SIMULATION OF DRYING SHRINKAGE OF CYLINDRICAL CONCRETE SPECIMENS UNDER RADIAL DRYING

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1. Introduction

Drying shrinkage of concrete is generally understood as a material response to a loss of moisture. In the presence of moisture distribution, as in the case of cylindrical concrete specimens under radial drying, this material response is manifested in a form of a complicated stress condition which yields different observable drying shrinkage strains for different measurement locations, such as along the centerline and the border of a cylindrical concrete specimen. Therefore the distribution of moisture inside a concrete specimen is considered to have a major role in the observable drying shrinkage behavior.

In this paper, an effort has been made to simulate the moisture distribution of mature cylindrical concrete specimens under a drying ambient condition using axisymmetric finite element modeling. A special care is taken to consider more properly the condition of moisture flow on the drying surface by adopting the concept of fictitious layer [1]. The effect of specimen height on shrinkage behavior is discussed.

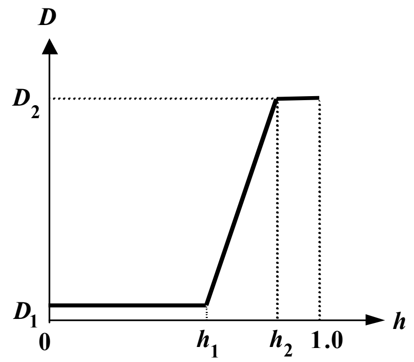

Figure 1. Humidity Dependence of Diffusivity

2. Model of Drying Shrinkage

The moisture diffusion is considered nonlinear in which the diffusivity D is dependent on the local relative humidity h by a simple tri-linear model, as shown in Fig. 1. In this model, the diffusivity D is constant (D_2) for local relative humidity values between 1.0 and $h_2 = 0.98$. The diffusivity D varies linearly from D_2 to D_1 for local humidity values between h_2 and h_1. The diffusivity assumes a constant value $D_1 = 0.15D_2$ for all local relative humidity lower than h_1.

The shrinkage model also considers a thin fictitious layer with thickness T connecting the drying surface of a specimen to the ambient air. Moisture is considered to diffuse linearly in this layer with diffusivity D_{fl}. The diffusivity of the fictitious layer D_{fl} is considered to be proportionally dependent on the ambient humidity, as given in Eq. 1,

$$D_{fl} = Ch_a \tag{1}$$

where h_a is the ambient relative humidity and C is the proportional constant. At the interface between the fictitious layer and the ambient air, a fixed boundary condition is applied.

The strain calculation considers a linear relationship between an incremental local relative humidity Δh and the corresponding incremental change of shrinkage strain $\Delta\varepsilon$, as given in Eq. 2,

$$\Delta\varepsilon_i = \alpha_{sh}\Delta h \tag{2}$$

where i=r,θ,z, and α_{sh} is the proportional constant.

The stress calculation takes into account the effect of creep by means of an effective modulus E_{eff}. For simplicity, the creep coefficient ϕ is considered constant and is equal to 1.0 for the current simulation, and the creep Poisson`s ratio v_{cr} is considered the same with the elastic Poisson's ratio v.

3. Numerical Simulation

The simulation is based on the experimental data of Wittmann [2]. In this experiment, cylindrical concrete specimens having the same radius r = 75 mm and different heights l = 30, 60, 120 and 240 mm are allowed to dry under an ambient humidity of 40% RH at an age of approximately 100 days. The end faces of the cylinders are sealed to allow for radial drying. The concrete composition has a water/cement ratio of 0.55 and a cement content of 400 kg/m^3. The aggregate size distribution approximately follows the Fuller curve.

The model of shrinkage in the previous section is implemented into a finite element modeling using a 4-node isoparametric axisymmetric linear element, with element size a x b = 0.75 x 0.2 mm. The same type of element is used to model the fictitious layer, and the fictitious layer thickness T is constant throughout the drying surface. Fig. 2(a) shows the quarter area of the

KEY WORDS: Simulation, Shrinkage, Drying, Concrete, Axisymmetric Specimen
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middle section of the specimen to be discretized, as shown in Fig. 2(b). The boundary conditions for displacement as well as for moisture flow are shown Fig. 2(b). The thick lines in this figure indicate sealed boundary condition from moisture transfer with the environment, while the thin gray lines indicate fixed boundary condition. It is important to note that, in order to account for the influence of the air above and below the specimen the bottom side of the lowest fictitious layer element is given a sealed boundary condition, whereas the top side of the uppermost fictitious layer element is given a fixed boundary condition. This condition means that specimens with lower height will deviate farther from the condition of radial drying so that different moisture distributions are expected for specimens with different heights.

