long-term deflections and prestress losses are important aspects to be considered in the design of reinforced and prestressedconcrete structures [6]. The time-dependent creep of concrete cancause excessive cracking and deflections or even failure. It canalso lead to stress re-distributions in statically indeterminatestructures. Thus, rational modelling of creep of concrete isrequired to ensure the safety and serviceability of structuresduring their service life.Concrete is a heterogeneous composite material, with a random microstructure at different length scales ranging from the nanometer scale to the macroscopic decimeter scale. At the macroscale, concrete is composed of aggregates and cement paste. At a microscale, the cement paste is made of several hydration products, with Calcium-Silicate-Hydrates (C-S-H) being the major hydration product[7].Experimental investigations by using nano indentation technique, by Ulm and co-workers have shown that concrete creep originates from the complex viscous behaviour of nano-meter sized building blocks of concrete, namely, Calcium Silicate Hydrates (C-S-H)[5].

Jennings et al. [4] have developed a structural model for CSH at the nanometer-scale accounting for the colloidal nature of CSH. At the nanoscale, The C-S-H in cement paste forms with two packing densities, corresponding to high-density (HD) and low-density (LD) morphologies. The creep of concrete is due to the rearrangement of the nanoscale C-S-H particles around the limit packing densities of compositionally similar but structurally distinct C-S-H phases present in the cement paste[5]. The recent advances made in nanomechanical testing techniques such as nanoindentation have made it possible to study the C-S-H phase at the nanostructure level[4,5].The nanoscale properties of the C-S-H phases can be further used in the multiscalemodeling to determine the creep properties of concrete [1].An attempt is made in this paper for estimating creep compliance for concrete at various ages.

This paper is organized as follows: the multi scale model for modeling creep of concrete is presented in the next section. The use of multi-scale model for estimation of elastic properties and creep properties of concrete is explained in section III. An example problem is given in section IV to illustrate the estimation of creep using this model. The summary and conclusions are presented in the last section.

II. MULTISCALE MODELLING OF CONCRETE CREEP

Bernard et al. [7] proposed a multi-scale model, starting atthe nanolevel of the C-S-H matrix, for determining the elasticmodulus of concrete. In this model, the microstructure isbroken down into the following four elementary levels. In the present study, this model is modified to determine the creep properties of concrete using the formulations proposed by Pichler and Lackner [1]. The different scales in the model are (Fig. 1):

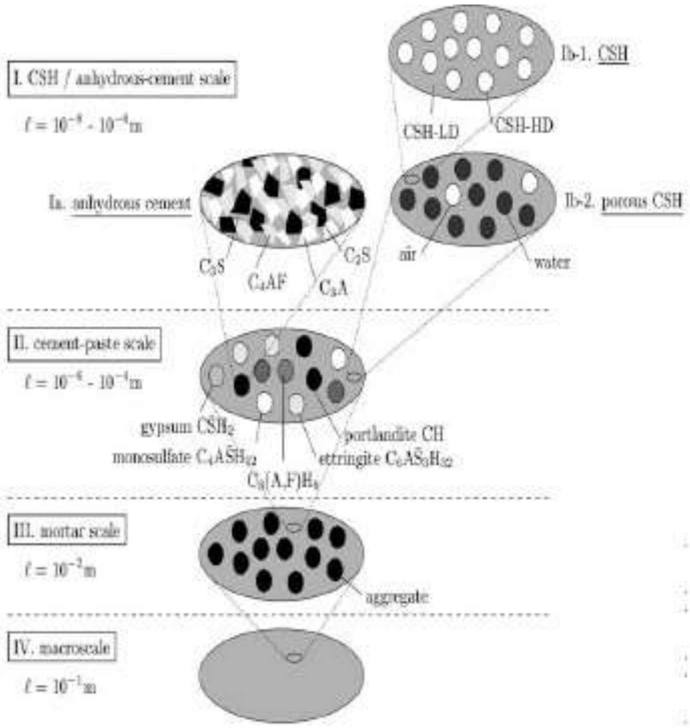


Fig.1Multi-scale microstructure model of concrete for upscaling the viscoelastic properties of concrete

