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Performance-based analysis of large steel truss roof structure in fire

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ABSTRACT

Due to the fast developments of large-space multi-functional architectures, large-span steel structures have been widely used in recent years. Therefore, the fire-resistance design of this kind of structures has attracted more attentions. Since traditional ISO834 standard fire curve is not suitable for large space structures, performance-based fire resistance design method is required. This paper presents the comprehensive case studies on the fire performance of a large space exhibition centre in Shanxi province, China under real fire scenarios including heating and cooling phases. The non-uniform fire temperature fields of the large space exhibition centre for the designed fire scenarios have been generated by using Fire Dynamic Simulator (FDS). A finite element (FE) model has been developed using FE software ANSYS for modelling the structural behaviour of the exhibition centre under different fire scenarios. Based on the results generated in this research some recommendations for the fire resistance design of large space steel truss structures have been proposed.

1. Introduction

With the developments of technology and economy, a variety of complex and large-scale buildings are getting more and popular. Larger span steel structures are adopted to satisfy the requirements of modern architectural designs. Thus, traditional –prescriptive- design method cannot meet the actual needs of constructions, especially for the fire resistance design of large space buildings, such as exhibition halls, stadiums, theatres, tall sharing spaces, and so on. Previous researches [1,2] indicate that prescriptive methods are sometimes too conservative or not safe enough for the structural fire engineering design of large-scale buildings. Therefore, at present performance-based design method is recommended for the fire resistance design of this kind of buildings, which has been proved by many researches and practical experience [3]. In the performance-based fire resistance design, the fire behaviour of a building should be analysed based on the space and structural character of the building and real fire scenarios that building may undergo [4]. The temperature field of the real fire scenarios in a large-scale building should be analysed and then coupled into the structural performance study of that building [5].

Compared to normal office buildings, a fire within a large space structure happens in a limited area within the building and the hot air only influences that part of the building's space. The temperature field within a large space structure is much more different than that a normal office building. Therefore, the standard temperature-time curve is not suitable to represent the temperature distribution within large space structures. Du and Li [6], Xue et al. [7] and Fan et al. [8] have developed the numerical models for predicting temperature fields of the fires in large space buildings based on the fire development using Fire Dynamics Simulator (FDS) [9]. The models mentioned above can more accurately simulate the temperature distribution of the fires within large space structures. However, these models do not consider the cooling process of a fire.

Currently, the researches on the structural response of large space steel truss structures under real fire scenarios are still limited, especially considering whole heating-cooling process. Liu et al. [10] carried out the full scale fire tests on two steel truss structures. The research indicated that the damage of planar circular steel tube truss was mainly caused by the local yielding of the web tubes. With the increase of load ratio, the fire resistance of a planar circular steel tube truss decreases gradually. Moreover, Zhao and Shen [11] have developed a numerical model by using finite element software ABAQUS to predict the fire resistance of the planer steel tube truss structures and the results showed that the fire-resistance of the structures decreased with increasing temperature and load ratio.

Li et al. [12,13] have developed a finite element model by using

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ABAQUS for analysing the non-linear fire performance of steel frames. The model took into account the material and geometric nonlinearities, and non-uniform temperature field within steel frames. Yin and Wang [14,15] have done a series of researches on the fire resistance of steel beams. However, the researches mentioned above didn't consider the characteristic of a fire in large space structures. From the authors' knowledge, the researches on the fire performance of large space steel tube truss structures under real fire scenarios are still very limited and further researches are needed. Therefore, the main objectives of this research are:

- Conduct a comprehensive case study by using performance-based approach on the fire resistance of a large space exhibition centre in Shanxi province, China under real fire scenarios including heating and cooling phases;
- Generate the non-uniform fire temperature fields of a large space exhibition centre for the designed fire scenarios by using FDS finite element package [9];
- Calculate the temperatures of the structural members within the large-space steel truss structure based on the local fire temperature fields. Then a finite element (FE) model is developed using FE software ANSYS. The non-uniform temperatures of different structural members within the large space exhibition centre are inputted into the FE model to simulate the structural behaviour of the exhibition centre under different fire scenarios;
- Give a comprehensive demonstration for practical engineers to show how fire resistance of a large-space steel truss structure can be assessed based on performance-based fire design approach;
- Propose some recommendations for the fire resistance design of large space steel truss structures.

