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

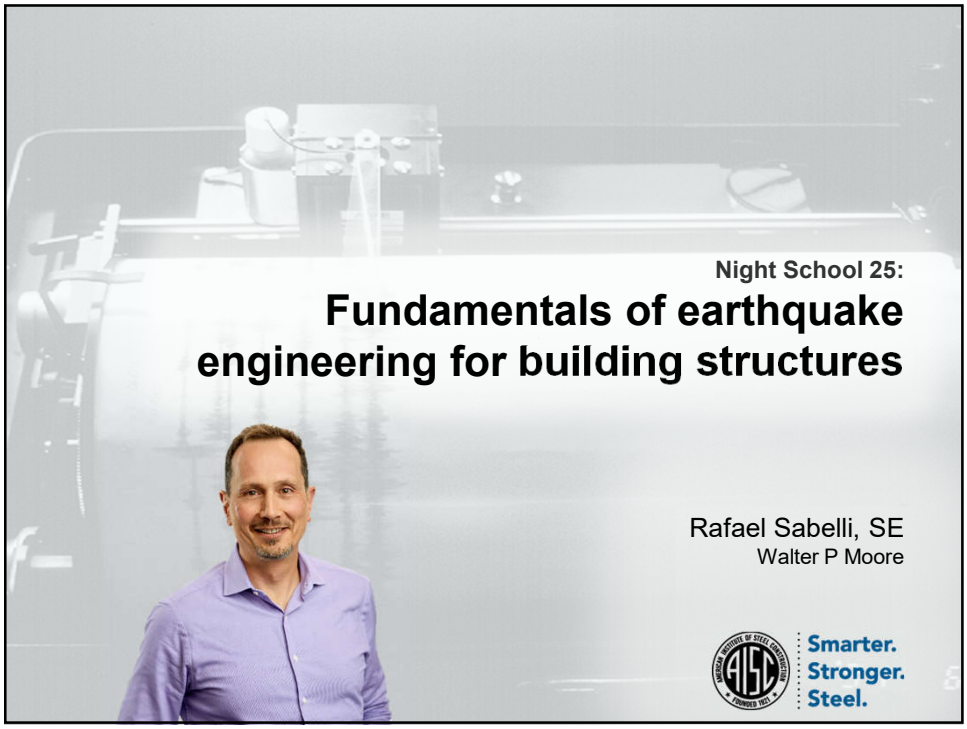
Steel Systems

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 is the design of steel framed structures.
- Describe braced frame intended behavior in seismic design.
- Explain post-elastic behavior of braced frames.



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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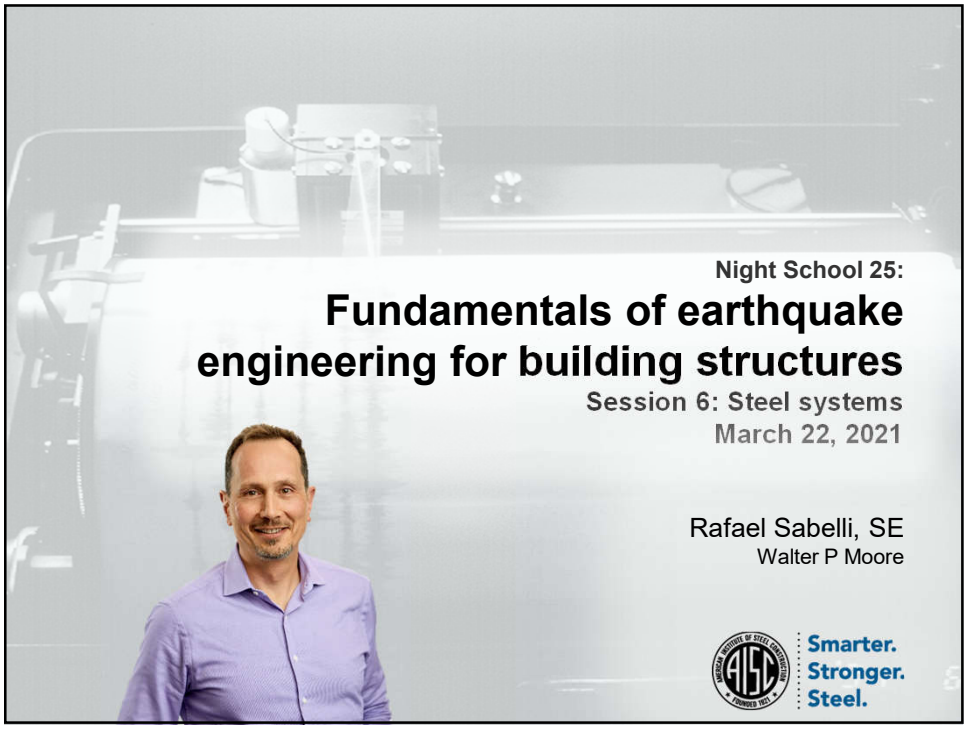

Session topics

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

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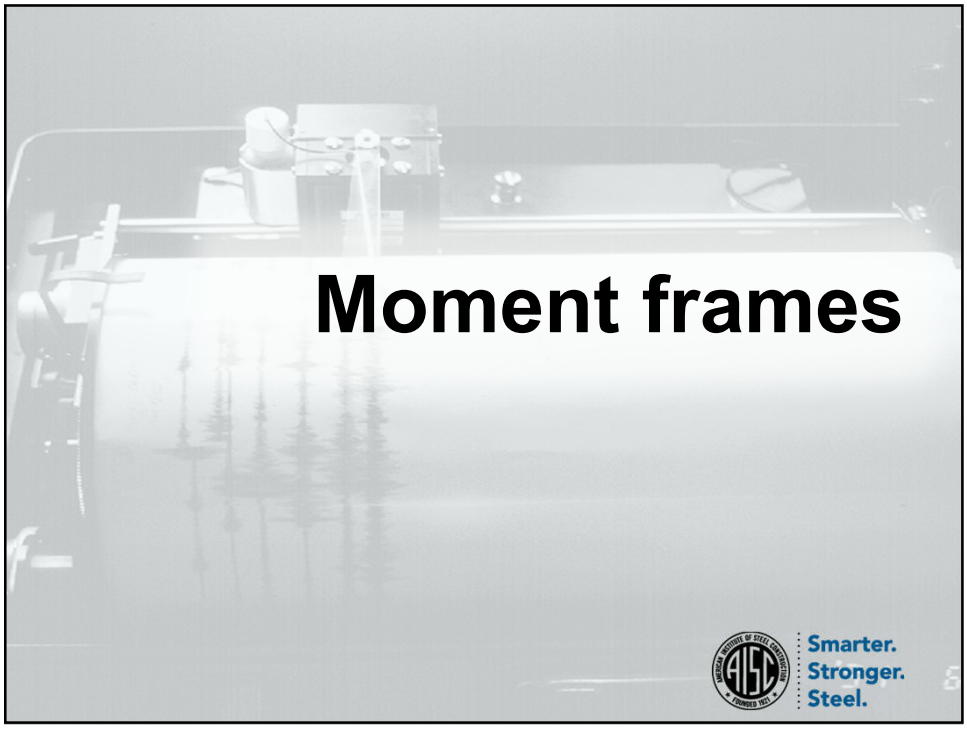

Moment frames

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

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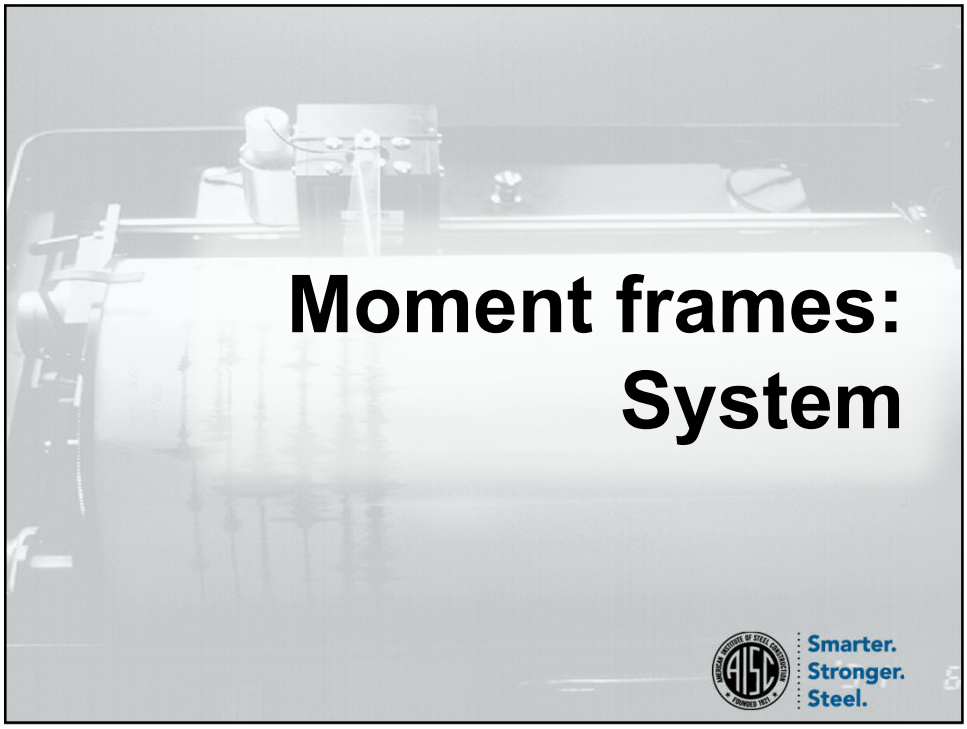
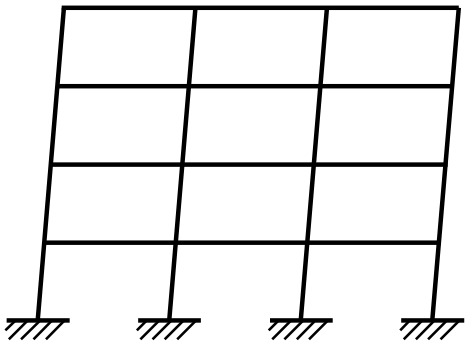


