


**AISC
Night School**


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We will begin shortly. Please standby.

**Fundamentals of earthquake engineering
for building structures**

Session 3: Building Dynamics and Response
March 1, 2021 | Rafael Sabelli





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Stronger.
Steel.



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Course Description

Session 4: Steel Behavior

March 8, 2021

This lecture presents the basic mechanics of steel behavior, including yield, elongation, strain-hardening, and rupture. Multi-axial stress and its effects will be discussed. Steel behavior issues related to welded joints as well as the important concept of steel toughness will be presented.



Learning Objectives

- Understand the material properties of steel.
- Explain the reasons for toughness requirements for structural steel.
- Describe the production process for structural steel and its effects on the properties.
- Explain the importance of detailing welded connections, particularly as it pertains to seismic design.



Night School 25:
Fundamentals of earthquake engineering for building structures

Rafael Sabelli, SE
Walter P Moore

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Course outline

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



9

Night School 25:
**Fundamentals of earthquake
engineering for building structures**
Session 4: Steel behavior
March 8, 2021

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Session topics

- Yield
- Toughness
- Production
- Welding



11

Steel

- System ductility is necessary for controlled seismic response
- System ductility can be provided, in part, through the use of ductile material
- Steel can provide high levels of ductility
- Proper detailing is required to allow steel to exhibit this ductility




12

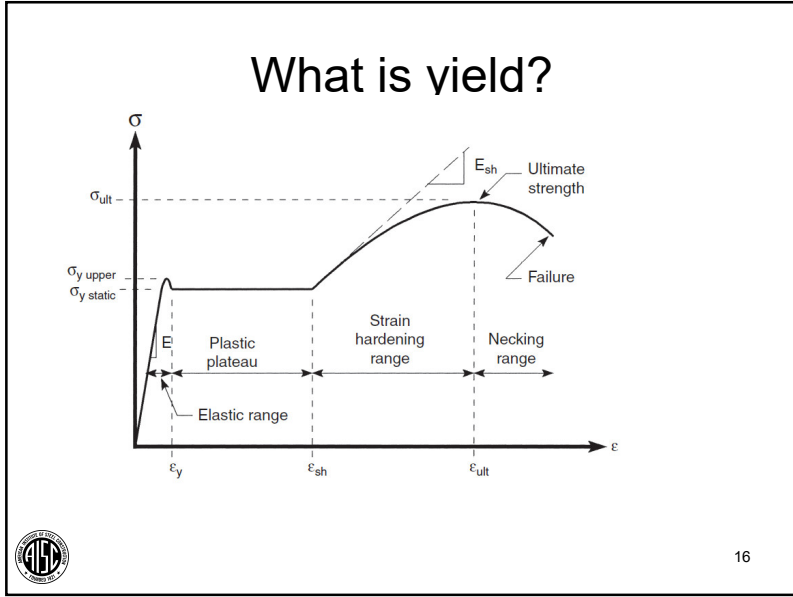
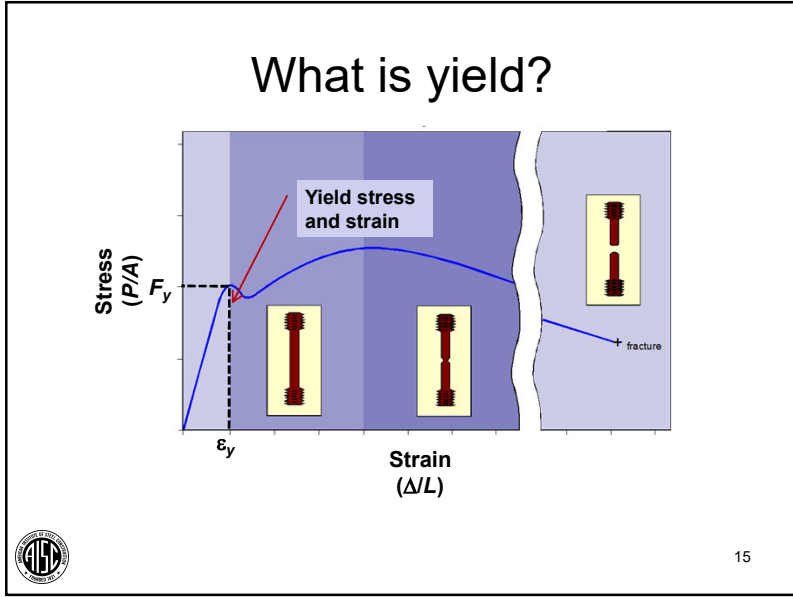


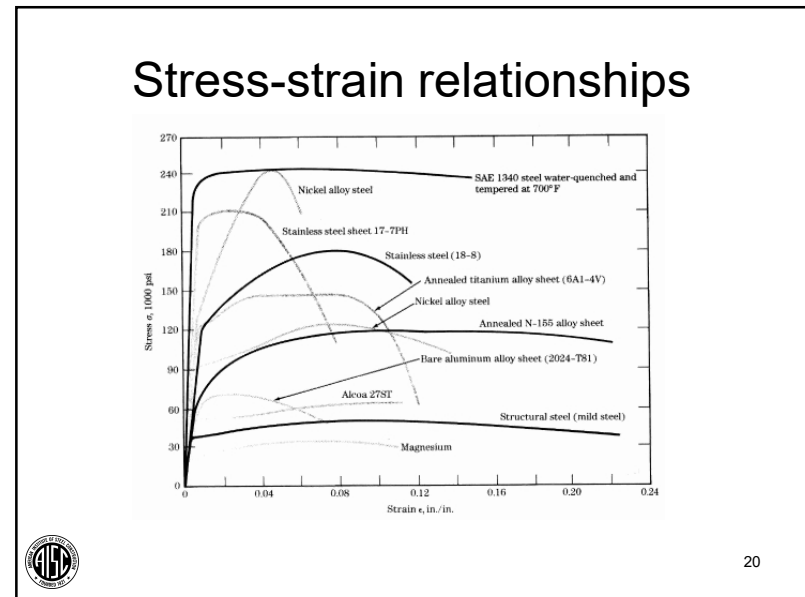
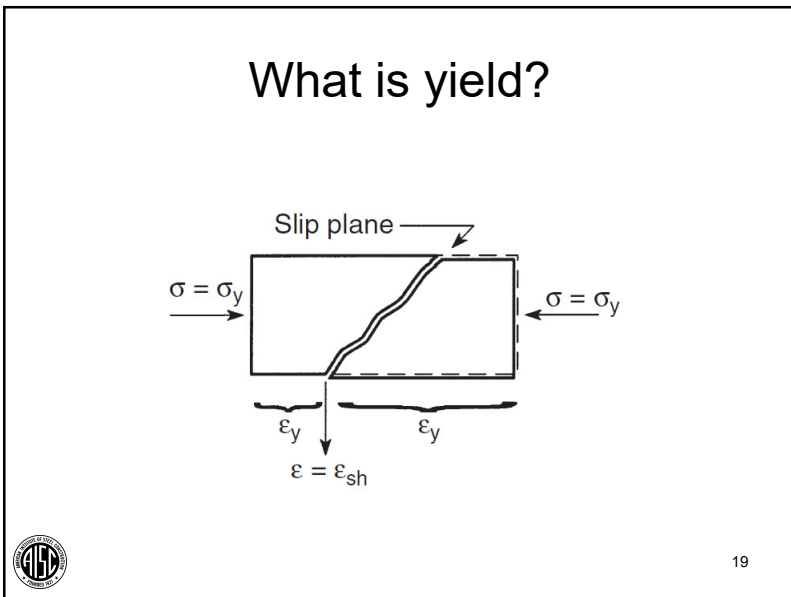
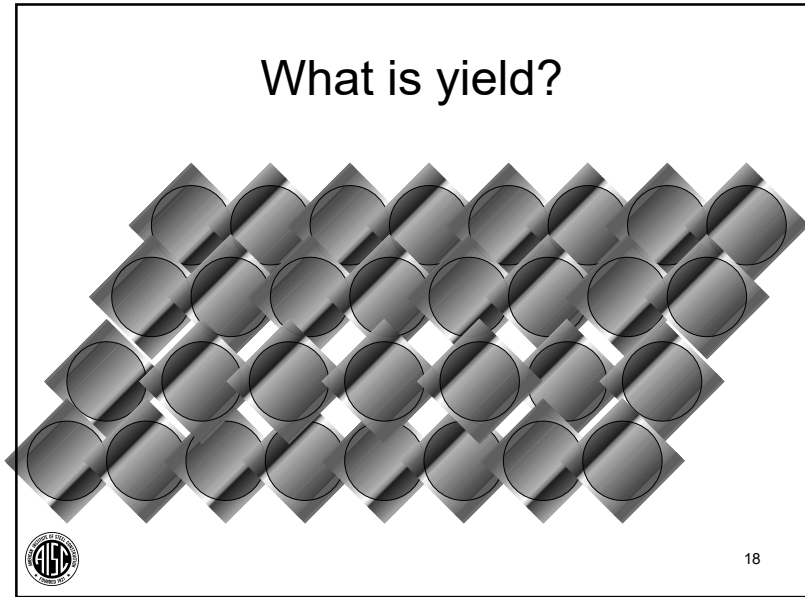
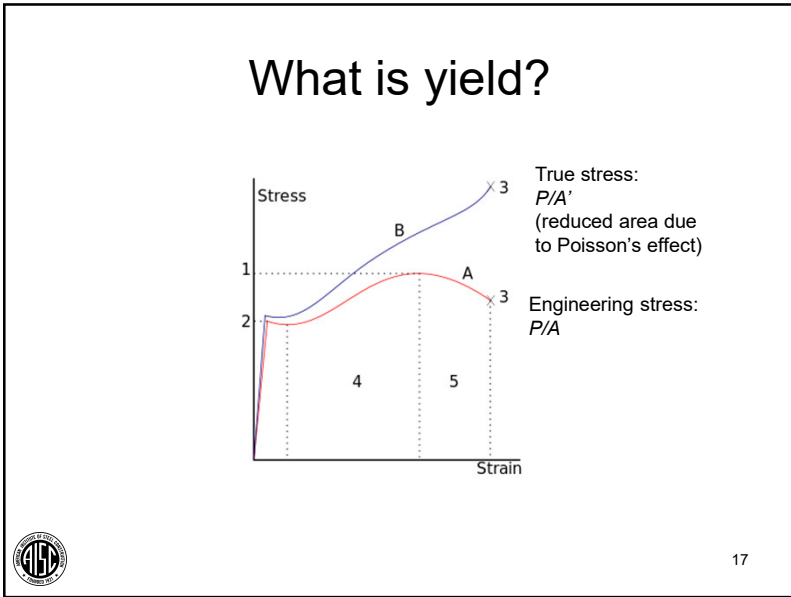
Yield

