Advances in Engineering Software 62–63 (2013) 119–130

Contents lists available at SciVerse ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Temperature heterogeneity during travelling fire on experimental building

Kamila Horová *, Tomáš Jána, František Wald

Department of Steel and Timber Structures, Czech Technical University in Prague, Czech Republic

ARTICLE INFO

Article history:
Available online 23 May 2013

Keywords:
Structural fire design
Travelling fire
Fire test
Thermal gradient
Homogenous temperature conditions
CFD modelling
Structural response

ABSTRACT

In order to follow modern trends in contemporary building architecture which is moving off the limits of current fire design models, assumption of homogeneous temperature conditions used for structural fire analysis needs to be validated. In this paper it is described, how temperature distribution in a medium-size fire compartment has been investigated experimentally by conducting fire test in two-storey experimental building in September 2011 in the Czech Republic. In the upper floor, a scenario of travelling fire was prepared. It has been observed that as flames were spreading across the compartment, considerable temperature gradients appeared. Numerical simulation of the travelling fire test conducted using FDS (Fire Dynamics Simulator) has been compared with simulation of compartment fire under uniform temperature conditions to highlight the potential impact of the gas temperature heterogeneity on structural behaviour. The temperature measurements from the fire test have been used for validation of the numerical simulation of travelling fire. The fire test has provided important data for design model of travelling fire and shown that its impact on structural behaviour is not in agreement with the assumption of homogenous temperature conditions.

1. Introduction

The traditional fire design methods used in structural fire analysis are based on the assumption of homogeneous temperature in the entire compartment. However, the justification of small temperature gradient in vertical and even smaller in horizontal direction has not been evaluated for large compartments which are typical for contemporary architecture.

Observations of real fires in large compartments such as in the World Trade Center or the Windsor Tower in Madrid, show that fires tend to travel across the area of an enclosure to consume fuel. Due to travelling of flames, regions of higher and lower temperatures appear. In order to validate this, experimental studies aimed at investigation of fire dynamics in modern buildings are needed, covering large open spaces, areas with high ceilings, atria or glass facades. Range of applicability of Eurocode [5] to modern architecture should be validated.

For the purpose of investigating dynamics of travelling fire, a full-scale compartment test was executed in Czech Republic in 2011 [12]. In the upper floor of the experimental building, a travelling fire scenario was prepared. Since the scale of experimental enclosure was not large in comparison to the scale of real buildings, high degree of temperature non-uniformity appeared. Differences in temperature of 400 °C of the upper smoke layer confirm that the homogeneous temperature assumption does not hold good by compartment fires.

To study travelling fire, CFD method with aid of FDS 5 [8] is used. Numerical results are validated by experimental measurements and compared to homogeneous temperature assumption of zone model to highlight the level of difference between both assumptions – traditional fire design model versus travelling fire model. Effect of heterogeneous temperature fields on the structural behaviour is discussed.

2. Traditional fire design models versus travelling fire

2.1. Assumption of homogeneous temperature conditions

The traditional fire design methods used for structural fire analysis are based on assumption of homogeneous temperature in the entire compartment. Regardless whether the standard temperature–time curve (ISO 834) or parametric temperature–time curve [5] is used, both analytical methods give one temperature distribution in all locations of an enclosure. Zone models as well as introduced analytical methods are based on energy balance which leads to uniform temperature distribution across the floor area. All methods based on the homogeneous temperature assumption adopted the justification that there is a small gradient in vertical temperature distribution and even smaller in horizontal direction.

* Corresponding author. Tel.: +420 224 354 763; fax: +420 233 337 466.
E-mail address: kamila.horova@fsv.cvut.cz (K. Horová).

0965-9978/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.advengsoft.2013.05.001

However, according to Stern-Gottfried et al. [11] the justification has not been evaluated any further. Due to lack of fire experiments in large compartments with real compartment conditions, fire loads, ignition sources and due to limited number of measuring devices, the presence of horizontal temperature heterogeneity was not investigated and is rarely reported [11].

Recently, traditional fire design methods have been criticised, mainly for post-flashover fires. In the test on compartment of $4.6 \times 4.6 \times 2.5$ m performed by Bohm and Hadvig, experimental measurements showed variance of gas temperature of 300 °C [11].

The experimental evidence of non-uniform temperature in the whole compartment was presented by Cooke [3] who undertook four tests with uniform fire loads of wooden cribs in compartment of $4.5 \times 8.75 \times 2.75$ m, ventilated at one end. As the fuel was ignited at the opposite side from the ventilation, burning moved quickly towards the opening. After fuel was consumed in well ventilated region, fire progressed away from the opening, back to the place of ignition, see Fig. 1.

