


AISC Night School


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Fundamentals of earthquake engineering for building structures

Session 6: Steel Systems
March 22, 2021 | Rafael Sabelli





Smarter. Stronger. Steel.



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Course Description

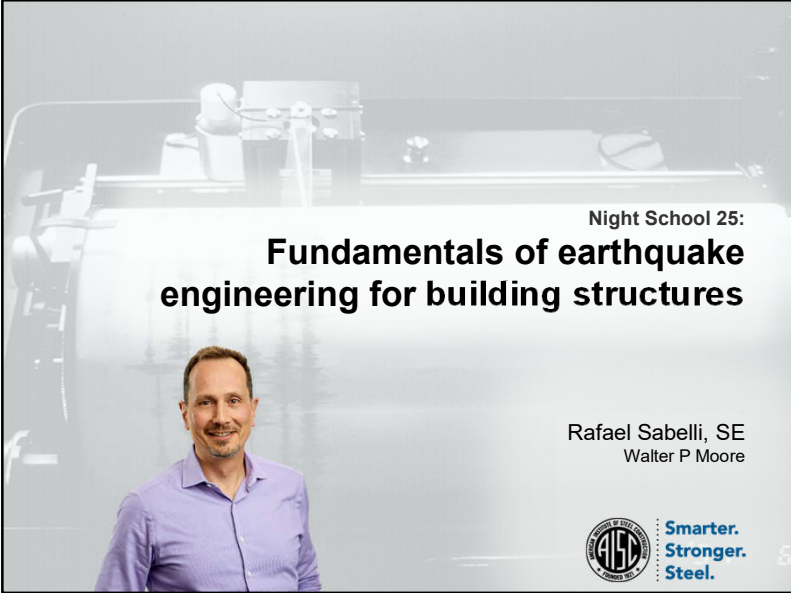

Steel Systems
March 22, 2021

This lecture will cover steel systems used in building design. Moment frames and braced frames will be covered. The presentation will include moment-frame intended behavior and source of inelastic drift as well as moment-frame analysis issues. There will be background discussion of moment-frame connection testing and lessons learned after the Northridge earthquake. The currently prequalified moment connections will be covered. Braced-frame configurations will be presented. The session will discuss behavior of braced frames in earthquakes and in testing. Detailed treatment of brace behavior in tension and compression and the design issues for gusset plates will be covered. There will be a discussion of the behavior of beam-column-gusset connection assemblies at large drifts and related design approaches.




Learning Objectives

- Describe moment frame intended behavior in seismic design.
- List the prequalified moment connections that are used in the design of steel framed structures.
- Describe braced frame intended behavior in seismic design.
- Explain post-elastic behavior of braced frames.



Night School 25:
Fundamentals of earthquake engineering for building structures


Rafael Sabelli, SE
Walter P Moore



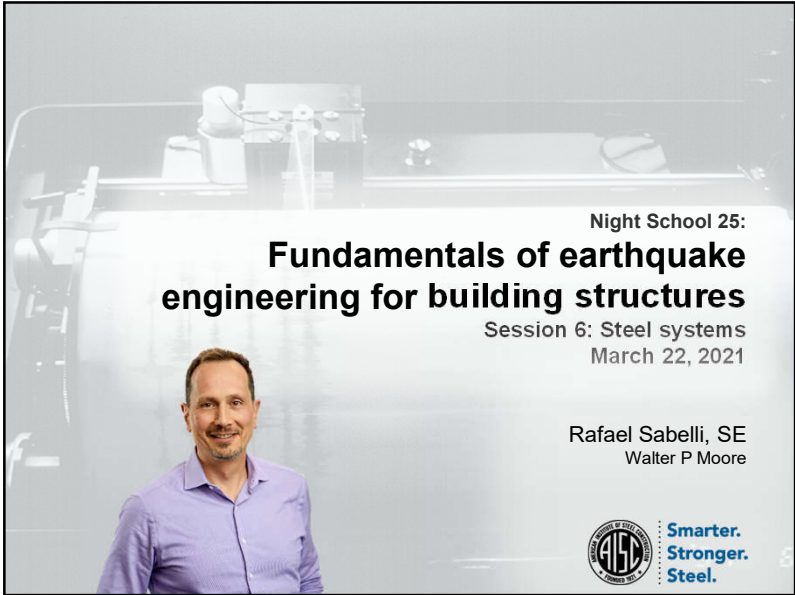
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Course outline

1. Seismology and earthquake effects
2. Dynamics and response
3. Building dynamics and response
4. Steel behavior
5. System ductility and seismic design
- 6. Steel systems**
7. Building configuration
8. Building codes




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Night School 25:
Fundamentals of earthquake engineering for building structures
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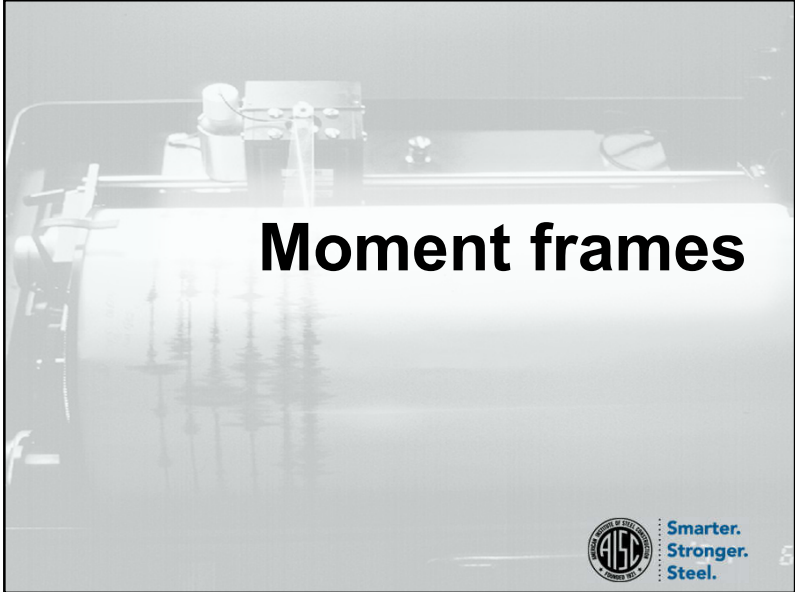
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Session topics


- Moment frames
 - System
 - Beam analysis
 - Column analysis
 - Connections
- Braced frames
 - Elastic behavior
 - Post-elastic behavior
 - Plastic-mechanism analysis



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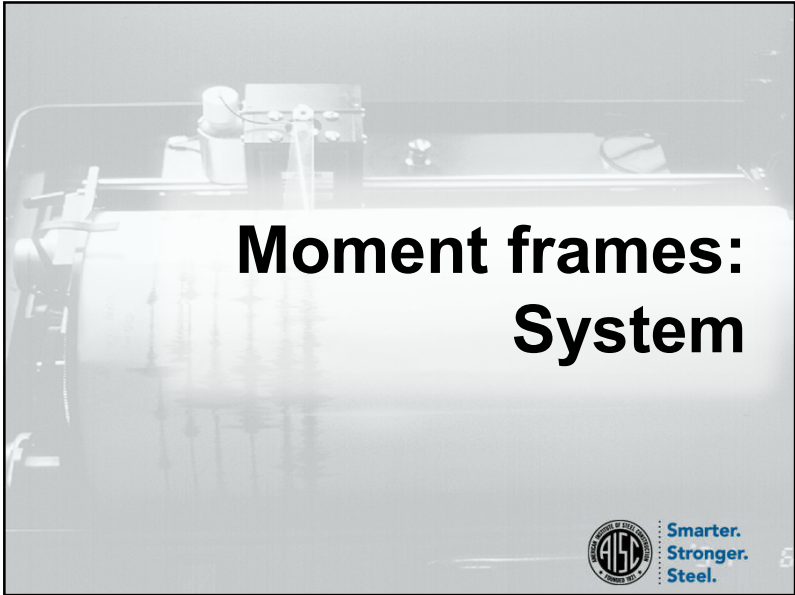
Moment frames



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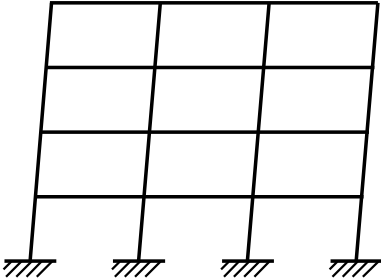
Moment frames