Lateral load resistance

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



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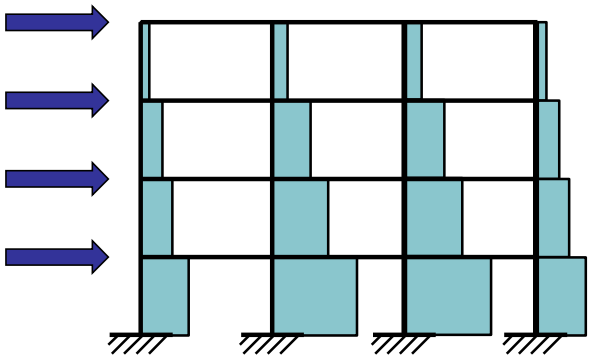
Column shear



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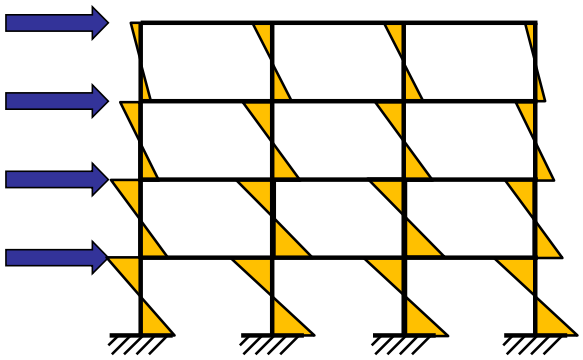
Column moment



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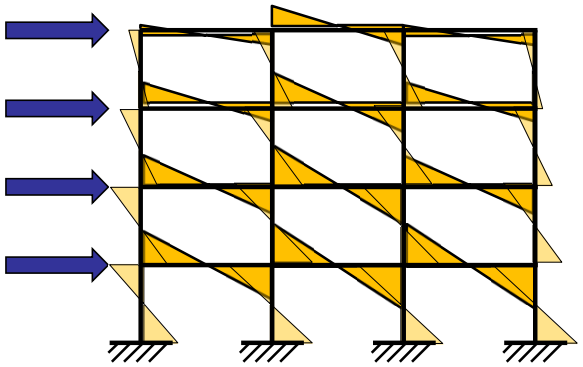
Beam moment



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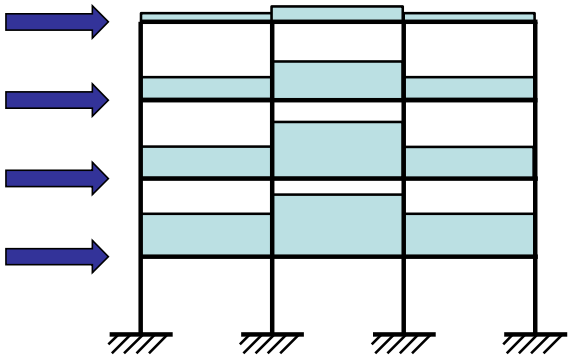
Beam shear



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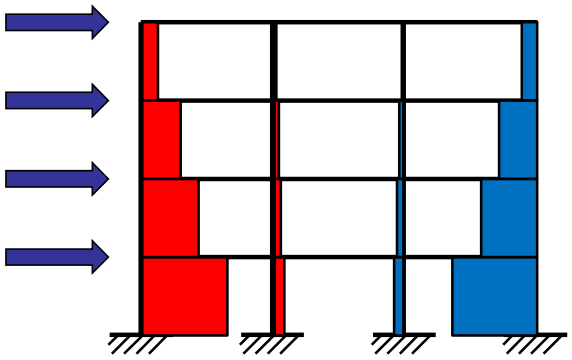
Overturning



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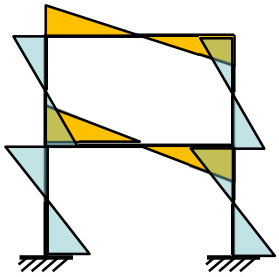
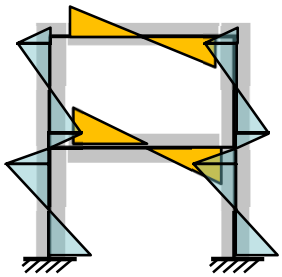
Moment detail



Centerline model



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

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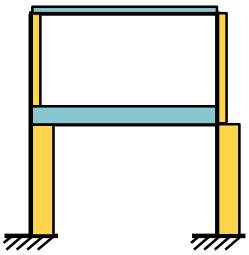
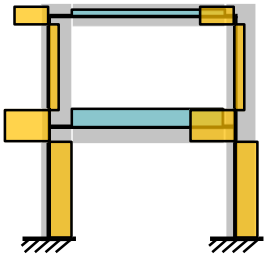
Shear detail



Centerline model



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

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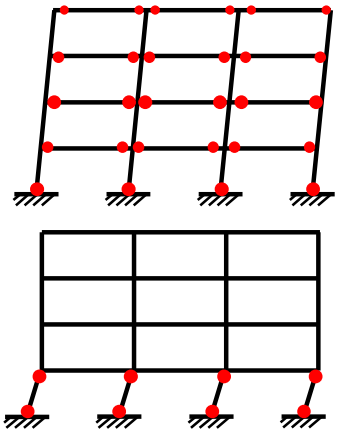
Ductility concept

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



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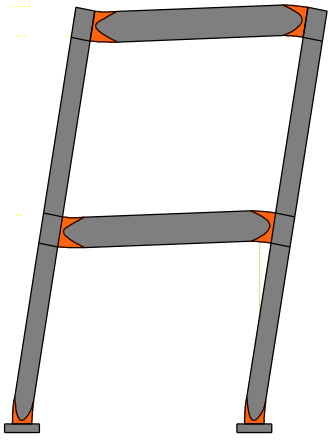
Plastic hinges in beams



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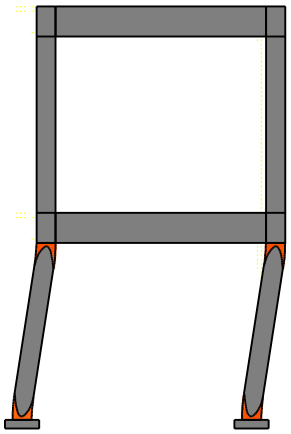
Plastic hinges in columns



Potential for soft story collapse

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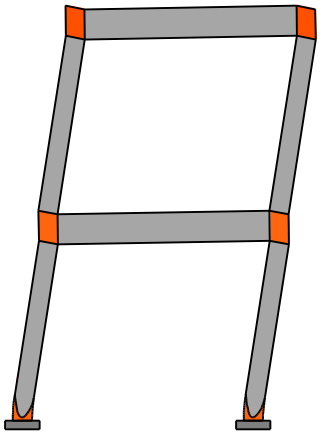
Plastic hinges in panel zones



Potential for column distortion

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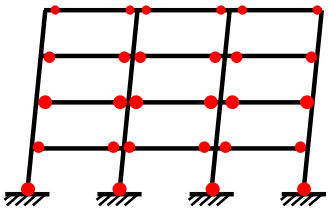
Fuse concept

- 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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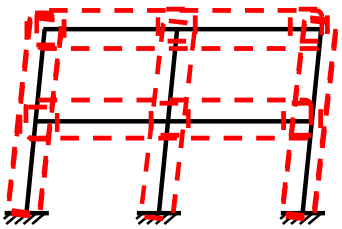
Elastic analysis

- 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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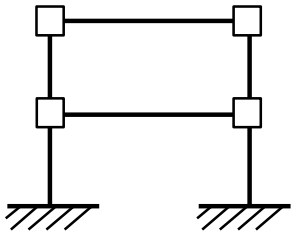
Analysis

- 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



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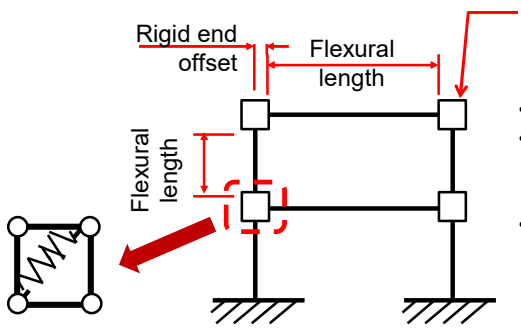
Panel zone model



