

General Design Considerations

General Considerations:

- 3 levels of inelastic response capability, depending on the level of ductility the system is expected to provide.
 - **Ordinary** – designed and detailed to provide limited ability to exhibit inelastic response w/out failure/collapse, through ductility and overstrength requirements.
 - This entails higher force demands w/ less stringent ductility and member stability requirements.
 - **Intermediate**
 - **Special**
- Each classification is characterized by the following **Seismic Performance Factors**
 - **Response Modification Coefficient (R)**
 - **Overstrength Factor (Ω_0)**
 - **Deflection Amplification Factor (C_d)**
- Designing to the AISC Seismic Provisions is mandatory for structures specifically references in ASCE 7, Table 12.2-1.
- For steel, this typically occurs in **Seismic Design Category D** and higher, where $R > 3$.
- Systems where $R > 3$ are intended to be designed to the AISC Seismic Provisions and AISC Specification.
- **The use of $R > 3$ in calculation of seismic base shear requires the use of a seismically designed and detailed system that is able to provide the level of ductility commensurate with the value of R selected in the design.**

General Design Considerations

Seismic Performance Factors

• **R = 3 Applications**

- For **SDC B & C** in ASCE 7 the designer can choose to use *AISC Spec.*
- The system's ductility will be that of conventional steel framing, not specifically designed or detailed for high seismic resistance.
- Typically more cost effective than structural systems designed with *AISC Seismic Provisions*.
- R=3 not usually available for composite structures. See ASCE 7 Table 12.2-1.

• **Deflection Amplification Factor (C_d)**

- Elastic story drift calculated w/ reduced lateral forces are multiplied by C_d to better estimate the total story drifts likely from the design earthquake ground motion.
- This typically affects compliance w/ allowable story drift, estimate separation between adjacent structures, and to determine seismic demands on elements of the structure that is not part of the SFRS.

• **Overstrength Factor (Ω_0)**

- AISC Seismic Provisions designate the elements 1) intended to dissipate the majority of the earthquake energy through ductile inelastic response and 2) those intended to remain essentially elastic.
- Overstrength Seismic Loads (E_{mh}) are used in some ASCE 7 load combinations and in AISC Seismic Provisions for elements in SFRS intended to remain essentially elastic.
- Overstrength Seismic Loads incorporate (Ω_0) for each given system.
- ASCE 7 & AISC Seismic Provisions introduced the capacity-limited seismic load (E_{cl}), which defines the lateral seismic load level associated w/ the maximum expected capacity of the designated yielding elements in the system. E_{cl} is an upper bound for the horizontal seismic loads on the SFRS and E_{mh} need not exceed E_{cl} .
- These special load combos are invoked for members or conx. whose inelastic behavior may cause poor system performance.

General Design Considerations

Seismic Performance Factors

• **Overstrength Factor (Ω_0)**

- Members and Conn. Requiring special seismic load combos including overstrength or capacity-limited horizontal seismic load effect in ASCE 7 include:
 - Elements supporting discontinuous walls or frames (Section 12.3.3.3)
 - Collectors for structures in SDC C through F (Section 12.10.2.1)
 - Batter Piles (Section 12.13.8.4)
 - Pile Anchorage (Section 12.13.8.5)
 - Pile Splices (Section 12.13.8.6)
- AISC Seismic Provisions uses the term Overstrength Seismic Load, referring to the use of ASCE 7 load combos that include Ω_0 .
- When overstrength seismic load is specified, it is acceptable for E_{mh} to either be based on Ω_0 or be equal to the capacity-limited seismic load E_{cl} .
 - Sometimes, E_{cl} must be used for E_{mh} in the special seismic load combos in ASCE 7. See AISC Seismic Provisions (Section B2).
- AISC 341-16 has a list of situations where overstrength or capacity-limited seismic load are permissible on page 1-15.

• **Redundancy Factor (ρ)**

- ASCE 7 (Section 12.3.4) stipulates a seismic redundancy factor based on the structure's configuration and number of independent SFRS elements. When structures do not satisfy minimum criteria, this factor amplifies the required strength of the lateral system.

