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Ductility: Another View
April 12, 2022

Smarter. Stronger. Steel.

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Course Description

Ductility: Another View
April 12, 2022

It is often said that "steel is an inherently ductile material," and yet this statement fails to explain how steel occasionally behaves in a brittle manner. Most texts include both yield and tensile strengths in the listing of mechanical properties, but sometimes steel fails with no sign of yielding before fracture. Structural engineers designing structures to resist earthquake loading rely on ductile behavior to absorb seismically-induced loads, and yet brittle fractures have been observed after earthquakes. These apparent paradoxes can be understood when the role of shear stresses and ductility is properly understood. Notches and constraint, known to be problematic when ductility is desired, can also be explained in terms of shear stresses. Designing structural systems to enable the development of shear stresses is essential if ductility is desired. This presentation will give insight into how ductility can be achieved and provide some insight into how Mohr's Circle can be used to easily explain ductility.

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Learning Objectives – Submitted for AIA CE Credit

- From the references provided in the presentation, describe ductility.
- Describe how notches and constraint can be problematic when ductility is desired.
- Explain how designing structural systems to enable the development of shear stresses is essential.
- Demonstrate how Mohr's Circle can be used to easily explain ductility.

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Ductility: Another View

April 12, 2022

Duane K. Miller, PE, ScD, The Lincoln Electric Company

LINCOLN ELECTRIC

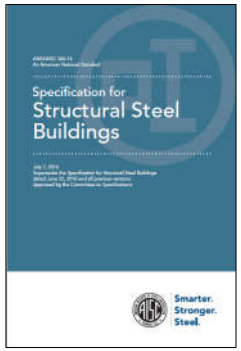
Smarter. Stronger. Steel.

Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

- Ductility: used 69 times
- Ductile: used 10 times
- Neither term defined in the glossary



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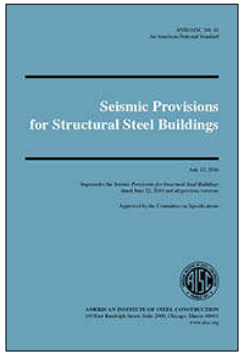
- Ductility: used 87 times
- Ductile: used 193 times
- Ductilities: used 2 times
- None of these terms are defined in the glossary

10

- Inelastic: used 374 times
- Not defined in the glossary



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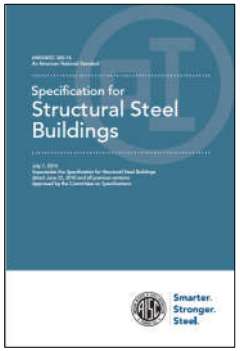
- Steel: used 2740 times
- Concrete: used 470 times
- Ratio: 5.8:1
- Why? **Steel >> Concrete**



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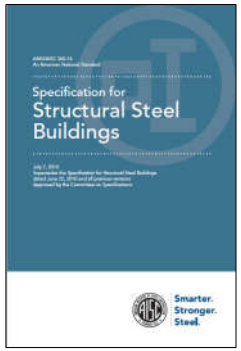
- Welding: used 236 times
- Bolting: used 41 times
- Ratio: 5.8:1
- Why? **Welding >> Bolting**



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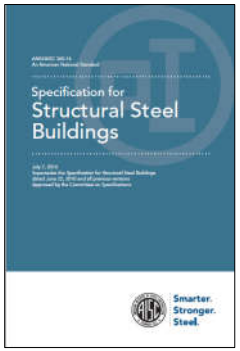
GLOSSARY

Percent elongation

Measure of **ductility**, determined in a tensile test as the maximum elongation of the gage length divided by the original gage length expressed as a percentage.



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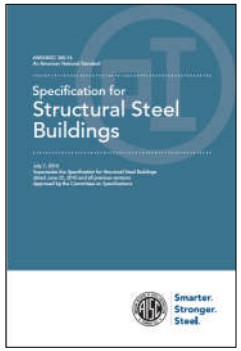
COMMENTARY GLOSSARY

Brittle fracture.

Abrupt cleavage with little or no prior **ductile** deformation.



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GLOSSARY

Ductile limit state

Ductile limit states include member and connection yielding, bearing deformation at bolt holes, as well as buckling of members that conform to the seismic compactness limitations of Table D1.1. Rupture of a member or of a connection, or buckling of a connection element, is not a **ductile** limit state.

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Elements of Material Science and Engineering: Van Vlack

Ductility—Permanent deformation before fracture; measured as elongation or reduction in areas.

17

Mechanical Behavior of Materials: Dowling

The engineering fracture strain is one measure of ductility.

Another measure of ductility is the percent reduction in area, called %RA….

18

Mechanical Metallurgy: Dieter

Fractures can be classified into two general categories, ductile and brittle. A ductile fracture is characterized by appreciable plastic deformation prior to and during the propagation of the crack. An appreciable amount of gross deformation is usually present at the fracture surfaces.

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Ductility: Another View

Outline

- Introduction

Ductility: Might have different meanings

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

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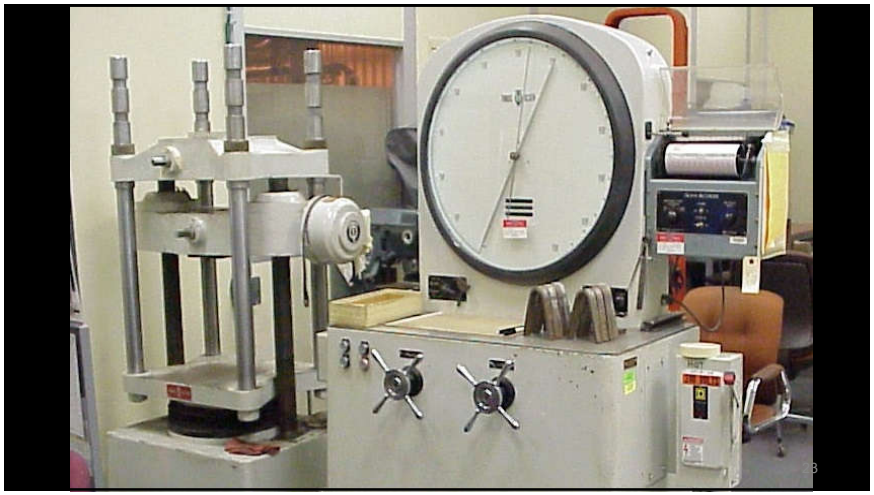

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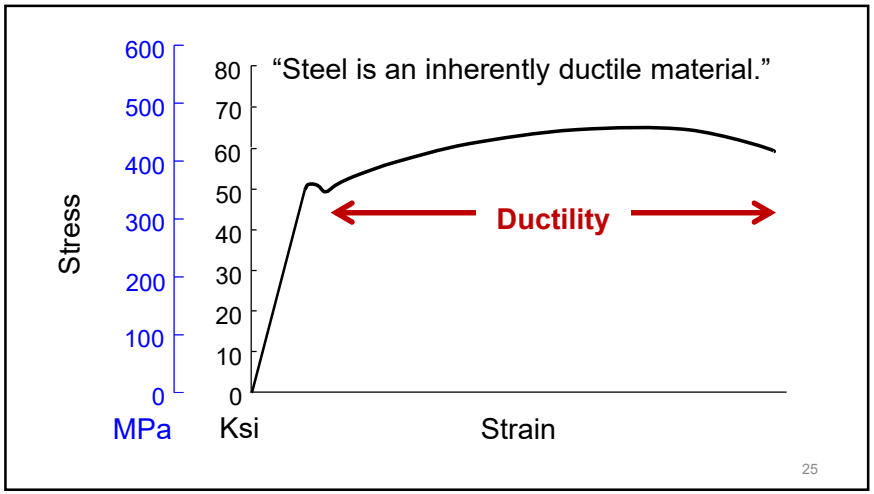

Ductility: Another View

Outline

- Introduction
- A Wrong View

Ductility is a material property, ductile material always leads to ductile performance.

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

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Omer W. Blodgett
1917-2017

29

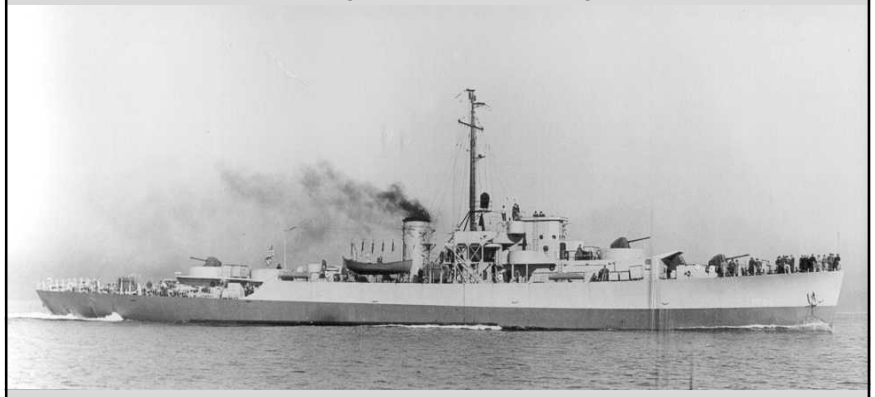
Globe Shipbuilding, Duluth Minnesota

30

One of ten V4-M-AV1 ocean-going tugs.

31

One of eight S2-S2-AQ1 Frigates



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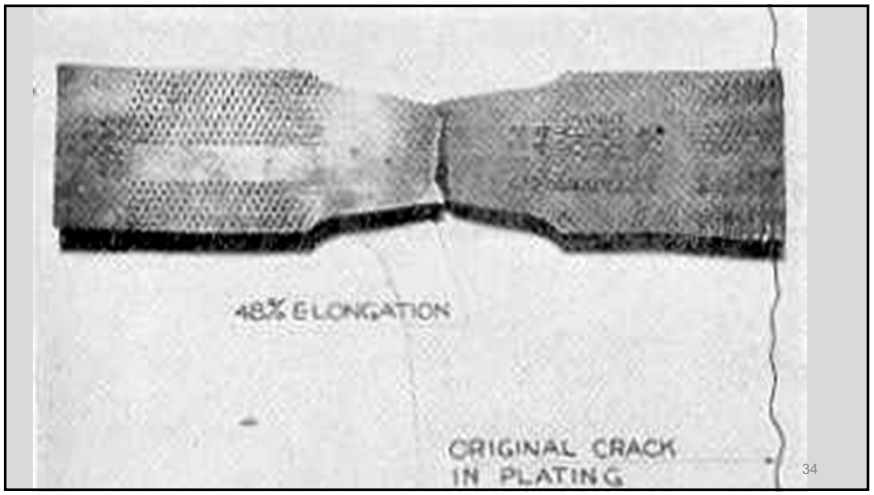
One of eleven C1-M-AV1 Cargo Vessels

33



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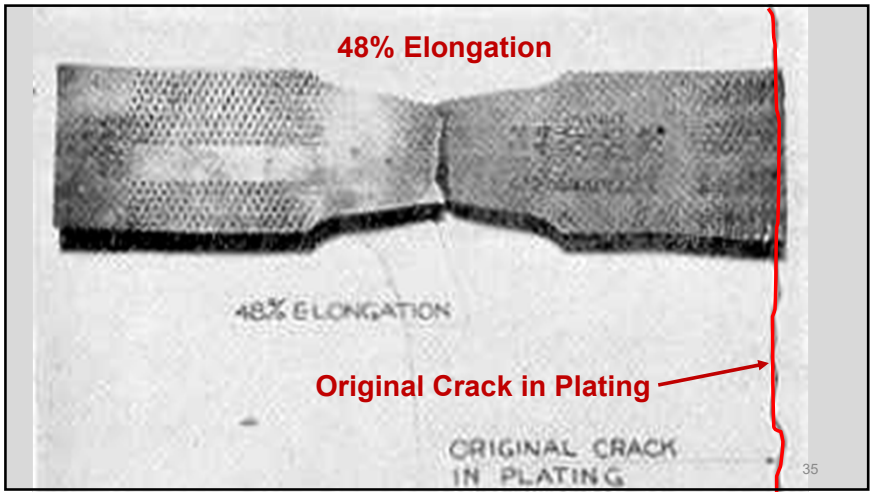

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Strength of Metals Under Combined Stresses

Maxwell Gensamer
1941

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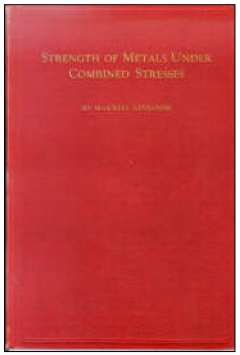
"This is an important concept and needs to be emphasized: no shear stress, no plastic deformation or flow."

Maxwell Gensamer



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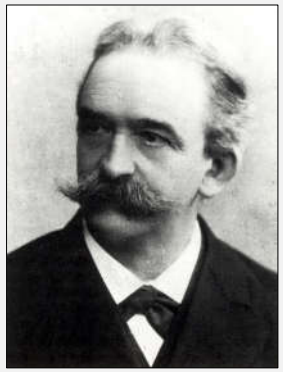
Christian Otto Mohr
1835 – 1918

Mohr's Circles



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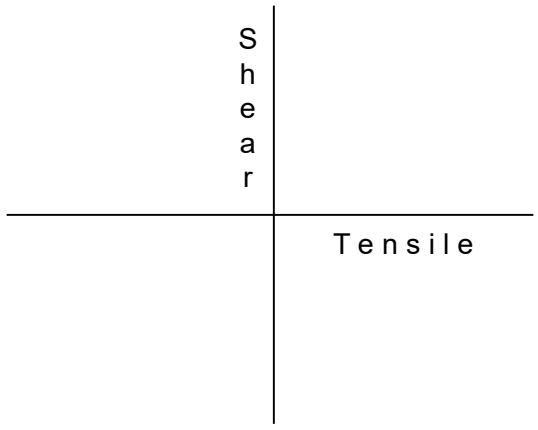

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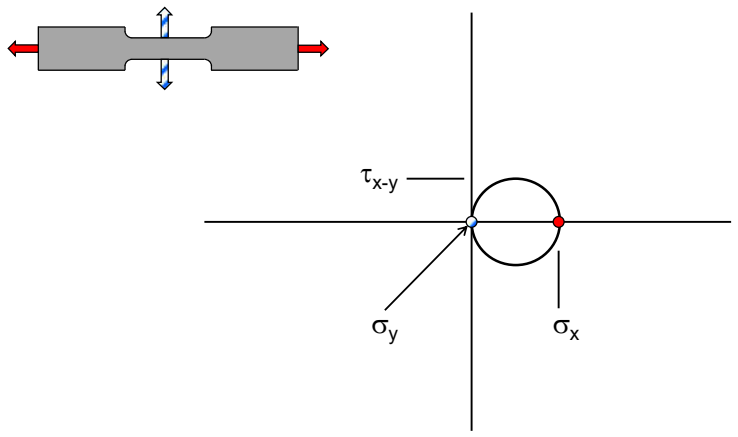

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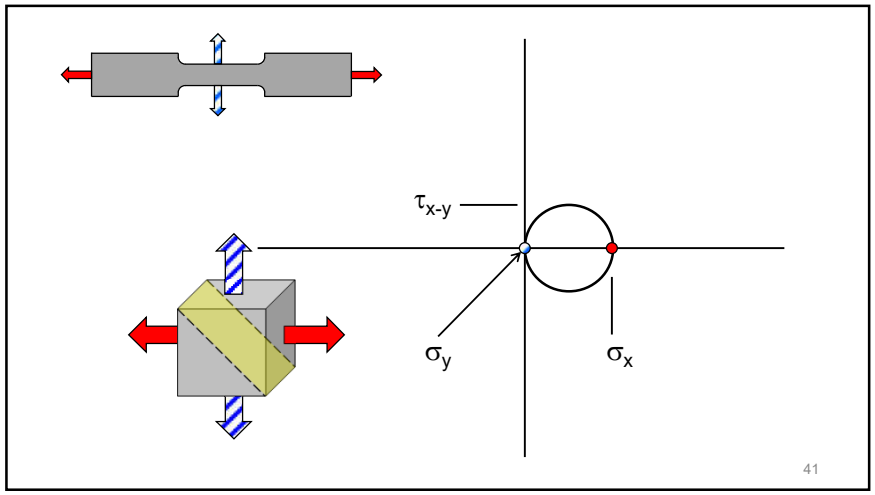

