The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Parameter study on the long-term deformation of concrete columns

Gyeong-Hee An[1] and *Jin-Keun Kim[2]

[1), 2)] *Department of Civil and Envrionmental Engineering, KAIST, Daejeon 305-701, Korea*
[2)] *kimjinkeun@kaist.ac.kr*

ABSTRACT

Prediction of long-term deformation of concrete member is important for most concrete-based civil structures, especially for large structures. Numerous researches have been conducted to demonstrate the long-term deformation of concrete, and relevant models have been developed. Although the models are applicable for the general cases considering the size of the member, environmental condition, cementitious materials and so on, but not for the complicate problems containing changes of the environment or shape of the reinforcing steel shape of SRC columns. However, those problems should be dealt with as the needs of various structures increase.

In this study, deformation will be predicted by taking into account moisture diffusion and relationship between the pore relative humidity and drying shrinkage or creep. The structure member is restricted to the columns in this research. Parameters like reinforcing steel shape and covering depth affecting the moisture diffusion behavior will be used for the deformation analysis and their effects will be synthesized to make useful conclusion. This research can help estimating the long-term deformation in various concrete columns.

1. INTRODUCTION

Through the numerous preceding researches, long-term deformation of concrete has been predicted quite reasonably. One of the things that are not considered in the model equations is the inner configuration of the cross-section which technically means the way of the moisture diffusion within the section. The effect of inner cross-sectional configuration on the long-term deformation would be the slower speed of the deformation.

The key idea is the fact that shrinkage is related to the moisture diffusion, and the inner configuration can affect the diffusion process. It means that the inner configuration of the cross-section can change the speed of deformation. Furthermore, the more the cross-section has influential shape to moisture diffusion, the more different the deformation will be from its conventional analysis results. An easy example

[1)] Graduate Student
[2)] Professor

is steel-reinforced concrete (SRC) columns. The ‗I-shape‘ steel beam is very influential component because the flanges of the reinforcing beam play like a waterproof barrier.

The moisture diffusion can be expressed as relative humidity in the cross-section. Observing the diffusion analysis results of ordinary RC and SRC columns, we can notify the difference of humidity distribution as time goes by. Because of the disturbance of steel flanges, moisture diffusion is slower in SRC columns and the deformation develops slower as a result. However, the current models cannot give the different results as they do not include the reinforcing steel shape related factors.

In this study, the sectional shape will be considered by calculating the long-term deformation of the section using free shrinkage data at every node in the section. This free shrinkage computed from the variation of relative humidity at each node is dependent on the moisture diffusion. In other words, the deformation at each time step will become different if the moisture diffusion process is different due to the internal shape.

We can scope how the deformation different on various kinds of sections by analysis in this paper as a basis for the research to modify current models. It gives good reasons why we should consider the sectional shape and helps civil engineers judge more reasonably when some structural members with special cross-sectional shape are used.

2. DISTINCTION OF THE RESEARCH

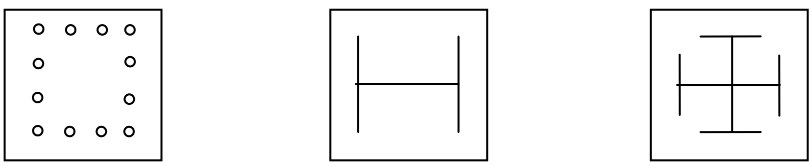
In this research, effects of each parameter will be summarized so that readers can see the differences easily. B3 model is used as the standard of the relative comparison between column sections.

Also, the effect of differential stress-induced creep, called drying creep normally, is considered more accurately compared to the previous research in Seol (2008) related to the column shortening on SRC columns. Therefore, the more accurate and broad prediction related to the loading situation is possible.

Lastly, this research gives theoretical basis and methods for analyzing long-term deformation in any other structures because the method is based on the analysis of elements in the entire structures. It means that this analysis can be applicable to any arbitrary shape of structural member, even not existing now but can be created later.

