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Predicting the maximum compressive beam axial force during fire considering local buckling

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ABSTRACT

Local buckling in floor beams has been one of the important observations in several fire events in steel buildings such as World Trade Center Tower 7 and large-scale fire experiments such as Cardington building test in U.K. Utilizing three dimensional finite element methods for complex geometry and nonlinear behavior of such connections, local buckling of the web followed by the buckling of the lower flange is observed to occur in early stages of fire, which causes instability to the floor system, and a significant reduction in the connection strength. The observations also suggest that the maximum compression in the floor beam is limited to the buckling capacity of the web and flanges near the connection. This paper contributes to such knowledge by investigating the local buckling of floor beams for different connection types at elevated temperatures using nonlinear finite element models. Moment connections are found to be more resistant to local buckling when compared to the shear connections. The results are also compared to the AISC design equation for plate buckling under ambient and elevated temperatures. Compared to the finite element analyses of this study, it is observed that at ambient temperature the AISC curve conservatively captures the buckling capacity of webs and flanges; at higher temperatures, AISC overestimates the capacity.

1. Introduction

Recent observations in experiments and numerical models using the finite element method [1,2,3] show that local buckling of a floor beam in the vicinity of the connection greatly reduces the axial capacity of the beam during both the heating and the cooling period in a natural fire. During the heating phase, the beam is under compression and the axial forces increase until the lower flange buckles at which point the compressive forces decrease. The deformations caused by the lower flange buckling near the connection reduce the tensile capacity of the connection [3]. Similar observations are made by Li and Guo [4] on the experiments of restrained steel beams with beam-to-column connections. They concluded that local buckling near the beam end reduced the stiffness of the restrained beam greatly. Such reduction in stiffness causes large beam deformations as observed in experiments by Liu et al. [5] and numerical simulations by Dai et al. [6]. Due to the extent of lower flange buckling, the bottom bolt region in a connection is significantly distorted which causes the bottom bolt region to carry less tensile load than other bolt regions during cooling of a fire. Therefore local buckling controls the maximum compressive and the maximum tensile force that a beam experiences in a fire.

An example of the beam axial force history during a fire is shown in Fig. 1. This example is from our previous study [2] of a subassembly from Cardington building test [1], where the beam (UB 305$\times$165$\times$50) is connected to a girder via the single plate connection. As seen in Fig. 1a, the beam is subjected to both web (circle a) and lower flange buckling (circle b) during the heating phase and its maximum compression is governed by the lower flange buckling. During the cooling phase (dashed lines), the web carries most of the tension and fails by a tension limit state (bolt-hole bearing), which is also affected by the extent of local buckling in the section. Fig. 1b shows the web, bottom flange and top flange section forces during fire. The onset of lower flange buckling closely coincides with the contact between the beam lower flange and girder web.

The aim of this paper is to investigate the strength of the wide flange beams considering local buckling under fire conditions. Previous research on local buckling of steel members focused on isolated plate buckling studies with idealized boundary conditions (pinned or fixed) [7,8,9]. These studies did not consider the flange (an "unstiffened plate") and the web (a "stiffened plate") interacting with each other. Feng et al. [10] and Maljaars et al. [11] did examine the interaction of plates in a structural section but for cold-formed thin-walled short columns and aluminum structures, respectively. In this paper we examine the ultimate buckling strength of the flange and webs of wide-flange sections as they interact with one another by using

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