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The collapse behaviour of braced steel frames exposed to fire

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ABSTRACT

Progressive collapse mechanisms of braced two-dimensional steel-framed structures, subjected to fire heating, are investigated using a robust static–dynamic procedure developed by the authors. 20 cases have been analysed to provide a comprehensive view of the mechanisms of progressive collapse for these frames, with different bracing systems under different fire conditions. The influences of stiffness and strength of the bracing systems are also analysed. The results indicate that the pull-in of columns is one of the main factors which generate progressive collapse. Horizontal "hat truss" bracing systems have limited capacity to avoid pull-in of columns supporting the heated floor, although they can directly redistribute the vertical load lost by buckling columns to adjacent columns. On the other hand, vertical bracing systems have the effect, not only of increasing the lateral restraint of the frame, which reduces the pull-in of the columns, but also of effectively preventing the collapse progressing from local to global. Stronger vertical bracing systems can redistribute load from a buckled column to its surrounding structural members. Frames with a combined hat and vertical bracing system can be designed to enhance the capability of the frame as much as possible to prevent progressive collapse when a heated column buckles.

1. Introduction

The robustness of structures in extreme accidental or malicious loading conditions, such as fire and explosion, is a major consideration for building designers. Robustness is strongly related to the inherent properties of a structure, such as redundancy, ductility and joint characteristics. Structural redundancy is described as the degree of static indeterminacy of a system, and is equivalent to the number of internal and external constraints beyond those which are necessary to prevent the structure from becoming a mechanism. This is not always true, because local mechanisms may form whilst the remainder of a structure is statically indeterminate. Redundancy allows structures to transfer their loads to their supports through a variety of different load paths. When one or more elements of the structure have failed, the forces previously carried by these elements can be transferred to the stiffer parts of adjacent structure to prevent either a local or global failure [1]. The redundancy of the structure also controls the number of plastic hinges which need to form in the structure to enable structural collapse [2]. The concept of structural redundancy is widely used in seismic design, because of its positive effects on structural resistance to earthquake forces. The concept can also be applied to the design against progressive collapse of steel and composite frames under fire conditions. Bracing systems, most commonly used to resist wind loading, can also be efficient measures against the lateral loads induced in a building due to seismic forces. They induce extra redundancy into framed structures, improving their capacity to prevent progressive collapse.

Several researchers have recently studied the potential of braced frames to prevent progressive collapse. Khandelwal et al. [3] investigated the progressive collapse resistance of steel frames with concentric and eccentric bracing. Jinkoo Kim et al. [4] studied the progressive collapse performance of braced frames with various bracing configurations, in the aftermath of accidental loss of a vertical element, using static push-down analysis and nonlinear time-history dynamic analysis. In the main, research [5–7] on progressive collapse of framed structures has focused on the 'missing column' scenario, in which the critical column is removed, without specifically considering the causes or the sequence of events leading up to this situation. However, in many cases the way a structure collapses will depend on the exact nature of the progression of intermediate events, each involving local damage, starting with some triggering event. In a fire situation, many elements of the structure may be heated simultaneously, so that the failure sequence may be critically affected by the weakening which has taken place in these parts. The main objective of this study has been to investigate the collapse mechanisms in fire situations of steel moment-resisting frames (MRF), fitted with different bracing systems.

2. Background of *Vulcan*

2.1. Elements developed in the Vulcan

This study was conducted using the computer programme *Vulcan*, which has been developed [8–13] at the University of Sheffield for

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