Study on the Equivalent Fire Load of Axially Loaded Concrete Columns

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Abstract. Building fire is dangerous to structures. It is important to accurately compute the equivalent fire load. First, temperature fields of a reinforced concrete column with four face exposed to fire were simulated using finite element method. Then, two step simplified model was applied to compute the transformed area of the column. Finally, the equivalent fire load was obtained based on the transformed area. Result shows that the method is applicable to compute the equivalent fire load.

Introduction

Building fire is a kind of common disaster. Building fire causes structural members high temperature, which will make the strength of concrete decrease. More and more researchers pay attention to anti-fire performance of reinforced concrete members or structures [1-3]. When the loads applied to the members remain unchanged, the stresses of the members increase with temperature rising. Suppose that the effective bearing sections of the structural members remain unchanged, it is equivalent to apply an increasing load with time. Therefore, effect of building fire can be equal to an extra load applied to structural members.

Columns are very important members in structures. When the bearing capacities of the columns are insufficient with occurrence of building fire, the structures may collapse. Therefore, it is important to study the equivalent fire load of columns suffering building fire. Axially loaded concrete columns are typical compressive members. In this study, the axially loaded concrete columns are acted as research objective, which is the basis of further study.

The Equivalent Sections of Concrete Columns suffering building fire

It can be assumed that concrete loses its strength when the temperature of the concrete is above a specific value, as the compressive strength of concrete decreases with temperature rising. Lin and Liu assume that the strength of concrete does not decrease when the temperature of concrete is below 500 ℃ and loses bearing capacity completely when the temperature is above 500℃ [4]. The assumption is simple but not accurate, which ignore the residual strength of concrete with temperature above 500℃. In this study, we assume that the strength of concrete does not decrease when the temperature of concrete is below 300℃, the strength decreases by 50% when the temperature is between 300℃ and 800℃, and loses bearing capacity completely when the temperature is above 800℃, as shown in Fig. 1. It will be more accurate to estimate the equivalent section of concrete columns. Therefore, the area of the equivalent section of a concrete column is the sum of the area with temperature below 300℃ and half the area with temperature between 300℃ and 800℃.

For a rectangle concrete column with the dimensions $b \times h$, its four faces are exposed to fire. The temperature contours of 300℃ and 800℃ are shown in Fig. 2. They can be treated as rectangles approximately with dimensions $b_3 \times h_3$ and $b_8 \times h_8$ respectively. The equivalent width, height and area of the rectangular concrete column are as follows,

$$b_T = b_3 + \frac{1}{2}(b_8 - b_3) = \frac{1}{2}(b_8 + b_3),$$ (1)

$$h_T = h_3 + \frac{1}{2}(h_8 - h_3) = \frac{1}{2}(h_8 + h_3),$$ (2)

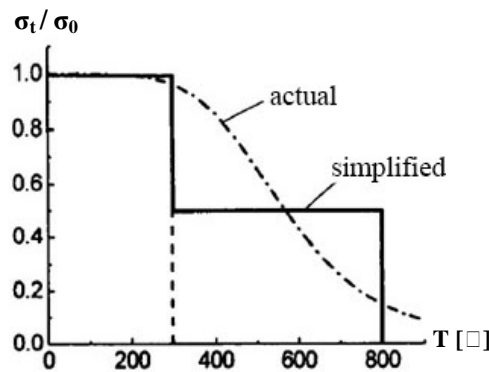$$A_T = b_T h_T = \frac{1}{4}(b_8 + b_3) \cdot (h_8 + h_3).$$ (3)
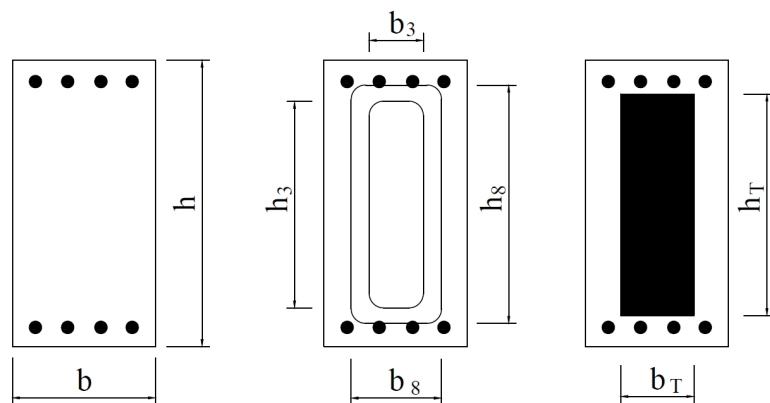