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

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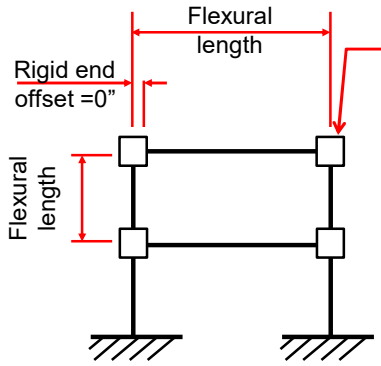
Panel zone approximation



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

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Moment frames: Beam analysis

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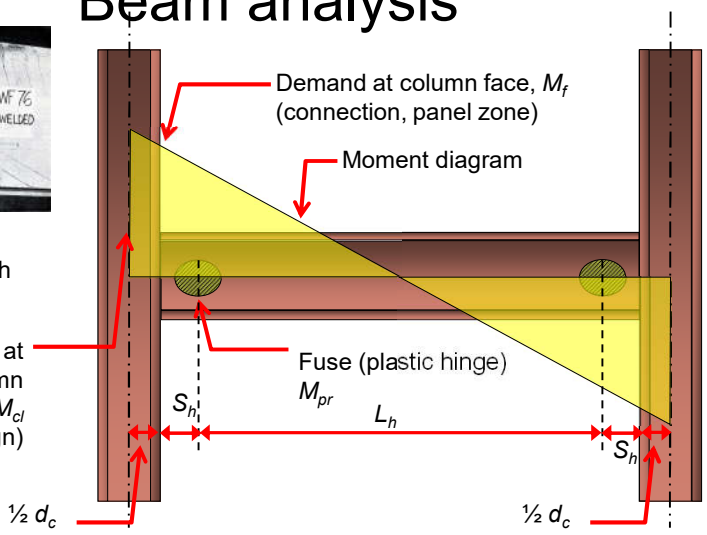
Beam analysis

Beam hinges form at ~1/2 beam depth from column face (s_h)



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Fuse moment

- $M_{pr} = C_{pr} R_y F_y Z_e$
  - Z_e = plastic section modulus
  - F_y = specified minimum yield strength
  - R_y = factor representing material overstrength
  - $R_y F_y$ = expected yield strength
  - C_{pr} = factor representing strain hardening (typically 1.15)

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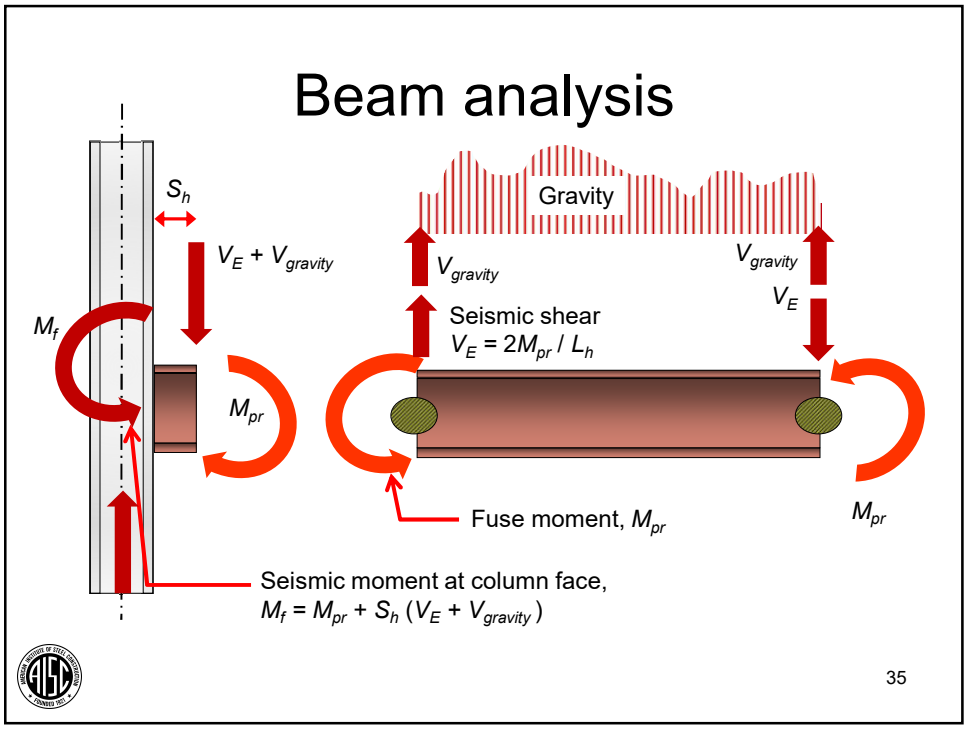

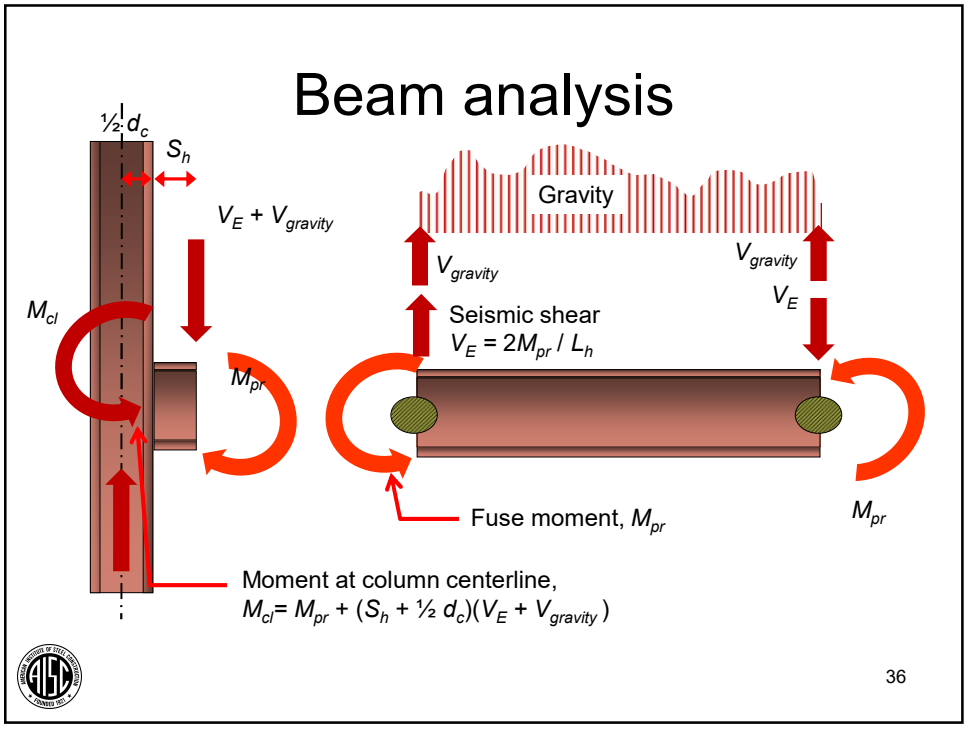

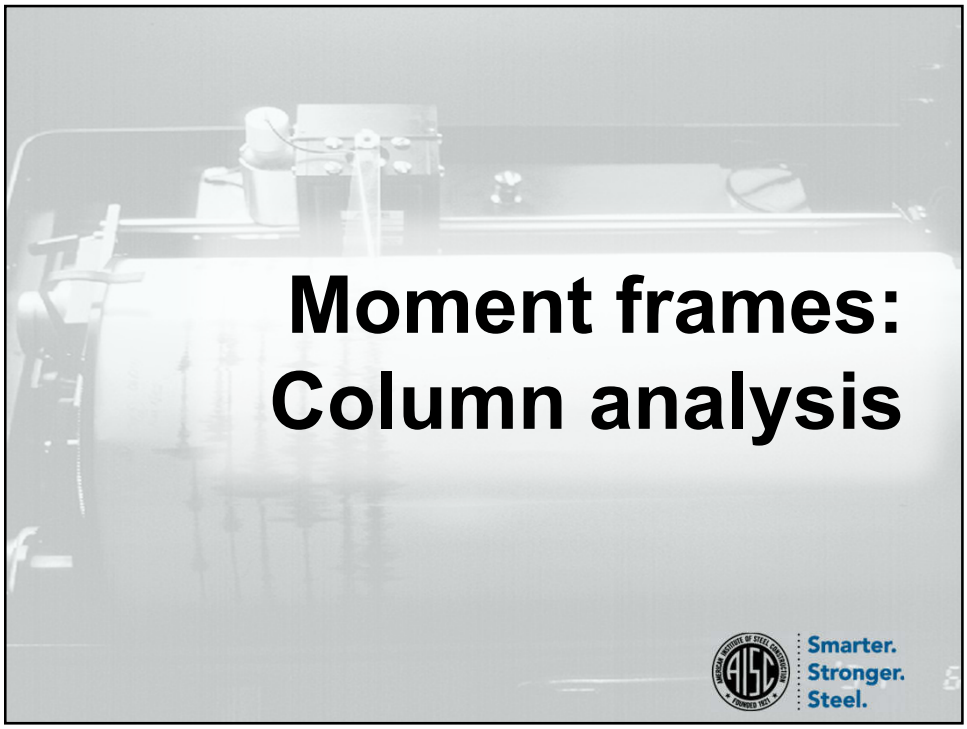

Column analysis

- 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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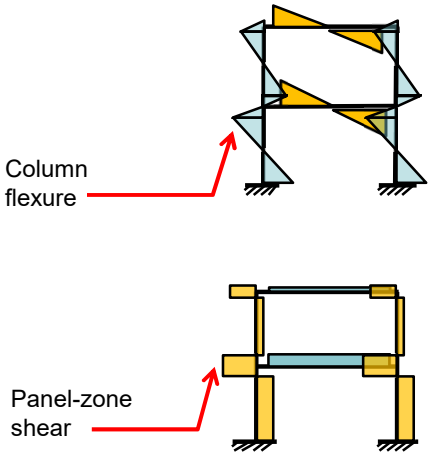
Column analysis

