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Seismic performance of steel frames with reduced beam section connections

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Abstract

Reduced beam section (RBS) moment resisting connections are among the most economical and practical rigid steel connections developed in the aftermath of the 1994 Northridge, California, earthquake. Although extensive experimental testing and some numerical simulations have shed light on the behavior of this type of connection, system level studies of RBS steel frames are still quite limited. As part of this research, nonlinear pushover and transient analyses of 4-, 8-, and 16-story frames with RBS connections are conducted with the objective of developing a better understanding of RBS frame behavior and exercising as well as critiquing the recently published FEMA-350 design specifications. The analyses confirm that in spite of inherently low overstrength, RBS frames are capable of economically providing good seismic performance in regions of high seismic risk. Other structural behavior issues with design implications are also discussed.

Keywords: Panel zone; Inelastic; Seismic; Steel; Moment; Frames; Northridge; Analysis; Reduced beam section; Overstrength; FEMA-350

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1. Introduction

In the aftermath of the Northridge earthquake, the US Federal Emergency Management Agency (FEMA) funded an extensive research program on steel frames that resulted in the publication of the [16] guideline document along with an accompanying set of state-of-the-art reports. Many of the recommendations in [16] have since found their way into the Seismic Provisions for Structural Steel Buildings [1] published by the American Institute of Steel Construction (AISC). The philosophy behind the AISC connection provisions, which is similar to the [16] philosophy, is to provide an adequate combination of connection stiffness, strength, and ductility to ensure acceptable seismic performance. Conformance with this requirement can be satisfied in one of two ways: by using a prequalified connection in accordance with Appendix P of the Seismic Provisions or by project-based connection testing. AISC is in the process of developing a new consensus-based ‘Connections’ standard to alleviate the need for project-based testing. This standard, which will be conceptually similar to FEMA-350’s Chapter 4, will outline design, detailing, and fabrication procedures for several connections that are considered prequalified without further testing.

All of the connections approved in [16] for Special Moment Resisting Frames combine improvements in welding along with detailing that induce the beam plastic hinge to form a short distance away from the beam-to-column interface. High demands at the beam-to-column interface, that are widely thought to have contributed to the observed brittle failures during the Northridge earthquake, are therefore significantly decreased. The type of detailing that shifts the plastic hinges away from the connection region generally falls into two main categories, reinforcement detailing and reduced beam section (RBS) detailing. In the former, reinforcement is provided at the beam–column interface, while in the latter, a region in the beam away from the interface is intentionally weakened by removing material from the beam flanges. Fig. 1 shows various possible configurations for the RBS detail.

Reduced beam section connections provide similar benefits to reinforced connections, but are more efficient and economical because they do not require the extra field welding and material associated with reinforced connections. RBS connections also have a number of advantages in design practice. Compared to reinforced connections, their use leads to reduced demands for continuity plates, panel zone reinforcement, and strong-column–weak-beam requirements. Although reducing the beam member section in the vicinity of the connection can lead to reduction in frame stiffness, in most practical cases, the use of RBS connections leads to a minimal increase in beam sizes to meet code stiffness requirements compared to reinforced connections. As a result of these characteristics, RBS connections are potentially the most economical type among post-Northridge connections.

Extensive experimental testing of RBS connections has shed light on the behavior of this type of detail. However, system level studies of RBS steel frames remain limited, which hinders widespread acceptance of this type of structural system. In this paper, previous work on RBS frames is first discussed and then numerical studies of 4-, 8-, and 16-story frames with RBS connections are presented. The analyses are geared towards: (1) providing readers with a better understanding of RBS frame behavior; and (2) exercising and critiquing the recently published [16] specifications for steel frames. These specifications are seminal in that they represent the first *probabilistic* performance-based seismic design guidelines to be published in the United States.