Perspectives in Science (2016) 7, 272—276

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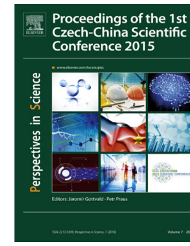

Contribution to fire resistance analysis of statically indeterminate structures☆

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

KEYWORDS
Fire resistance;
Fire loading;
Testing;
Indeterminate structure;
Plastic hinges

Abstract Structural fire resistance, as integral part of structural design, is determined by testing or by calculations. This paper is focused on statically indeterminate structures where thermal expansion is restrained and significant internal forces occur in the structure leading to possible plasticization and subsequent redistribution of internal forces. In this paper different approaches of fire resistance testing are described, together with brief description of two experiments focussed on verification of behaviour of a statically indeterminate steel frame exposed to high temperature which were carried out at VŠB-TU Ostrava. The paper is complemented with calculation of steel and concrete simple frame structure exposed to elevated temperature.

Introduction

Fire resistance analysis is becoming the integral part of structural design. Fire resistance is determined by testing or by calculation, using, e.g. European standards, Eurocodes. Testing and consequently calculation of the fire resistance is explored more for the statically determinate structural elements than for the complex often statically indeterminate structure as a whole. Prediction of the behaviour of indeterminate structure is complicated due to internal forces caused by restriction of thermal expansion. In general it is supposed that significant internal forces are leading to local plasticization and subsequent redistribution of internal forces.

Fire resistance testing

Testing in accredited laboratory

In Czech Republic there is one accredited laboratory for fire resistance testing and it is located in Veseli nad Luznici.

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

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http://dx.doi.org/10.1016/j.pisc.2015.11.042

a) b)

Figure 1 (a) Accredited laboratory, Veseli nad Luznici, (b) fire in simple building, Veseli nad Luznici.

Laboratory provides testing of both vertical and horizontal structures according to criteria of resistance *R*, entirety *E*, insulation *I* and smoke protection *S*. It is possible to control the growth of the temperature and to measure the temperatures on unexposed side of the structure, exceptionally also within the cross-section of the structure. Structural elements, e.g. precast panel or column, are exposed both to thermal and mechanical load. Criterion for fire resistance according to load bearing capacity is limit deflection or limit growth of deflection. However arrangement of the laboratory allows only testing of particular structural elements, Fig. 1a. As this testing is very expensive it is common to examine a few, sometimes only two specimens, which do not allow perform statistical analysis, nevertheless measured temperatures and deformations are very valuable for fire resistance calculations (Bradacova and Kucera, 2013; Cajka and Mateckova, 2013, 2010; Kralik, 2014; Kucera et al., 2014). Experiments with several similar structural elements provide concept of expected behaviour of this structural element type exposed to fire and are utilized as a basis for tables which allow operative fire resistance determination on safe side.

Testing of simple buildings

Mechanical behaviour of structural element could vary from behaviour of the real structure that is why experiments of fire in simple building are also performed. In the literature it is possible to find the conclusions from several years testing in Cardington. Czech Technical University in Prague also organised experimental fire in buildings in 2008 in Mokrsko and 2011 in Veseli nad Luznici, Fig. 1b. Experiments are described and analysed in series of papers, they were focused mainly on advanced analysis of steel and steel concrete structures (Pultar et al., 2010). As the experiments in real buildings are technically and financially demanding they are still only sporadic.

Testing at VSB — technical university

Authors are interested in statically indeterminate structures exposed to fire. It is generally assumed that significant internal forces caused by cross-section warming lead to plasticization and redistribution of internal forces. This assumption is not possible to prove with experiments in accredited laboratory and was proved only indirectly with the experiments in real buildings. The idea than was to carry out experiment with the structure which is not space demanding but which includes fixed supports. The experiment was carried out in thermal technical chamber at Faculty of Safety Engineering, Fig. 2a. In pilot program in 2012 and 2013 there were two specimens tested (frame 1 and frame 2, Fig. 2b and c, first exposed only to thermal load, second exposed both to thermal and mechanical load (Lausova et al., 2015, 2014).

Description of the experiment

Both tested models were made of the same hollow rectangular steel profile 50/4, material Fe360/S235, bottom frame girder was surrounded with concrete. The frame spans were 1.5 m, the height 0.5 m. The static schemes of both models are seen on the Fig. 2b and c. Within the experiments temperatures and also strains were measured.

The temperatures were scanned on the selected points of the frame and in chamber space as well, using K-type sheathed thermometers with 1 mm diameter.

In the frame 1 strains were measured in points T1—T4 according to Fig. 2b by four strain gauges 1-XC11-3/350 m intended for testing up to 350 °C. The strain gauges were placed on the internal sides of the frame. In the frame 2 the strain was scanned by four special strain gauges LZE-NC-W250G-120/2M, which are intended for measurement of strain up to 1200 °C. These strain gauges were attached to the structure at two places T2 and T4 acc. to Fig. 2c, always in pairs in perpendicular direction on the internal sides of the frame. Mechanical load of the frame 2 was provided with concrete beam ($g = 0.6\,kN\,m^{-1}$) and was placed in a way to avoid the beam and frame interaction.

Evaluation of the experiment

Gas temperature and temperatures of selected places on the frame were evaluated in (Lausova et al., 2015). During the experiment an approximate uniform temperature distribution was obtained over the structures of the frame 1 and frame 2. There could be seen slowing the temperature rise in the steel section compared with the gas temperature. The temperature in the upper side of the frame beam was lower than in other measured places on the frame 2, which was intentionally caused by thermal loss on upper surface of the cross section into the relatively colder concrete beam.