Design of Seismic-Resistant Steel Building Structures

1. Introduction and Basic Principles

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with the support of the
American Institute of Steel Construction.

Version 1 - March 2007

Design of Seismic-Resistant Steel Building Structures

1 - Introduction and Basic Principles

2 - Moment Resisting Frames

3 - Concentrically Braced Frames

4 - Eccentrically Braced Frames

5 - Buckling-Restrained Braced Frames

6 - Special Plate Shear Walls

1 - Introduction and Basic Principles

- Performance of Steel Buildings in Past Earthquakes
- Codes for Seismic Resistant Steel Buildings
- Building Code Philosophy and Approach
- Overview of AISC Seismic Provisions
- AISC Seismic Provisions - General Requirements Applicable to All Steel Systems

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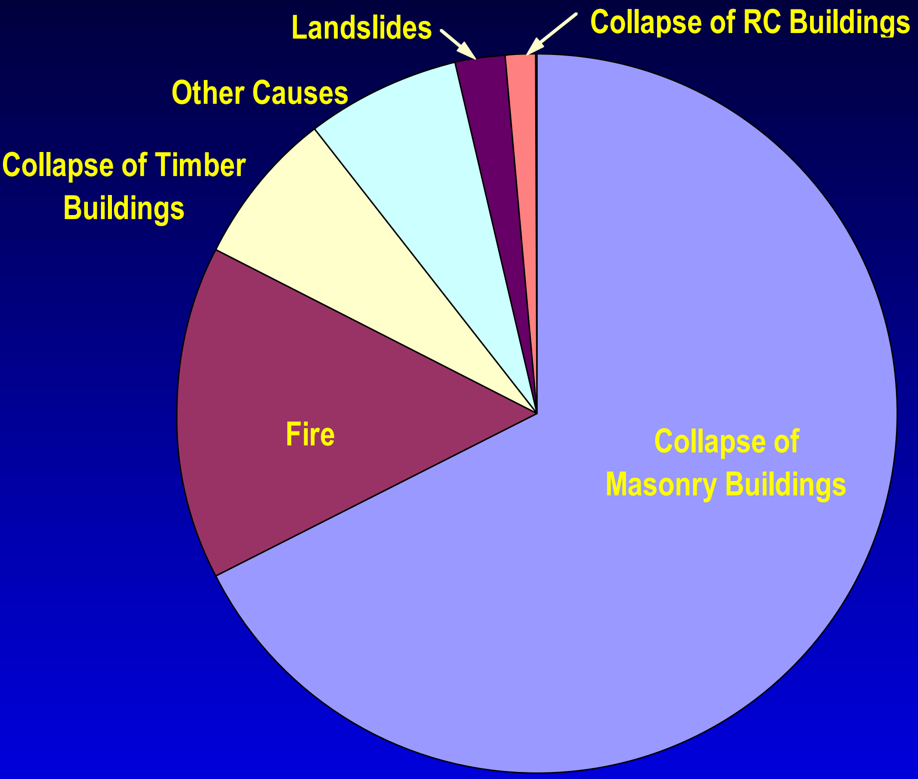
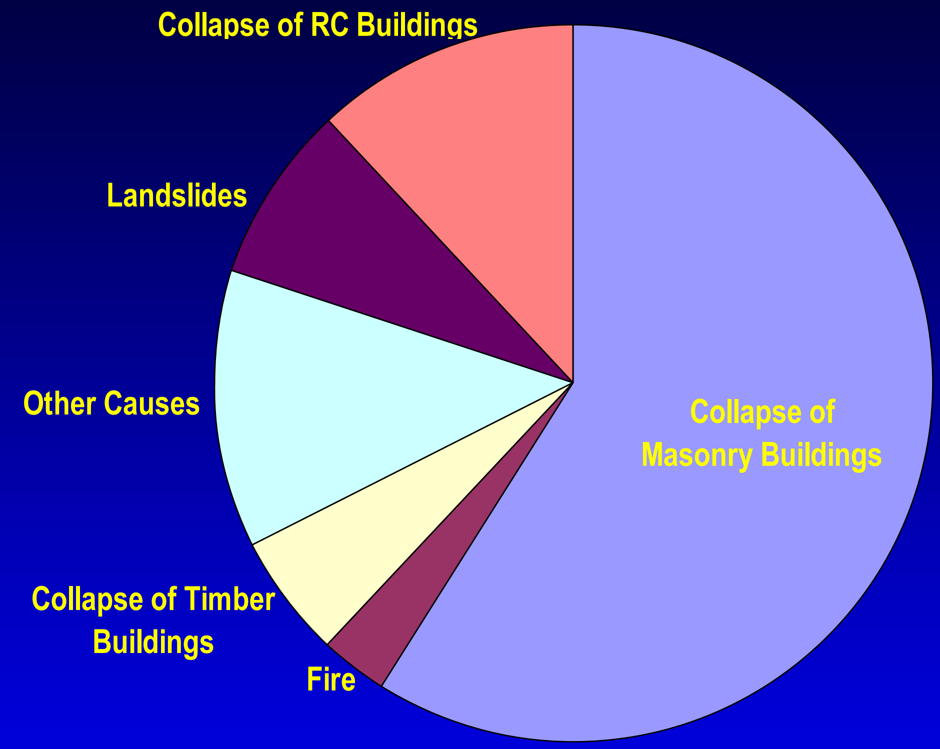


Earthquake Fatalities: 1900 - 1949

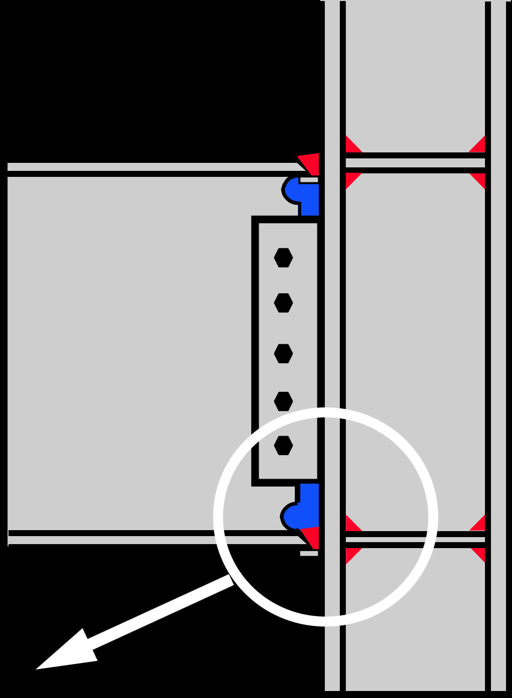
(795,000 Fatalities)

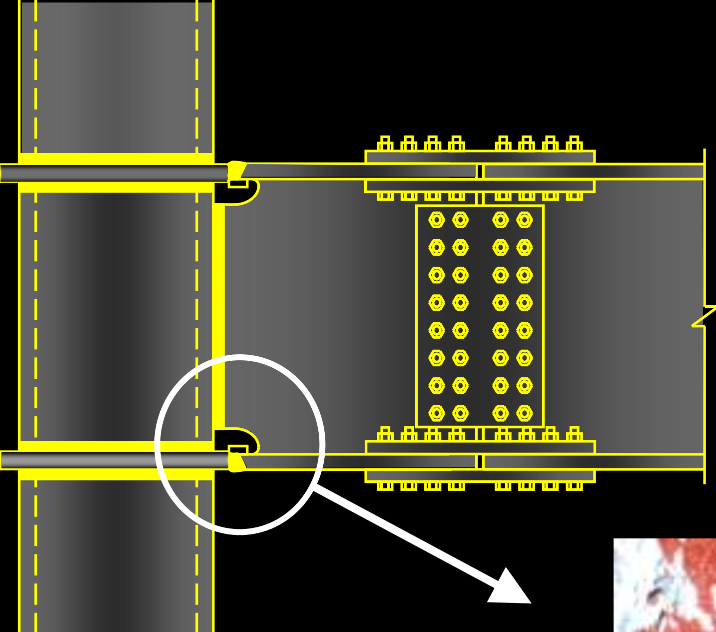


Earthquake Fatalities: 1950 - 1990

(583,000 Fatalities)

Causes of Earthquake Fatalities: 1900 to 1990






B3

Introduction and Basic Principles

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US Seismic Code Provisions for Steel

- Structural Engineers Association of California (SEAOC) *Blue Book* – 1988:
  First comprehensive detailing provisions for steel

- American Institute of Steel Construction (AISC) *Seismic Provisions*
  - 1st ed. 1990
  - 2nd ed. 1992
  - 3rd ed. 1997
    - Supplement No. 1: February 1999
    - Supplement No. 2: November 2000
  - 4th ed. 2002
  - 5th ed. 2005

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Conventional Building Code Philosophy for Earthquake-Resistant Design

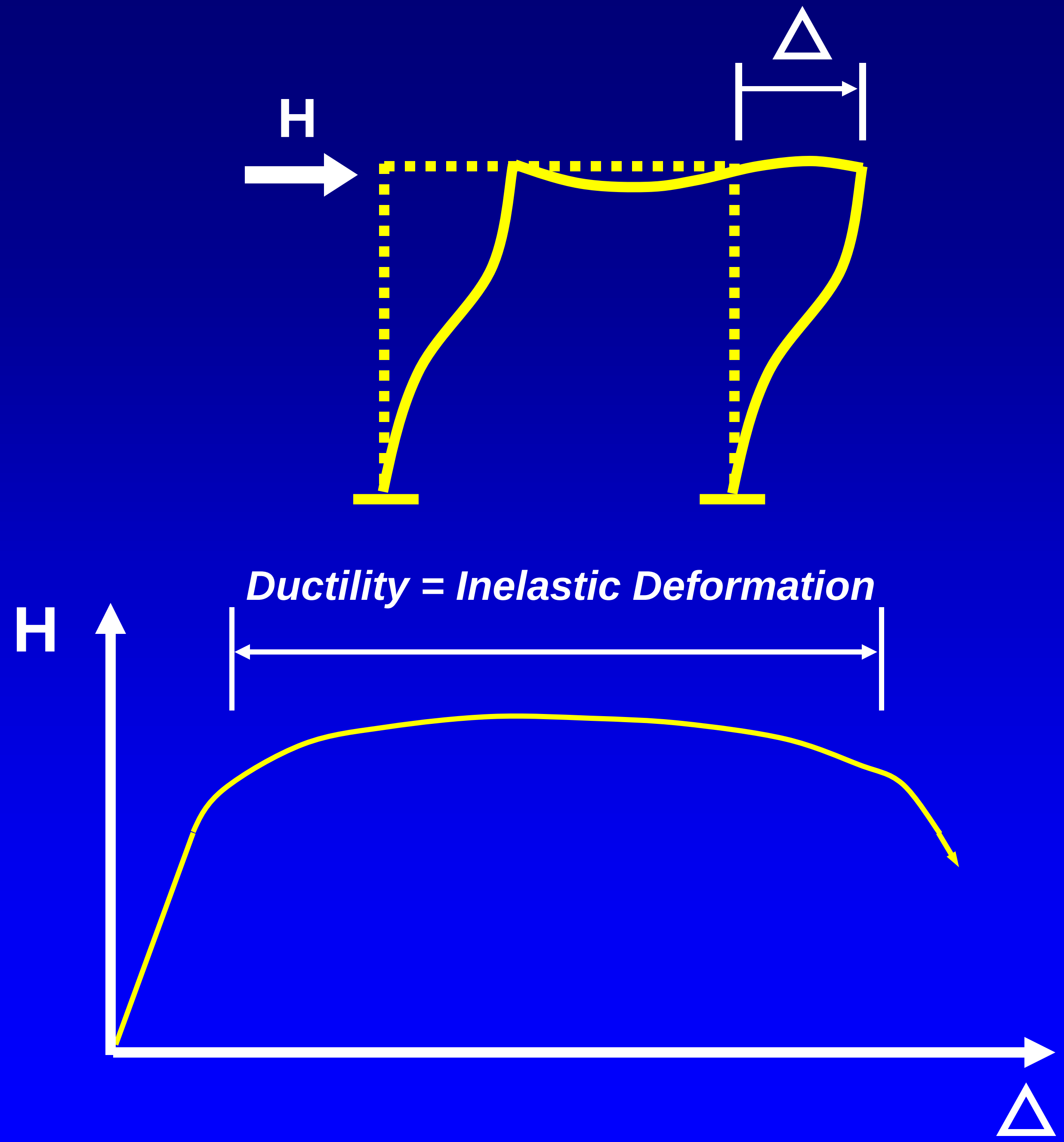
Objective: Prevent collapse in the extreme earthquake likely to occur at a building site.

Objectives are not to:

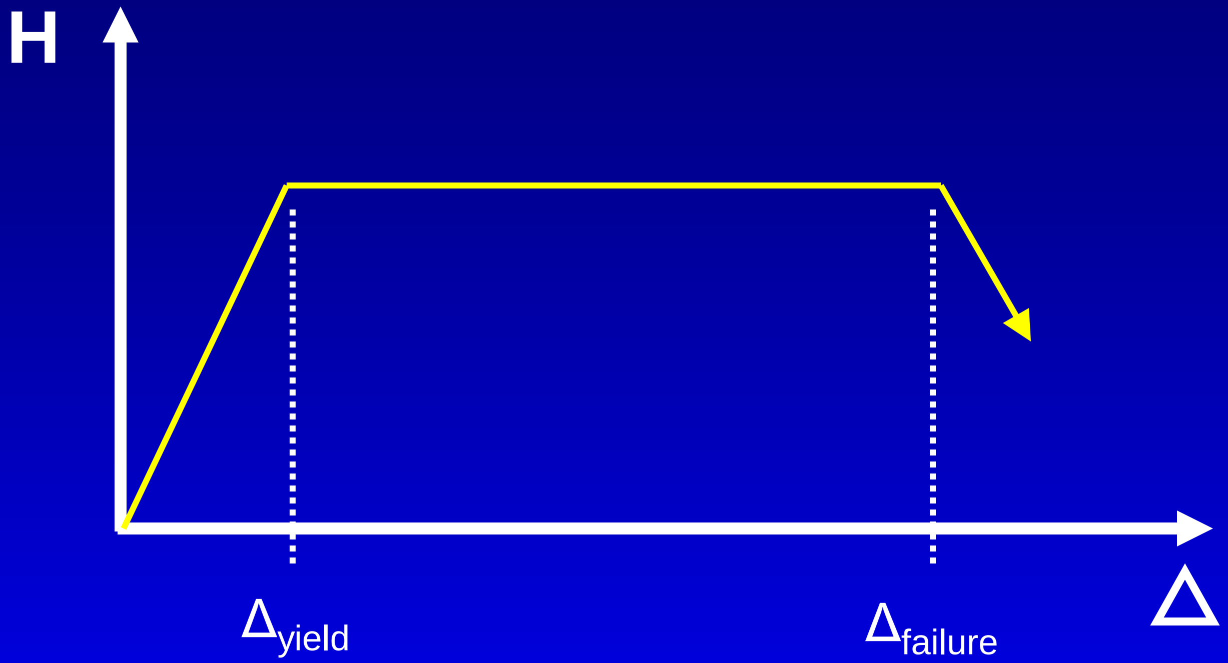
- limit damage
- maintain function
- provide for easy repair

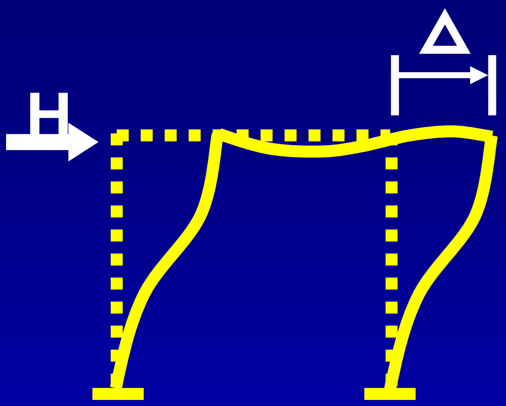
To Survive Strong Earthquake without Collapse:

Design for Ductile Behavior

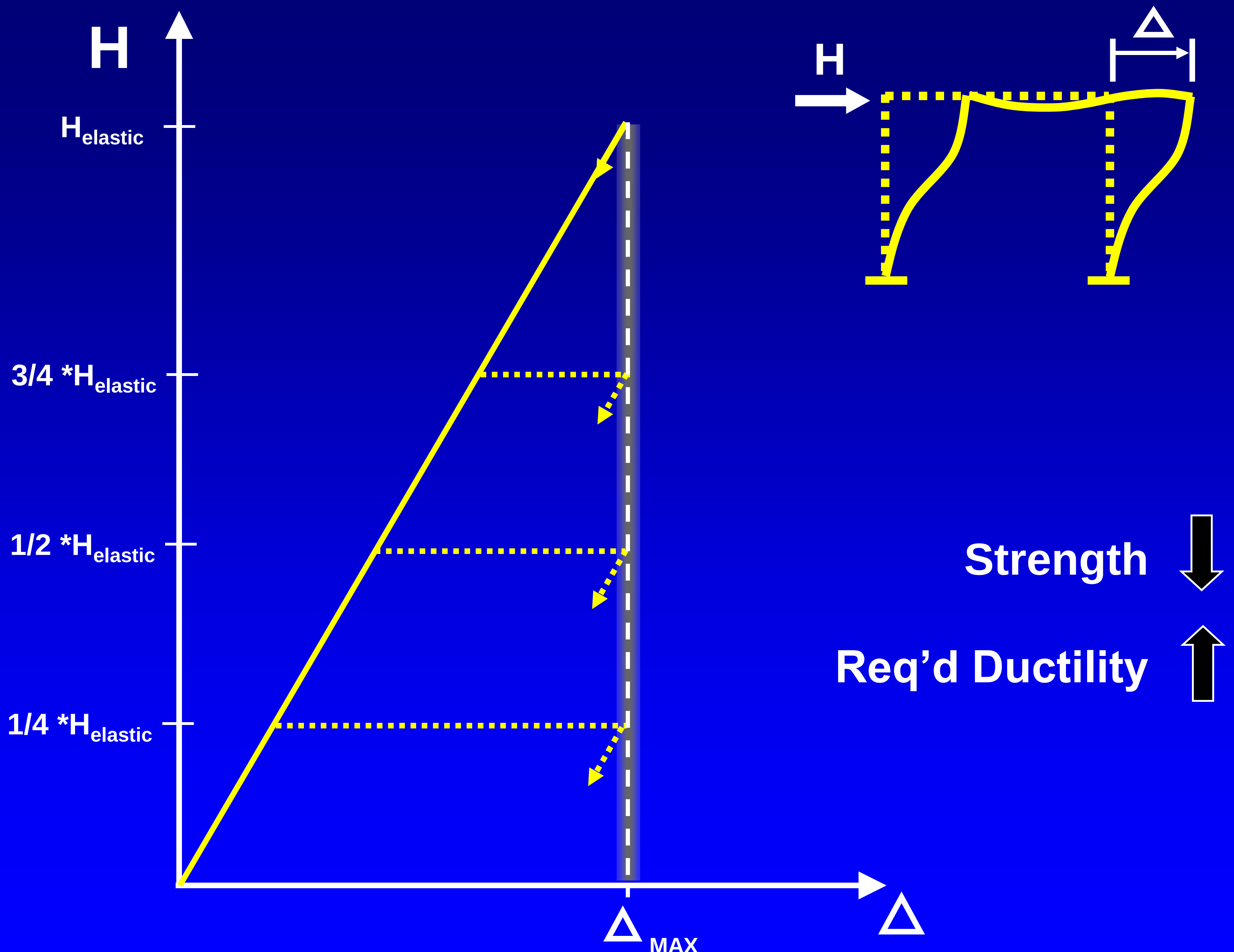


Δ
H
Ductility = Inelastic Deformation
H
Δ





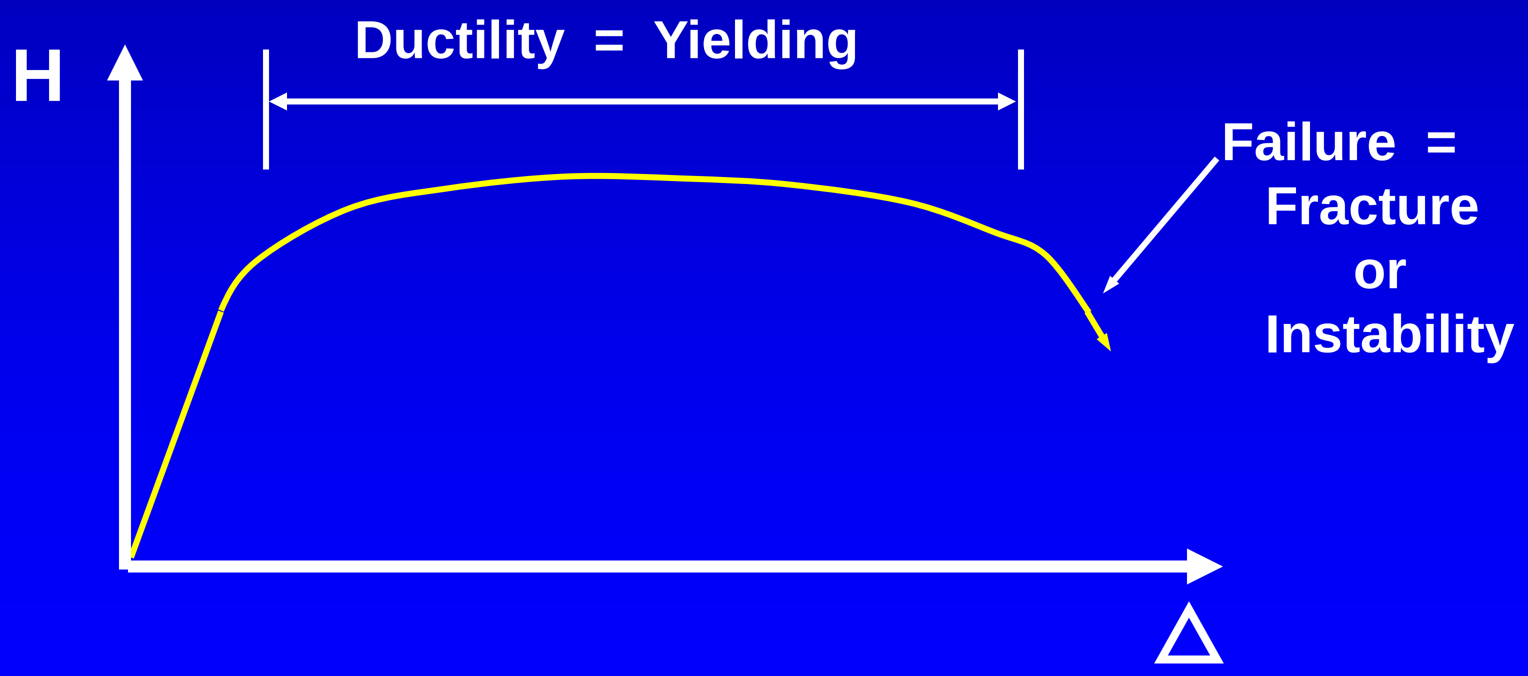
$$\textbf{Ductility Factor} \quad \mu = \frac{\Delta_{failure}}{\Delta_{yield}}$$



H
Helastic
3/4 *Helastic
1/2 *Helastic
1/4 *Helastic
Δ MAX
Δ
H
Δ
Strength
Req'd Ductility

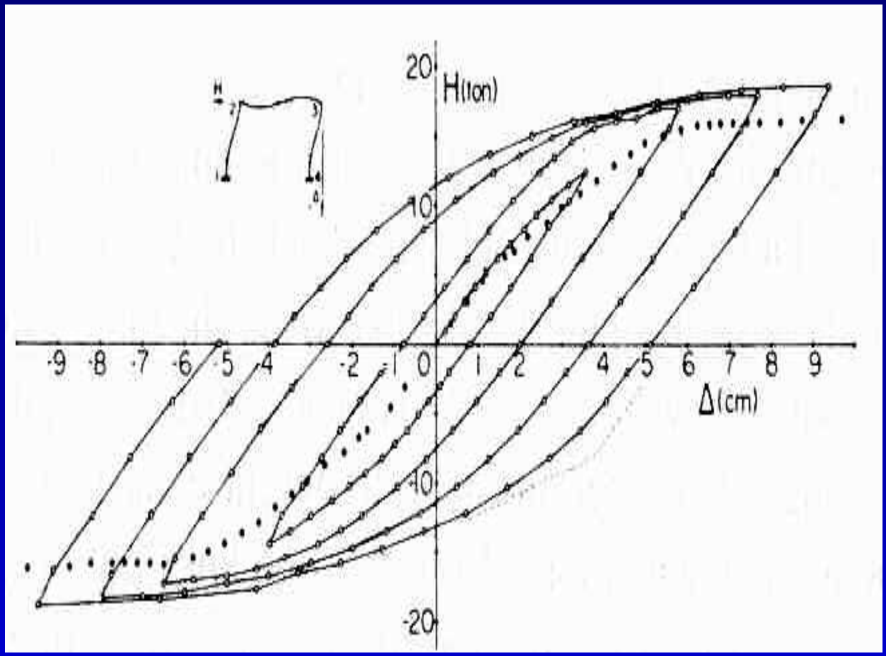
Ductility in Steel Structures: ***Yielding***

Nonductile Failure Modes: ***Fracture or Instability***

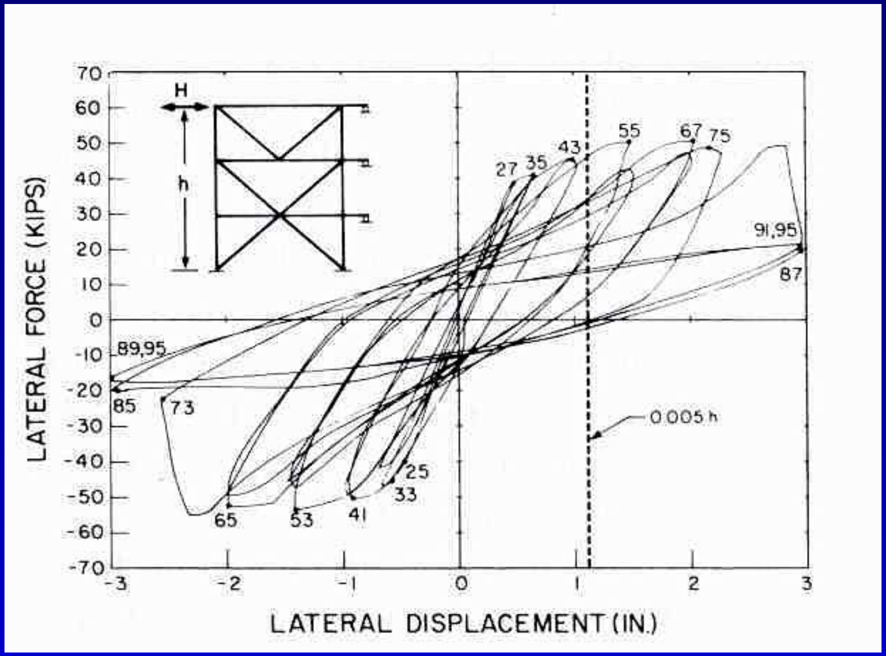


Developing Ductile Behavior:

- Choose frame elements ("fuses") that will yield in an earthquake; e.g. beams in moment resisting frames, braces in concentrically braced frames, links in eccentrically braced frames, etc.
- Detail "fuses" to sustain large inelastic deformations prior to the onset of fracture or instability (i.e. , detail fuses for ductility).
- Design all other frame elements to be stronger than the fuses, i.e., design all other frame elements to develop the plastic capacity of the fuses.



(a)



(b)

Examples of:

(a) More Ductile Behavior

(b) Less Ductile Behavior

Key Elements of Seismic-Resistant Design

Required Lateral Strength

ASCE-7:

Minimum Design Loads for Buildings and Other Structures

Detailing for Ductility

AISC:

Seismic Provisions for Structural Steel Buildings

Design EQ Loads – Base Shear per ASCE 7-05:

$$V = C_s W$$

$$C_s = \frac{S_{DS}}{\left(R/I\right)} \leq \frac{S_{D1}}{T\left(R/I\right)}$$

R factors for Selected Steel Systems (ASCE 7):

SMF	(*Special Moment Resisting Frames*):	R = 8
IMF	(*Intermediate Moment Resisting Frames*):	R = 4.5
OMF	(*Ordinary Moment Resisting Frames*):	R = 3.5
EBF	(*Eccentrically Braced Frames*):	R = 8 or 7
SCBF	(*Special Concentrically Braced Frames*):	R = 6
OCBF	(*Ordinary Concentrically Braced Frames*):	R = 3.25
BRBF	(*Buckling Restrained Braced Frame*):	R = 8 or 7
SPSW	(*Special Plate Shear Walls*):	R = 7

Undetailed Steel Systems in Seismic Design Categories A, B or C (AISC Seismic Provisions not needed) — **R = 3**

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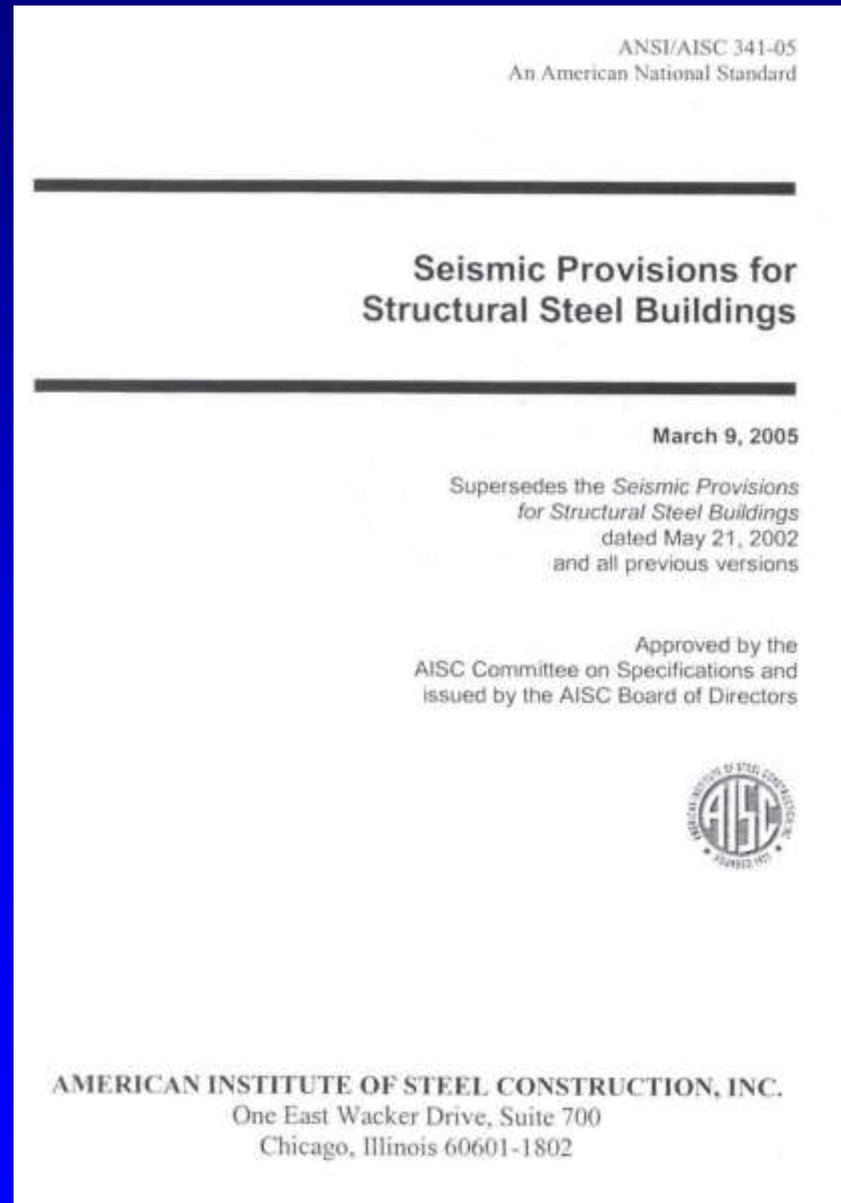
2005 AISC Seismic Provisions



ANSI/AISC 341-05
An American National Standard

Seismic Provisions for Structural Steel Buildings

March 9, 2005

Supersedes the *Seismic Provisions for Structural Steel Buildings* dated May 21, 2002 and all previous versions

Approved by the AISC Committee on Specifications and issued by the AISC Board of Directors

AMERICAN INSTITUTE OF STEEL CONSTRUCTION, INC.
One East Wacker Drive, Suite 700
Chicago, Illinois 60601-1802

Organization of the *2005 AISC Seismic Provisions*

Part I: Seismic design provisions for structural steel buildings

Part II: Seismic design provisions for composite structural steel and reinforced concrete buildings

AISC *Seismic Provisions for Structural Steel Buildings* – Part I

9. Special Moment Frames (SMF)
10. Intermediate Moment Frames (IMF)
11. Ordinary Moment Frames (OMF)
12. Special Truss Moment Frames (STMF)
13. Special Concentrically Braced Frames (SCBF)
14. Ordinary Concentrically Braced Frames (OCBF)
15. Eccentrically Braced Frames (EBF)
16. Buckling Restrained Braced Frames (BRBF)
17. Special Plate Shear Walls (SPSW)
18. Quality Assurance Plan

Appendix P:	**Prequalification of Beam-to-Column and Link-to-Column Connections**
Appendix Q:	**Quality Assurance Plan**
Appendix R:	**Seismic Design Coefficients and Approximate Period Parameters**
Appendix S:	**Qualifying Cyclic Tests of Beam-to-Column and Link-to-Column Connections**
Appendix T:	**Qualifying Cyclic Tests of Buckling Restrained Braces**
Appendix W:	**Welding Provisions**
Appendix X:	**Weld Metal / Welding Procedure Specification Toughness Verification Test**

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2005 AISC Seismic Provisions

General Provisions Applicable to All Systems

Highlights of

Glossary and Sections 1 to 8

Glossary - Selected Terms

Applicable Building Code **(ABC)**

ABC = Building code under which the structure is designed (the local building code that governs the design of the structure)

Where there is no local building code - use ASCE 7

AISC Seismic Provisions:

Glossary - Selected Terms

Seismic Load Resisting System (SLRS)

Assembly of structural elements in the building that resists seismic loads, including struts, collectors, chords, diaphragms and trusses

Glossary - Selected Terms

Seismic Use Group (SUG): ASCE 7-02

Classification assigned to a structure based on its use.

