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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.





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



Course objectives

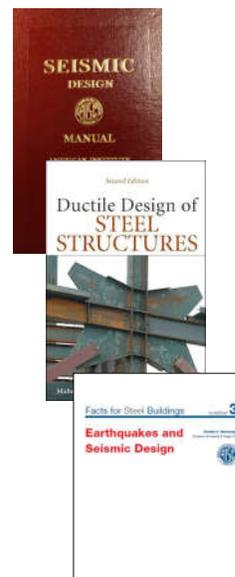
- Understand the principles of seismic design of steel structures.
- Understand the application of those principles to two common systems:
 - Special Moment Frames
 - Buckling-Restrained Braced Frames.
- Understand the application of design requirements for those systems.



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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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There's always a solution in steel.

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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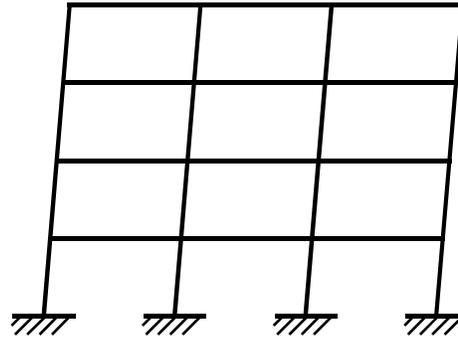
Moment-frame behavior

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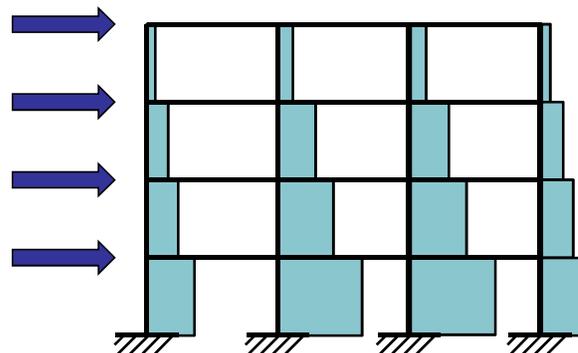
Lateral load resistance

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

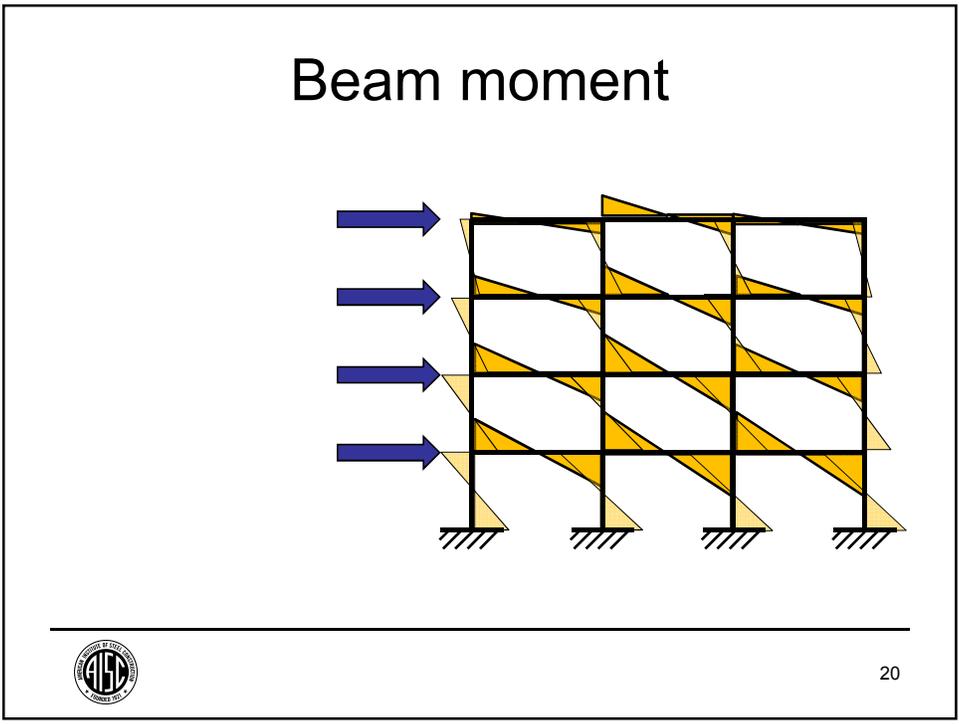
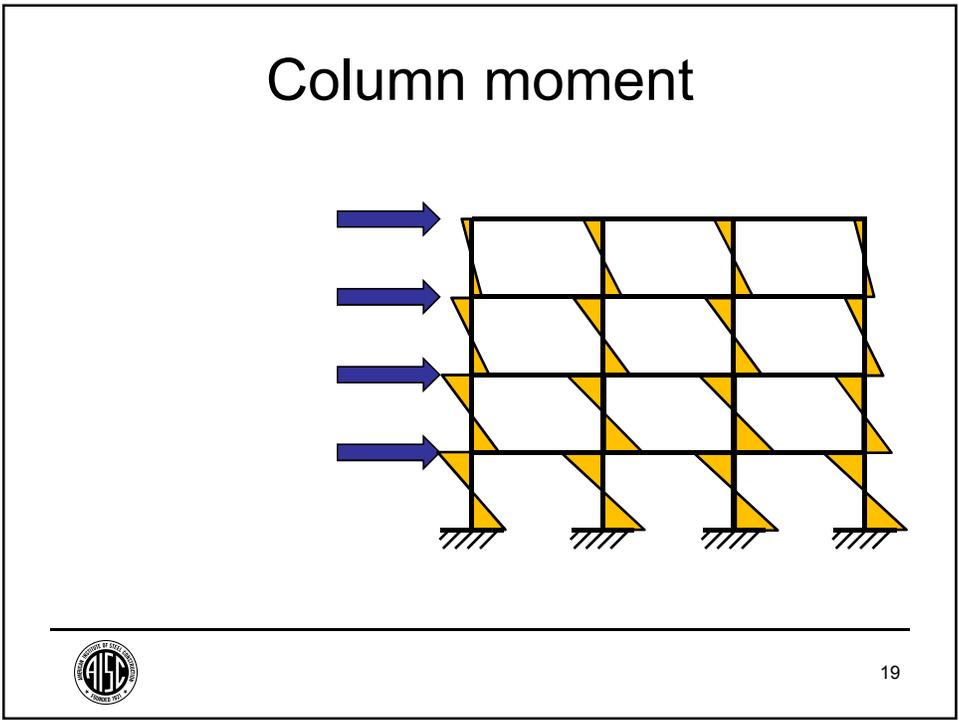


