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Mechanical Property of Concrete Filled Steel Tube Reinforced Concrete (CFSTRC) Columns Subjected to two-opposite-side Fire

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Abstract: The present study established a numerical investigation on the behavior of concrete filled steel tube reinforced concrete (CFSTRC) columns under combined loading and two-opposite-side fire. The FEA model was verified by the experimental results of CFST columns subjected to non-uniform fire. The comparison demonstrated an acceptable accuracy for the proposed FEA model. Afterwards, the FEA model was used to analyze the temperature distribution and failure modes of CFSTRC columns subjected to two-opposite-side fire, the influence of fire surface on the fire resistance of the column was also analyzed. The results show that the temperature distribution of the column section is biaxial symmetry, the highest temperature appears at the intersection of the fire surface and the symmetry axis, and the lowest temperature appears at the center of the columns; the load ratios and fire surface have a great influence on the mechanical property of the columns subjected two-opposite-side fire.

INTRODUCTION

The concrete filled steel tube reinforced concrete (CFSTRC) column is composed of a central concrete filled steel tube and an outer steel reinforced concrete composite column. It is widely used in high-rise buildings because of its high bearing capacity, good plasticity and toughness, and good seismic performance.

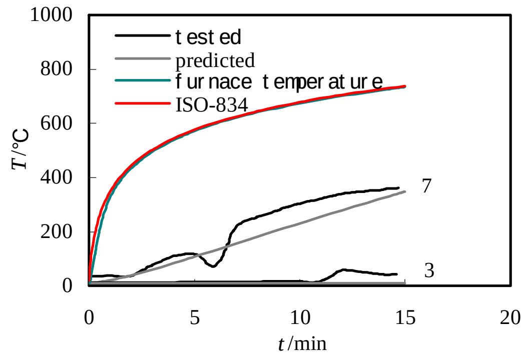
Some scholars have studied and analyzed the fire performance of concrete filled steel tubular columns and reinforced concrete columns under non-uniform fire. Experimental study on fire resistance of RC columns with different faces exposed to fire were reported by Wu *et al.* (2007); a lot of research work has been doing on the temperature field and fire performance of concrete filled steel tube columns under non-uniform fire(Yang *et al.* 2010; Lv 2010). However, research on the non-uniform fire mechanical performances of CFSTRC structures are rare (Xu *et al.* 2014), Consequently, the mechanical behaviors of CFSTRC columns under frequent fire and the repair reinforcement of this component after frequent fires should be thoroughly investigate. On the basis of the situation, a finite element analysis (FEA) model was developed to analyze the fire behavior of CFSTRC columns subjected to both mechanical loading and two-opposite-side fire.

FINITE ELEMENT ANALYSIS MODEL

The present study established a FEA model of CFSTRC columns based on the ABAQUS finite element analysis platform. For the temperature model of CFSTRC columns, the steel tube, core concrete, endplate, and reinforced concrete outside the CFST adopted DC3D8, whereas the reinforcing steel bars employed DC1D2. The ISO–834 (1999) international standard temperature curve was used to simulate the fire. The present study adopted the steel and concrete thermal parameters expressed by Lie (1994). For the mechanical model of CFSTRC columns, solid elements (C3D8) were used for the endplates and steel pipe, reinforced concrete, and core concrete, whereas truss elements (T3D2) were used for the steel bars. The present study adopted the steel stress-strain models presented by Lie and Chabot (1990) as well as the thermal expansion models for steel and concrete proposed in Lie (1994). The compressed stress-strain relationship models of the core concrete and reinforced concrete under fire were acquired from Han (2007) and Lie (1994), respectively. The detailed modeling method of CFSTRC columns under loading and non-uniform fire referred Xu *et al* (2014).

Validation of the FEA model

Lv (2010) previously examined two pillars of CFST columns for direct comparison to evaluate the reliability of the FEA model. The comparisons between the finite element predicted results and the tested results of the CFST columns are presented in Figure 1. It can be found that the predicted curves were well agreed with tested curves. Figures 1 validated the prediction offered by the FEA model in terms of the tested results of the CFST columns subjected non-uniform fire.



