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Course Description

Session 1: Introduction to Effective Seismic Design
February 5, 2018

The presentation begins with a discussion of earthquakes as a significant load case. The session will review structural dynamics as related to seismic response and review response spectrum as a way to characterize seismic demand. The presentation will then review steel and system ductility before concluding with a discussion on steel lateral systems.

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Learning Objectives

- List the reasons for seismic design.
- Describe structural dynamics as related to seismic response.
- Describe response spectrum as a way to characterize seismic demand.
- Explain the benefits of system ductility.
- Identify steel lateral systems.

There's always a solution in steel.

Seismic Design in Steel: Concepts and Examples

Session 1: Introduction to Effective Seismic Design
February 5, 2018

Rafael Sabelli, SE

structural STEEL

Course objectives

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

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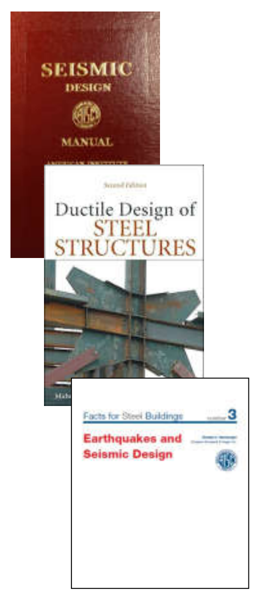
Resources

- AISC *Seismic Design Manual*
- *Ductile Design of Steel Structures*, Bruneau, Uang, and Sabelli, McGraw Hill.
- *Earthquakes and Seismic Design,* Facts for Steel Buildings #3. Ronald O. Hamburger, AISC.
- Other publications suggested in each session



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Other resources

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

Part I: Concepts

1. **<u>Introduction to effective seismic design</u>**
2. Seismic design of moment frames
3. Seismic design of braced frames
4. Seismic design of buildings

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Course outline

Part II: Application

5. Planning the seismic design
6. Building analysis and diaphragm design
7. Design of the moment frames
8. Design of the of braced frames

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Session 1: Introduction to effective seismic design

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Session topics

- The need for seismic design
- Structural dynamics
- Seismic response spectra
- System ductility
- Steel ductility
- Steel lateral systems steel systems

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The need for seismic design

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Largest earthquakes

Date	Location	Magnitude
May 22, 1960	**Valdivia, Chile**	**9.5**
March 27, 1964	**Prince William Sound, Alaska, USA**	**9.2**
December 26, 2004	**Indian Ocean, Sumatra, Indonesia**	**9.1–9.3**
November 4, 1952	Kamchatka, Russia (then USSR)	9
March 11, 2011	Pacific Ocean, Tōhoku region, Japan	9.0
September 16, 1615	Arica, Chile	8.8 (est.)
November 25, 1833	Sumatra, Indonesia	8.8–9.2 (est.)
January 31, 1906	Ecuador – Colombia	8.8
February 27, 2010	Valdivia , Chile	8.8
January 26, 1700	Pacific Ocean, North America	8.7–9.2 (est.)
July 8, 1730	Valparaiso, Chile	8.7 (est.)
November 1, 1755	Atlantic Ocean, Lisbon, Portugal	8.7 (est.)
February 4, 1965	**Rat Islands, Alaska, USA**	**8.7**
July 9, 869	Pacific Ocean, Tōhoku region, Japan	8.6-9.0 (est.)
September 20, 1498	Pacific Ocean, Nankai Trough, Japan	8.6 (est.)
October 28, 1707	Pacific Ocean, Shikoku region, Japan	8.6 (est.)
August 15, 1950	Assam, India – Tibet, China	8.6
March 9, 1957	**Andreanof Islands, Alaska, USA**	**8.6**
April 1, 1946	**Aleutian Islands, Alaska, USA**	**8.6**
March 28, 2005	Sumatra, Indonesia	8.6

Valdivia, Chile, 1960 M=9.5

- >2,000 killed
- >3,000 injured
- >2,000,000 homeless
- >$550 million damage
- Tsunamis
  - 61 deaths, $75 million damage in Hawaii
    - $500,000 damage in the United States west coast
  - 138 deaths and $50 million damage in Japan
  - 32 dead or missing in the Philippines

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Costliest earthquakes

Name	Magnitude	Property loss (US 2013 $)
2011 Tōhoku earthquake, Japan	**9**	**$235 billion**
1995 Great Hanshin (Kobe) earthquake, Japan	6.9	$100 billion
2008 Sichuan earthquake, China	8	$75 billion
2010 Chile earthquake, Chile	8.8	$15–30 billion
1994 Northridge earthquake, United States	**6.7**	**$20 billion**
2012 Emilia earthquakes, Italy	5.9 (est.)	$13.2 billion
2011 Christchurch earthquake, New Zealand	6.3	$12 billion
1989 Loma Prieta earthquake, United States	7	$11 billion
921 earthquake, Taiwan	7.6	$10 billion
1906 San Francisco earthquake, United States	7.7 to 7.9 (est.)	$9.5 billion

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Northridge, CA, 1994, M=6.7

- $20 billion in losses
- 60 people killed
- > 7,000 injured
- 20,000 homeless
- >40,000 buildings damaged
- 1.8g maximum recorded acceleration

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Deadliest earthquakes

Date	Location	Fatalities	Magnitude
January 23, 1556	Shaanxi, China	820,000–830,000 (est.)	8.0 (est.)
December 16, 1920	Ningxia–Gansu, China	273,400	7.8
July 28, 1976	Hebei, China	242,769	7.8
May 21, 526	Antioch, Turkey (Byzantine Empire)	240,000	7.0 (est.)
December 26, 2004	Indian Ocean, Sumatra, Indonesia	230,210	9.1–9.3
October 11, 1138	Aleppo, Syria	230,000	Unknown
January 12, 2010	**Haiti**	**222,570-316,000**	**7**
December 22, 856	Damghan, Iran	200,000 (est.)	7.9 (est.)
March 22, 893	Ardabil, Iran	150,000 (est.)	Unknown
September 1, 1923	Kantō region, Japan	142,800	7.9
December 28, 1908	Messina, Italy	123,000	7.1
October 6, 1948	Turkmenistan	110,000	7.3
December 31, 1703	Edo, Japan	2,300-12,000	8.2
November 1, 1755	Lisbon, Portugal	15,000–60,000	8.5–9.0 (est.)

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Haiti, 2010, M=7.0

- 200,000-316,000 people killed
- 300,000 injured
- 1.3 million displaced
- Port-au-Prince
  - 97,294 houses destroyed
  - 188,383 houses damaged
- Felt as far as southern Florida, northern Colombia and northwestern Venezuela.

