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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

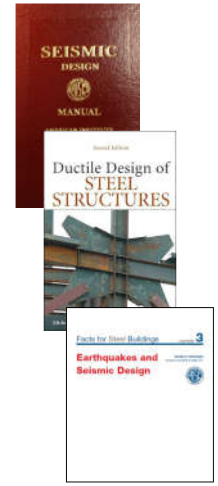
Rafael Sabelli, SE

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.

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

Other resources

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

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

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

13

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Session 2: Seismic design of moment frames

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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)

15

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Moment-frame behavior

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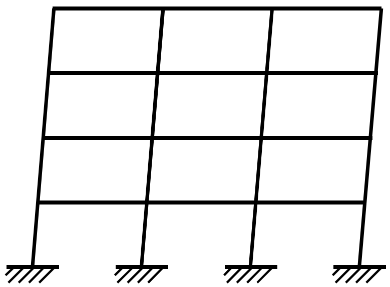
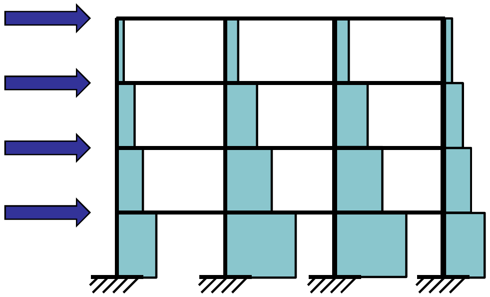
Lateral load resistance

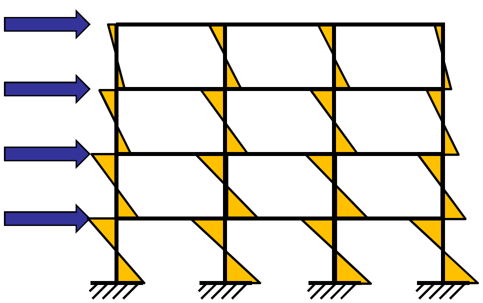
- Column shear
- Column moment
- Beam moment
- Beam shear
- Overturning



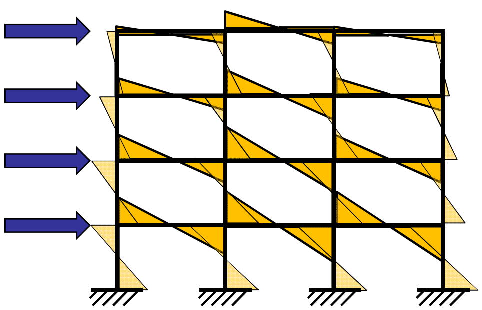
Column shear



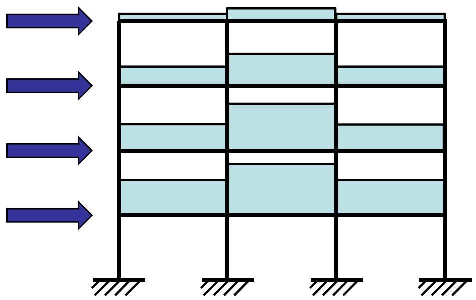
Column moment



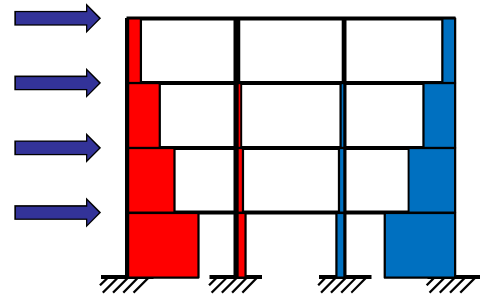
Beam moment



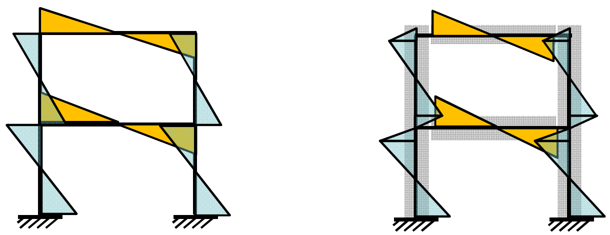
Beam shear



Overturning



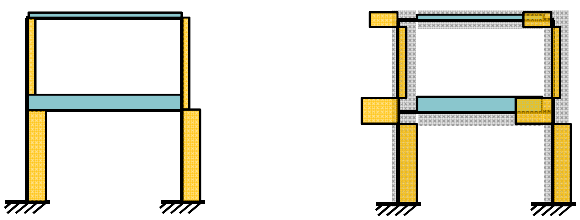
Moment detail



Centerline model

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

Shear detail

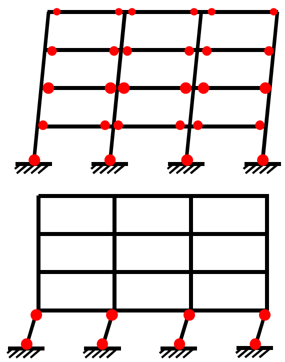


Centerline model

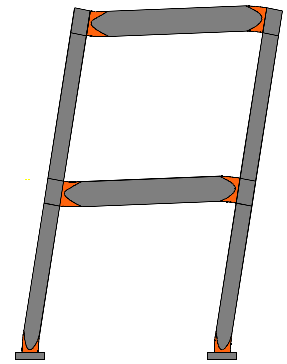
Model with member depth:
Beams stop short of centerlines
Shear reversal in columns at connection
High shear in column at connection