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



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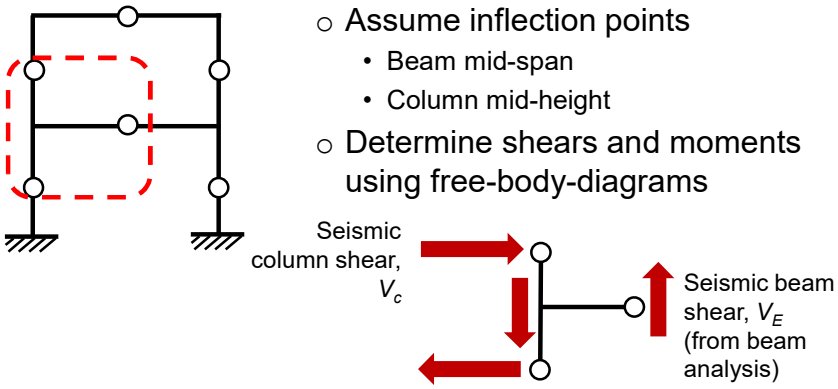
Column analysis

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



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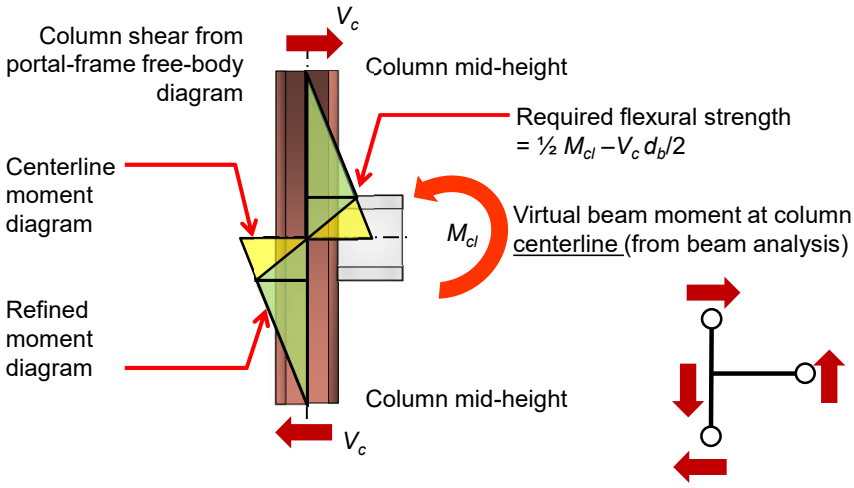
Column analysis: flexure



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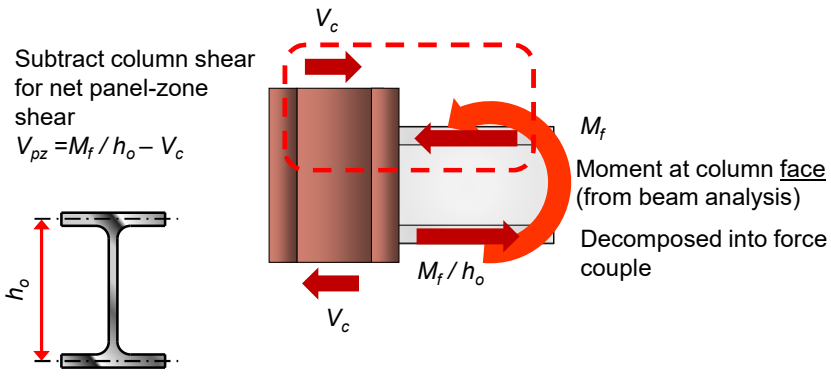
Column analysis: panel zone



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Panel zone strength

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

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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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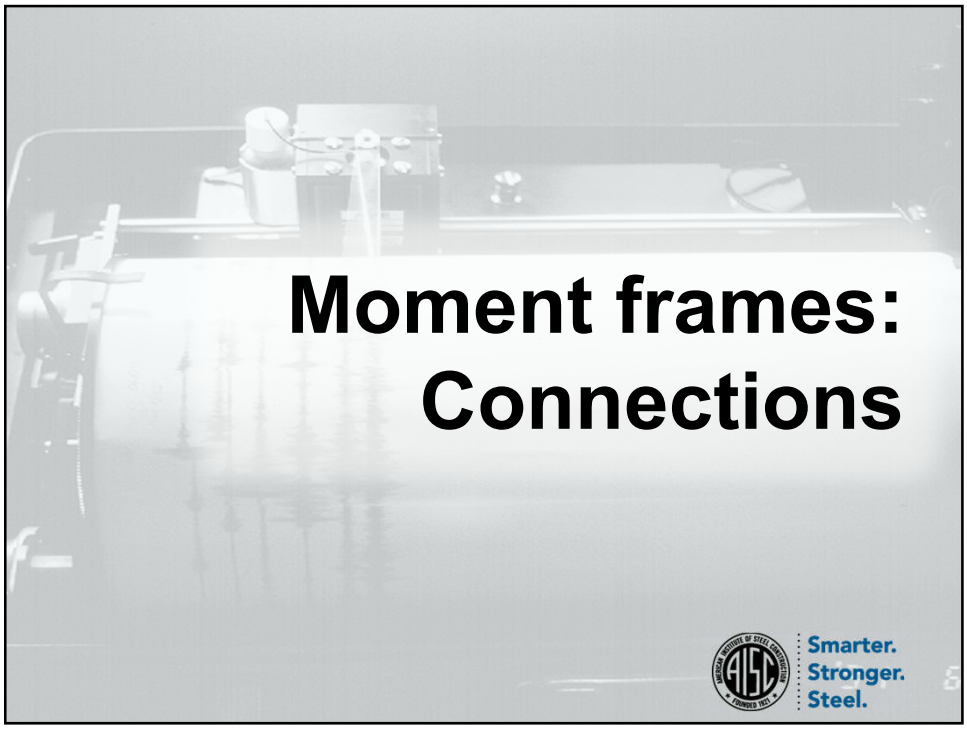

Moment connections

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

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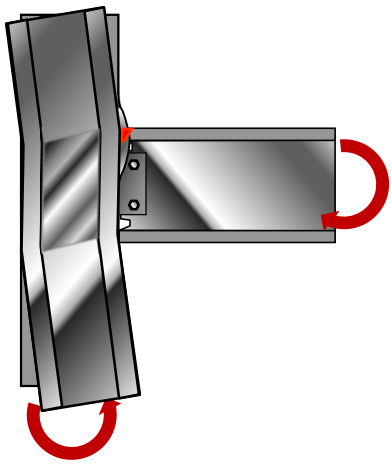
Connection limit States



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

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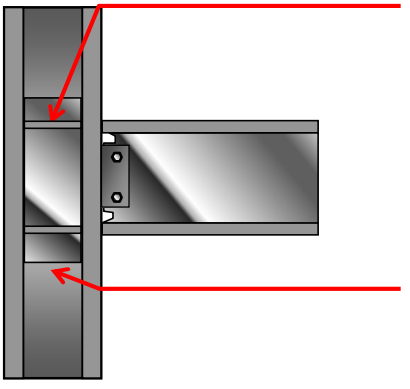
Connection limit States



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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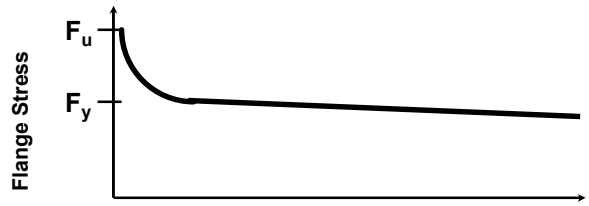
Lack of web participation



Bolted connection too flexible

Flexural stresses concentrate in flange

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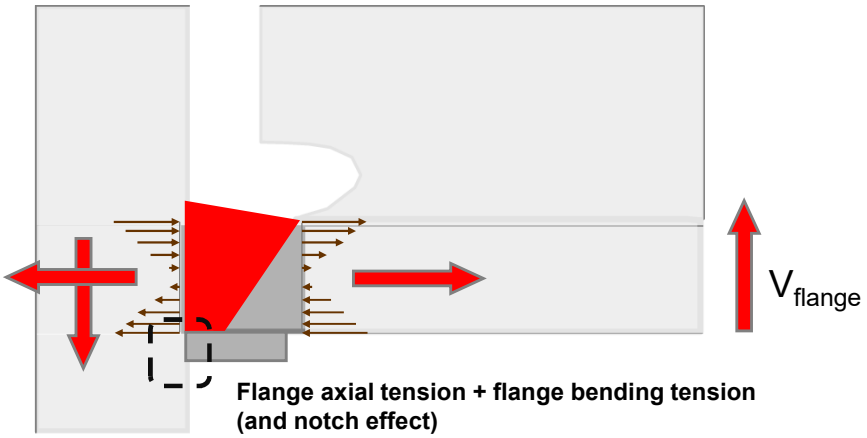
Increase in Flange Stress Due to Shear in Flange