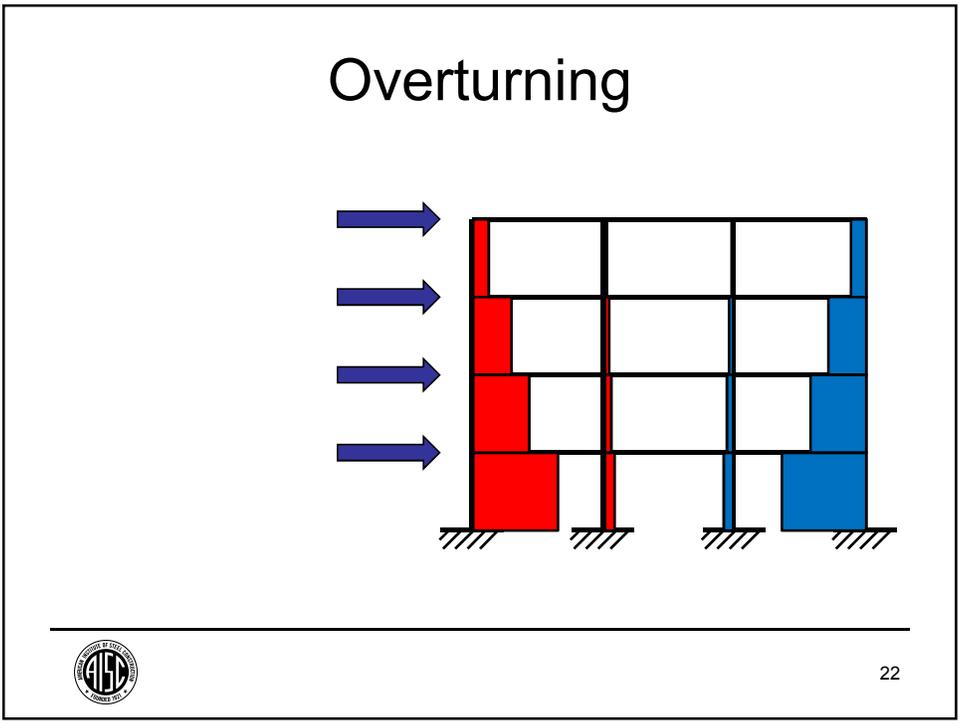
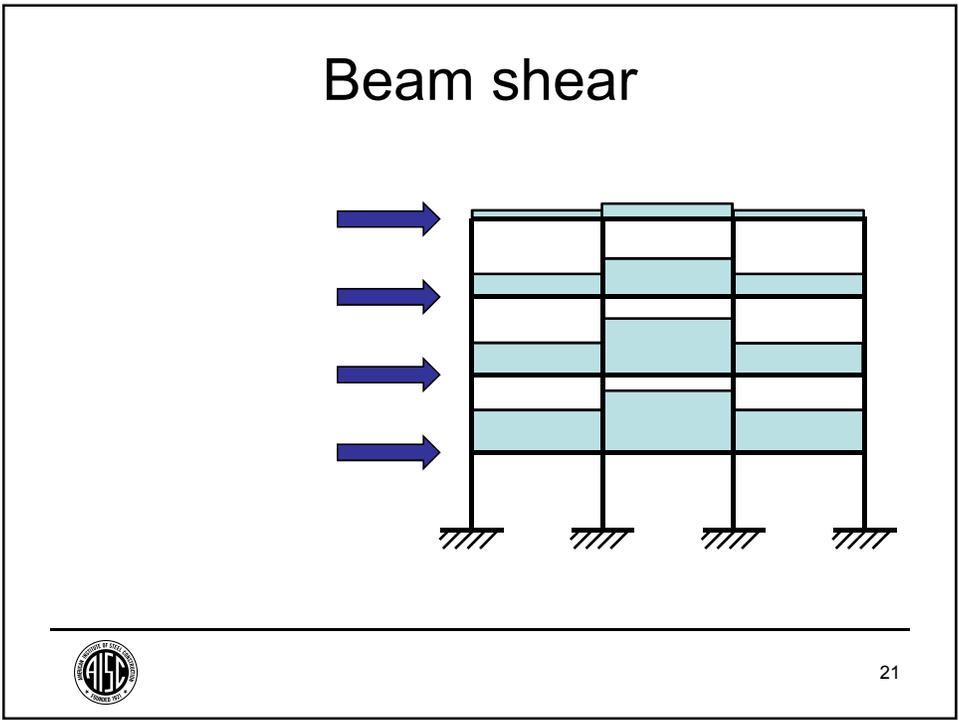
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Column shear

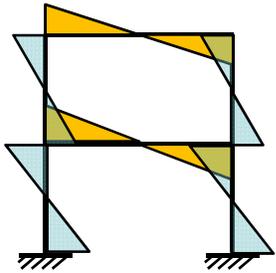


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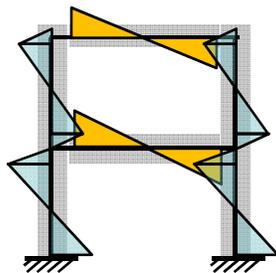




Moment detail



Centerline model

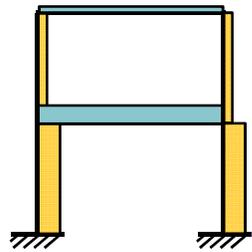


Model with member depth:

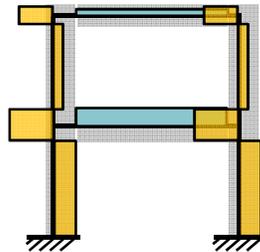
Beams stop short of centerlines
 Moment reversal in columns at connection
 High moment gradient in column at connection



Shear detail



Centerline model



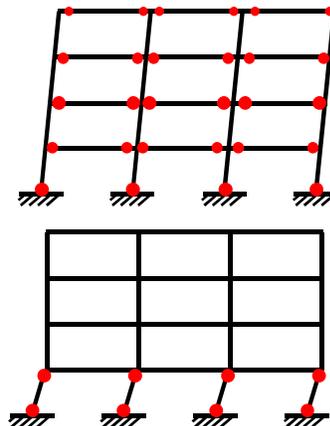
Model with member depth:

Beams stop short of centerlines
 Shear reversal in columns at connection
 High shear in column at connection



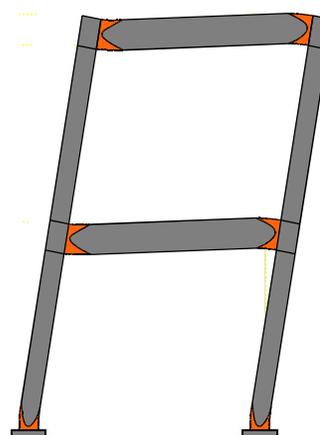
Ductility concept

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



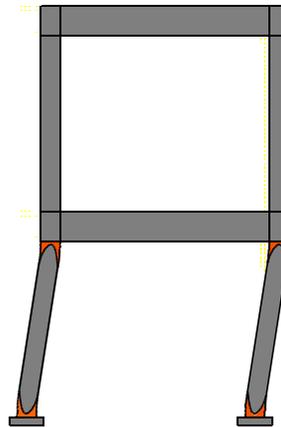
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Plastic hinges in beams



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Plastic hinges in columns

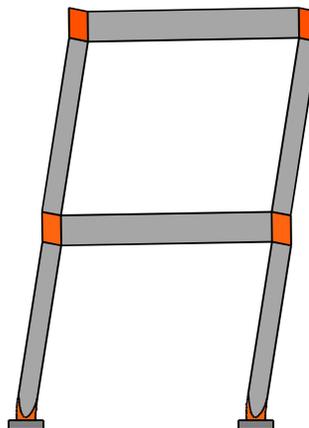


Potential for soft story collapse



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Plastic hinges in panel zones



Potential for column distortion

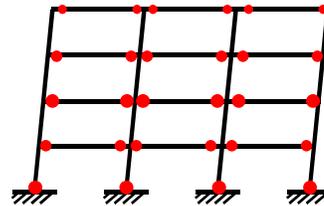


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Fuse concept

- 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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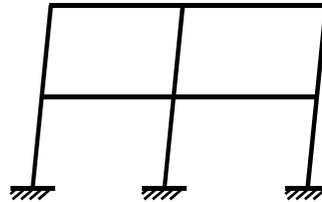
There's always a solution in steel.