The simulation is performed using the parameters given in Table 1, and the results are shown in Figs. 3, 4 and 5. It is shown in Fig. 3 that the moisture distribution and the state of stresses are such that at an age of drying of 220 hours shorter specimens give significantly higher shrinkage strains compared to that of the longer specimens. The difference in shrinkage strain between the measurements along the centerline and that on the border is also higher for specimens with lower heights. This behavior can be simulated closely in the current simulation. Figs. 4 and 5 show shrinkage developments along the centerline and on the border respectively. It is shown that better agreement with the experimental data can be obtained with the shrinkage development at the border, whereas along the centerline some discrepancy is still observed. It is considered that the discrepancy is mainly due to the fact that the stress state in the area around the centerline is not very accurate.

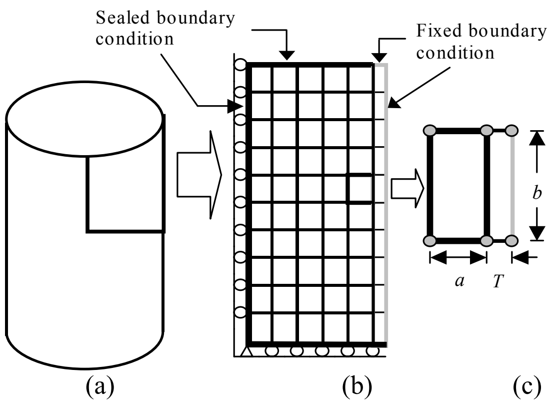

Figure 2. Discretization and boundary conditions

Table 1. Parameters used in simulation

D_2 (cm²/day)	h_1	C (cm²/day)	T (mm)	α_{sh}	ν	E_{eff} (Gpa)
3.0	**0.6**	**0.0035**	**1.0**	**0.01**	**0.2**	**25**

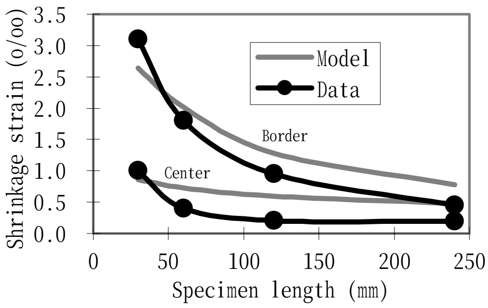

Figure 3. Shrinkage for different specimen heights after 220 hours

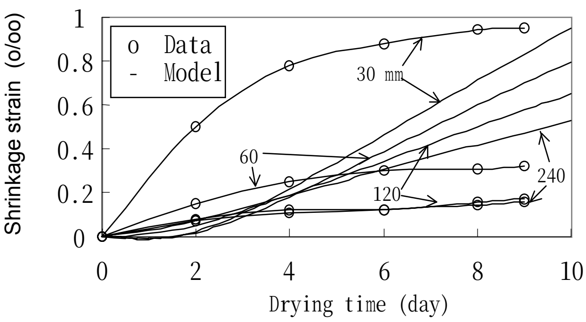

Figure 4. Shrinkage development at center

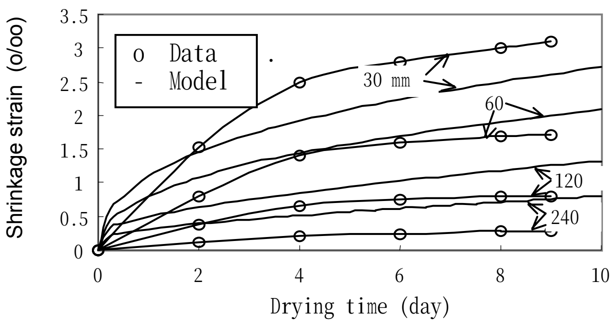

Figure 5. Shrinkage development at border

4. Conclusion

A proper boundary condition for drying surface, such as the fictitious layer, which is capable to take into account the influence of the surrounding air, instead of only that perpendicular to drying surface, is necessary for more accurate prediction of moisture distribution and shrinkage strain.

The shrinkage strain behavior on the border can be simulated using axisymmetric finite element modeling. However, the simulation of the behavior along the centerline of the specimen indicates the necessity of more elaborate modeling.

References

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[2] Wittmann, F.H.: On the influence of stress on shrinkage of concrete, *Creep and Shrinkage of Concrete*, Ed. Z.P. Bazant and I. Carol, E&FN Spon, pp.151-159, 1993.