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

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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

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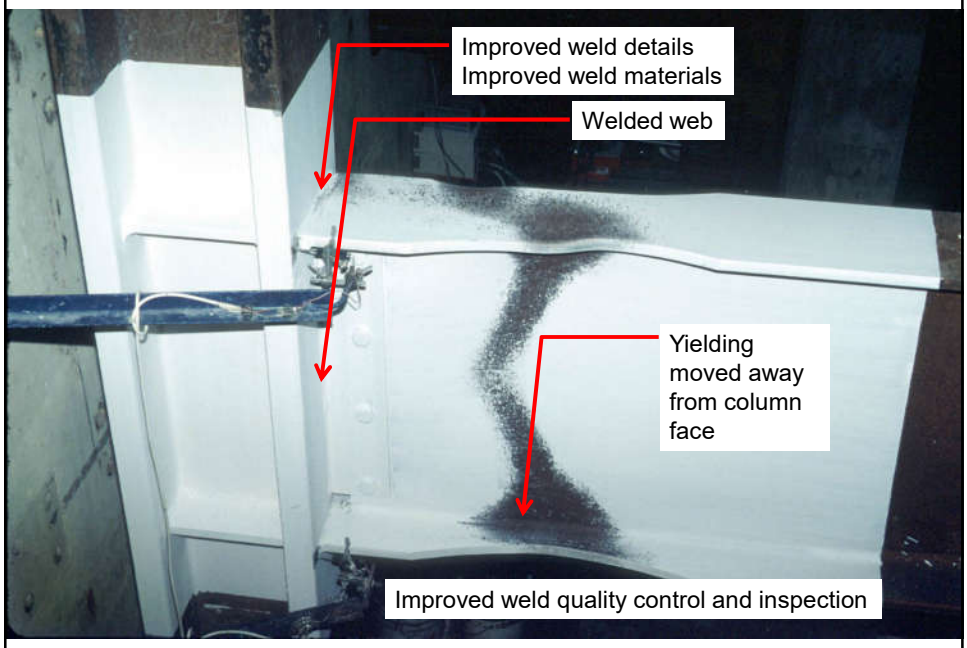

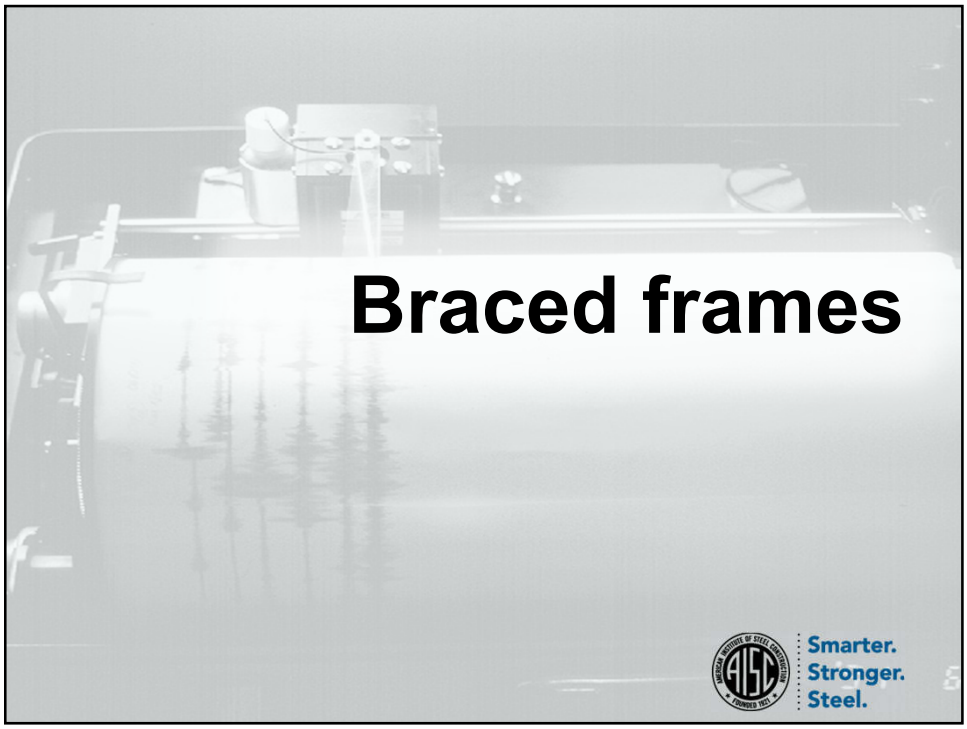

Braced frames

- Elastic behavior
- Post-elastic behavior
- Plastic mechanism

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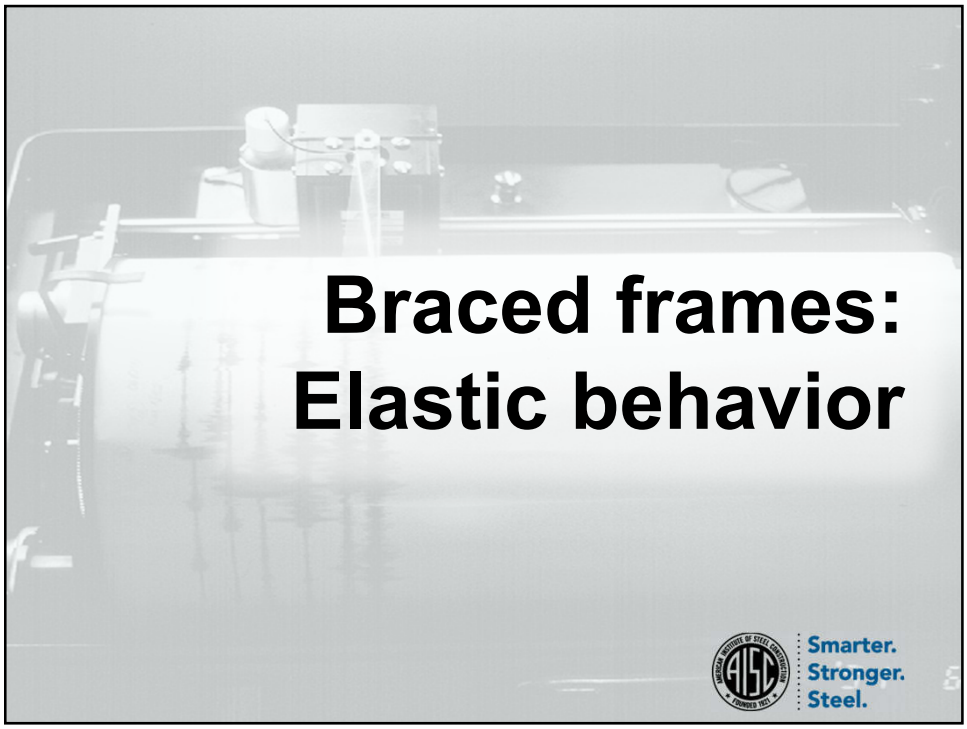
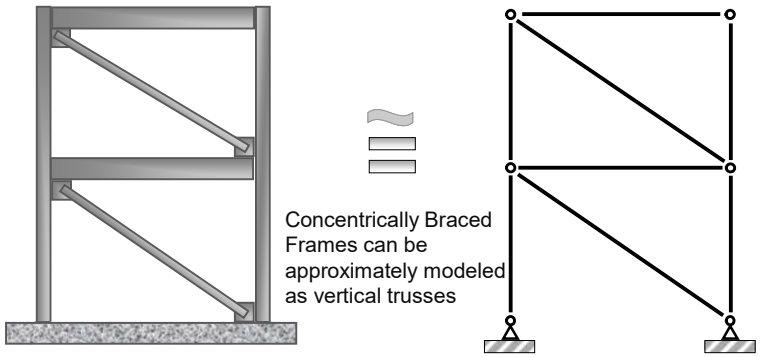


CBF Elastic Behavior

Truss System



Concentrically Braced Frames can be approximately modeled as vertical trusses

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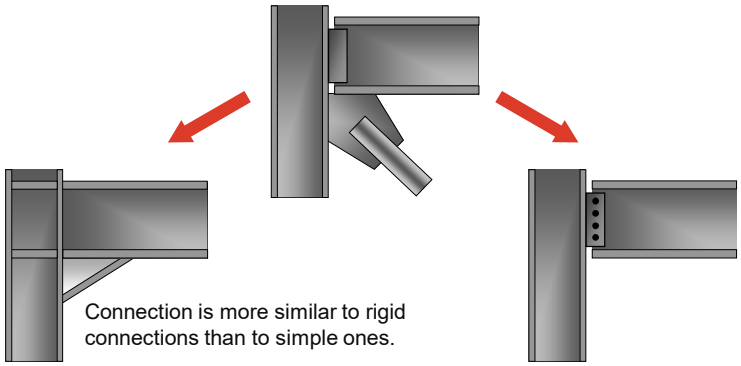
CBF Elastic Behavior

Flexure: Connection Fixity



Connection is more similar to rigid connections than to simple ones.