Part 2: Analysis

Wind & Seismic Design

- **2.2 Role of Structural Analysis in Design**
 - AISC Seismic Provisions Chapter C requires analysis of SFRS conform to applicable building codes & AISC Spec.
 - **Ductile Design Mechanism**
 - Limit inelastic actions to certain components of SFRS to develop a reliable ductile design mechanism that dissipates energy.
 - **Capacity Design**
 - Design philosophy where inelastic actions from ground motions are concentrated in predetermined critical zones of the SFRS.
 - AISC implements Capacity Design by using the **Overstrength Factor (Ω_0)**
- **Stability Design Methods in AISC Spec. (also look at AISC DG 28 “Stability Design of Steel Buildings”)**
 - 3 stability design methods
 - Direct Analysis Method (AISC Spec Chapter C)
 - Permitted for all steel structures.
 - Requires second order effects be considered.
 - K is taken as 1.0
 - Effective Length Method (AISC Spec Appendix 7, Section 7.2)
 - Interaction btw frame behavior and members is approximated by effective length factor K.
 - K represents the influence of the system on the strength of an individual member.
 - First-Order Analysis Method (AISC Spec Appendix 7, Section 7.3)
 - Second order effects are captured by application of an additional lateral load of 0.42% of the story gravity load.
 - K=1.0

Part 4: Moment Frames

OMF Example Topic	Page
4.2.1: OMF Story Drift & Stability Check	4-7
4.2.2: OMF Column Strength Check	4-10
4.2.3: OMF Beam Strength Check	4-14
4.2.4: OMF Beam-Column Conx. Design	4-17
Determine governing flexural strength limit state	4-19

- **Ordinary Moment Frames (OMF)**
 - See ASCEE 7 12.2.5.6 for which SDC these frames are permitted.
 - Detailing requirements are reduced and seismic forces are larger.
 - Not req'd to have special detailing of panel zones or specific relationship btw beam & col strength
 - Connection failure should not be the first significant inelastic event.
 - They are typically less ductile than other inelastic responses.
 - AISC Seismic Provisions Section E1.6
 - **Fully Restrained (FR)** Moment Conx. must satisfy 1 of 3:
 1. Designed for req'd flexural strength = expected flexural strength multiplied by 1.1 and divided by α_s
 - $M_n = 1.1R_y M_p / \alpha_s = 1.1R_y F_y Z_x / \alpha_s$ (Eqn 4-1)
 2. Designed for req'd flexural strength & shear = max moment and shear that can be transferred to the connection by the system. Limiting aspects include:
 - Flexural yield of column < beam
 - Panel-zone shear strength in column
 - Foundation uplift
 - Overstrength seismic load
 3. Conx. Btw WF beam and WF col (flange to flange) in OMF can be designed to requirements of IMF (E2.6) & SMF (E3.6) or a special conx from AISC 358.
 - **Partially Restrained (PR)**
 - AISC Seismic Provisions E1.6c: PR conx must develop over 50% of M_{p_beam} .

Part 4: Moment Frames

- Panel Zone behavior**

- Strong panel – inelastic strength greater than surrounding area → inelastic deformation in the frame occurs in the beam
 - Weak panel – inelastic strength lower than surrounding area → inelastic deformation occurs in panel-zone (not used in SMF)
 - Balanced panel – inelastic strength similar to/shared with surrounding area
- Limit local column deformations that can reduce ductility by analyzing panel zones and continuity plates