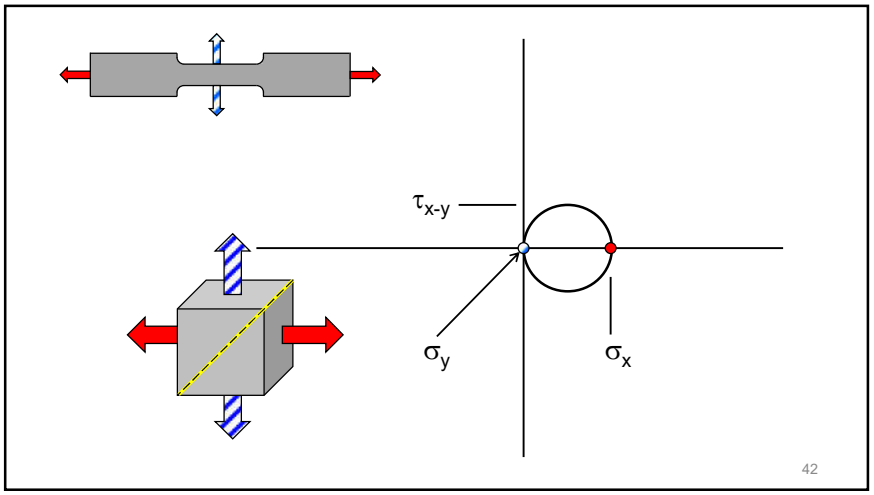

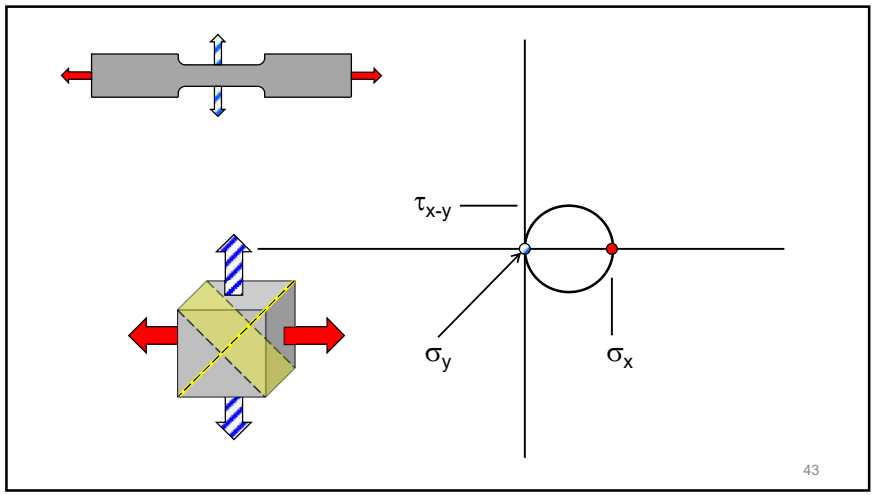

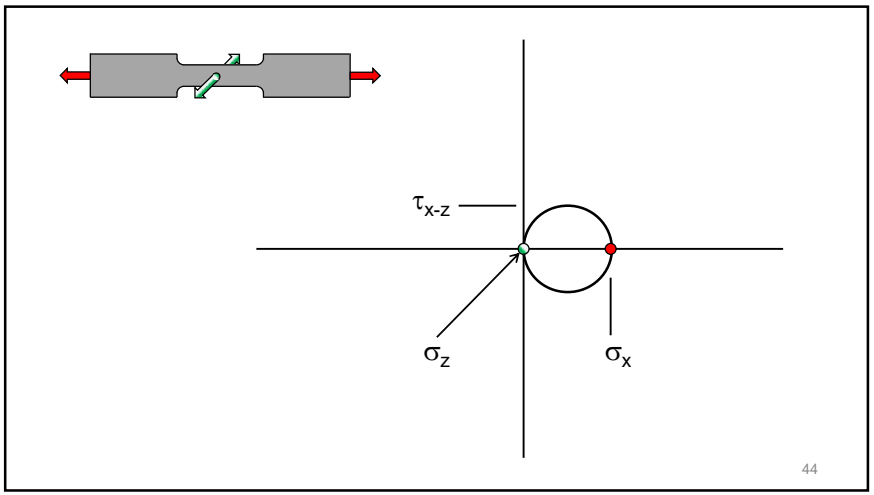

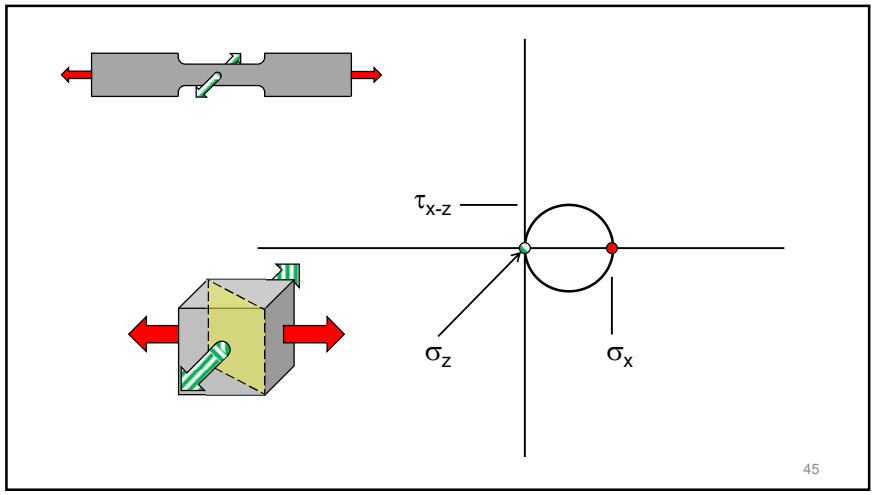

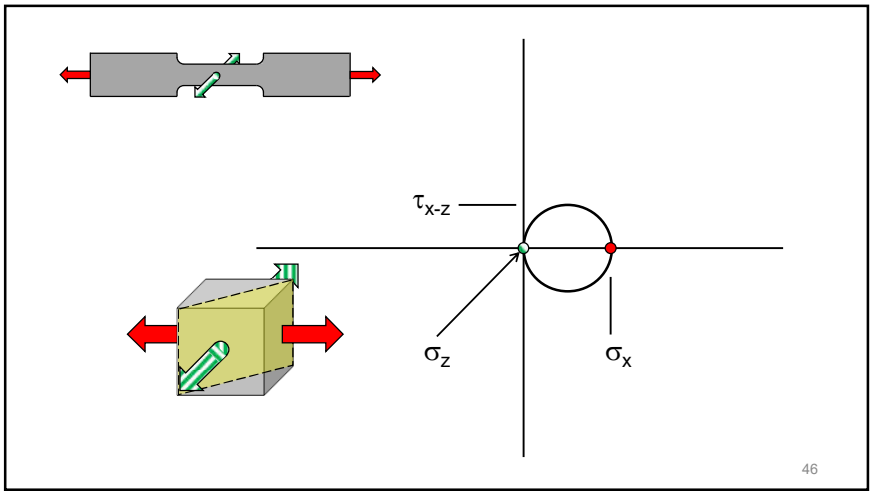

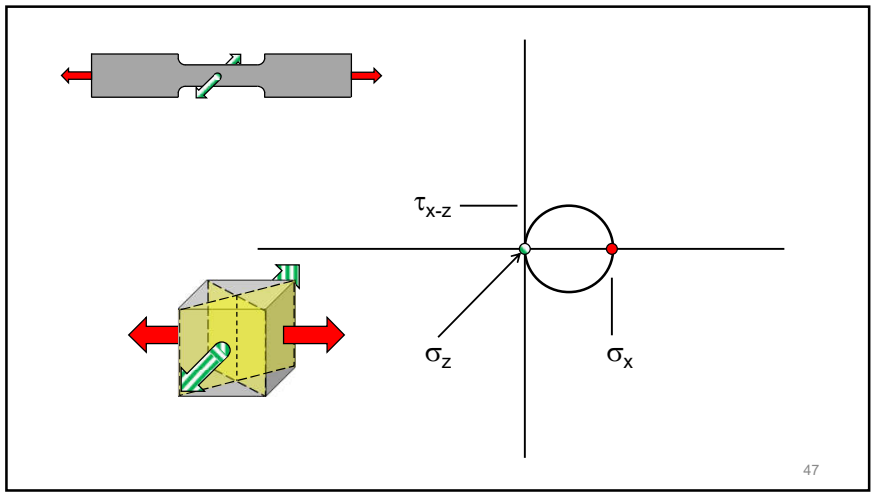

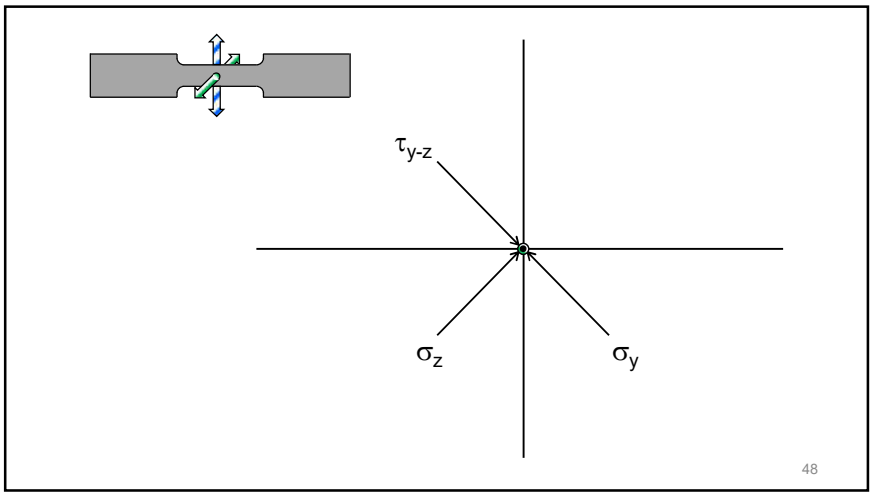

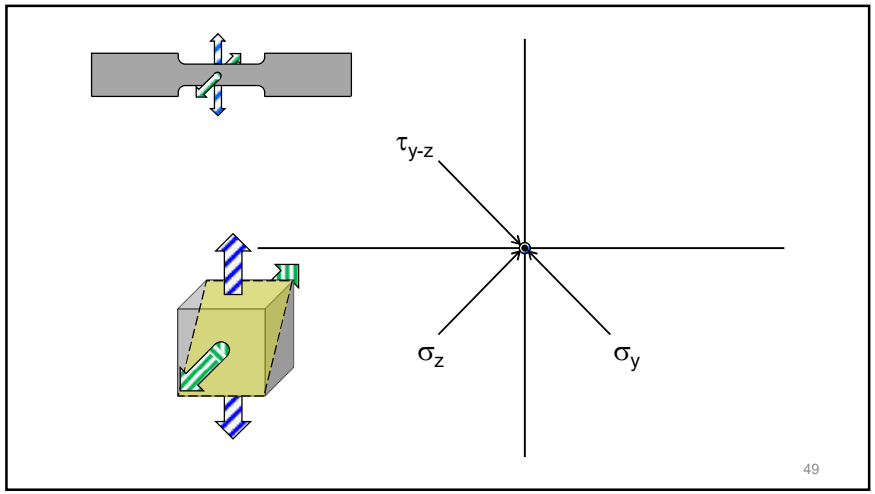

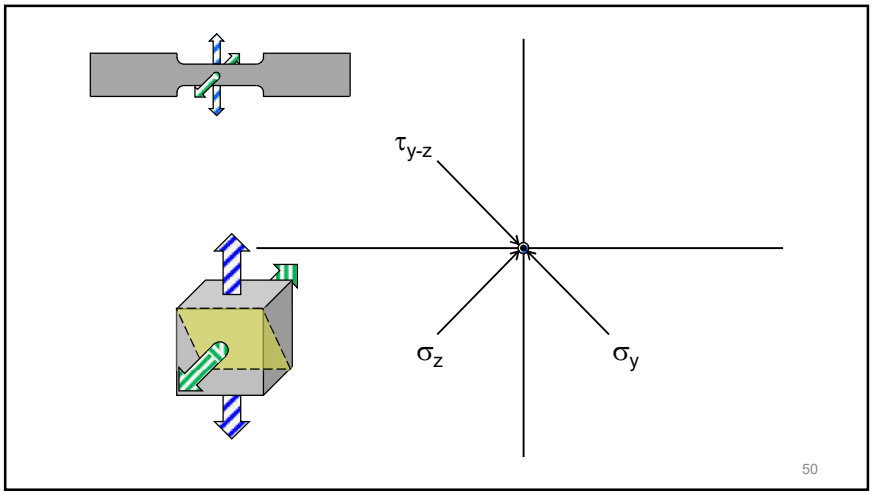

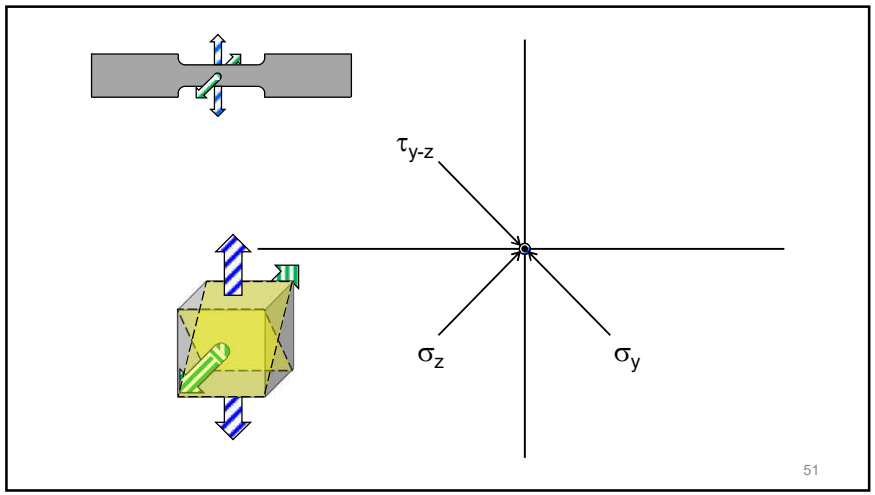

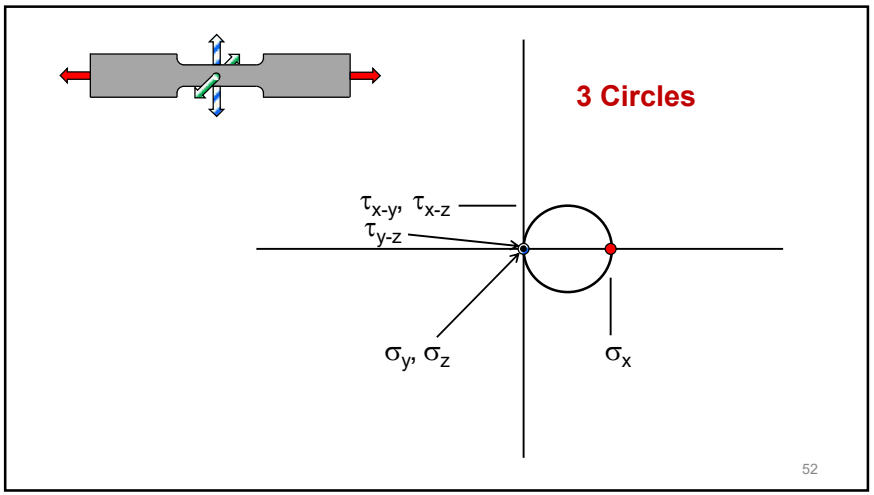

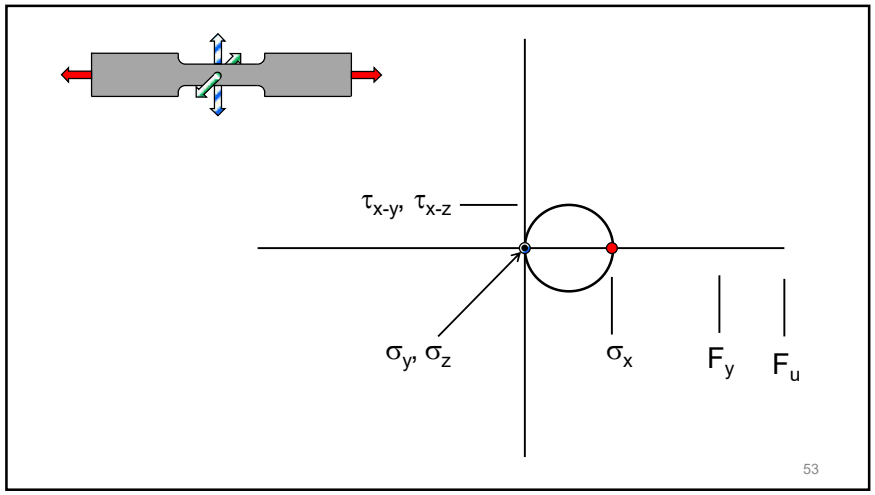

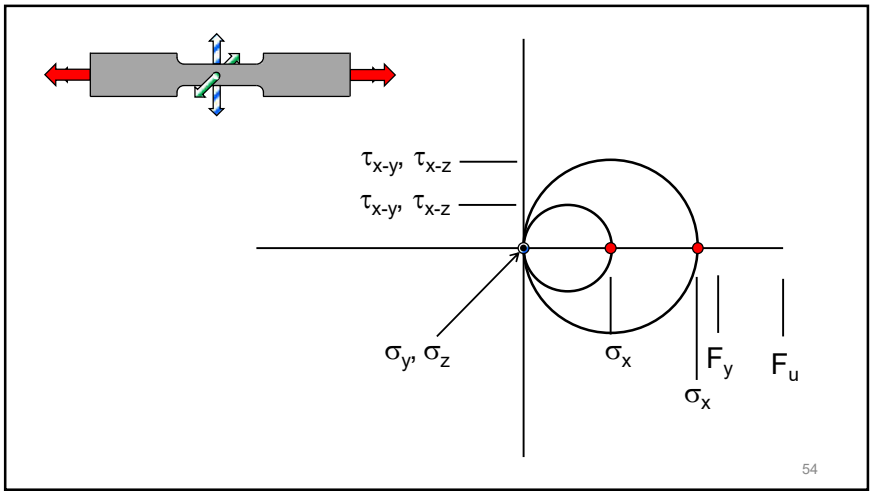

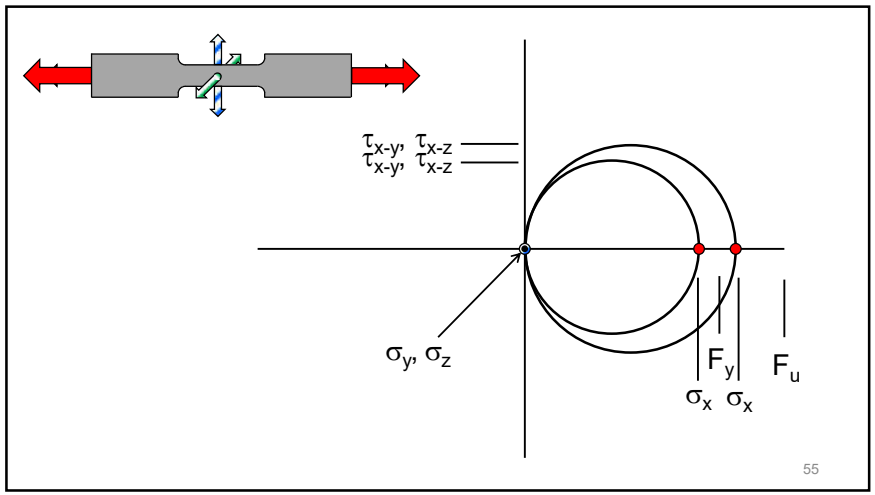

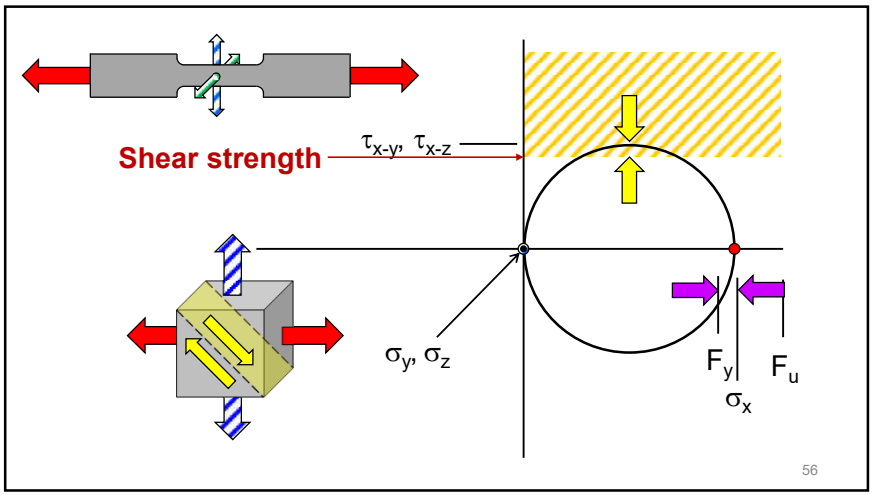

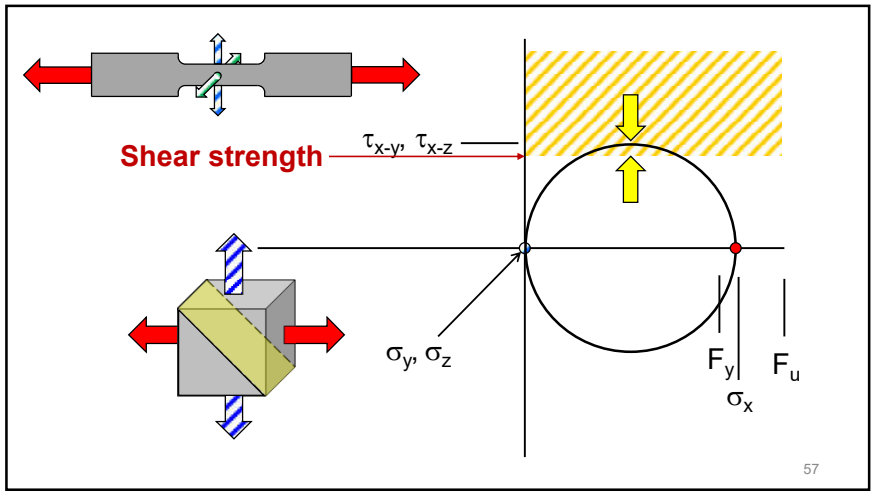

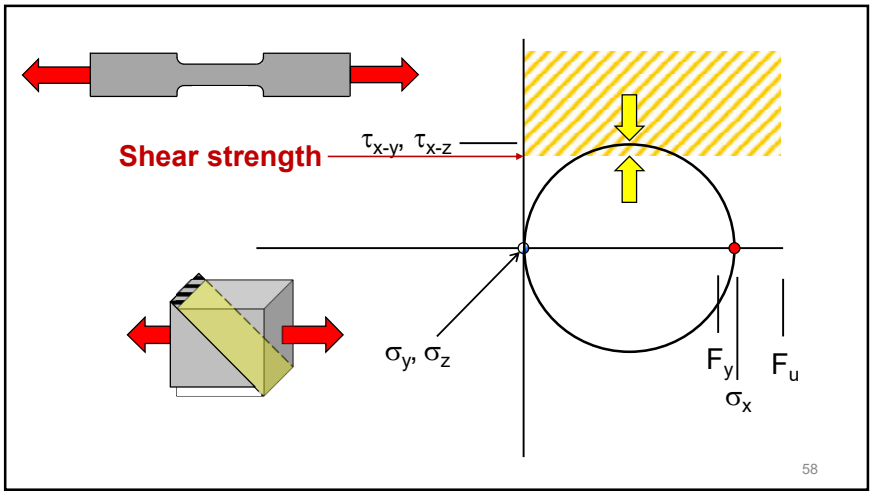

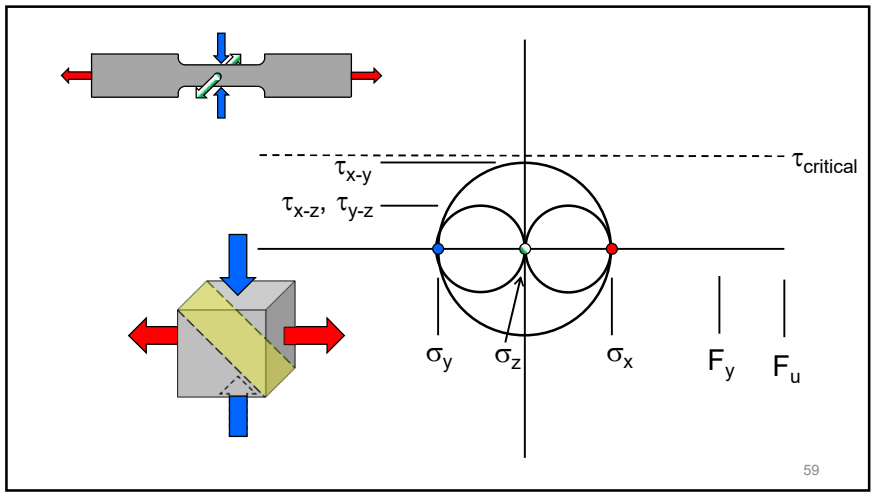

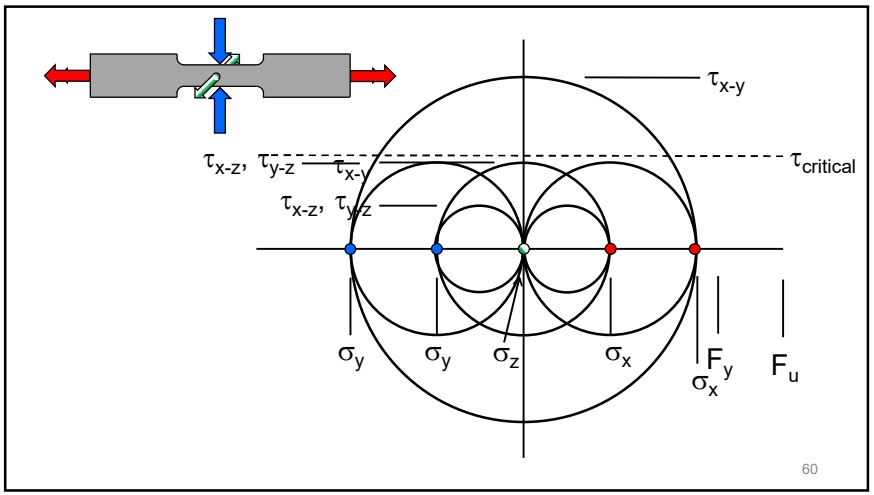

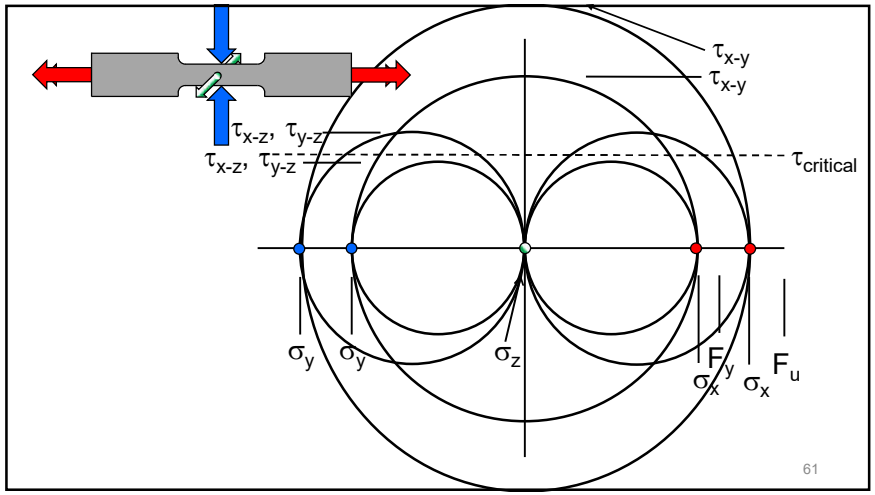

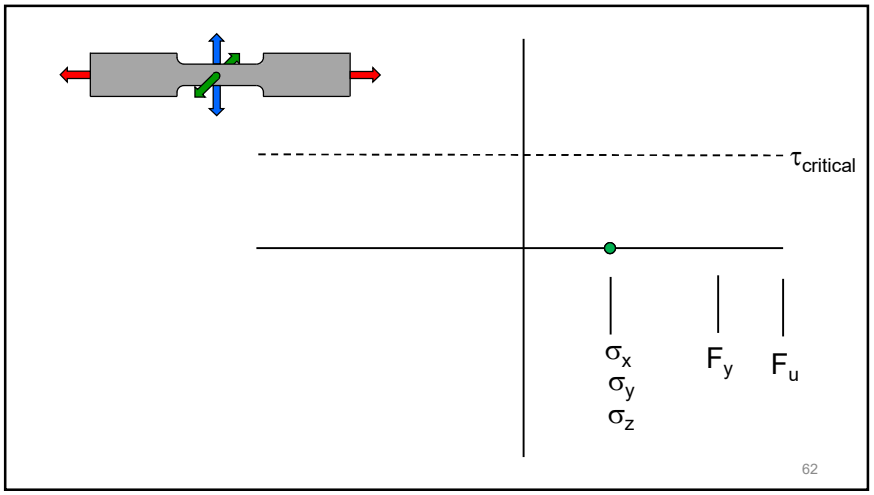

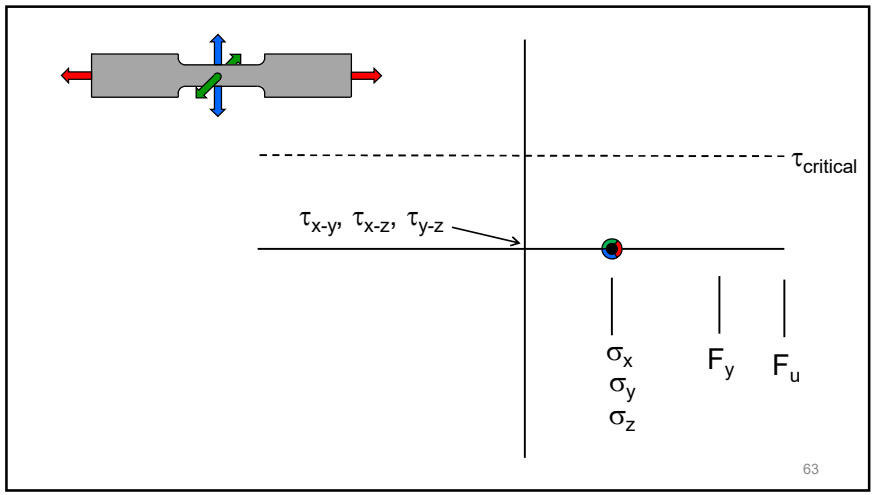

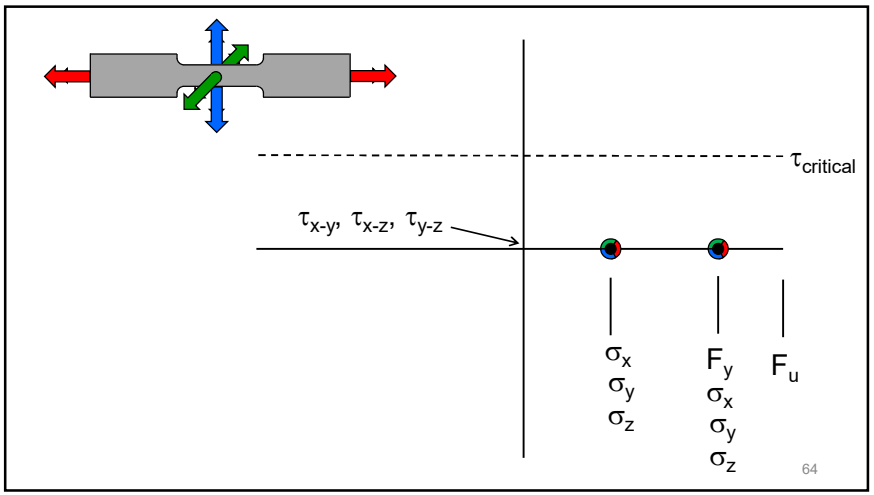

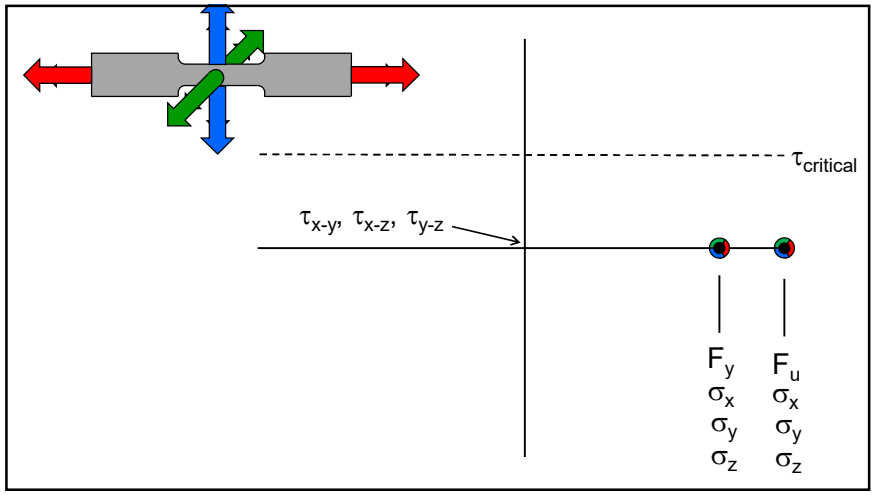

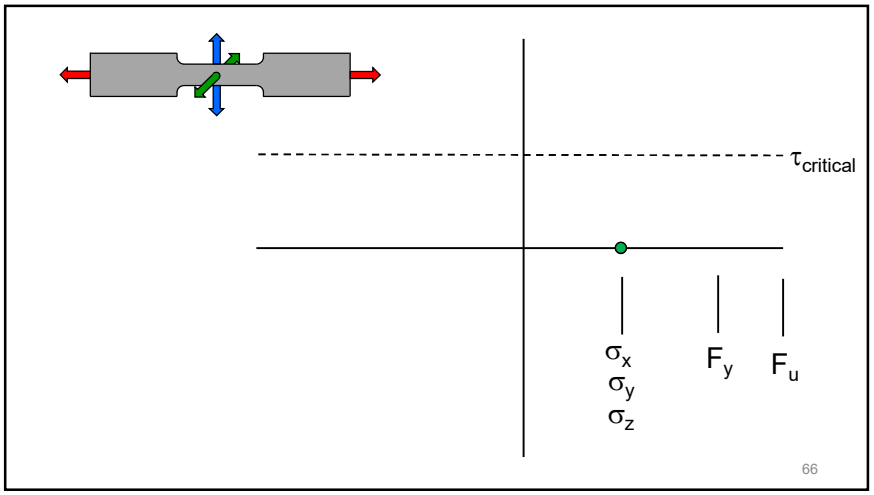

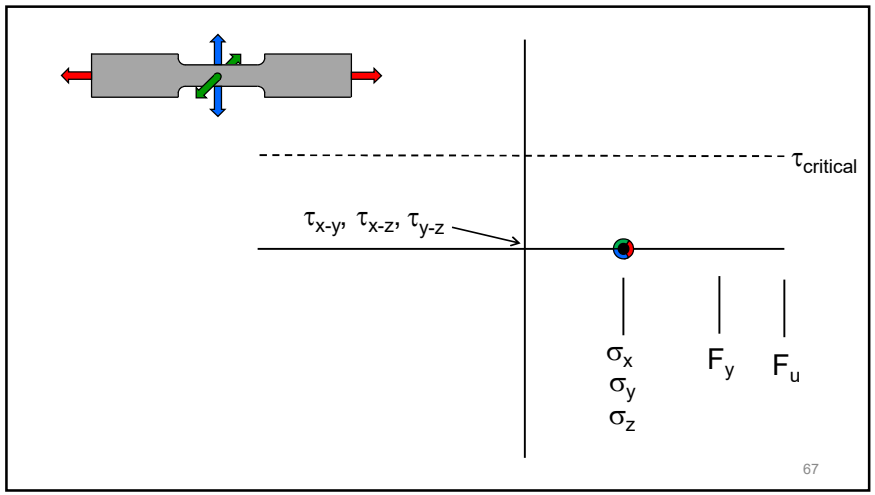

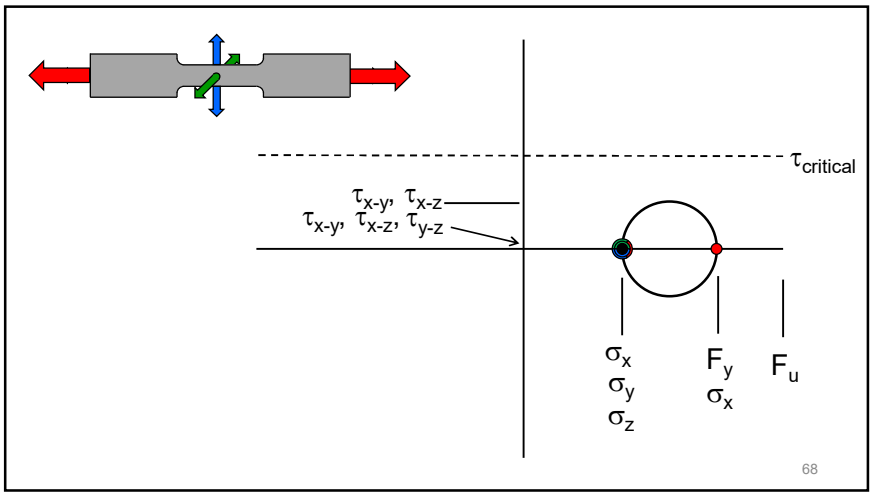

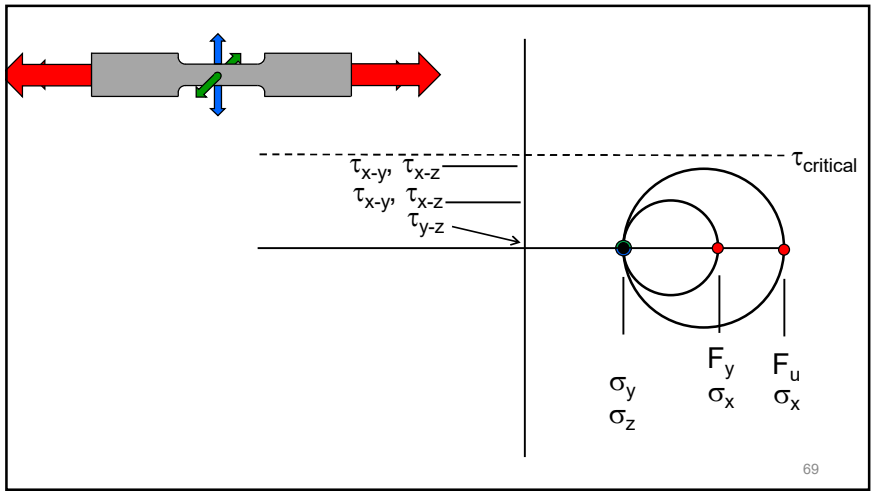

STRENGTH OF METALS UNDER COMBINED STRESSES

"So, if $\sigma_{max.}$ (the normal stress) first reaches the critical value for cohesive failure, the metal will be brittle (behave in a brittle fashion); whereas if $\tau_{max.}$ (the shear stress) first reaches the critical value for plastic deformation, the metal will deform, that is, behave in a ductile fashion.

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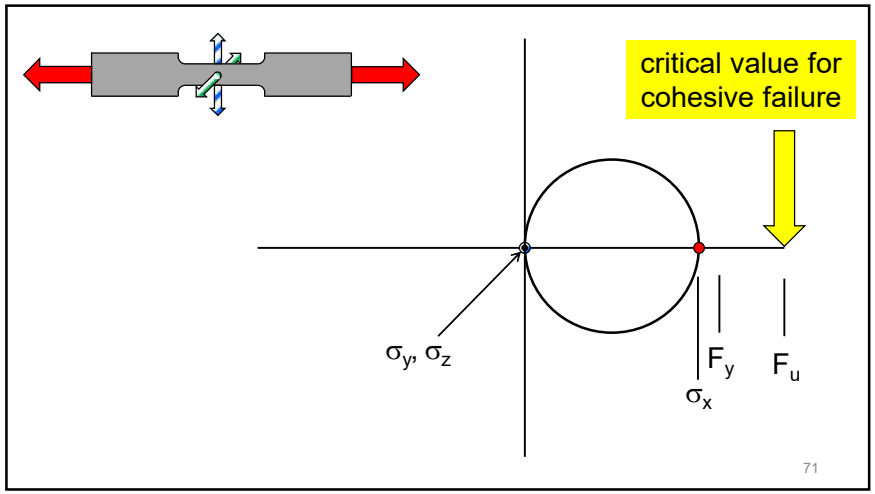

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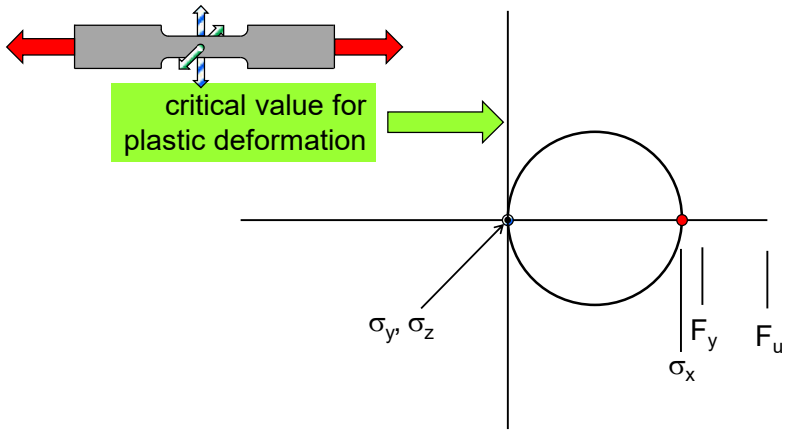
72



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STRENGTH OF METALS UNDER COMBINED STRESSES

"It is well known that a metal may be ductile under one set of conditions and brittle under another. Ductility and brittleness, then are properties that must be considered as referring to some particular set of testing or service conditions."

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View

Ductility is function of the testing or service conditions.

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Strength of Metals Under Combined Stresses

Maxwell Gensamer
1941

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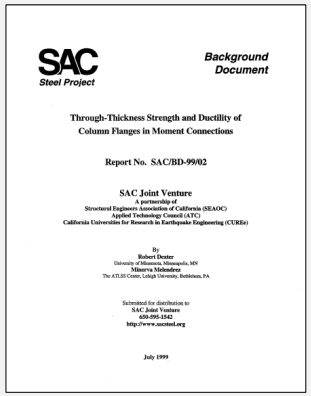
Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

Robert Dexter

Minerva Melendrez

July 1999



SAC Steel Project

Background Document

Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

Report No. SAC/BD-99/02

SAC Joint Venture

A partnership of
Structural Engineers Association of California (SEAOC)
Applied Technology Council (ATC)
California Universities for Research in Earthquake Engineering (CUREe)

By
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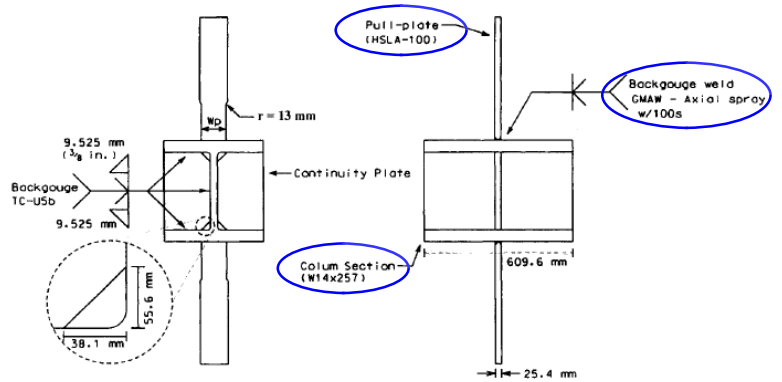
Through-Thickness Strength and Ductility of Column Flanges in Moment Connections



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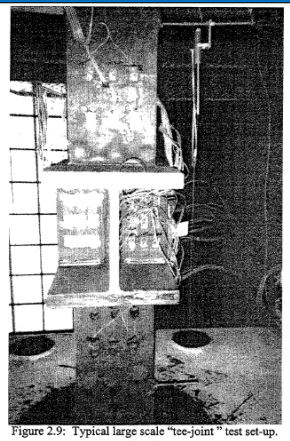

Figure 2.9: Typical large scale "tee-joint" test set-up.

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Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

ABSTRACT

More than forty tee joints were fabricated with high-strength (690 MPa yield strength) "pull" plates welded transversely to opposite flanges of short 610 mm lengths of heavy Grade 50 and Grade 65 column sections. The tee-joint specimens were tested in tension through the pull plates. The tests were performed to determine strength, deformation, and fracture behavior of the flanges of wide-flange column sections when loaded in the through-thickness direction under constrained conditions similar those of a welded beam-to-column the connection. (Each pull plate represents a beam tension flange.) The through-thickness strength of the column flanges exceeded 690 MPa in these tests. This result can be explained by the existence of triaxial constraint of the column flange material, which creates hydrostatic tension stresses, raising the apparent through-thickness strength. This effect is an inherent consequence of the Von-Mises and other yield criteria. Three-dimensional finite-element analyses of these specimens using the Von-Mises yield criterion predict this effect and give results consistent with the experiments.

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Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

4.1 Conclusions

1) Forty-one tee tests were performed including 27 specimens with good welds, 7 specimens with intentionally poor welds or details intended to induce a brittle fracture, and 7 specimens with eccentricity intended to induce bending and prying. These tee-tests showed that the

These tee-tests show that the through-thickness tensile strength of constrained column flange material in a beam-to-column joint exceeds the minimum specified ultimate strength of Grade 50 or Grade 65 beam flanges.

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Through-Thickness Strength and Ductility of Column Flanges in Moment Connections

7) The yield strength in the uniaxial through-thickness tensile specimens can be as low as 90 percent of the yield strength in the longitudinal direction. The reduction in area in this direction can be as low as 13 percent, compared to typical values of 70 percent. This low ductility is not a significant problem, because the through thickness strength exceeds the

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This low ductility is not a significant problem, because the through thickness strength exceeds the force and stress levels that could be produced by beam flanges. If the column flange does not yield in the through-thickness direction, there is no significant demand for ductility in the through-thickness direction.

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TRIAXIALITY AND FRACTURE OF STEEL MOMENT CONNECTIONS

Triaxiality and Fracture of Steel Moment Connections

By B. W. Schafer,[1] Associate Member, ASCE, R. P. Ojdrovic,[2] Member, ASCE, M. S. Zarghamee,[3] Fellow, ASCE

Abstract: The connections of welded steel moment frames undergo a complex multiaxial state of stress that leads to high levels of stress triaxiality. As triaxiality increases, the propensity for fracture increases. Classic engineering models of fracture and modern microscale models of fracture mechanisms explicitly consider the role of triaxiality. Nonetheless, triaxiality is generally not directly considered by structural engineers. In this paper, triaxiality is defined as the ratio of the maximum principal stress to the von Mises stress. Triaxiality and maximum principal stress demands are investigated for tests on fractured notched round bars, small-scale tension specimens, and a full-scale moment connection. Based on analysis of the tests, it is proposed that, for fractures driven by triaxiality demands, the maximum principal stress at fracture is a function of the level of triaxiality. Calculation of the triaxiality demands requires 3D nonlinear analysis and depends on the loading, connection geometry, and postyield stress-strain relationships of all parent and weld metals. Examination of a welded steel moment connection indicates particularly high triaxiality demands. The triaxiality demands indicate that fracture of these connections may be governed by triaxiality even when high toughness parent and weld metals are used.

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FRACTURE AND TRIAXIALITY

Historical Role of Triaxiality in Engineering Behavior of Materials

Gensamer (1941) provided a classical model to explain the role of triaxiality on the observed differences between macroscale brittle and ductile behavior (Fig. 3). A given state of stress (e.g., pure tension $\tau_{max} = 1/2\sigma_{max}$) defines the slope of a line in the space. As loading magnitude increases, the material follows this line and eventually reaches a critical value of τ_{max}, indicating yielding, or a critical value of σ_{max}, indicating fracture. A new state of stress with a lower slope (lower τ_{max}/σ_{max}) has a higher propensity for fracture. The inverse of the slope (i.e., σ_{max}/τ_{max}) is a measure of triaxiality. Although Gensamer's model (1941) alone does not provide a

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Definition of Triaxiality and Triaxiality Measures

Stress triaxiality (hereafter referred to as triaxiality) is often discussed in relation to the existence of tensile stress in the directions other than the primary stress direction. Constraint on a material's ability to flow is an important way to increase triaxiality. In its simplest terms, triaxiality is the ratio of the state of stress a material undergoes to the stress that contributes to yielding. Let us define two definitions for triaxiality (T_1 and T_2) applicable to a ductile metal following von Mises yield criteria:

$$T_1 = \frac{\sigma_{hydrostatic}}{\sigma_{eff}} \quad (1)$$

$$T_2 = \frac{\sigma_1}{\sigma_{eff}} = \frac{\sigma_{max}}{\sigma_{eff}} \quad (2)$$

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$$T_1 = \frac{\sigma_{hydrostatic}}{\sigma_{eff}}$$

$$T_2 = \frac{\sigma_1}{\sigma_{eff}} = \frac{\sigma_{max}}{\sigma_{eff}}$$

$$\sigma_{hydrostatic} = \frac{\sigma_1 + \sigma_2 + \sigma_3}{3}$$

$$\sigma_{eff} = \sqrt{\frac{1}{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}$$

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View

Ductility is function of the testing or service conditions.