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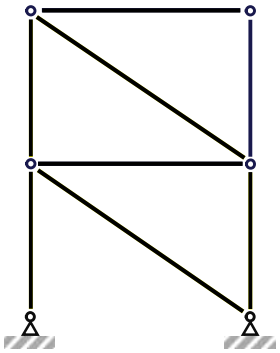
CBF Elastic Behavior



Shear	Braces resist shear.
Overturning	Overturning forces are delivered to columns and base.

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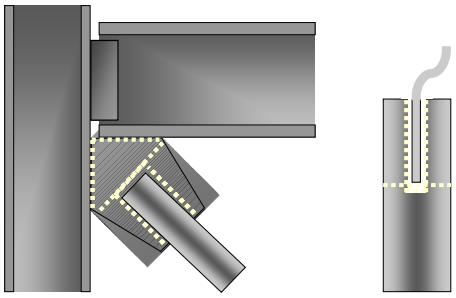
Connection limit states

Connections: Brace End

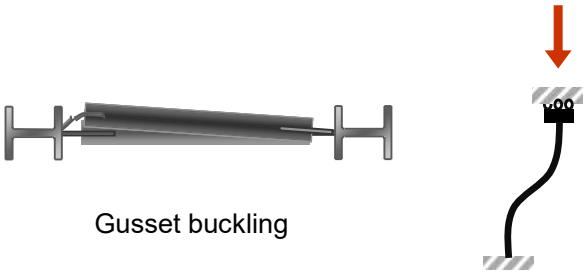


- Brace net section fracture
- Brace block shear fracture
- Brace-to-gusset weld fracture
- Gusset block shear fracture
- Gusset tension yield or fracture
- Gusset or weld failure at column
- Gusset or weld failure at beam
- Gusset buckling

73

Connection limit states

Connections: Brace End



Gusset buckling

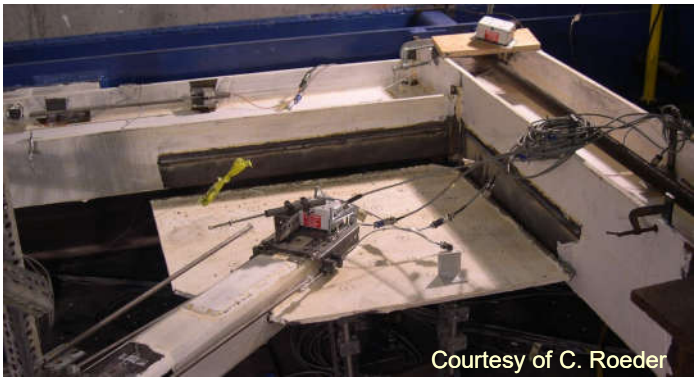
74

Brace Fracture

75

Post-Elastic Behavior

Unfavorable Modes: Connection Fracture



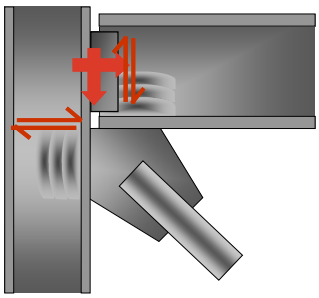
76

Connection Instability

77

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

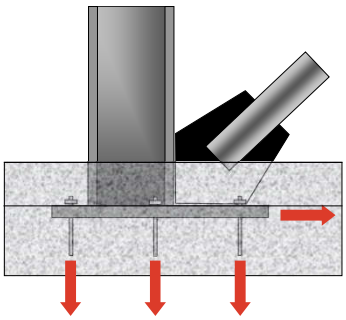
78

Beam Instability

79

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.

80

Braced frames: Post-elastic behavior

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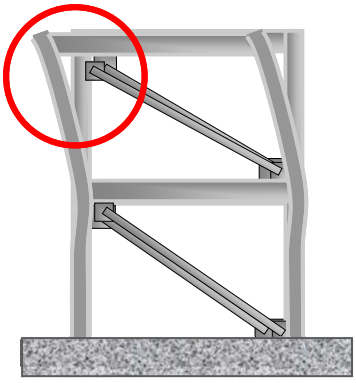
Post-Elastic Behavior

Unfavorable Modes: Connection Fracture

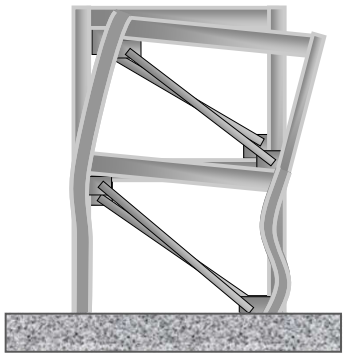


Connection fracture must not be the governing limit state.

82

Post-Elastic Behavior

Unfavorable Modes: Column Buckling

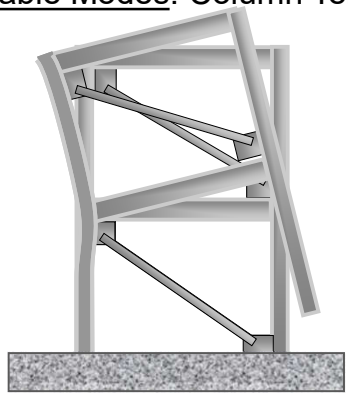


Column buckling must not be the governing limit state.

83

Post-Elastic Behavior

Unfavorable Modes: Column Tension Fracture

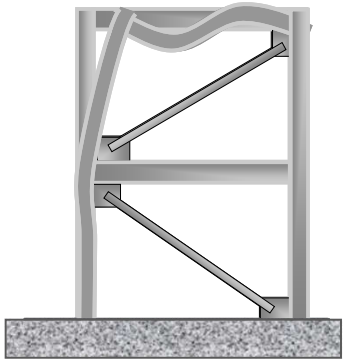


Column tension fracture must not be the governing limit state.

84

Post-Elastic Behavior

Unfavorable Modes: Beam Failure

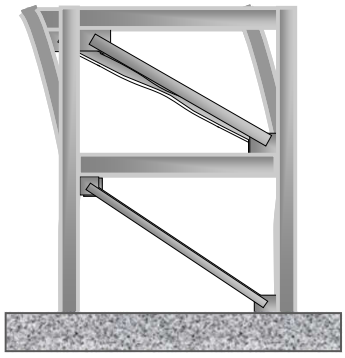


Beam failure must not be the governing limit state.

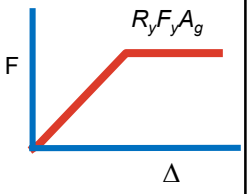
85

Post-Elastic Behavior

Preferred Modes: Brace Tension Yielding



Brace yielding should be a governing limit state.



Consider maximum effects due to brace force ($R_yF_yA_g$)

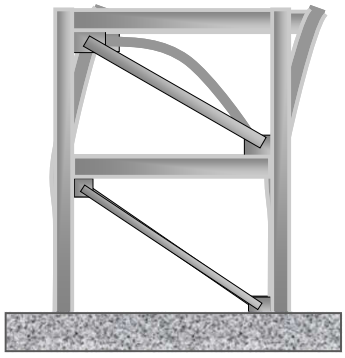
86

Brace Elongation (Tension Only)

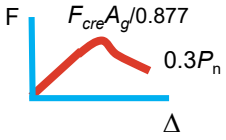
87

Post-Elastic Behavior

Preferred Modes: Brace Buckling



Brace buckling should be a governing limit state.



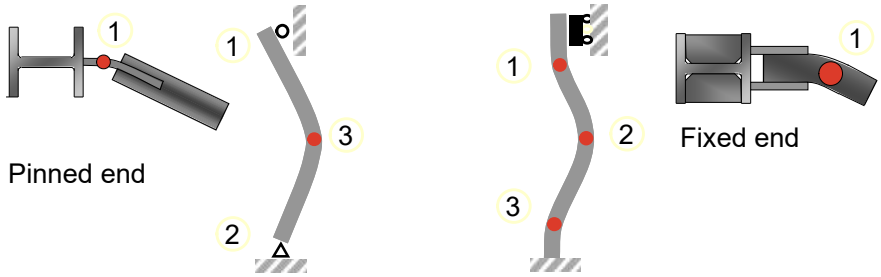
Consider maximum effects due to brace force (sometimes $P = R_yP_n$, sometimes $P = 0.3P_n$)

88

Brace Buckling

Flexural buckling (Compression)

Buckling: 3 hinges



89

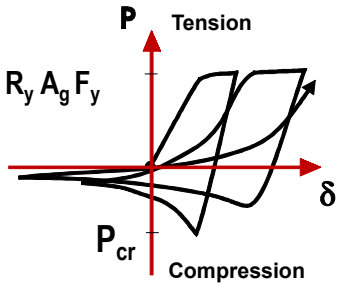
Brace Buckling

90

Brace Buckling: Effect on Other Elements

91

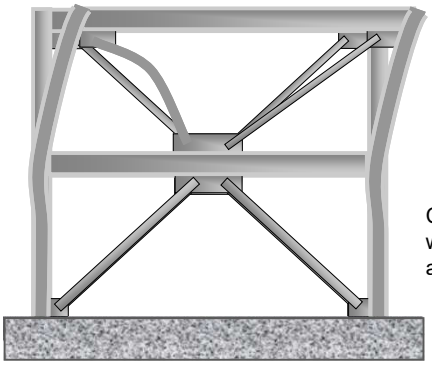
Brace cyclic behavior



92

System Behavior with Brace Yielding

Column Flexure

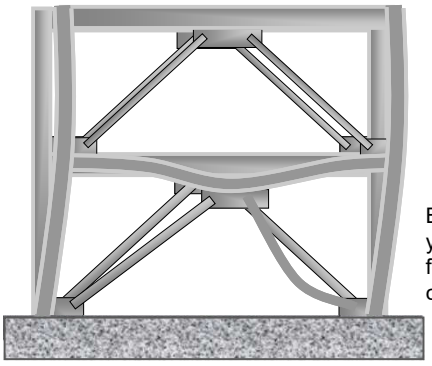


Columns must bend when braces buckle and yield.