- System
 - Lateral load resistance
 - Analysis
 - Ductility concept
 - Proportioning
- Members
 - Beam analysis
 - Column forces
- Connections

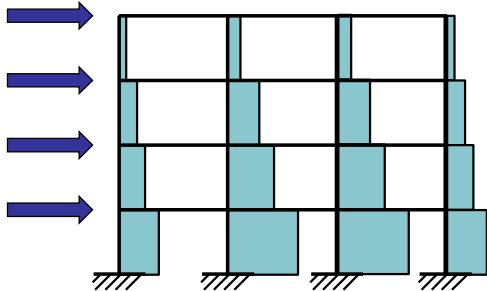


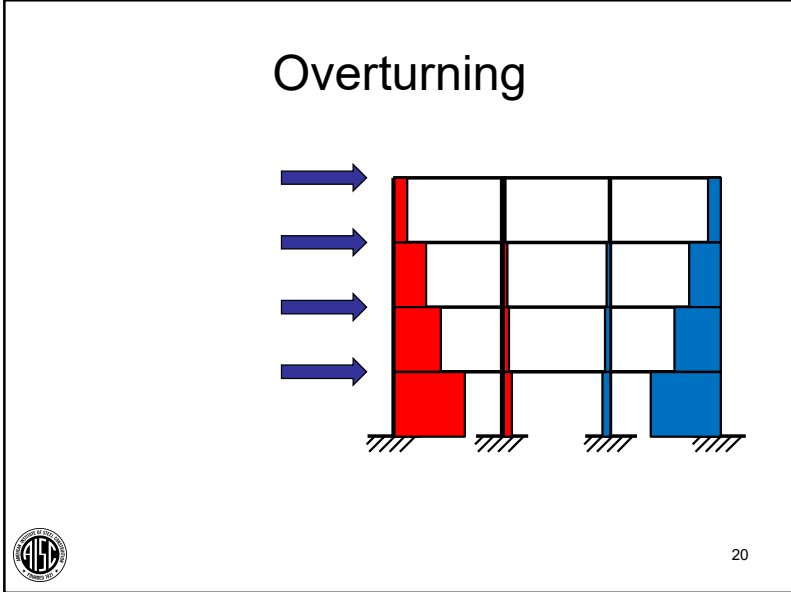
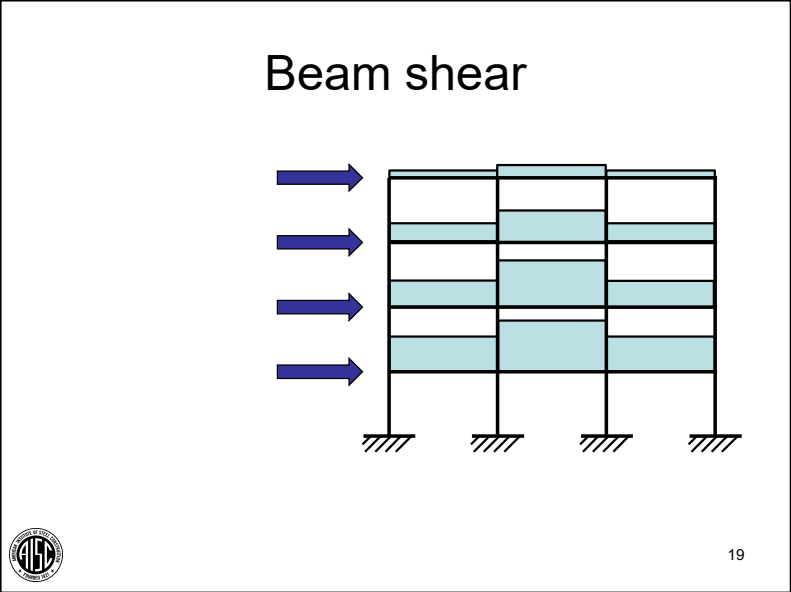
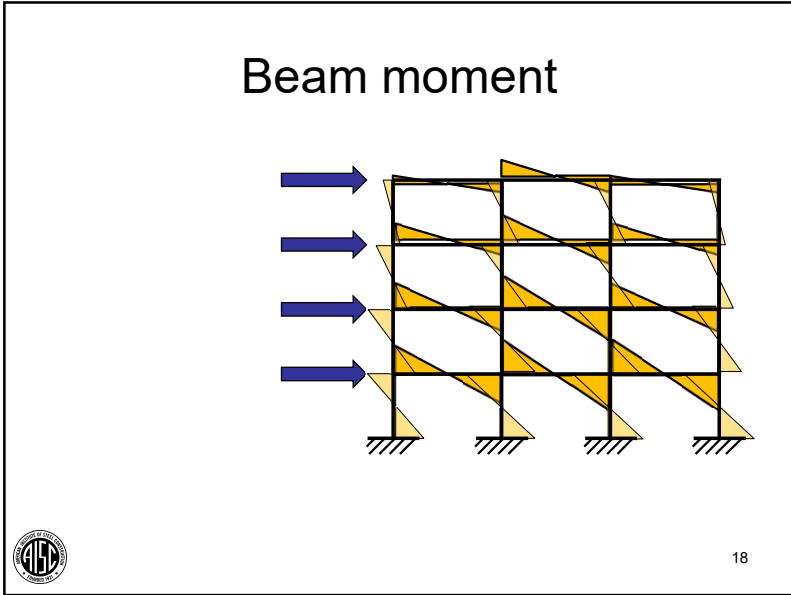
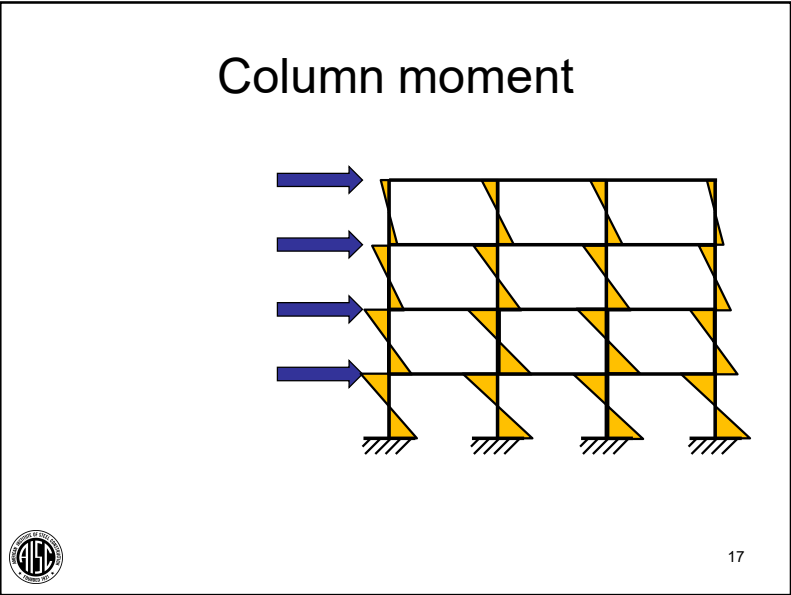
Lateral load resistance

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



Column shear






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



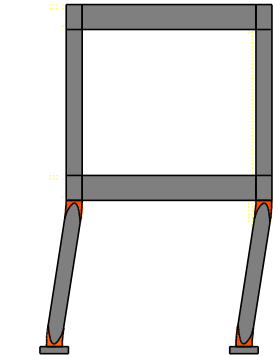
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Plastic hinges in beams



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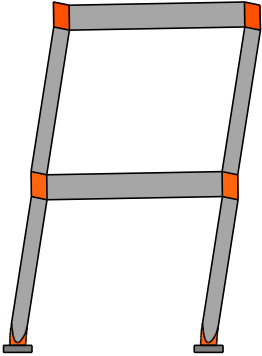
Plastic hinges in columns



Potential for soft story collapse



Plastic hinges in panel zones

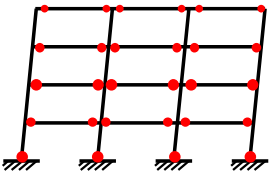


Potential for column distortion



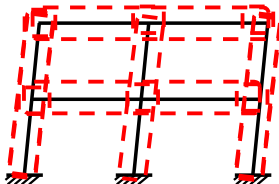
Fuse concept

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



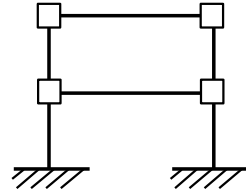
Elastic analysis

- 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)