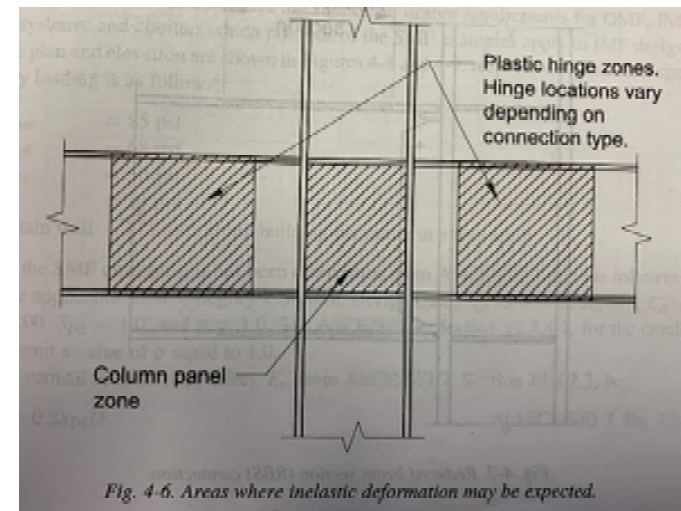
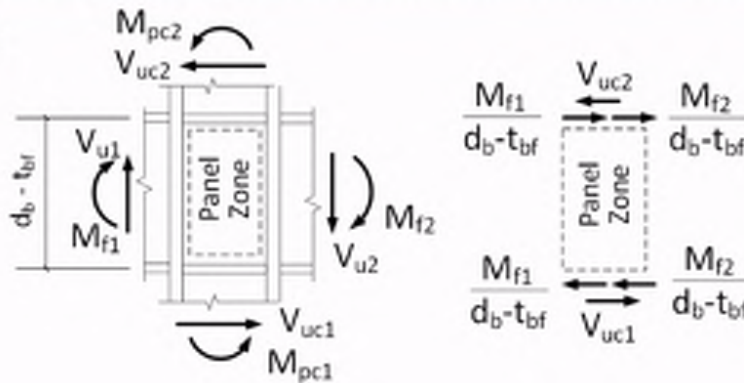
Column Panel Zone Shear Demand

- Requirement**

Provisions
§E3.6e

$$R_v \leq \phi R_n$$

$$\phi_v = 1.0$$



Part 4: Moment Frames

- Panel Zone behavior**

- Strong panel – inelastic strength greater than surrounding area → inelastic deformation in the frame occurs in the beam
 - Weak panel – inelastic strength lower than surrounding area → inelastic deformation occurs in panel-zone (not used in SMF)
 - Balanced panel – inelastic strength similar to/shared with surrounding area
- Limit local column deformations that can reduce ductility by analyzing panel zones and continuity plates

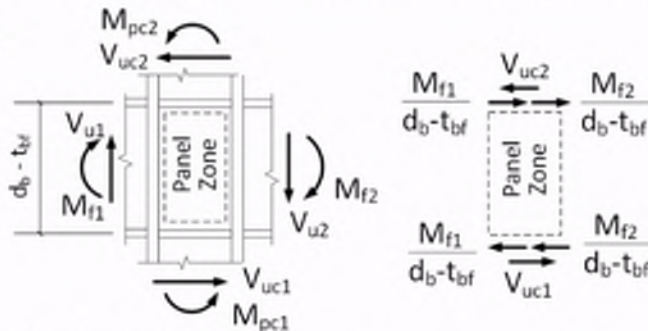
Column Panel Zone Shear Demand

- Requirement**

Provisions
§E3.6e

$$R_u \leq \phi R_n$$

$$\phi_v = 1.0$$



- Demand (Required Strength)**

$$R_u = \sum \frac{M_f}{d_b - t_f} - V_c$$

Column shear is always opposing beam flange forces.

Moment at Face of Column

$$M_f = M_{pr} + V_{ub} S_h$$

Column Shear :
$$V_c \cong \frac{\sum M_f}{\frac{h_{above}}{2} + \frac{h_{below}}{2}}$$

Column Panel Zone Shear Strength

- Design Panel Zone Strength**

- Specification §J10.6
- If panel zone is considered in frame stability and $P_r \leq 0.75 P_e$

$$R_n = \underbrace{(0.6 F_y)}_{\text{Plastic shear strength}} d_c t_w \underbrace{\left(1 + \frac{3 b_f t_{cf}^2}{d_b d_c t_w}\right)}_{\text{Increase for column flanges}} \quad (J10-11)$$

- If $R_u \leq \phi R_n$ then done.
- If $R_u > \phi R_n$ then add doubler plates.

