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Fundamentals of earthquake engineering for building structures

Session 5: System ductility and seismic design

March 15, 2021 | Rafael Sabelli

Smarter. Stronger. Steel.

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Course Description

System ductility and seismic design

March 15, 2021

System ductility and seismic design of steel framed structures was presented in this lecture. This lecture included a discussion of the relationship between steel material ductility and system ductility. The concept of capacity design and its application at the member and system levels as well as plastic mechanism analysis as it is used in the design of steel systems was explained. This session then presented the fuse concept and its application to different steel seismic systems.

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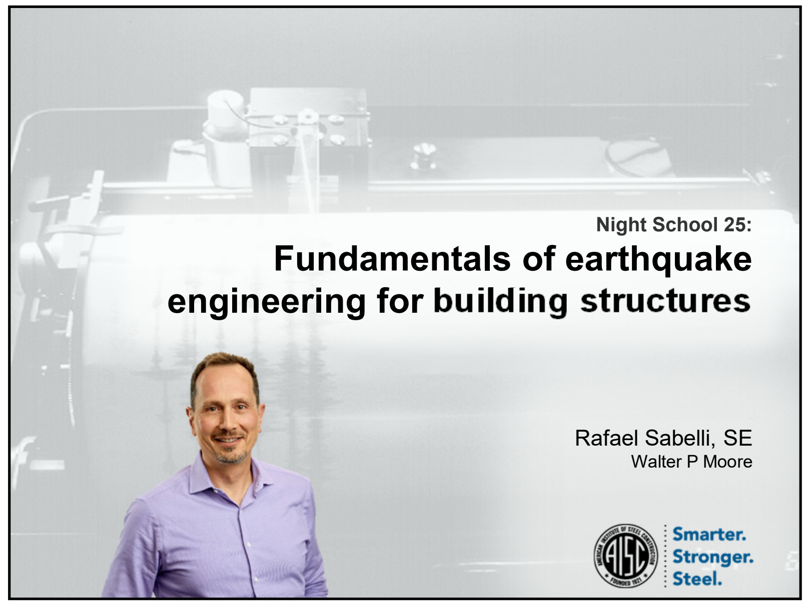
Learning Objectives

- Review the concepts of earthquake effects, dynamics and steel behavior.
- Describe the relationship between steel material ductility and system ductility.
- Compare modes of behavior of moment frames vs. concentrically braced frames.
- Describe plastic mechanism analysis.



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

Session 5: System ductility and seismic design
March 15, 2021

Rafael Sabelli, SE
Walter P Moore

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Stronger.
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Session topics

- Review
- Steel ductility
- Capacity design
- P-Delta
- Expected modes of behavior
- Plastic-mechanism analysis

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Review

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Review

- Earthquake effects
- Dynamics
- Steel behavior

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Earthquake effects

- Earthquakes release energy as seismic waves
- Waves cause horizontal shaking
- Structures must withstand shear and overturning

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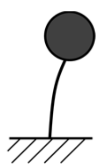
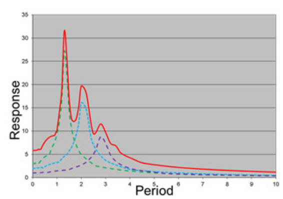
Dynamics

- Structures have natural periods of vibration
- Excitation of these periods may cause large response
- Seismic response is period dependent





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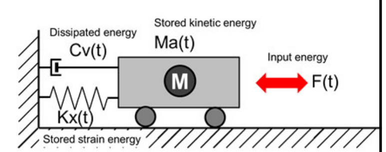
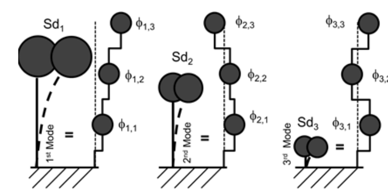
Dynamics

- Damping (energy absorption) reduces response
- Building structures may have many modes of response





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Dynamics

- System ductility
  - Damage to structure
    - Structure maintains integrity
  - System ductility can reduce response
    - Reduced accelerations
    - Displacement may not be reduced
  - System ductility absorbs energy
  - System ductility lengthens effective period

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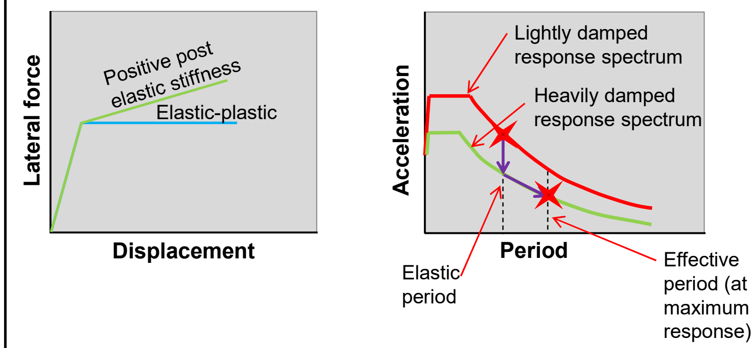
Reduced response



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Steel behavior

- Mild structural steel has excellent elongation characteristics
  - Material is ductile
- Steel material must be allowed to yield to provide ductility
  - Restraint reduces ductility
  - Non-ductile behaviors may govern over ductile ones
  - Proper proportioning and detailing is essential

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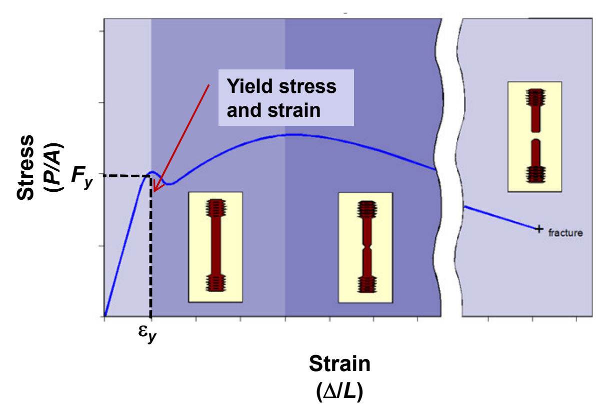
Yield behavior of mild steel



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Bridging the gap

- System ductility capacity is desirable for good seismic behavior
- Steel material provides excellent ductility
- Does a structural system made of a ductile material provide ductility?
  - Yes, if…

