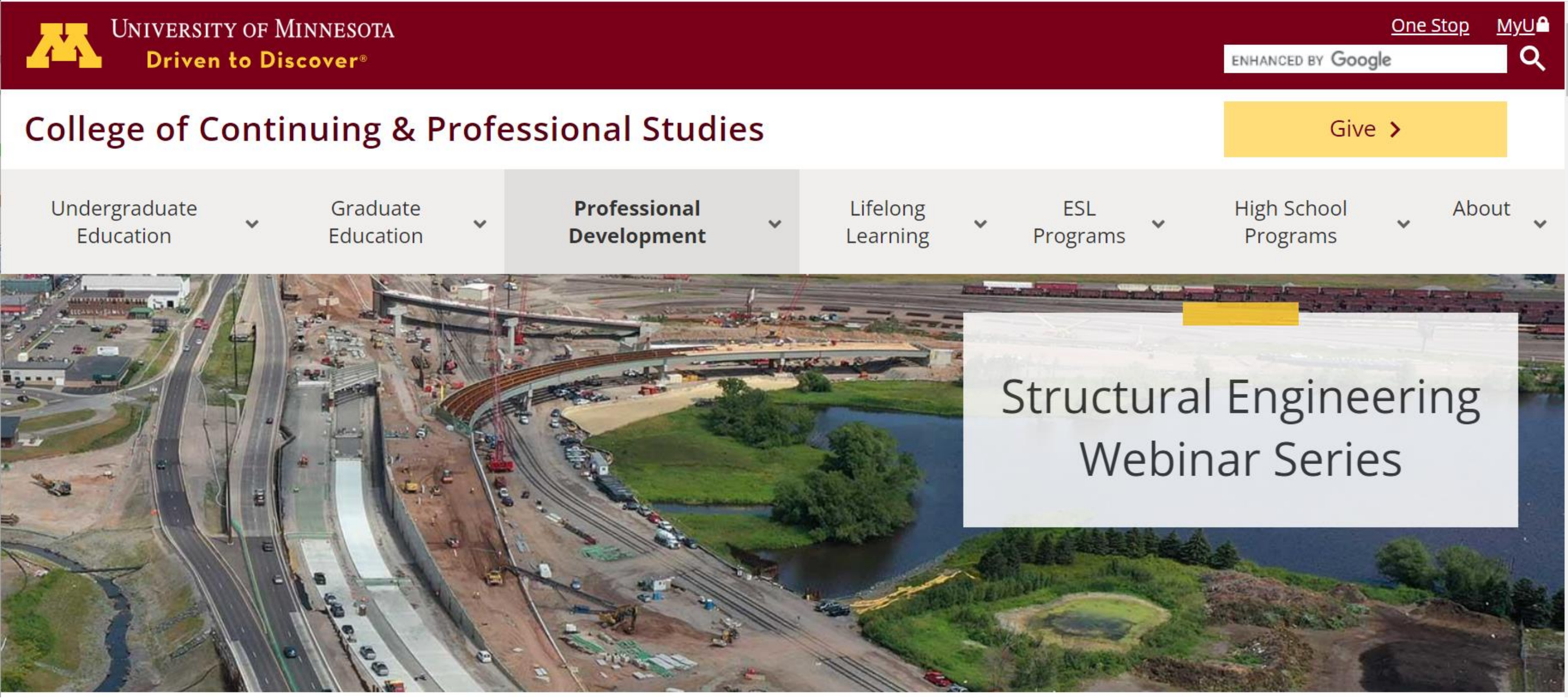


LISTEN to the STEEL

Ductility: Another View

LINCOLN® ELECTRIC

Ductility: Another View

Outline

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

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

The engineering fracture strain is one measure of ductility.

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

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.

GLOSSARY

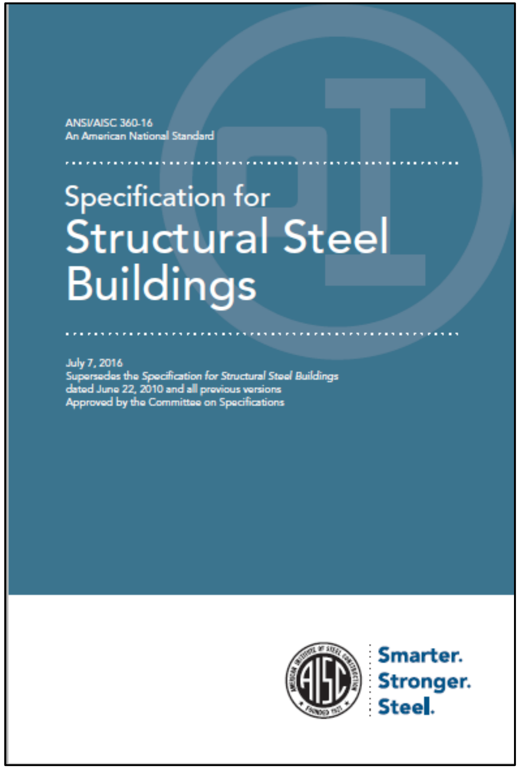
Ductile limit state

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.

GLOSARY

Percent elongation

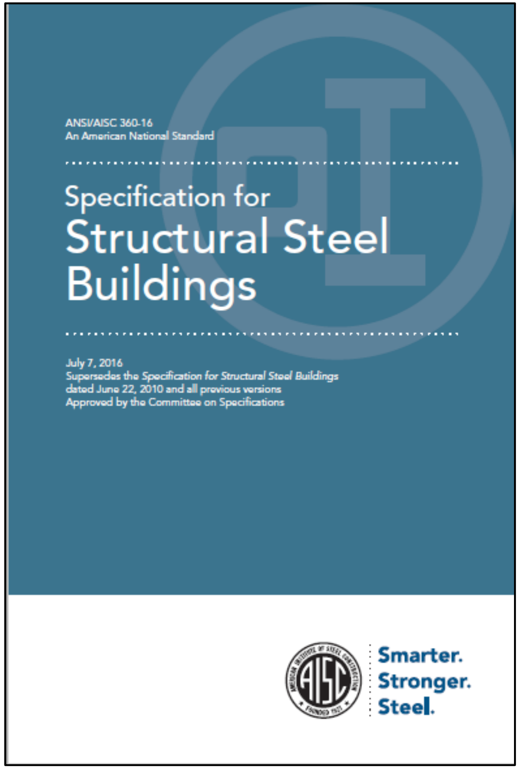
Measure of **ductility**, determined in a tensile test as the maximum elongation of the gage length divided by the original gage length expressed as a percentage.



COMMENTARY GLOSSARY

Brittle fracture.

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



Ductility: Another View

Outline

- Introduction

Might mean different things to different people.

Ductility: Another View

Outline

- Introduction
- A Wrong View
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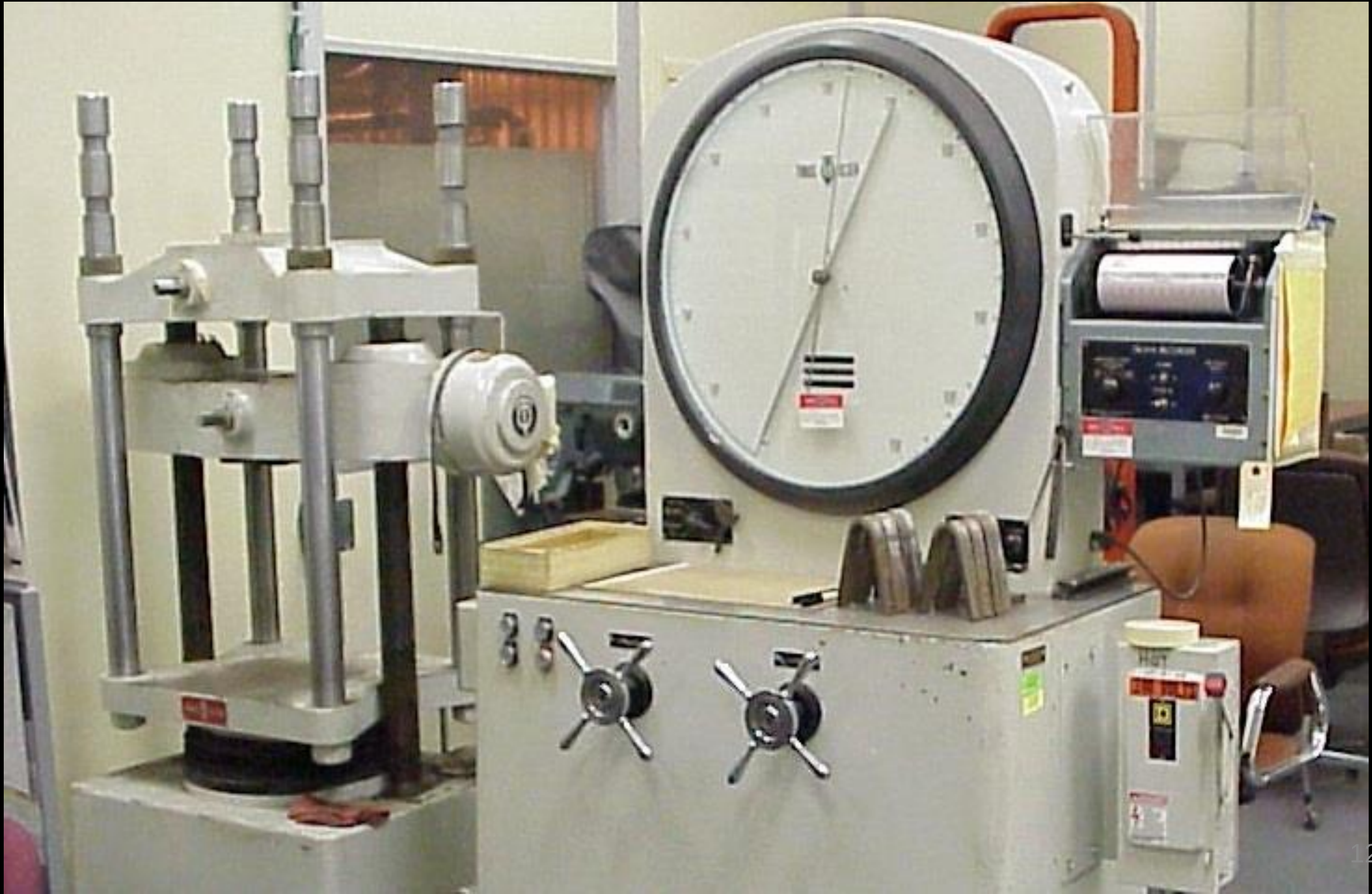
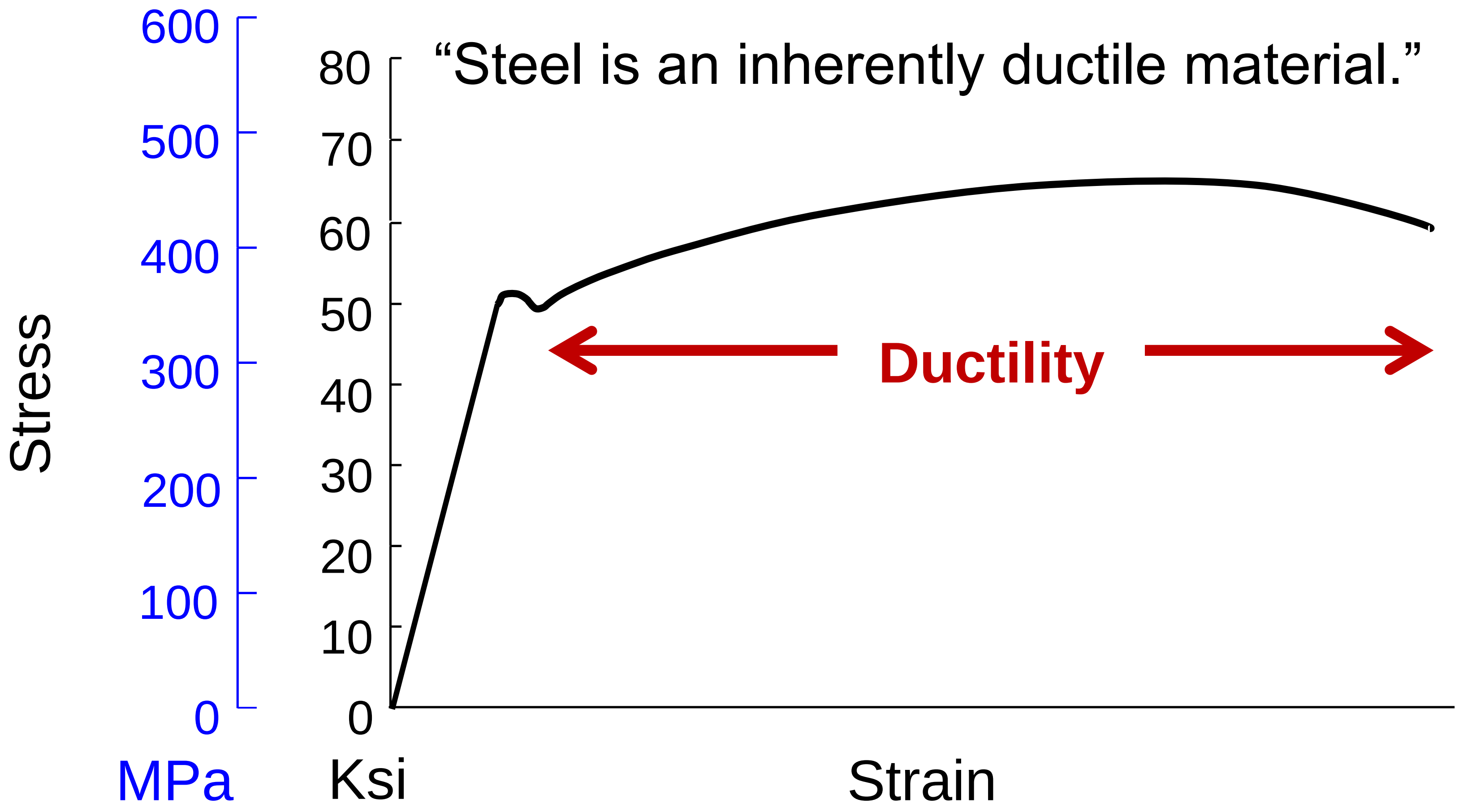



"Steel is an inherently ductile material."
Stress
600
500
400
300
200
100
0
MPa
80
70
60
50
40
30
20
10
0
Ksi
Ductility
Strain


SS SCHENECTADY

Ductility: Another View

Outline

- Introduction
- A Wrong View

Ductility is a material property

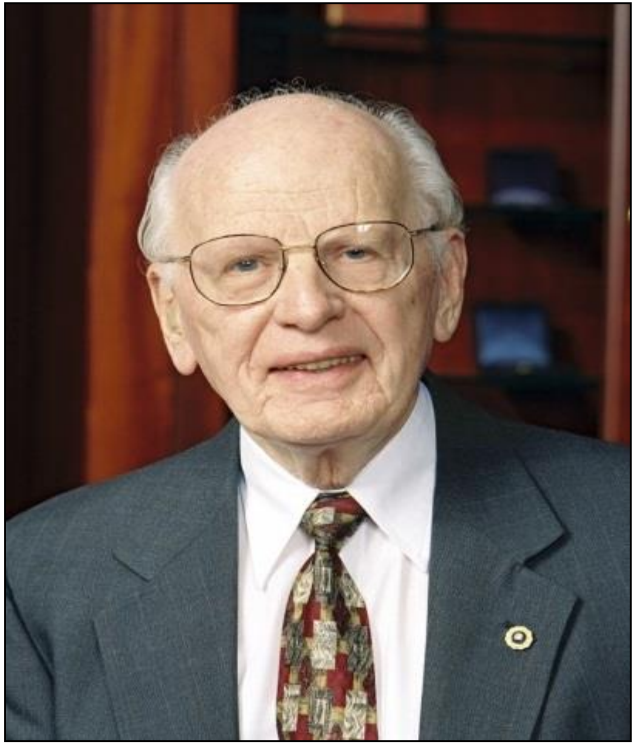
Ductile material always leads to ductile performance

Ductility: Another View

Outline

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

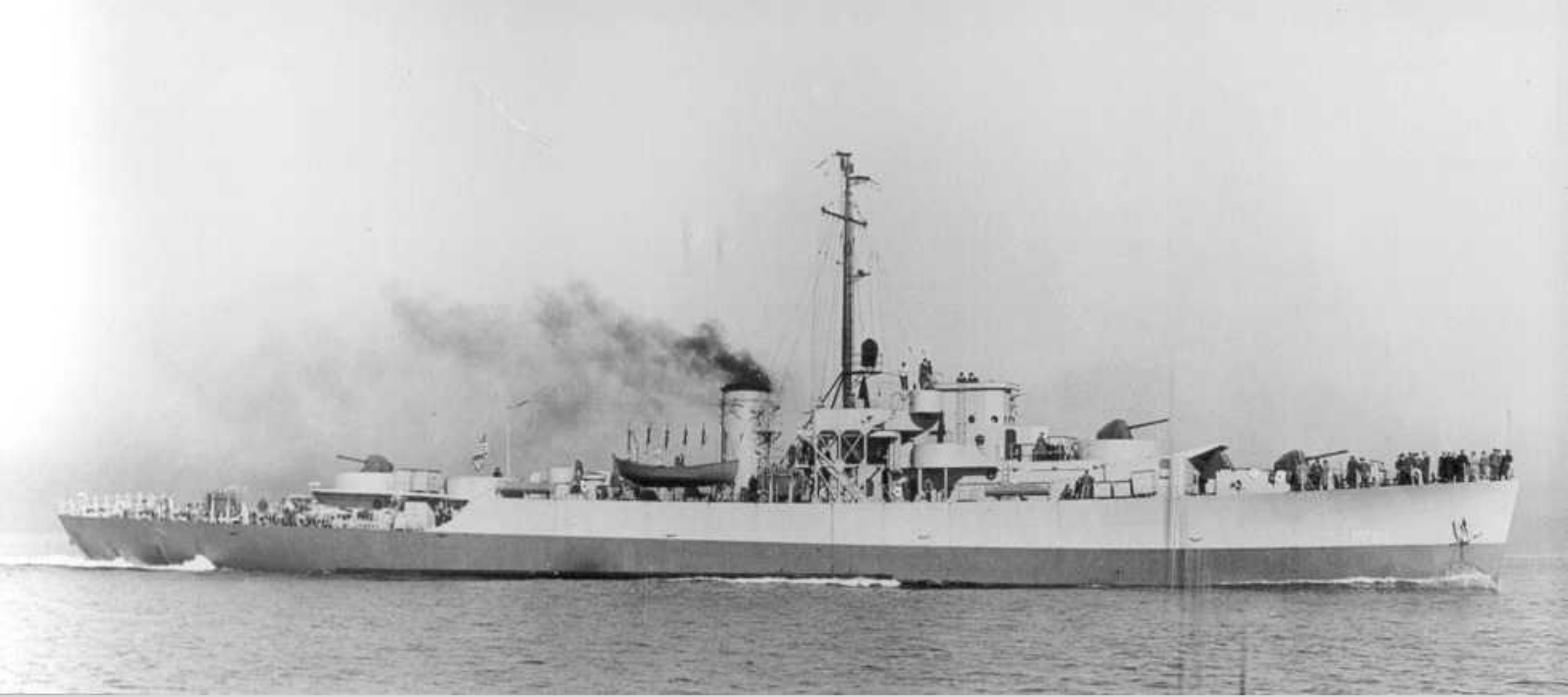
Omer W. Blodgett
1917-2017



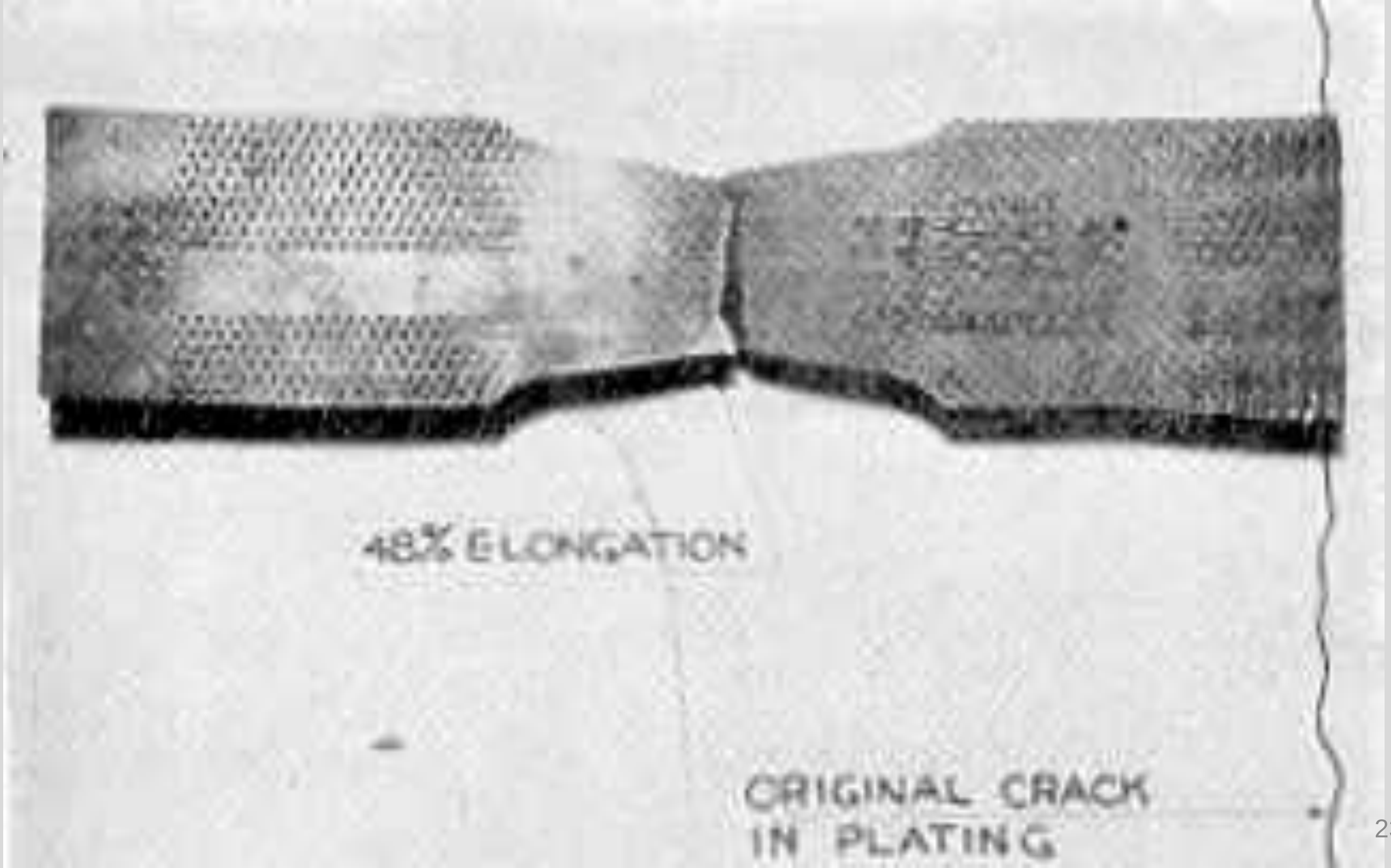
Globe Shipbuilding, Duluth Minnesota

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

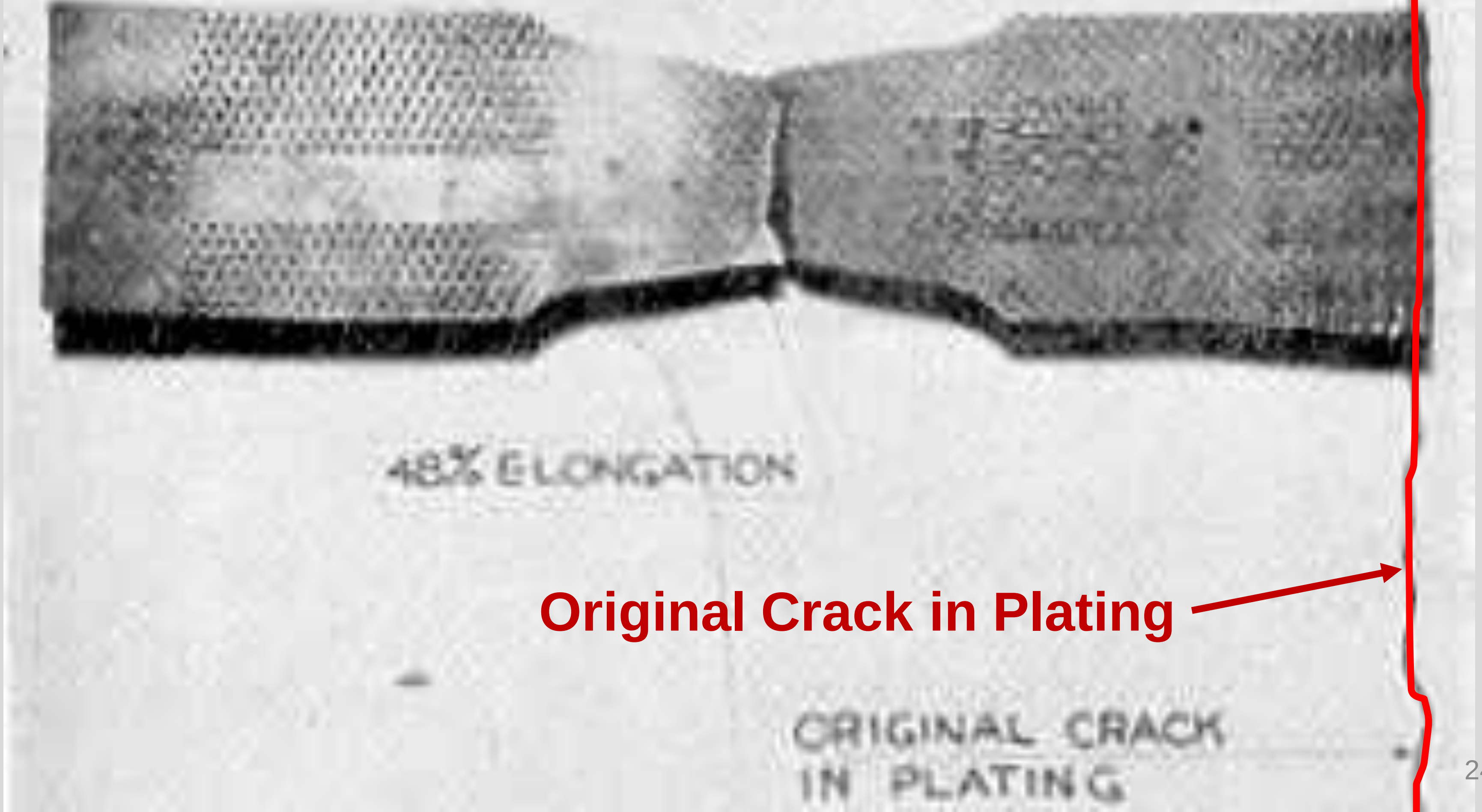
One of eight S2-S2-AQ1 Frigates



One of eleven C1-M-AV1 Cargo Vessels

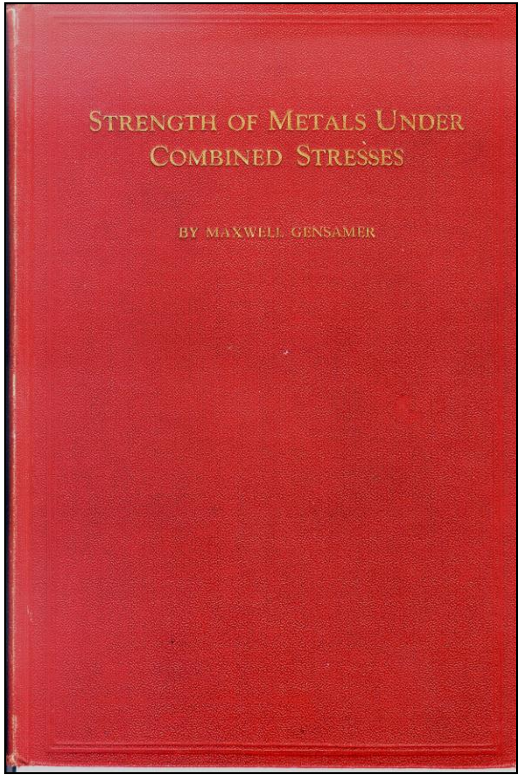

48% ELONGATION
ORIGINAL CRACK
IN PLATING

48% Elongation



Original Crack in Plating

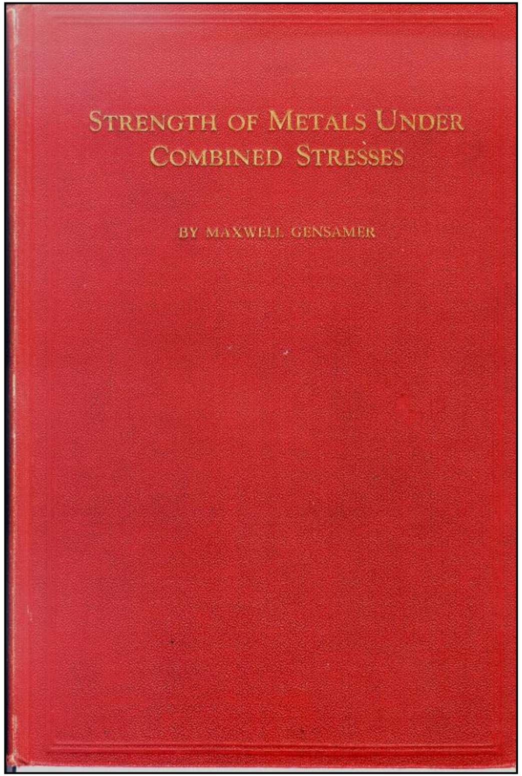
Strength of Metals Under Combined Stresses



Maxwell Gensamer
1941

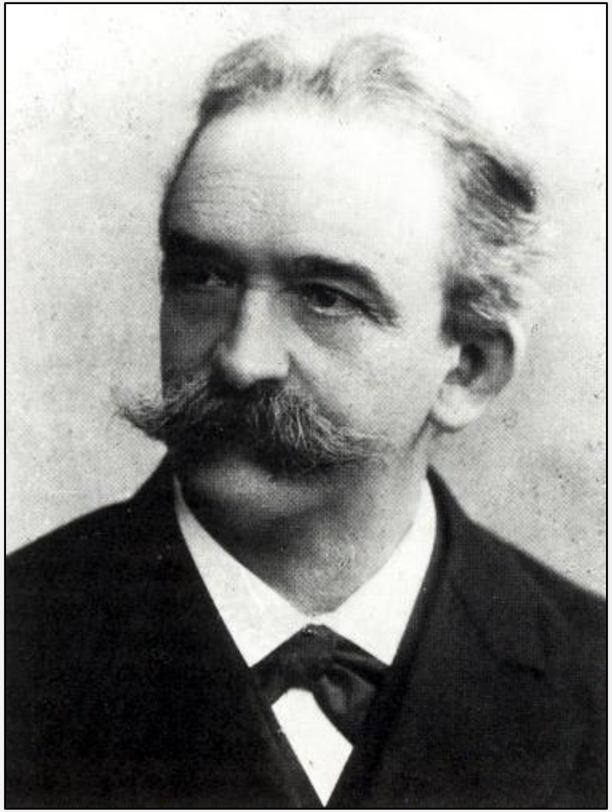
"This is an important concept and needs to be emphasized: no shear stress, no plastic deformation or flow."