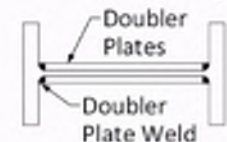
- Doubler Plates §E3.6e**

- Get ϕR_n using:

$$t_w = t_{cw} + t_{dp}$$

- Minimum thickness of column web or doubler plates:

$$t \geq \frac{d_z + w_z}{90} \quad \begin{aligned} d_z &= d_b - 2t_{fb} \\ w_z &= d_c - 2t_{fc} \end{aligned}$$



- Also detailing (§E3.6e(3))

Part 4: Moment Frames

- **Panel Zone behavior**
 - Strong panel – inelastic strength greater than surrounding area → inelastic deformation in the frame occurs in the beam
 - Weak panel – inelastic strength lower than surrounding area → inelastic deformation occurs in panel-zone (not used in SMF)
 - Balanced panel – inelastic strength similar to/shared with surrounding area
- Limit local column deformations that can reduce ductility by analyzing panel zones and continuity plates

Continuity Plates (Column Web Stiffeners)

Continuity Plates (§E3.6f)

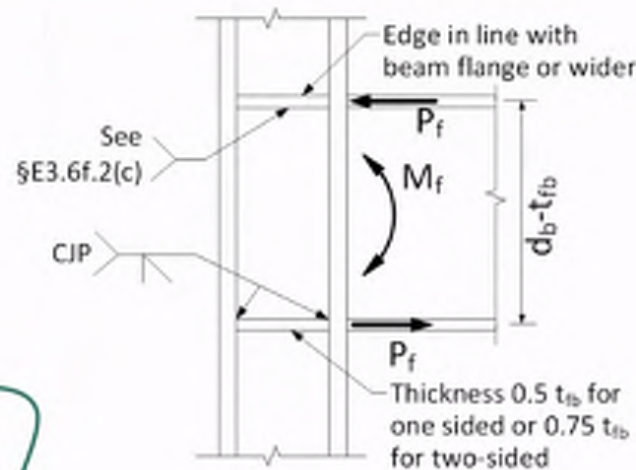
- Provide continuity plates if either of the following:

(a) Required by Section J10 of Specification using force: $P_f = M_f / (d_b - t_{fb})$

reduce by 0.85 if welded web

(b) Column flange thickness less than t_{lim}

- Follow detailing in *Specification J10.8* and *Seismic Provisions E3.6f.2*.



$$t_{lim} = \frac{b_{bf}}{6}$$

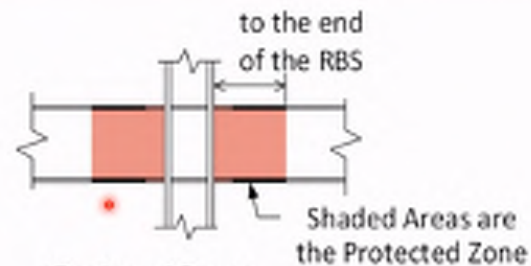
For beam welded to flange of W shape or built-up I

Part 4: Moment Frames

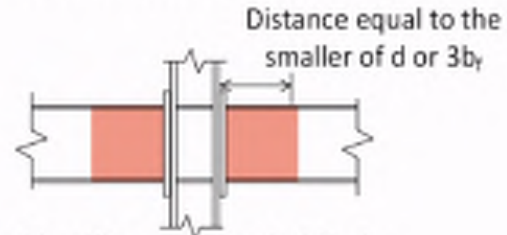
- **Restrict Attachments in Plastic Hinges (Protected Zones)**
 - Refer to AISC 358

Protected Zone

- **Locations (AISC 358)**
 - Where inelastic strains are expected.
 - Different for each connection (see AISC 358).



Reduced Beam
Section Connection



Unstiffened Extended End-
Plate Connection

Part 4: Moment Frames

- **Demand Critical Welds**
 - Refer to AWS D1.8 as supplement.