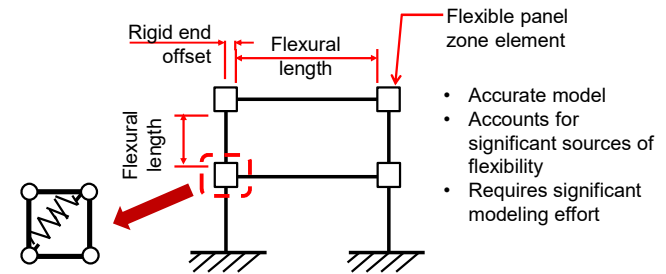
Analysis

- 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



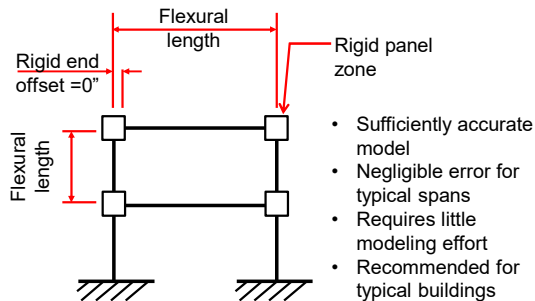
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Panel zone model



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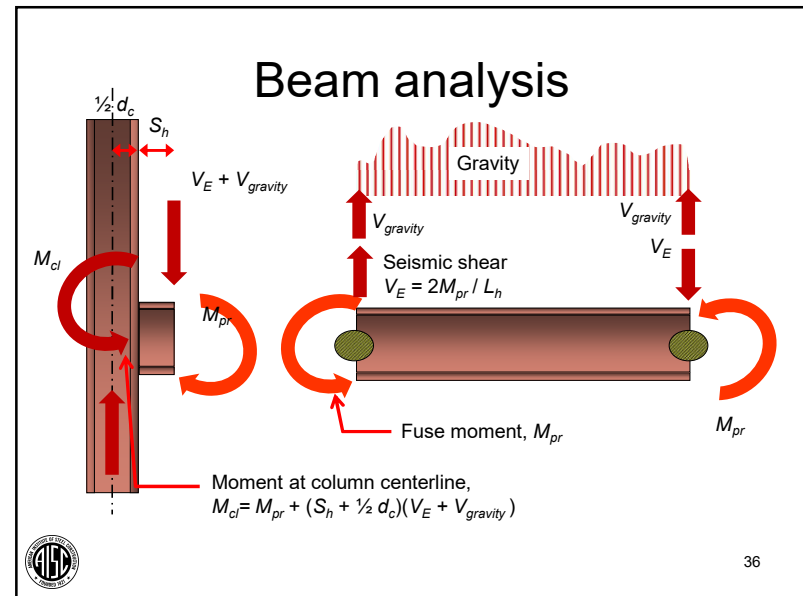
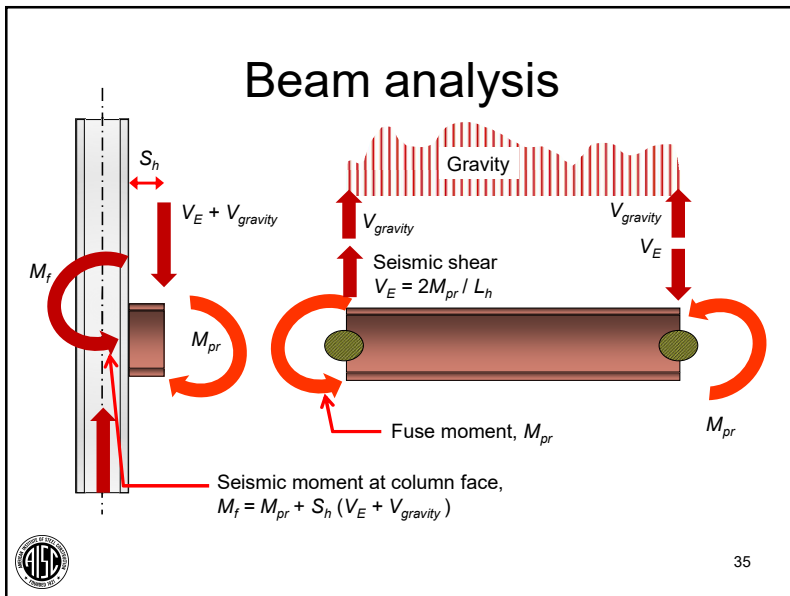
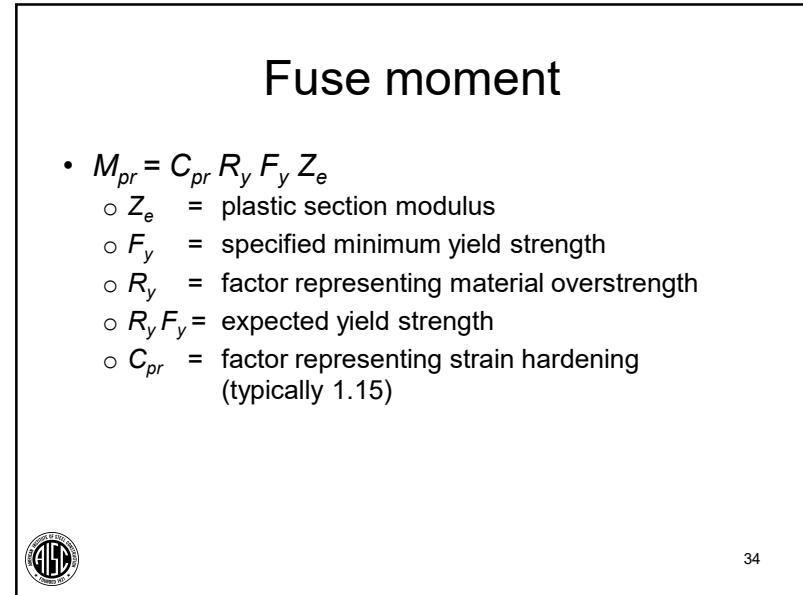
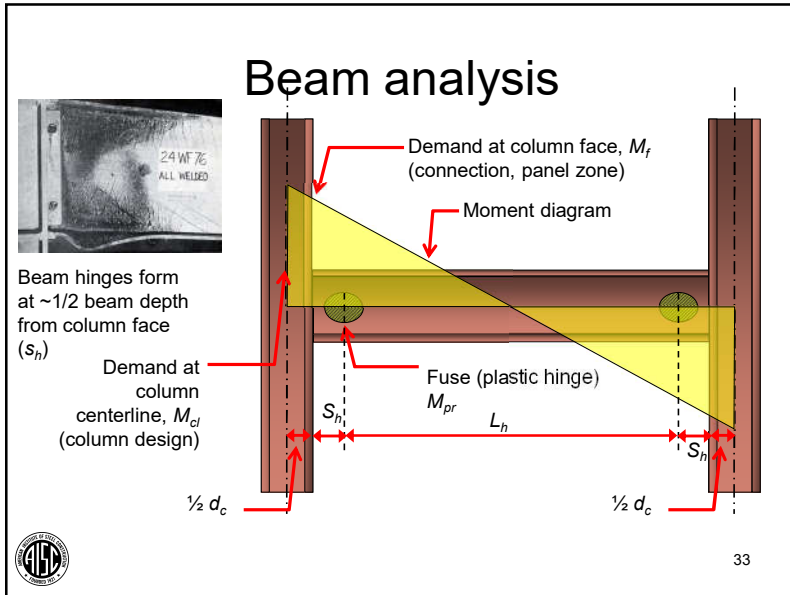
Panel zone approximation

