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AISC Night School

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Course Description

Session 2: Introduction to Effective Seismic Design
February 12, 2018

This session begins with a discussion of moment-frame intended behavior and source of inelastic drift and includes a discussion of moment-frame analysis issues. Next, the lecture discusses moment-frame connection testing and lessons learned after the Northridge earthquake before addressing the treatment of connection design and member stability of moment frames.

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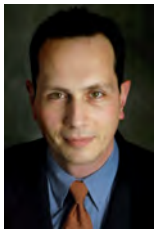
Learning Objectives

- Describe the intended behavior of moment-frames as a lateral system.
- List moment-frame analysis issues.
- Identify lessons learned from the Northridge earthquake.
- List connection design requirements for special moment frames.

There's always a solution in steel.

Seismic Design in Steel: Concepts and Examples

Session 2: Seismic Design of Moment Frames
February 12, 2018



Rafael Sabelli, SE

structural STEEL

Course objectives

- Understand the principles of seismic design of steel structures.
- Understand the application of those principles to two common systems:
  - Special Moment Frames
  - Buckling-Restrained Braced Frames.
- Understand the application of design requirements for those systems.

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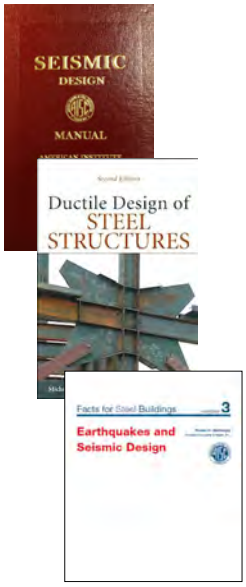
Resources

- AISC *Seismic Design Manual*
- *Ductile Design of Steel Structures*, Bruneau, Uang, and Sabelli, McGraw Hill.
- *Earthquakes and Seismic Design,* Facts for Steel Buildings #3. Ronald O. Hamburger, AISC.
- Other publications suggested in each session



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Other resources

- AISC Solutions Center
  - 866.ASK.*AISC* (866-275-2472)
  - Solutions@AISC.org
- AISC Night School
  - Nightschool@AISC.org

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Course outline

Part I: Concepts

1. Introduction to effective seismic design
2. **Seismic design of moment frames**
3. Seismic design of braced frames
4. Seismic design of buildings

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Course outline

Part II: Application

5. Planning the seismic design
6. Building analysis and diaphragm design
7. Design of the moment frames
8. Design of the of braced frames

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Session 2: Seismic design of moment frames

Session topics

- Moment-frame behavior
- Analysis of moment frames
- Moment-frame connections and Northridge lessons
- Beam-to-column connection design and construction
- Prequalified connections
- Additional topics (time permitting)

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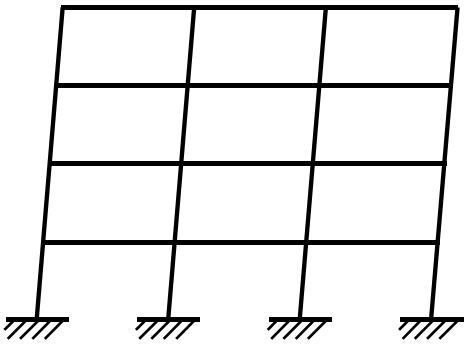
Moment-frame behavior

Lateral load resistance

- Column shear
- Column moment
- Beam moment
- Beam shear
- Overturning



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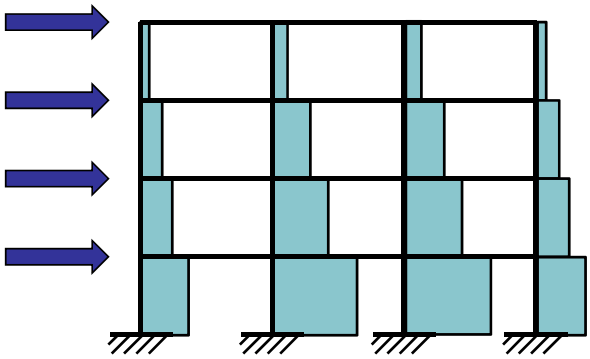
Column shear



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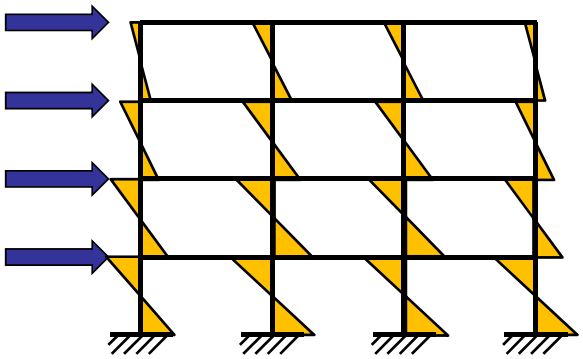
Column moment



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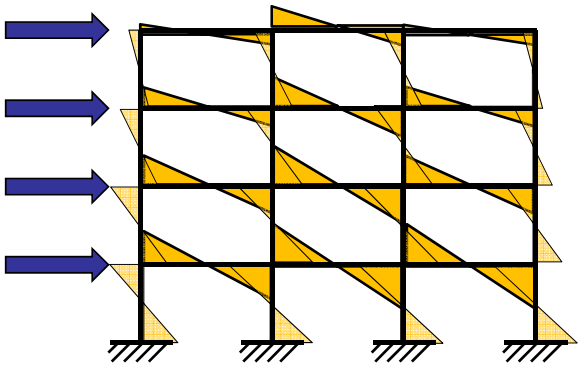
Beam moment



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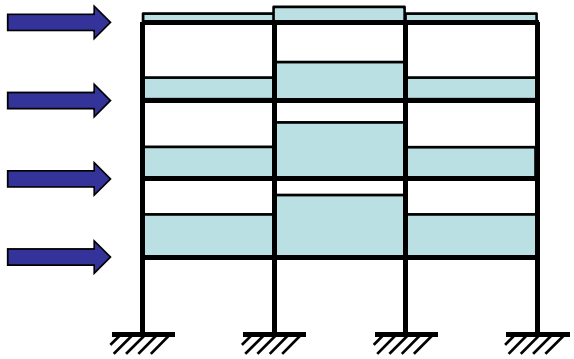
Beam shear



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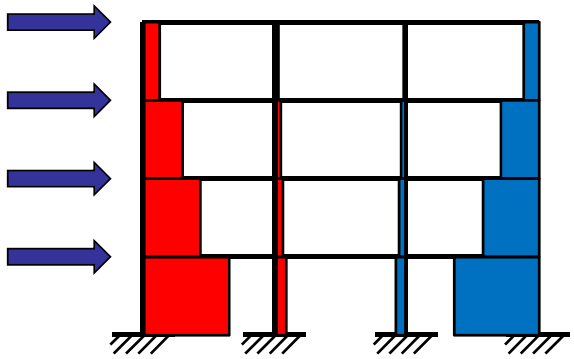
Overturning



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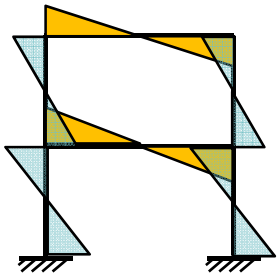
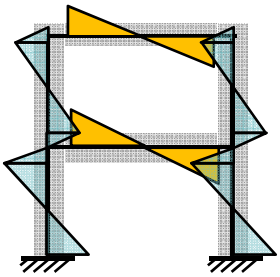
Moment detail



Centerline model



Model with member depth:
Beams stop short of centerlines
Moment reversal in columns at connection
High moment gradient in column at connection

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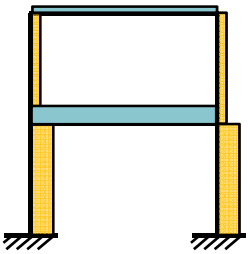
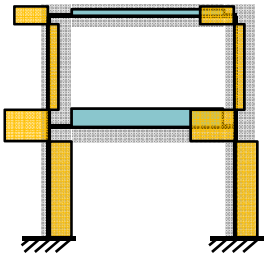
Shear detail



Centerline model



Model with member depth:
Beams stop short of centerlines
Shear reversal in columns at connection
High shear in column at connection