Ductility concept

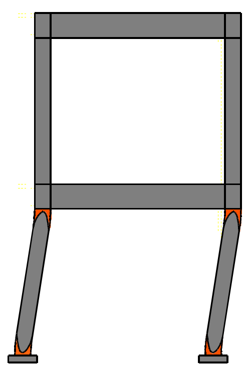
- Encourage
  - Flexural hinging in beams
- Avoid
  - Flexural yielding of columns



Plastic hinges in beams

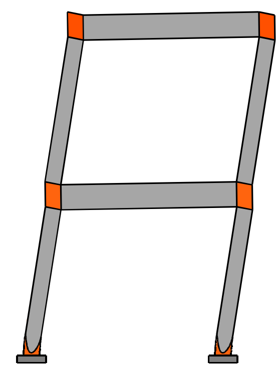


Plastic hinges in columns



Potential for soft story collapse

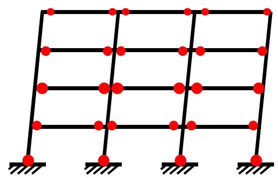
Plastic hinges in panel zones



Potential for column distortion

Fuse concept

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



29

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Elastic analysis of moment frames

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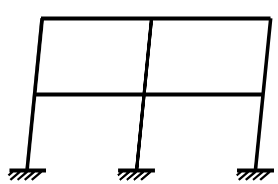
Elastic analysis

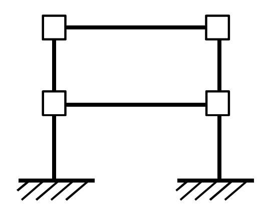
- Sources of flexibility
  - Axial deformations
    - Columns at bay ends
  - Flexural bending deformations
    - Beams and columns
  - Shear deformations
    - Typically only significant at connections
  - Connections
    - Panel-zone shear
    - Special connections (RBS)



31

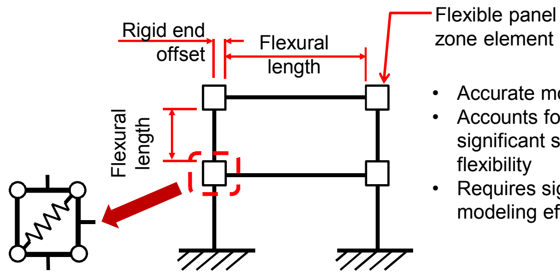
Analysis

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



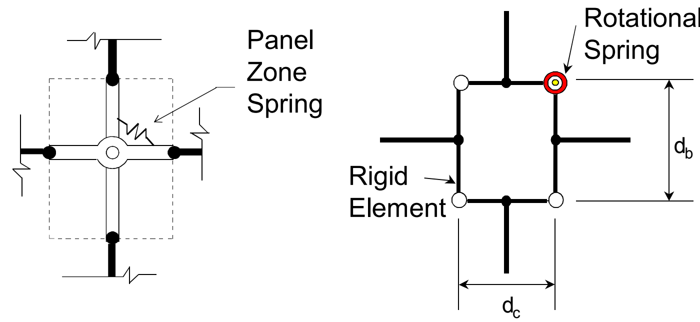
32

Panel zone model



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

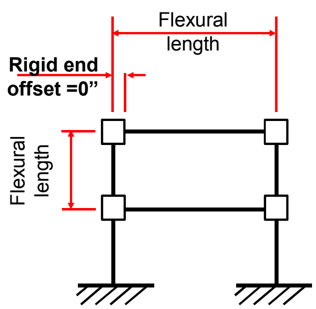
Panel zone models



Scissor Elements (approximate)

Parallelogram Model (eight additional elements)

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

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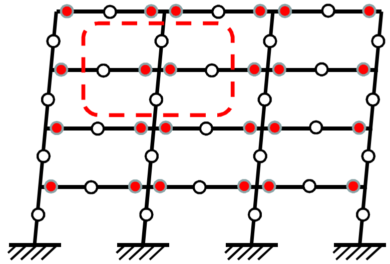
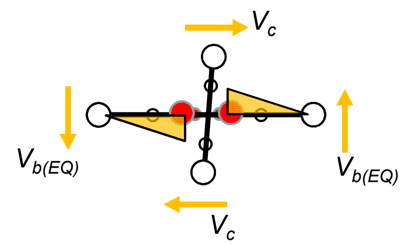
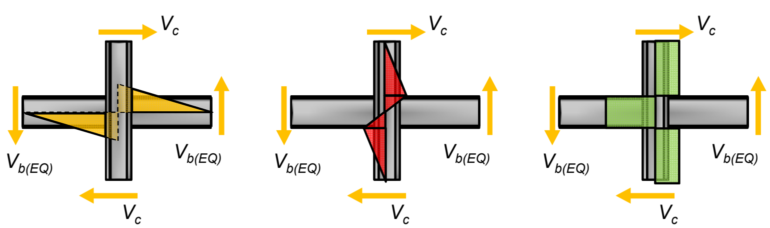
Portal frame to understand special moment frames