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Steel ductility

- Material ductility
- Section ductility
- Member ductility
- System ductility

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Material ductility

- Desirable
  - Elongation capacity
  - Predictable yield strength
- Undesirable
  - Brittle failure
  - Low strain capacity

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Material ductility

- Provide
  - Mild structural steel
  - Length over which material can develop strain
- Avoid or eliminate
  - Work-hardened material
  - Highly restrained conditions
  - High through-thickness loading
  - Notches

Codes limit the steel materials that are suitable for the seismic-load-resisting-system

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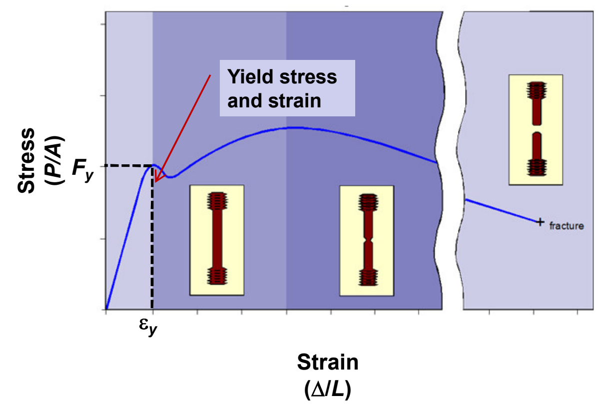
Material ductility



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Section ductility

- Desirable
  - Yielding of entire section
  - Yielding in tension and compression
- Undesirable
  - Local buckling
  - Tensile rupture

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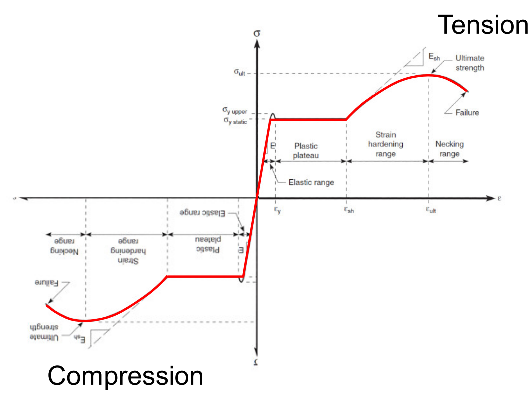
Section ductility



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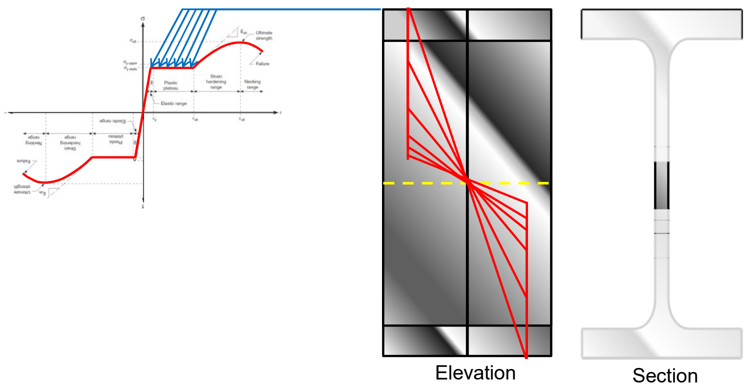
Section ductility



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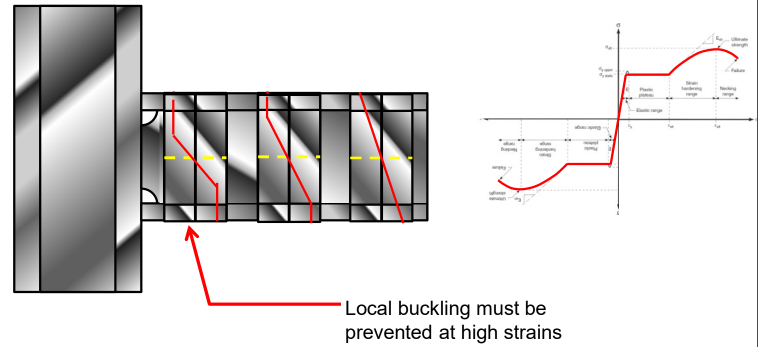
Section ductility



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Local buckling

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Section ductility

- Provide
  - ○ Ductile material
  - ○ Highly compact sections
    - Flanges
    - Webs
- Avoid or eliminate
  - ○ Slender sections
  - ○ Holes
  - ○ Reductions in cross section
  - ○ (Configure weld access holes to avoid local rupture)

Codes provide compactness requirements for members of the seismic-load-resisting-system

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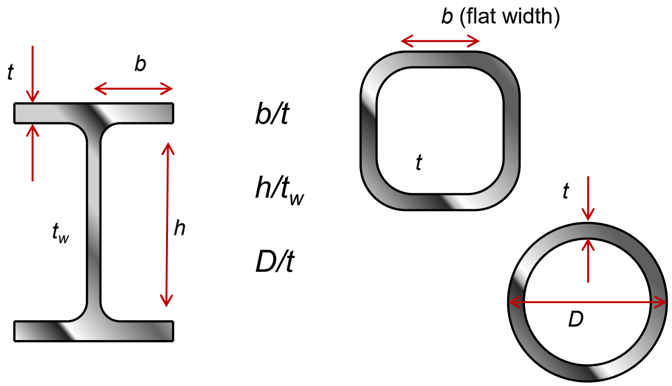
Compactness



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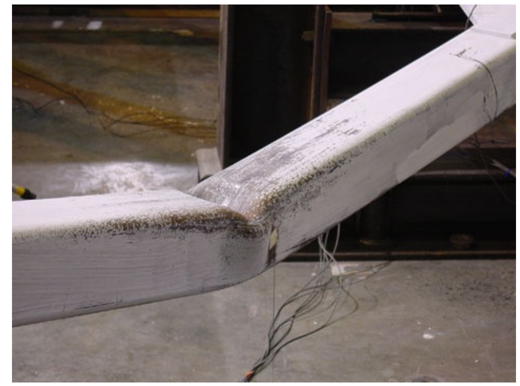
Local buckling