Elastic analysis of moment frames



Elastic analysis

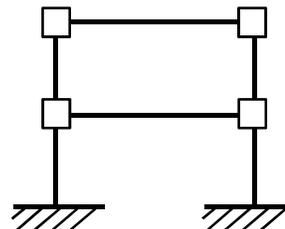
- Sources of flexibility
 - Axial deformations
 - Columns at bay ends
 - Flexural bending deformations
 - Beams and columns
 - Shear deformations
 - Typically only significant at connections
 - Connections
 - Panel-zone shear
 - Special connections (RBS)



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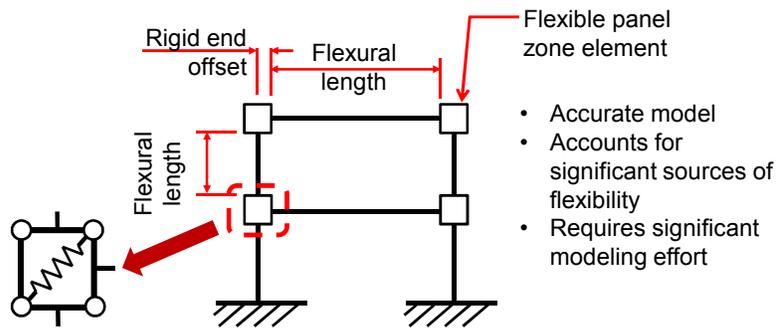
Analysis

- 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)



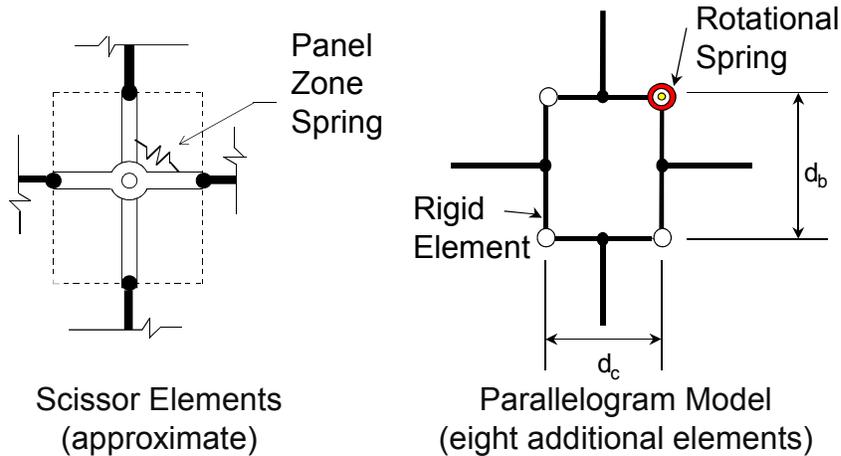
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Panel zone model



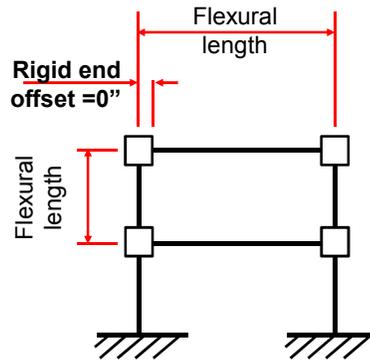
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Panel zone models



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Panel zone approximation



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



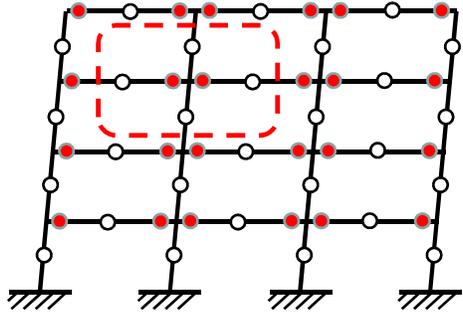
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There's always a solution in steel.

Inelastic analysis of moment frames

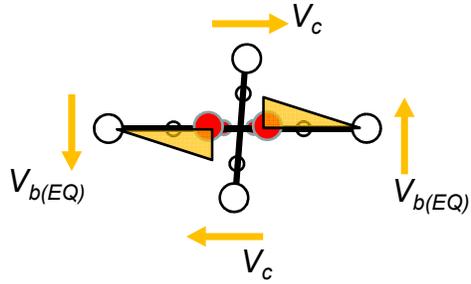


Portal frame to understand special moment frames



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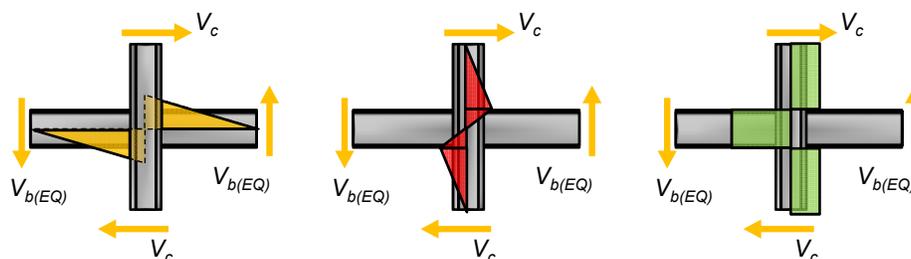
Portal frame to understand special moment frames



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Portal frame to understand special moment frames



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Beam analysis

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



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Beam analysis

Demand at column face, M_f
(connection, panel zone)

