Reclamation Building Seismic Safety Program

Guideline No. 4

Handbook for the Seismic Evaluation of Buildings: A Prestandard (FEMA-310)

Welded Steel Moment Frames (Pre-Northridge Connections)

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Background: Within FEMA-310, chapter 3, *Screening Phase (Tier 1)*, section 3.7, *Structural Checklists*, Common Building Types S1 and S1A (steel moment frames with stiff diaphragms and steel moment frames with flexible diaphragms) are the types of structures which could have welded steel moment-framed (WSMF) connections (dubbed “Pre-Northridge Connections” or “Pre-Northridge Design” as a result of the Northridge Earthquake of January 17, 1994).

The 1997 Uniform Building Code (UBC) (ICBO, 1997) introduced a single pre-qualified moment connection design. The "qualification" of the connection was based primarily on research conducted in the 1970s. The UBC pre-qualified connection was subsequently adopted into the 1992 American Institute of Steel Construction, Inc. (AISC) Seismic Provisions. Although the building codes did not formally adopt the pre-qualification of this standard connection until the late 1980s and early 1990s, the use of this connection detail was widespread in WSMF construction since the 1970s.

Welding was typically performed using the semi-automatic, self-shielded, flux-cored arc welding process (FCAW-S) and with weld filler metals without specific rated notch toughness. The toughness of this material could be further compromised by excessive deposition rates. As a result, brittle fractures could initiate in welds with large defects, as stresses approximating the yield strength of the beam steel, precluding the development of ductile behavior. Some older buildings, particularly erected prior to 1964 (approximately), may have welds deposited by the shielded metal arc welding (SMAW) process. Some such welds may have significant notch toughness, on the order of 40 ft-lbs at normal service temperatures.

Within FEMA-310, chapter 3, *Screening Phase (Tier 1)*, section 3.7, *Structural Checklists*, subsections 3.7.3S, *Supplemental Structural Checklist For Building Type S1: Steel Moment Frames With Stiff Diaphragms*, and 3.7.3AS, *Supplemental Structural Checklist For Building Type S1A: Steel Moment Frames With Flexible Diaphragms*, refer to a statement titled *MOMENT-RESISTING CONNECTIONS*, which reads "All moment connections shall be able to develop the strength of the adjoining members or panel zones." The checklists are triggered only if the building meets the following criteria: (1) Moderate for an IO or (2) High for LS and IO (FEMA-310, table 3-2, page 3-6).

Policy: Screening Phase (Tier 1)

Within FEMA-310, chapter 4, *Evaluation Phase (Tier 2)*, section 4.4, *Procedures for Lateral-Force-Resisting Systems*, subsection 4.4.1.3.3, *Commentary*, indicates ". . .the Tier 1 evaluation statement is considered non-compliant for full penetration flange welds and a more detailed analysis is required to determine the adequacy of these moment-resisting connections." Therefore, if the connections meet the criteria for a WSMF, Screening Phase (Tier 1), Report Section 6.5, should include the following statement:

- *Lateral-Force-Resisting System - Moment-Resisting Connections (FEMA-310, Subsection 4.4.1.3.3)*

The steel moment-resisting frame consists of welded connections with complete penetration flange welds and a bolted or welded shear tab connection at the web (Pre-Northridge Connections). This type of connection is considered non-compliant with Tier 1 evaluation criteria and requires a more detailed analysis to determine the adequacy of the moment-resisting connections.

Evaluation Phase (Tier 2)

Within FEMA-310, chapter 4, *Evaluation Phase (Tier 2)*, section 4.4, *Procedures for Lateral-Force-Resisting Systems*, subsection 4.4.1.3.3, *Commentary*, provides reasoning and guidance. A Tier 2 example analysis is outlined in Appendix A (example 2, A2.4.4, page A-27).

If the connections meet the Tier 2 evaluation criteria then they are compliant and no further action is required. However, if the connections do not meet the Tier 2 evaluation criteria, then mitigation is required and a conceptual rehabilitation scenario should be developed. The structure can be modified as a whole (e.g., new lateral-force-resisting system, etc.) and/or individual connection modification can be an effective means of obtaining a more reliable performance.

If mitigation is required, recommended criteria for upgrade of steel buildings is outlined within chapter 5 of FEMA-351, *Recommended Seismic Evaluation* and *Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings* (SAC Joint Venture, July 2000).

Chapter 6 of FEMA-351 presents a series of pre-qualified connection upgrades: Improved Welded Unreinforced Flange (IWURF) Connection, Welded Bottom Haunch (WBH) Connection, Welded Top and Bottom Haunch (WTBH) Connection, and Welded Cover Plated Flange (WCPF) Connection. FEMA-355D, *State of the Art Report on Connection Performance*, provides extensive information on the testing and performance of the pre-qualified connections.

Two approaches are available for seismic upgrades of steel moment-frame structures—a “simplified approach” and a “systematic approach.” In the simplified approach, modifications are made to individual moment-resisting connections to improve their ability to provide ductile inelastic behavior. No analysis or evaluations are performed as part of the design of these modifications to assess whether the overall structural system is capable of meeting specific performance objectives. In the systematic approach, a complete evaluation of the performance capability of the structure is performed in order to verify the performance capability of the upgraded structure. Upgrades may include connection modifications providing supplemental lateral-force-resisting elements, such as braced frames or shear walls, or introducing response modification measures such as base isolation or energy dissipation devices.

As part of the Tier 2 evaluation, it is recommended that the simplified approach be followed and that the systematic approach be reserved for the actual final rehabilitation design.

It should be noted that the FEMA-351 recommended criteria supercedes the evaluation and upgrade recommendations for existing WSMF buildings contained in FEMA-267, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment Frame Structures* (SAC Joint Venture, 1995) and the *Interim Guidelines Advisories, No. 1 and 2* (FEMA-267A and FEMA-267B) (SAC Joint Venture,1997).

The following should be included in the evaluation:

- A conceptual rehabilitation scenario (sketches, unit quantities, supporting data, etc.) should be presented in FEMA-310, Appendix G. The conceptual rehabilitation scenario need not be supported with structural calculations, but plate sizes, elements sizes, and welds should be laid out using sound engineering judgment.

- A cost estimate should be included in FEMA-310, Appendix H.

- FEMA-310, Report Section 9.3 should reflect the non-compliance and should briefly outline the conceptual rehabilitation scenario and should recommend that final rehabilitation designs be conducted in accordance with the FEMA 356 prestandard and the FEMA 351 recommended criteria.

Note: IO = Immediate Occupancy Performance Level
LS = Life Safety Performance Level