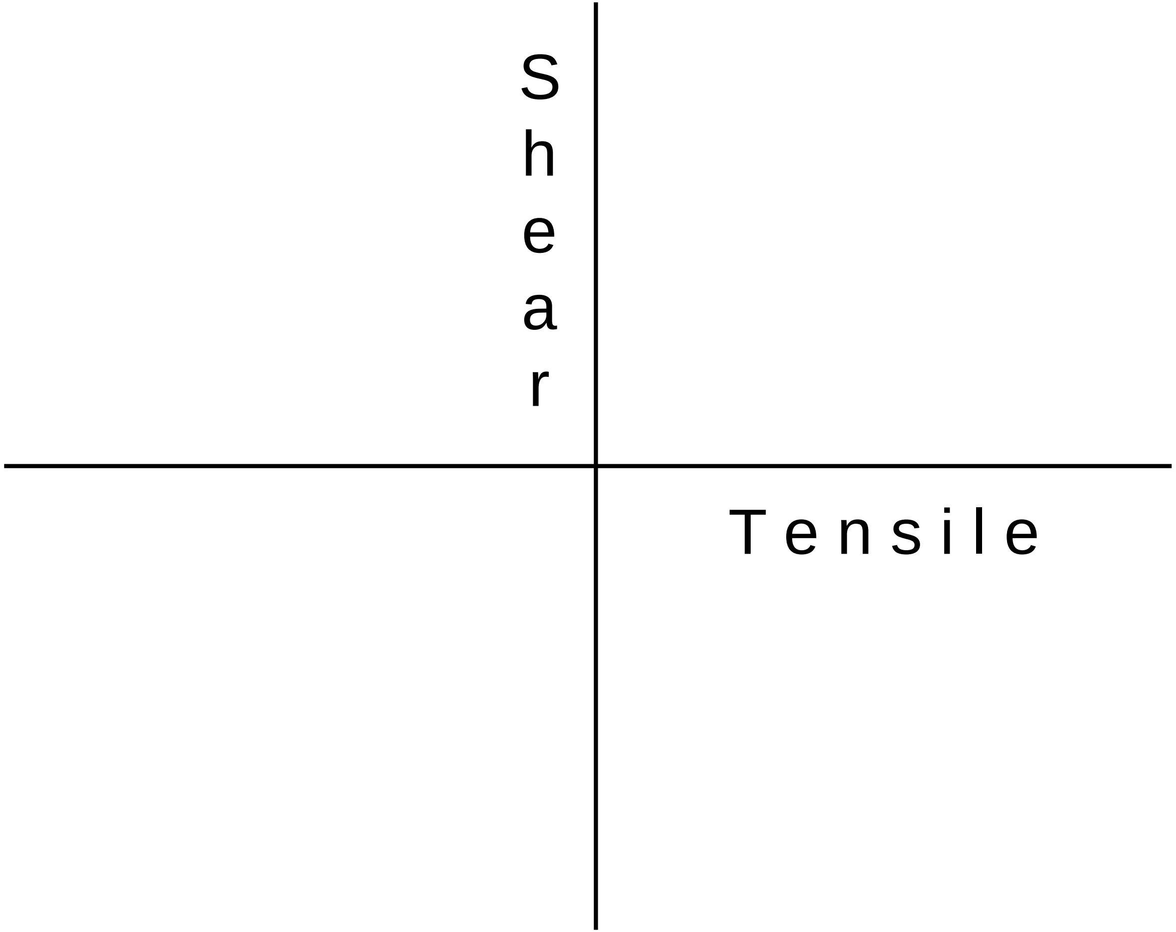
Maxwell Gensamer

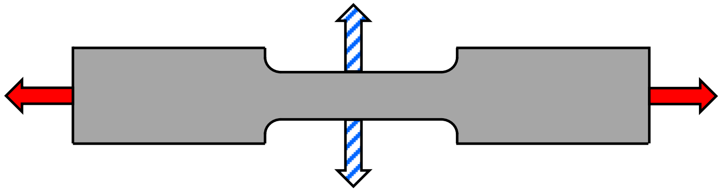


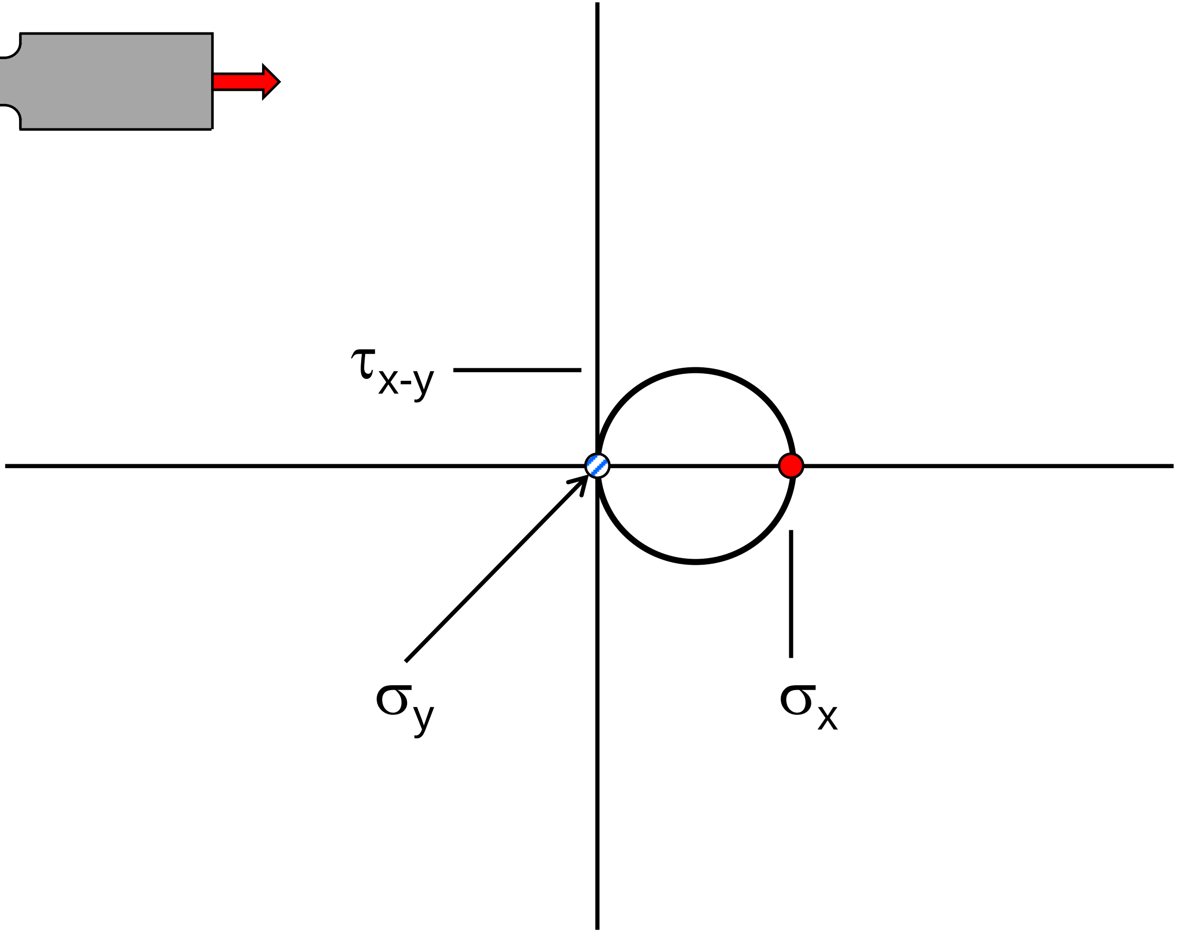
Christian Otto Mohr
1835 – 1918

Mohr's Circles

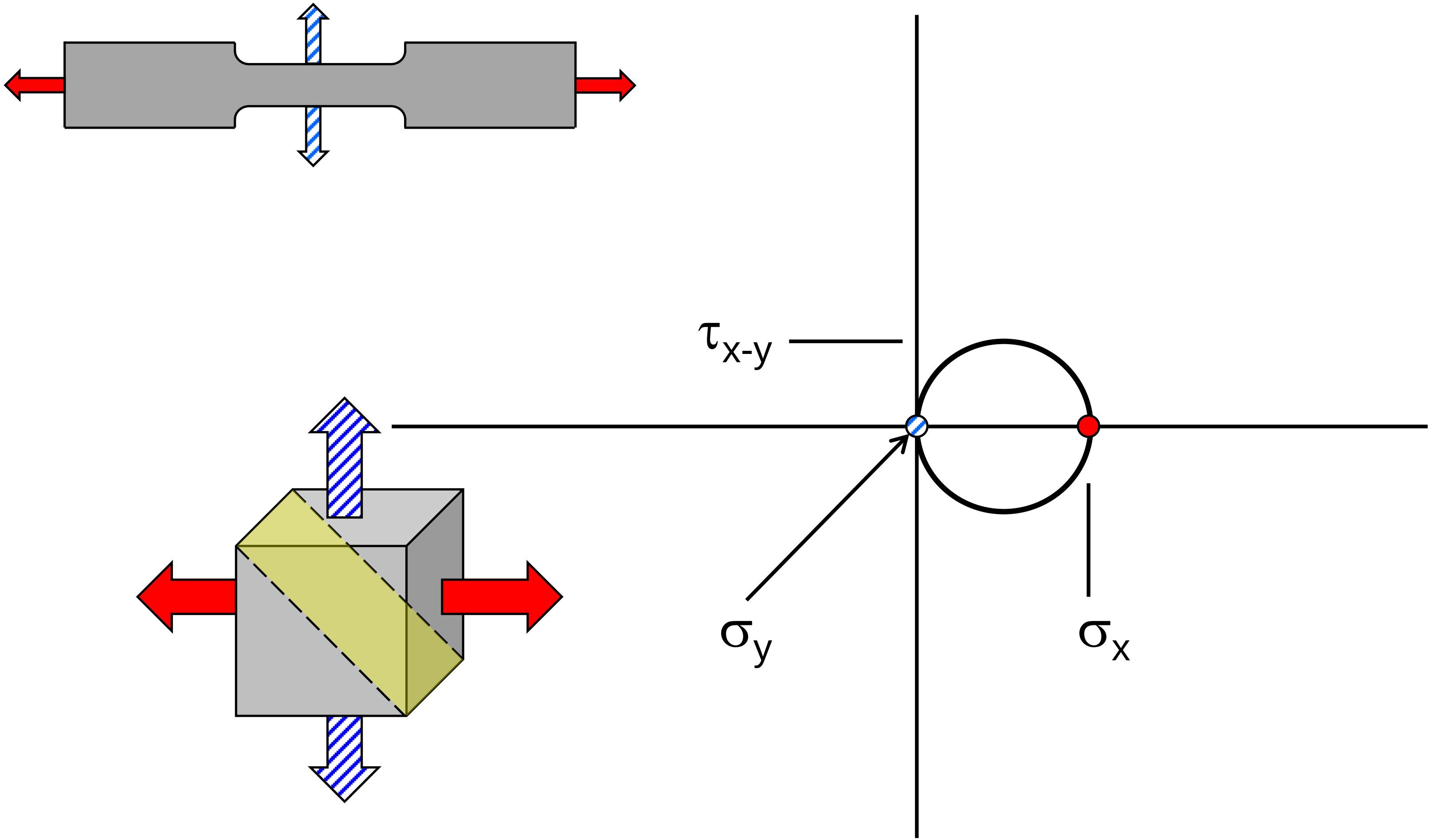



Shear
Tensile

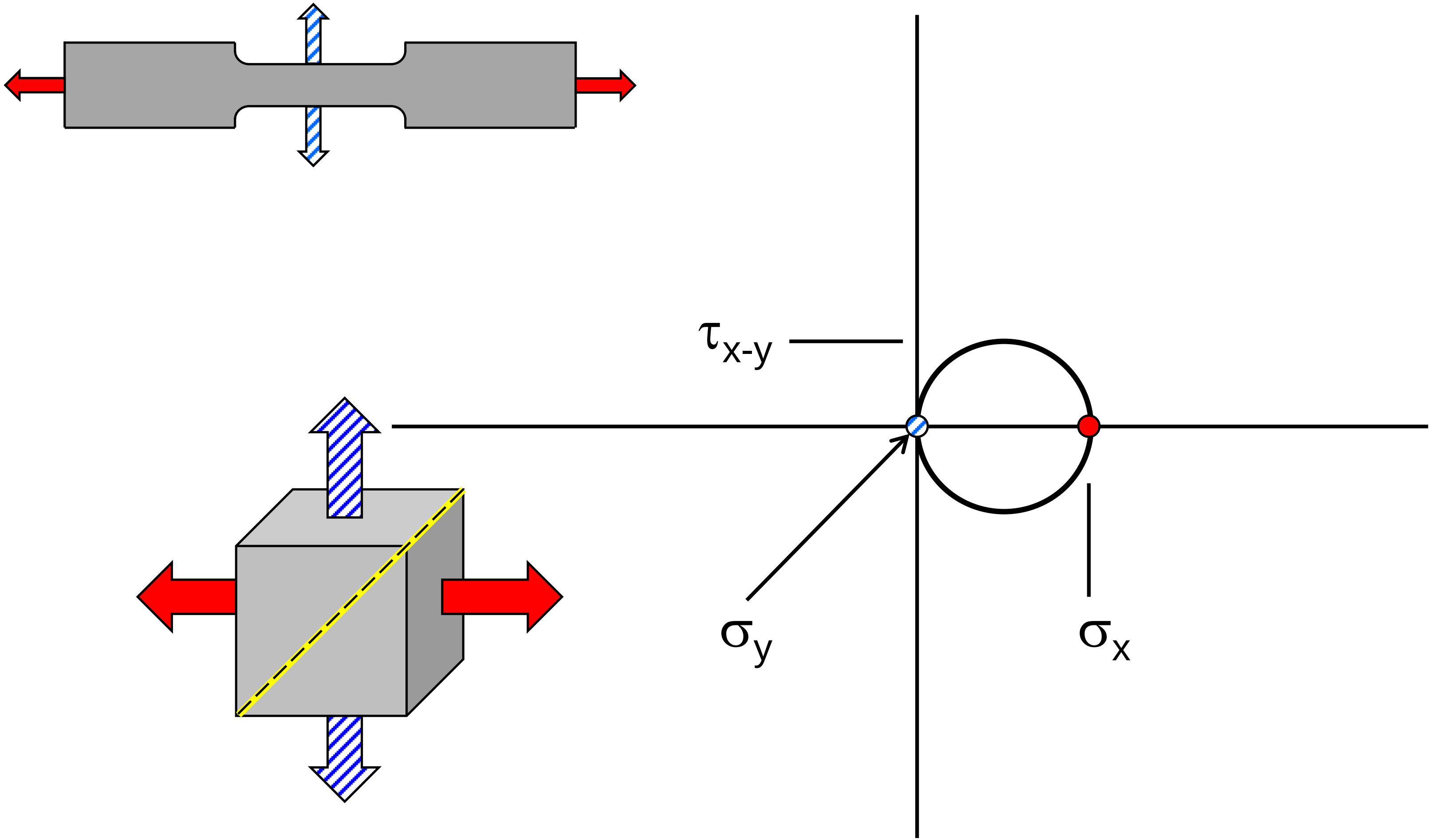




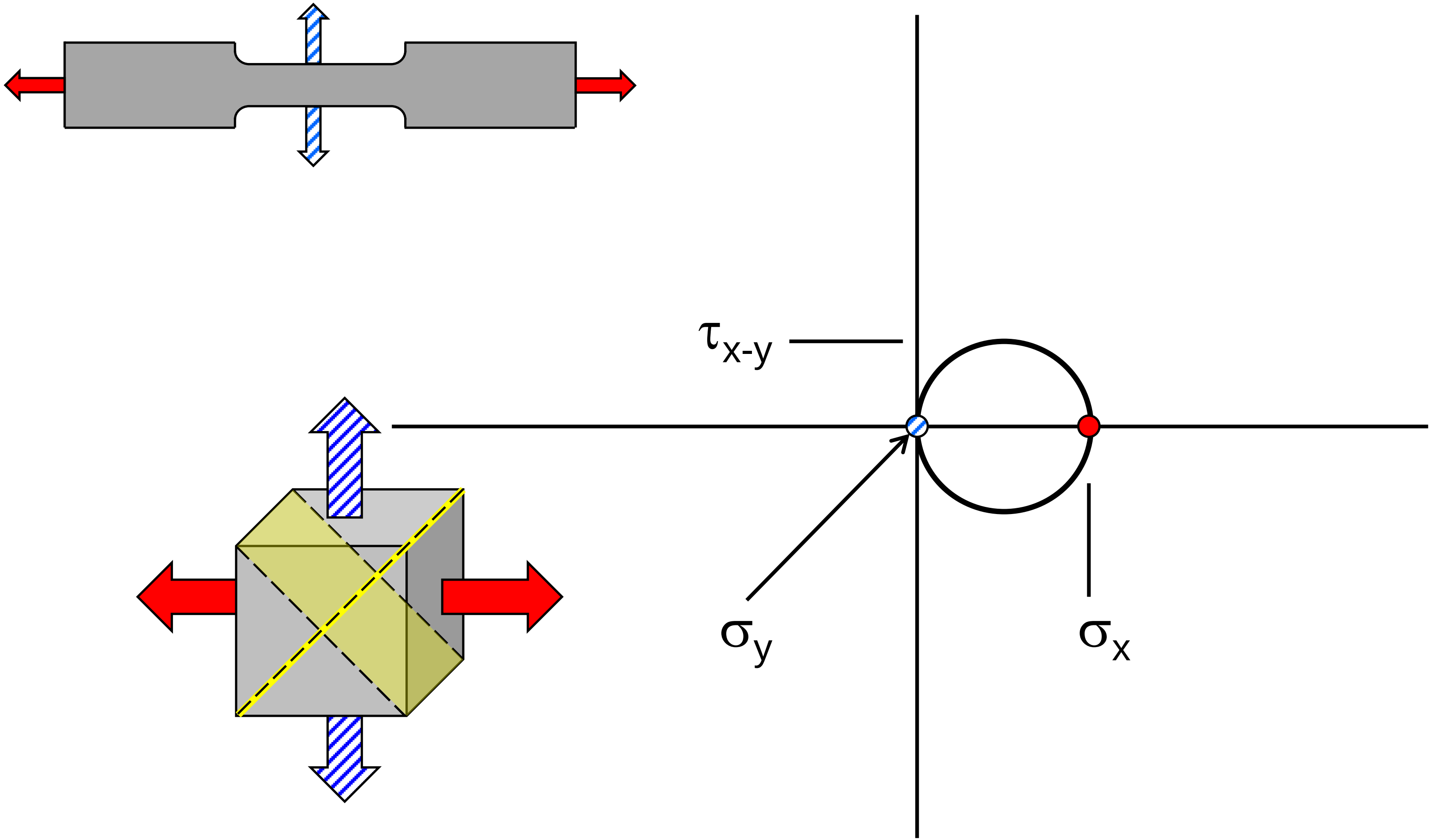
τx-y
σy
σx

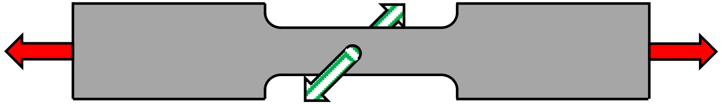


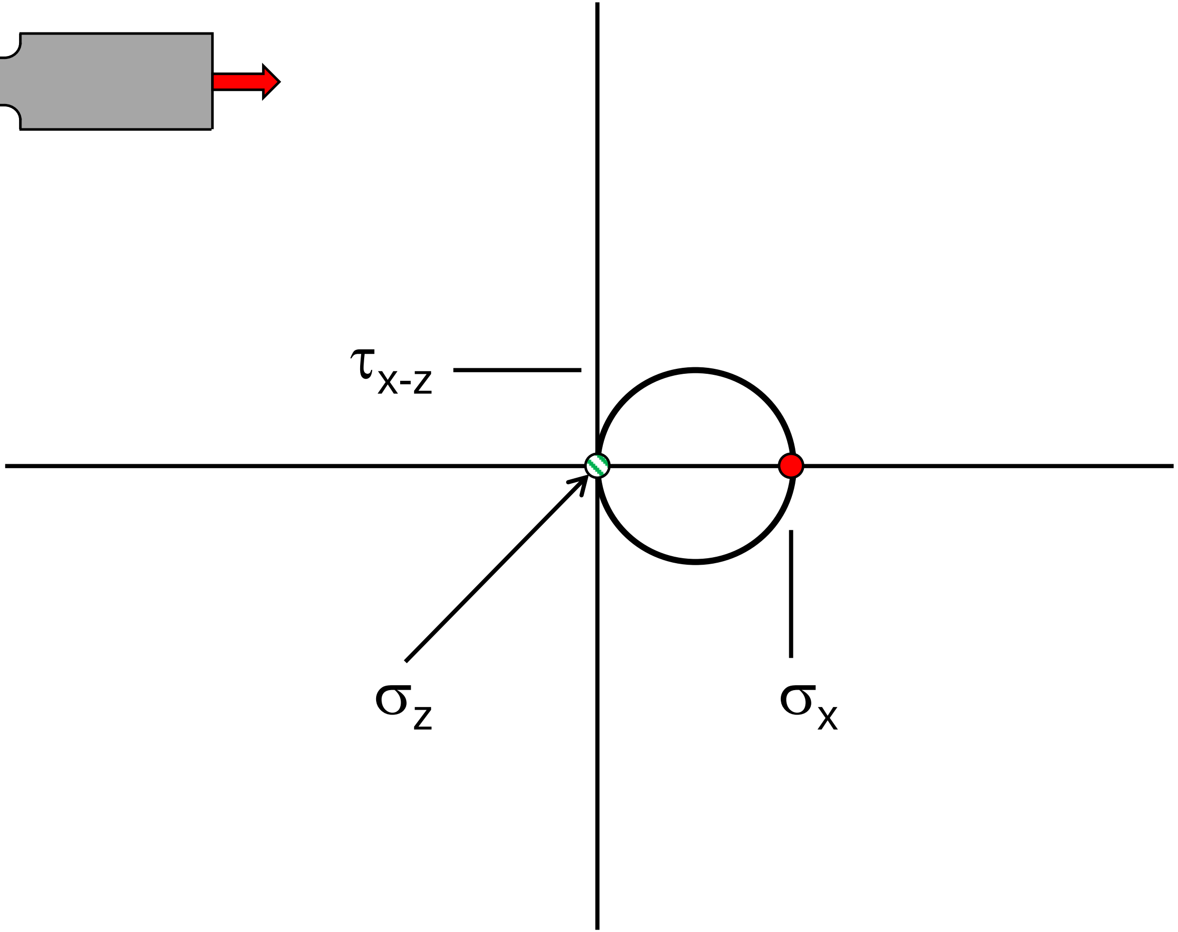
τ_{x-y}
σ_y
σ_x



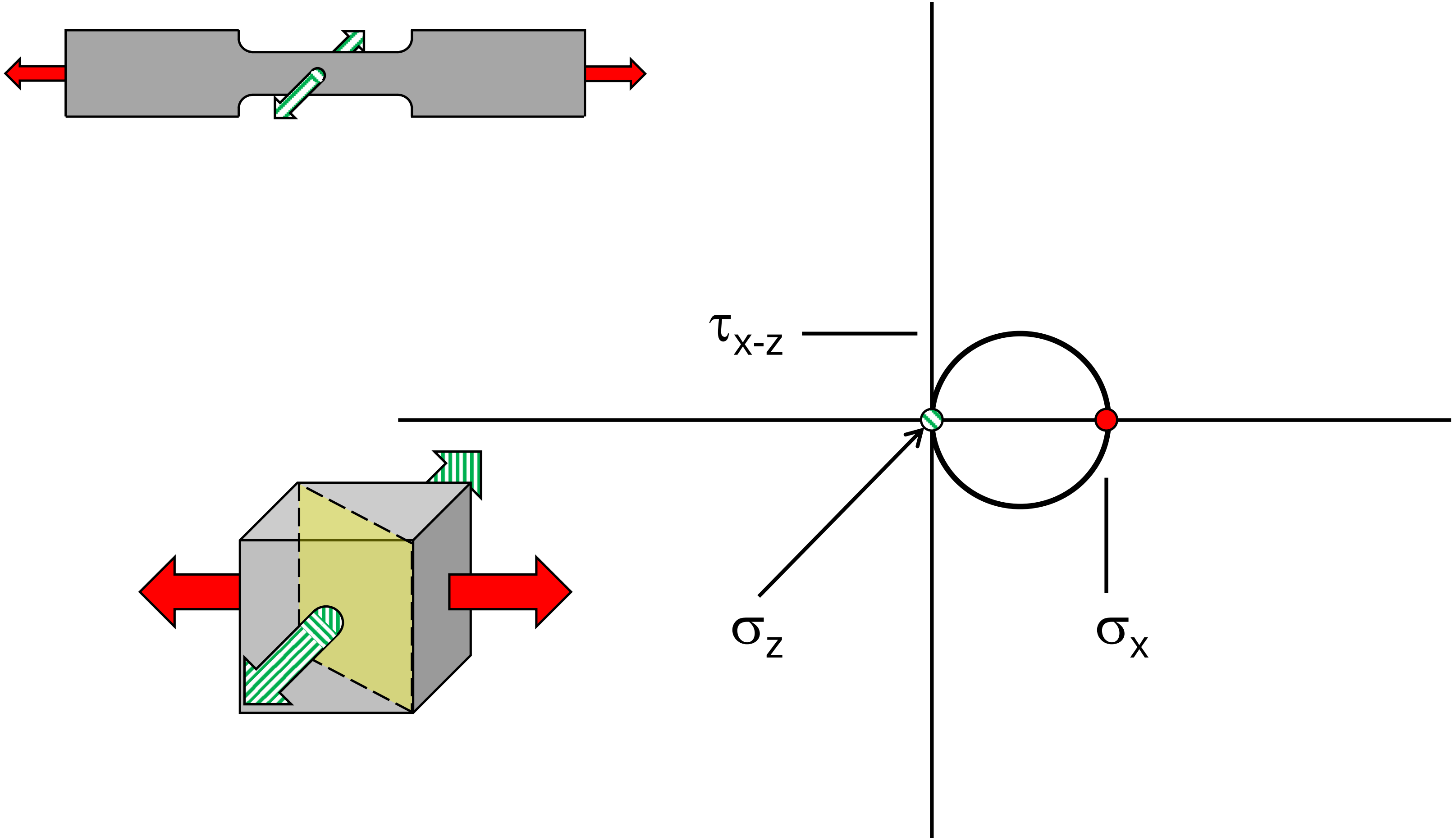
$\tau_{x\text{-}y}$
σ_y
σ_x

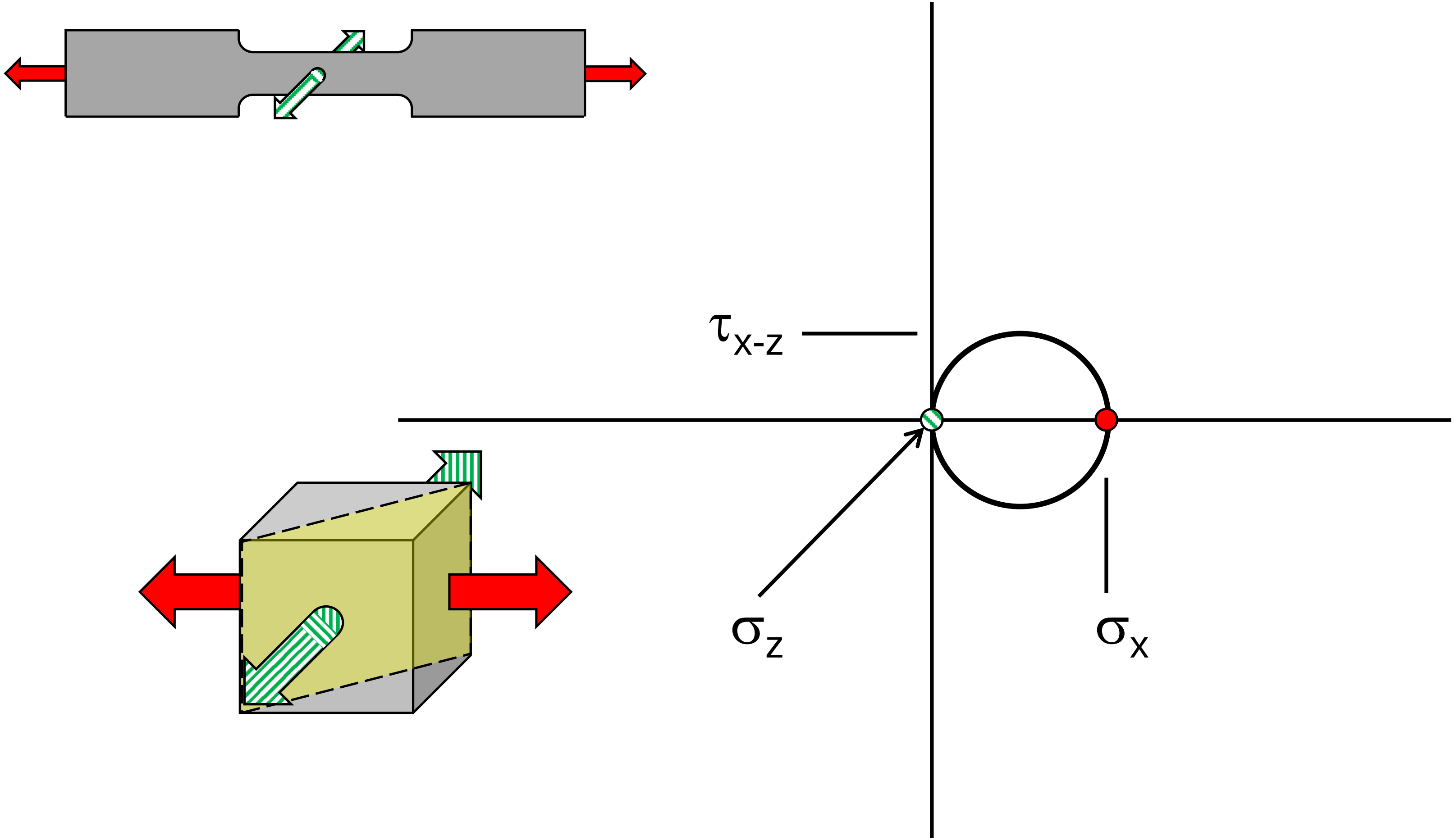

τ_{x-y}
σ_y
σ_x

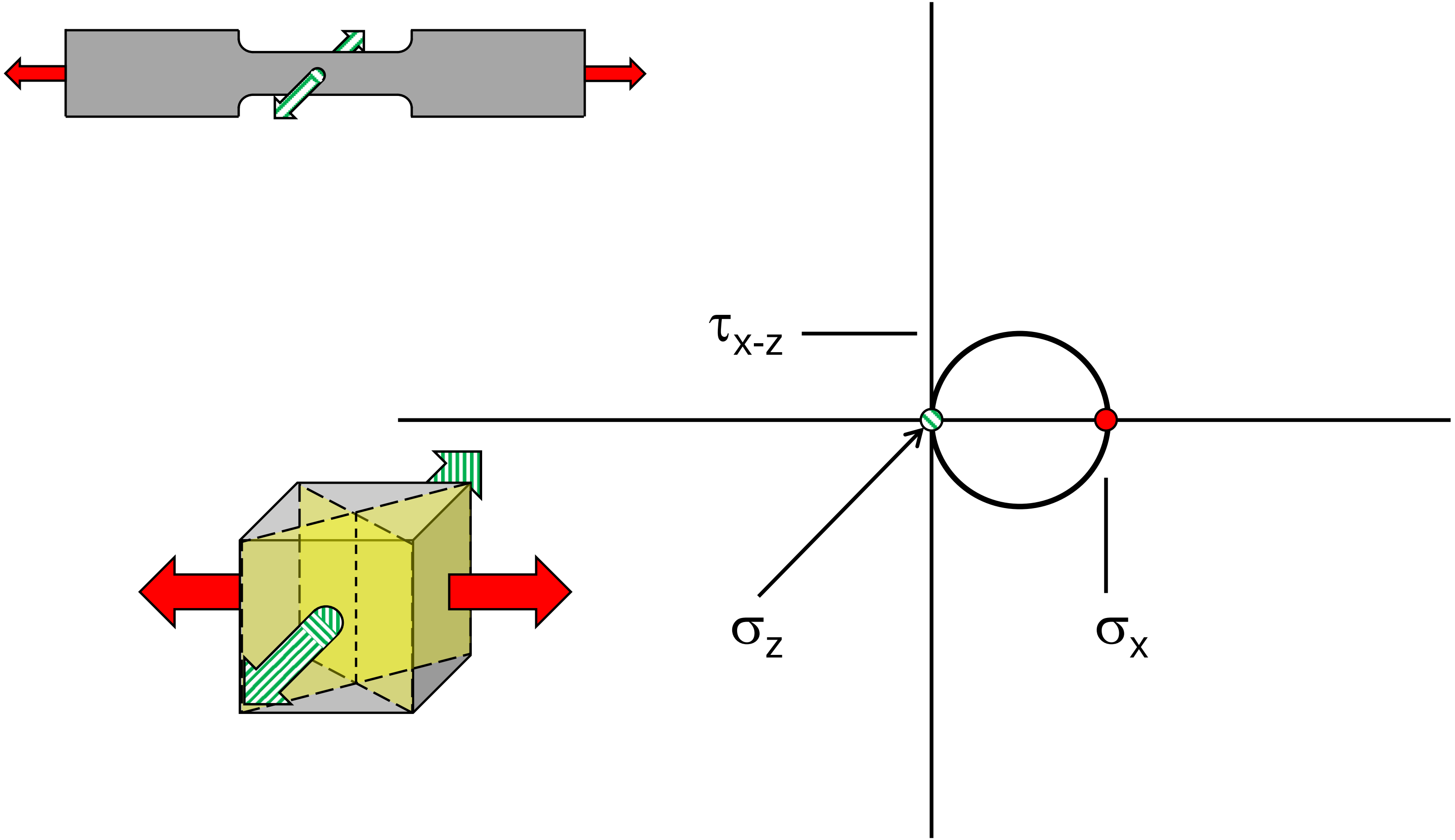


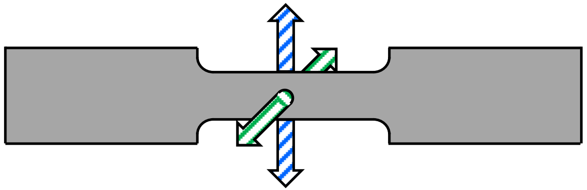


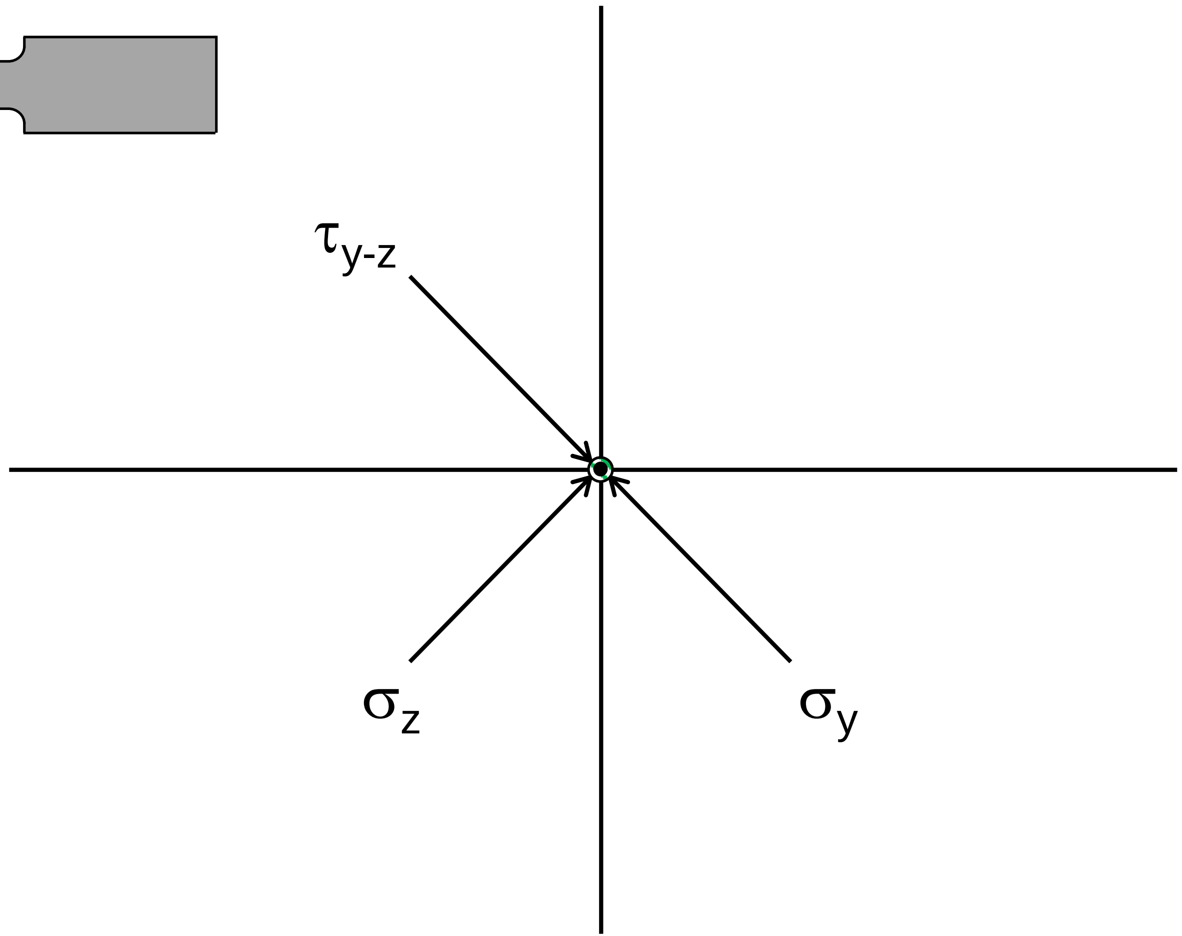
$\tau_{x\text{-}z}$
σ_z
σ_x


τx-z
σz
σx

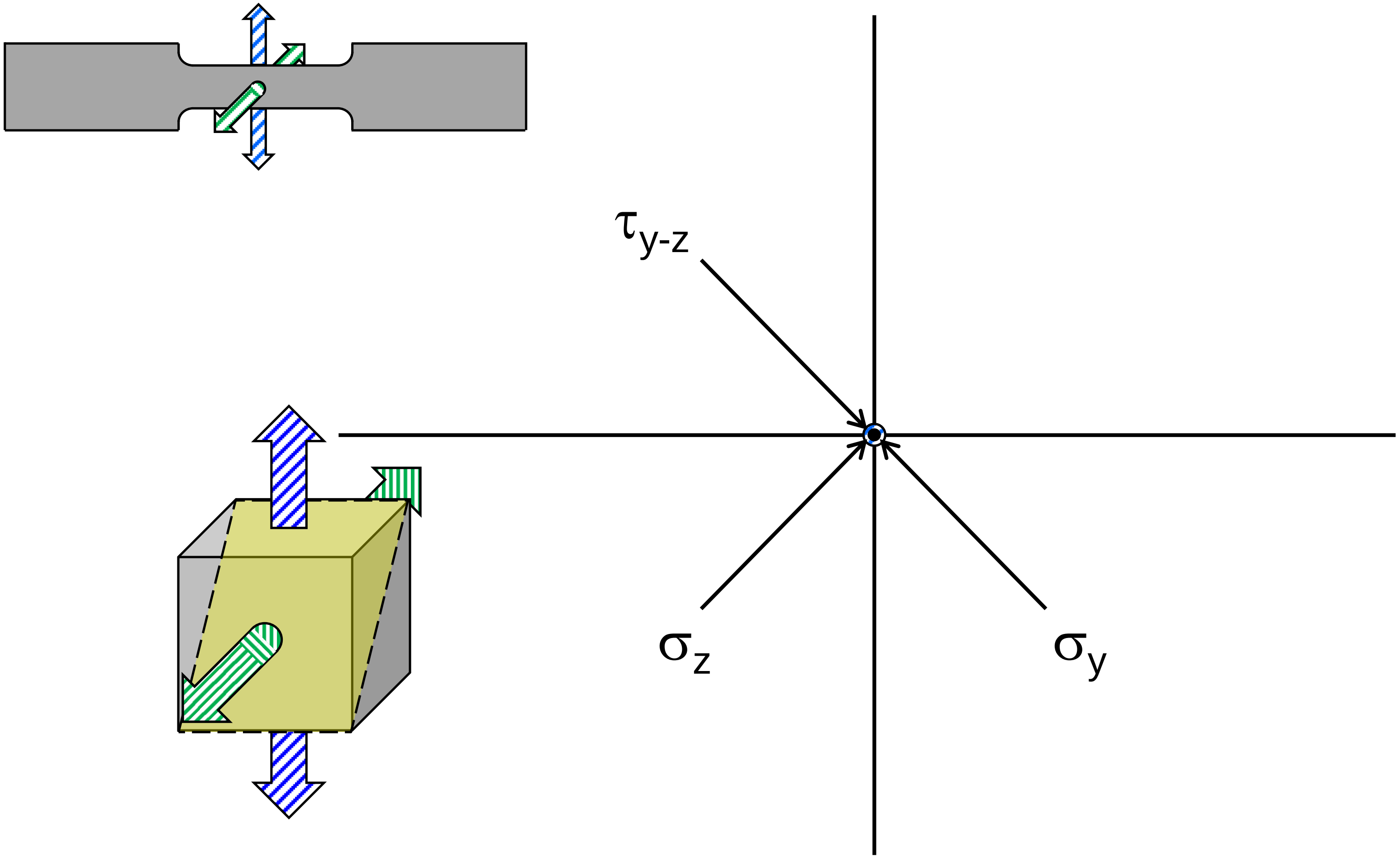

τ_{x-z}
σ_z
σ_x


τx-z
σz
σx

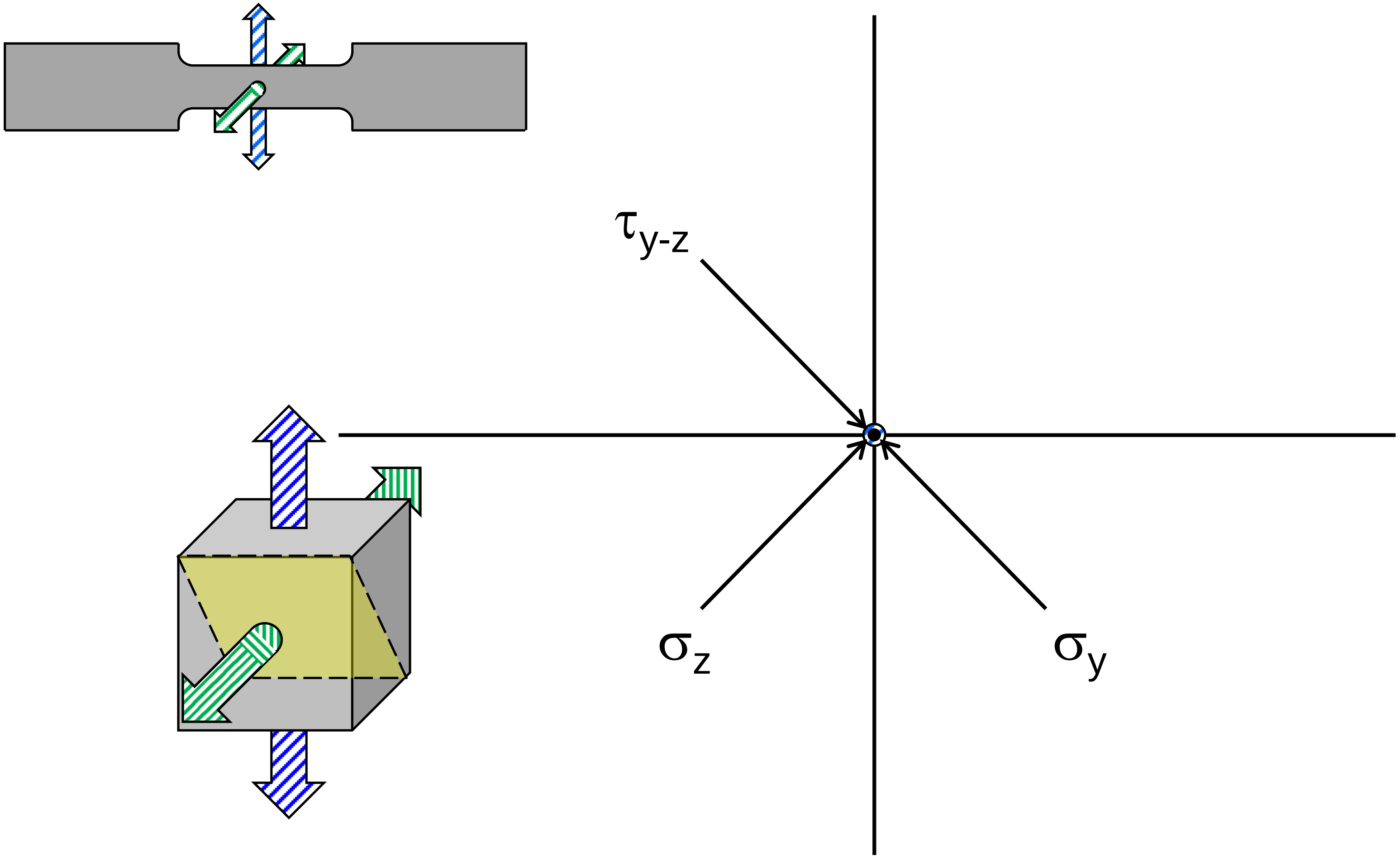




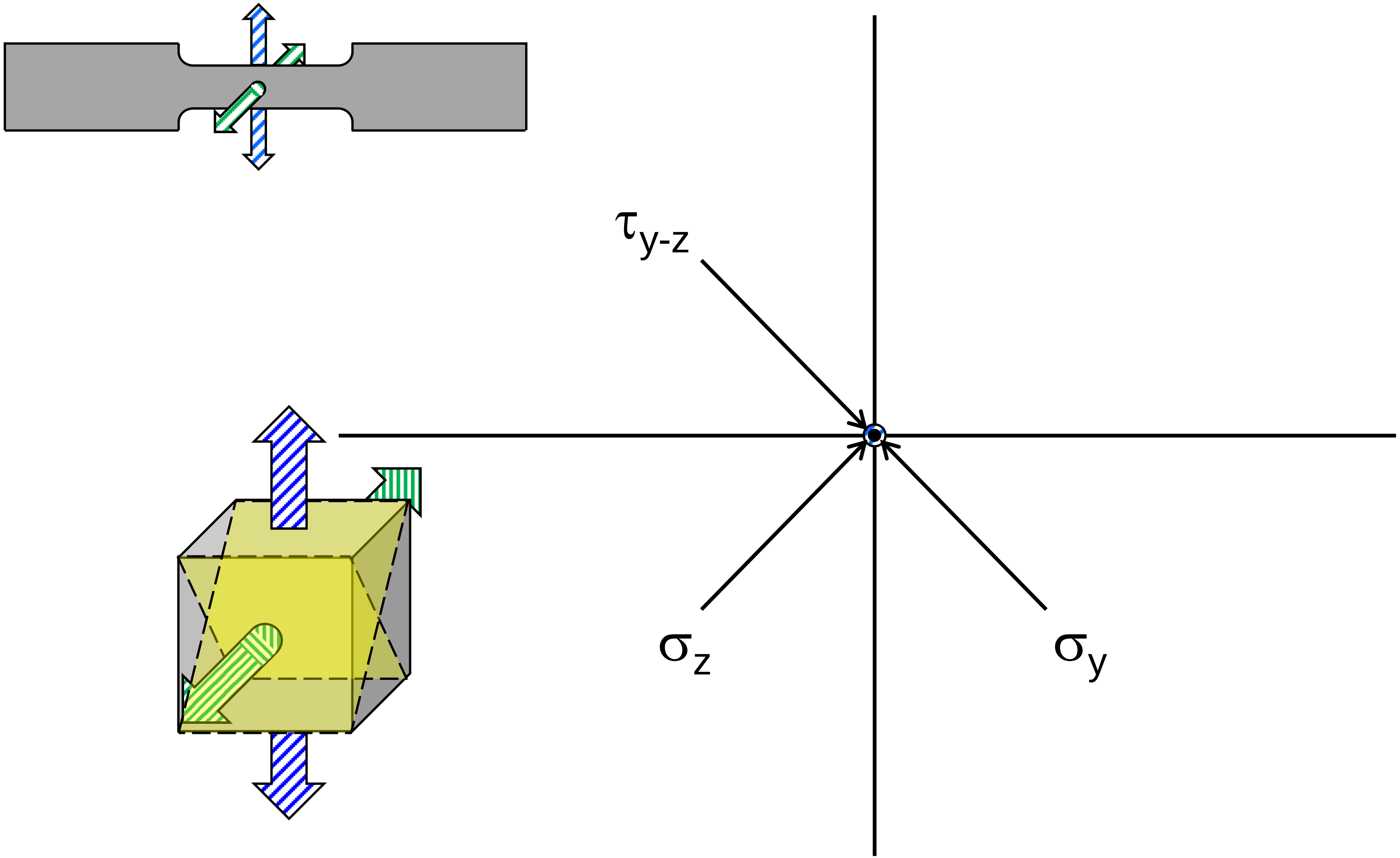
τy-z
σz
σy



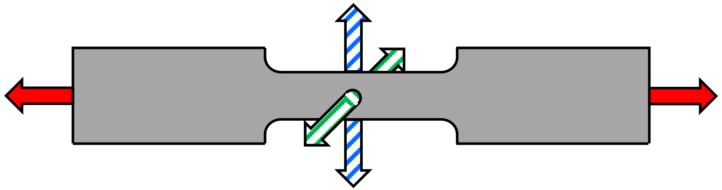
τ_{y-z}
σ_z
σ_y



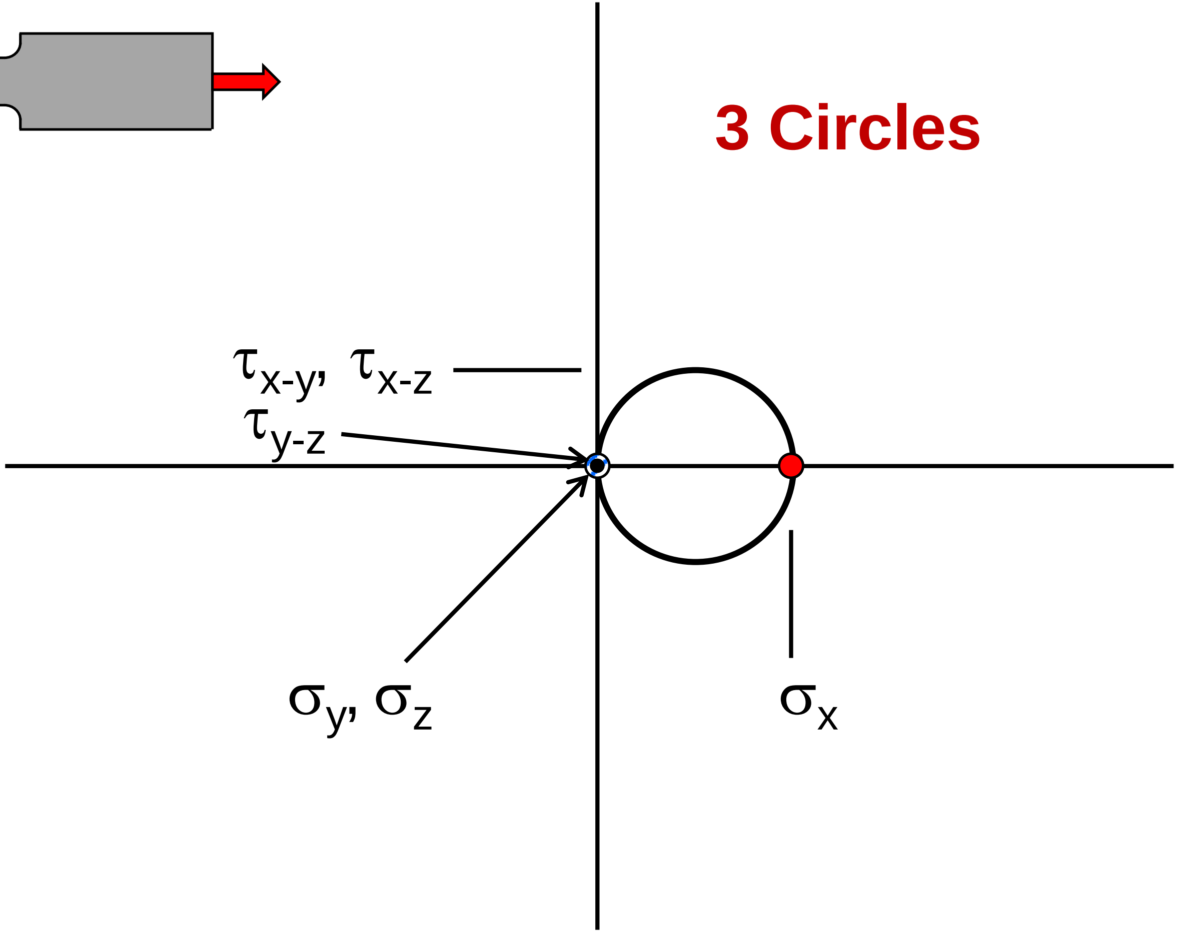
τ_{y-z}
σ_z
σ_y

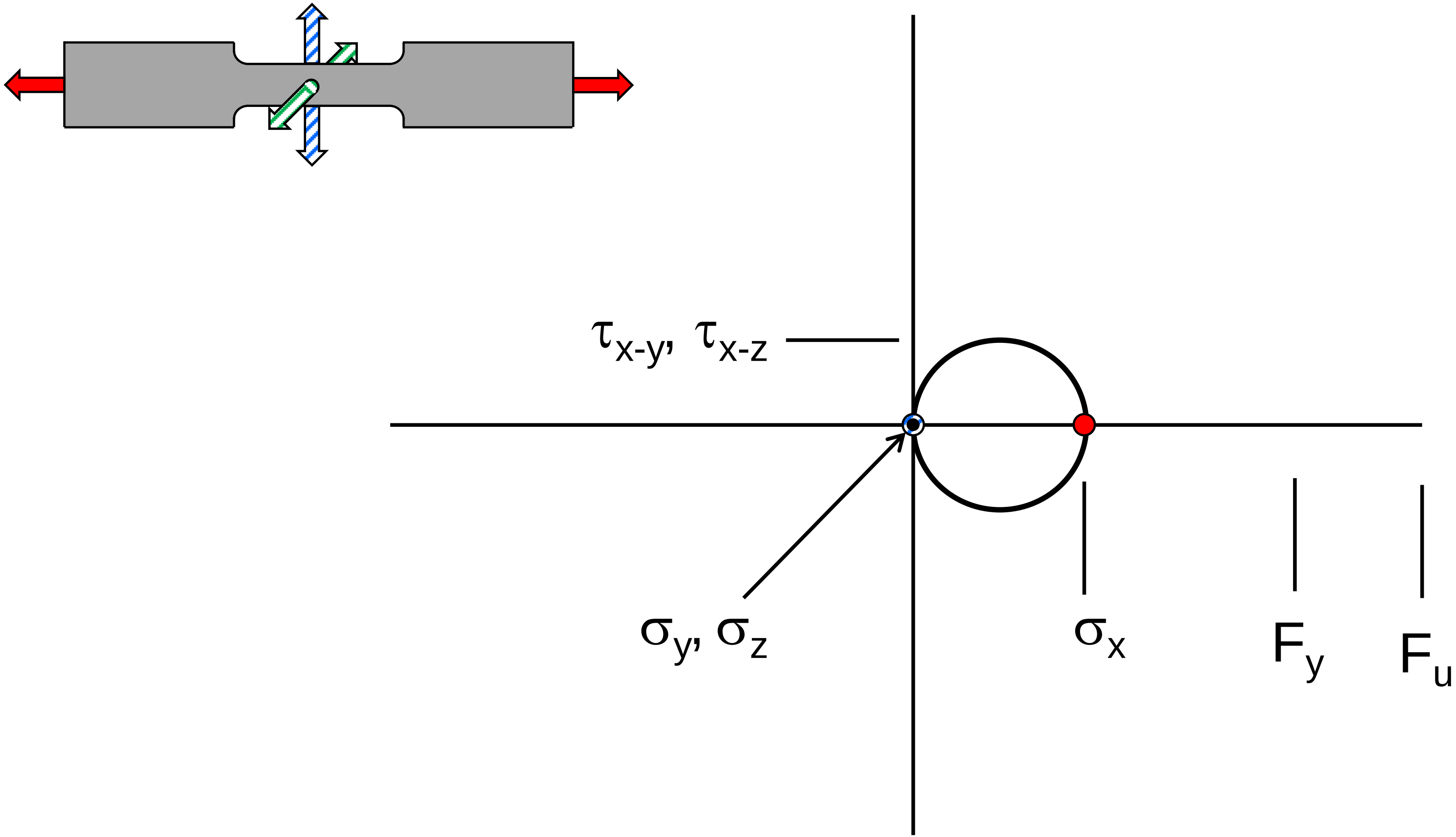


$\tau_{y\text{-}z}$
σ_z
σ_y

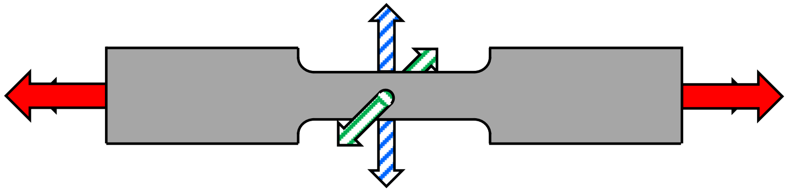


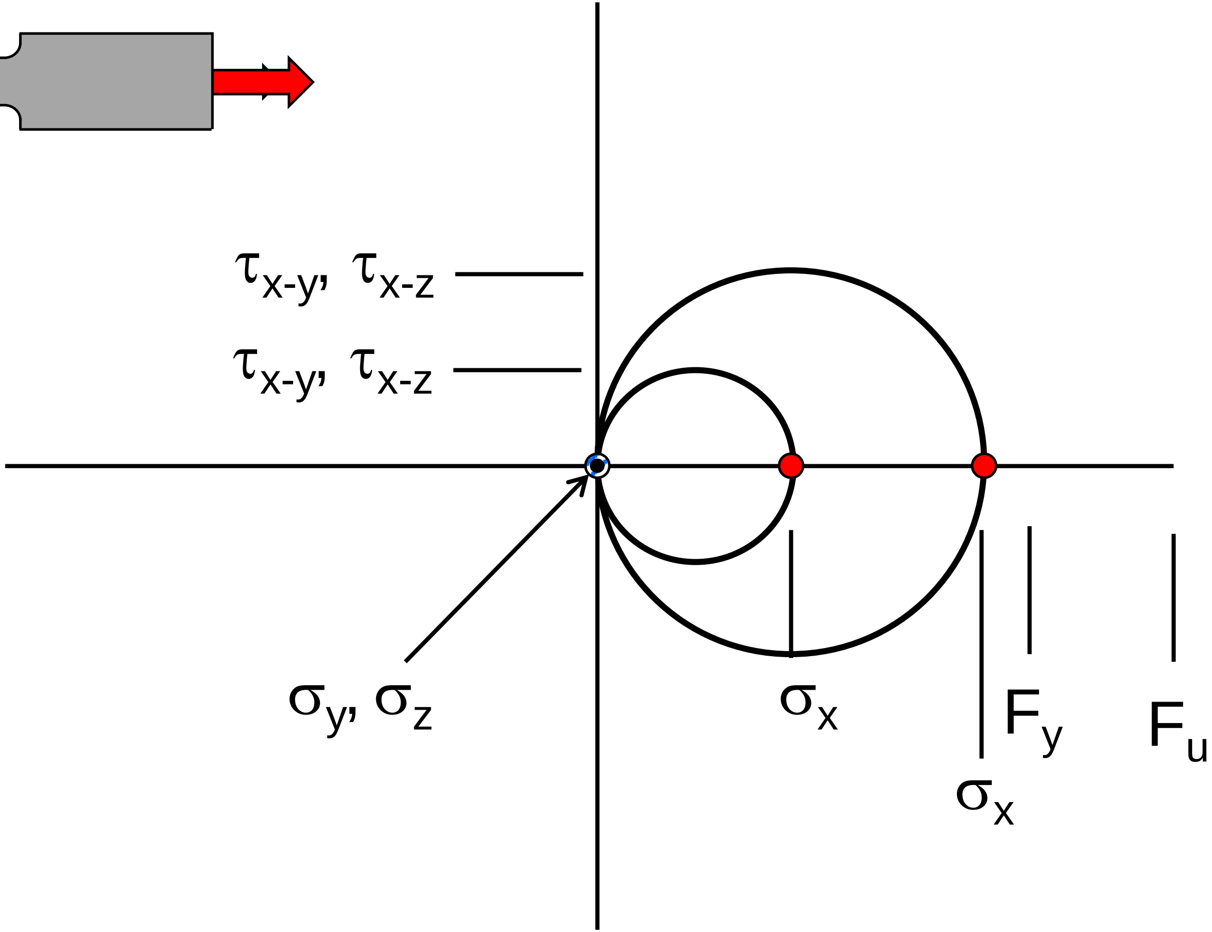
3 Circles



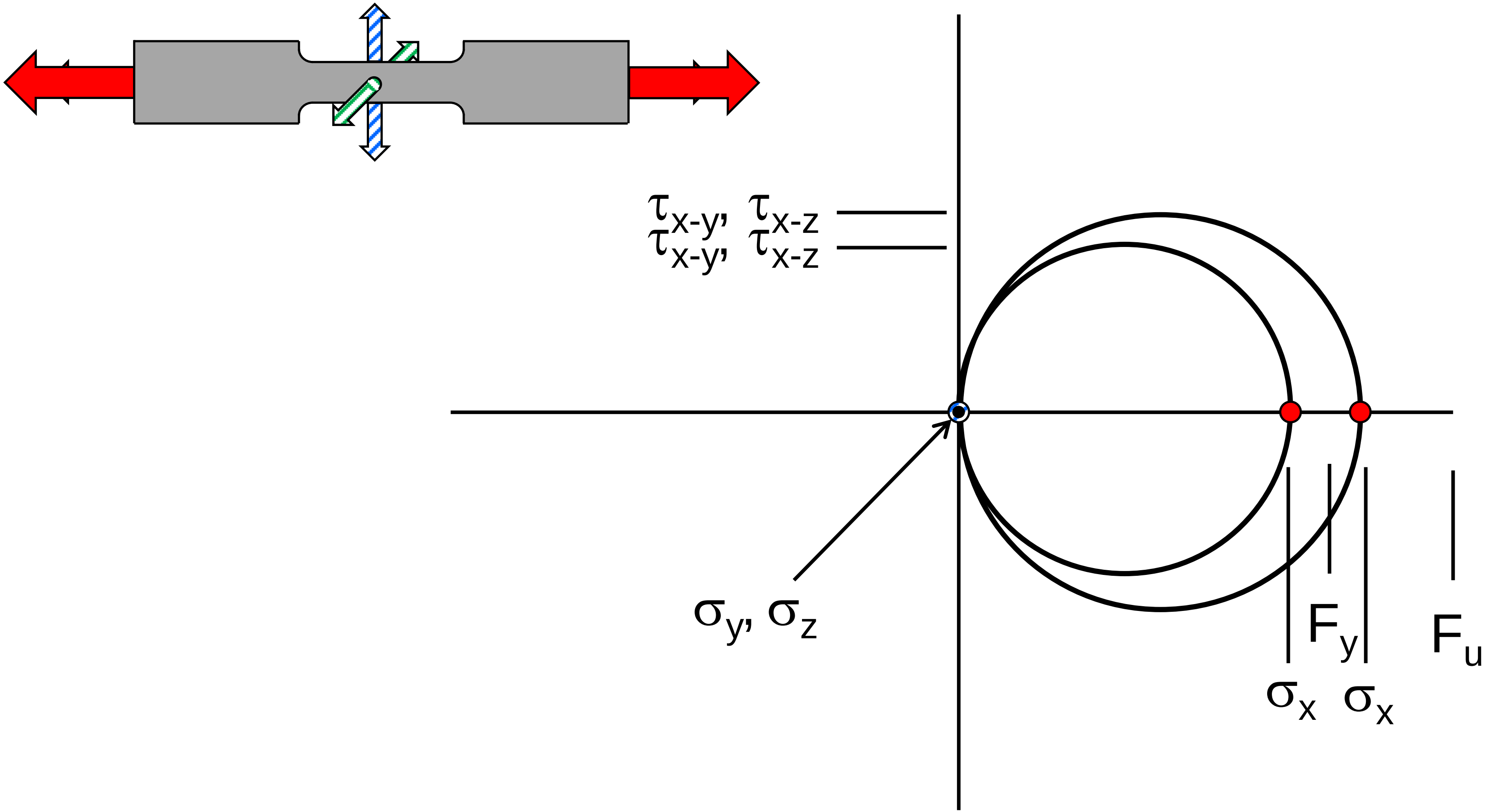


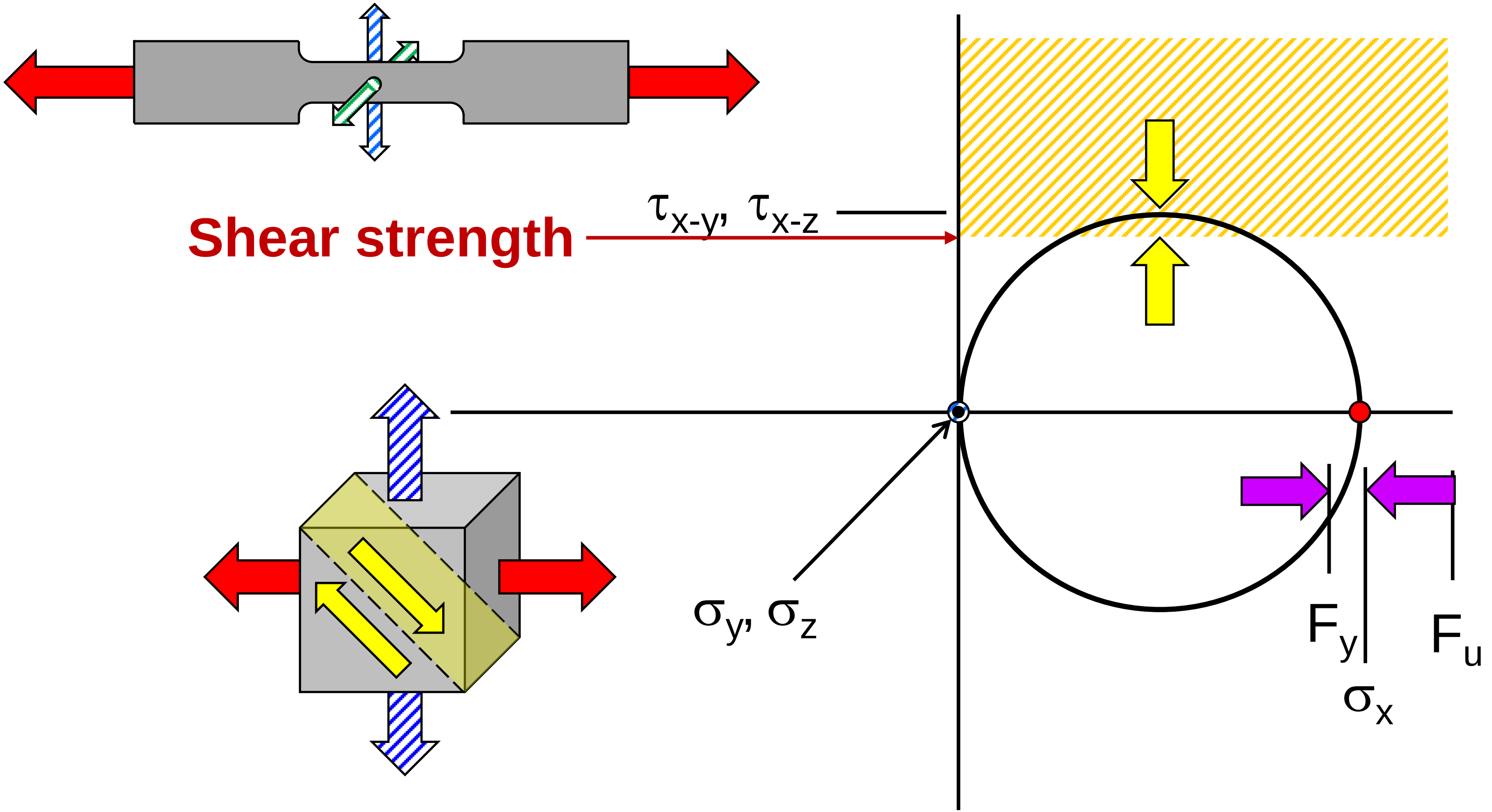
τx-y, τx-z
σy, σz
σx
Fy
Fu

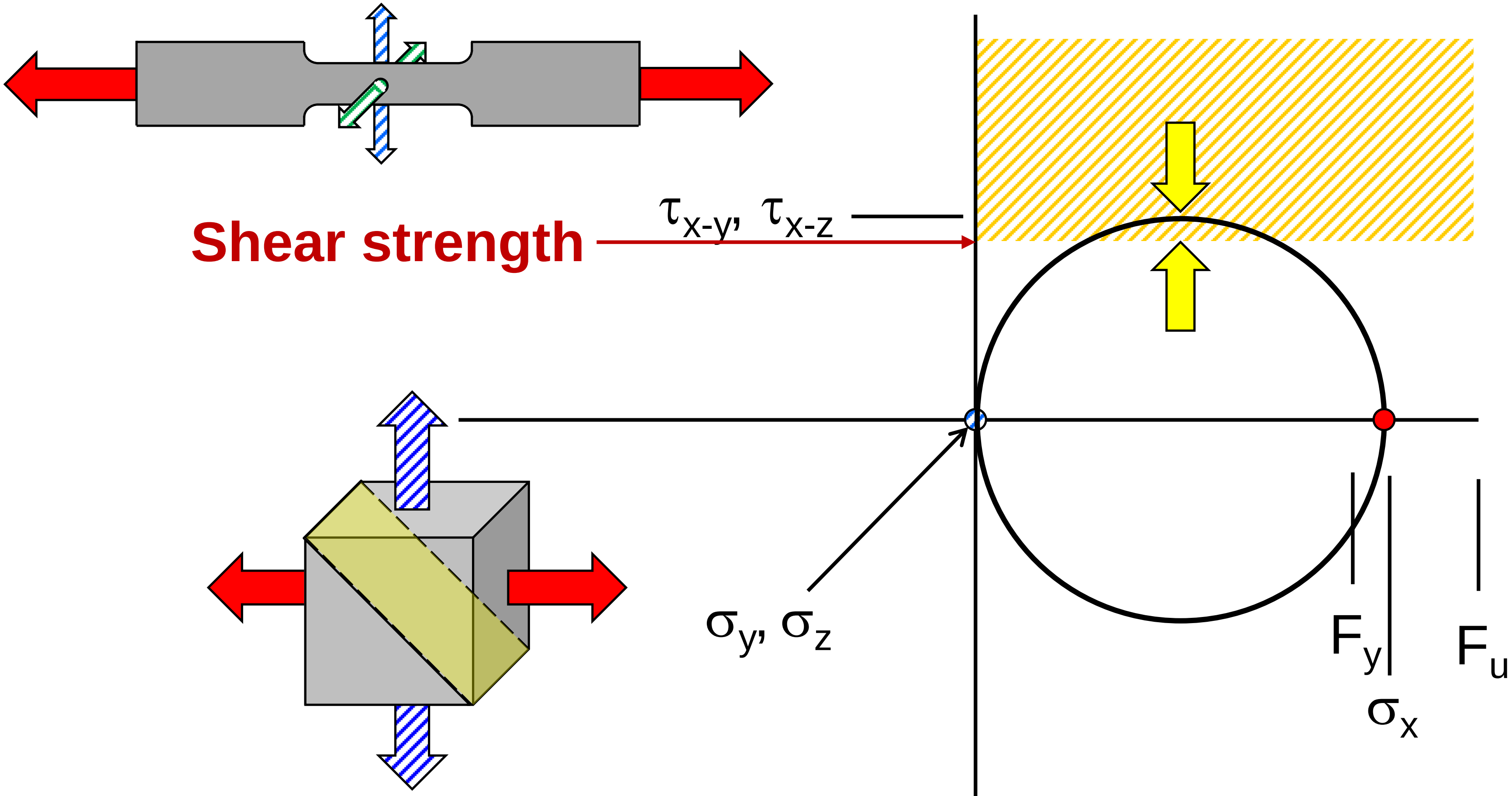




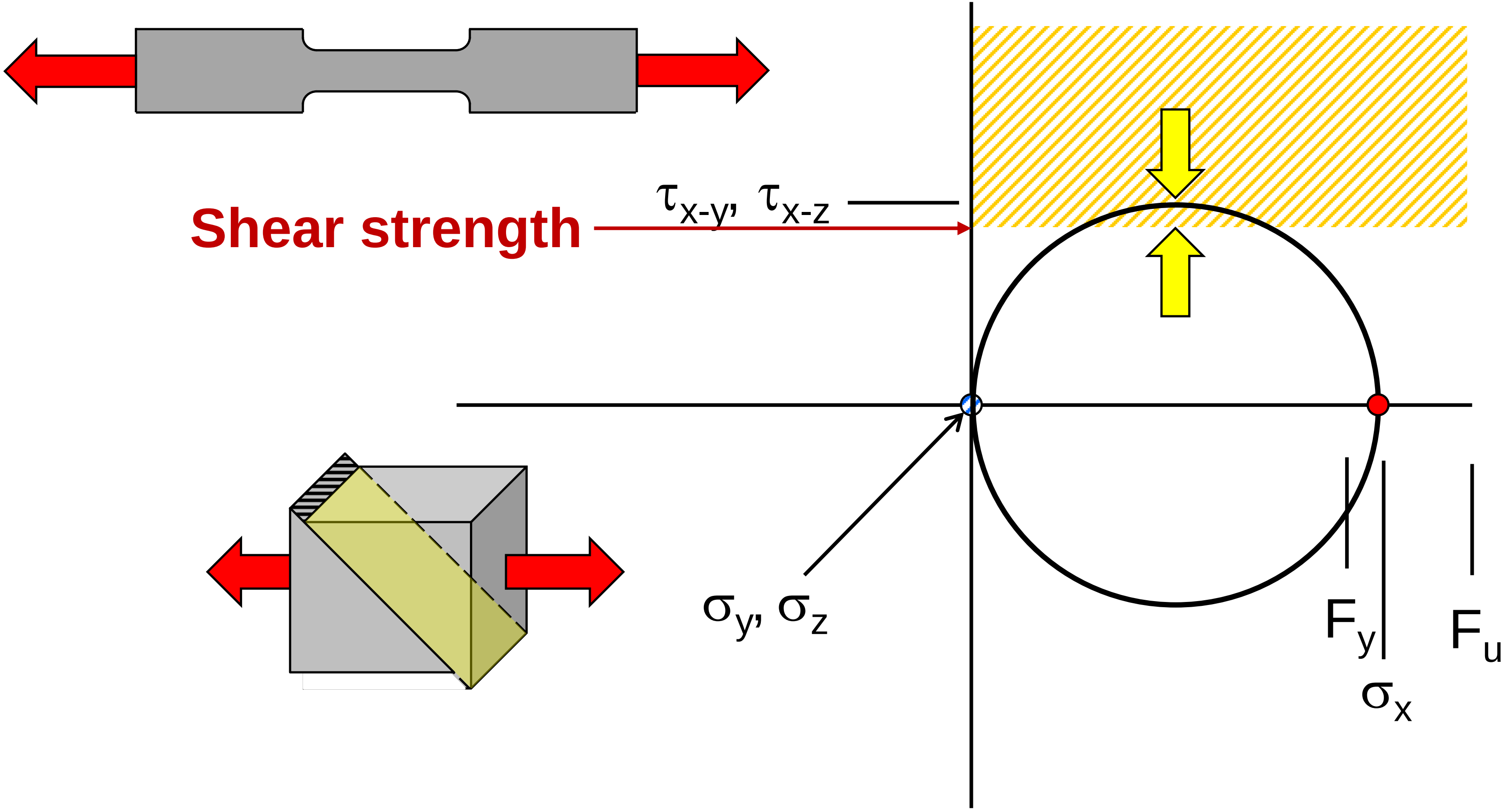
$\tau_{x\text{-}y}$, $\tau_{x\text{-}z}$
$\tau_{x\text{-}y}$, $\tau_{x\text{-}z}$
σ_y, σ_z
σ_x
F_y
F_u
σ_x


τx-y, τx-z
τx-y, τx-z
σy, σz
Fy
Fu
σx
σx

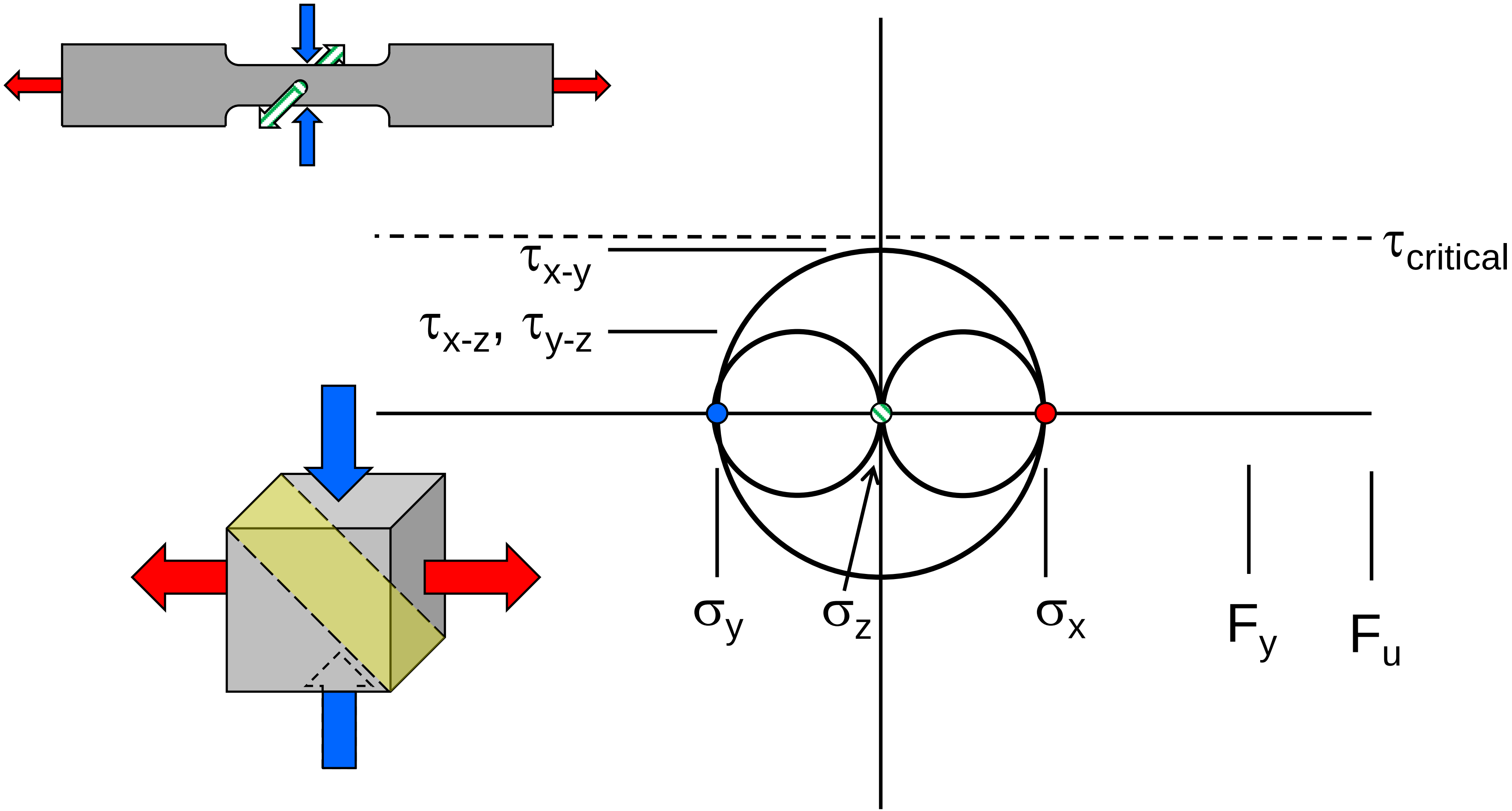

Shear strength
τx-y, τx-z
σy, σz
Fy
Fu
σx

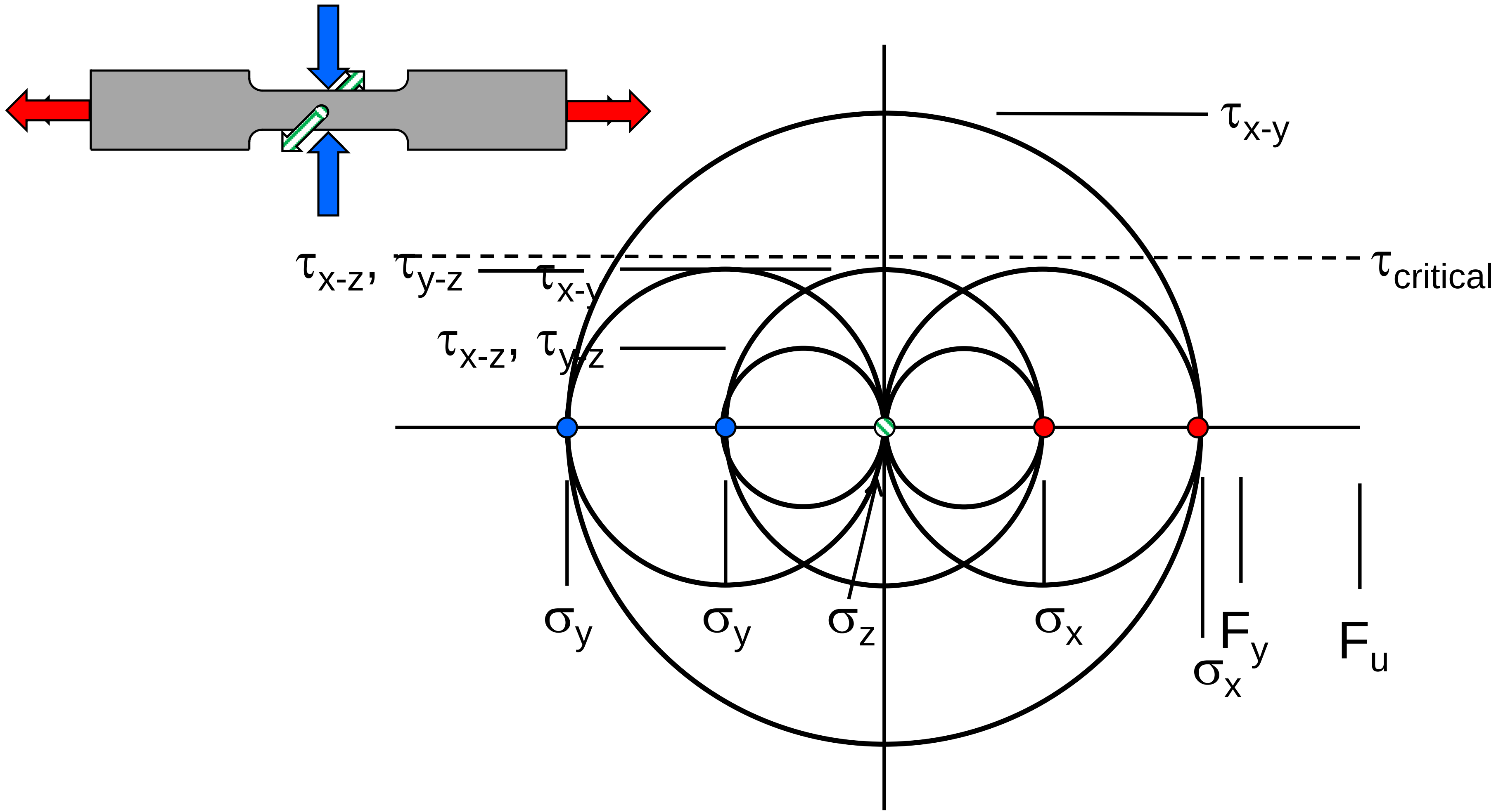


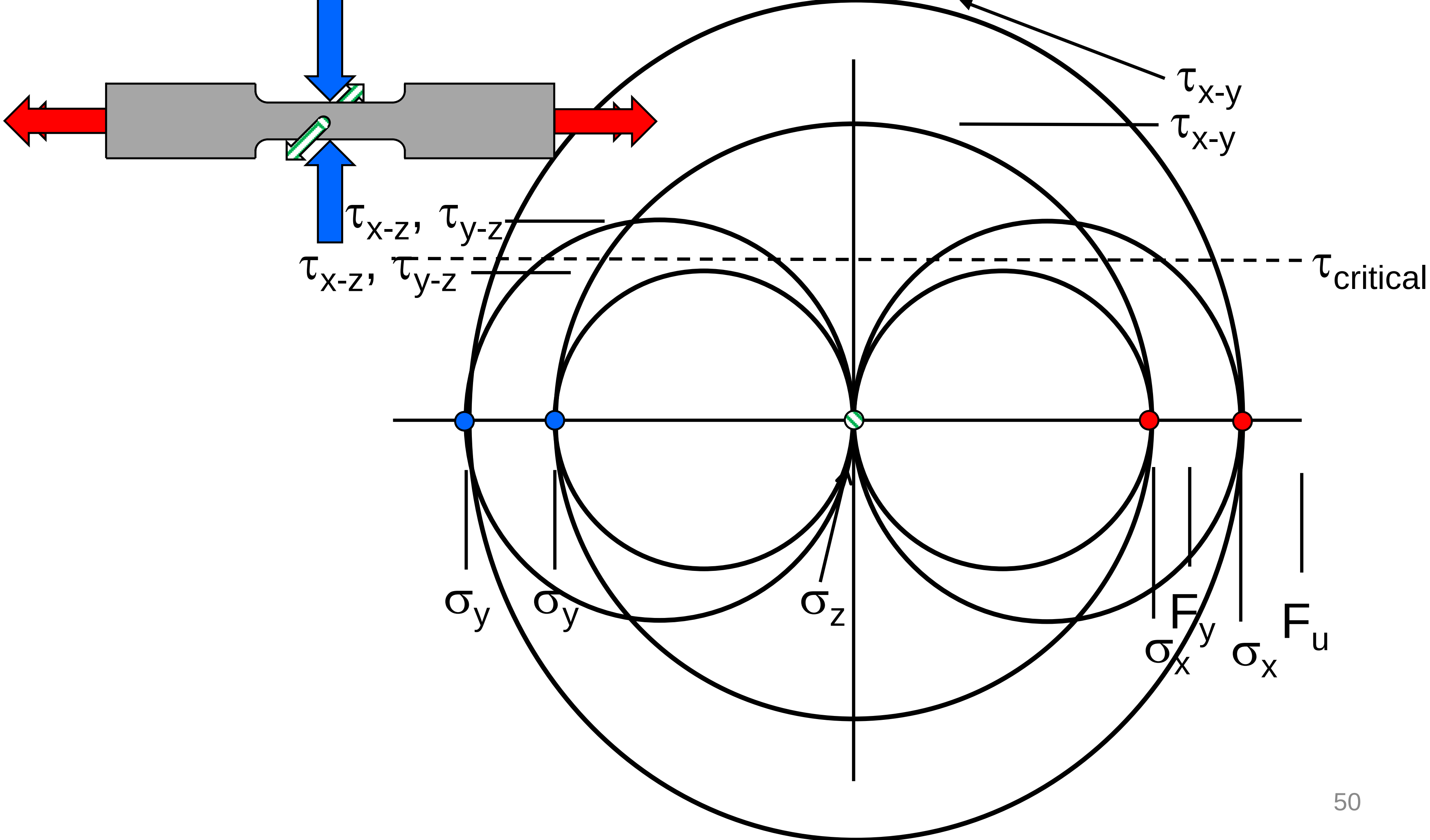
Shear strength
τx-y, τx-z
σy, σz
Fy
Fu
σx



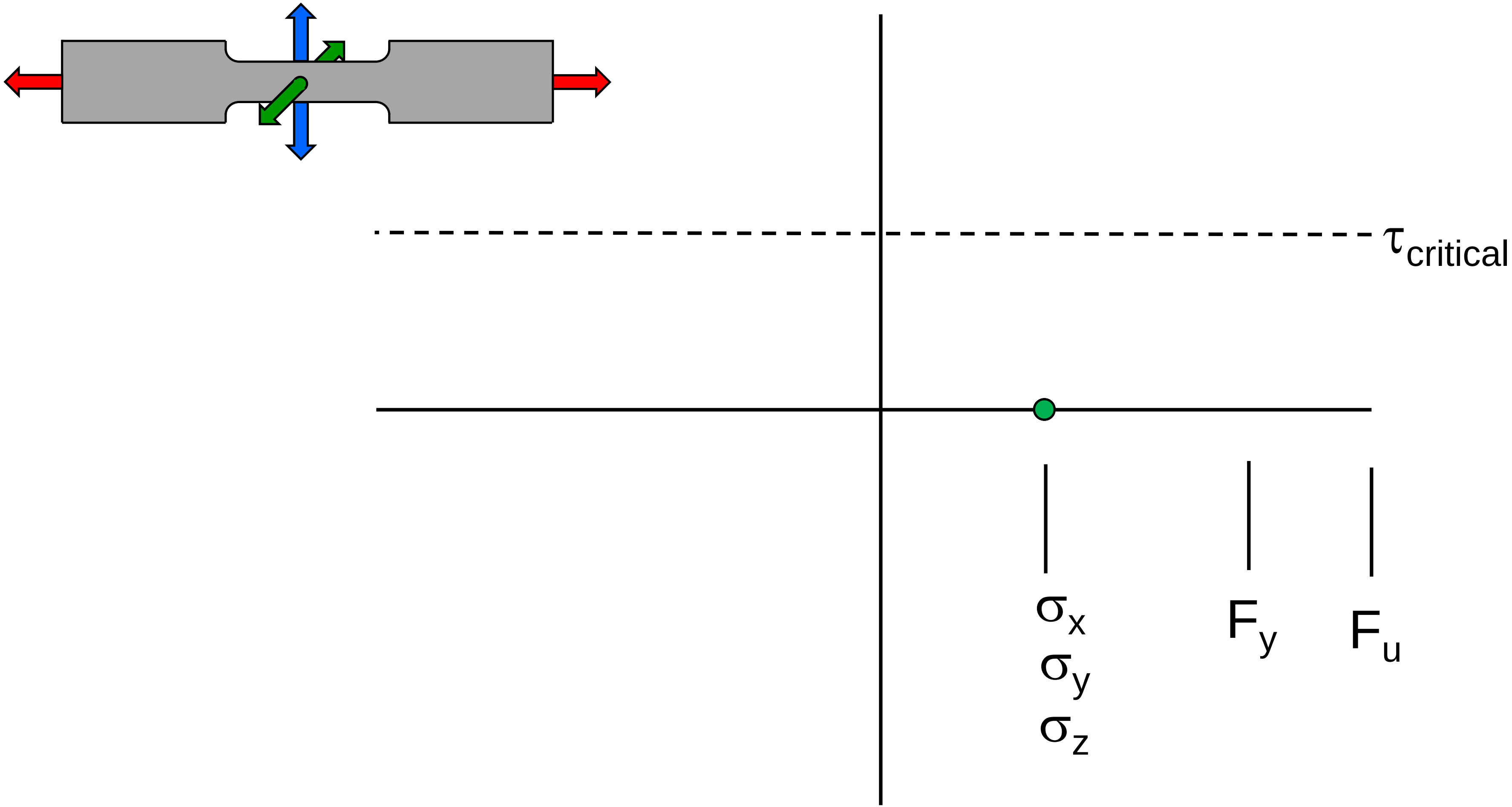
τx-y, τx-z
Shear strength
σy, σz
Fy
Fu
σx

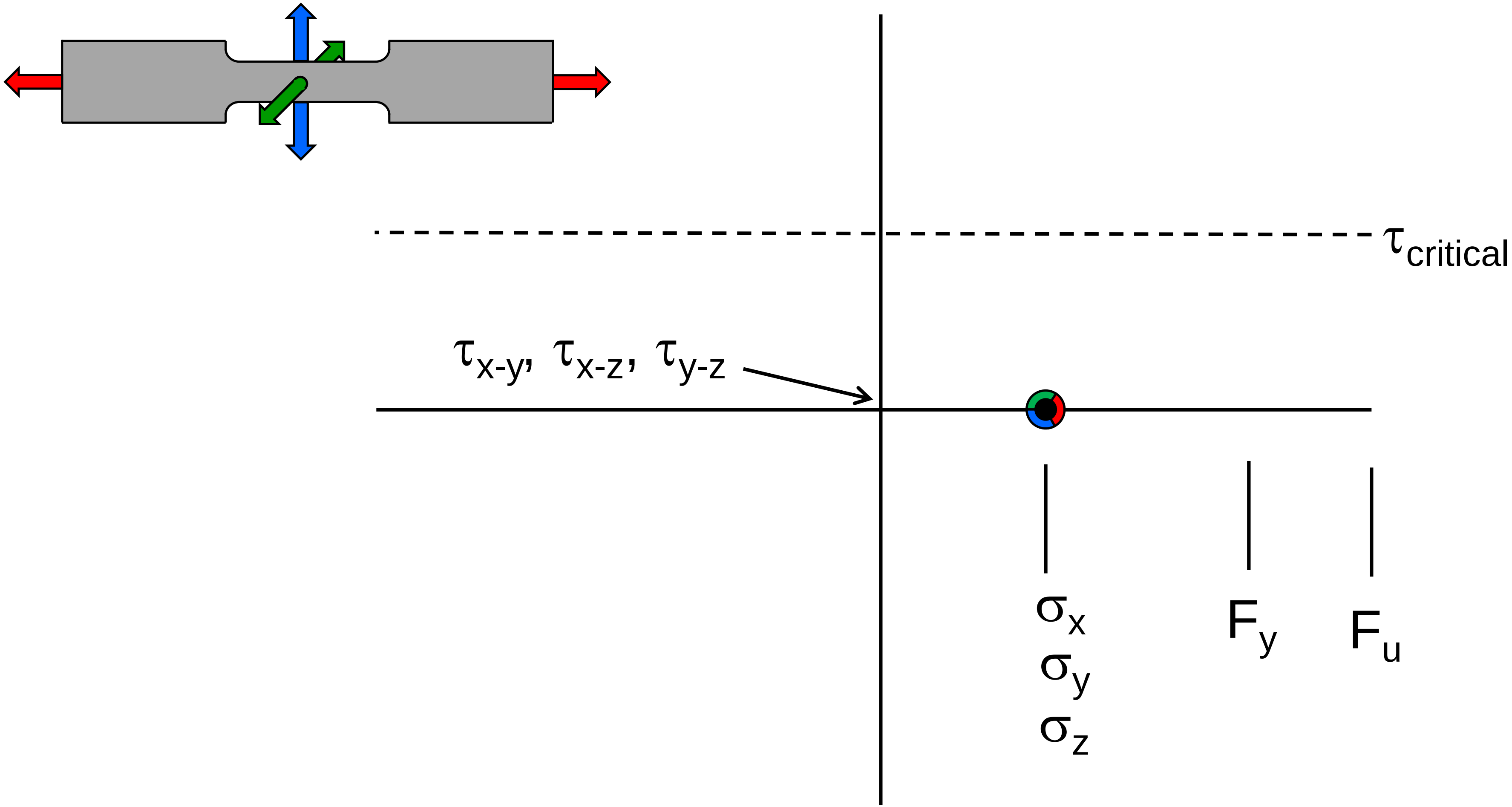

τcritical
τx-y
τx-z, τy-z
σy
σz
σx
Fy
Fu


τx-y
τx-z, τy-z
τx-y
τcritical
τx-z, τy-z
σy
σy
σz
σx
σx
Fy
Fu

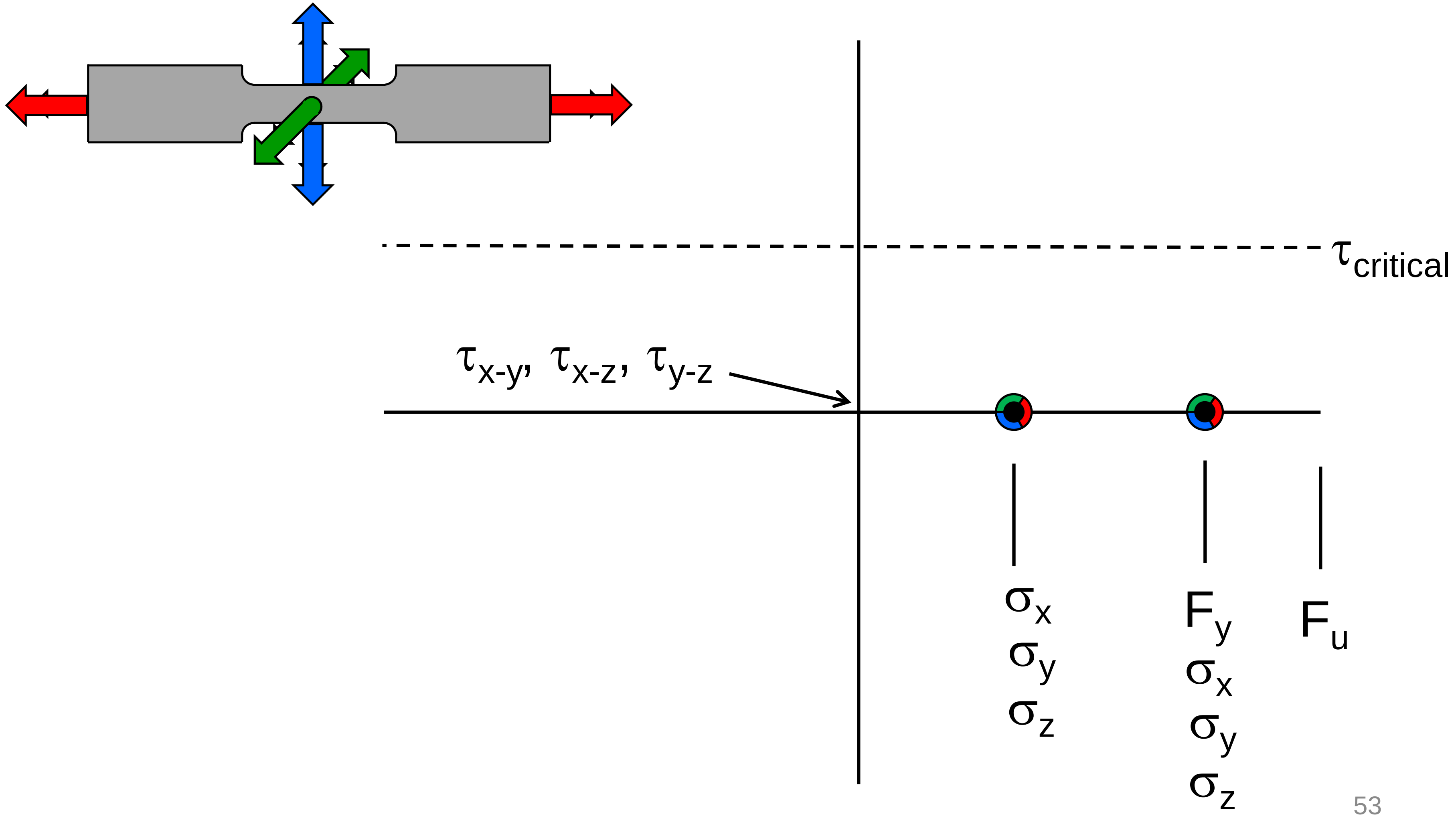


τx-y
τx-y
τx-z, τy-z
τx-z, τy-z
τcritical
σy
σy
σz
Fy
σx
σx
Fu

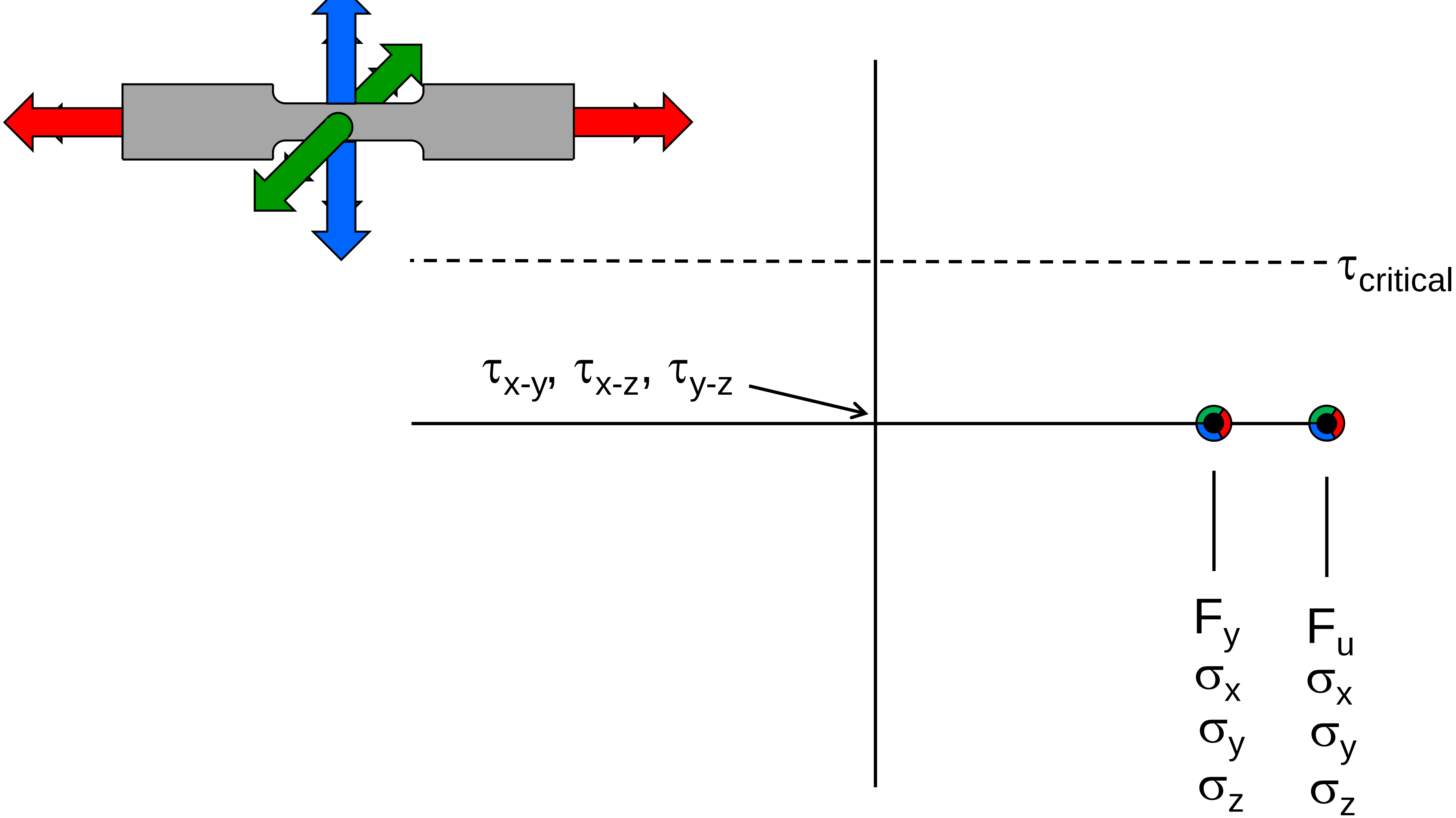

τcritical
σx
σy
σz
Fy
Fu



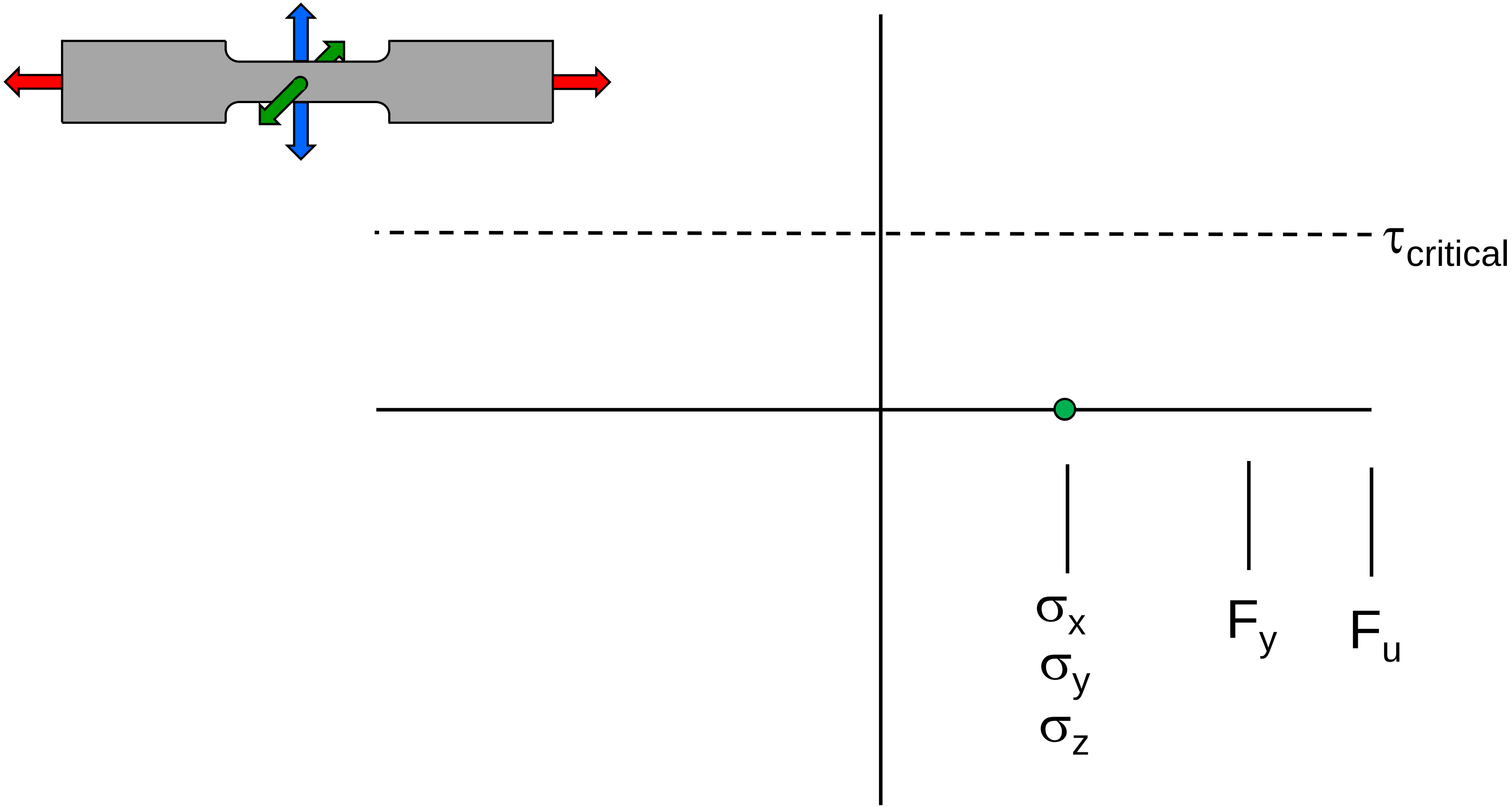
$\tau_{critical}$
τ_{x-y}, τ_{x-z}, τ_{y-z}
σ_x
σ_y
σ_z
F_y
F_u

