Internal Force Analysis of Reinforced Concrete Structure with Bearing Column Girder Transfer Floor in Fire

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***Abstract*—A model of 4-story reinforced concrete structure with a large transfer girder in the first floor is established. Using the nonlinear FEM software ABAQUS to analyze the internal forces of the model which is exposed to fire and coupling with vertical loads. The internal forces of the transfer structure model in five kinds of fire conditions are analyzed, and the relation curves between the internal forces and heating time of member sections are plotted. The numerical results show that on the basis of the internal forces produced by the vertical load in room temperature, with the heating time increasing, the internal forces of the reinforced concrete transfer structure redistribute to varying degrees and that of some sections just change the magnitude, others also change the direction. The internal force redistribution mainly occurs within 90min of the initial fire, and the variation trend and range of internal forces caused by different fire conditions are also different. In the whole process of the fire, the internal forces of the transfer structure are constantly changing because of the effect of additional internal forces, especially the internal force superposition in some member sections may exceed expectations which are designed for room temperature, so it could impact the section safety. Therefore, the potential fire impact should be considered in designing the key structures like transfer structures.**

***Index Terms*—Reinforced concrete, Transfer structure, Fire, Internal force analysis**

I. Introduction

Nowadays, the buildings develop gradually in the direction of the complex shape and functional diversity, and the structural forms are also becoming more diverse. Different function floors require different spaces, and result in structural changes. It is necessary to set up the structural transfer layer between different structure forms to ensure the effective transmission of structural force [1]-[2]. However, with the development of cities, as one of the main disasters, the fire threat has become increasingly serious. Fire resistance of building structure main components has become a hot research topic in the field of building fire safety [3]-[5]. The transfer floor as a key transmission part, the force conditions are complicated, especially when there is a fire, the high temperature and the load would make a severe internal force redistribution, and pose a threat to the safety of the whole structure. Therefore, it is of great practical significance to carry out the research on the internal force changes and redistribution laws of reinforced concrete structure with bearing column girder transfer floor. A model of 4-story reinforced concrete structure with a large transfer girder in the first floor was applied fire and vertical load by using the nonlinear FEM software ABAQUS. The internal forces of the transfer structure model in five kinds of fire conditions were analyzed, and the internal force changes and redistribution laws of this kind of transformation structure in fire were discussed.

II. Model Establishment and Fire Conditions

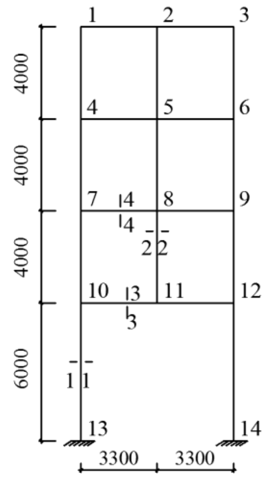

Figure 1. The transfer structure model

The transfer structure model was a 4-story reinforced concrete structure with a beam supporting column floor at the bottom layer. The bottom layer had a span of 6.6 m. The height of the first floor was 6.0 m and the others were all 4.0 m. The model was shown in Fig. 1. The reinforcement of member sections was shown in Fig. 2. The strength grade of the concrete was C30, and of the

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reinforcement was HRB335. The main reinforcement cover thickness of the beam and column were all 25 mm. The applied line load was 27.36 kN/m on each floor. The pre-processing module of the ABAQUS finite element software was used to establish a 3D entity model. Considering the contingency of a fire, five kinds of fire conditions were designed, which were the large opening space at bottom on fire (condition 1), the second floor on fire (condition 2), the third floor on fire (condition 3), the forth floor on fire (condition 4), and the bottom two floors all on fire (condition 5), as shown in Fig. 3 (FC is for fire condition).