2. Fire scenarios design for large space structures

2.1. Project overview

Fig. 1 shows a 52,000 m^2 exhibition centre located in Taiyuan, Shanxi Province, China. This exhibition centre was used in this paper for the comprehensive case study on the thermal and structural behaviours of a large space exhibition centre. The exhibition centre is a typical large space frame structure with a large-span roof constructed with steel trusses. As shown in Fig. 2 the building is composed by two circles, with an out circle of 229 m in diameter and an inner circle of 50 m in diameter. The total area of the first layer is 46,600 m^2 and was designed to be one fireproofing zone. As an exhibition centre, it consists of six exhibition halls (the area of 1# and 6# is 6518 m^2 and that of 2# to 5# is 4675 m^2), a main entrance hall (3693 m^2) and a circle gallery (3670 m^2) in the inner centre. The whole roof of the building was constructed by spatial intersection steel trusses into an arc structure. The lowest position on the bottom chord of the steel truss structure is 12 m and the highest point on the steel truss structure is 26 m.

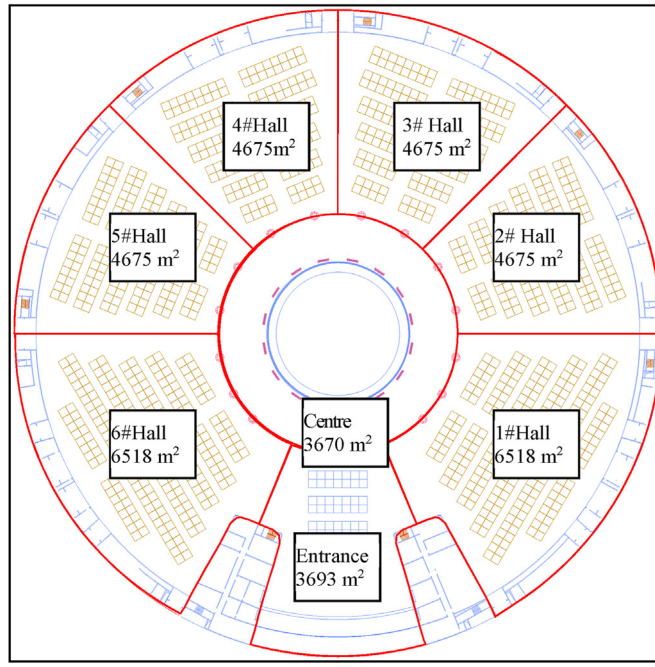

Fig. 2. The floor layout of the exhibition centre.

It can be seen that the area of the fireproofing zone is much larger than the requirements specified by the Chinese code for fire protection design of buildings (GB 50016-2014) [16], which is 10,000 m^2 for maximum. The maximum evacuation distance of 114.5 m, which is the radius of the out circle of the building, is also larger than the value specified by the code. Therefore, it is needed to adopt performance-based approach for the fire-resistance design of such large buildings.

According to the Chinese fire safety design codes [16,17], the performance-based fire resistance designed approach for this lager space exhibition centre is needed. The detail procedures are:

(1) To determinate typical upper-bound and lower-bound design fire scenarios and corresponded fire temperature distribution histories within a structure;
(2) Calculate the temperature fields for all structural members inside the structure for the required fire exposing time;
(3) Compute the loading conditions of the structure, which take into account the load combination effect according to the Chinese codes;

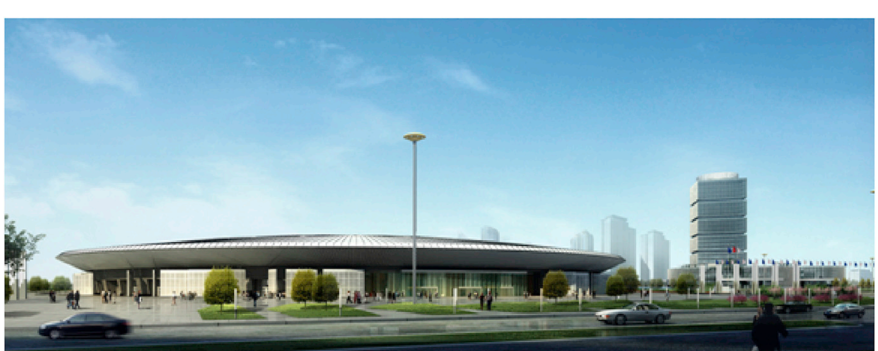

Fig. 1. A 52,000 m^2 exhibition centre located in Taiyuan, Shanxi Province, China.