Seismic-Resistant Structures: What to Know When Estimating Cost

BY PATRICK M. HASSETT, S.E.

There's a lot to consider when it comes to estimating costs for steel projects in high-seismic areas.

WITH THE ADVENT OF NEW NATIONAL CODES, SEISMIC DESIGN AND CONSTRUCTION MAY PRESENT NEW CHALLENGES FOR MANY STRUCTURAL ENGINEERS AND STEEL FABRICATORS AND ERECTORS. In California and other areas of the western United States, the seismic connections of a seismic load-resisting system (SLRS) are normally designed by the engineer of record and are included in the bid documents.

However, design conventions vary across the country, and often, the connection design expertise lies with the fabricator or erector's engineer. There are many considerations when it comes to the connection, material, and quality requirements of seismic-resistant steel structures. When the steel fabricator or erector encounters a project in a high-seismic region, he should identify potential cost items that are not specifically shown on the structural design drawings.

Structural Design Criteria

First, is the building in a high-seismic region? The U.S. Geological Survey (USGS) web site (**www.usgs.gov**) can be referenced for seismic hazard maps. For design, the ASCE 7-05 seismic maps are used.

If the building is in or near a seismic hazard zone, the estimator should look for the Seismic Design Category (SDC) to be specified on the structural drawings. The SDC is a classification assigned to a structure based on its Occupancy Category and the severity of the design earthquake ground motion at the site as defined in ASCE 7-05.

If the building is in SDC D,E, or F, ASCE 7-05 Section 14.1.3 requires the building to be designed under the criteria of AISC/ANSI 341-05, *Seismic Provisions for Structural Steel Buildings*.

Also, if the building is designed with an SLRS *R* factor greater than 3, the *Seismic Provisions* apply regardless of the SDC. *R* factors are given in the AISC 7-05 for the various systems, and are based on the ductility performance of the system. Systems capable of higher energy absorption have higher *R* values, and systems with higher *R* values generally have higher connection costs.

AISC Seismic Provisions

Section 5.1 of the *Seismic Provisions* requires the listing of the following design properties to be included on the design documents. If this information is not provided, it should be requested prior to bidding:

1. Designation of the seismic load-resisting system (SLRS).
2. Designation of the members and connections that are part of the SLRS.
3. Configuration of the connections.
4. Connection material specifications and sizes.
5. Locations of demand-critical welds.
6. Lowest anticipated service temperature (LAST) of the steel structure, if the structure is not enclosed and maintained at a temperature of 50 °F or higher.
7. Locations and dimensions of protected zones.
8. Locations where gusset plates are to be detailed to accommodate inelastic rotation.
9. Welding requirements as specified in Appendix W, Section W2.1. as follows:
   - locations where back-up bars are required to be removed.
   - locations where supplemental fillet welds are required when backing is permitted to remain.
   - locations where fillet welds are used to reinforce groove welds or to improve connection geometry.
   - locations where weld tabs are required to be removed.
   - splice locations where tapered transitions are required.
   - the shape of weld access holes, if a special shape is required.
   - joints or groups of joints in which a specific assembly order, welding sequence, welding technique, or other special precautions are required.

Cost Implications of the Provisions

Given that the *Seismic Provisions* are required for an SLRS, what are some of the requirements that have cost implications?

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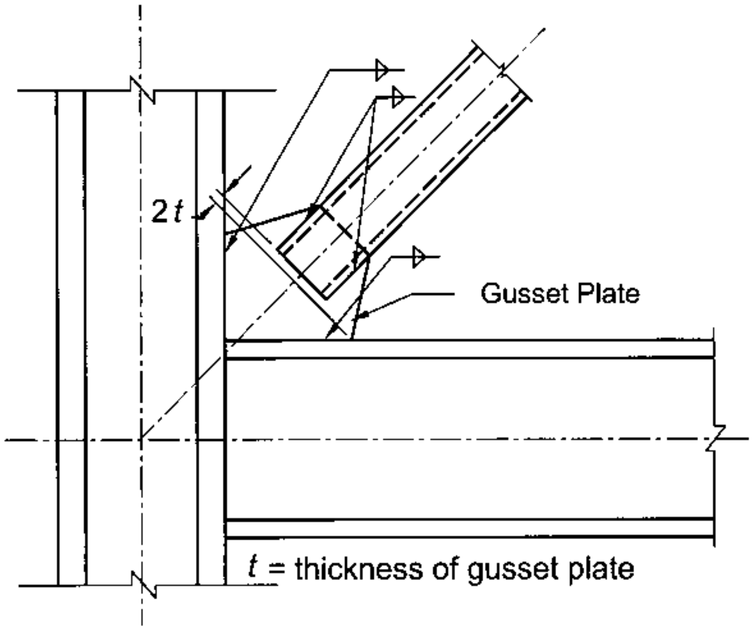


Fig. C-I-13.2. Brace-to-gusset plate requirement for buckling out-of-plane bracing system. (Source: AISC *Seismic Provisions*)

Shop drawings. The estimator should be sure to include in the detailing scope the following listed requirements for shop drawings, from section 5.2 of the *Seismic Provisions*:

1. Designation of the members and connections that are part of the SLRS.
2. Connection material specifications.
3. Locations of demand-critical shop welds.
4. Locations and dimensions of protected zones.
5. Gusset plates drawn to scale when they are detailed to accommodate inelastic rotation.
6. Welding requirements as specified in Appendix W, Section W2.2.