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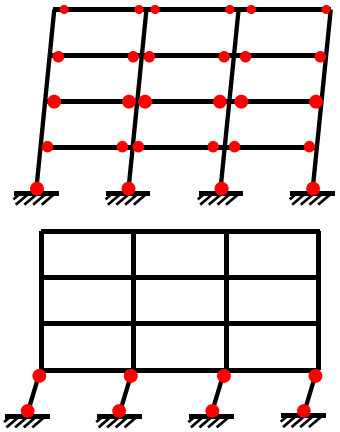
Ductility concept

- Encourage
  - o Flexural hinging in beams
- Avoid
  - o Flexural yielding of columns



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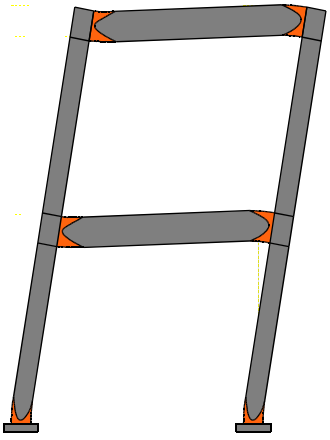
Plastic hinges in beams



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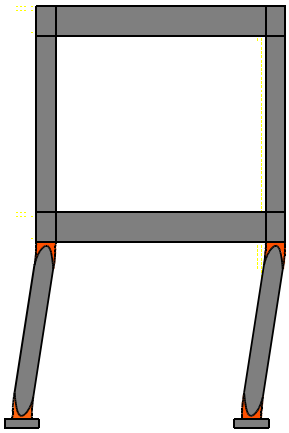
Plastic hinges in columns



Potential for soft story collapse

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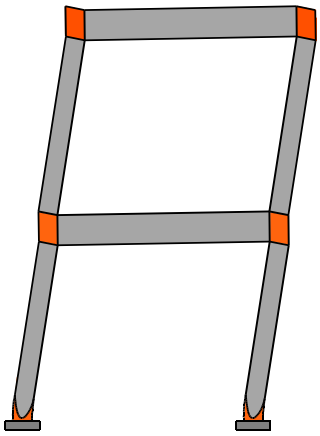
Plastic hinges in panel zones



Potential for column distortion

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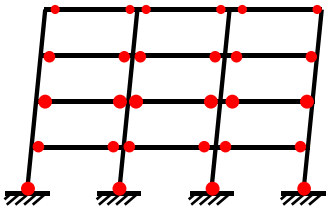
Fuse concept

- Fuse
  - Beam flexural plastic hinges
- Proportioning
  - Derive seismic forces from beam hinges for:
    - Beam shear
    - Column
      - Shear
      - Flexure
      - Axial
      - Panel zone shear



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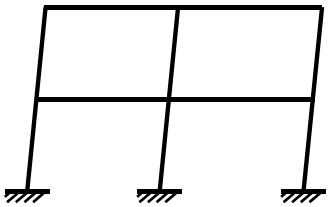
There's always a solution in steel.

Elastic analysis of moment frames

Elastic analysis

- Sources of flexibility
  - o Axial deformations
    - Columns at bay ends
  - o Flexural bending deformations
    - Beams and columns
  - o Shear deformations
    - Typically only significant at connections
  - o Connections
    - Panel-zone shear
    - Special connections (RBS)



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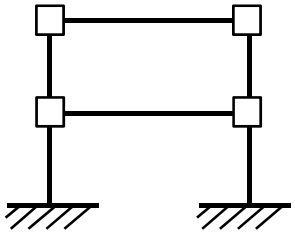
Analysis

- Panel-zone shear
  - o High shear in column web at connection
  - o Shear deformation allows relative rotation of beam and column
  - o Two ways of modeling
    - Explicitly model flexibility
    - Use extra beam and column flexibility to represent panel-zone flexibility (centerline model)



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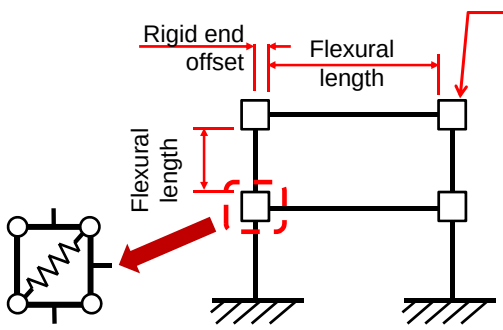
Panel zone model



- Accurate model
- Accounts for significant sources of flexibility
- Requires significant modeling effort

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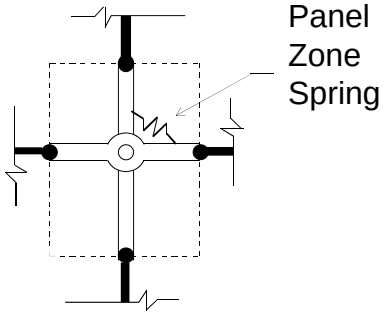
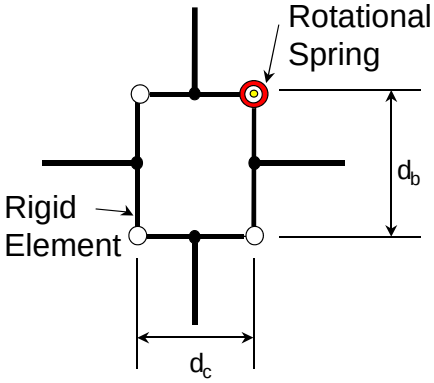
Panel zone models



Scissor Elements (approximate)



Parallelogram Model (eight additional elements)

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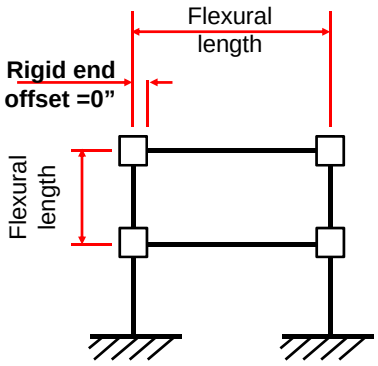
Panel zone approximation



- Sufficiently accurate model
- Negligible error for typical spans
- Requires little modeling effort
- Recommended for typical buildings

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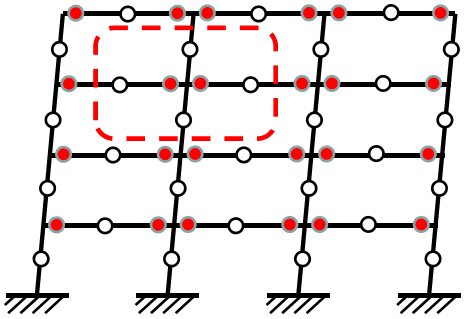
Inelastic analysis of moment frames

Portal frame to understand special moment frames



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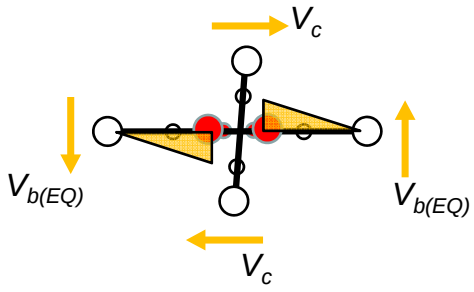
Portal frame to understand special moment frames



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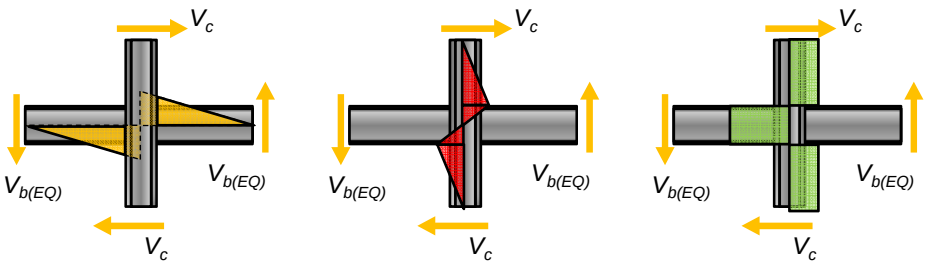
Portal frame to understand special moment frames