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Design for earthquakes

- Prevents large-scale loss of life
  - Partial collapse
  - Total collapse
- Reduces economic loss
  - Total loss of building
  - Repair cost
  - Loss of use
- Permits more speedy regional recovery

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Design for earthquakes

- Structural design
  - Prevent excessive deformation
    - Maintain lateral resistance
    - Maintain lateral stability
    - Maintain vertical support
    - Maintain evacuation routes

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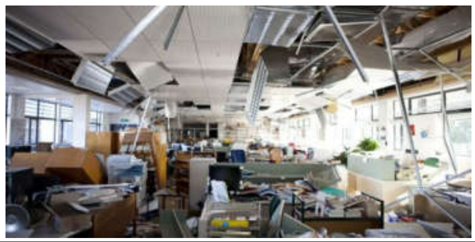
Design for earthquakes

- Non-structural (Architectural, MEP)
  - Limit falling hazards
  - Prevent obstacles to evacuation
  - Maintain emergency systems



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Design for earthquakes

- Structural design
  - Vertical motion
    - Loads gravity system
    - Usually minor effect
  - Horizontal motion
    - Shear deformation
    - Overturning
    - Most significant effect

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Horizontal forces

USGS

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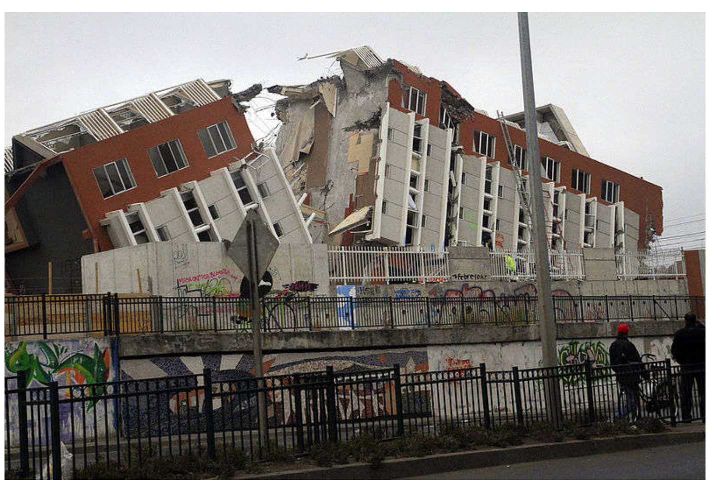
Overturning



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Earthquake effects

- Horizontal shaking
  - Buildings must be designed to resist horizontal shaking, and related overturning
  - Strategies include:
    - Strength
    - Stiffness
    - Displacement capacity
    - Energy absorption

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There's always a solution in steel.

Structural dynamics

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STEEL

Response spectra

- Response history
- Period-dependent response

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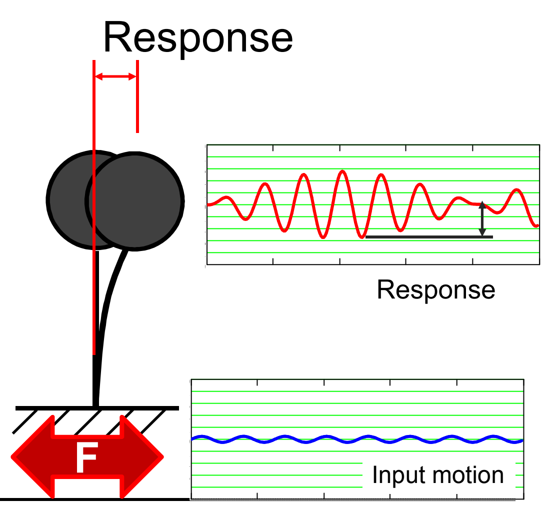
Response history

"Response" may be
Displacement
Acceleration
Velocity
Any quantity of interest



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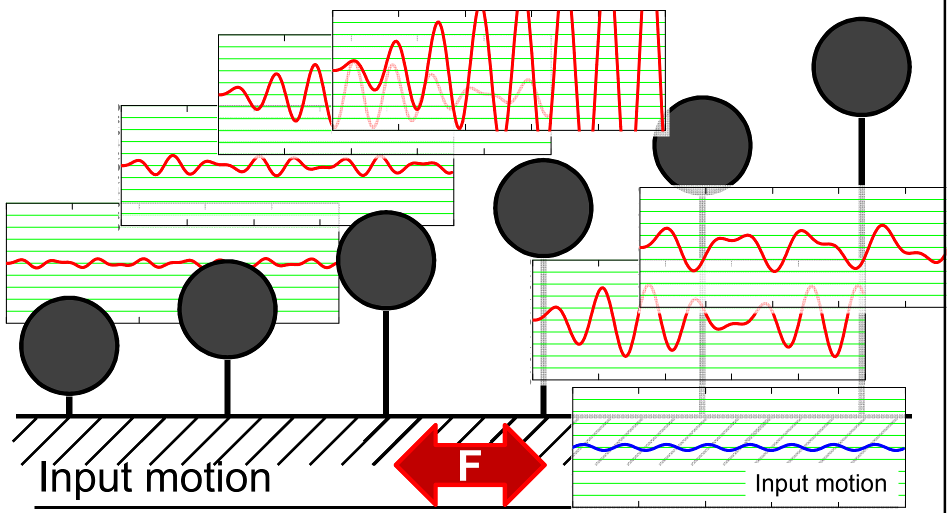
Period-dependent response



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Seismic response spectra

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Seismic response spectra

- Earthquake response spectrum
- General seismic response spectrum
- Spectrum types

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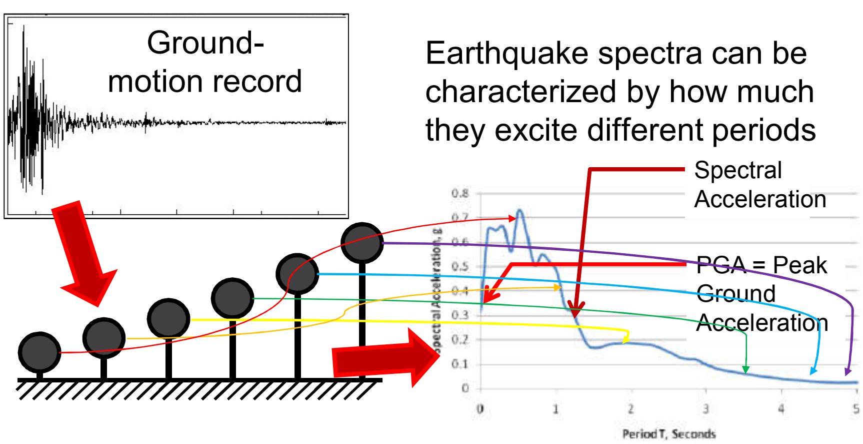
Seismic response spectrum

Earthquake spectra can be characterized by how much they excite different periods



Response spectrum (acceleration)

Acceleration response spectra are used in design

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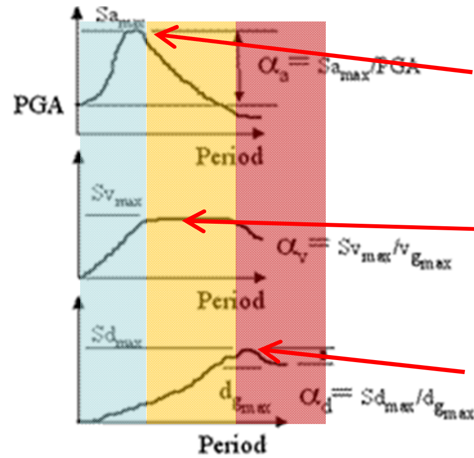
Acceleration, velocity, and displacement spectra

(Pseudo) acceleration response spectrum

(Pseudo) velocity response spectrum

Displacement response spectrum



"Constant acceleration"

"Constant velocity"

"Constant displacement"