Erection drawings. The estimator should be sure to include in the detailing scope the following listed requirements for erection drawings, from Section 5.3 of the *Seismic Provisions*:

1. Designation of the members and connections that are part of the SLRS.
2. Locations of demand-critical field welds.
3. Field connection material specifications and sizes.
4. Locations and dimensions of protected zones.
5. Locations of pretensioned bolts.
6. Field welding requirements as specified in Appendix W, Section W2.3.

Special material requirements. The mill order estimate should include costs for toughness requirements from Section 6.3, Heavy Section CVN Requirements:

For structural steel in the SLRS, in addition to the requirements of *Specification* Section A3.1c, hot rolled shapes with flanges 1½ in. thick and thicker shall have a minimum Charpy V-Notch toughness of 20 ft-lb at 70 °F, tested in the alternate core location as described in ASTM A6 Supplementary Requirement S30. Plates 2 in. thick and thicker shall have a minimum Charpy V-Notch toughness of 20 ft-lb at 70 °F, measured at any location permitted by ASTM A673, where the plate is used in the following:

1. Members built up from plate.
2. Connection plates where inelastic strain under seismic loading is expected (such as gussets for special concentrically braced frames).
3. As the steel core of buckling-restrained braces.

Connections in the SLRS. Because the basic philosophy of seismic design is dependent on the ductile yielding of structural elements, the connection design must be based on the expected yield stress of members rather than the minimum specified yield stress. The R_y factors listed for various materials in Table I-6-1 of the *Seismic Provisions* are used to adjust the minimum specified yield stress to the expected yield stress.

Bolted Connections. Bolted connections may use bearing values, but must be tightened to a slip-critical condition with "Class A" surface preparation. See Section 7.2 of the *Seismic Provisions*. Also note that "bolts and welds shall not be designed to share force in a joint or the same force component in a connection."

Protected Zones. Within protected zones the member must be unscathed by tack welds, erection aids, air-arc gouging, or any other attachments that are not part of the SLRS design. Protected zones are defined in the *Seismic Provisions* for each SLRS.

Continuity Plates and Stiffeners. Special detailing is specified for the corners of these plates in order to avoid welding in the *k* areas.

Column Splices and Bases. Most commonly, column splices of SLRS in high-seismic regions are specified as CJP welds or bolted to develop the full capacity of the upper column. However, depending on the system and the loads, the fabricator or erector's engineer may be able to value engineer the splices to reduce cost, per Section 8.4.

Column splices not part of the SLRS also have special requirements. Because of the shear demand imparted on the column from drift during a seismic event, the column splices must be designed for a shear of M_p/H, per Section 8.4b.

Column bases must be designed for loading as specified in Section 8.5. The intent of the requirements is to develop the required strengths of the steel elements that are connected to the column base.

Moment Frames. Special and intermediate moment frame connections must be "prequalified" in accordance with AISC ANSI 358-05, *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications* (the "CPRP"). Alternatively, the *Seismic Provisions* allow a connection to be qualified by test.

The most commonly used moment connection (not proprietary) is the reduced beam section (RBS). Quality control of the beam to column welding, flange-reducing cuts, and the weld access holes are critical to the performance of this system. The requirements of this system are detailed in the CPRP.

Braced Frames. The *Seismic Provisions* outline the requirements for the various braced brame systems. Ordinary concentric braced frames (OCBF) have few detailing requirements for the brace connections. The ductility of the system is low, hence they have the lower *R* factor, and forces and members for this system are higher.

Special concentric braced frames (SCBF) have special detailing requirements as listed in the *Seismic Provisions*. The ductility of the system is higher than the OCBF, and therefore a higher *R* factor is used, allowing lower design forces and lighter members than the OCBF.

The connection must be designed for the full expected tensile strength of the brace. Gusset detailing is critical to the energy dissipation of the system. The brace connection may be designed to take the expected plastic moment of the brace without detailing for the bend line. More typically, the gusset is designed with a potential bend line (see Fig. C-I-13.2). This detailing permits end rotation of the brace when it buckles under severe seismic loading. Field welding costs will most often need to include the removal of back-up bars.

Often, the geometry of these connections is considered laborious, and these gussets tend to become very large. (See "Seismic Detailing of Gusset Plates for Special Concentrically Braced Frames" at **www.steeltips.org** for more on SCBF.)

Eccentric braced frames. This system derives its energy dissipation from the shear and or flexural yielding of the link: the portion of the girder between the brace and the column, or between two braces. Special detailing, as shown in Fig. C-I-15.6, is required for the stiffening of the link as well as the brace-to-girder connection.