Demand Critical Welds

- **Locations (§E3.6a)**
 - Welds where inelastic strains are expected.
 - Beam-to-column, column splices, column-to-base plate (with exceptions), others as specified in AISC 358.
- **Requirements (§A3.4b and AWS D1.8)**
 - Specify demand critical welds on drawings.
 - Filler metals must have high elongation and CVN toughness.

For E70: Elongation > 22%
CVN toughness > 20 ft-lb at 0° F

Part 4: Moment Frames

- Section 4.6: Design Tables
 - Table 4-1: Comparison of Requirements for OMF, IMF, & SMF

Comparison of Requirements for SMF, IMF, & OMF AISC Table 4-1			
Topic	Special Moment Frame	Intermediate Moment Frame	Ordinary Moment Frame
Story Drift Angle	0.04 radians	0.02 radians	No specific minimum
Connection Flexural Strength	Performance confirmed by testing per AISC Seismic Provisions Chapter K; connection achieves minimum 80% of nominal plastic moment of the beam at story drift angle of 0.04 radians	Performance confirmed by testing per AISC Seismic Provisions Chapter K; connection achieves minimum 80% of nominal plastic moment of the beam at story drift angle of 0.02 radians	FR: Develop $1.1R_y M_p / \alpha_s$ of beam, maximum moment developed by system or satisfy requirements in AISC Seismic Provisions Sections E1.6b, E2.6, & E3.6.
Connection Shear Strength	V for load combination including overstrength plus shear from application of $E_c I = 2M_p r / L_h$ Mpr per eq 5.8-5 of AISC 358	V for load combination including overstrength plus shear from application of $E_c I = 2 * 1.1 * R_y M_p / L_h$	V for load combination including overstrength plus shear from application of $E_c I = 2 * 1.1 * R_y M_p / L_c f$
	OR Lesser V permitted if justified by analysis. See also the exception provided in AISC Seismic Provisions E3.6d	OR Lesser V permitted if justified by analysis. See also the exception provided in AISC Seismic Provisions E2.6d	OR Lesser V permitted if justified by analysis.
Panel-Zone Shear Strength	For $P_r \leq 0.75P_c$, compute strength per AISC Specification Eq. J10-11. For $P_r > 0.75P_c$, compute strength per AISC Specification J10-12.	No additional requirements beyond AISC Spec.	No additional requirements beyond AISC Spec.
Panel-Zone Thickness	$t \geq (d_z + w_z) / 90$	No additional requirements beyond AISC Spec.	No additional requirements beyond AISC Spec.

Continuity Plates	To match tested condition or AISC 358, Section 2.4.4.	To match tested condition or AISC 358, Section 2.4.4.	Provide continuity plates as req'd by AISC Seismic Provisions Section E1.6b.
Beam-Column Proportion	AISC Seismic Eq. E3-1	No additional requirements beyond AISC Spec.	No additional requirements beyond AISC Spec.
Width-to-Thickness Limits	Beams and columns to satisfy AISC Seismic Provisions Section D1.1 for highly ductile members	Beams and columns to satisfy AISC Seismic Provisions Section D1.1 for moderately ductile members	No additional requirements beyond AISC Spec.
Stability Bracing of Beams	Beam bracing req'd to satisfy AISC Seismic Provisions Section D1.2b for highly ductile members	Beam bracing req'd to satisfy AISC Seismic Provisions Section D1.2a for highly ductile members	No additional requirements beyond AISC Spec.
Column Splice	Splices satisfy AISC Seismic Provisions Section D2.5 and E3.6g; bolts or CJP groove welds	Splices satisfy AISC Seismic Provisions Section D2.5 and E3.6g; bolts or CJP groove welds	No additional requirements beyond AISC Spec.
Protected Zone	As established by ANSI/AISC 358 for each prequalified conx.; generally, one-half beam depth beyond centerline of plastic hinge	As established by ANSI/AISC 358 for each prequalified conx.; generally, one-half beam depth beyond centerline of plastic hinge	None