- What is yield?
- Steel stress-strain relationships
- Cyclic behavior
- Dynamic behavior
- Fatigue
- Multi-axial stress
- Variability and predictability



14





Poisson's effect

Resistance to volume change creates shear distortion in steel matrix

21

Poisson's effect

$$\epsilon_{\text{long}} = \Delta L / L$$

$$\epsilon_{\text{trans}} = \Delta L' / L$$

$$\nu = \epsilon_{\text{trans}} / \epsilon_{\text{long}}$$

$$= \frac{E}{2G} - 1$$

$$\nu = 0.3 \text{ for steel}$$

22

Yield and strength

Elastic stress distributions are non-uniform

Non-ductile materials cannot be fully utilized

23

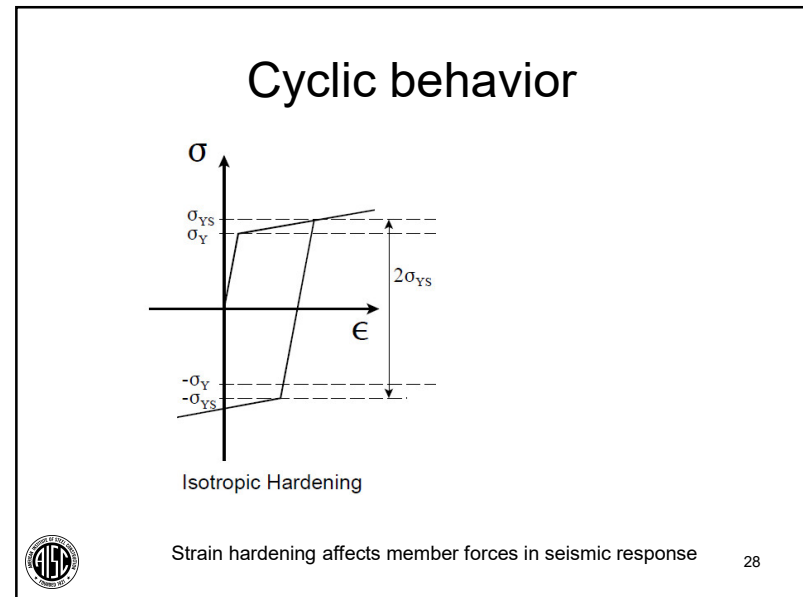
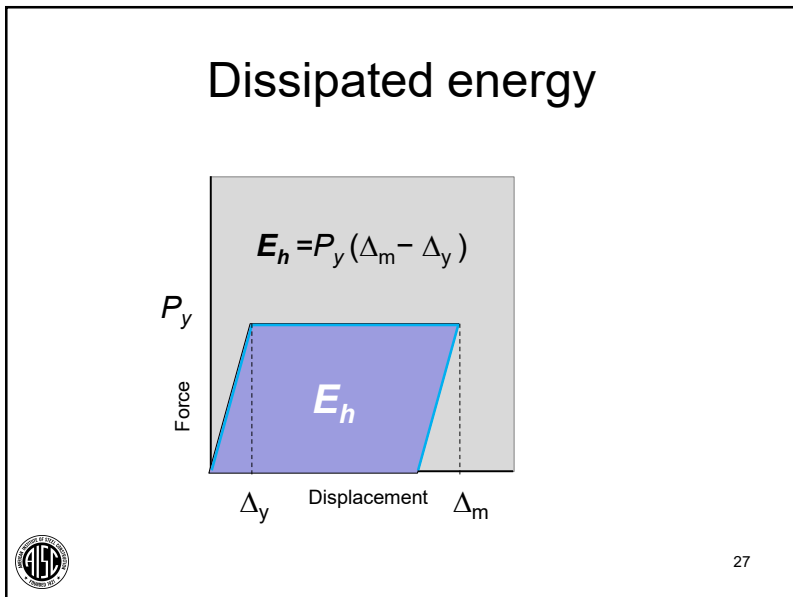
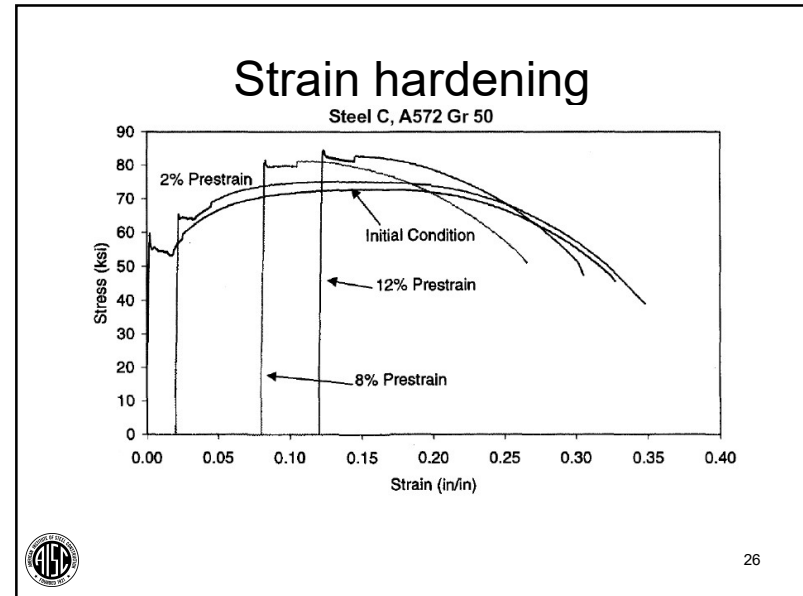
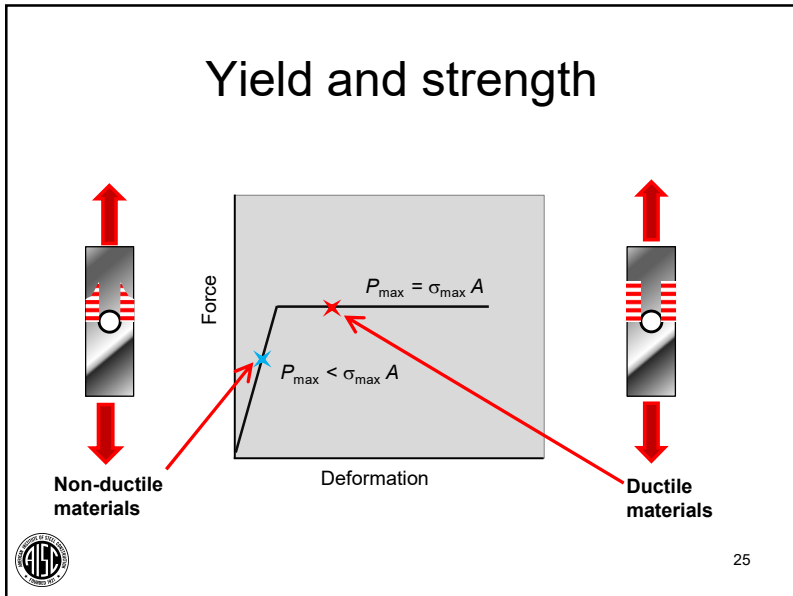
Yield and strength

Elongation permits development of full strength

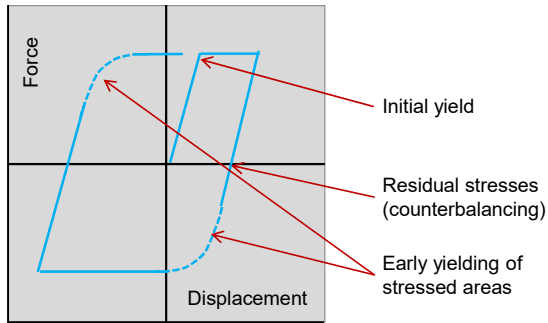
Ductile materials can be fully utilized

24

Steel design strength equations typically incorporate local ductility

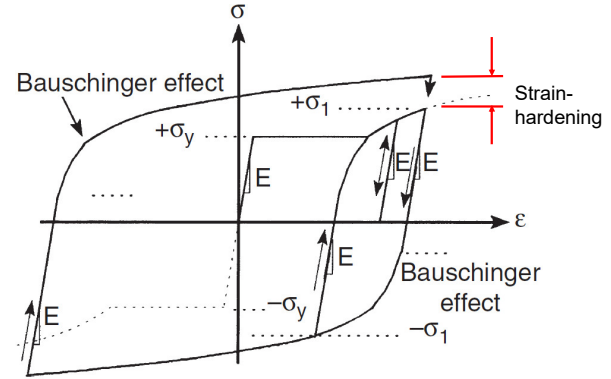


Bauschinger effects



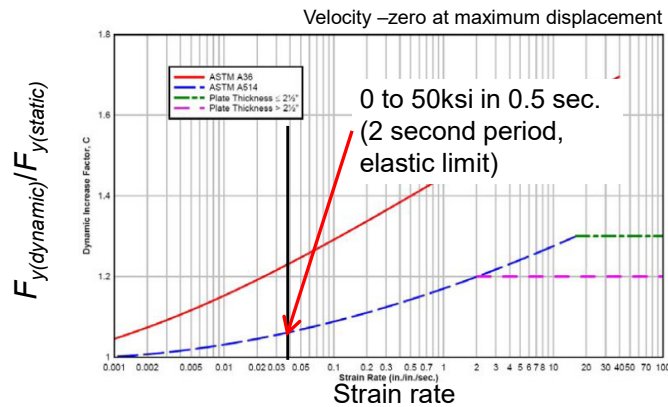
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Cyclic behavior