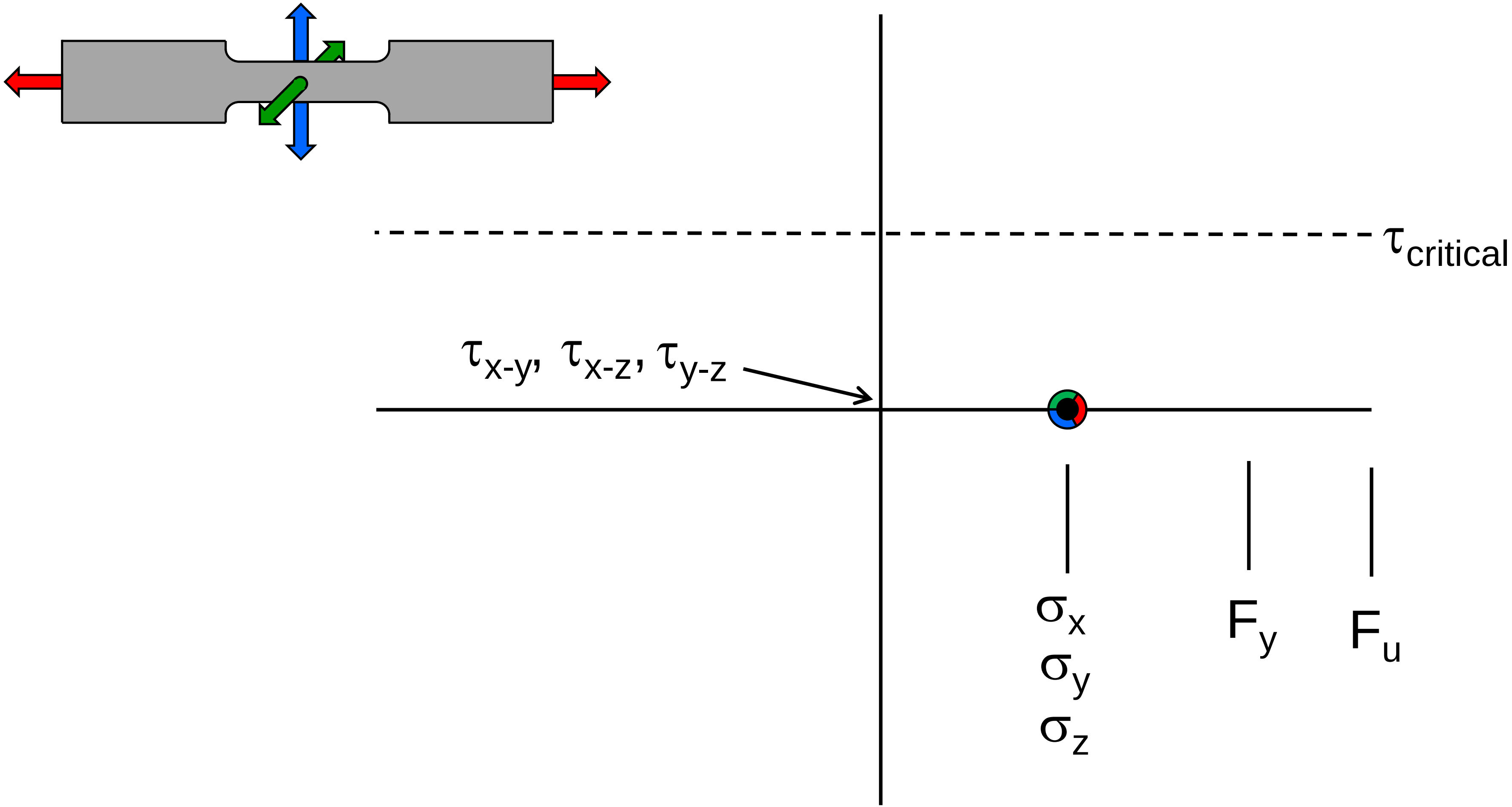


$\tau_{critical}$
τ_{x-y}, τ_{x-z}, τ_{y-z}
σ_x
σ_y
σ_z
F_y
σ_x
σ_y
σ_z
F_u

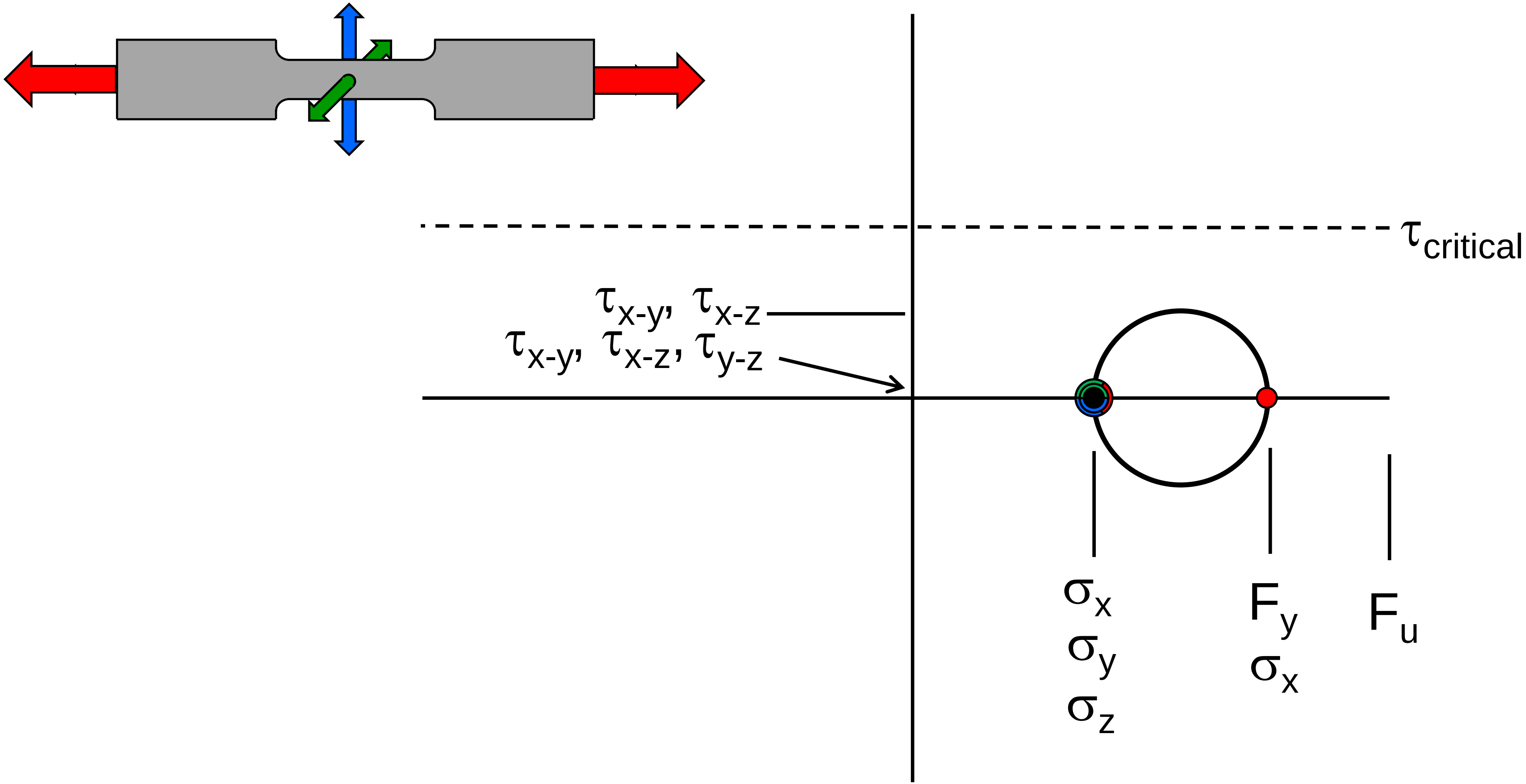


τcritical
τx-y, τx-z, τy-z
Fy
σx
σy
σz
Fu
σx
σy
σz

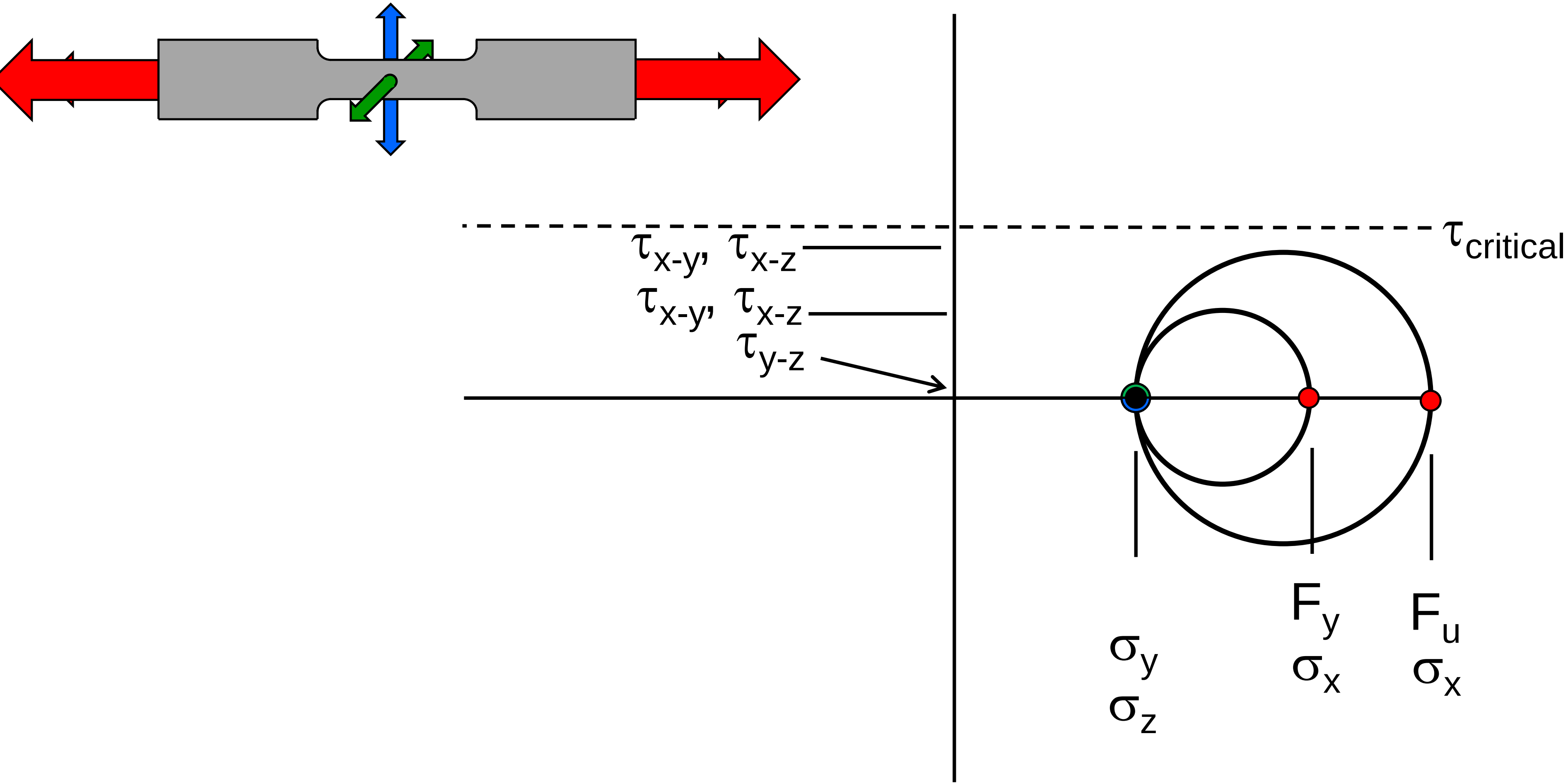

$\tau_{critical}$
σ_x
σ_y
σ_z
F_y
F_u



$\tau_{critical}$
τ_{x-y}, τ_{x-z}, τ_{y-z}
σ_x
σ_y
σ_z
F_y
F_u

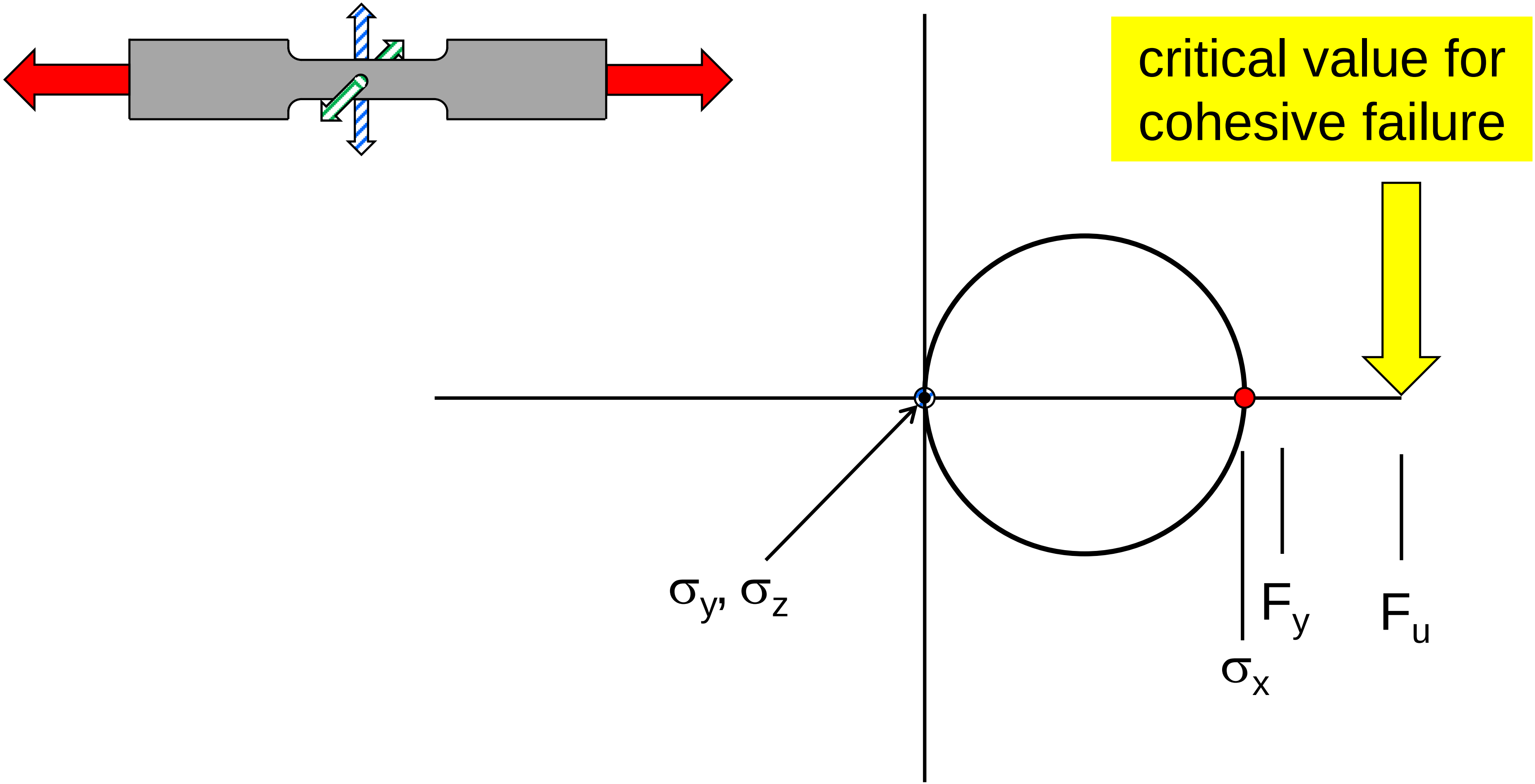


$\tau_{critical}$
τ_{x-y}, τ_{x-z}
τ_{x-y}, τ_{x-z}, τ_{y-z}
σ_x
σ_y
σ_z
F_y
σ_x
F_u


τcritical
τx-y, τx-z
τx-y, τx-z
τy-z
σy
σz
Fy
σx
Fu
σx

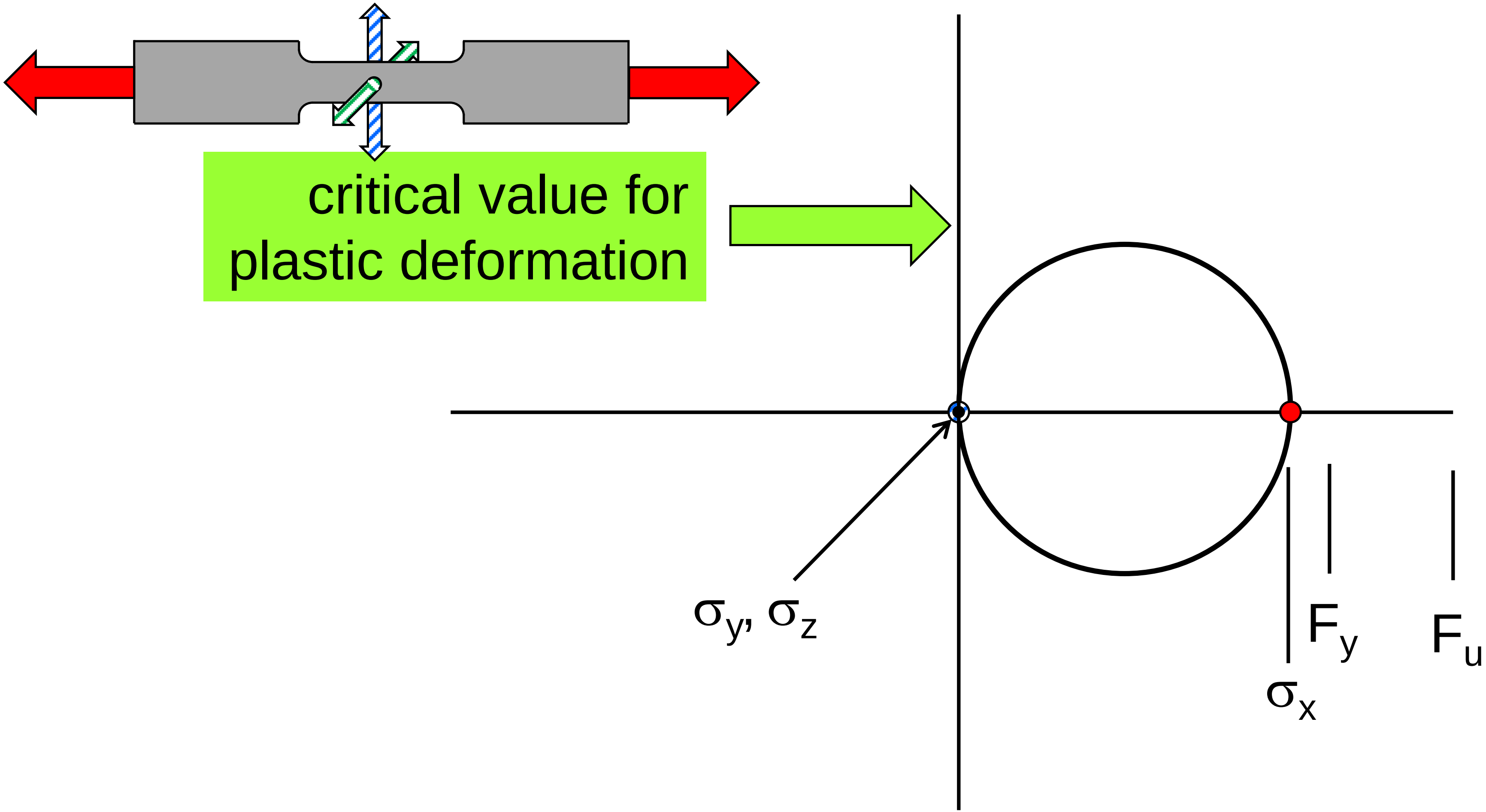
STRENGTH OF METALS UNDER COMBINED STRESSES

"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.


critical value for cohesive failure
σy, σz
σx
Fy
Fu

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.


critical value for
plastic deformation
σy, σz
σx
Fy
Fu

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."

Ductility: Another View

Outline

- Introduction
- A Wrong View
- A Corrected View

Ductility is function of the testing or service conditions.

Ductility: Another View

Outline

- Introduction
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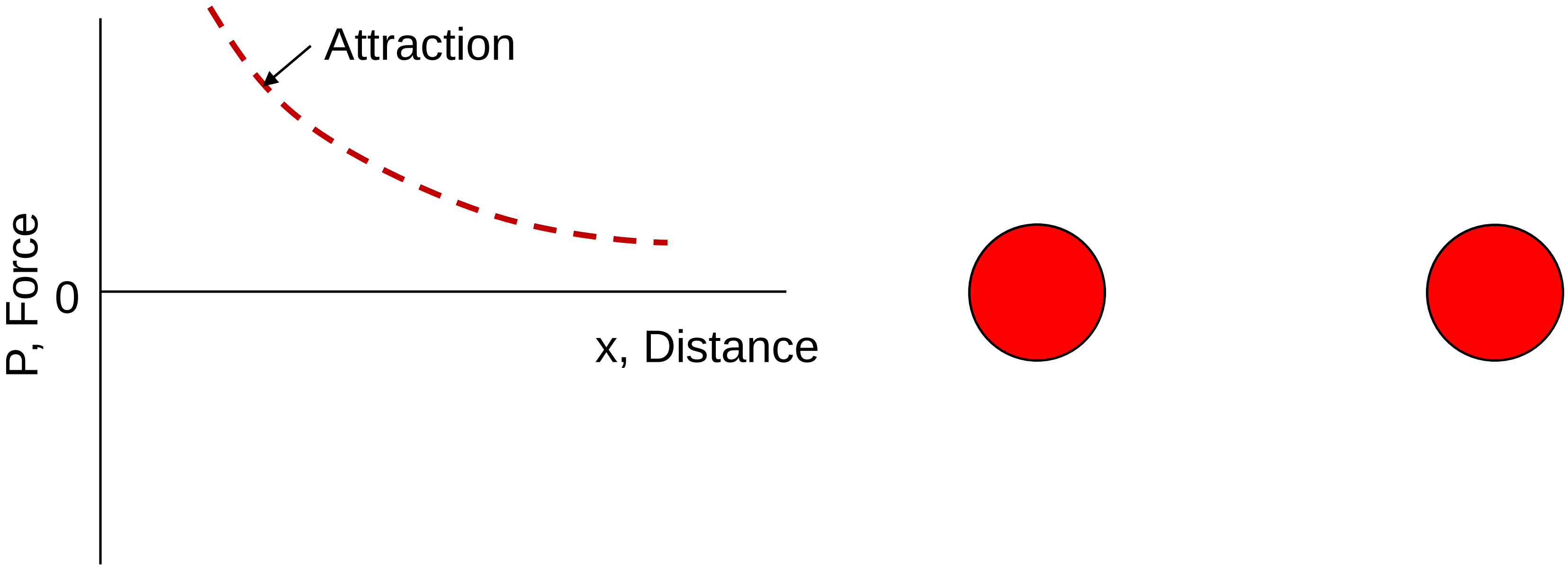
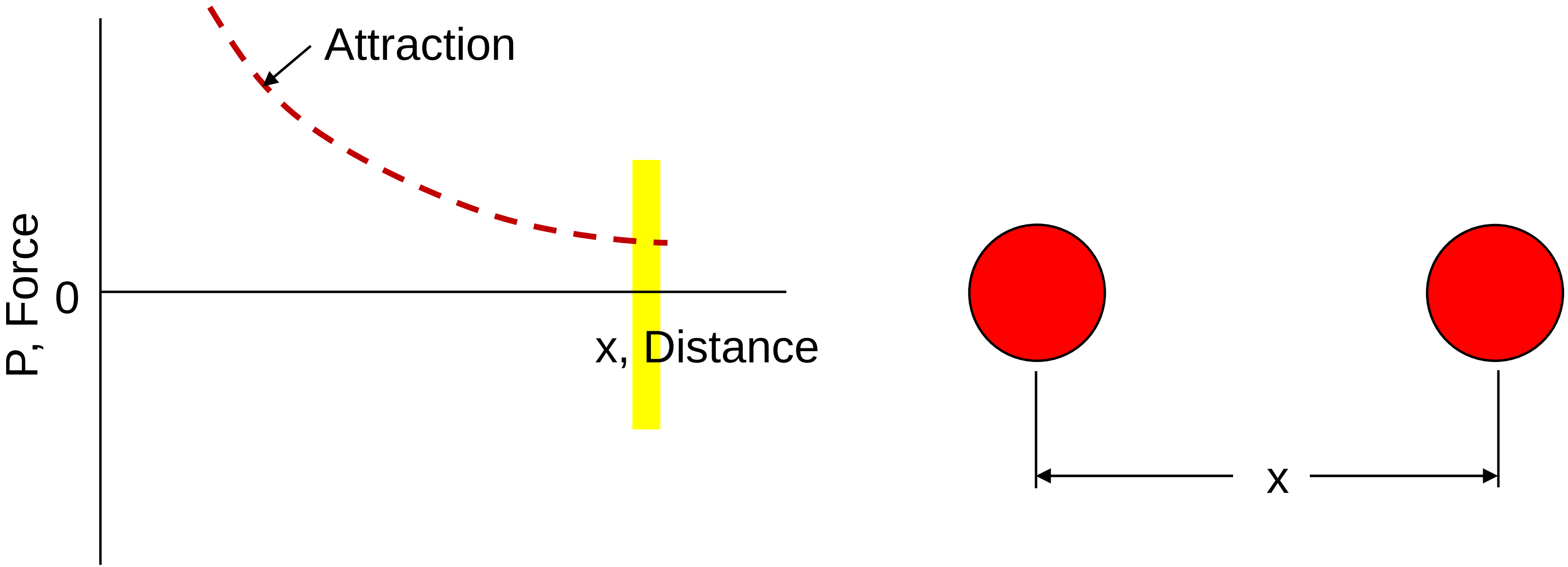
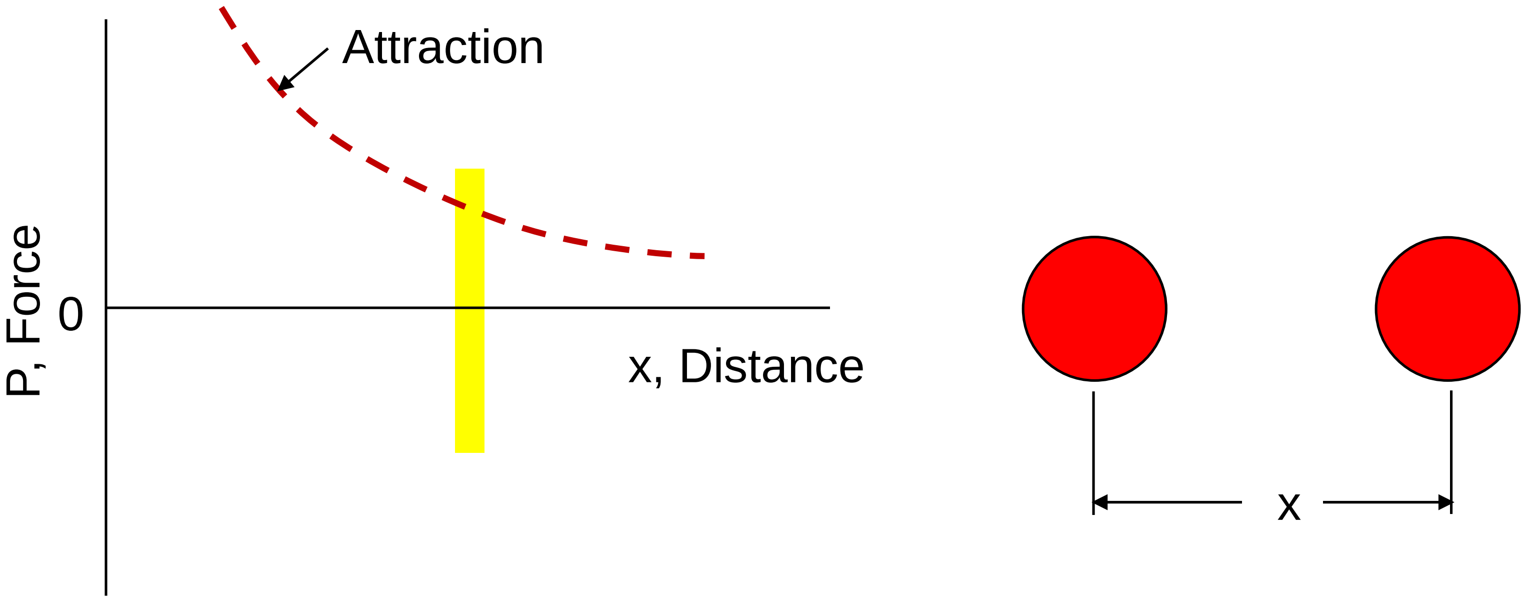
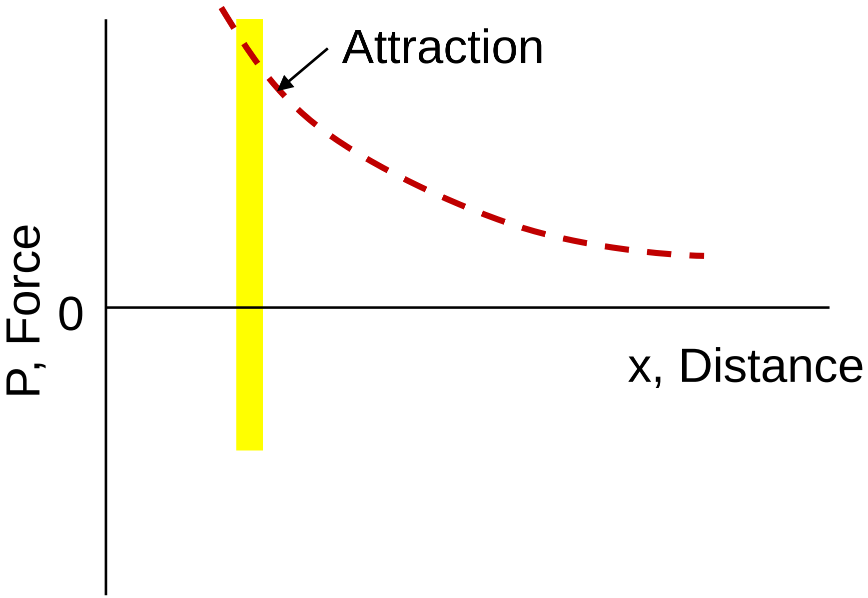
- The View of Physics
- Application of the Correct View

Lennard Jones Potential

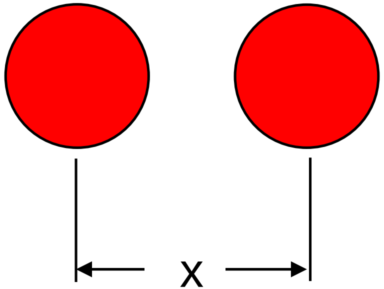



Attraction
P, Force
0
x, Distance
x

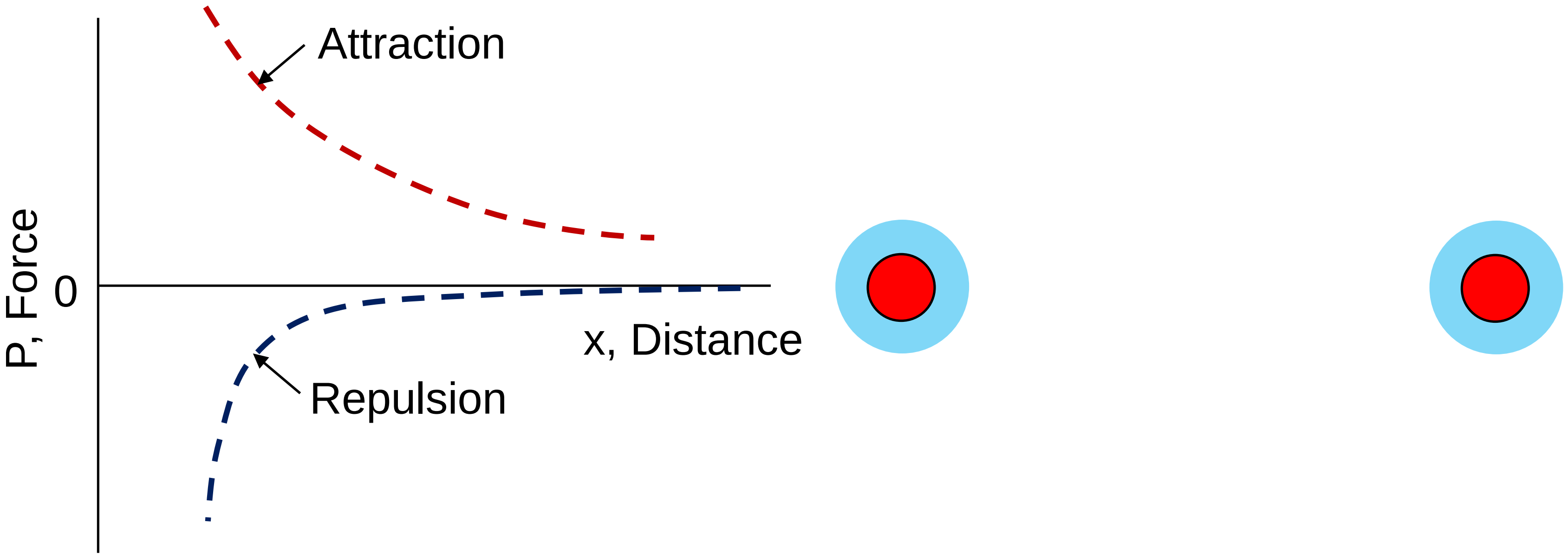

Attraction
P, Force
0
x, Distance
x



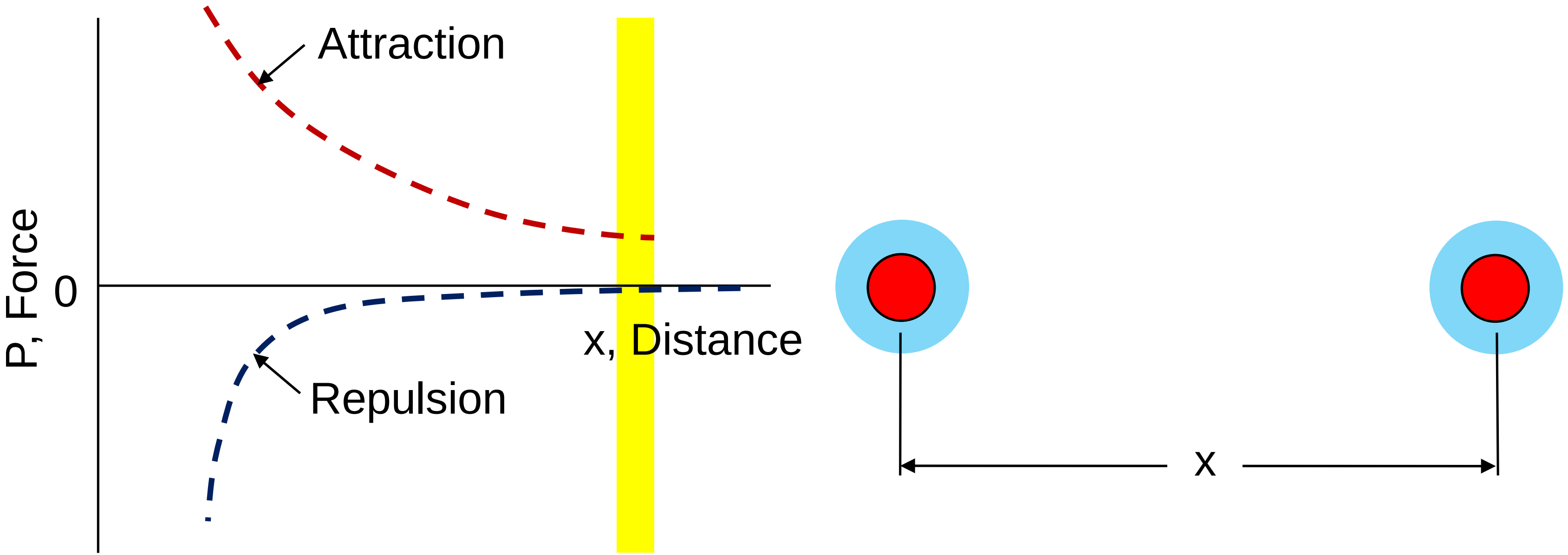
Attraction
P, Force
0
x, Distance

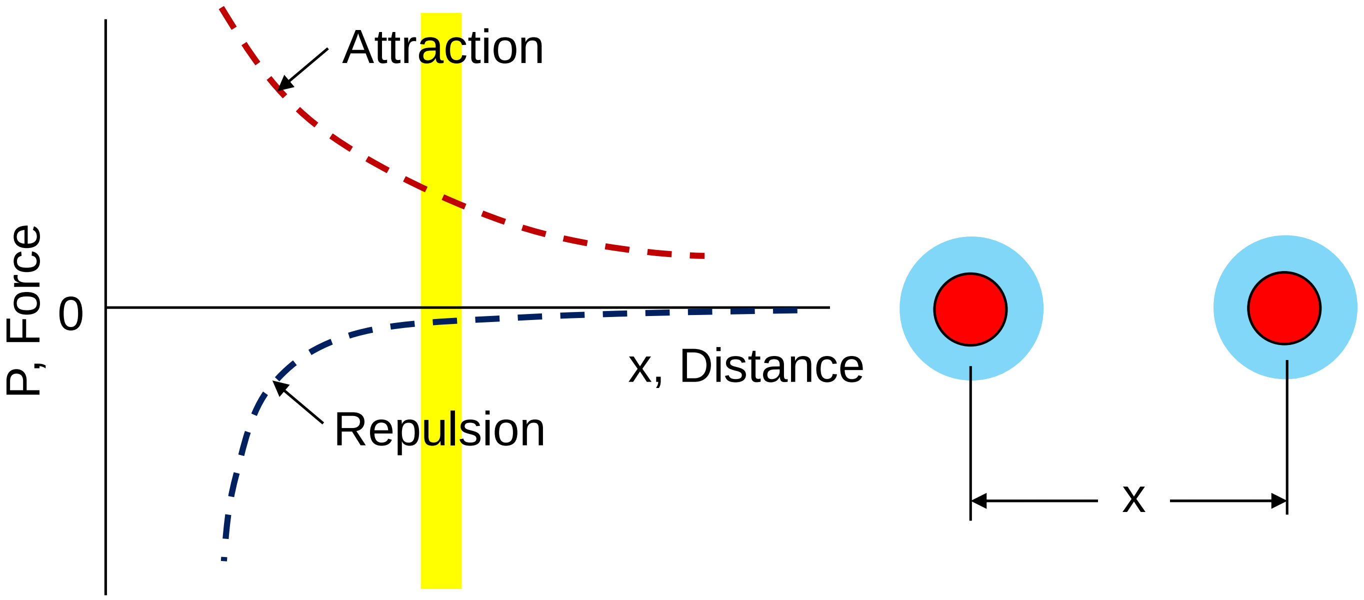


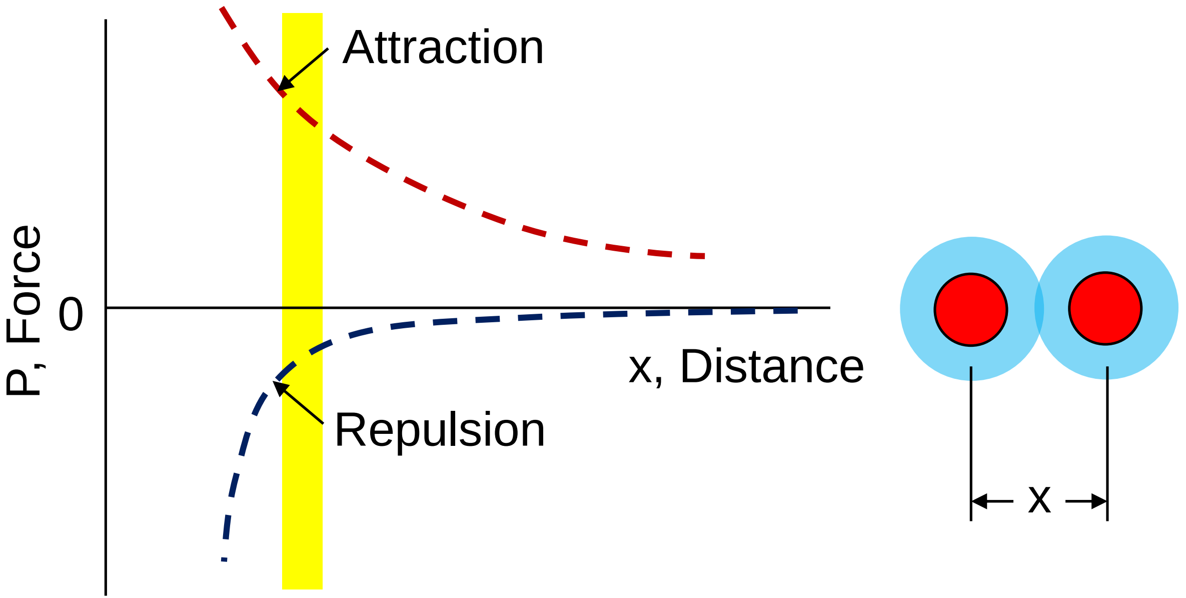
x



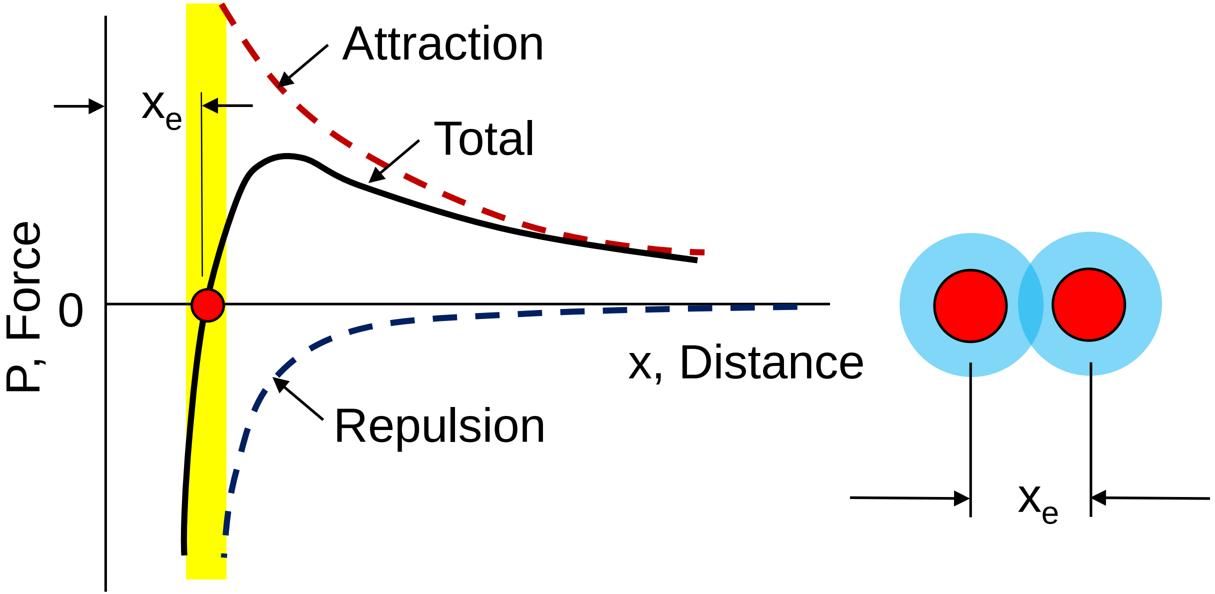
Attraction
P, Force
0
x, Distance
Repulsion

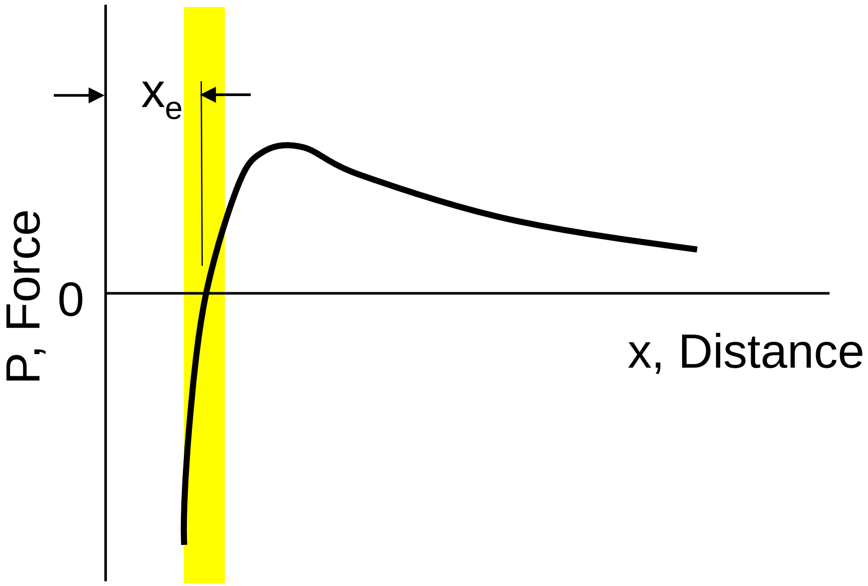

Attraction
P, Force
0
x, Distance
Repulsion
x

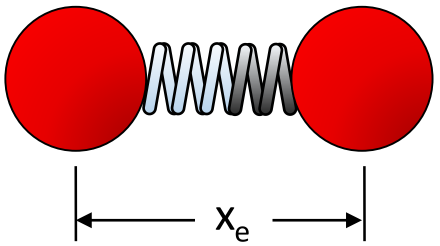

Attraction
P, Force
0
x, Distance
Repulsion
x



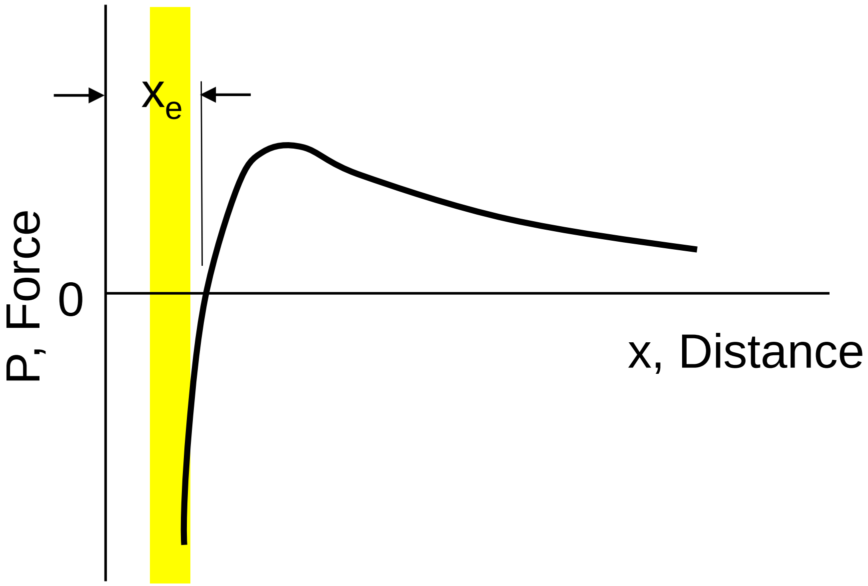
Attraction
P, Force
0
x, Distance
Repulsion
x

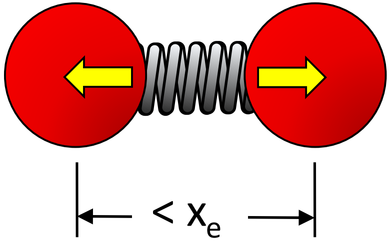

Attraction
Total
Repulsion
P, Force
0
x, Distance
x_e
x_e


P, Force
0
x_e
x, Distance

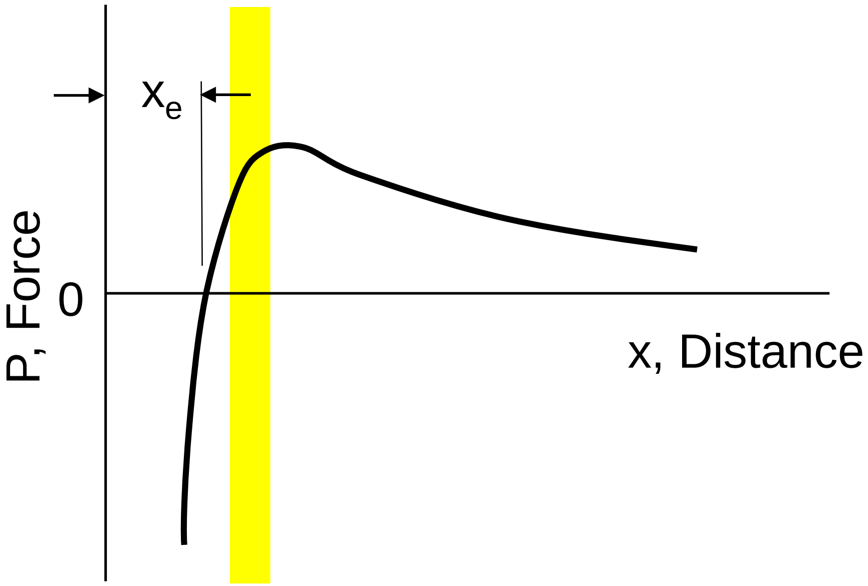

x_e

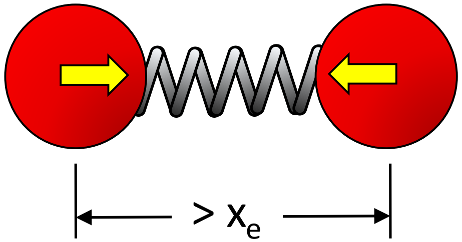
Compressive Strength



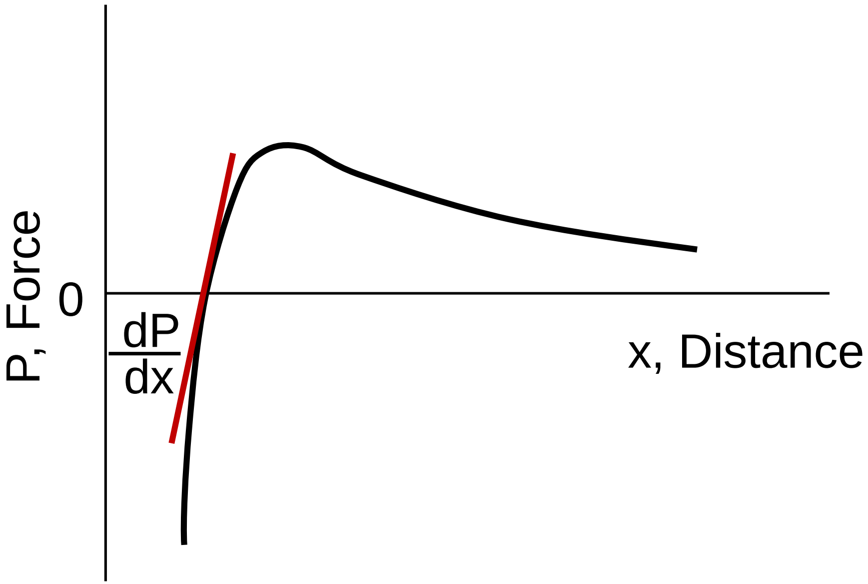


Tensile Strength





Modulus of Elasticity



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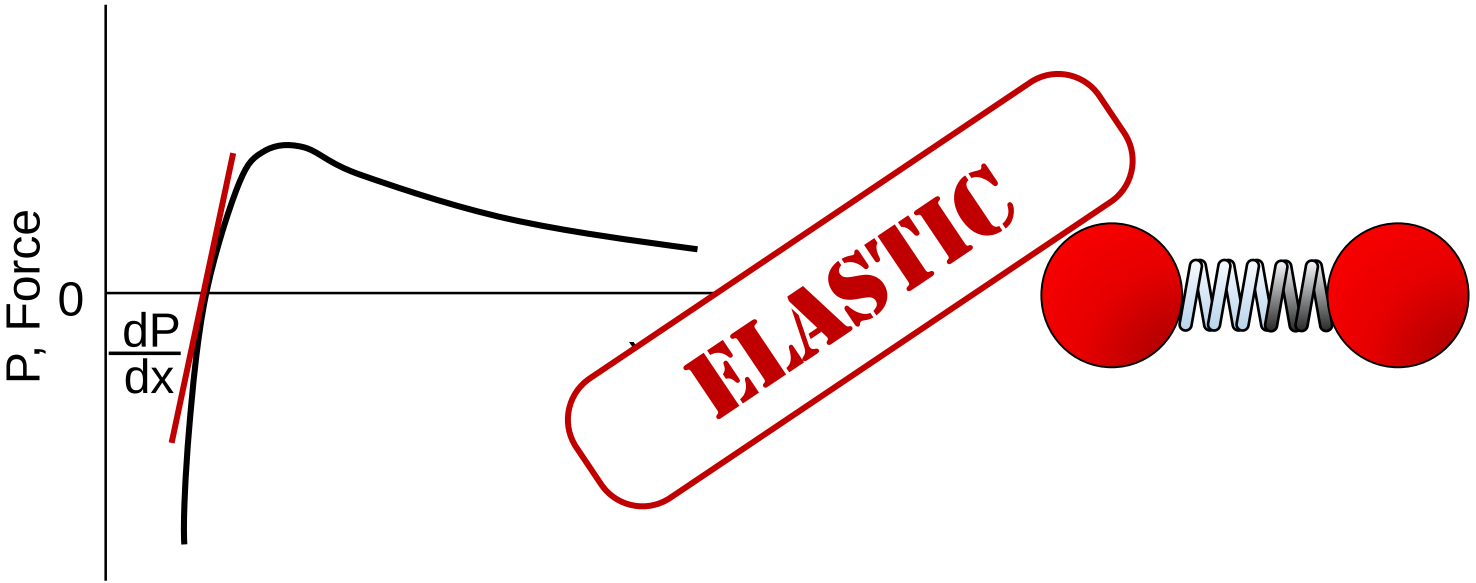
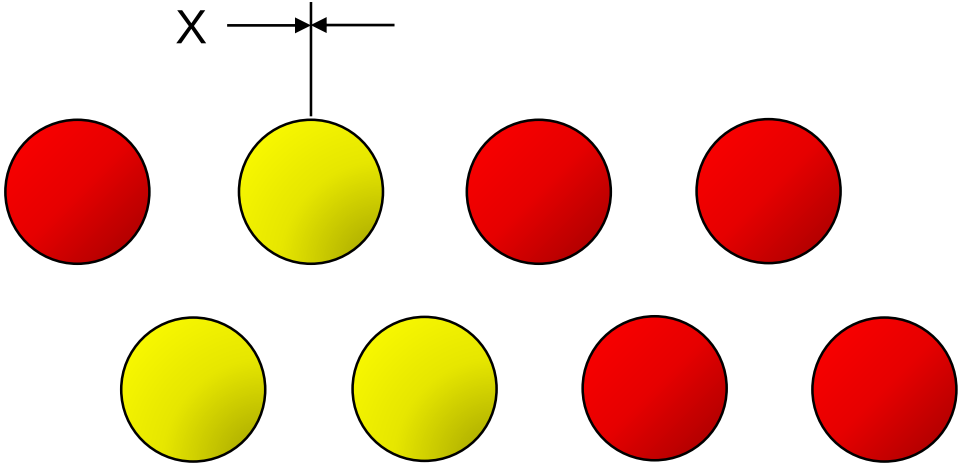
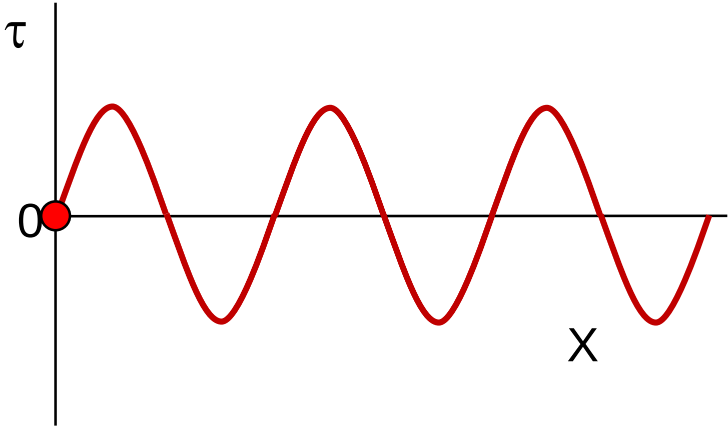
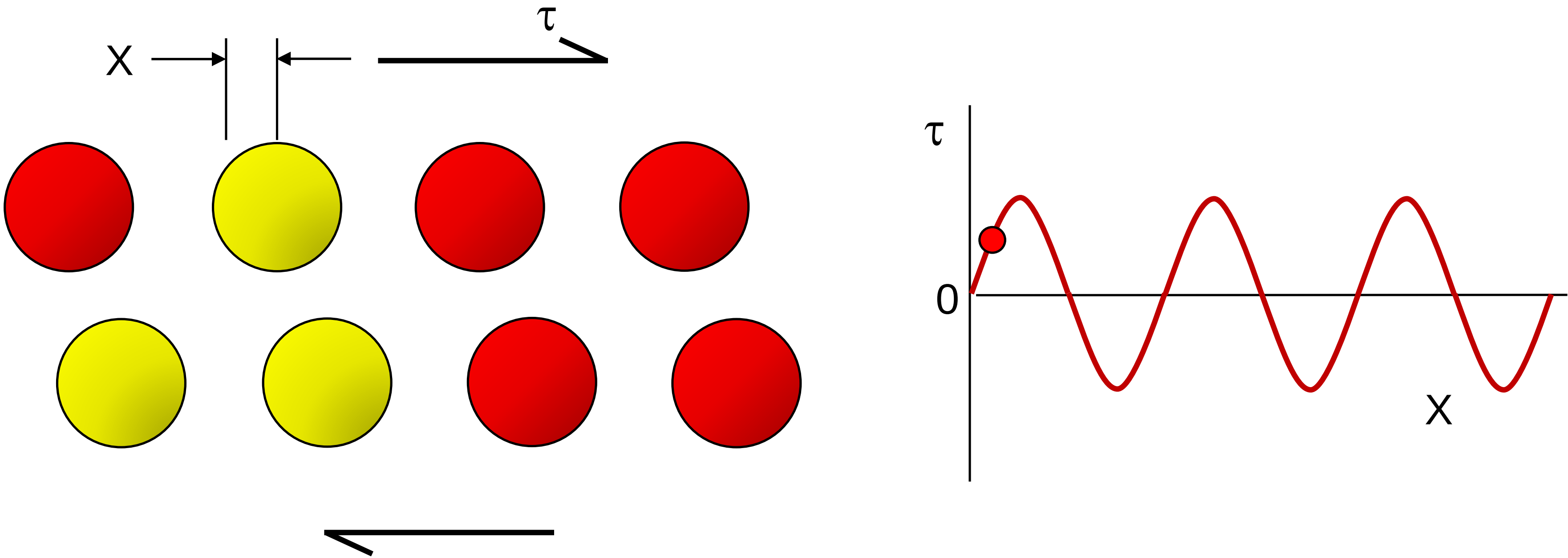
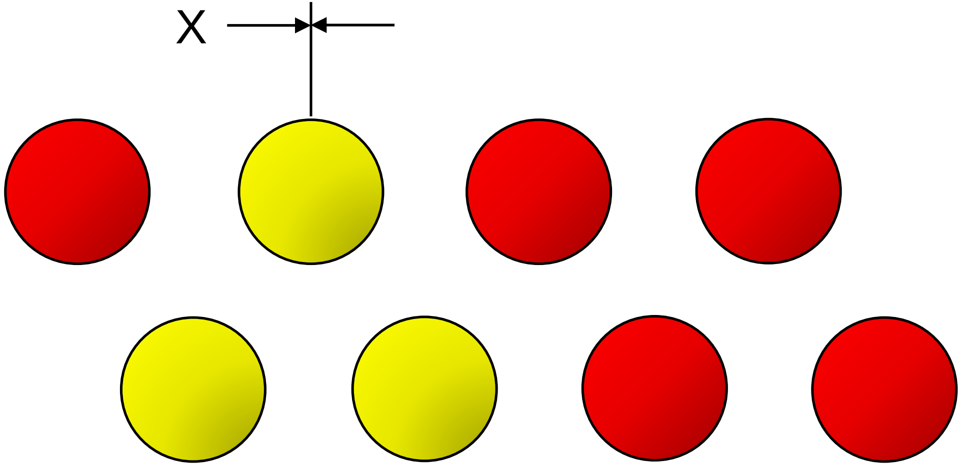
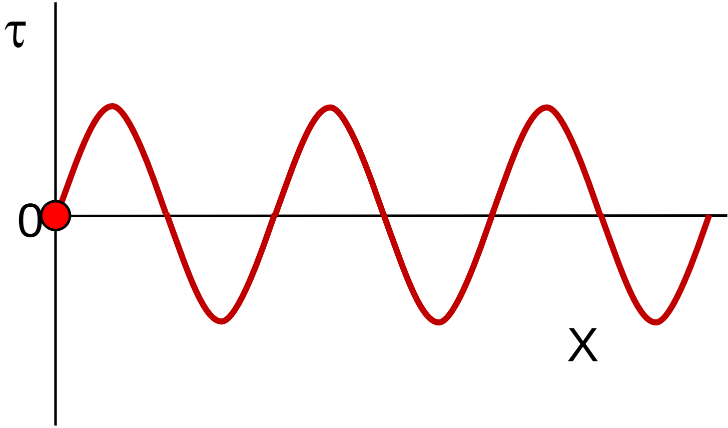



