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Structural behavior of simple steel structures with non-uniform longitudinal temperature distributions under fire conditions

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Abstract

The paper focuses on the effects of longitudinally non-uniform temperature distributions on structural fire response up to failure of thermally protected steel structures, composed of beams and columns in simple frame situations. The evolution of non-uniform longitudinal temperature distributions stems from the inherent continuity of the construction and was addressed in a previous paper. Structural analysis was accomplished by the existing program SAFIR. Stand-alone beams and columns, as well as simple frames were analyzed. Results demonstrate that the longitudinal non-uniform temperature distributions affect the patterns of structural behavior, causing a shift and delay in the formation of plastic hinges, and resulting in an increased period of structural stability. It is demonstrated that this increase is larger than that associated with using advanced tools for structural analysis. However, the improvement of the apparent fire resistance of beams is usually larger than that of columns.

1. Introduction

Design for structural fire safety is undergoing a worldwide transition from a prescriptive Code-driven activity to a performance-based design process. This

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requires a scientific infrastructure and proven tools for predicting the structural response of actual buildings under fire conditions, and a thorough understanding of the various factors, which affect the structural behavior of various typical structural components and assemblies. Analytical investigation of individual components under uniform temperature conditions has prevailed during the 1960s and 1970s. Culver showed in a very early paper [1] that significant effects of some specific, longitudinally non-uniform, linear temperature distributions affect the buckling resistance of slender steel columns. However, realistic structures, composed of more than one member, cannot be solved analytically. Research and analysis of assemblies, performed by means of finite-element computer codes, has thus started in the 1970s [2]. A state-of-the-art paper by Witteveen [3], concerning structural behavior under fire conditions, addressed some points that were not pursued in previous research efforts. Amongst these, it includes transverse and longitudinal non-uniformity of temperature distributions. However, the complexity of the non-linear problem, and the poor capacity of the available computers, made it probably unfeasible to address these topics until the beginning of the 1990s.

Most efforts in the recent studies of steel structures have been devoted to two main topics: (a) Effects of structural continuity, including joint flexibility and frame action of steel structures [4–6]. (b) Effect of non-uniform transverse temperature distribution across the height of steel beams, or across the thickness of columns, on their structural behavior under fire conditions, and mainly on their structural fire resistance [6–9].

Frame analysis in the first group of works was usually performed for uniformly heated components. The comparisons were made with simply supported beams subjected to the same loads (but, consequently, with different loading-ratios)) and identical temperature evolutions. Differences in fire resistance of up to 6 min have been attributed to the frame configuration, as well as increments of up to 70°C in the so-called critical temperature. In the next section the author shows that when using identical loading-ratios, rather than identical loads, this improvement is not observed.

Works in the second group demonstrate that, when beams are in full contact with a cooler floor slab along the entire width of their upper flange, they may experience a temperature difference of approximately hundreds degree centigrade between the upper and lower flange. They also present the structural behavior due to this non-uniformity, but do not compare apparent fire-resistance periods to those obtained for the uniform temperature distributions, except for Franssen [6] who mentions that the difference is very small, but does not provide data. The works in both groups, however, assumed a uniform temperature distribution along the structural components. Despite the early papers of Culver and Witteveen, none of the investigations has addressed the effects of the inherent longitudinal non-uniform temperature distributions.

In a previous paper [10] the author presented a mathematical model and some results for the inherent longitudinal non-uniform temperature distributions in continuous steel structures induced by the heat sinks at floor levels. Results indicated