30

Dynamic behavior

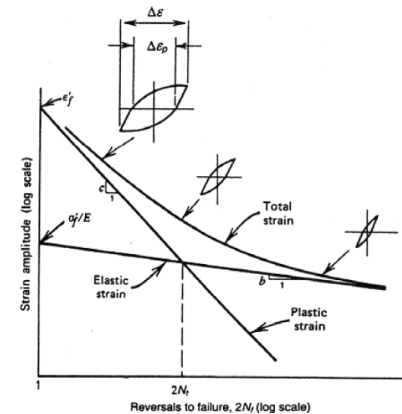


Rate-of-loading is implicitly addressed in seismic design

31

Fatigue

Low-cycle fatigue:
 Few cycles of high (inelastic) amplitude
 Example:
 Seismic yielding



High-cycle fatigue:
 Many cycles of low (elastic) amplitude
 Example:
 Highway traffic



Seismic design methods implicitly address low-cycle fatigue

32

Multi-axial stress

33

34

Von Mises interaction

$$\sigma_y = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]}$$

$\sigma_3 = 0$

$$\sigma_y = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

Sometimes we can assume $\sigma_3 = 0$

- Plates
- Webs

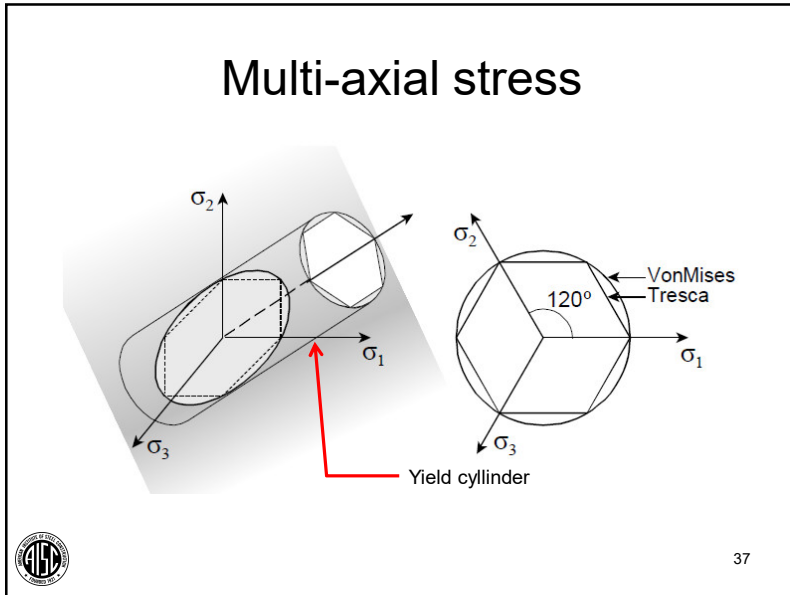
$$\sigma_y^2 = 3\tau^2$$

$$\tau_y = \frac{1}{\sqrt{3}}\sigma_y \approx 0.6\sigma_y$$

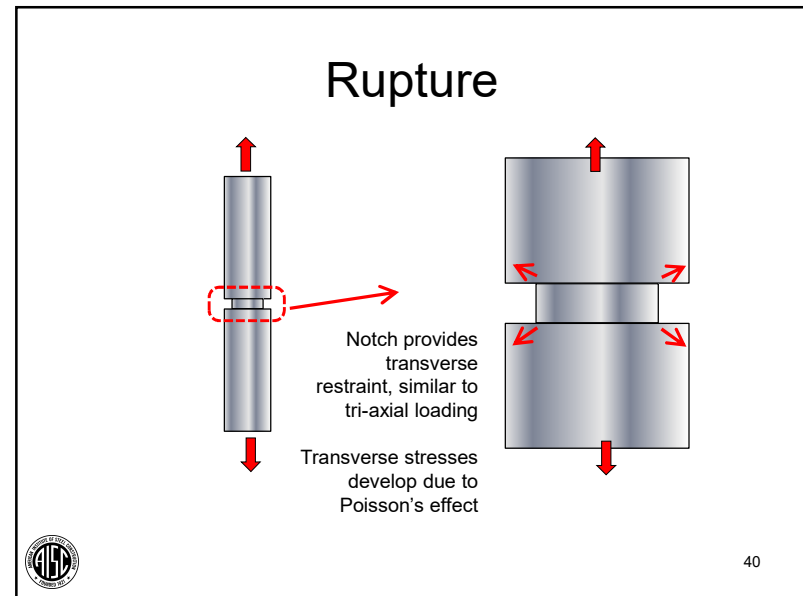
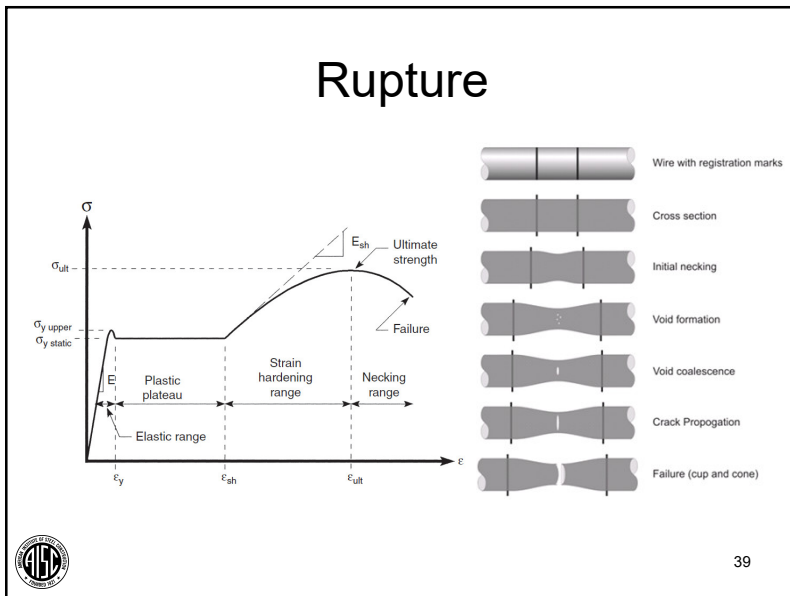
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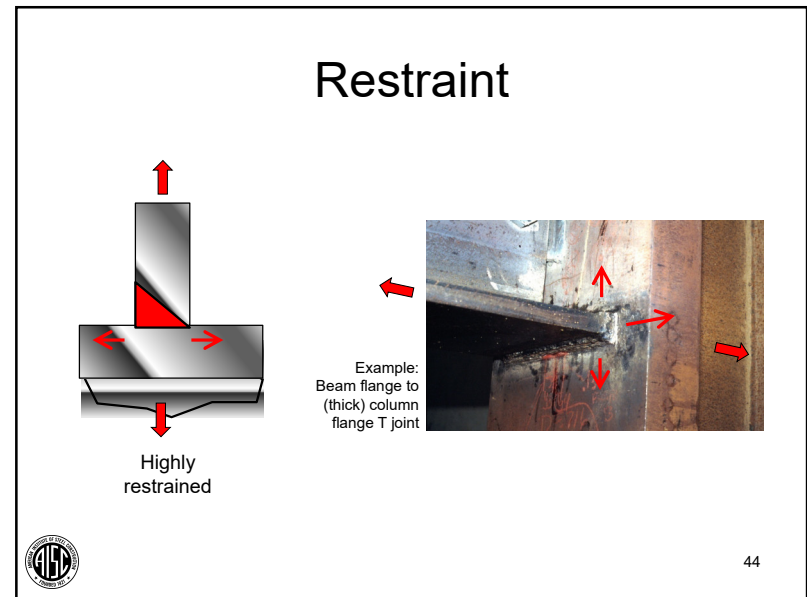
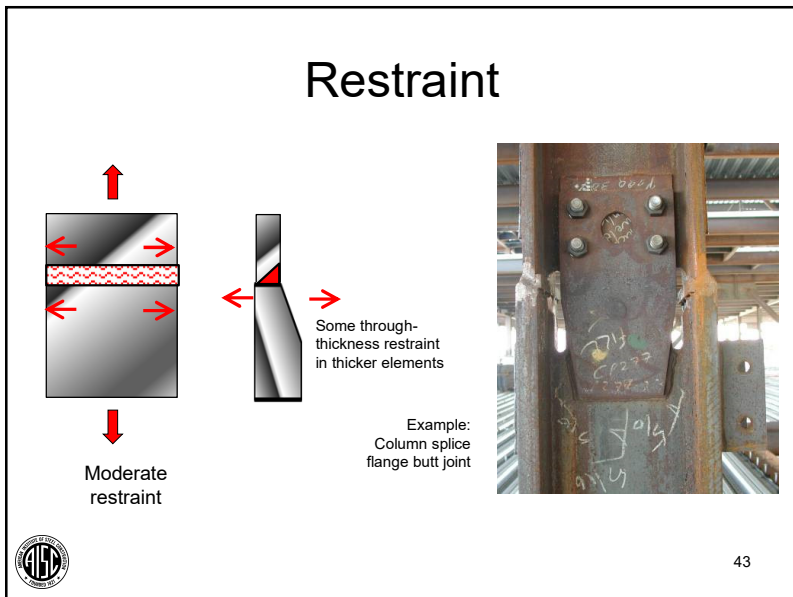
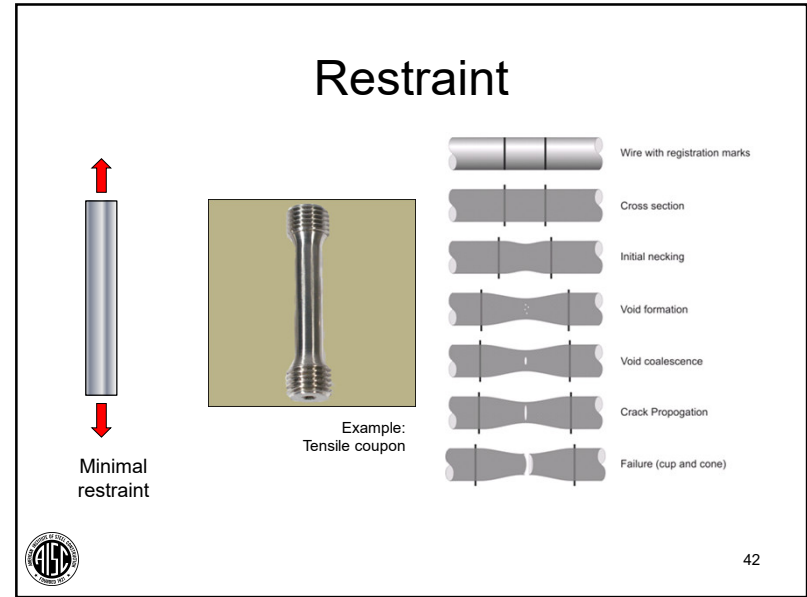
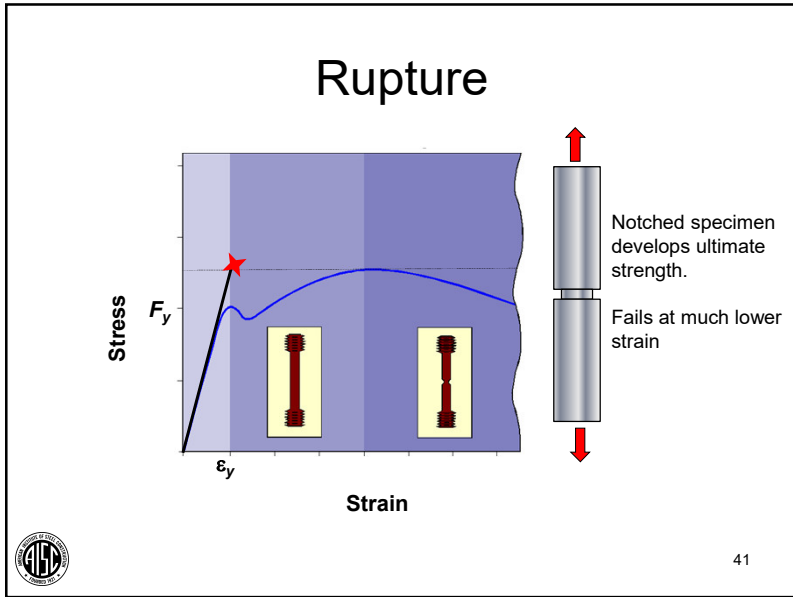
Shear and tension

