Numerical simulation of the creep phenomenon of steel fiber reinforced concrete

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Abstract

In this article the authors propose a numerical simulation method to investigate the influence of steel fibers on the creep property of fiber reinforced concrete (FRC). A finite element (FE) model of concrete structured with randomly distributed fibers is generated by using random numbers for fiber distribution and Delaunay triangulation for the triangular meshing, after slight modification of the location of fibers for better numerical results. The finite element model is prepared in 2-D as a plane stress problem. Through a number of numerical tests the results show that the randomness of fiber location influences the creep phenomenon within several percents of the one of regularly prepared fiber.

Keywords: Fiber reinforced concrete; Random distribution; Short fibers; Finite element; Tensile behaviour; Damage; Nonlinear analysis; Creep

1. Introduction

The mechanism of the effect of fiber on matrix creep strain can be described as follows. As the matrix undergoes creep along the compressive loading direction, due to the stiffness difference of fiber and matrix, a shear stress along the fiber and matrix interface is developed. The fiber is subjected to compression and the matrix is subjected to tension. The direction of the fiber has a great effect on creep reduction. If the fiber locates parallel to the direction of the compressive stress, it will generate the greatest influence on creep reduction. Previous models [3,4] depend on converting the random distribution of fibers to an equivalent align distribution in order to find equations to calculate the creep strain of fiber reinforced concrete.

As an alternative to extensive experimentation, this study is implemented to predict the creep strain of concrete reinforced by short steel fiber. The actual random distribution is used to calculate the creep strain using finite element method. The load is first applied and the initial stress and strain are calculated. The creep strain is then calculated in different ages according to the work of Bazant and Baweja [5]. The tensile stress, which is generated from the existence of steel fibers in the compression zone of concrete, reduces the creep strain in the combined material.

2. Finite element modelling

Some previous attempts to model fiber reinforced concrete were achieved in [1,2,4]. But modelling the random distribution of fibers is still lacking. This paper is an attempt to model FRC with random distribution of short fibers. However, the random distribution may generate poor mesh quality. Therefore, much attention should be given to the distribution of fibers in order to get a fine mesh model. The steel fibers are distributed randomly inside the concrete domain using random numbers. A function, which generates random numbers from 0.0 to 1.0, is used to distribute fibers in the domain.

Figure 1 shows the modification of fibers crossing in order to avoid the generation of bad mesh quality. The angle between each two crossed fibers should not be less than 30° to avoid the numerical errors that might occur from the small angle because they cause the coupled systems of algebraic equations that numerical methods yield to be ill-conditioned. The distance between crossing point of two fibers and the end of one of them should not be less than $l/10$ where l is the length of the fiber. In

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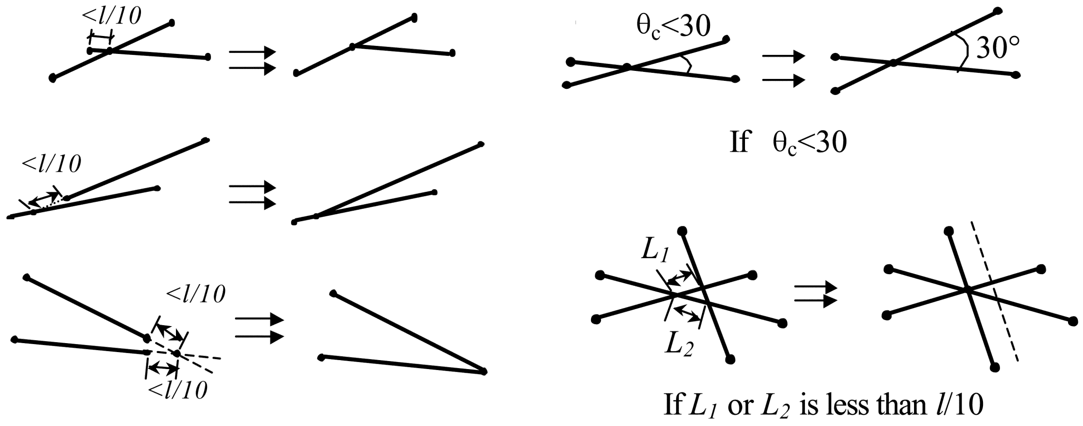

Fig. 1. Modification of fibers crossing.

the case of crossing between three fibers as shown in Fig. 1, if L1 or L2 is less than $l/10$, the third fiber is moved parallel to its position until the three fibers meet in one point. The modification of fiber positions is done for all fibers in iterative processing until all the positions of all fibers are modified.