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

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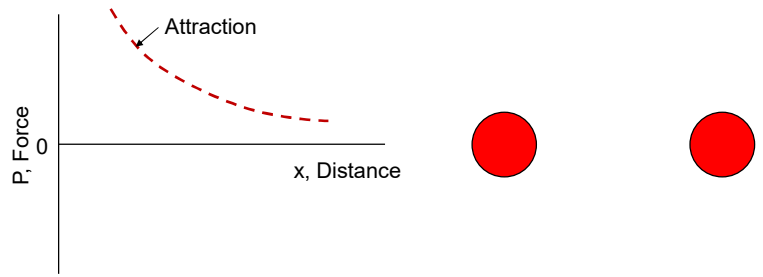
Lennard Jones Potential



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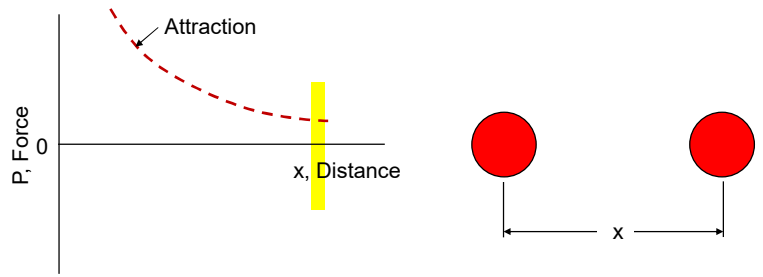

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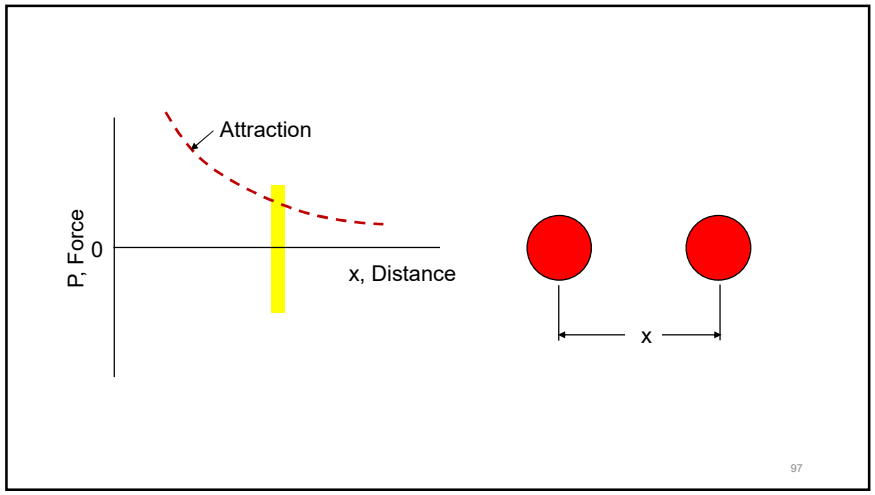
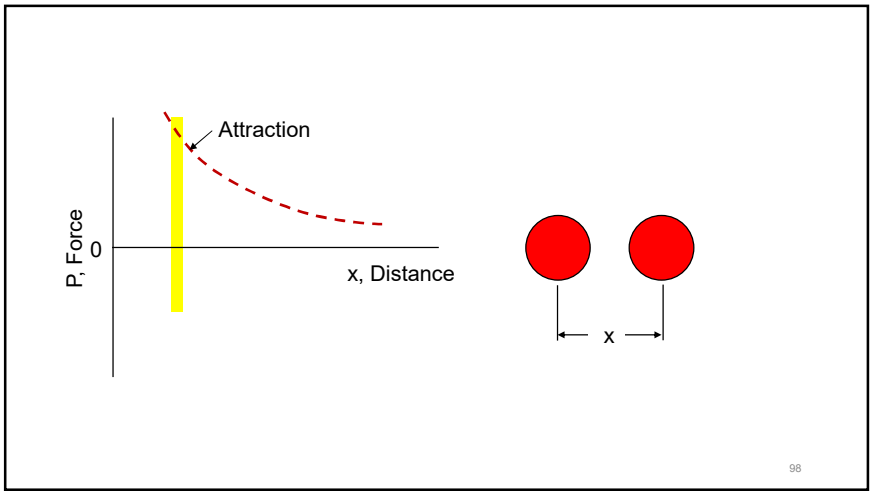
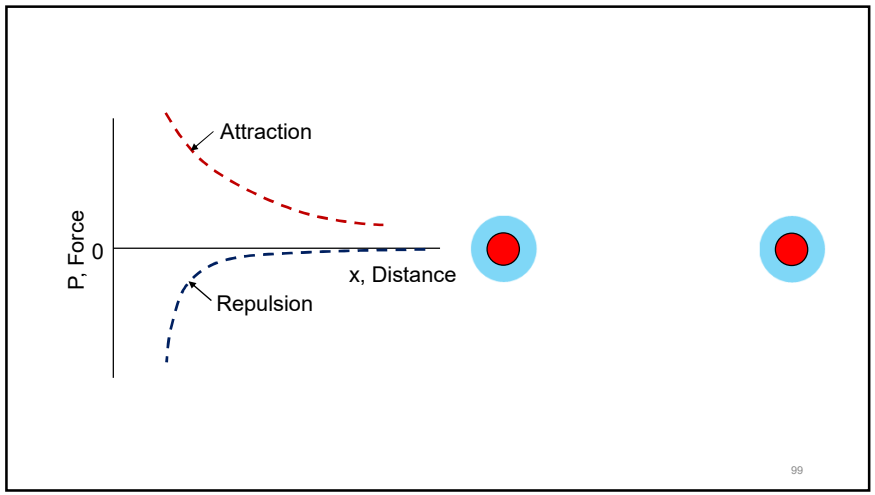
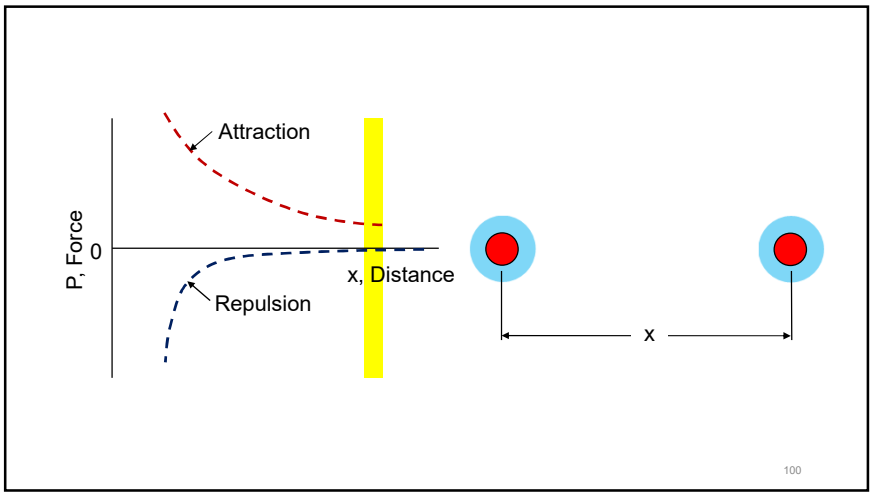
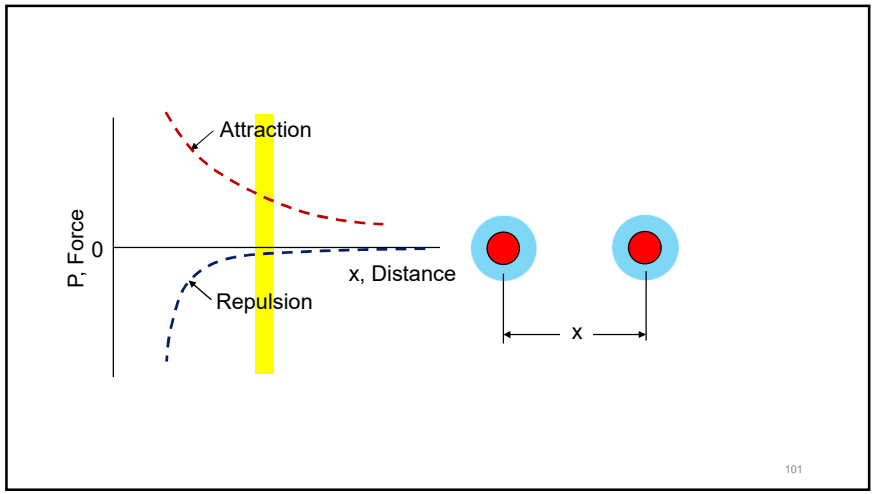
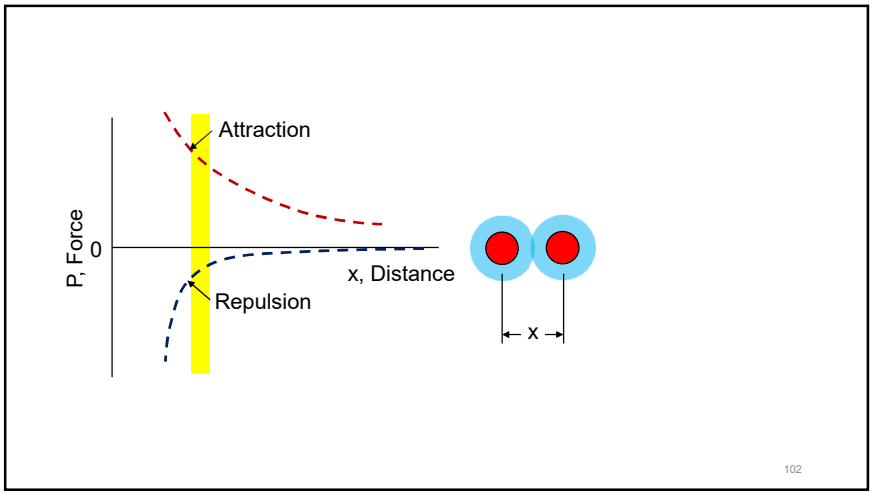


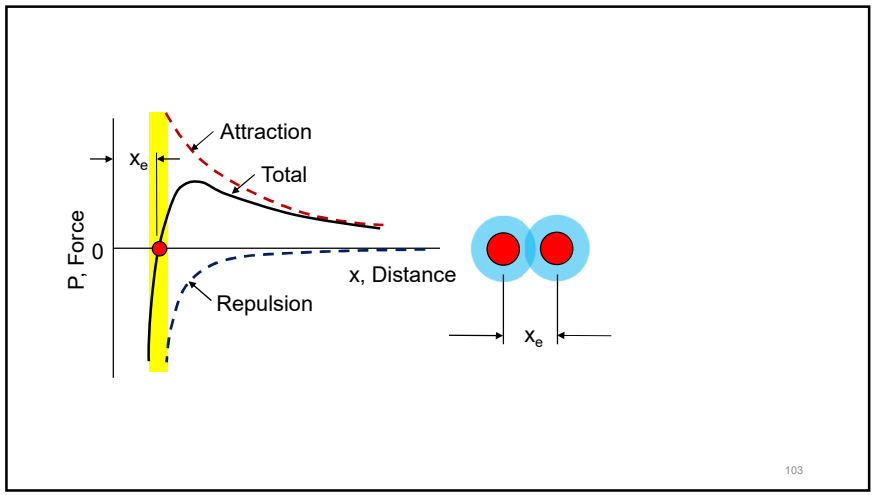


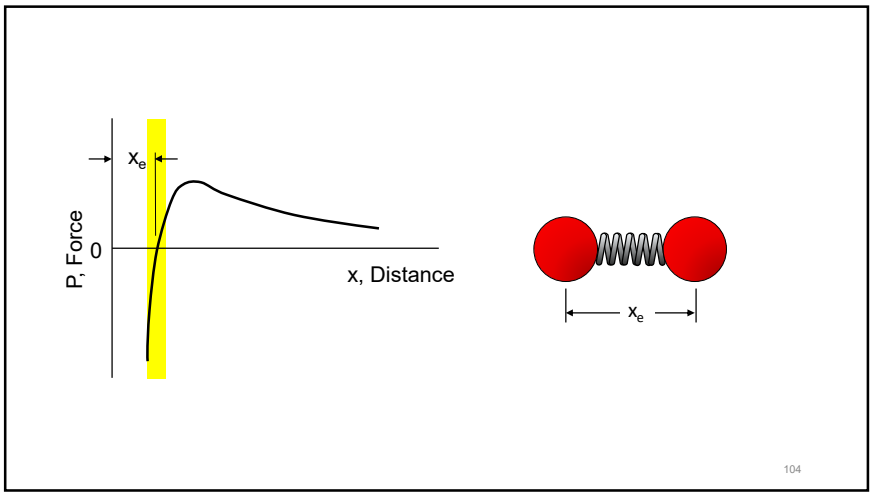




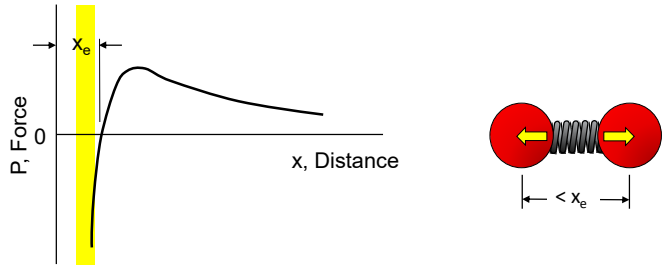








Compressive Strength



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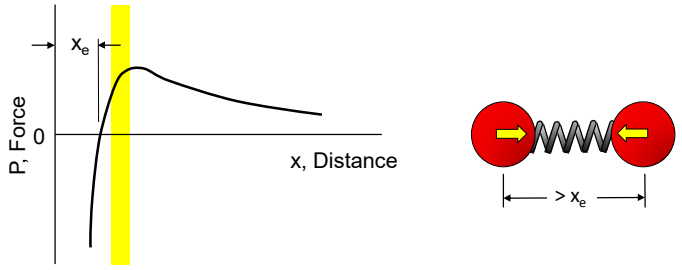
Tensile Strength



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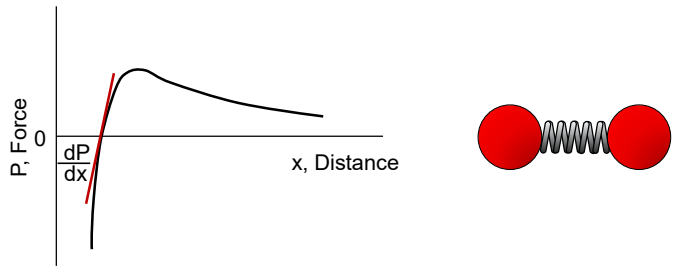
Modulus of Elasticity



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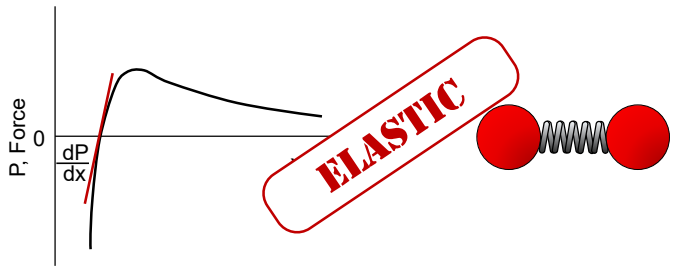

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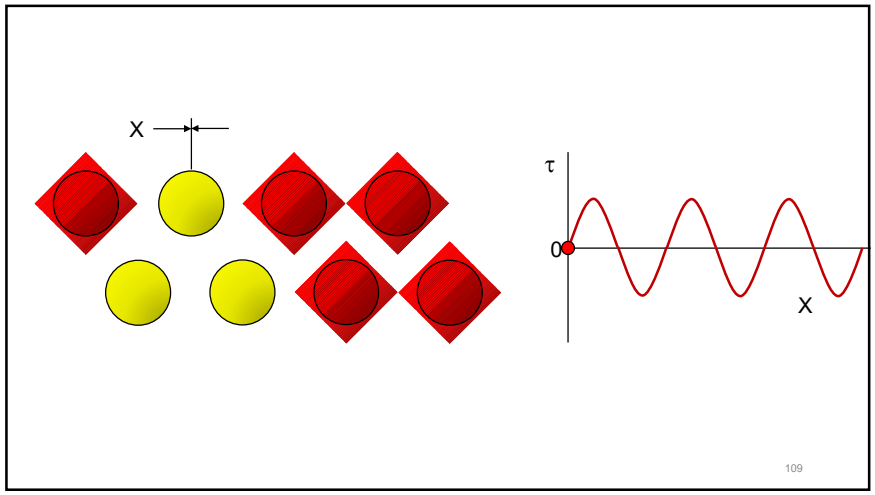
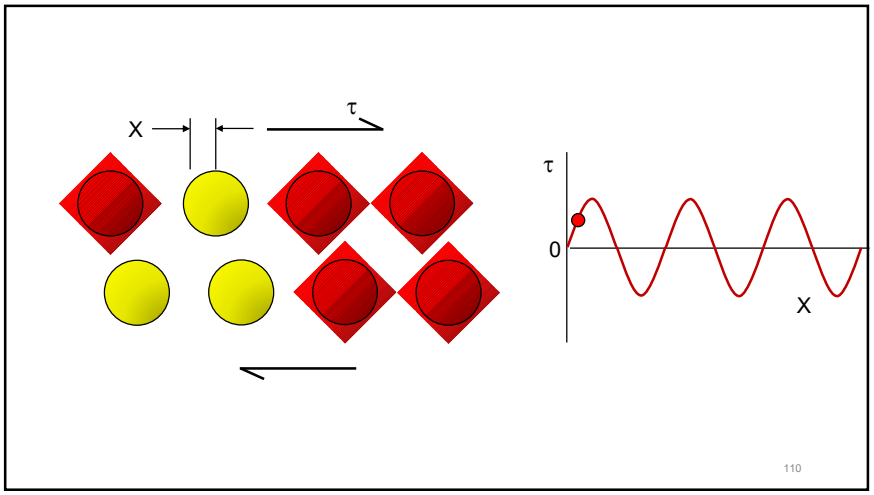
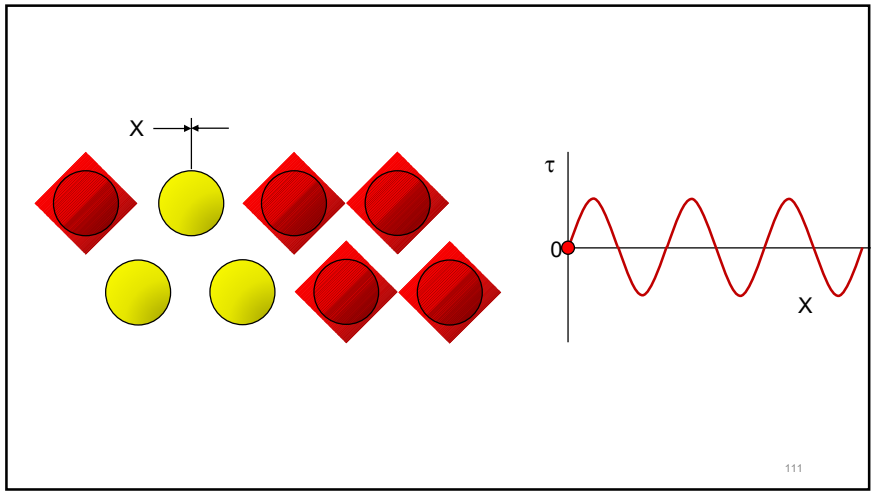
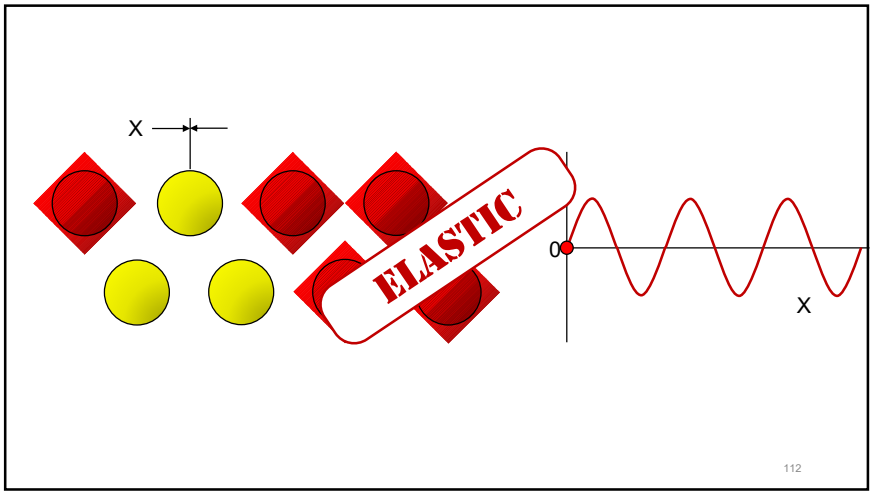
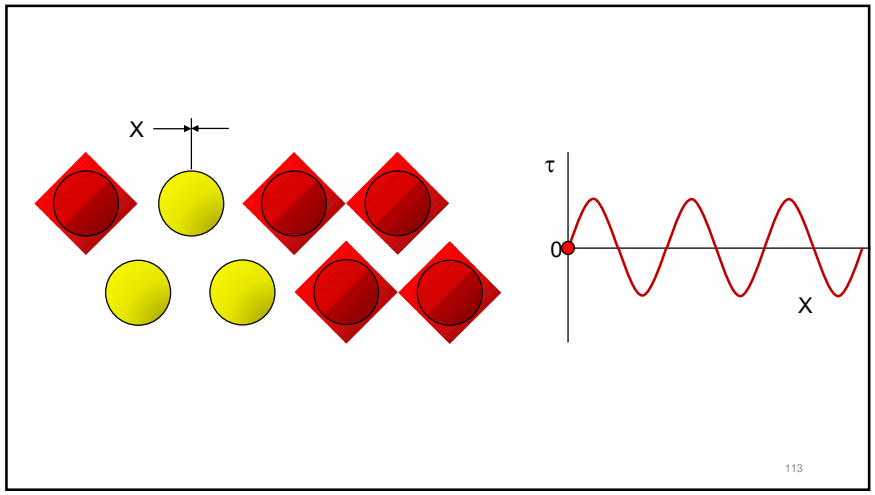
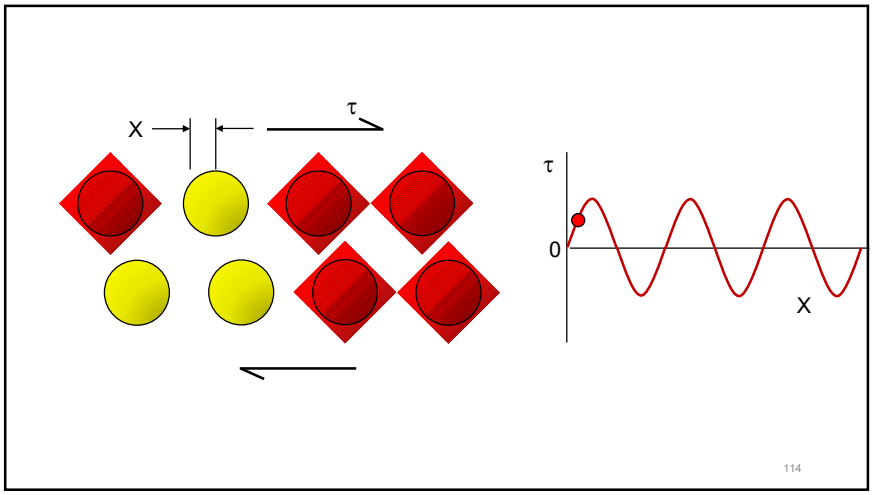