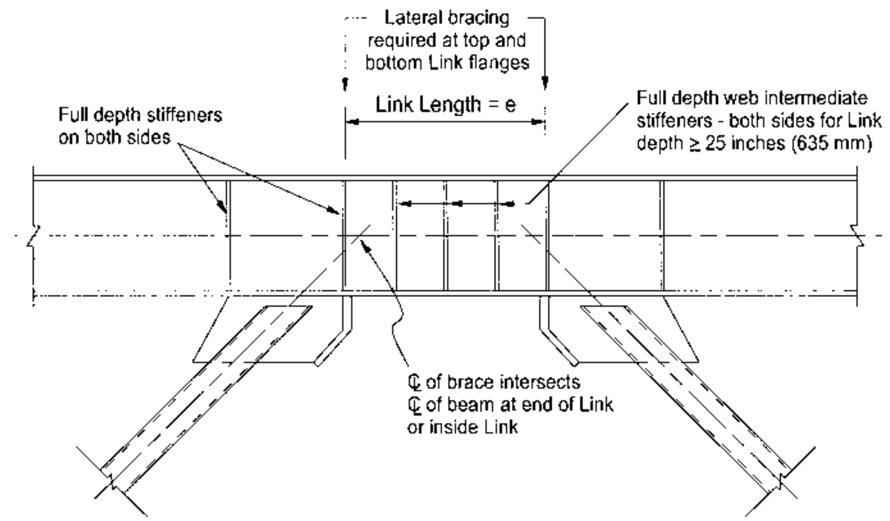


Fig. C-I-15.6. EBF with HSS bracing. (Source: AISC *Seismic Provisions*)

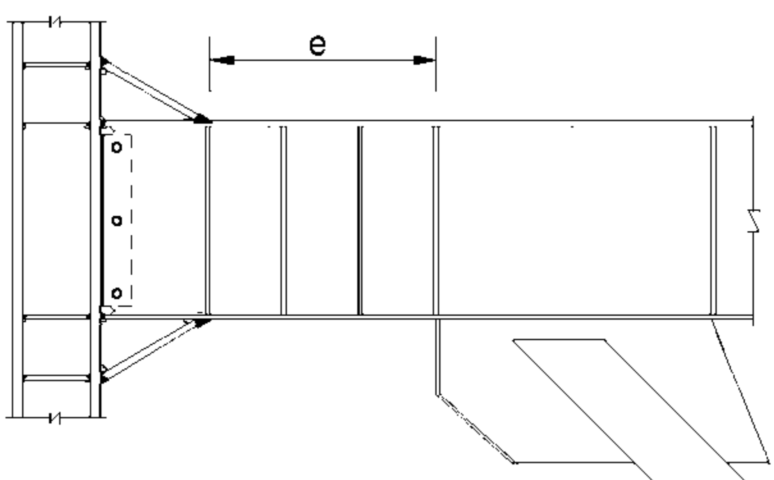
Steel plate shear walls. This relatively new system derives its energy dissipation from the yielding of the plate shear wall in diagonal tension. Normally, this system would have to be well detailed on a set of bid documents.

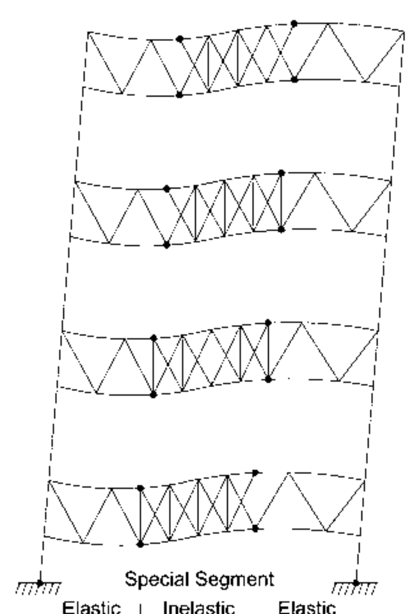
Special truss moment frames. Another new system, it derives its energy dissipation from the yielding of specially designed truss segment members of girder trusses. Chord members are designed to yield in flexure, while diagonals are to yield in axial tension or compression buckling. Normally, this system would be well detailed for an engineer to be able to present it on a set of bid documents. Stitch welding, as well as out-of-plane bracing, must also be considered.

Buckling restrained brace frame. This relatively new system derives its energy dissipation from the yielding of core plates in specially designed and tested (proprietary) buckling restrained braces. The core is axially isolated from its sheath, which braces the core from out-of-plane global buckling. Normally, this system would be well detailed for an engineer to be able to present it on a set of bid documents. Design criteria would be given for the strength requirements of the gusset connections. Gussets are not designed to bend or yield.

Detailed Review

The AISC Seismic Provisions contain the bulk of the requirements that pertain to the material, quality, and connection design requirements for buildings in high seismic regions, and it is advisable to reference the *Seismic Provisions* to review, in detail, the specific topics that pertain to the project in consideration. MSC





Above: Fig. C-I-15.4. Example of a reinforced link-to-column connection. (Source: AISC *Seismic Provisions*)

Right: Fig. C-I-12.2. Intended yield mechanism of STMF with diagonal web members in special segment. (Source: AISC *Seismic Provisions*)