93

System Behavior with Brace Yielding

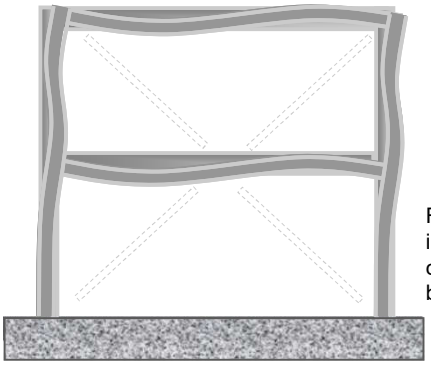
Beam Flexure



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

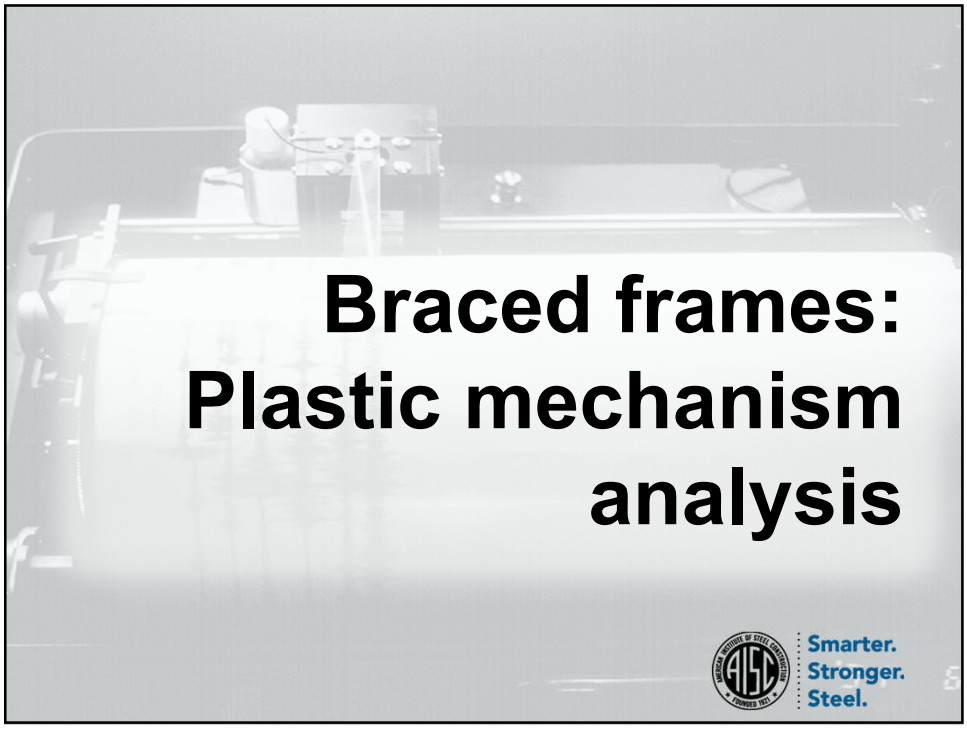
94

Frame Participation

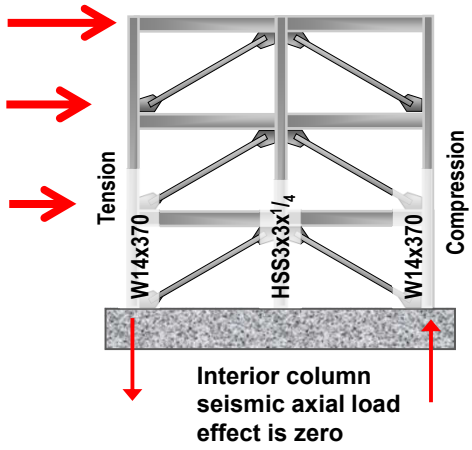


Flexural forces are induced in rigidly-connected columns and beams due to drift.