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Ductility

Inelastic response

- Concept
- Types of nonlinear behavior
- Effective stiffness and period
- Energy dissipation
- Damping

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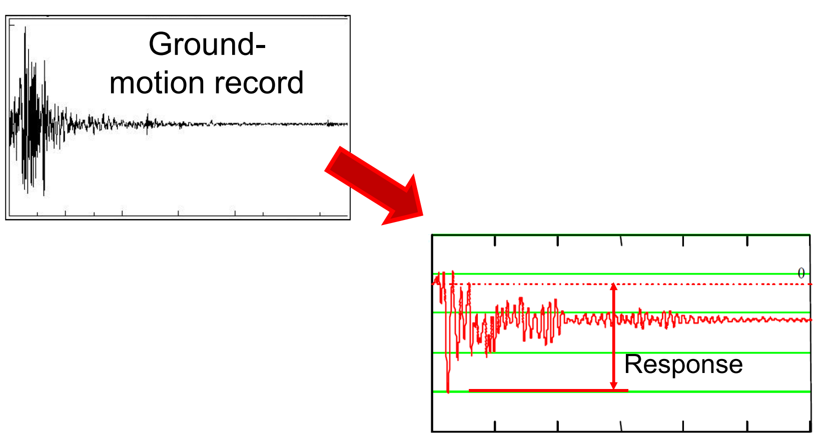
Inelastic response



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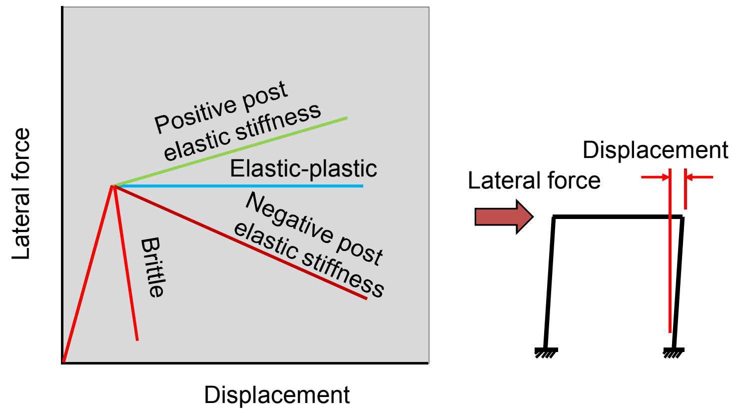
Types of nonlinear behavior



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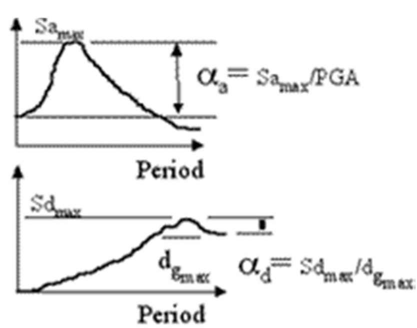
Period elongation

- Inelasticity increases period
  - Increased period reduces acceleration response
  - Increased period increases displacement response

$$T = 2\pi\sqrt{M/K}$$



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Reduced design spectrum

- Elastic response spectrum
  - Accelerations corresponding to elastic response spectrum
  - Uneconomical design
- Inelastic response
  - Accelerations corresponding to *reduced* elastic response spectrum
  - Implicitly allows for structural damage

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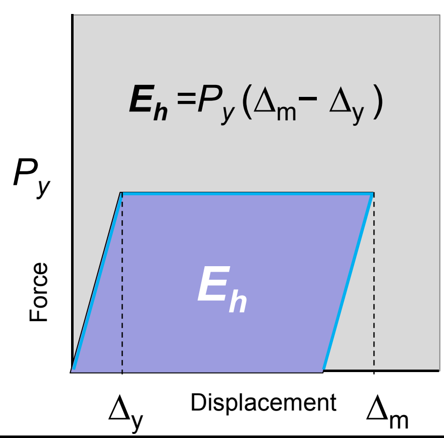
Dissipated energy



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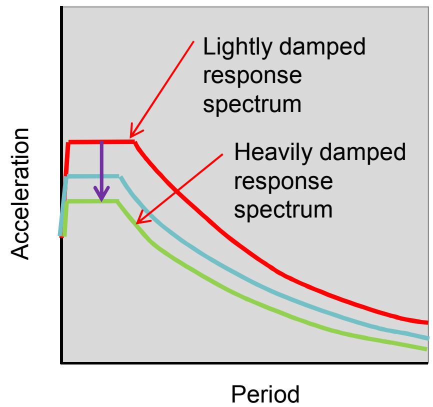
Damping and response

Response reduction due to damping permits use of reduced design forces



Inelasticity increases damping

Increased damping reduces response

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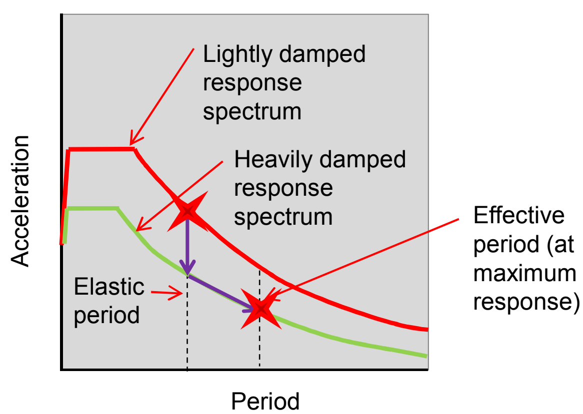
Reduced response

Response reduction due to damping and period shift permit use of reduced design forces (*R* factor)



Codes use a reduced elastic response spectrum to approximate the effects of period elongation and energy absorption

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Reduced design spectrum

- Reduced elastic response spectrum
  - Degree of reduction depends on system characteristics
    - Ductility
      - Displacement capacity
    - Post-elastic stiffness
    - Hysteretic damping
    - Cyclic degradation
  - Approximates inelastic response spectrum
    - Time-history response of inelastic oscillators

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System ductility

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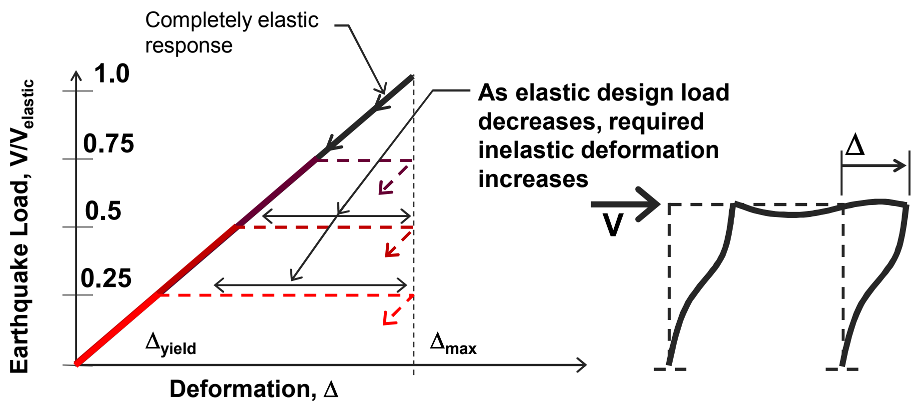
Inelastic response

- As required elastic strength goes down (i.e. larger ***R*-factor**) required inelastic deformation increases