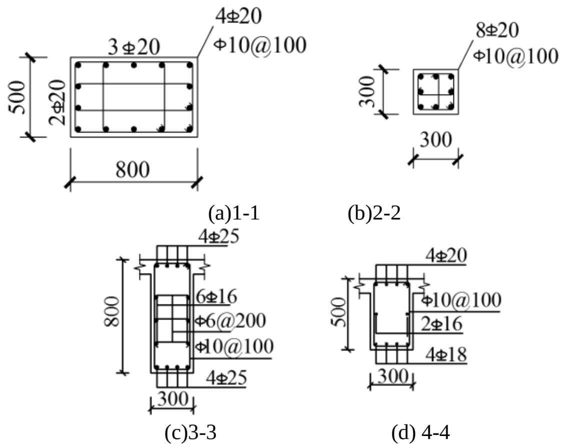


Figure 2. Reinforcement of member sections

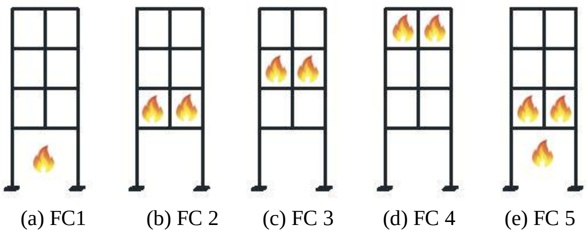


Figure 3. Fire conditions

III. Parameter Value for Numerical Simulation

The density of concrete was 2400 kg/m^3. The thermal expansion coefficient in high temperature was recommended according to the literature [7]. The elastic modulus in high temperature was evaluated according to the literature [6]. The heat conduction coefficient, specific heat capacity, compressive and tensile strength, constitutive relation in high temperature were recommended according to the literature [8]. The density of reinforcement was taken 7850 kg/m^3. The thermal expansion coefficient in high temperature was evaluated according to the literature [8]. The heat conduction coefficient, specific heat capacity, yield strength, elastic modulus and constitutive relation in high temperature were adopted according to the literature [9]. The heating curve adopted the ISO834 international standard heating curve [10], as shown in Fig. 4.

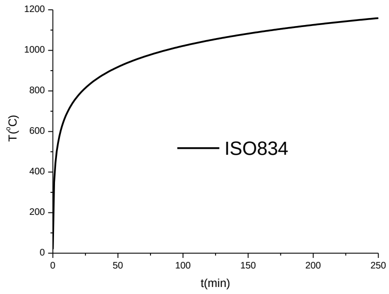


Figure 4. ISO834 international standard heating curve

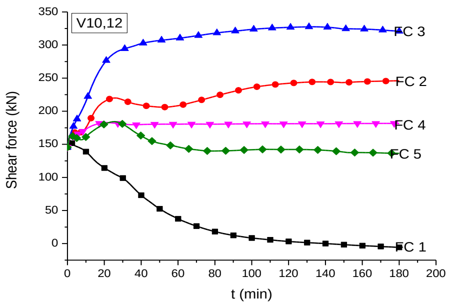
IV. Internal Force Analysis of the Transfer Structure Model in Fire

The transfer structure model exposed to fire and coupling with vertical loads by using the software ABAQUS. The internal forces of the transfer structure model in five kinds of fire conditions were analyzed. The internal force change rules with the heating time increasing of the transfer model member sections were obtained.

The internal force directions were defined as follows: The shear force was positive for the clockwise around the member section, negative for the anticlockwise around the member section. The axial force was positive for tension and negative for pressure. The bending moment was positive for the clockwise around the left section of members and anticlockwise around the right section of members, negative for the clockwise around the right section of members and anticlockwise around the left section of members.

A. Shear Force Analysis

The shear force variation of six members in the transfer structure model was analyzed. The relation curves between each section shear force and heating time for the 5 kinds of fire conditions are shown in Fig. 5. Among them, V10, 12 represents the 10 end shear force of member 10-12, and so on.



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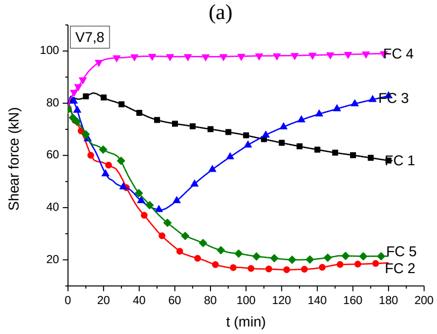

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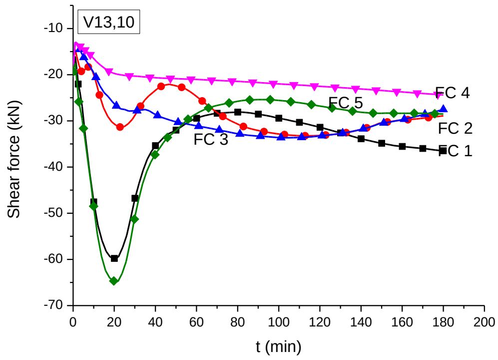