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Local buckling

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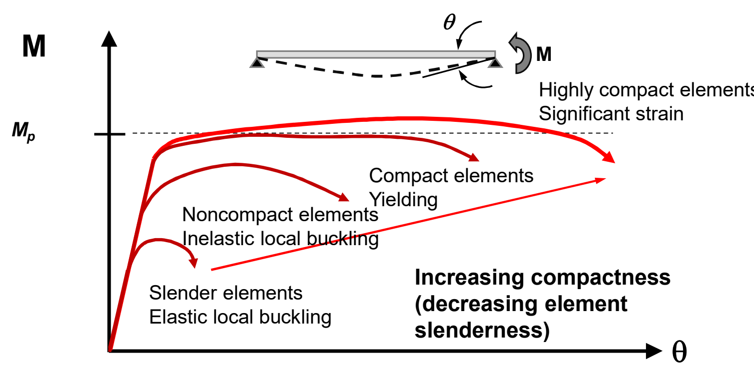
Width-thickness ratios



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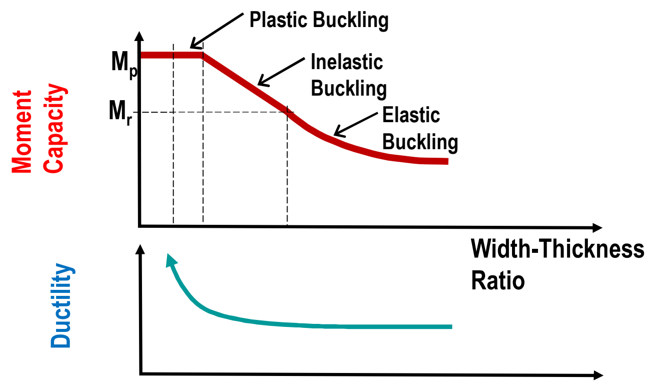
Width-thickness ratios



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Member ductility

- Desirable
  - Member yielding
    - Flexural hinging
    - Axial yielding
    - Shear yielding
- Undesirable
  - Connection failure
  - Member instability

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Member ductility

- Provide
  - Ductile material
  - Ductile section
  - Lateral bracing
  - Connections stronger than members
- Avoid or eliminate
  - Unstable conditions
  - Weak connections
  - Weak areas of members

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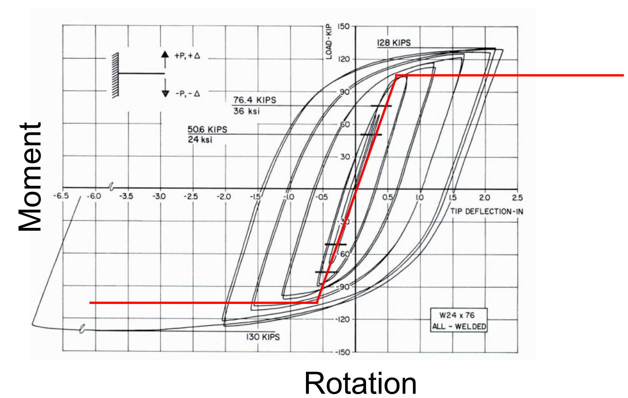
Member ductility



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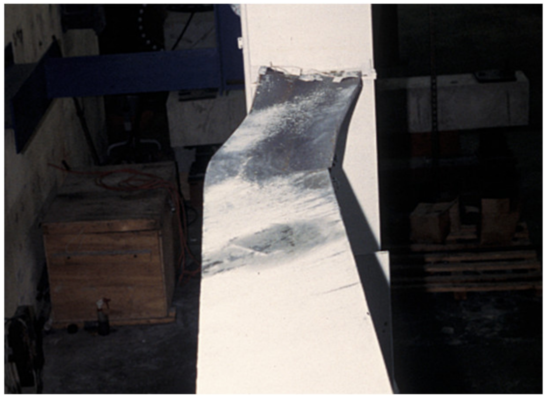
Member instability



Codes provide lateral-bracing requirements for members of the seismic-load-resisting-system

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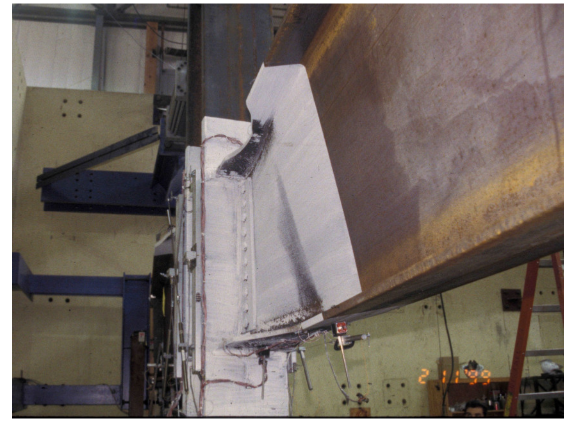
Member instability



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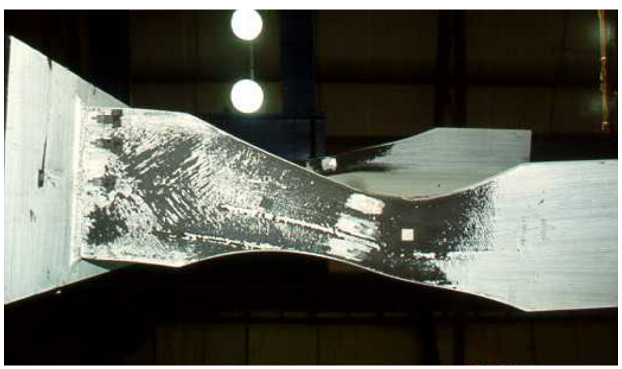
Member instability



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Lateral bracing

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Lateral bracing

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Lateral bracing

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Connection failure

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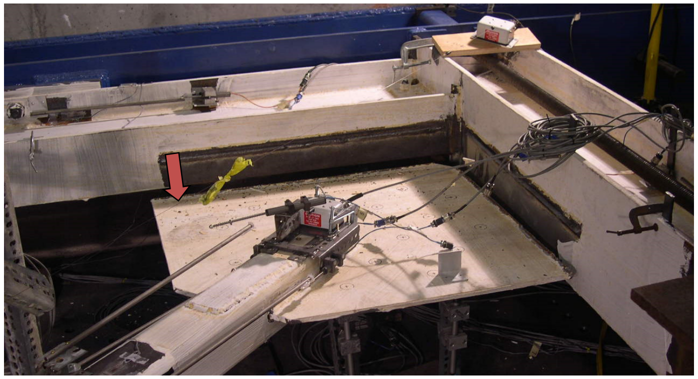
Connection failure