3. LONG-TERM DEFORMATION ANALYSIS PROCEDURE

Overall procedure is as in the following. First, we choose the interesting section and generate meshes. Fig. 1 shows the interesting sections roughly.



(a) RC (b) SRC1 (c) SRC2

Fig. 1 Column section layout

Then, moisture diffusion analysis is conducted and humidity information of each node at every time step is stored. Using this humidity information, shrinkage and creep during one time step at each node are calculated as each element is under free of restraint. Finally, the deformation of the section is acquired by considering the restraint between the elements based on the assumption that plane remains plane after the deformation. Details of each procedure are represented below.

3.1 Moisture Diffusion Analysis

Water in the concrete diffuses and this phenomenon can be expressed with the pore humidity as Eq. (1).

$$\frac{\partial h}{\partial t} = \mathrm{div}(D\, grad\, h) \tag{1}$$

where D is the moisture diffusion coefficient and h is the pore relative humidity.

CEB-FIP('90) provides diffusion coefficient equation for isotherm condition as follows.

$$D(h) = D_1\left(\alpha + \frac{1-\alpha}{1+[(1-h)/(1-h_c)]^n}\right) \tag{2}$$

where D_1 is the maximum diffusion coefficient when $h=1.0$, α is the ratio of the minimum and the maximum moisture diffusion coefficient, h_c is the pore relative humidity when $D(h)=0.5D_1$ and n is an exponent. CEB-FIP('90) model provides approximate value for $\alpha=0.05$, $h_c=0.8$, and $n=15$.

Boundary condition is summarized as Eq. (3).

$$D\left(\frac{\partial h}{\partial n}\right)_S = f(h_{en}-h_s) \tag{3}$$

where f is the surface factor, h_{en} is the humidity of environment, and h_s is the humidity of concrete surface. Some examples of surface factor f are provided from experiments in the paper of Sakata (1983).

Diffusion theory is used as formulated above to see moisture distributions at each time step. After much trial and error, maximum moisture diffusion coefficient D_1 and surface factor f are decided to give best results by comparing the B3 model results of long-term deformation of the ordinary RC section.

3.2 Differential Long-Term Deformation Analysis

Long-term deformation of the concrete consists of drying shrinkage, basic creep and drying creep. In this research, B3 model equation is used as it is for the basic creep.

However, for the drying shrinkage and drying creep, we used equation (4) which are appropriate for calculating shrinkage of each mesh from humidity variation at restraint-free condition like in Bazant (1994).

$$\Delta\varepsilon_{drying} = \varepsilon_s^0 g_s(t)\left(1 + r\sigma(t)\right)\Delta f_s(h) \tag{4}$$

where ε_s^o is the ultimate free shrinkage, $g_s(t) = E_c(t_0)/E_c(t)$, and the function $f_s(h) = 1 - h$ is chosen in this paper. As we can think easily, the humidity h is different everywhere in the section during the diffusion process. Therefore, we should calculate equation (4) at each point and consider the plane condition for getting the final sectional deformation.

If the total strain of the section is restrained, the restraint stress due to the free shrinkage can be calculated as in Eq. (5).

$$\Delta\sigma_{restraint}(t_i, t_{i-1}) = -\frac{E_c(t_{i-1})}{1 + \phi_{basic}(t_i, t_{i-1})}\left(\sum_{j=1}^{i-2}\frac{\Delta\sigma_c(t_{j+1}, t_j)}{E_c(t_j)}(\phi_{basic}(t_i, t_{i-1}) - \phi_{basic}(t_i, t_{i-1})) + \Delta\varepsilon_{drying}(t_i, t_{i-1})\right) \tag{5}$$

Summing up this restraint stress, and applying it to the section reversely, we can get the final shrinkage of the interesting section.

4. EFFECT OF THE REINFORCING STEEL SHAPE IN SRC COLUMNS

To see the effect of the reinforcing steel shape, all parameters are fixed except the steel shape. Here, the area of the reinforcing steel is set to be almost zero to find the effect on concrete only, so RC can be thought like plain concrete. For SRC sections, the area of reinforcing steel is also almost zero but located to be able to affect the moisture diffusion process.