Codes use a response reduction factor ***R*** to represent the degree of ductility that can be tolerated

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Ductility

- Definition
  - Capacity and demand
- Force reduction
- Inelastic response spectra

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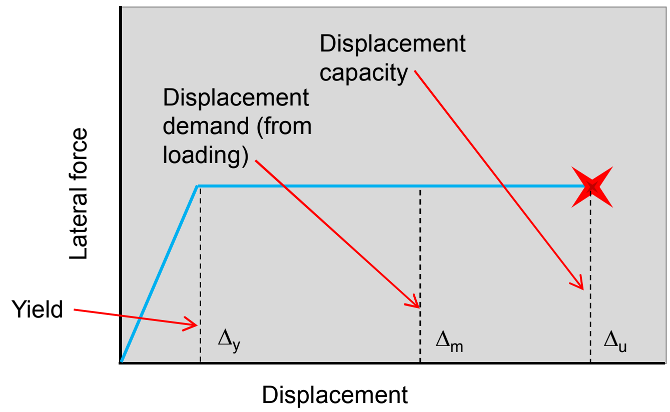
Ductility



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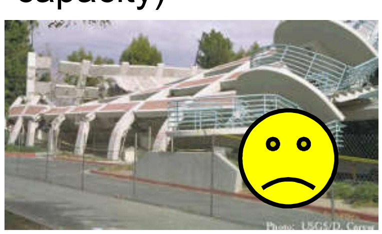
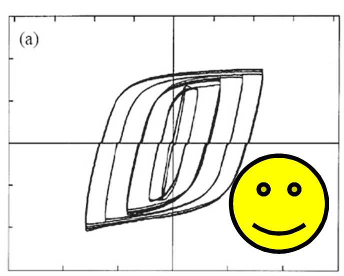
Ductility

- That building experienced a lot of ductility (demand) (more than its ductility capacity)



- That specimen exhibited a lot of ductility (capacity)



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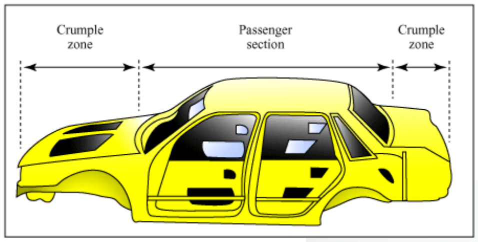
Ductility



Good to have it

Bad to use it

Designing for ductility <u>is</u> designing for structural damage

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Force reduction

- $V = C_y W$ design base shear
- $C_y = C_e / R_\mu$
  - $C_y W$ = reduced required lateral strength
  - $C_e W$ = required strength of elastic system
  - R_μ = reduction factor due to ductility

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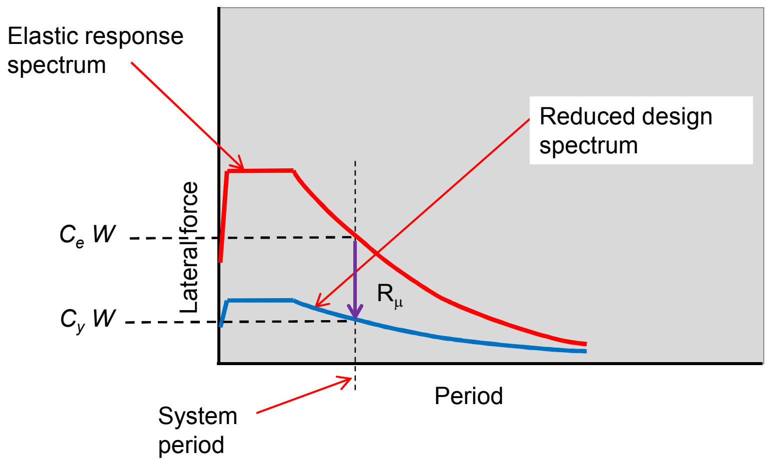
Inelastic response spectrum



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Steel ductility

Steel ductility

- Steel behavior
- Material ductility
- Section ductility
- Member ductility
- System ductility

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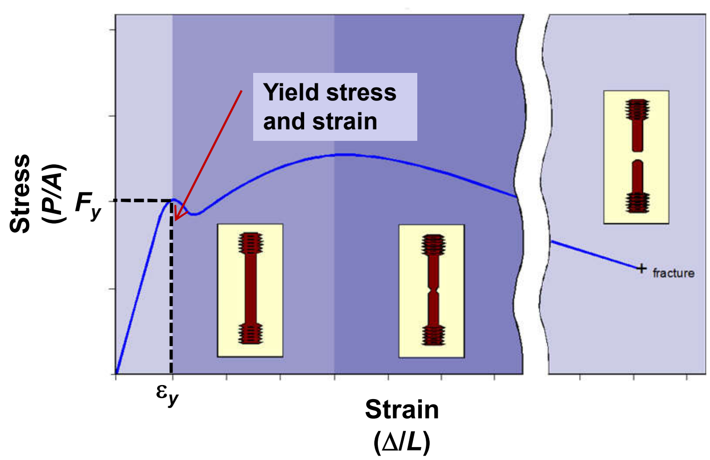
What is yield?



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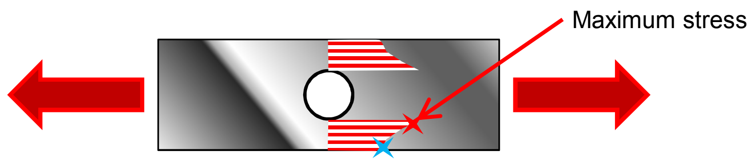
Yield and strength



Elastic stress distributions are non-uniform

Non-ductile materials cannot be fully utilized

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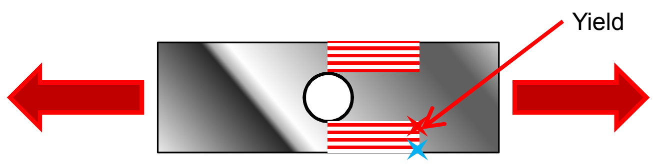
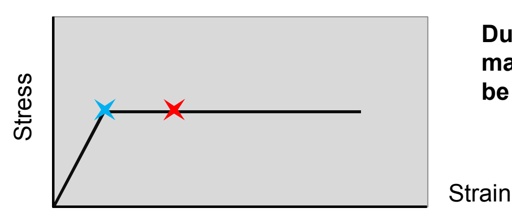
Yield and strength



Elongation permits development of full strength



Ductile materials can be fully utilized

Steel design strength equations typically incorporate local ductility

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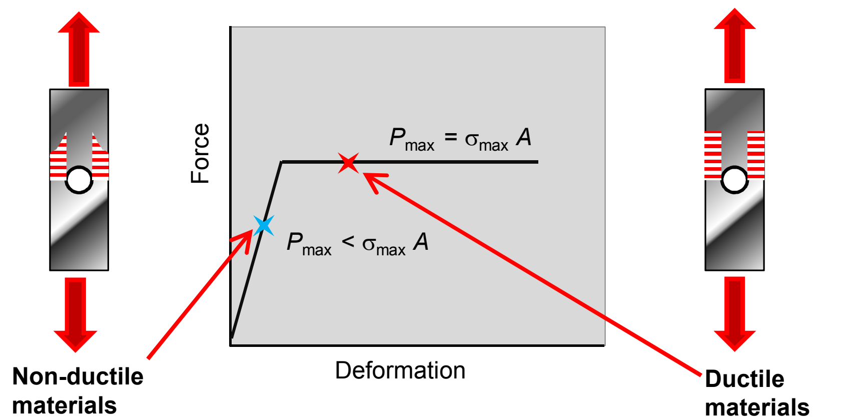
Yield and strength