Codes provide amplified connection forces for members of the seismic-load-resisting-system

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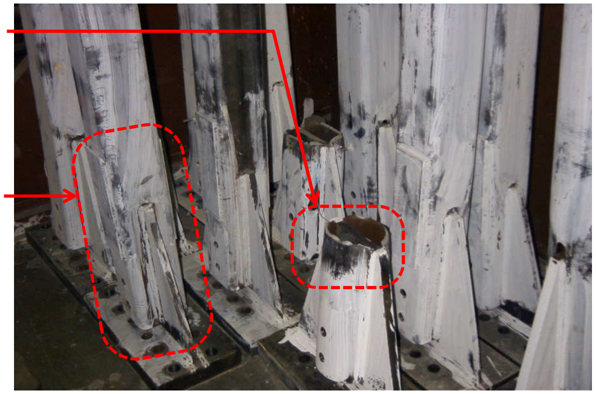
Connections

Weak connection

Strong connection



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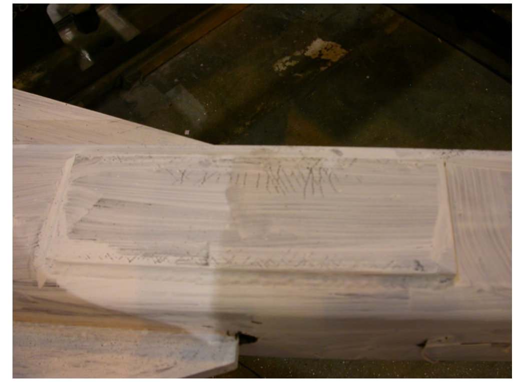
Strong connections



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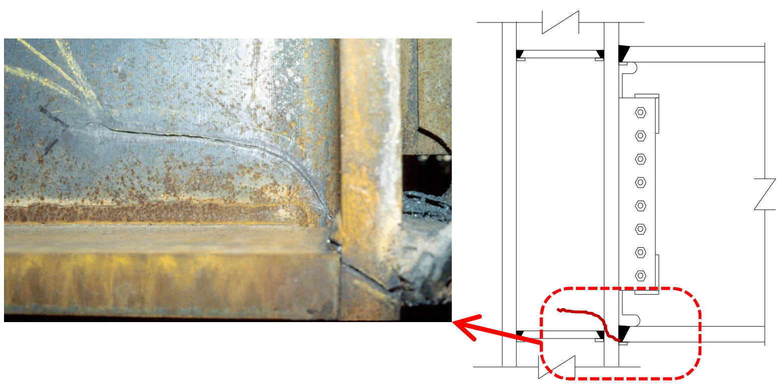
Connection failure



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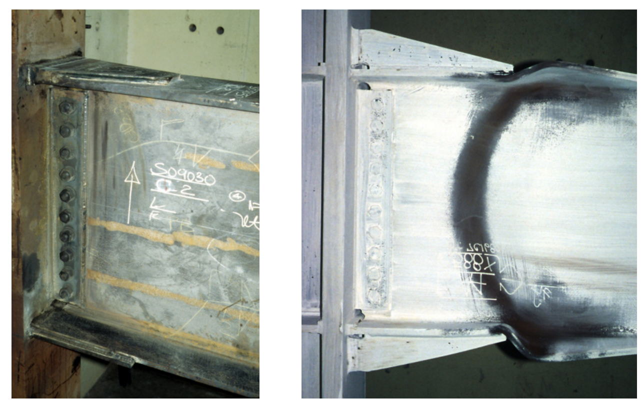
Strong connections



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Strong connections

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Strong connections

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System ductility

- Desirable
  - Large displacement capacity
  - Distributed ductility demands
  - Maintain lateral resistance at large drifts
  - Damage-tolerant design
- Undesirable
  - Loss of lateral resistance
  - Excessive member ductility demands
  - Instability
  - System that cannot tolerate higher earthquake demand

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System ductility

- Provide
  - Ductile material, sections, members
  - Sufficient strength
  - Sufficient stiffness
  - System proportioned to spread yielding
  - Members capable of providing ductility
  - Members with post-yield stiffness (hardening)
- Avoid or eliminate
  - Weak zones
  - Un-proportioned overstrength
  - Members with negative post-yield stiffness

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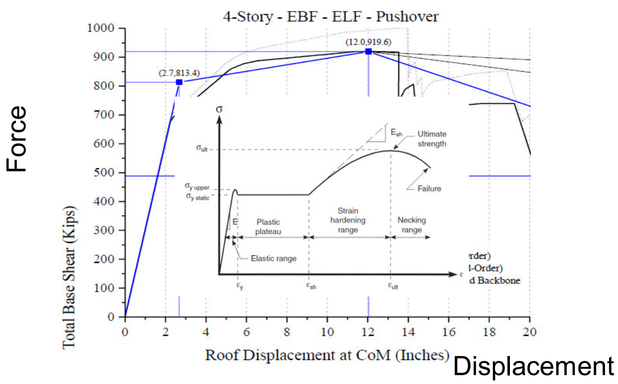
System ductility



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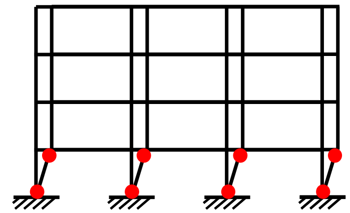
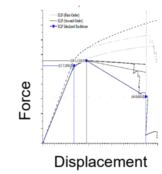
System ductility



Concentrated ductility



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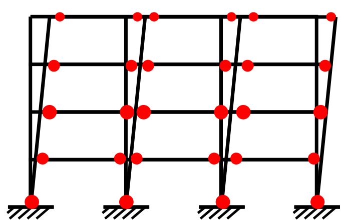
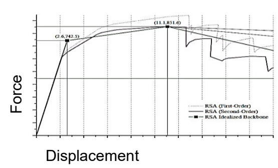
System ductility



Distributed ductility



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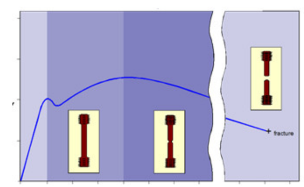
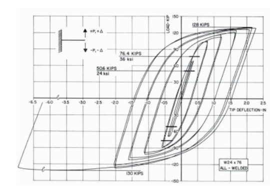
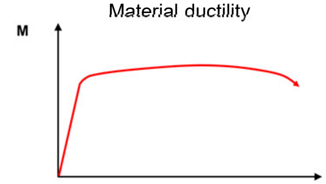
Ductility



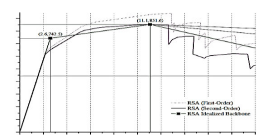
Material ductility



Member ductility



Section ductility



System ductility

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Capacity design

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Steel.

