Seismic Evaluation of Beam-Column Joint Specimens of RC Special Moment Frames

Abstract

This study summarizes the results of a research project aimed at investigating the inelastic rotation capacity of beam-column joints of reinforced concrete special moment frames. All of the test specimens were classified as special moment frame (SMF), based on the design and detailing requirements of the ACI 318-02 provisions. The acceptance criteria, originally defined for steel moment frame connections in the 1997 edition of the AISC Seismic provisions, were used to evaluate the beam-column joints of the reinforced concrete moment frames. A total of 39 test specimens were examined in detail. Most of the joints that satisfy the design requirements for special moment frame structures were found to be ductile up to a plastic rotation of 3% without any major degradation in strength. This is mainly due to the stringent ACI 318-02 requirements for special moment frame joints. The presence of transverse beams increases confinement and shear resistance of joints, which results in better performance than for joints without transverse beams. All of the SMF connections that satisfy the ACI 318-02 limitations on joint shear stress turned out to meet the acceptance criteria.

Keywords: Moment Frame, Rotation Capacity, Seismic Performance, Inelastic Deformation, Joint Shear Strength, Earthquake Engineering, Beam-column Joints

1. Introduction

The 1994 Northridge earthquake, which was classified as a moderate earthquake, caused many connections of steel MRF to fail, resulting in significant economic losses for the building owners. One of the most recent efforts to limit the level of damage in structures subjected to earthquakes was initiated by the American Institute of Steel Construction (AISC). The revised “Seismic Provisions for Structural Steel Buildings” (hereafter referred to as the AISC Seismic provisions) are the provisions adopted throughout the U.S. for the design and construction of structural steel and composite structural steel/reinforced concrete (RC) building...
systems in seismic regions. Included are relatively new requirements for beam-to-column connections in special moment frames (SMF), intermediate moment frames (IMF), and ordinary moment frames (OMF), driven mainly by the observed brittle fractures in the beam-column connections of buildings in recent earthquakes. In the AISC Seismic provisions, satisfactory seismic performance levels are achieved by requiring minimum levels of expected inelastic rotation capacity at the joints for the various framing types. Section 9.2a of the 1997 AISC Seismic provisions requires that beam-column joints and connections of SMF systems used as part of the seismic-force-resisting system be able to undergo an inelastic rotation of at least 0.03 radians when subjected to a qualifying cyclic test in accordance with Appendix A. In addition to the minimum level of inelastic rotation, the acceptance criteria also focus on the maximum rate of degradation in strength with inelastic deformations. When this rate of degradation is too large, moment demands from P-Delta effects may increase significantly, which can lead to frame instability. Fig. 1 shows the acceptance criteria: the flexural strength Mmax at 0.03 radians must be greater than or equal to Mp, where Mmax is the maximum moment recorded in the tests andMp is the nominal plastic flexural strength.

The main objective of this study is to evaluate the seismic performance of special and intermediate RC moment frames based on the performance criteria of the AISC Seismic Provisions. All available test results on RC moment frames were compiled and analyzed as part of this investigation. The significant design variables that are examined and evaluated for RC systems in regards to the performance criteria are joint shear stress, beam-column flexural strength ratio, transverse reinforcement ratio in the joint, and column depth-to-beam reinforcement diameter ratio. This research contributes to a better understanding of the typical behavior of RC moment connections when subjected to seismic loads. The findings and recommendations of this study may be used to modify the response modification factors assigned to RC SMF and IMF in the future seismic codes.

2. Test Results for Special Moment Frames (SMF)

Earthquake resistant designs require a structure to behave with controlled deformation and limited damage, if any, when subjected to a design level earthquake. Since moment frames generally experience fairly large inelastic deformations in some structural members when subjected to an expected maximum ground motions, it is important that the systems possess adequate strength and stiffness to withstand seismic events without collapse. This can be accomplished by following the design and detailing requirements prescribed in the building codes. For RC structures, the appropriate design and detailing requirements are provided in Chapter 21 of the ACI 318-02. These detailing requirements are related to the type of structural framing system, seismic risk level at the site, level of energy dissipation (or toughness), and occupancy of the structure.

The terms special, intermediate, and ordinary are indicative of the degree of required toughness for seismic design. This classification leads to different levels of required detailing that are specified in the ACI 318-02. Cast-in-place SMF structures must conform to Sections 21.2 through 21.5, which