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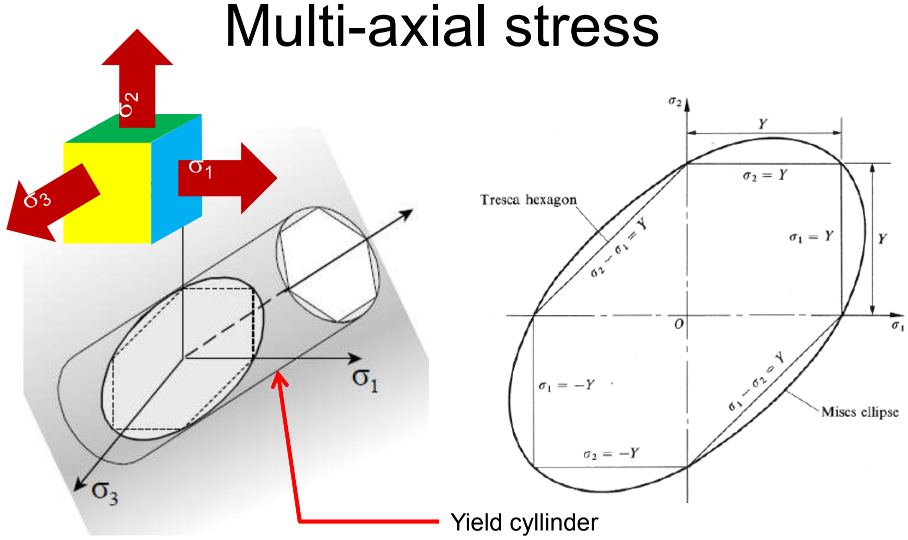
Multi-axial stress



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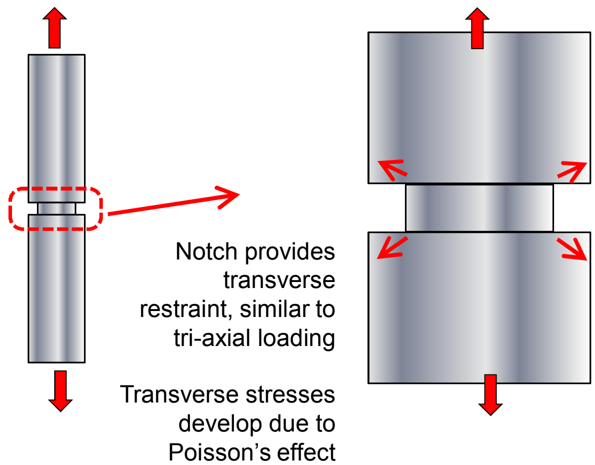
Rupture



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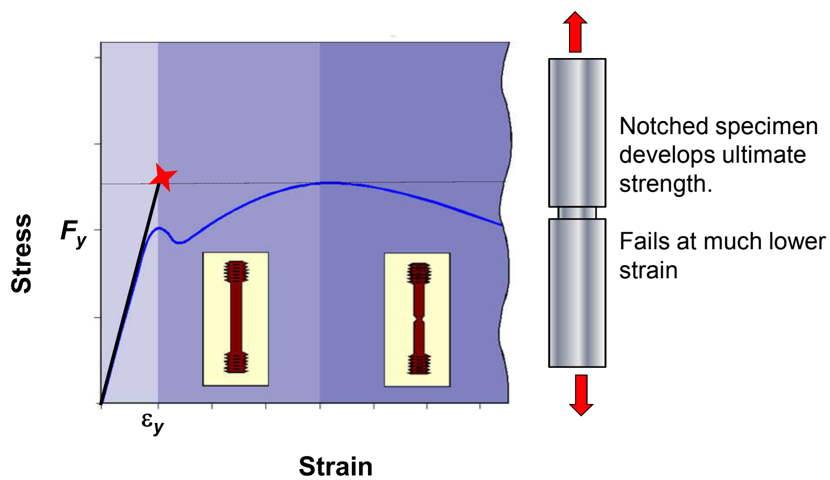
Rupture



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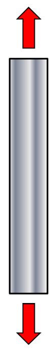
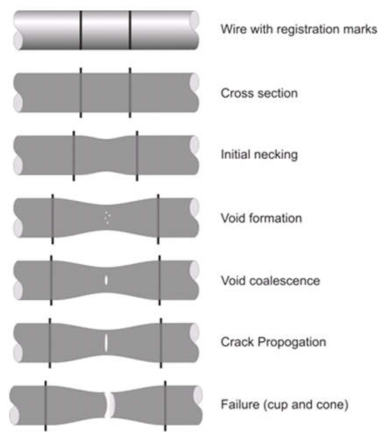
Restraint



Minimal restraint

Example:
Tensile coupon



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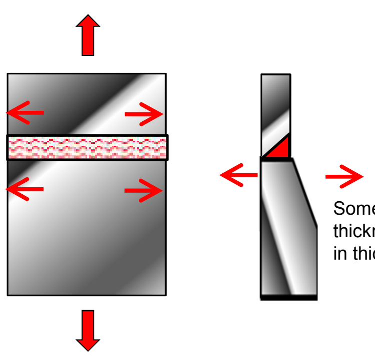
Restraint



Moderate restraint

Some through-thickness restraint in thicker elements

Example:
Column splice flange butt joint

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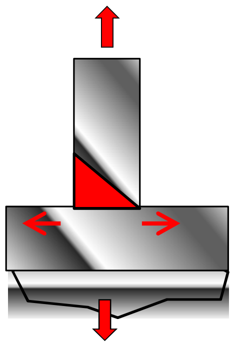
Restraint



Highly restrained

Example:
Beam flange to (thick) column flange T joint

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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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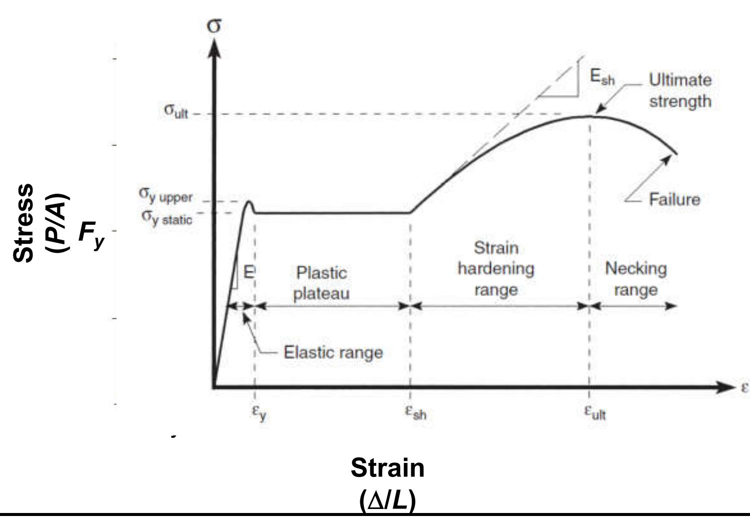
Material ductility