ASCE 7-05: No longer uses "Seismic Use Groups"

Now defines Occupancy Categories

Occupancy Categories (ASCE 7-05)

Occupancy Category	Description	Importance Factor *I*
IV	**Essential facilities** (Hospitals, fire and police stations, emergency shelters, etc) **Structures containing extremely hazardous materials**	**1.5**
III	**Structures that pose a substantial hazard to human life in the event of failure** (buildings with 300 people in one area, day care facilities with capacity more than 150, schools with a capacity more than 250, etc)	**1.25**
II	**Buildings not in Occupancy Categories I, III, or IV** (most buildings)	**1.0**
I	**Buildings that represent a low hazard to human life in the event of failure** (agricultural facilities, temporary facilities, minor storage facilities)	**1.0**

Glossary - Selected Terms

Seismic Design Category (SDC)

Classification assigned to a structure based on its Occupancy Category and the severity of the anticipated ground motions at the site

SDCs: A

B

C

D

E

F

Increasing seismic risk

and

Increasingly stringent seismic design and detailing requirements

To Determine the Seismic Design Category (ASCE 7-05):

Determine *Occupancy Category*

Determine S_S and S_1

S_S = spectral response acceleration for maximum considered earthquake at short periods

S_1 = spectral response acceleration for maximum considered earthquake at 1-sec period

S_s and S_1 are read from maps (or from USGS website)

Determine *Site Class*

Site Class depends on soils conditions - classified according to shear wave velocity, standard penetration tests, or undrained shear strength

Determine S_{MS} and S_{M1}

Spectral response accelerations for maximum considered earthquake adjusted for the Site Class;

$S_{MS} = F_a S_s \qquad S_{M1} = F_v S_1$

F_a and F_v depend on Site Class and on S_s and S_1

Determine S_{DS} and S_{D1}

Design spectral response accelerations

$S_{DS} = 2/3 \times S_{MS} \qquad S_{D1} = 2/3 \times S_{M1}$

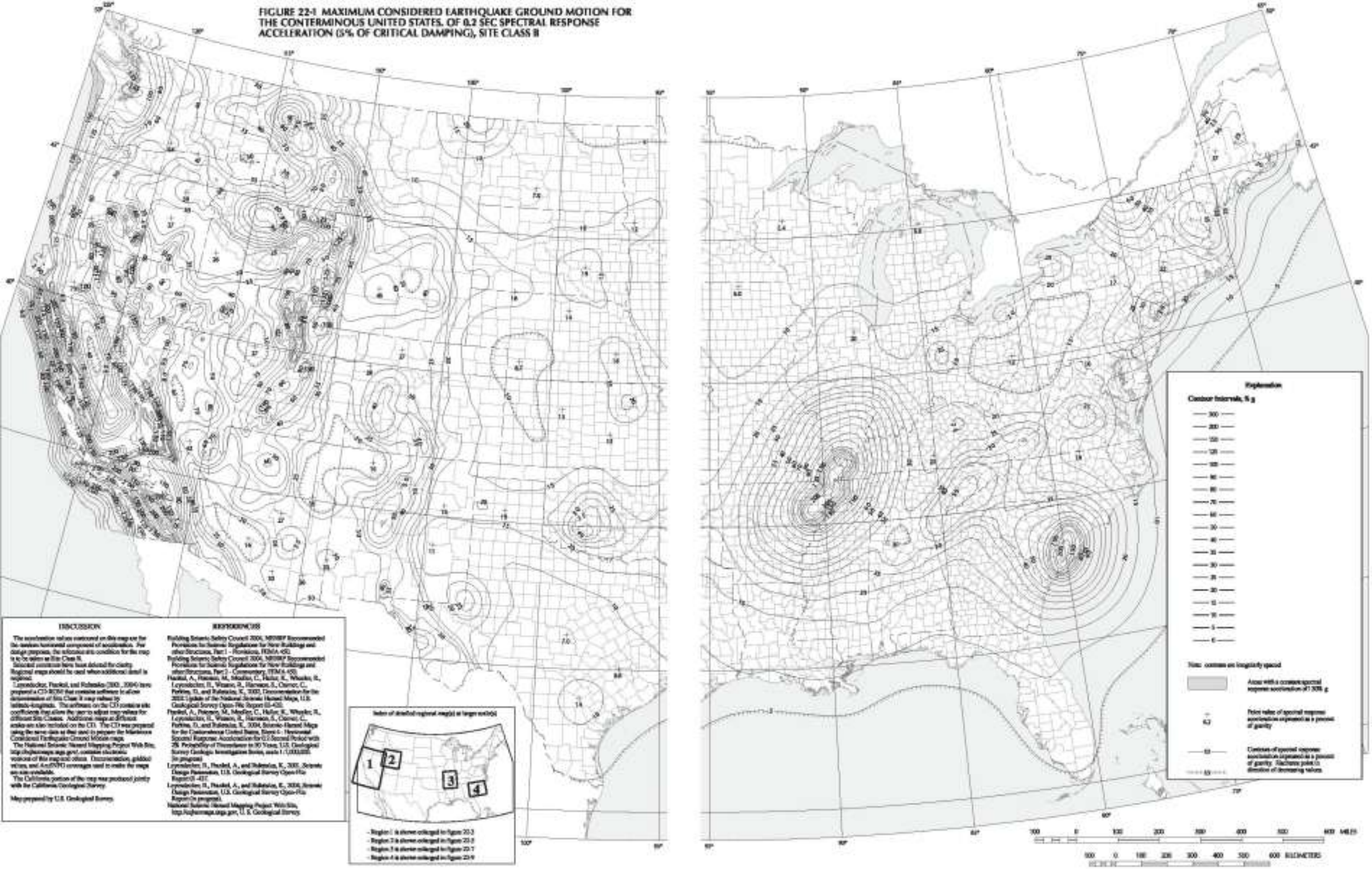


FIGURE 22-1 MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR THE CONTERMINOUS UNITED STATES, OF 0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B
DISCUSSION
REFERENCES
Explanation

Map for S_S

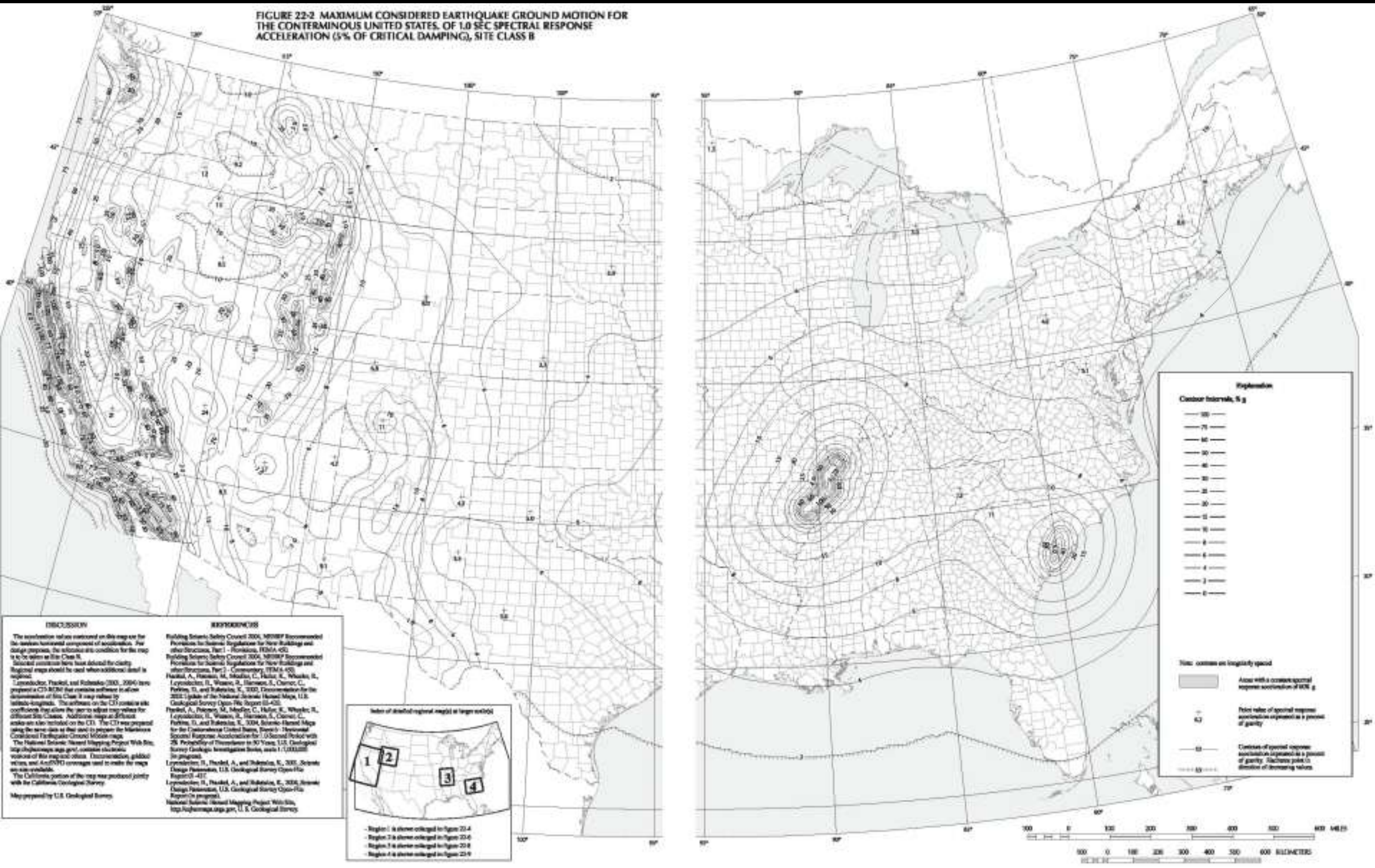


FIGURE 22-2 MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR
THE CONTERMINOUS UNITED STATES, OF 1.0 SEC SPECTRAL RESPONSE
ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B
DISCUSSION
REFERENCES
Explanation

Map for S_1

Seismic Hazard Maps

- Interactive program available from USGS website.
  - Seismic design values for buildings
  - Input longitude and latitude at site, or zip code
  - Output S_S and S_1
- http://earthquake.usgs.gov/research/hazmaps/design/

To Determine the Seismic Design Category (ASCE 7-05):

Evaluate *Seismic Design Category* According to Tables 11.6-1 and 11.6-2;

The *Seismic Design Category* is the most severe value based on both Tables.

Table 11.6-1

Seismic Design Category Based on Short Period Response Accelerations

Value of S_{DS}	Occupancy Category		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D[a]	D[a]	D[a]

[a] For sites with $S_1 \geq 0.75g$: *Seismic Design Category = E* for OC I, II, or III

Seismic Design Category = F for OC IV

Table 11.6-2

Seismic Design Category Based on 1-Second Period Response Accelerations

Value of S_{D1}	Occupancy Category		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \leq S_{D1} < 0.133g$	B	B	C
$0.133g \leq S_{D1} < 0.20g$	C	C	D
$0.20g \leq S_{D1}$	D[a]	D[a]	D[a]

[a] For sites with $S_1 \geq 0.75g$: *Seismic Design Category = E* for OC I, II, or III

Seismic Design Category = F for OC IV

AISC Seismic Provisions: Sections 1 to 8

1. Scope
2. Referenced Specifications, Codes and Standards
3. General Seismic Design Requirements
4. Loads, Load Combinations and Nominal Strengths
5. Structural Design Drawings and Specifications, Shop Drawings and Erection Drawings
6. Materials
7. Connections, Joints and Fasteners
8. Members

AISC Seismic Provisions:

Section 1 - Scope

The *Seismic Provisions* apply to the *seismic load resisting system (SLRS)* and to splices in columns not part of the SLRS

The *Seismic Provisions* are used in conjunction with the AISC *Specification for Structural Steel Buildings*

AISC Seismic Provisions:

Section 1 - Scope (cont)

Use of *Seismic Provisions* is mandatory for Seismic Design Category D, E or F.

Use of *Seismic Provisions* are mandatory for Seismic Design Categories A, B or C; when using R > 3

For Seismic Design Categories A, B or C: can design using R=3, and provide no special detailing (just design per main AISC Specification)

AISC Seismic Provisions:

Section 3 - General Seismic Design Requirements

Go to the *Applicable Building Code* for:

- **Occupancy Category**
- **Seismic Design Category**
- **Limits on Height and Irregularity**
- **Drift Limitations**
- **Required Strength**

AISC Seismic Provisions:

Section 4

Loads, Load Combinations and Nominal Strengths

4.1 Loads and Load Combinations

4.2 Nominal Strength

AISC Seismic Provisions:

4.1 Loads and Load Combinations

Go to the *Applicable Building Code* for Loads and Load Combinations.

Basic LRFD Load Combinations (ASCE-7):

1.4D

1.2D + 1.6L + 0.5(L_r or S or R)

1.2D + 1.6(L_r or S or R) + (0.5L or 0.8W)

1.2D + 1.6W + 0.5L + 0.5(L_r or S or R)

0.9D + 1.6W

1.2D + 1.0E + 0.5L + 0.2S

0.9D + 1.0E

Load Combinations Including *E*

Definition of *E* for use in basic load combinations:

For Load Combination: 1.2D + 1.0E + 0.5L + 0.2S

$$E = \rho\, Q_E + 0.2\, S_{DS}\, D$$

For Load Combination: 0.9D + 1.0E

$$E = \rho\, Q_E - 0.2\, S_{DS}\, D$$

$$E = \rho\, \underbrace{Q_E}_{\text{effect of horizontal forces}} \pm \underbrace{0.2\, S_{DS}\, D}_{\text{effect of vertical forces}}$$

E	=	the effect of horizontal and vertical earthquake-induced forces
Q_E	=	effect of horizontal earthquake-induced forces
S_{DS}	=	design spectral acceleration at short periods
D	=	dead load effect
ρ	=	reliability factor (depends on extent of redundancy in the seismic lateral resisting system; ρ varies from 1.0 to 1.5)

Substitute *E* into basic load combinations:

For Load Combination: $1.2D + 1.0E + 0.5L + 0.2S$

substitute: $E = \rho\, Q_E + 0.2\, S_{DS}\, D$

$$\Rightarrow \boxed{(1.2 + 0.2\, S_{DS})\, D + 1.0\, \rho\, Q_E + 0.5L + 0.2S}$$

For Load Combination: $0.9D + 1.0E$

substitute: $E = \rho\, Q_E - 0.2\, S_{DS}\, D$

$$\Rightarrow \boxed{(0.9 - 0.2\, S_{DS})\, D + 1.0\, \rho\, Q_E}$$

AISC Seismic Provisions:

4.1 Loads and Load Combinations (cont.)

Where *amplified seismic loads* are required by the *AISC Seismic Provisions*:

The horizontal portion of the earthquake load *E* shall be multiplied by the *overstrength factor* Ω_o prescribed by the applicable building code.