In 2007, Welch described fire tests in a compartment of area of 12×12 m and height of 3 m [13]. Thanks to advanced technical equipment and measuring devices, temperature fields were recorded, see Fig. 2. In this figure, moving fields of higher and lower temperatures can be observed. Although the maximum temperature difference was not significant, the difference in heat flux at the ceiling structure was considerable.

2.2. Temperature heterogeneity during travelling fire

Observations of real fires in large compartments such as in the World Trade Center or the Windsor Tower in Madrid, show that fires tend to travel. As flames spread within the floor to consume fuel, regions with high temperatures and regions with elevated temperatures are created. Temperature distribution in the entire enclosure is highly non-uniform.

Recently, several models of travelling fire have been introduced. Clifton [2] developed a model for fire in large compartments in which the assumption of uniform burning cannot be applied. The fire can be described by dividing the compartment into a number of design areas. In these areas, fully-developed burning occurs before moving to other areas. The gas temperature–time relationship within a design area is assumed to follow a parametric fire curve and the maximum size of the design area should not exceed 100 m^2. In case of recommended ventilation and specified fire load, the time during which fire occurs in each design area is 20 min [2].

More recently, Rein [9] and Stern-Gottfried [10] have developed an alternative method for modelling travelling fires in large compartments. They suggest that due to localised burning, the gas temperature consists of near-field (temperature of flames, usually around 1200 °C) and far-field temperatures (temperature of hot gases layer). The far-field temperature T_{ff} varies with the distance from the fire. Its distribution can be determined with aid of computational fluid dynamics models or by hand calculation suggested by Rein and Stern-Gottfried as

$$T_{ff} = \frac{\left[\int_{r_{nf}}^{r_{ff}} T^4 dr\right]^{0.25}}{(r_{ff} - r_{nf})^{0.25}} \tag{1.1}$$

where r_{ff} is the radius of the far-field, r_{nf} the radius of the near-field and T is the near-field temperature [10]. Using this model, the temperature–time curve for any structural element is showed in Fig. 3, where T_{nf} is the near-field temperature in °C, T_{ff} is the far-field temperature in °C, T_∞ is ambient temperature in °C, t_{pre} is the time after ignition but before the fire arrives, T_b is the time of fire burning locally at the element and t_{post} is the time after the fire has travelled past the element, see [9].

3. Experimental study

3.1. Experimental background

In order to investigate dynamics of travelling fire, a full-scale compartment test was constructed in the Czech Republic in 2011 [12]. Since the scale of experimental enclosure was not large in comparison to the scale of real buildings, high degree of temperature non-uniformity appeared. Differences in temperature of the upper smoke layer of 400 °C confirm that the homogeneous temperature assumption does not hold good in compartment fires.

3.2. Experimental building

A two-storey composite steel–concrete experimental structure of dimensions $10.4 \times 13.4 \times 9$ m was designed, representing a part of an administrative building. Composite ceiling slab consisted of

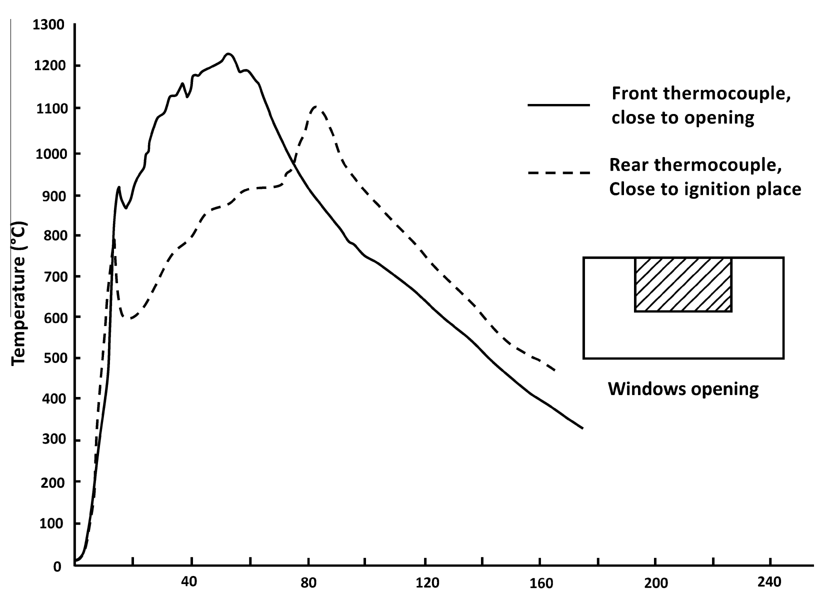

Fig. 1. Gas temperature measurement at two different locations during Cooke test [3].