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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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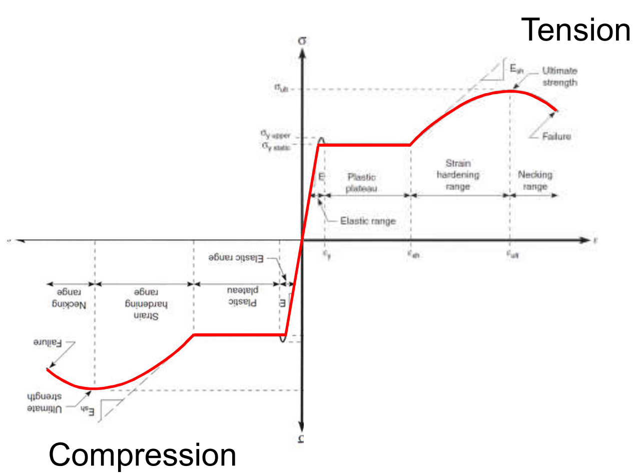
Section ductility



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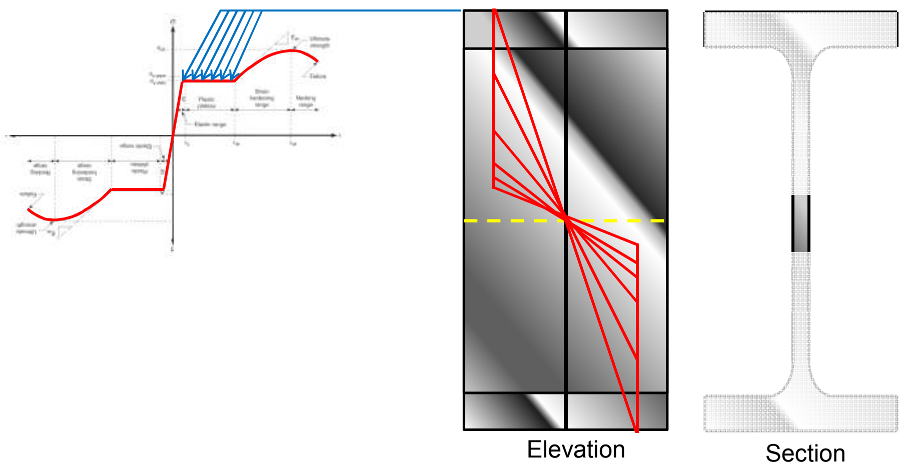
Section ductility



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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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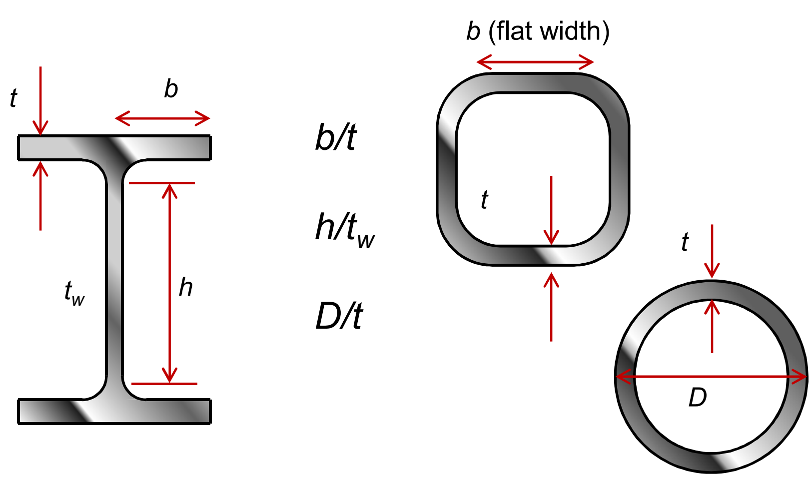
Compactness



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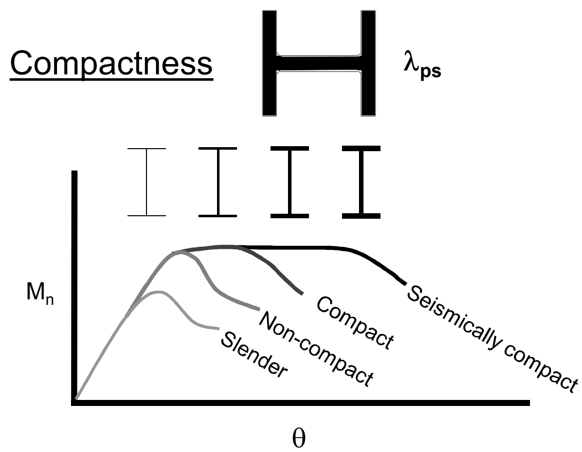
Bracing Members: Limitations



Member ductility

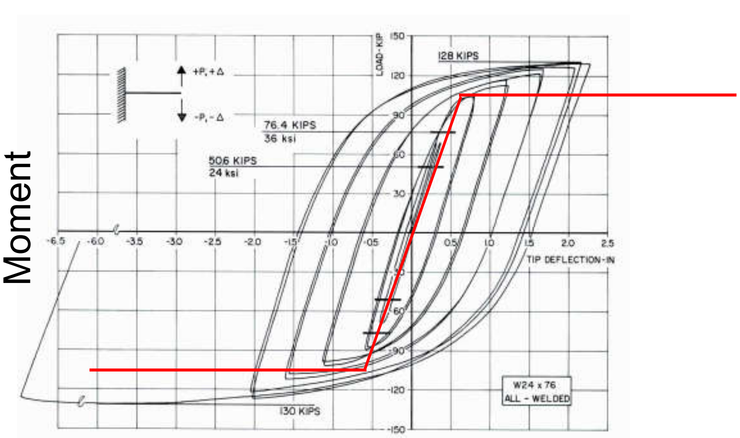
- Desirable
  - Member yielding
    - Flexural hinging
    - Axial yielding
    - Shear yielding
- Undesirable
  - Connection failure
  - Member instability

Member ductility

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

Member ductility

Moment



Rotation

Member instability

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Lateral bracing

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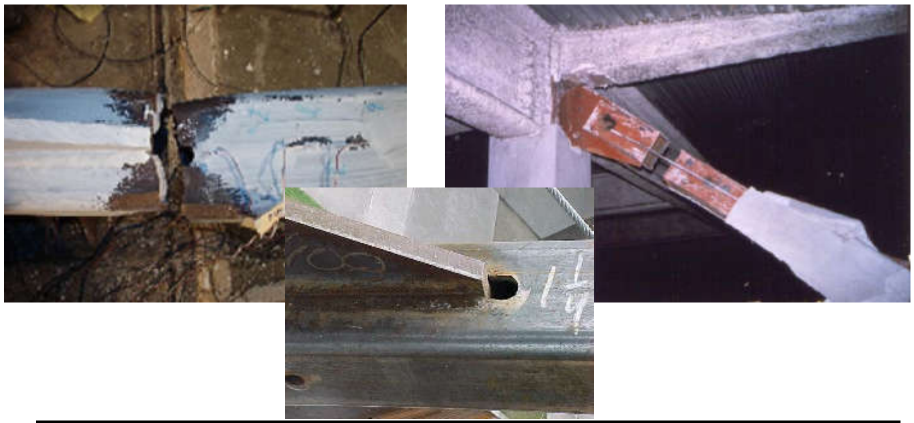
Connection failure