Fig. 1 Model of strength of concrete

Fig. 2 Rectangular column with four faces exposed to fire

The Transformed Areas of Reinforced Concrete Columns

Because of the difference in elastic modulus between rebar and concrete, the area of rebar can be transformed into that of concrete. The initial transformed area of reinforced concrete column A_0 is,

$$A_0 = bh + (n-1)A_s,$$ (4)

where n is the ratio of the elastic modulus of rebar to that of concrete, and A_s is the area of rebar. The transformed area of reinforced column at time t is,

$$A_t = A_T + (n-1)A_s, \qquad a_t \leq c,$$ (5)

$$A_t = A_T + (n-1)(A_s - A_s'), \qquad a_t > c,$$ (6)

Where A_s and A_s' are the area of all rebar and that of the rebar lost bearing capacity respectively, and a_t is the thickness of concrete lost bearing capacity. a_t can be expressed as follows,

$$a_t = \frac{1}{2}b - \frac{1}{4}\left(b_3 + b_8\right) \quad \text{or} \quad a_t = \frac{1}{2}h - \frac{1}{4}\left(h_3 + h_8\right). \tag{7}$$

The Equivalent Fire Load of Axially Loaded Reinforced Concrete Columns

The stress of a rectangular column with four faces exposed to fire at time t, s_t, is,

$$s_t = N_0 / A_t. \tag{8}$$

Where N_0 is the axial force. Suppose that the stress of A_0 is s_t, and then we can obtain a greater axial force, N_t. N_t has the following expression,

$$N_t = s_t \cdot A_0. \tag{9}$$

The difference is the equivalent fire load, F_e. F_e can be expressed as follows,

$$F_e = N_t - N_0. \tag{10}$$

Substituting Eq. (8) and (9) into Eq. (10) yields

$$\frac{F_e}{N_0} = \frac{A_0}{A_t} - 1. \tag{11}$$

Where F_e / N_0 is relative equivalent fire load.

Numerical Example

In this study, the example of Lie and Irwin [5] is used to compute the equivalent fire load. First, temperature fields at different time are simulated by finite element analysis. And then, the temperature contours of 300□ and 800□ are obtained based on the temperature fields. The distance between temperature contours and the surface of column is shown in Table 1. Finally, the relation between the relative equivalent fire load and fire duration is derived, as shown in Fig. 3.

It is can be found that the relative equivalent fire load gradually increases with time. When the rebar lose its bearing capacity, the relative equivalent fire load increases more quickly. When fire duration lasts 3 hours, the equivalent fire load is approximately triple the axial force.

Table 1 The distance between temperature contours and the surface of column [mm]

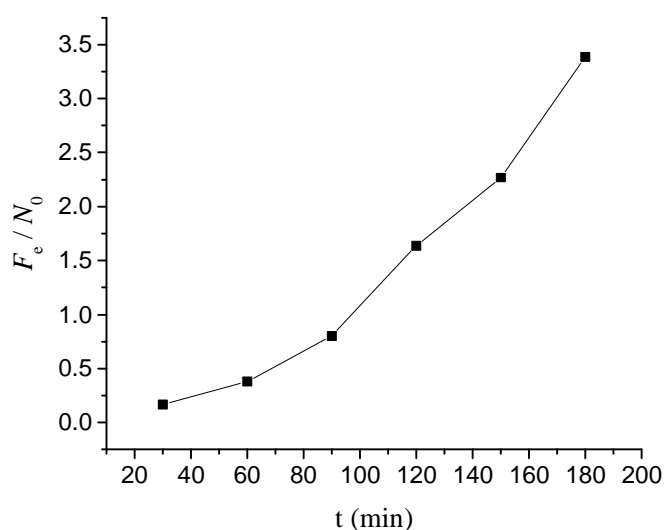| Time [min]	30	60	90	120	150	180
C_1=300□	30.5	45.75	76.25	91.5	104.17	119.42
C_2=800□	0	15.25	29.21	35	45.75	58.42

Fig. 3 The relation between the relative equivalent fire load and fire duration

Conclusions

By using ANSYS thermal analysis, we can obtain the temperature distribution in cross section at different time. According to demand, temperature contours at different time can be extracted. Instead of 500 ℃ boundary, two step simplified model was used to compute the equivalent fire load. Result shows that the method is applicable for reinforced concrete columns with four faces exposed to fire.

Acknowledgements

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