Parameters for diffusion and deformation analysis are decided by comparing the B3 model prediction and corresponding analysis result of RC, regarded as plain concrete, section. Fig. 2 shows the comparison of B3 model prediction and the analysis results adjusted to give best coincidence at each level of external load. The section has a side of 1500mm and 100mm covering depth. Environmental temperature is 20 degree and relative humidity is 65%. External stress is applied at age 28 days.

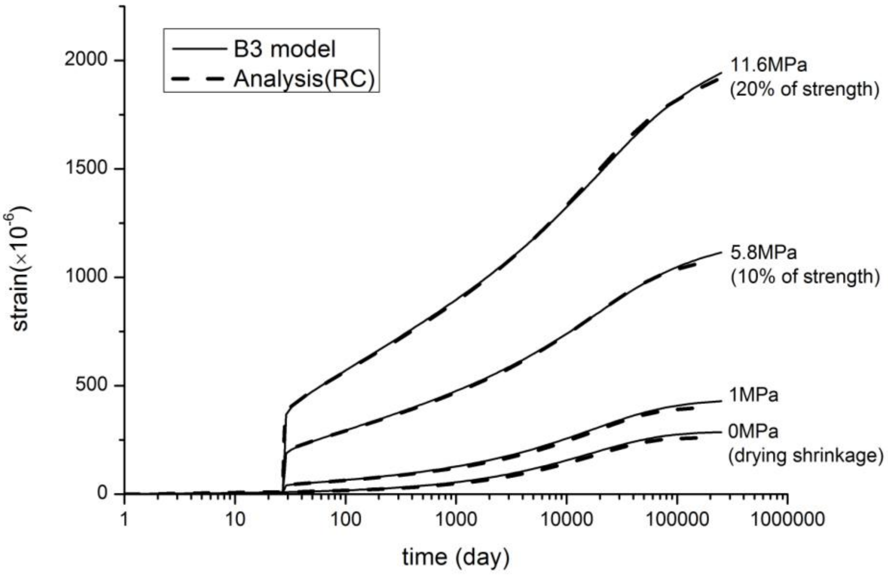


Fig. 2 Comparison of analysis (RC) and B3 model

Fig. 3, Fig. 4 and Fig. 5 also have same condition with Fig. 2.

Fig. 3 and Fig. 5 shows drying shrinkage, the zero external stress condition, of each section and these figures show the significant difference. As marked on Fig. 3 and Fig. 5, drying shrinkage occurred at the same age, 10000 days, are dependent on the shape of reinforcing steel shape. Here, we should notice again that this analysis result is based on the B3 model prediction as a standard. It means that the graph can change depending on the standard we choose. If we choose our experimental result is true for plain concrete, then all parameters decided in Fig. 2 will be changed and the shape of the graph will be so.

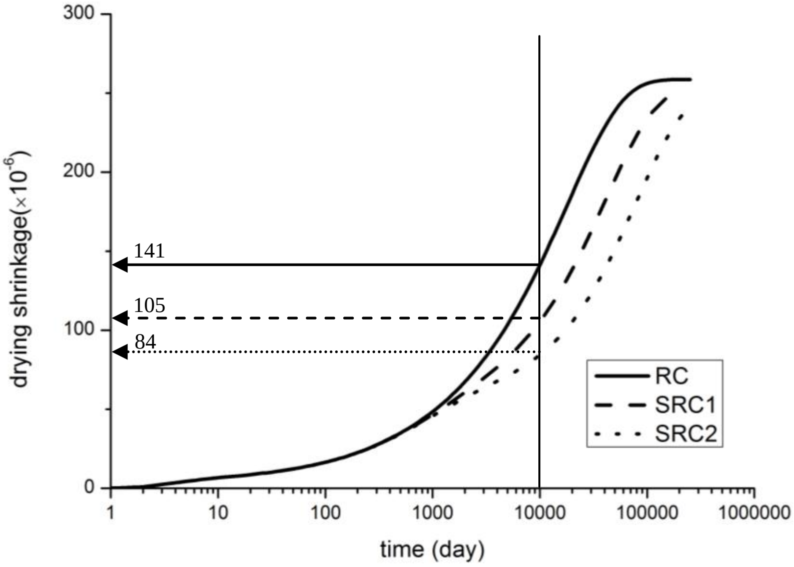


Fig. 3 Comparison of drying shrinkage (1500mm, covering depth : 100mm)