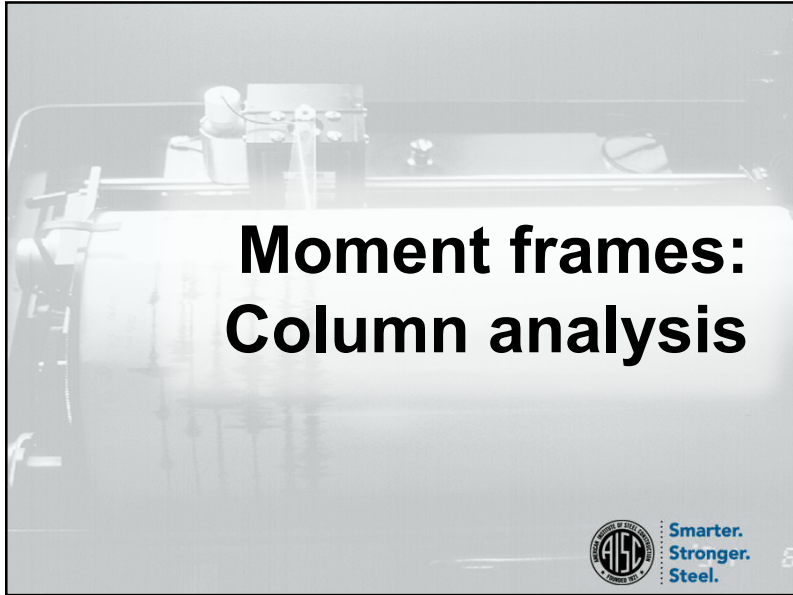


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Moment frames: Beam analysis







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 flexure

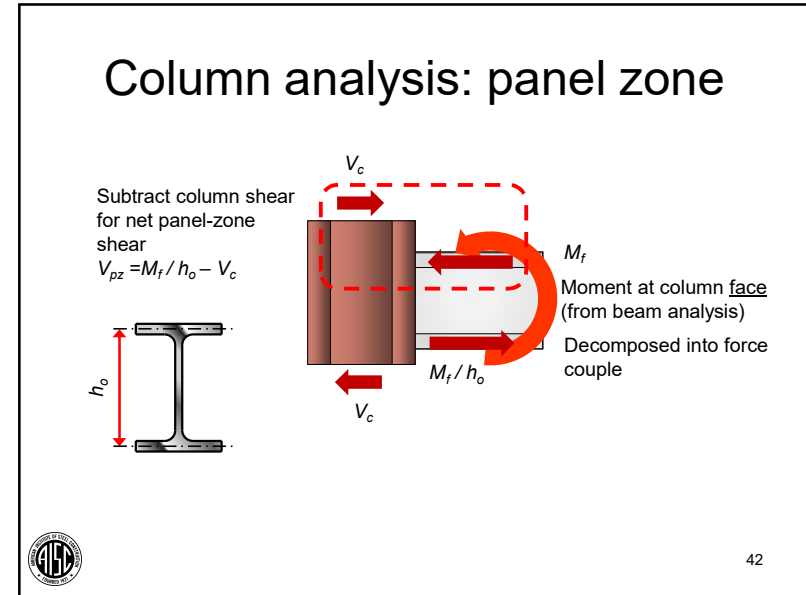
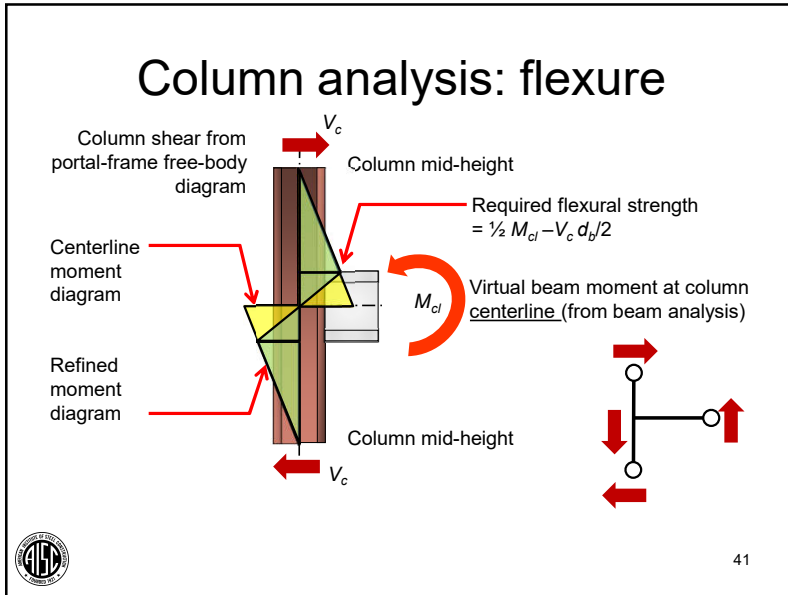
Panel-zone shear

Column analysis

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

Seismic column shear, V_c

Seismic beam shear, V_E (from beam analysis)

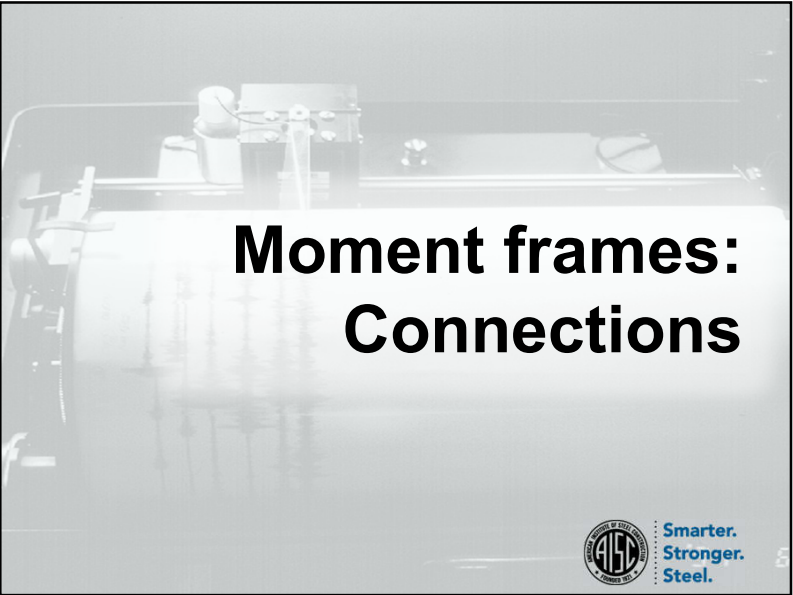


Panel zone strength

AISC 360 J10.6	Low axial force	High axial force
Panel zone deformation <u>not</u> modeled	$P_r \leq 0.4P_c$ $0.60F_y d_c t_w$	$P_r > 0.4P_c$ $0.60F_y d_c t_w \left(1.4 - \frac{P_r}{P_c} \right)$
Panel zone deformation modeled	$P_r \leq 0.75P_c$ $0.60F_y d_c t_w^* \left(1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_w} \right)$	$P_r > 0.75P_c$ $0.60F_y d_c t_w^* \left(1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_w} \right) \left(1.9 - \frac{1.2P_r}{P_c} \right)$

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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 independent of panel zone modeling
 - Based on (beam) member strength
 - Unlike wind, stability
 - Panel zone (seismic) deformations required to be included (per codes)
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Moment connections

- Design
- Construction
- Observed problems (Northridge)
- Current practice

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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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Connection construction



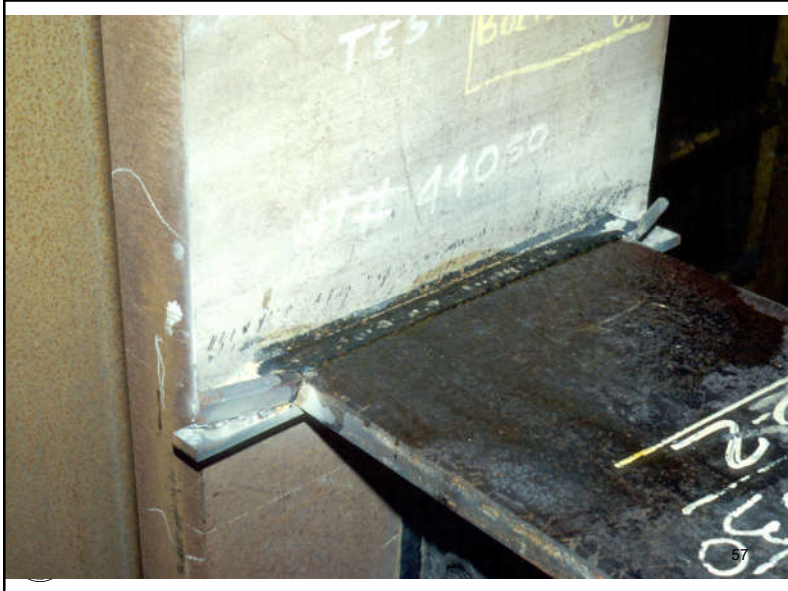
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Northridge earthquake

