Seismic Fuses

BY JASON ERICKSEN, S.E.

Structural fuses help increase the predictability of a building's behavior—and dissipate seismic energy—in the event of an earthquake.

ONE OF THE MOST DIFFICULT SETS OF FORCES FOR ENGINEERS TO ASSESS IS THAT CAUSED BY EARTHQUAKES. The base shear and distribution of forces are based on the properties of the building itself, as well as the ground motions of an earthquake, which are impossible to predict. In addition, the actual stiffness of a building is only an estimate and can change during the earthquake as members yield.

To survive a large earthquake, a building's structure must dissipate the energy imparted by the ground accelerations. Introducing a fuse into the structural frame can provide this dissipation, as well as create a predictable structural response to an unpredictable set of forces. In fact, documents such as the *International Building Code* mandate such a solution.

In terms of AISC seismic-related documents, AISC *Seismic Provisions for Structural Steel Buildings* is intended for structures with high ductility demands. This generally corresponds to Seismic Design Categories D, E, and F as determined in the applicable building code. Stated simply, the *Seismic Provisions* apply whenever the response modification factor R is taken greater than 3.

The seismic load resisting system (SLRS) is the portion of the structure that resists the forces created by the earthquake, and provides the means to dissipate energy in a ductile manner. In steel buildings the energy dissipation is largely accomplished through cyclic yielding of specific segments of specific steel members. The *Seismic Provisions* contain a series of requirements for members of the SLRS to provide stable system ductility, and have two overall goals: to force deformations to occur in specific locations (fuses); and to ensure that frames can undergo controlled deformation in a ductile, well-distributed manner.

The Fuse Concept

By forcing the ductility demand to the fuses, the behavior of the system becomes more predictable. The fuse is usually one member type of each frame system, and the *Seismic Provisions* intend for these elements to stay ductile through cyclic yielding. These members are generally required to have low width-to-thickness ratios to avoid local buckling, and eventually fractures, well into the elastic range. They must also be adequately braced to avoid member buckling at large deformations.

The remaining frame members are designed to remain essentially elastic while the fuse yields dissipate the energy. These members are often sized based on the expectation that the fuse is the overloaded element in the system.

Controlled Deformation

As the fuse yields, the force distribution in the system changes as the deformations increase. The post-yielding force distribution can be very different from the elastic and the "non-yielding" elements, and connections can experience inelastic behavior. These deformations are cyclic, which further increases the demands. As such, the *Seismic Provisions* contain requirements for members and connections of the SLRS outside of the fuse, such as limiting width-to-thickness ratios to delay or preclude local buckling, and bracing requirements to address member and global stability. The *Seismic Provisions* are also intended to result in distributed deformations throughout the frame to increase the level of available energy dissipation and the corresponding level of ground motion that can be withstood.

A Visual Summary

The figures on the following pages identify the fuse in four common seismic force-resisting systems: moment frames, eccentrically braced frames, special plate shear walls, and concentrically braced frames. The figures describe how the fuse dissipates energy and highlight some of the requirements in the *Seismic Provisions* that help ensure the desired behavior. For more information refer to the *Seismic Provisions* and Commentary.

The *Seismic Provisions* include requirements for two other seismic load-resisting systems as well: Buckling Restrained Braced Frame (BRBF) and Special Truss Moment Frame (STMF). Refer to the *Seismic Provisions* and Commentary for more information on these systems.

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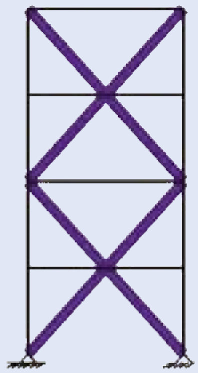
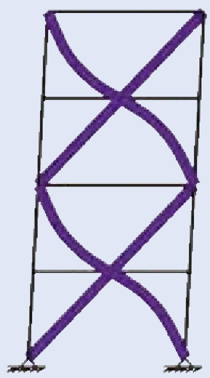
Qualifying Connections for Use

It is not the intent of AISC *Seismic Provisions* to require project-specific tests for all designs. For many commonly employed combinations of beam and column sizes, there are readily available test reports in publications from AISC, FEMA, and others. In addition, connections can be prequalified. See the January 2007 issue of MSC (www.modernsteel.com) for a discussion on how moment connections are qualified, and for detailed information on the two prequalified connection types included in the standard *Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications* (ANSI/AIC 358-05).





CONCENTRICALLY BRACED FRAMES

Fuse: Tension yielding of braces and compression bucking of braces for SCBF.

Special Concentrically Braced Frames (SCBF)

- ➜ Energy dissipation is achieved through tension yielding and compression buckling of the braces.
- ➜ The cumulative effect of the requirements in the *Seismic Provisions* is intended to result in braces that maintain a high level of ductility and hysteretic damping.
- ➜ Limiting the member slenderness ratio provides for a reasonable relative compression buckling strength of the brace, as compared to the tension yield strength.
- ➜ Width-thickness limits help forestall local buckling and subsequent fracture during repeated inelastic cycles.
- ➜ The connection of the brace to the beam and column must be proportioned for the expected tension and compression strength of the brace to delay a connection mechanism.
- ➜ The brace is expected to buckle in compression, and the gusset plate must be designed for the flexural strength of the brace. The gusset plate may also be detailed to accommodate the rotations of the buckled brace.