Moment diagram

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

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

Fuse (plastic hinge)
 M_{pr}

L_h

s_h

$1/2 d_{col}$

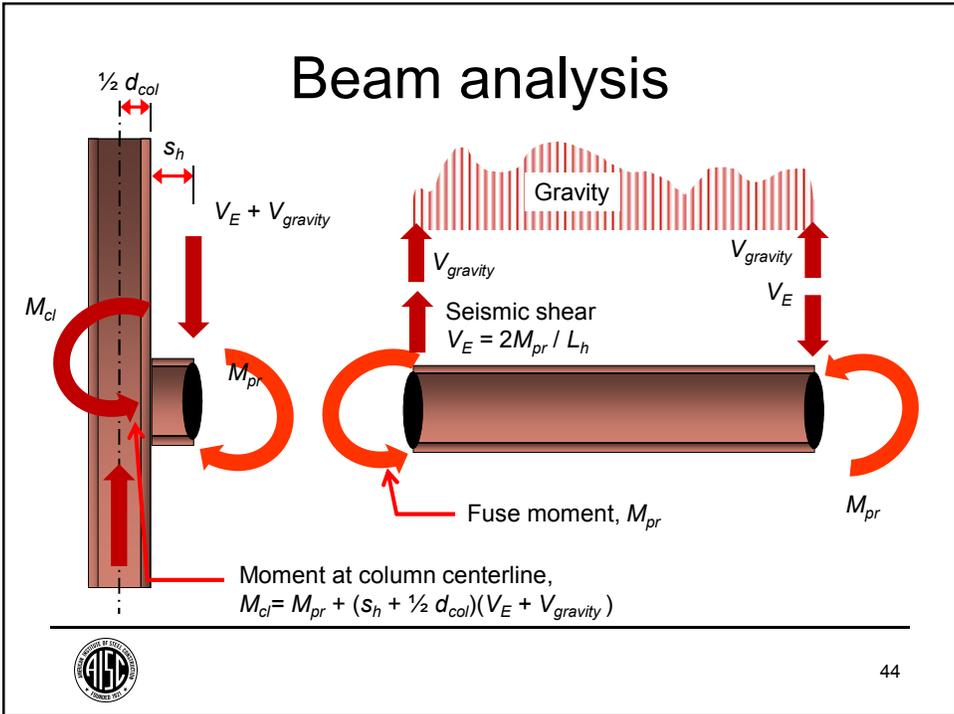
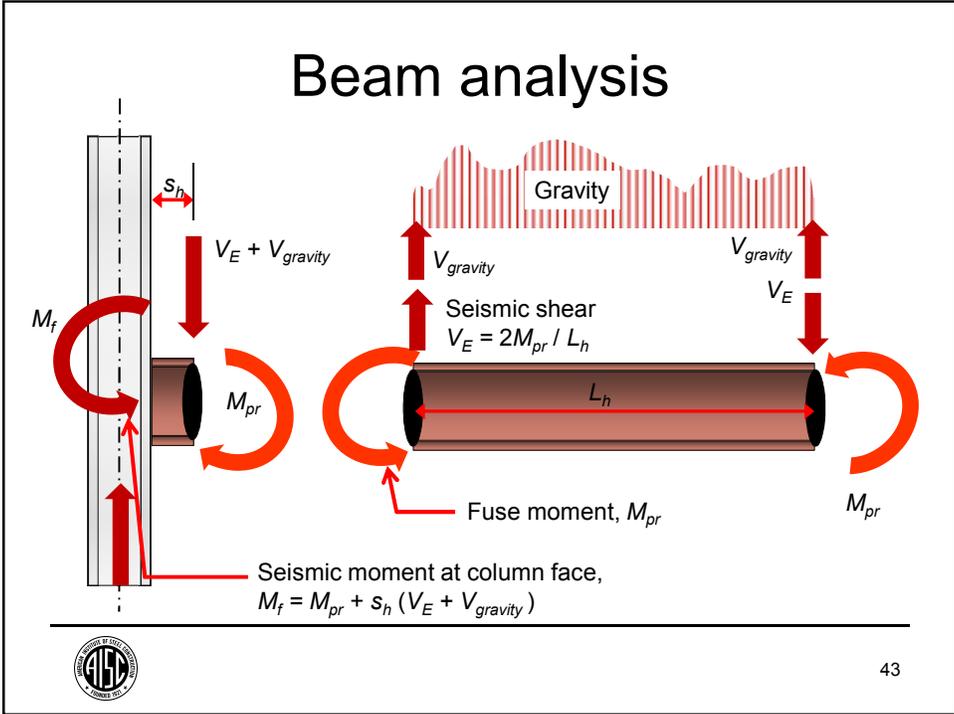
$1/2 d_{col}$

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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

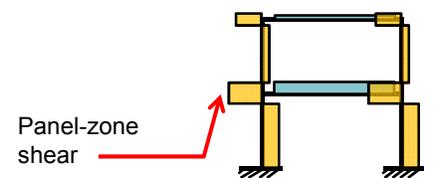
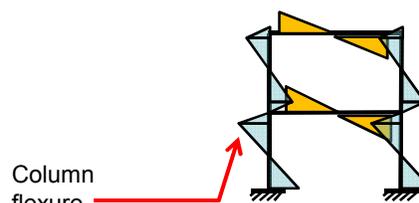
- Forces from beam analysis
 - Based on beam strength
- Strong-column/weak-beam analysis
 - Promote beam yielding over column yielding
- Panel-zone demands
 - Promote beam yielding over panel-zone yielding
- Column shear affects demands
 - Estimate using “portal frame”



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Column analysis

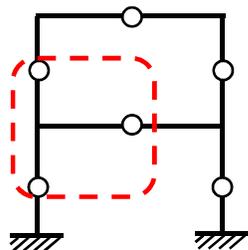
- Use beam capacity to determine:
 - Column flexure
 - Panel-zone shear
- Requires determining column shear
 - Corresponding to beam flexural strength



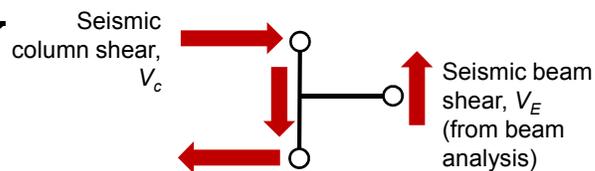
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Column analysis

- Portal frame

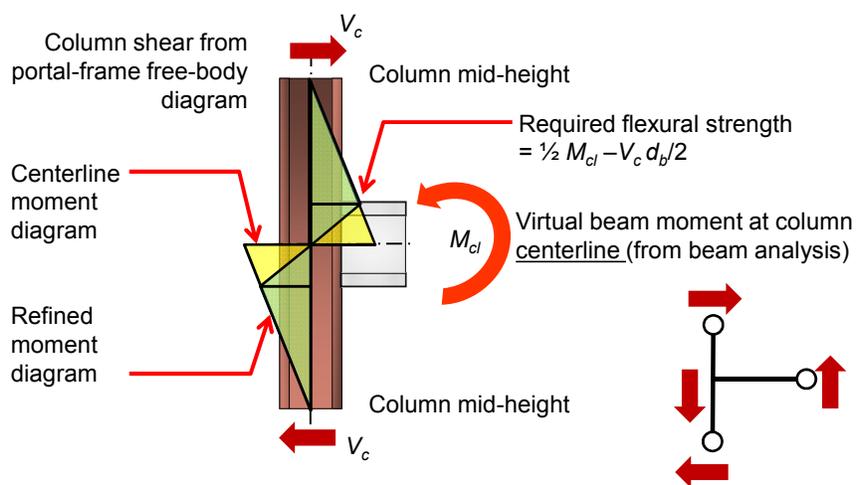


- Assume inflection points
 - Beam mid-span
 - Column mid-height
- Determine shears and moments using free-body-diagrams



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Column analysis: flexure



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Column shear

$$V_c = \frac{V_E L/2}{h_c/2} = \frac{V_E L}{h_c}$$

$$V_c = 1/2 \frac{V_E L}{h_c}$$

$$V_c = \frac{\sum[V_E L/2]}{h_c/2} \approx 2 \frac{V_E L}{h_c}$$

$$V_c = \frac{\sum[V_E L/2]}{h_c} \approx \frac{V_E L}{h_c}$$


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There's always a solution in steel.