Definition of *Amplified Seismic Load* (ASCE-7)

For Load Combination: $1.2D + 1.0E + 0.5L + 0.2S$

Amplified Seismic Load: $E = \Omega_o Q_E + 0.2 S_{DS} D$

For Load Combination: $0.9D + 1.0E$

Amplified Seismic Load: $E = \Omega_o Q_E - 0.2 S_{DS} D$

Basic load combinations incorporating *Amplified Seismic Load*:

For Load Combination: 1.2D + 1.0E + 0.5L + 0.2S

substitute: $E = \Omega_o Q_E + 0.2 S_{DS} D$

$\Rightarrow$ $\boxed{(1.2 + 0.2 S_{DS}) D + \Omega_o Q_E + 0.5L + 0.2S}$

For Load Combination: 0.9D + 1.0E

substitute: $E = \Omega_o Q_E - 0.2 S_{DS} D$

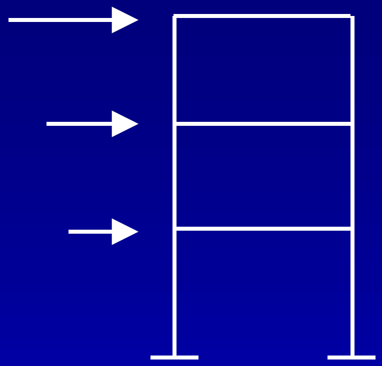
$\Rightarrow$ $\boxed{(0.9 - 0.2 S_{DS}) D + \Omega_o Q_E}$

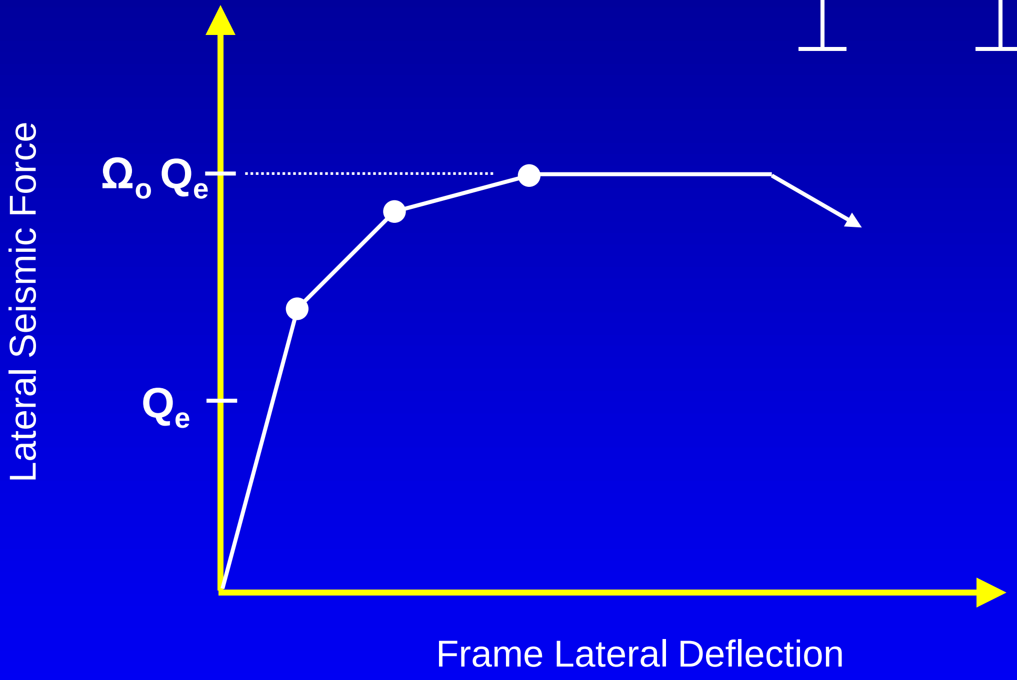
Seismic Overstrength Factor: Ω_o

Per ASCE-7:

System	Ω_o
Moment Frames (SMF, IMF, OMF)	3
Concentrically Braced Frames (SCBF, OCBF)	2
Eccentrically Braced Frames (EBF)	2
Special Plate Shear Walls (SPSW)	2
Buckling Restrained Braced Frames (BRBF)	
- moment resisting beam-column connections	2.5
- non-moment resisting beam-column connections	2

Amplified Seismic Load





Amplified Seismic Load, $\Omega_o Q_e$, is intended to provide an estimate of a frame's plastic lateral strength

AISC Seismic Provisions:

Section 6
Materials

6.1 Material Specifications

6.2 Material Properties for Determination of Required Strength of Members and Connections

6.3 Heavy Section CVN Requirements

AISC Seismic Provisions:

6.1 Material Specifications

For members in which inelastic behavior is expected:

Specified minimum $F_y \leq 50$ ksi

Exceptions:

- Columns for which only expected yielding is at the base;
- Members in OMFs and OCBFs (permitted to use up to F_y = 55 ksi)

6.2 Material Properties for Determination of Required Strength of Members and Connections

Expected Yield Strength $= R_y F_y$

Expected Tensile Strength $= R_t F_u$

F_y = *minimum specified yield strength*

F_u = *minimum specified tensile strength*

R_y and R_t are based on statistical analysis of mill data.

Table I-6-1

R_y and R_t Values for Different Member Types

Application	R_y	R_t
Hot-Rolled Shapes and Bars:		
ASTM A36	1.5	1.2
ASTM A572 Gr 42	1.1	1.1
ASTM A992; A572 Gr 50 or Gr 55; ASTM A913 Gr 50, 60 or 65; ASTM A588; A1011 HSLAS Gr 50	1.1	1.1
ASTM A529 Gr 50	1.2	1.2
ASTM A529 Gr 55	1.1	1.2
Hollow Structural Sections (HSS):		
ASTM A500 Gr B or Gr C; ASTM A501	1.4	1.3
Pipe:		
ASTM A53	1.6	1.2
Plates:		
ASTM A36	1.3	1.2
ASTM A572 Gr50; ASTM A588	1.1	1.2

Example: *A36* angles used for brace in an SCBF

F_y	=	36 ksi		
F_u	=	58 ksi		
$R_y F_y$	=	1.5×36 ksi	=	54 ksi
$R_t F_u$	=	1.2×58 ksi	=	70 ksi

Example: *A992* wide flange used for beam in an SMF

F_y	=	50 ksi		
F_u	=	65 ksi		
$R_y F_y$	=	1.1×50 ksi	=	55 ksi
$R_t F_u$	=	1.1×65 ksi	=	72 ksi

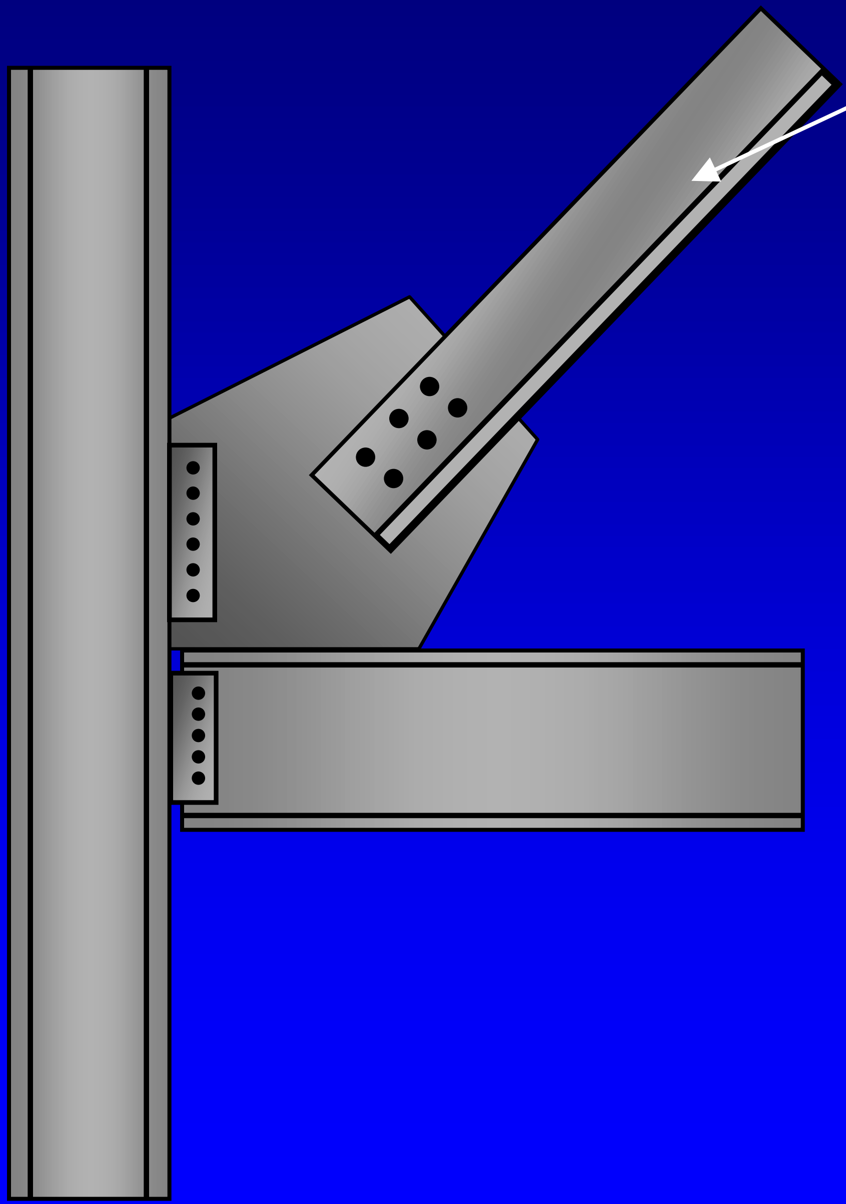
AISC Seismic Provisions:

6.2 Material Properties for Determination of Required Strength of Members and Connections (*cont*)

Where specified in the *Seismic Provisions*, the required strength of a member or connection shall be based on the *Expected Yield Strength, $R_y F_y$* of an adjoining member.

The *Expected Tensile Strength, $R_t F_u$* and the *Expected Yield Strength, $R_y F_y$* may be used to compute the nominal strength for rupture and yielding limit states within the same member.

Example: SCBF Brace and Brace Connection

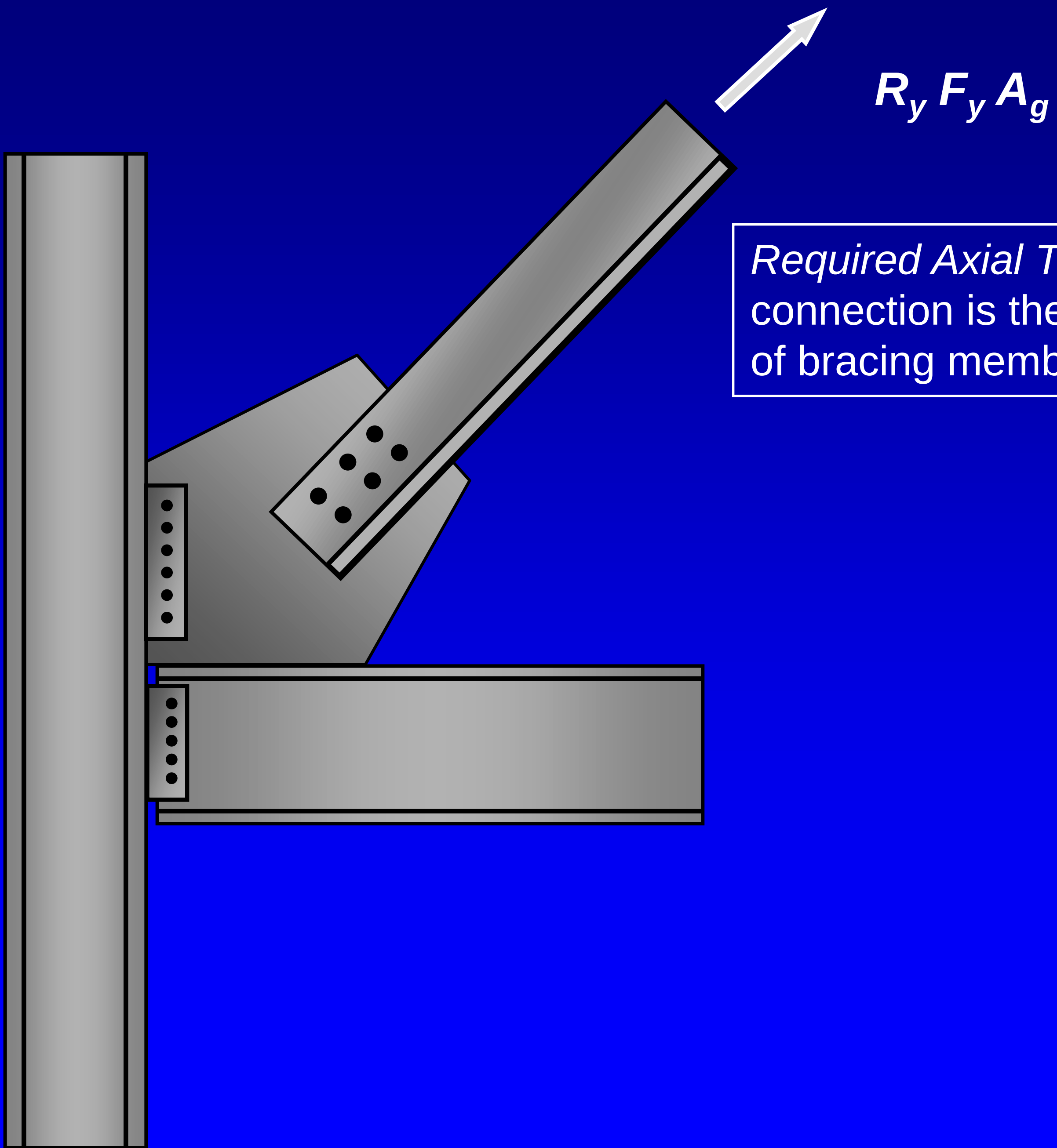


To size brace member:

Required Strength defined by code specified forces (using ASCE-7 load combinations)