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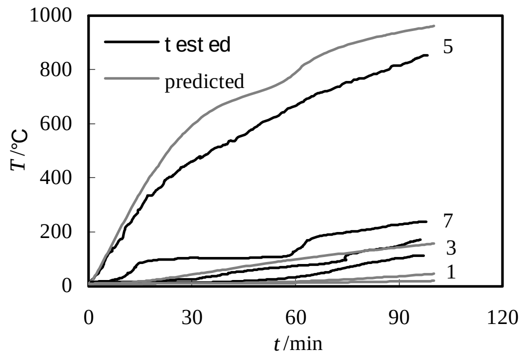

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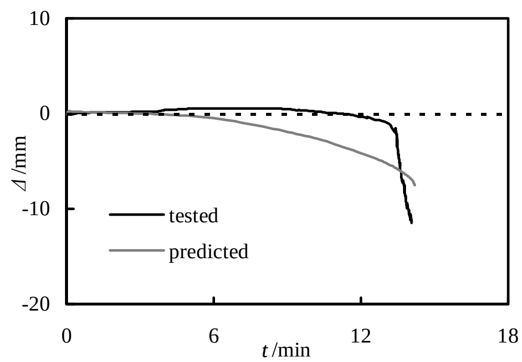

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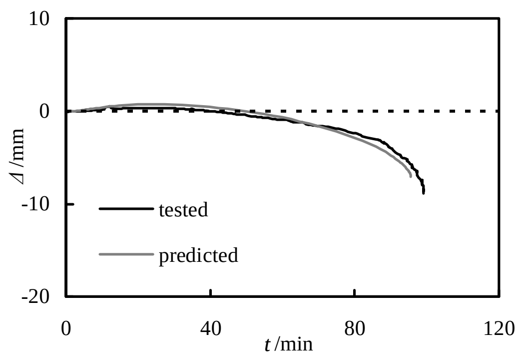


(d) S6

Figure 1. The comparison of tested results and predicted results of CFST columns

MECHANICAL BEHAVIOR OF THE CFSTRC COLUMNS

A square cross-section CFSTRC column was adopted as the sample column of analysis: its cross-section height (*B*) was 600 mm; the outside diameter of steel tube (*D*) was 360 mm; the thickness of steel tube (*t*) was 10 mm; the component height (*H*) was 7200 mm, and the whole height was fired; the cube strength of concrete (f_{cu}) inside and outside of the steel tube was 60 MPa and 40 MPa, respectively; the yield strength of steel was 345 MPa; 12Φ20 steel bars were used as the longitudinal bars, which had a yield strength (f_{yb}) of 400 MPa; φ10 steel bars were used as the stirrups in the columns, which had a yield strength (f_{yb}) of 300 MPa; the eccentricity was 150 mm.

The temperature distribution

Figure 2 illustrates the temperature profiles of the CFSTRC column sections at different times, which exhibited an increase in column heat with an increase in time. It can be seen from the figure 2 that the temperature field of the column section is in a biaxial symmetrical distribution, and the fired surface temperature is higher, the back surface temperature is lower. The temperature gradient in the high temperature region of column section is obvious, the highest and lowest temperatures of the cross-section all increased. The area of high temperature section is increased, while the area of low temperature section is decreased, thus meaning continuous heat transfer from the high temperature area to the low temperature area. The temperature of the CFST is lower in the fire process, and its mechanical properties remains well, the CFST bear the load which is offloaded by external reinforced concrete due to the deterioration of high temperature materials; The highest temperature appears at the intersection of the column fire surface and the symmetry axis and the lowest temperature appears at the center of columns.