- Good performance of steel buildings
- Some unexpected damage to welded steel moment frames
- Some construction defects discovered



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Northridge Moment Connection Damage

- Typical damage: bottom flange weld fracture
 - Or in adjacent base metal
- Little or no ductility
- FEMA funded SAC Joint venture
 - SEAOC, ATC, CUREE
 - Investigation of causes
 - Development of procedures



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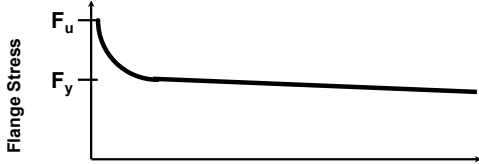
Northridge Moment Connection Damage

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



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Lack of web participation



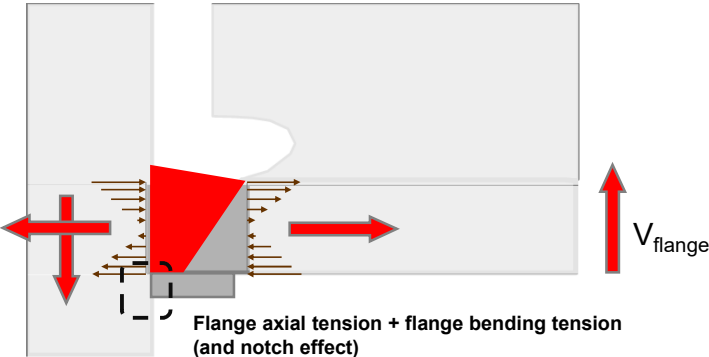
Bolted connection too flexible

Flexural stresses concentrate in flange



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Increase in Flange Stress Due to Shear in Flange

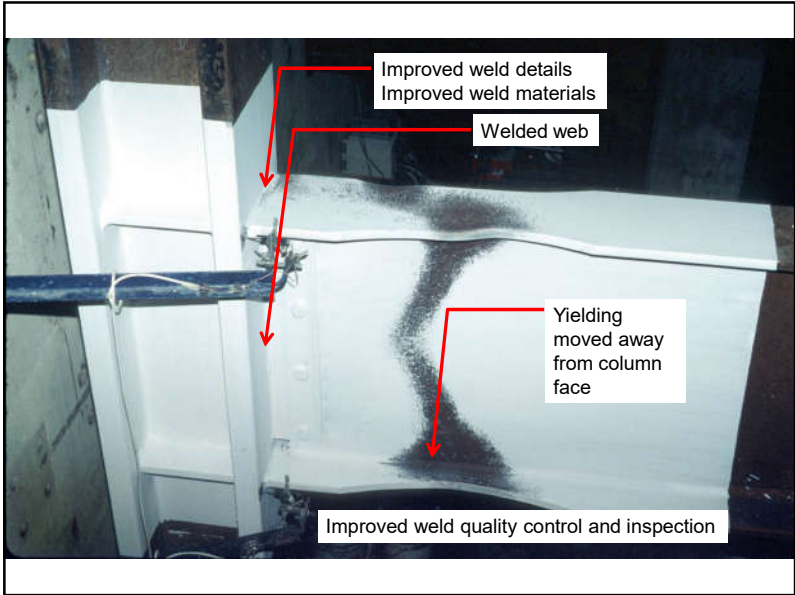


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Current practice

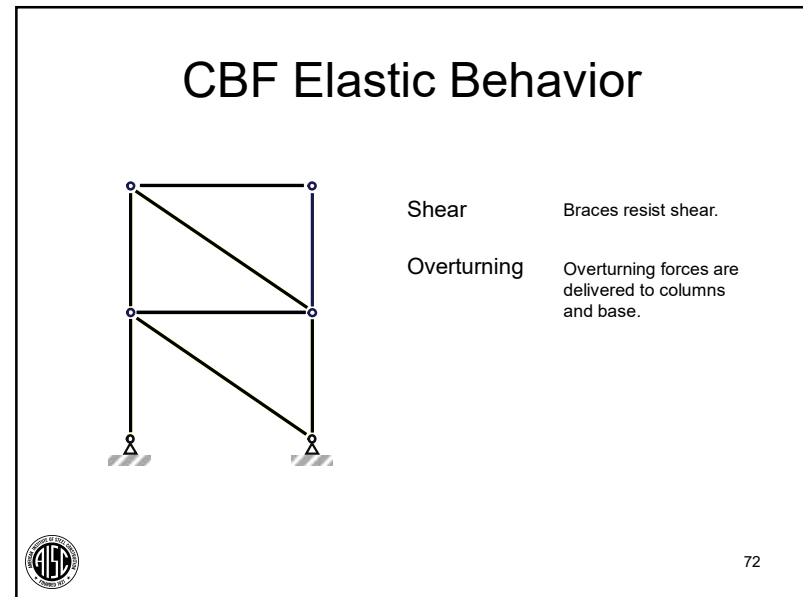
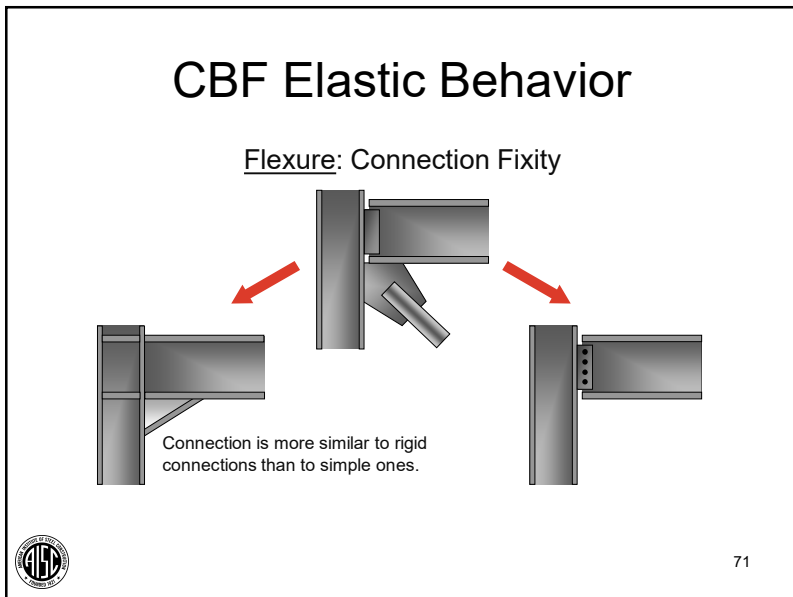
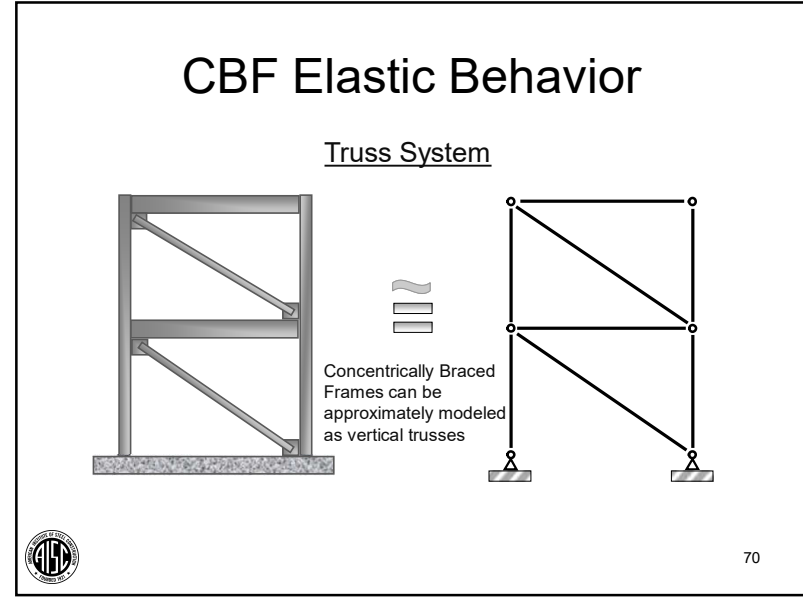
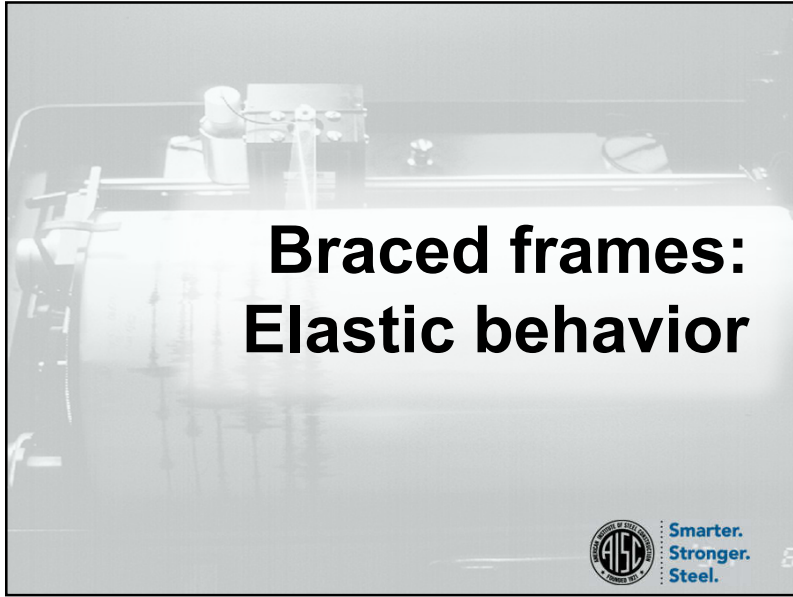
- Move hinge away from column face
- Weld beam web
- Improve weld access hole to relieve restraint
- Reinforce or remove backing
- Use tough materials
- Improved welding techniques