Capacity design

- Local level
  - Proportioning
  - Expected strength
- System level
  - "Fuse" concept
  - System capacity

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Terminology

Term		Symbol	Description
Allowable strength		R_n/Ω	Nominal strength divided by safety factor for ASD-level design
Design strength		ϕR_n	Nominal strength multiplied by resistance factor for LRFD-level design
Nominal strength		R_n	Reliable strength of a component considering specified properties
Capacity demand	Expected strength	$R_y F_y A$ (example)	Reliable strength of a component considering expected properties
	Adjusted strength	$1.1\ R_y F_y Z$ (example)	Expected strength adjusted considering strain-hardening and other inelastic-deformation effects

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Capacity design (local)

- Concept
  - Proportion connections so that member yielding can occur
    - Adjacent members, too
- Implementation
  - Estimate member capacity
  - Use member capacity as demand on connection

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Capacity design (local)

- Upper-bound capacity
  - Design tends to lower-bound
- Strength equation
- Material strength
- Strain hardening
- Effect on connection
  - Moment gradient

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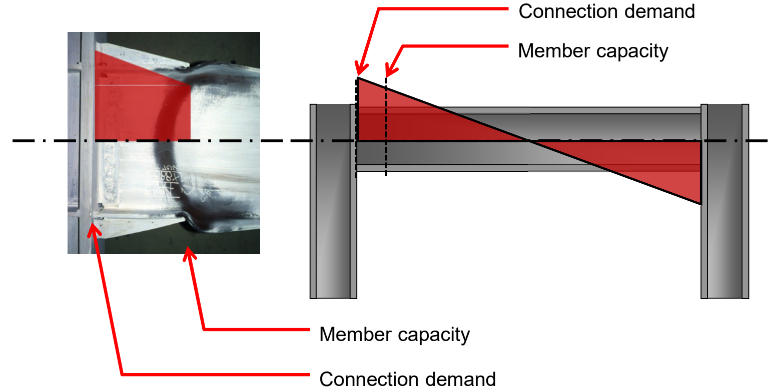
Effect on connection



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Capacity design (local)

- Yielding member
  - Examples:
    - Axially yielding brace
    - Beam flexure
  - Yielding occurs due to gravity + seismic
    - Member yield is full load on connection
    - Force is limited by member capacity

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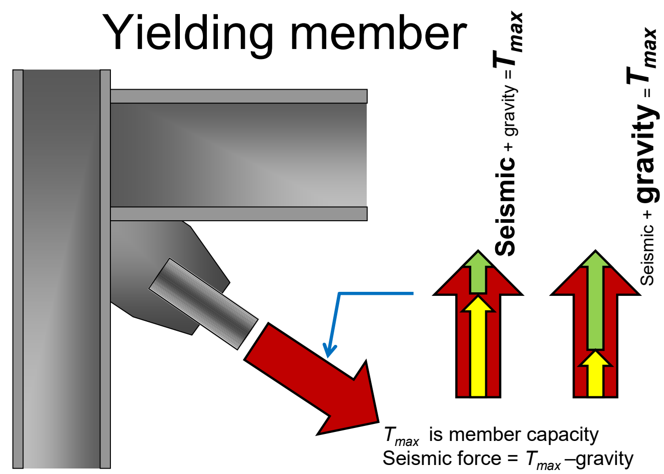
Yielding member



Member capacity design forces are not combined with gravity loads for design.

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Capacity design (local)

- Member yield effect
  - Example:
    - Shear in beam due to flexural yield
  - Yielding occurs in another mode
    - Example: flexural beam yielding, not shear yielding
  - Gravity is also present
    - Capacity load and seismic must be combined
    - Force is not at member capacity limit

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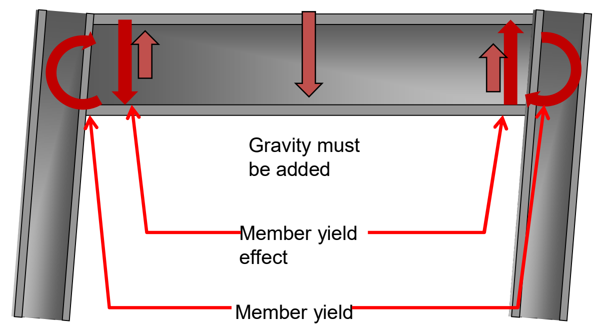
Member yield effect



Member yield effect forces are combined with gravity loads for design.

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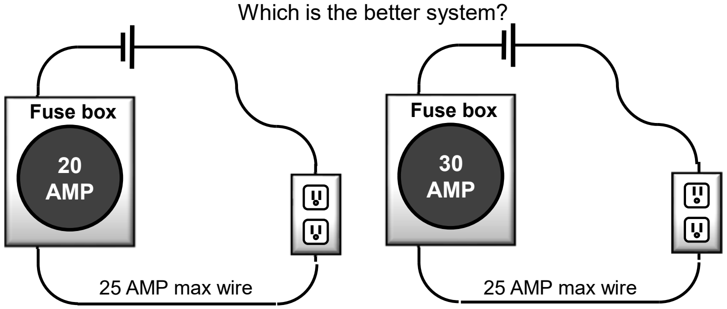
Capacity design (system): Fuse concept

Which is the better system?