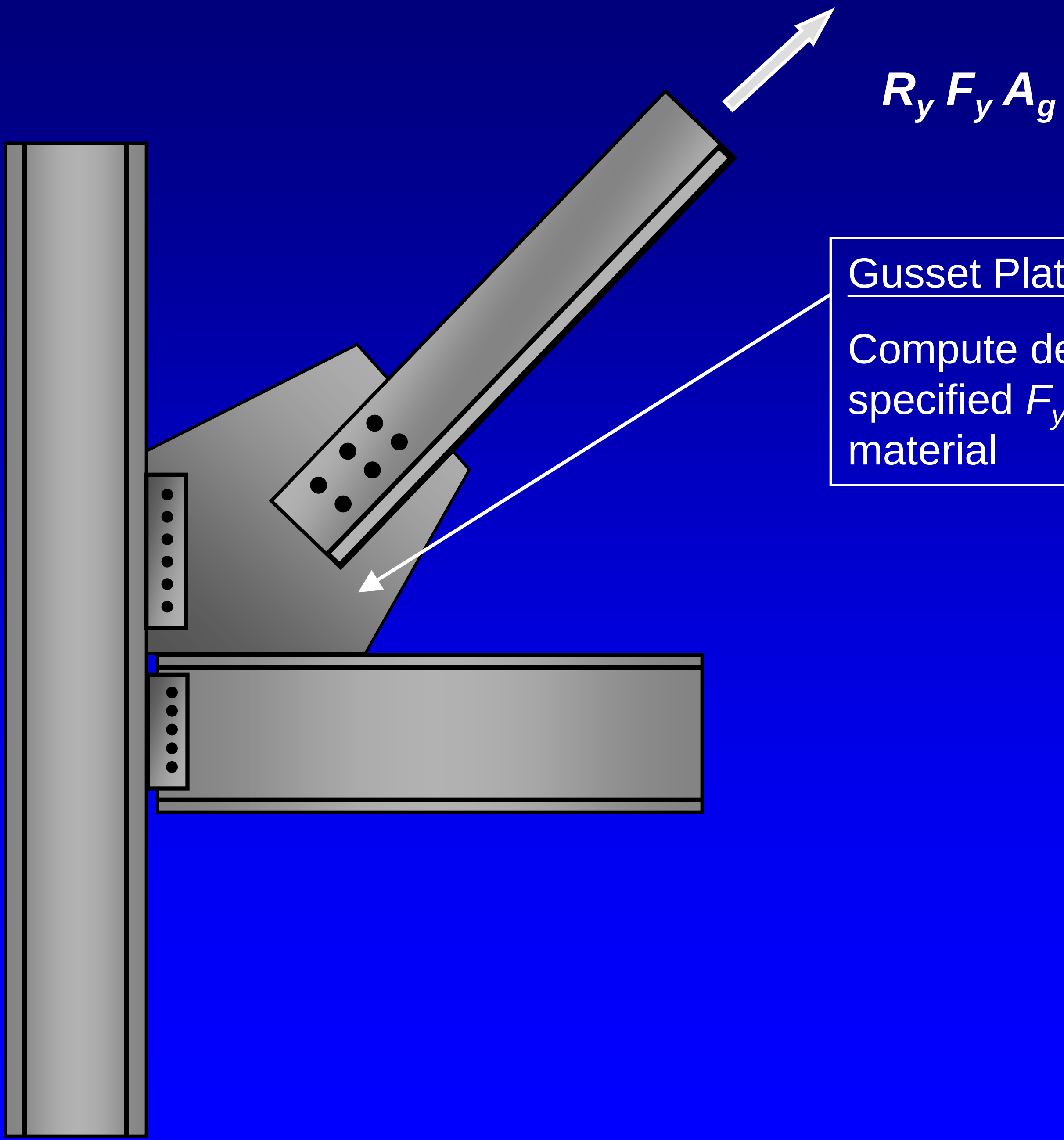
Design Strength of member computed using minimum specified F_y

Example: SCBF Brace and Brace Connection (cont)



Required Axial Tension Strength of brace connection is the *expected yield strength* of bracing member $= R_y\ F_y\ A_g$

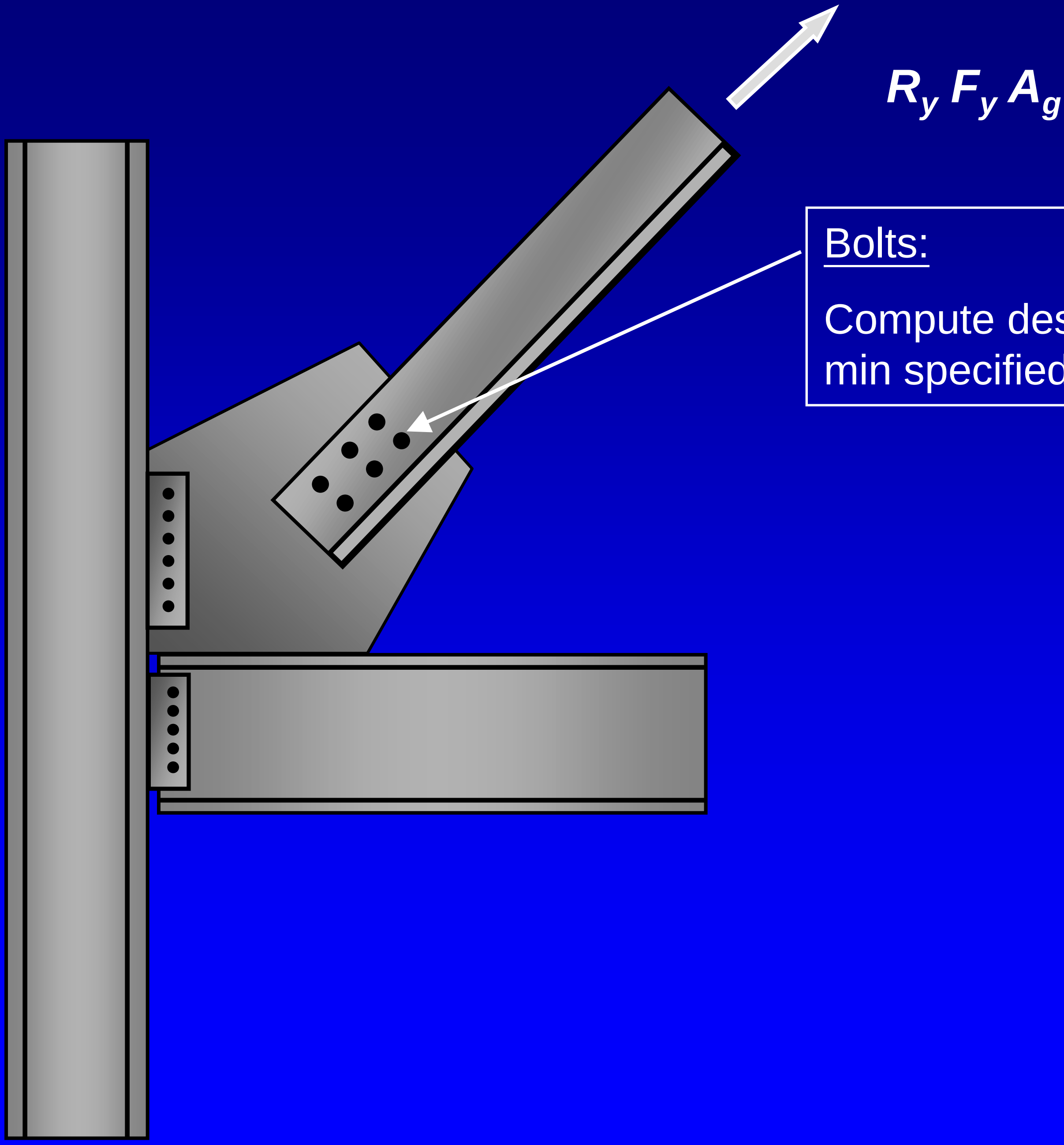
Example: SCBF Brace and Brace Connection (cont)



Gusset Plate:

Compute design strength using min specified F_y and F_u of gusset plate material

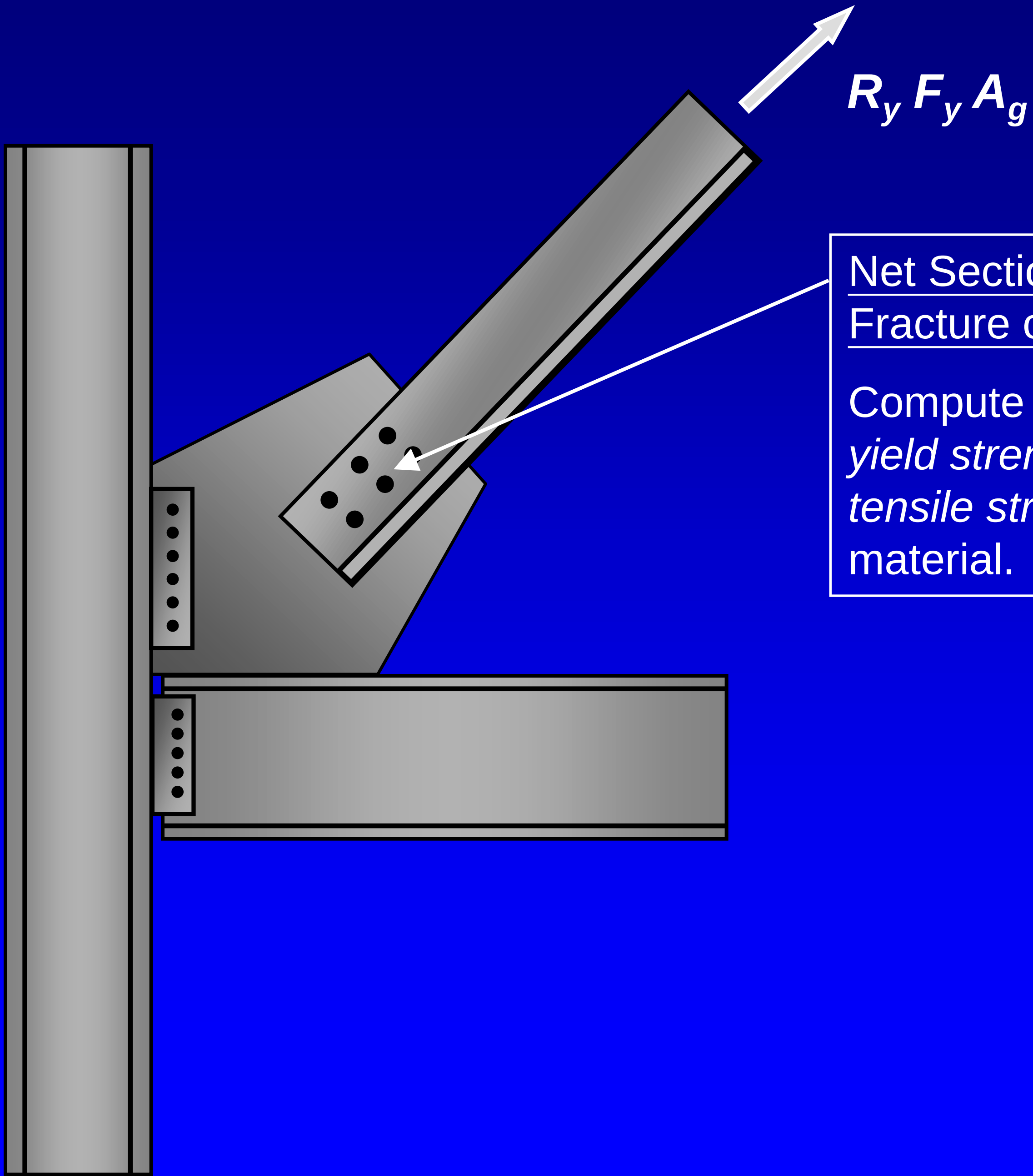
Example: SCBF Brace and Brace Connection (cont)



Bolts:

Compute design shear strength using min specified F_u of bolt

Example: SCBF Brace and Brace Connection (cont)



Net Section Fracture and Block Shear Fracture of Bracing Member:

Compute design strength using *expected yield strength*, R_yF_y and *expected tensile strength*, $R_t\ F_u$ of the brace material.

AISC Seismic Provisions:

Section 7

Connections, Joints and Fasteners

7.1	Scope
7.2	Bolted Joints
7.3	Welded Joints
7.4	Protected Zone
7.5	Continuity Plates and Stiffeners

7. Connections, Joints and Fasteners

7.1 Scope

Connections, joints and fasteners that are part of the *seismic load resisting system* (SLRS) shall comply with the AISC *Specification* Chapter J, and with the additional requirements in this section.

Connections in the SLRS shall be configured such that a *ductile limit state* in either the connection or in the connected member controls the design.

AISC Seismic Provisions:

7. Connections, Joints and Fasteners

7.2 Bolted Joints

Requirements for bolted joints:

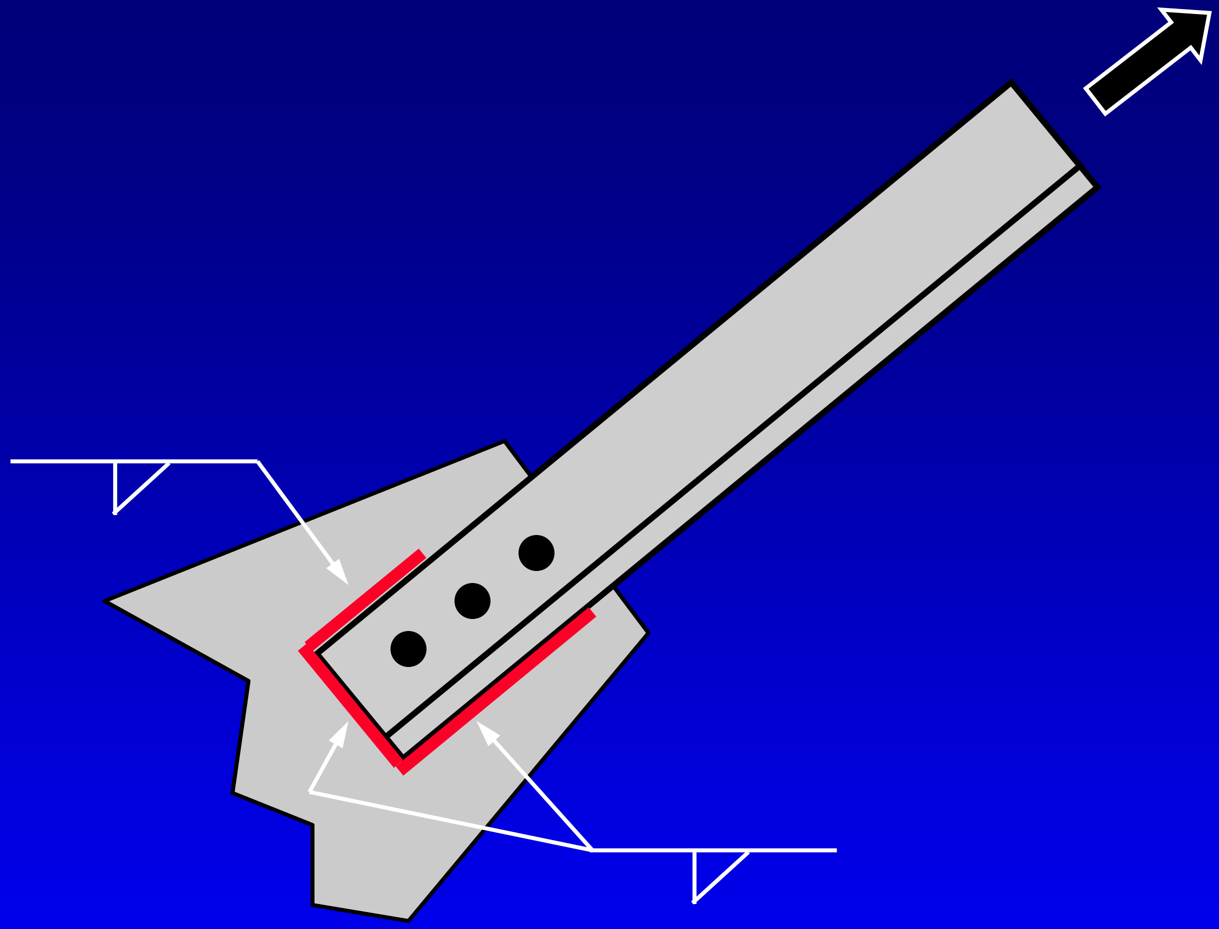
- All bolts must be high strength (A325 or A490)
- Bolted joints may be designed as bearing type connections, but must be constructed as slip critical
  - bolts must be pretensioned
  - faying surfaces must satisfy Class A surface requirements
- Holes: standard size or short-slots perpendicular to load (exception: oversize holes are permitted for diagonal brace connections, but the connection must be designed as slip-critical and the oversize hole is permitted in one ply only)
- Nominal bearing strength at bolt holes cannot exceed 2.4 $d\ t\ F_u$

AISC Seismic Provisions:

7. Connections, Joints and Fasteners

7.2 Bolted Joints (cont)

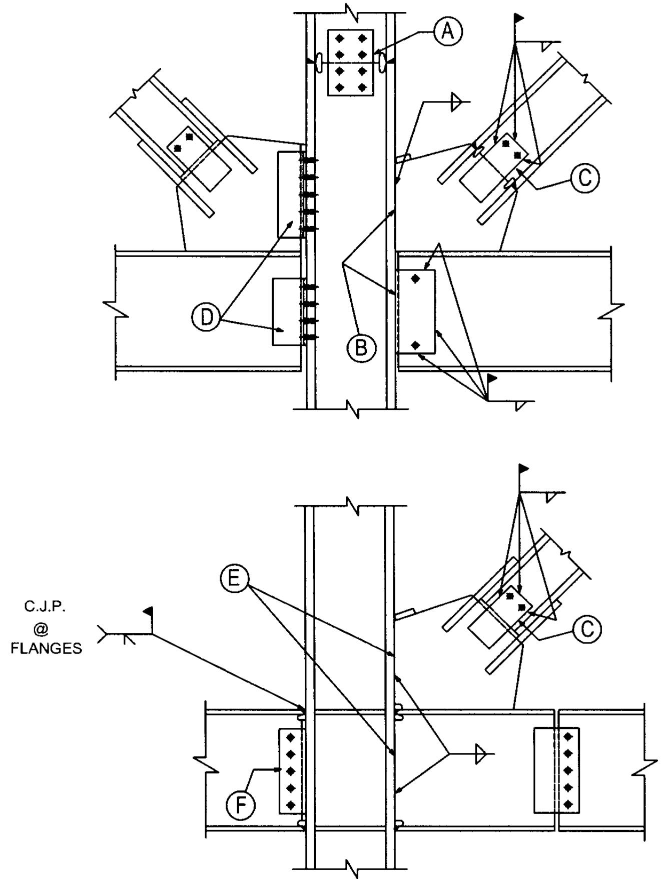
Bolts and welds shall not be designed to share force in a joint, or the same force component in a connection.