x

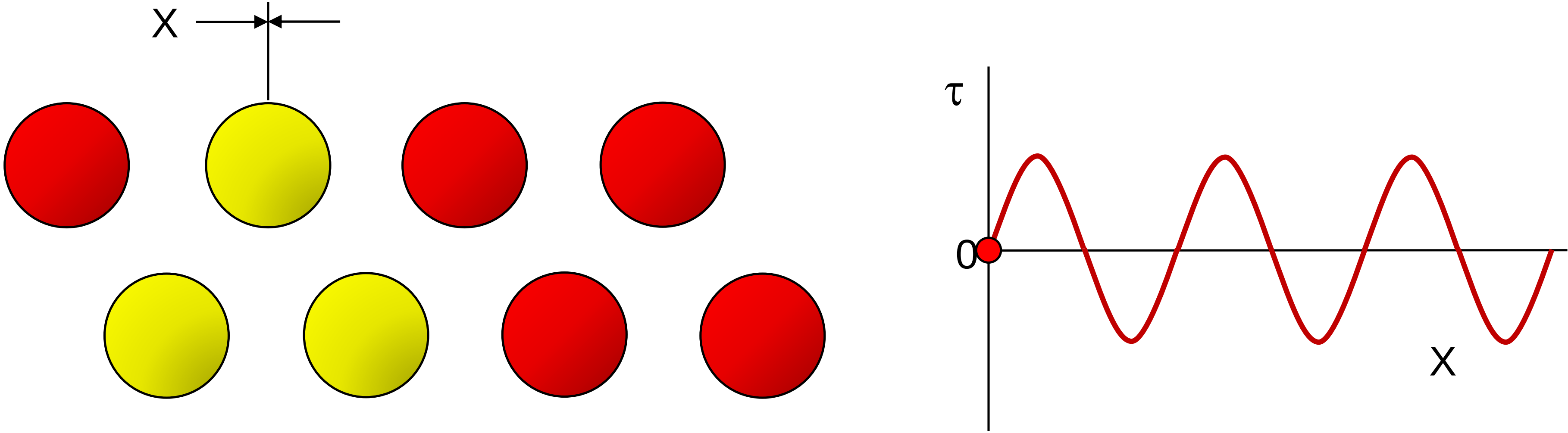

τ
0
x

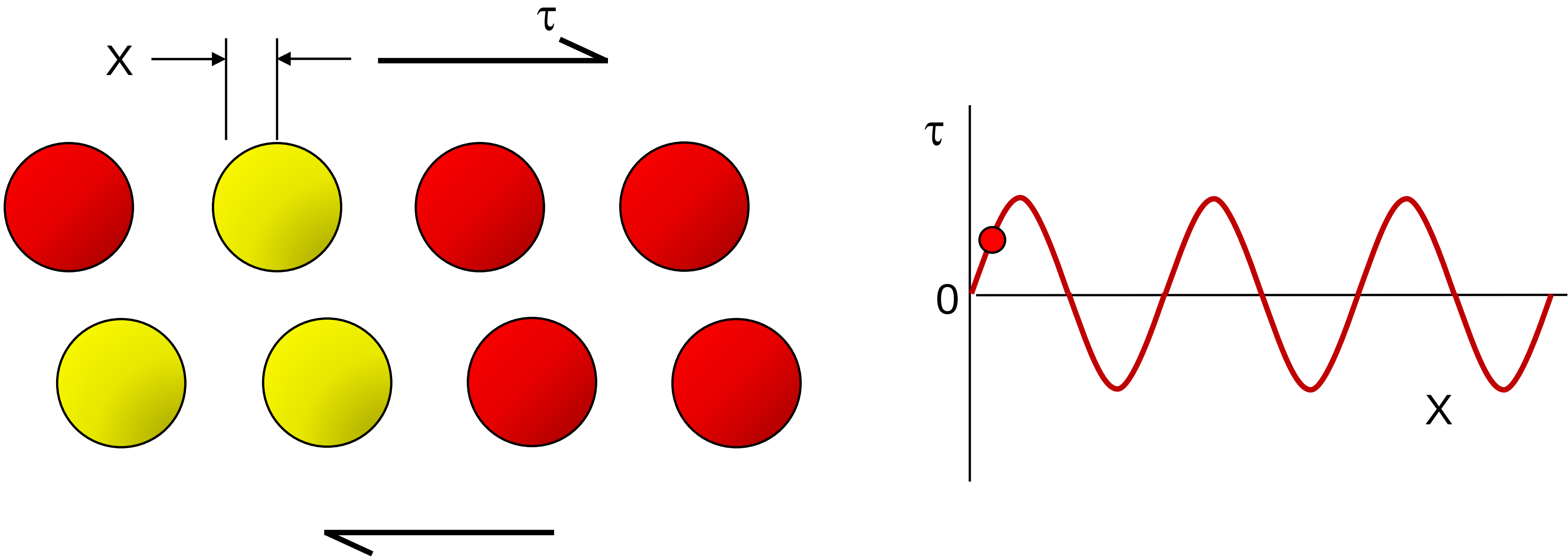

x
τ
τ
0
x


x

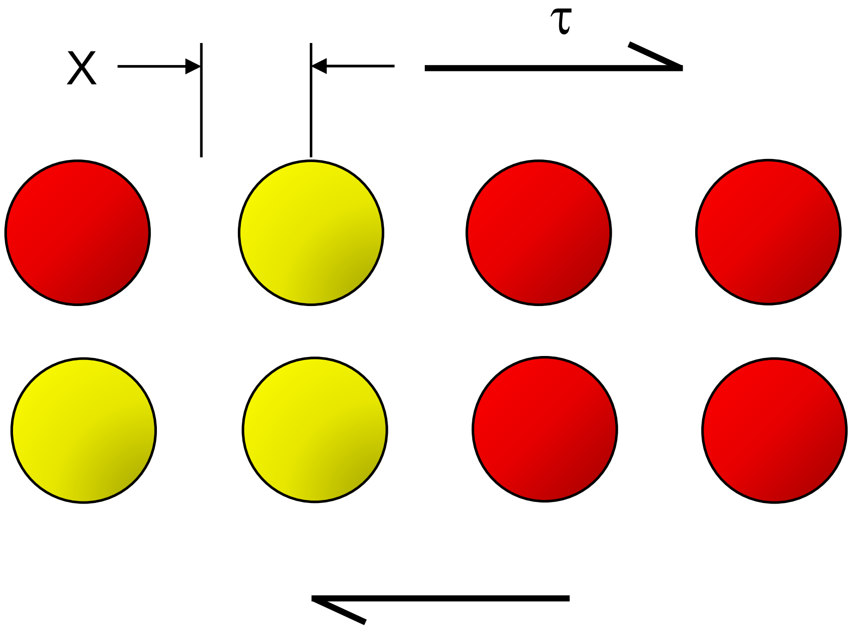

τ
0
x

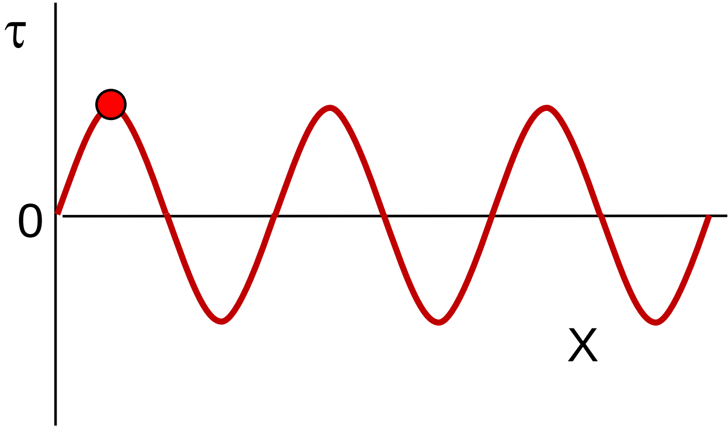

X
ELASTIC
0
X

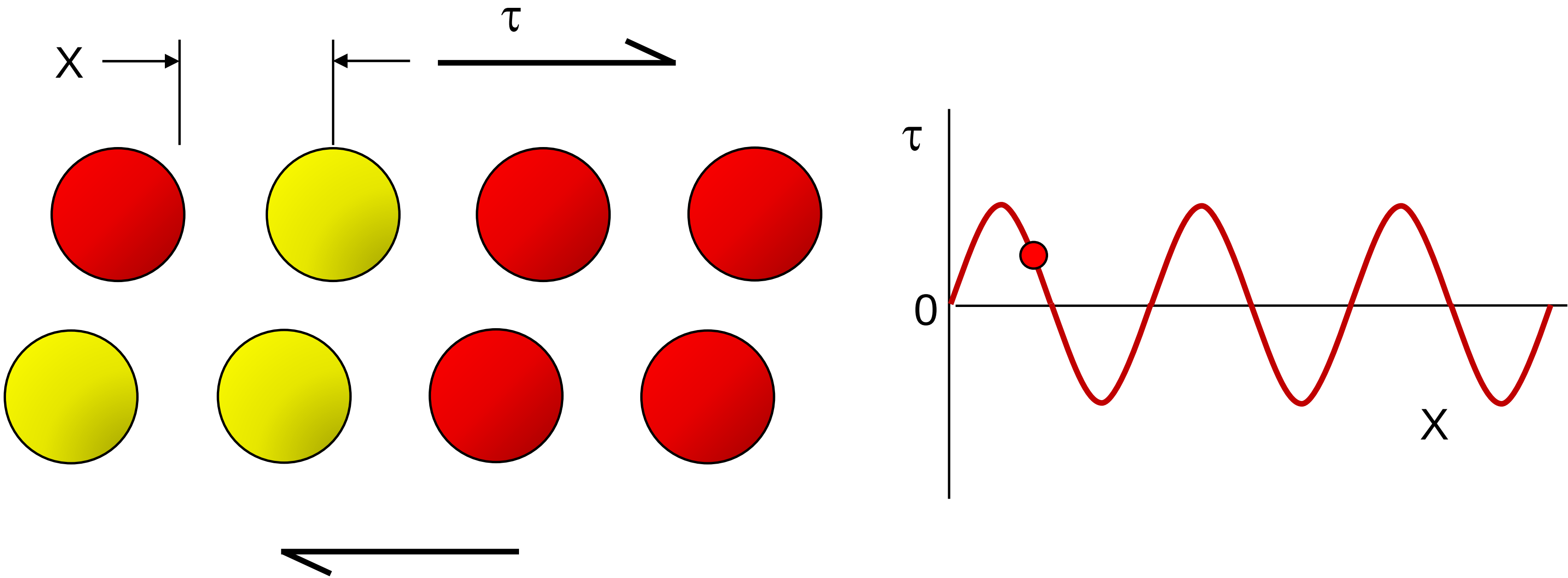

x
τ
0
x



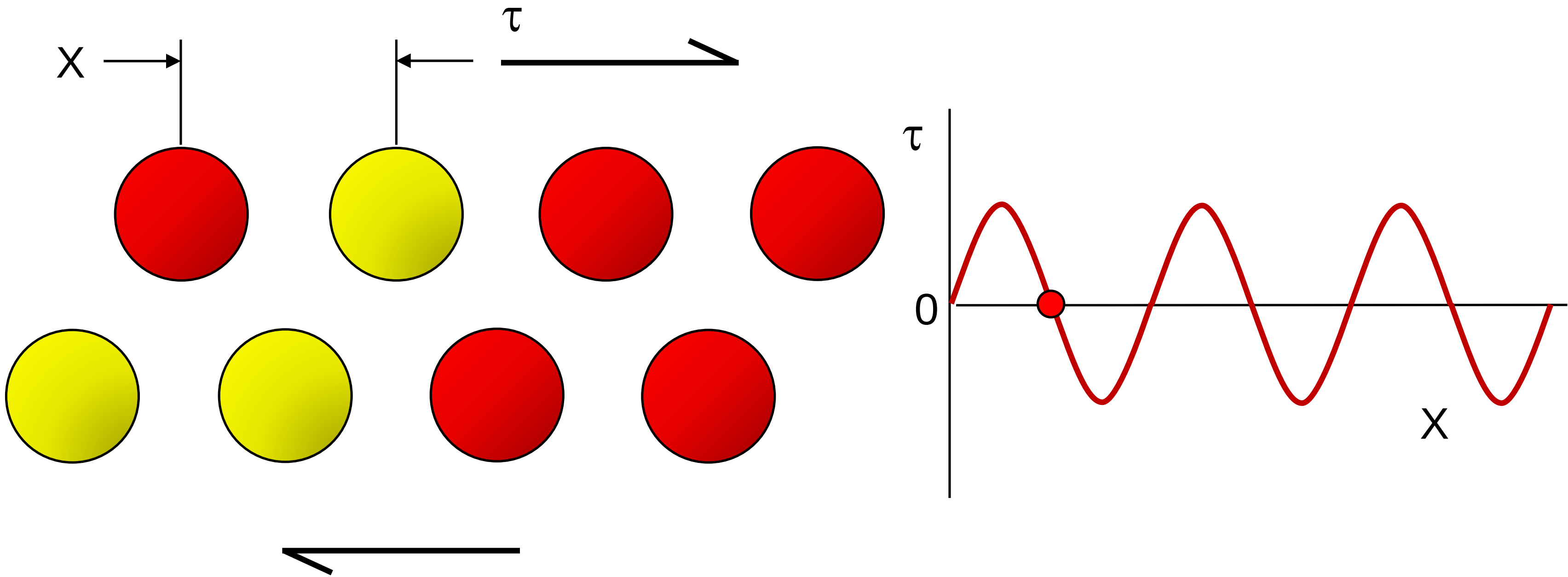
x
τ
τ
0
x


τ
x

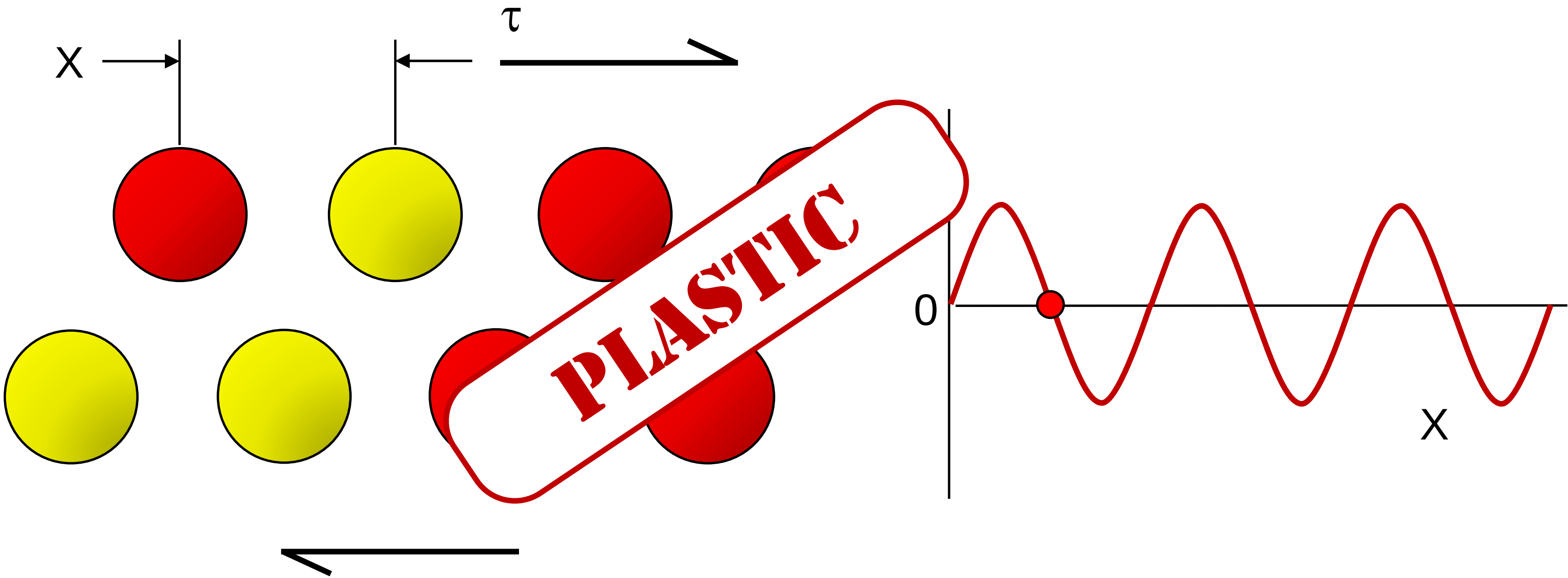

τ
0
x

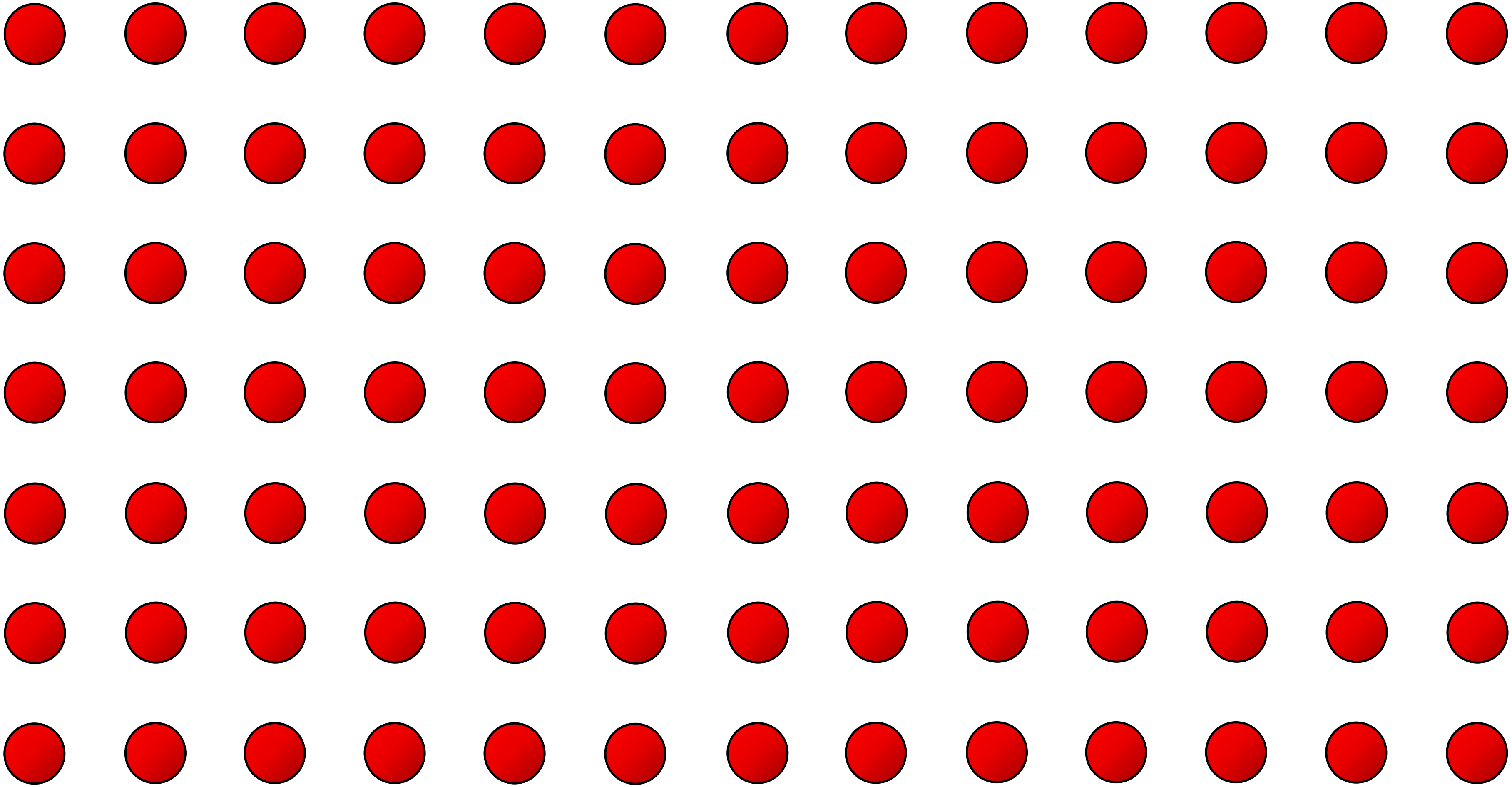


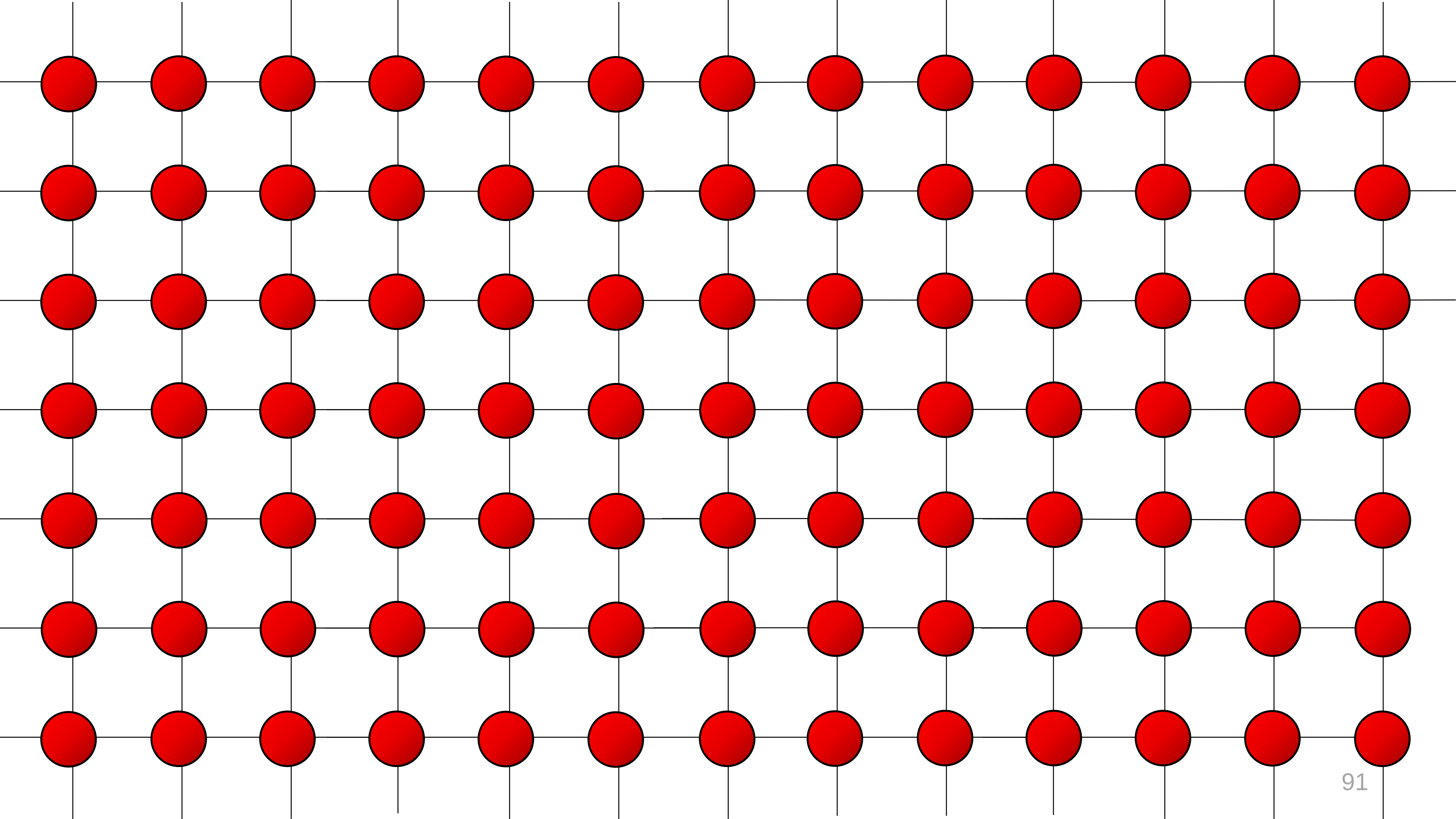
X
τ
τ
0
X

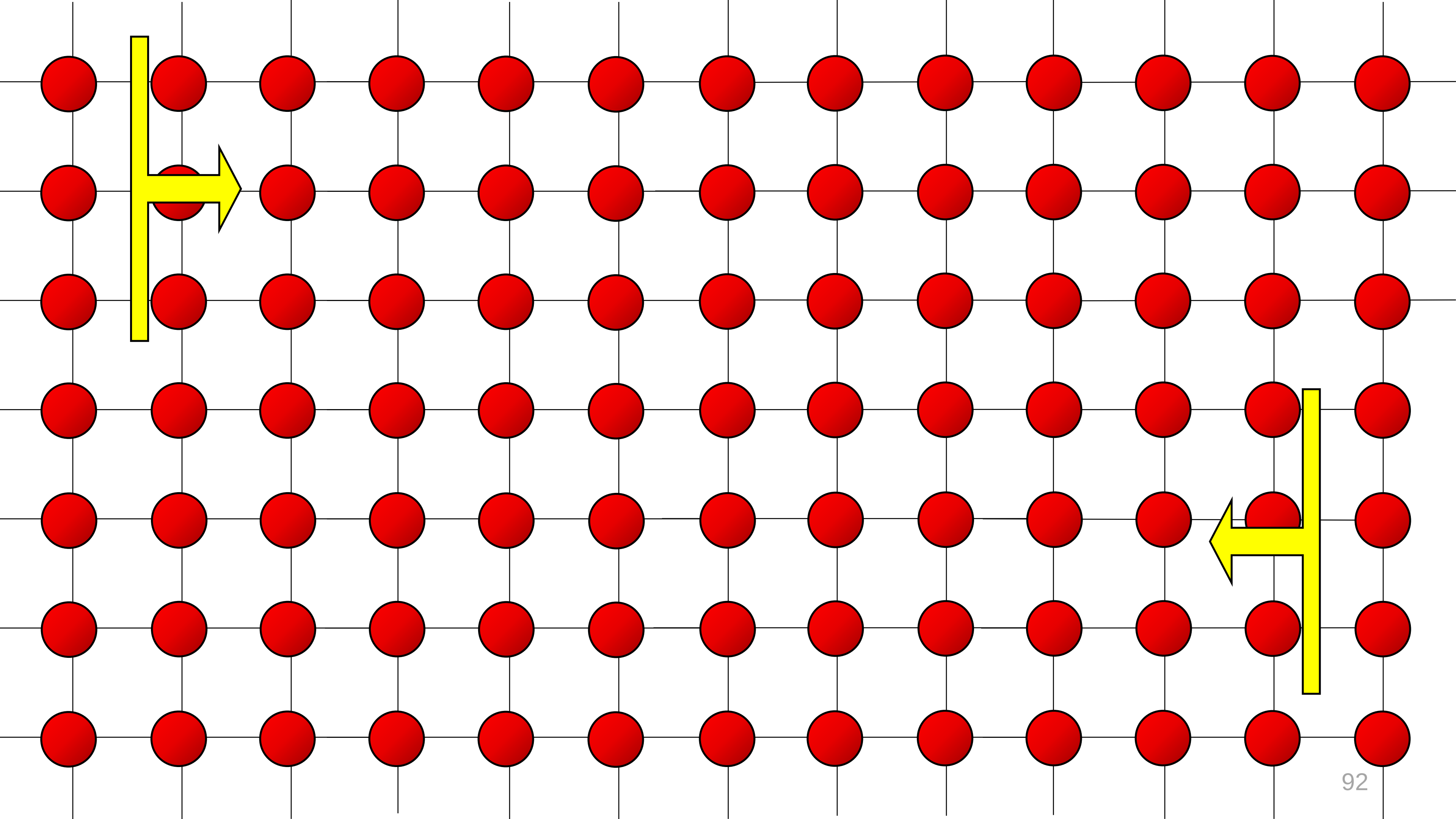


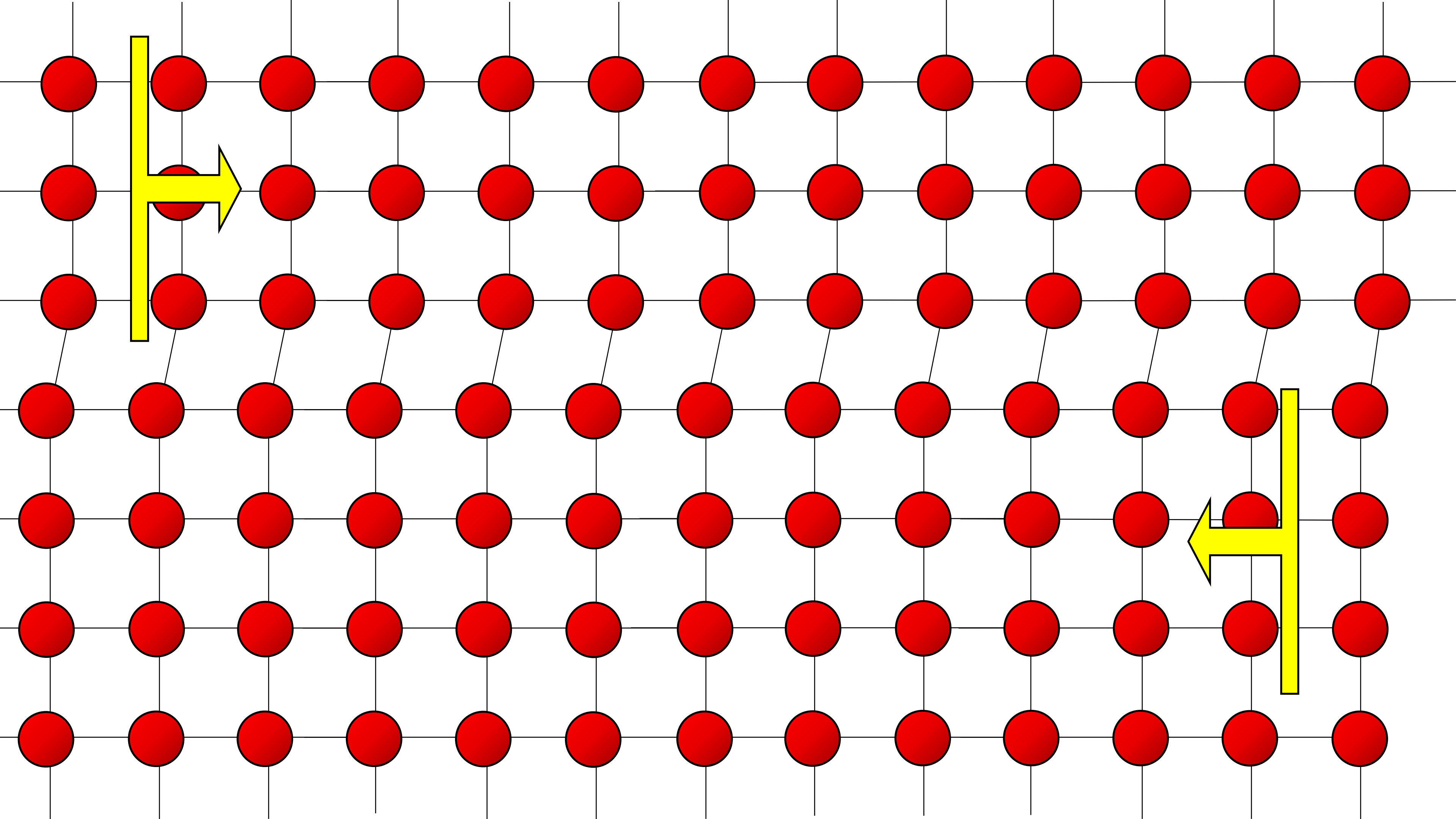
τ
x
τ
0
x

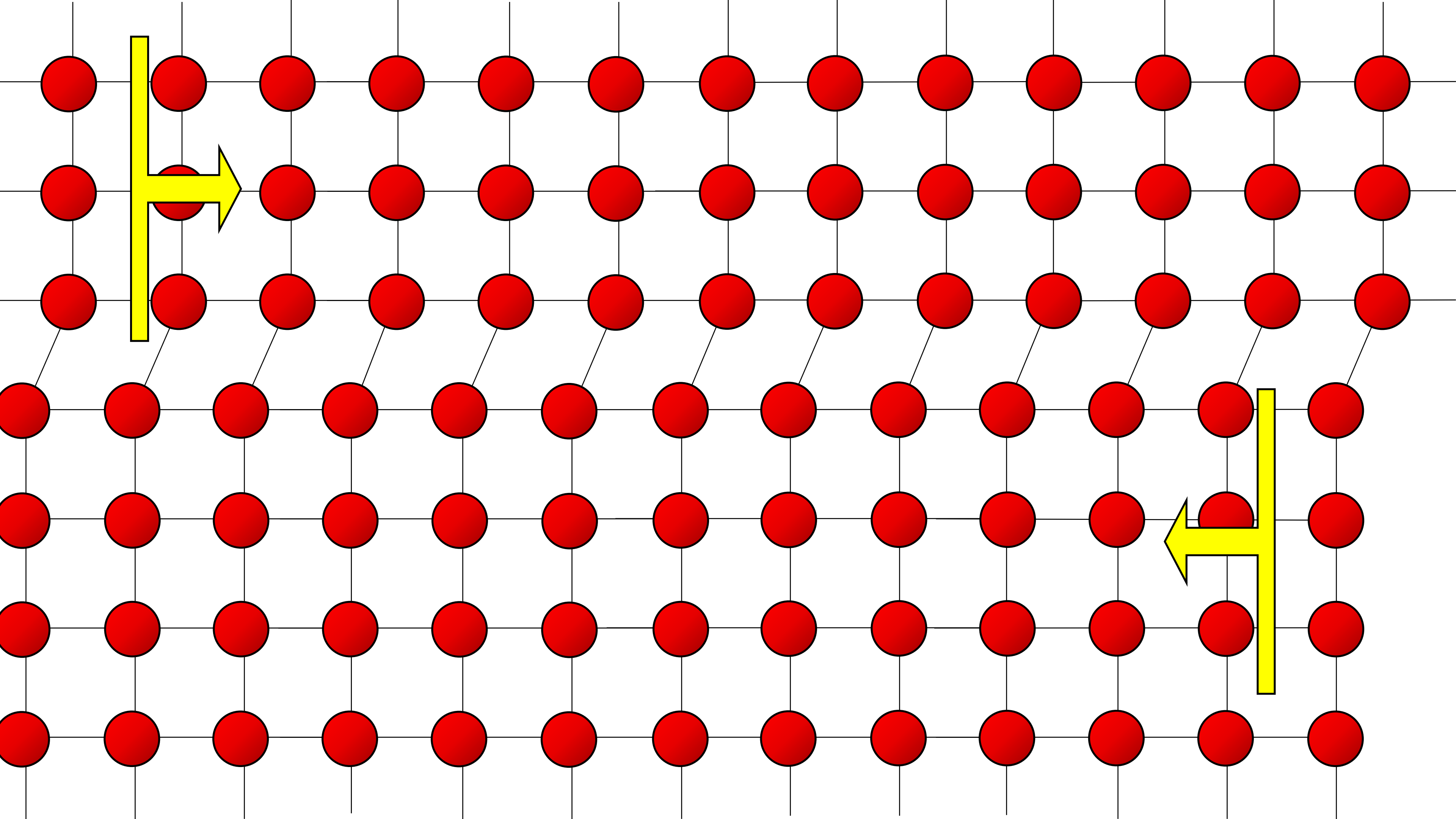

x
τ
PLASTIC
0
x

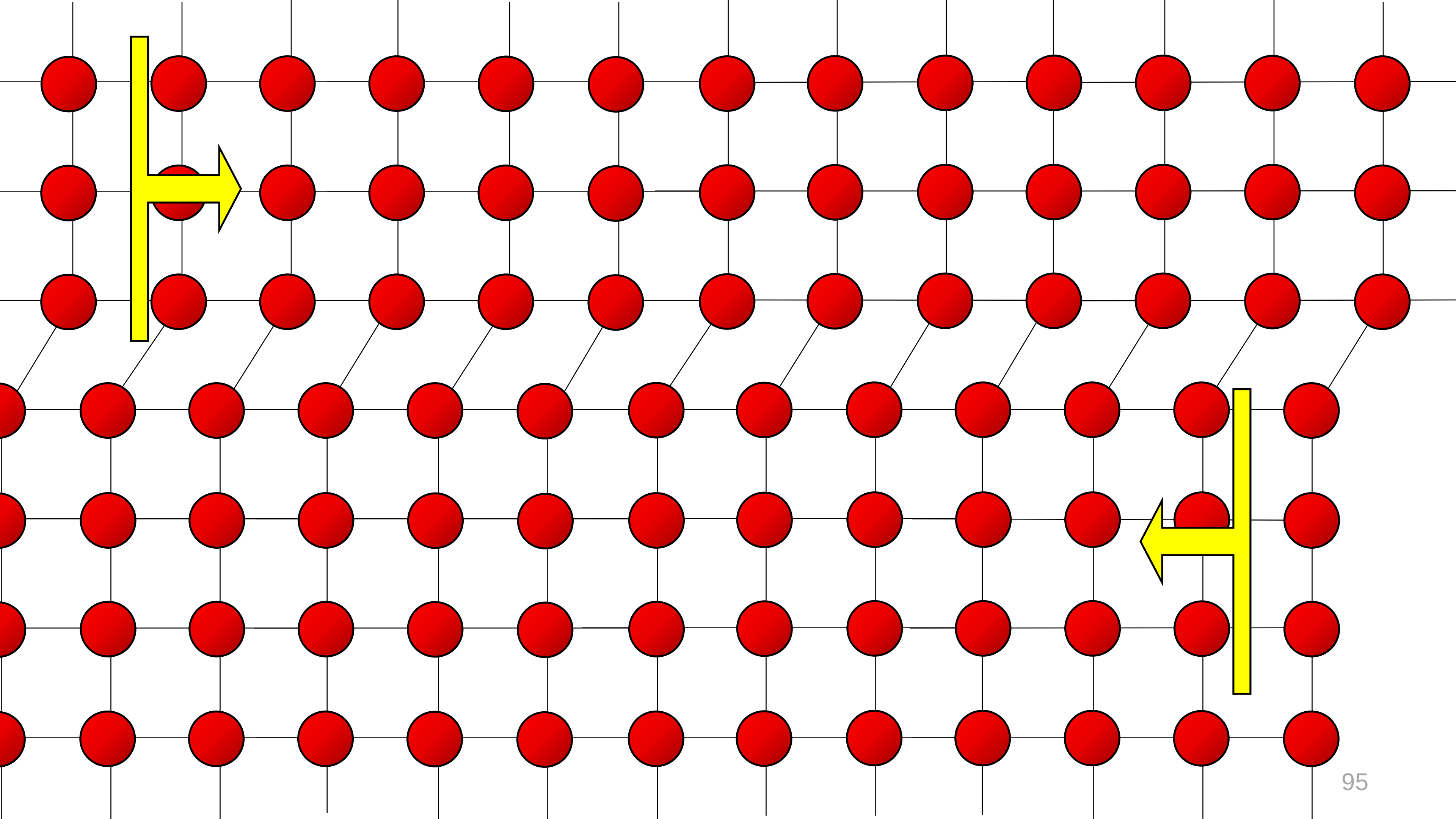


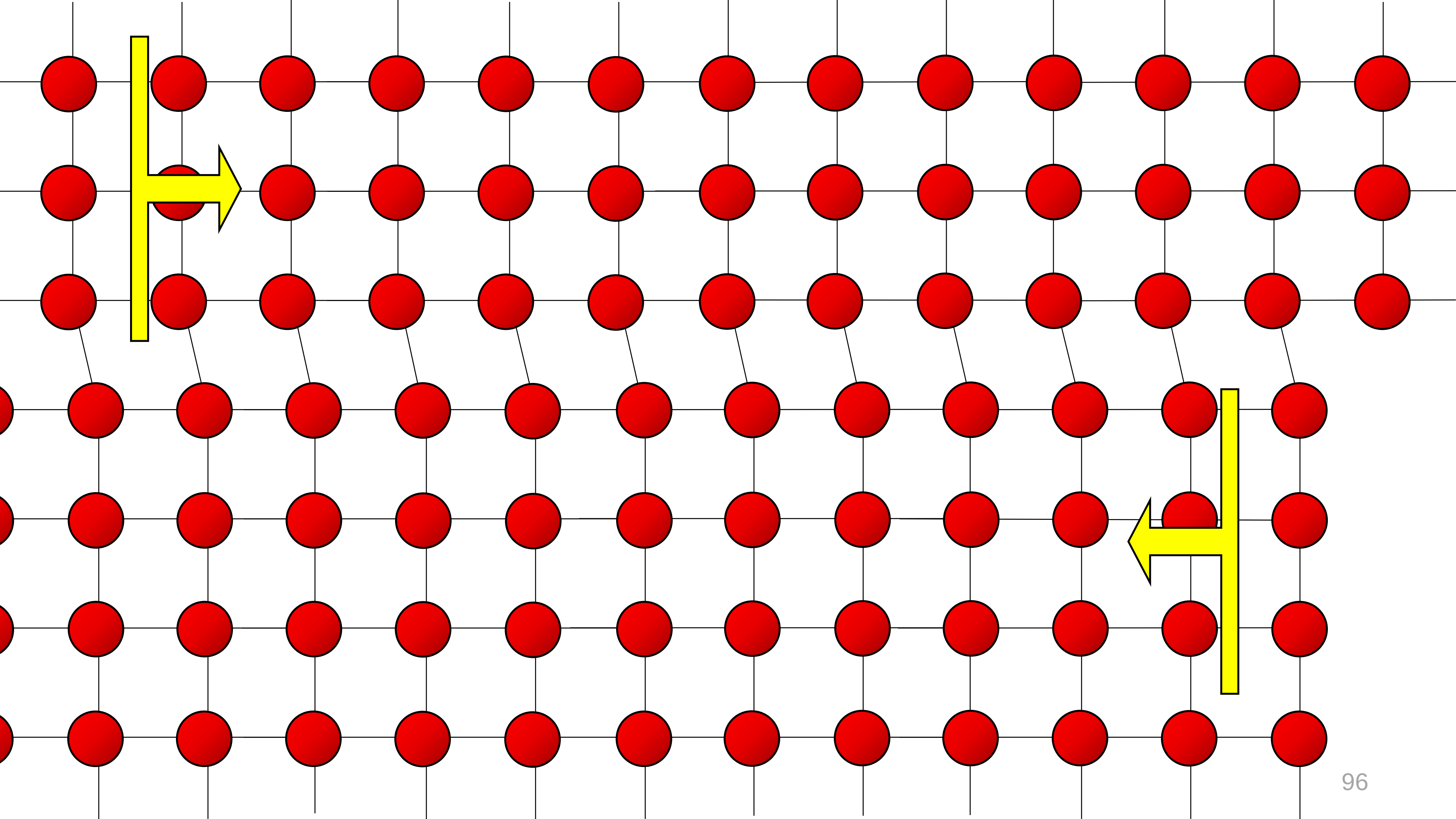


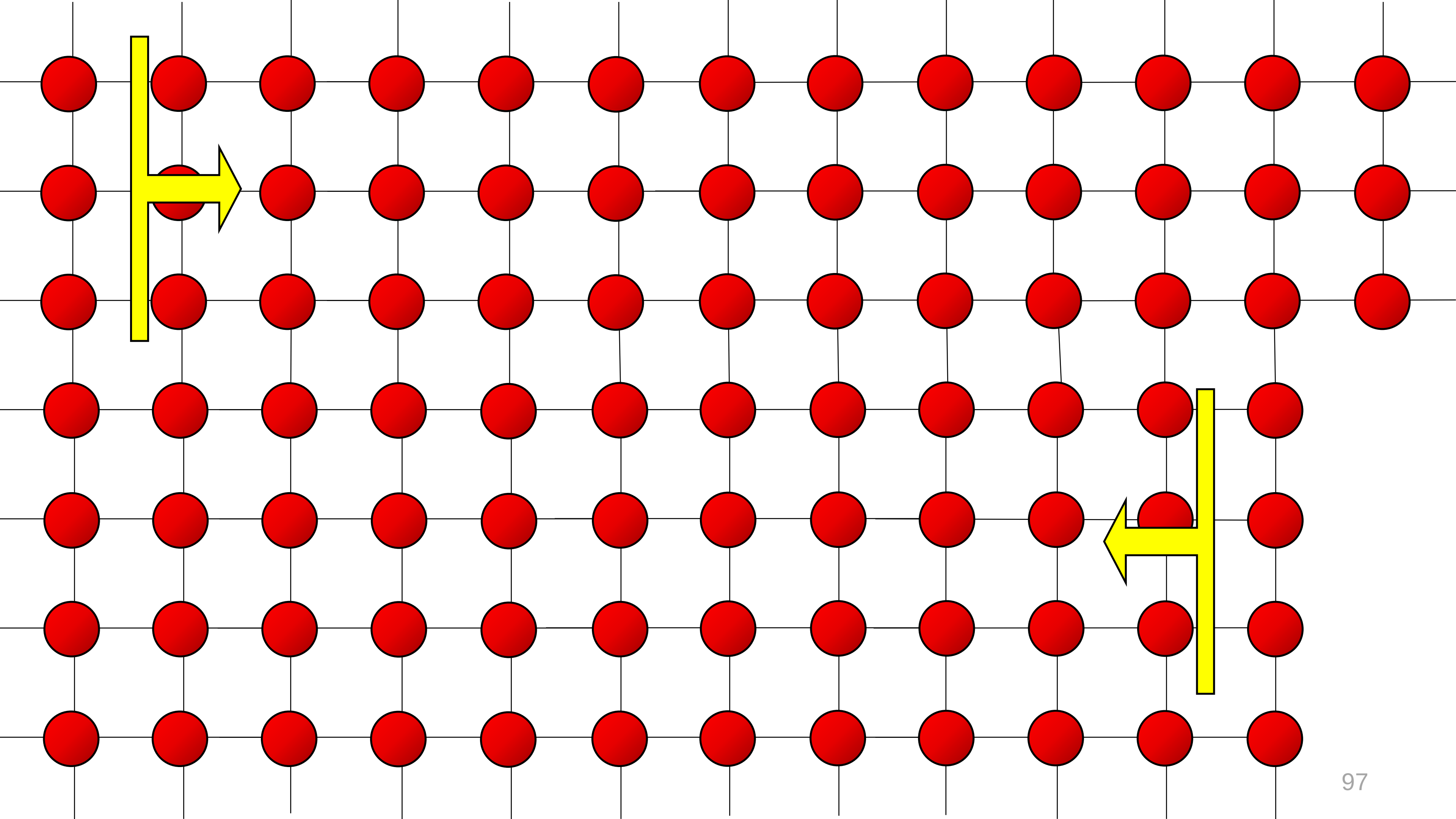


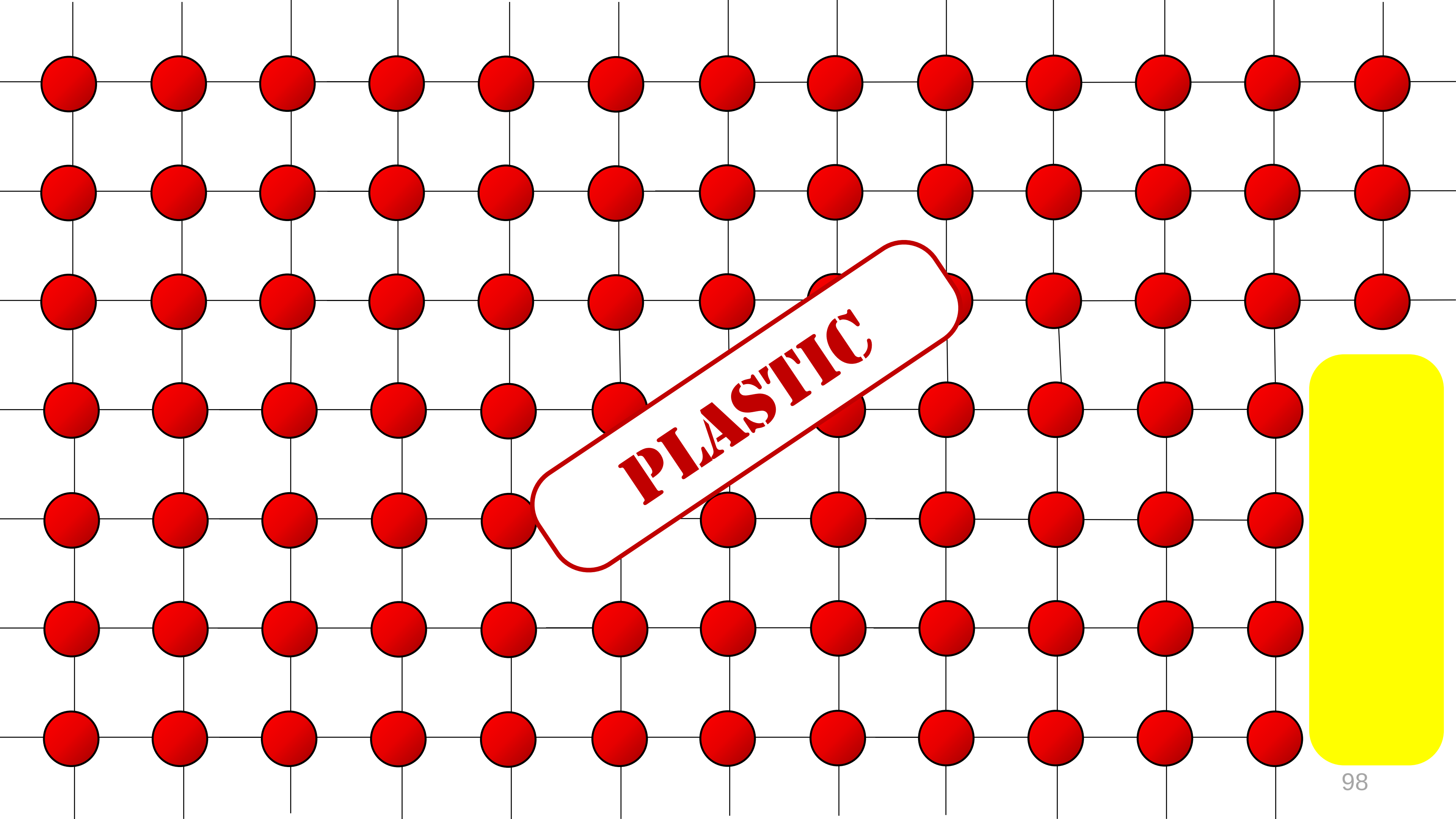








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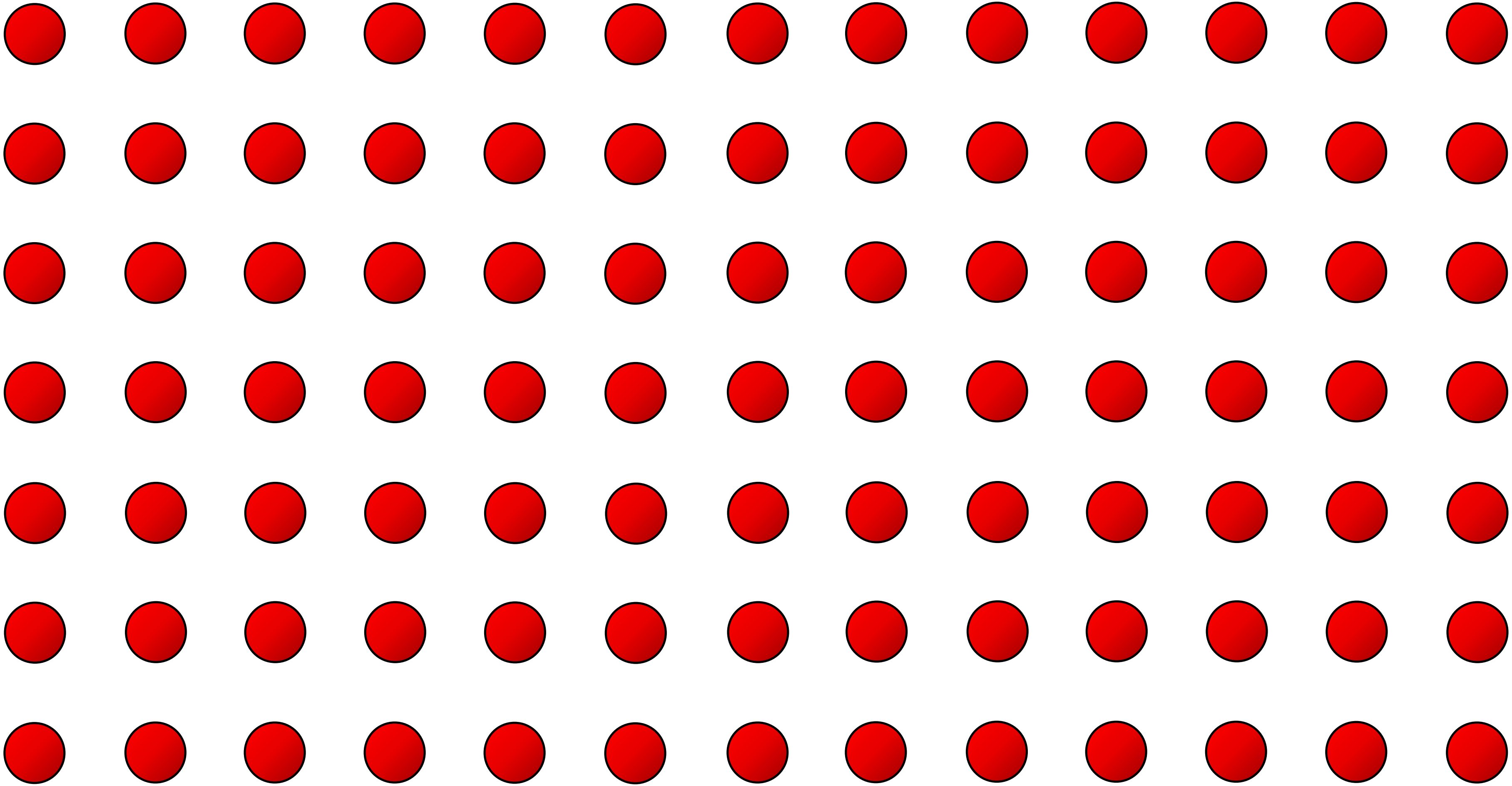
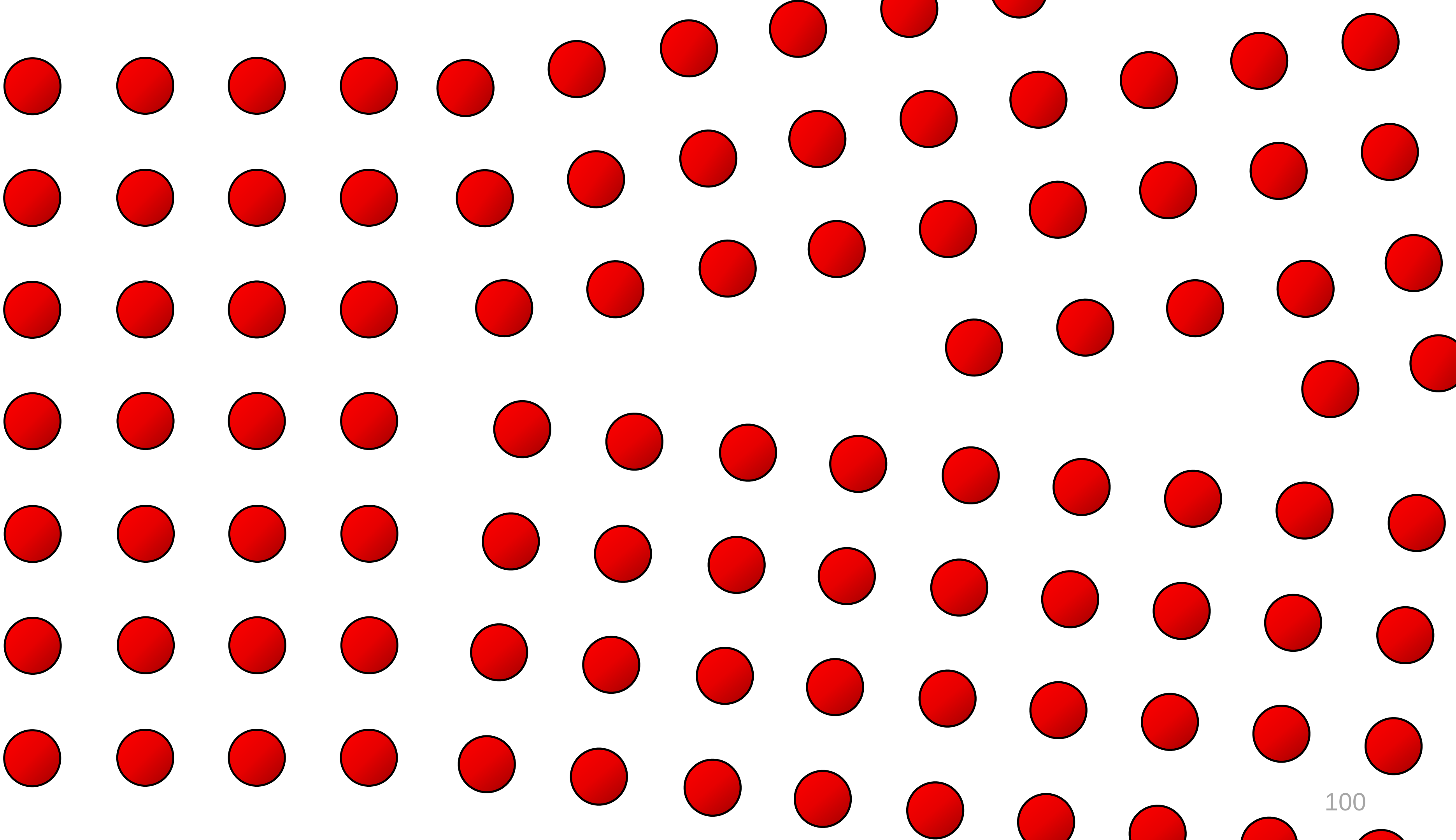
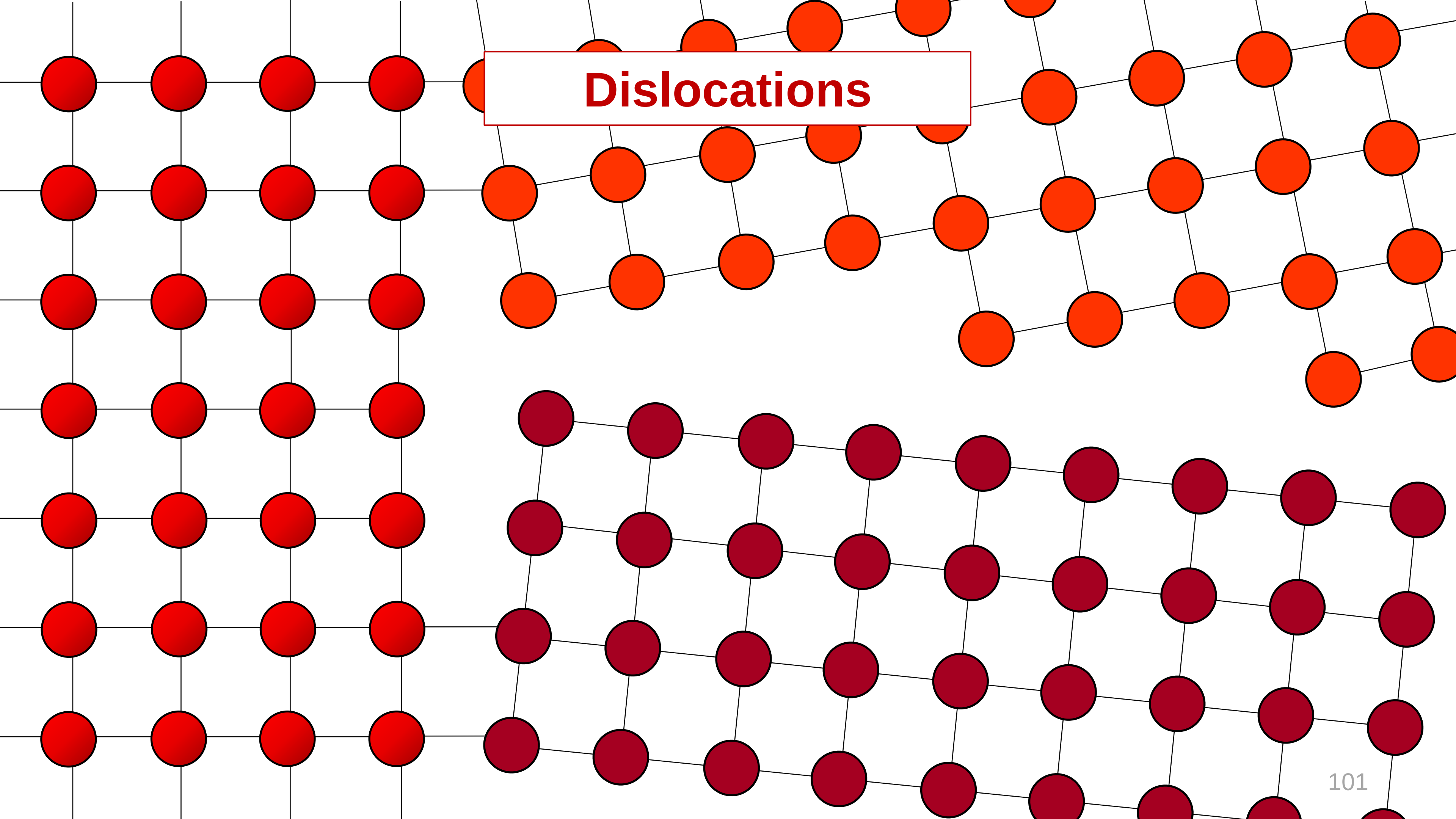
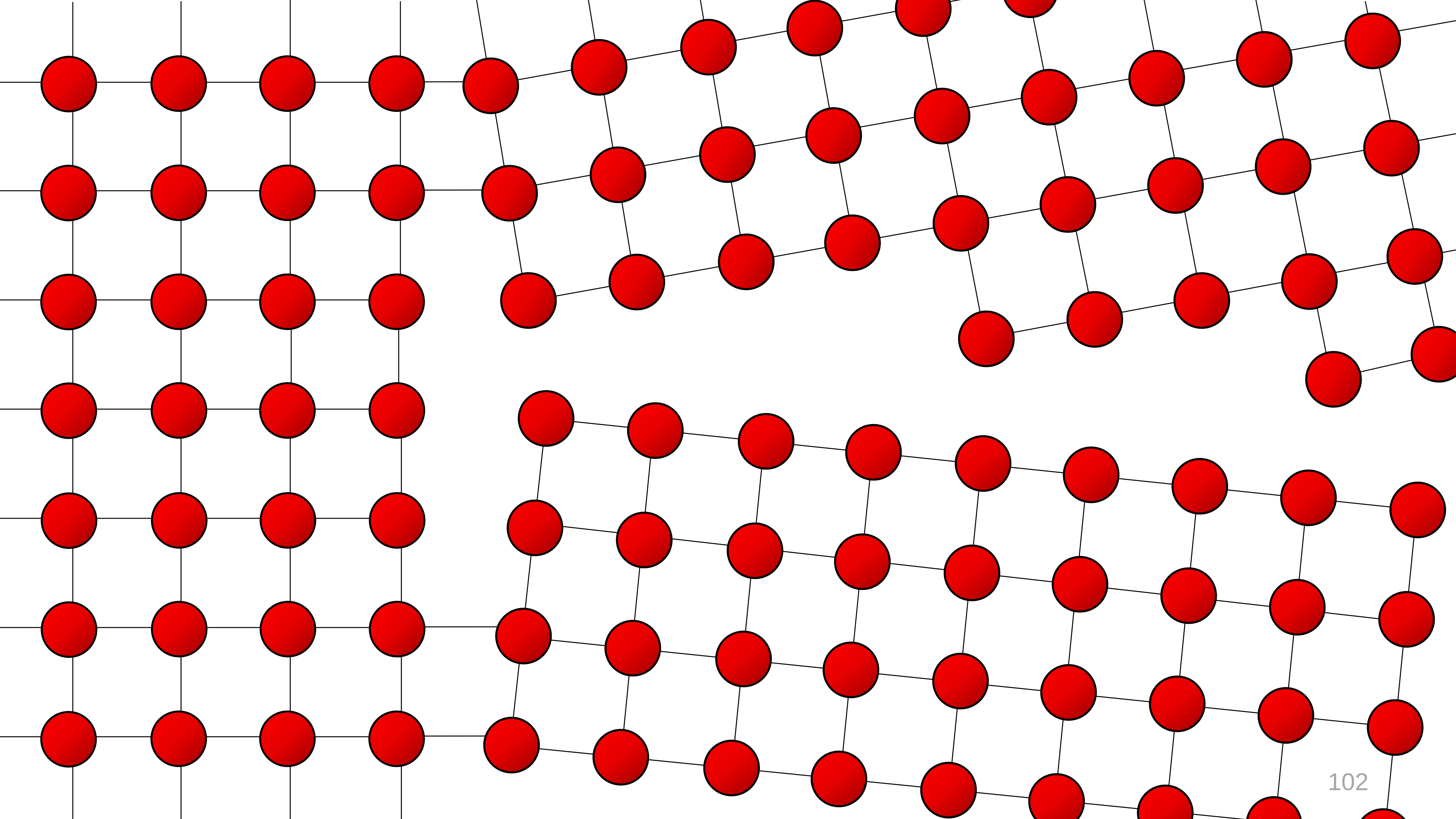
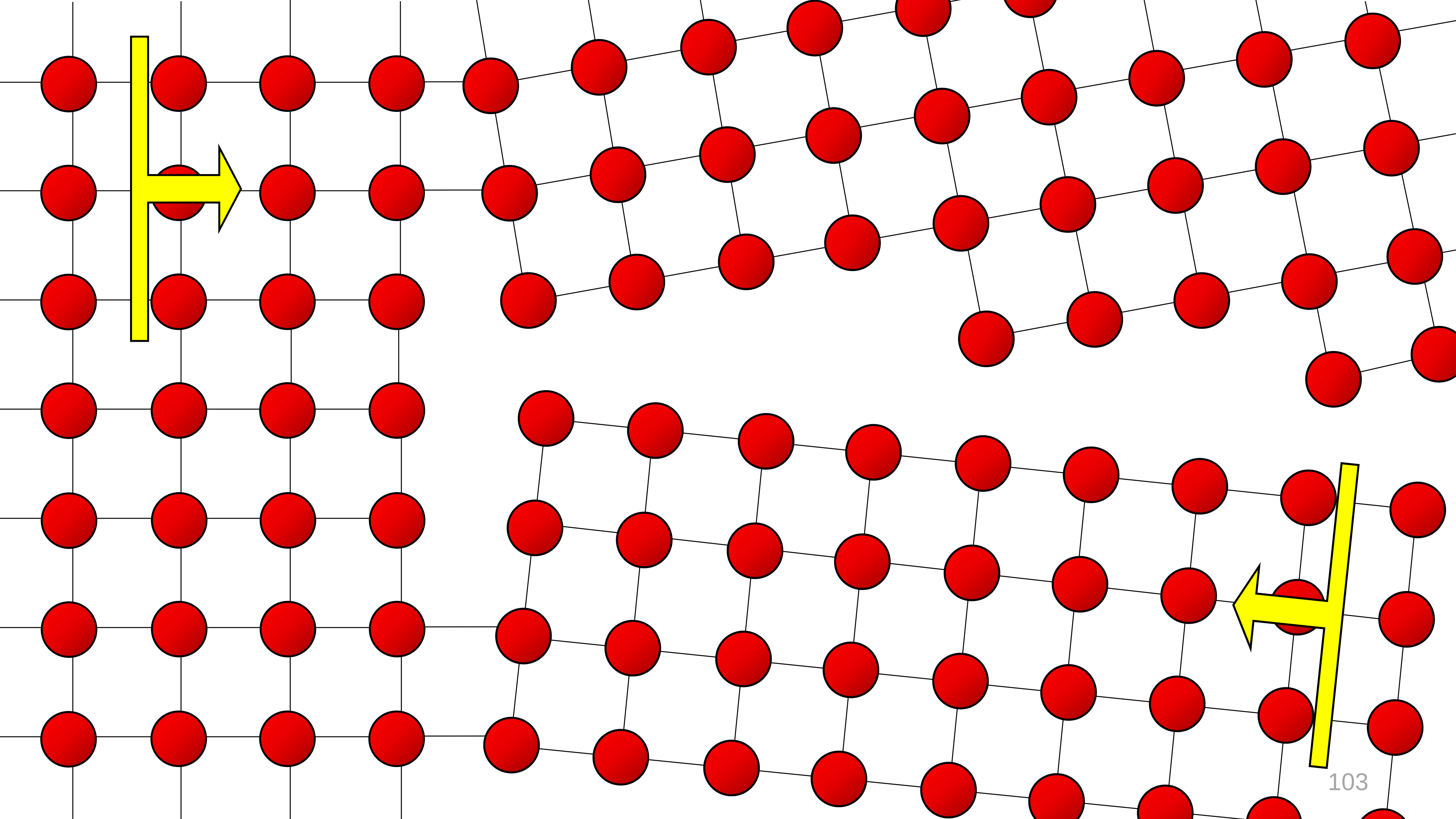