System quality is not only due to strength;
Proportioning is key to good behavior

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Capacity design (system)

- Concept
  - Proportion frame to encourage optimal yielding pattern
  - Size members to preclude concentration of ductility demand
- Implementation
  - Select “fuse” members
    - Members that are ductile
    - Yielding does not compromise system integrity
  - Select mechanism
  - Use fuse capacity to size other members

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Capacity design (system)

- Fuses
  - Moment frames
    - Beam plastic hinges
  - Concentrically braced frames
    - Braces
  - Eccentrically braced frames
    - Links

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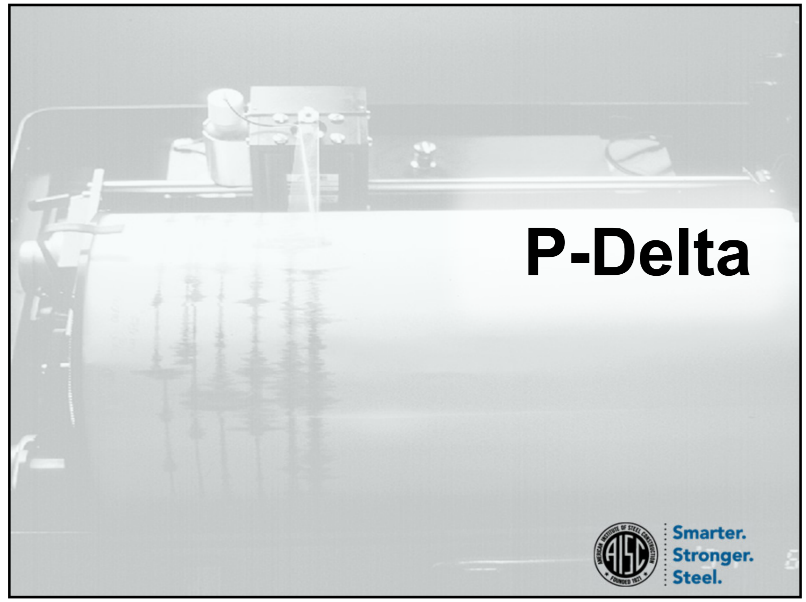

P-Delta

- System stability second order effects are typically considered in design
  - Wind loads
  - Stability under gravity loads
- Attempt to arrive at the actual condition
  - Decreased stiffness (Direct Analysis Method)
  - Imperfections

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P-Delta

- Seismic design
  - Unreduced stiffness typically used
    - Drift calculations
    - Period determination
  - Arriving at the actual condition is difficult
    - Use reduced forces and amplification of displacement is extremely approximate
      - Neglecting inelastic P-Δ effects may not affect this limited accuracy
  - Current practice is to consider P-Δ effects at the elastic level

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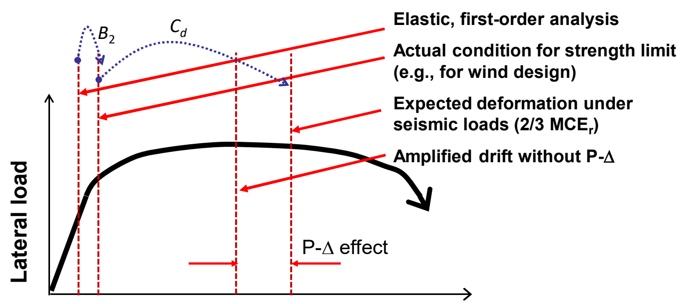
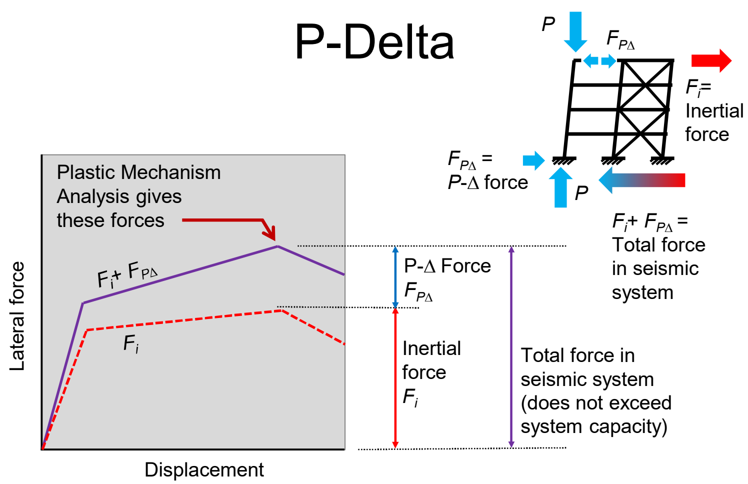
P-Delta



P-Delta

- P-Δ
  - Fuse design
    - Amplify forces for P-Δ effect
  - Capacity-designed elements
    - Do not amplify forces for P-Δ effect
    - P-Δ is part of load that reaches system capacity
  - Reduces inertial force that can be resisted
  - Does not add to system capacity

P-Delta



Expected modes of behavior

- Moment frames
- Concentrically braced frames
  - Buckling braces
  - Buckling-restrained braces
- Eccentrically braced frames
- Steel plate shear walls

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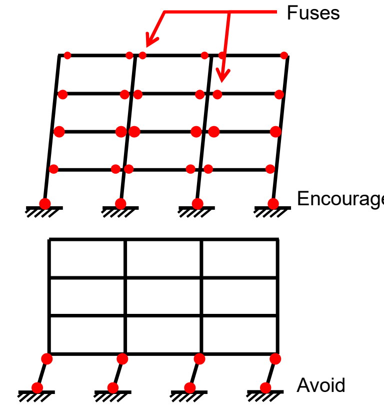
Moment frames

- Encourage
  - Flexural hinging in beams
- Avoid
  - Flexural hinging in columns
    - (occurs at base)
  - Connection failure
  - Excessive column panel-zone yielding



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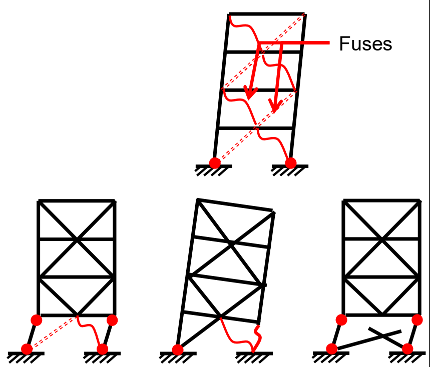
Concentrically braced frames

- Encourage
  - Yielding of braces
  - Buckling of braces
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of beams or columns
  - Connection failure



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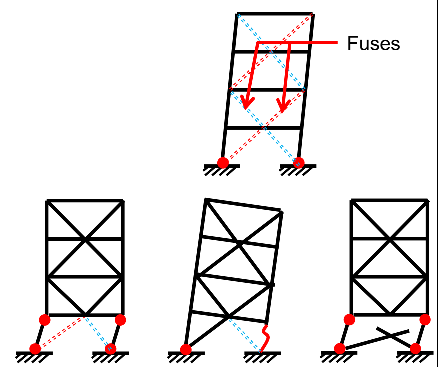
Buckling restrained braced frames