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Beam analysis

- Forces from beam plastic hinge formation
  - o Expected strength
  - o Strain Hardening
- Determine expected hinge location
  - o Typically not at column face
- Determine corresponding shear
- Determine demands on connection
- Determine demands on column

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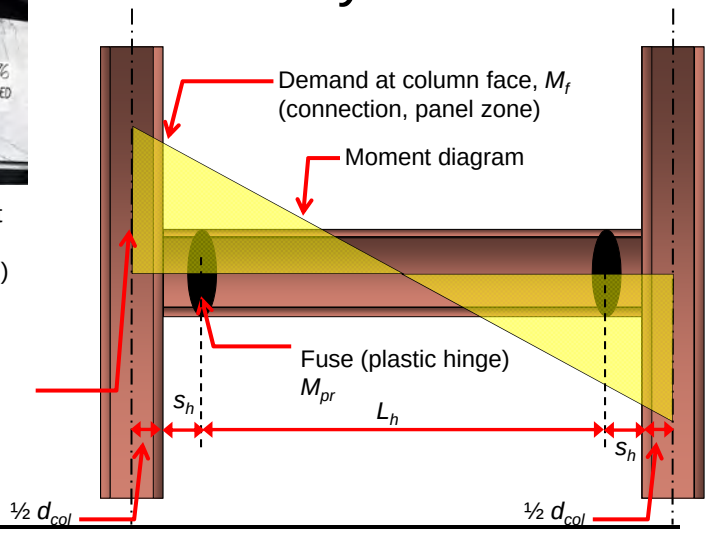
Beam analysis

Beam hinges form at ~1/2 beam depth from column face (s_h) (Some connections shift this slightly)

Demand at column centerline, M_{cl} (column design)



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Plastic-hinge moment

- $M_{pr} = 1.1\, R_y\, F_y\, Z$ (AISC 341-10 §E3.4a)
  - Z = plastic section modulus
  - F_y = specified minimum yield strength
  - R_y = factor representing material overstrength
  - $R_y F_y$ = expected yield strength
  - 1.1 = factor representing strain hardening
- $M_{pr} = 1.15\, R_y\, F_y\, Z$ (AISC 341-16 §E3.4a)
  - C_{pr} = 1.15 given in AISC 358

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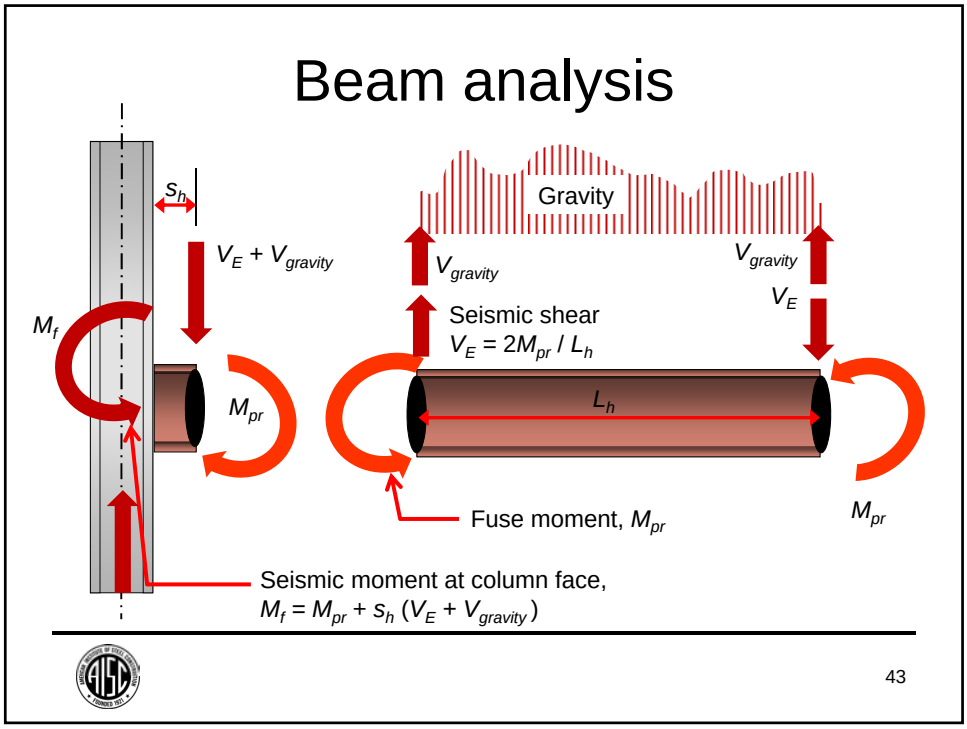

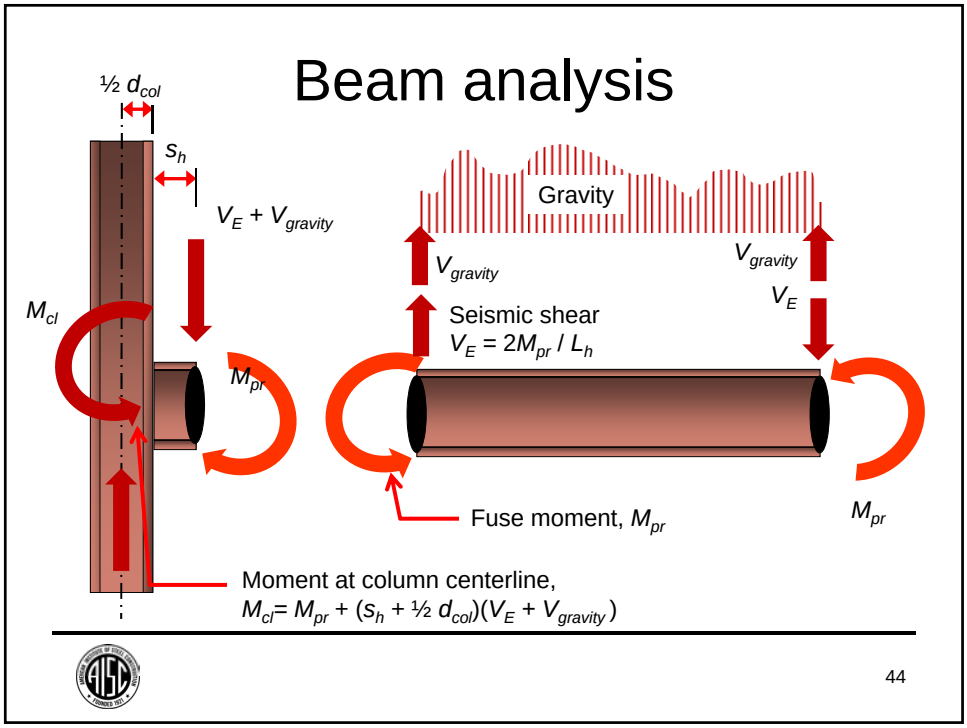

Column analysis

- Forces from beam analysis
  - o Based on beam strength
- Strong-column/weak-beam analysis
  - o Promote beam yielding over column yielding
- Panel-zone demands
  - o Promote beam yielding over panel-zone yielding
- Column shear affects demands
  - o Estimate using “portal frame”

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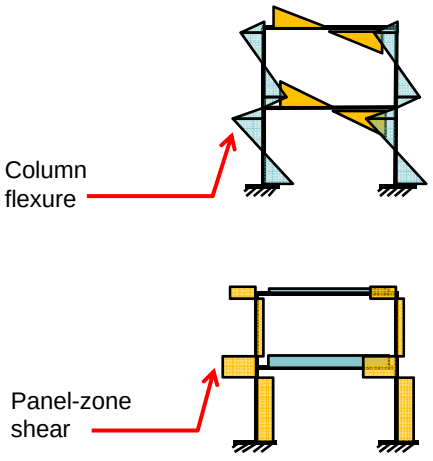
Column analysis

- Use beam capacity to determine:
  - o Column flexure
  - o Panel-zone shear
- Requires determining column shear
  - o Corresponding to beam flexural strength