Braced frames

- Elastic behavior
- Post-elastic behavior
- Plastic mechanism


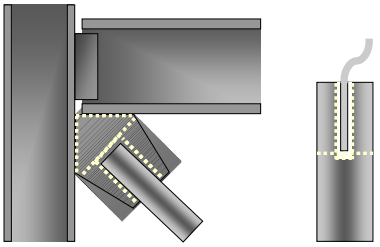




Connection limit states

Connections: Brace End

- Brace net section fracture
- Brace block shear fracture
- Brace-to-gusset weld fracture
- Gusset block shear fracture
- Gusset tension yield or fracture
- Gusset or weld failure at column
- Gusset or weld failure at beam
- Gusset buckling


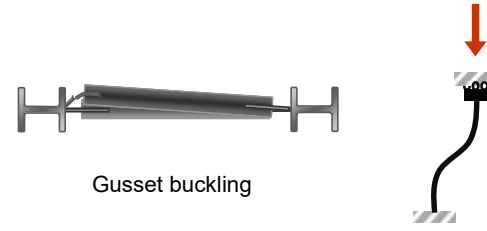


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Connection limit states


Connections: Brace End

- Gusset buckling




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Brace Fracture



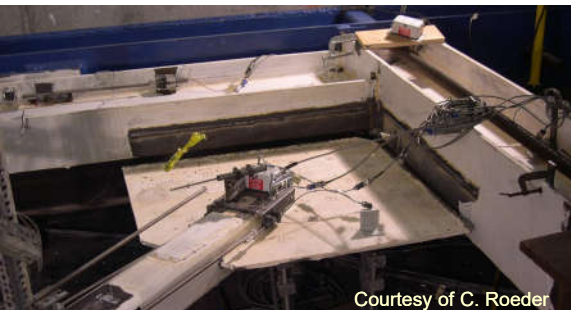
Courtesy of R. Tremblay




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Post-Elastic Behavior

Unfavorable Modes: Connection Fracture



Courtesy of C. Roeder



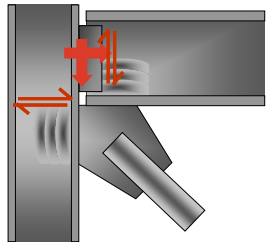
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Connection Instability



Connection limit States

Connections: Brace End



- Column web yielding
- Column web crippling
- Column web shear
- Beam web yielding, crippling, shear
- Beam-column connection, shear
- Beam-column connection, axial

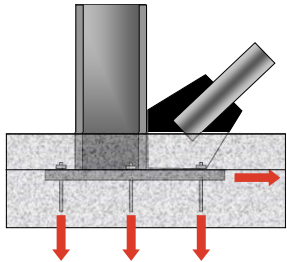


Beam Instability



Base-plate limit states


Connections: Base Plate



- Shear
- Tension
- Resistance to horizontal and vertical force components must be provided. Different mechanisms (with different limit states) can be used.



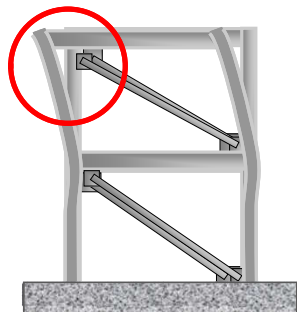
Braced frames: Post-elastic behavior




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Post-Elastic Behavior

Unfavorable Modes: Connection Fracture



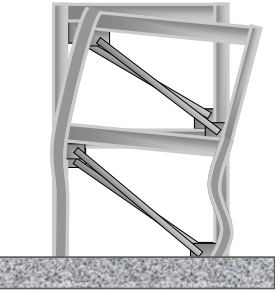
Connection fracture must not be the governing limit state.




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Post-Elastic Behavior

Unfavorable Modes: Column Buckling



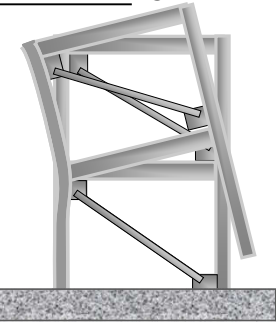
Column buckling must not be the governing limit state.




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Post-Elastic Behavior

Unfavorable Modes: Column Tension Fracture



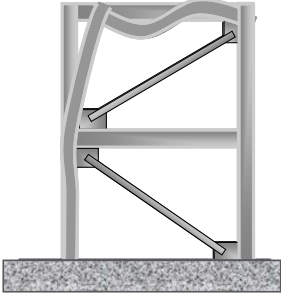
Column tension fracture must not be the governing limit state.




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Post-Elastic Behavior

Unfavorable Modes: Beam Failure



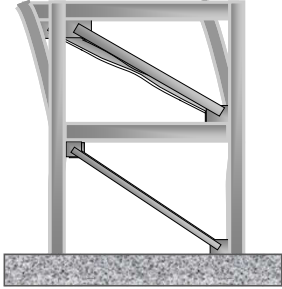
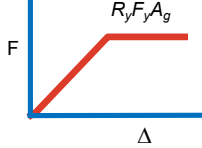
Beam failure must not be the governing limit state.



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Post-Elastic Behavior

Preferred Modes: Brace Tension Yielding

Brace yielding should be a governing limit state.

Consider maximum effects due to brace force ($R_y F_y A_g$)



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Brace Elongation (Tension Only)



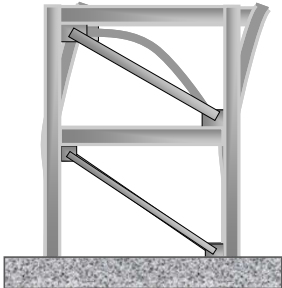
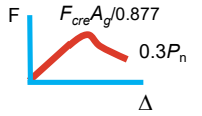
Courtesy of R. Tremblay



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Post-Elastic Behavior

Preferred Modes: Brace Buckling

Brace buckling should be a governing limit state.