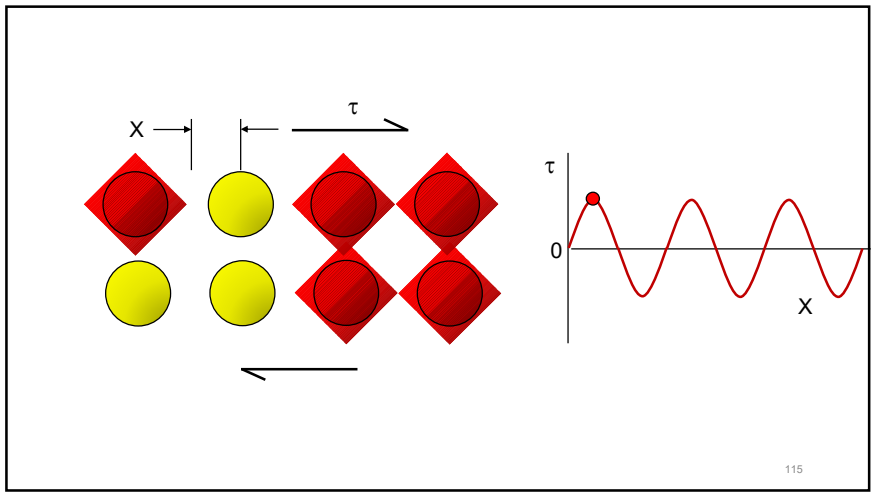


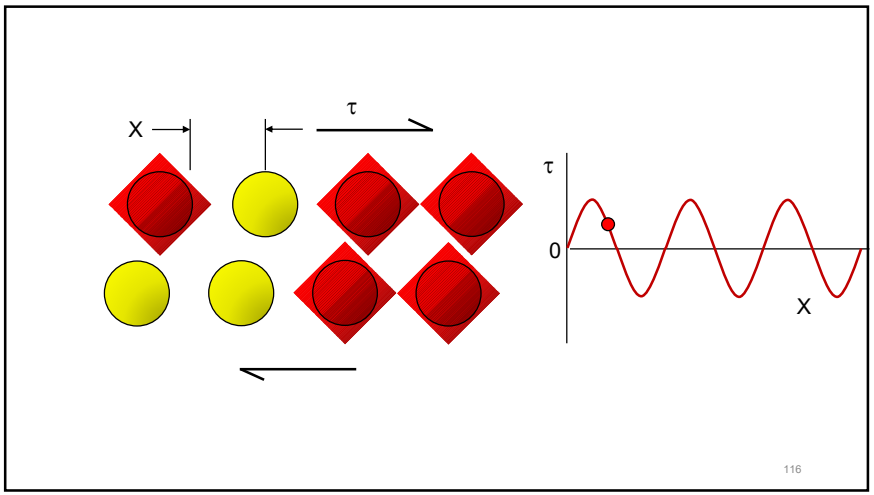


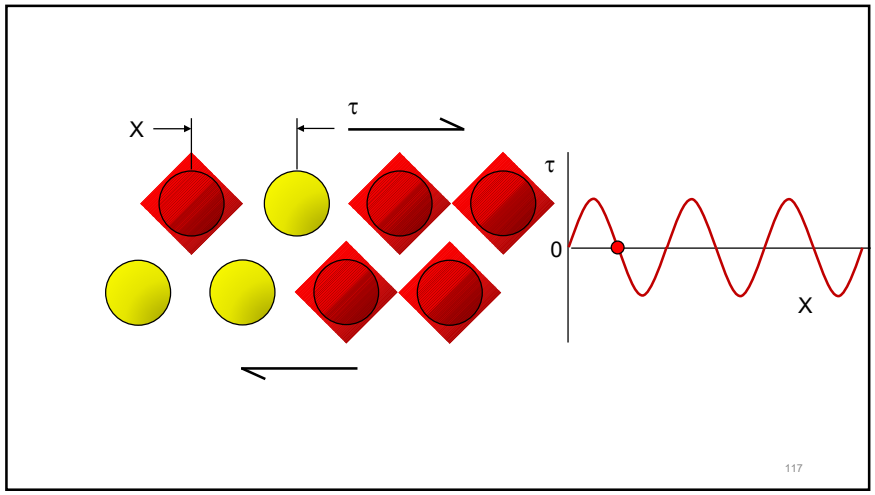


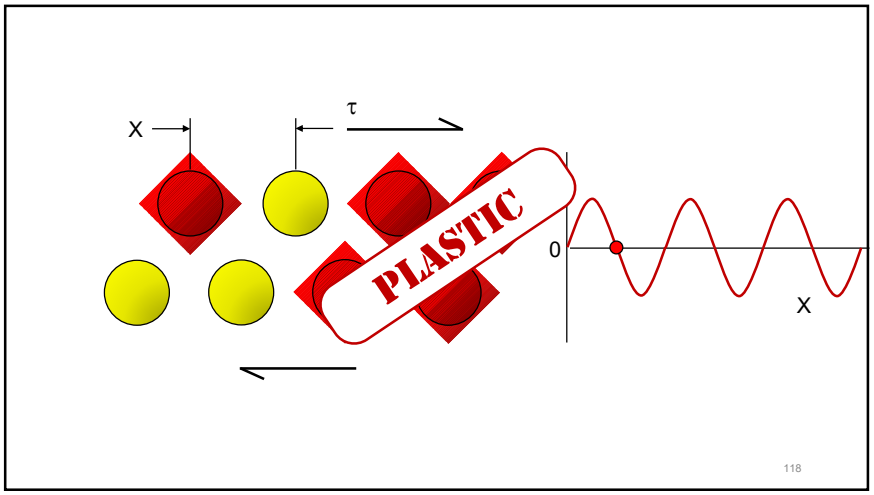


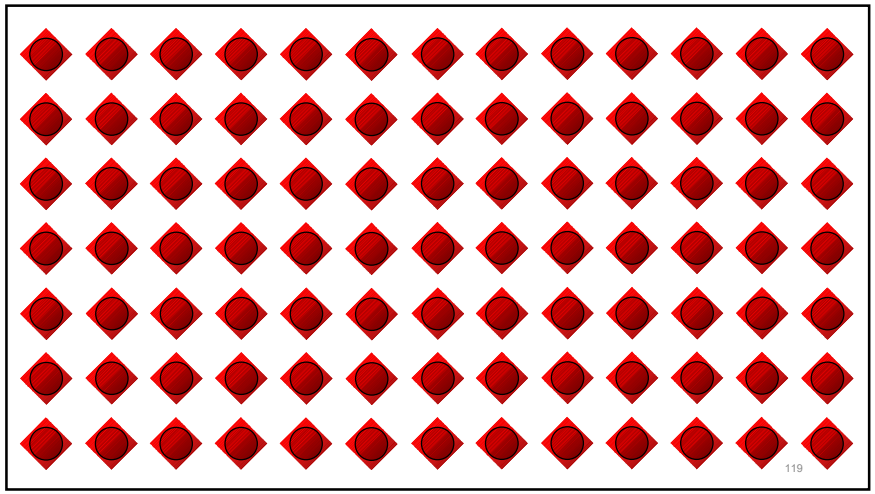


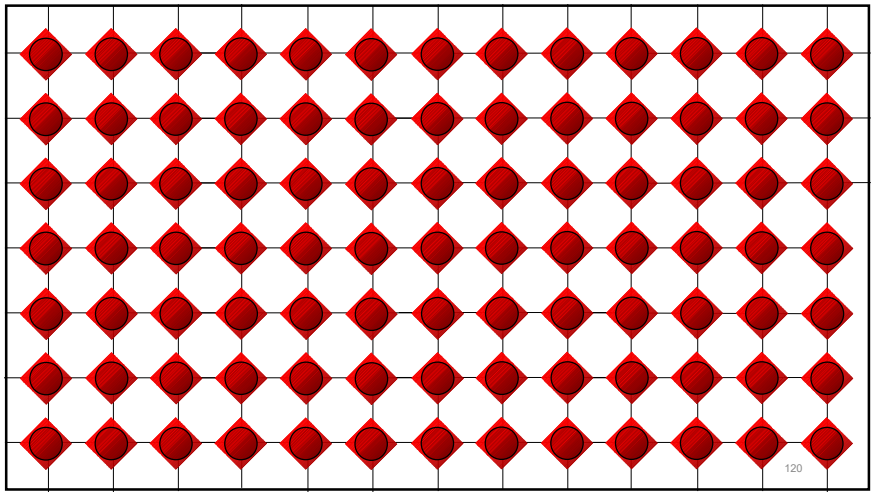


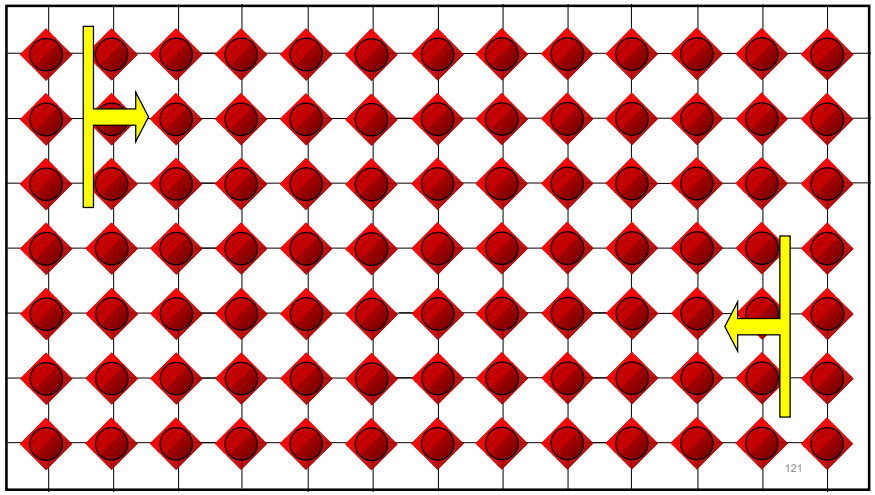


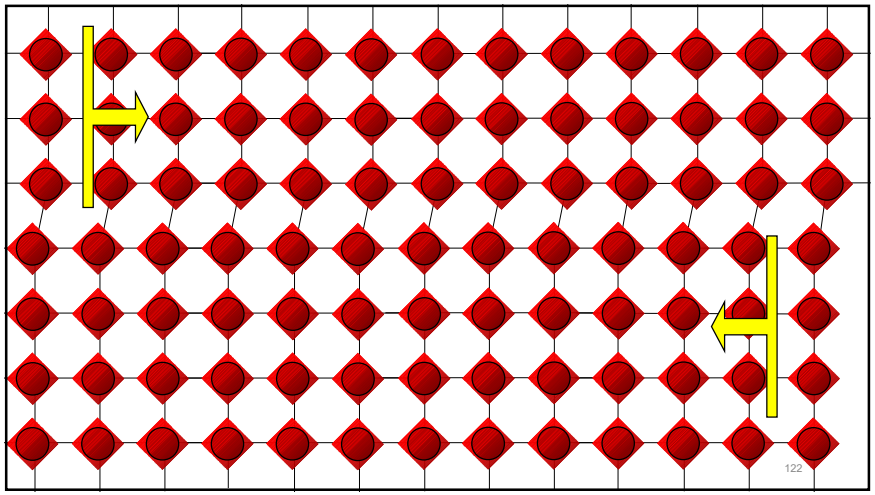


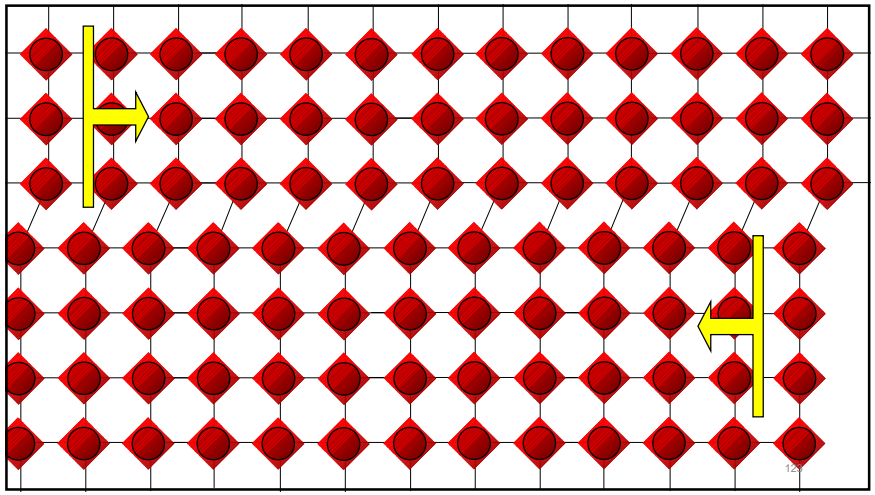


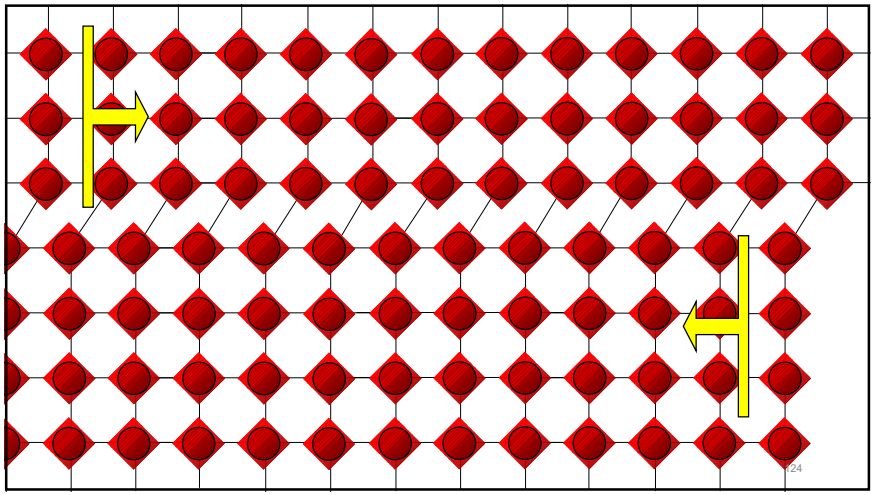


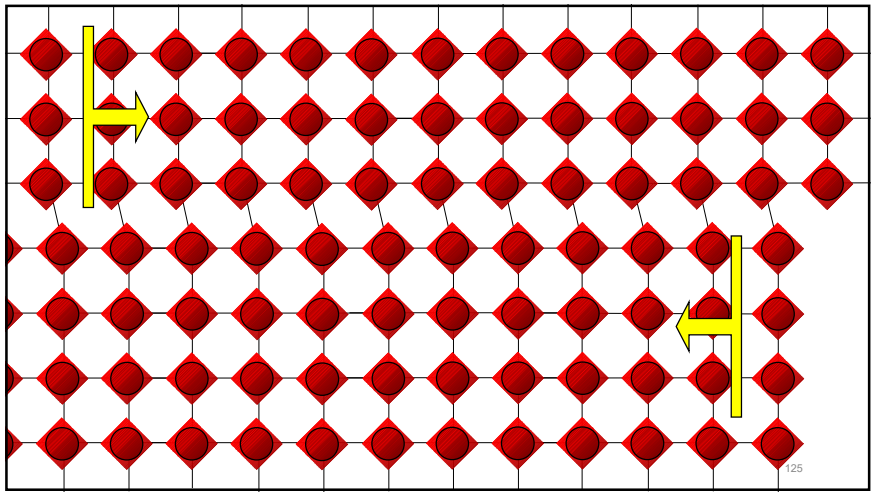


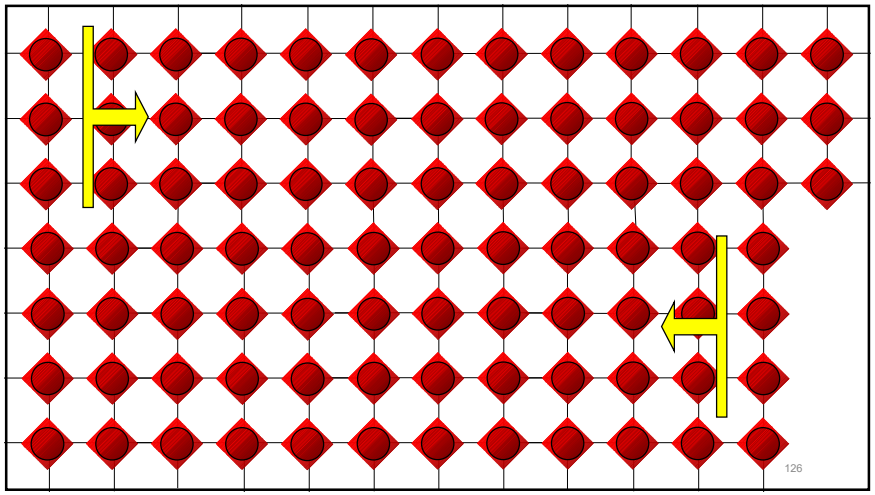


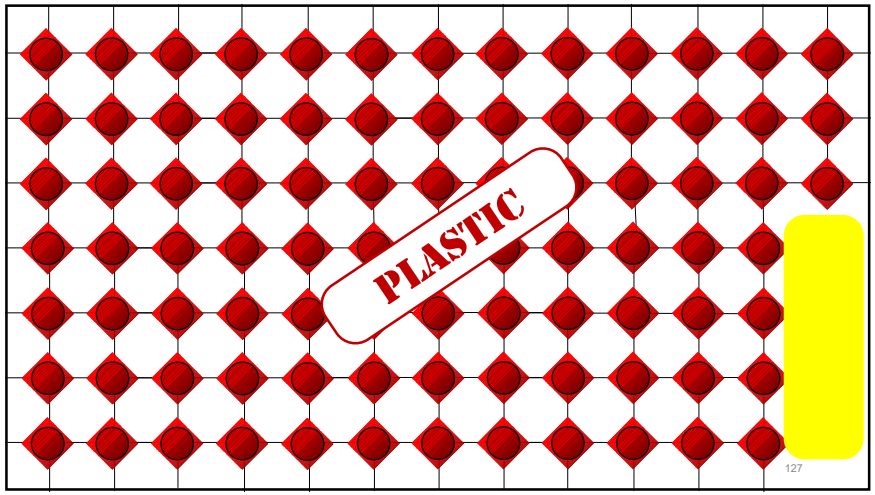


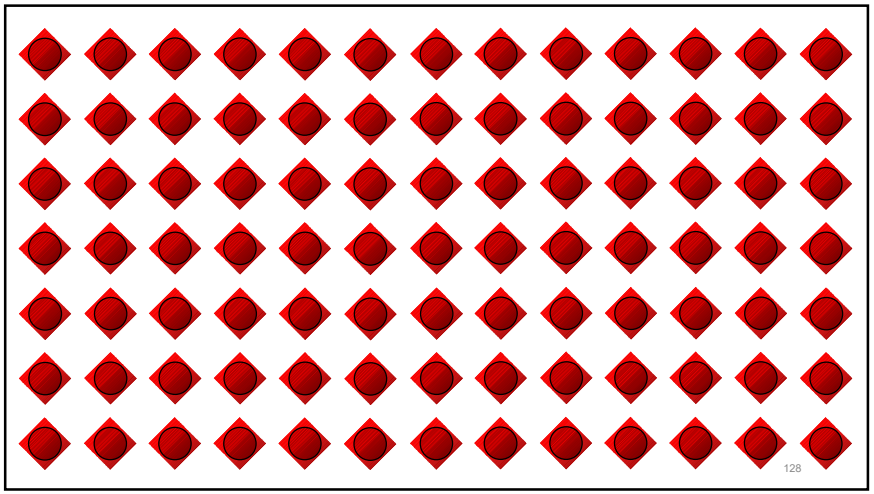


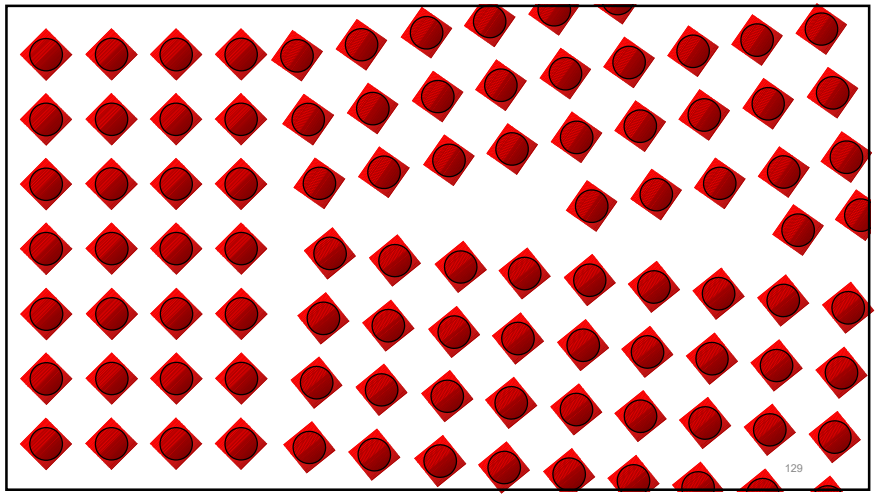


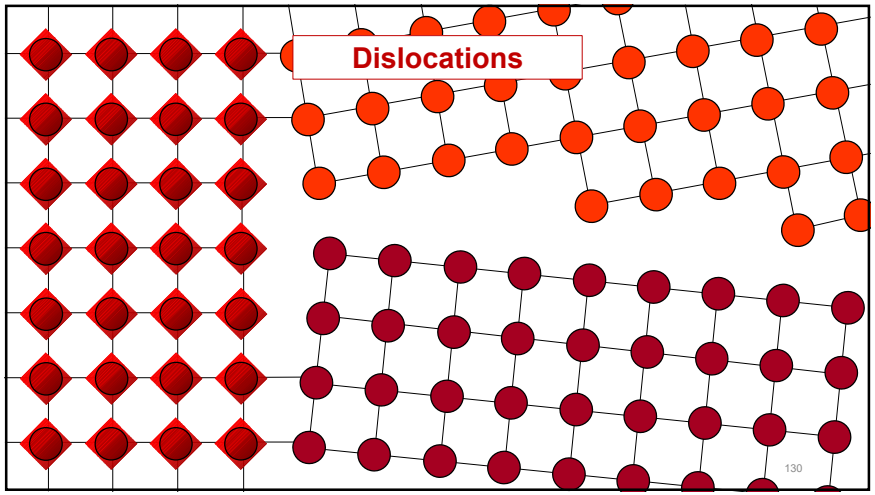


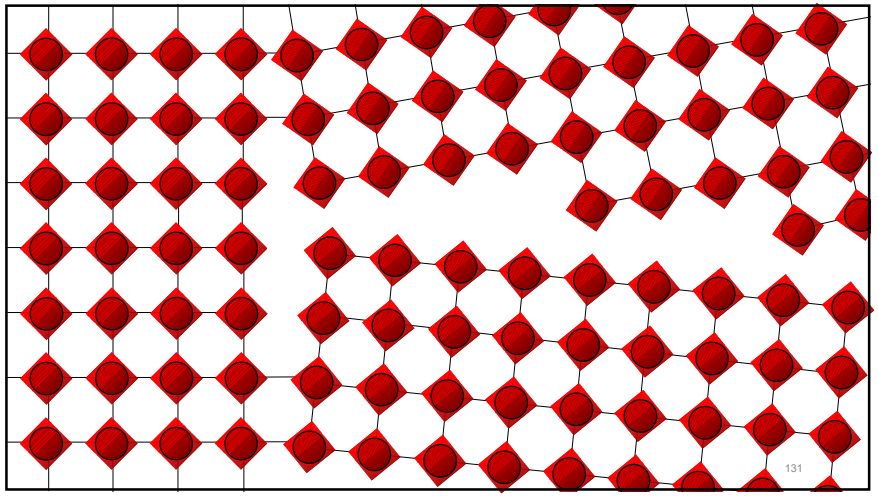


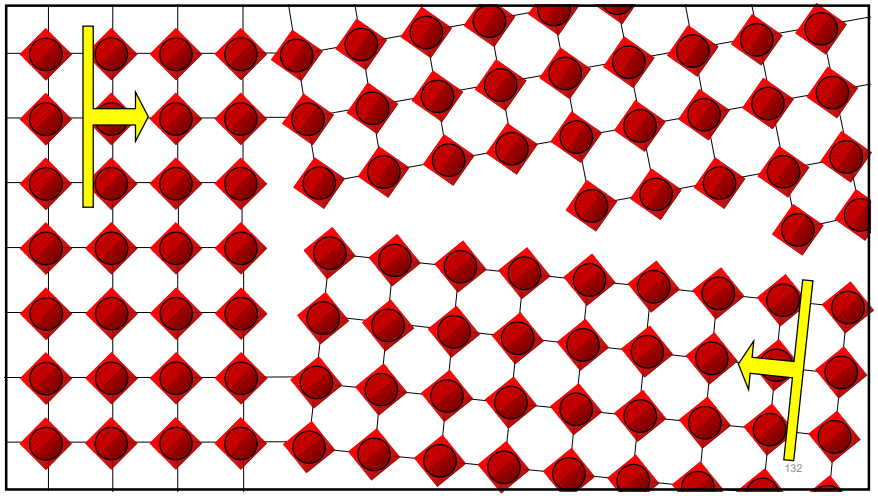


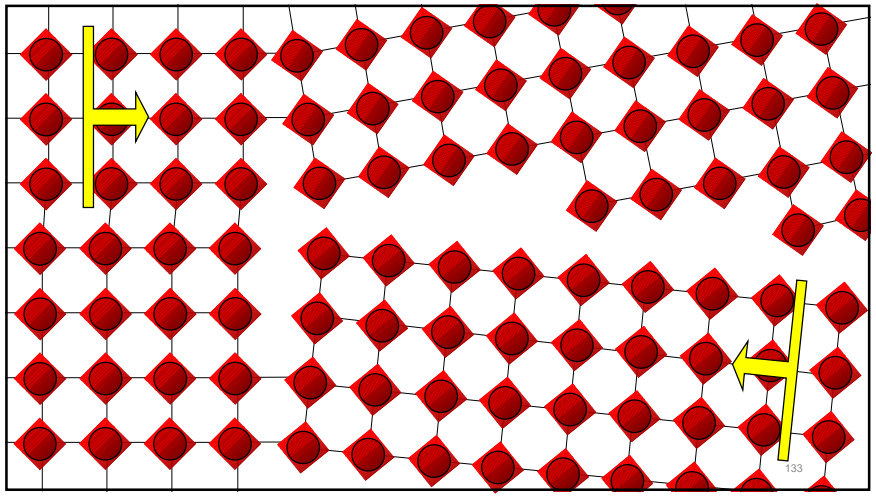


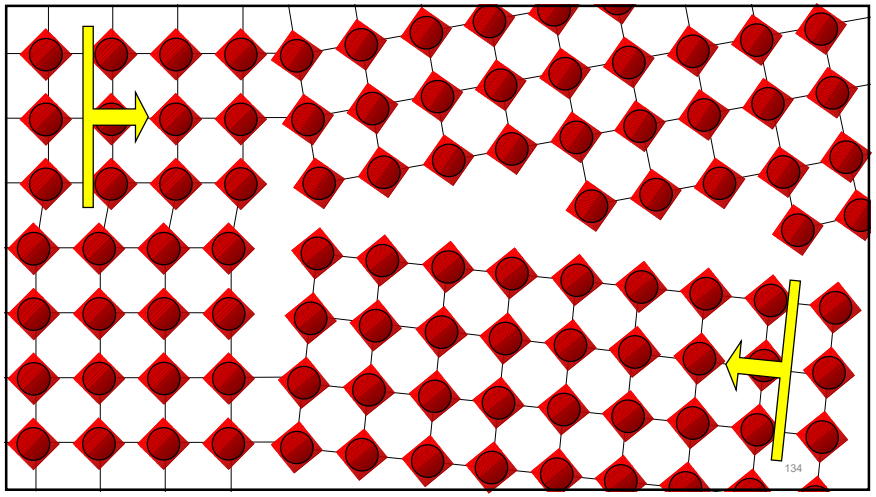


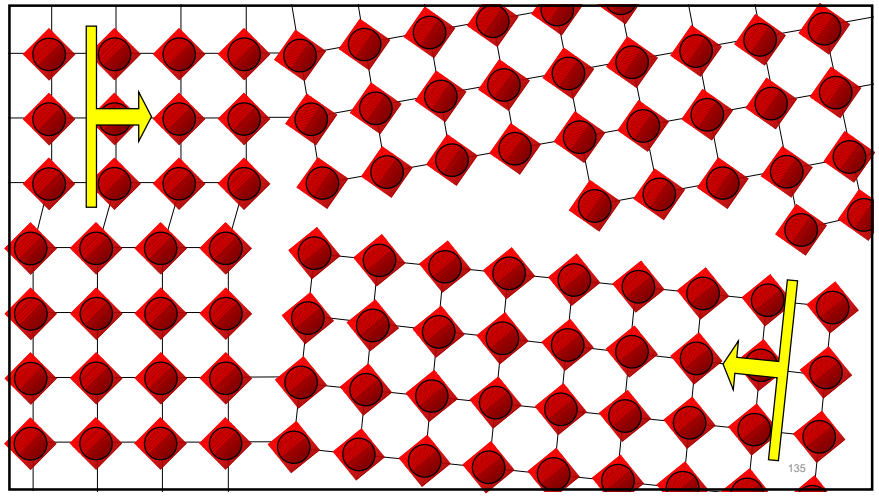


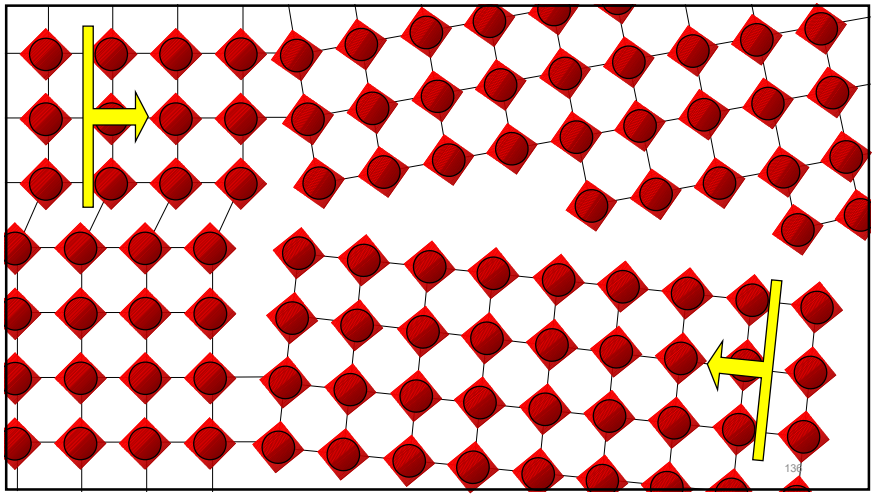


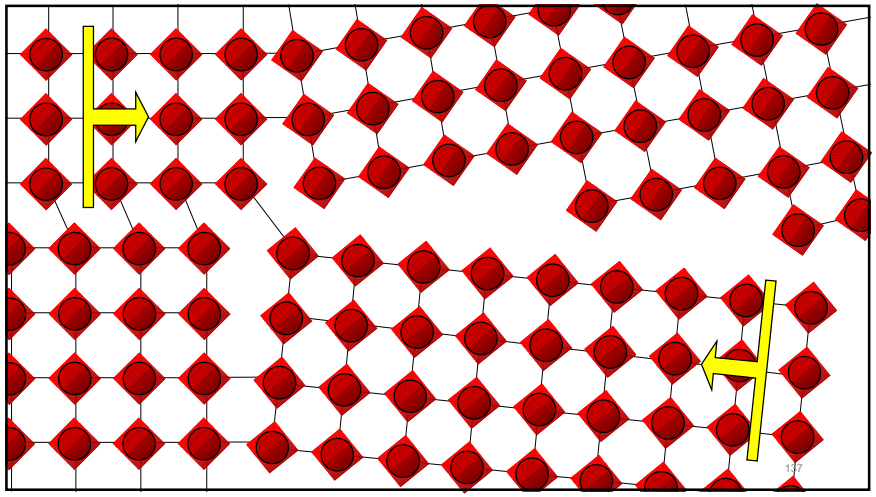


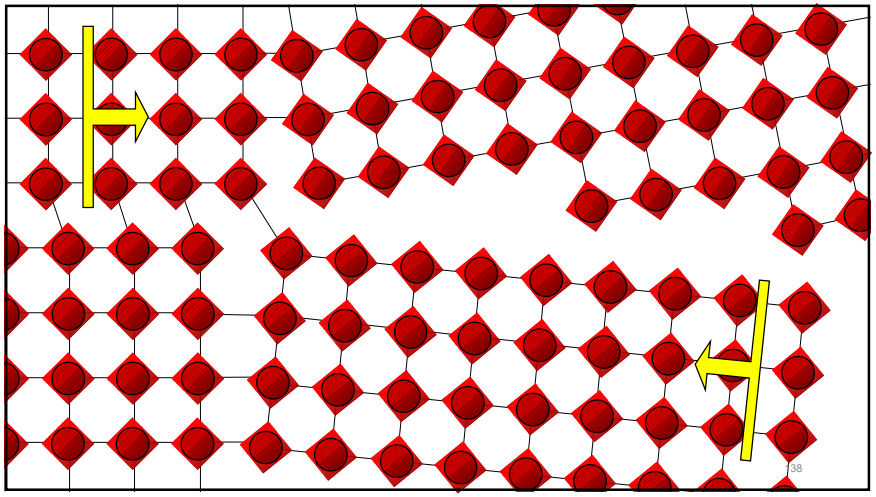


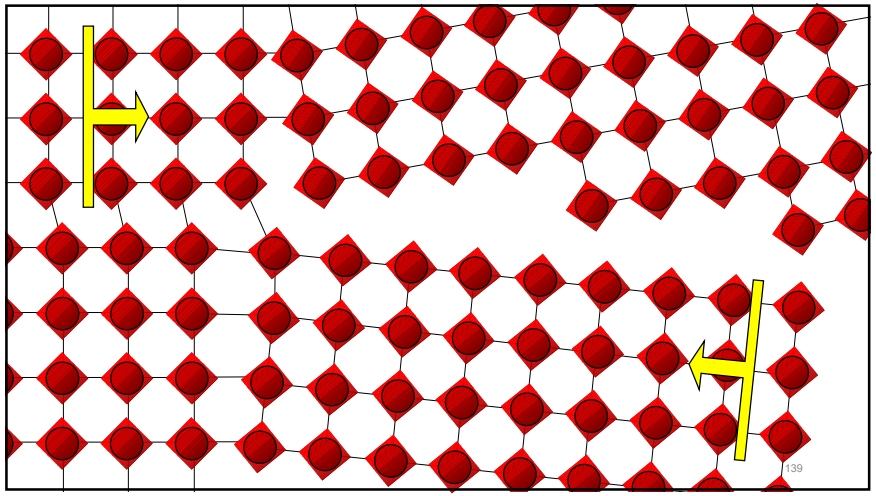


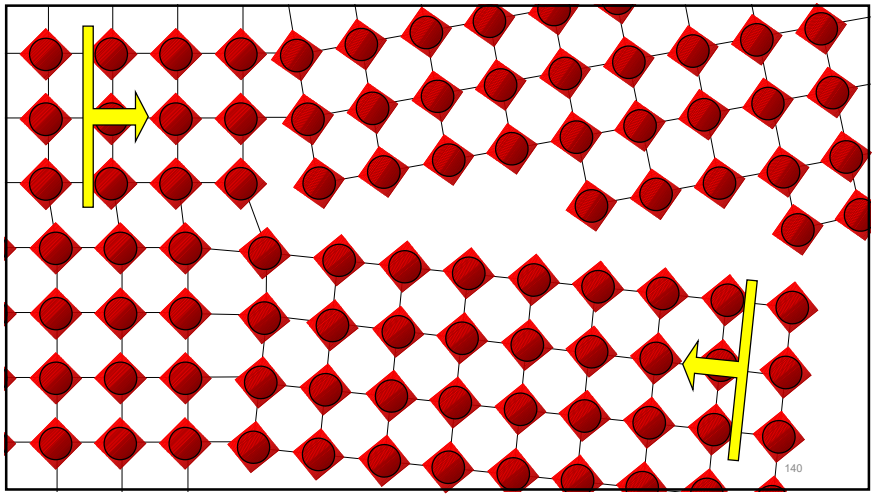


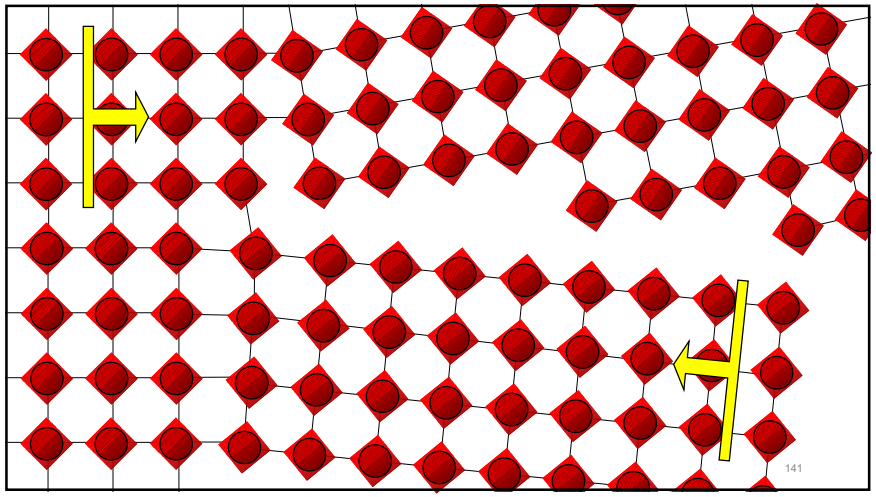


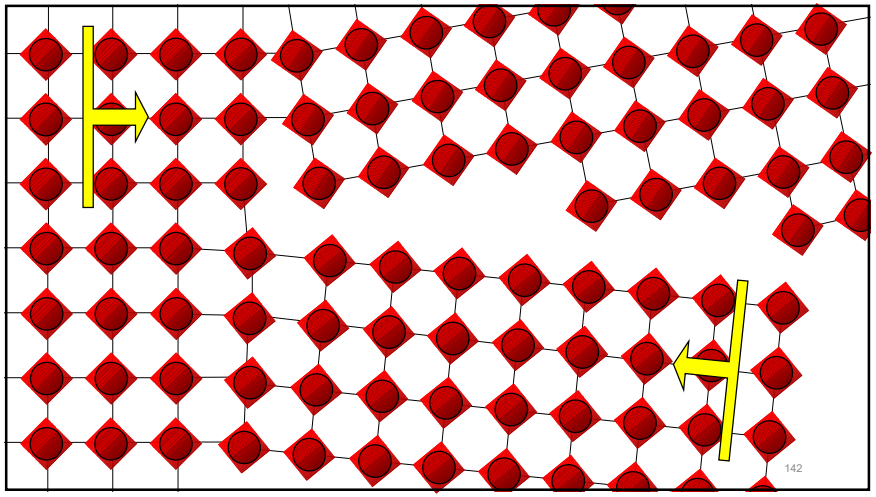


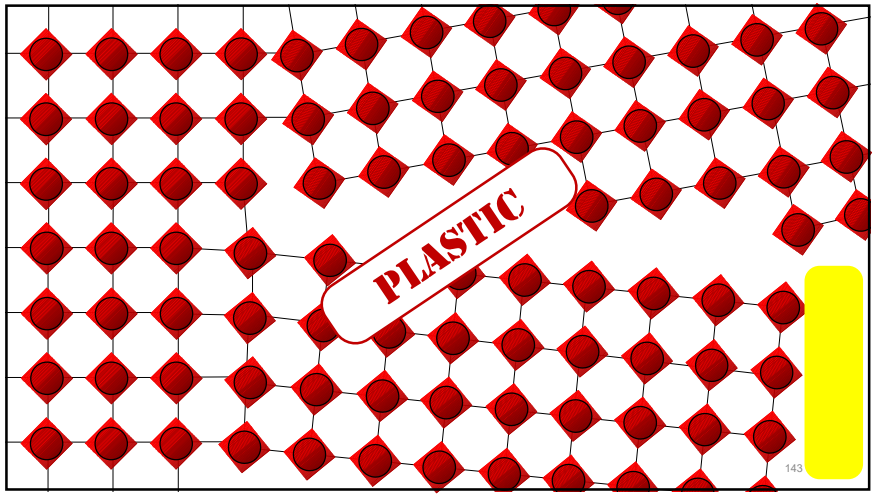


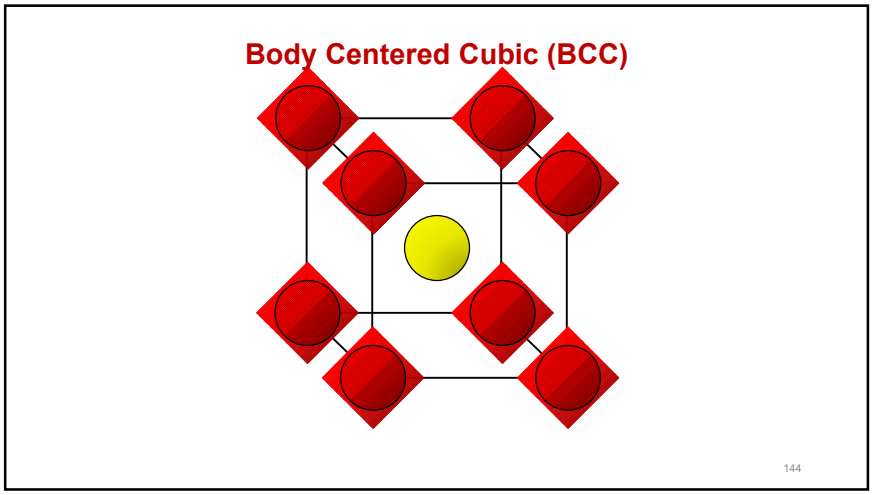




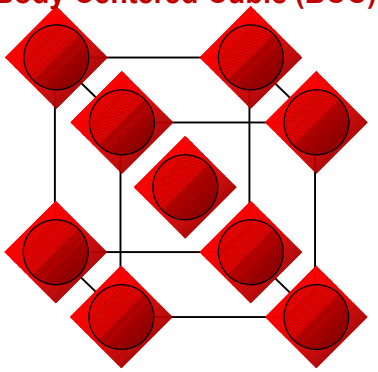








Body Centered Cubic (BCC)



Atomic Packing

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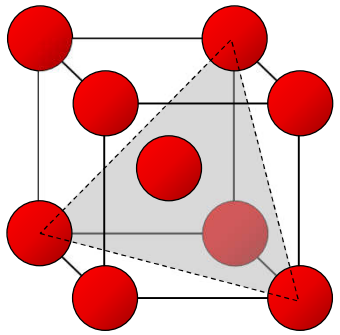
Body Centered Cubic (BCC)



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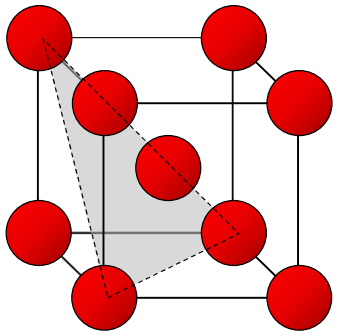

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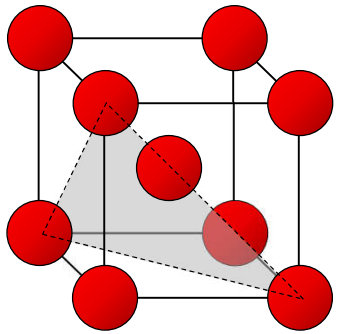
Body Centered Cubic (BCC)



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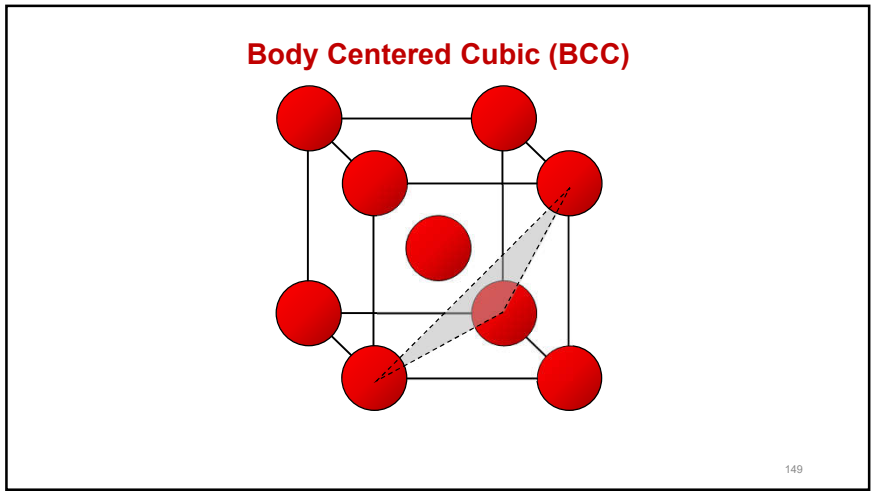