Bolts and welds sharing same force:

Not Permitted

Fig. C-I-7.1a. Desirable details that avoid shared forces between welds and bolts.



(A) A bolted web connection may be designed to resist column shear while welded flanges resist axial and/or flexural forces.

(B) Connection using both gusset and beam web welded to column allows both elements to participate in resisting the vertical component of the brace force. Note erection bolts may be used to support beam temporarily.

(C) Flanges and web are both welded to resist axial force in combination. Bolts are for erection only.

(D) Both web of beam and gussets are bolted to column allowing sharing of vertical and horizontal forces.

(E) A stub detail allows both gusset and beam web to be shop welded to column. Flanges of supported beam may be welded to transfer flexural and axial forces.

(F) For beam moment connections, bolted webs can resist shear while welded flanges resist flexural and axial forces. (moment connections must meet the requirements of sections 9, 10, or 11 of the provisions as required.)

AISC Seismic Provisions:

7. Connections, Joints and Fasteners

7.3 Welded Joints

Welding shall be performed in accordance with Appendix W

Welding shall be performed in accordance with a *welding procedure specification* (WPS) as required in AWS D1.1 and approved by the engineer of record.

WPS variables (voltage, current, wire feed speed, etc) shall be within the limits recommended by the filler metal manufacturer.

AISC Seismic Provisions:

7. Connections, Joints and Fasteners

7.3a Welded Joints - General Requirements

All welds in the SLRS shall have a minimum Charpy V-Notch (CVN) toughness of:

20 ft-lbs at 0 ^{o}F

CVN rating of filler metal may be determined using AWS classification test methods.

AISC Seismic Provisions:

7. Connections, Joints and Fasteners

7.3b Welded Joints - Demand Critical Welds

Welds designated as *Demand Critical* shall have a minimum Charpy V-Notch (CVN) toughness of:

20 ft-lbs at -20 ^{o}F (per AWS test methods)

AND

40 ft-lbs at 70 ^{o}F (per AISC Seismic Provisions - Appendix X)

AISC Seismic Provisions:

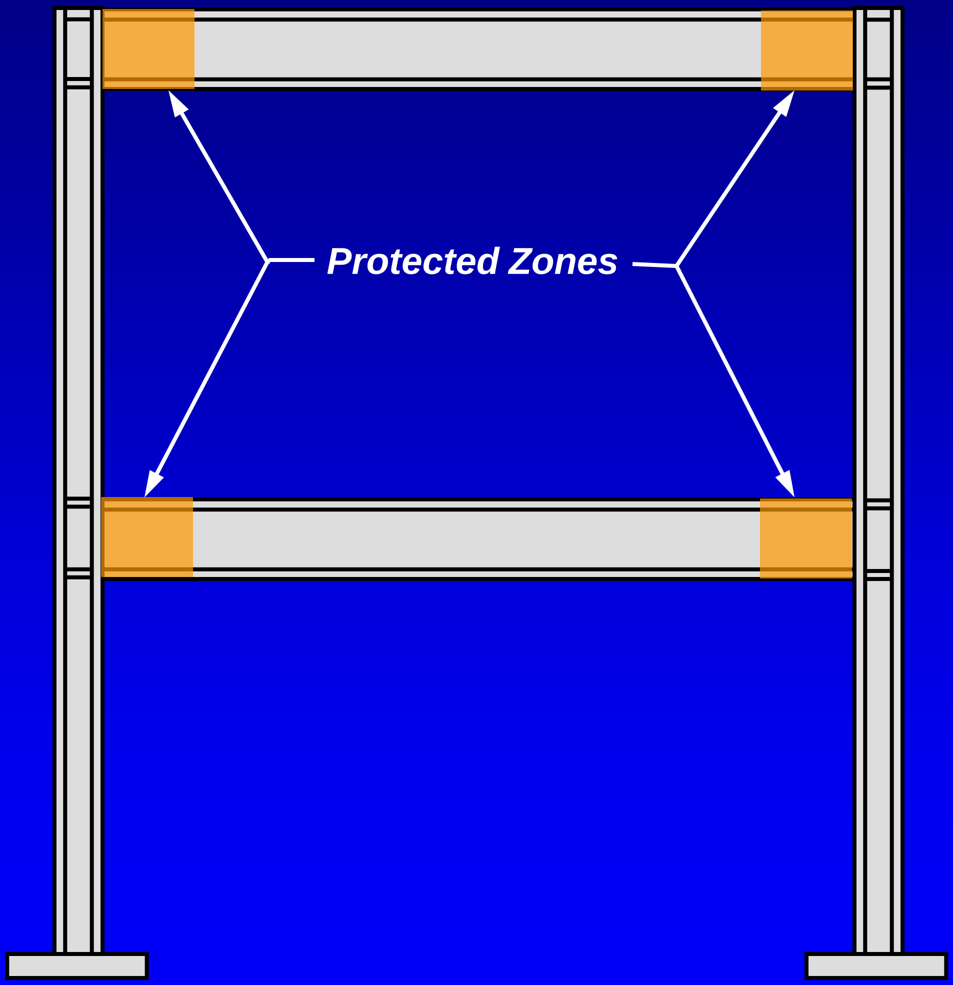
7. Connections, Joints and Fasteners

7.4 Protected Zone

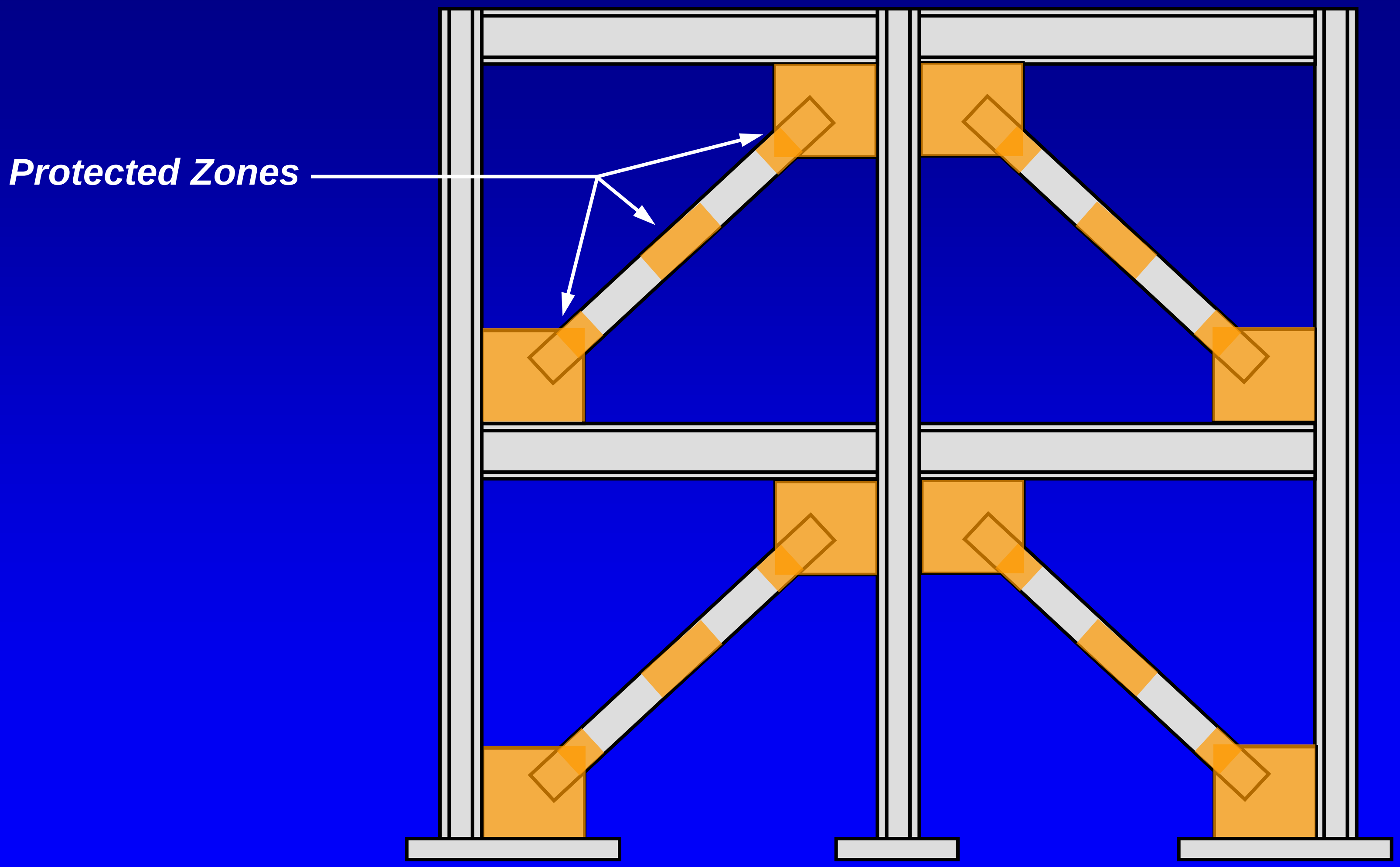
Portions of the SLRS designated as a *Protected Zone*, shall comply with the following:

- No welded shear studs are permitted.
- No decking attachments that penetrate the beam flange are permitted (no powder actuated fasteners); but, decking arc spot welds are permitted.
- No welded, bolted, screwed, or shot-in attachments for edge angles, exterior facades, partitions, duct work, piping, etc are permitted.
- Discontinuities from fabrication or erection operations (such as tack welds, erection aids, etc) shall be repaired.

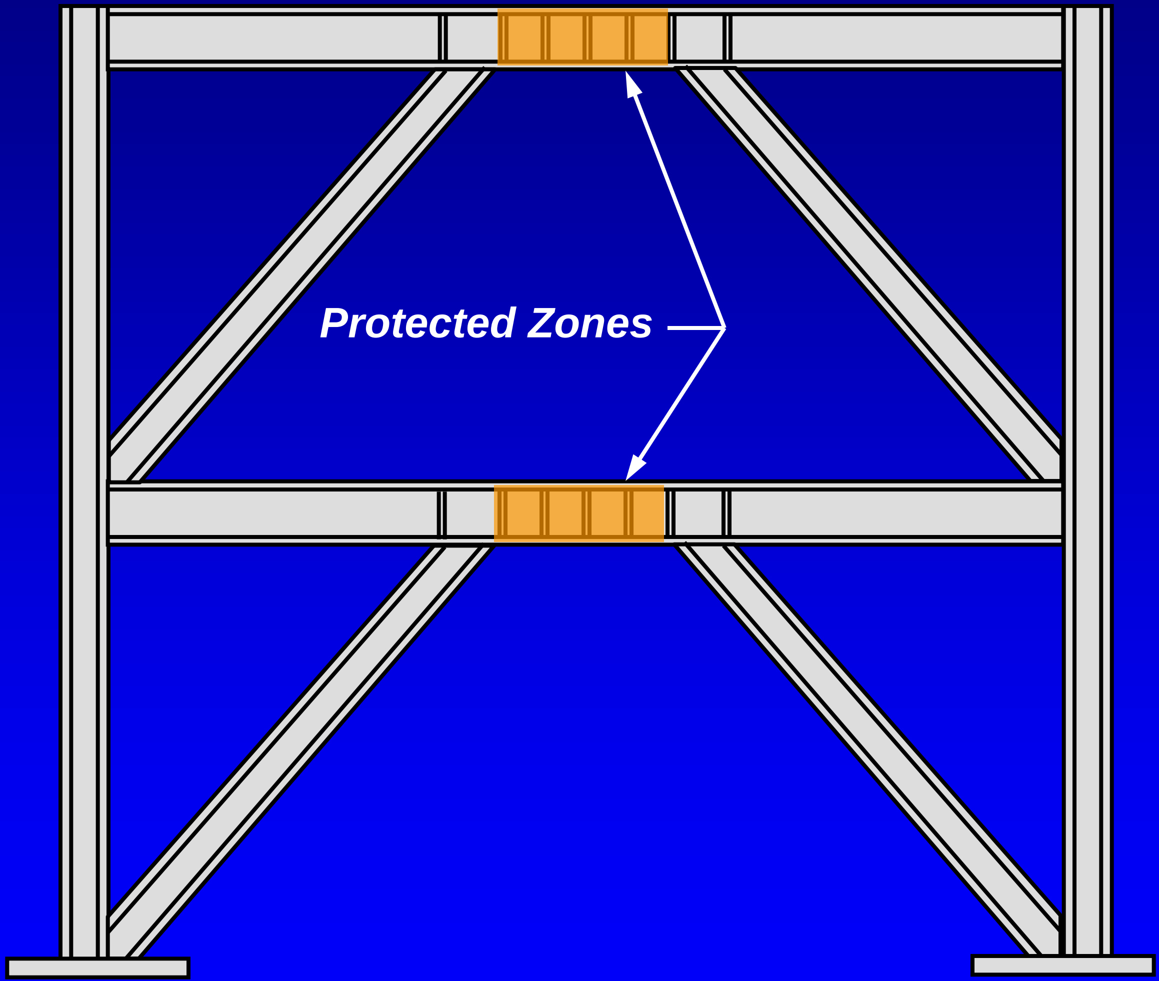
Examples of *Protected Zones:* SMF



Examples of *Protected Zones:* SCBF



Examples of *Protected Zones:* EBF



AISC Seismic Provisions:

Section 8

Members

8.1 Scope

8.2 Classification of Sections for Local Buckling

8.3 Column Strength

8.4 Column Splices

8.5 Column Bases

AISC Seismic Provisions:

8.2 Classification of Sections for Local Buckling

Local buckling of members can significantly affect both strength and ductility of the member.

Members of the SLRS that are expected to experience significant inelastic action (e.g. beams in SMF, braces in SCBF, links in EBF, etc), must satisfy strict width-thickness limits to assure adequate ductility can be developed prior to local buckling.

Such members must be ***seismically compact.***

For *seismically compact* sections, the width-thickness ratios of the elements of the cross-section cannot exceed λ_{ps}, as specified in Table I-8-1.