Creep coefficient of each section is represented in Fig. 4. Because B3 model for creep is used, creep coefficient has similar characteristic of B3, but clear difference between the sections. It could not get from ordinary model equations.

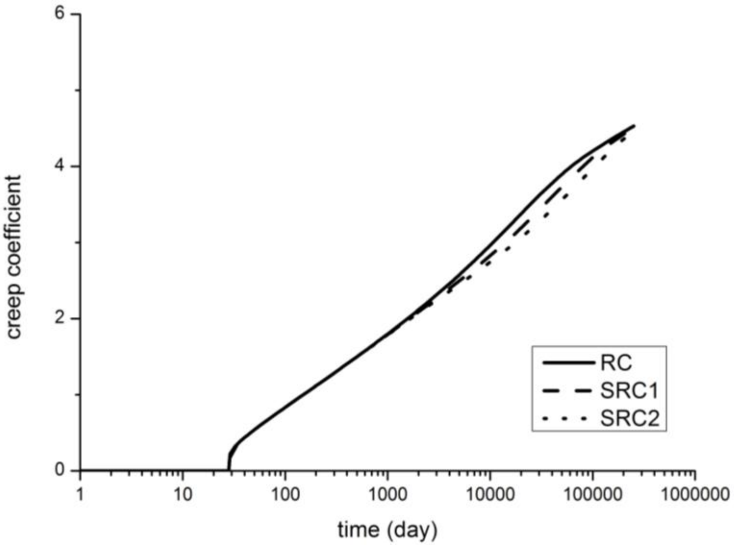


Fig. 4 Comparison of creep coefficient (1500mm, covering depth : 100mm)

In the same previous condition except for the section size, we can see following result in Fig. 5. It shows the analysis result for 600mm size section. The covering depth 100mm is quite large portion for 600mm size section, so the division of the graph starts relatively late when thinking about the moment that shrinkage almost finishes. Comparing Fig. 3 and Fig. 5 helps understanding the difference.

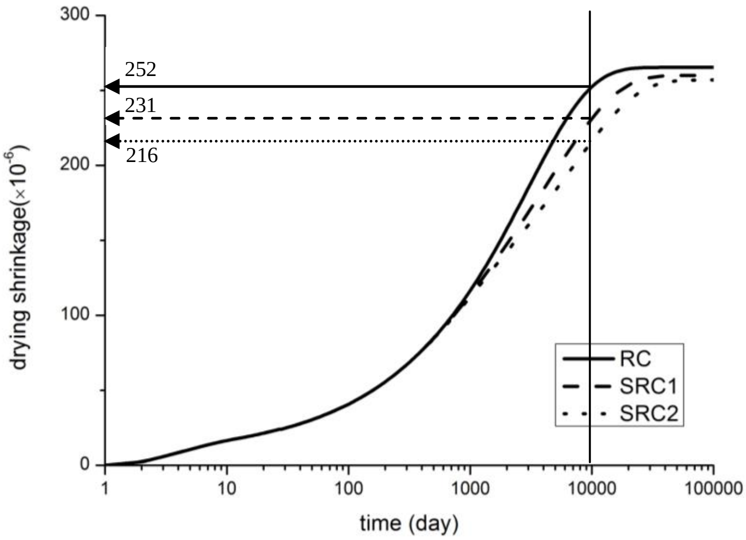


Fig. 5 Comparison of drying shrinkage (600mm, covering depth : 100mm)

Because the covering depth is equal in Fig. 3 and Fig. 5, the point of division of the graph is similar around 1000 days in both 1500mm size and 600mm size sections.