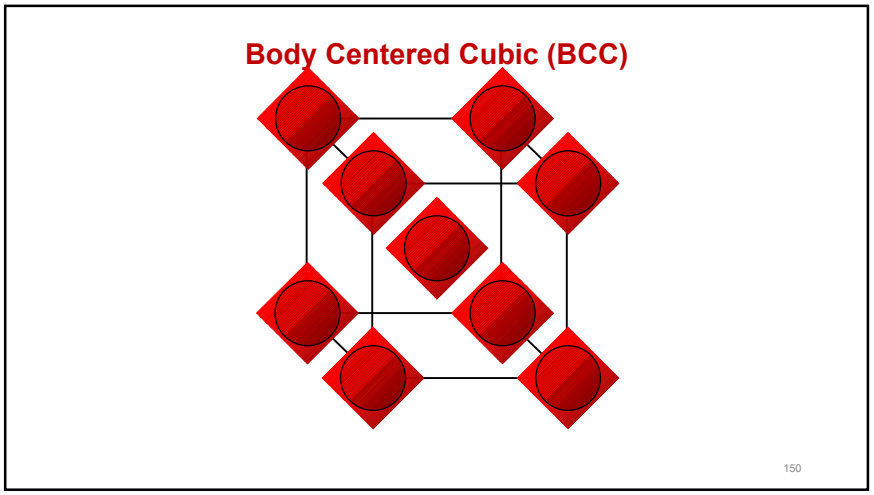

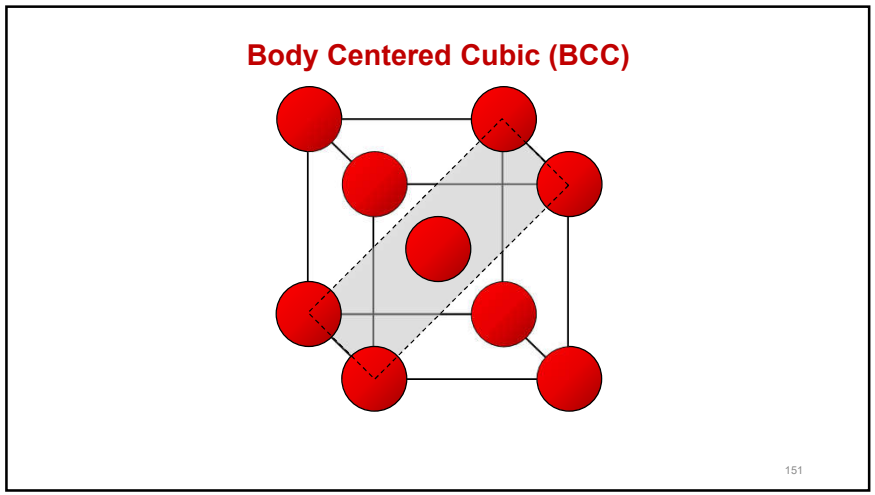

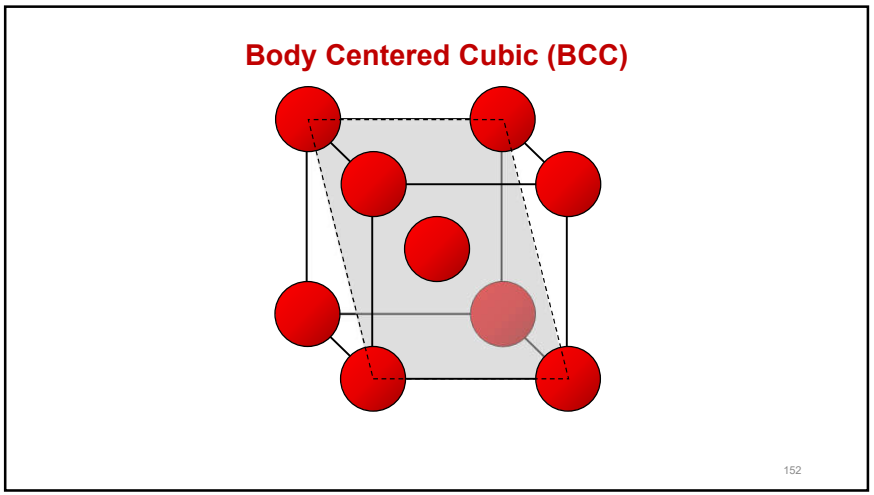

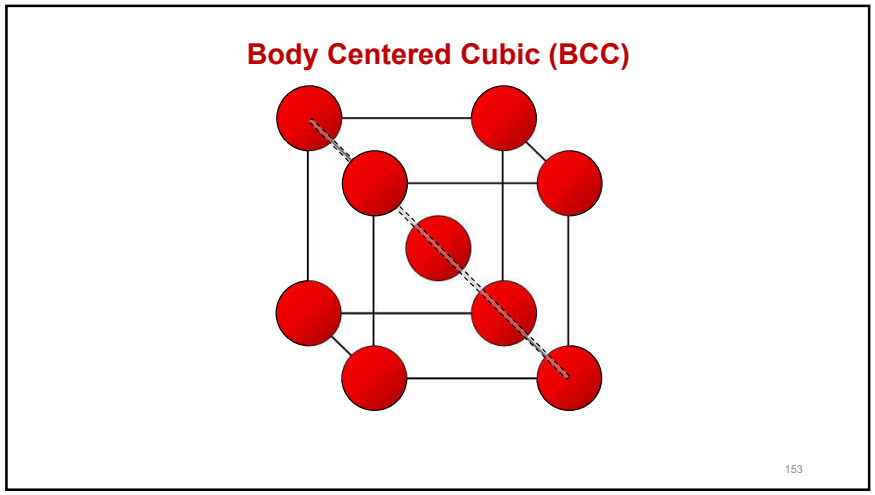

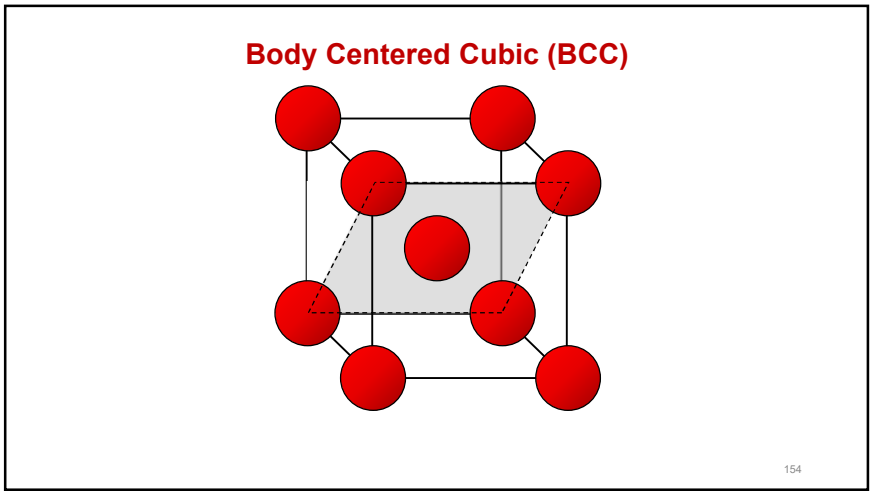

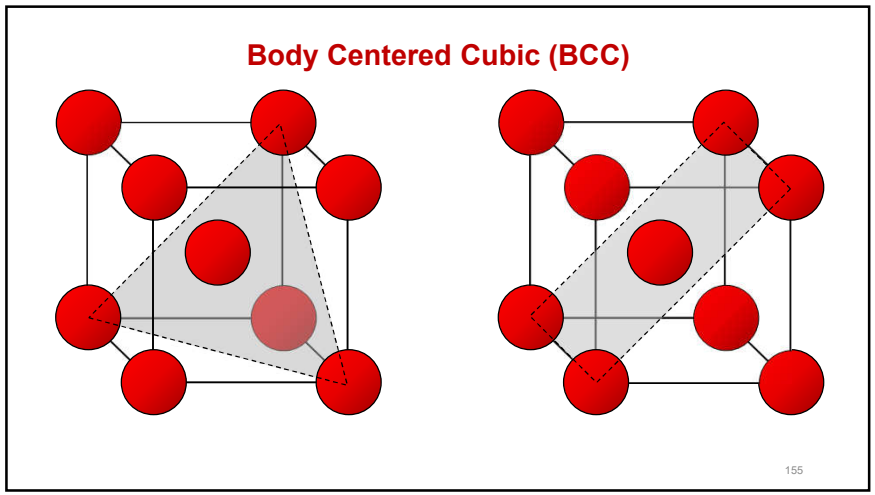

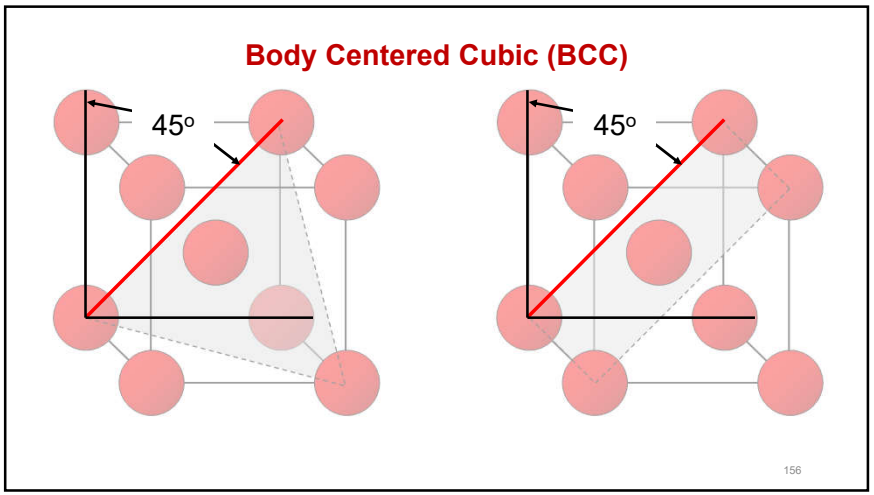

Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics

Lennard Jones Potential, Atomic Interactions, Dislocations, Atomic Packing

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

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STRENGTH OF METALS UNDER COMBINED STRESSES

"It is well known that a metal may be ductile under one set of conditions and brittle under another. Ductility and brittleness, then are properties that must be considered as referring to some particular set of testing or service conditions."

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AISC 341-16 Seismic Provisions

Commentary A1 Scope

Structural steel systems in seismic regions are generally expected to dissipate seismic input energy through controlled inelastic deformations of the structure. The Provisions supplement the Specification for such applications. The seismic design loads specified in the building codes have been developed considering the energy dissipation generated during inelastic response.

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How to Achieve Controlled Inelastic Deformations

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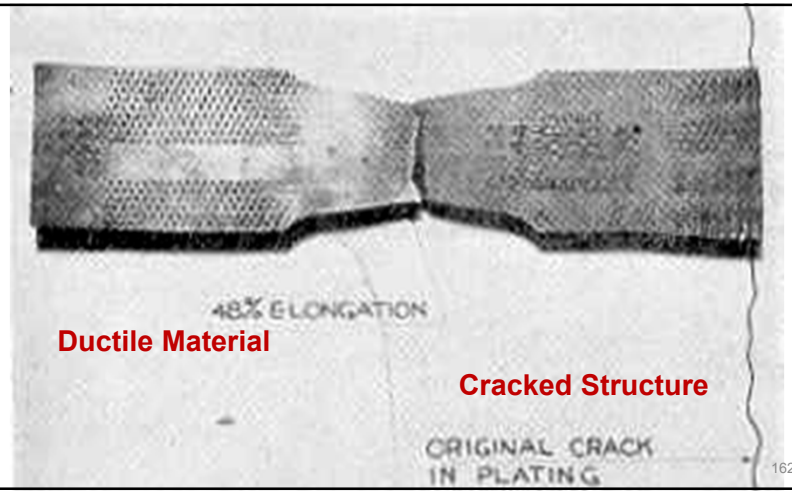

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How to Achieve Controlled Inelastic Deformations

- Select a ductile material

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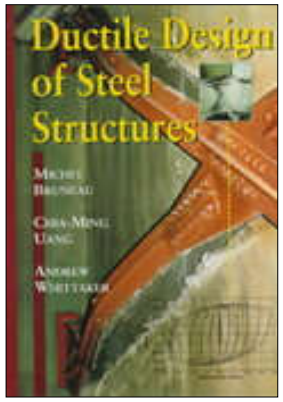
Ductile Design of Steel Structures

Bruneau
Uang
Whittaker

1998



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Ductile Design of Steel Structures

Preface

"Many practicing engineers have wrongly believed for years that the ductile nature of the structural steel material directly translates into inherently ductile structures."

Correct view: the ductile nature of steel does not directly translate into a ductile structure.

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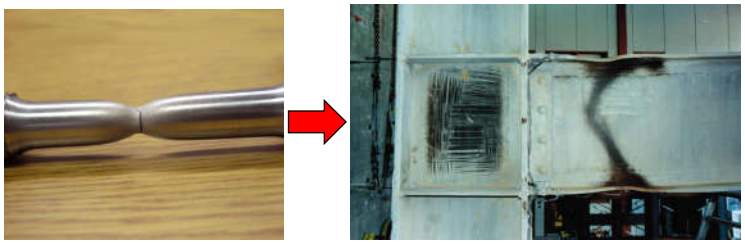
Ductile Material **Ductile Structure**



Correct view: the ductile nature of steel does not directly translate into a ductile structure.

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Ductile Design of Steel Structures

Chapter 1 Introduction

"However, there are many situations in which an explicit approach to the design of ductile steel structures is necessary because the inherent material ductility alone is not sufficient to provide the desired ultimate performance."

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How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture
  (triaxial stress, constraint, notches, low temperatures, high strain rates)

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Ductile Design of Steel Structures

Chapter 1 Introduction

"To achieve this ductile response, one must recognize and avoid conditions that may lead to brittle failures and adopt appropriate design strategies to allow for stable and reliable hysteretic energy-dissipation mechanisms. This sort of thinking is relatively new in structural engineering."

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Barsom and Rolfe: Fatigue and Fracture Control in Structures

Most structural materials exhibit considerable strain (deformation) before reaching the tensile or ultimate strength….However, under conditions of low temperature, rapid loading and/or high constraint (e.g., when the principle stresses σ_1, σ_2, and σ_3 are essentially equal), even ductile materials may not exhibit any deformation before fracture.

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A triaxial state-of-stress can also result from uniaxial loading when notches or geometric discontinuities are present. A triaxial state-of-stress will cause the yield stress of the material to increase above it nominal value, resulting in brittle fracture by cleavage, rather than ductile shear deformations.

page 2-38

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How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses

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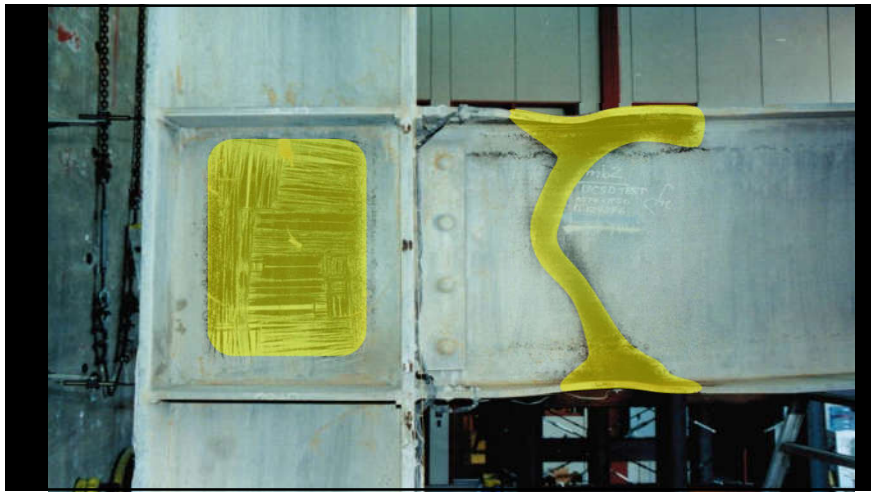