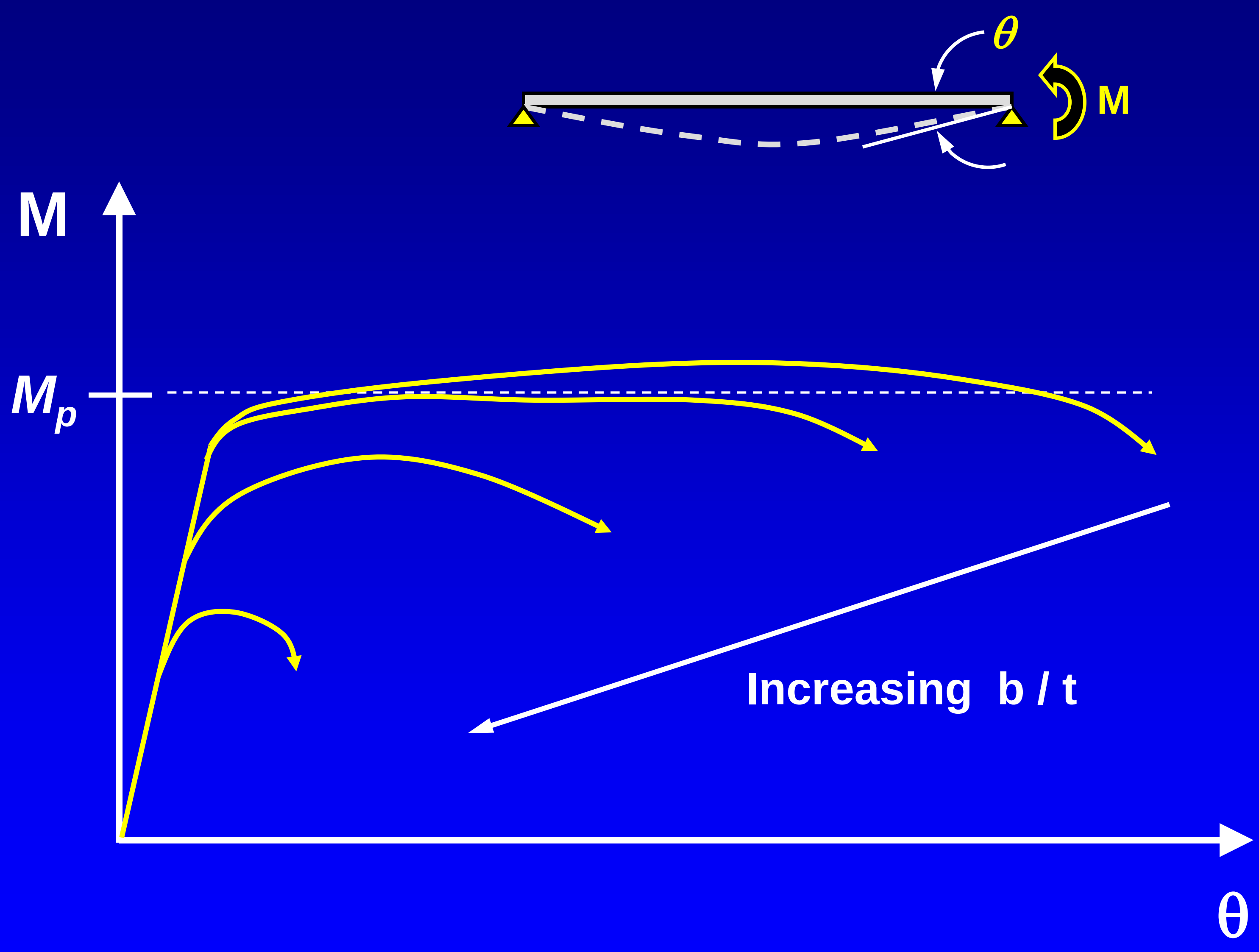
Local buckling of a moment frame beam.....

Local buckling of an EBF link.....

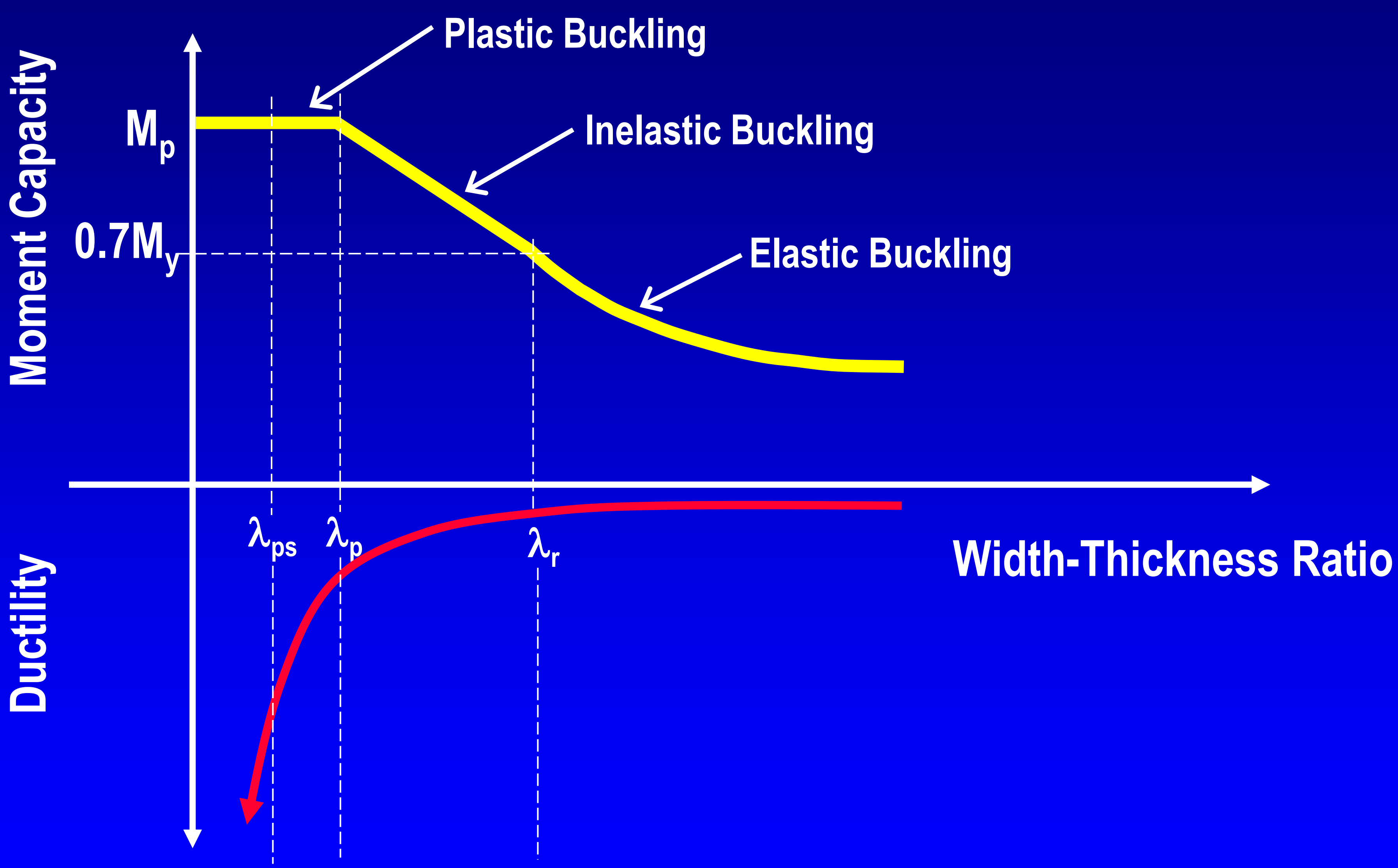
Local buckling of an HSS column....

Local buckling of an HSS brace.....

Effect of Local Buckling on Flexural Strength and Ductility



Effect of Local Buckling on Flexural Strength and Ductility



AISC Seismic Provisions:

TABLE I-8-1

Limiting Width-Thickness Ratios for Compression Elements

	Description of Element	Width Thick-ness Ratio	Limiting Width-Thickness Ratios λ_{ps} (seismically compact)
Unstiffened Elements	Flexure in flanges of rolled or built-up I-shaped sections [a], [c], [e], [g], [h]	*b/t*	$0.30\sqrt{E/F_y}$
	Uniform compression in flanges of rolled or built-up I-shaped sections [b], [h]	*b/t*	$0.30\sqrt{E/F_y}$
	Uniform compression in flanges of rolled or built-up I-shaped sections [d]	*b/t*	$0.38\sqrt{E/F_y}$
	Uniform compression in flanges of channels, outstanding legs of pairs of angles in continuous contact, and braces [c], [g]	*b/t*	$0.30\sqrt{E/F_y}$
	Uniform compression in flanges of H-pile sections	*b/t*	$0.45\sqrt{E/F_y}$
	Flat bars[f]	*b/t*	2.5
	Uniform compression in legs of single angles, legs of double angle members with separators, or flanges of tees [g]	*b/t*	$0.30\sqrt{E/F_y}$
	Uniform compression in stems of tees [g]	*d/t*	$0.30\sqrt{E/F_y}$

Note: See continued Table I-8-1 for stiffened elements.

AISC Seismic Provisions:

TABLE I-8-1 (cont.)
Limiting Width-Thickness Ratios for Compression Elements

	Description of Element	Width Thickness Ratio	Limiting Width-Thickness Ratios λ_{ps} (seismically compact)
Stiffened Elements	Webs in flexural compression in beams in SMF, Section 9, unless noted otherwise	h/t_w	$2.45\sqrt{E/F_y}$
	Webs in flexural compression or combined flexure and axial compression [a], [c], [g], [h], [i], [j]	h/t_w	for $C_a \le 0.125$ [k] $3.14\sqrt{\frac{E}{F_y}}(1-1.54C_a)$ for $C_a > 0.125$ [k] $1.12\sqrt{\frac{E}{F_y}}(2.33-C_a) \ge 1.49\sqrt{\frac{E}{F_y}}$
	Round HSS in axial and/or flexural compression [c], [g]	D/t	$0.044\ E/F_y$
	Rectangular HSS in axial and/or flexural compression [c], [g]	b/t or h/t_w	$0.64\sqrt{E/F_y}$
	Webs of H-Pile sections	h/t_w	$0.94\sqrt{E/F_y}$

[a] Required for beams in SMF, Section 9 and SPSW, Section 17.
[b] Required for columns in SMF, Section 9, unless the ratios from Equation 9-3 are greater than 2.0 where it is permitted to use λ_p in Specification Table B4.1.
[c] Required for braces and columns in SCBF, Section 13 and braces in OCBF, Section 14.
[d] It is permitted to use λ_p in Specification Table B4.1 for columns in STMF, Section 12 and columns in EBF, Section 15.
[e] Required for *link* in EBF, Section 15, except it is permitted to use λ_p in Table B4.1 of the *Specification* for flanges of *links* of length $1.6M_p / V_p$ or less.
[f] Diagonal web members within the special segment of STMF, Section 12.
[g] Chord members of STMF, Section 12.
[h] Required for beams and columns in BRBF, Section 16.
[i] Required for columns in SPSW, Section 17.
[j] For columns in STMF, Section 12; columns in SMF, if the ratios from Equation 9-3 are greater than 2.0; columns in EBF, Section 15; or EBF with flanges of *links* of length $1.6\ M_p / V_p$ or less, it is permitted to use the following for λ_p:

for $C_a \le 0.125$, $\lambda_p = 3.76\sqrt{\frac{E}{F_y}}(1-2.75C_a)$

for $C_a > 0.125$, $\lambda_p = 1.12\sqrt{\frac{E}{F_y}}(2.33-C_a) \ge 1.49\sqrt{\frac{E}{F_y}}$

[k] For LRFD, $C_a = \frac{P_u}{\phi_b P_y}$

For ASD, $C_a = \frac{\Omega_b P_a}{P_y}$

where
P_a = *required compressive strength* (ASD), kips (N)
P_u = *required compressive strength* (LRFD), kips (N)
P_y = axial yield strength, kips (N)
ϕ_b = 0.90
Ω_b = 1.67

AISC Seismic Provisions:

8.3 Column Strength

When $P_u / \phi P_n > 0.4$ (where P_u is computed without consideration of the *amplified seismic load*)

Then, the *required axial compressive strength* and *tensile strength* of the column, considered in the absence of any applied moment, shall be determined using the load combinations including the *amplified seismic load:*

$$(1.2 + 0.2\ S_{DS})\ D + \Omega_o\ Q_E + 0.5L + 0.2S$$

$$(0.9 - 0.2\ S_{DS})\ D + \Omega_o\ Q_E$$

AISC Seismic Provisions:

8.3 Column Strength (cont)

Exception:

The *required axial compressive* and *tensile strength* of a column need not exceed:

a) The maximum load transferred to the column considering 1.1R_y times the nominal strengths of the connecting beam or brace elements

b) The limit as determined from the resistance of the foundation to overturning uplift.

AISC Seismic Provisions:

8.3 Column Strength (cont)

Exception:

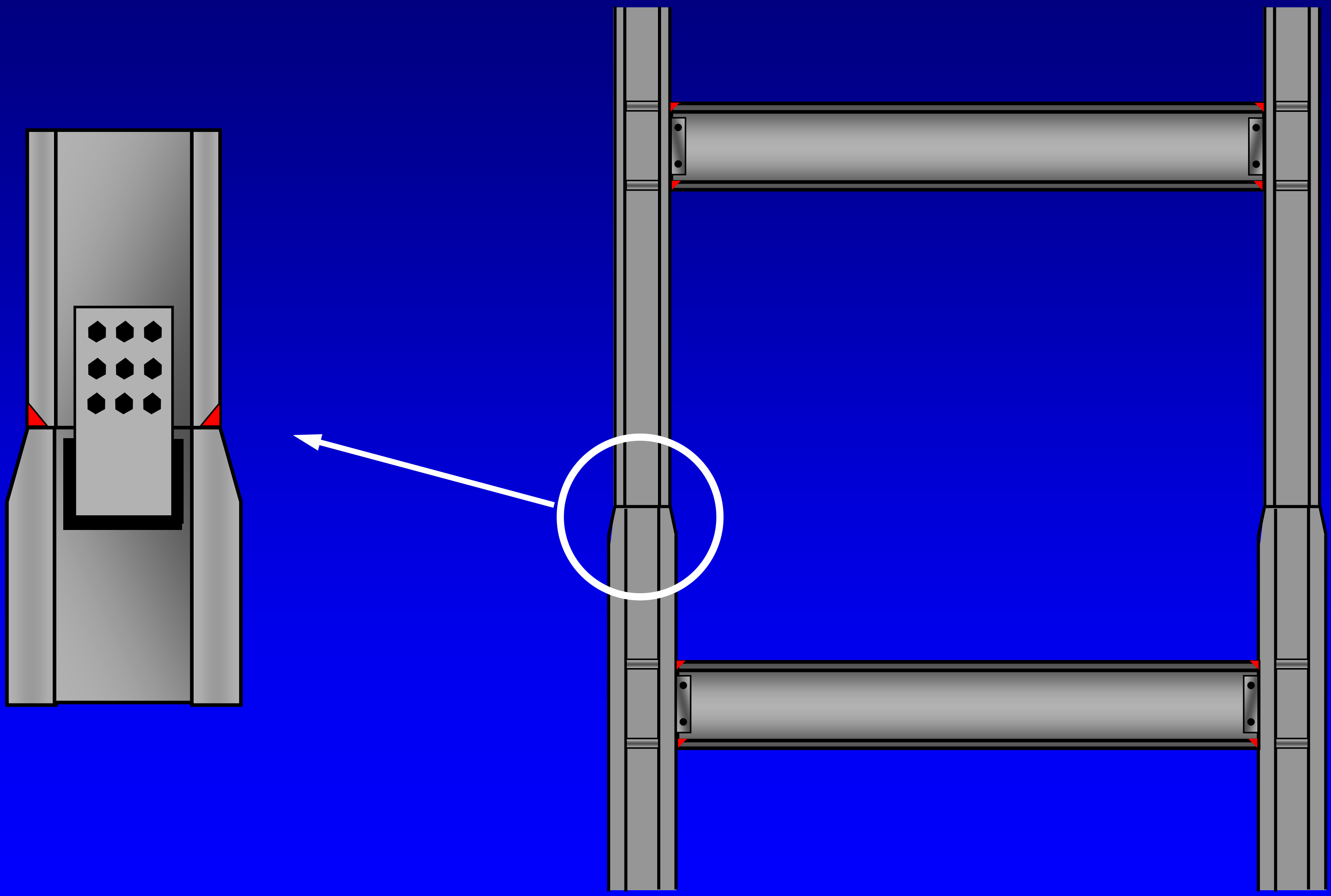
The *required axial compressive* and *tensile strength* of a column need not exceed:

a) The maximum load transferred to the column considering $1.1R_y$ times the nominal strengths of the connecting beam or brace elements

b) The limit as determined from the resistance of the foundation to overturning uplift.