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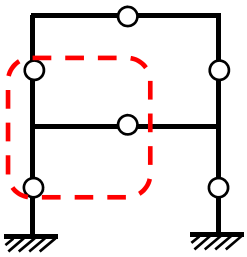
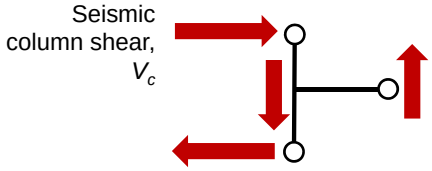
Column analysis

- Portal frame
  - o Assume inflection points
    - Beam mid-span
    - Column mid-height
  - o Determine shears and moments using free-body-diagrams





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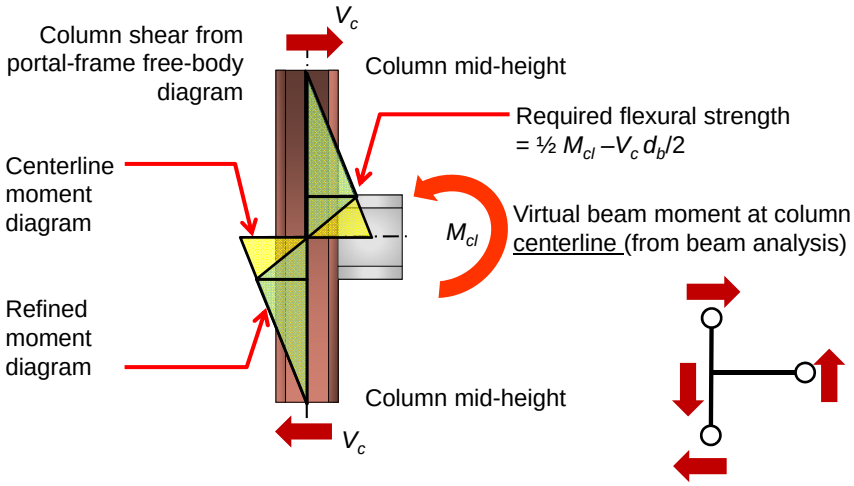
Column analysis: flexure



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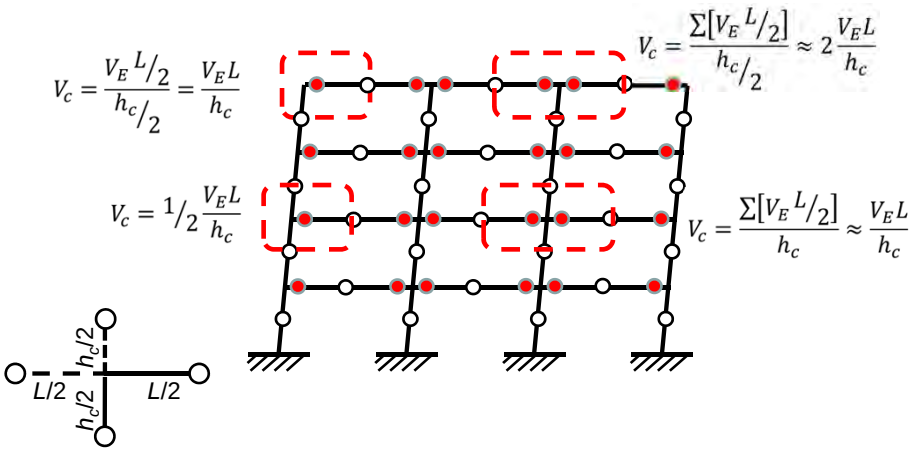
Column shear



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Moment-frame connections and Northridge lessons

Northridge earthquake

- Good performance of steel buildings
- Some unexpected damage to welded steel moment frames
- Some construction defects discovered
- Typical damage: bottom flange weld fracture
  - Or in adjacent base metal

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Northridge Moment Connection Damage

- High strain at beam flange groove welds
- Inadequate participation of beam web
- Effect of weld access hole
- Effect of column flange bending
- Materials (toughness and overstrength)
- Welding techniques

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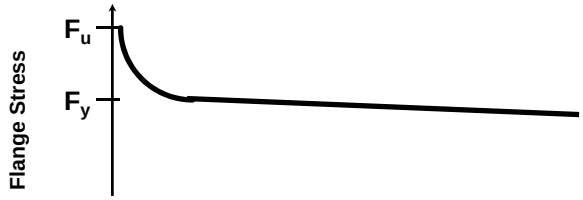
Lack of web participation



Bolted connection too flexible

Flexural stresses concentrate in flange

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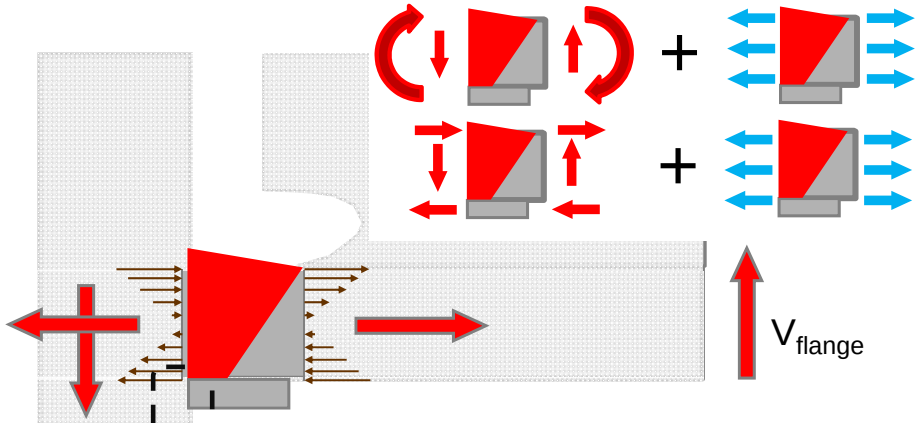
Increase in Flange Stress Due to Shear in Flange



Flange axial tension + flange bending tension (and notch effect)

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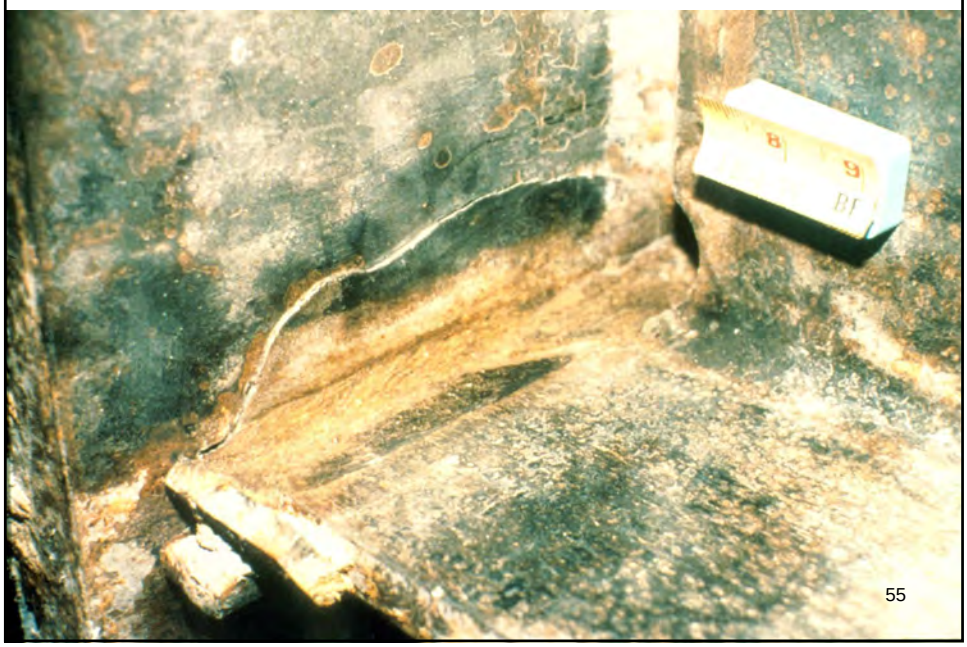

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Current practice

- Beam hinge moved away from column face
- Welded beam web
- Improved weld access hole to relieve restraint
- Backing reinforced or removed
- Higher toughness welds
- Improved welding techniques
- Improved inspection