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



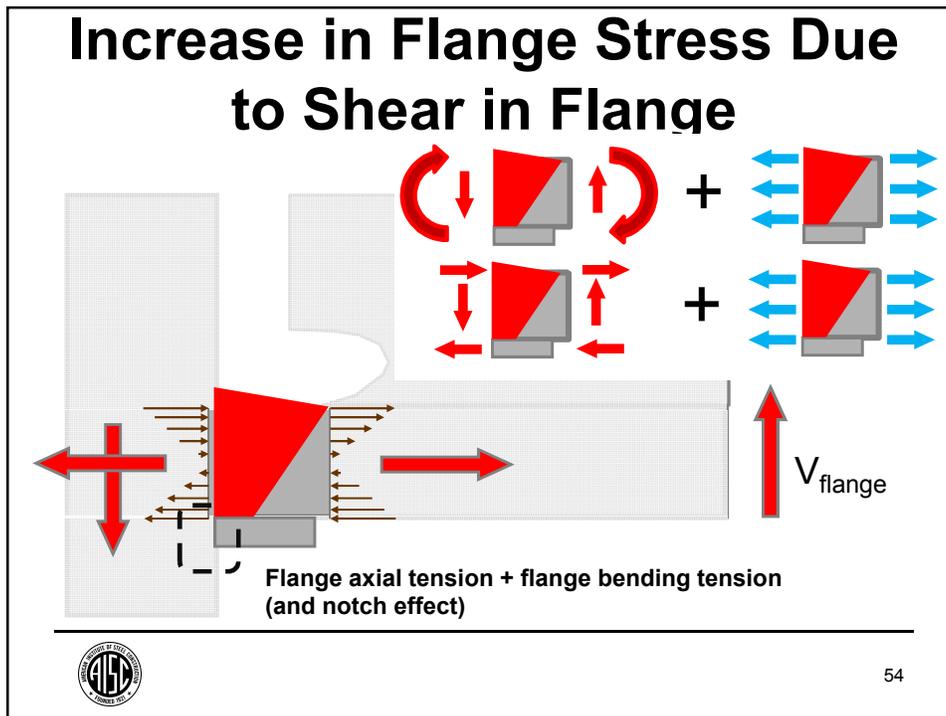
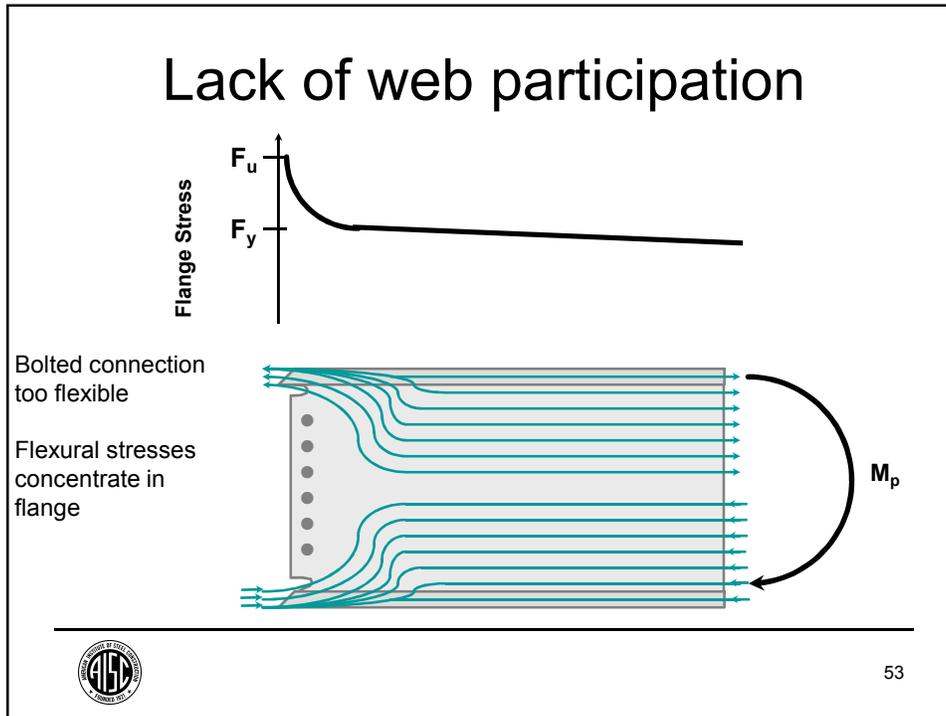
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Northridge Moment Connection Damage

- 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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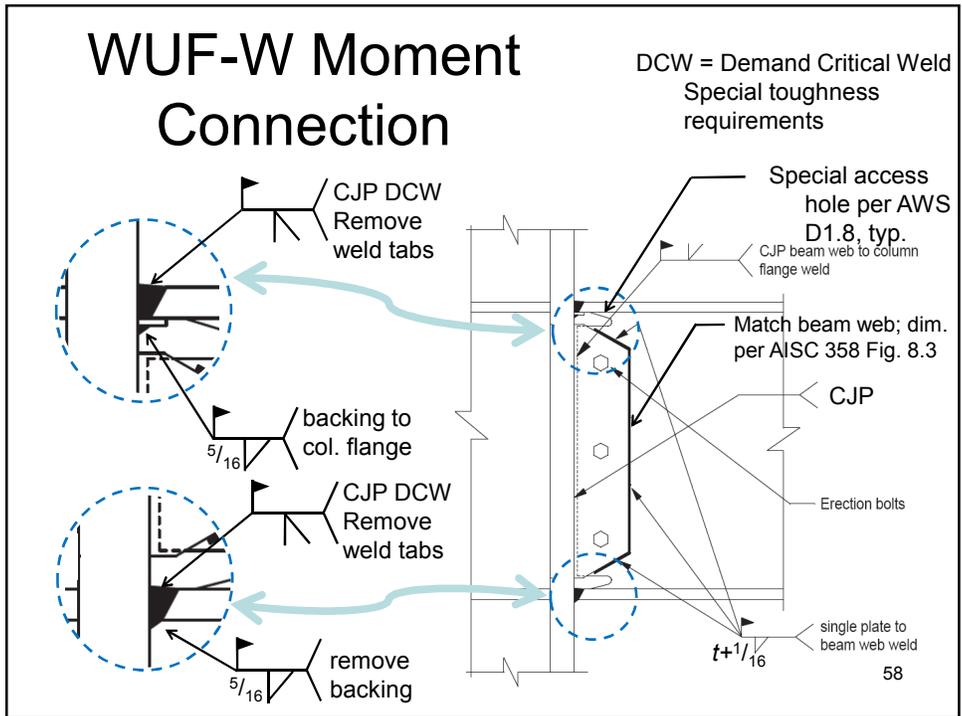
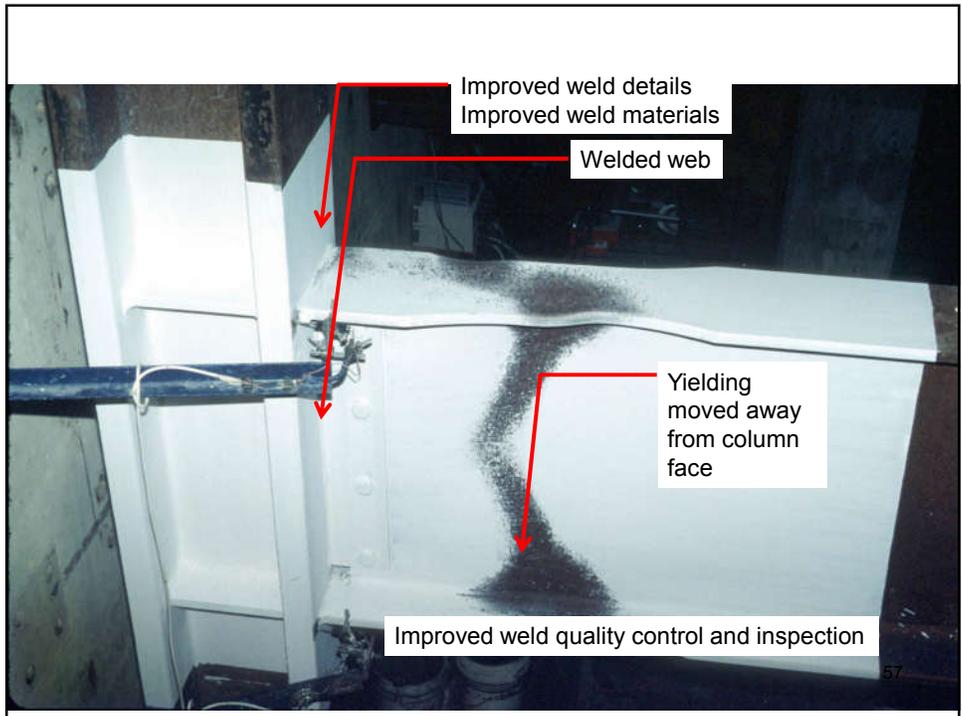