Portal frame to understand special moment frames



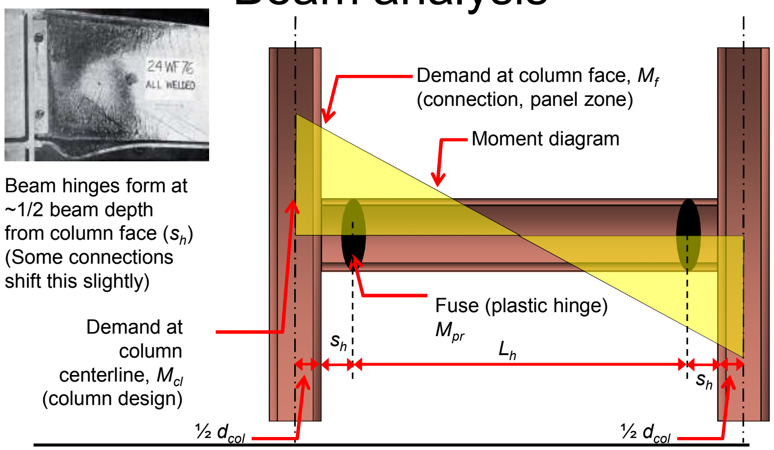
Portal frame to understand special moment frames



Beam analysis

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

Beam analysis



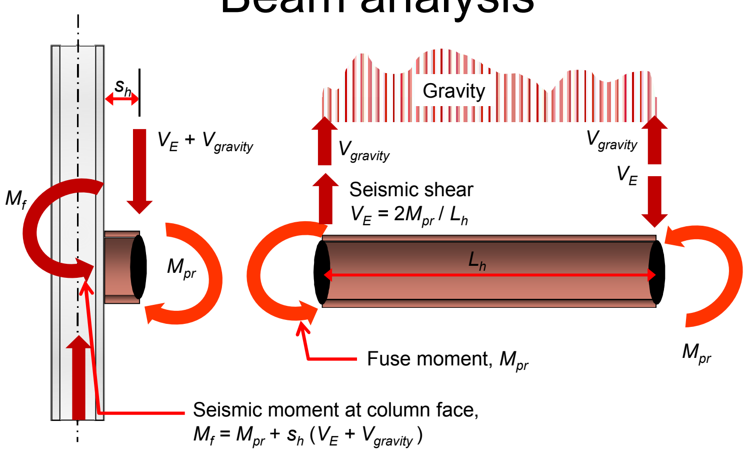
41

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

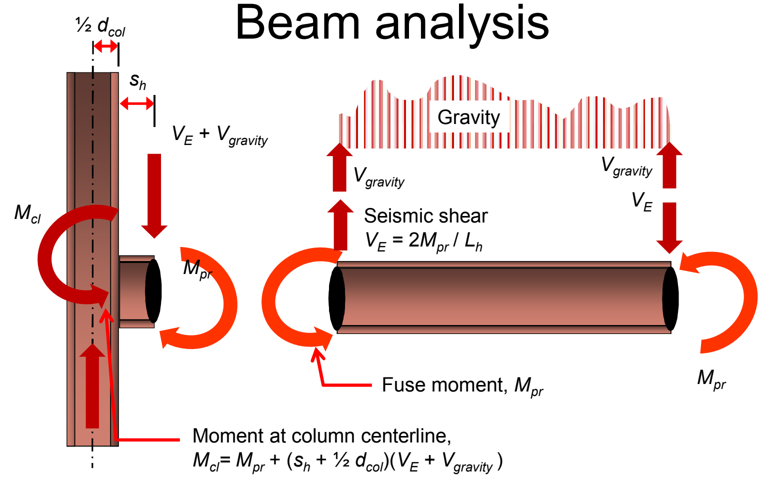
42

Beam analysis



43

Beam analysis



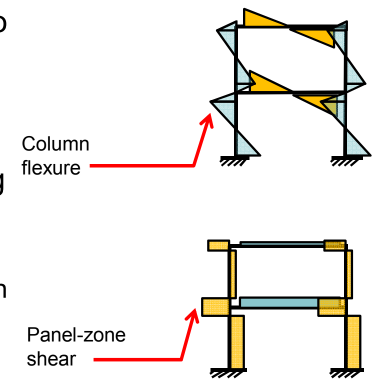
44

Column analysis

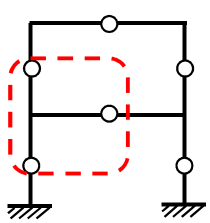
- Forces from beam analysis
  - Based on beam strength
- Strong-column/weak-beam analysis
  - Promote beam yielding over column yielding
- Panel-zone demands
  - Promote beam yielding over panel-zone yielding
- Column shear affects demands
  - Estimate using "portal frame"

Column analysis

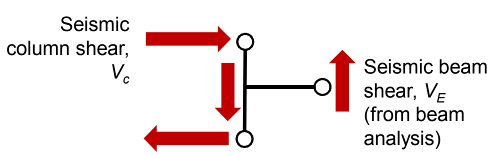
- Use beam capacity to determine:
  - Column flexure
  - Panel-zone shear
- Requires determining column shear
  - Corresponding to beam flexural strength