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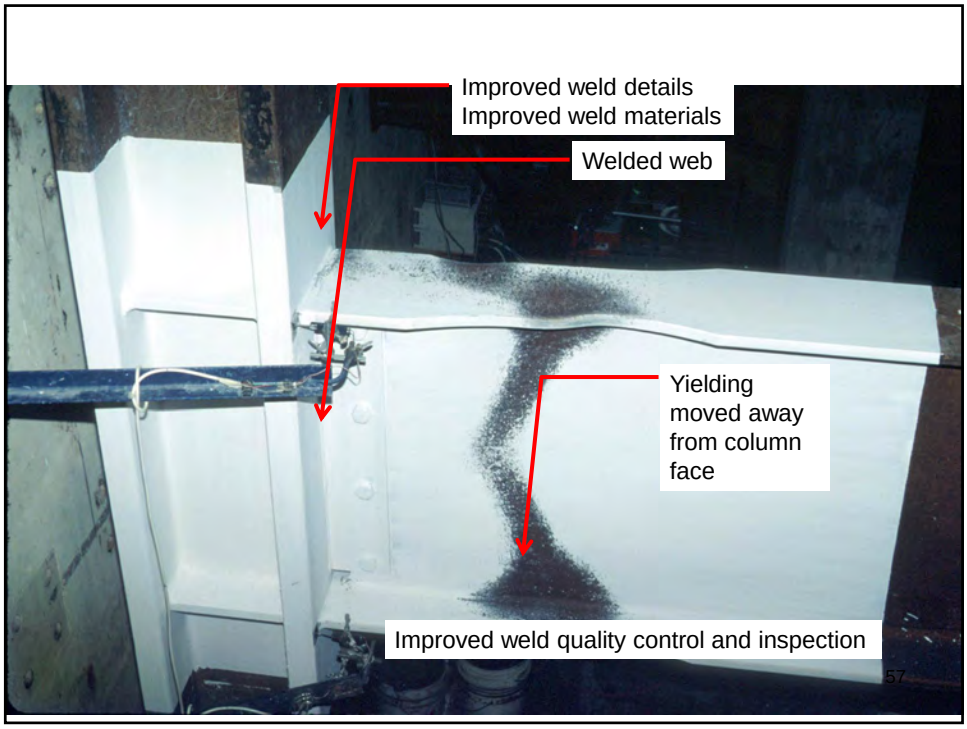
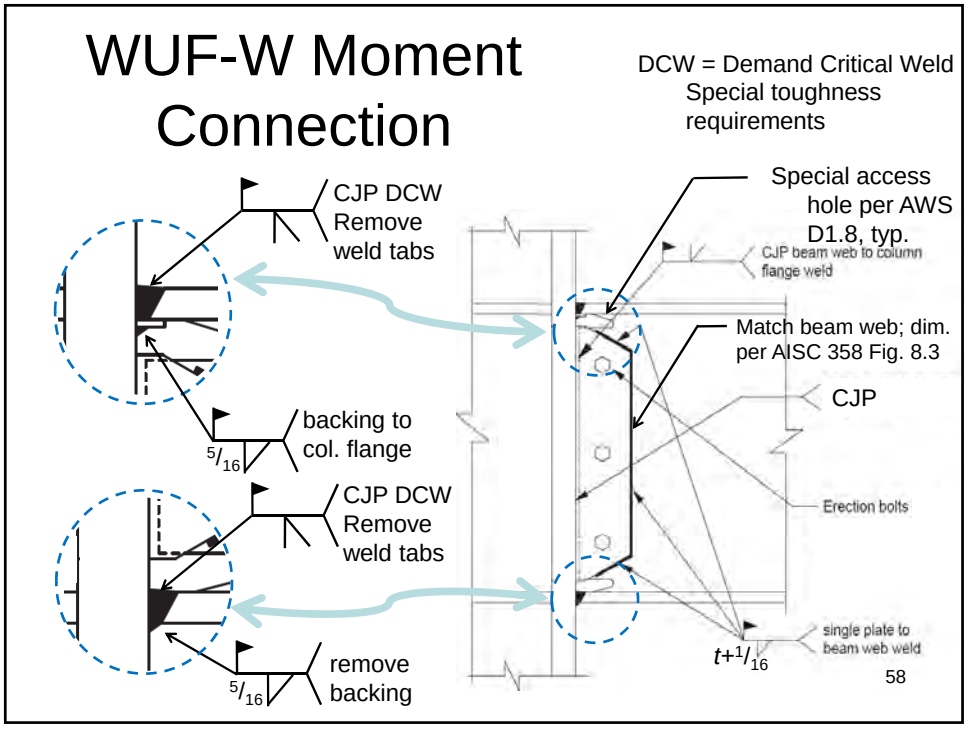
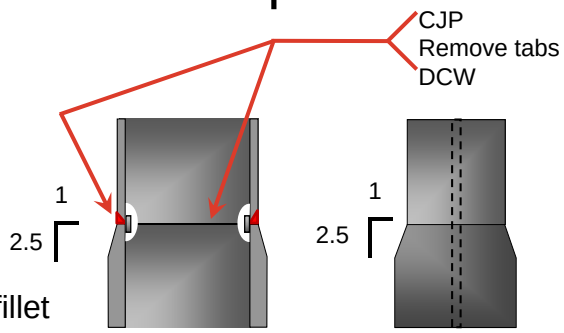




SMF Column Splice

- Weld tabs
  - (remove)
  - Grind to ¼”
- Backing
  - (remain)
  - No supplemental fillet
- AISC 341-16
  - PJP allowed
  - 85% or greater effective throat
  - Multiple limitations



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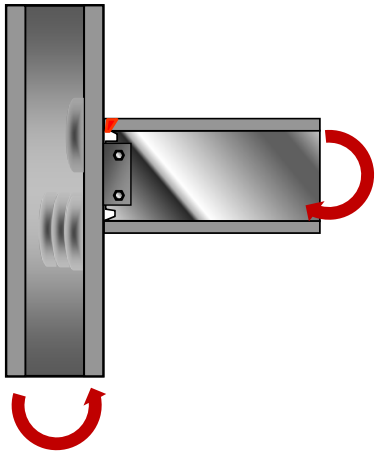
Beam-to-column connection design and construction

Connection limit States



- Beam flange weld rupture
- Column flange bending
- Column web yielding
- Column web crippling
- Column panel-zone shear
- (Beam shear connection)

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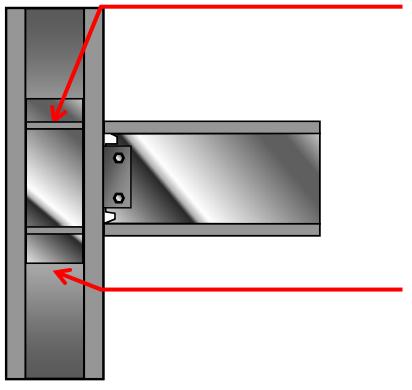
Connection limit States



Continuity plates (stiffeners) increase capacity for:
- Flange bending
- Web local yielding
- Web crippling

Doubler plates increase capacity for:
- Web local yielding
- Web crippling
- Panel-zone shear

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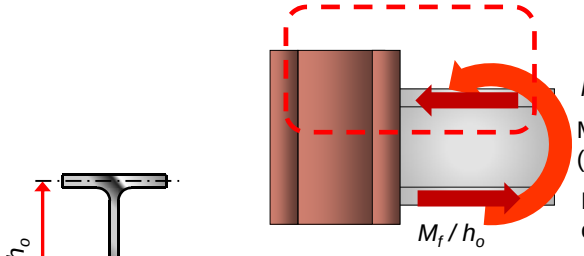
Column analysis: local limit states



M_f
Moment at column face (from beam analysis)

Decomposed into force couple

$P_f = M_f / h_o$
Refinement: instead of M_f / h_o, you may use $0.85 M_f / h_o$ for connections with welded webs for local forces (WLY, WC, continuity plates).