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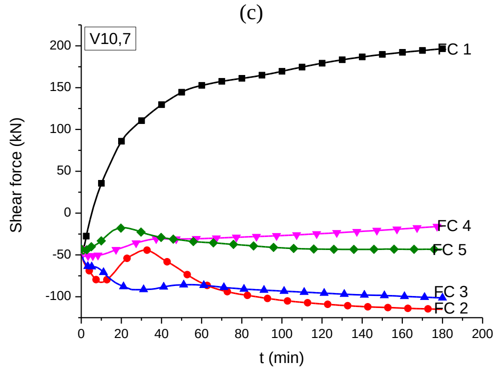

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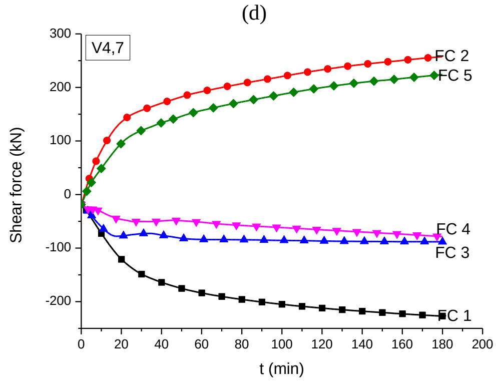

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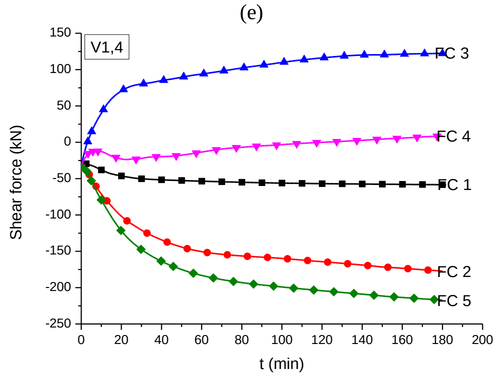

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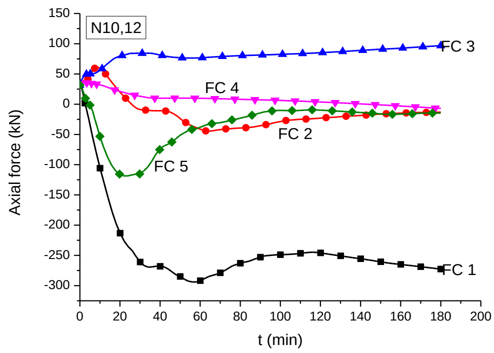
Figure 5. Relation curves between shear force and heating time

The shear force V10,12 of the transfer girder end shows a contrary trend in fire condition 1 and 3. In fire condition 3, the shear force increases gradually at the beginning of heating, and remains basically stable after heating for 30 min; In fire condition 1, the shear force decreases gradually at beginning, and basically reduces to zero after heating for 100 min, then keeps stable. In fire conditions 4 and 5, the shear force changes less. The shear force V7.8 of the second floor beam end shows a similar trend in fire condition 2 and 5, that is the shear force decreases gradually before heating for 90 min, then keeps stable. In fire condition 3, the shear force decreases gradually at beginning, then turns to increase at 50 min of heating. In fire condition 1 and 4, the shear force changes less. The shear force V13.10 of the side column bottom shows a similar trend in fire condition 1 and 5, that is the absolute value first increases dramatically and then decreases, and the peak appears around 20 min of heating. After 60 min of heating, it obviously recovers and remains constant; In fire conditions 2, 3 and 4, the shear force fluctuates slightly. The shear force V10, 7 changes most obviously in fire condition 1, that the direction changes at initial heating, then increases gradually. In the other four fire conditions (Fire conditions 2.3.4 and 5), the shear force changes less. The shear force V4, 7 is small in room temperature. After the heating begins, it shows a similar trend in fire conditions 2 and 5, and contrary to the fire condition 1. In fire conditions 3 and 4, the shear force changes less. For the shear force V1.4 of side column top, the absolute value increases gradually in fire conditions 2 and 5, and remains basically stable after heating for 50 min. In the fire condition 3, the shear force changes in direction at initial heating, then increases gradually, and remains basically stable after heating for 30 min.

