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Refined plastic-hinge model for analysis of steel-concrete structures exposed to fire

Alexandre Landesmann *

Civil Engineering Program, Federal University of Rio de Janeiro - COPPE/UFRJ, P.O. Box 68506 21945-970 Rio de Janeiro/RJ, Brazil

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ABSTRACT

This paper is concerned with the application of a proposed approach, denoted as *SAAFE* Program (*System for Advanced Analysis for Fire Engineering*), developed to provide inelastic analysis of steel and composite (steel-concrete) 2D framed-structures exposed to fire. The method, although similar in concept to earlier plastic-hinge approaches, differs in relation to both numerical methodology and precision, allowing accurate description of the structural non-linear response with little computational effort, when compared to that of the general *FEM* formulation. The analysis is based on the *two-level approach*, in which the cross-section and member are continuously performing in an interactive way. The variation on member is performed by a transient heat-transfer analysis model, accounting for thermo-dependent properties of heated materials. A second-order plastic-hinge model is formulated in a succinct format considering yielding progress during fire and accurate identification of member instability. Obtained results for calibration examples are compared to those of the *FEM* approach, showing reasonable agreement. A proposed multi-storey composite framed structure is assessed by SAAFE, outlining the advantage of considering advanced analysis in the current fire-design practice of structures.

1. Introduction

The ideal combination of strengths – with concrete efficient in compression and steel in tension – can significantly enhance structural members by providing both strength and reduction of size. While steel can improve resistance and speed of construction concrete can provide corrosion protection and thermal insulation to steel at elevated temperatures. The extensive use of steel-concrete composite members, to increase fire resistance of steel frames, can be evidenced by the availability of several current simplified design methods, such as: part 1.2 of the EC4 [1], the Appendix 4 of the American recommendation (AISC/LRFD) [2] among others [3, 4]. Although the proposed design equations are very straightforward to be used, they possess many shortcomings in safe and economical design of structures subjected to fire, *e.g.* checking is performed for isolated members only and a uniform temperature is assumed for steel members. As a consequence, code equations are not able to describe the actual behaviour of structures subjected to fire, especially, when global deformations are large and nonlinear behaviour becomes relevant (*e.g.*, [5, 6]). By contrast, applications of sophisticated FEM-based (*Finite Element Method*) approaches have grown in importance over the last decade [7–13], and it has become possible to simulate a complete structural system, including both thermal and mechanical responses to design-basis fire. Nevertheless, the significantly large amount of produced data and the computational effort involved in the modelling process make it difficult to interpret the produced results. Alternative solution techniques are still needed that could provide a less time-consuming accurate response. As a matter of fact, results for isolated steel and steel-concrete composite members [13] indicated that typical savings in computing time is about 5 to nearly 8 times lower, when comparing plastic-hinge with the FE approach. In this context, the original *Advanced Analysis Concept* ([14], among others) has been extended to study the global performance of steel framed structures subjected to compartment fires [15–17]. Accordingly, this paper is concerned with the development of an inelastic hinge-based numerical tool, denoted as *SAAFE* Program (*System for Advanced Analysis for Fire Engineering*), able to perform material and geometric non-linearity analysis of 2D steel-concrete composite framed structures under fire conditions, in a simple and efficient manner [18–20]. The basis of the *two-level approach* [21] is considered by SAAFE, in which cross-section and member analyses are continuously connected over the computation process. The proposed plastic-hinge model, which has previously been implemented for steel frames [16,22,23], is adapted herein to assorted composite sections configurations under fire.

Because of its simple and efficient modelling, it can be extended to virtually any kind of material behaviour. In addition, SAAFE approach can integrally represent nonlinear material behaviour of an entire steel-concrete section in line and also, obtain a faster and better-controlled convergence than the plastic zone method [22]. The presented model is derived from inelastic moment–curvature-temperature-thrust response of composite elements under fire, representing a smooth transition from initial yield to full plastic domain under the interaction of axial

* Tel.: +5521 2562 8493; fax: +5521 2562 8484.
E-mail address: alandes@coc.ufrj.br.

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