AISC 341-16

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Continuity plates (E3.6f)

- Design for deficiency
  - Column limit states
    - WLY
    - WC
    - (FLB)
  - $P_f = 0.85^{2016} M_f / h_o$
  - Cont. Plate:
    - $R_u = P_f - \text{Min}(\phi R_n)$
- Additional requirements
  - $t_{cf} > b_f/6$
    - (flange stiffness)

$$t_{cf} \geq 0.4\sqrt{1.8 b_{bf} t_{bf} \frac{R_{yb} F_{yb}}{R_{yc} F_{yc}}}$$

    - (FLB)
    - $P_f = 1.5 b_{bf} t_{bf} R_{yb} F_{yb}$
      - (341-10 only!)
  - Otherwise, use cont. plates

AISC 341 has requirements for continuity plates when used

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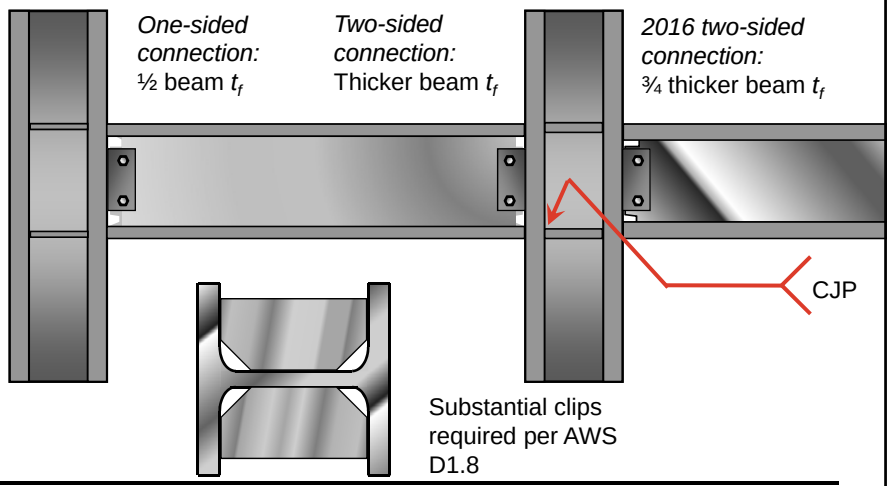
Continuity plates



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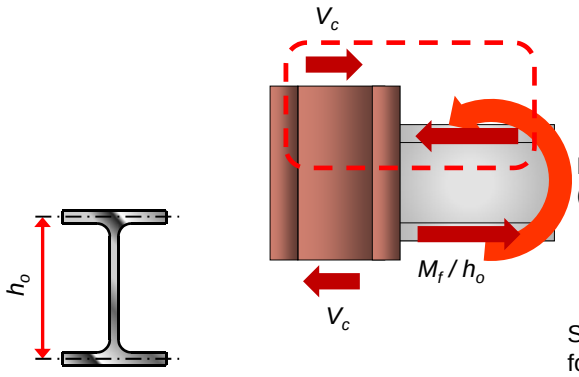
Column analysis: panel zone



Moment at column face (from beam analysis)

Decomposed into force couple

Subtract column shear for net panel-zone shear

$V_{pz} = M_f / h_o - V_c$

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Panel zone strength

AISC 360 J10.6	Low axial force	High axial force
Panel zone deformation <u>not</u> modeled	$P_r \le 0.4P_c$ $0.6F_y d_c t_w$	$P_r > 0.4P_c$ $0.6F_y d_c t_w \left[1.4 - \frac{P_r}{P_c}\right]$
Panel zone deformation modeled	$P_r \le 0.75P_c$ $0.6F_y d_c t_w \left[1 + \frac{3b_{cf}t_{cf}^2}{d_b d_c t_w}\right]$	$P_r > 0.75P_c$ $0.6F_y d_c t_w \left[1 + \frac{3b_{cf}t_{cf}^2}{d_b d_c t_w}\right]\left[1.9 - \frac{1.2P_r}{P_c}\right]$

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Panel zone strength

- Axial force
  - o High axial force rare for moment-frame columns
- Panel zone deformations
  - o Seismic panel zone shear demand is often independent of panel zone modeling
    - Based on (beam) member strength
    - Unlike wind, stability
  - o Panel zone (seismic) deformations required to be included (per codes)
  - o Second term requires large PZ deformations

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Proportioning (SC/WB) E3.4a

- Strong-Column/Weak-Beam (SC/WB)
  - o Ratio>1 required for SMF
    - Ratio>1 Makes story mechanism unlikely
    - Ratio>2 Makes column yielding unlikely

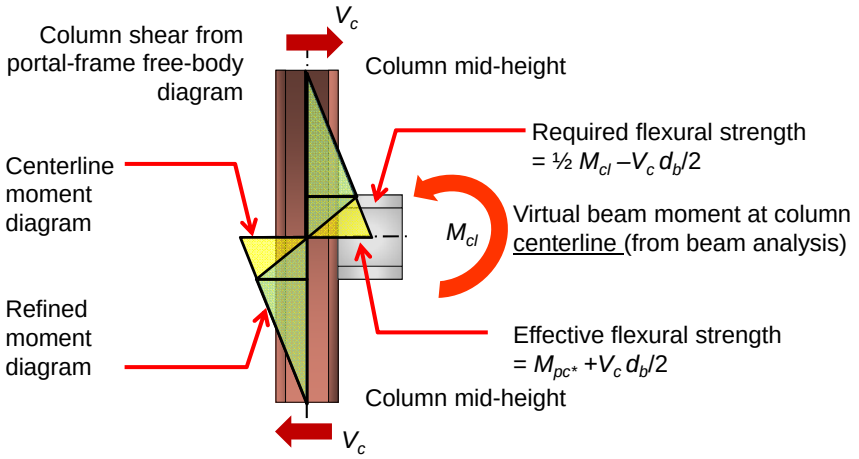
$$\frac{\Sigma M^*_{pc}}{\Sigma M^*_{pb}} > 1.0$$

$$\Sigma M^*_{pc} = \Sigma Z_c (F_{yc} - P_{uc}/A_g) + V_c\, d_b/2$$

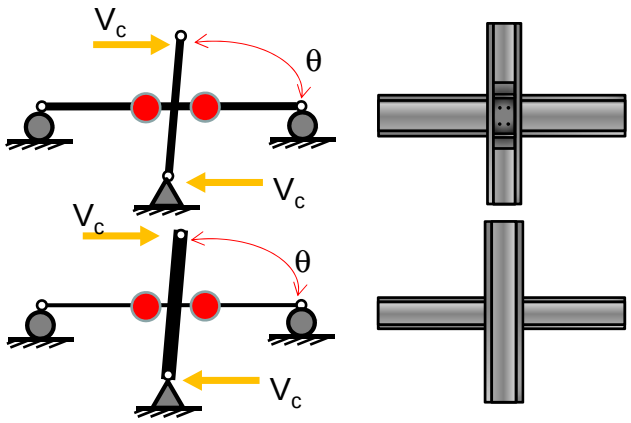
$$\Sigma M^*_{pb} = \Sigma\left[1.1 R_y F_{yb} Z_b + (s_h + d_c/2)(2M_{pr}/L_h \pm V_g)\right]$$

1.15 in 341-16

Proportioning (SC/WB)



Elimination of doublers and continuity plates



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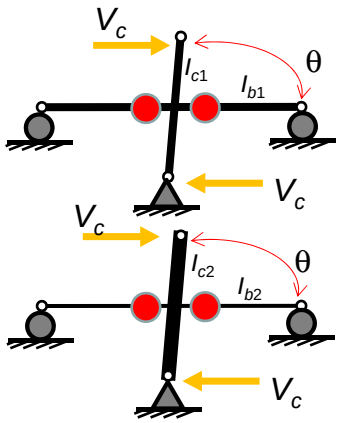
Elimination of doublers and continuity plates



Add flexibilities

$F_1 = {}^{\theta}/_{V_c} = F_{col1} + F_{beam1}$

Maintain flexibility of assembly

$F_2 = F_1 = F_{col2} + F_{beam2}$

$F_{beam2} = F_{col1} + F_{beam1} - F_{col2}$

$$I_{B2} \geq \frac{1}{\frac{N_c}{N_b}\frac{h}{L}\left({}^{1}/_{I_{C1}} - {}^{1}/_{I_{C2}}\right) + {}^{1}/_{I_{B1}}}$$

For $\Delta < \Delta_{all}$:

$$I_{B2} \geq \frac{1}{\frac{N_c}{N_b}\frac{h}{L}\left({}^{\Delta_{all}}/_{\Delta I_{C1}} - {}^{1}/_{I_{C2}}\right) + {}^{\Delta_{all}}/_{\Delta I_{B1}}}$$

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Connection construction

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- Typical welded-flange beam-to-column connection
  - Most SMF connections now require welded web
- Field welds made from welding platforms

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- Inspection
  - Ensures quality
    - Joints experience high strain
    - Access conditions are difficult
    - Critical joints for lateral resistance

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Conformance Demonstration

- Ordinary Moment Frame (OMF [no testing or prequalification])
  - Develop beam strength
  - Use high notch-toughness
  - Provide special joint detailing at welded beam flanges and continuity plates
- Special and Intermediate Moment Frames (SMF [E3.6c] & IMF [E2.6c])
  - Use prequalified connection; or
  - Use tested connection
    - Similar sizes to project
    - 4% rotation for SMF
    - 2% rotation for IMF

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There's always a solution in steel.