Current practice

- 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

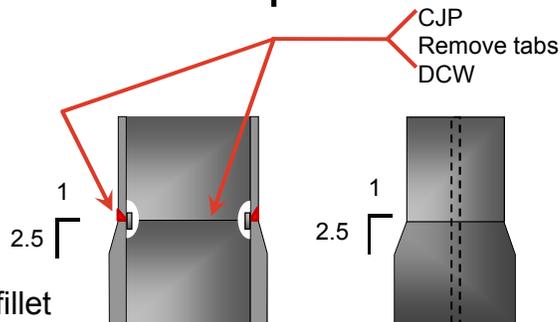


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SMF Column Splice

- Weld tabs
 - (remove)
 - Grind to 1/4"
- Backing
 - (remain)
 - No supplemental fillet
- AISC 341-16
 - PJP allowed
 - 85% or greater effective throat
 - Multiple limitations



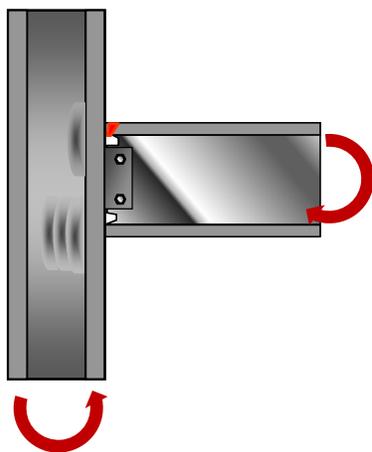
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There's always a solution in steel.

Beam-to-column connection design and construction



Connection limit States

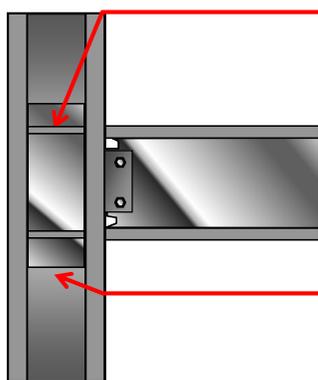


- Beam flange weld rupture
- Column flange bending
- Column web yielding
- Column web crippling
- Column panel-zone shear
- (Beam shear connection)



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Connection limit States



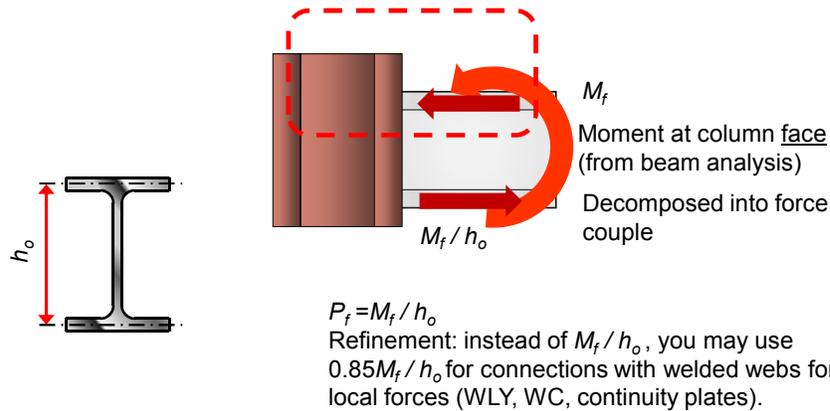
Continuity plates (stiffeners)
increase capacity for:
Flange bending
Web local yielding
Web crippling

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



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Column analysis: local limit states



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

One-sided connection: $\frac{1}{2}$ beam t_f

Two-sided connection: Thicker beam t_f

2016 two-sided connection: $\frac{3}{4}$ thicker beam t_f

CJP

Substantial clips required per AWS D1.8



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Column analysis: panel zone

V_c

M_f

Moment at column face (from beam analysis)

Decomposed into force couple

M_f / h_o

V_c

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 not 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	$P_r \leq 0.75P_c$ $0.6F_y d_c t_w \left[1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_w} \right]$	$P_r > 0.75P_c$ $0.6F_y d_c t_w \left[1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_w} \right] \left[1.9 - \frac{1.2P_r}{P_c} \right]$



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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



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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

$$\frac{\sum M_{pc}^*}{\sum M_{pb}^*} > 1.0 \quad \sum M_{pc}^* = \sum Z_c(F_{yc} - P_{uc}/A_g) + V_c d_b/2$$

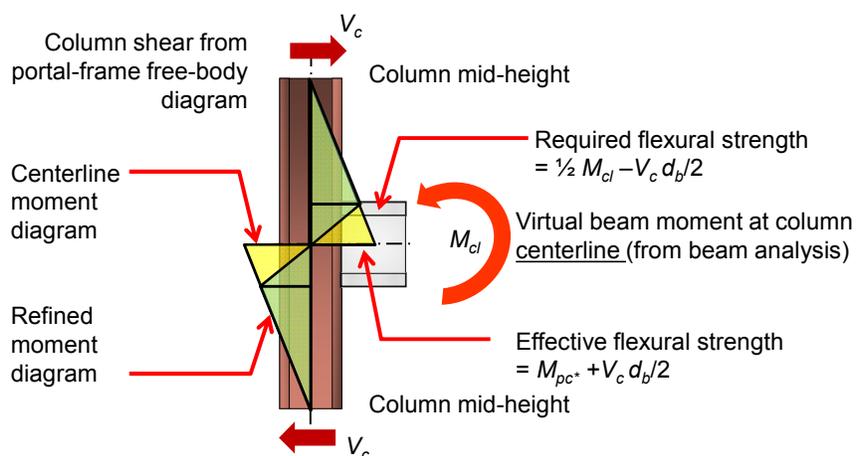
$$\sum M_{pb}^* = \sum [1.1R_y F_{yb} Z_b + (s_h + d_c/2)(2M_{pr}/L_h \pm V_g)]$$