Scale I: Comprises the four clinker phases, high-density CSH (CSH-HD) and low-density CSH (CSH-LD), and the water and air phase. The four clinker phases, which do not exhibit time dependent behaviour, are condensed into one material phase (Scale Ia). The constituents showing time-dependent behaviour, on the other hand, are combined at Scale Ib-1, where CSH-HD is located in the space confined by the previously formed CSH-LD. At the porous CSH scale (Scale Ib-2), water and air are considered as inclusions in a matrix constituted by the homogenized material of Scale Ib-1.

Scale II (cement-paste scale): Comprises the anhydrous cement (homogenized material of ScaleIa), gypsum CSH_2, portlandite CH, and reaction products from C3A and C4AF hydration form inclusions in a matrix constituted by the homogenized material of Scale Ib-2.

Scale III (mortar or concrete scale): Aggregates are represented as inclusions in the cement paste (homogenized material of Scale II). In addition to aggregates and cement paste, the interface transition zone (ITZ) may be introduced at Scale II. Since the ITZ mainly influences strength and transport properties of concrete rather than viscous deformations, it is not considered in the present model.

Scale IV (macroscale): Concrete is treated as a continuum.

III. UPSCALING ELASTIC AND CREEP PARAMETERS

Upscaling elastic parameters:Mori-Tanaka SCHEME: In case the microstructure is characterized by distinct matrix/inclusion-type morphology Mori-Tanaka (MT) scheme is used. The MT scheme is applied at Scales Ib.1, Ib.2, II, III, and IV with the material phases given by r∈ {matrix material m and multiple inclusions, such as, e.g., water and air at Scale Ib.2}.The material matrix m is represented by low-density CSH at Scale Ib.1, the homogenized material determined at Scale Ib.1 at Scale Ib.2, the homogenized material determined at Scale Ib.2 at Scale II, and the homogenized material determined at Scale II at Scale III. Using this scheme, the homogenized values of bulk modulus (k_{eff}) and shear modulus (μ_{eff}) are obtained from:

$$\mu_{eff} = \frac{\sum_x f_r \mu_r \left[1+\beta\left(\frac{\mu_r}{\mu_m}-1\right)\right]^{-1}}{\sum_x f_r \left[1+\beta\left(\frac{\mu_r}{\mu_m}-1\right)\right]^{-1}} \quad (1)$$

$$k_{eff} = \frac{\sum_x f_r k_r \left[1+\alpha\left(\frac{k_r}{k_m}-1\right)\right]^{-1}}{\sum_x f_r \left[1+\alpha\left(\frac{k_r}{k_m}-1\right)\right]^{-1}} \quad (2)$$

$$\alpha = \frac{3k_m}{3k_m+4\mu_m} \quad (3)$$

$$\beta = \frac{6(k_m+2\mu_m)}{5(3k_m+4\mu_m)} \quad (4)$$

Where *m* denotes the matrix and *r* denotes the inclusion. $k_m$and $k_r$are the bulk modulii of matrix and inclusion, respectively, and $\mu_m$and $\mu_r$are the shear modulii of matrix andinclusion, respectively.

Upscaling creep parameters:
Viscous material response is characterized by (i) anincrease of deformation during constant loading (creep) and (ii) a decrease of stress for constraint deformation (relaxation). The viscous response is commonly described by the creep compliance J [Pa^{-1}].The creep compliance associated with uniaxial loading is determined as

$$\mathrm{J(t)} = \frac{\varepsilon(t)}{\sigma 0} \quad (5)$$

The long-term compliance rate, as a function of the respective creep parameter $J_{CSH}^{v,dev}$ of CSH:

$$J_{eff,1b2}^{v,dev} = J_{CSH}^{v,dev}\frac{f_{CSH}+\frac{5}{3}(f_l+f_g)}{f_{CSH}}\,(\text{At Scale Ib. 2}) \quad (6)$$

