Application of ABAQUS on the Research of the Thermal Field of SRC Columns

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Abstract. According to the basic principles of heat transfer, the thermal field of SRC columns under fire is analyzed by finite element analysis software ABAQUS and the calculated results agree well with experimental data at home and abroad. On this base, the influence of parameters of sectional dimensions, length-to-width ratio of the section, steel ratio and reinforcement ratio to the distributing circumstance of thermal field of SRC columns are analyzed. The results show that parameters of sectional dimensions and length-to-width ratio are the most important factors affecting the distributing circumstance of thermal field of SRC columns. The larger the parameters of sectional dimensions, the lower the component temperature. The greater the length-to-width ratio, the greater the component temperature is. Steel ratio and reinforcement ratio have almost no effect on the distributing circumstance of thermal field of SRC columns. The achievements make it possible to study further the mechanical performance of SRC columns at high temperature.

Keywords. Steel reinforced concrete columns, thermal field, numerical simulation, influencing factors.

1. Introduction
Among the many disasters, fire has the highest probability and the highest frequency. A large number of buildings are destroyed by fire every year internationally, and the cumulative losses are considerable. After high temperature, the mechanical properties of building materials will decrease to varying degrees, and the load-bearing capacity of the structure will drop rapidly, causing a certain degree of damage or even serious damage to the structure. In addition to structural collapse and casualties caused by building fires, more indirect economic losses are caused by structural failure. It can be seen that it is very important to carry out research on structural fire resistance. SRC structure is a relatively new structural system. Because of its high strength, high rigidity, good ductility, and very good seismic performance, it is widely used in various heavy-duty structures, large-span structures, high-rise structures, and the buildings in the earthquake zone [1]. However, there have been certain studies on the performance of reinforced concrete structures under fire at home and abroad [2-5], and there are few studies on SRC structure. Therefore, the research on the fire resistance of SRC structure has important theoretical significance and engineering application value.

This paper calculate the distributing circumstance of thermal field of SRC columns with ABAQUS, and analyzes the influence of section perimeter, section aspect ratio, steel content and reinforcement ratio on the distributing circumstance of thermal field of SRC columns. Further study the mechanical properties at high temperature and fire resistance of SRC columns.
2. Calculation Model of Temperature Field of SRC Column under Fire and Analysis of Influencing Factors

2.1. Calculation Model of Temperature Field of SRC Column under Fire

The heat transfer between concrete and steel and steel bars is realized by heat conduction. Due to the concrete, the surface of the section steel and the steel bar is not perfectly flat, resulting in incomplete contact. The contact interface is only partial surface contact, even point contact. This will hinder the heat conduction between the two materials, that is, contact thermal resistance. The influencing factors of contact thermal resistance are more complicated, and currently they are mainly determined directly through experiments. Because of the lack of theoretical and experimental data, it is safe to ignore the thermal contact resistance.

This paper uses ABAQUS to solve the temperature field of SRC columns. Among them, the 20-node three-dimensional solid element DC3D20 is used for concrete, the four-node shell element DS4 is used for section steel, and the two-node bar element DC1D2 is used for reinforcement and stirrup. Firstly, the initial temperature load is applied to the SRC column, and then heat convection and heat radiation between the column and the surrounding environment are defined. However, heat is transferred between the steel frame and the section steel and the concrete through heat conduction, and no contact thermal resistance is assumed. Building fires are usually extinguished within 2 hours. This paper analyzes the temperature field and fire resistance of SRC columns under fire conditions of 1 hour, 2 hours and 3 hours respectively, and the sub-step length is 5 min.

2.2. Calculation Model of Temperature Field of SRC Column under Fire

Under the action of fire, the distributing circumstance of thermal field of the structure has a great influence on its fire resistance. In order to improve the fire resistance of buildings, it is necessary to analyze the factors that affect the internal temperature field of the components. The main factors affecting the internal temperature field of the component are: the perimeter of the section \((C=2H+2B)\), \(H\) is the long side of the section, \(B\) is the short side of the section), the aspect ratio of the section \((\beta=H/B)\), including Steel ratio \((\alpha=Asb/Ac)\), \(Asb\) is the cross-sectional area of section steel, \(Ac\) is the full cross-sectional area of concrete) and reinforcement ratio \((\rho=As/Ac)\), As is the total cross-sectional area of steel bars, and Ac is the full cross-sectional area of concrete). The thickness of the concrete protective layer of the longitudinal reinforcement is 30mm, and the thickness of the concrete protective layer of the section steel is 50 mm. The column is heated on all sides, and the temperature is raised using the ISO-834 standard heating curve [6]. Based on typical calculation examples, this paper calculates the temperature field of ten SRC columns under different fire durations, including three cross-section perimeters, three cross-sectional aspect ratios, four steel ratios, and three reinforcement ratios distributed. The middle section of the column has four measuring points, as shown in figure 1.