1.15 in 341-16



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Proportioning (SC/WB)



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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

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

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

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

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

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


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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

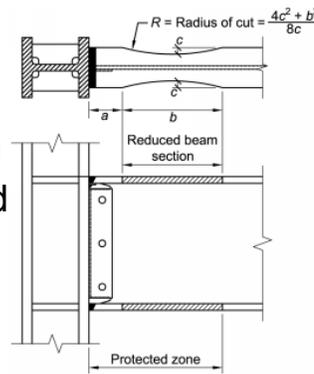
- AISC 341 requires “conformance demonstration” of connections
 - Qualification testing
 - Limited extrapolation
 - “Prequalification”
 - Based on testing
 - Applicability determined by expert panel
 - Published standard
- AISC 358
 - AISC prequalification standard
 - Produced by AISC prequalification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



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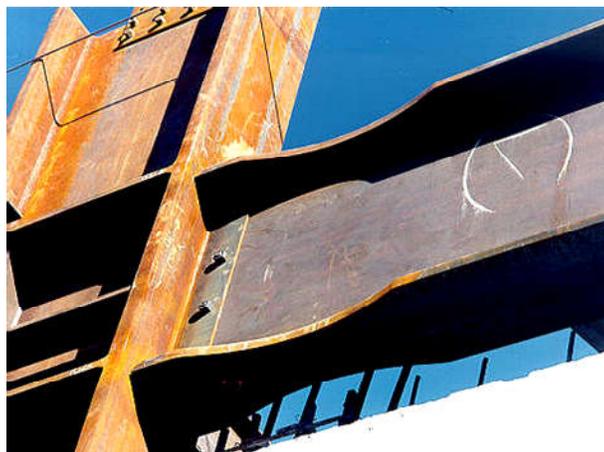
Reduced beam section

- 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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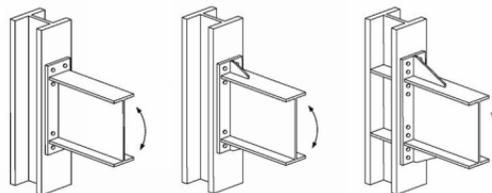
Reduced beam section



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Bolted end plate

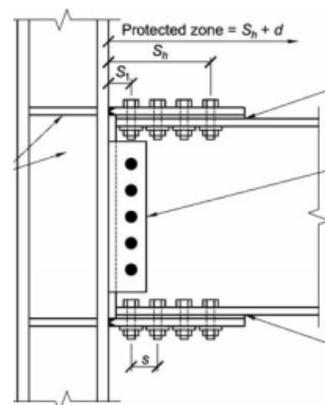
- End-plate connection at column face
 - Stronger than beam
 - Capacity design
 - Flexural yielding of
 - Bolt tension
 - Weld tension
 - Weld shear
 - etc.



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Bolted flange plate

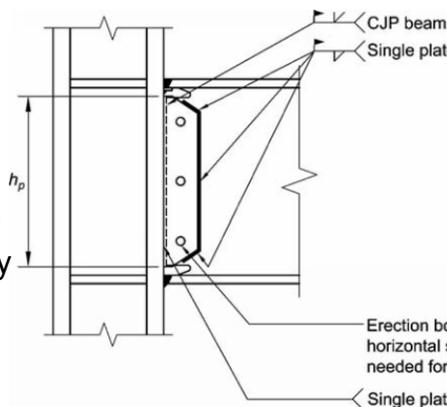
- Beam is fuse
- Flange plates transfer moment to column
- Web does not participate in transferring moment
- Multiple bolt-related limit states



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Welded unreinforced flange, welded web (WUF-W)

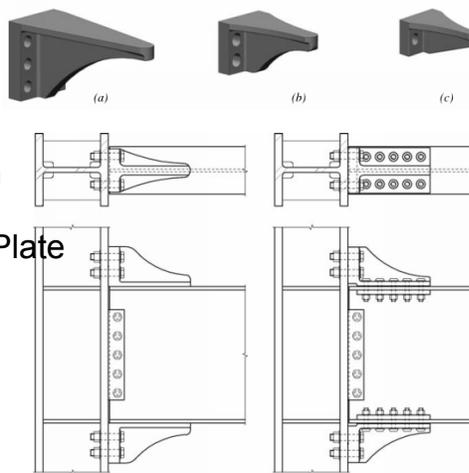
- Welded web
- Improved materials
 - Toughness
 - Limited tensile strength
- Improved welding details
 - Restraint relief provided by special access hole
 - Backing details
 - Removal of weld tabs
- Improved QA/QC



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Kaiser Bolted bracket

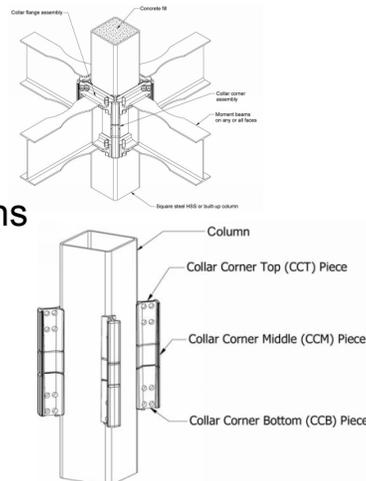
- Proprietary
- High-strength cast-steel brackets
- Configuration
 - Bolted or welded to beam
 - Bolted to column
- Similar to Bolted Flange Plate
 - Beam expected to yield
- Capacity design used for
 - Bracket
 - Column
 - Local limit states in beam



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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