By changing the covering depth from Fig. 3, we can get Fig. 6. We can notice that the division occurs earlier than in Fig. 3. Although there is no graph in this chapter, it is obvious that the division will occurs slower than Fig. 3 if the covering depth is increased. Also, at the same moment, 10000 days, the shrinkage of SRC section is a little bit decreased. That's because the area under the disturbance of reinforcing steel became larger and deformation is affected at the beginning, but it disappears finally.

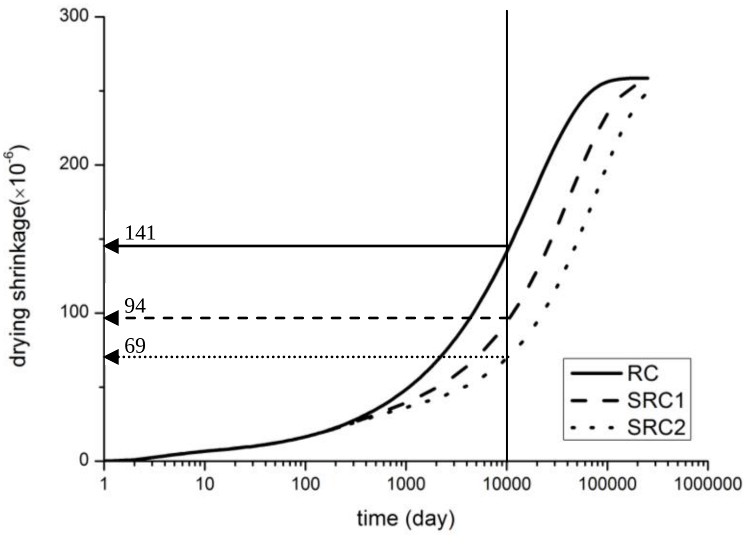


Fig. 6 Comparison of drying shrinkage (1500mm, covering depth : 50mm)

5. CONCLUSIONS

As observed so far, the inner configuration of the section affects moisture diffusion and long-term behavior of concrete consequently. If the reinforcing steel shape of the section disturbs moisture diffusion, the drying related strain becomes slower as a result of diffusion speed. Therefore, diffusion related factor like reinforcing steel shape and covering depth of it should be counted. It will help to give better prediction of long-term deformation of concrete. However, more researches are needed to modify model equations commonly used in practice.

ACKNOWLEDGEMENTS

This work (20111520100090) was supported by the Nuclear Research & Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy. The authors wish to express their gratitude for the financial support that has made this study possible.

REFERENCES

Bažant, Z.P. and Baweja, S.(1995), “Creep and shrinkage prediction model for analysis and design of concrete structures—Model B3.” *Mater. Struct.,* **28**(6), 357–365.

Bažant, Z.P. and Xi, Y.(1994), “Drying creep of concrete: constitutive model and new experiments separating its mechanisms”, *Mater. Struct.*, **27**, 3-14.

Bažant, Z.P.(1988), *Mathematical Modeling of Creep and Shrinkage of concrete*, John Wiley, New York.

Bažant, Z.P. and Chern, J.C.(1987), “Stress-induced thermal and shrinkage strains in concrete”, *J. Eng. Mech., ASCE,* **113**(10), 1493-1511.

Kim, J.-K. and Lee, C.-S. (1998), “Prediction of differential drying shrinkage in concrete”, *Cement Concrete Res*, **28**(7), 985-994.

Kim, J.-K. and Lee, C.-S. (1999), “Moisture diffusion of concrete considering self-desiccation at early ages”, *Cement Concrete Res*, **29**(12), 1921-1927.

Sakata K (1983), “A study on moisture diffusion in drying and drying shrinkage of concrete”, *Cement Concrete Res*, **13**(2), 216-224.

Seol, H.-C., Kwon, S.-H., Yang, J.-K., Kim, H.-S., and Kim, J.-K., “Effect of differential moisture distribution on the shortening of steel-reinforced concrete columns”, *Mag Concr Res*, **60**(5), 313-322.