After distributing fibers randomly in the domain and correcting their positions, the Delaunay triangulation for 2-D case is used to divide the domain into triangular elements to construct the mesh model. The least number of nodes is the number of points that define the boundaries in addition to the number of points that define the fibers (the start points, the end points, and the crossing points). Additional nodes should be added to create a fine mesh model. Figure 2 shows 23 fibers distributed in a 100×200 mm^2 concrete specimen with volume fraction 1%; 500 nodes are used to create the mesh model.

3. Numerical analysis

The analysis is valid only for basic creep in which moisture content is constant, i.e. drying shrinkage is not taken into consideration. The creep law in the current study is assumed to be linear with respect to the stress history. The linearity means that at constant uniaxial stress σ applied at concrete age t' the correspondent $\varepsilon(t)$ at any time $t \geq t'$ may be written as

$$\varepsilon(t) = \sigma J(t, t') \tag{1}$$

where $J(t,t')$ is the uniaxial compliance function, a material property characterizing creep strain which is derived by Bazant et al. [5].

Calculation of creep strain is done in two steps:

- Initial state: For the given initial loads, the program yields the stresses, strains, and displacements at time t_1 just after the load application.
- Change from t_1 to t: The elastic modulus of the material is set to $E'(t, t_1)$, which is the age-adjusted effective modulus. The creep strain at the age $(t–t_1)$ is calculated from the equation

$$\Delta\varepsilon = \beta(t, t_1)\frac{C_v}{E(t_1)}\sigma(t_1) \tag{2}$$

where β is a time dependent dimensionless creep coefficient, which is defined as the ratio of the creep strain for the load duration $t–t_1$ to the initial elastic strain at age t_1. The calculation is made according to the work of Bazant and Baweja [5], with C_v as the unit elastic compliance matrix.

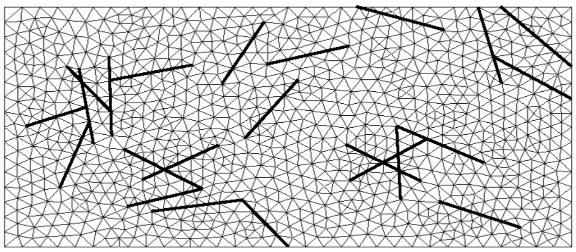

Fig. 2. FE mesh.

4. Results

A numerical model is introduced to show the influence of short steel fibers to reduce the creep strain. A concrete specimen with dimensions 400×100×1500 mm with 4-points loading is analyzed. Short steel fibers 30 mm long and 0.6 mm diameter are distributed randomly with

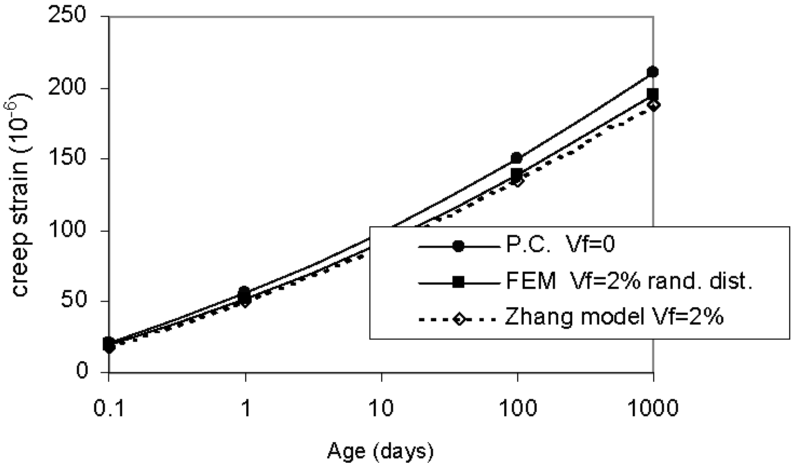

Fig. 3. Creep strain for fiber reinforced concrete with 2% fibers randomly distributed.