36



- ### Rupture
- Separation of material under stress
 - Non-ductile limit
 - Multi-axis interactions do not apply
- 38





Variability and predictability

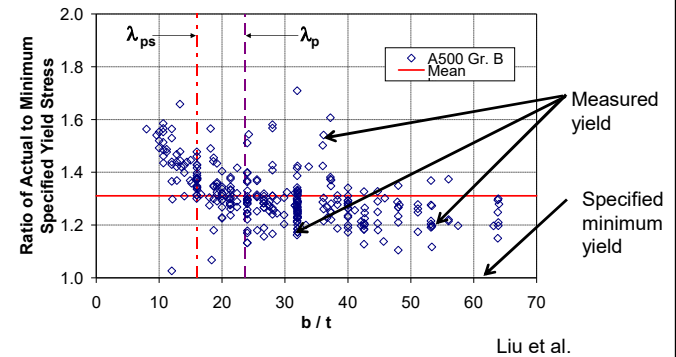
- Steel yield strength is higher than specified minimum
 - Typically 110%-120%
 - As high as 160%
 - Varies with material and section type
- There is some variability in expected strength



Steel variability is considered in seismic design for "capacity design" procedures

45

Variability and predictability



46

Expected strength

- $R_y F_y$
- Expected (mean) yield strength for material
- NOT maximum yield strength
- Determined by AISC using industry-wide data

TABLE A3.1
 R_y and R_t Values for Steel and Steel Reinforcement Materials

Application	R_y	R_t
Hot-rolled structural shapes and bars:		
• ASTM A36/A36M	1.5	1.2
• ASTM A1043/A1043M Gr. 36 (250)	1.3	1.1
• ASTM A992/A992M	1.1	1.1
• ASTM A572/A572M Gr. 50 (345) or 55 (380)	1.1	1.1
• ASTM A913/A913M Gr. 50 (345), 60 (415), 65 (450), or 70 (485)	1.1	1.1
• ASTM A588/A588M	1.1	1.1
• ASTM A1043/A1043M Gr. 50 (345)	1.2	1.1
• ASTM A529 Gr. 50 (345)	1.2	1.2
• ASTM A529 Gr. 55 (380)	1.1	1.2
Hollow structural sections (HSS):		
• ASTM A500/A500M Gr. B	1.4	1.3
• ASTM A500/A500M Gr. C	1.3	1.2
• ASTM A501/A501M	1.4	1.3
• ASTM A53/A53M	1.6	1.2
• ASTM A1085/A1085M	1.25	1.15
Plates, Slabs, and Sheets:		
• ASTM A36/A36M	1.3	1.2
• ASTM A1043/A1043M Gr. 36 (250)	1.3	1.1
• ASTM A1011/A1011M HSLAS Gr. 55 (380)	1.1	1.1
• ASTM A572/A572M Gr. 42 (290)	1.3	1.0
• ASTM A572/A572M Gr. 50 (345), Gr. 55 (380)	1.1	1.2
• ASTM A588/A588M	1.1	1.2
• ASTM A1043/A1043M Gr. 50 (345)	1.2	1.1
Steel Reinforcement:		
• ASTM A615/A615M Gr. 60 (420)	1.2	1.2
• ASTM A615/A615M Gr. 75 (520) and Gr. 80 (550)	1.1	1.2
• ASTM A706/A706M Gr. 60 (420) and Gr. 80 (550)	1.2	1.2



47

Toughness



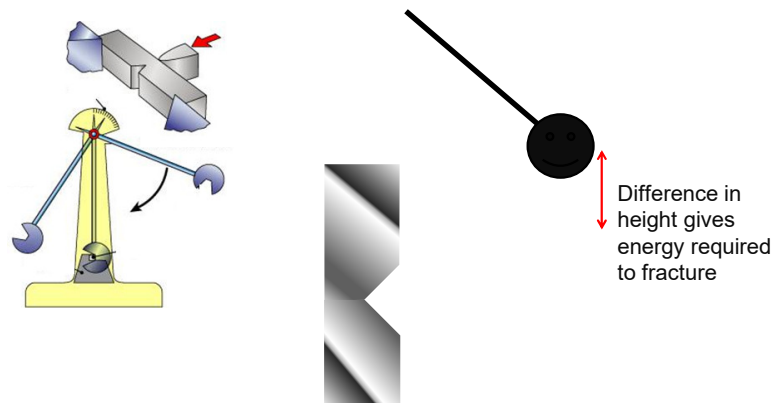
Toughness

- What is toughness?
- Toughness and cyclic loading
- Temperature
- Thick elements



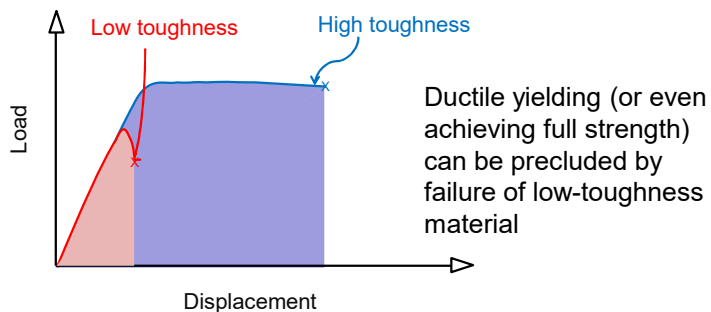
49

What is toughness?