Consider maximum effects due to brace force (sometimes $P = R_y P_n$, sometimes $P = 0.3 P_n$)



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Brace Buckling

Flexural buckling (Compression)

Buckling: 3 hinges

Pinned end

Fixed end

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Brace Buckling

Courtesy of S. Mahin
U.C. Berkeley, 2004

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Brace Buckling: Effect on Other Elements

Courtesy of R. Tremblay

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Brace cyclic behavior

P Tension

$R_y A_g F_y$

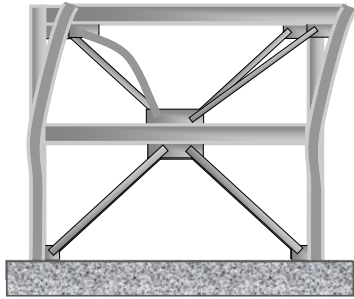
P_{cr} Compression

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System Behavior with Brace Yielding

Column Flexure



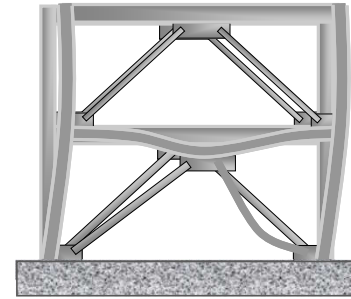
Columns must bend when braces buckle and yield.



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System Behavior with Brace Yielding

Beam Flexure

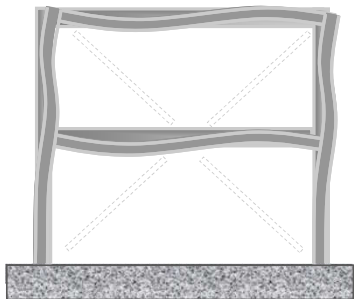


Brace buckling and yielding induce flexural forces in beams in this configuration.



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Frame Participation



Flexural forces are induced in rigidly-connected columns and beams due to drift.

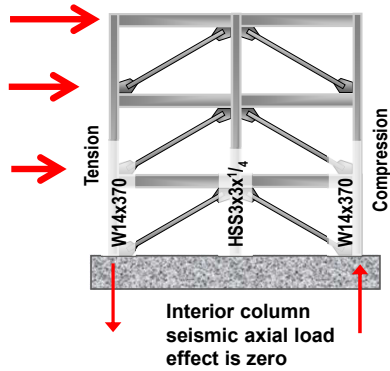


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Braced frames: Plastic mechanism analysis

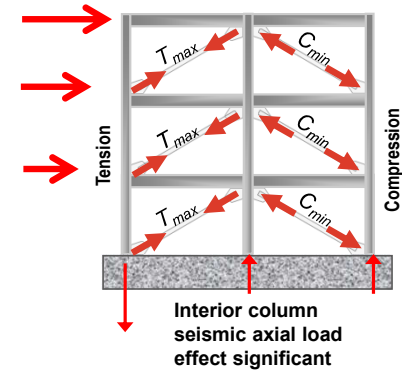
Smarter.
Stronger.
Steel.

What elastic analysis misses



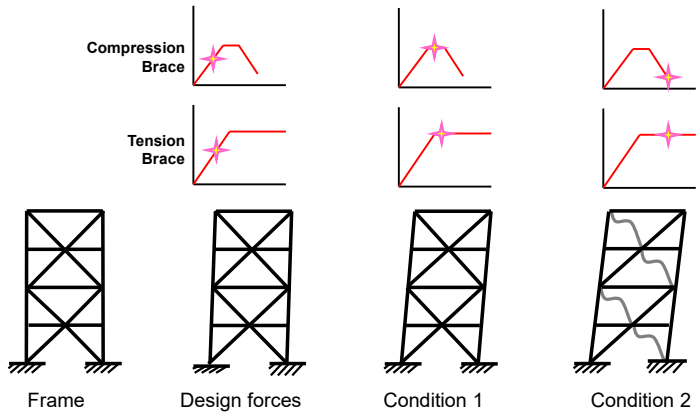
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What elastic analysis misses



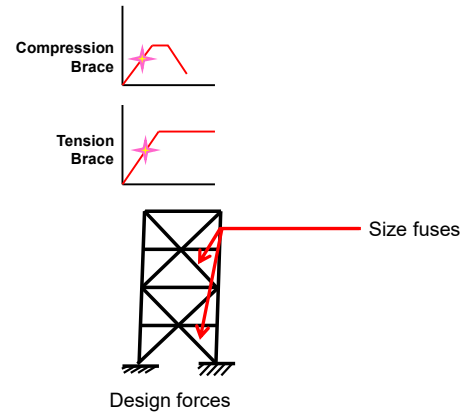
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Plastic mechanism analyses

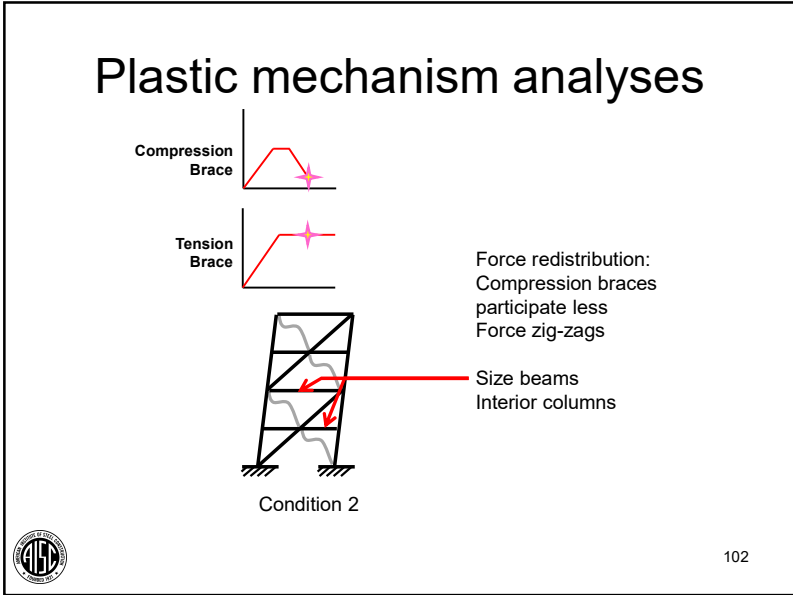
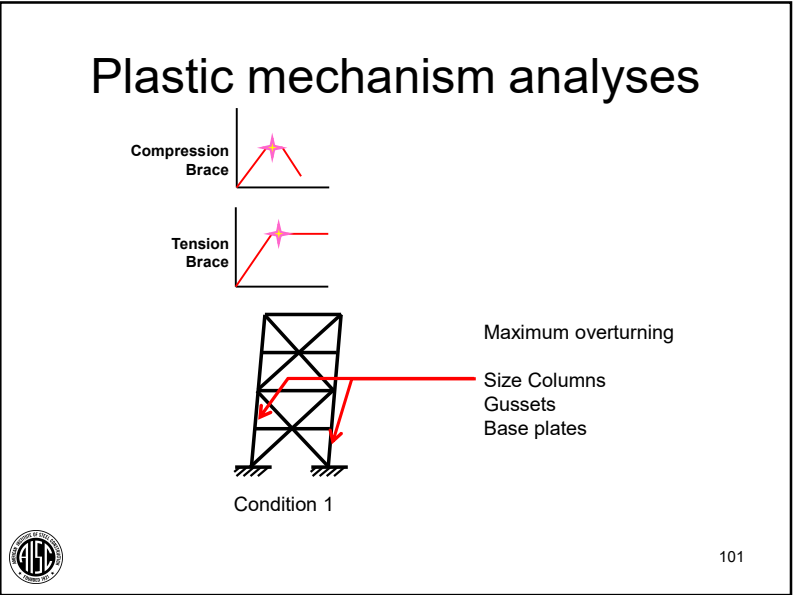


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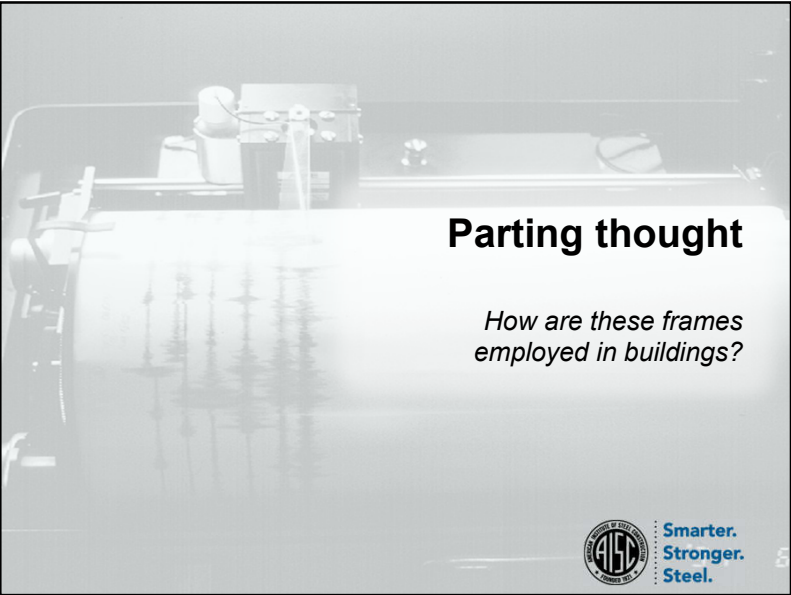
Design forces



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- ### Summary
- Moment-frame ductility stems from beam yielding
 - Braced-frame ductility stems from brace buckling and yielding
 - Capacity-design procedures allow proper proportioning to ensure ductile behavior
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Parting thought

How are these frames employed in buildings?



