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Cyclic flexural analysis and behavior of beam-column connections with gusset plates

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ABSTRACT

This research investigates the cyclic flexural behavior of double-angle concentrically braced frame beam-column connections using three-dimensional nonlinear finite element analysis. Prior experimental research demonstrated that such connections possess appreciable flexural stiffness, strength, and ductility. The reserve capacity provided by these connections plays a significant role in the seismic behavior of low-ductility concentrically braced frames, so knowledge about the impact of connection parameters on local limit states and global connection performance is needed for employing reserve capacity to design and assess concentrically braced frames. Finite element models were developed and validated against prior experiments with focus on the limit states of failure of the fillet weld between the gusset plate and beam, low-cycle fatigue fracture of the steel angles joining the beam and gusset plate to the column, and bolt fracture. The models were used to evaluate the flexural stiffness, strength, and ductility of braced frame connections with primary attention on the effects of beam depth, angle thickness, and a supplemental seat angle. The finite element analysis demonstrated that increasing beam depth and angle thickness and adding a supplemental seat angle all increased the stiffness and strength of the connection while maintaining deformation capacity. A procedure to estimate the flexural behavior of beam-column connections with gusset plates was developed based on the results of the numerical simulations.

1. Introduction

Empirical evidence from past earthquakes and data from numerical simulations indicate that secondary lateral force resisting capacity, or "reserve capacity," plays a significant role in the seismic collapse behavior of low-ductility steel framed buildings. In the 1994 Northridge earthquake, steel framed buildings did not collapse even though many connections in the lateral force resisting systems sustained undesirable damage due to non-ductile limit states [1]. This collapse resistance is typically attributed to the inherent reserve capacity in the buildings, which was provided primarily by the flexural strength of the gravity connections and by continuous gravity columns. Similarly, Hines et al. [2] studied a suite of low-ductility concentrically braced frame (CBF) systems designed for a moderate seismic region and demonstrated that increasing reserve capacity uniformly improved collapse performance. This reserve capacity was represented by adding rigid connections in gravity frames and by modeling the braced frame beam-column connections with gusset plates as rigid connections rather than as ideal pins, which is typically assumed in design. In contrast to the beneficial impact of reserve capacity, increasing primary system strength had little effect on collapse performance. Thus, Hines et al. [2] concluded that reserve capacity, due to the flexural response of connections not considered to be part of the primary lateral force resisting system, is particularly important for moderate seismic regions.

In moderate seismic regions, it is common for steel seismic lateral force resisting systems, particularly CBFs, to be designed using a response modification coefficient, *R*, of three, which allows for seismic detailing to be ignored. In addition, although justification for implementation of the $R=3$ provision is not well documented, the provision was based partially on the assumption that all steel framed buildings possess some level of reserve capacity [3]. Despite the critical role that reserve capacity plays in the performance of $R=3$ systems, there has been relatively little study of reserve capacity. Flexural response of typical gravity frame connections was investigated extensively by Liu and Astaneh-Asl [4, 5] and flexural strength in CBF beam-column connections was observed experimentally by Gross and Cheok [6], Uriz and Mahin [7] and Kishiki et al. [8]. The flexural behavior of CBF connections, however, was not studied comprehensively until recently when Stoakes and Fahnestock [9] conducted a full-scale experimental program and demonstrated that beam-column connections with gusset plates have appreciable flexural stiffness, strength and ductility. This experimental program suggests that beam-column connections with gusset plates can be used as part of a reserve capacity system that provides seismic stability after failure of the primary lateral force resisting system. Stoakes and Fahnestock [9] made the assumption that the flexural response of a beam-column connection with gusset plate is activated when the welds joining the brace to the gusset plate fail. In addition, it was

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