50

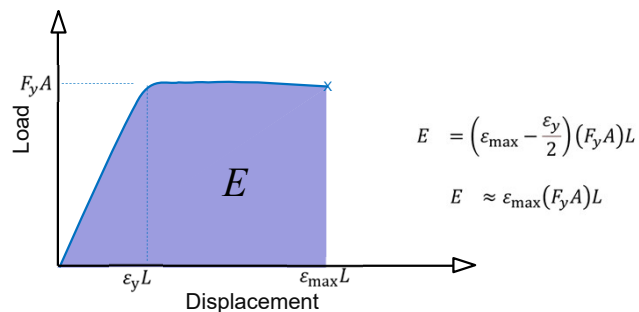
Toughness and energy absorption



Minimum toughness is required for seismic design at critical locations

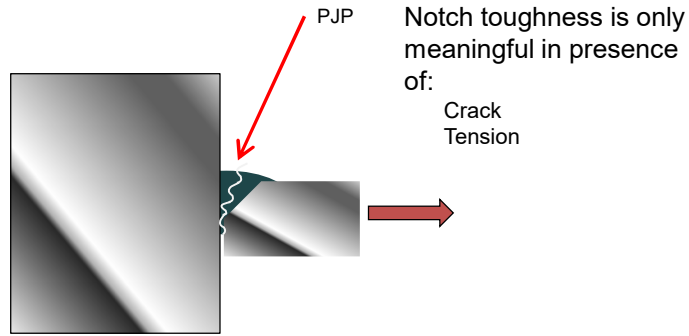
51

Toughness and energy absorption



52

Toughness and cyclic loading

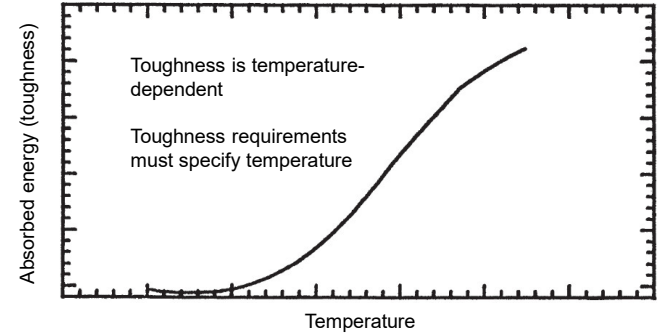


Notch toughness is only meaningful in presence of:
Crack
Tension



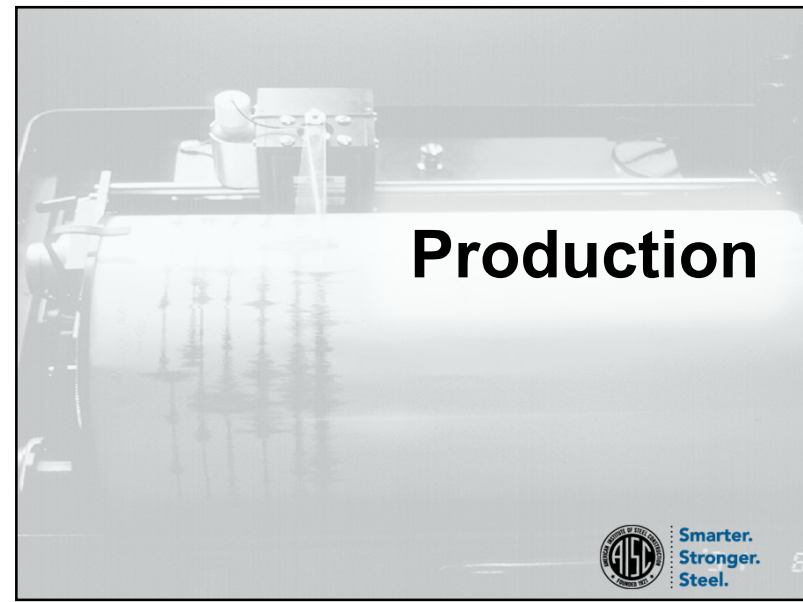
PJP welds have reduced design strength to reflect notch effect

Toughness and temperature



Toughness and thickness

- High notch toughness is necessary for all elements subject to high strains, especially cyclic
- Thinner plates and sections have notch toughness
- Thicker material may have lower toughness due to restraint in through-thickness direction



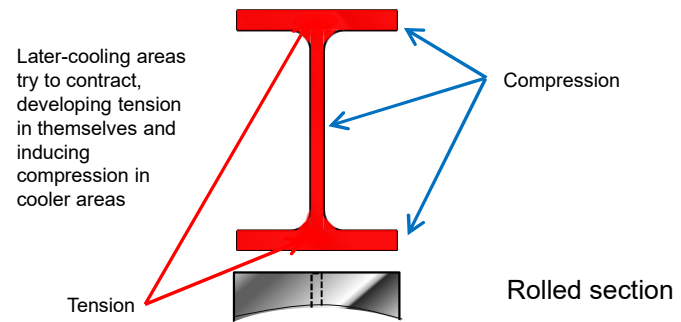
Production

- Residual stresses
- The “k region”
- Laminations



57

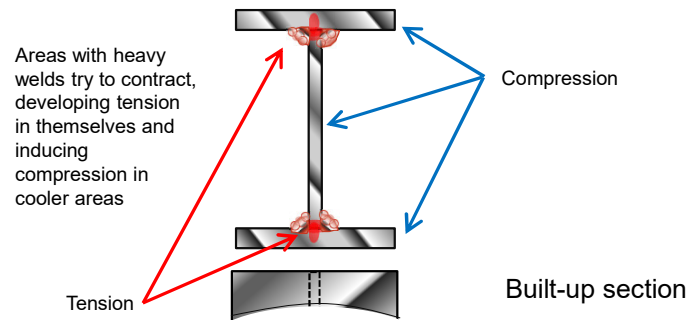
Residual stresses



Design strengths reflect residual stress where it has an effect

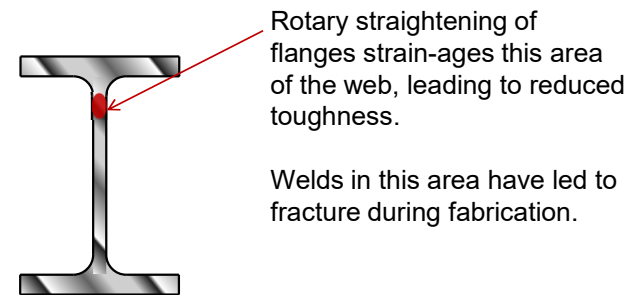
58

Residual stresses



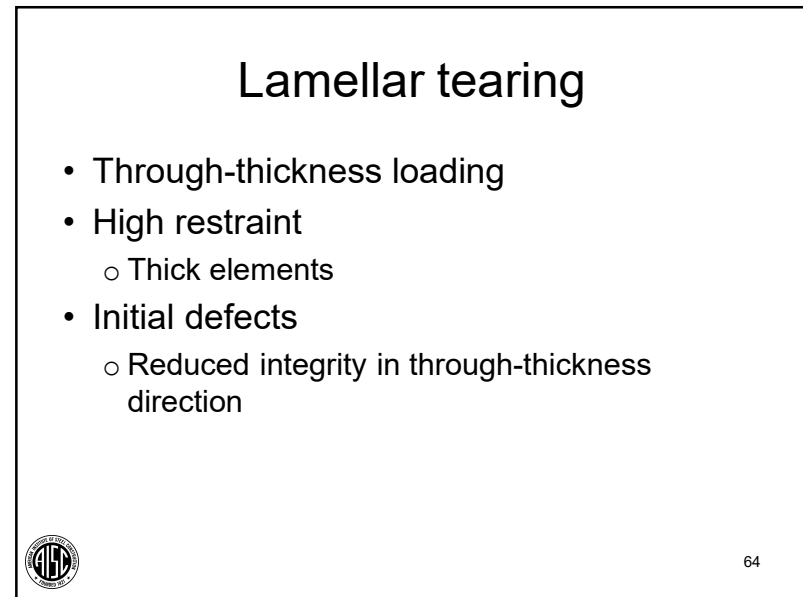
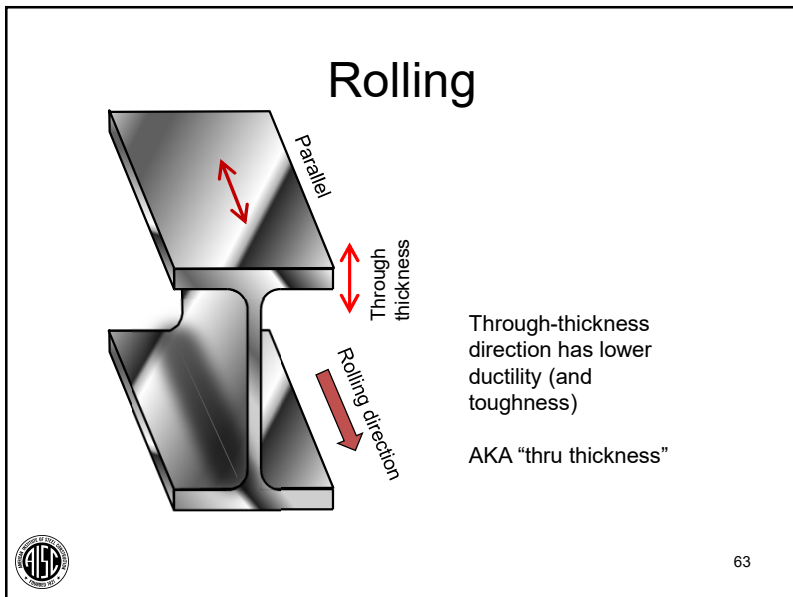
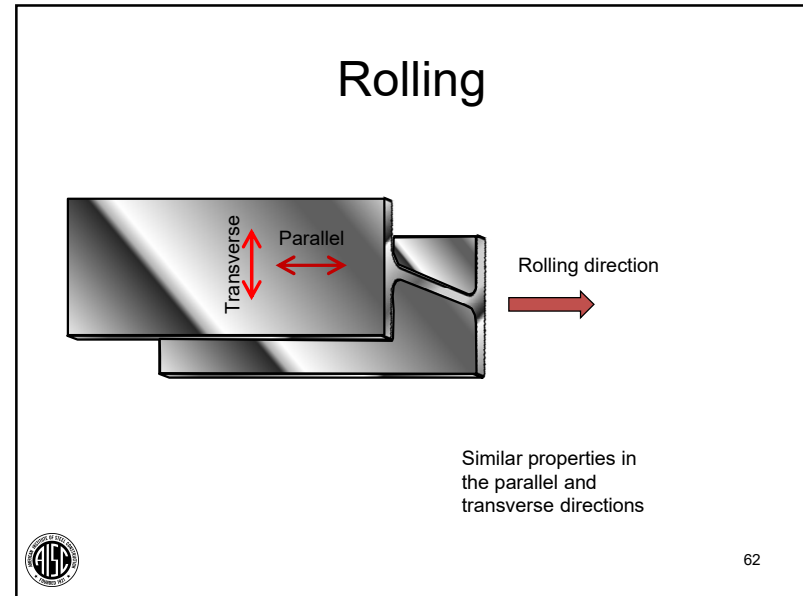
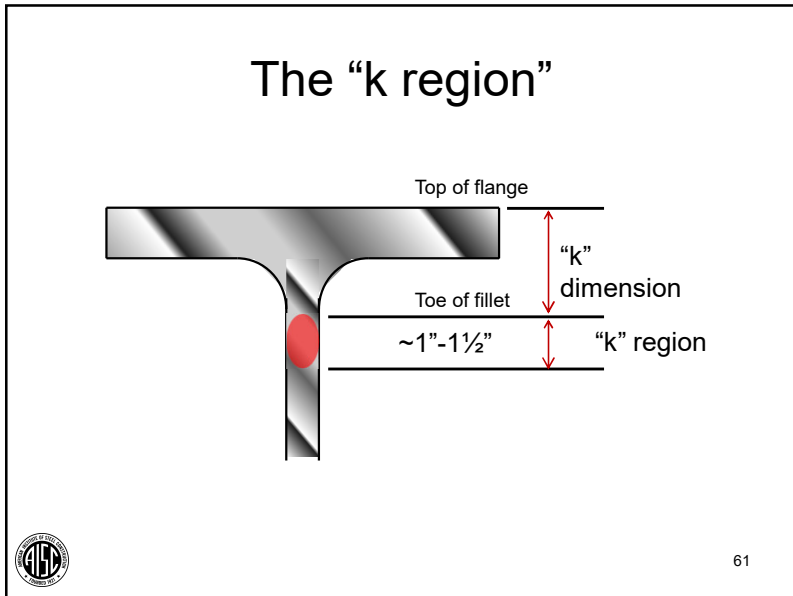
59