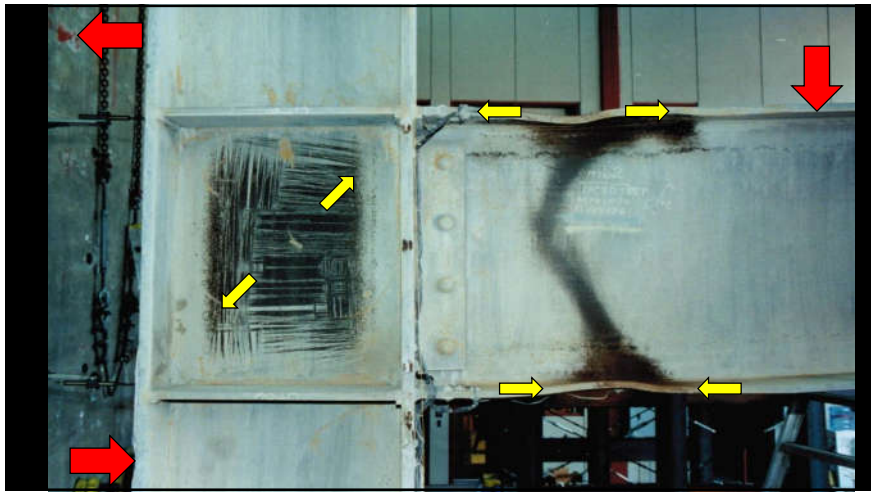

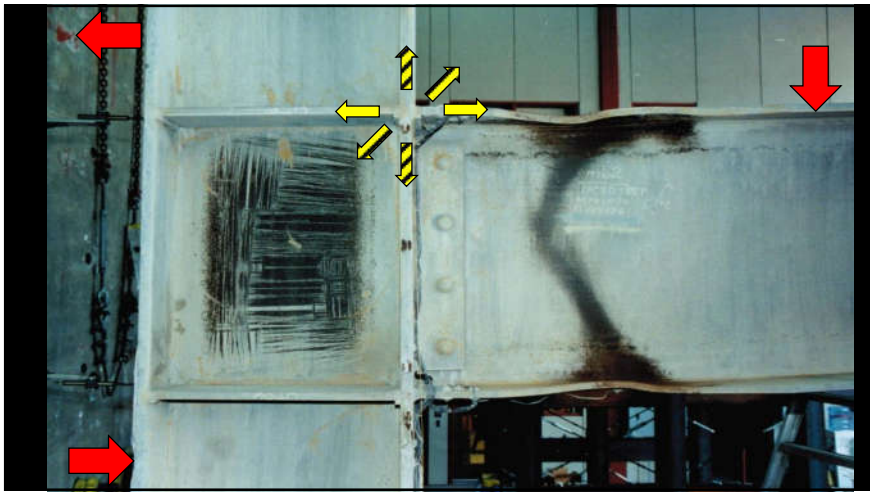

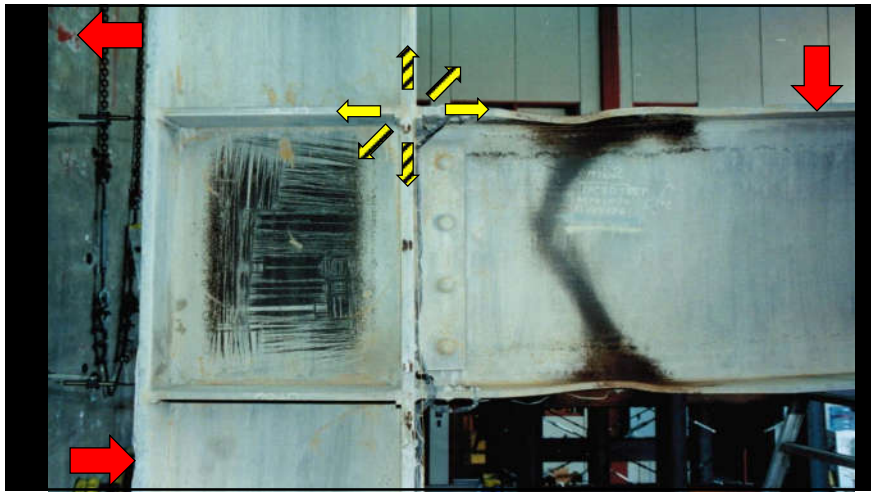

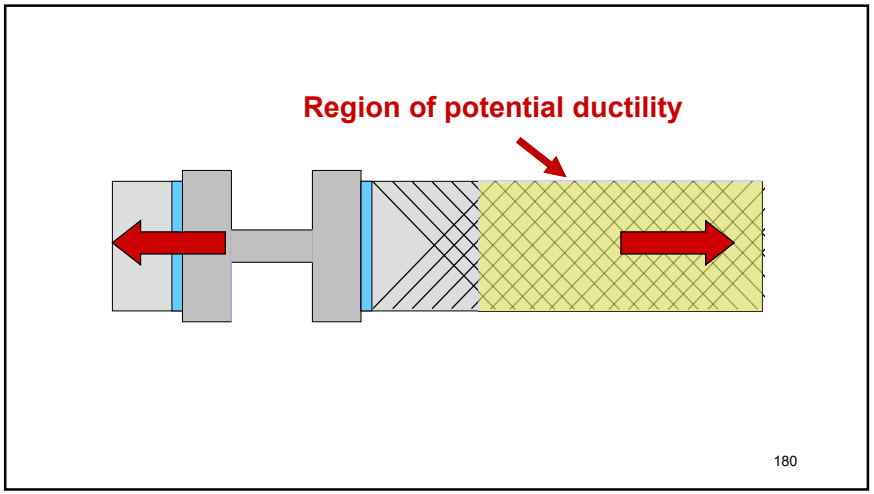

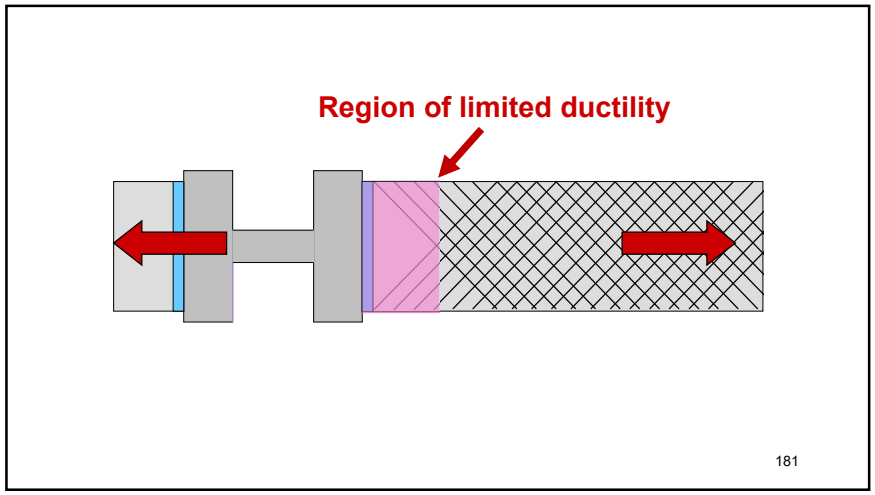

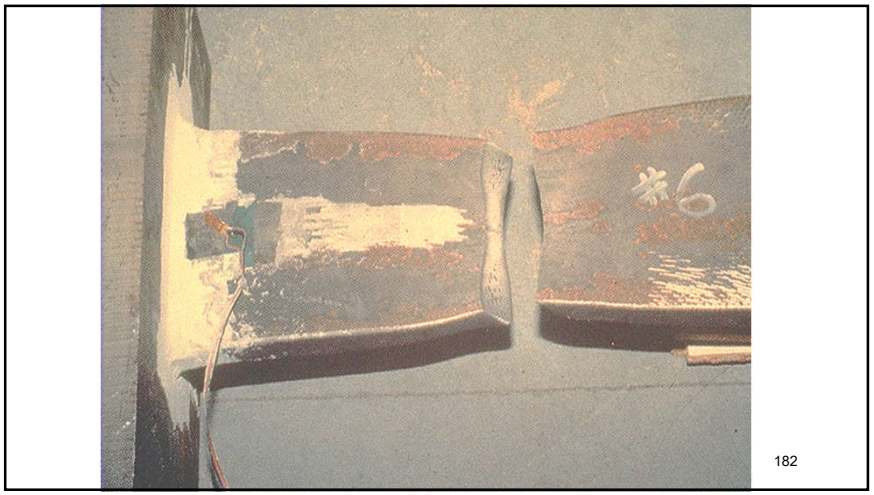

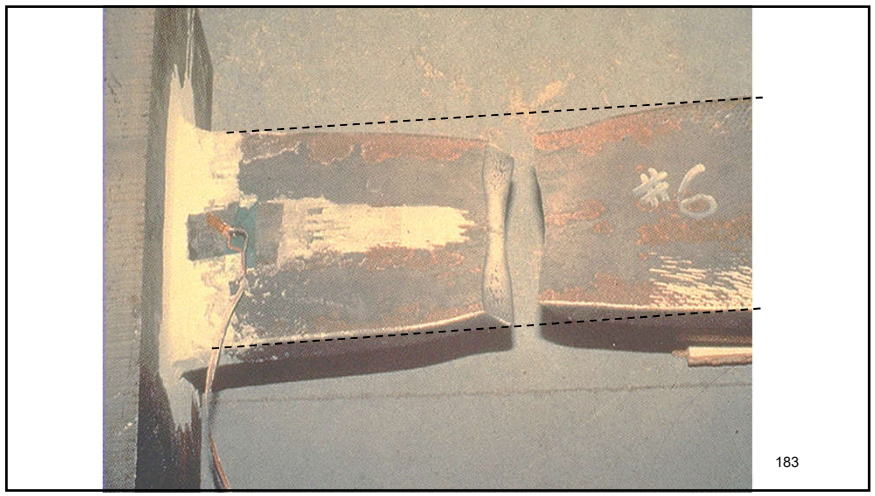

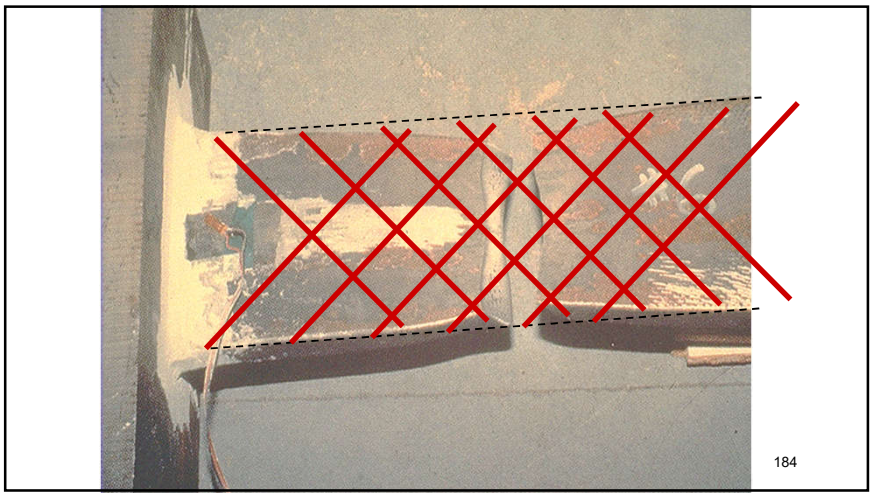

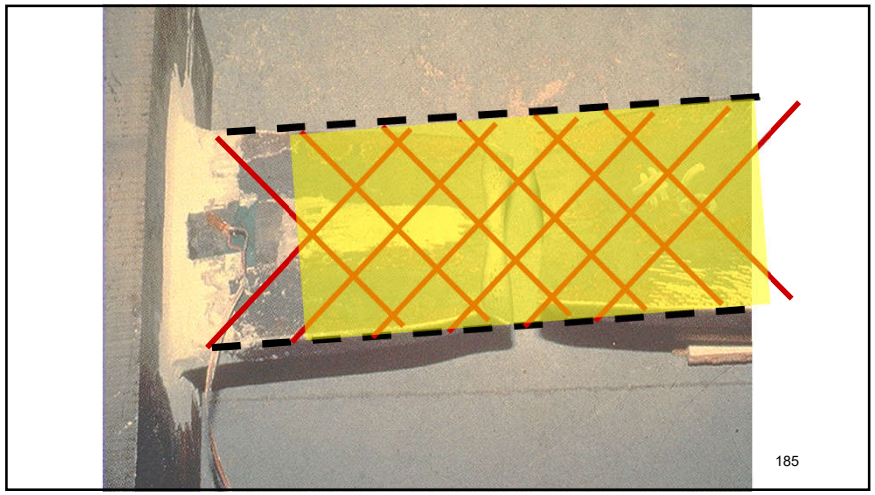

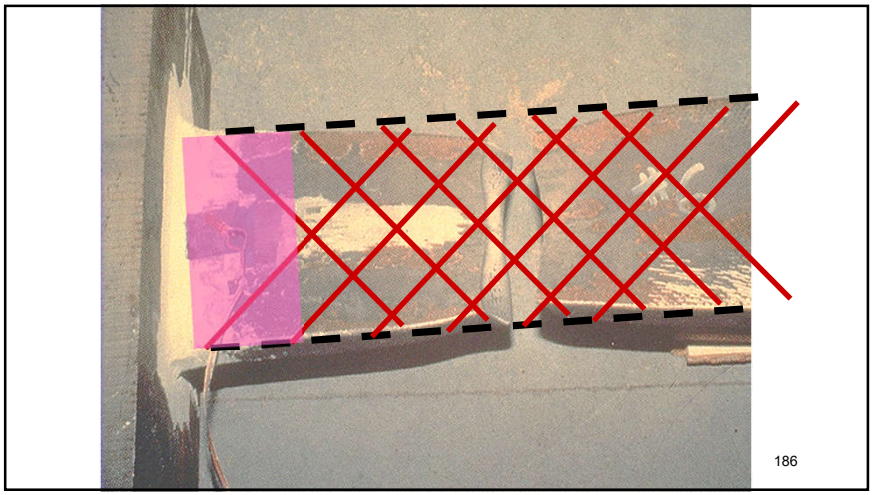

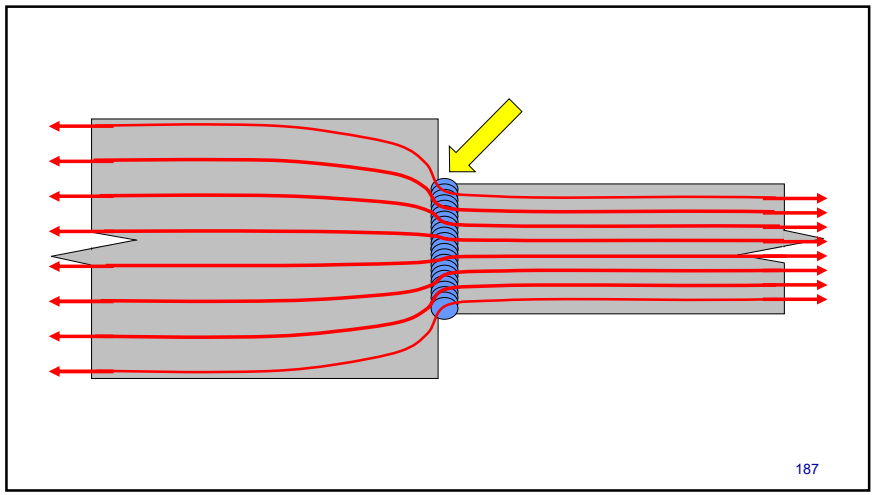

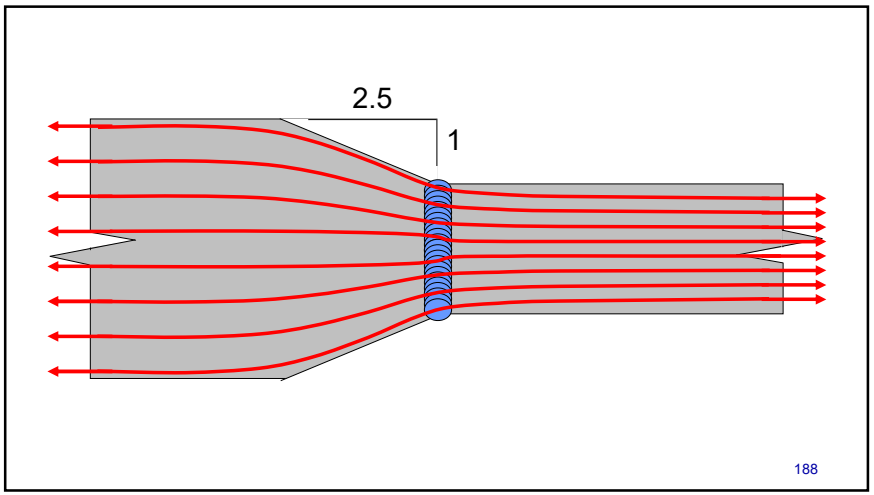

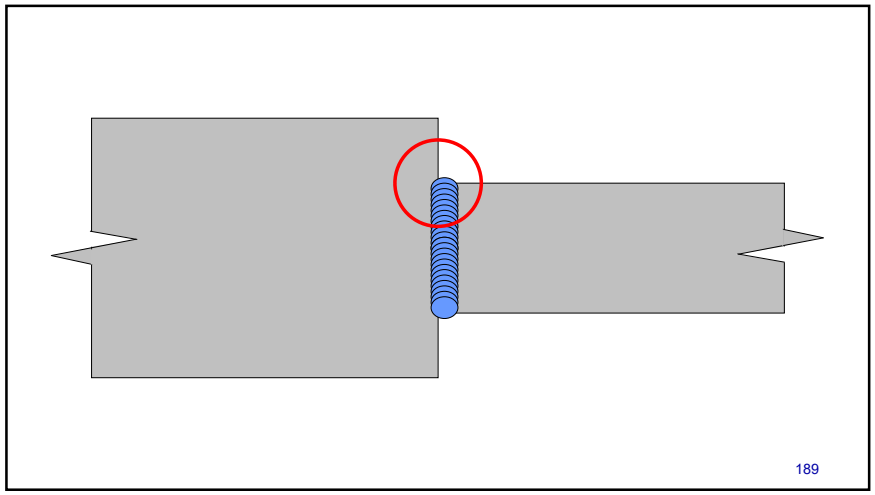

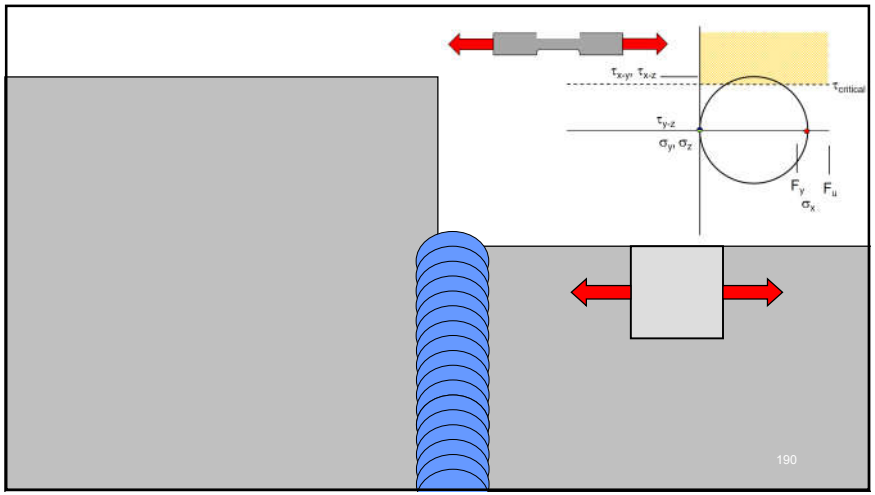

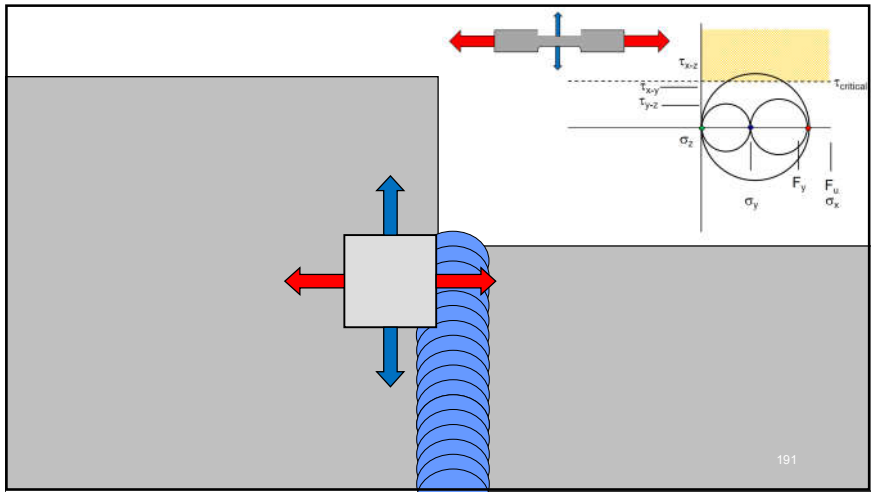

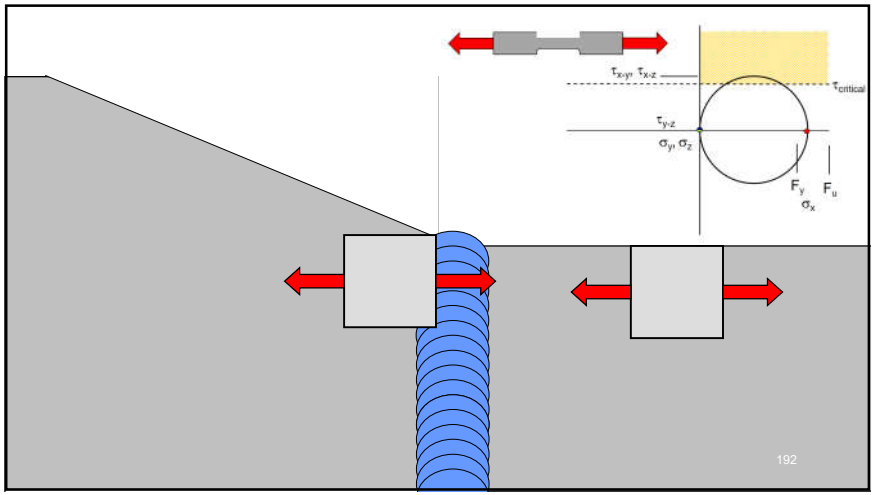

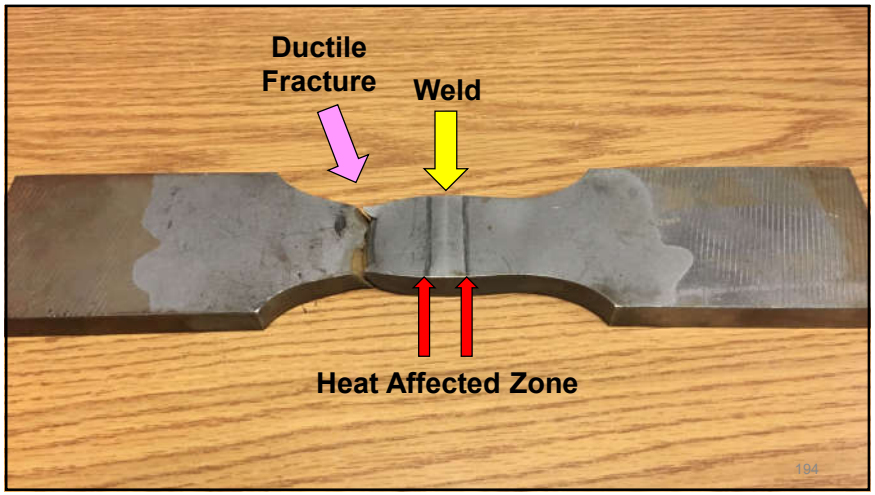

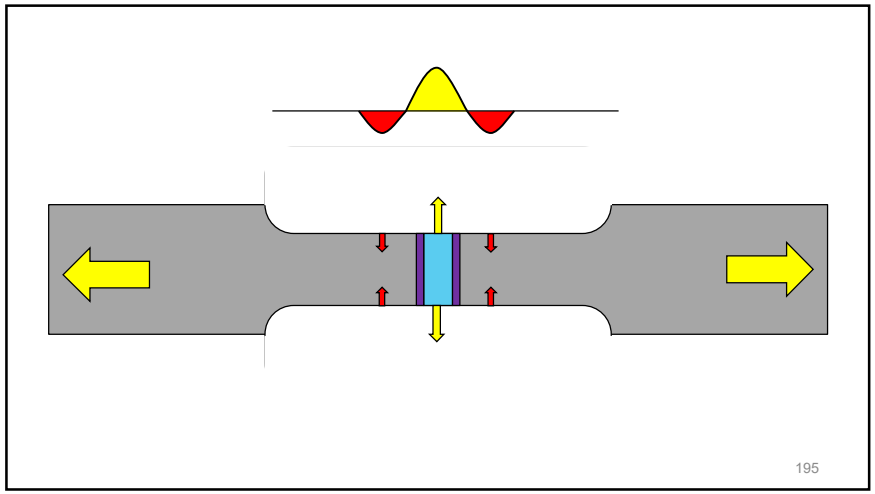

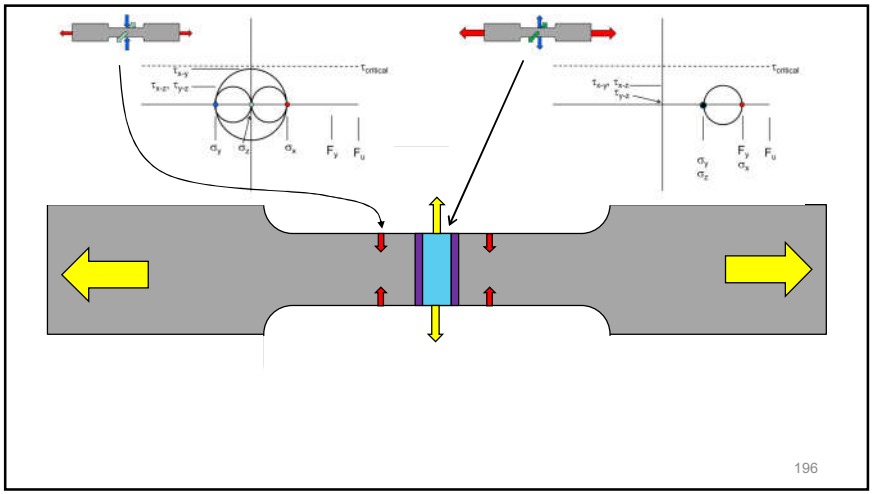

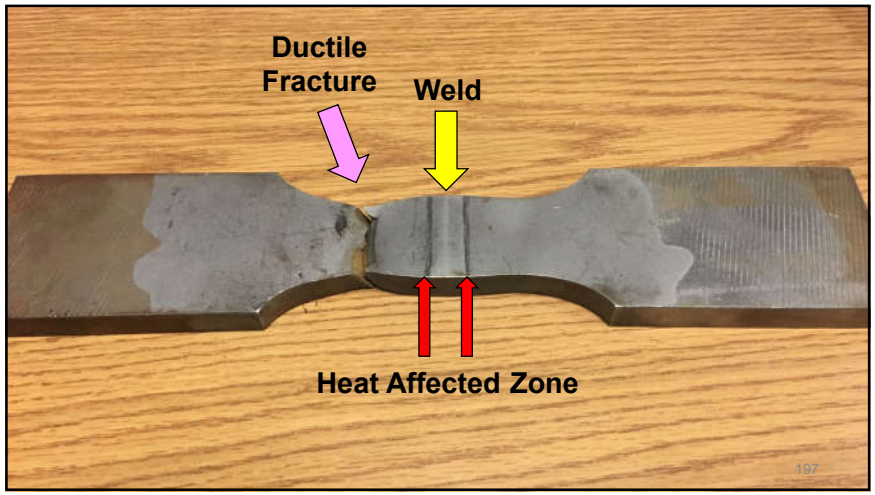

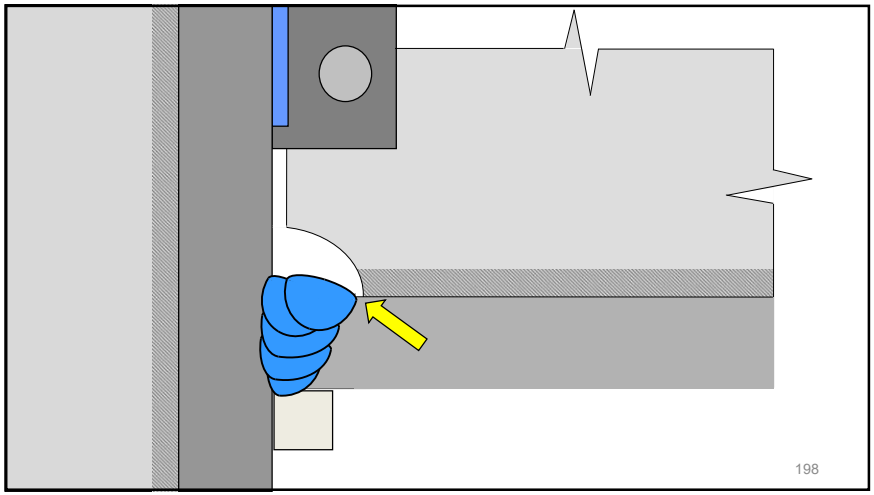

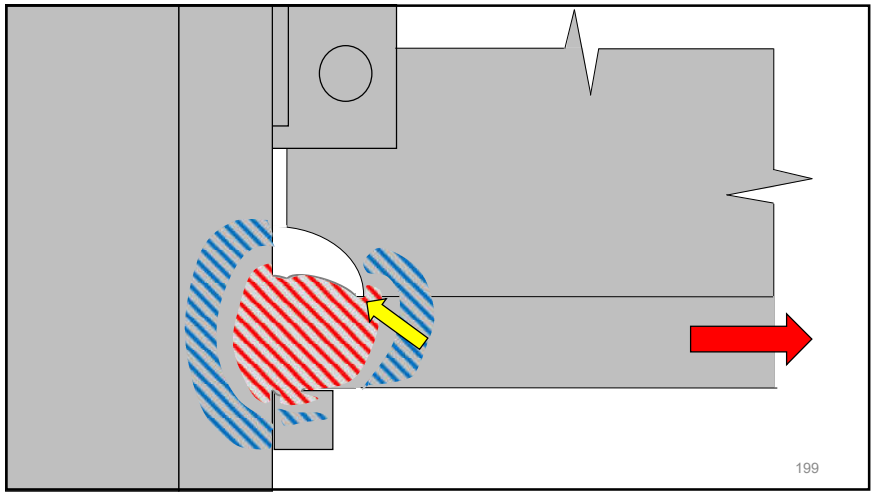

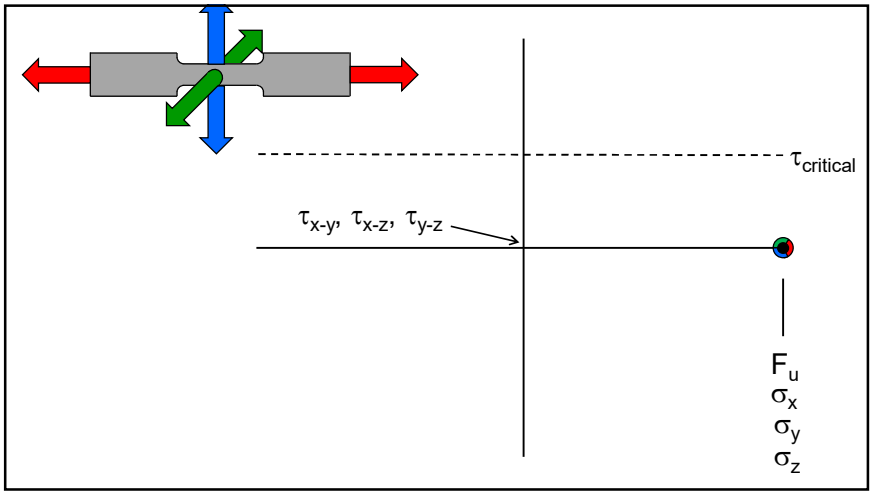

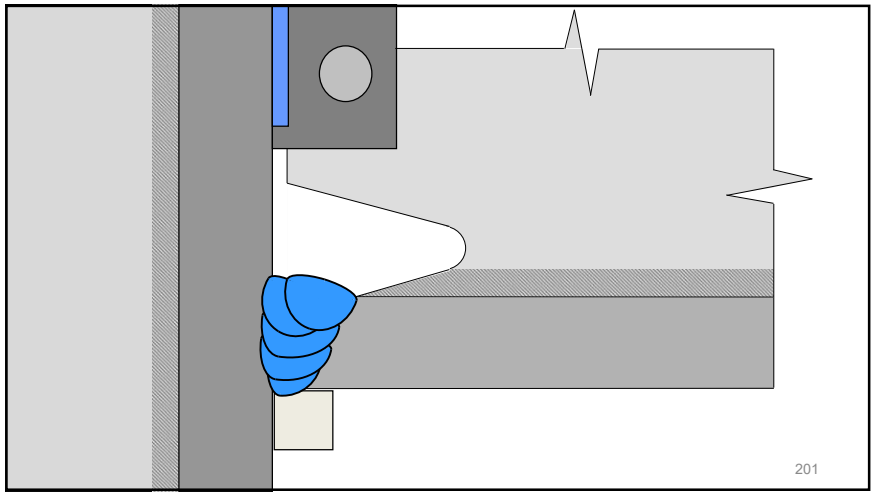

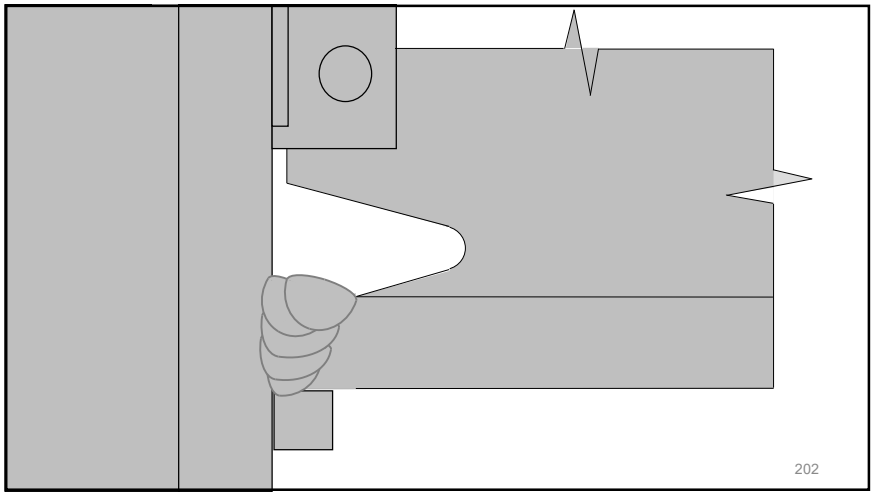

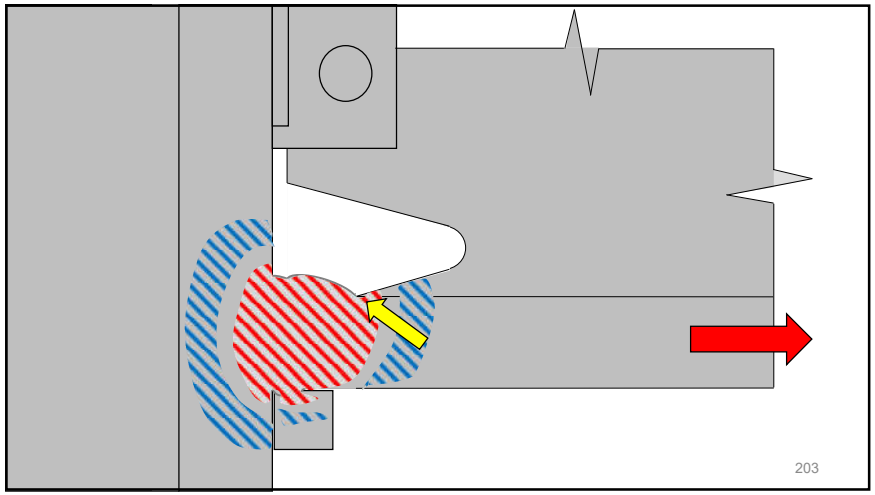

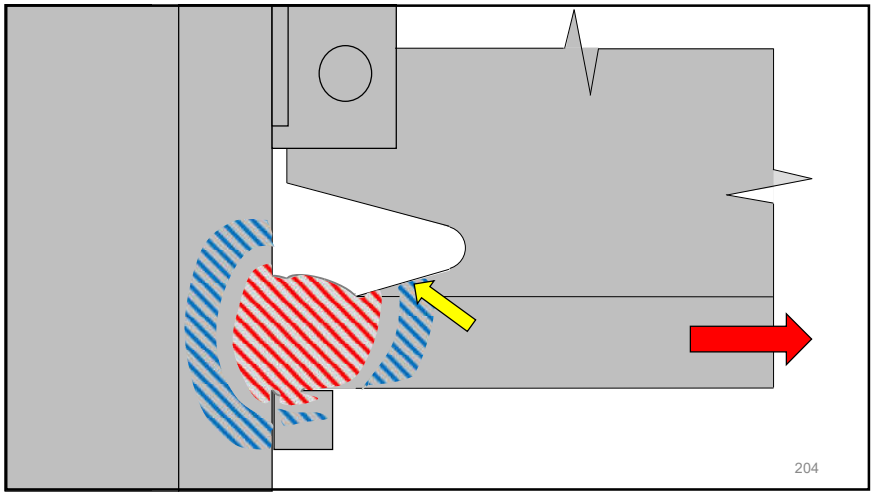

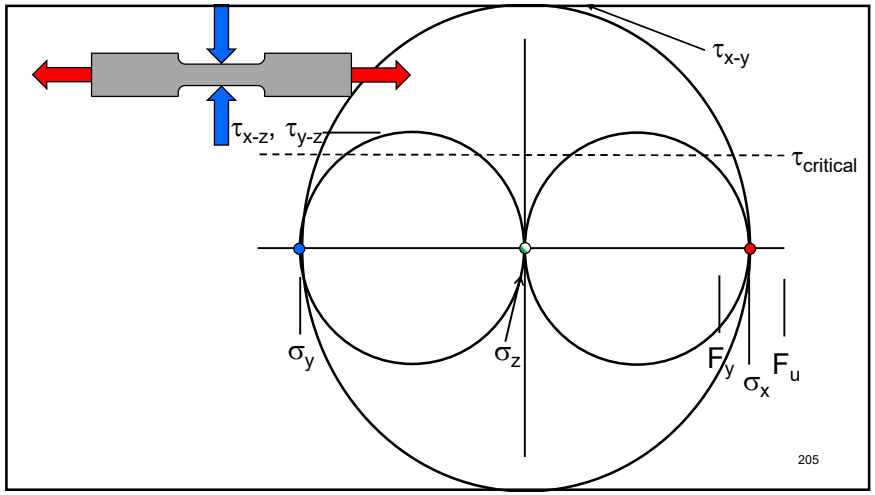

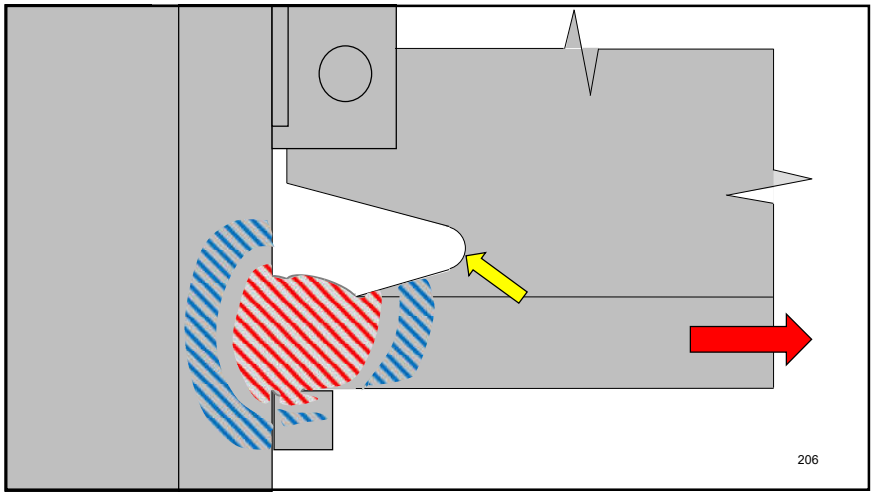

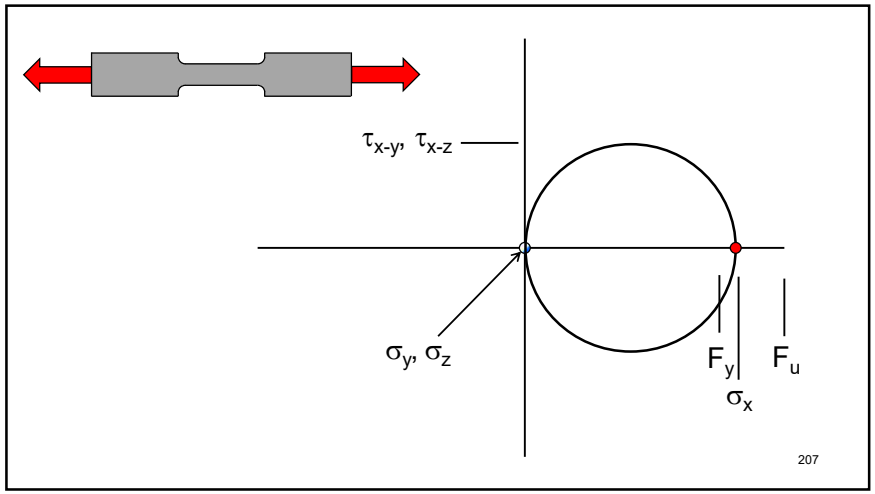

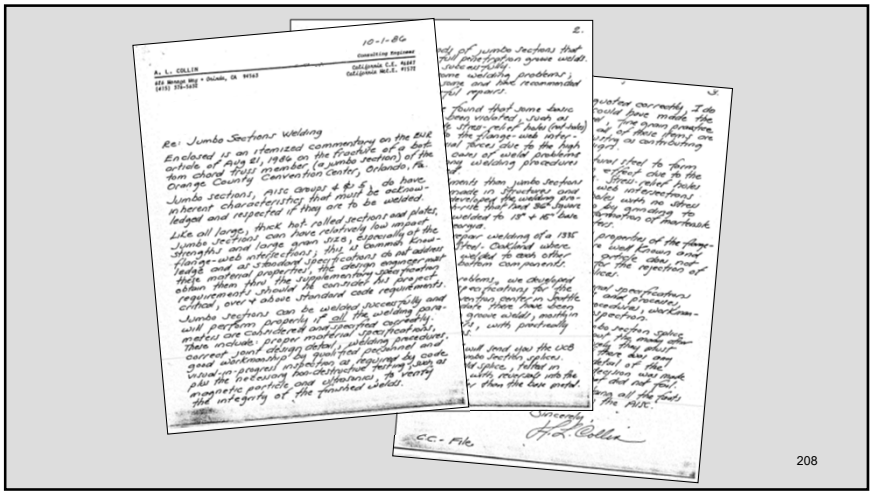

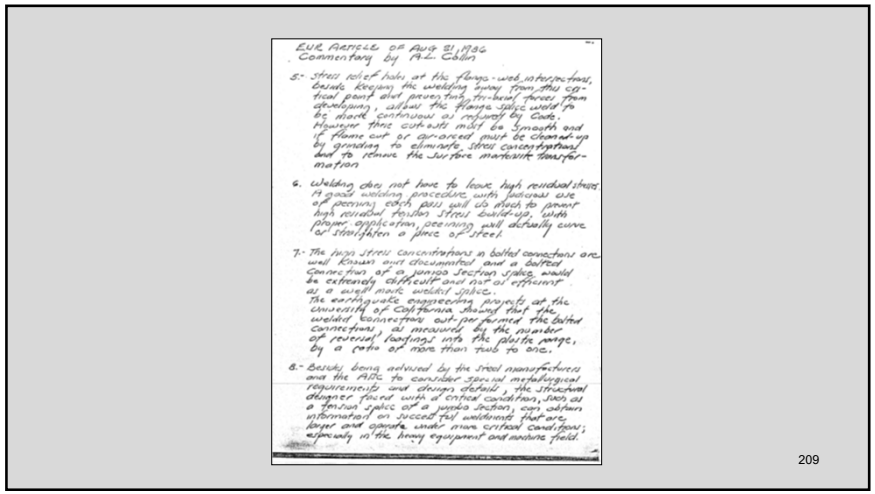
EUR ARTICLE OF Aug 21, 1986
Commentary by A.L. Collin

5.- Stress relief holes at the flange-web intersections, beside keeping the welding away from this critical point and preventing tri-axial forces from developing, allows the flange splice weld to be made continuous as required by Code. However these cut-outs must be smooth and if flame cut or air-arced must be cleaned-up by grinding to eliminate stress concentrations and to remove the surface martensitic transformation

6. Welding does not have to leave high residual stress. If good welding procedure with judicious use of peening both ends will do much to prevent high residual tension stress build-up, with proper application peening will actually cure or straighten a piece of steel.

7.- The high stress concentrations in bolted connections are well known and documented and a bolted connection of a jumbo section splice would be extremely difficult and not at efficient as a well made welded splice.
The earthquake engineering projects at the University of California showed that the welded connections out-performed the bolted connections, as measured by the number of reversal loadings into the plastic range, by a ratio of more than two to one.

8.- Besides being advised by the steel manufacturers and the AISC to consider special metallurgical requirements and design details, the structural designer faced with a critical condition, such as a tension splice at a jumbo section, can obtain information on succesful welding that are larger and operate under more critical conditions; especially in the heavy equipment and nuclear field.

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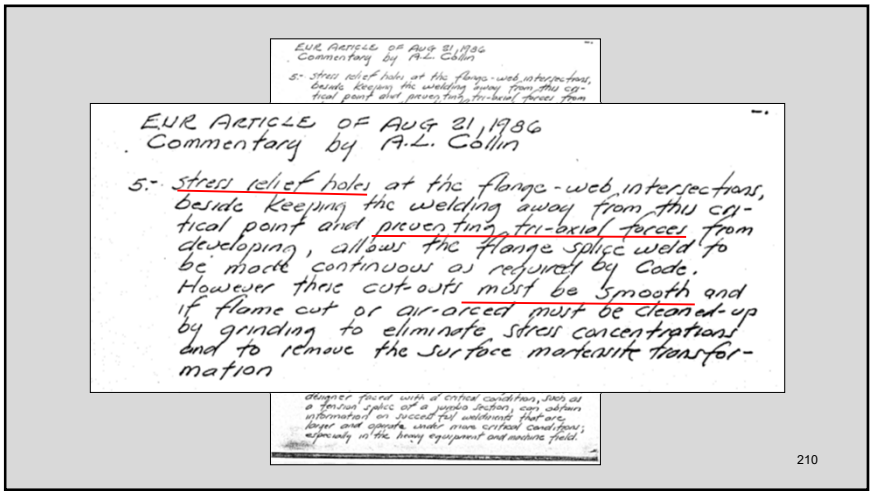
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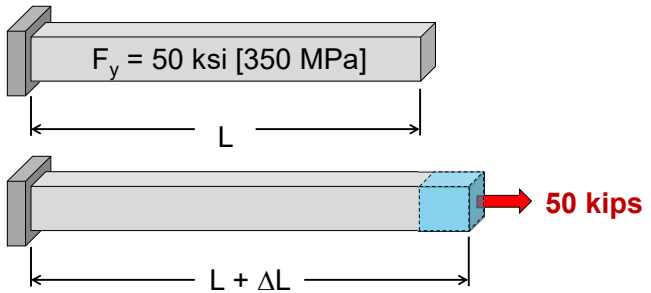
210

Another need for ductility: welding depends on it.

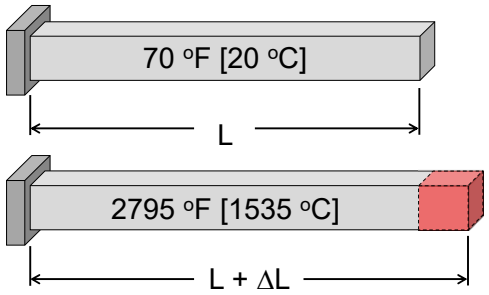
211

$$\Delta L = \frac{PL}{AE} \qquad \Delta L = \frac{50(10)}{1(30E3)} = 0.016 \text{ in } (0.16\ \%)$$



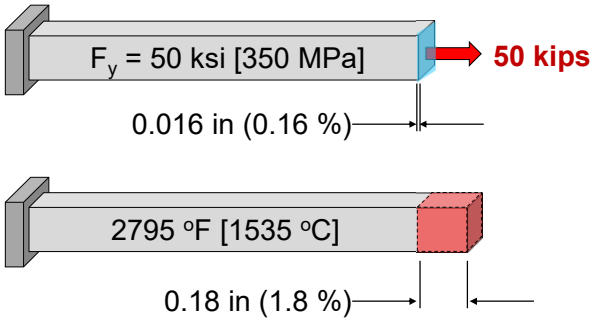
212

$\Delta L = L(\Delta T)C_{exp}$ $\Delta L = 10(2795 - 70)(6.6E-6) = 0.18$ in (1.8 %)



213

Thermal elongation = 10X yield point elongation



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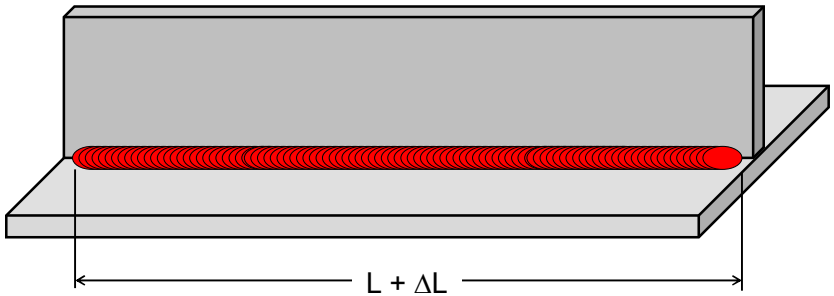

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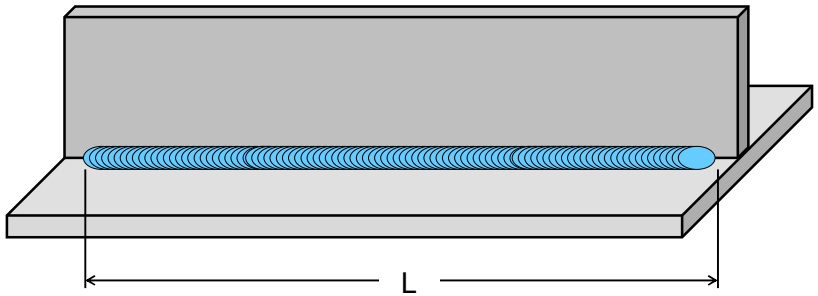

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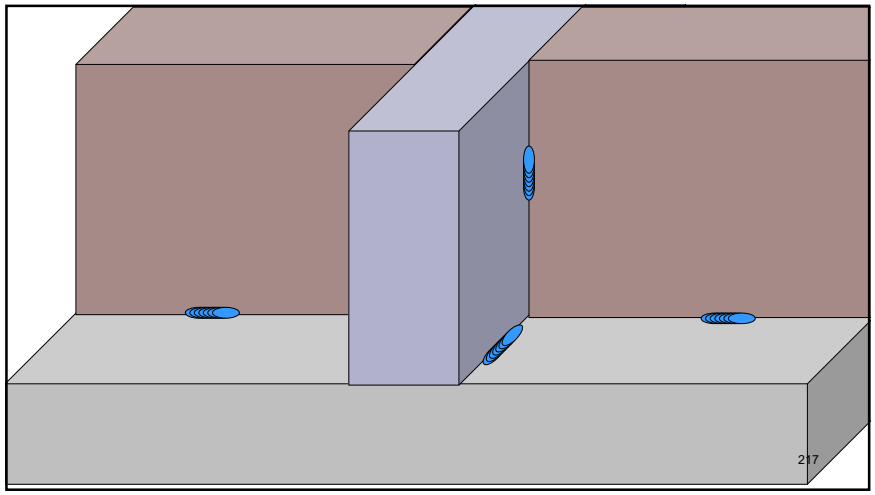

