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Modification of the long-term deformation models for steel reinforced concrete columns

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HIGHLIGHTS

- Existing long-term deformation models cannot consider the characteristics of SRC columns.
- Modified long-term deformation models are suggested for reasonable prediction of SRC columns.
- Modification is based on the analytical long-term deformation of various columns.
- Only the geometry of the wide-flange steel is necessary for the modified models.
- Modified models are simple and useful for designing buildings with SRC columns.

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ABSTRACT

It is important to predict the long-term deformation of steel reinforced concrete (SRC) columns especially for high-rise buildings. This research aims to modify the existing creep and shrinkage models for SRC columns. Modified models are suggested by inserting appropriate coefficients to consider the delayed long-term deformation of SRC columns resulted from the slower moisture diffusion due to the wide-flange steel. The coefficients are determined through the parametric study and it is found that the geometry of wide-flange steel is a dominant factor. The suggested models are applicable for square SRC columns with the size of wide-flange steel is over half of the total size of column. Comparison of the prediction with the experiment shows that the suggested models are quite reasonable.

1. Introduction

Long-term deformation of concrete, the drying shrinkage and drying creep, are closely related to the moisture diffusion of concrete [1,2]. Factors that affect the moisture diffusion and the long-term deformation are the ambient relative humidity, temperature, size of the member, compressive strength of concrete, type of cement and so on [1,3]. The existing shrinkage and creep models such as ACI 209R-92 [4], *fib*2010 [5], and B3 [6] consider these factors. However, for steel reinforced concrete (SRC) columns, wide-flange steel is another important factor should be considered because it hinders moisture diffusion. The moisture diffusion occurs more slowly by wide-flange steel, and shrinkage and creep consequently develops slowly as shown by the experimental results [7,8].

Long-term deformation of SRC columns should be predicted more carefully because SRC columns are frequently used for high-rise buildings. However, the existing models do not consider the effect of wide-flange steel on the long-term deformation. Therefore, the modified long-term deformation models for concrete in SRC columns are necessary.

In this research, modified drying shrinkage and drying creep model equations for typical SRC columns are suggested depending on the geometry of wide-flange steel. Shrinkage and creep of various SRC columns are analytically evaluated for the modification. Two models, *fib*2010 [5] and B3 [6], are modified by comparing the analysis results of SRC columns to those of RC columns. ACI model [4] is not dealt with because it does not separate the drying creep and basic creep for the creep model. Models are modified by inserting appropriate coefficients in the time function of each existing model because wide-flange steels mainly affect the speed of deformation, not the ultimate amount of deformation. Modified models generally give more reasonable prediction for SRC columns and it is experimentally verified.

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2. Analytical prediction of the long-term deformation of SRC columns

2.1. Analytical program

2.1.1. Procedure of the analysis

The long-term deformation of SRC columns should be predicted for the modification of the existing models, and it is predicted analytically in this paper by the analytical method suggested in the previous studies [7–9]. Overall analytical procedure follows the previous researches, hence the procedure is shortly explained herein.

The analytical procedure can be divided into three steps: section modeling, moisture diffusion analysis, and deformation analysis. Depending on the type of section modeled, moisture distribution by diffusion analysis [10–12] is evaluated. Eventually, the long-term deformation can be predicted based on the change of moisture distribution [13–16]. Each SRC column shows different long-term deformation because the moisture distribution is different depending on the conditions such as type of wide-flange steel. The analytical results from various columns are used for the regression analysis to suggest the modified models.

For the section modeling step, it is important to model the wide-flange steel to affect only the moisture diffusion, not to affect the stiffness of the column because the main subject of this research is to demonstrate the change of the long-term deformation due to the moisture diffusion, not due to the reinforcement ratio. Therefore, wide-flange steel is modelled to be thin as much as possible but still to prevent moisture diffusion.

2.1.2. Parameters for the analysis

There are several parameters such as diffusion coefficient or surface factor which are essential for the analysis. Short explanations about the analytical parameters are as follows.

The diffusion coefficient$D$ is defined as Eq. (1) [5].

$$D(h) = D_1\left(a + \frac{1-a}{1+[(1-h)/(1-h_c)]^m}\right) \quad (1)$$

where h is the pore relative humidity, D_1 is the maximum moisture diffusion coefficient when $h = 1.0$, a is the ratio of the maximum D to minimum D, h_c is the pore relative humidity at $D = 0.5D_1$ and m is an exponent.