The “k region”

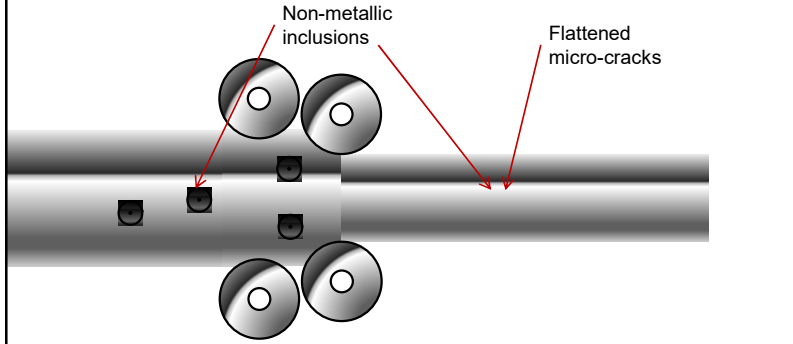


Welds to this region are proscribed in seismic design

60



Lamellar defects




The diagram shows a cross-section of a steel beam with several defects. Two circular regions are labeled 'Non-metallic inclusions'. Two elongated, flattened regions are labeled 'Flattened micro-cracks'. The AISC logo is in the bottom left corner.

65

Surface roughness

- Surface defects may initiate cracks
- 500 micro-inches provides sufficient smoothness



The image shows an orange on the right and a close-up of a steel surface on the left. The orange is used as a visual metaphor for surface roughness. The AISC logo is in the bottom left corner.

Codes require this smoothness at critical locations

66

Welding

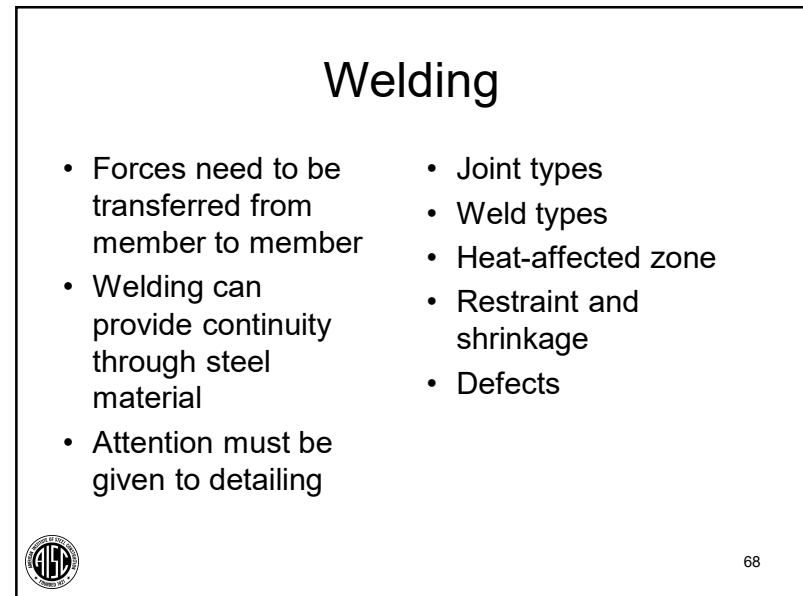


The image shows a welding process in progress. The AISC logo and the slogan 'Smarter. Stronger. Steel.' are in the bottom right corner.

67

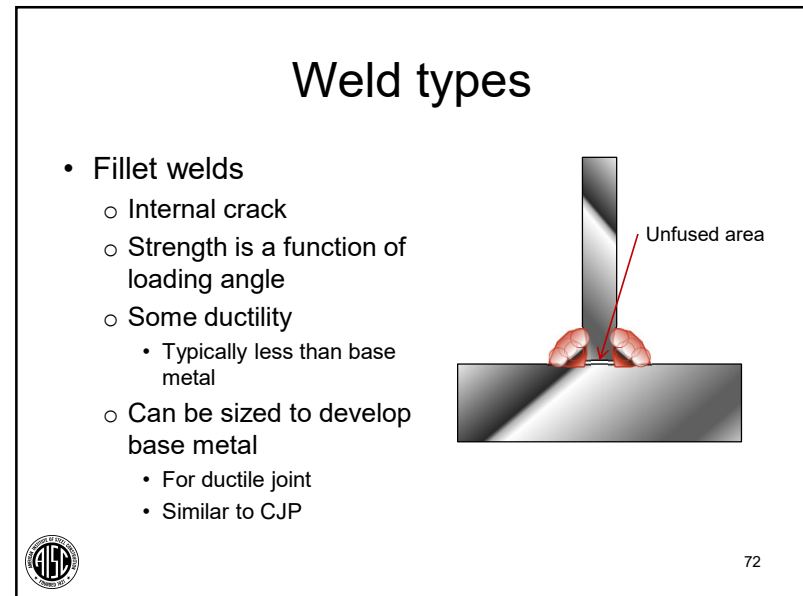
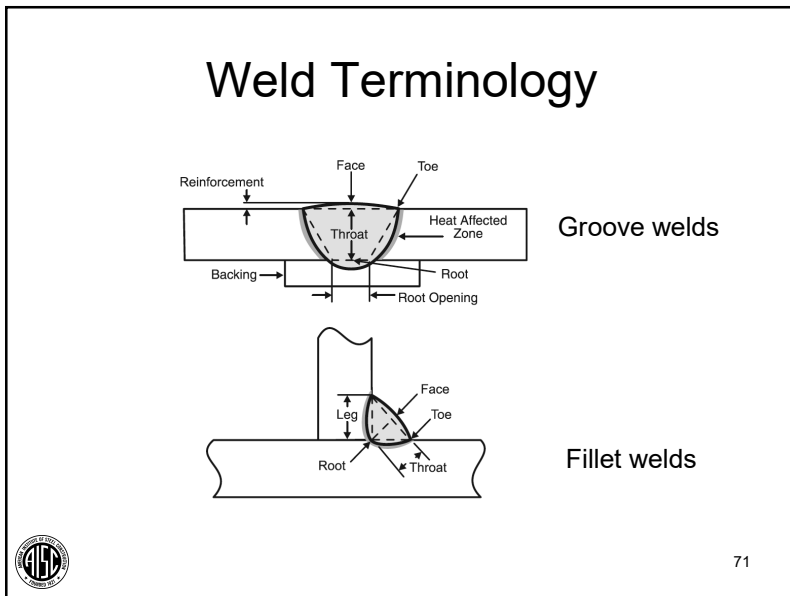
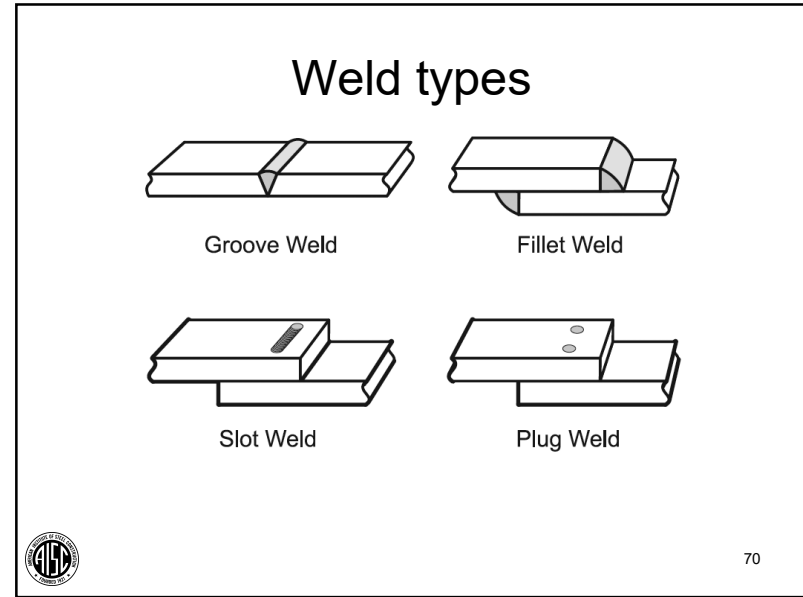
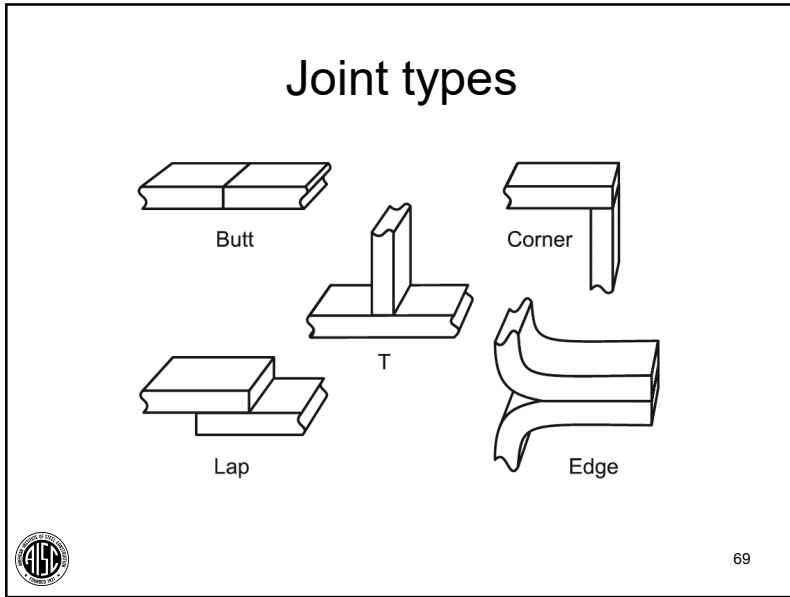
Welding