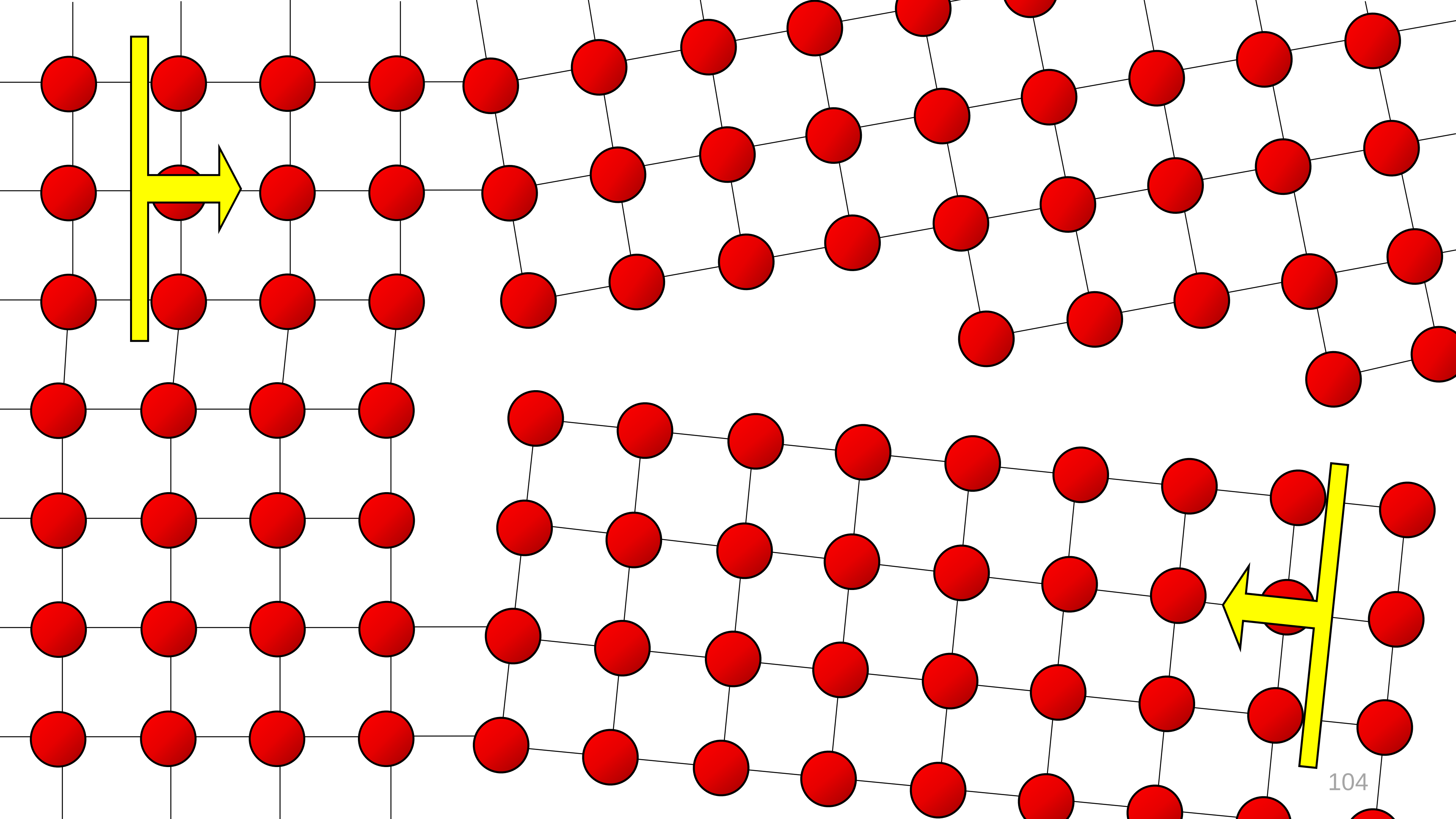


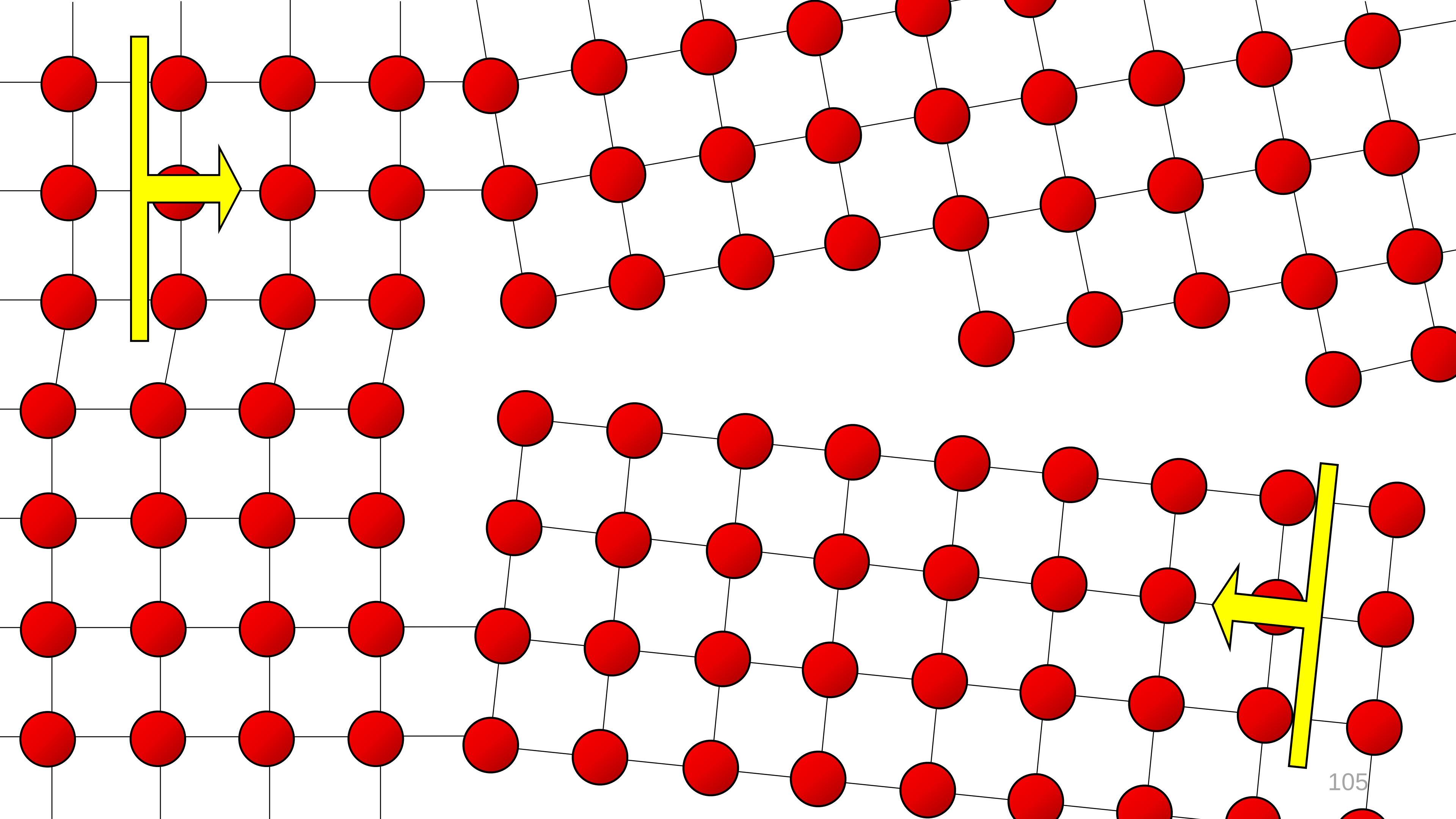
Dislocations

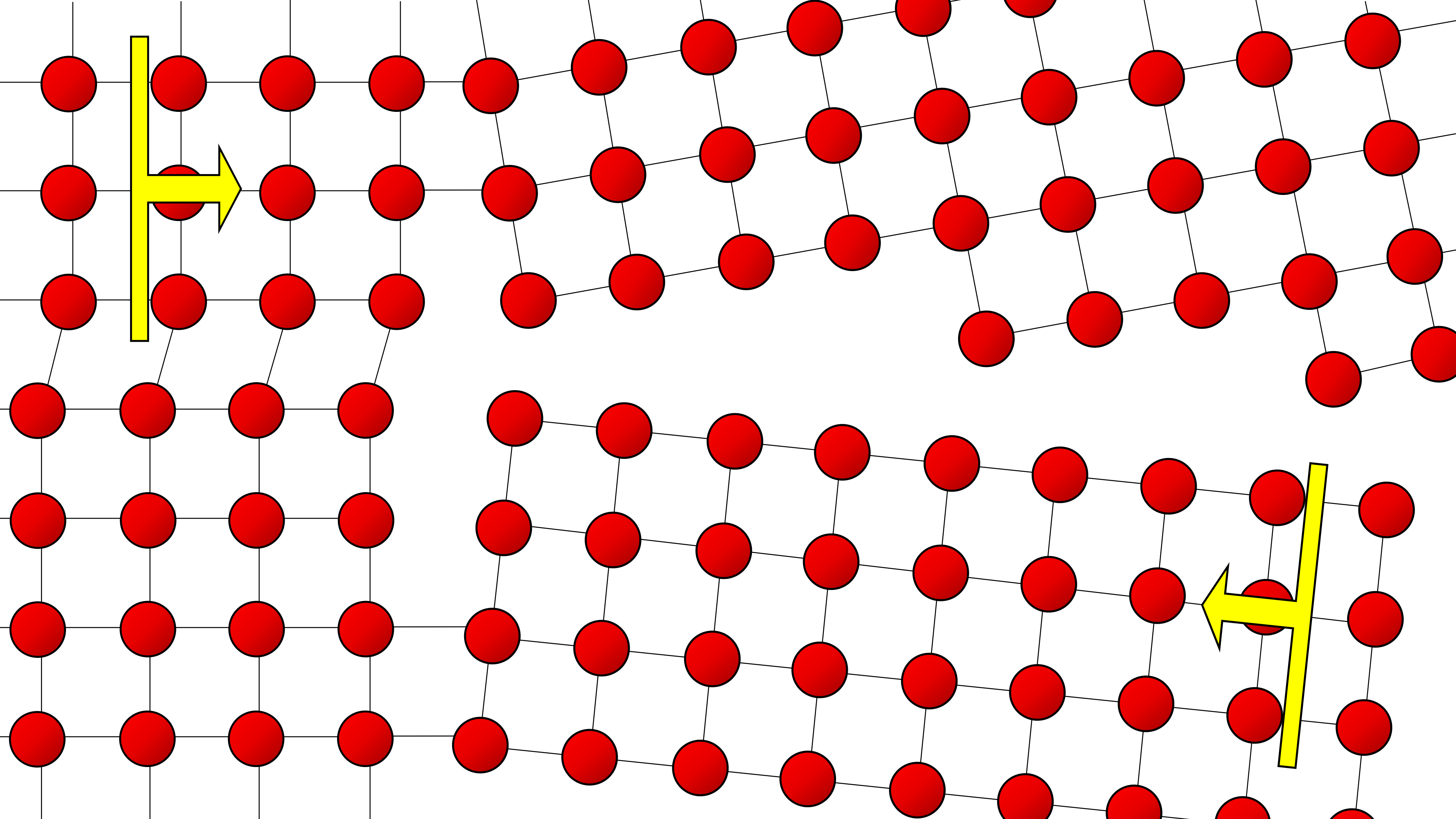


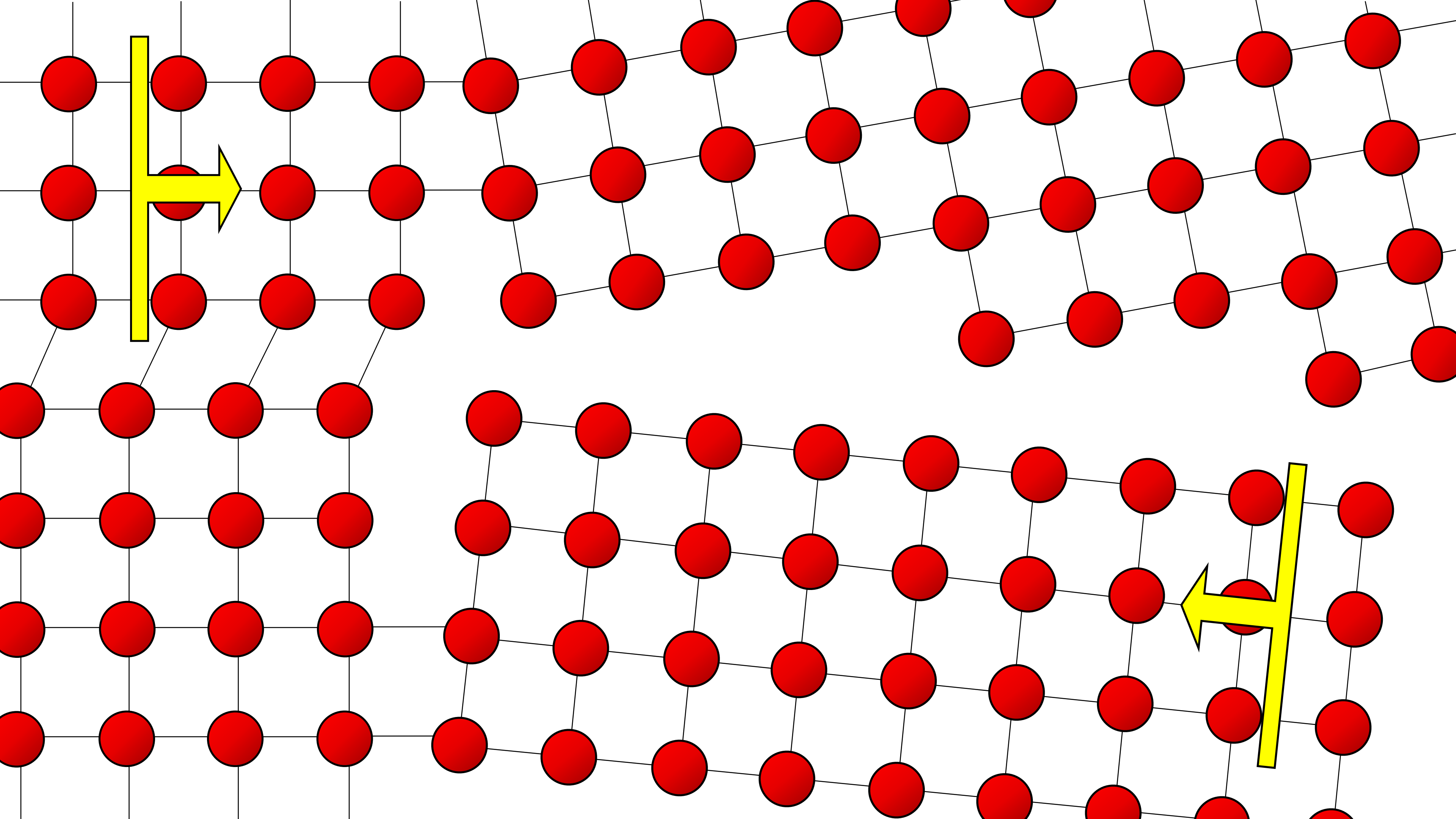


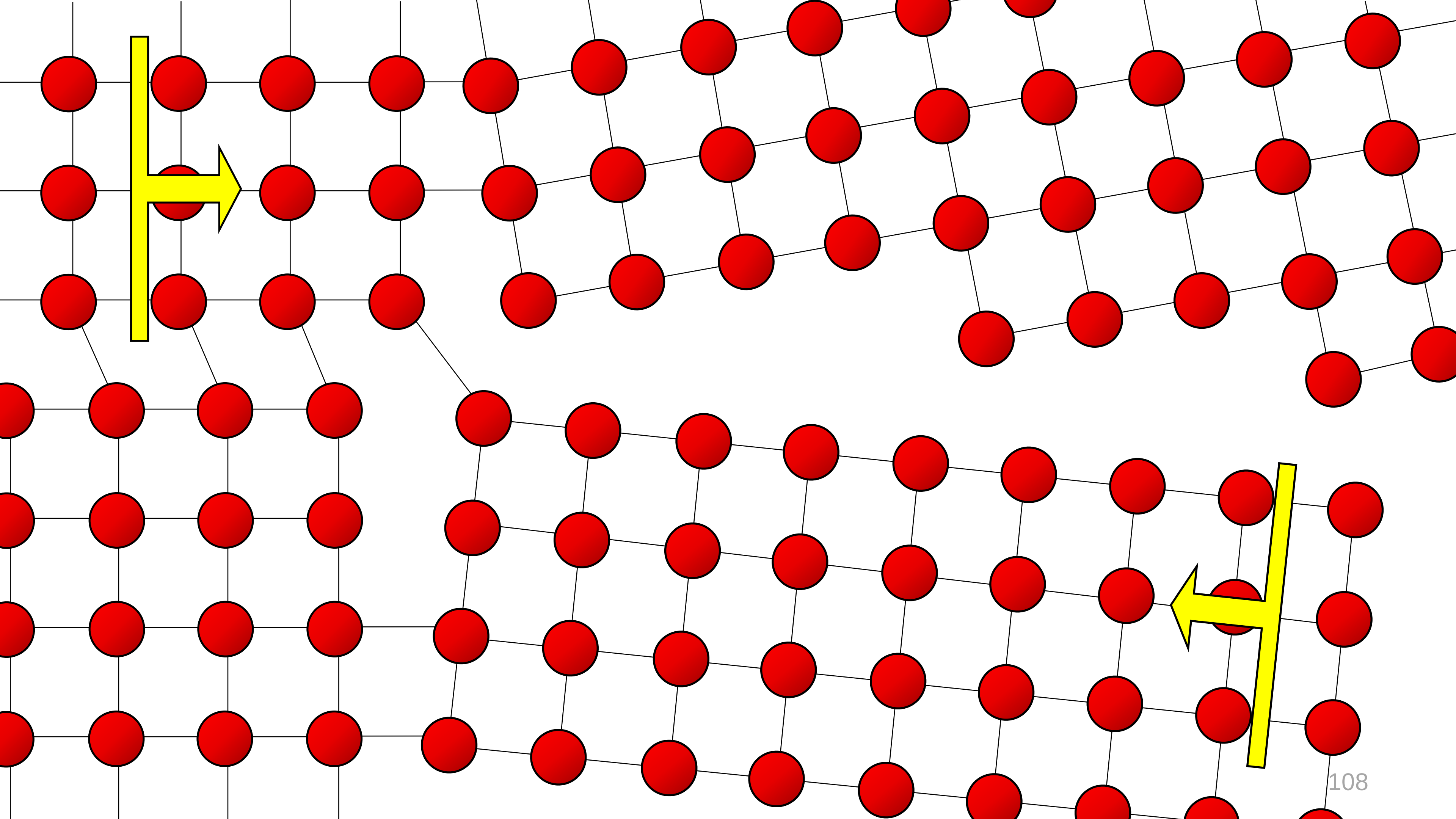


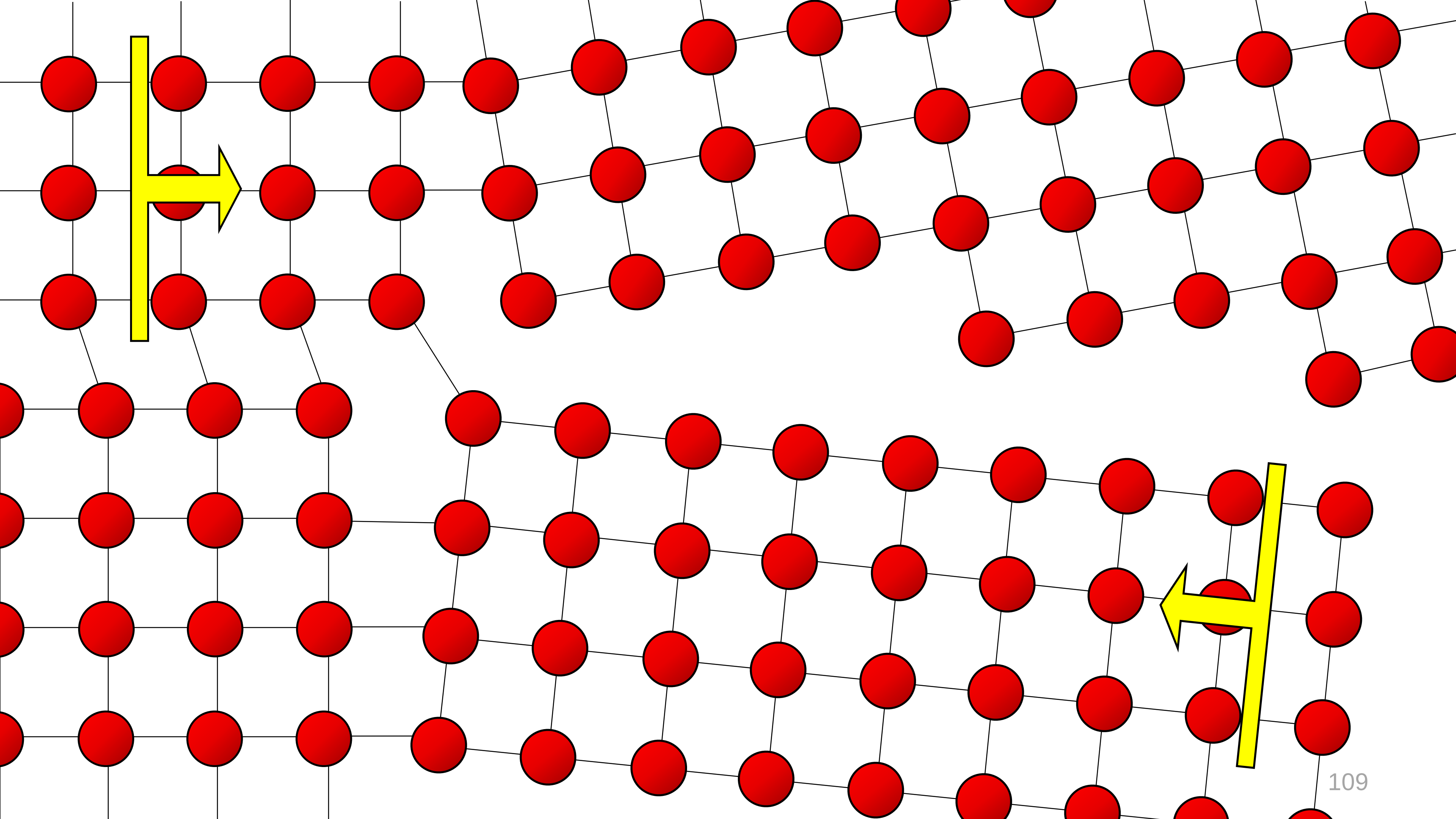


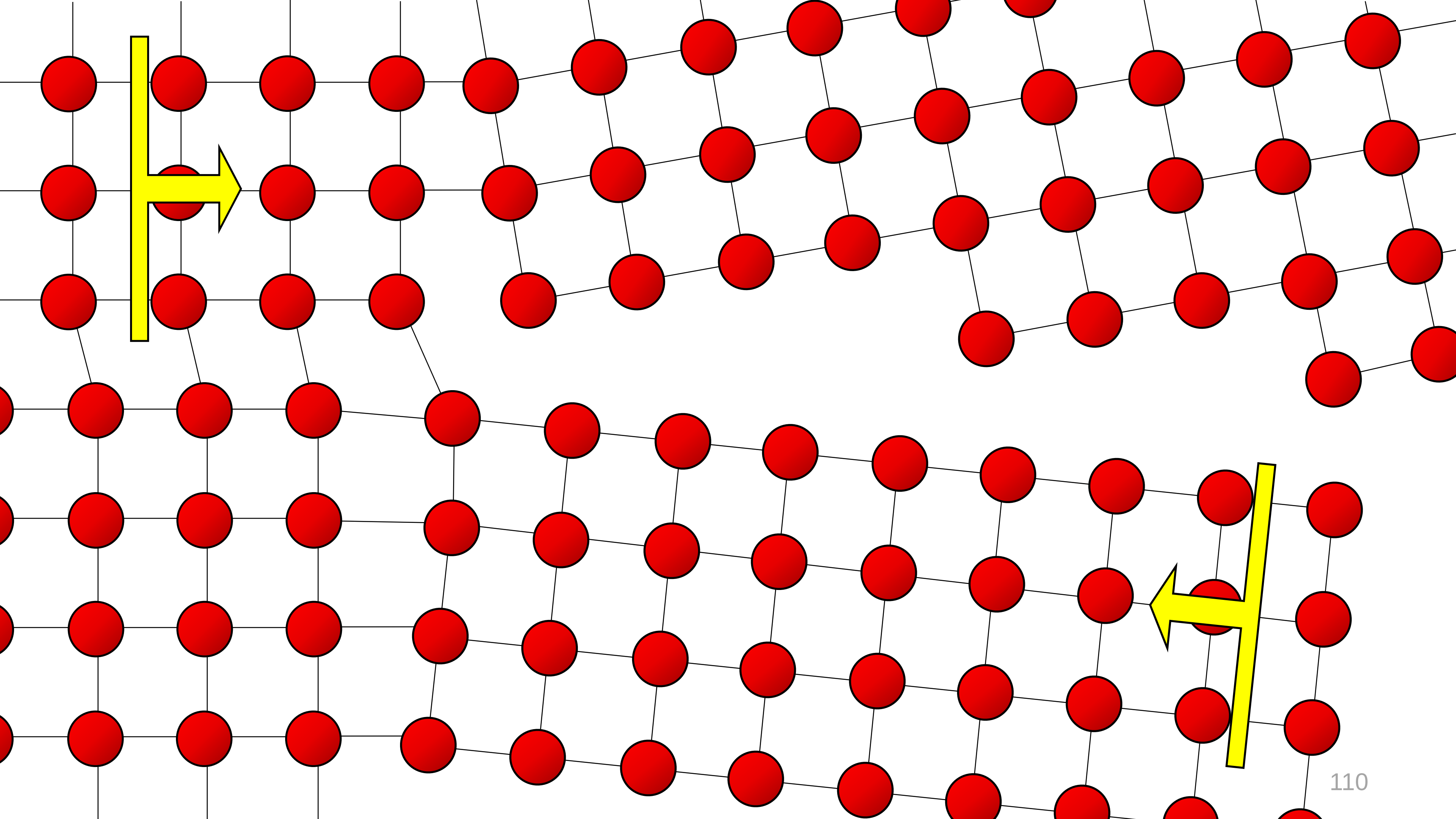


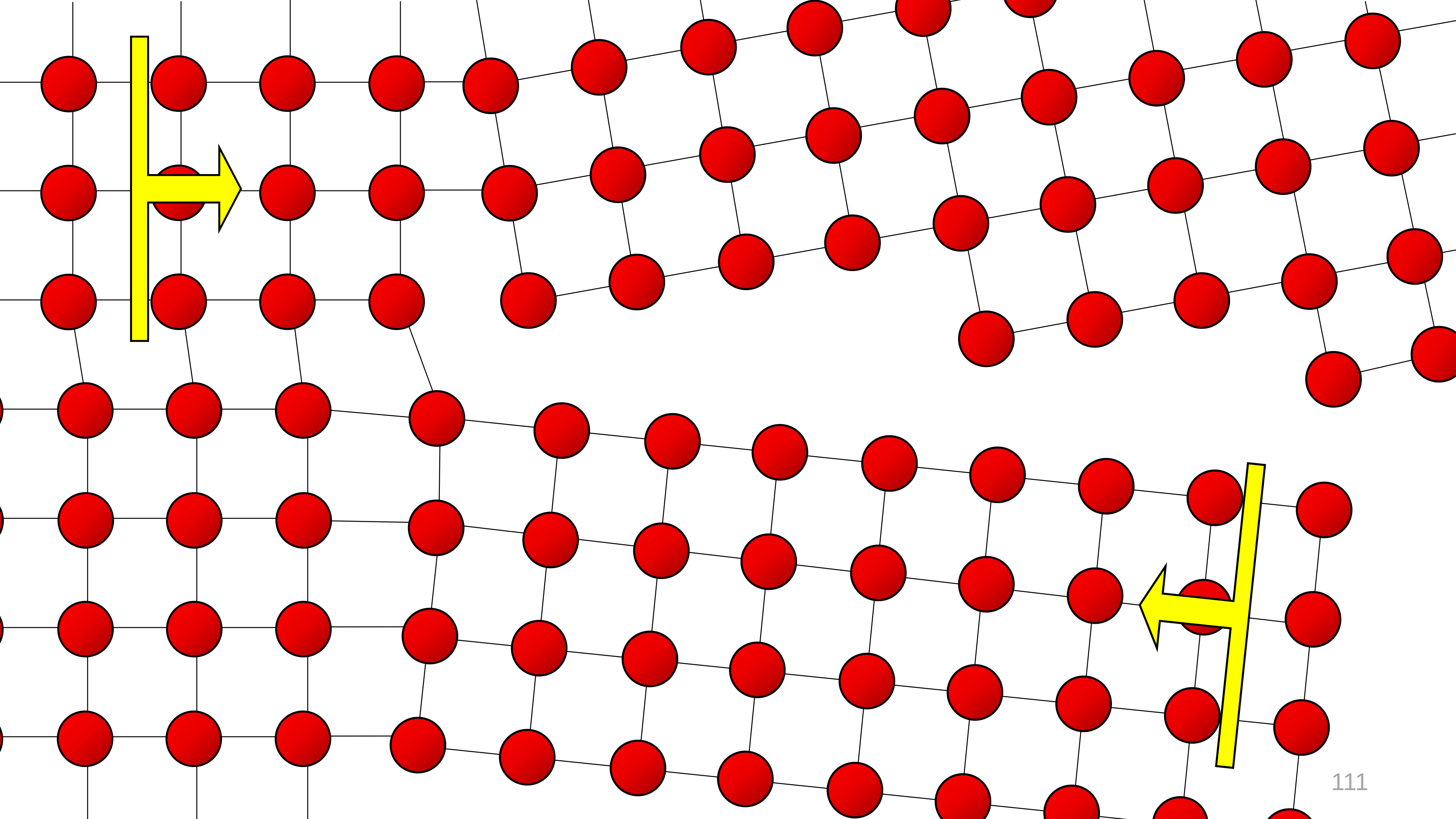


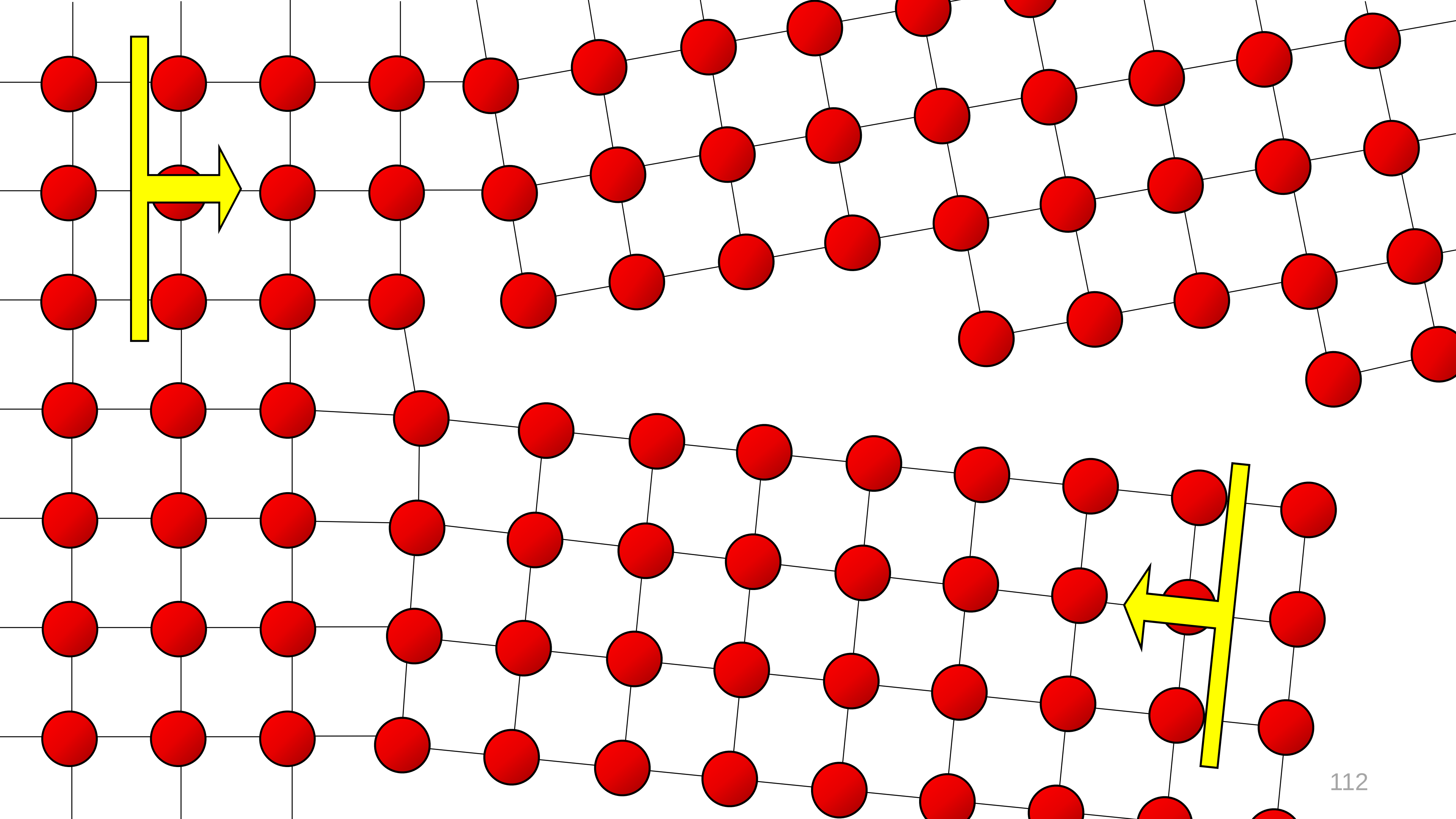


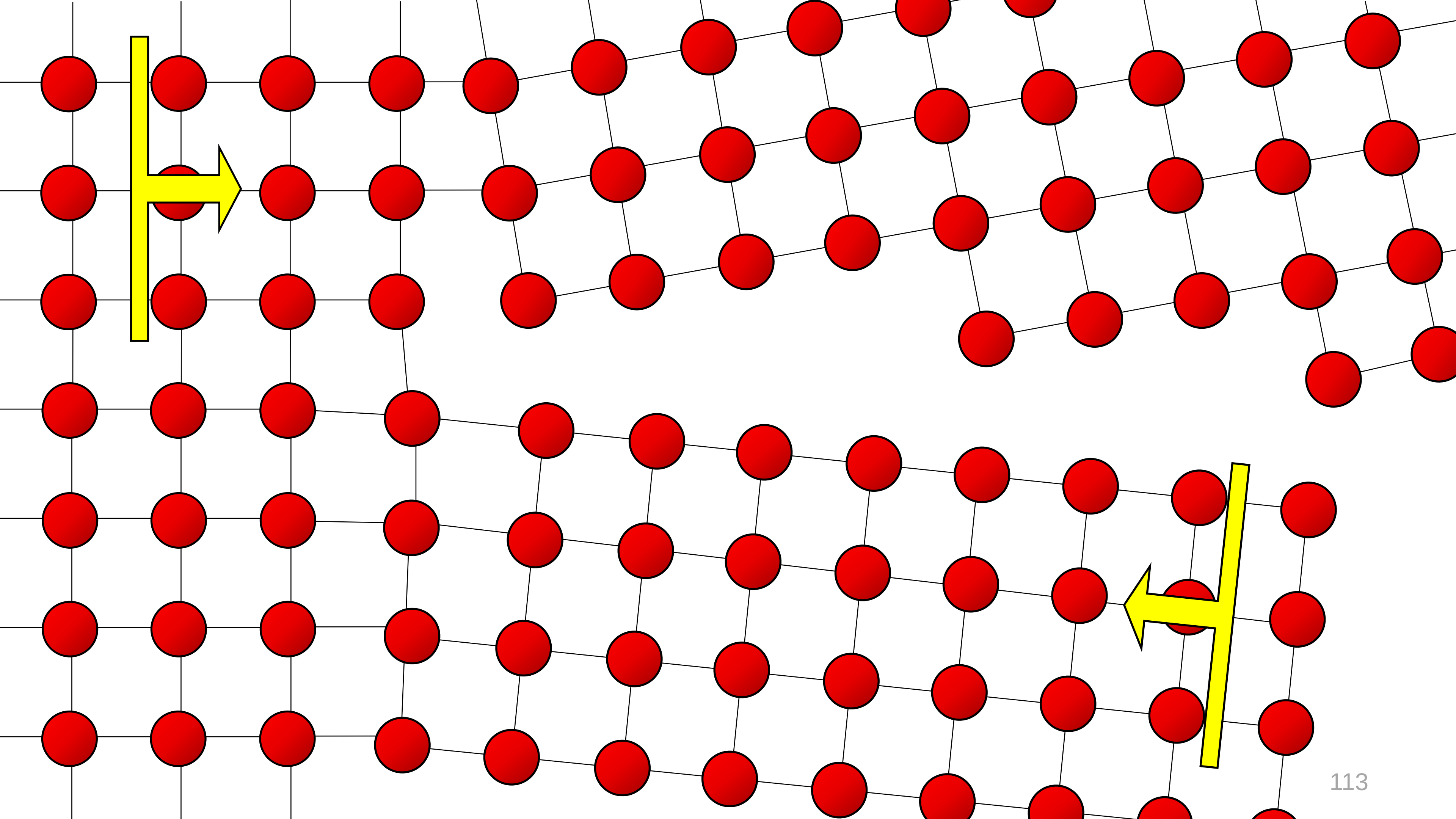


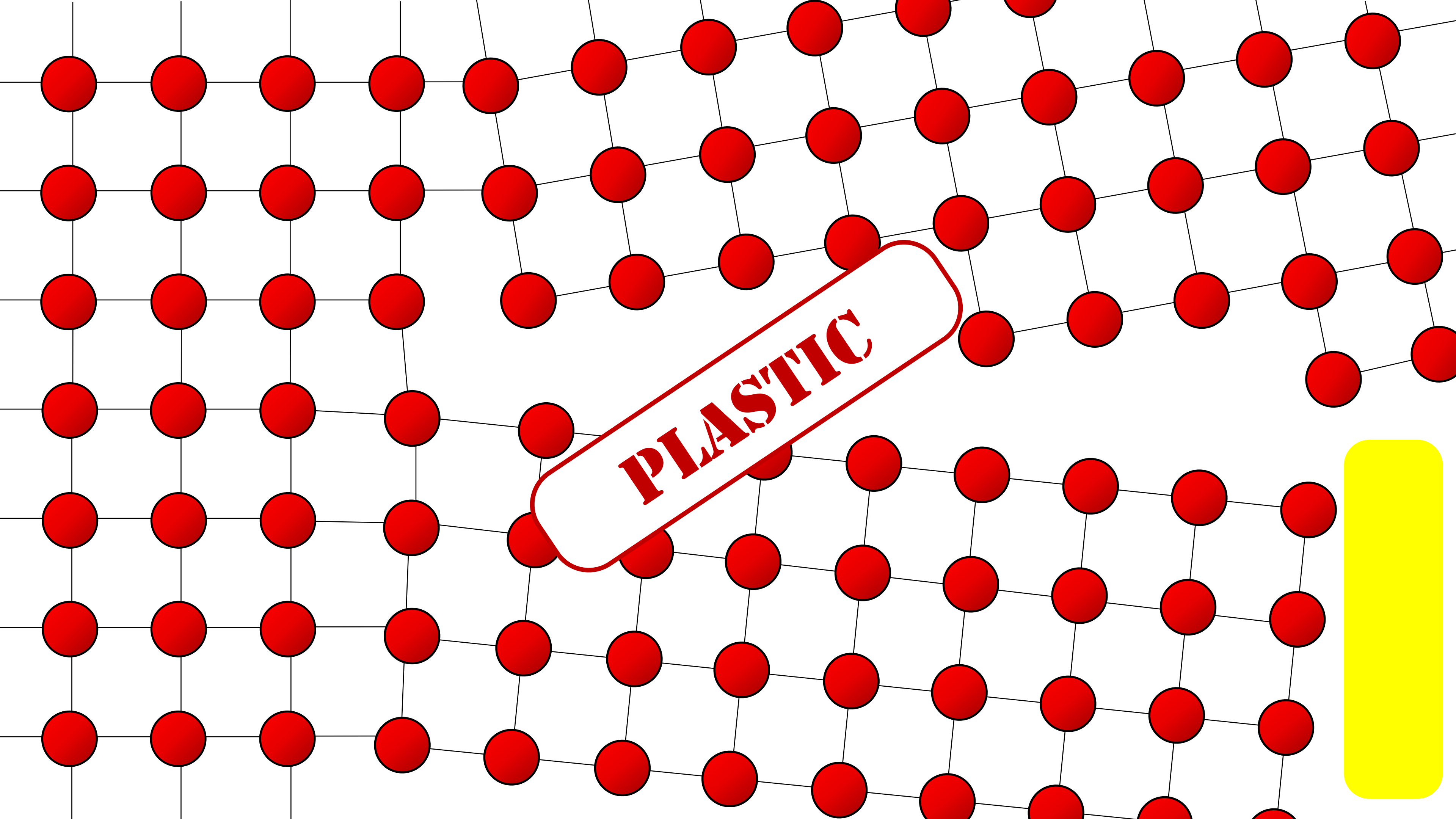








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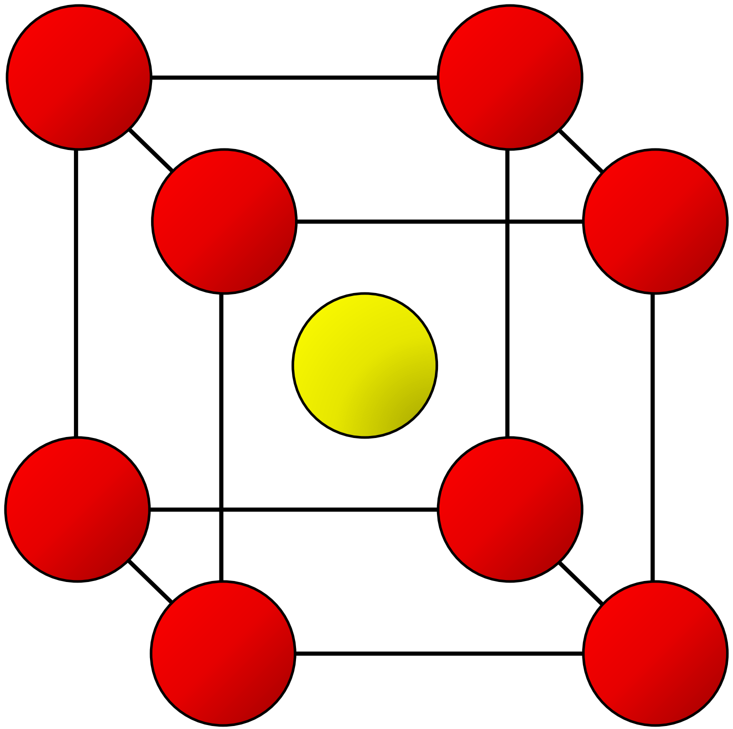
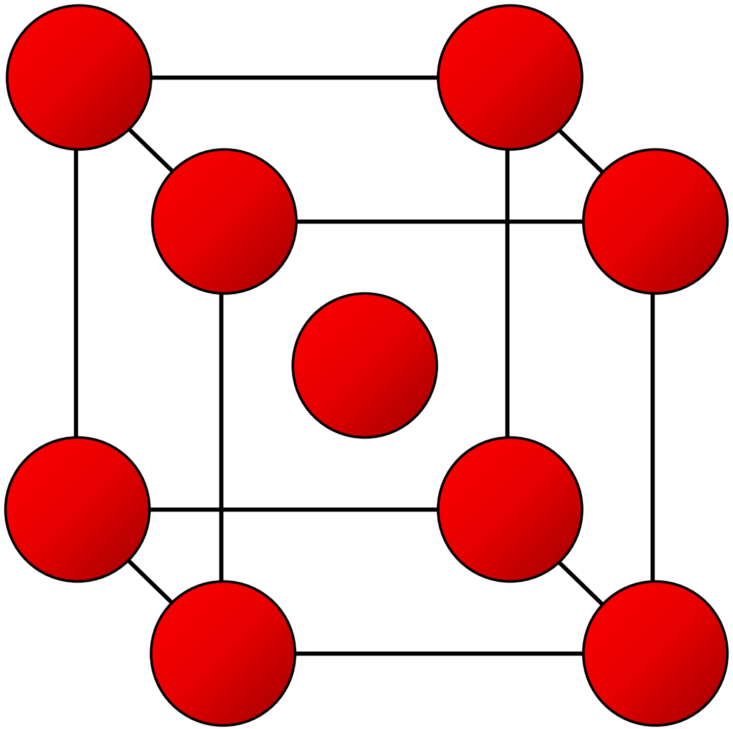
Body Centered Cubic (BCC)

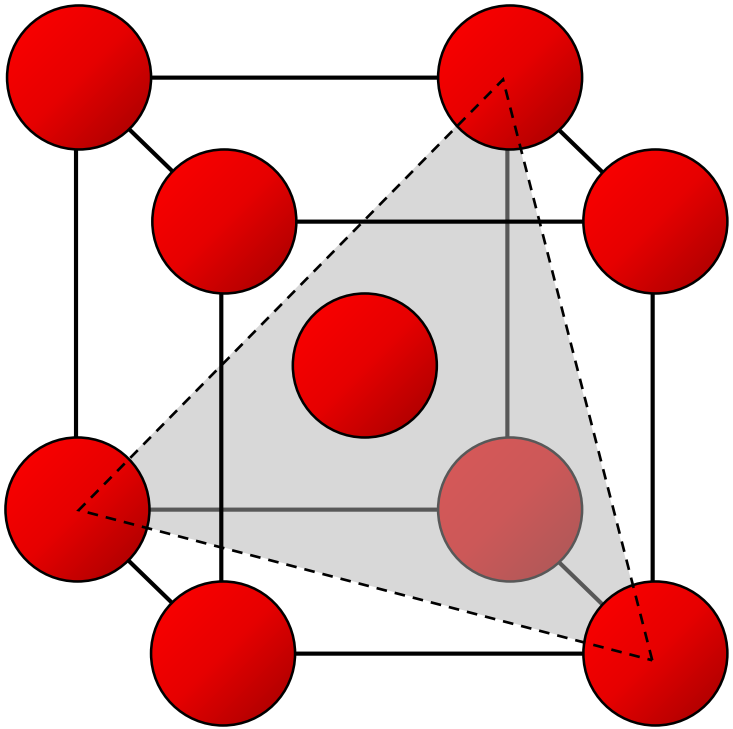


Body Centered Cubic (BCC)

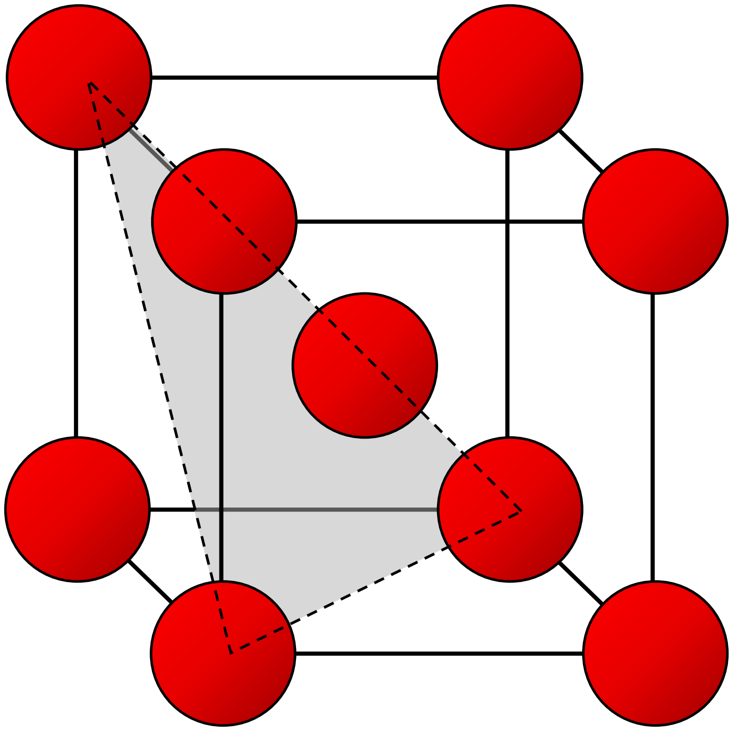


Atomic Packing

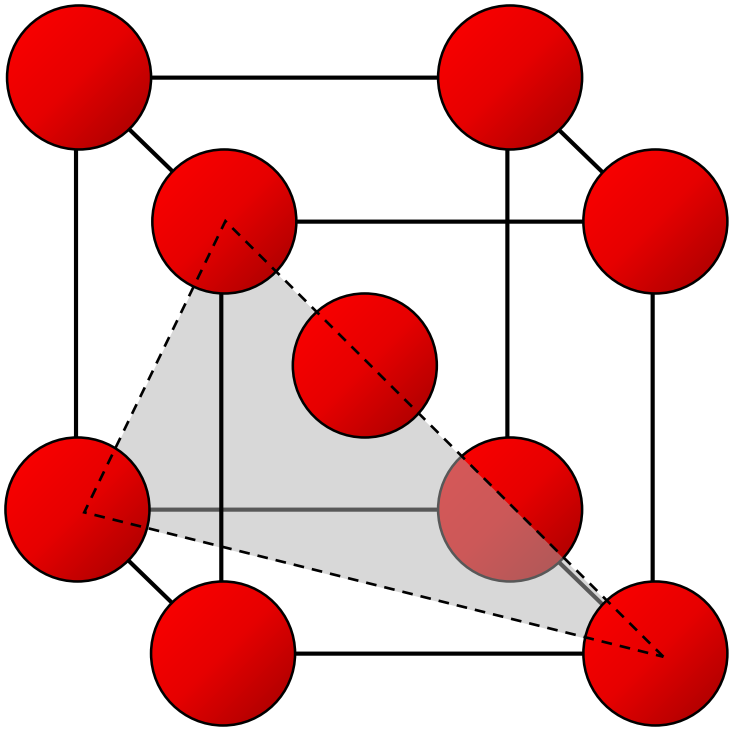
Body Centered Cubic (BCC)



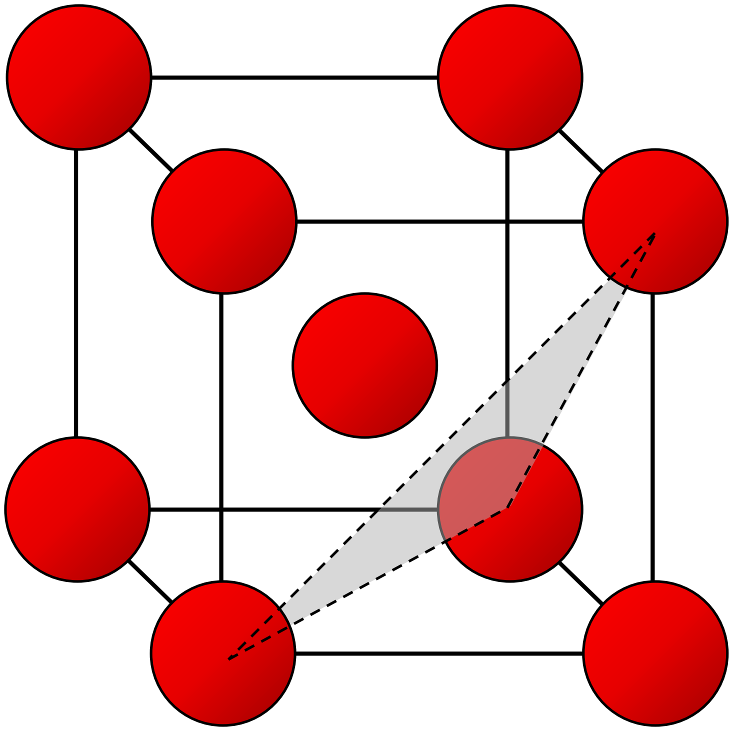
Body Centered Cubic (BCC)



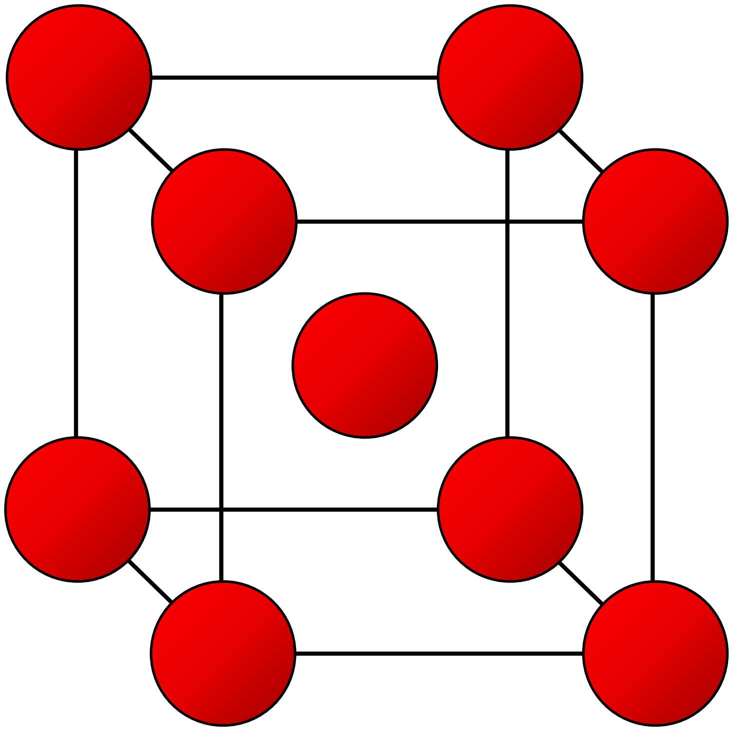
Body Centered Cubic (BCC)



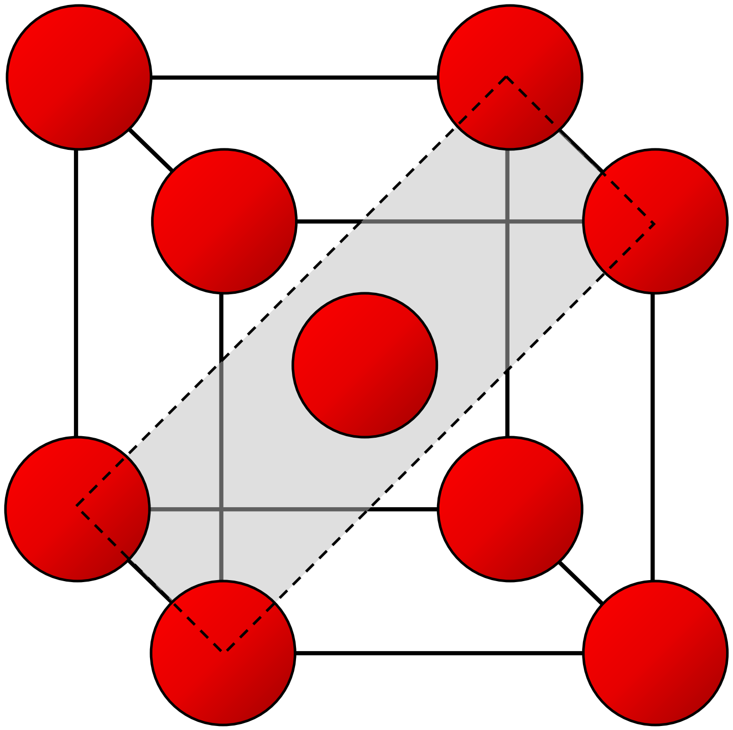
Body Centered Cubic (BCC)



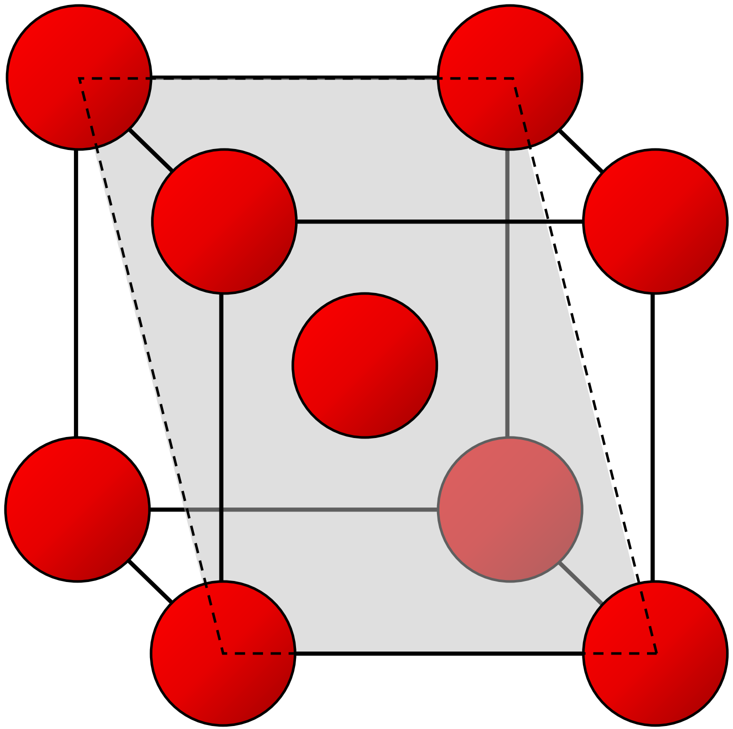
Body Centered Cubic (BCC)



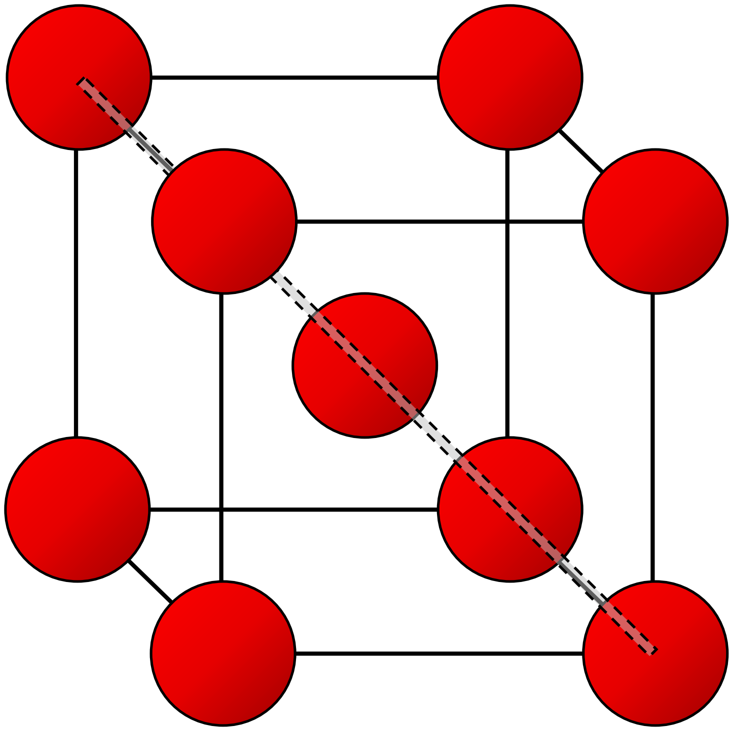
Body Centered Cubic (BCC)



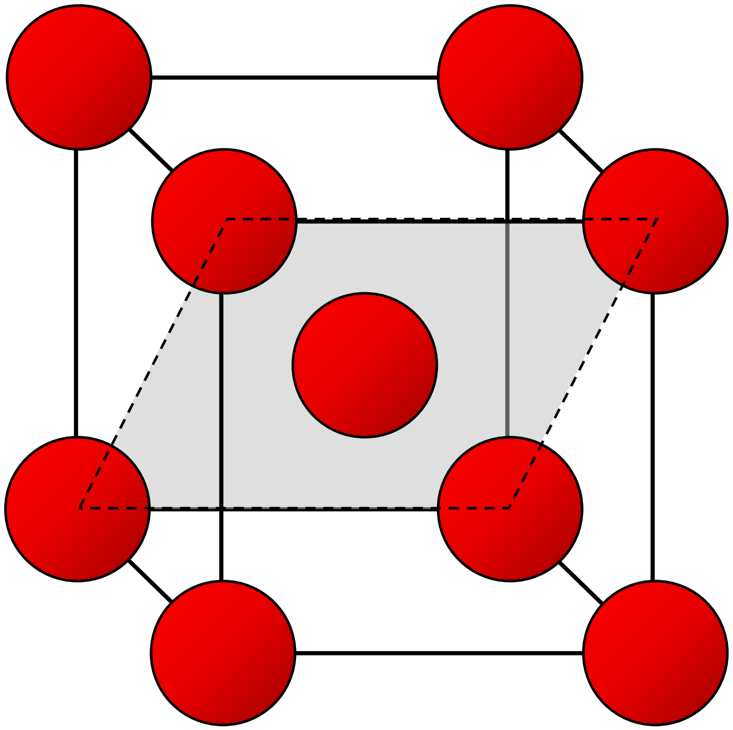
Body Centered Cubic (BCC)



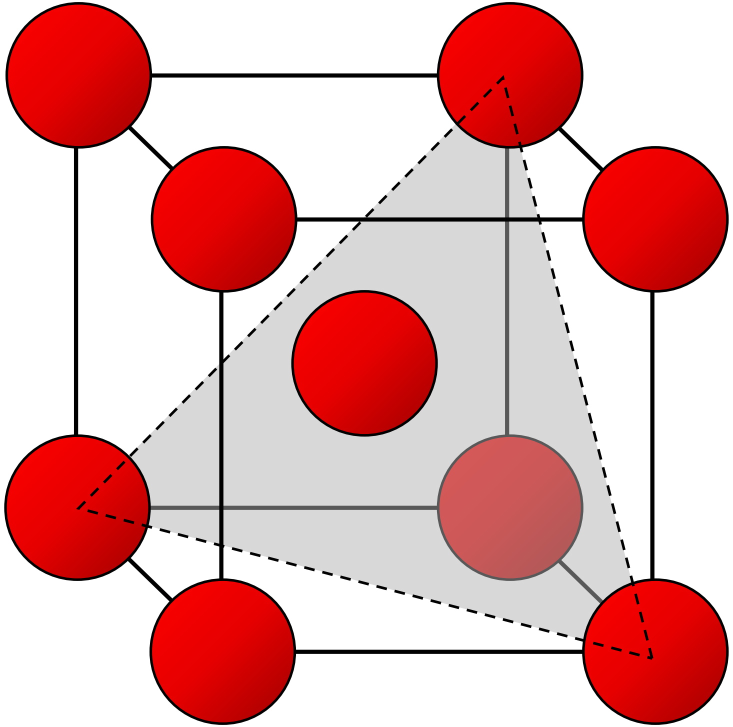
Body Centered Cubic (BCC)

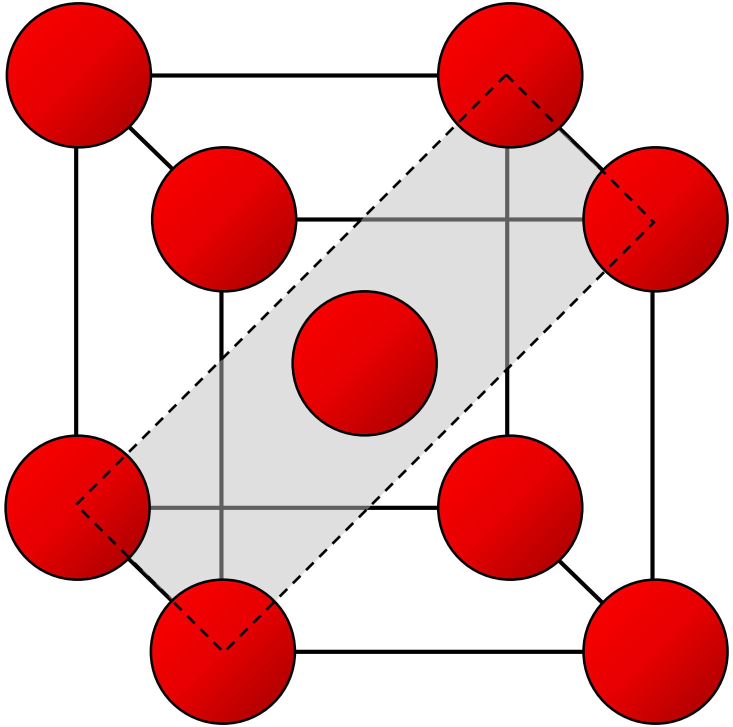


Body Centered Cubic (BCC)



Body Centered Cubic (BCC)





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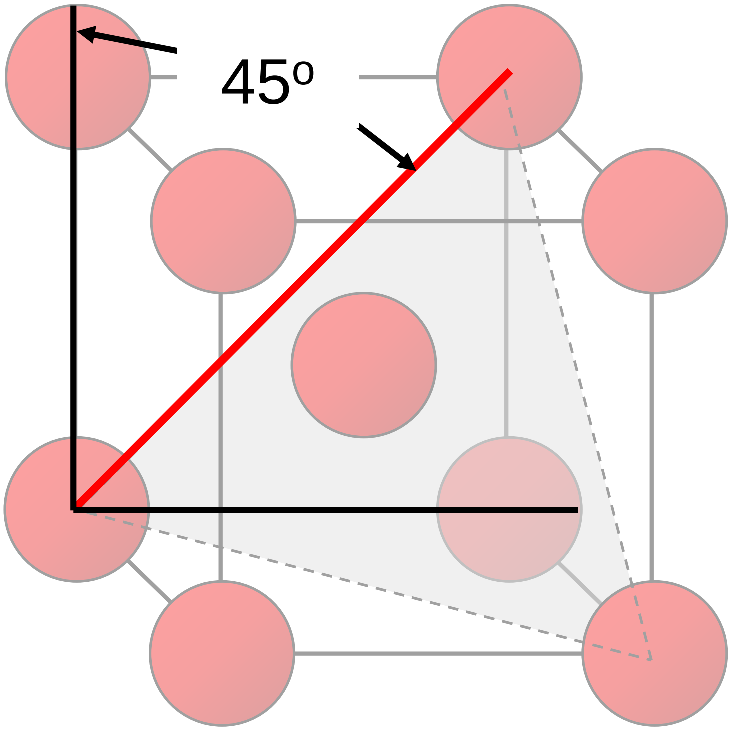
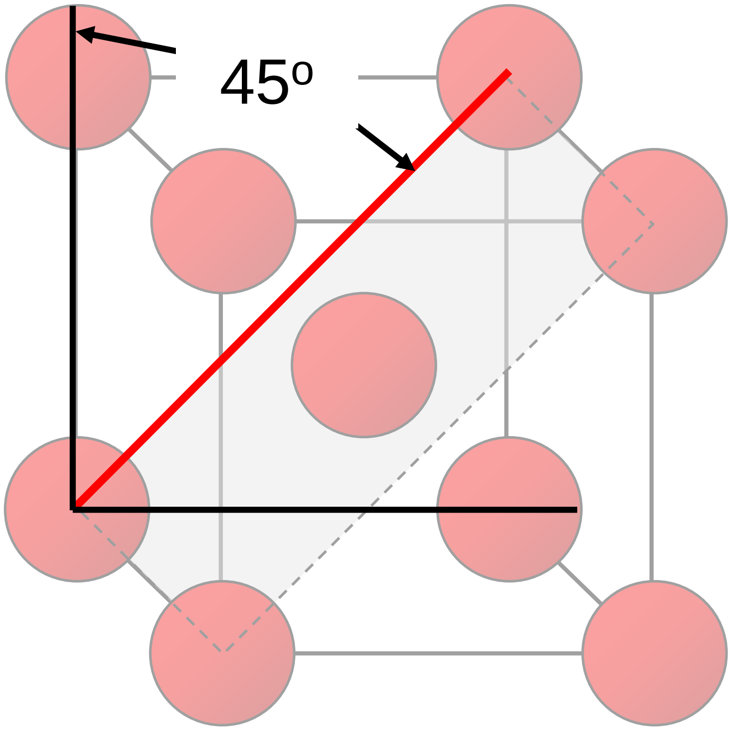




Ductility: Another View

Outline

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

Lennard Jones Potential, Atomic Interactions, Dislocations, Atomic Packing

Ductility: Another View

Outline

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

STRENGTH OF METALS UNDER COMBINED STRESSES

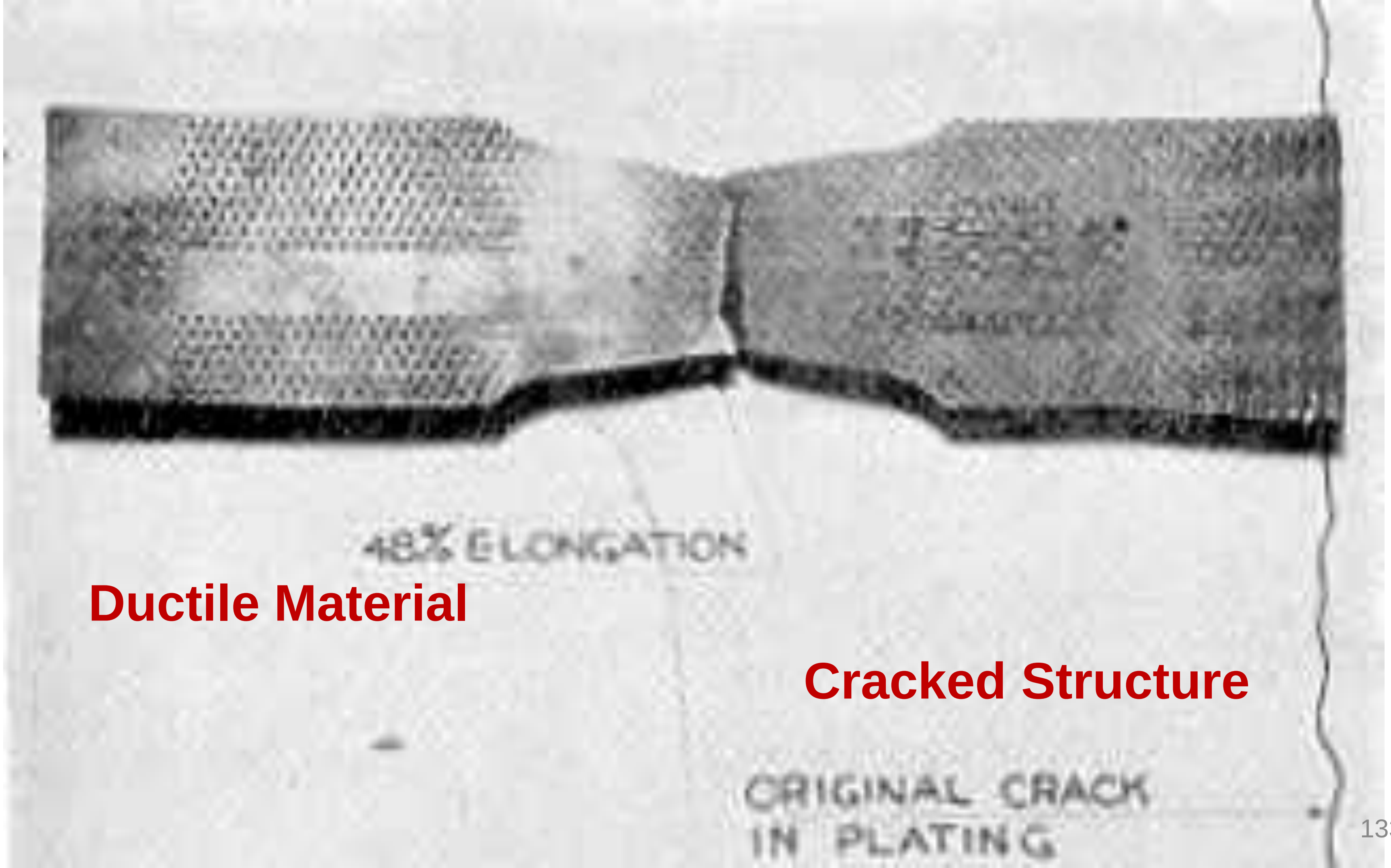
"It is well known that a metal may be ductile under one set of conditions and brittle under another. Ductility and brittleness, then are properties that must be considered as referring to some particular set of testing or service conditions."

