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Storey-based stability of unbraced steel frames at elevated temperature

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ABSTRACT

The evaluation of the lateral stability of steel frames subject to elevated temperatures is different from that at ambient temperature. This is because the degradation of the Young's Modulus of steel associated with elevated temperature will lead to the loss of column lateral stiffness. In this study, the lateral stability of unbraced steel frames subjected to elevated temperature is investigated based on the concept of storey based buckling. First, to simulate a steel column exposed to the elevated temperature, an analytical model was proposed to examine the effects of axial loading, elevated temperature, and thermal boundary restraints on the lateral stiffness of steel columns in unbraced frames. Then, a method of evaluating the stability capacity of unbraced steel frames at elevated temperature is proposed. Numerical examples are presented to demonstrate the evaluation procedure of the proposed method and investigate the frame stability subjected to different scenarios of frame members exposed to the elevated temperature. The validity of the proposed method is verified by the numerical analysis with the use of finite element analysis.

1. Introduction

Conventionally, steel framed structures are designed to sustain the various loads and maintain the stability at ambient temperature. In case of a fire, common practice relies on fireproofing system to maintain the fire resistance and integrity of the structural system. However, the recent adoption of Annex K “Structural design for fire conditions” in CSA S16-09 [1] provides an innovative way of designing steel framed structures for fire conditions instead of solely relying on traditional fire protection techniques which are quite costly. At the mean time, the adoption of Annex K in CSA S16-09 [1] brings a great challenge for structural engineers as there is no design guide available at this moment. Therefore, assessing the stability performance of steel frames in fire conditions is of importance for the engineering design community.

The evaluation of the stability of a compressive member in steel frames subject to elevated temperatures is different from that at ambient temperature due to thermal effects. In recent years, the stability of steel columns at elevated temperature has been extensively studied through experimental investigation and theoretical development. Ali and O'Connor [2] conducted a series of tests on axially-restrained steel columns subjected to quasi-standard fire. An experimental study to investigate the failure time of unprotected steel columns subjected to axial restraint at elevated temperature has been carried out by Tan et al. [3]. Li et al. [4] performed two fire tests on axially and rotationally restrained steel columns that have different axial restraint stiffness. On the other hand, the restraints that affect the stability of steel columns at elevated temperature were widely investigated by several researchers [5–7] with theoretical derivations. However, the foregoing researches and the current design code [1] primarily focused on the issue of the isolated column at elevated temperature without consideration of stiffness interaction among columns in the same storey in resisting frame instability due to the effect of applied load and elevated temperature. One of the fire protection measures for buildings is to contain a fire in one compartment. Therefore, while assessing the stability of columns that are experiencing elevated temperature, the restraints provided by the members which are not experiencing the elevated temperature should not be ignored. Column stability at elevated temperature should be evaluated in the context of the steel frame rather than as an isolated column. The behavior of steel frames subjected to elevated temperature has been studied by several researchers [8–11] with numerical simulation, which often requires significant computational efforts. Toh et al. [12] proposed a simple Rankie method based on empirical approach to approximate the strength and stability of steel frames in fire. However, as the empirical approximation was established for simple portal frames, the applicability of method to steel frames in practice is yet to be validated. Huang and Tan [13] proposed new sub-frame and isolated-member models to investigate the fire resistance of beams and columns subjected to compartment fire. Nevertheless, the proposed method only focused on the braced frames rather than unbraced frames. Considering the fact that current design methods endeavor to warrant the stability and integrity of building structures at ambient temperature, there is an urgent need to develop practical storey-based approaches to evaluate the stability of steel frames subjected to the elevated temperature.

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