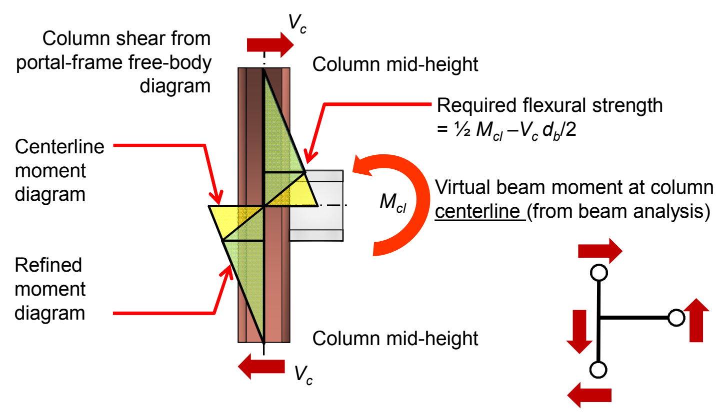
Column analysis



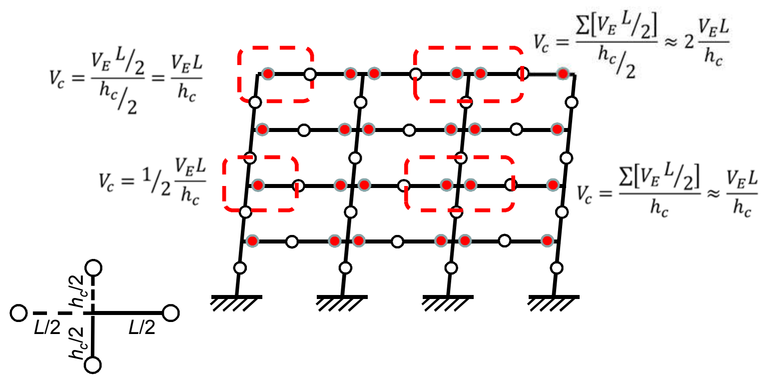
- Portal frame
  - Assume inflection points
    - Beam mid-span
    - Column mid-height
  - Determine shears and moments using free-body-diagrams



Column analysis: flexure



Column shear



There's always a solution in steel.

