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An improved tie force method for progressive collapse resistance design of reinforced concrete frame structures

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ABSTRACT

Progressive collapse of structures refers to local damage due to occasional and abnormal loads, which in turn leads to the development of a chain reaction mechanism and progressive and catastrophic failure. The tie force (TF) method is one of the major design techniques for resisting progressive collapse, whereby a statically indeterminate structure is designed through a locally simplified determinate structure by assumed failure mode. The method is also adopted by the BS8110-1:1997, Eurocode 1, and DoD 2005. Due to the overly simplified analytical model used in the current practical codes, it is necessary to further investigate the reliability of the code predictions. In this research, a numerical study on two reinforced concrete (RC) frame structures demonstrates that the current TF method is inadequate in increasing the progressive collapse resistance. In view of this, the fundamental principles inherent in the current TF method are examined in some detail. It is found that the current method fails to consider such important factors as load redistribution in three dimensions, dynamic effect, and internal force correction. As such, an improved TF method is proposed in this study. The applicability and reliability of the proposed method is verified through numerical design examples.

1. Introduction

Progressive collapse of structures refers to local damage due to occasional and abnormal events such as gas explosions, bombing attacks, and vehicular collisions. The local damage causes a subsequent chain reaction mechanism spreading throughout the entire structure, which in turn leads to a catastrophic collapse. In general, progressive collapse of structures is characterized by a disproportion in size between the triggering event and the resulting collapse [1].

Since the 1968 partial collapse of London's Ronan Point apartment tower, many nations have started investigations on progressive collapse resistance and published a series of design codes, specifications, and guidelines. These include the British Standard and Regulation [2–4], Eurocode [5,6], NBCC [7], ASCE7-05 [8], ACI318 [9], GSA 2003 [10], and DoD 2005 [11]. Moore [12] investigated two building cases under an occasional event, and the study shows that progressive collapse resistance can be effectively improved by the UK provisions. Nevertheless, the current design codes and guidelines are not considered to completely satisfy the progressive collapse design requirements. In this regard, Dusenberry [13] suggested that further research is necessary to aid better understanding of the mechanisms of progressive collapse resistance of structures. This may include further study of the strength and ductility of structural elements and systems under the limit state. From a conceptual point of view, Nair [14] described three approaches to enhance the progressive collapse resistance of structures, namely, increasing redundancy (or alternate load paths), local resistance, and interconnection (or continuity). Nair [14] also identified that the current international codes and standards focus primarily on the redundancy increase, with little emphasis on the remaining two approaches. In the area of conceptual study, Starossek [15] suggested that the progressive collapse of structures can be classified into six types, namely, the pancake, zipper, domino, section, instability and mixed types; and different treatments should be used for different types of collapse. After investigating analysis and design methods for progressive collapse resistance, Izzuddin et al. [16] proposed a simplified approach to progressive collapse assessment of steel-framed multi-story buildings, and Vlassis et al. [17] developed a new design-oriented methodology considering impact from failed floors.

In the current codes of practice, the tie force (TF) method is one of the two quantitative methods for progressive collapse design. The other is the alternate path (AP) method, which can be classified into linear elastic static, linear elastic dynamic, nonlinear static, and nonlinear dynamic approaches. In the TF

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