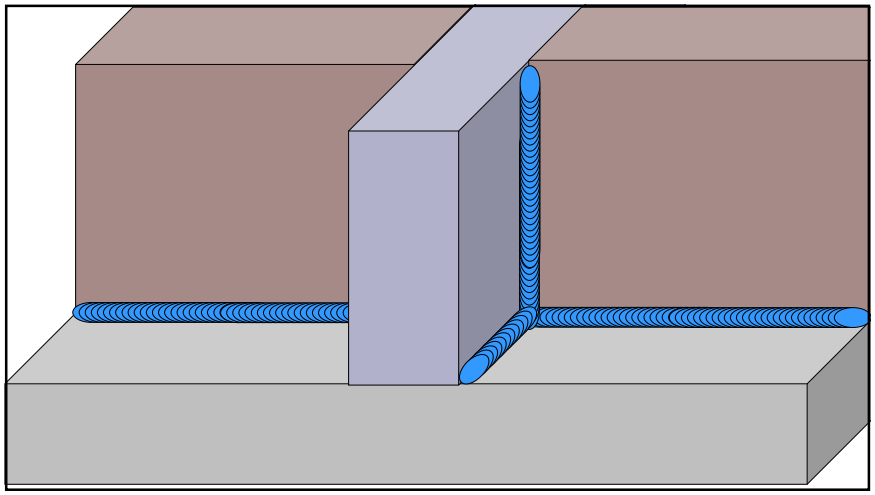

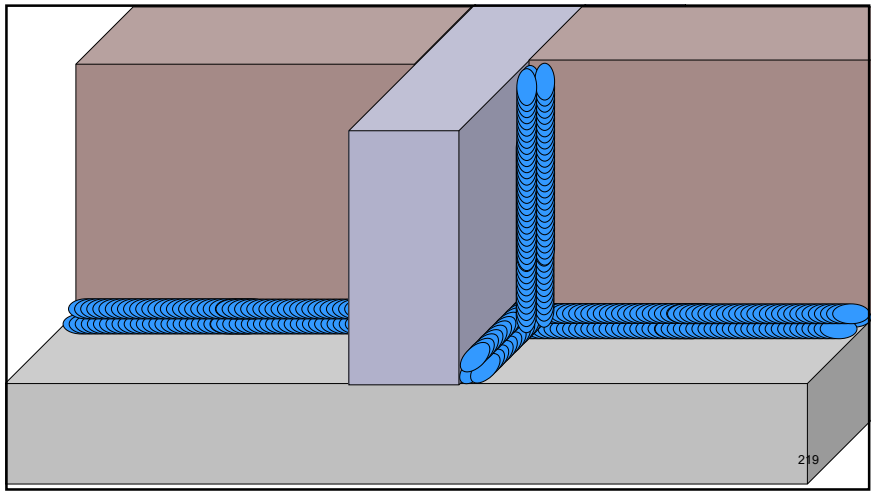

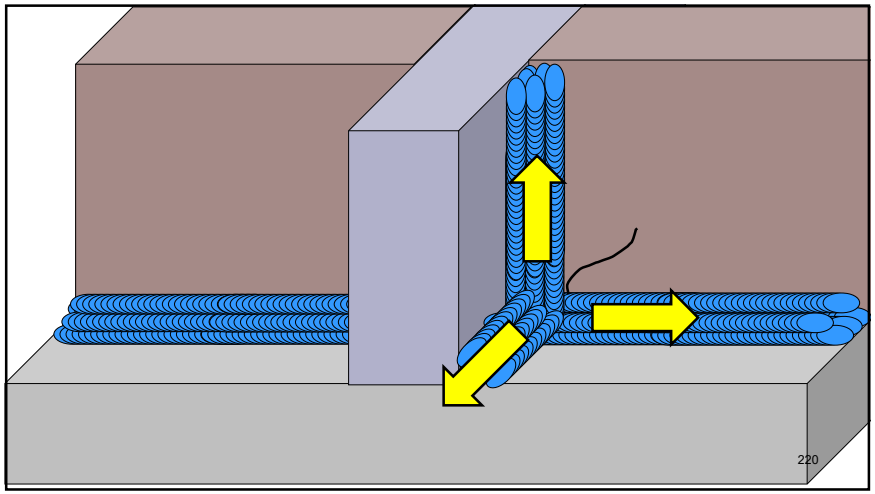

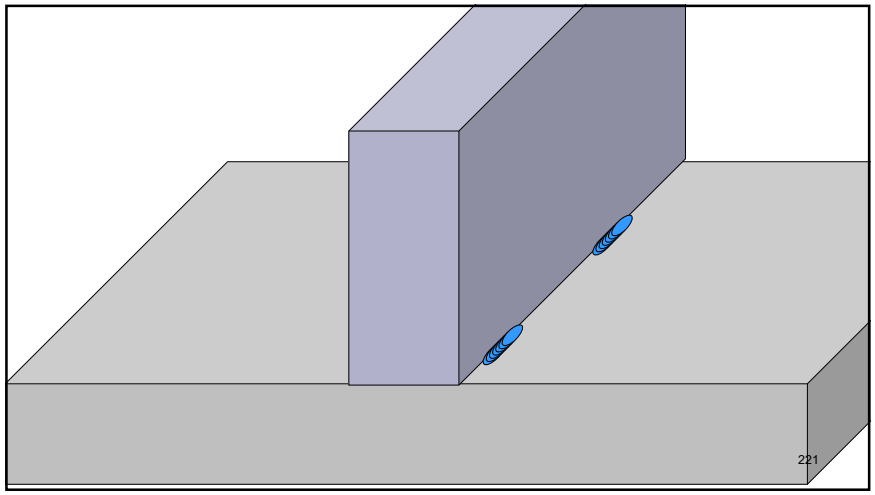

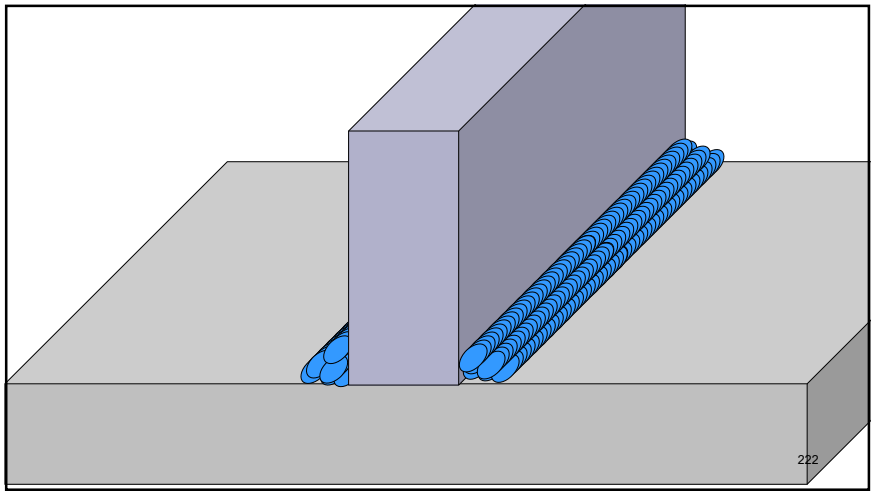

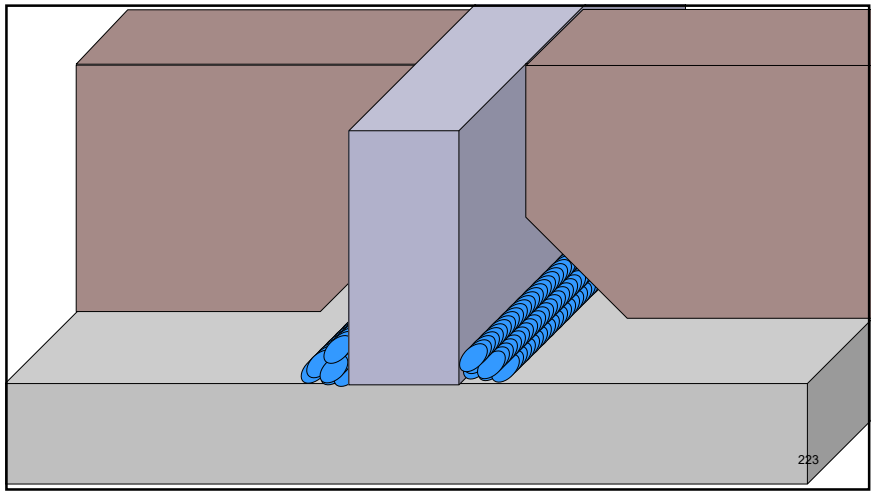

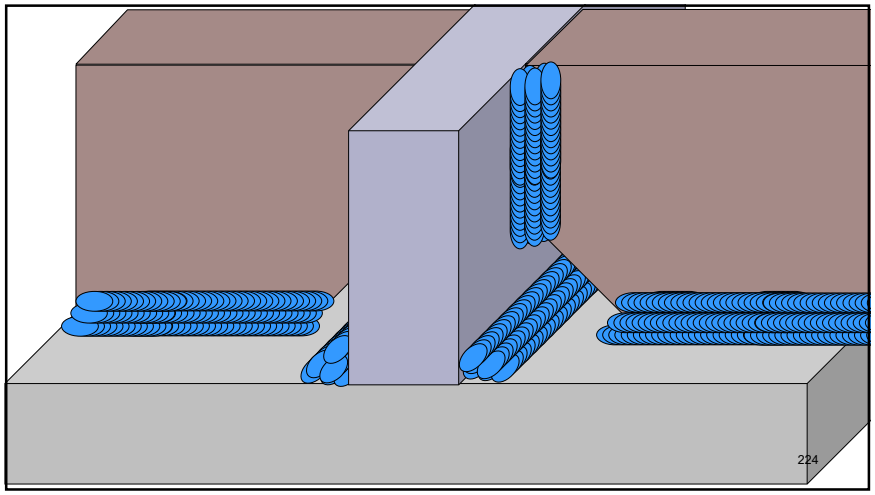

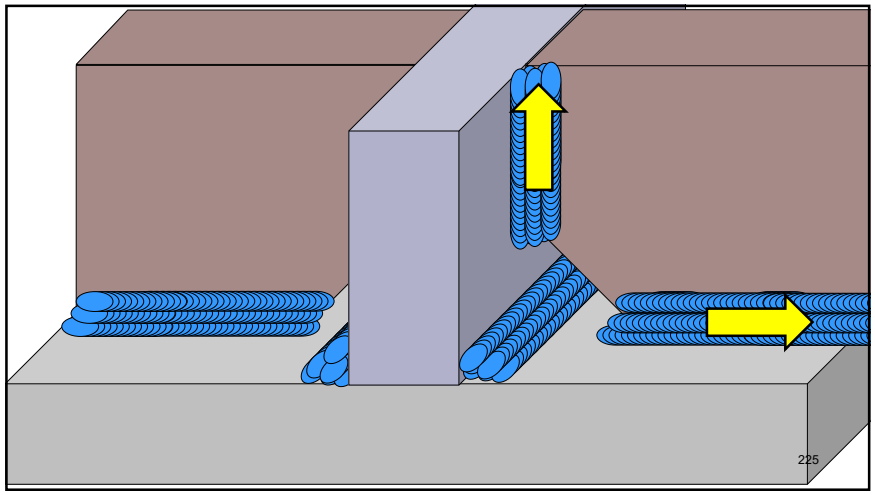

How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength

Demand > Resistance

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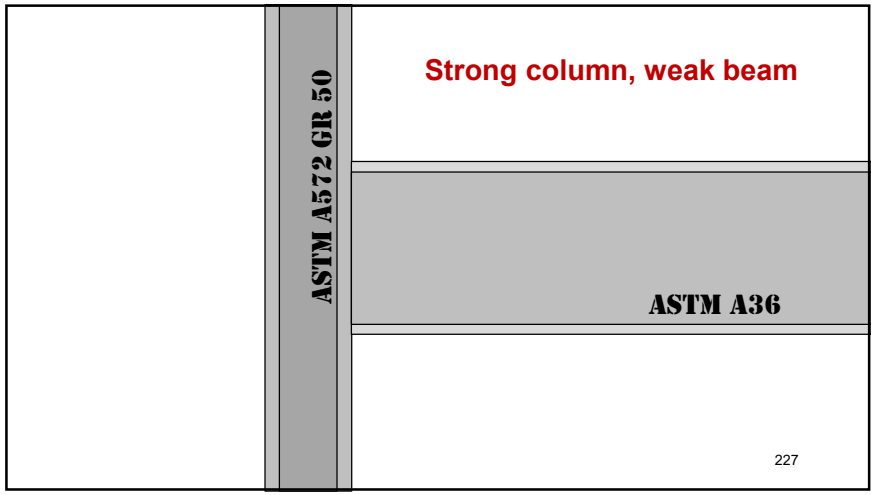

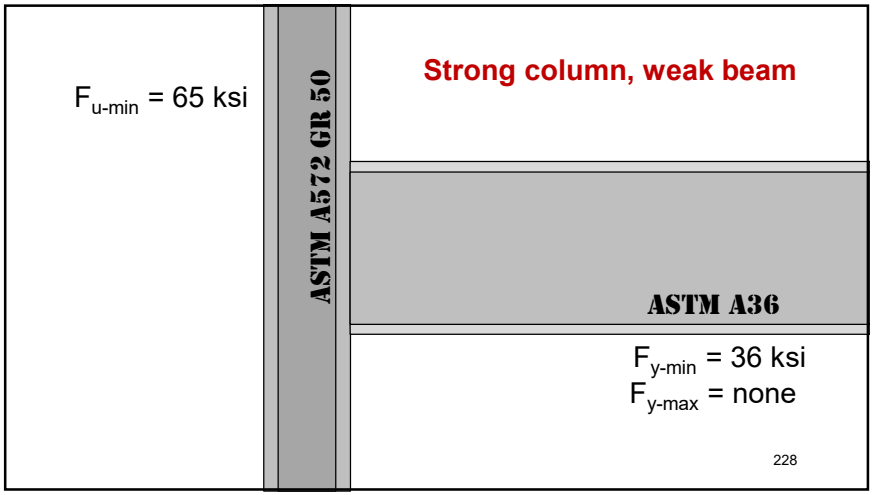

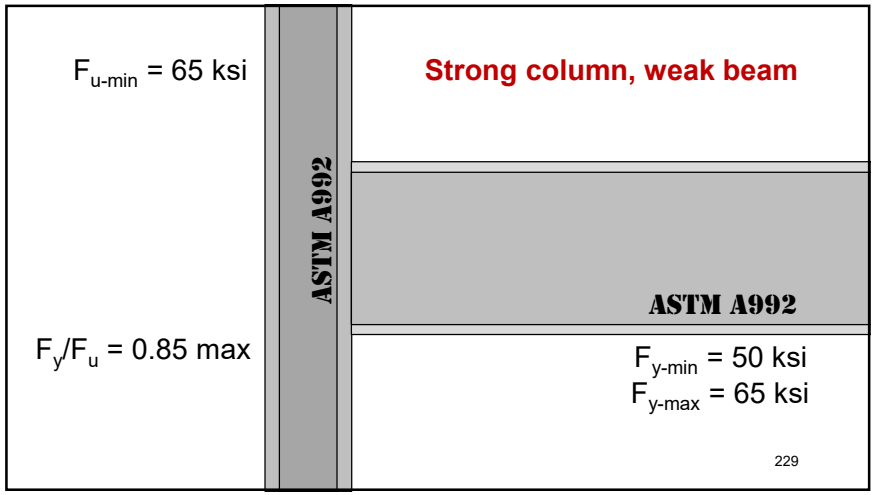

How to Achieve Controlled Inelastic Deformations

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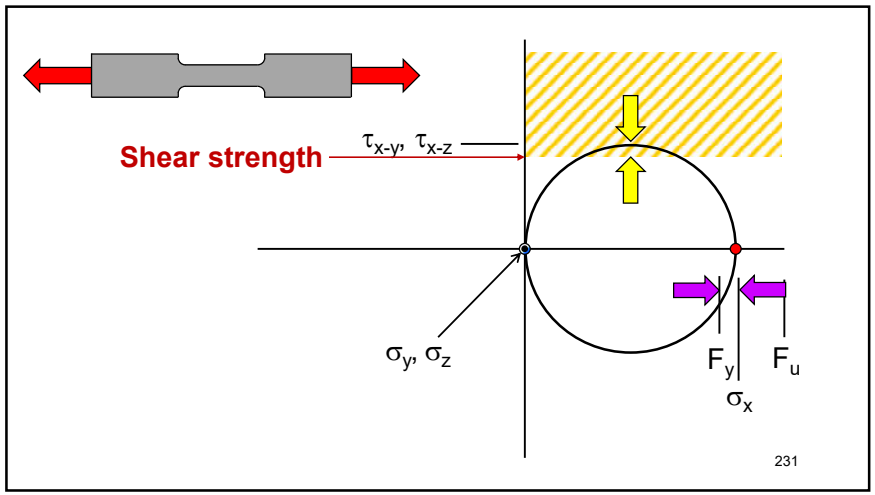
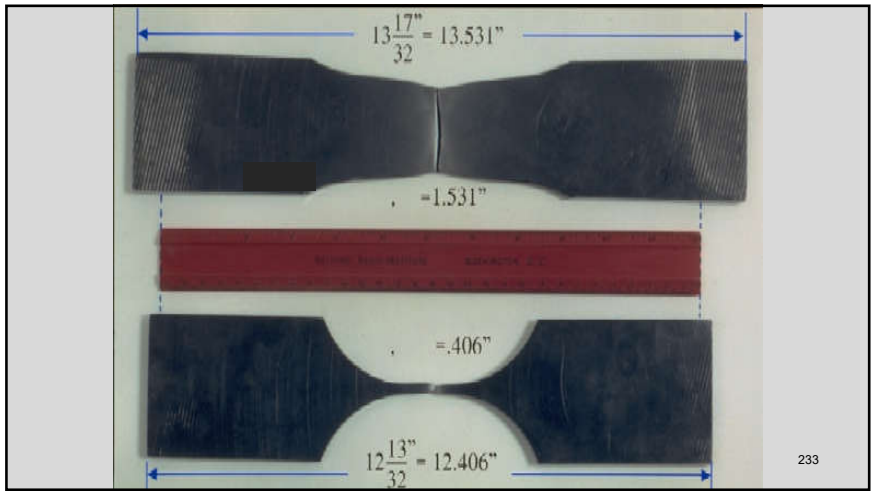
230

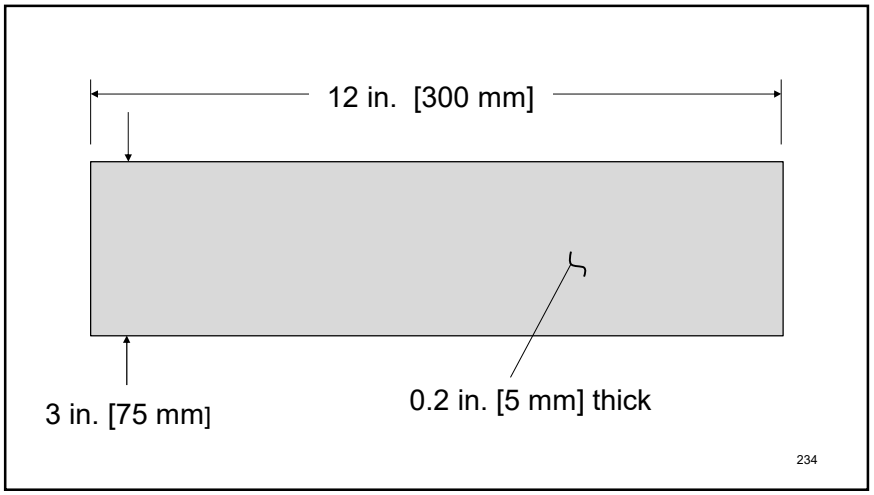


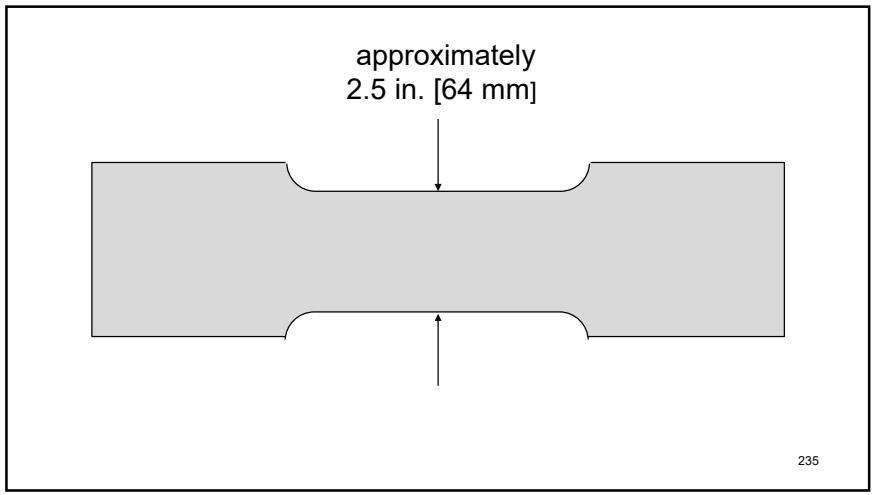
How to Achieve Controlled Inelastic Deformations

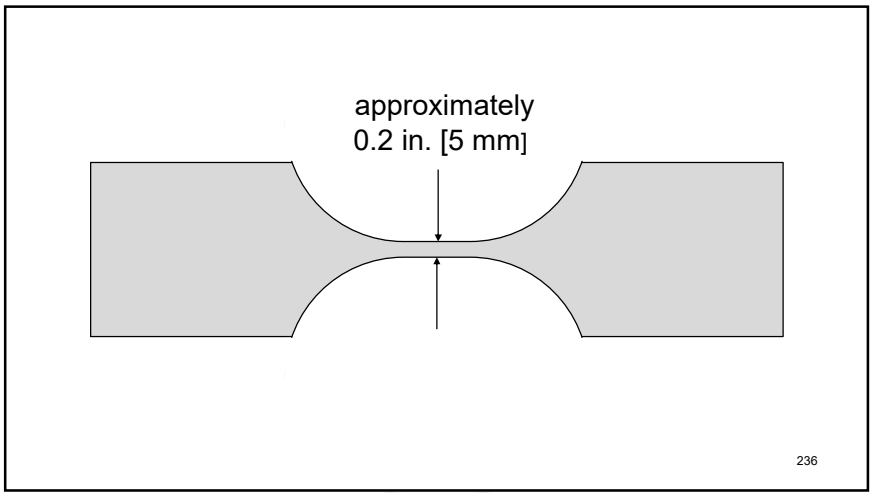
- Select a ductile material
- Avoid conditions that prompt brittle fracture
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength
- Ensure enough material is present to create meaningful displacements