$$J_{eff,II}^{v,dev} = J_{eff,1b2}^{v,dev}\frac{f_m}{f_m+\frac{5}{2}(1-f_m)}\,(\text{At Scale II}) \quad (7)$$

$$J_{eff,III}^{v,dev} = J_{eff,II}^{v,dev}\frac{f_m}{f_m+\frac{5}{2}(1-f_m)}\,(\text{At Scale III}) \quad (8)$$

$$J_{eff,IV}^{v,dev} = J_{eff,III}^{v,dev}\frac{f_m}{f_m+\frac{5}{2}(1-f_m)}\,(\text{At Scale IV}) \quad (9)$$

Where the indices "l", "g", and "m" refer to the liquid, gaseous, and matrix phase

The uniaxial viscoelastic compliance function is

$$J_{IIII}^{v,age}(t-\tau) = \frac{1}{9}\frac{1}{k_{eff}[\xi(\tau)]}+\frac{1}{3}\frac{1}{\mu_{eff}[\xi(\tau)]} + \int_\tau^t \left\{\frac{1}{9}\frac{J_{eff}^{v,vol}[\xi(\tau)]}{t-\tau+\tau_{eff}^{v,vol}[\xi(t)]}+\frac{1}{3}\frac{J_{eff}^{v,dev}[\xi(\tau)]}{t-\tau+\tau_{eff}^{v,dev}[\xi(t)]}\right\}dt \quad (10)$$

Where$\xi(\tau)$and $\xi(t)$are the degrees of hydration at the time of loading and at the time of predicting creep compliance, respectively. To determine the degree of hydration at any stage hydration kinetics models were used [3].

$$\sqrt[3]{1-\xi_x} = -\sqrt{2D}\frac{\sqrt{t-t^*}}{\mathrm{R}} + \sqrt[3]{1-\xi_x^*} \qquad (11)$$

Where ξ_x is the degree of hydration of clinkers, x∈ (C_3S, C_2S, C_3A, C_4AF)

The degree of hydration and the volume fractions can also be determined using freely available software such as CEMHYD 3D and HYMOSTRUC software packages were used [2]. The input parameters required at each level for the MT scheme are the relative volume fractions, shear modulii and bulk modulii of the matrix and inclusion. Determination of volume fractions are discussed below:

The volume fractions of the different phases (at the cement-paste scale) can be determined as a function of the hydration degrees ξx and the mass fractions of the clinker phase's m_x.

$$f_{CSH}(t) = \left[\xi_{C_3S}(t)\frac{m_{C_3S}0.5M_{CSH}}{M_{C_3S}\rho_{CSH}} + \xi_{C_2S}(t)\frac{m_{C_2S}0.5M_{CSH}}{M_{C_2S}\rho_{CSH}}\right]\rho \qquad (12)$$

$$\rho = \frac{1}{\sum_x \frac{m_x}{\rho_x} + \frac{w/c}{\rho_H}\sum_x m_x} \qquad (13)$$

Where x∈{C_3S, C_2S, C_3A, C_4AF, C H2} and mx represents the mass fractions of the four clinker phases and gypsum.

Scale III: In this level, the matrix phase is the cement paste, whose homogenised elastic properties are determined in scale II. The sand particles are the inclusions. The relative volume fractions are given by:

$$f_I = \frac{s/\rho_s}{c/\rho_c + s/\rho_s + w/\rho_w} \qquad (14)$$

$$f_m = 1 - f_I \qquad (15)$$

Where*s* is the sand content, *c* is the cement content and *w* is the water content. ρ_s, $\rho_c$and $\rho_w$are the mass densities of sand,cement and water, respectively.

Scale IV: In this level, the matrix phase is the cement mortar, whose homogenised elastic properties are determined in scale III. The coarse aggregates are the inclusions. The relative volume fractions are given by:

$$f_I = \frac{g/\rho_s}{c/\rho_c + (s+g)/\rho_s + w/\rho_w} \qquad (16)$$

$$f_m = 1 - f_I \qquad (17)$$

Where*g* is the aggregate content.