AISC Seismic Provisions:

8.4 Column Splices

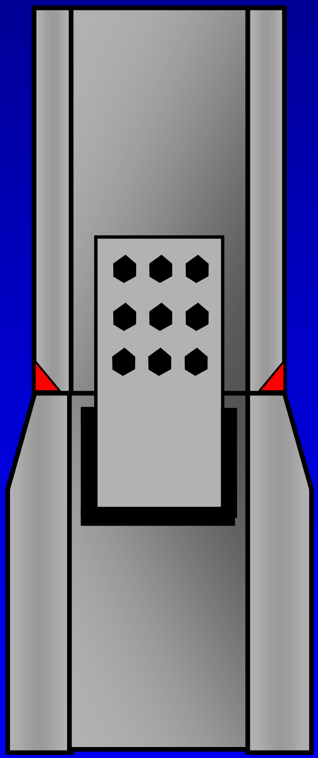


AISC Seismic Provisions:

8.4 Column Splices

8.4a. General

Column splices in any SLRS frame must satisfy requirements of Section 8.4a.



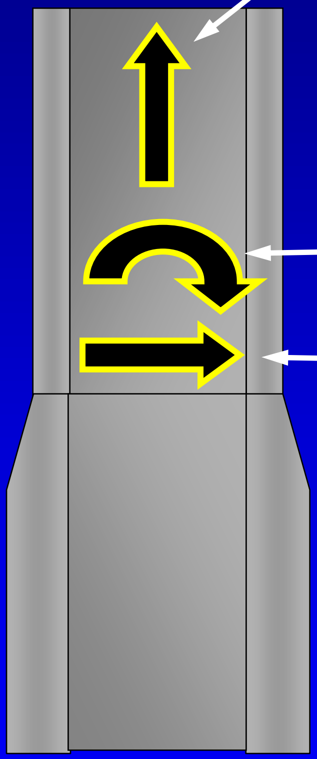
Additional requirements for columns splices are specified for:

- Special Moment Frames (Section 9.9)
- Intermediate Moment Frames (Section 10.9)
- Special Concentrically Braced Frames (Section 13.5)
- Buckling Restrained Braced Frames (Section 16.5c)

AISC Seismic Provisions:

8.4 Column Splices

8.4a. General



$P_{u\text{ - splice}}$ — Based on amplified seismic loads or capacity design analysis

$M_{u\text{ - splice}}$, $V_{u\text{ - splice}}$ — Based on code level forces

The required strength of column splices shall equal the required strength of columns, including that determined from Section 8.3

AISC Seismic Provisions:

8.4 Column Splices

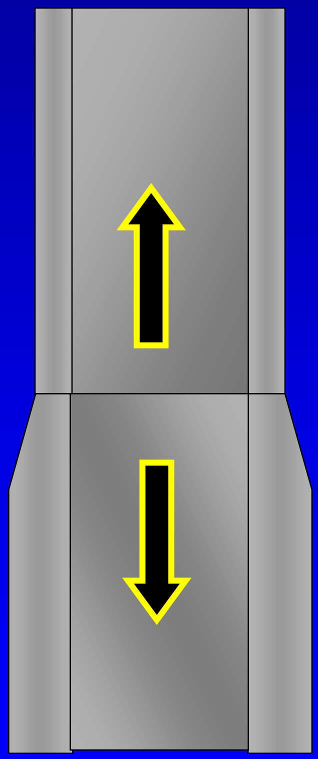
8.4a. General (cont).

Welded column splices subjected to net tension when subjected to amplified seismic loads, shall satisfy both of the following requirements:

1. If partial joint penetration (PJP) groove welded joints are used, the design strength of the PJP welds shall be at least 200-percent of the required strength.

   And....

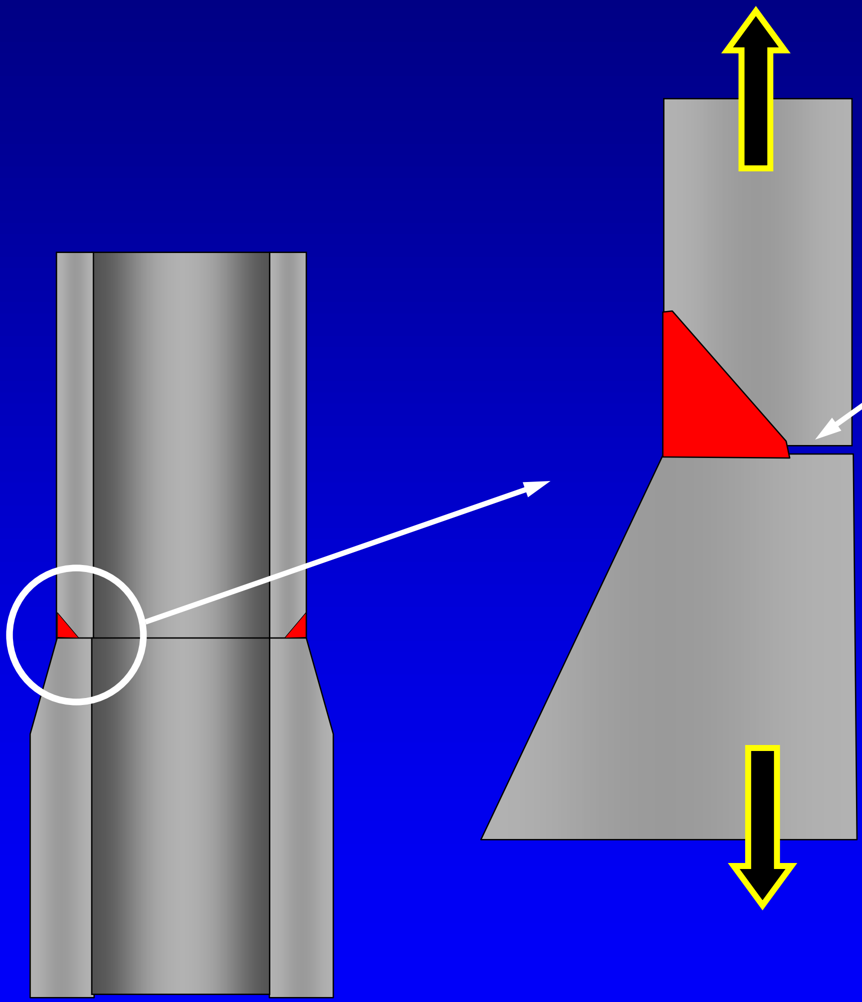
2. The design strength of each flange splice shall be at least 0.5 R_y F_y A_f for the smaller flange



AISC Seismic Provisions:

8.4 Column Splices

8.4a. General (cont).



PJP Groove Weld

Stress concentration: Fracture initiation point.

Design PJP groove weld for 200 % of required strength

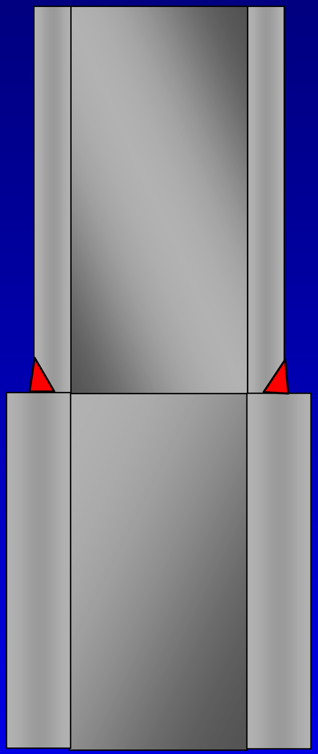
(PJP Groove welds not permitted in column splices for Special and Intermediate Moment Frames)

AISC Seismic Provisions:

8.4 Column Splices

8.4a. General (cont).

Where PJP grove welds are used, beveled transitions are not required.



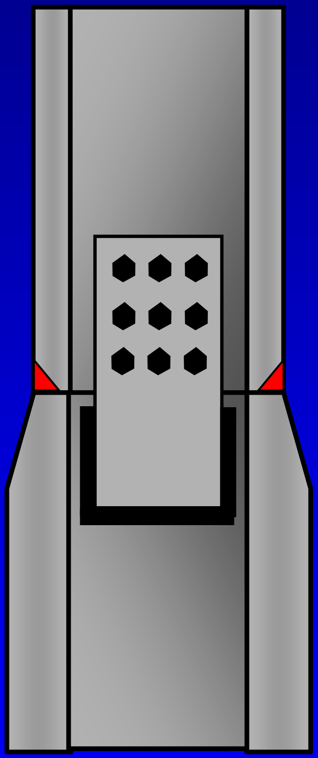
Where Complete Joint Penetration (CJP) groove welds are used, beveled transitions are required per AWS D1.1

AISC Seismic Provisions:

8.4 Column Splices

8.4a. General (cont).

Column web splices shall be bolted or welded, or welded to one column and bolted to the other.

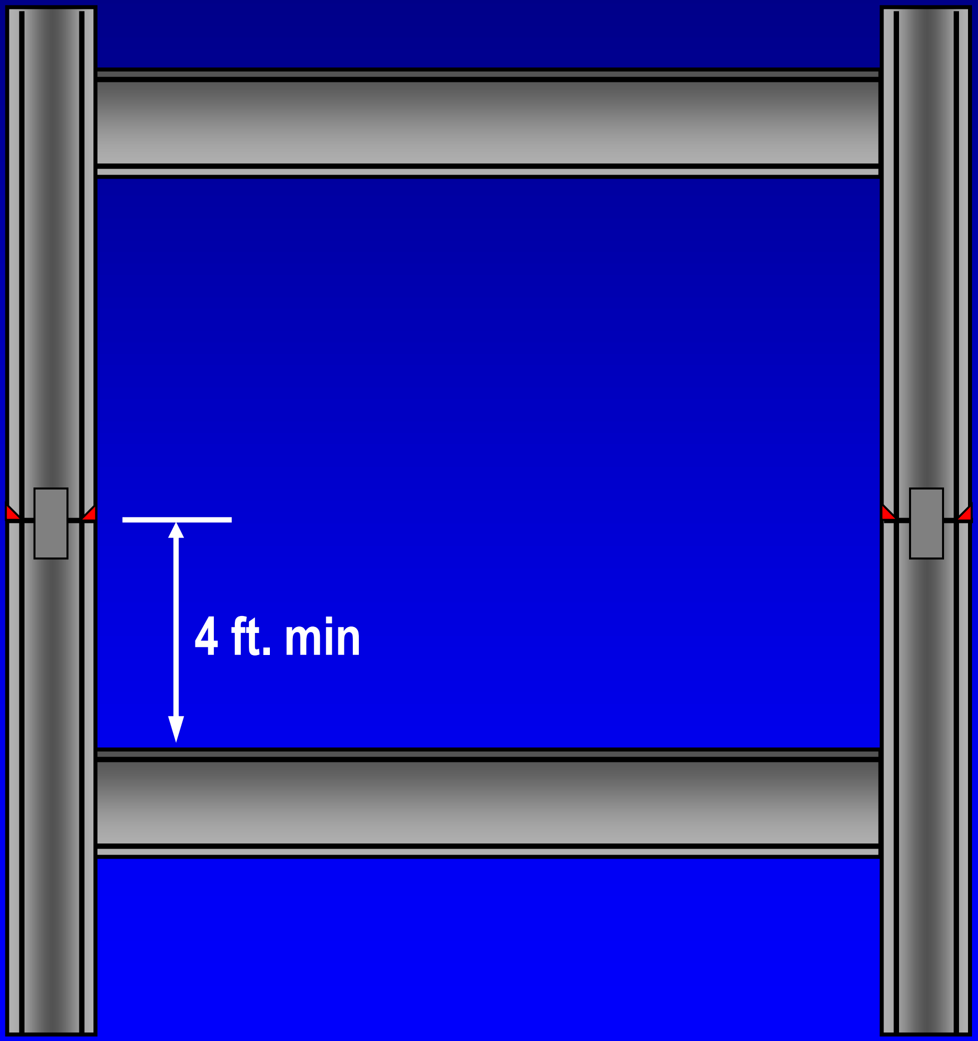


AISC Seismic Provisions:

8.4 Column Splices

8.4a. General (cont).

Splices made with fillet welds or PJP welds shall be located at least 4-ft. from beam-to-column connections

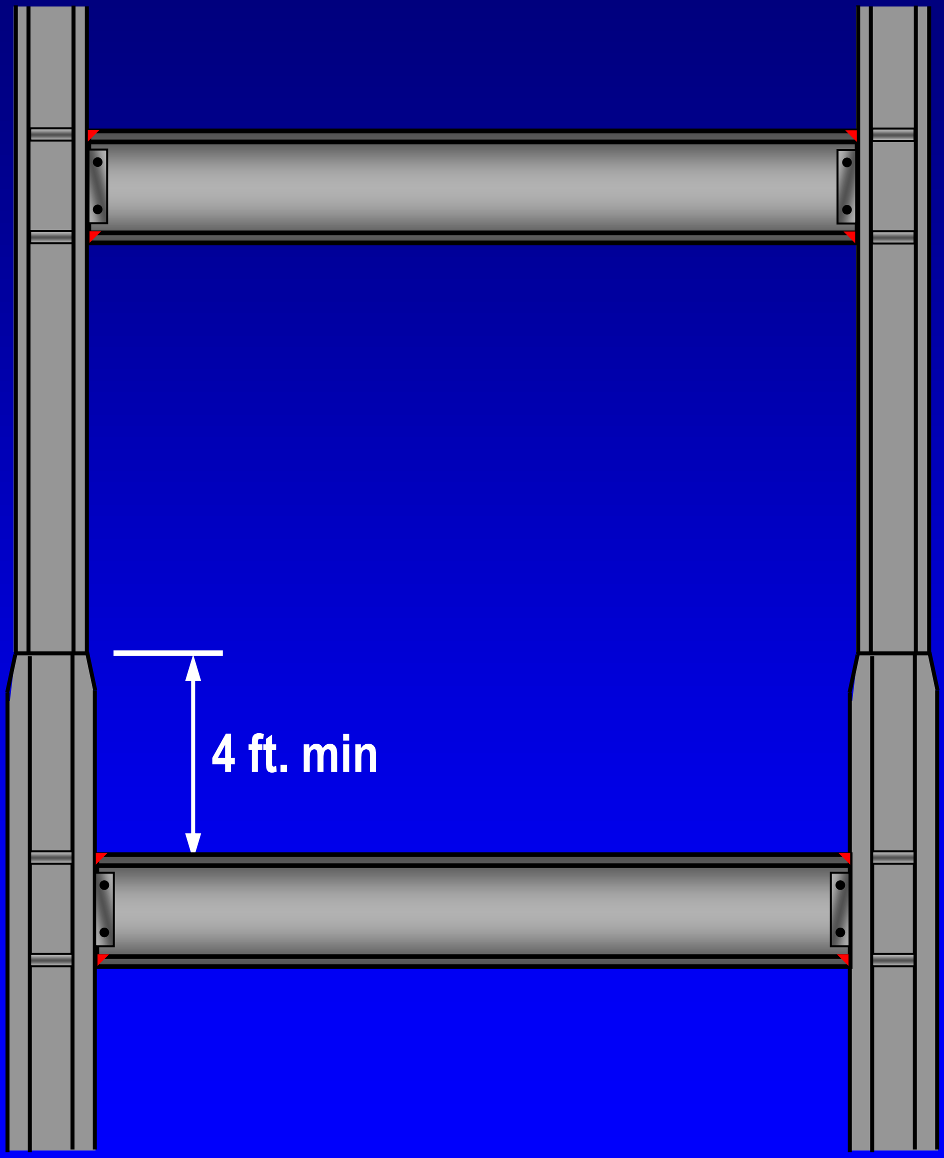


AISC Seismic Provisions:

8.4 Column Splices

8.4a. General (cont).

Splices made with fillet welds or PJP welds shall be located at least 4-ft. from beam-to-column connections

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***AISC Seismic Provisions*: Sections 1 to 8**

1. Scope
2. Referenced Specifications, Codes and Standards
3. General Seismic Design Requirements
4. Loads, Load Combinations and Nominal Strengths
5. Structural Design Drawings and Specifications, Shop Drawings and Erection Drawings
6. Materials
7. Connections, Joints and Fasteners
8. Members