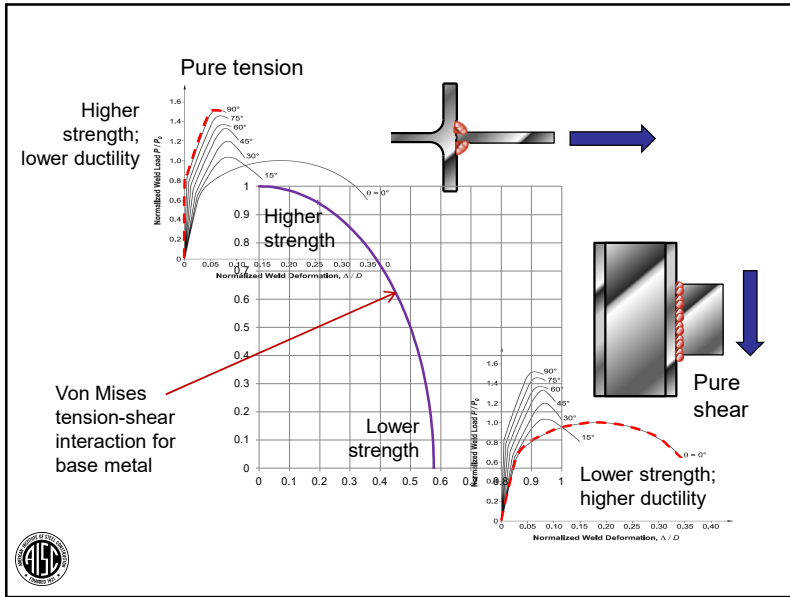
- Forces need to be transferred from member to member
- Welding can provide continuity through steel material
- Attention must be given to detailing
- Joint types
- Weld types
- Heat-affected zone
- Restraint and shrinkage
- Defects



The image shows a welding process in progress. The AISC logo is in the bottom left corner.

68



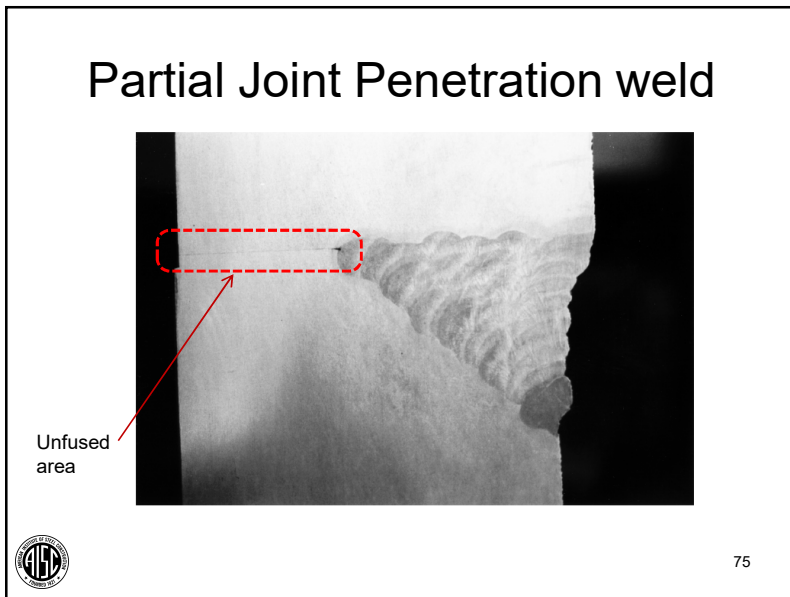


Weld types

- Partial Joint Penetration
 - "PJP"
 - External crack
 - Cannot develop base metal
 - Internal crack

Unfused area

74



Weld types

- Complete Joint Penetration
 - AKA
 - CJP
 - CP
 - Full Pen

Reinforcement

Face

Toe

Heat Affected Zone

Throat

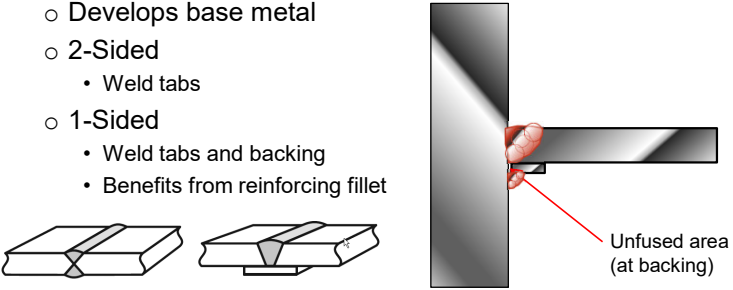
Root

Root Opening

76

Weld types

- Complete Joint Penetration
 - Develops base metal
 - 2-Sided
 - Weld tabs
 - 1-Sided
 - Weld tabs and backing
 - Benefits from reinforcing fillet

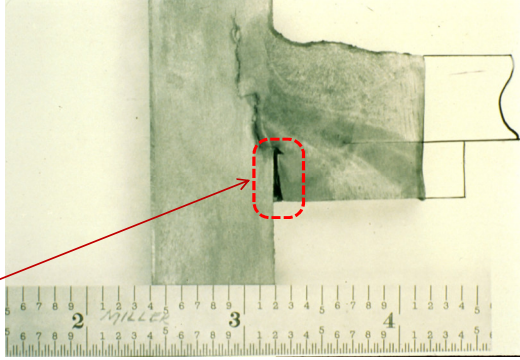


Unfused area
(at backing)

Codes require backing removal or reinforcement at critical tension locations

77

Backing

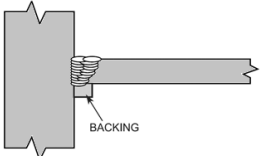


Unfused area

78

Backing

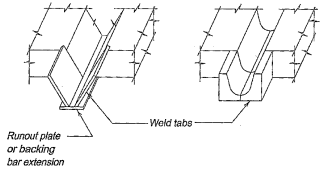
- Backing used to support and retain molten filler metal
- Backing – also called “weld backing,” “backing bars,” “back-up bars”, and “backing strips”
- Fusible backing– weld is intended to bond to backing (e.g. steel backing)
- Non-fusible backing– weld not intended to bond to backing (e.g. ceramic and copper)



79

Weld tabs

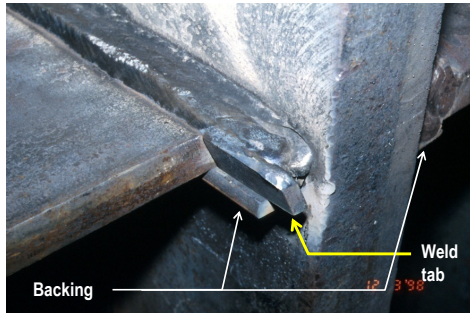
- Weld tabs (“runoff tabs”) are extensions of the parts being welded that allow the weld to be started and stopped outside of the joint
- Provide for similar geometry as the preparation
- Generally required to be removed after welding



Codes require weld-tab removal at most locations in the seismic-load-resisting system

80

CJP



81

Heat-affected zone

- AKA "HAZ"
- Base metal affected by weld heat
- Properties affected by rate of cooling
 - Rapid cooling results in brittle steel
 - Pre-heat slows cooling



82

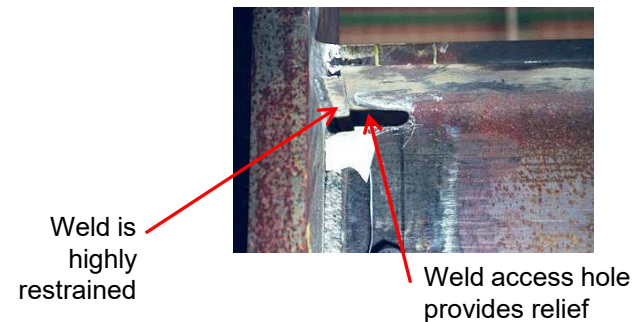
Restraint and shrinkage

- Weld shrinkage induces demands
 - Stress
 - Strain
- Good detailing provides length for moderate strain to relieve cooling stresses
- Through-thickness loading is problematic
- Highly restrained conditions do not provide relief

