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Numerical Analysis of Steel Portal Frame Exposed to Fire

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Abstract

The paper presents a numerical comparative study which is concerned with the behavior of a steel hollow section portal frame exposed to elevated temperatures while considering the effect of both thermal and structural responses incorporating material and geometric nonlinearities. The work provides a study of deformations and stresses affecting the failure behavior of a solved portal frame. The failure temperature is evaluated while respecting variable material characteristics in time of growing temperature. This work presents an investigation of the portal frame with the uniform and non-uniform temperature distribution over the height of the rafter using finite element software SCIA Engineer.

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Keywords: Portal steel frame; fire; failure mechanism; FEM; numerical modeling

1. Introduction

This paper presents a parametric study of the steel portal frame exposed to fire. Behaviour of the frame structure exposed to fire depends on the restraint at member ends and the degree of force redistribution during fire development. The valid standards for fire design situation allow using simplified methods of calculation based on empirical formulae for thermal analysis of structures [1]. These assumptions may result in solutions, which can be suitable for structural element calculations, but may not be enough e.g. for structures where elevated temperature causes additive internal forces due to restrained conditions. In these cases, advanced calculations must be carried out. It is very important to make a comparison with experimental testing, which used to be very difficult and expensive.

In the calculations of structures exposed to elevated temperature the effect of both thermal and structural responses incorporating material and geometric nonlinearities must be considered. 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

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static analysis. Furthermore, variable values of material properties, which depend on temperature, must be taken into account [2].

Some results from the natural fire Cardington tests are described in parametric studies [3,4], where the influence of the end-restraints of steel beams and the problem of local buckling are highlighted. Numerical studies [5,6] show differences in thermal field in the hollow and open cross sections and show the importance of determining the exact temperature distribution in the section of restrained structures.

2. Frame structure

Numerical studies dealing with structures exposed to fire used to be carried out using special software programs intended for fire analysis. The idea of the authors is to analyze the problem of steel structures exposed to fire in the widely distributed commercial software and to compare the results with a special software intended for fire analysis. In this study the portal hollow section frame exposed to elevated temperature is solved in SCIA Engineer and the results are compared with the analysis made by the software SAFIR in [7]. Both software are based on FEM.

In this paper, the authors intend to avoid the problem with the buckling of the lower flange in fire [4] due to the hollow section and the problems of the end-restraints, therefore is supposed to be protected rigid beam-column connection. In this paper, inner forces and normal stress from material and geometrical linear and nonlinear solutions are evaluated. This study evaluates the failure temperature predicted through the suggested failure criterion.

This study is also based on authors experimental testing carried out in the thermal technical chamber at the faculty of Safety engineering in 2012 with the steel hollow section frame structure with fixed supports [5] where the formation of plastic hinges was monitored.

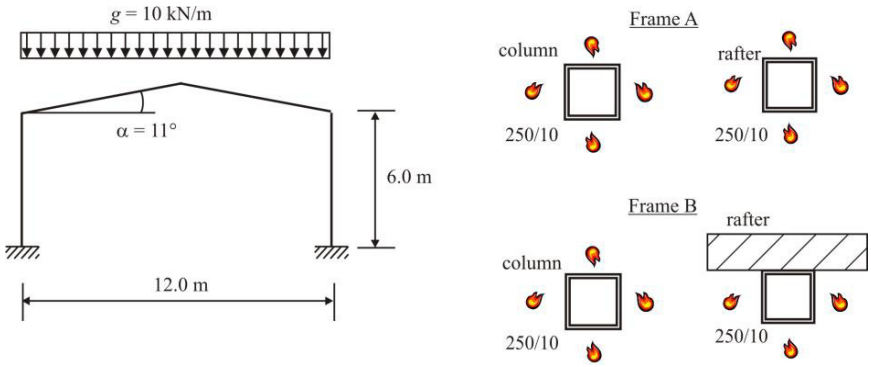

Fig. 1. Static schema of portal frame and heated cross-sections.

2.1. Static schema and loading

Static schema of the portal frame can be seen in Fig. 1. The unprotected frame consists of two columns with fixed ends and a rafter with inclination $\alpha = 11$ °, all of the hollow cross-section 250/10. The rafter of the frame is loaded with a uniformly distributed mechanical load of $g = 10$ kN/m, which remained constant throughout the structural analysis. The frame is also subjected to fire load according to the standard ISO-834 fire curve [1]. Two cases of temperature load are solved. In the first case (frame A, Fig. 1) there is supposed to be uniformly heated columns and a rafter. In the second case (frame B, Fig. 1) the columns are heated from all sides and the rafter from three sides. Comparative study [7] did not show clearly whether it was used in the calculation non-uniformly distributed temperature over the height of the rafter, or whether roof panels laid directly on the frame structure and cooled it from above. Therefore, in this study there are solutions for both cases (frame A, frame B).