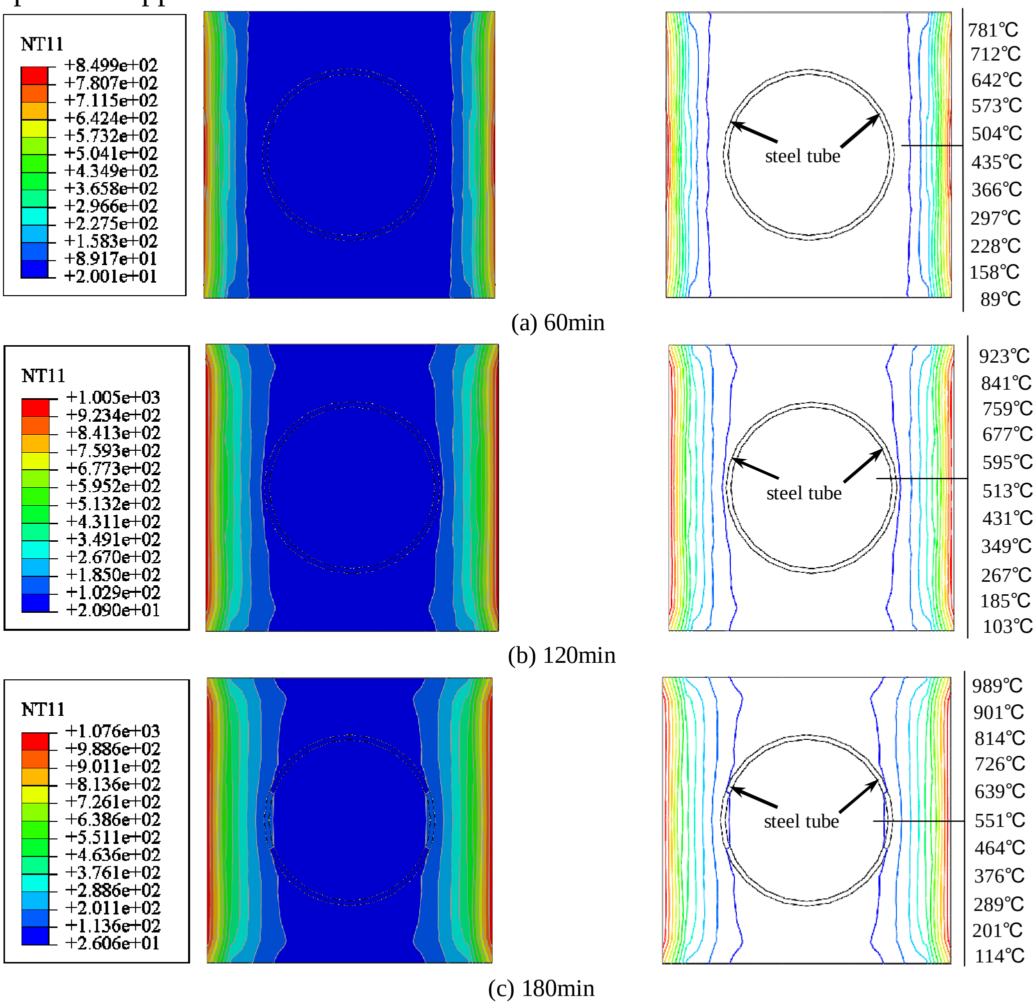
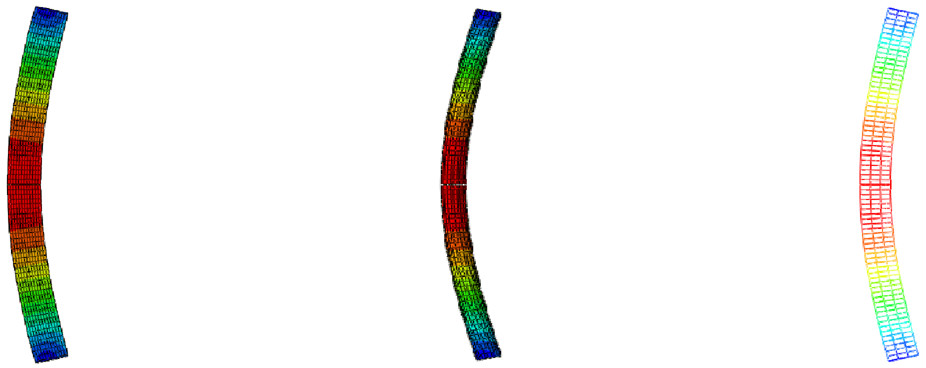


Figure 2. Temperature profiles of CFSTRC columns section at different time

Failure mode

Figure 3 illustrates the failure mode of the CFSTRC columns under two-opposite-side fire, wherein overall instability failure is observed for the CFSTRC columns. The internal steel tube did not exhibit local buckling in the fire given the presence of the external reinforced concrete and the core concrete. Moreover, the CFSTRC columns exhibited good plasticity and stability.