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Strong connections

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Strong connections

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Strong connections

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Expected strength

- Expected yield
  - 110%-160%F_y
  - Varies by material
  - Code specifies how much to consider
    - $F_{ye} = R_y F_y$
    - Values of R_y
      - Appropriate for each material
      - Appropriate for seismically compact sections
- Strain hardening
  - <10% for typical braces
  - 10%-40% for BRBF, EBF
  - 10%-20% for moment frames
  - System requirements specify how much to consider

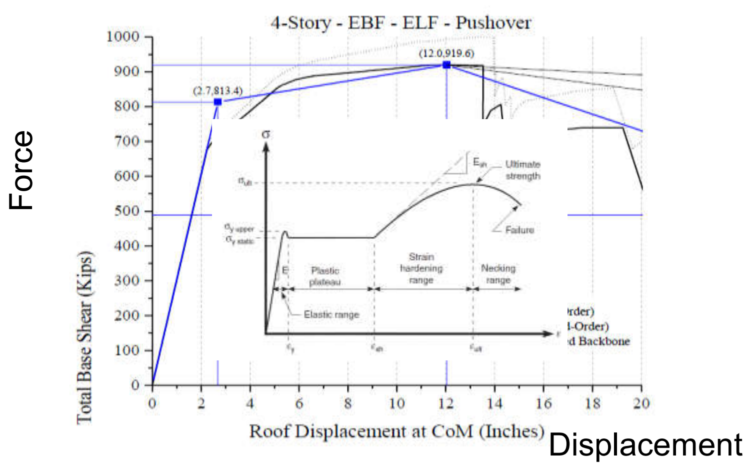
System ductility

- 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

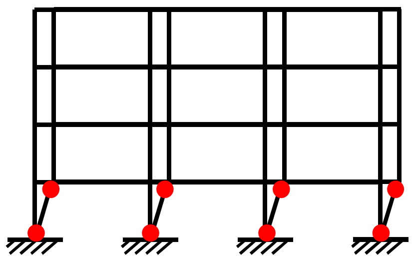
System ductility

- 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

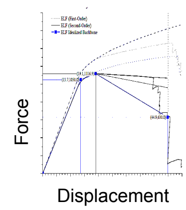
System ductility



System ductility



Concentrated ductility



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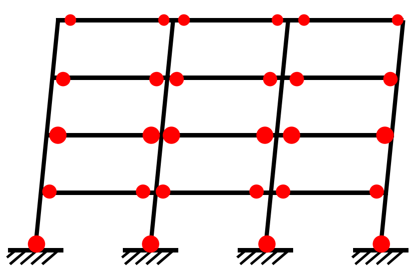
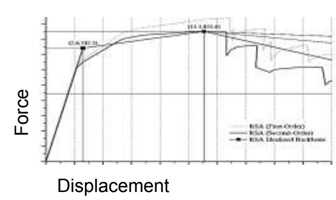
System ductility



Distributed ductility

Distributed ductility is encouraged by proportioning members, including having similar seismic demand-to-capacity ratios for all beams.



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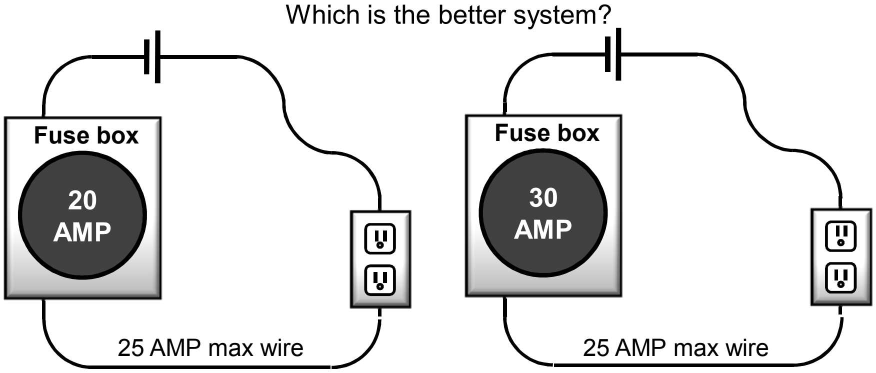
Capacity design (system): Fuse concept

Which is the better system?



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

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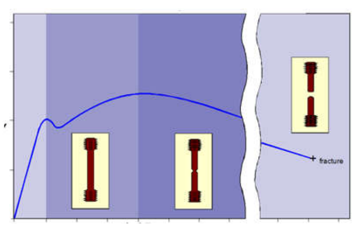
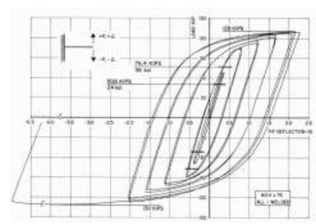
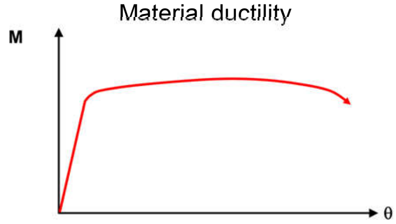
Ductility



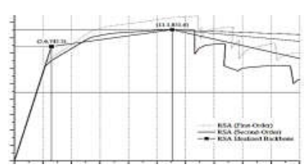
Material ductility



Member ductility



Section ductility



System ductility

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There's always a solution in steel.

Steel lateral systems

structural
STEEL

Steel lateral systems

- Steel Moment Frames
  - Conventional Moment Frames
  - Special Truss Moment Frames
- Steel Braced Frames and Shear Walls
- Composite Moment Frames
- Composite Braced Frames and Shear Walls

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Moment Frames

- Special
  - Detailed and proportioned for large inelastic drift
  - Low required strength (*R*=8)
- Intermediate
  - Detailed and proportioned for moderate inelastic drift
  - Medium required strength (*R*=4.5)
- Ordinary
  - Detailed and proportioned for small inelastic drift
  - High required strength (*R*=3.5)

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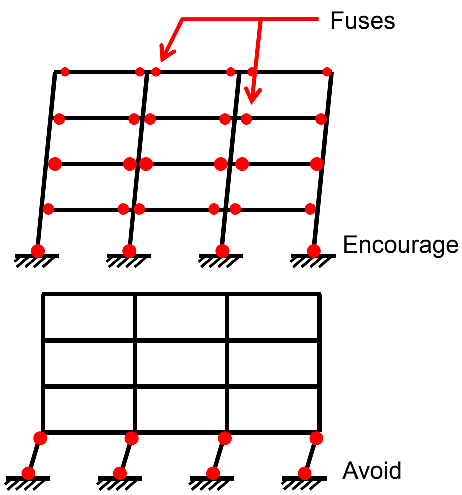
Moment frames

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



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Braced Frames

- Buckling-restrained Braced Frames
  - Detailed and proportioned for large inelastic drift
  - Low required strength (*R*=8)
- Special Concentrically Braced Frames
  - Detailed and proportioned for moderate inelastic drift
  - Medium required strength (*R*=6)
- Ordinary Concentrically Braced Frames
  - Detailed and proportioned for small inelastic drift
  - High required strength (*R*=3.25)