Moment-frame connections and Northridge lessons

structural STEEL

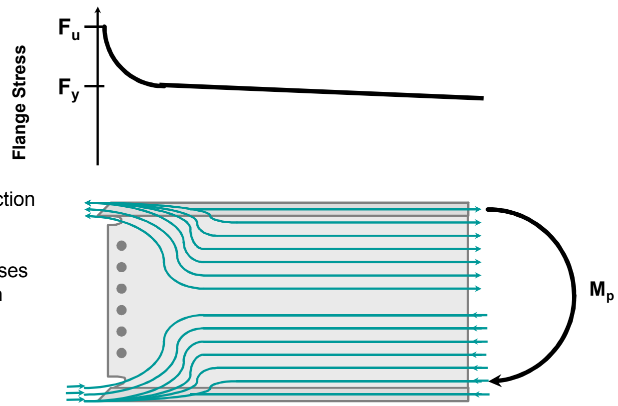
Northridge earthquake

- 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

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

Lack of web participation

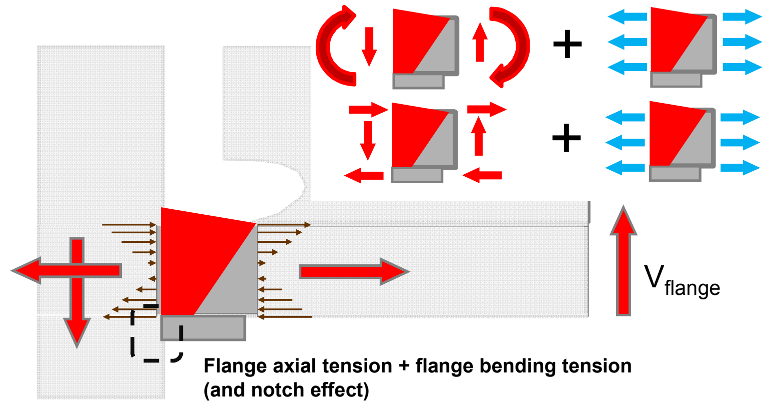


Bolted connection too flexible

Flexural stresses concentrate in flange

53

Increase in Flange Stress Due to Shear in Flange



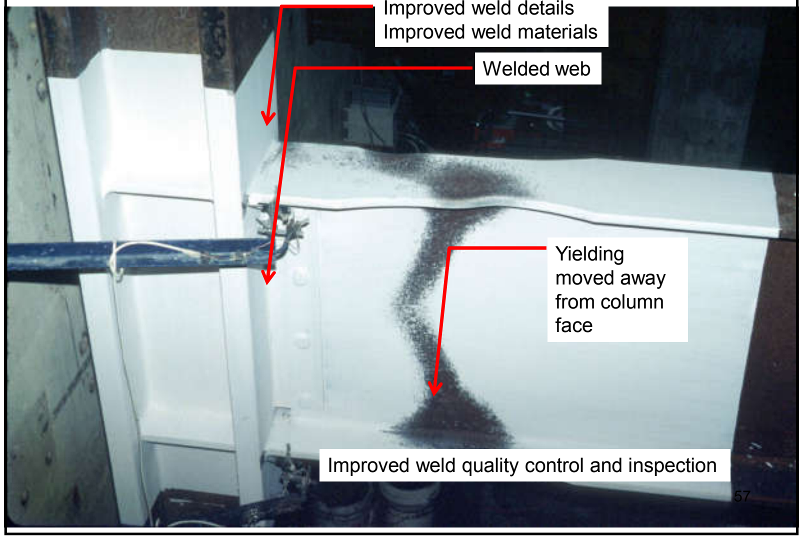
54

55

Current practice

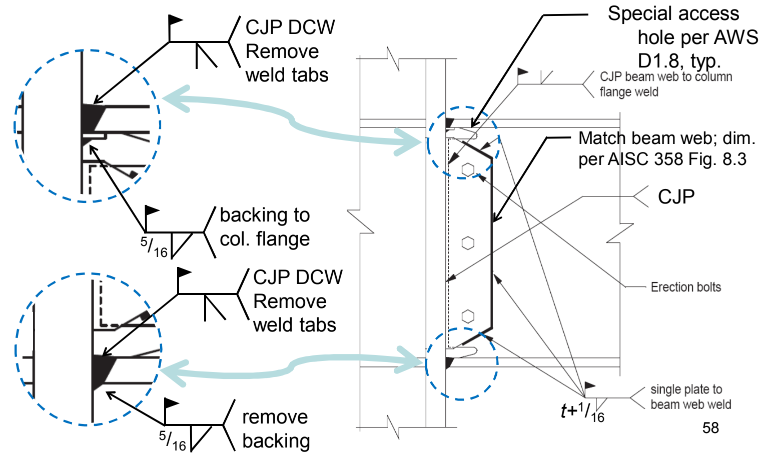
- Beam hinge moved away from column face
- Welded beam web
- Improved weld access hole to relieve restraint
- Backing reinforced or removed
- Higher toughness welds
- Improved welding techniques
- Improved inspection

56



WUF-W Moment Connection

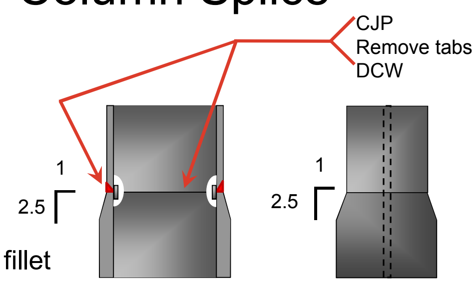
DCW = Demand Critical Weld
Special toughness requirements



58

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



59

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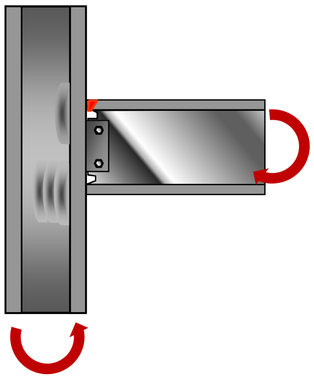
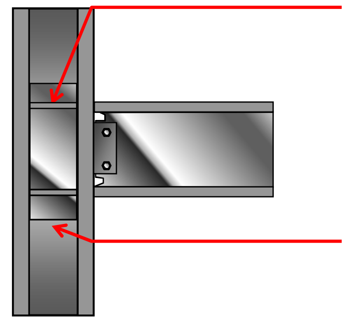
Beam-to-column connection design and construction

Connection limit States



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

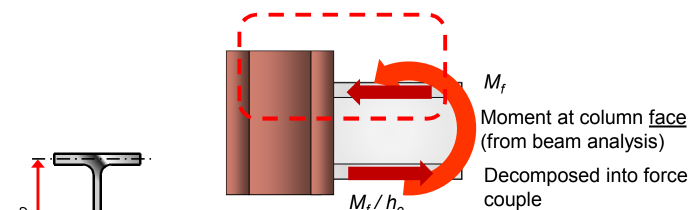
Connection limit States



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

Column analysis: local limit states



$P_f = M_f / h_o$

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

Continuity plates (E3.6f)

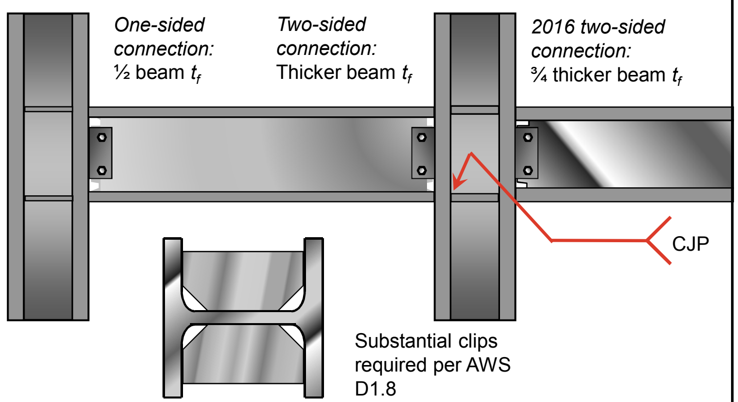
- Design for deficiency
  - Column limit states
    - WLY
    - WC
    - (FLB)
  - $P_f = 0.85^{2016} M_f / h_o$
  - Cont. Plate:
    - $R_u = P_f - \text{Min}(\phi R_n)$
- Additional requirements
  - $t_{cf} > b_f/6$
    - (flange stiffness)

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

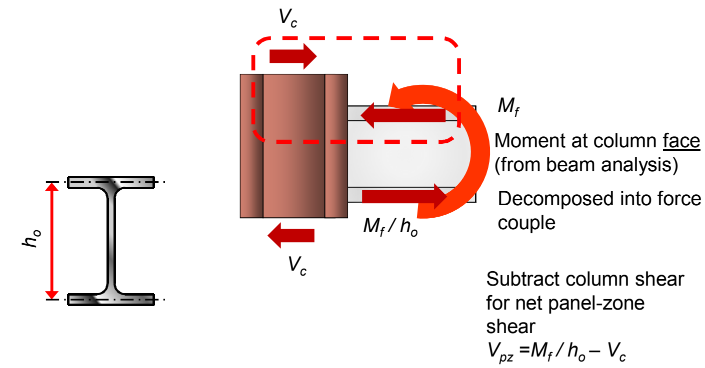
    - (FLB)
    - $P_f = 1.5 b_{bf} t_{bf} R_{yb} F_{yb}$
      - (341-10 only!)
  - Otherwise, use cont. plates