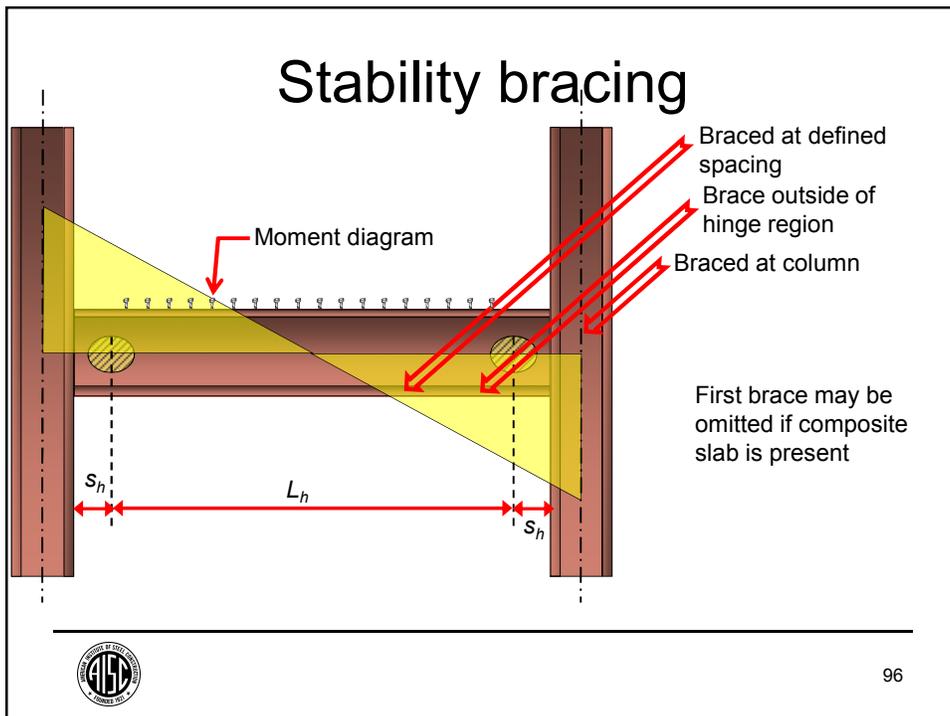
94

There's always a solution in steel.

Additional topics



Stability bracing

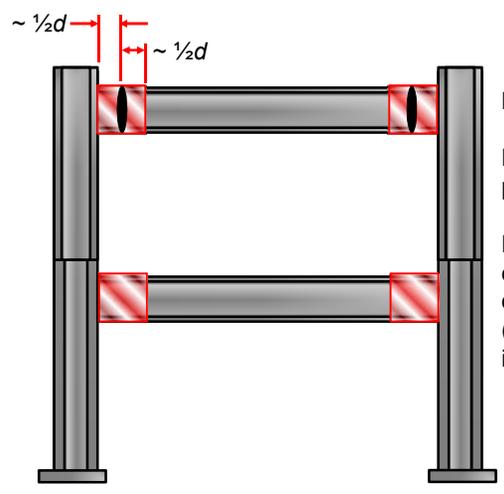


Stability bracing



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Protected zones



Beam-to-column connections

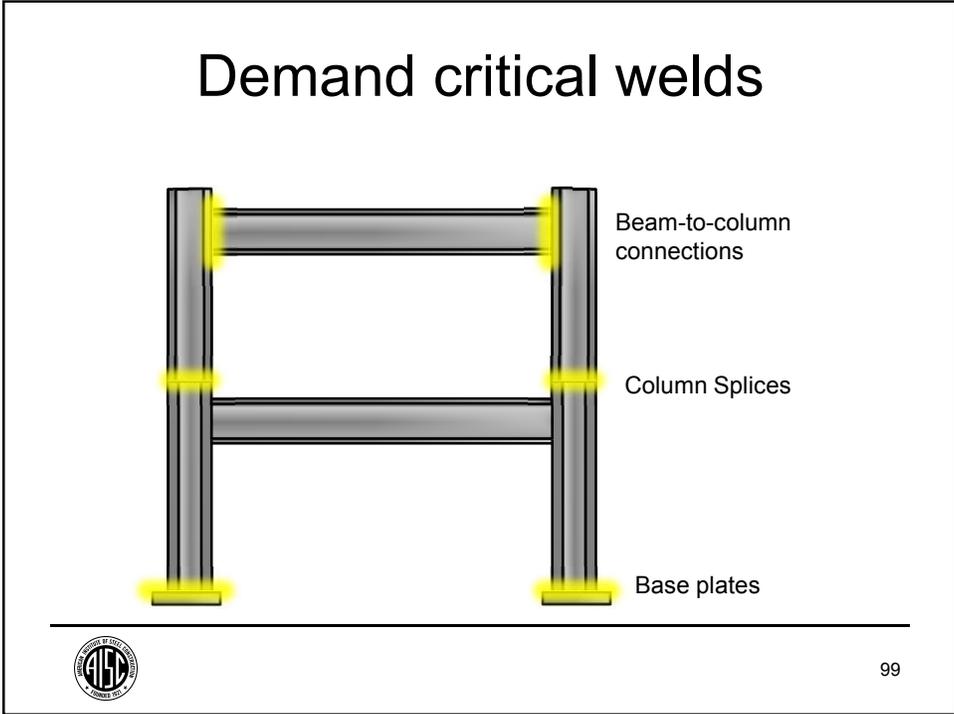
Protected zones defined for prequalified connections

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



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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

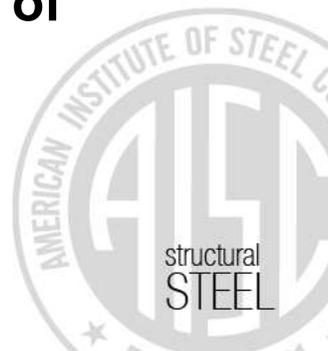


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End of session 2

Next:

Seismic design of braced frames



There's always a solution in steel.



Additional resources



Question time

There's always a solution in steel.



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.

AISC > MYAISC > COURSE RESOURCES > SEISMIC DESIGN IN STEEL

Seismic Design in Steel

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Videos	Quiz	Attendance
R1: Introduction To Effective Seismic Design	N/A	Handouts	Video Passcode: 16649F51	Available 07/23/2018 5:00 PM EDT	N/A
R2: Seismic Design Concepts - Moment Frames	N/A	Handouts	Video Passcode: 18221218	Available 07/23/2018 5:00 PM EDT	N/A
R3: Seismic Design Concepts - Braced Frames	N/A	Handouts	Video Passcode: 3402005	Available 07/23/2018 5:00 PM EDT	N/A
R4: Seismic Design Concepts - Design	N/A	Handouts	Video Passcode: 31308	Available 07/23/2018 5:00 PM EDT	N/A
R5: Bonus Q+A	N/A		Available 08/31/2018 5:00 PM EDT	N/A	N/A
L1: Application - Planning the Seismic Design	Sep 10 2018 1:30PM EDT	Handouts	Available 09/12/2018 5:00PM EDT	Available 09/12/2018 5:00PM EDT	Pending
L2: Application - Building Analysis/Diaphragms	Sep 17 2018 1:30PM EDT	Handouts	Available 09/19/2018 5:00PM EDT	Available 09/19/2018 5:00PM EDT	Pending
L3: Application - Moment Frames	Sep 24 2018 1:30PM EDT	Handouts	Available 09/26/2018 5:00PM EDT	Available 09/26/2018 5:00PM EDT	Pending
L4: Design of the Braced Frames	Oct 1 2018 1:30PM EDT	Handouts	Available 10/03/2018 5:00PM EDT	Available 10/03/2018 5:00PM EDT	Pending
Seismic Design in Steel - Final Exam	Oct 3 2018 12:00AM EDT			Available 10/05/2018 5:00PM EDT	



8-Session Package Registrants

Videos and Quizzes

Videos

- 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.

Quizzes

- 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

Attendance and PDH Certificates

- 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.

EEU Certificates – Certificate of Completion

- 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.

Distribution of Certificates

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