B. Axial Force Analysis

The axial force variation of six members in the transfer structure model was analyzed. The relation curves between each section axial force and heating time for the 5 kinds of fire conditions are shown in Fig. 6. Among them, N10, 12 represents the 10 end axial force of member 10-12, and the rest can be done in the same manner.



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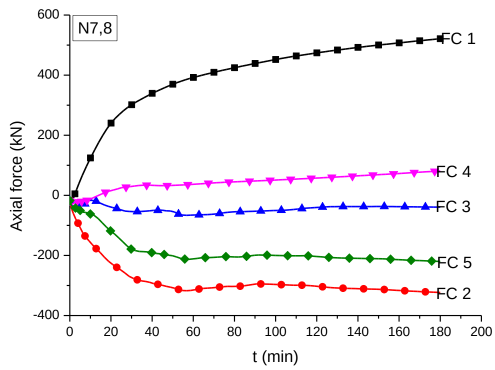

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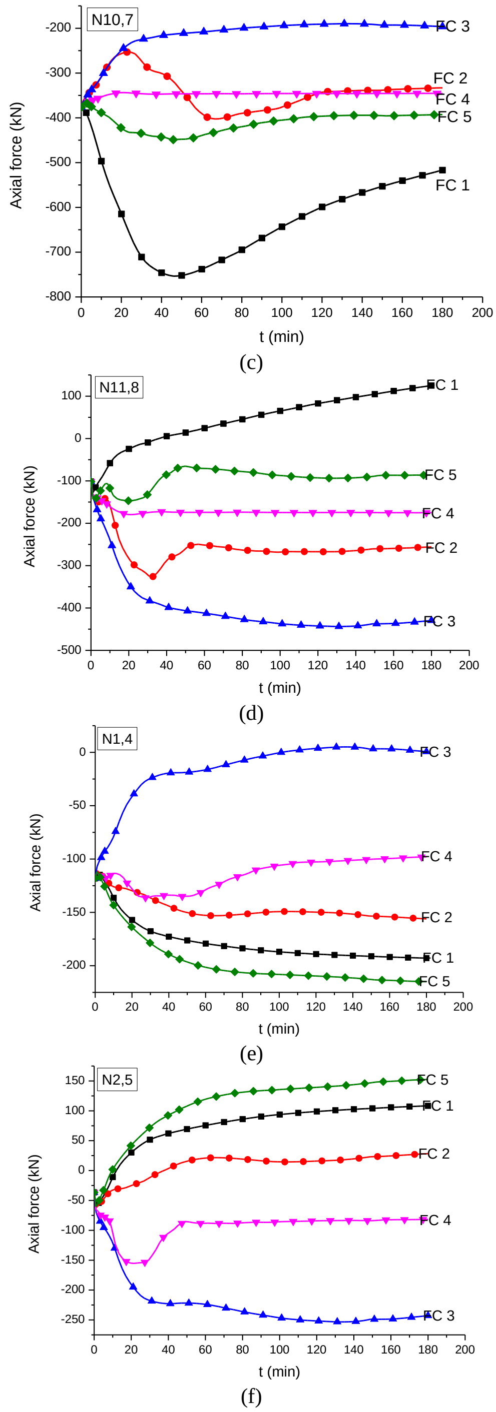
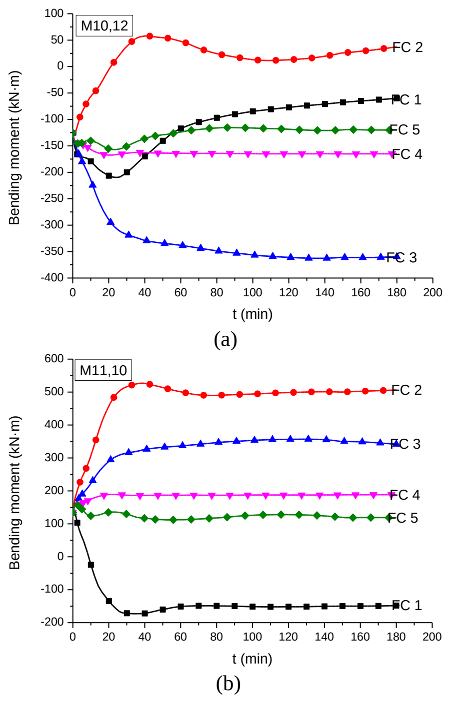


