Perspectives in Science (2016) **7**, 247—252

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/pisc

Thermal transient analysis of steel hollow sections exposed to fire☆

Lenka Lausova*, **Iveta Skotnicova**, **Vladimira Michalcova**

Faculty of Civil Engineering, VSB-Technical University of Ostrava, Ludvika Podeste 1875/17, Ostrava-Poruba 708 33, Czech Republic

Received 23 October 2015; accepted 19 November 2015
Available online 12 December 2015

KEYWORDS
Fire loading;
Steel hollow section;
Non-uniform temperature distribution;
Statically indeterminate frame;
Experiment;
Numerical modelling

Summary The paper describes a study of non-uniform temperature distribution across the section of steel structures where elevated temperature causes additive internal forces due to restrained conditions. The work provides comparison of a heat field at the time of fire in the non-protected steel hollow cross-sections of different sizes. The study compares simplified calculations according to valid standard and numerical simulations in finite element analysis of steel structures exposed to fire loading from three sides. Numerical thermal analysis is also compared with results obtained from the fire testing in VSB-Technical University of Ostrava.

Introduction

The valid standards for fire design situation allow simplified methods of calculation based on empirical formulae for thermal analysis of structures (Wald et al., 2005). These assumptions may result in conservative solutions, which can be suitable for structural element calculations, but they cannot be used e.g. for structures where elevated temperature causes additive internal forces due to restrained conditions.

The whole structural function as a system depends on a stress—strain state of particular elements. Methods based on elementary principles of mechanics while respecting the influence of growing temperature must be applied in structures design. Various analysis stages must be considered for calculation and the task has to be solved as a combined one both in thermal and structural analysis. The temperature distribution in a section is obtained in thermal analysis and the stress—strain state of a structure at the time of growing temperature is solved in static analysis. Furthermore, variable values of material properties, which depend on temperature, must be taken into account.

The paper evaluates hollow steel non-protected profiles exposed to elevated temperature with special attention to non-uniformly distributed temperature over the section. Moreover, results from experimental testing of a steel statically indeterminate frame in the technical chamber carried out in VSB-TU of Ostrava are presented and compared

☆ This article is part of a special issue entitled ''Proceedings of the 1st Czech-China Scientific Conference 2015''.

* Corresponding author.
E-mail addresses: lenka.lausova@vsb.cz (L. Lausova), iveta.skotnicova@vsb.cz (I. Skotnicova), vladimira.michalcova@vsb.cz (V. Michalcova).

http://dx.doi.org/10.1016/j.pisc.2015.11.040

with the results from numerical modelling in the ANSYS software.

Standard solution

Temperature distribution can be calculated in the section for a given temperature load on the basis of Fourier equation (Wald et al., 2005) if there are known thermal characteristics of the materials from which the structure element is composed. The simplest way to determine the temperature of steel sections is the simplified method according to the valid standard EN 1993-1-2 by heat transfer from the gas temperature. Thus, the temperature can be determined in the open and hollow cross-sections, with or without fire protection, and also temperature rise at the beam heated on three sides.

Furthermore, it is possible to determine the temperature in the section numerically with the incremental method (Wald et al., 2005), which assesses the temperature change in the section for a given time period. Increment section temperature is calculated from the temperature of the gas through the heat flow and it is dependent on the so called section factor, specific heat and density of the material. Slowing rise of temperature at protected sections is influenced by thermal characteristics of the protective material and its thickness. The section factor may generally be determined by dividing of the circumference part exposed to fire and the cross-sectional area. The section factor at hollow sections where t (thickness of the section) is much smaller than b (width of the section) is determined by relation $1/t$ (Wald et al., 2005). Calculation of the section factor for all above mentioned cases of cross-sections can be found in valid standard with the exception of the hollow steel cross-section heated from three sides, which is the aim of this article.

Due to the high value of thermal conductivity of material the temperature distribution in steel cross-sections is more uniform than e.g. in concrete elements (Cajka and Mateckova, 2010, 2013; Handbook 5, 2005; Wald et al., 2005). To simplify the problem a uniform temperature distribution in the whole cross-section is assumed. At the section exposed to fire on three sides the temperature of the bottom flange and the web is almost identical. However, the temperature of the upper flange is lower. This is due to heat losses at the top surface of the upper flange to the relatively cold concrete slabs. Steel hollow sections show bigger differences in temperature distribution compared to open sections. As was mentioned above, according to standard the uniform temperature distribution can be considered in all steel sections. This uniform temperature in the whole section is derived from the temperature of the bottom flange exposed to fire. Under certain conditions it is useful to apply numerical methods for temperature field calculation (Delgado et al., 2015; Gardner and Ng, 2006; Lausova et al., 2014, 2015; Yin and Wang, 2003).

Calculations of statically indeterminate structures exposed to elevated temperature

This paper is focused on the calculation of non-uniform temperature distribution across the section which causes additional bending moments in structures where the thermal expansion is prevented by restrained conditions. The assumption of necessity to monitor temperature and stress—strain state at the beginning of the fire at statically indeterminate structures is confirmed in (Lausova et al., 2014, 2015). The influence of non-uniform heating of the section at simultaneous relatively low total temperature at the beginning of fire may decide further progression of stress. During the following minutes this influence does not show itself as much as at the start from two reasons:

- participation of the total temperature increase becomes more significant than non-uniform temperature distribution
- at temperatures above 200 °C the Young's modulus decreases and thus internal forces drop down.

On the other hand, in steel structures at elevated temperatures above 400 °C the yield stress decreases (carrying capacity of the section). All these assumptions must be taken into account when calculating statically indeterminate structures under fire loading.

Experimental results

In this paper the measured surface temperature from experimental testing are used as boundary conditions in numerical simulation. The fire test was realized in VSB-TU Ostrava in 2012 in the technical chamber of the Faculty of Safety Engineering (Lausova et al., 2014, 2015). The simple steel frame with fixed ends was tested. Both columns and beam of the frame were of the same hollow squared cross-section 50/4, the beam was exposed to fire load from three sides, the columns from all sides. Temperatures were measured on the frame and also in the component parts of ceiling, as seen in Fig. 1. The temperatures obtained from the testing are shown on the graph in Fig. 2.

Measuring points T1—T4 were placed on the frame parts exposed to fire load, the measuring point T2-top edge was placed on the upper edge of the beam under the ceiling structure cooling the steel (Fig. 1). On Fig. 2 there can be clearly seen that measured values of the temperature on the upper side of the beam are lower than temperatures on other sides of the beam cross-section as well as other parts of the structure.

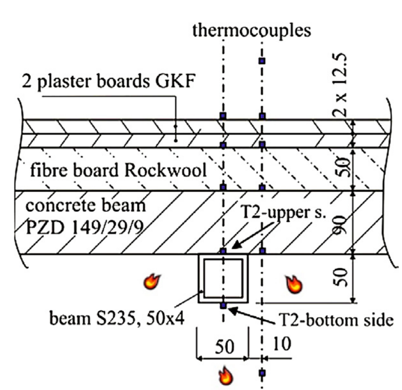

Figure 1 Ceiling structure with the position of T2.