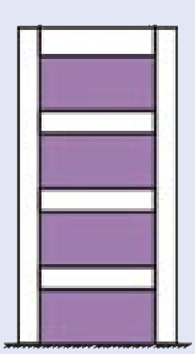
Ordinary Concentrically Braced Frames (OCBF)

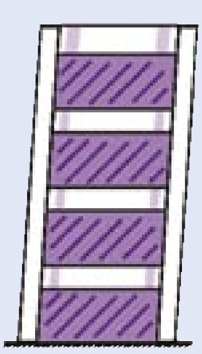
- ➜ Limited elastic deformation is expected.
- ➜ The frames are designed for higher forces and use larger members to account for the limited system ductility.
- ➜ Compression buckling of the brace is not expected
- ➜ There are far fewer design requirements for OCBF than for SCBF.
- ➜ The use of this system is limited to low ductility demand structures by the applicable building code (ABC).

Note on SCBF Brace Connections

Section 13.3b of AISC *Seismic Provisions for Structural Steel Buildings* states that connections must be designed for the expected plastic flexural strength of the brace about the critical buckling axis. This satisfies the requirement of confining the inelastic rotation to the brace.

This section also contains an exception that allows connections to be designed to accommodate the rotations as opposed to being designed to force them into the brace. For a single gusset plate connection, this can be accomplished by detailing the gusset to allow the brace to buckle out of plane by terminating the brace before the gusset's line of restraint. The Commentary describes one method to accomplish this, demonstrating that where a single gusset plate connection is used, the rotations can be accommodated as long as the brace end is separated by at least two times the gusset thickness from a line perpendicular to the brace axis, about which the gusset plate may bend unrestrained by beam, column, or other brace joints. This exception is a more common method for confining the inelastic rotation to the brace.





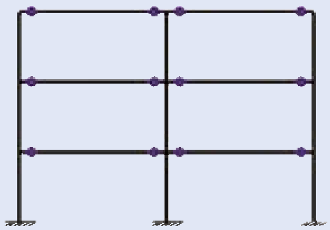
SPECIAL PLATE SHEAR WALLS

Fuse: Shear yielding of the web-plates with tension field action.

- ➜ The Special Plate Shear Wall (SPSW) is new to the 2005 *Seismic Provisions*.
- ➜ Yielding of the webs occurs by development of tension field action at an angle in the neighborhood of 45° and compression buckling of the plate in the orthogonal direction. This yielding provides the energy dissipation in this system.
- ➜ With the exception of the horizontal boundary element (beam) hinging at its ends, the boundary elements are designed to remain nominally elastic and provide enough strength and stiffness to fully yield the plates.
- ➜ The connections of the web to the boundary elements are also designed to resist the maximum force developed by the tension field action of the webs fully yielding.
- ➜ The boundary elements also have flange bracing and element width-thickness ratio limits similar to SMF to allow for the plastic mechanism of the SPSW.

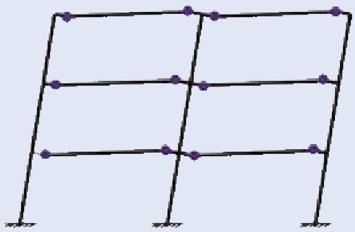
MOMENT FRAMES

Fuse: Flexural yielding of beams near ends. Panel Zones may have yielding in SMF.



Special Moment Frames (SMF)

- ➜ Connections must meet specific strength and rotation criteria, and conformance is demonstrated using either the prequalification process of Appendix P or testing per Appendix S.
- ➜ The beams have flange bracing requirements and width-to-thickness ratio limits more restrictive than the AISC *Specification for Structural Steel Buildings*.
- ➜ Columns are proportioned to preclude hinging in the column (the so-called "strong-column weak-beam" requirement). This requirement avoids a single-story mechanism in the frame and allows the yielding to progress through multiple floors.



Intermediate Moment Frames (IMF)

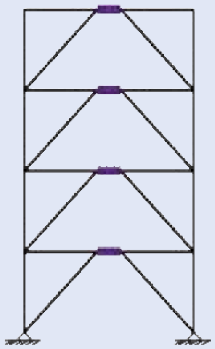
- ➜ Connections must meet specific strength and rotation criteria, and conformance is demonstrated using either the prequalification process of Appendix P or testing per Appendix S with less restrictive requirements than SMF.
- ➜ The beams have flange bracing requirements and width-to-thickness ratio limits more restrictive than the AISC *Specification for Structural Steel Buildings*, but less restrictive than SMF beams.

Ordinary Moment Frames (OMF)

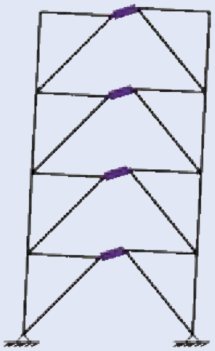
- ➜ Intended to have little inelastic connection rotation. This system uses larger members and design forces to limit connection rotation demands.
- ➜ The beam-column moment connection design is prescriptive.
- ➜ Limited in their application as allowed by the ABC.

ECCENTRICALLY BRACED FRAMES

Fuse: Shear and/or flexural yielding of the links.



- ➜ Eccentrically braced frames (EBF) are braced frames in which at least one end is connected so that the brace force is transmitted through shear and bending of a short beam segment called the link.
- ➜ Energy is dissipated through shear and/or flexural yielding in this link.
- ➜ The braces, columns, portions of the beam outside the link, and all related connections are designed to remain nominally elastic as the link deforms and reaches its expected strength. The force in each member of the frame developed by the fully yielded and stain-hardened link is determined and replaces the earthquake load (often designated as *E* in the ABC) in the design load combinations.



- ➜ This system is essentially a hybrid, offering lateral stiffness approaching that of concentrically braced frames and ductility approaching that of a special moment frame system.
- ➜ System configurations other than that shown are allowed and are discussed in the Commentary to the *Seismic Provisions*.