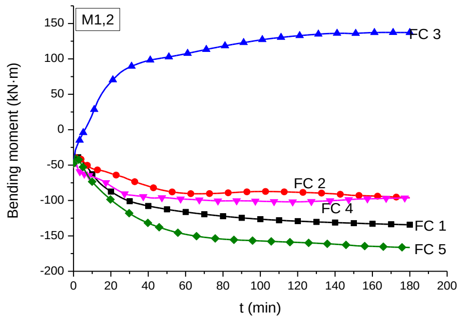
Figure 6. Relation curves between axial force and heating time

Axial force N10,12 of the transfer girder end is a small tension under room temperature and static load. After the heating begins, the axial force is converted from tension to pressure and the absolute value increases dramatically in fire condition 1, and the pressure is basically stable after heating for 50min. The same thing that happens in fire condition 5. But different from the fire condition 1, the pressure peaks at about heating for 25min in fire condition 5, and then gradually recovers to zero after heating for 90min. Axial force N7, 8 is a tension in fire condition 1, and increases gradually with the heating time increasing, and keeps basically stable after heating for 50min. The axial force variation trend in fire condition 2 and 5 is opposite to that of fire condition 1, and shows that the pressure increases gradually and remains basically stable after heating for 40min. In fire condition 3 and 4, the axial force changes less. For axial force N10.7, in fire condition 1, the absolute value increases gradually at beginning, then slowly recovers, and the pressure peaks at about heating for 45min. The peak pressure is nearly double the pressure value under room temperature and static load. In fire condition 3, the pressure decreases gradually before heating for 30 min, then keeps stable. In fire condition 2, the axial force produces fluctuations, but basically returns to its initial state eventually. Axial force N11, 8 of the second floor central column shows that the pressure turns to tension and increases gradually in fire condition 1. In fire condition 3, the pressure rapidly increases before heating for 30min, then basically keep stable. Axial force N1, 4 of the top floor side column shows that the pressure increases gradually in fire condition 1 and 5, then basically keep stable after heating for 60min. It indicates that the bottom floor in fire will have a certain effect on the internal forces of the whole structure. In fire condition 3, the pressure decreases gradually to zero after heating for 40 min, then keep stable. Axial force N2, 5 of top floor central column shows that the pressure increases gradually until heating for 30 min, then keep stable in fire condition 3. In fire condition 1 and 5, the axial force shows that the pressure turns to tension.

C. Bending Moment Analysis

The bending moment variation of eight members in the transfer structure model was analyzed. The relation curves between each section bending moment and heating time for the 5 kinds of fire conditions are shown in Fig. 7. Among them, M10, 12 represents the 10 end bending moment of member 10-12, and the rest can be done in the same manner.





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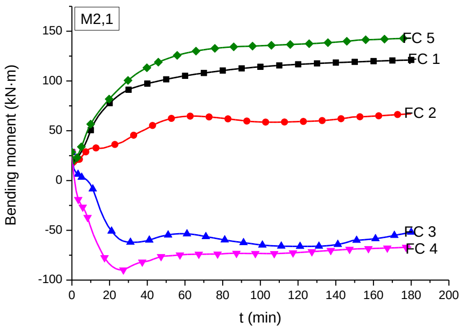

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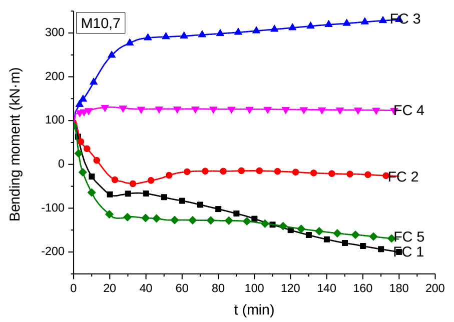

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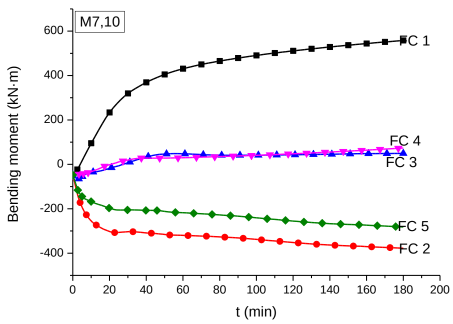