![Figure 1. Measurement of the column section.](image-url)
2.2.1. The Influence of Section Perimeter on Temperature Field. The relationship between the temperature of the measuring point and the circumference of the section is shown in figure 2. The section perimeter has a greater influence on the temperature field of the component. As the perimeter of the section increases, the low thermal conductivity of concrete hinders the temperature transfer into the column, and the internal temperature of the component decreases rapidly. And the farther away from the surface of the column, the more obvious the decreasing trend. When the section circumference of the column is between 1000 mm – 2000 mm, the temperature of the component decreases with the increase of section circumference and the temperature drop is larger. The figure shows that the longer the fire time, the greater the influence of the section perimeter on the temperature of the component.

![Influence of perimeter on measurement temperature](image)

2.2.2. The Effect of Section Aspect Ratio on Temperature Field. The relationship between the temperature of the measuring point and the aspect ratio of the section is shown in figure 3. The section aspect ratio has a relatively large influence on the temperature field of the component. In the case of a certain section perimeter, the increase in the aspect ratio reduces the width of the section, thereby reducing the heat transfer path in the width direction, resulting in higher internal temperature of the component. And the farther away from the surface of the column, the more obvious the tendency of temperature rise. When the aspect ratio of the column is between 1.5 and 2, the temperature of the
component increases with the increase of the aspect ratio. The figure shows that the longer the fire time, the greater the effect of the aspect ratio on the temperature of the component.

![Graphs showing influence of aspect ratio on temperature](image)

**Figure 3.** Influence of aspect ratio on measurement temperature.

2.2.3. *The Influence of Section Steel Ratio on Temperature Field.* The relationship between the measured point temperature and the steel content is shown in figure 4. The steel content has almost no effect on the temperature change of the concrete in the component. With the increase of steel content, the temperature of section steel tends to rise. This is mainly because steel has good thermal conductivity. However, because the section steel is surrounded by a thicker concrete protective layer, the temperature of the section steel does not increase greatly with the increase of the steel content. The fire resistance of the section steel concrete structure is much better than that of the steel structure. The figure shows that the longer the fire time, the greater the influence of the steel content on the temperature of the internal section steel of the component.
2.2.4. The Influence of Cross-Section Reinforcement Ratio on Temperature Field. The relationship between the temperature of the measuring point and the reinforcement ratio is shown in figure 5. The reinforcement ratio of steel reinforced concrete members is relatively small. The figure shows that the reinforcement ratio has almost no effect on the internal temperature of the column.
3. Conclusions
(1) Calculation model for the temperature field of SRC columns under fire has been established, which can simulate the temperature field of SRC columns and analyze the fire resistance performance.
(2) The factors affecting the temperature field of SRC columns are numerically analyzed. The results show that the section perimeter and aspect ratio are the most important factors affecting the internal temperature field distribution of SRC columns. The larger the section circumference, the lower is the component temperature. The greater the section aspect ratio, the greater is the component temperature. The steel content and reinforcement ratio have almost no effect on the temperature field distribution of SRC columns.

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References

[1] Zhao H T and Zhang S M 2005 Principles of Combined Structure Design (Beijing: Higher Education Press).

[2] Lie T T and Irwin R J 1993 Method to calculate the fire resistance of reinforced concrete columns with rectangular cross section ACI Structural Journal 90(1) 52-60.

[3] Lie T T and Woollerton J L 1998 Fire resistance of reinforced concrete columns: test results Internal report of the Institute of Architecture of the National Research Council of Canada 569 302.

[4] Lie T T and Celikkol B 1991 Method to calculate the fire resistance of circular reinforced concrete columns ACI Materials Journal 88(1) 84-91.

[5] Xu Y Y and Wu B 2009 Fire resistance of reinforced concrete columns with L-, T-, and +- shaped cross-sections Fire Safety Journal (44) 869-880.

[6] International Standard ISO834 1980 Fire-Resistance Tests Elements of Building Construction.