Impact of the Fire Propagation on the Residual State of the Peripherally Supported Grid Structure

Gan Tang 1*, Renyi Shi 1, Zhanjie Li 2, Lingfeng Yin 3 and Weiwei Li 3

1 Department of Civil Engineering, Nanjing University of Aeronautics and Astronautics, YuDao Street 29, Nanjing; 210016, China
2 Department of Engineering, SUNY Polytechnic Institute, Utica, NY 13502, USA
3 School of Civil Engineering, Southeast University, Sipailou 2, Nanjing; 210096, China
Email: tanggan@sina.com

Abstract. The objective of this paper is to computationally investigate the structural residual states of the peripherally supported grid structure under different fire propagation paths and reveal the path impact on the structure. The results demonstrate that the fire propagation path has a significant impact on the residual deformation of the grid structure while it has negligible impact on the distribution of residual axial member force. Hence, the structural residual states are quite different of different fire propagation paths.

Keywords. Fire, propagation path, grid structure, residual state.

1. Introduction
Under fire, the high temperature changes the mechanical properties of the steel material. Outinen et al. [1] carried out a series of experimental tests of steel and obtained abundant experimental data of the mechanical properties under high temperature. Yang et al. [2] investigated the buckling behaviour and failures of axial steel members based on the constitutive models under high temperature. Wong [3] studied the member behaviour with the consideration of the constraining effect from other members under elevated temperature. Moreover, the study also computationally investigated the member behaviour with fire protection. Koo et al. [4] used the data from sensors in the tested structure for the Monte-Carlo fire model to learn the fire propagation, Du and Li [5] studied the influence of nonlinear variation of physical and mechanical properties of steel on the load-carrying capacity of a grid structure. Also, based on that, they investigated the impact of the end supports on the structural fire resistance behaviour.

The current research of grid structures under fire focus on the specific temperature curves and the nonlinear analysis of the structure based on the fire performance. There are limited researches on the influence parameters to the fire response of the structure when fire happens. There are lots of causes of fire with different fire intensity and lots of fire propagation paths. Different regions of the structure may not go through the same fire development (developing, fully developed, and deceasing) at the same time. Thus, there is a need to investigate the propagation path and its impact on the residual structural states under fire. In the paper, the influence of the propagation paths is computationally studied for the peripheral supported grid structure.
2. Computational Model

2.1. The Grid Structure
The grid structure studied here is shown in figure 1. The structure is located in Nanjing subjected to a dead load of 0.5 kN/m² and a live load of 0.5 kN/m². The grid is 3 m x 3 m and the height is 2.5 m. The top chords of the grid structure are peripherally supported as shown using a hinge. The member is a tube using Q345B steel. Based on the detailed design, the member dimensions used are 140 x 6, 140 x 4, and 114 x 4. The temperature curve is shown in figure 2. Link 8 element in ANSYS is adopted for the computational model.

![Figure 1. Grid structure layout diagram.](image1)

![Figure 2. Temperature-time curve of each steel tube.](image2)

2.2. Fire Propagation Path
During the fire, there are a variety of fire propagation paths. The fire source is usually located in one region of the structure, which could be a point fire source or a line fire source. In this study, several typical fire propagation paths were selected as shown in figures 3 and 4. The structure under these fire propagation paths will be subjected to asynchronous elevated temperature and their impact on the structural residual deformation and residual axial member force are computationally evaluated. Note the asynchronous elevated temperature means that the structural members are subjected to different temperature under different fire propagation paths before the peak temperature.
2.3. The Propagation Speed and Peak Temperature
The fire propagation is very complex, especially when the fire is originated outside the structure. Lots of uncertainties exist in determining the fire propagation speed. Based on the literature in [6] and [7], three propagation speeds were selected in this study, including 50 mm/s, 100 mm/s, and 150 mm/s. In addition, the peak temperature in the grid structure is assumed to be 700 °C.

![Figure 3](image-url)  
**Figure 3.** Propagation path of point fire source (Shadow part represents fire source).