AISC 341 has requirements for continuity plates when used

Continuity plates



Column analysis: panel zone



Panel zone strength

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

Panel zone strength

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

Proportioning (SC/WB) E3.4a

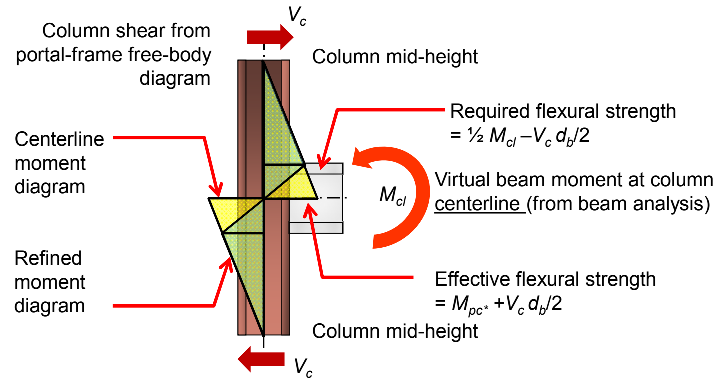
- Strong-Column/Weak-Beam (SC/WB)
  - Ratio>1 required for SMF
    - Ratio>1 Makes story mechanism unlikely
    - Ratio>2 Makes column yielding unlikely

$$\frac{\Sigma M^*_{pc}}{\Sigma M^*_{pb}} > 1.0 \qquad \Sigma M^*_{pc} = \Sigma Z_c(F_{yc} - P_{uc}/A_g) + V_c\, d_b/2$$

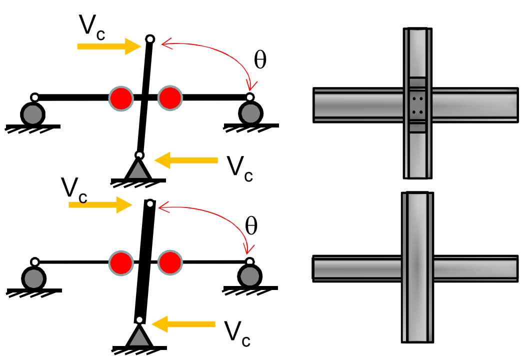
$$\Sigma M^*_{pb} = \Sigma\left[1.1 R_y F_{yb} Z_b + (s_h + d_c/2)(2M_{pr}/L_h \pm V_g)\right]$$

1.15 in 341-16

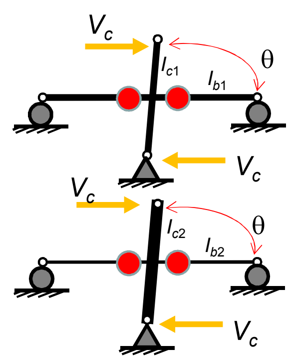
Proportioning (SC/WB)