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.

How to Achieve Controlled Inelastic Deformations


48% ELONGATION
Ductile Material
Cracked Structure
ORIGINAL CRACK
IN PLATING

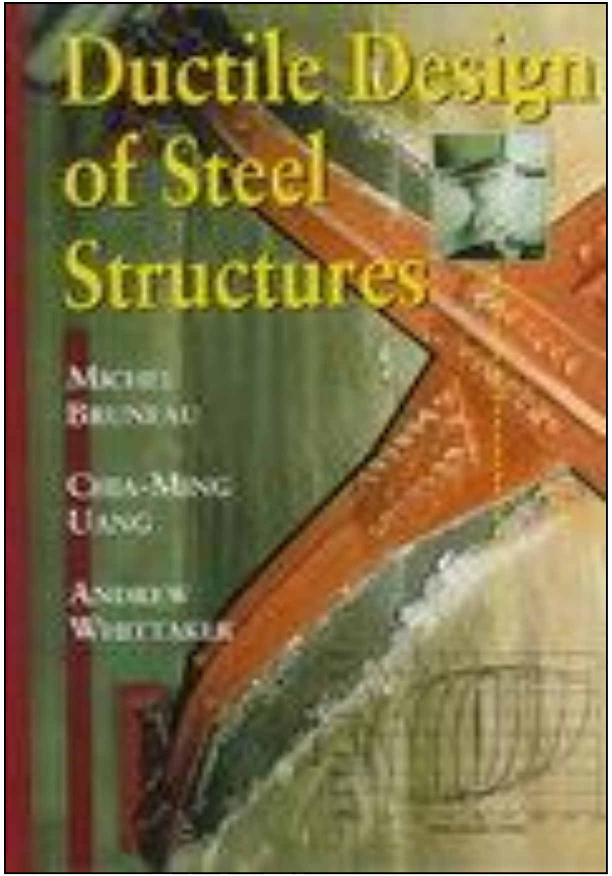
How to Achieve Controlled Inelastic Deformations

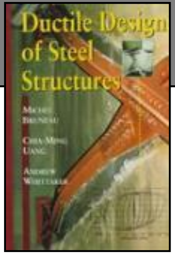
- Select a ductile material

Ductile Design of Steel Structures

Bruneau
Uang
Whittaker

1998





Preface

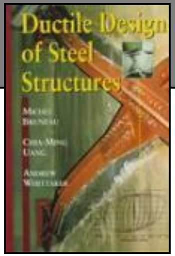
"Many practicing engineers have wrongly believed for years that the ductile nature of the structural steel material directly translates into inherently ductile structures."

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

Ductile Material

Ductile Structure

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



Chapter 1 Introduction

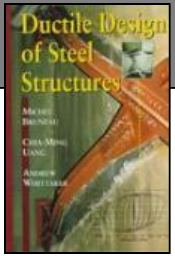
"However, there are many situations in which an explicit approach to the design of ductile steel structures is necessary because the inherent material ductility alone is not sufficient to provide the desired ultimate performance."

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)

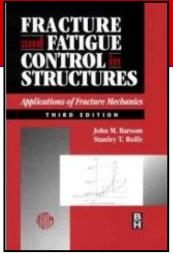
Ductile Design of Steel Structures



Chapter 1 Introduction

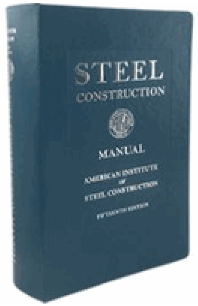
"To achieve this ductile response, one must recognize and avoid conditions that may lead to brittle failures and adopt appropriate design strategies to allow for stable and reliable hysteretic energy-dissipation mechanisms. This sort of thinking is relatively new in structural engineering."

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.

STEEL CONSTRUCTION MANUAL 15th Edition



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

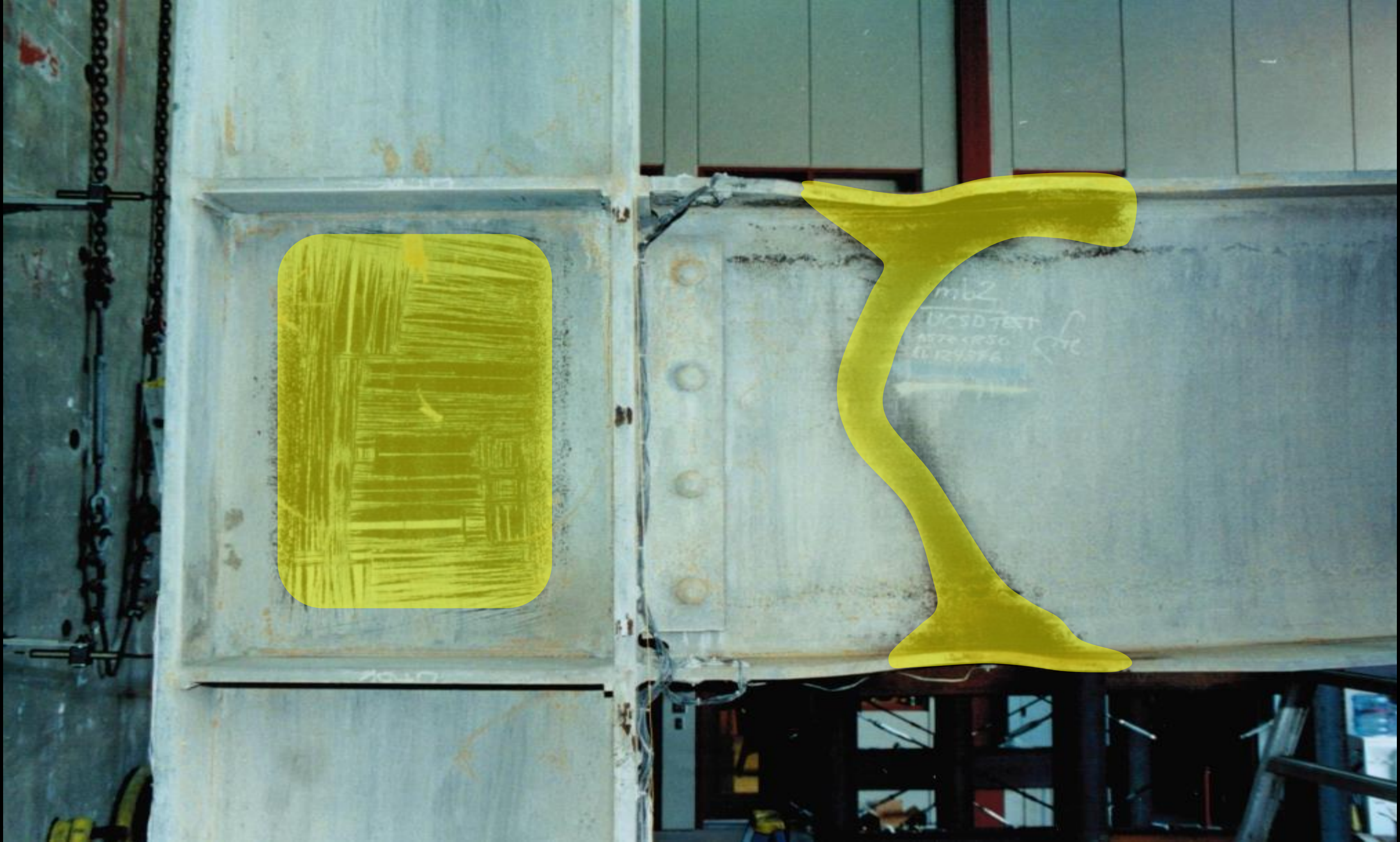
How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture

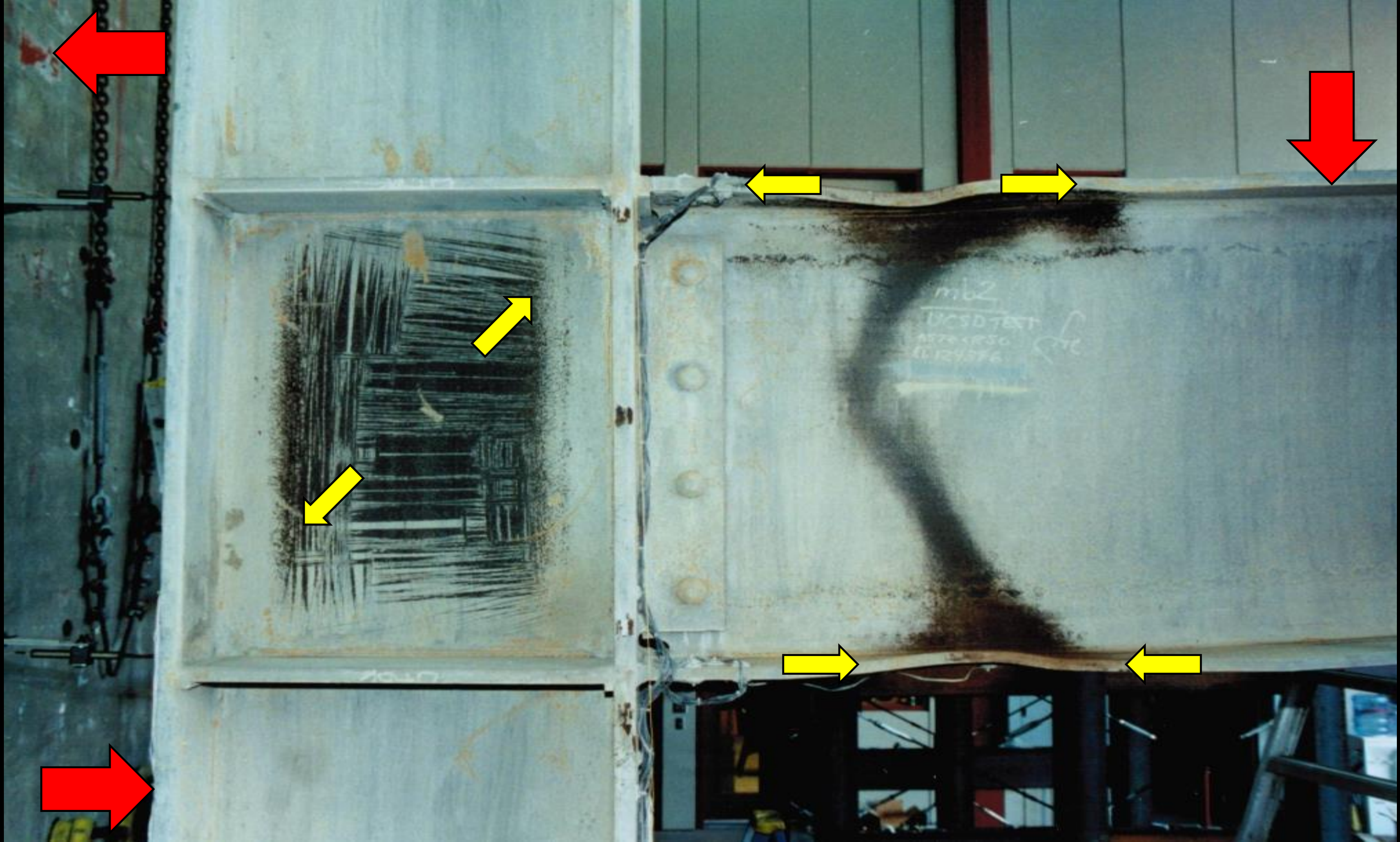
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses


mb2
UCSD TEST


mb2
UCSD TEST


UCSD TEST


mb2
UCSD TEST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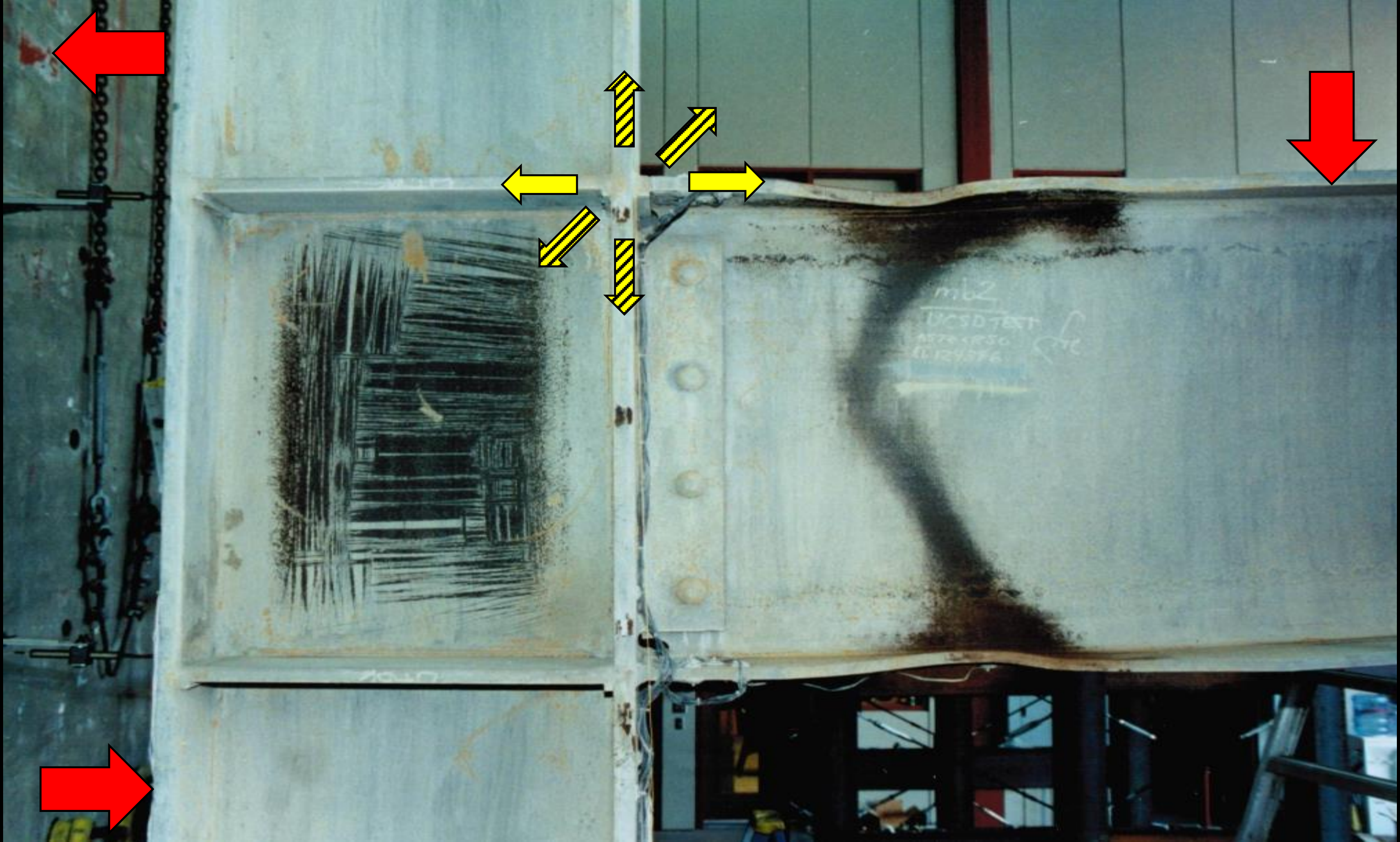
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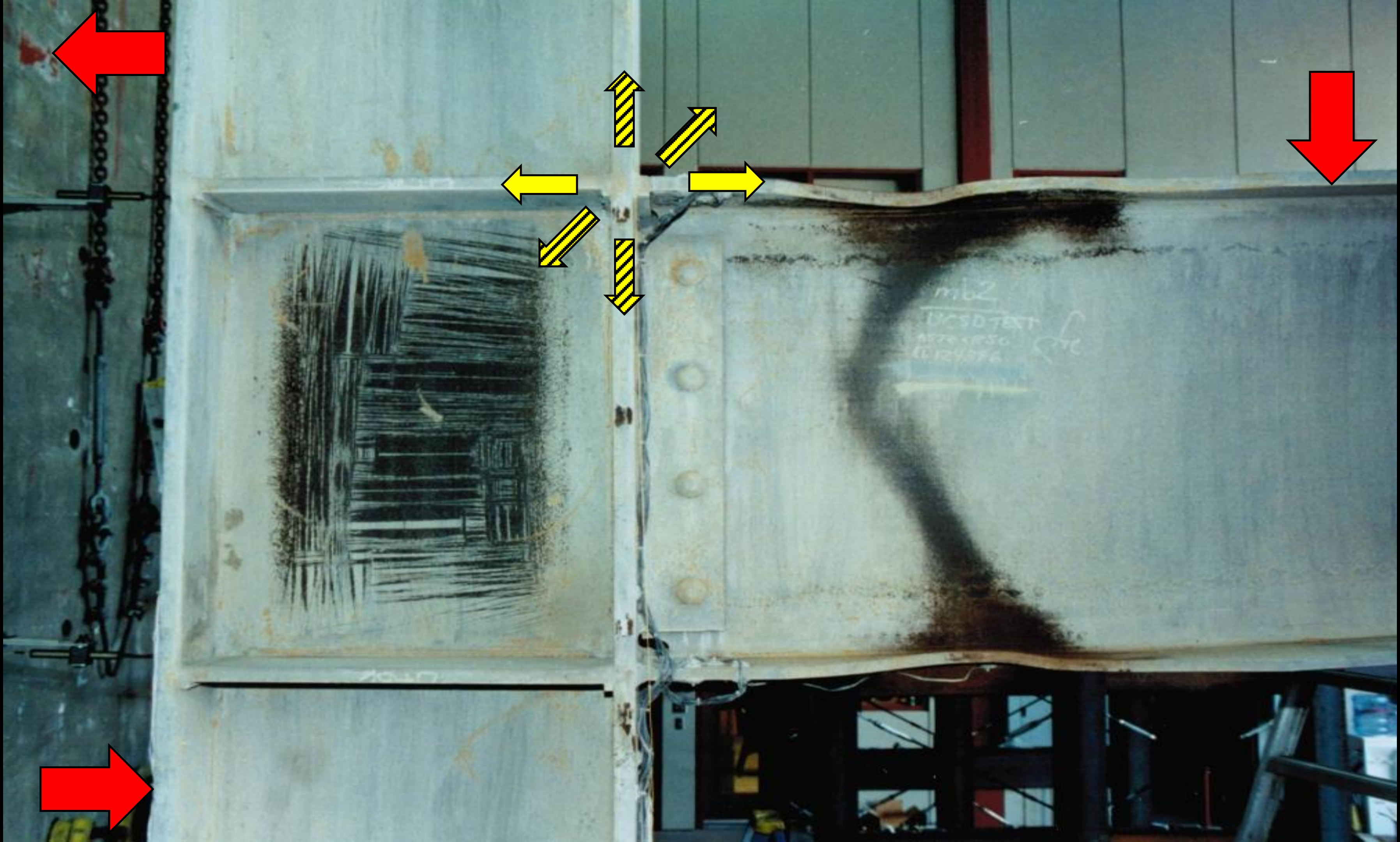
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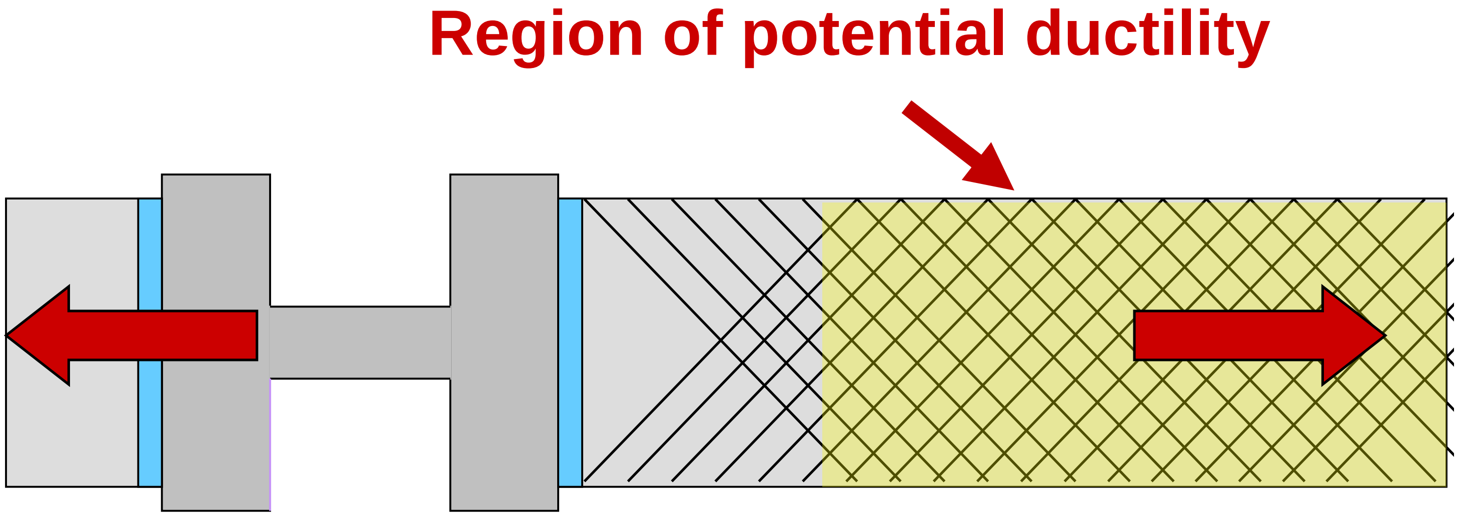
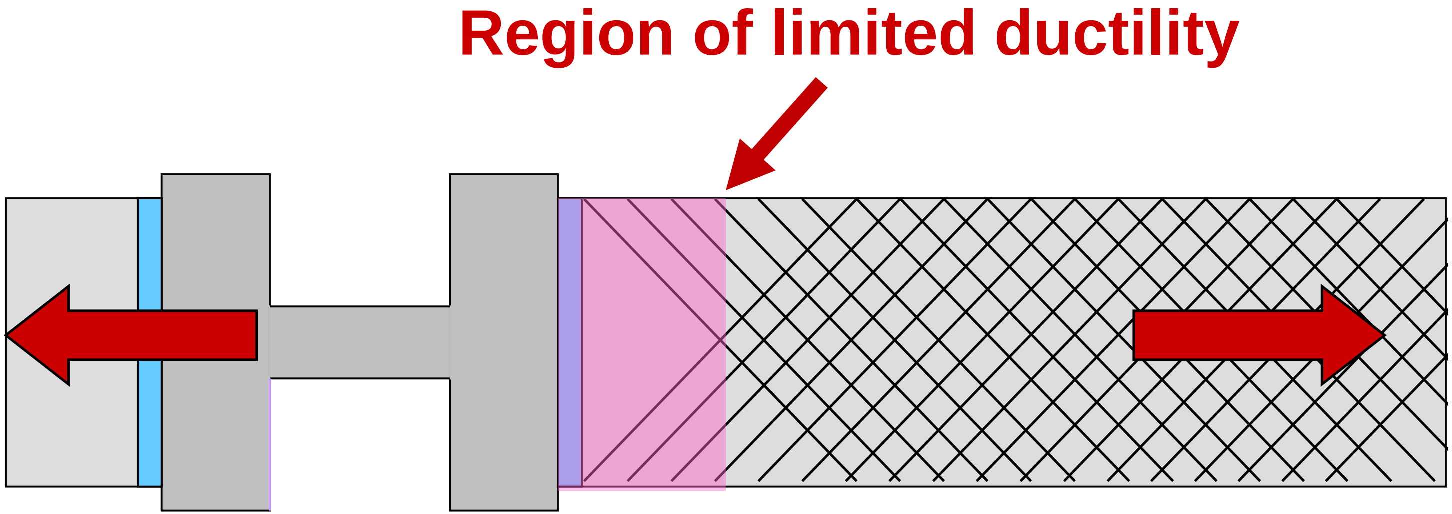
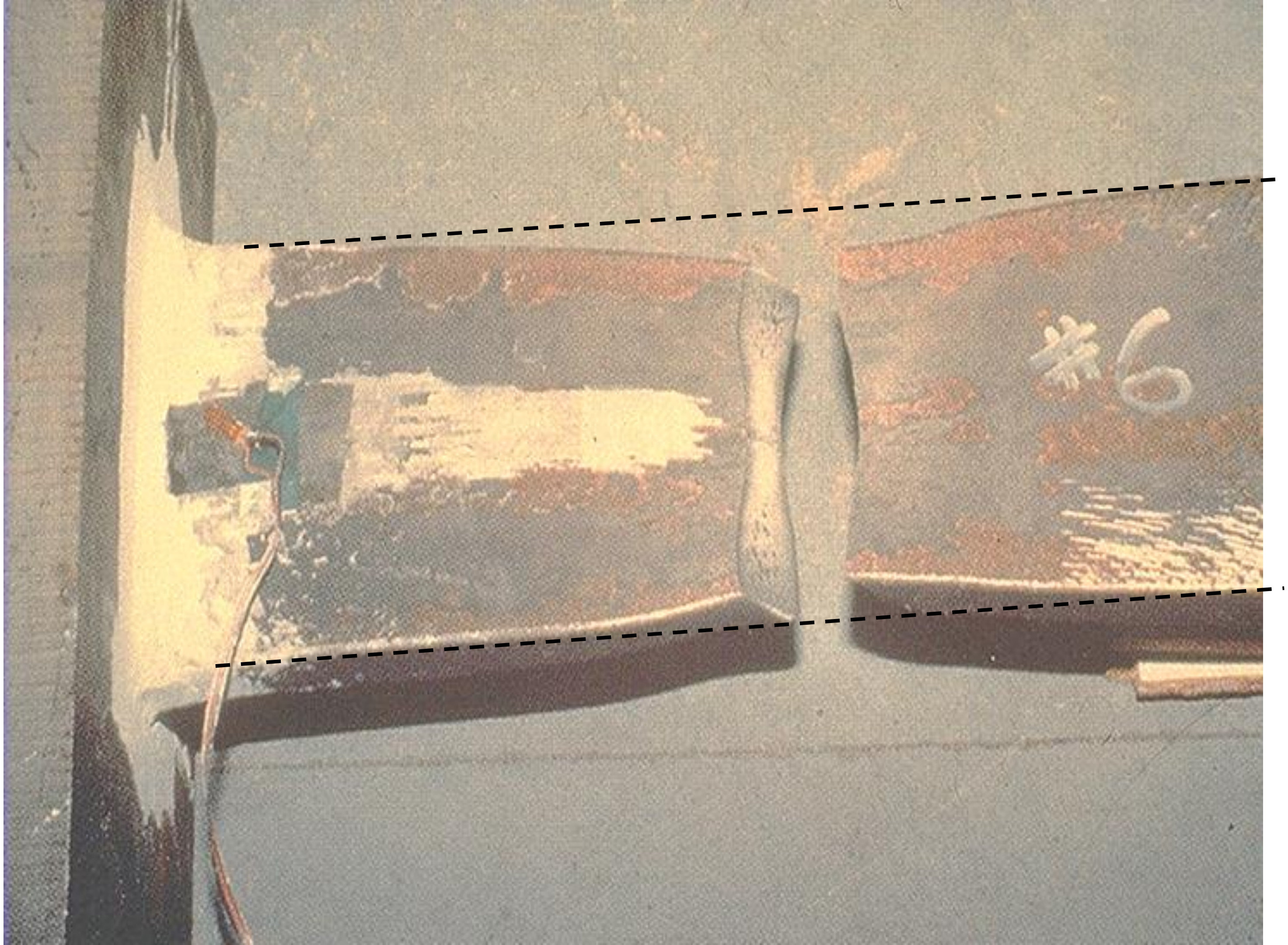

Region of potential ductility


Region of limited ductility


#6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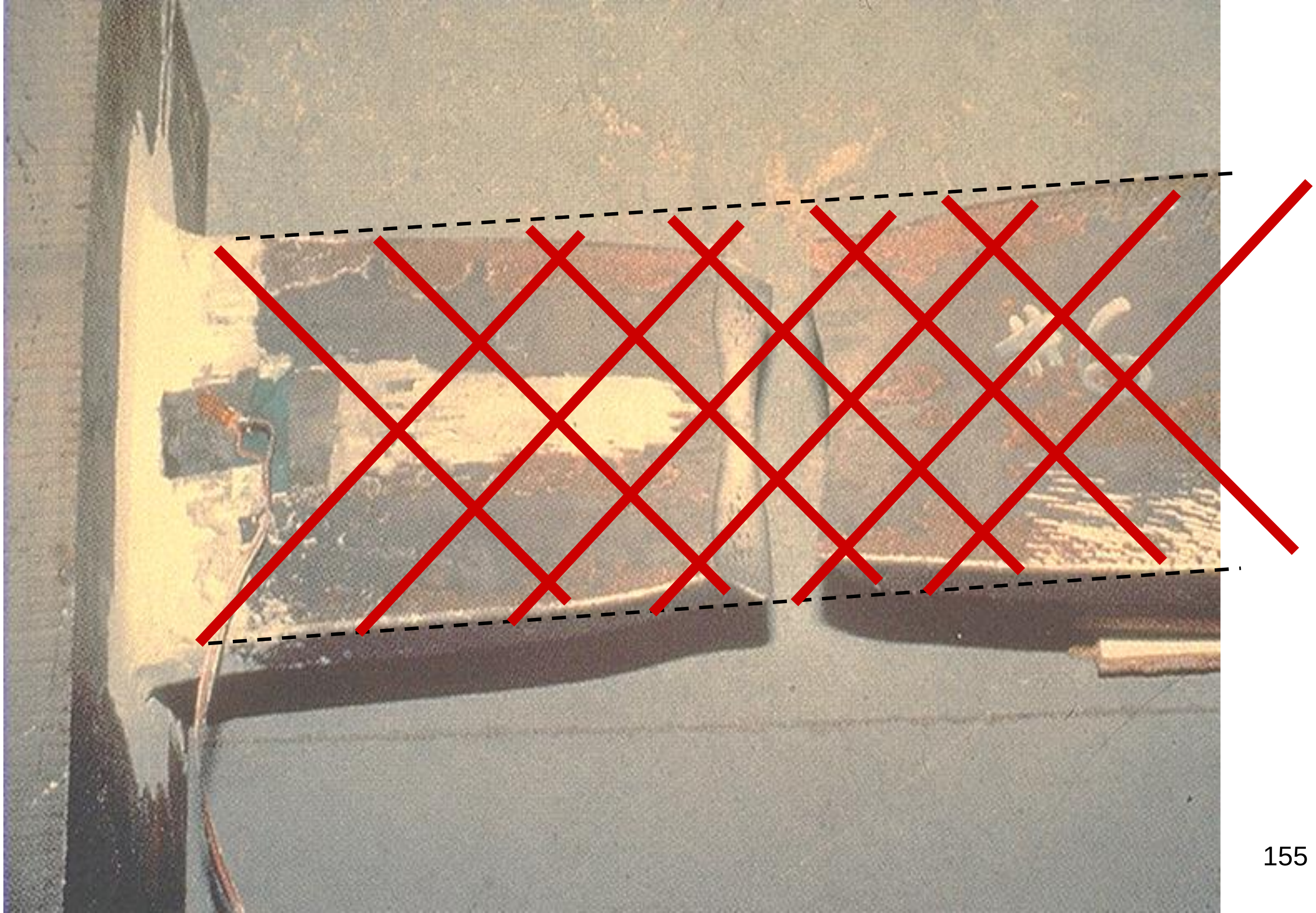

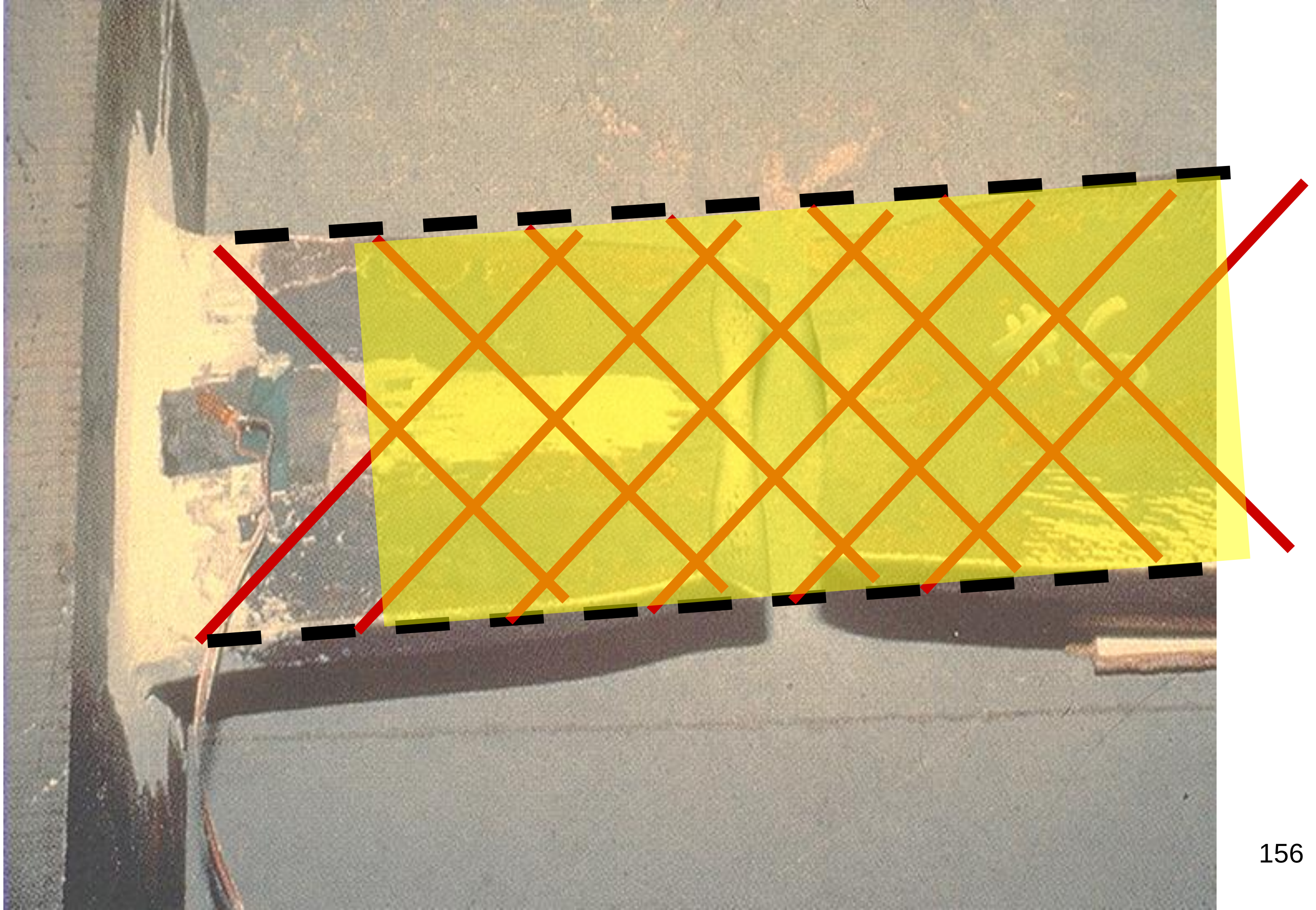

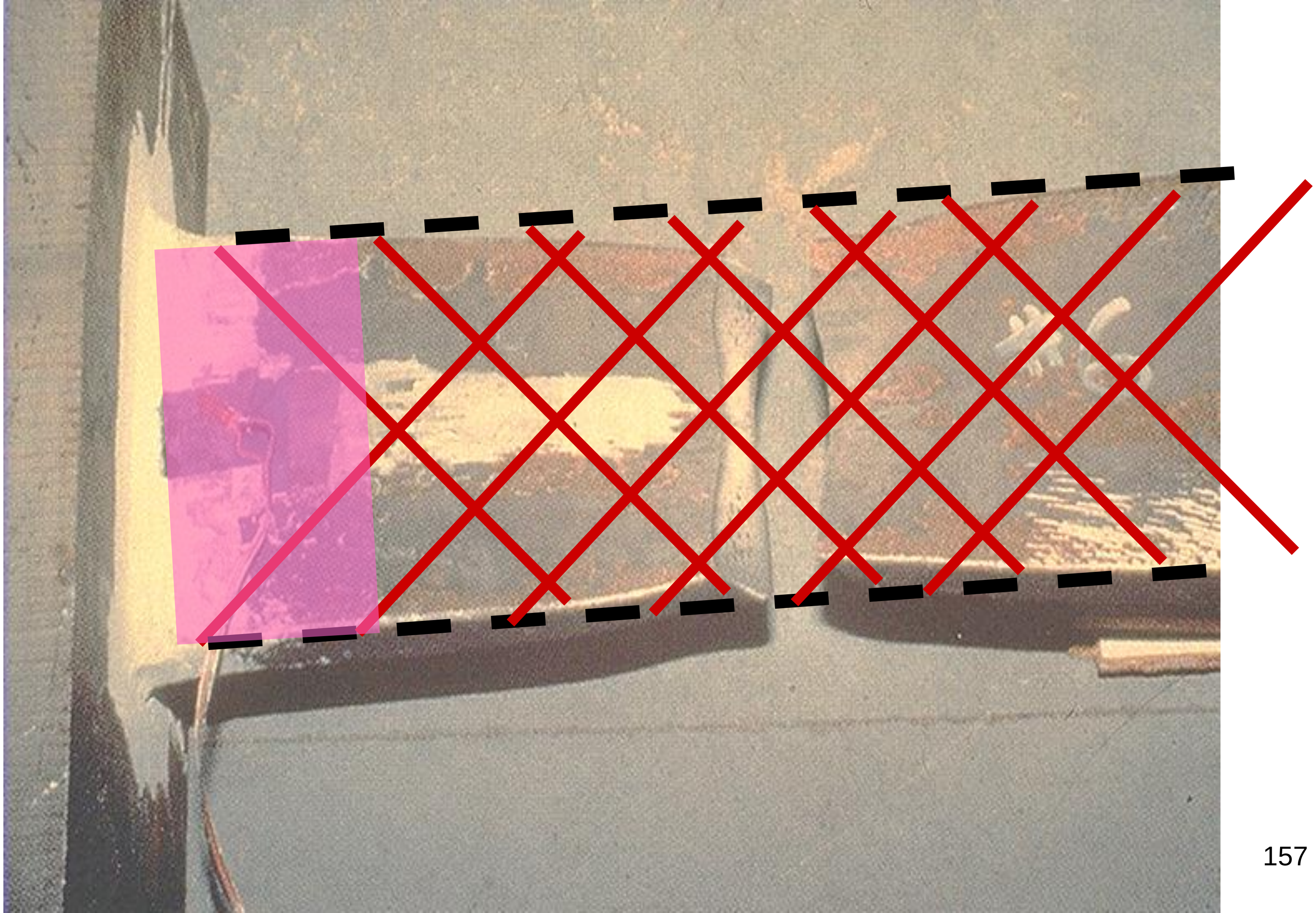

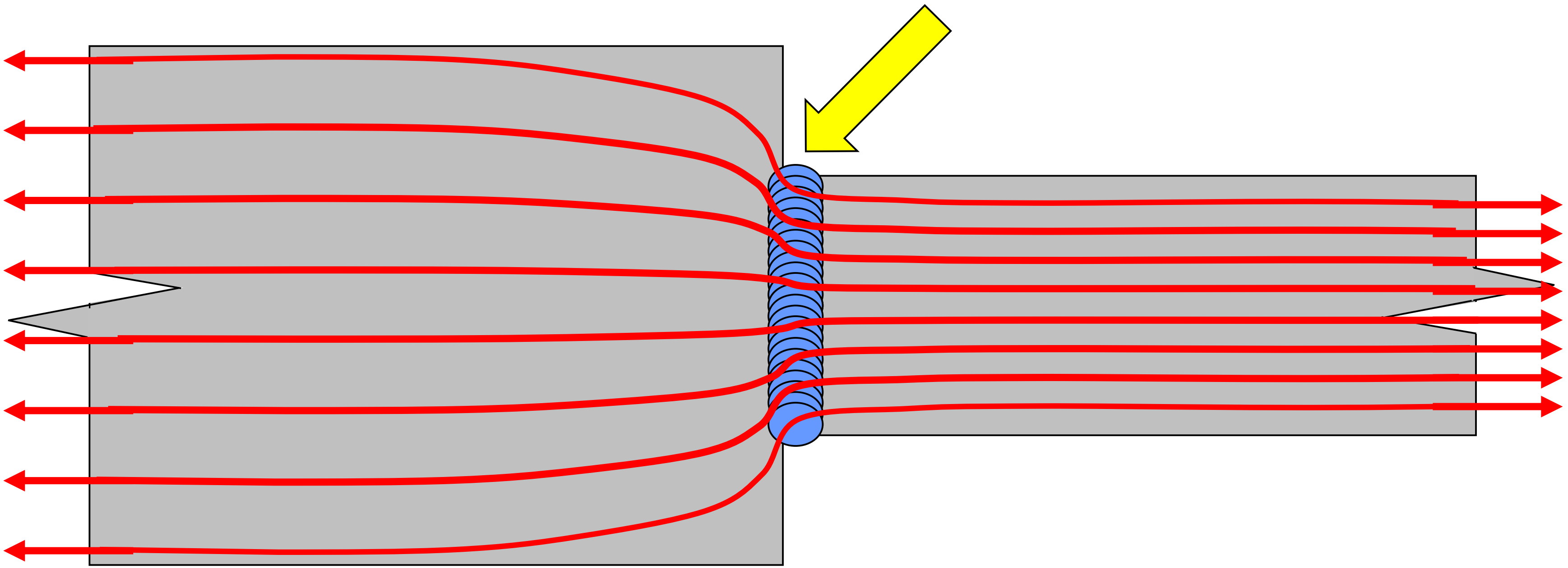

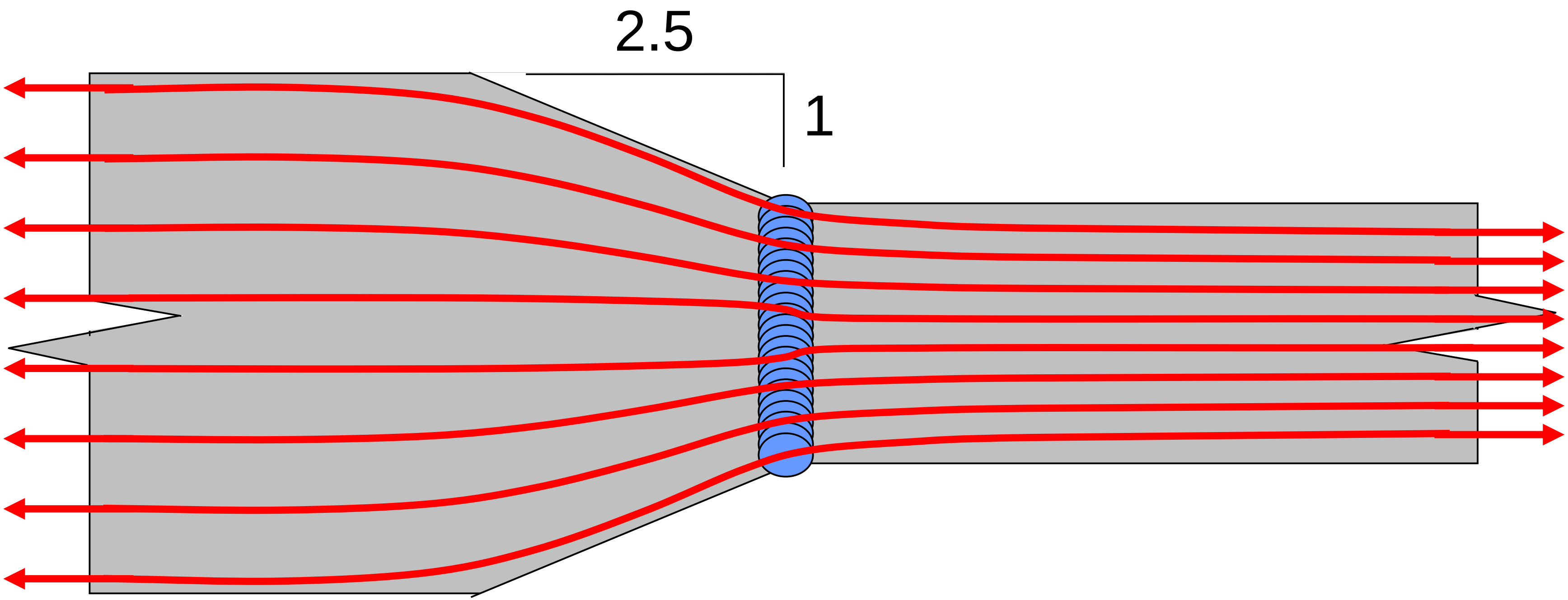
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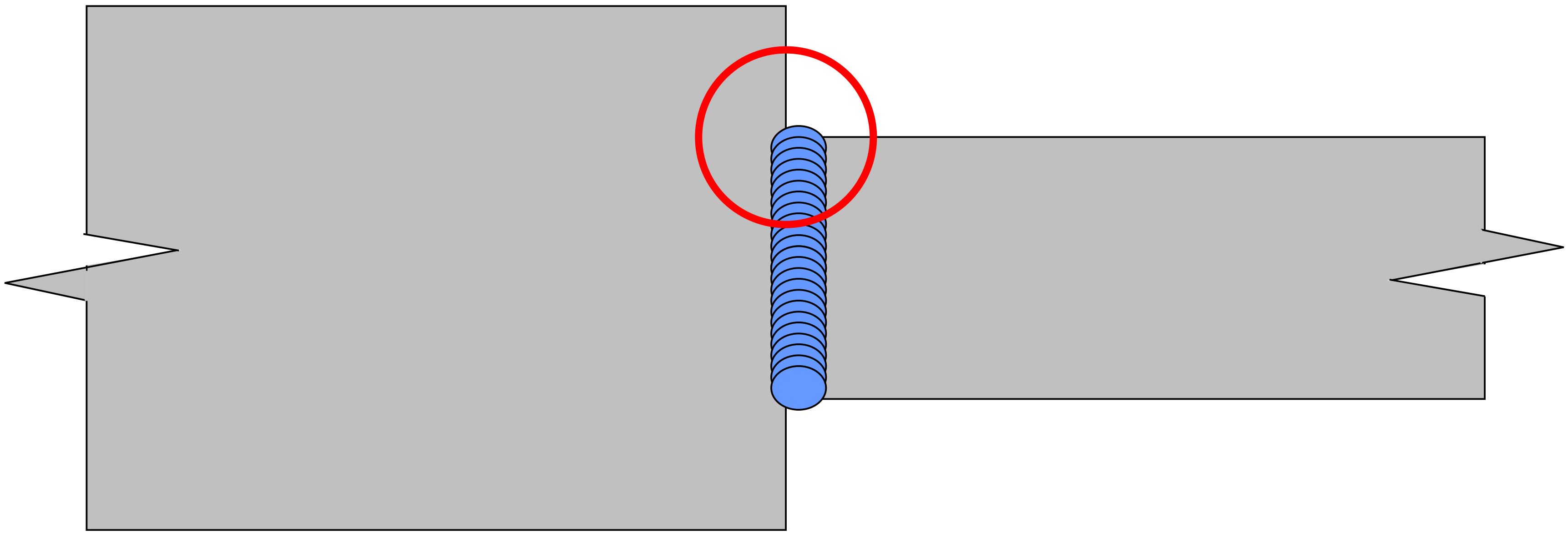
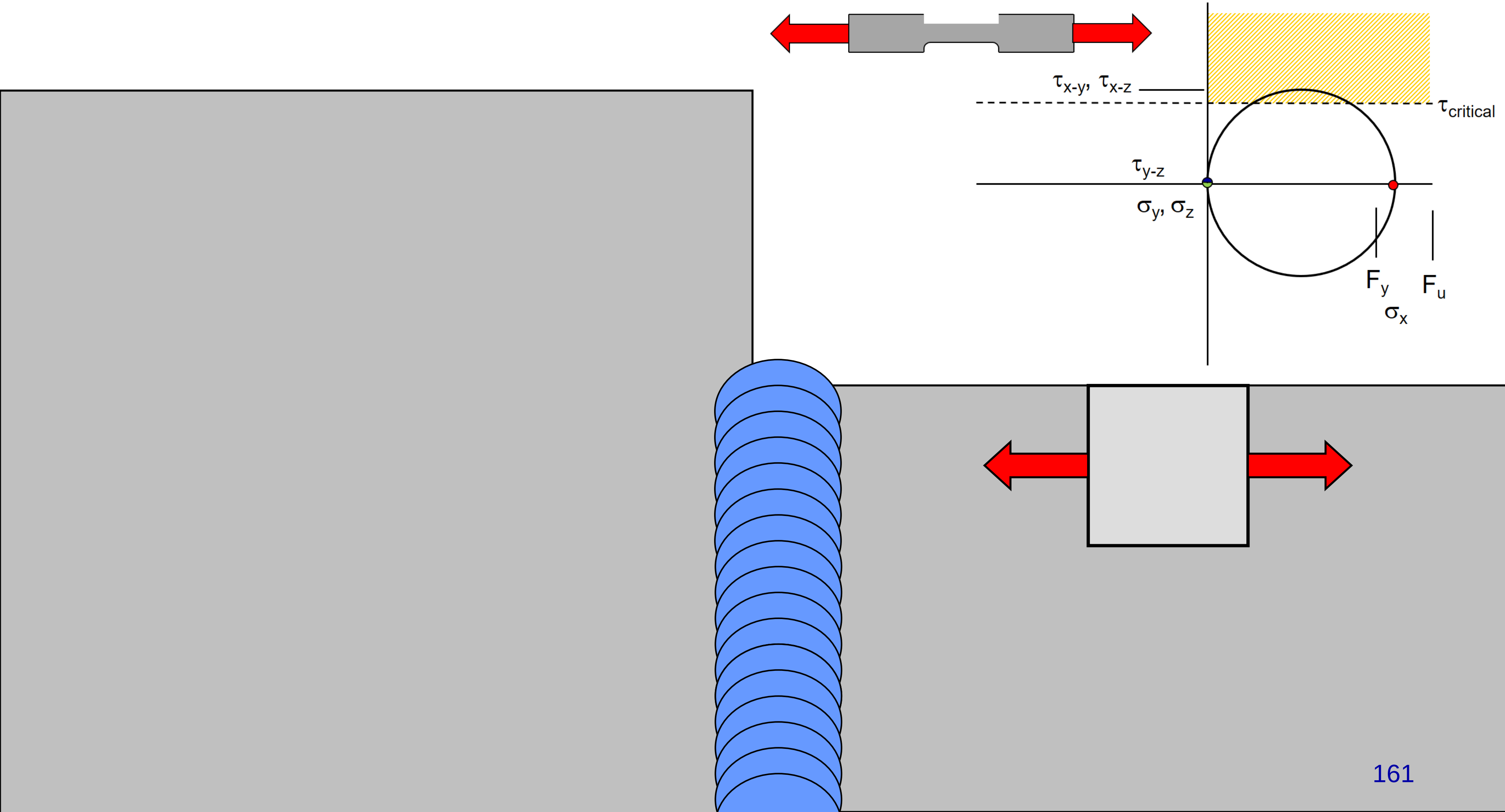
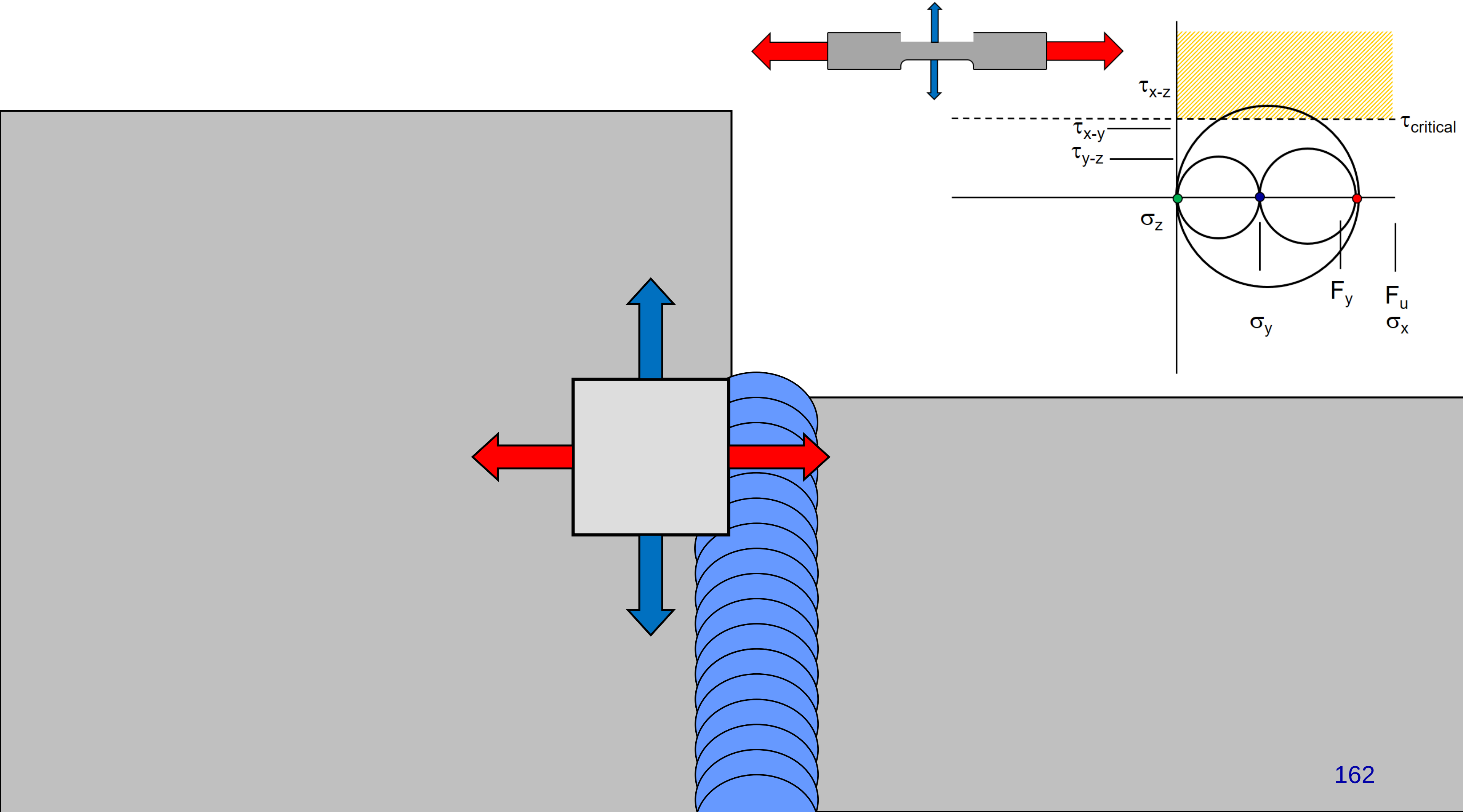
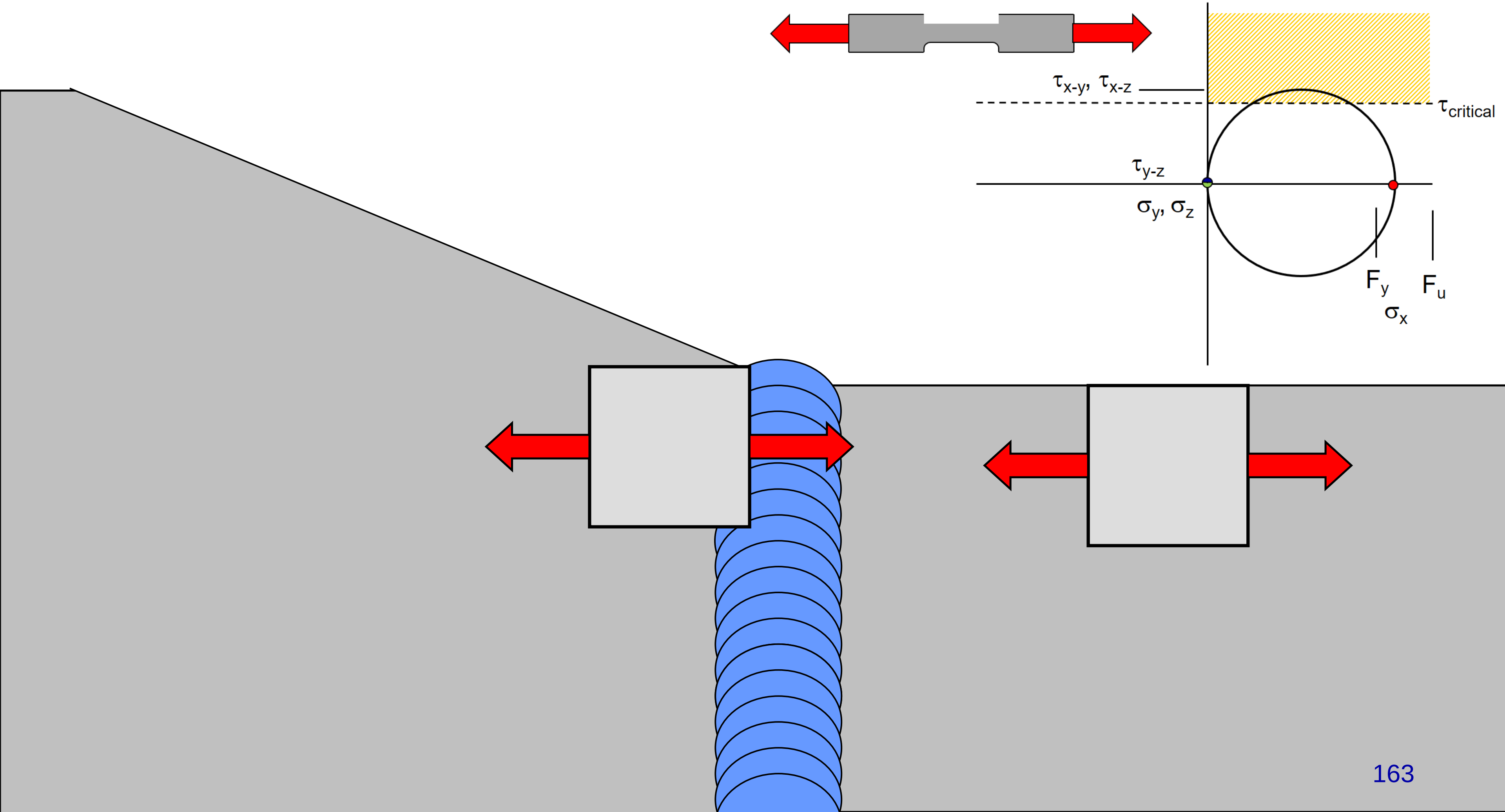