![Figure 4](image-url)  
**Figure 4.** Propagation path of line fire source (Shadow part represents fire source).

3. The Impact of the Fire Propagation Paths on the Residual States of Grid Structures
Figure 5 shows the residual deformation and residual axial member forces of the peripherally supported grid structure under different fire propagation paths for a point fire source with a propagation speed of 100 mm/s as an illustration. The residual states of the structures under different propagation paths and speeds are summarized in table 1.

Based on the above results, the following observations can be obtained:

1. The residual axial forces distribute differently under different propagation paths. Even the maximum and minimum residual axial member forces are the same under different propagation paths, the bottom chords in the middle of the grid structure do have a large residual axial force under the propagation paths II and III. For example, with the point fire source with a propagation speed of 100 mm/s, the residual axial force of one of the bottom chords in the middle is 200 kN under path I while 400 kN under path II or III.

2. The residual deformation of the grid structure varies significantly under different propagation paths. Under the propagation paths I and II, the maximum residual joint deformation is close to the point fire source. Also, the large residual deformation regions are also close to the point fire source. These are due to the fact that those regions close to point fire source endure high elevated temperature longer.

3. The grid structure has the largest residual deformation under the propagation path III, which indicates the highest risk. These can be observed from table I. Thus, when designing the grid structure for fire resistance, extra attention should be paid to case III, where the fire is originated from the center of the structure, either a point fire source or a line fire source.
Figure 5. The residual states of grid structures in each propagation path. Note: Point fire source with a propagation speed is 100mm/s, unit: m, N.
Table 1. Summary of the residual states of the peripherally supported grid structure under different propagation paths.

| Fire source | Propagation speed (mm/s) | Propagation paths | Maximum residual displacement (mm) | Maximum residual displacement coordinate (m) | Maximum residual axial member forces (kN) | Minimum residual axial member forces (kN) |
|-------------|-------------------------|-------------------|-----------------------------------|---------------------------------------------|------------------------------------------|------------------------------------------|
| point fire source | 50 | First path | 660.2 | (21,18,0) | 871 | -477 |
| | | Second path | 875.7 | (24,15,0) | 871 | -477 |
| | | Third path | 1122 | (24,18,0) | 871 | -477 |
| | 100 | First path | 719.6 | (21,18,0) | 871 | -477 |
| | | Second path | 882 | (24,15,0) | 871 | -477 |
| | | Third path | 1017 | (24,18,0) | 871 | -477 |
| | 150 | First path | 725.8 | (21,18,0) | 871 | -477 |
| | | Second path | 864 | (24,18,0) | 871 | -477 |
| | | Third path | 986 | (24,18,0) | 871 | -477 |
| line fire source | 50 | First path | 608.5 | (21,18,0) | 871 | -477 |
| | | Second path | 626.3 | (24,15,0) | 871 | -477 |
| | | Third path | 1023 | (24,18,0) | 871 | -477 |
| | 100 | First path | 673.8 | (21,18,0) | 871 | -477 |
| | | Second path | 690 | (24,15,0) | 871 | -477 |
| | | Third path | 948 | (24,18,0) | 871 | -477 |
| | 150 | First path | 711.7 | (24,18,0) | 871 | -477 |
| | | Second path | 736 | (24,18,0) | 871 | -477 |
| | | Third path | 936 | (24,18,0) | 871 | -477 |

4. Conclusions
Based on the study, the following conclusions can be drawn:

(1) For the peripherally supported grid structure, under propagation paths I and II, the maximum residual joint deformation gravitates toward the point fire source. So are the large residual deformation regions. Under the propagation path III, the maximum residual joint deformation is at the center and the residual deformation shows symmetry.

(2) The impact of the fire propagation path is mainly reflected through the residual deformation not the residual axial member forces. Thus, in fire investigation, the fire development may be deduced through the residual deformation with the help of residual axial member forces.

(3) The fire propagation paths influence the grid structure’s residual states. Different residual states are observed under different fire propagation paths. Thus, design consideration should include how the fire propagates.

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