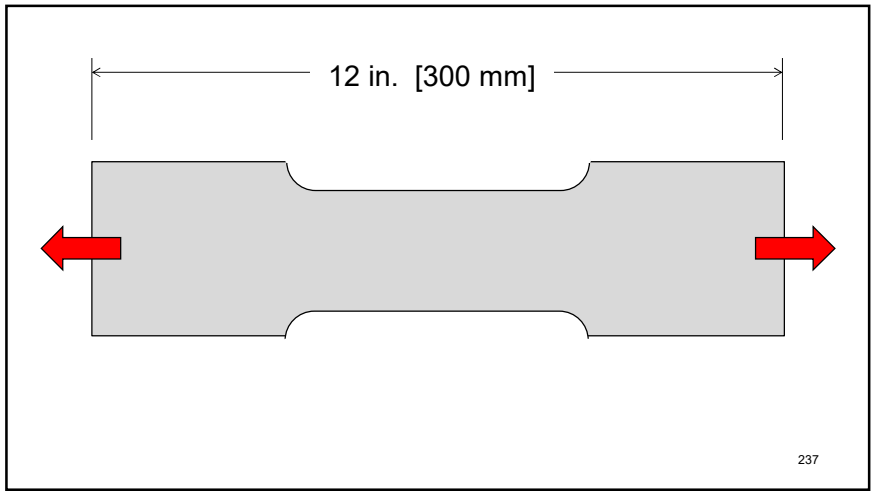
232

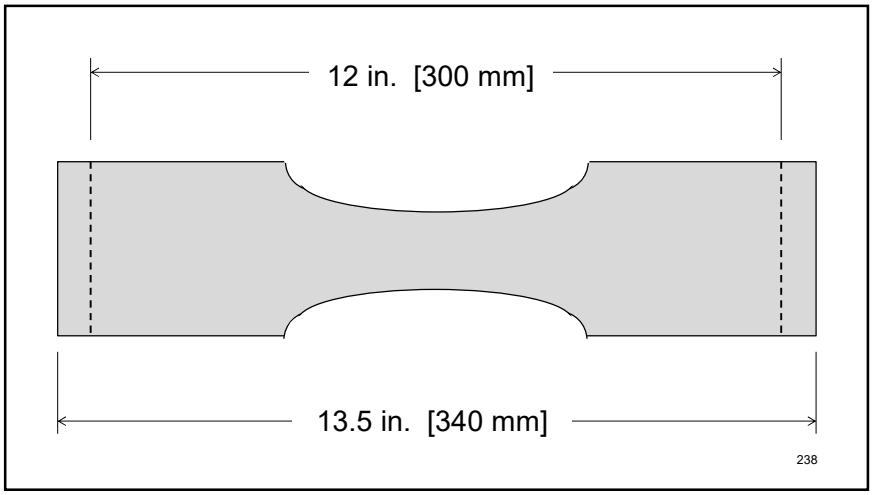


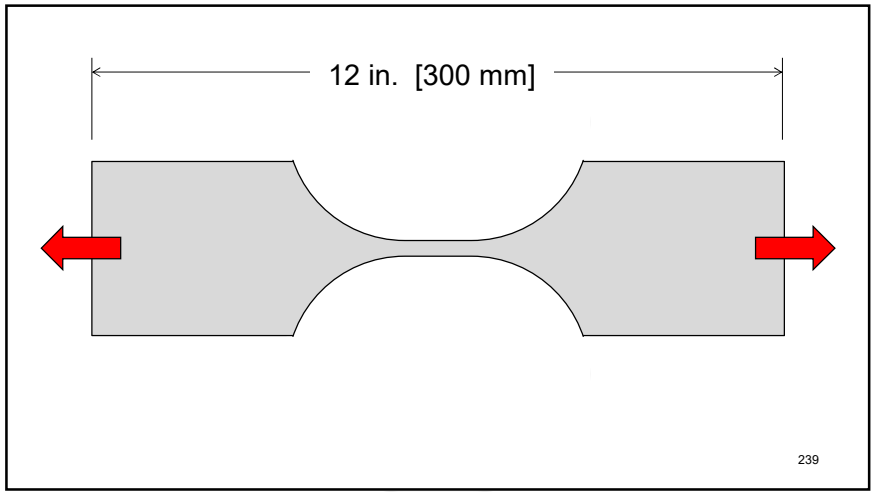


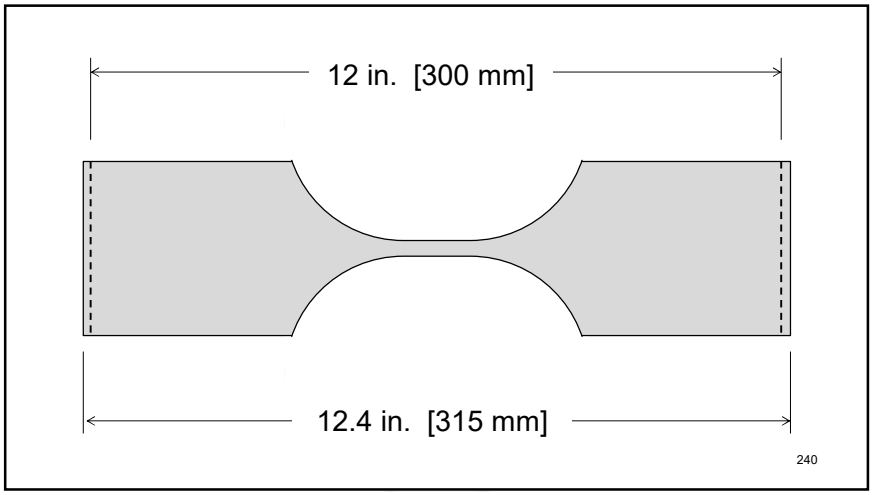


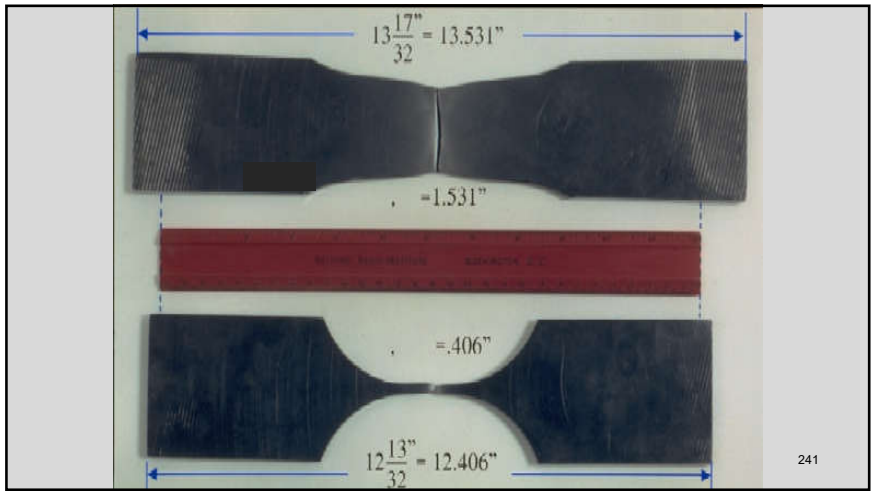


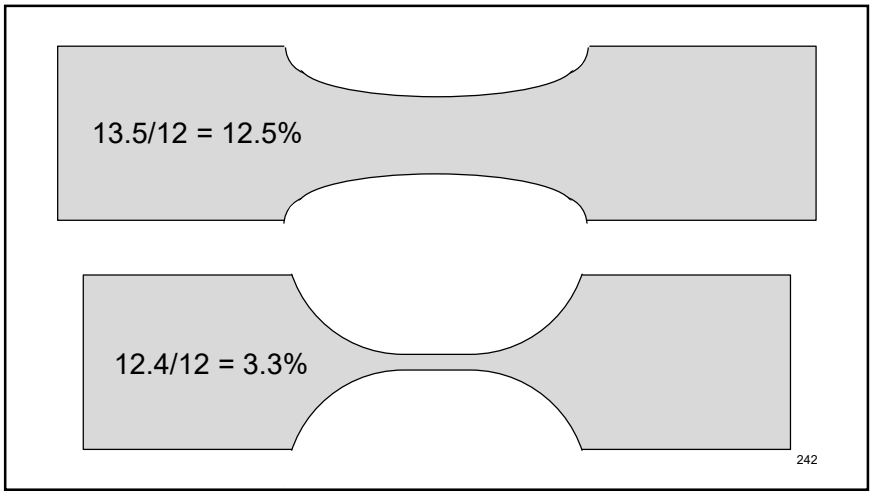


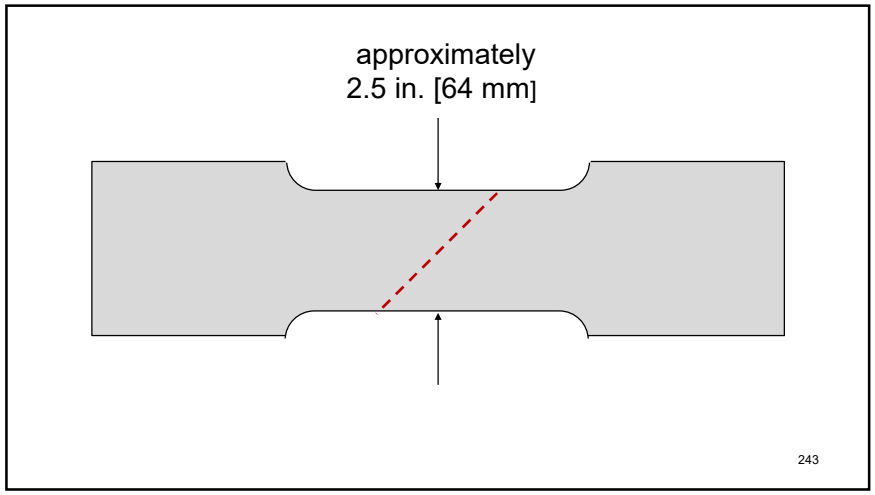


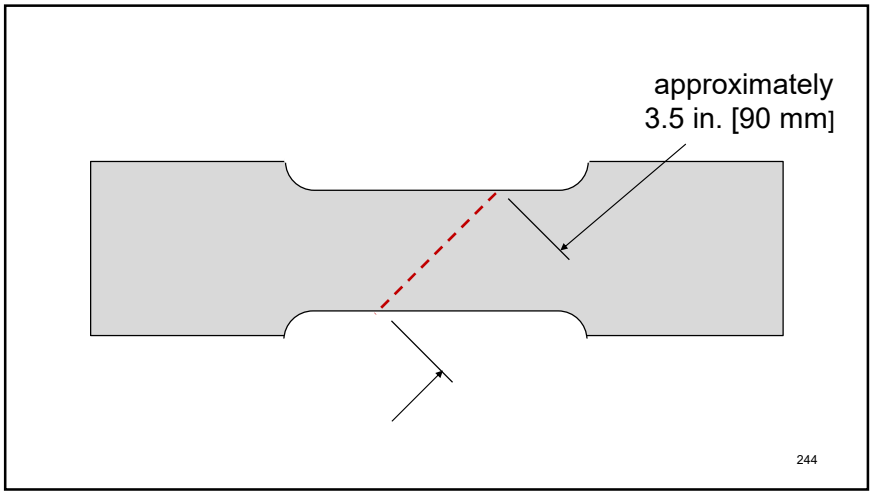


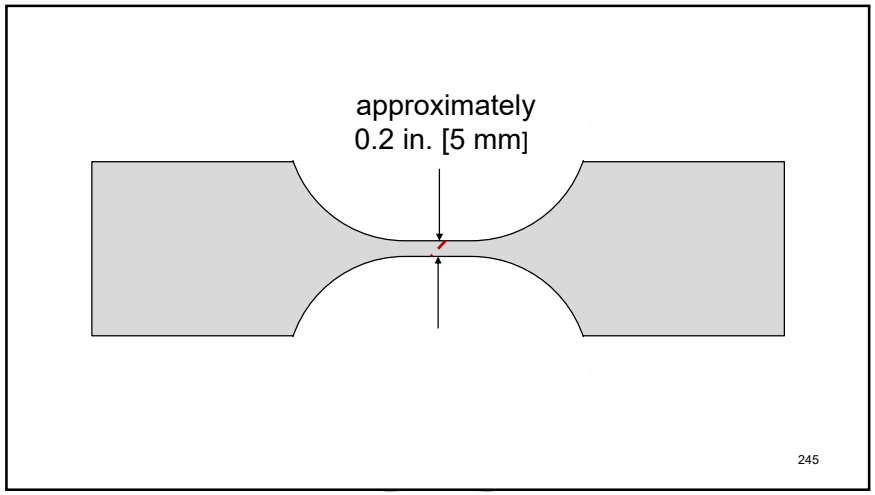


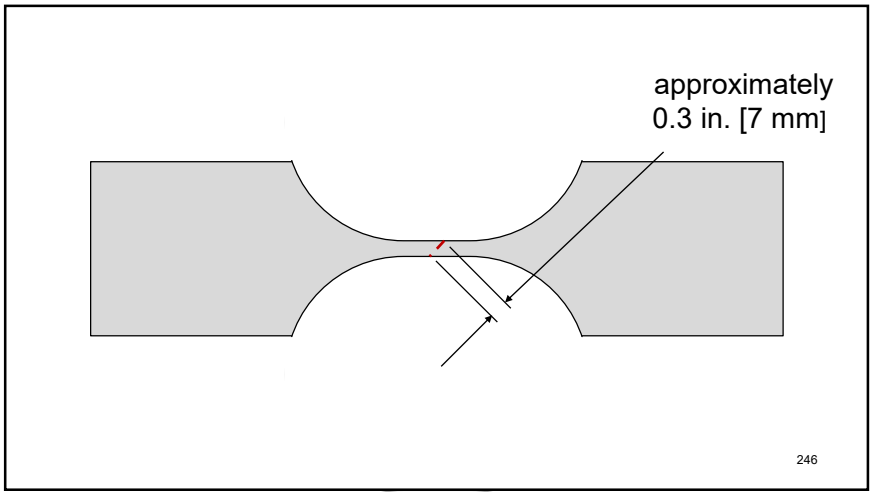


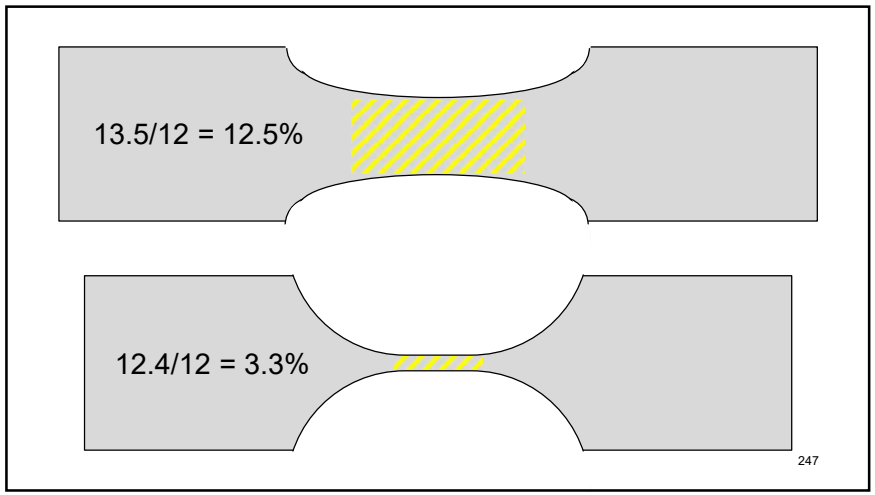


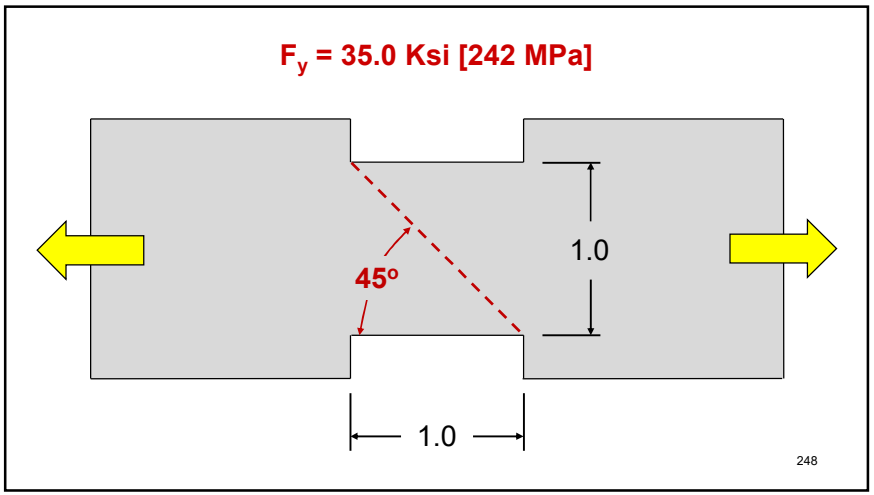


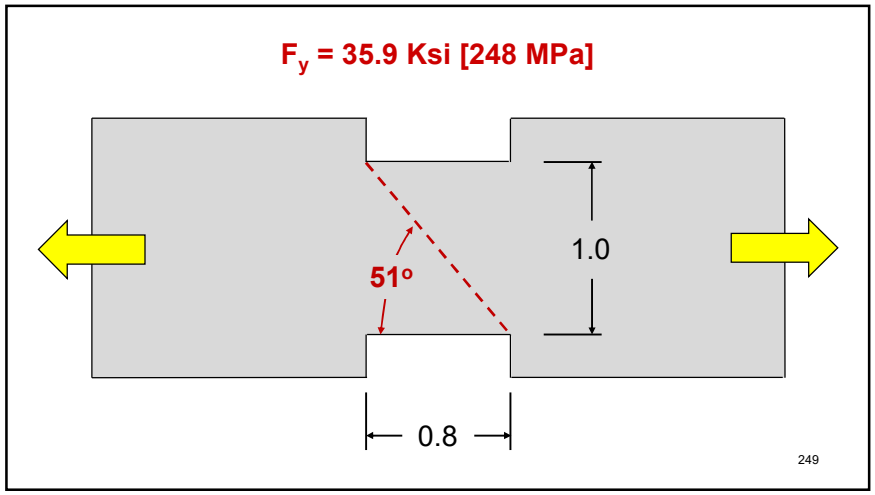


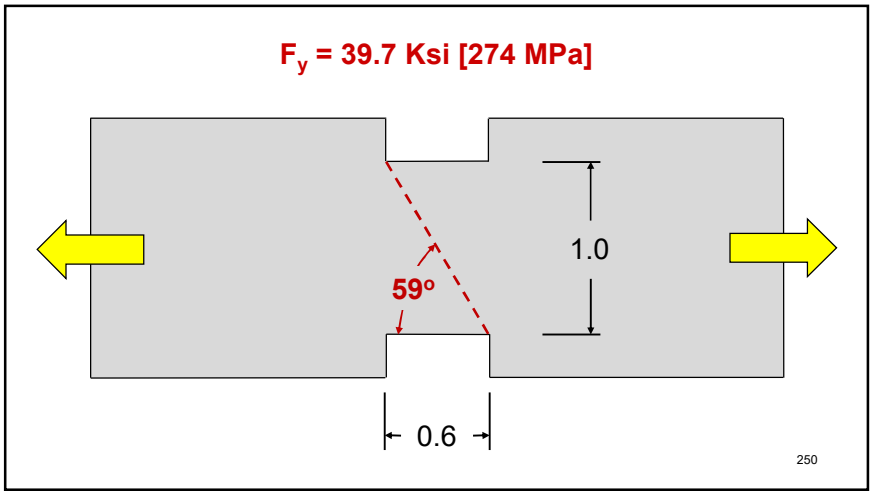


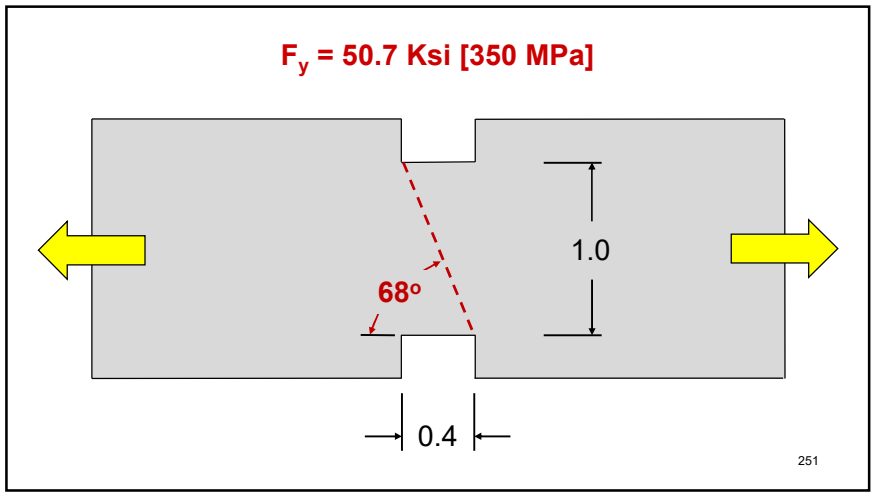


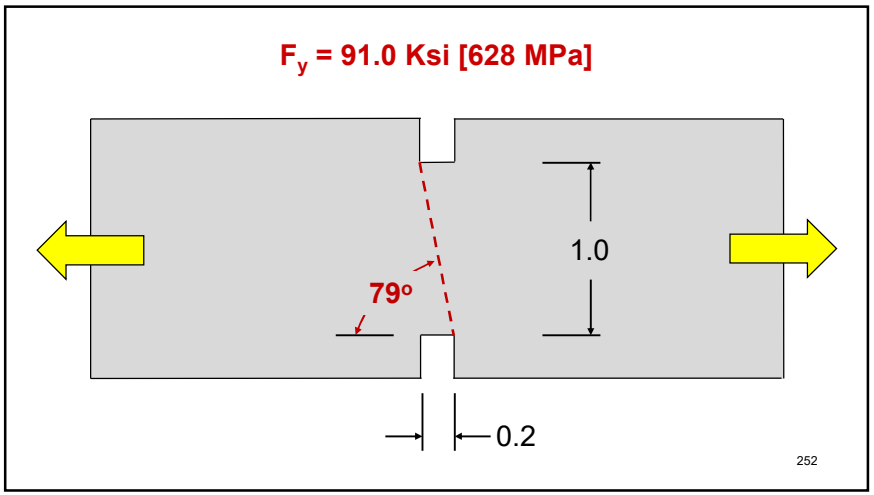












Width	Length	Angle	Yield Stress (ksi)	Yield Stress (MPa)
1.0	1.0	45°	35.0	242
	0.8	51°	35.9	248
	0.6	59°	39.7	274
	0.4	68°	50.7	350
	0.2	79°	91.0	628

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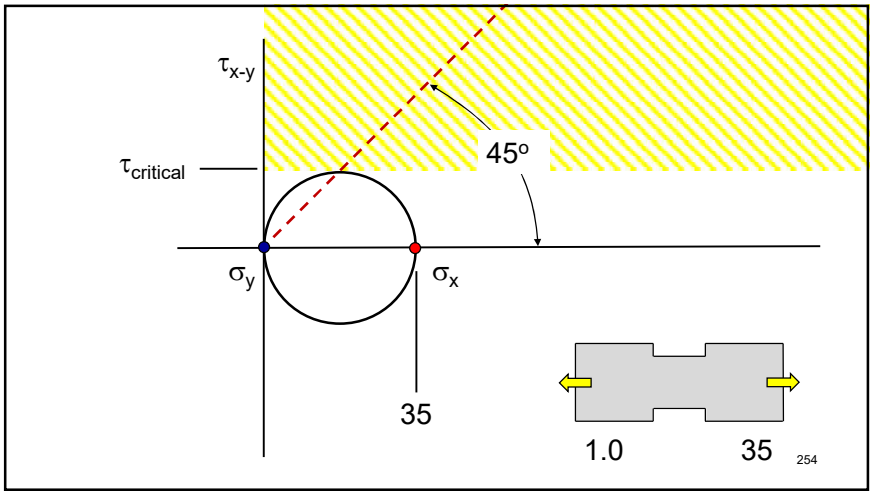

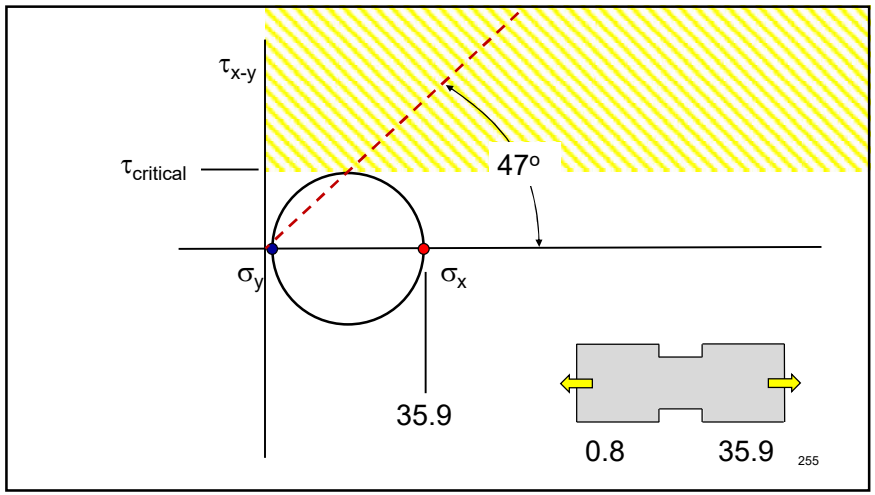

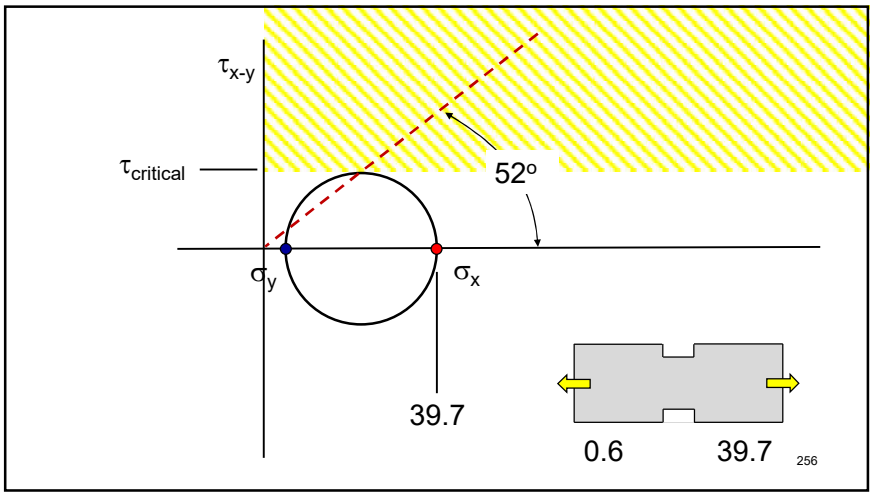

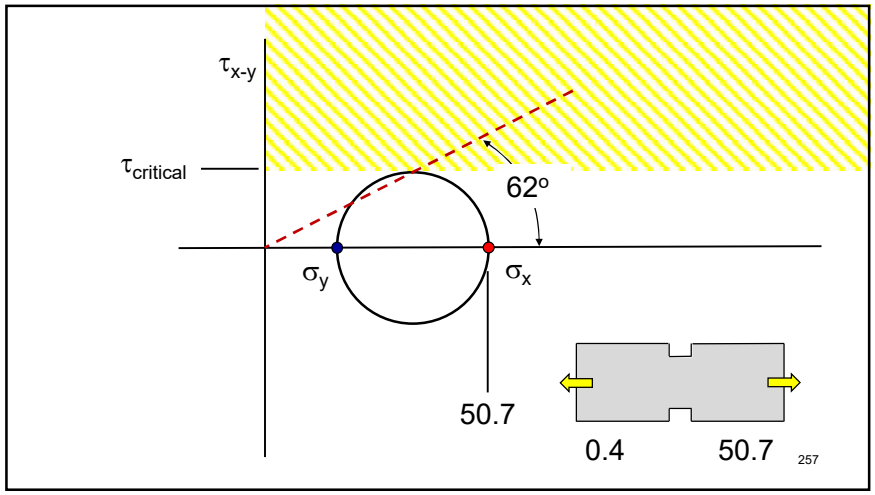

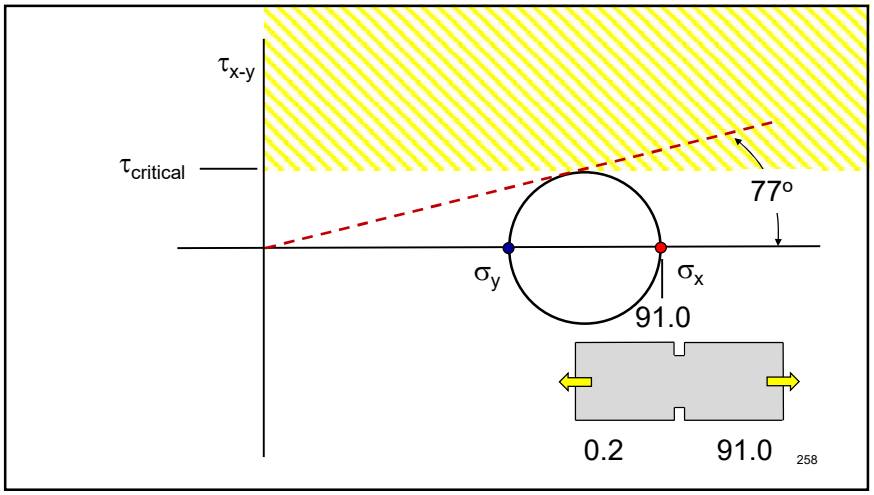

Width	Length	Angle	Yield Stress (ksi)	Yield Stress (MPa)	Angle-graphical	%
1.0	1.0	45°	35.0	242	45°	0
	0.8	51°	35.9	248	47°	8
	0.6	59°	39.7	274	52°	13
	0.4	68°	50.7	350	62°	10
	0.2	79°	91.0	628	77°	2

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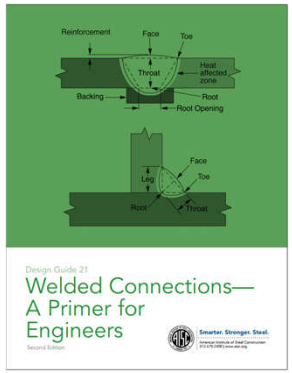
AISC Design Guide 21, 2nd Edition

Welded Connections–

A Primer for Engineers



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Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short

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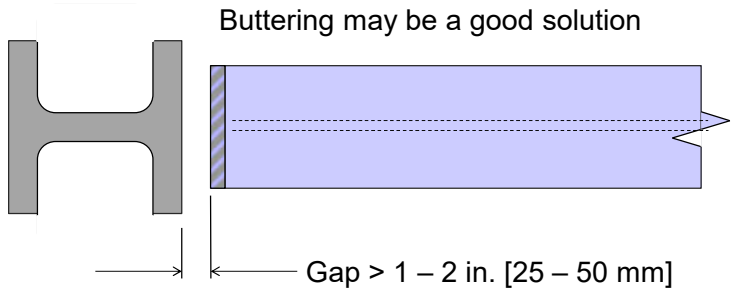
Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short



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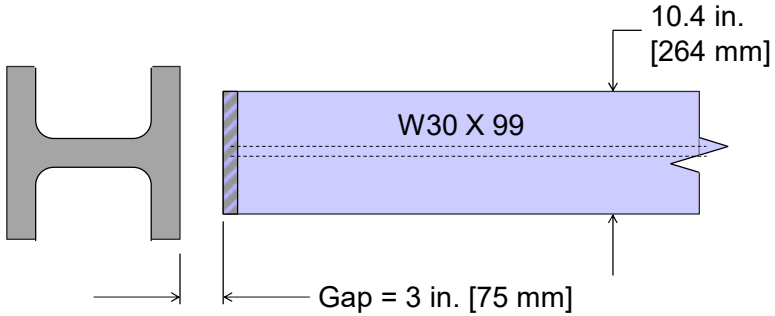
Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short



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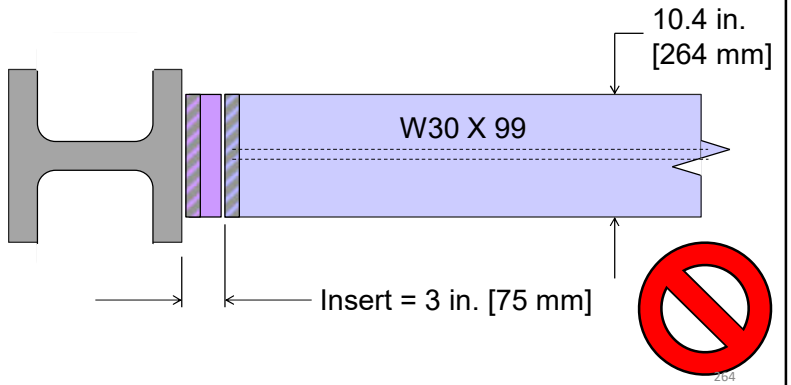
Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short



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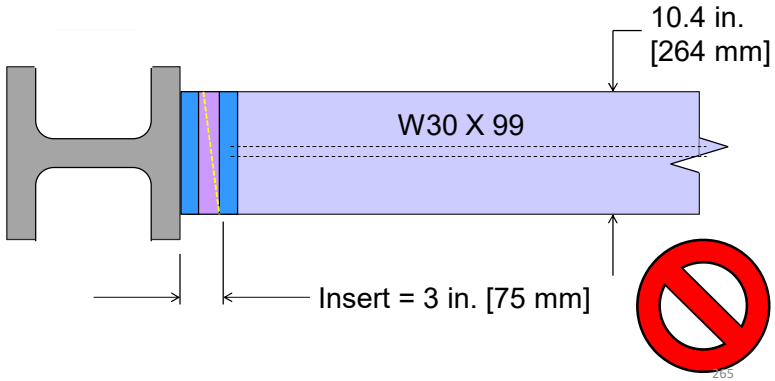
Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short



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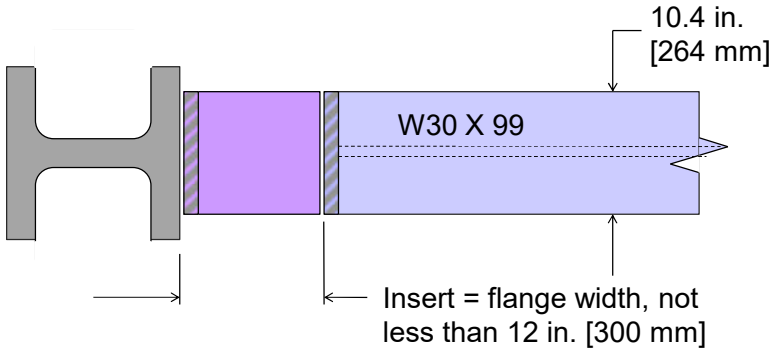

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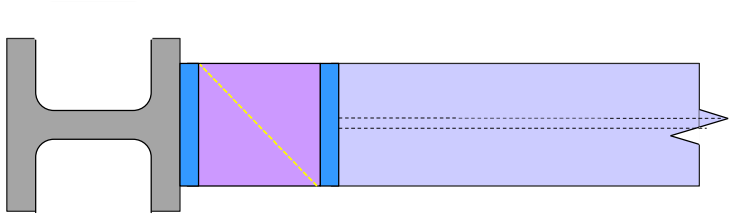
Chapter 15: Problems and Fixes

15.5 Fixing Members That Are Cut Short



The additional material between the two parallel welds accommodates weld shrinkage strains.

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How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength
- Ensure enough material is present to create meaningful displacements
- Ensure movement is in a meaningful direction

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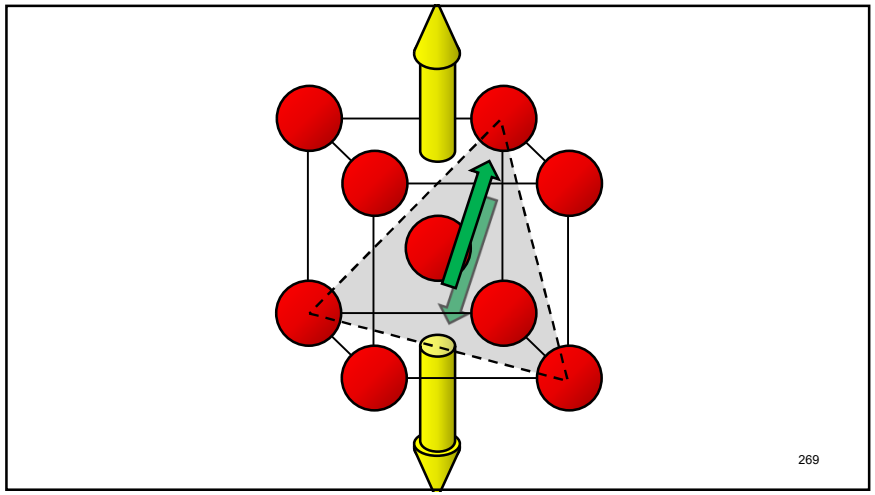

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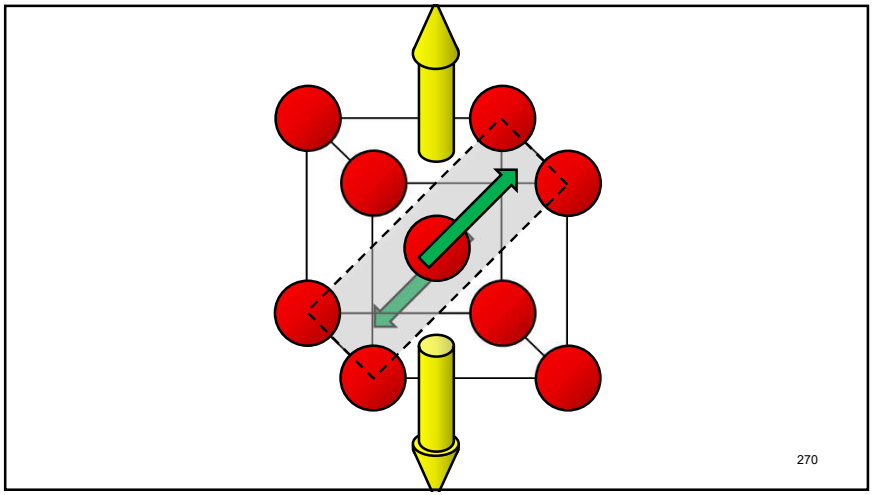

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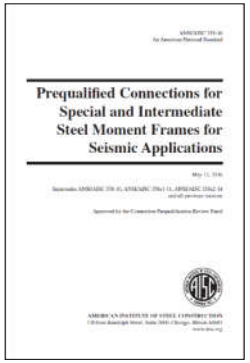
ANSI/AISC 358-16
An American National Standard

Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications



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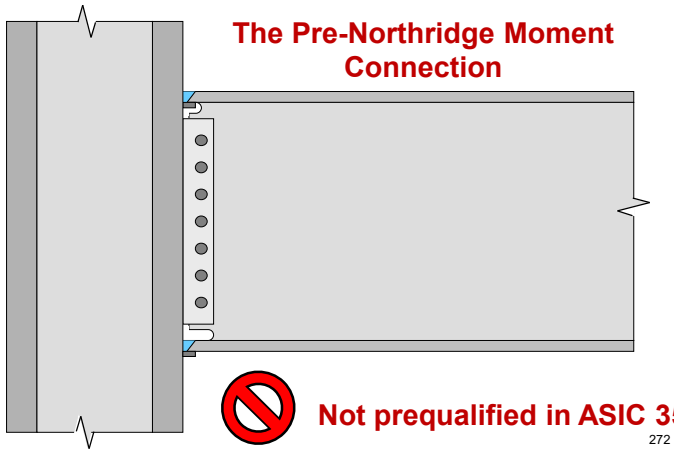

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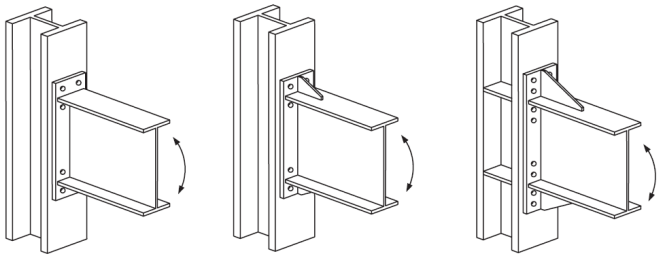
AISC 358-16 Prequalified Connections

Bolted End Plate Moment Connection



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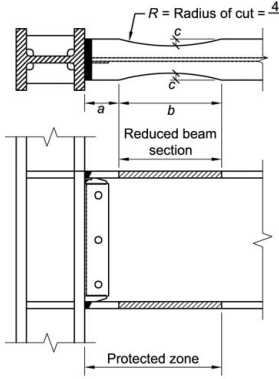
AISC 358-16 Prequalified Connections

Reduced Beam Section (RBS) Moment



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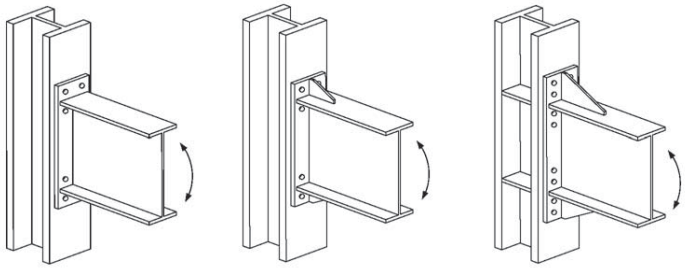
AISC 358-16 Prequalified Connections

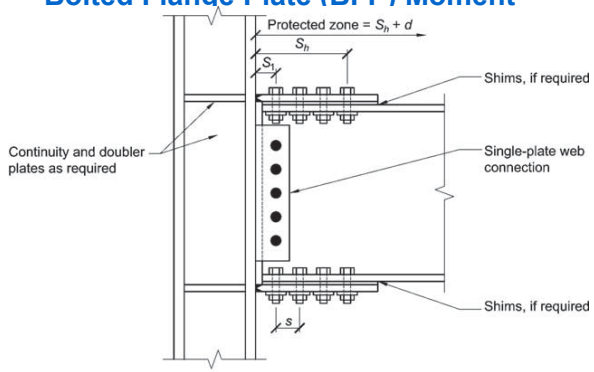
Bolted Unstiffened and Stiffened Extended End-Plate moment connections (BUUEP, BSEEP)



275

AISC 358-16 Prequalified Connections

Bolted Flange Plate (BFP) Moment



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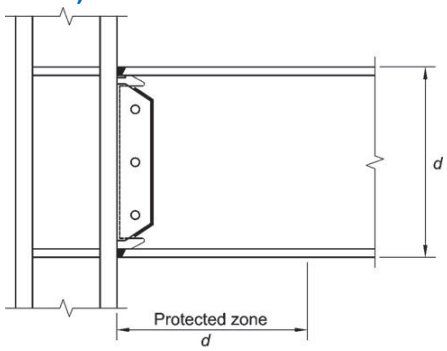
AISC 358-16 Prequalified Connections

Welded Unreinforced Flange-Welded Web (WUF-W) Moment Connection



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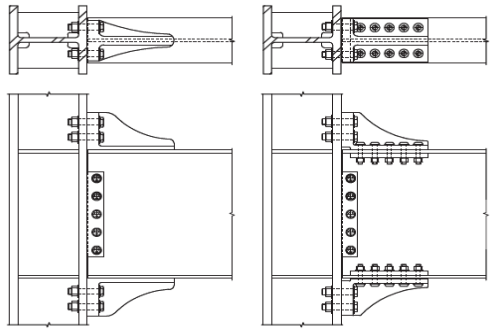
AISC 358-16 Prequalified Connections

Kaiser Bolted Bracket (KBB) Moment Connection



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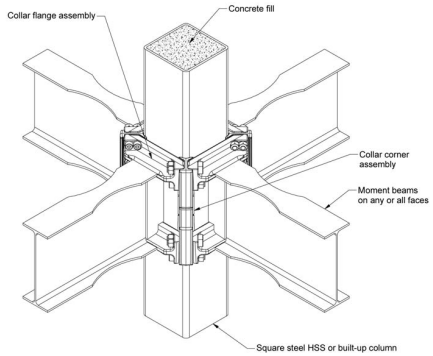
AISC 358-16 Prequalified Connections

CONXTECH ® CONXL™ Moment Connection



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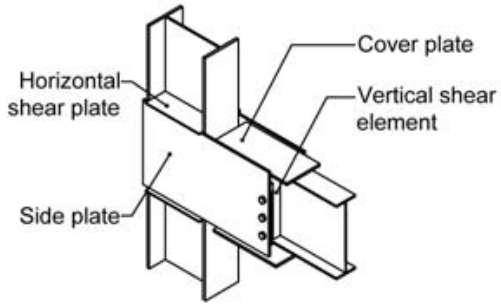
AISC 358-16 Prequalified Connections

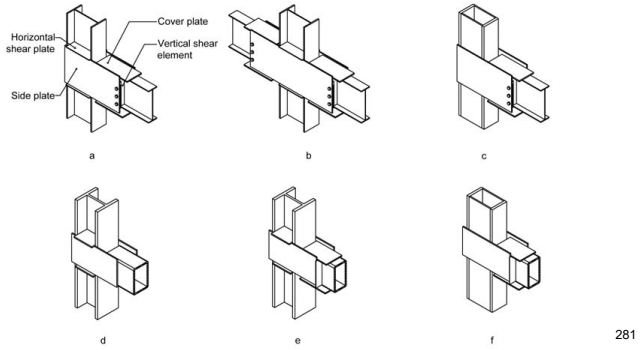
SidePlate® Moment Connection



280

AISC 358-16 Prequalified Connections

SidePlate® Moment Connection



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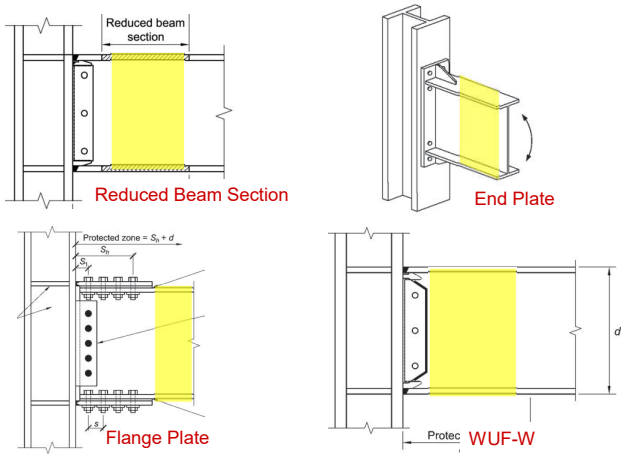

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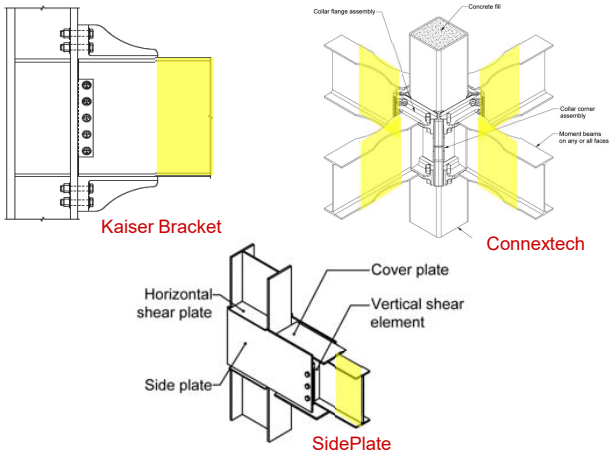

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Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View
- The View of Physics
- Application of the Correct View

AISC | Questions?

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CEU / PDH Certificates

For those participating at their own connection…

- Reporting attendance is not necessary.
- Certificates will be issued based on AISC's attendance record.
- You will be receiving certificates via email from registration@aisc.org.

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CEU / PDH Certificates

For those participating at one connection with a group…

- Main registrant will report attendance via an online form. (The link will be provided in an email from registration@aisc.org.)
  - Username: Same as AISC website username.
  - Password: Same as AISC website password.
- Once attendance has been reported, each group member will be receiving certificates via email from registration@aisc.org.

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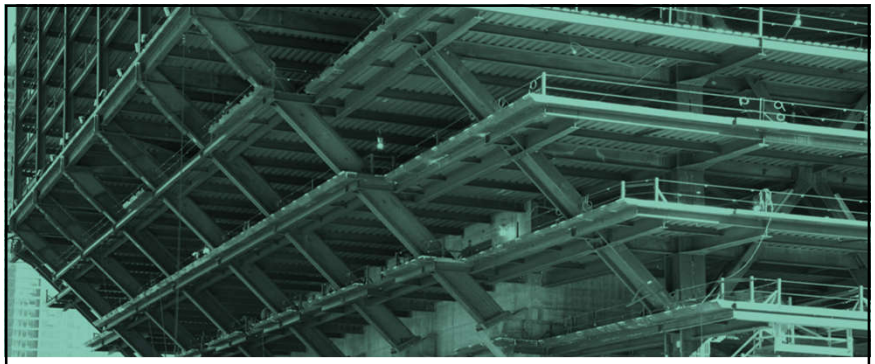

AISC | Thank you

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