The proposed method for estimation of creep does not require any prior information regarding the mechanical properties of concrete such as modulus of elasticity or compressive strength. The input parameters include basic mix properties, cement characteristics, elastic properties of the aggregates, andviscous properties of CSH.

IV. EXAMBLE

The results of experimental investigations carried out by Laplante[7] on creep of concrete is used in this paper to study the performance of the model. The input parameters considered are given in Table 1.The elastic properties at different scales determined using the multi-scale model are given in Table 2. The rate of creep compliance determined at different scales are given in Table 3.

Table 1 Input Parameters

Parameters	**Laplante mix[7]**	**Bazant mix [8]**
water/cement-ratio (w/c)	0.5	0.49
Cement content(kg/m^3)	342	350
Sand content (kg/m^3)	670	560
Coarse Aggregate content (kg/m^3)	1200	1125
Young's modulus of aggregateGPa	65	65
Age @ loading (days)	28	7,90,365

Table 2 Elastic properties of concrete using upscaling procedure at the age of loading

Scale	**Bulk modulus (k_{eff}) GPa**	**Shear modulus (μ_{eff}) GPa**	**Elastic modulus (GPa)**
Scale 1b	15.682	9.873	24.481
Scale 1b2	9.619	6.054	15.012
Scale II	10.885	6.867	17.021
Scale III	13.801	11.070	26.205
Scale IV	21.540	16.228	32.912

Table 3Creep compliance rate at the age of loading

Scale	**Creep compliance rate (1/GPa)**
C-S-H ($J_{C-S-H}^{v,dev}$)	0.07
Scale 1b2 ($J_{eff,1b2}^{v,dev}$)	0.107
Scale II ($J_{eff,II}^{v,dev}$)	0.026
Scale III ($J_{eff,III}^{v,dev}$)	0.009
Scale IV ($J_{eff,IV}^{v,dev}$)	0.003

The variation in creep compliance with time is shown in Fig. 2 and variation in creep compliance with age of loading is shown in Fig.3.From Fig.2 it is noted that, as expected the creep compliance increases with time. Also, the creep compliance increases at a higher rate at the initial stages, but reduces to a constant rate as age of concrete increases. It is also noted from Fig. 2 that the values of creep compliance obtained using the multi-scale model are in agreement the experimental results, indicating usefulness of the proposed model for predicting creep of concrete.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