- Encourage
  - Yielding of braces
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of beams or columns
  - Connection failure



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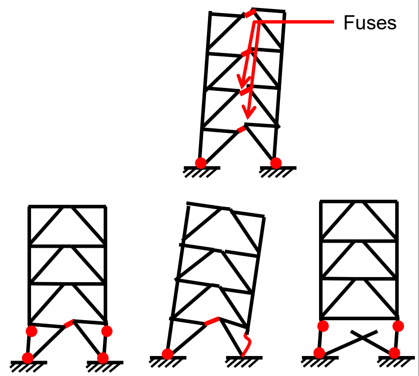
Eccentrically braced frames

- Encourage
  - Yielding of link
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of braces, beams or columns
  - Connection failure



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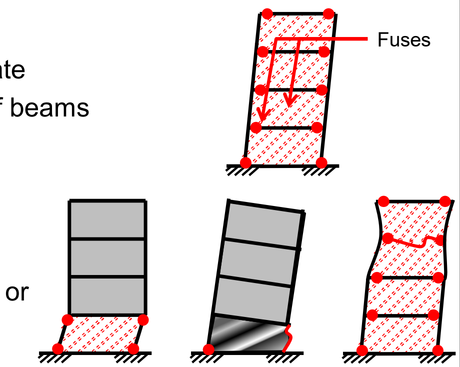
Steel plate shear walls

- Encourage
  - Yielding of web plate
  - Flexural yielding of beams
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of beams or columns
  - Connection failure



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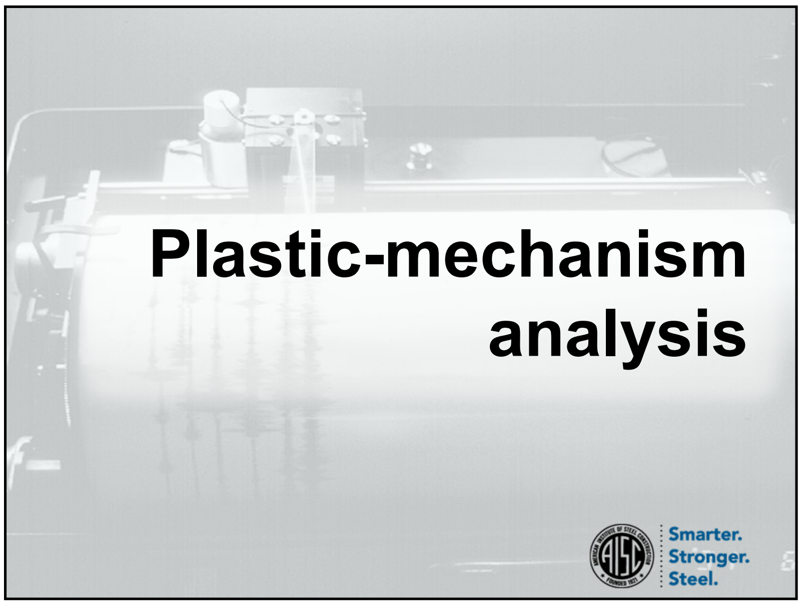

Plastic-mechanism analysis

- Prior to plastic-mechanism analysis
  - Select “fuse” members
    - Members that are ductile
    - Yielding does not compromise system integrity
  - Size fuses to appropriate demand
    - Proportion fuses to encourage distributed ductility
    - Avoid un-proportioned overstrength

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Plastic-mechanism analysis

- Select mechanism
  - Realistic deformation mode
  - Consider other modes
- Use fuse capacity to size other members
  - Realistic fuse capacity
    - Material overstrength
    - Strain hardening

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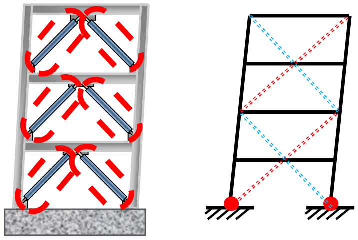
Plastic mechanism analysis

- Example: buckling-restrained braced frame
- Select fuse
  - Braces
- Select mechanism
  - First mode



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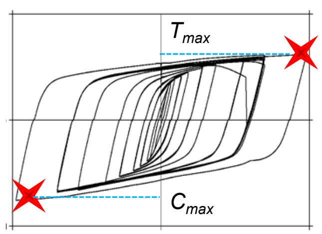
Plastic mechanism analysis

- Estimate fuse capacity
  - Expected material strength
  - Strain hardening



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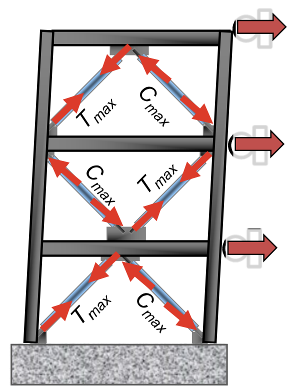
Plastic mechanism analysis

- Apply fuse capacity as load on other members
  - Fuse = total load on brace connections
  - Combine with gravity for
    - Beams
    - Columns



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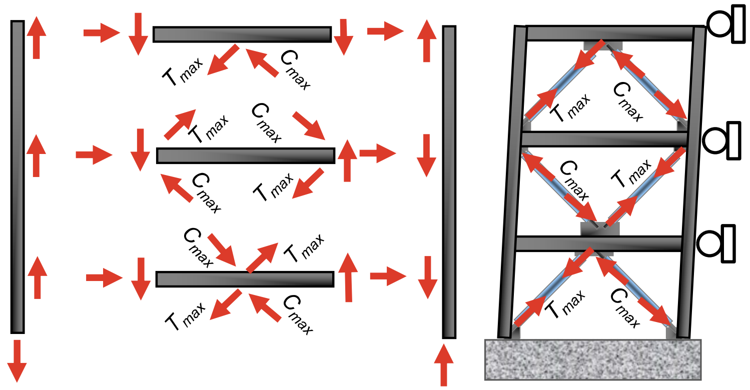
Plastic mechanism analysis



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Summary

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Summary

- System ductility aids in providing reliable seismic response
- System ductility arises from
  - Ductile material
  - Ductile sections
  - Ductile members
  - Ductile system proportioning
    - Capacity design

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Parting thought

How are these principles applied to various system types?