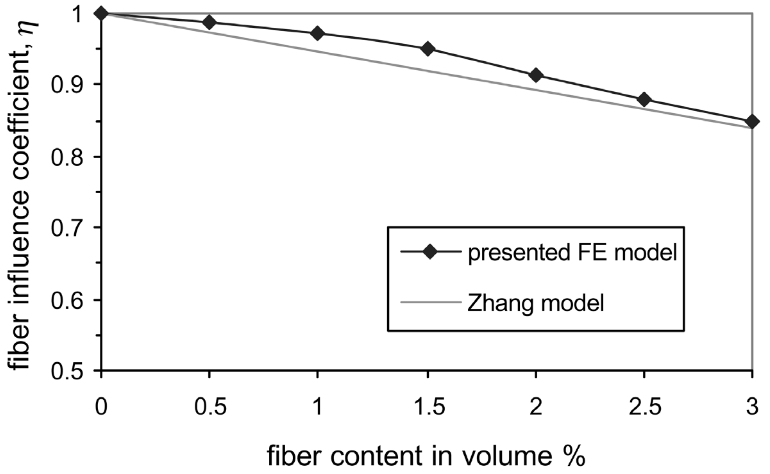

Fig. 4. Comparison between FE and Zhang models.

several fiber contents inside the specimen. The creep strain has been calculated as the average of 10 models with random distribution of fibers under a load of 20 KN which is less than 50% of the ultimate load. It was found that the creep strain is varying from point to point according to the location of steel fibers. To evaluate the average value of creep strain, it is calculated in all elements in a small portion of the structure in the compression zone. The average value of the creep strain is calculated and compared with the correspondent values for plain concrete and the Zhang model [4].

Figure 3 shows the results of the average creep strain of 2% inclusion of steel fibers which is calculated from random distribution using FEM compared with the creep strain in the Zhang model, which is based on converting the random distribution to a periodic one. As expected, incorporating short steel fibers can significantly influence the composite creep performance. The results show good agreement between both models, even though it is a little bit higher in the FE model.

The difference between both models may be explained in Fig. 4, which shows a comparison between the FE and Zhang models. The figure shows the fiber influence factor η, which is the ratio between creep strain of FRC to its correspondent of plain concrete for fiber contents. From Fig. 4 it is noticed that, when the fiber content is very low, both models are agreeable because the effect of fibers on creep is still very small when the fiber content is very low. The creep strain values in this case approach from the correspondent values in plain concrete. As the fiber content increases, the difference between the two models appears clearer. The two models become agreeable again when using a high fiber content as shown in Fig. 4. The reason may be explained as the random distribution of fibers has a clear effect when the fiber content is low because of the relatively large space from fiber to fiber which leads to increase the error that occurred from converting the random distribution to a periodic one. When the fiber content is high the distribution of fibers becomes condensed, hence the error of conversion becomes smaller and the random distribution converged from the periodic distribution. From Fig. 4 the random distribution of the current FE model starts to converge from the periodic distribution of the Zhang model [4] after 2% volume content of fibers.

5. Conclusion

This article attempts to investigate the influence of reinforcing concrete steel fibers on the creep performance of concrete using FE model, which is based on the actual random distribution of fibers. This distribution is modified in order to get a fine mesh model. The model prediction of the creep strain is compared to the model of Zhang, which is based on converting the random distribution of fibers to a periodic distribution.

Through a number of numerical tests we find that, as expected, incorporating short steel fiber can significantly reduce the creep strain of the composite. The difference of creep phenomenon between random fiber distribution and regular fiber distribution depends on the volume content of fiber. Beyond a fiber content of 2%, converting the random distribution to periodic distribution is possible. The current model is better to use when the fiber content is low.

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