95

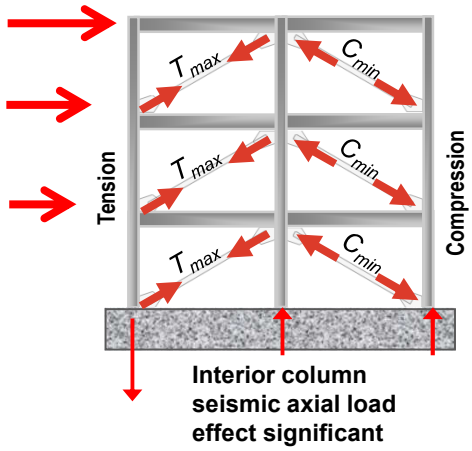


What elastic analysis misses



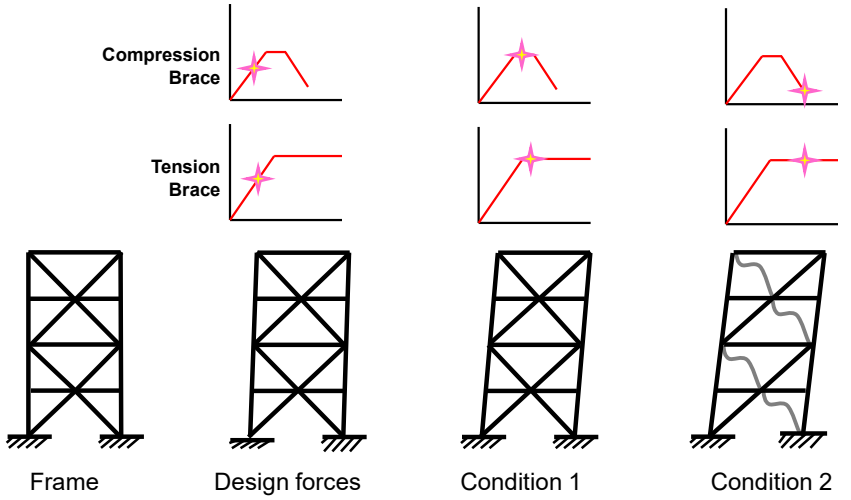
97

What elastic analysis misses



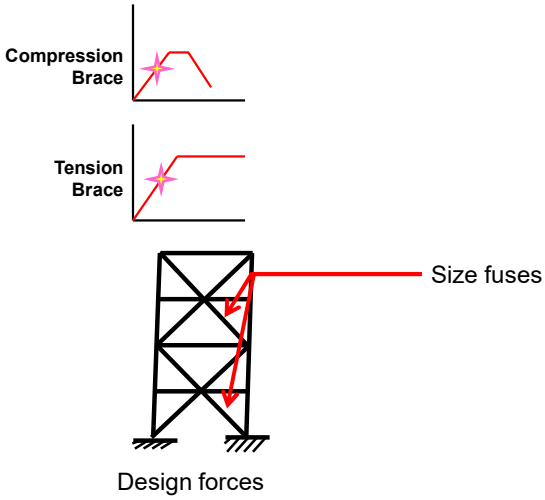
98

Plastic mechanism analyses



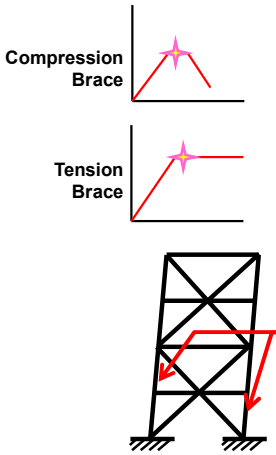
99

Design forces



100

Plastic mechanism analyses



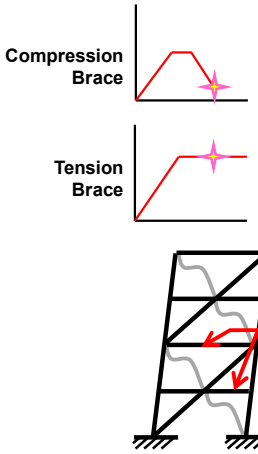
Maximum overturning

Size Columns
Gussets
Base plates

Condition 1

101

Plastic mechanism analyses



Force redistribution:
Compression braces participate less
Force zig-zags

Size beams
Interior columns

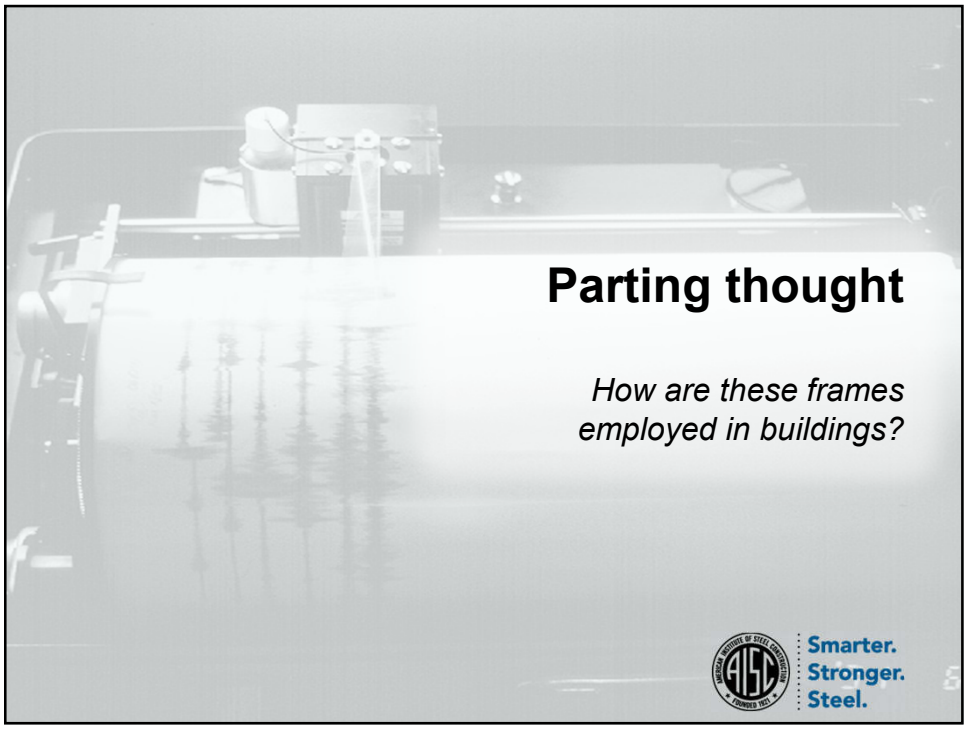
Condition 2

102

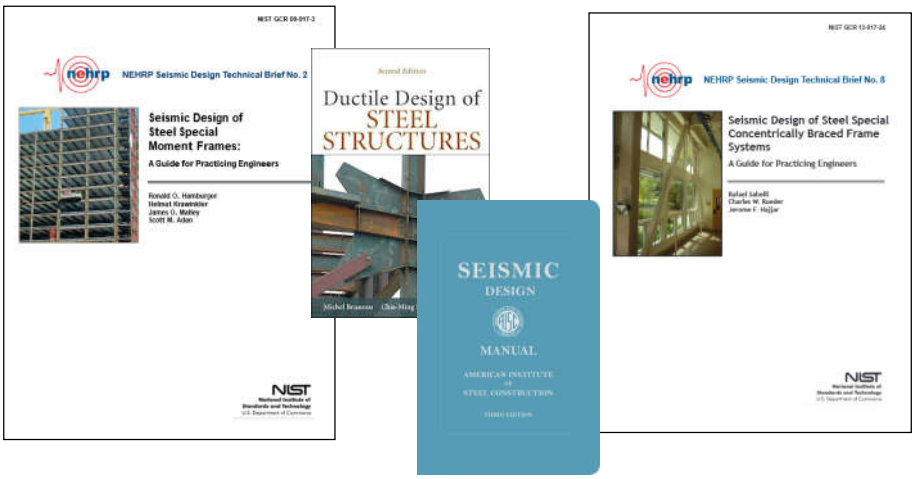
Summary

- 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

104



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.

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8-Session Registrants

CEU / PDH Certificates

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

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8-Session Registrants

CEU / PDH Certificates

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

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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.

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8-Session Registrants

Course Resources

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

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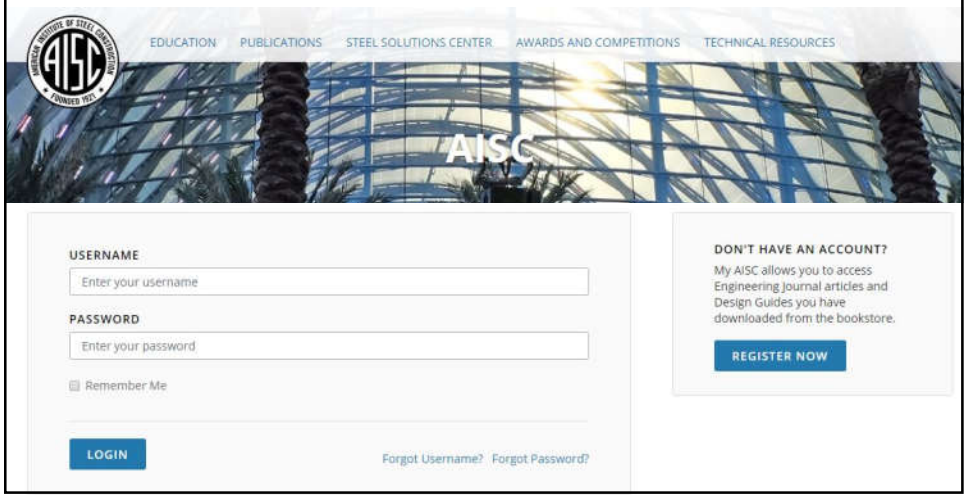
8-Session Registrants

Course Resources

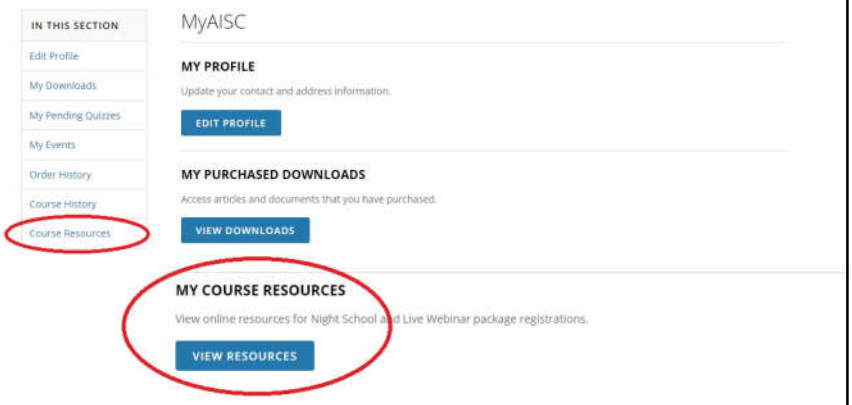
Go to www.aisc.org and sign in.



8-Session Registrants

Course Resources

Go to www.aisc.org and sign in.



8-Session Registrants

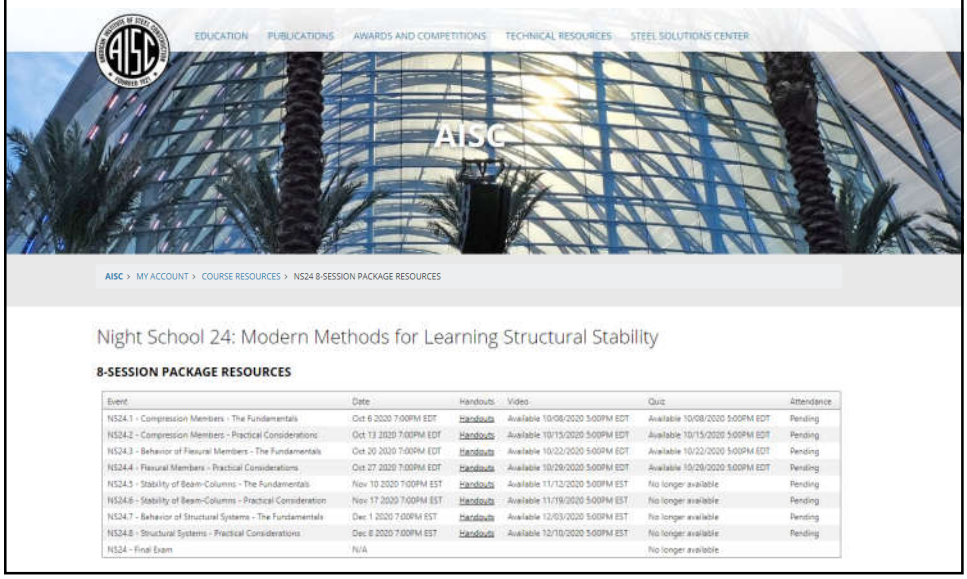
Course Resources

Course Resources

Event	Start Date
Seismic Design in Steel	1/1/1900 12:00:00 AM
4-Session Package-Design of Façade Attachments	5/9/2019 1:30:00 PM
NS 15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
NS 16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
NS 17 4-Session Package-Night School 17: Design of Façade Attachments	7/16/2018 7:00:00 PM
NS 18 8-Session Package-Night School 18: Steel Construction: Mill To Topping Out	10/15/2018 7:00:00 PM
NS 19 8-Session Package-Night School 19: Connection Design	2/4/2019 7:00:00 PM
NS 20 8-Session Package-Night School 20: Classical Methods of Structural Analysis	6/3/2019 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/16/2018 1:30:00 PM

8-Session Registrants

Course Resources



AISC | Thank you.

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