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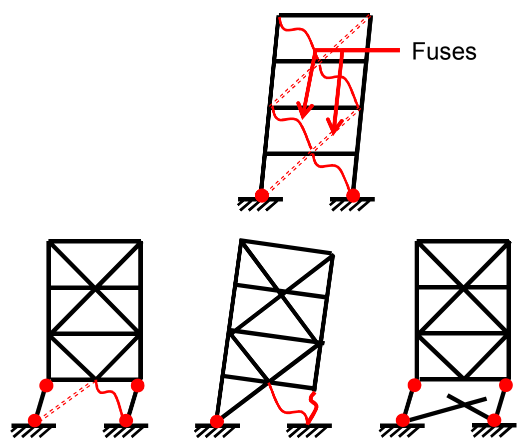
Concentrically braced frames

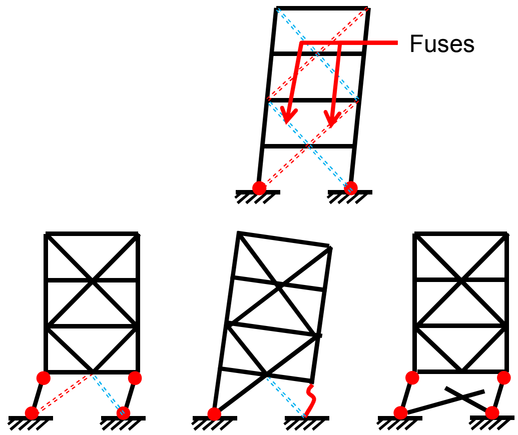
- Encourage
  - Yielding of braces
  - Buckling of braces
- Avoid
  - Flexural hinging in columns (story mechanisms)
  - Buckling of beams or columns
  - Connection failure



100

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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Braced Frames

- Eccentrically Braced Frames
  - Detailed and proportioned for large inelastic drift
  - Low required strength (R=8)
- Special Plate Shear Walls
  - Detailed and proportioned for large inelastic drift
  - Low required strength (R=7)

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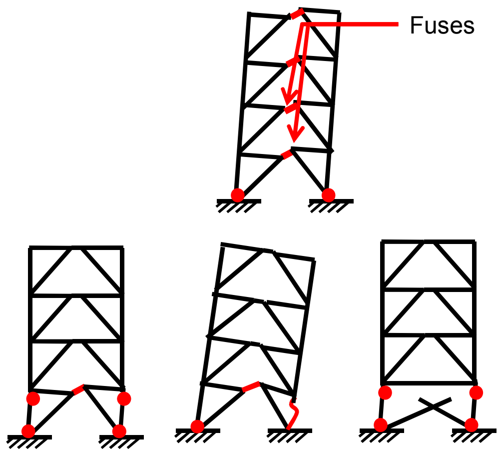
Eccentrically braced frames

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



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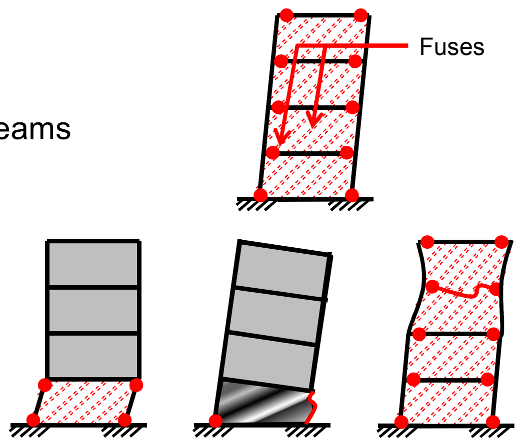
Steel plate shear walls

- 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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There's always a solution in steel.

Summary

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Summary

- Seismic design is necessary for structural safety
- Building response to ground motions is affected by period
- System ductility permits design for reduced forces
- Steel provides excellent ductility, if properly designed
- Steel lateral systems each have a set of strength, detailing, and proportioning requirements

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There's always a solution in steel.

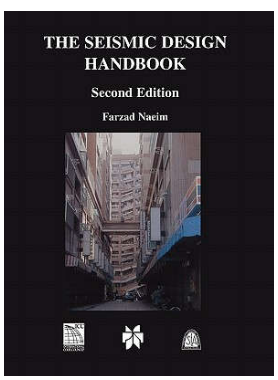
End of session 1

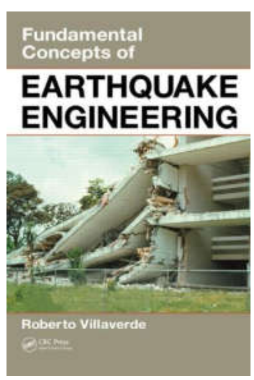
Next:

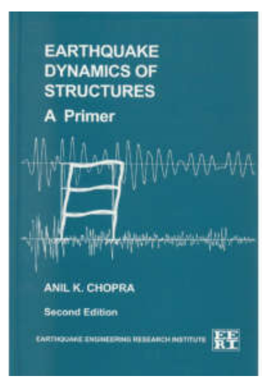
Seismic design of moment frames

structural STEEL

Additional resources







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There's always a solution in steel.

Question time

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8-Session Package Registrants

Course Resources

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

AISC › MYAISC › COURSE RESOURCES › SEISMIC DESIGN IN STEEL

Seismic Design in Steel

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Introduction To Effective Seismic Design	N/A	Handouts	View Passcode: 16NSRS1	Available 07/23/2018 5:00 PM EDT	N/A
R2: Seismic Design Concepts - Moment Frames	N/A	Handouts	View Passcode: 16221218	Available 07/23/2018 5:00 PM EDT	N/A
R3: Seismic Design Concepts - Braced Frames	N/A	Handouts	View Passcode: 3610305	Available 07/23/2018 5:00 PM EDT	N/A
R4: Seismic Design Concepts - Design	N/A	Handouts	View Passcode: 31308	Available 07/23/2018 5:00 PM EDT	N/A
R5: Bonus Q+A	N/A		Available 08/31/2018 5:00 PM EDT	N/A	N/A
L1: Application - Planning the Seismic Design	Sep 10 2018 1:30PM EDT	Handouts	Available 09/12/2018 5:00PM EDT	Available 09/12/2018 5:00PM EDT	Pending
L2: Application - Building Analysis/Diaphragms	Sep 17 2018 1:30PM EDT	Handouts	Available 09/19/2018 5:00PM EDT	Available 09/19/2018 5:00PM EDT	Pending
L3: Application - Moment Frames	Sep 24 2018 1:30PM EDT	Handouts	Available 09/26/2018 5:00PM EDT	Available 09/26/2018 5:00PM EDT	Pending
L4: Design of the Braced Frames	Oct 1 2018 1:30PM EDT	Handouts	Available 10/03/2018 5:00PM EDT	Available 10/03/2018 5:00PM EDT	Pending
Seismice Design in Steel - Final Exam	Oct 3 2018 12:00AM EDT			Available 10/05/2018 5:00PM EDT	

8-Session Package Registrants

Videos and Quizzes

Videos

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

Quizzes

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

8-Session Package Registrants

Course Credit

Attendance and PDH Certificates

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

EEU Certificates – Certificate of Completion

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

Distribution of Certificates

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