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Steel.




End of session 6

Next:
**Session 7:
Building configuration**

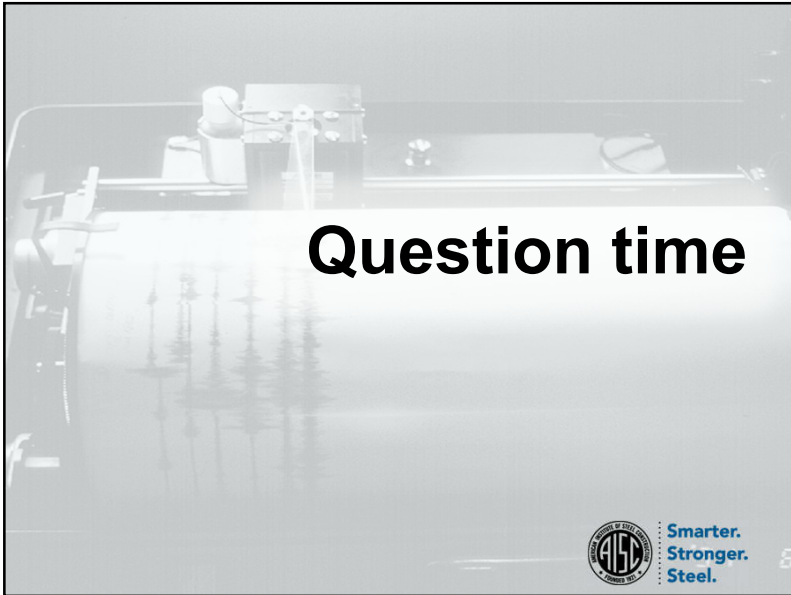


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Additional resources

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Question time



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Single-Session Registrants

CEU / PDH Certificates

- 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 the course.



8-Session Registrants

CEU / PDH Certificates

One certificate will be issued at the conclusion of the course.



8-Session Registrants

Attendance and PDH Certificates

- You have two options to receive credit for a given session.
 - Option 1: Watch the live session. Credit for live attendance will be displayed on the Course Resources table within two days of the session.
 - Option 2: Watch the recording and pass the associated quiz.

Videos and Quizzes

- For each session, find access within two business days after the live air date. (An email will be sent from nightschool@aisc.org.)
- Reasons for quiz:
 - EEU – You must take all quizzes and the final exam to receive EEU.
 - PDHs – If you watch a recorded session, you must pass quiz for PDHs.
 - Reinforce what you learn in the lectures and get more out of the course!

Distribution of Certificates

All certificates will be issued after the course is completed. Only the registrant will receive a certificate for the course.



8-Session Registrants

Course Resources

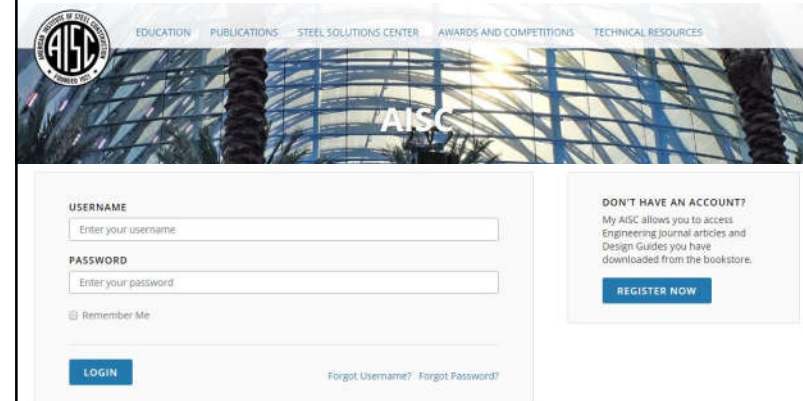
Find all your handouts, quizzes and quiz scores, recording access, and attendance information in one place!



8-Session Registrants

Course Resources

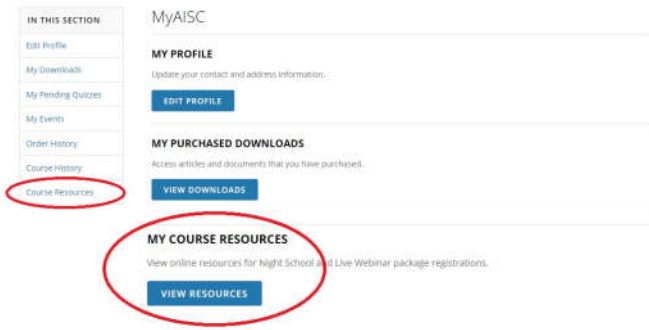
Go to www.aisc.org and sign in.



8-Session Registrants

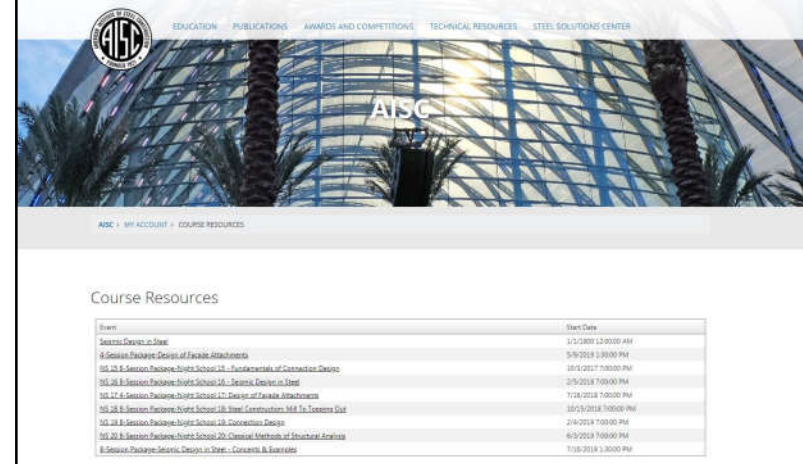
Course Resources

Go to www.aisc.org and sign in.




8-Session Registrants


Course Resources



8-Session Registrants

Course Resources


EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER



AISC > MY ACCOUNT > COURSE RESOURCES > NS24 8-SESSION PACKAGE RESOURCES

Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6, 2020 7:00PM EDT	Available	Available 10/06/2020 5:00PM EDT	Available 10/06/2020 5:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13, 2020 7:00PM EDT	Available	Available 10/13/2020 5:00PM EDT	Available 10/13/2020 5:00PM EDT	Pending
NS24.3 - Behavior of Neutral Members - The Fundamentals	Oct 20, 2020 7:00PM EDT	Available	Available 10/20/2020 5:00PM EDT	Available 10/20/2020 5:00PM EDT	Pending
NS24.4 - Neutral Members - Practical Considerations	Oct 27, 2020 7:00PM EDT	Available	Available 10/27/2020 5:00PM EDT	Available 10/27/2020 5:00PM EDT	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 3, 2020 7:00PM EDT	Available	Available 11/03/2020 5:00PM EDT	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Considerations	Nov 10, 2020 7:00PM EDT	Available	Available 11/10/2020 5:00PM EDT	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Nov 17, 2020 7:00PM EDT	Available	Available 11/17/2020 5:00PM EDT	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Nov 24, 2020 7:00PM EDT	Available	Available 11/24/2020 5:00PM EDT	No longer available	Pending
NS24 - Final Exam	N/A	Available	Available 12/01/2020 5:00PM EDT	No longer available	Pending



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| Thank you.



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Stronger.
Steel.