Elimination of doublers and continuity plates



Elimination of doublers and continuity plates



Add flexibilities

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

Maintain flexibility of assembly

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

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

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

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

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

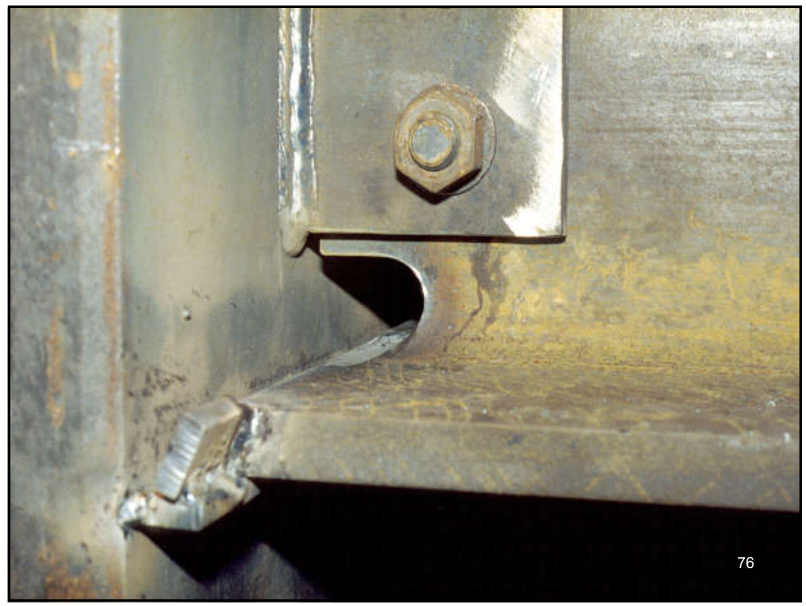
Connection construction

73

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

74

75



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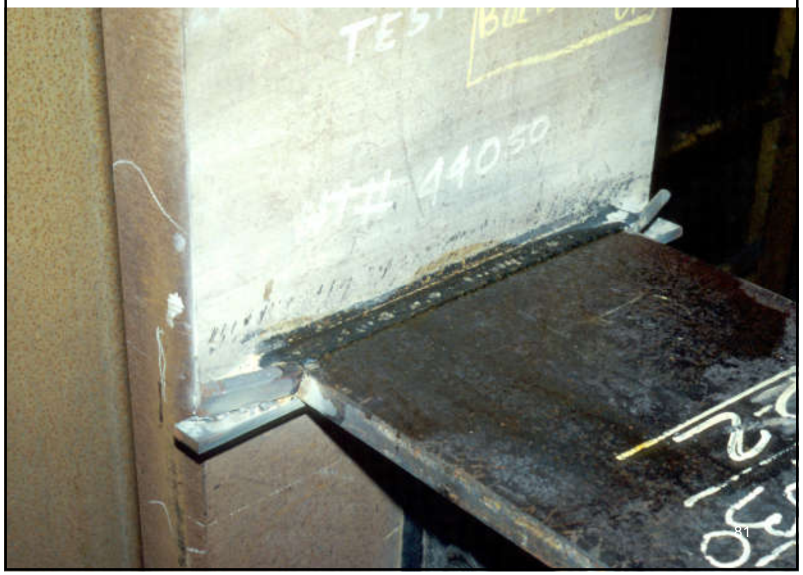

81

82

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

83

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

84

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Prequalified connections

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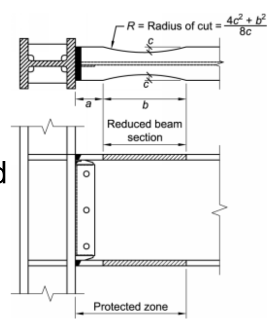
Prequalified connections

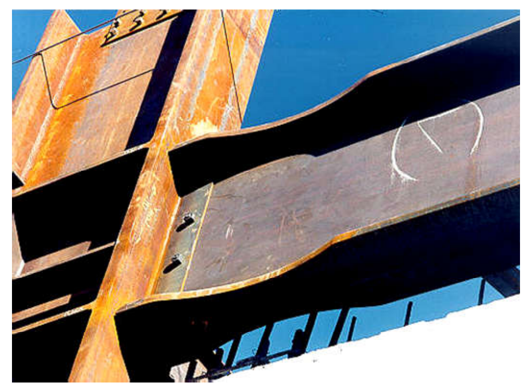
- AISC 341 requires "conformance demonstration" of connections
  - Qualification testing
    - Limited extrapolation
  - "Prequalification"
    - Based on testing
    - Applicability determined by expert panel
    - Published standard
- AISC 358
  - AISC prequalification standard
  - Produced by AISC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

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

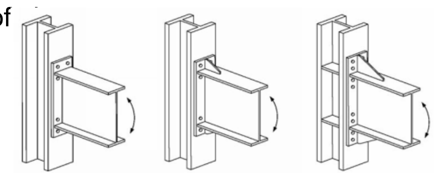


Reduced beam section



Bolted end plate

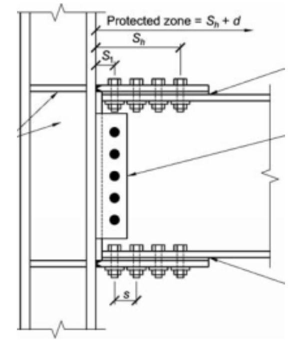
- End-plate connection at column face
  - Stronger than beam
  - Capacity design
    - Flexural yielding of
    - Bolt tension
    - Weld tension
    - Weld shear
    - etc.



89

Bolted flange plate

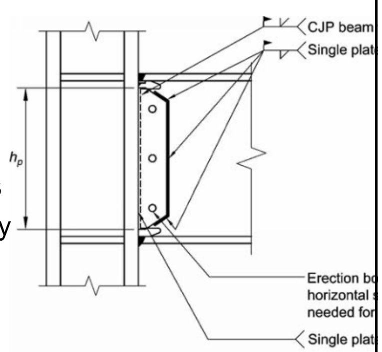
- Beam is fuse
- Flange plates transfer moment to column
- Web does not participate in transferring moment
- Multiple bolt-related limit states



90

Welded unreinforced flange, welded web (WUF-W)

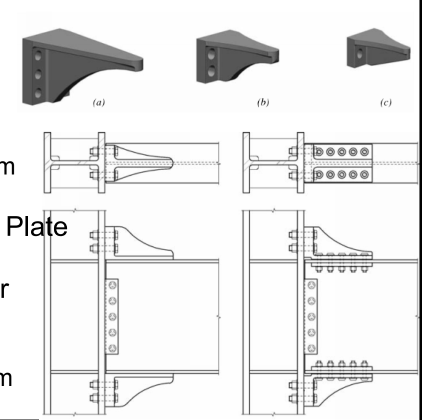
- Welded web
- Improved materials
  - Toughness
  - Limited tensile strength
- Improved welding details
  - Restraint relief provided by special access hole
  - Backing details
  - Removal of weld tabs
- Improved QA/QC



91

Kaiser Bolted bracket

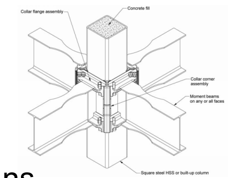
- Proprietary
- High-strength cast-steel brackets
- Configuration
  - Bolted or welded to beam
  - Bolted to column
- Similar to Bolted Flange Plate
  - Beam expected to yield
- Capacity design used for
  - Bracket
  - Column
  - Local limit states in beam

