Modification of the Constitutive Model of Concrete Material Considering the Effect of Structural Size

Hongyu Zhou*, Qi Tang, Yun Zhou and Yanan Liu
College of Architectural and Civil Engineering, Faculty of Urban Construction, Beijing University of Technology, room1-206, Architectural & Civil Engineering West Building, Chaoyang, Beijing, China
Email: zhouhy@emails.bjut.edu.cn

Abstract. As the size of the structure increases, the size effect on the mechanical properties of the structure cannot be ignored. During the service period, the reinforced concrete structure will be affected by the size effect. At present, there is no item concerning material size effect in the current regulations in my country. This paper summarizes the existing size effect theory and finds a function that expresses the size effect of concrete. The peak strength size effect coefficients of domestic and foreign researchers are analyzed, and the logarithmic function form is used to calculate the peak strength size effect coefficients obtained by various researchers. The average value was fitted. We found the size effect coefficient of the ultimate strain of concrete based on the test results, and took the size effect coefficient of the ultimate strain of the concrete with a cube side length of 150 mm as one for analysis. Finally we revised the constitutive relationship of concrete.

Keywords. Concrete, size effect, constitutive model.

1. Introduction
Nowadays, the reinforced concrete frame structure is still the most widely used structural form in China. During its service period, it will be subjected to various dynamic loads (earthquake, explosion, wind, etc.). In addition, a large number of experimental studies have found that the mechanical properties of concrete are closely related to the geometric dimensions of the specimens. Reinforced concrete beams, columns and other components show obvious size effects with the change of cross-sectional dimensions. With the development of technology and economy today, a large number of super high-rise buildings have emerged, and the seismic mechanical properties of their structures are bound to be affected by the size effect. The actual structural components are huge in size and are affected by the test conditions. It is difficult to achieve full-scale structural tests in the test. The structure can only be scaled down to a certain scale. Then, whether the scaled test can be directly equivalent to the original structure effect is concerned. Therefore, it has important scientific significance and practical application value to carry out the research on the size effect of structure level. Concrete is a kind of quasi-brittle material. The failure mode under loading condition is derived from the development and expansion of internal microcracks. With the increase of load, the cracks in concrete gradually fuse with each other and form larger cracks. Eventually, the specimens are gradually destroyed. Before the failure of the specimen, the formation of large cracks varies with the size of the specimen, and the final size of the specimen has an obvious influence on the mechanical properties of concrete [1].
2. Size Effect Theory

Size effect means that with the increase of structure size, the mechanical property index represented by strength is no longer constant [2]. The size effect theories in solid mechanics obtained by domestic and foreign researchers mainly include the following three kinds [2-8].

2.1. Weibull Statistical Size Effect Theory

According to Weibull statistical Size effect theory, the structural cross-section is distributed with a weak spot, which is called a defect. When the structure is destroyed, it starts from the defect position. If the cross-sectional size of the structure is larger, the possibility of defects in the structure is greater. There are the more defects in the structure, the wider the defects will develop. In other words, the probability of defects in the structure varies with the size of the structure. Subsequently, the size effect theory based on random intensity was proposed.

2.2. Bazant’s Size Effect Theory Based on Energy Release Criteriat

The concrete material is made by mixing cement, sand, stone, and water. When it is stirred and cured, the internal aggregates and the cementitious materials interact to store energy. Professor Bazant believes that the process of cracking in concrete will be accompanied by the release of energy, the size effect caused by the redistribution of stress and the gradual release of stored energy due to the existence of long cracks and large micro-cracks, and deduced the following Size effect rate equation:

$$\sigma_N = \frac{Bf_t}{\sqrt{1 + \beta^2}}$$

among them $\beta = \frac{D}{D_b}$.

After that, some amendments to the theory have been proposed. They are the correction of Bazant size effect rate under large size conditions, the correction of Bazant size effect rate under non-geometrically similar conditions, the correction of Bazant size effect rate under non-notch conditions, and the universal size effect rate correction.

2.3. Size Effect Theory Based on Crack Fractal Characteristics

A. Carpinter believes that the evolution process of the material cracking zone is related to the fracture and size effect. Applying the theory of fractal and fractal dimension, the mathematical relationship between the fracture behavior of the material and the fractal dimension is established, and the size based on the fractal theory is determined.

3. Modification of Constitutive Model of Concrete Material Size Effect

3.1. Correction of Size Effect of Concrete Peak Stress

Because domestic and foreign researchers are based on different size effect theories, the equations that characterize the size effect rate are not the same, but these equations have one thing in common after data fitting, that is, the size effect of concrete can be expressed by a unified function:

$$\frac{f_{cu}(D)}{f_{cu}} = \kappa(D)$$

The research results of many researchers are summarized [9-12], as shown in figure 1.
The data obtained by the researchers were averaged and the resulting averages were fitted. After several fittings, it is found that the logarithmic curve is the best, and the expression of the peak intensity dimensional effect coefficient is as follows:

$$f_{u}(D) = f_{u0} - 0.23\ln(D) + 2.179$$  \hspace{1cm} (3)

where: $D$ is the side length of the concrete cube.

Fit the average value of the data obtained by the above researchers. The fitting process and image are shown in figure 2.

**Figure 1.** Peak strength size effect coefficient.

**Figure 2.** The average value of the data obtained by various researchers.
3.2. Correction of Size Effect of Concrete Peak Strain
Because there are few studies on the size effect of concrete peak strain, the correction of peak strain in this paper adopts the test result of C40 in the test data of Su Jie [12], as follows:

\[ \varepsilon_0 / \varepsilon_{0,100} = 0.0097 \times d / d_{100} - 0.0292 \times f_{cu} / 20 + 0.0203 \times f_{cu} / 20 \times d / d_{100} + 1 \]  

(4)

Because the concrete constitutive in the specification is based on a cube with a side length of 150 mm, while the data obtained by Su Jie is based on a side length of 100 mm, the data of Su Jie C40 is processed as follows:

\[ \varepsilon_0 / \varepsilon_{0,150} = \varepsilon_0 / \varepsilon_{0,100} \times \varepsilon_{100} / \varepsilon_{0,150} \]  

(5)

3.3. Modification of the Size Effect of the Ultimate Strain of Concrete
Because the research on the size effect of ultimate strain is very limited, the correction of the ultimate strain in this paper is based on the test data of Su Jie [12], Pan Qingsong [13] and Peng Chen et al. [14], taking the strain corresponding to 50% of the peak stress (the value taken in the "Specification for Design of Concrete Structures") as the ultimate strain. As shown in the figure 3 below:

![Figure 3. Size effect coefficient of ultimate strain.](image_url)

Figure 3. Size effect coefficient of ultimate strain.

Based on the research results of domestic and foreign scholars, the data is fitted with the least square method to obtain the stress-strain curves of concrete cubes of different scales as shown in figure 4.

![Figure 4. Stress-strain curves of C40 concrete cube at different scales.](image_url)
4. Conclusion

(1) As the geometric size of the specimen increases, the peak stress and peak strain show a gradual downward trend.

(2) As the geometric size of the specimen increases, the size effect of the ultimate strain becomes more and more significant, showing a gradual decrease.

(3) Based on previous models, a concrete stress-strain constitutive model considering the effect of size is proposed. When the size effect is considered, the proposed stress-strain curve model can achieve better performance.

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