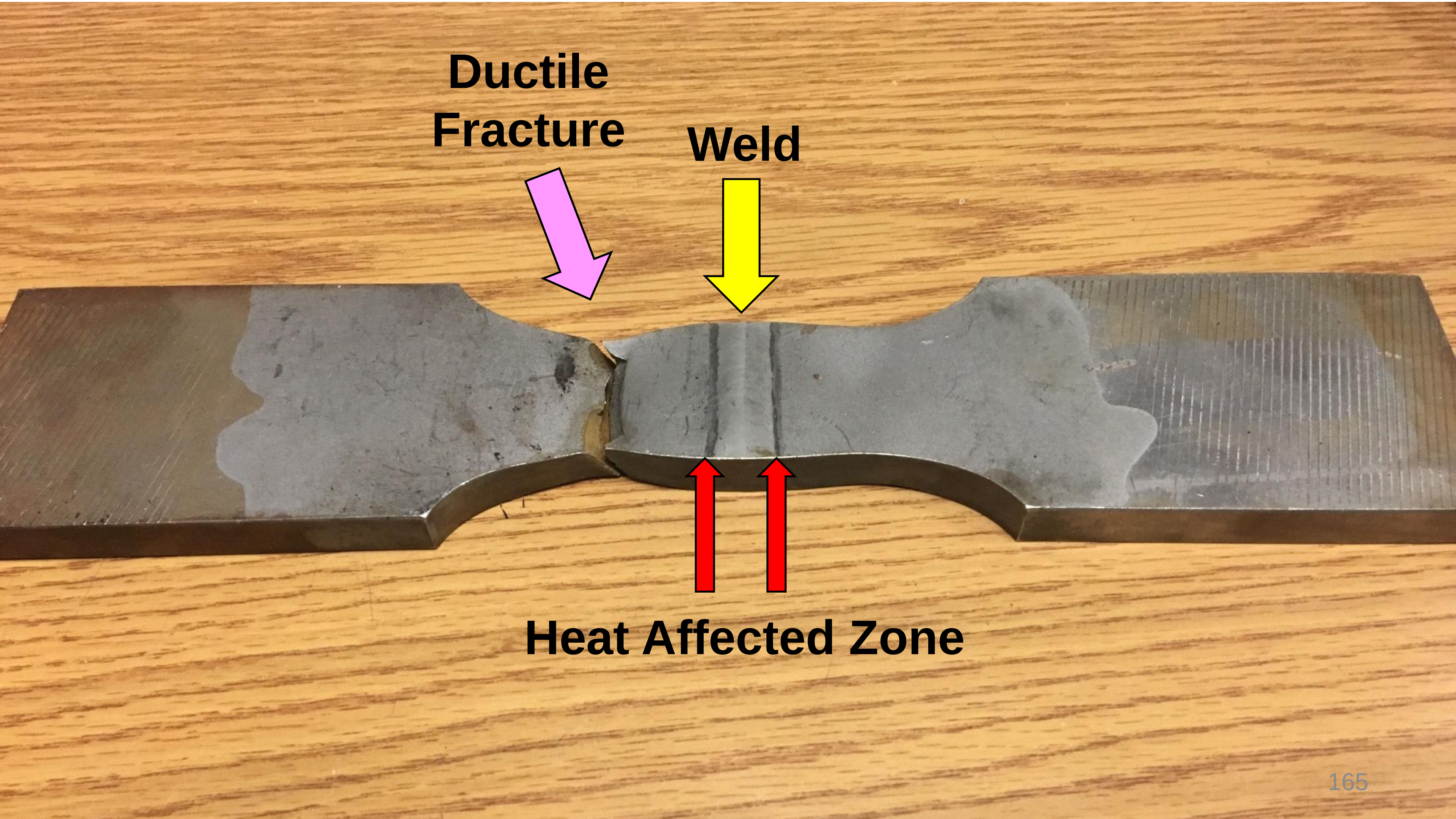
τ_{x-y}, τ_{x-z}
$\tau_{critical}$
τ_{y-z}
σ_y, σ_z
F_y
F_u
σ_x

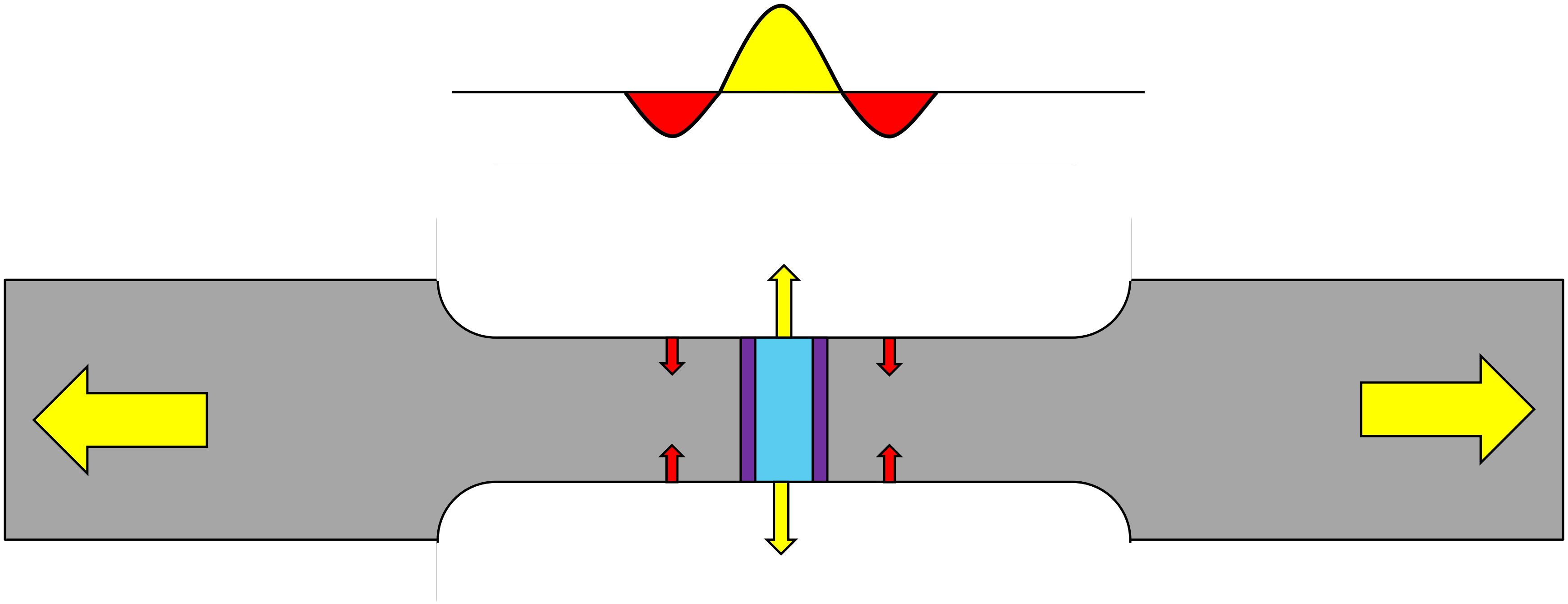


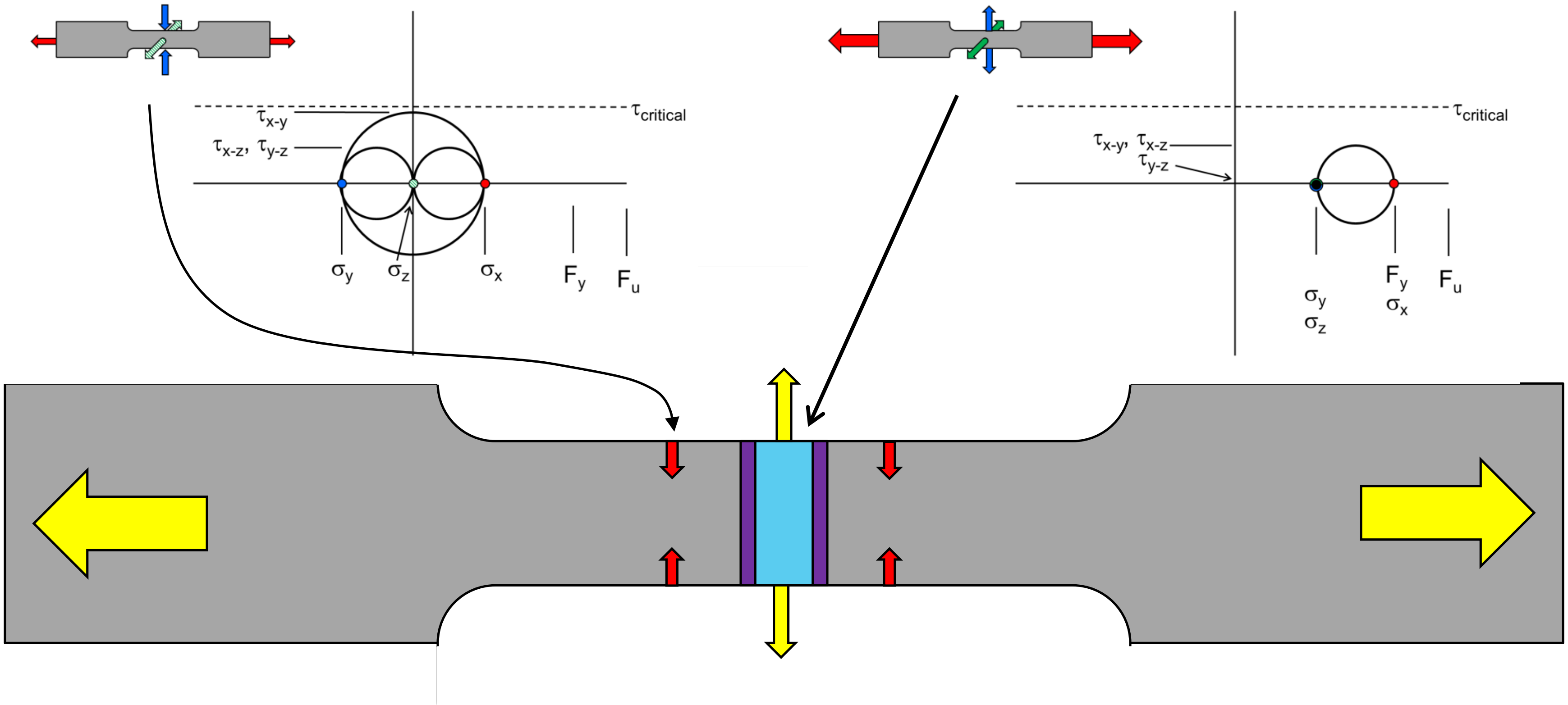
τx-z
τx-y
τy-z
τcritical
σz
σy
Fy
Fu
σx

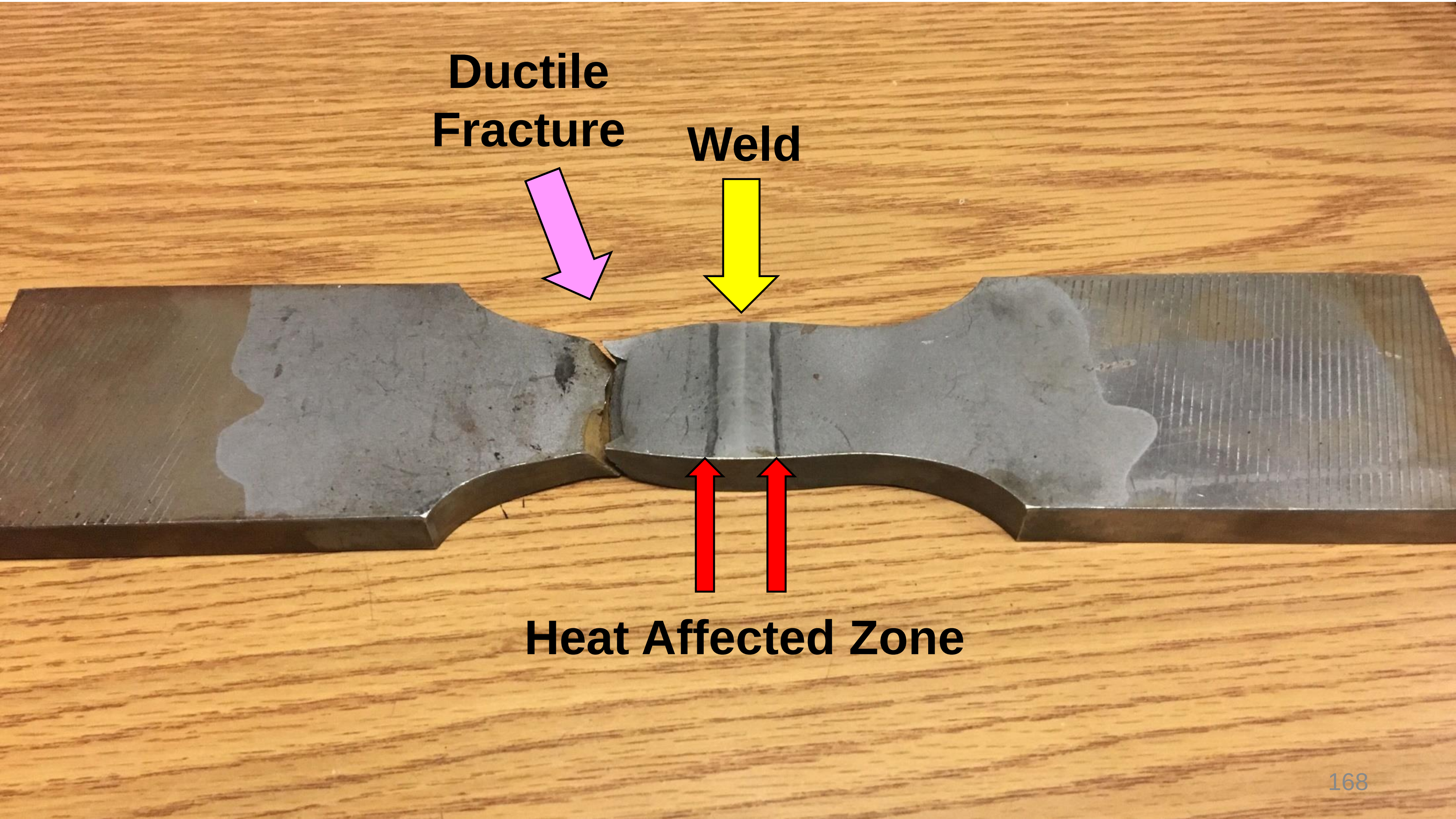


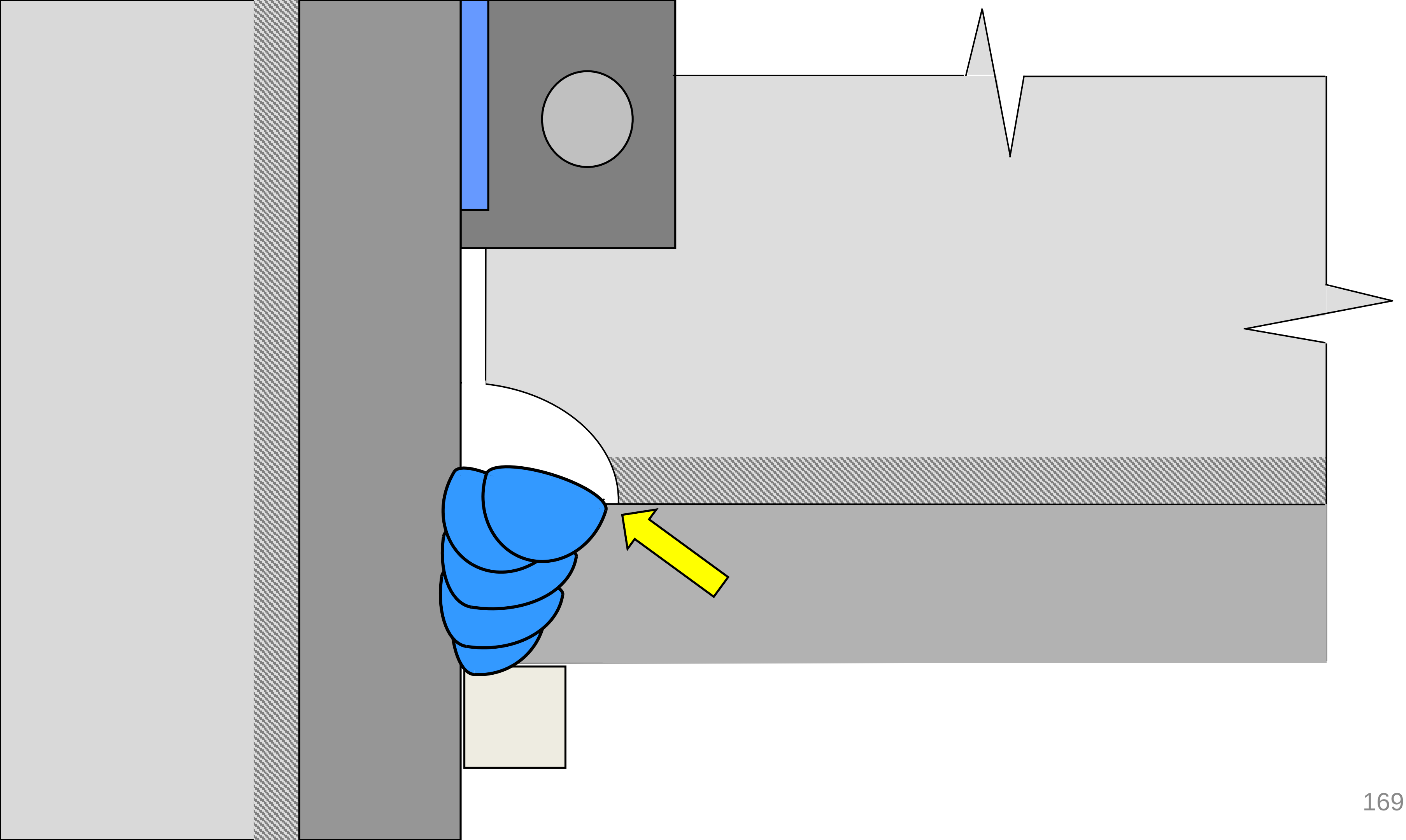
τx-y, τx-z
τcritical
τy-z
σy, σz
Fy
Fu
σx

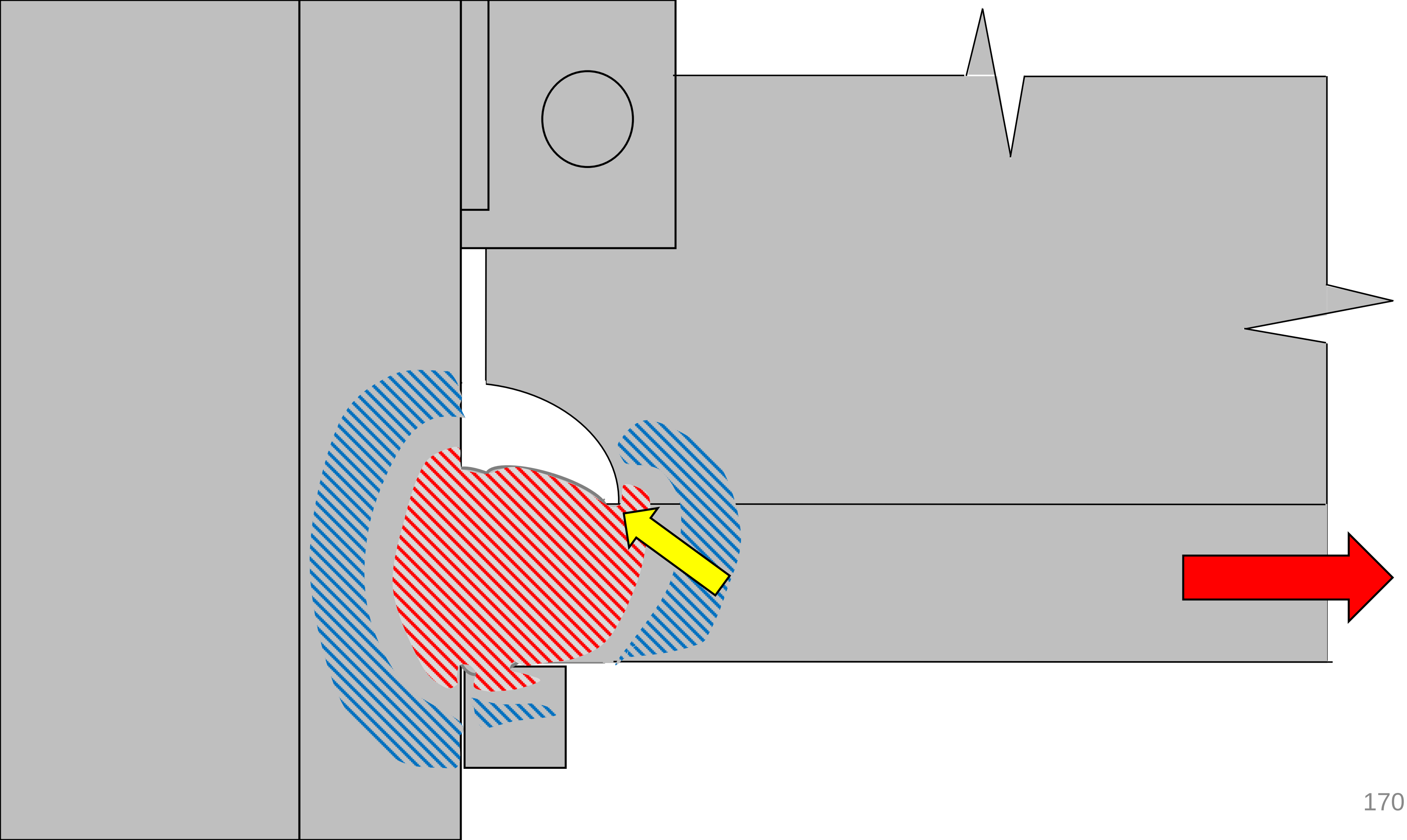

Ductile
Fracture
Weld
Heat Affected Zone

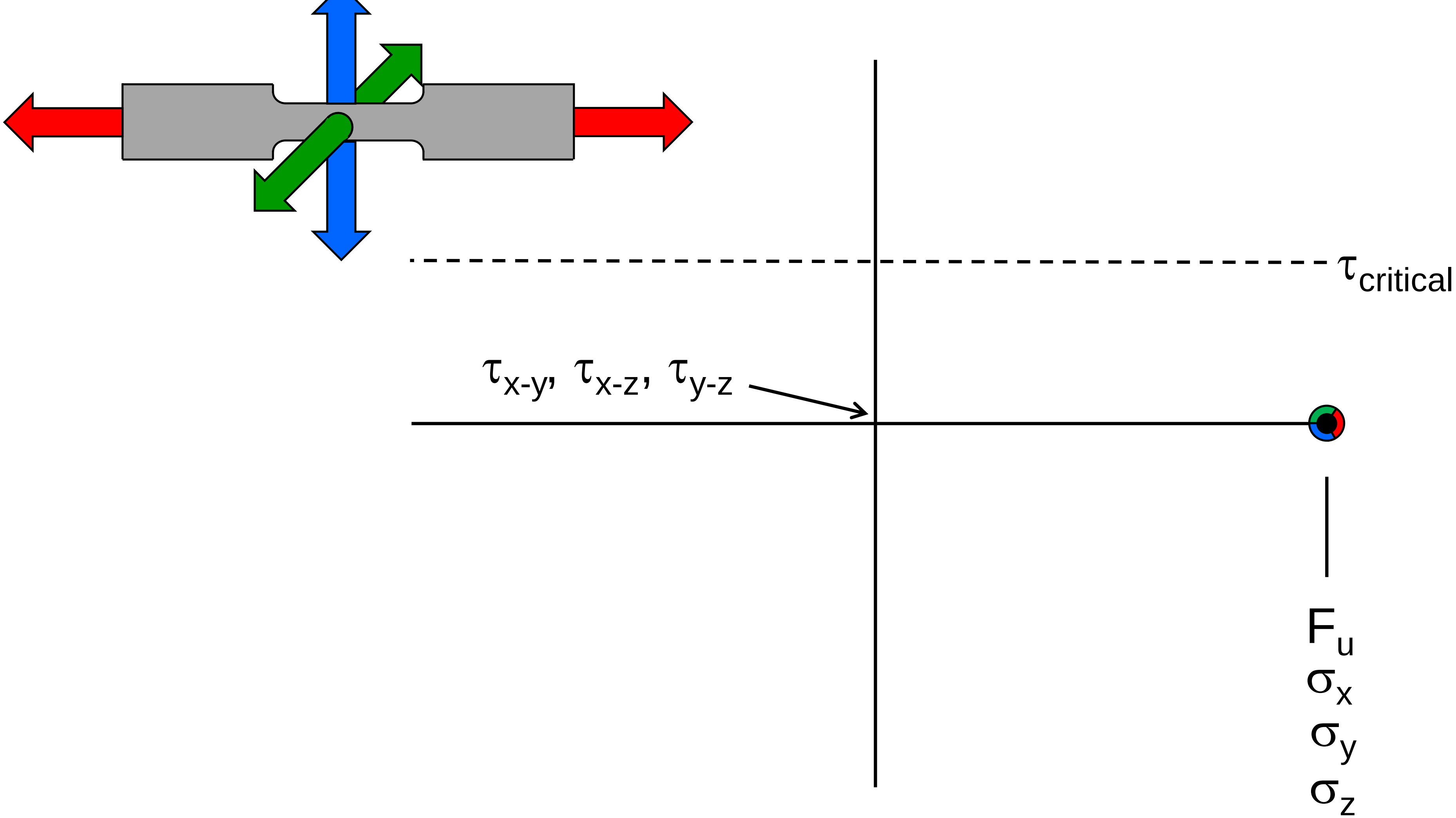



τcritical
τx-y
τx-z, τy-z
σy
σz
σx
Fy
Fu
τcritical
τx-y, τx-z
τy-z
σy
σz
Fy
σx
Fu

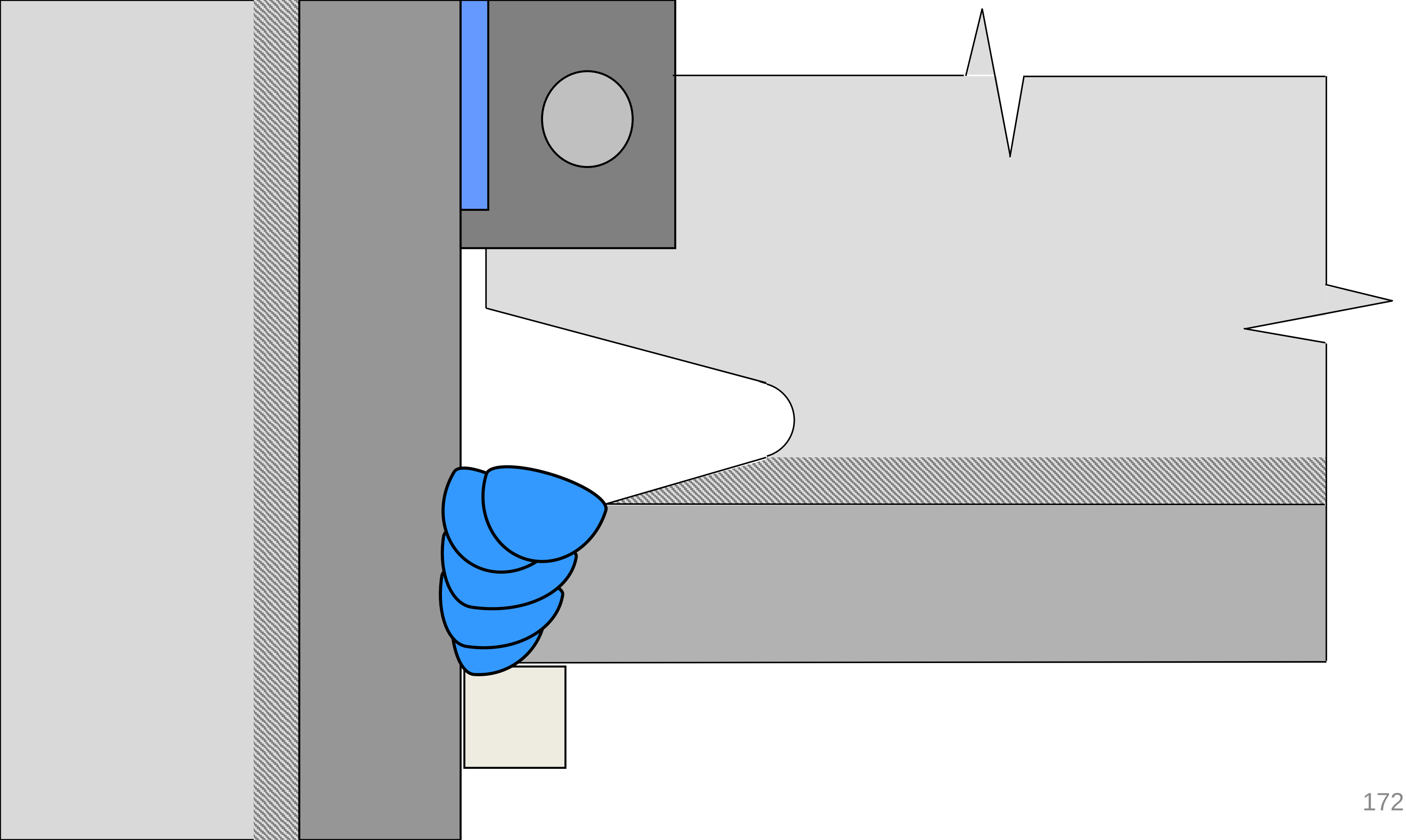

Ductile
Fracture
Weld
Heat Affected Zone

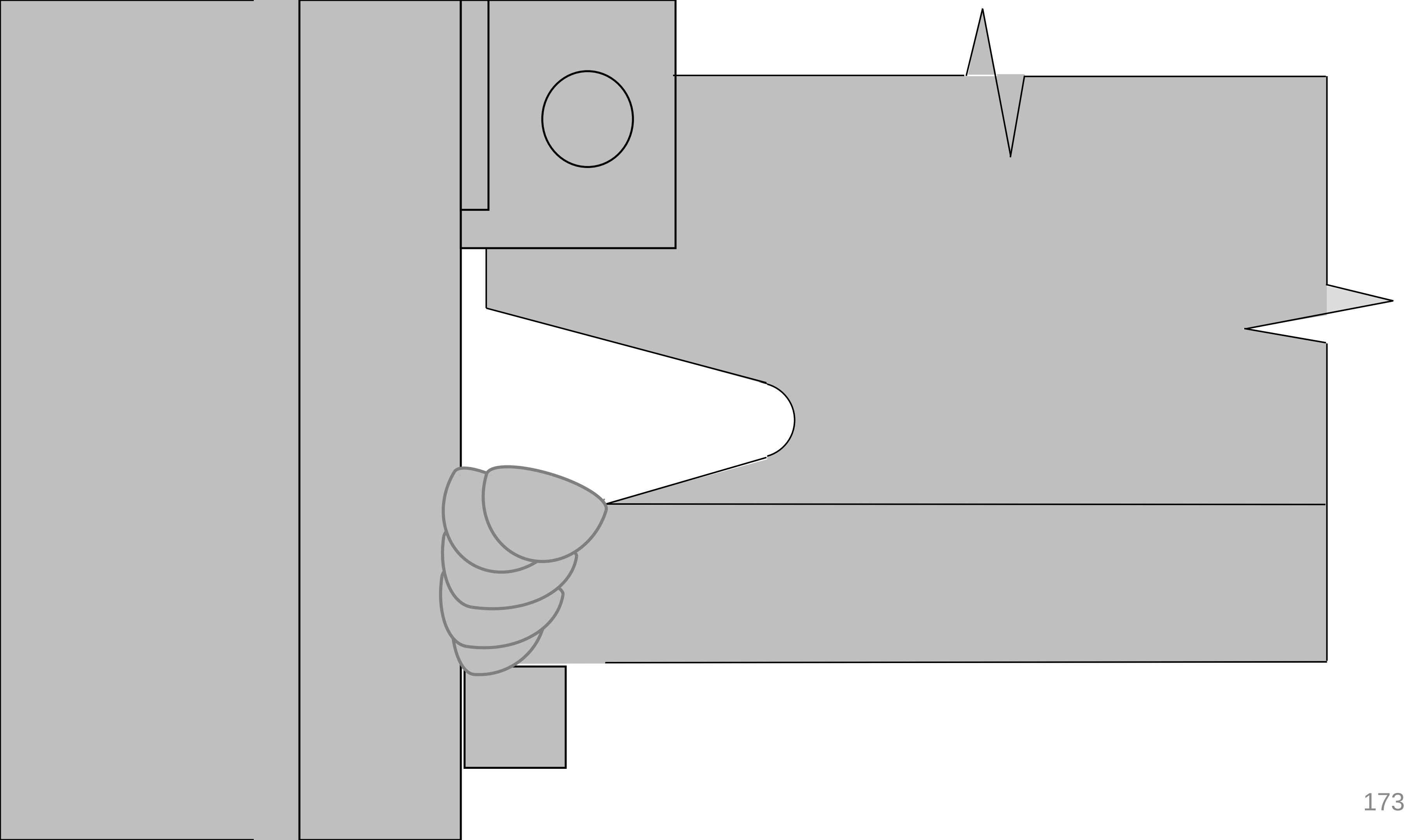


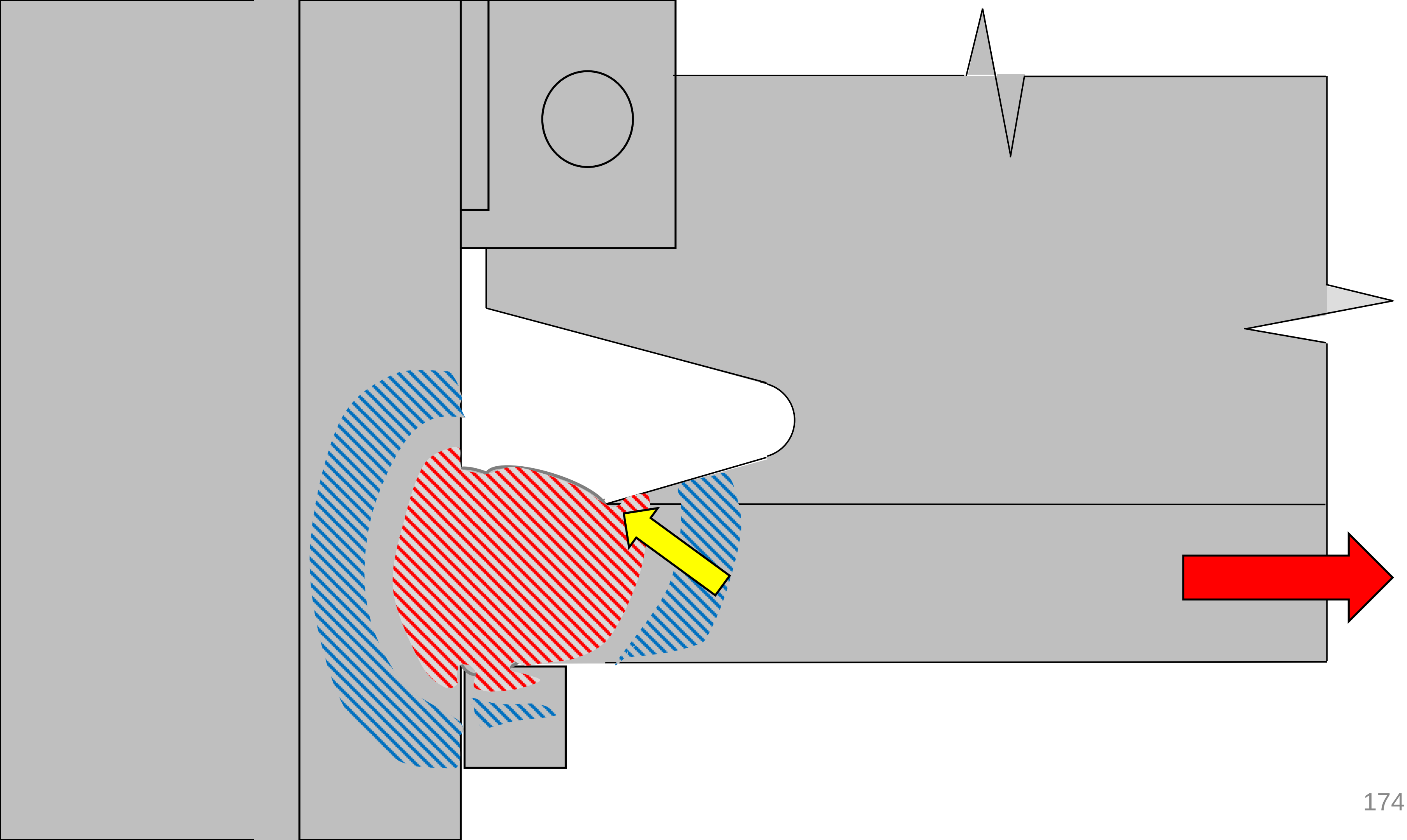


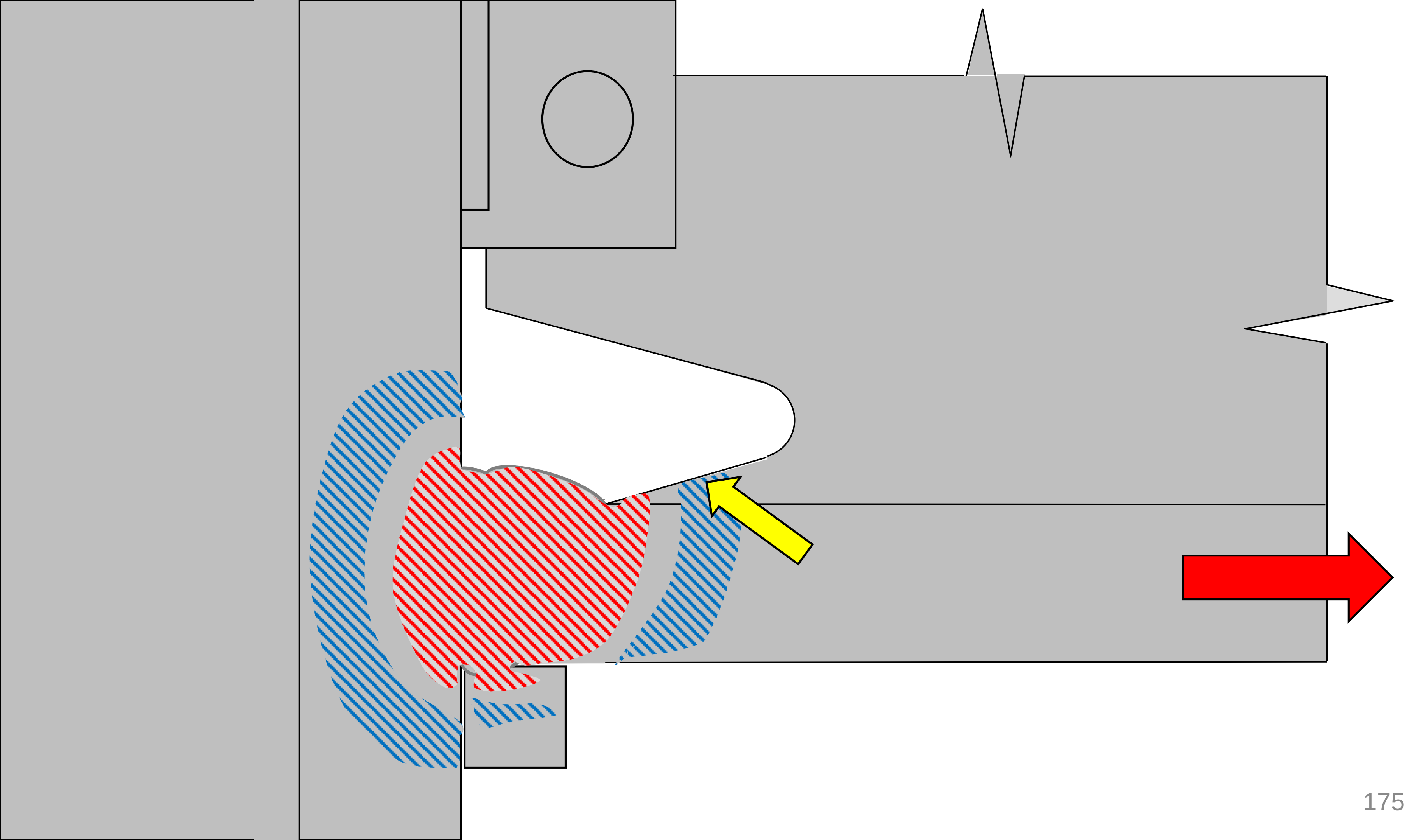


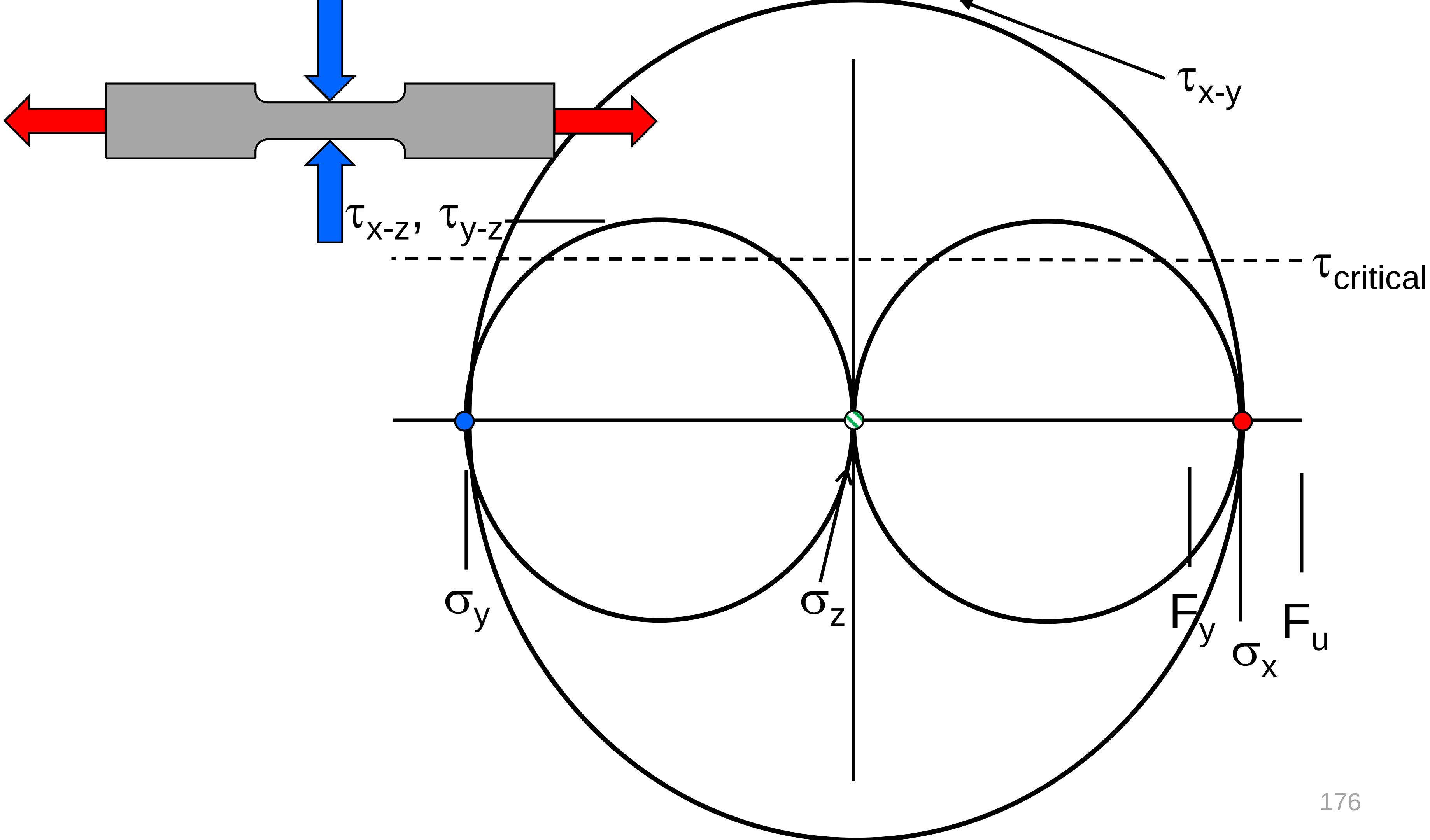
$\tau_{critical}$
τ_{x-y}, τ_{x-z}, τ_{y-z}
F_u
σ_x
σ_y
σ_z



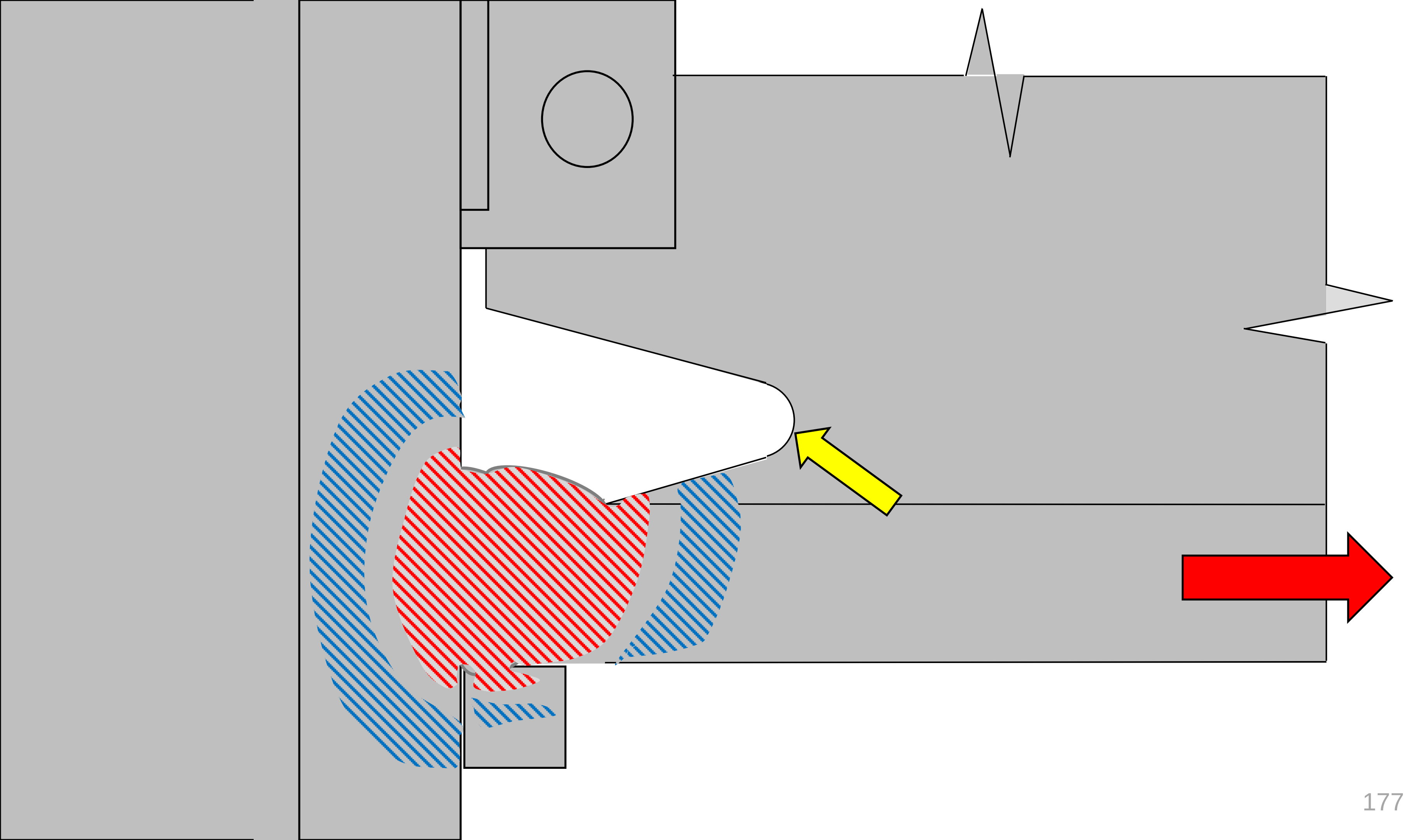


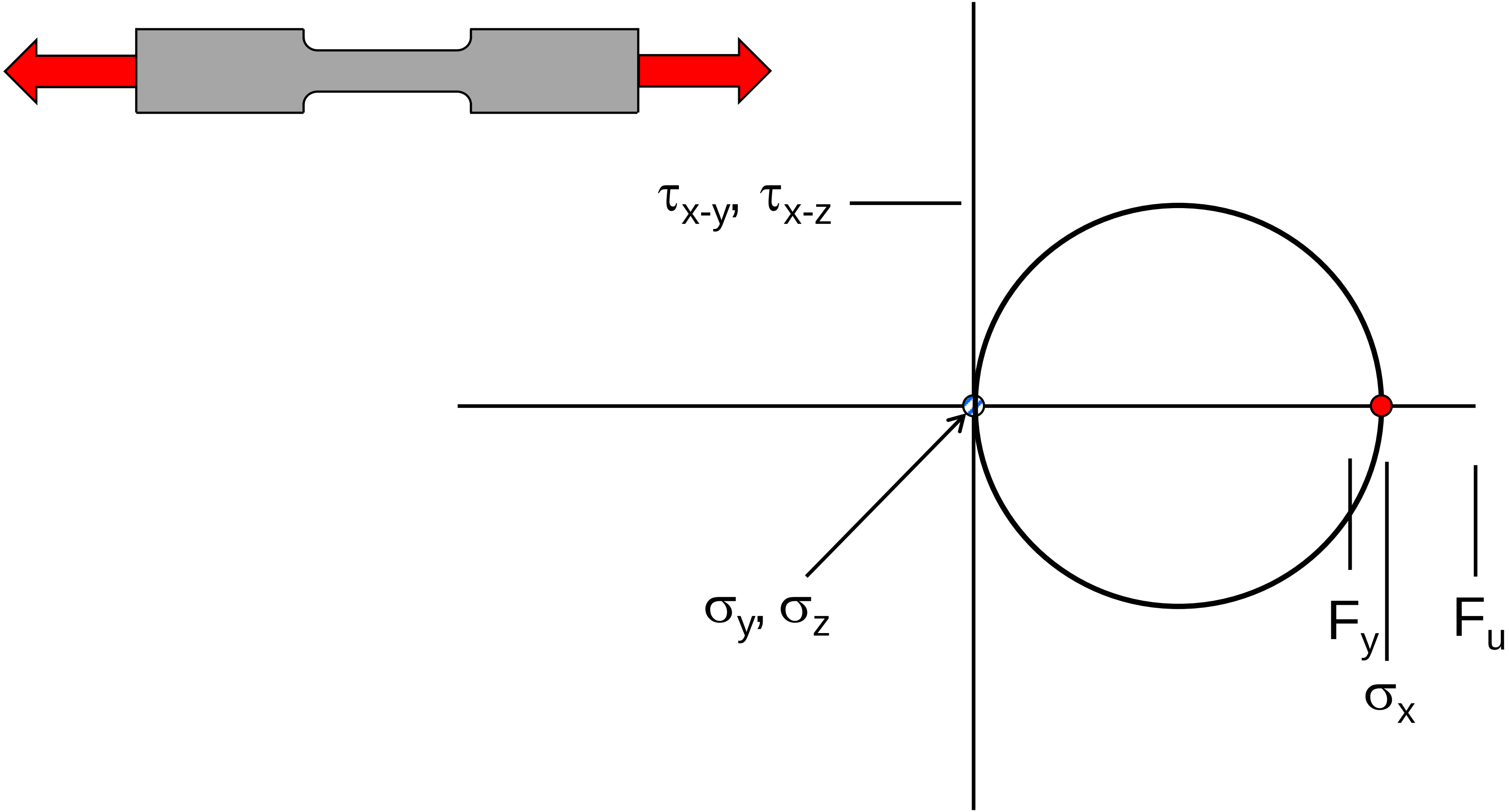






τx-y
τx-z, τy-z
τcritical
σy
σz
Fy
σx
Fu





τx-y, τx-z
σy, σz
Fy
Fu
σx

10-1-86

Consulting Engineer

A. L. COLLIN
California C.E. #6847
California Met.E. #1572

626 Moraga Way • Orinda, CA 94563
(415) 376-5632

Re: Jumbo Sections Welding

Enclosed is an itemized commentary on the ENR article of Aug 21, 1986 on the fracture of a bottom chord truss member (a jumbo section) of the Orange County Convention Center, Orlando, Fa.

Jumbo sections, AISC Groups 4 & 5, do have inherent characteristics that must be acknowledged and respected if they are to be welded.

Like all large, thick hot-rolled sections and plates, Jumbo sections can have relatively low impact strengths and large grain size, especially at the flange-web intersections; this is common knowledge and as standard specifications do not address these material properties, the design engineer must obtain them thru the supplementary specification requirements should he consider his project critical, over & above standard code requirements.

Jumbo sections can be welded successfully and will perform properly if all the welding parameters are considered and specified correctly. These include: proper material specifications, correct joint design detail, welding procedures, good workmanship by qualified personnel and visual-in-progress inspection as required by code plus the necessary non-destructive testing, such as magnetic particle and ultrasonics, to verify the integrity of the finished welds.

2.

ods of jumbo sections that
full penetration groove welds.
successfully.
ome welding problems;
some and have recommended
ful repairs.

found that some basic
been violated, such as
e stress-relief holes (rat-holes)
o the flange-web inter-
ial forces due to the high
cases of weld problems
any welding procedures
d.

ments than jumbo sections
made in structures and
developed the welding pro-
h-rise that had 36" square
welded to 13" + 15" base
eorgia.

repair welding of a 1335
Steel- Oakland where
welded to each other
bottom components.

roblems, we developed
specifications for the
vention center in Seattle
date there have been
groove welds, mostly in
s, with practically
s.

will send you the UCB
mbo section splices.
ld splice, tested in
with reversals into the
than the base metal.

3.

quoted correctly, I do
could have made the
eel, fine grain practice
all of these items are
ustry as contributing
sign.

tural steel to form
effect due to the
. Stress-relief holes
web intersections
holes with no stress
by grinding to
formation of martensite
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properties of the flange-
re well known and
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plices.

eral specifications
, and processes,
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spection.

mbo section splice
out the many other
rely they must
there was any
detail of the
decision was made
hat did not fail.
ating all the facts
the AISC.

Sincerely,

A. L. Collin

C.C. - File.

ENR 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 stresses. A good welding procedure with judicious use of peening each pass will do much to prevent high residual tension stress build-up. With proper application, peeining will actually curve 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 as 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 of a jumbo section, can obtain information on successful weldments that are larger and operate under more critical conditions; especially in the heavy equipment and machine field.

ENR 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 cri-
tical point and preventing tri-axial forces from

ENR ARTICLE OF AUG 21, 1986
Commentary by A.L. Collin

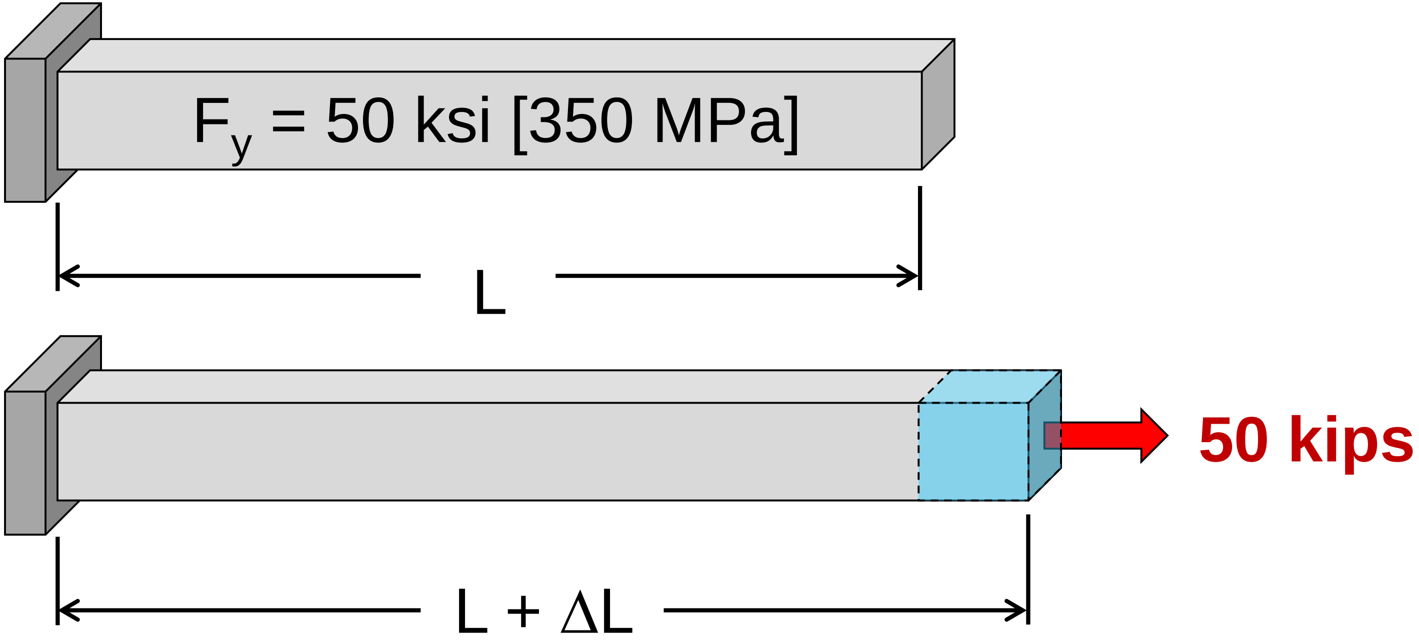
5.- Stress relief holes at the flange-web intersections, beside keeping the welding away from this critical point and preventing tri-axial forces from developing, allows the flange splice weld to be made continuous as required by Code. However these cut-outs must be smooth and if flame cut or air-arced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

designer faced with a critical condition, such as a tension splice of a jumbo section, can obtain information on successful weldments that are larger and operate under more critical conditions; especially in the heavy equipment and machine field.

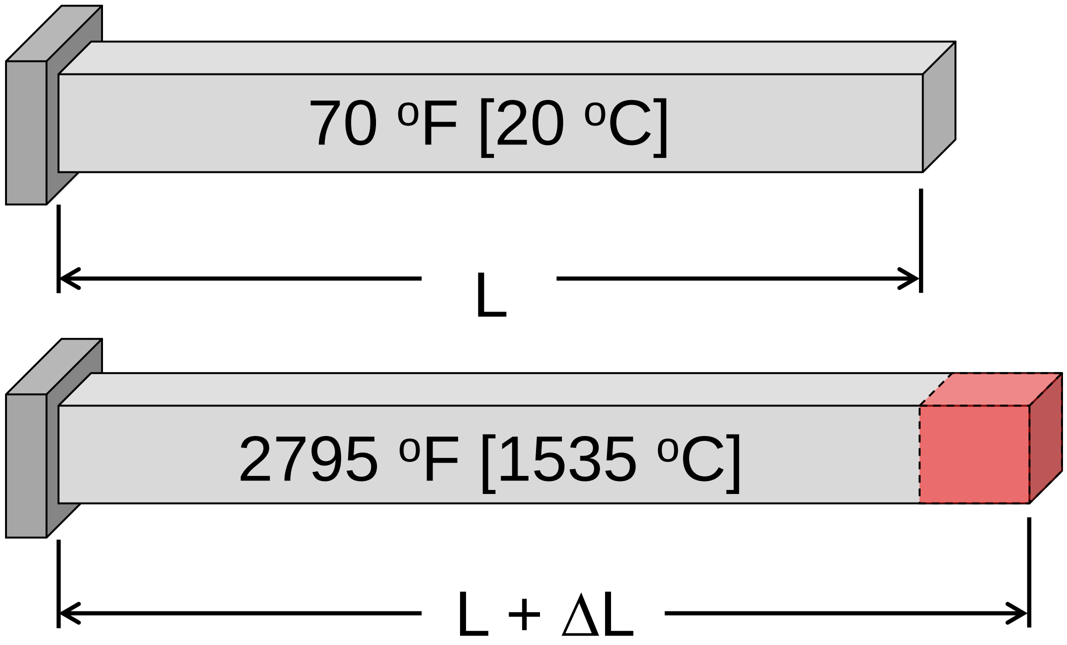
Another need for ductility: welding depends on it.

$$\Delta L = \frac{PL}{AE}$$

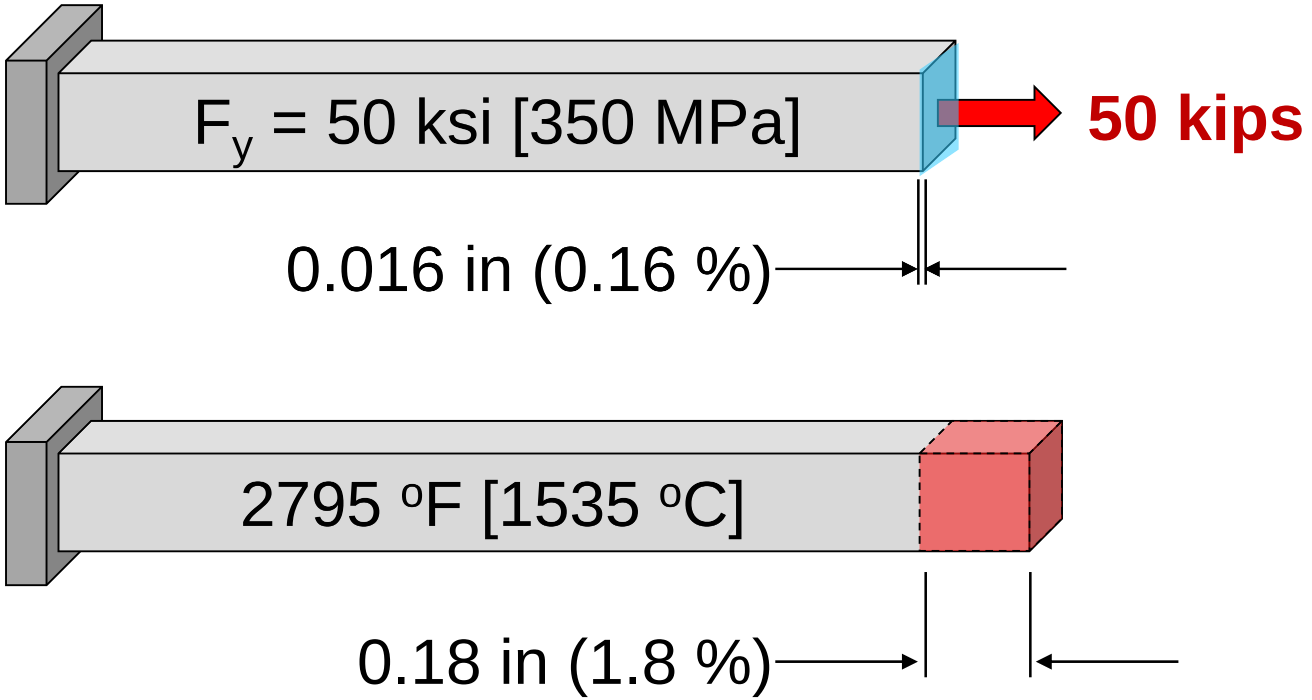
$$\Delta L = \frac{50(10)}{1(30E3)} = 0.016 \text{ in } (0.16\ \%)$$

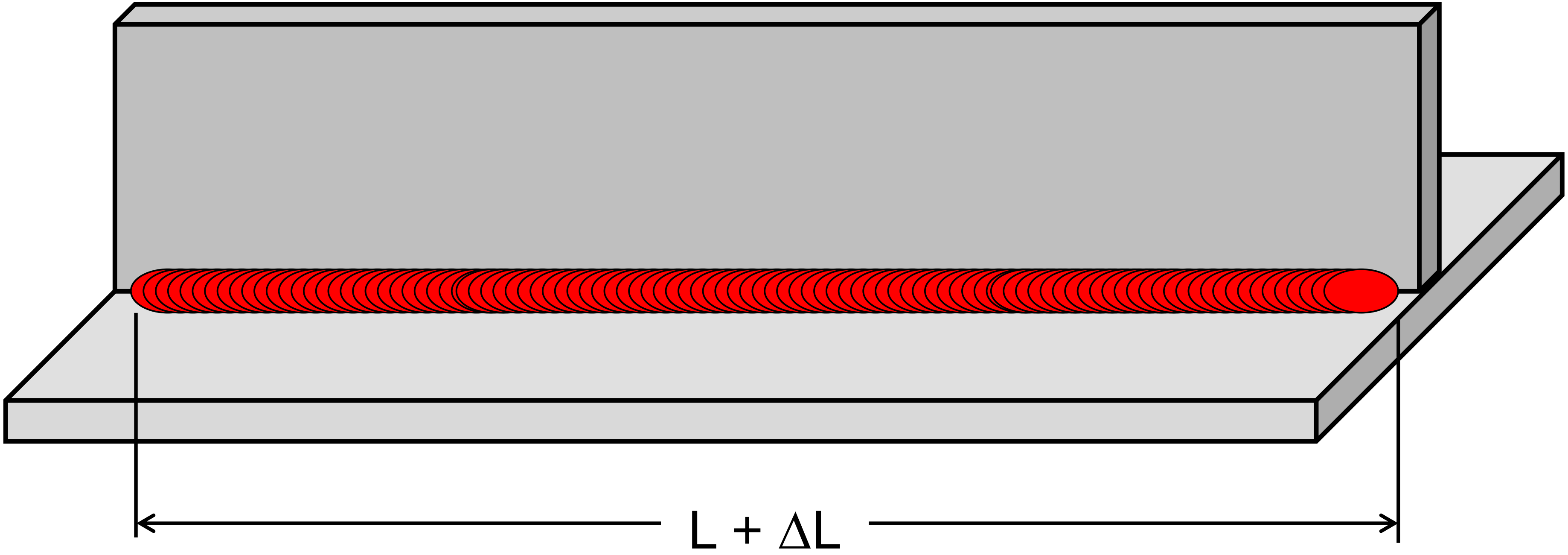


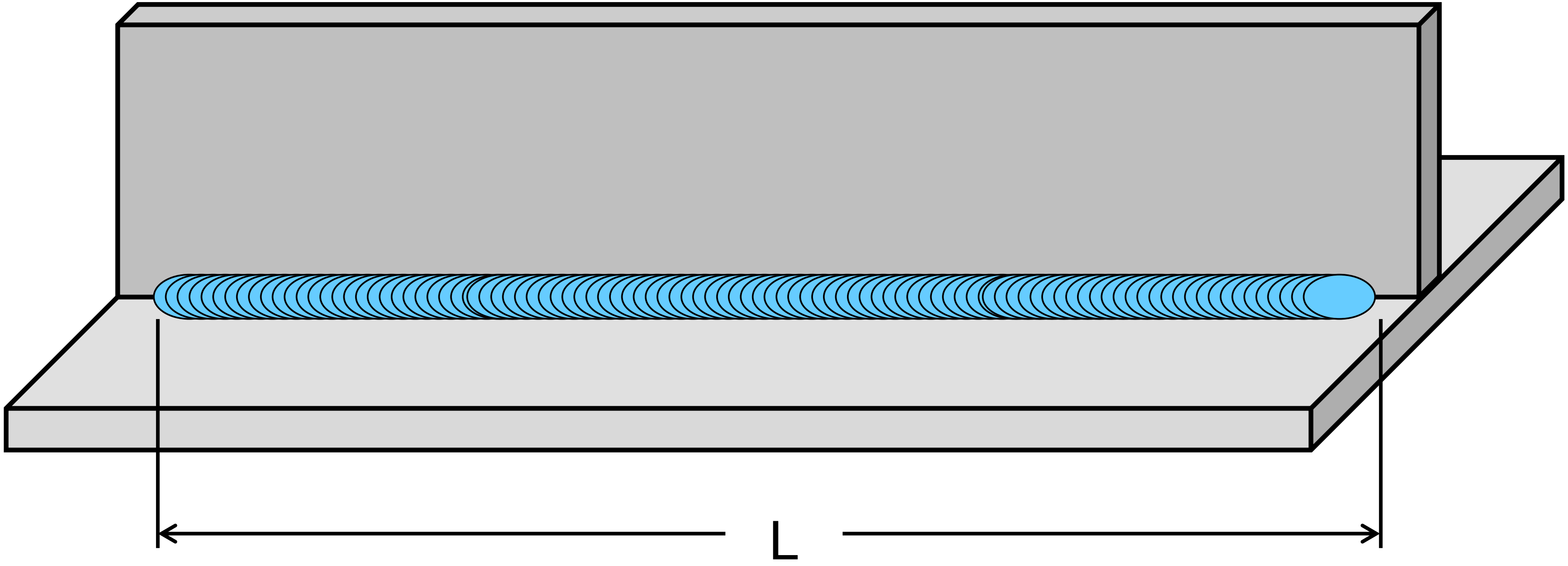
$\Delta L = L(\Delta T)C_{exp}$ $\Delta L = 10(2795 - 70)(6.6E\text{-}6) = 0.18$ in (1.8 %)



