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Investigation of the influence of design and material parameters in the progressive collapse analysis of RC structures

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ABSTRACT

This contribution deals with the modelling of reinforced concrete (RC) structures in the context of progressive collapse simulations. One-dimensional nonlinear constitutive laws are used to model the material response of concrete and steel. These constitutive equations are introduced in a layered beam approach, in order to derive physically motivated relationships between generalised stresses and strains at the sectional level. This formulation is used in dynamic progressive collapse simulations to study the structural response of a multi-storey planar frame subjected to a sudden column loss (in the impulsive loading range). Thanks to the versatility of the proposed methodology, various analyses are conducted for varying structural design options and material parameters, as well as progressive collapse modelling options. In particular, the effect of the reinforcement ratio on the structural behaviour is investigated. Regarding the material modelling aspects, the influence of distinct behavioural parameters can be evaluated, such as the ultimate strain in steel and concrete or the potential material strain rate effects on the structural response. Finally, the influence of the column removal time in the sudden column loss approach can also be assessed. Significant differences are observed in terms of progressive failure patterns for the considered parametric variations.

1. Introduction

Progressive collapse is a situation in which a local failure in a structure leads to a load redistribution, resulting in an overall damage to an extent disproportionate to the initial triggering event. Some examples of such a structural collapse occurred in the last decades, such as the Ronan Point apartment building in London, which partially collapsed in 1968 due to a gas explosion, or the Murrah Federal Building in Oklahoma City, which was destroyed in 1995 following the explosion of a bomb truck. Owing to the catastrophic nature of its consequences, progressive collapse has drawn an increasing interest in the civil engineering research community to derive new design rules.

Different simulation approaches dealing with the issue of progressive collapse can be found in the literature. This paper aims at contributing to the one referred to as the 'alternate load path' approach, which consists in considering stress redistributions throughout the structure following the loss of a vertical support element [1–3].

The recommendations for this approach presented by the United States Department of Defense (DoD) [2] and the General Services Administration (GSA) [3] suggest the use of step-by-step procedures for linear static, nonlinear static and nonlinear dynamic analyses. Other works propose static nonlinear calculations accounting for dynamic inertial effects via load amplification factors for steel structures [4–8]. The DoD and GSA guidelines specify a dynamic load amplification factor of 2 to account for dynamic effects in static computations for both reinforced concrete and steel structures, which was considered to be highly conservative by some authors working on steel structures [4,5,8–10] and on reinforced concrete frames [11]; while insufficient for others whose research is focused on steel frames [12–14]. In order to obtain a systematic estimate of the dynamic load factors, equivalent static pushover procedures have been identified for steel structures, based on energetic considerations [4–6,8]. An optimisation approach based on nonlinear dynamic analyses was adopted in [8] in order to determine the most appropriate values for these factors, by performing a parametric study on topological variables for regular steel frames.

Apart from these equivalent quasi-static approaches, which constitute a major part of the related literature, nonlinear dynamic procedures were recently conducted for both reinforced concrete and steel structures, to a variable extent of complexity [9–12,14–22]. While in most of the recent works the structures are still modelled using 2D frames [9,10,12,14,19,20], full nonlinear 3D dynamic computations with geometrically nonlinear

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