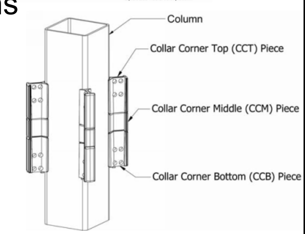


92

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





93

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

94

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Additional topics

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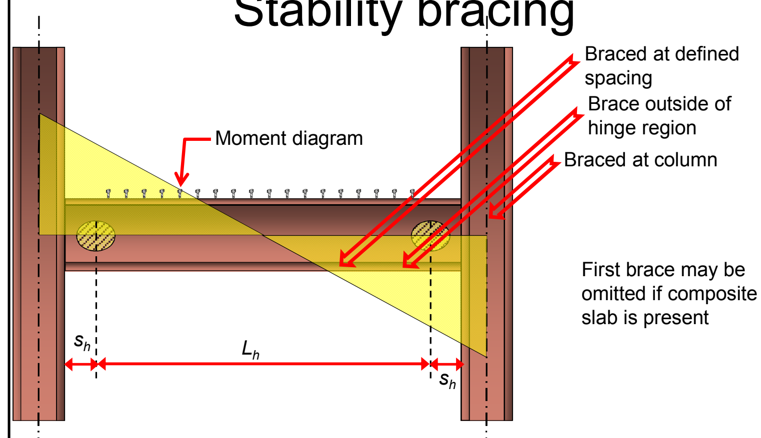
Stability bracing

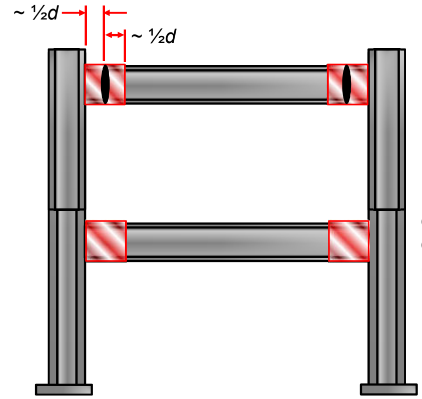


96

Stability bracing

97

Protected zones



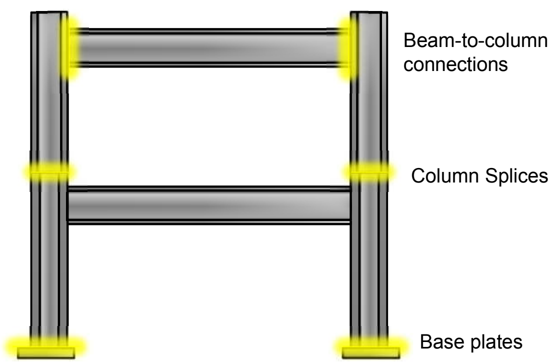
Beam-to-column connections

Protected zones defined for prequalified connections

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

98

Demand critical welds



99

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Summary

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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

101

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End of session 2

Next:

Seismic design of braced frames

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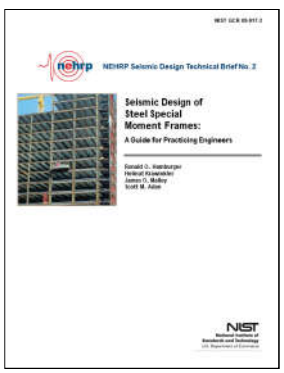
Additional resources



103

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Question time

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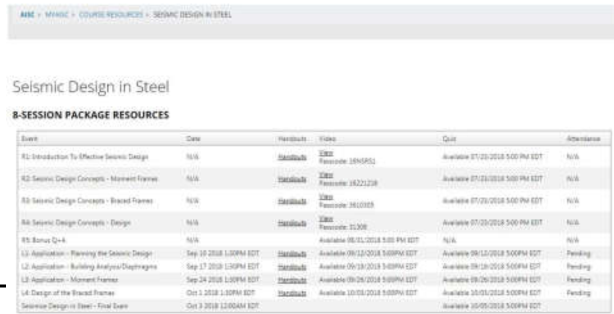
8-Session Package Registrants

Course Resources

1. Log on to your AISC account and go to Course Resources.
   https://www.aisc.org/myaisc/course-resources/
2. Locate your course.
3. Access handouts, videos, quizzes, quiz scores and attendance records.



8-Session Package Registrants

Videos and Quizzes

<u>Videos</u>

- For Sessions R1 – R4, find access to recordings starting July 16. Recording access expires on October 22.
- Bonus Q&A Session R5 will be available starting August 31.
- For Sessions L1 – L4, find access to recordings within two days after the live air date. Recording access expires three weeks after the live session.

<u>Quizzes</u>

- For Sessions R1 – R4, find access to quizzes starting July 23. Quizzes are due on October 22.
- For Sessions L1 – L4, find access to quizzes within two days after the live air date. Quizzes are due three weeks after the live session.
- A final exam will also be given.
- Quiz scores are displayed in the Course Resources table.

8-Session Package Registrants

Course Credit

<u>Attendance and PDH Certificates</u>

- For Sessions R1 – R4, you must pass the quiz to receive credit for the session.
- For Sessions L1 – L4, you have two options to receive credit for the session.
  - Option 1: Watch the session live. Credit for live attendance will be displayed in the Course Resources table within two days of the session.
  - Option 2: Watch the recording and pass the quiz.

<u>EEU Certificates – Certificate of Completion</u>

- In addition to PDH certificates earned for each individual session, an EEU (Equivalent Education Unit) certificate of completion will be issued for participants who complete the full course. Participants must pass at least 7 of 8 quizzes and the final exam to earn the EEU.

<u>Distribution of Certificates</u>

- All certificates (PDH and EEU) will be issued after the final session. Only the registrant will receive certificates for the course.