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Fire Behaviors of double-layer grid structures under a new temperature-time curve

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Abstract

Double-layer grid structures with long span are widely applied by complex buildings such as airport terminal halls, super high-way train stations, conference & exhibition halls, sport studios, warehouses and so on. As the area of the fire source located in the large volume space is rather smaller than that of floor, this kind of fire scenario is named as localized fire with non-uniform temperature distribution. In present paper, a new temperature-time curve has been firstly developed to describe the transient non-uniform temperature distribution in localized fire, which is dependent on the space size, heat release rate of fire source. Then, the mechanical behaviors of global double-layer grid structures subjected to localized fire have been investigated by using numerical method. As a part of the structure is subjected to heating strongly and the heated members are restrained by the adjacent members which are heated slightly, some chords hold the characteristic of axially restrained members. The mechanical behaviors of chords with different axial restraint stiffness due to different non-uniform temperature distribution which can be described by the new temperature-time curve have been deeply studied. The initial imperfection can strongly improve the buckling resistance for axially restrained chords. An analytic method has been developed to estimate the fire resistance of double-layer grid structures exposed to localized fire.

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Keywords: Double layer grid structures; fire resistance; localized fire; restrained chord

1. Introduction

Nomenclature	
x	distance from the vertical axis to the point in the horizontal plane
z	height of the horizontal plane
t	fire time from ignition
$T_g(0)$	ambient temperature

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T_g^{max}	maximum temperature
$f(t)$	regression function of temperature dependent on fire time from ignition
k_{sm}	regression function of temperature dependent on distance from fire source
Q	heat release rate
H	height of ceiling
β	regression parameter dependent on fire growth type, given by Table 1
D	effective diameter of fire bed
A_q	area of fire bed
η	temperature non-uniform distribution parameter, given by Table 2
k_c	axial stiffness of chords at elevated temperature
E_T	elastic modulus at elevated temperature
ε_{th}	thermal strain
I	second moment of area
$u_{m,0}$	vertical displacement at the end of a chord due to bending at ambient temperature

The wider use of electronic computers and the development of software to enable space grid structures to be analysed more accurately increased confidence in their use for larger span and greater height structures. Since the late 1980s, a large number of double-layer grid structures have been erected and covered 2,000,000m^2 area per year in China. It has been extensively and successfully made in railway stations, airport terminal building, exhibition halls, storage buildings, factories and so on. Architects always prefer to display clear and uncluttered grid structures for the most aesthetic appeal. Although the numerical analysis can more accurately investigate the fire safety of double layer grid structures with longer and longer span. It is necessary that proposed design strategies for double layer grid structures to obtain or improve the initial fire-resistance capacity dependent on key factors. The aim of this present study is to capture the behaviors of double-layer grid structures exposed to localized fire and understand how to improve their fire-resistance.

Actually, a few previous research papers on the fire-resistance analysis of double-layer grids have been published. In 1993, reference [1] emphasized that natural fires model should be introduced for large compartment fire scenarios. Progressive collapse of double-layer grid structures is commonly characterized by the sequential buckling of individual chords at elevated temperature. Then, a step by step numerical analytical method is performed by reference [1] to investigate the fire resistance of the grid. It is worth noting that reference [2] proposed that at ambient temperature, the analysis proceeding should be extended to the post-buckling stage rather than member removal at buckling stage. In present paper, the response of a global double-layer grid structure subject to localized fire, which has been described by a new temperature-time curve, has been investigate using by numerical simulation. The mechanical of chords in global double-layer grid structure is similar to that of the typical axially restrained members exposed to localized fire. An analytical method has been proposed to capture the transient axial force of chords through the full range which is from pre-buckling to post-buckling stage. This analytical method can benefit to the design strategies of fire safety design.

2. Non-uniform temperature distribution in localised fires

Based on the zone model, there are a few temperature-time relationships to describing localized fire given in NFPA 92B [3] and EN1991-1-2 [4]. Based on the field model, a new temperature-time curve has been introduced in reference [5] to describe the non-uniform temperature distribution. The database resulted from a series of large space fire scenarios simulated by FDS (Fire Dynamics Simulator), revealed three important facts.

Firstly, the localized fire temperature distributions are non-uniform and pole asymmetric from the fire source. Then, Eq. (1) ~Eq. (4) have been proposed to describe the transient non-uniform temperature distribution, $T(x,z,t)$, for localized fires and the virtual space for localized fire scenario shown as Fig. 1.

$$T(x,z,t) = T_g(0) + T_g^{max} \cdot f(t) \cdot k_{sm} \tag{1}$$