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Robustness of multi-storey car parks under vehicle fire

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ABSTRACT

While recent studies on structures subject to fire have focused on individual structural members, sub-frames, or entire structures, issues of robustness due to the possible loss of columns exposed to fire have received less attention. This paper is concerned with the realistic modelling of a multi-storey car park under a vehicle fire scenario occurring near an internal column, where emphasis is given to the robustness and ductility response of the floor systems subsequent to column buckling. To address this, a detailed heat transfer analysis according to the proposed fire scenario is conducted to obtain realistic temperature distributions within the structure. For the subsequent structural analysis, two structural models with different modelling sophistications are established, namely, a detailed slab model and a simplified grillage model. Dynamic analysis is performed to trace potential dynamic effects, where the inelastic joint response is considered in detail for the purpose of robustness assessment. Based on the undertaken nonlinear analysis, three major failure modes, specifically single-span failure, double-span failure, and shear failure, are identified which can potentially trigger progressive collapse. Finally, the significance of dynamic effects along with column buckling under fire is evaluated, where it is found that the actual ductility demands fall between two idealised extreme cases, namely 'static column loss' and 'sudden column loss'.

1. Introduction

Vehicle fires which develop in an unprotected steel/composite car park can lead to severe heating of the nearby structural elements (connections, beams and columns). This may result locally in a significant reduction of the carrying capacity of one or two columns and subsequently to a loss of global stability of the structure. The corresponding mechanisms can be referred to as 'fire induced progressive collapse'. Public awareness of building safety against instability and collapse has significantly risen during the past few decades. The collapse incident of London Ronan Point apartment block in 1968 initiated a worldwide concern towards this collapse mechanism. The World Trade Centre failures in 2001 served to bring issues of progressive collapse back to the fore, even though it is argued that these failures were not entirely disproportionate to the initiating event. Although there have been fewer instances of global failure directly caused by vehicle fires only (i.e. in the absence of other extreme load conditions), there is a considerable interest in evaluating the inherent robustness of car parks under localised fire affecting a column and the immediate floor region. In this context, it is important to evaluate the nonlinear system response realistically accounting for the post-buckling reduction in column resistance, which goes beyond current practice in fire resistant design where failure is typically associated with the buckling of the column under its initial axial load.

While to some extent fire induced progressive collapse features some common characteristics with blast or impact induced progressive collapse, structural robustness under fire conditions has its own unique mechanism. This is due to the fact that thermal effects such as thermal expansion, thermal bowing and material deterioration considerably affect and complicate the prediction of the post-buckling structural response. In addition, a dynamic increase factor (DIF) is normally applied to determine ductility demands under a sudden column loss scenario, but typical values are too conservative for fire induced column loss. Therefore, current progressive collapse design recommendations are not directly applicable to vehicle fire conditions. Several vehicle fire tests on car parks were conducted in the 1970s and 1980s [1–3] with no progressive collapse observed, but the tested vehicles had much less heat release than that of modern cars manufactured during the last decade; accordingly, these tests do not provide sufficient evidence for car park safety under localised fire induced by modern vehicles with a much greater heat release. Wang and Wald [4] suggested several possible solutions for robustness design of structures under fire conditions, but these were only prescriptive recommendations and did not offer a quantifiable framework. Some other researchers [5,6] investigated the robustness of structures subject to fire, though the fire was considered to occur subsequent to blast loading causing

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