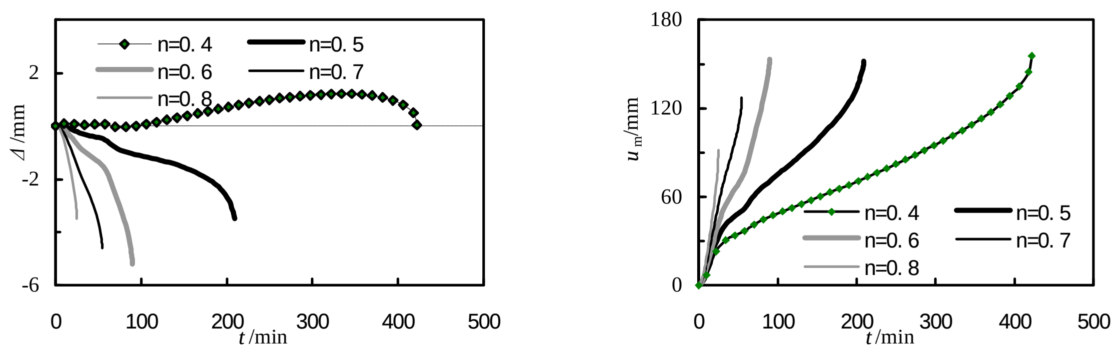


(a) The overall damage form (b) CFST (c) Steel reinforcement cage

Figure 3. Typical failure modes

Column deformation

Figure 4(a) presents the deformation variations with fire-exposed time in the CFSTRC columns under different fire load ratios. The fire load ratio had a significant influence on the fire resistance of the CFSTRC columns such that larger fire load ratios resulted in lower fire resistances. The present study demonstrated a fire resistance for the CFSTRC columns at 422, 209, 90, 54, and 25 min with a fire load ratio of 0.4, 0.5, 0.6, 0.7, and 0.8, respectively. when n < 0.5, the fire resistance of the column is greater than 180 minutes that the columns meet the requirements of fire resistance.



(a) axial deformation (b) Mid-height deflection

Figure 4. Deformation versus time curves of CFSTRC column under fire load ratio

Figure 4(b) presents the lateral deformation versus the fire duration time at the mid-height section of the CFSTRC columns under different fire load ratios. The lateral deformation at the mid-height section of the CFSTRC columns increased with increasing fire duration times, thus sharp rapidly increasing the deformation near the failure.

The fire surface influence on fire resistance of columns

Figure 5 presented fire surface influence on fire resistance of columns. As can been seen from figure 5 that the fire surface have significant influence on fire resistance of columns, the fire resistance of columns under two-opposite-side fire and four side fire is 90 minutes and 47 minutes, respectively. The main reason is that the temperature of the column section is higher under four-side fire, and the material damage under high temperature is serious, the fire resistance of columns was smaller. For the columns under two-opposite-side fire, the fire area is smaller, the whole section temperature is lower than that of the four side fire columns, the material deterioration is lighter, and the fire resistance is larger

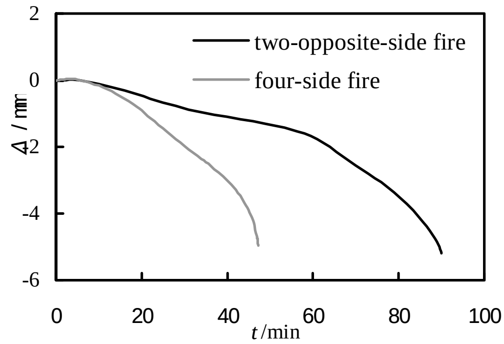


Figure 5 Fire surface influence on fire resistance of CFSTRC columns

Conclusions

The following main conclusions may be drawn:

(1) The finite element analysis model of CFSTRC column was established, the calculated results were in good agreement with the experiment results, and the finite element analysis mode was able to calculate the mechanical behaviors of CFSTRC columns under two-opposite-side fire.

(2) The distribution of temperature field in the cross section presents biaxial symmetry, the highest temperature appears at the intersection of the fire surface and the symmetry axis, and the lowest temperature appears at the center of the columns.

(3) The load ratios have significant effect on the fire resistance and axial deformation of CFSTRC columns under two-opposite-side fire. The large the load ratio is, the fire resistance of CFSTRC columns is smaller and the axial tensile deformation was not apparent.

(4) The fire surface have great influence on the fire resistance of the columns.

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