Prequalified connections

Prequalified connections

- AISC 341 requires "conformance demonstration" of connections
  - Qualification testing
    - Limited extrapolation
  - "Prequalification"
    - Based on testing
    - Applicability determined by expert panel
    - Published standard
- AISC 358
  - AISC prequalification standard
  - Produced by AISC prequalification panel
  - Multiple connections
    - Design methods
    - Limits
    - Requirements

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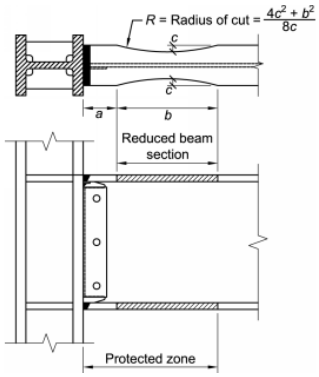
Reduced beam section

- Beam intentionally weakened to create controlled yielding
- Connection at face of column stronger than reduced section
- Capacity design ensures good performance
- Reduction in stiffness
- Potential reduction in stability



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Reduced beam section

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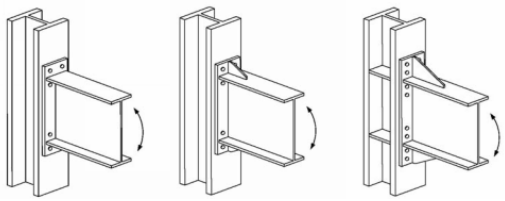
Bolted end plate

- End-plate connection at column face
  - o Stronger than beam
  - o Capacity design
    - Flexural yielding of
    - Bolt tension
    - Weld tension
    - Weld shear
    - etc.



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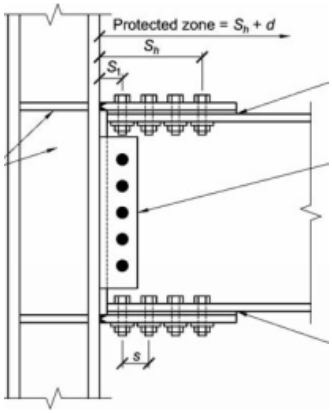
Bolted flange plate

- Beam is fuse
- Flange plates transfer moment to column
- Web does not participate in transferring moment
- Multiple bolt-related limit states



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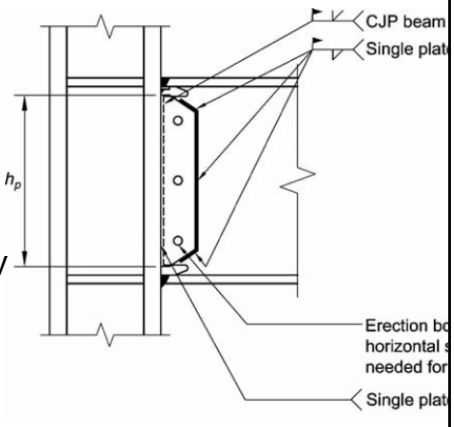
Welded unreinforced flange, welded web (WUF-W)

- Welded web
- Improved materials
  - Toughness
  - Limited tensile strength
- Improved welding details
  - Restraint relief provided by special access hole
  - Backing details
  - Removal of weld tabs
- Improved QA/QC



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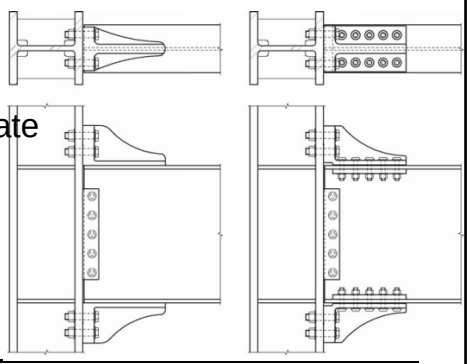
Kaiser Bolted bracket

- Proprietary
- High-strength cast-steel brackets
- Configuration
  - Bolted or welded to beam
  - Bolted to column
- Similar to Bolted Flange Plate
  - Beam expected to yield
- Capacity design used for
  - Bracket
  - Column
  - Local limit states in beam



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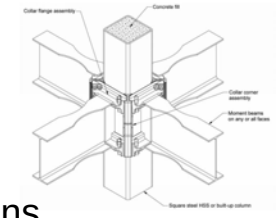
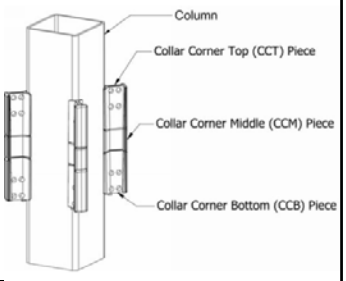
CONXL (ConXtech)

- Proprietary
- 2-way system
- Bolted collars
- 16” concrete-filled box columns
- RBS if required
  - (to meet SC/WB)
- Beam expected to yield
  - Capacity design
  - Consideration of both axes





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Other Connections

- AISC 341
  - Allows prequalified connections
  - Defines prequalification
- AISC CPRP meets requirements for prequalification body
- Other entities may also meet requirements
  - ICC-ES
- Connections
  - Slotted Web
    - ICC-ES report
  - Free Flange
  - Welded Haunch

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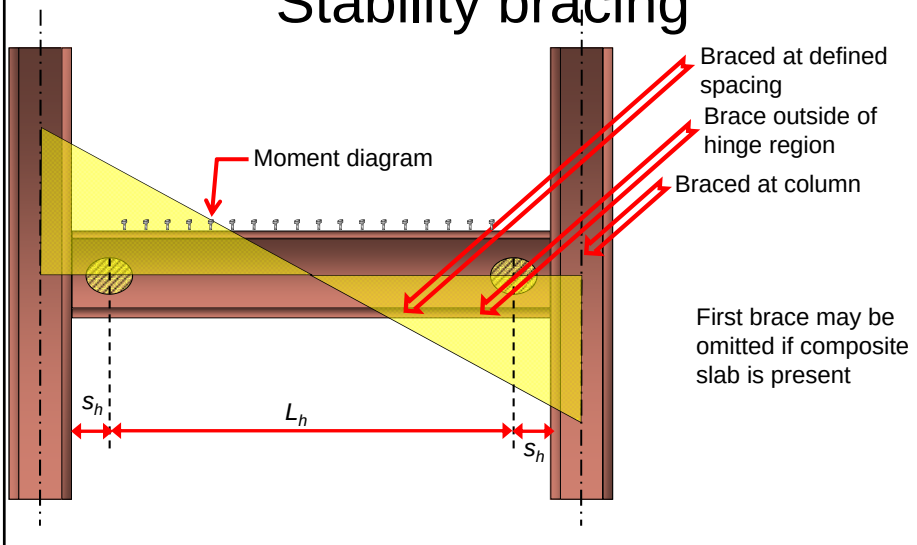
There's always a solution in steel.