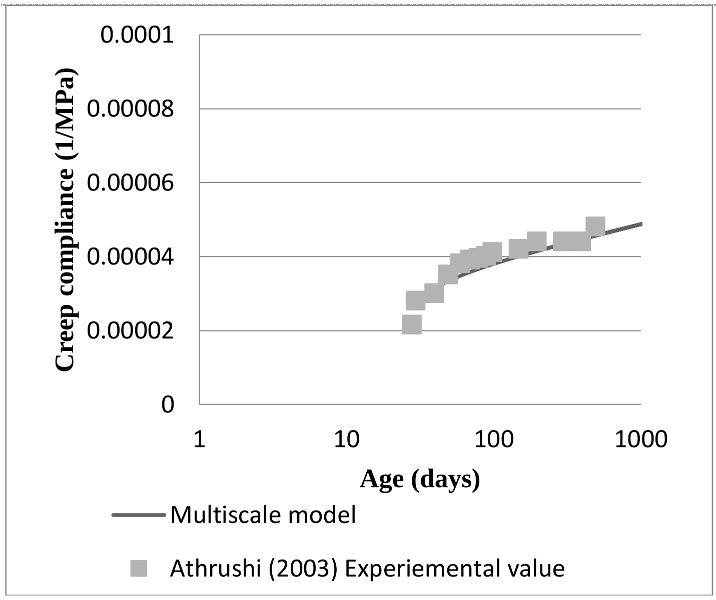
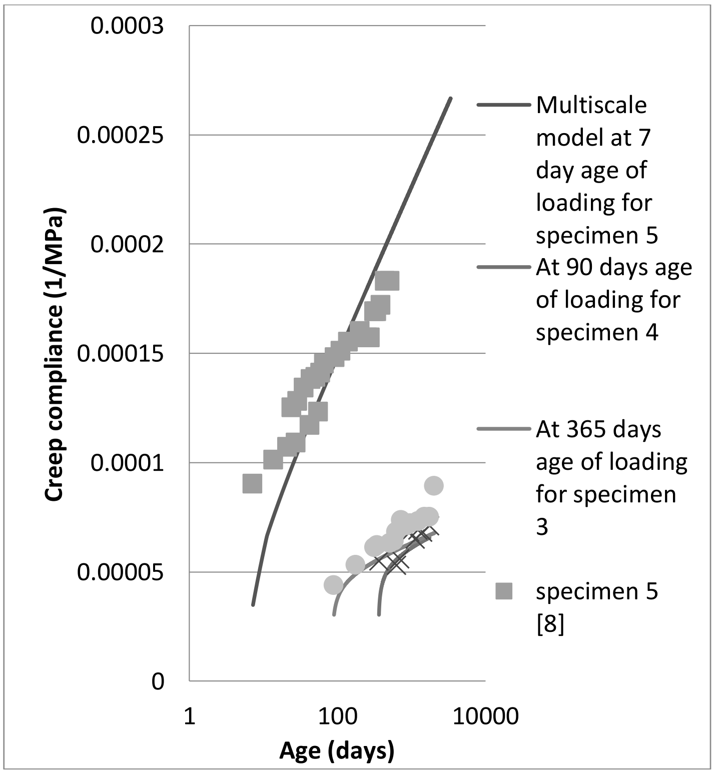


Fig. 2 Variation of creep compliance with age



. Fig.3 Creep compliances at different ages of loading.

V. CONCLUSION

A method for estimation of creep of concrete through multi-scaling ofconcrete ispresented. This method requires only the intrinsic materialparameters and mix-design details for estimating the creep ofconcrete. The usefulness of the method is illustrated with the help ofan example. After further validating the performance of the model using results of experimental investigations available in literature, this model will be used for determining the time dependent deflection in reinforced concrete flexural elements

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

VI. REFERENCES

[1] Ch. Pichler, R. Lackner "A multiscale creep model as basis for simulation of early-age concrete behavior" Computers and Concrete, 5(2008) 295-328.
[2] Dale P. Bentz "A Three-Dimensional Cement Hydration and Microstructure Development ModelingPackage",Version 3.0 ,NISTIR 7232.
[3] Jaesung Lee, "A multiscale model for modulus of elasticity of concrete at high temperatures" Cement and Concrete Research vol. 39 (2009) 754–762.
[4] Jennings, H. M., "Colloid model of C-S-H and implications to the problem of creep and shrinkage",Material and Structures., 37(2004) 59-70.
[5] M. Vandamme, "The Nanogranular Origin of Concrete Creep: A Nanoindentation Investigation of Microstructure and Fundamental Properties of Calcium-Silicate-Hydrates", Ph.D. Dissertation, Departmentof Civil and Environmental Engineering, Massachusetts Institute of Technology, 2008.
[6] N. J. Gardner and M. J. Lockman "Design Provisions for Drying Shrinkage and Creep of Normal-Strength Concrete "ACI Materials Journal 98 (2001) 159-167.
[7] O. Bernard, F.J. Ulm and E. Lemarchand, "A multiscale micromechanics-hydration model for the early-age elastic properties of cement-based materials", Cement and Concrete Research, 33 (2003) 1293-1309

CITE AN ARTICLE

Divyapriya, C., Lalitha, S., & Alaguraj, M. (n.d.). MULTISCALE MODELING OF CONCRETE FOR DETERMINING CONCRETE CREEP COMPLIANCE. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *6*(11), 328-334.