The surface factor f which is essential for the boundary condition of the diffusion analysis is defined as Eq. (2) [17].

$$D\left(\frac{\partial h}{\partial n}\right)_s = f(h_{en} - h_s) \quad (2)$$

where f is the surface factor, h_{en} is the ambient relative humidity, h_s is the surface relative humidity, and n is the unit outward normal at the surface.

The ultimate free shrinkage, ε_s^o and the constant for shrinkage, r are the two parameters used for calculating the drying shrinkage and drying creep as Eq. (3) [13].

$$\Delta\varepsilon_{SH} = \varepsilon_s^o \frac{E_c(t_\infty)}{E_c(t)}(1 + r\sigma_c)\Delta h \quad (3)$$

where ε_{SH} is shrinkage and stress-induced shrinkage which is also known as drying creep, E_c is the Young's modulus of concrete, σ_c is the stress of concrete, and t_∞ is the ultimate time of drying.

2.1.3. Conditions for the analysis

SRC columns whose cross-sections are square and wide-flange steels are placed as shown in Fig. 1(b)–(d) are analyzed in this research. These SRC columns are commonly used for the construction of buildings. Ordinary RC columns as shown in Fig. 1(a) are also analyzed for comparison with SRC columns. RC columns can be regarded as plain concrete columns because the moisture diffusion is not disrupted by the reinforcement. Therefore, RC column in Fig. 1(a) is named as 'P'. SRC column in Fig. 1(b) is named as 'H' because of the shape of wide-flange steel. For the same reason, columns in Fig. 1(c) and (d) are named as 'C' because the shapes of wide-flange steel look like a cross. The numbers in parenthesis after 'C' mean the ratio of flange to web length of wide-flange steel. In other words, SRC columns in Fig. 1(c) and (d) are named as 'C (0.5)' and 'C(0.75)' because they both have cross-like wide-flange steel and their flanges are 0.5 and 0.75 times of their webs, respectively.

Other conditions besides the geometry of wide-flange steel are the total size of column d, ratio of web of wide-flange steel to total size of column γ as shown in Fig. 1, and ambient relative humidity RH. Three sizes of column d = 500, 1000, 1500 mm are analyzed with six different ratios γ = 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 under the three ambient humidities RH = 30, 50, 70%.

2.2. Characteristics of the long-term deformation of SRC columns

Long-term deformation of concrete in SRC columns develops slower than RC columns. It is not because of the reinforcement ratio of SRC column. It is from the moisture diffusion of concrete delayed by the wide-flange steel [7–9]. All the columns herein have nearly zero reinforcement ratio to investigate the long-term deformation of 'concrete' due to the different moisture diffusion. Therefore, all the results can be directly used for the modification of models of concrete.

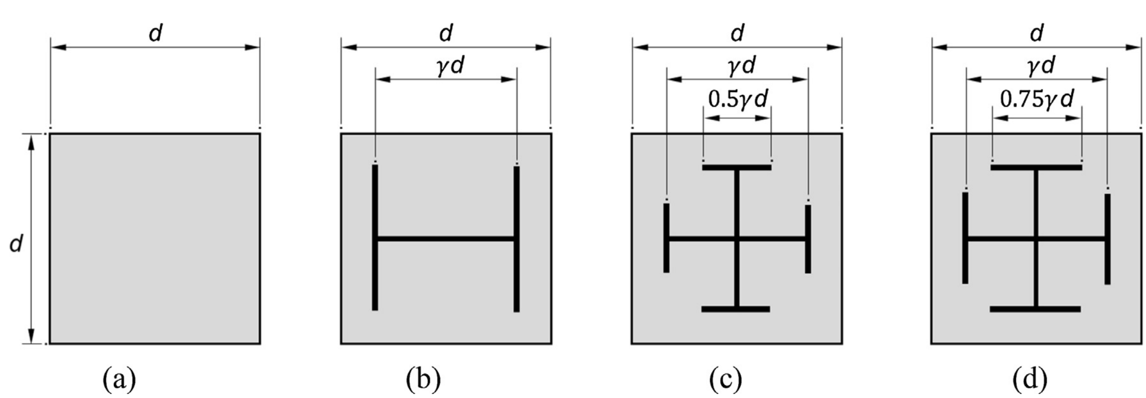

Fig. 1. Geometry of the wide-flange steel in column: (a) P; (b) H; (c) C(0.5); (d) C(0.75).