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End of session 5

Next:
Session 6:
Steel systems

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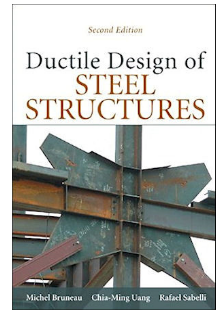
Additional resources



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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.

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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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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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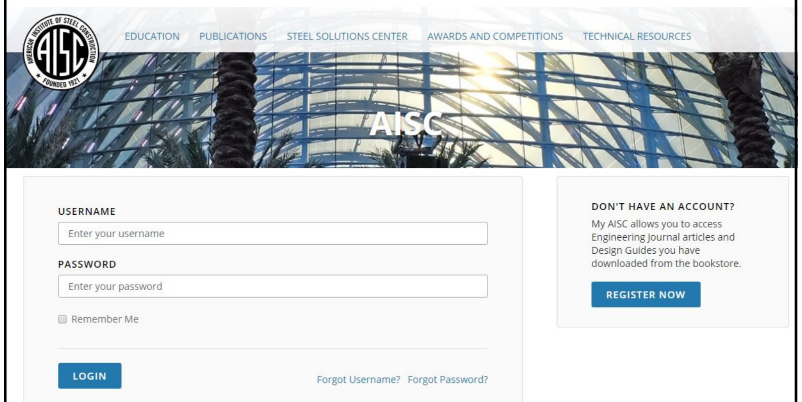
8-Session Registrants

Course Resources

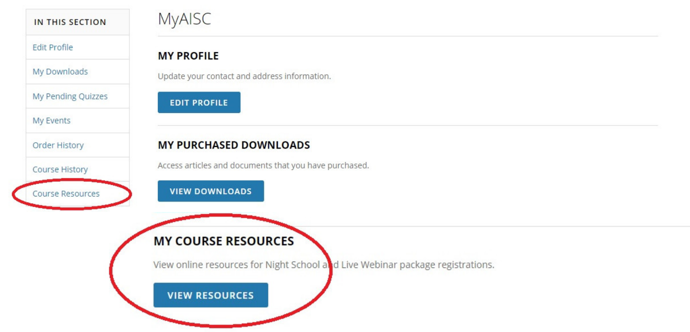
Go to www.aisc.org and sign in.



8-Session Registrants

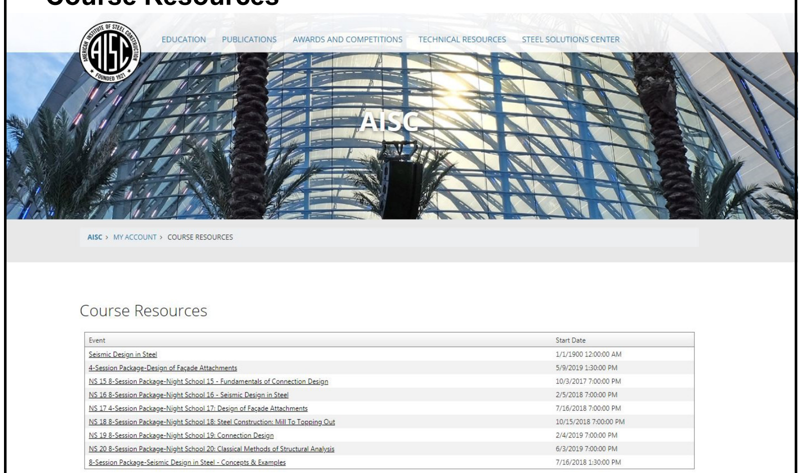
Course Resources

Go to www.aisc.org and sign in.



8-Session Registrants

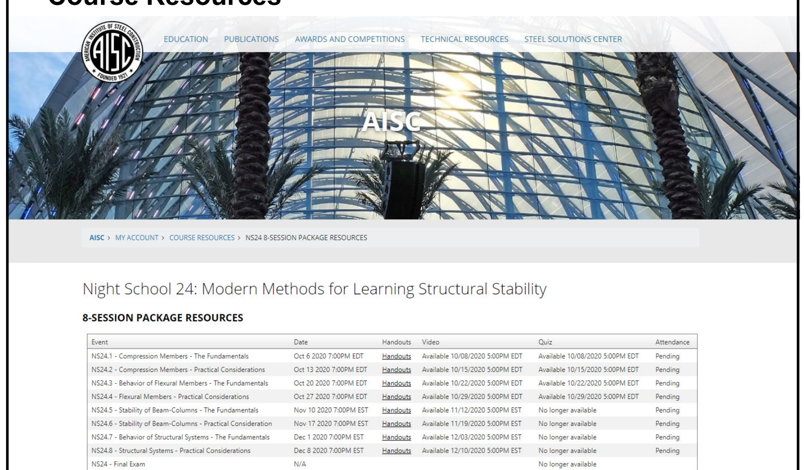
Course Resources



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



Event	Date	Handouts	Video	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EDT	Handouts	Available 10/08/2020 5:00PM EDT	Available 10/08/2020 5:00PM EDT	Pending
NS24.2 - Compression Members - Practical Considerations	Oct 13 2020 7:00PM EDT	Handouts	Available 10/15/2020 5:00PM EDT	Available 10/15/2020 5:00PM EDT	Pending
NS24.3 - Behavior of Flexural Members - The Fundamentals	Oct 20 2020 7:00PM EDT	Handouts	Available 10/22/2020 5:00PM EDT	Available 10/22/2020 5:00PM EDT	Pending
NS24.4 - Flexural Members - Practical Considerations	Oct 27 2020 7:00PM EDT	Handouts	Available 10/29/2020 5:00PM EDT	Available 10/29/2020 5:00PM EDT	Pending
NS24.5 - Stability of Beam-Columns - The Fundamentals	Nov 10 2020 7:00PM EST	Handouts	Available 11/12/2020 5:00PM EST	No longer available	Pending
NS24.6 - Stability of Beam-Columns - Practical Consideration	Nov 17 2020 7:00PM EST	Handouts	Available 11/19/2020 5:00PM EST	No longer available	Pending
NS24.7 - Behavior of Structural Systems - The Fundamentals	Dec 1 2020 7:00PM EST	Handouts	Available 12/03/2020 5:00PM EST	No longer available	Pending
NS24.8 - Structural Systems - Practical Considerations	Dec 8 2020 7:00PM EST	Handouts	Available 12/10/2020 5:00PM EST	No longer available	Pending
NS24 - Final Exam	N/A			No longer available	


AISC | Thank you.
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