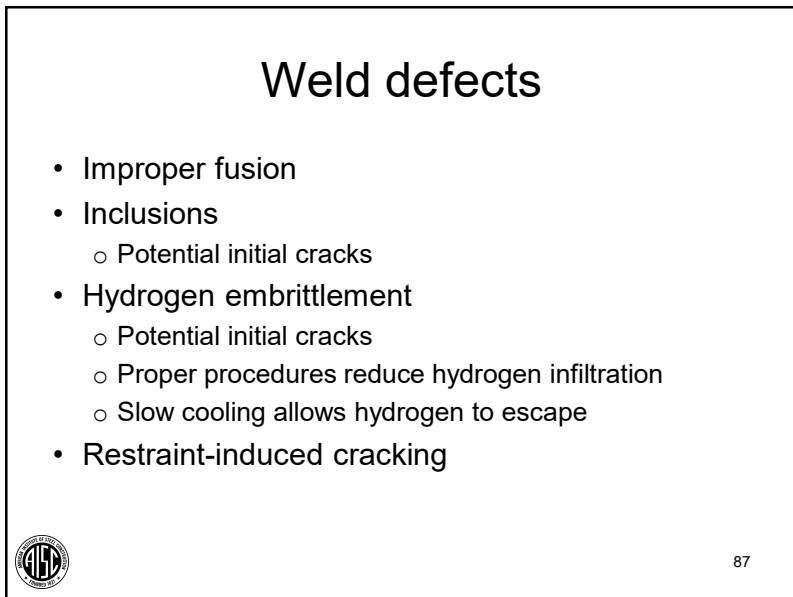
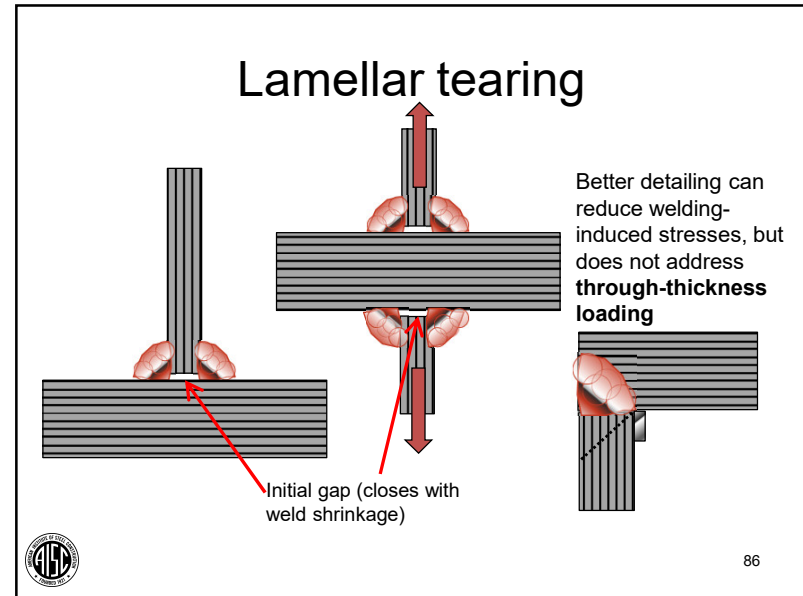
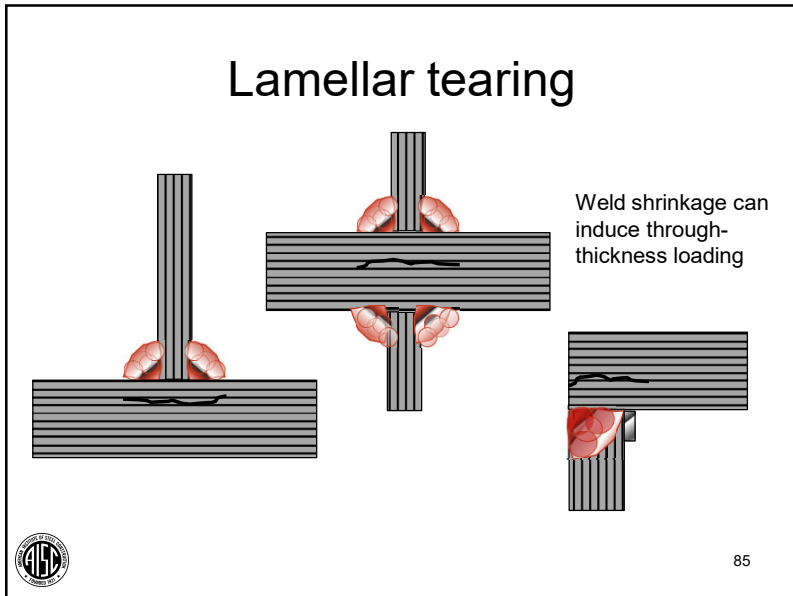


83

Restraint and shrinkage



84



Summary

- Steel material of the right type can provide the foundation for high levels of ductility
- Care must be taken to maintain this ductility
 - At welded joints
 - At locations of high restraint
 - In certain regions affected during rolling and fabrication



89

Parting thought

Is using a ductile material sufficient for system ductility?



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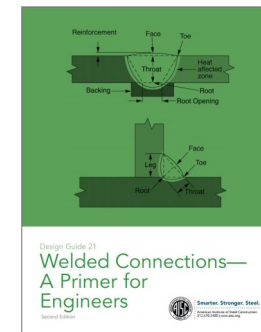
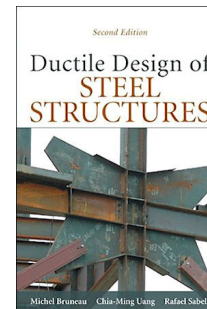
End of session 4

Next:
**Session 5:
System ductility and
seismic design**

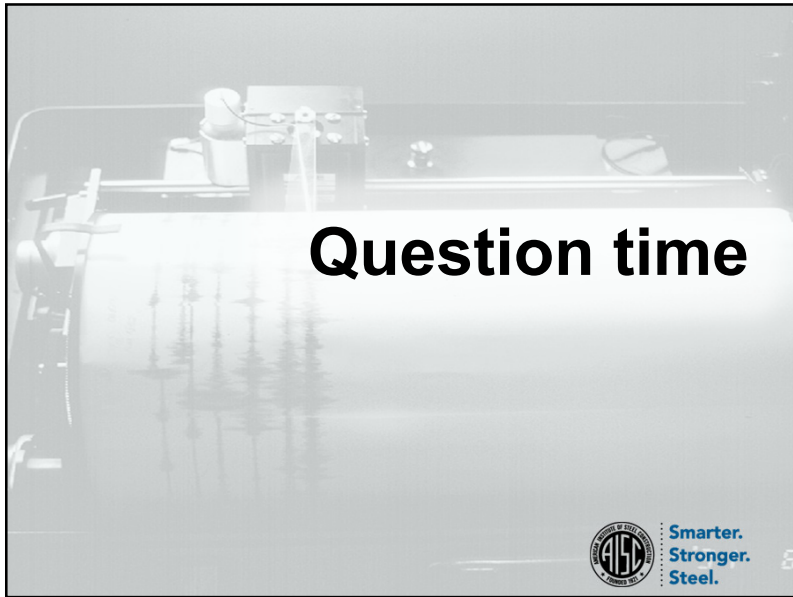


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Steel.

Additional resources




92



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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Attendance and PDH Certificates

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

Videos and Quizzes

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

Distribution of Certificates

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



8-Session Registrants

Course Resources

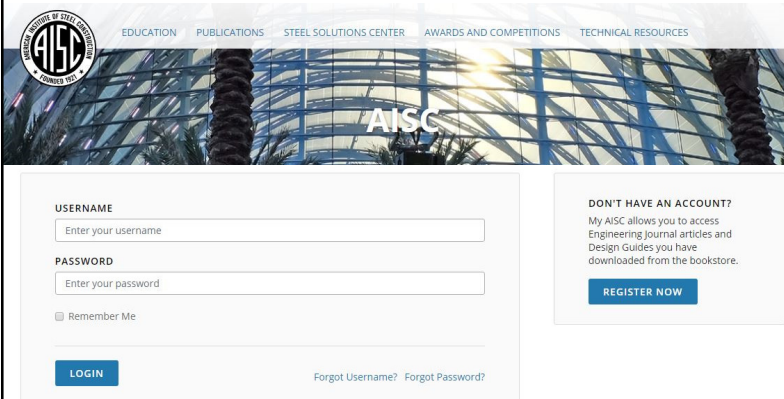
Find all your handouts, quizzes and quiz scores, recording access, and attendance information in one place!



8-Session Registrants

Course Resources

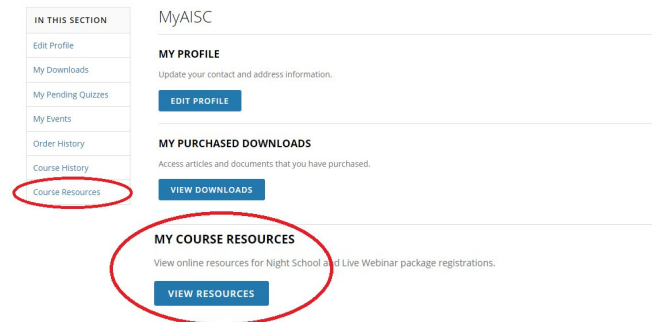
Go to www.aisc.org and sign in.



8-Session Registrants

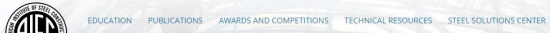

Course Resources

Go to www.aisc.org and sign in.



8-Session Registrants

Course Resources



[AISC](#) > [MY ACCOUNT](#) > [COURSE RESOURCES](#)

Course Resources

Event	Start Date
Seismic Design in Steel	1/11/1990 12:00:00 AM
8-Session Package-Design of Flexible Attachments	5/16/2019 1:00:00 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	2/9/2018 7:00:00 PM
NS 17.8-Session Package-Night School 17 - Design of Facade Attachments	7/16/2018 7:00:00 PM
NS 18.8-Session Package-Night School 18 - Steel Construction: Mill To Tensile 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	6/9/2019 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	11/16/2018 1:00:00 PM

8-Session Registrants

Course Resources

[AISC](#) > [MY ACCOUNT](#) > [COURSE RESOURCES](#) > [NS24.8-SESSION PACKAGE RESOURCES](#)

Night School 24: Modern Methods for Learning Structural Stability

8-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
NS24.1 - Compression Members - The Fundamentals	Oct 6 2020 7:00PM EDT	handouts	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	Pending
NS24.3 - Behavior of Axial Members - The Fundamentals	Oct 20 2020 7:00PM EDT	handouts	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	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
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
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
NS24.8 - Structural Systems - Practical Considerations	Dec 8 2020 7:00PM EST	handouts	Available	12/10/2020 5:00PM EST	Pending
NS24 - Final Exam	N/A				No longer available




[AISC](#) | Thank you.



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