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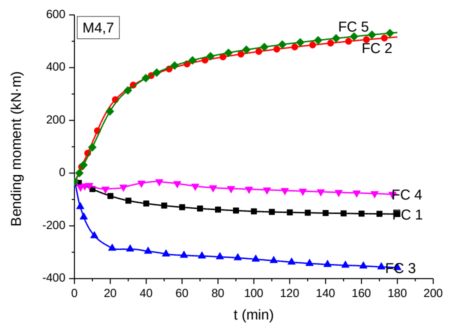

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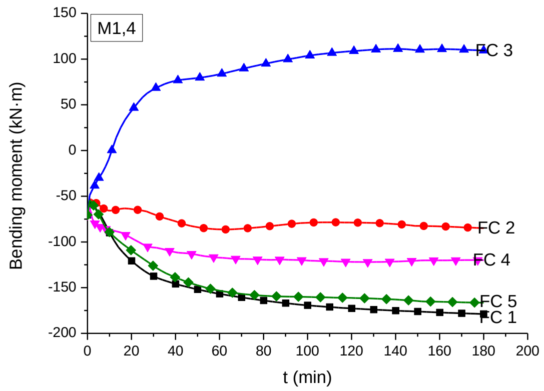

(h)

Figure 7. Relation curves between bending moment and heating time

Bending moment M10,12 of the transfer girder end shows that in fire condition 1, the absolute value first increases and then decreases, and keeps stable after heating for 60 min. In fire condition 2, the absolute value reduces to zero and then goes back up, and keeps stable after heating for 40 min. Bending moment M11,10 shows a contrary trend in fire condition 1 and 2, and happens mainly in 30min of initial heating, then keeps stable. And in fire condition 1, it also changes the direction. It can be seen in Fig. 7 (a) and (b), the bending moment of the transfer girder changes little in fire condition 4 and 5. Bending moment M1, 2 of top floor beam, in fire condition 3, changes the direction at initial heating, then increases gradually, and keeps stable after heating for 30 min. The tendency of bending moment is similar in the other four fire conditions, but the range is slightly different. That is increases slightly before heating for 40 min, then keeps stable. Bending moment M2. 1 in fire condition 1 and 5, increases gradually at initial heating, and basically keeps stable after heating for 50min. In fire condition 3 and 4, bending moment changes the direction and the absolute value increases gradually, and keeps stable after heating for 30min. Bending moment M10, 7 increases gradually and keeps stable after heating for 40min in fire condition3. In fire condition 1, 2 and 5, the bending moment changes the direction at initial heating, and after that, the trend is similar, but the range is slightly different. Bending moment M7, 10, in fire condition 1, changes the direction and increases gradually, then keeps stable after heating for 50min. In fire condition 2 and 5, the absolute value increases slightly at initial heating, then basically keep stable. Bending moment M4, 7 shows a similar trend in fire condition 2 and 5 that is increases gradually at initial heating and keeps stable after heating for 50 min. In fire condition 3, the absolute value increases gradually first and keeps stable after heating for 20min. Bending moment M1, 4, in fire condition 3, the absolute value decreases gradually to zero at initial heating, and changes the direction, then keeps stable after heating for 20min. In fire condition 1 and 5, the absolute value increases gradually and keeps stable after heating for 40 min.

V. Conclusion

(1) Based on the internal force of the beam supporting column transfer structure model under room temperature and static load, additional internal force is produced obviously with the heating time increasing, then it causes obvious internal force changing.

(2) In each fire conditions, for internal forces of member sections, with the heating time increasing, some increase, some decrease, some even change directions. The range of changes would even exceed many times the value of internal forces at room temperature.

(3) With the heating time increasing, the internal forces of member sections will be significantly redistributed, and the redistribution is most obvious and severe before 90 min of heating. This might be related to the heating curve selected for the model.

(4) For the transfer girder in first floor, heating evenly and away from the fire floor make a small change to bending moments and bear forces. In different fire conditions, the axial forces of the transfer girder change obviously and often change the direction.

(5) During the whole heating process, the internal force superposition of some member sections may exceed the prediction designed for room temperature and affect the safety of the structure. Therefore, the potential fire impact should be considered in designing the key structures like the transfer structure.

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