Additional topics

Stability bracing



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Stability bracing

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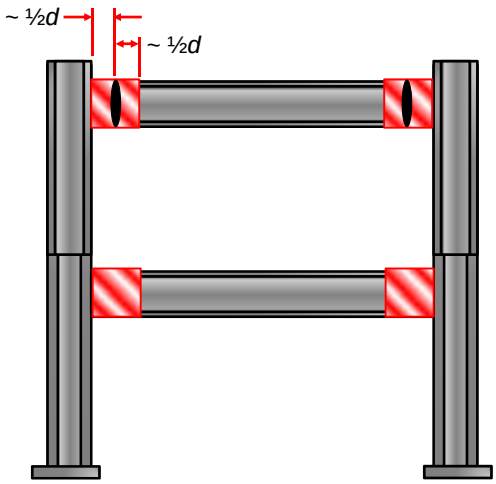
Protected zones



Beam-to-column connections

Protected zones defined for prequalified connections

Protected zones must be established for connections qualified by testing (considering the extent of inelastic strain)

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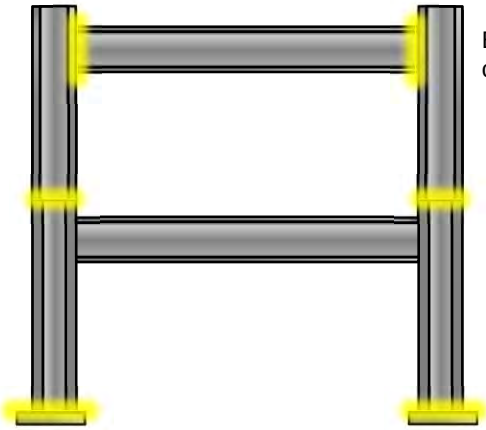
Demand critical welds



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Summary

There's always a solution in steel.

Summary

- Moment frames provide inelastic drift through beam hinging
- Proportioning moment frames to favor beam hinging increases the inelastic drift capacity
- Highly-restrained welded joints at beam-to-column connections require attention to detail to allow beam yielding before rupture
- There are many prequalified connections have been developed that provide reliable performance

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There's always a solution in steel.

End of session 2

Next:

Seismic design of braced frames

structural STEEL

Additional resources

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Question time

There's always a solution in steel.

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Individual Webinar Registrants

CEU/PDH Certificates

Within 2 business days…

- New reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

8-Session Registrants

CEU/PDH Certificates

One certificate will be issued at the conclusion of all 8 sessions.

8-Session Registrants

Access to the quiz: Information for accessing the quiz will be emailed to you by Wednesday. It will contain a link to access the quiz. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG

Quiz and Attendance records: Posted Tuesday mornings.
www.aisc.org/nightschool - click on Current Course Details.

Reasons for quiz:

- EEU – must take all quizzes and final to receive EEU
- CEUs/PDHS – If you watch a recorded session you must take quiz for CEUs/PDHs.
- REINFORCEMENT – Reinforce what you learned tonight. Get more out of the course.

NOTE: If you attend the live presentation, you do not have to take the quizzes to receive CEUs/PDHs.

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Access to the recording: Information for accessing the recording will be emailed to you by this Wednesday. The recording will be available for three weeks. For 8-session registrants only. EMAIL COMES FROM NIGHTSCHOOL@AISC.ORG.

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Night School Resources for 8-session package Registrants

Find all your handouts, quizzes and quiz scores, recording access, and attendance information all in one place!

Night School Resources for 8-session package Registrants

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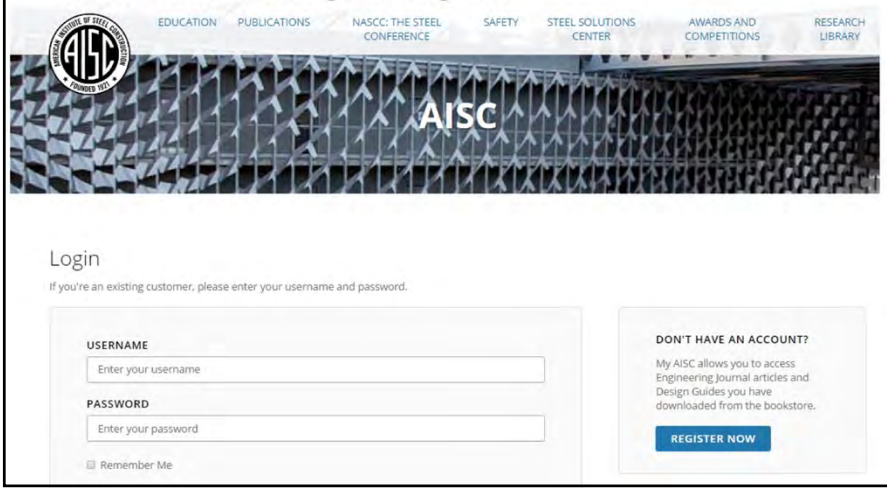

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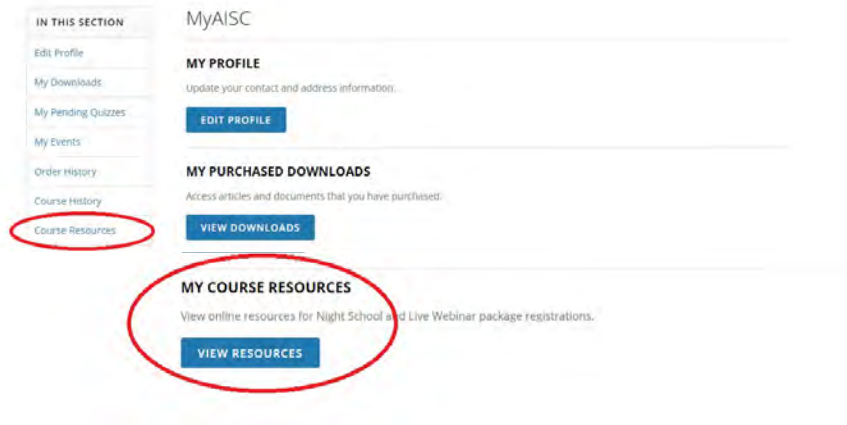

Night School Resources for 8-session package Registrants

Course Resources

Event	Start Date
NS 13 8-Session Package-Night School 13 - Design of Industrial Buildings	1/30/2017 7:00:00 PM
NS 14 8-Session Package-Night School 14 - Fundamentals of Stability	6/5/2017 7:00:00 PM

Night School Resources for 8-session package Registrants

Night School 13: Design of Industrial Buildings

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS13 - Design Criteria	1/30/2017 7:00:00 PM	Handouts	View Passcode: NS13DSN	Pass Score: 80	Pending
NS13 - Economic Considerations	2/6/2017 7:00:00 PM	Handouts	Available 02/08/2017 5pm EST	Available 02/08/2017 5pm EST	Pending
NS13 - Lateral Load Systems and Details	2/13/2017 7:00:00 PM	Handouts	Available 02/15/2017 5pm EST	Available 02/15/2017 5pm EST	Pending
NS13 - Preliminary Design Procedures	2/27/2017 7:00:00 PM	Handouts	Available 03/01/2017 5pm EST	Available 03/01/2017 5pm EST	Pending
NS13 - Crane Girder Design and Frame Analysis	3/6/2017 7:00:00 PM	Handouts	Available 03/08/2017 5pm EST	Available 03/08/2017 5pm EST	Pending
NS13 - Frame Member and Connection Design	3/13/2017 7:00:00 PM	Handouts	Available 03/15/2017 5pm EST	Available 03/15/2017 5pm EST	Pending
NS13 - Transfer Crane Girder & Longitudinal Bldg Bracing Dsn	3/27/2017 7:00:00 PM	Handouts	Available 03/29/2017 5pm EST	Available 03/29/2017 5pm EST	Pending
NS13 - Building Envelope and Bracing Design	4/3/2017 7:00:00 PM	Handouts	Available 04/05/2017 5pm EST	Available 04/05/2017 5pm EST	Pending
NS13 - Final Exam	4/10/2017 7:00:00 PM			Available 04/12/2017 5pm EST	

Night School Resources for 8-session package Registrants

- Weekly “quiz and recording” email.
- Weekly updates of the master Quiz and Attendance record found at www.aisc.org/nightschool. Scroll down to Quiz and Attendance records.
  - Updated on Tuesday mornings.

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- Webinar connection information:
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- Link to handouts also found here.