Thermal elongation = 10X yield point elongation




L + ΔL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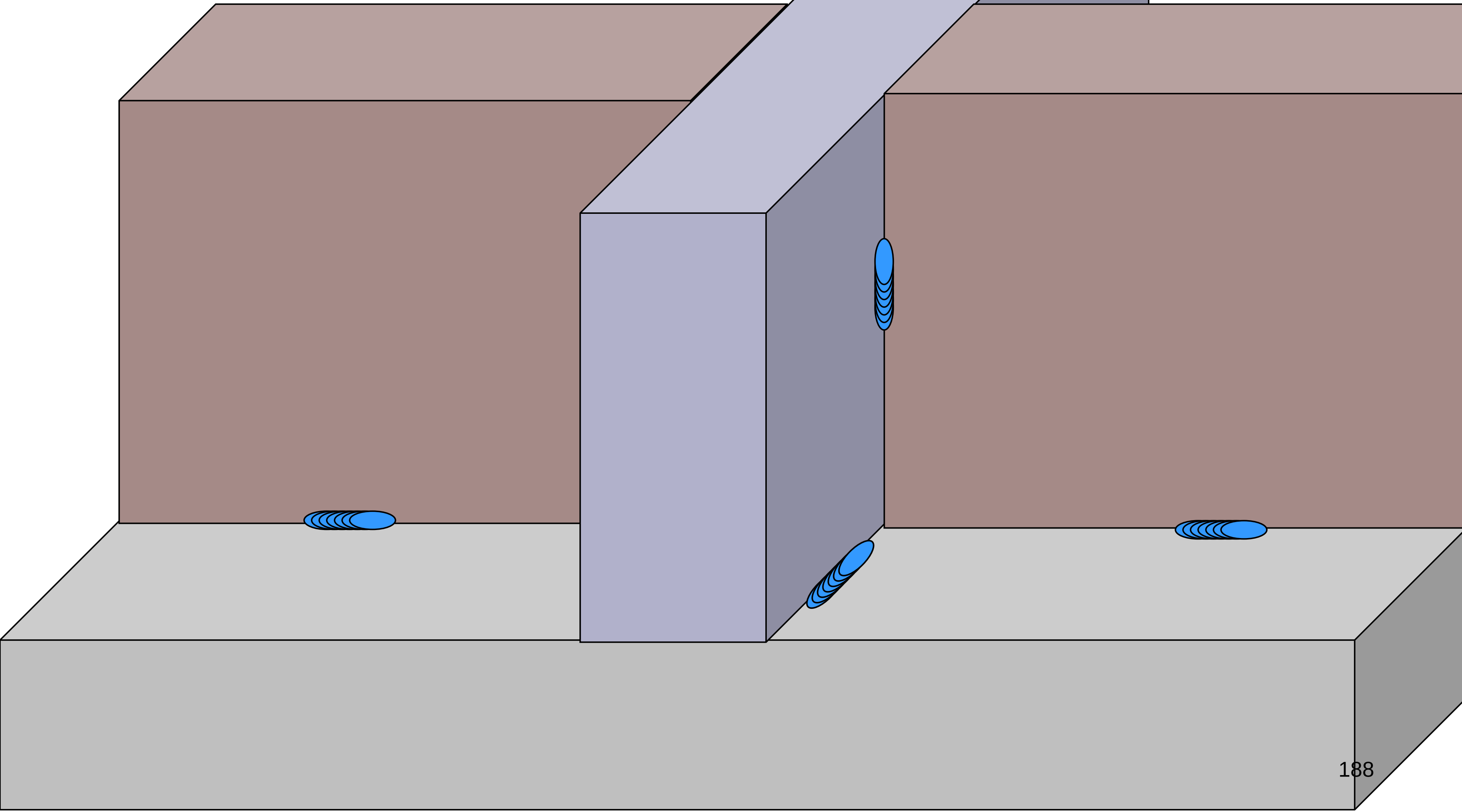

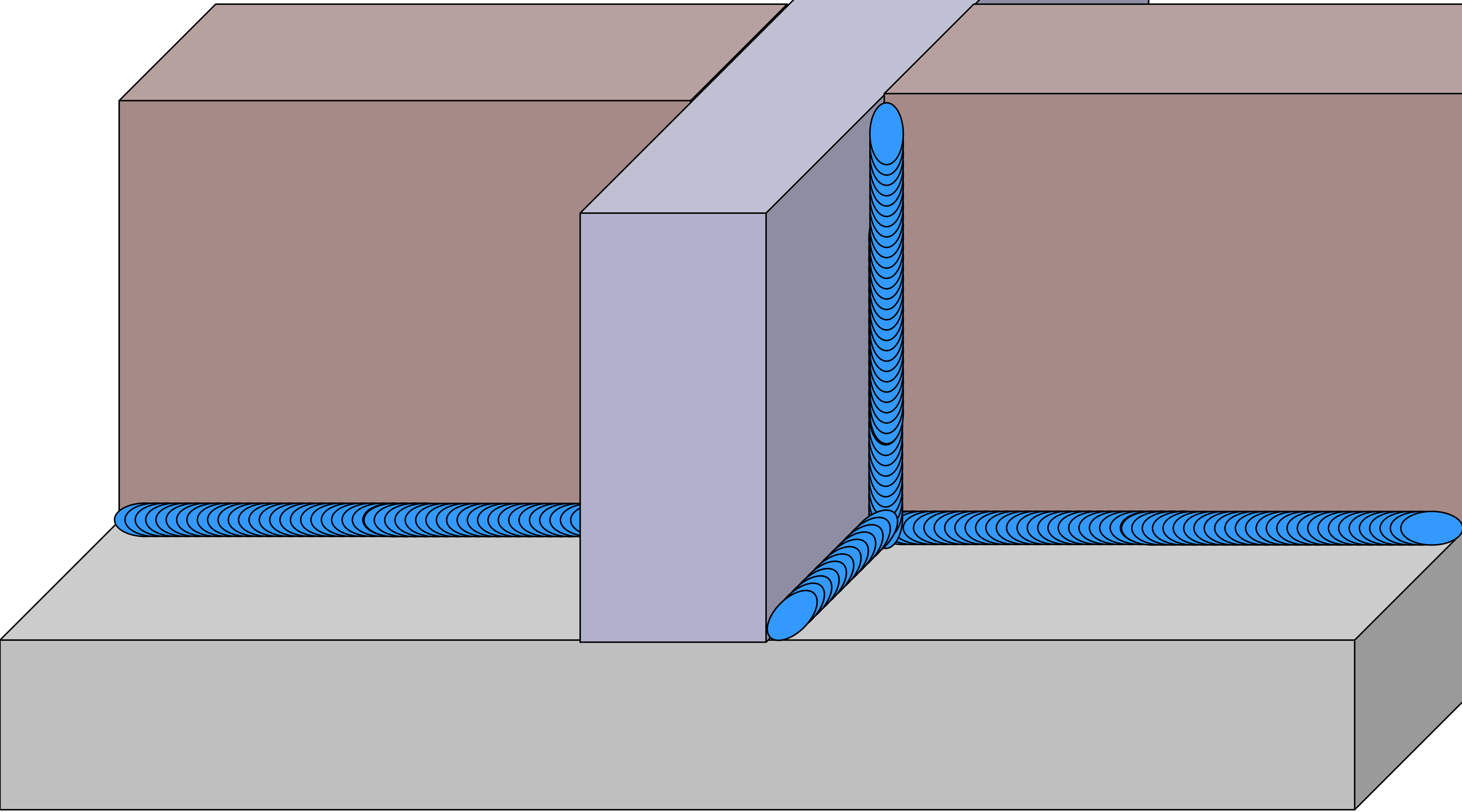

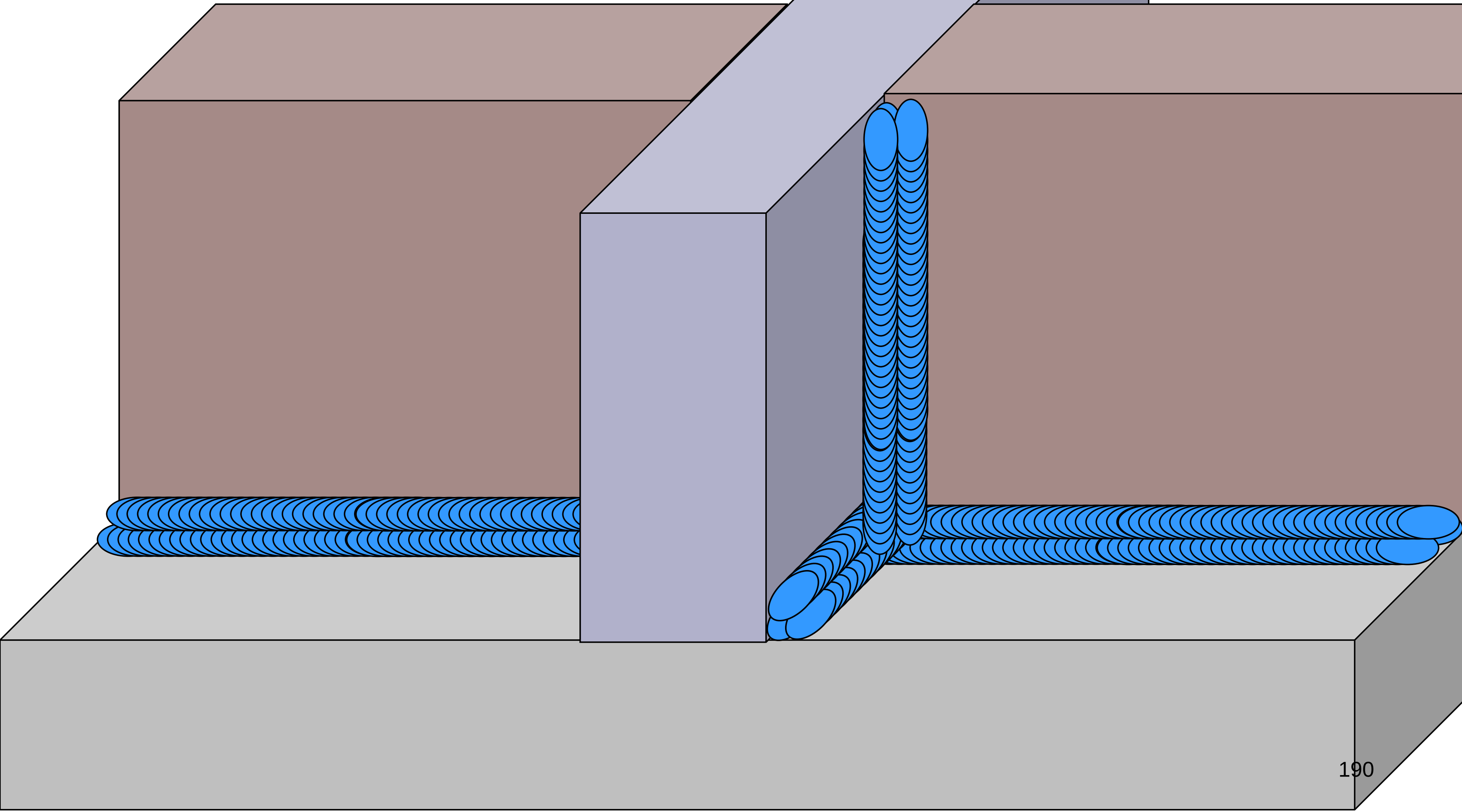

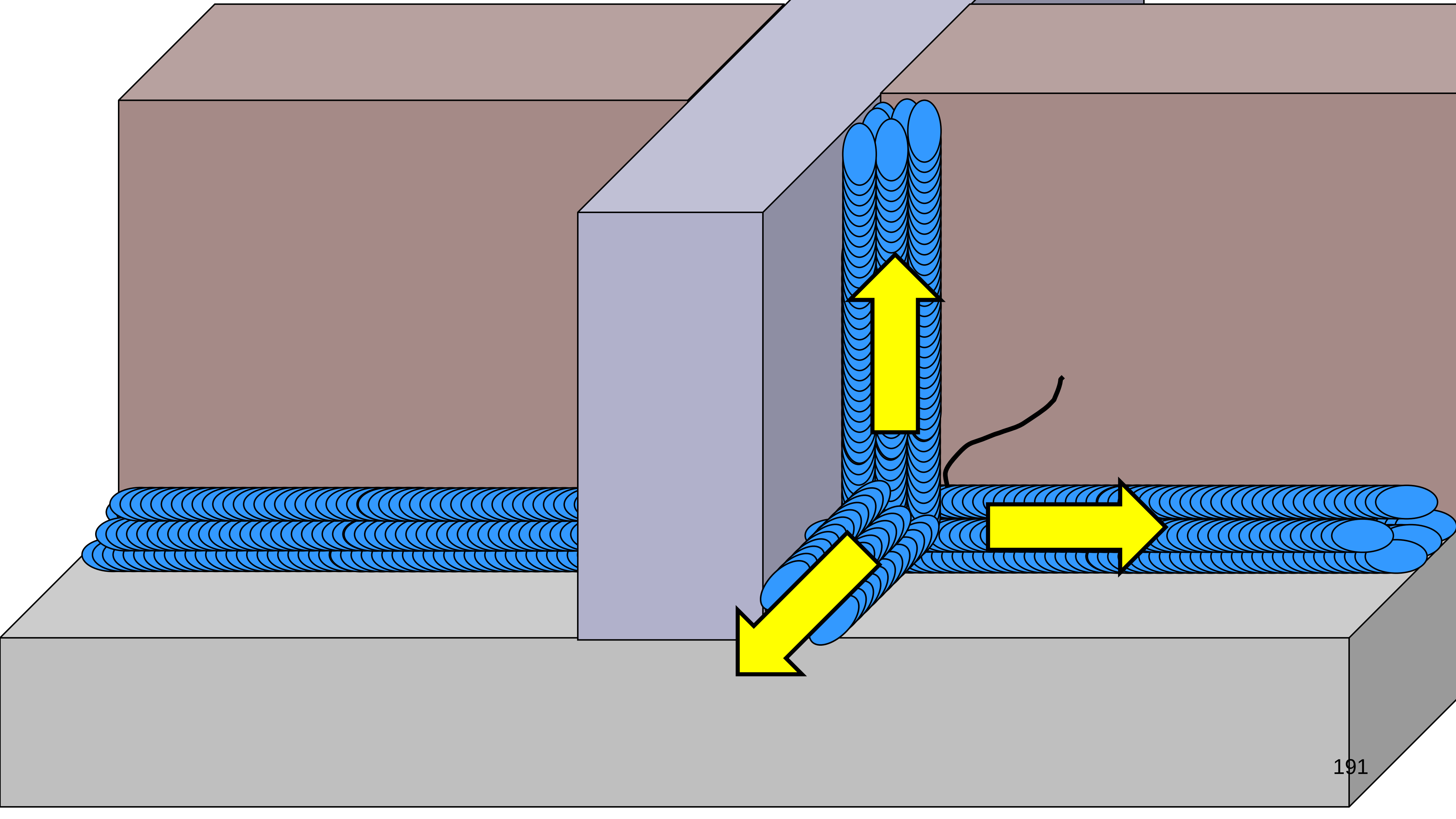

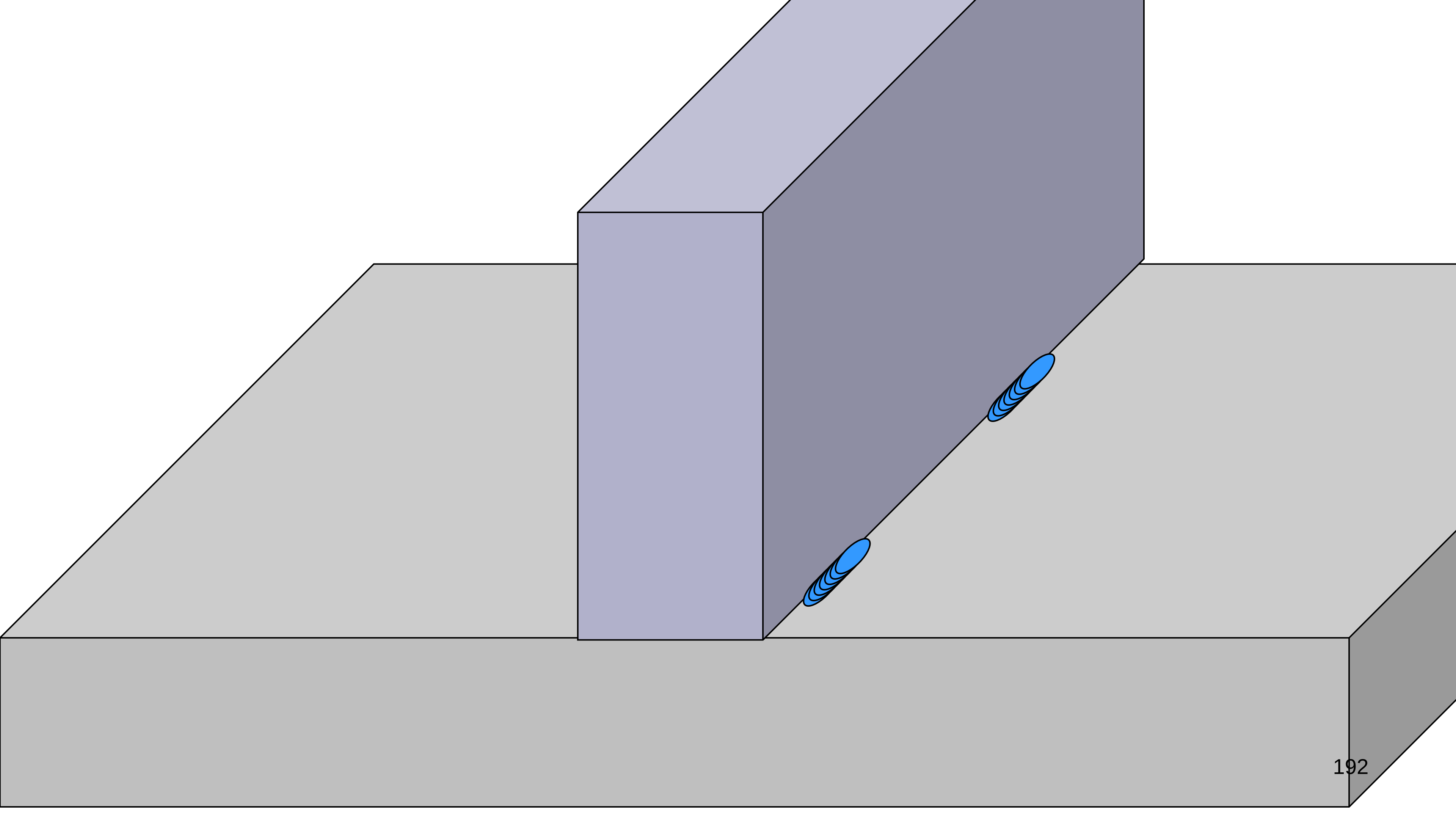

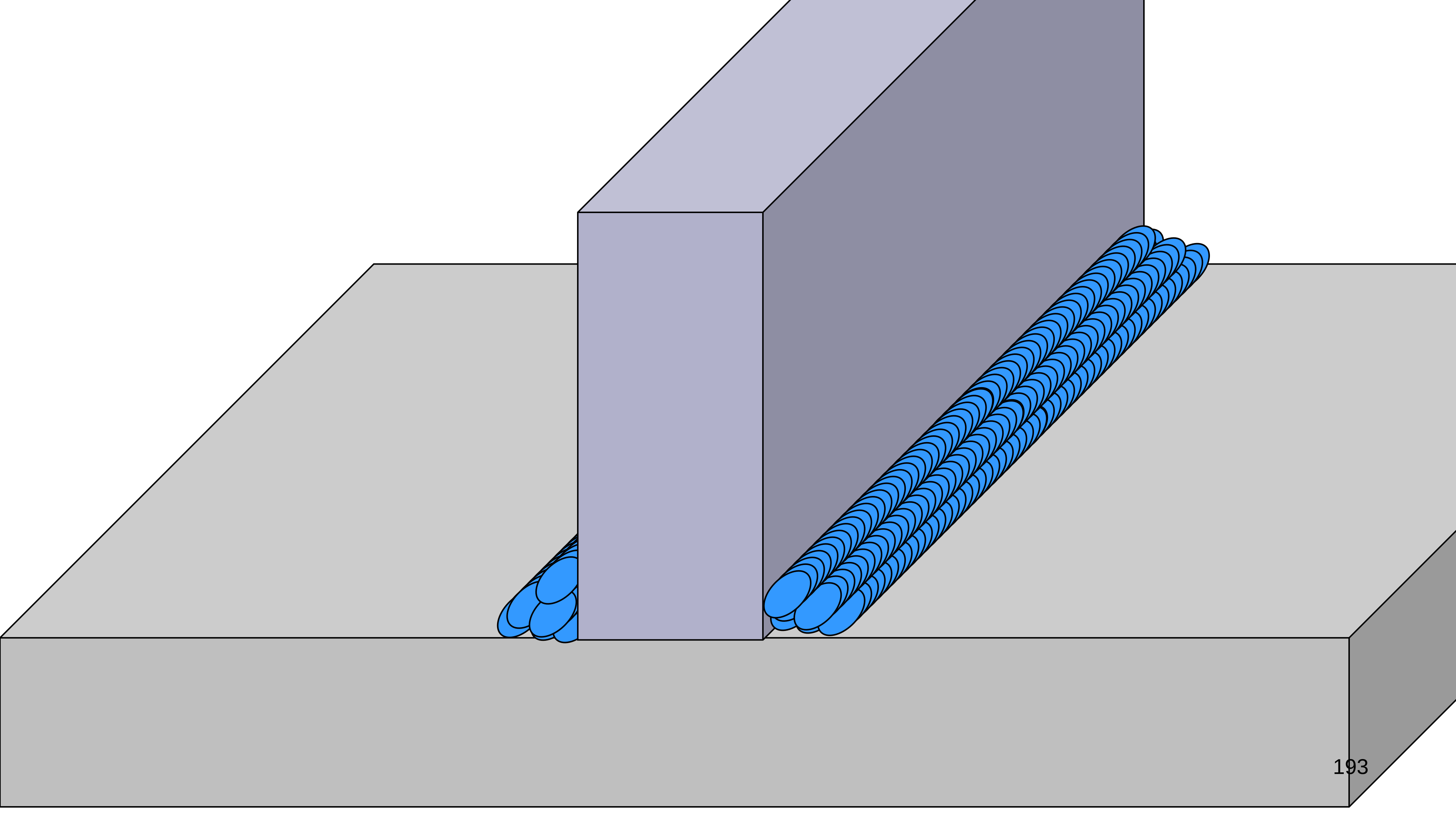

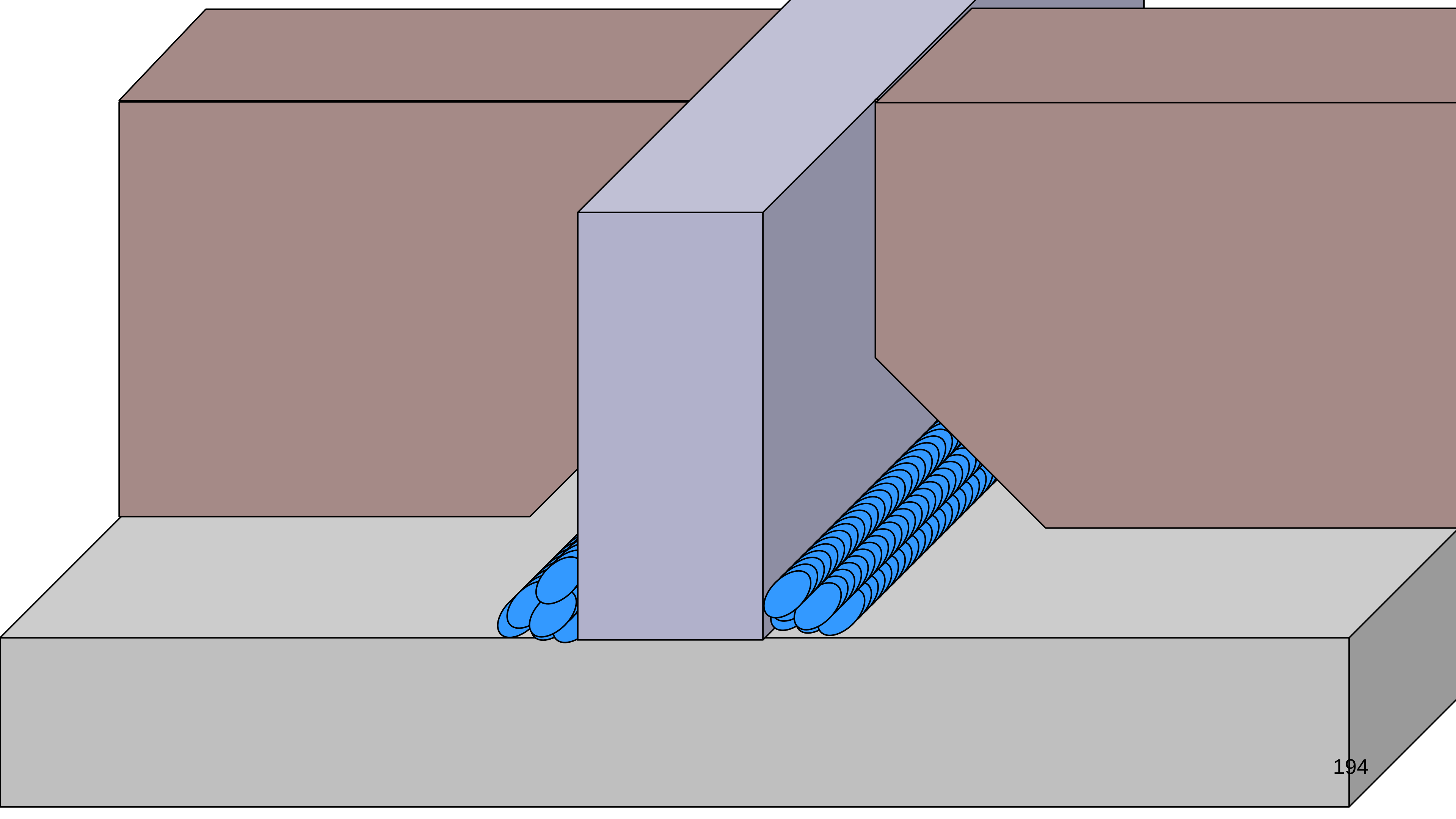

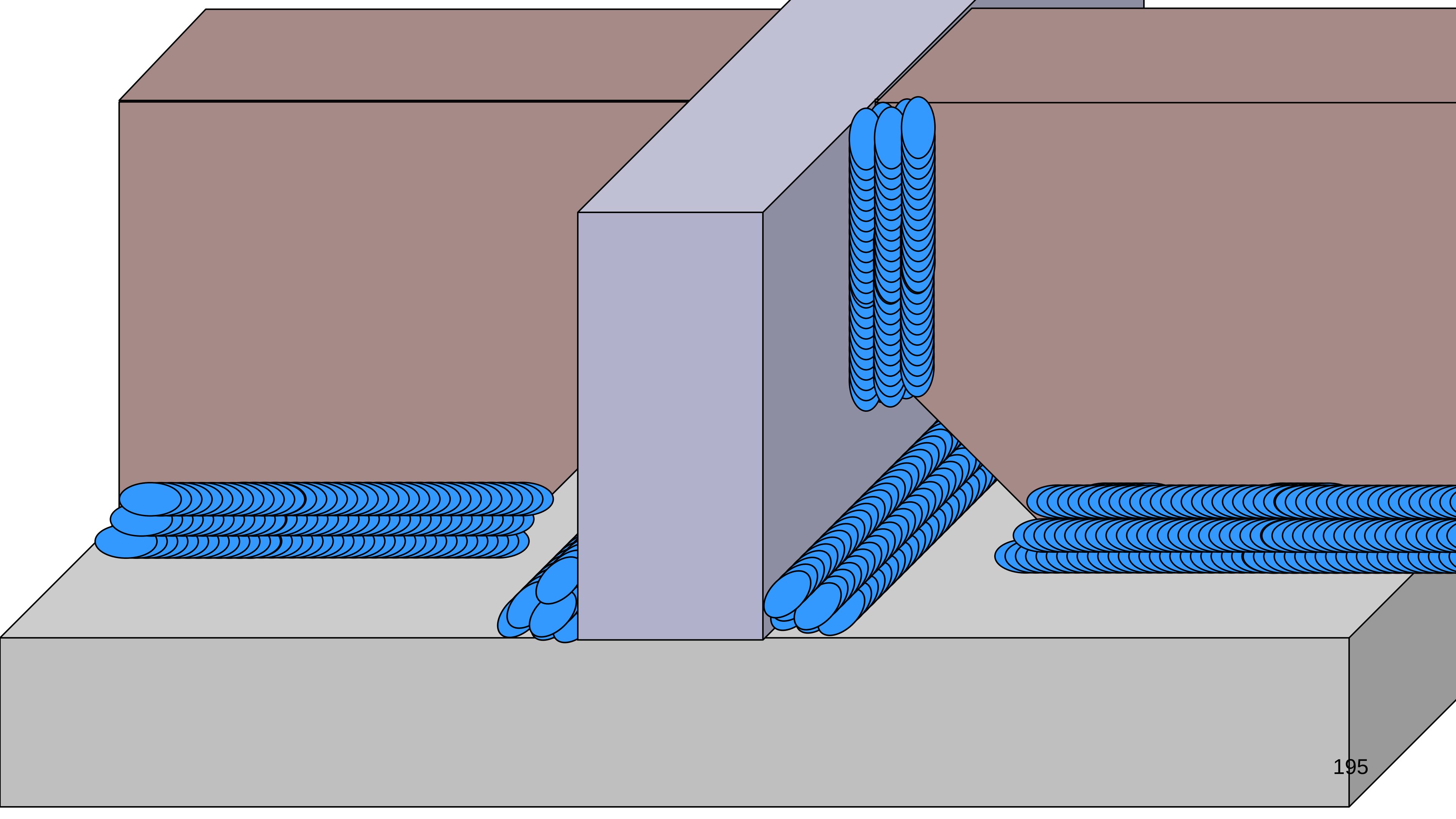
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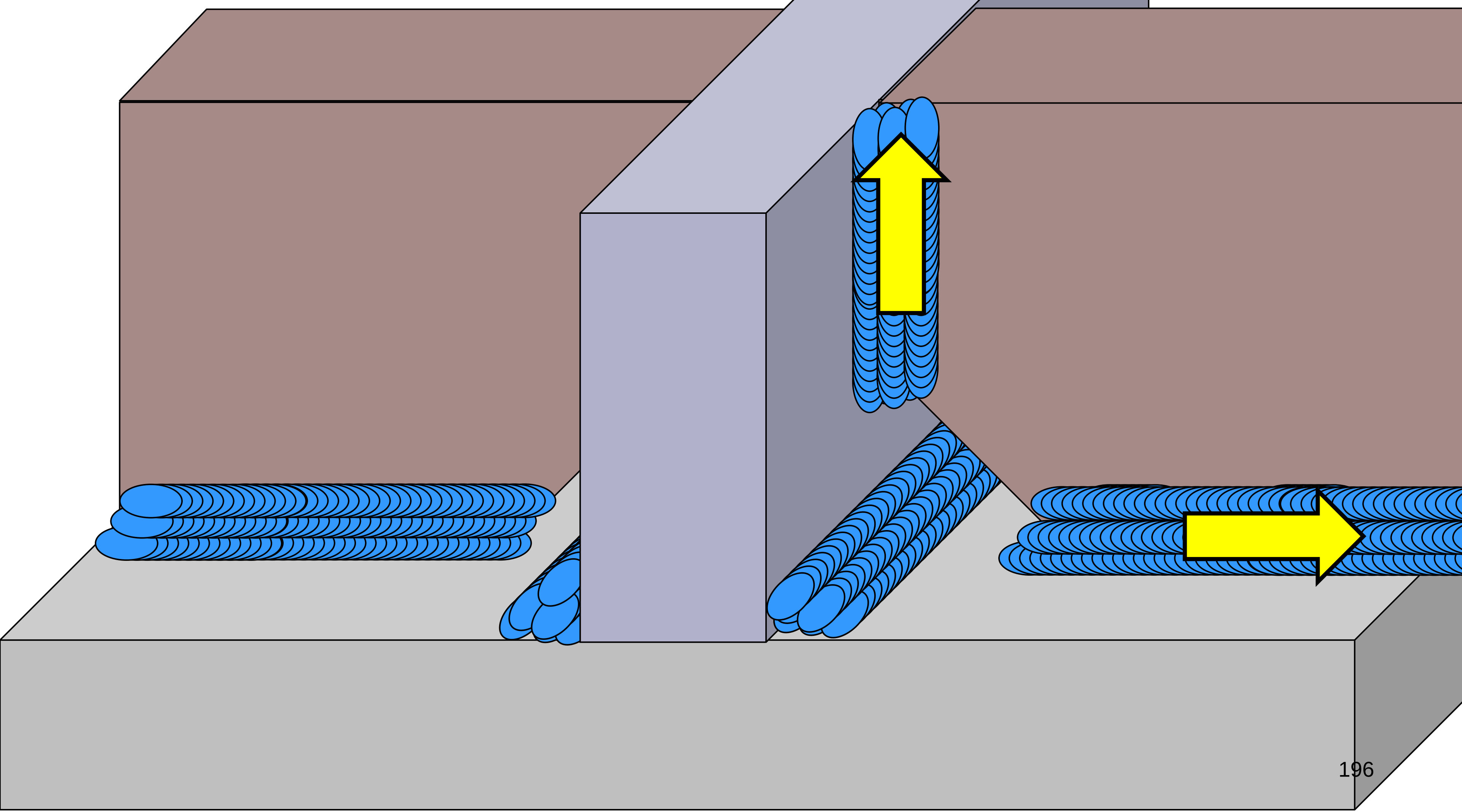


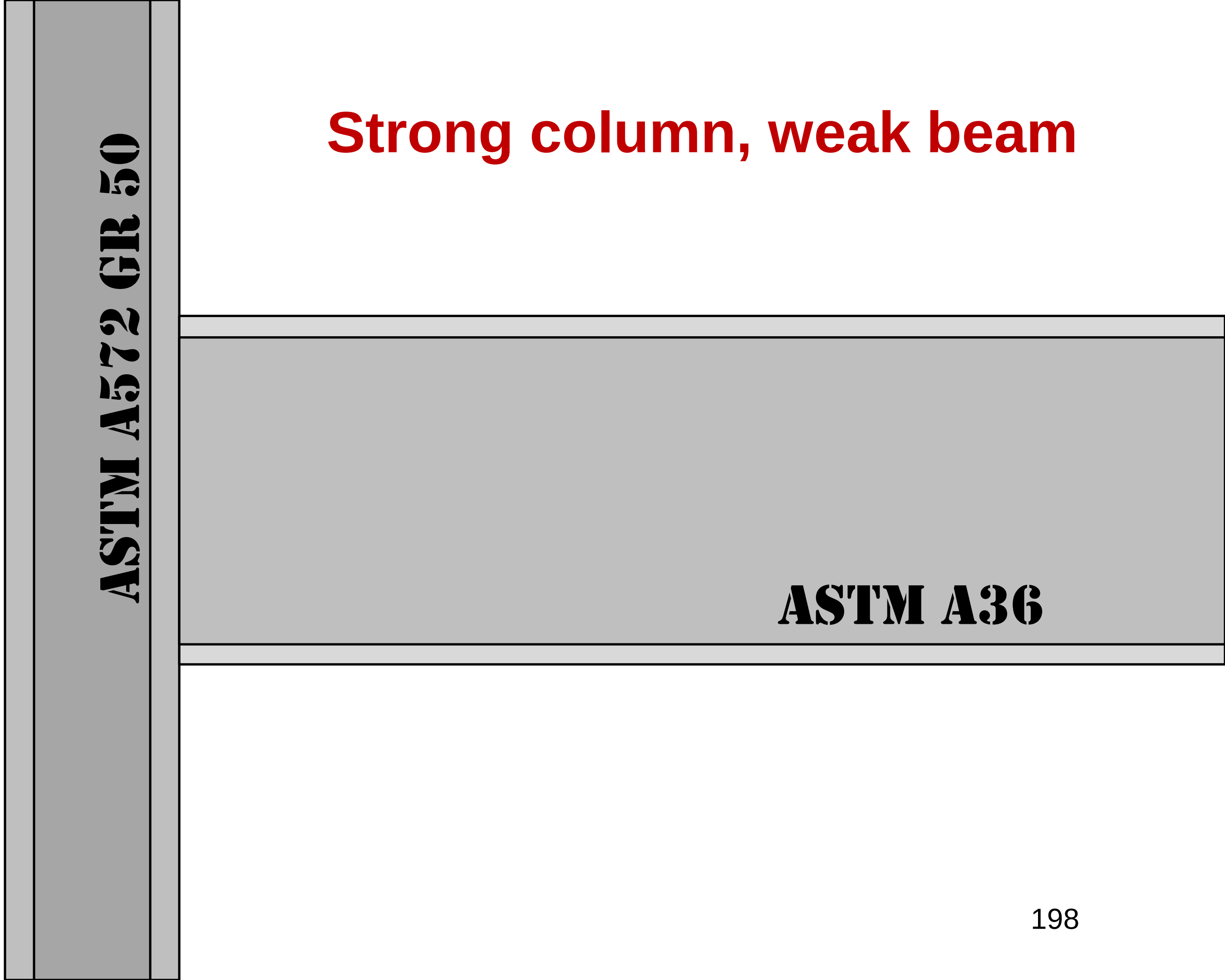
How to Achieve Controlled Inelastic Deformations

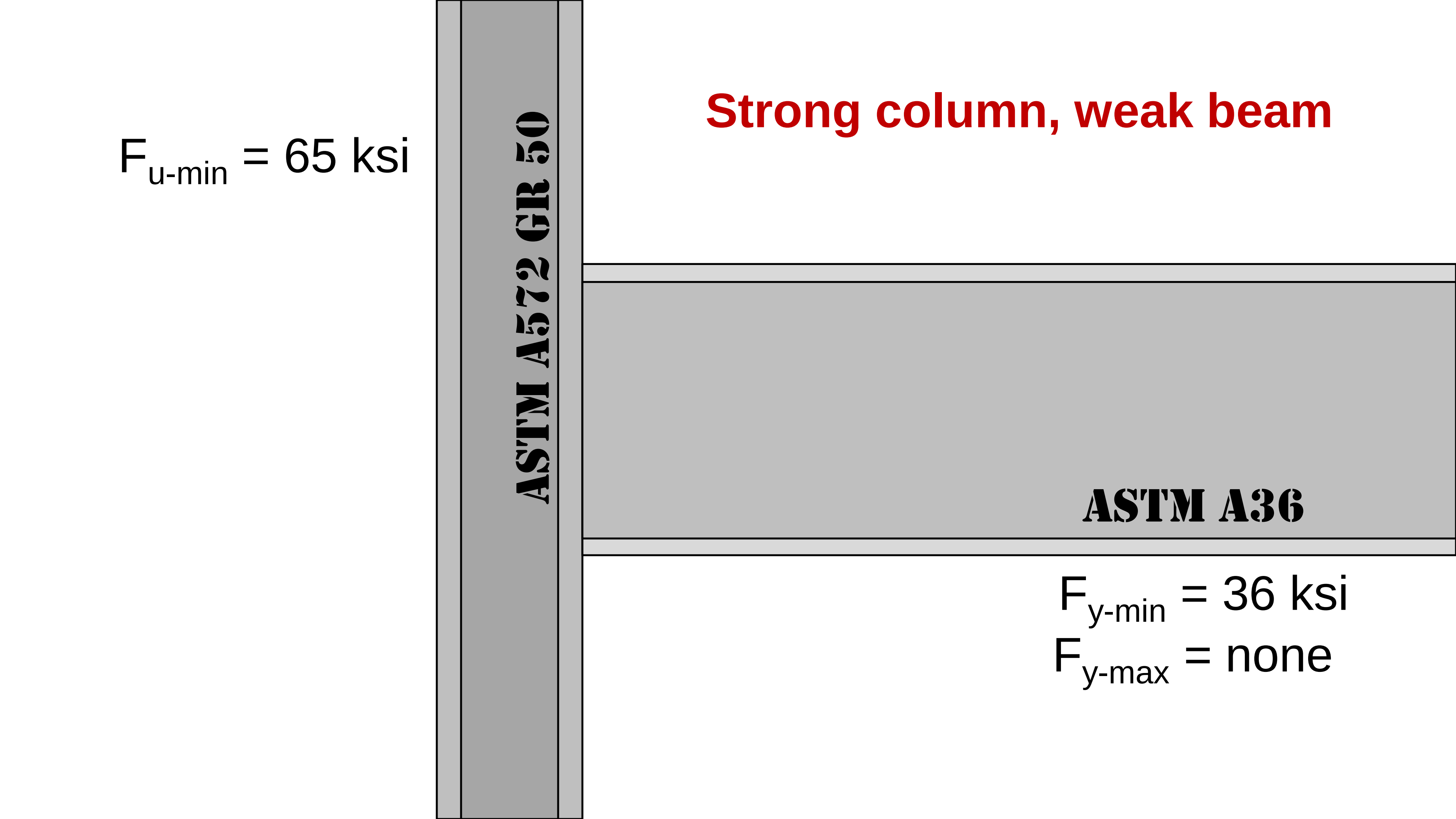
- Select a ductile material
- Avoid conditions that prompt brittle fracture

  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength

Demand > Resistance

Strong column, weak beam



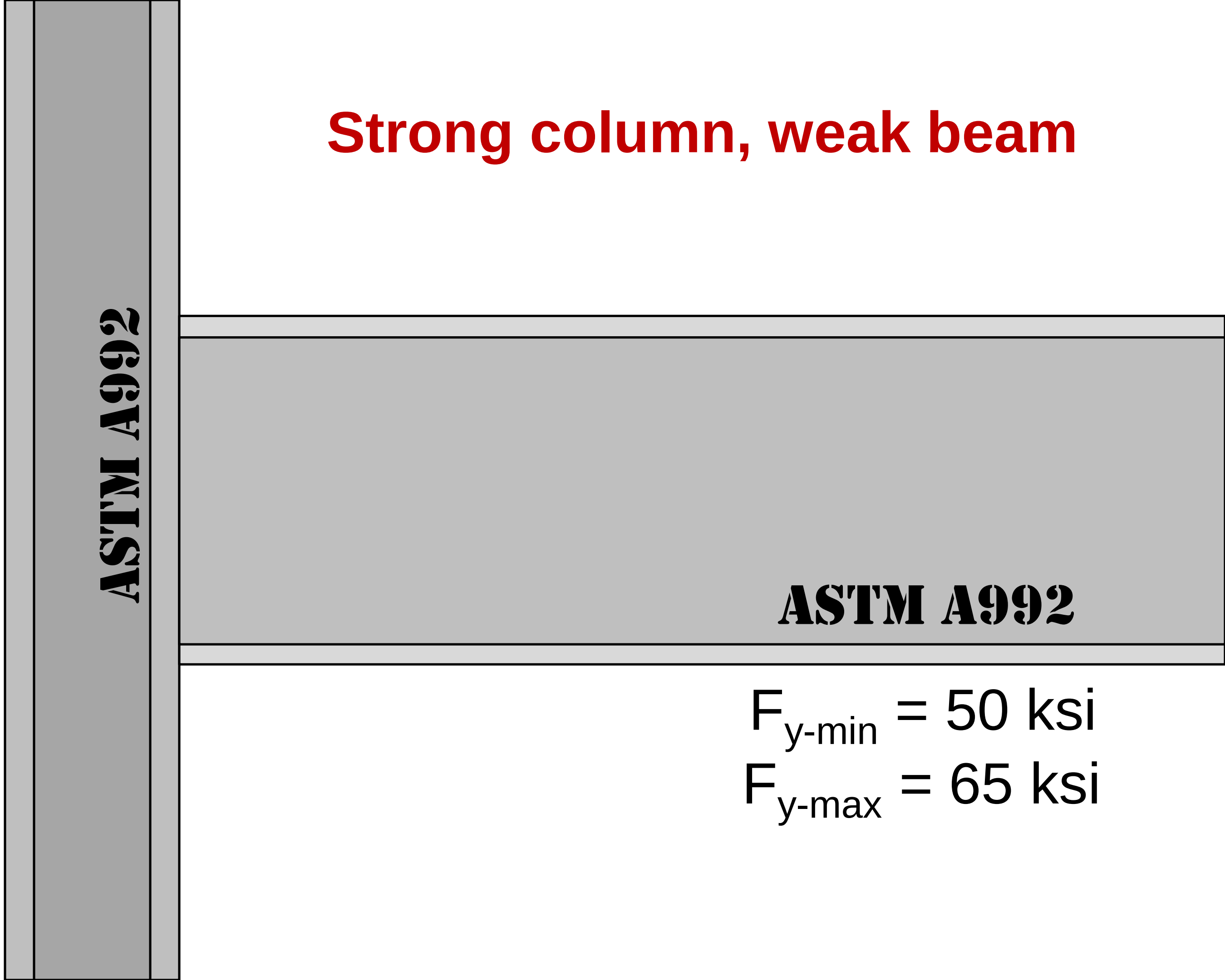


Strong column, weak beam
$F_{u\text{-}min}$ = 65 ksi
ASTM A572 GR 50
ASTM A36
$F_{y\text{-}min}$ = 36 ksi
$F_{y\text{-}max}$ = none

Strong column, weak beam

$F_{u\text{-}min}$ = 65 ksi

F_y/F_u = 0.85 max



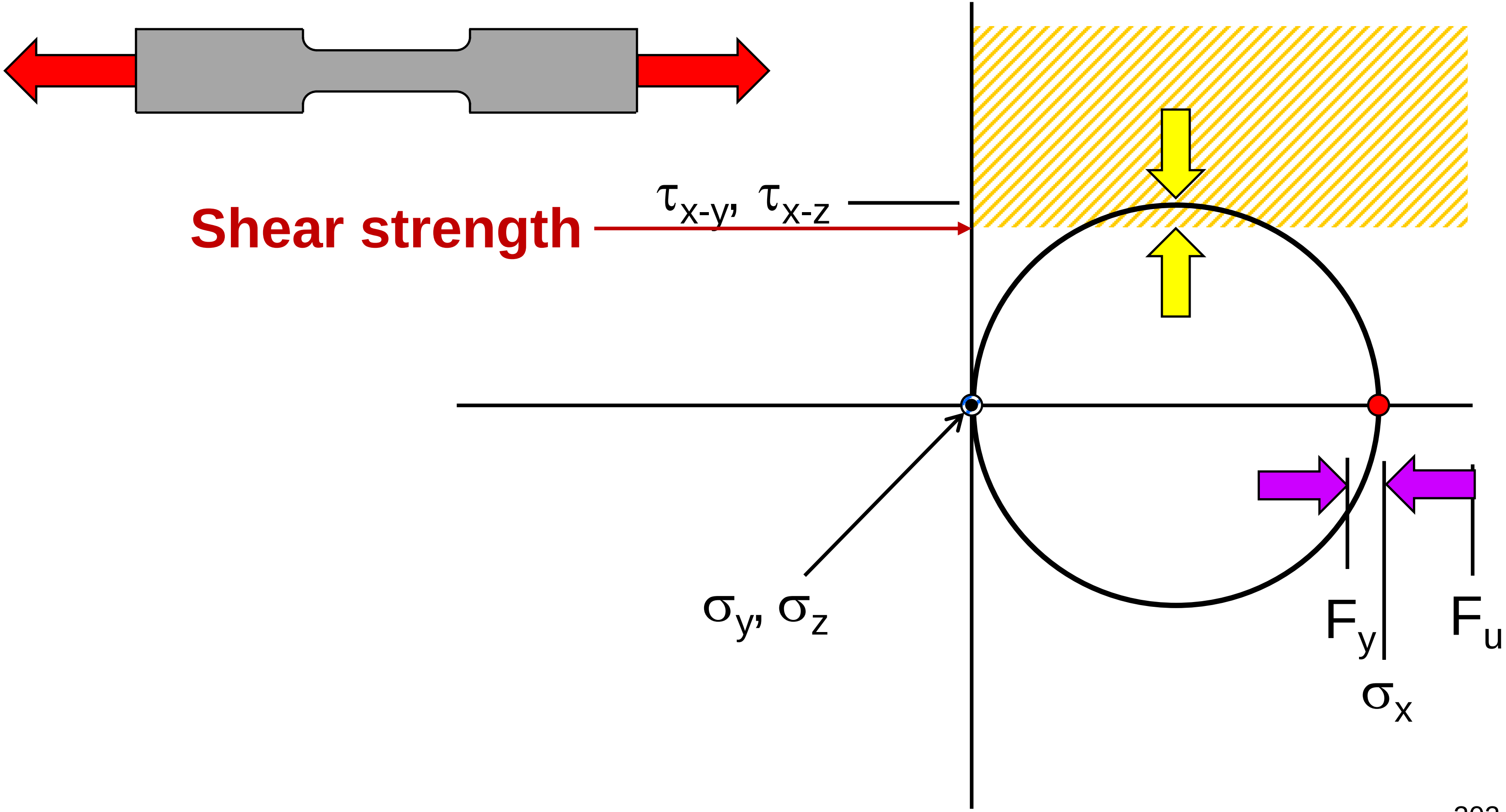
$F_{y\text{-}min}$ = 50 ksi

$F_{y\text{-}max}$ = 65 ksi

How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture

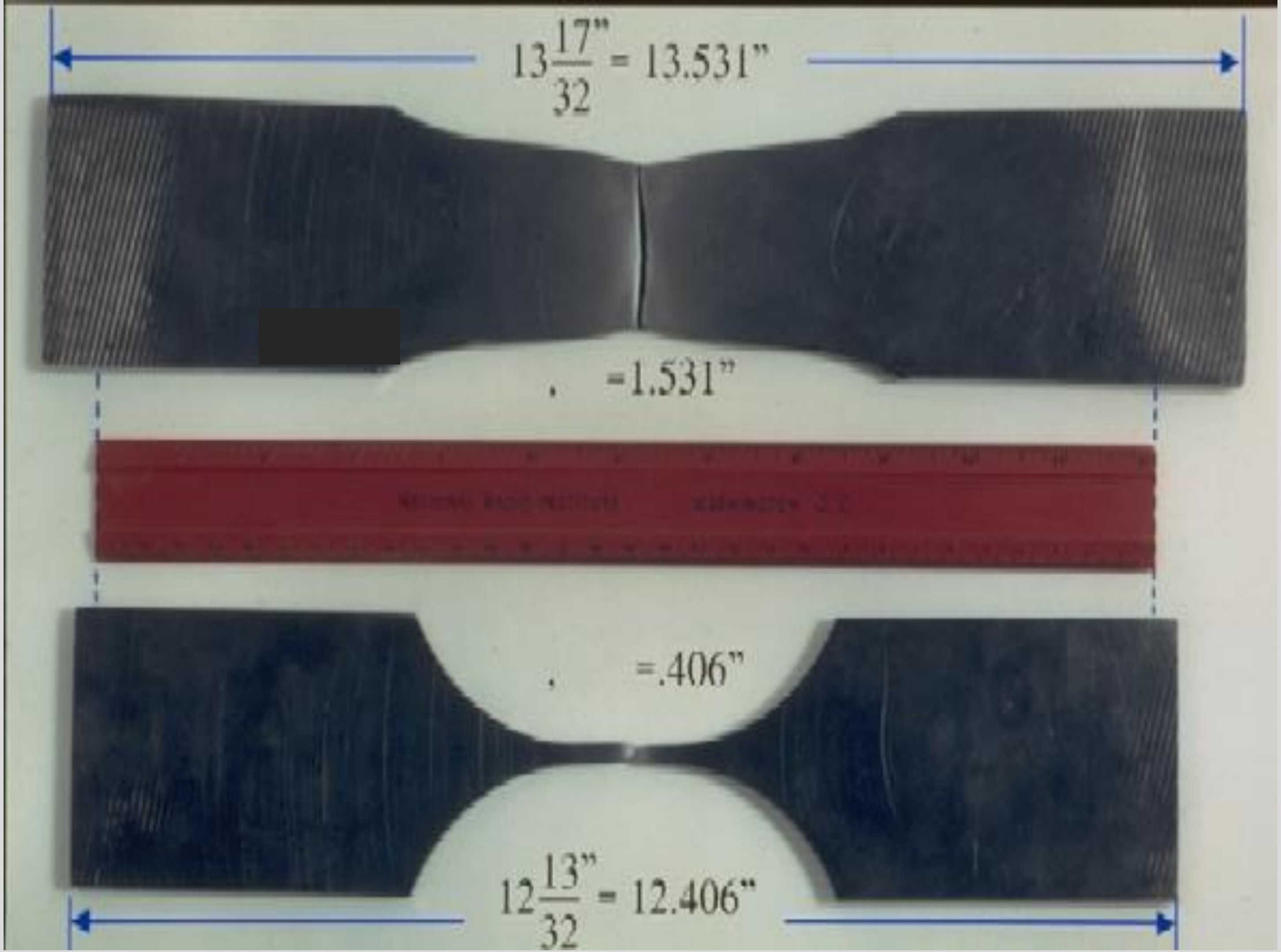
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength

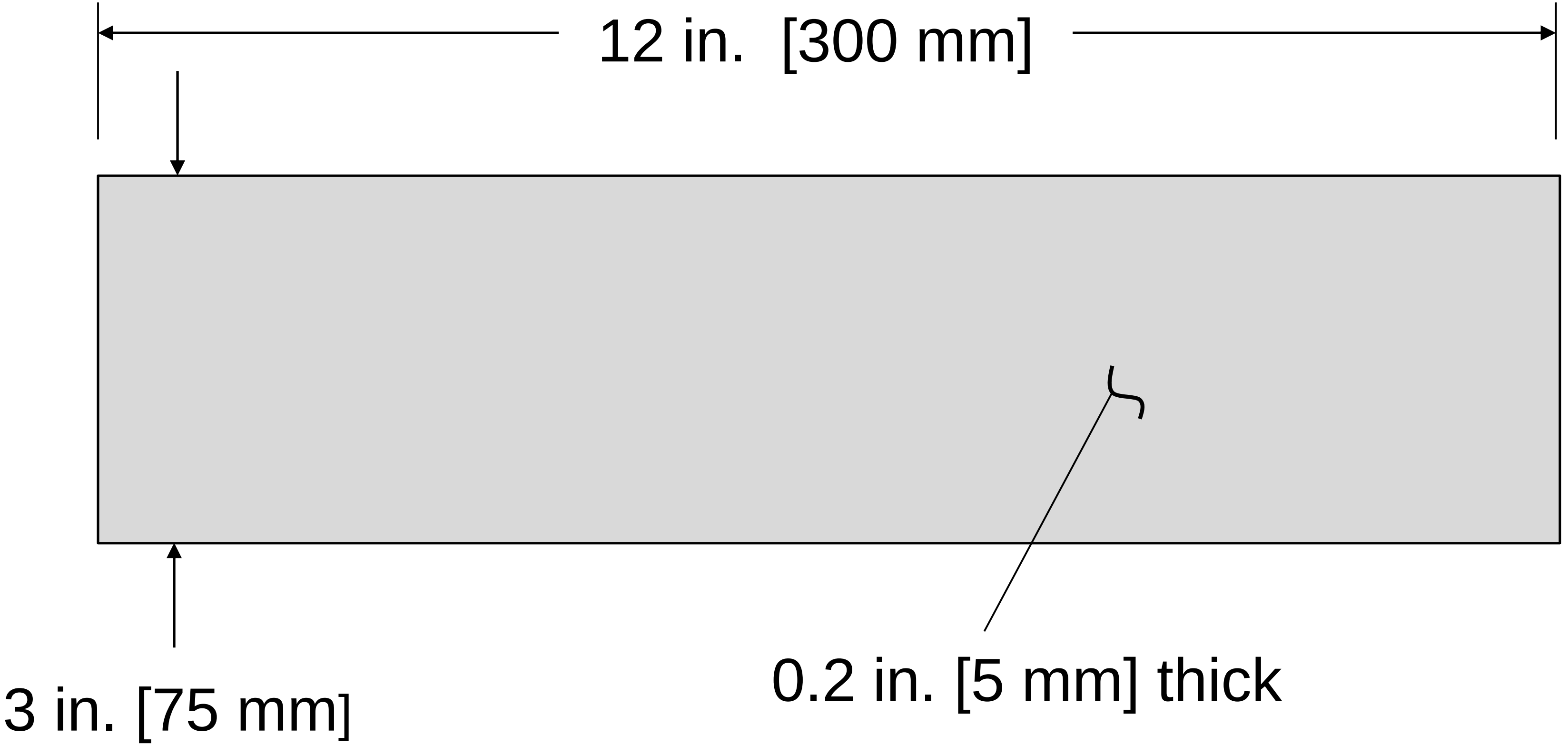

Shear strength
τ_{x-y}, τ_{x-z}
σ_y, σ_z
F_y
F_u
σ_x

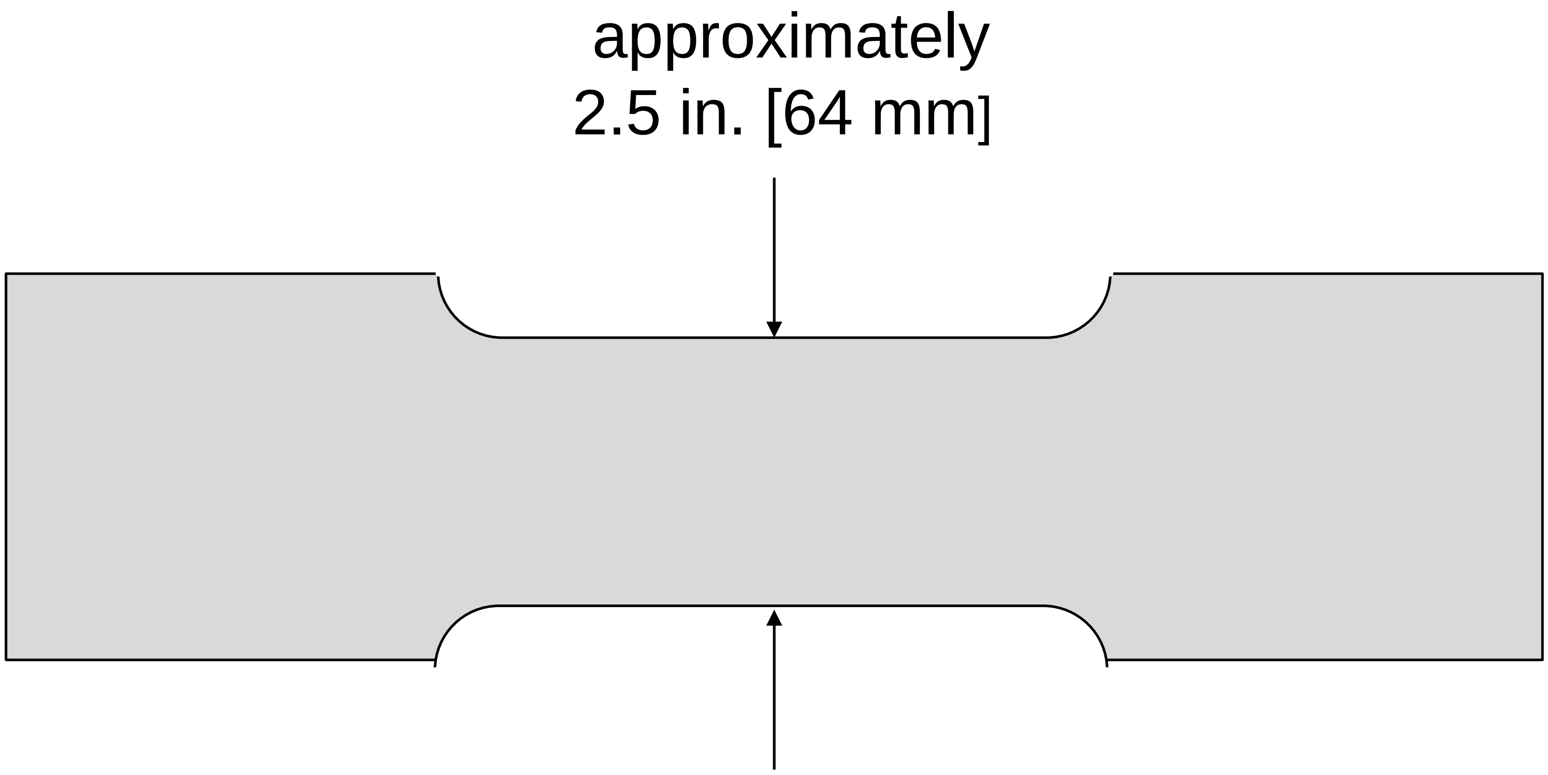
How to Achieve Controlled Inelastic Deformations

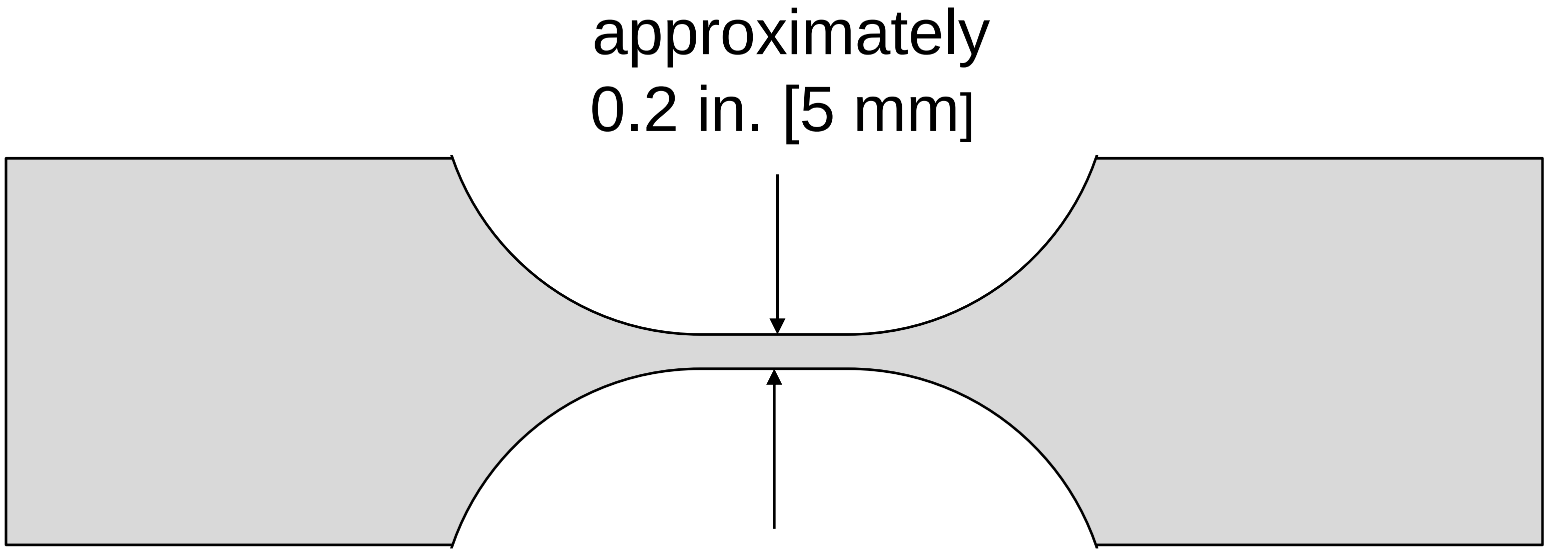
- Select a ductile material
- Avoid conditions that prompt brittle fracture

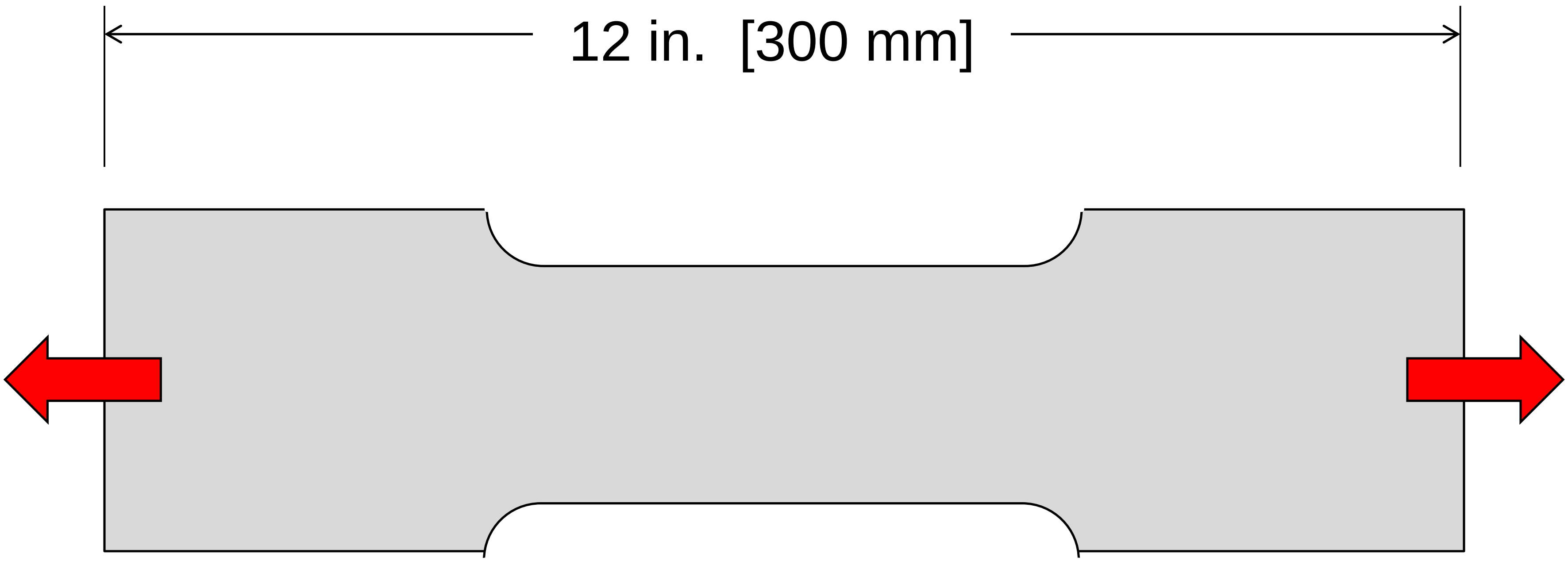
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength
- Ensure enough material is present to create meaningful displacements

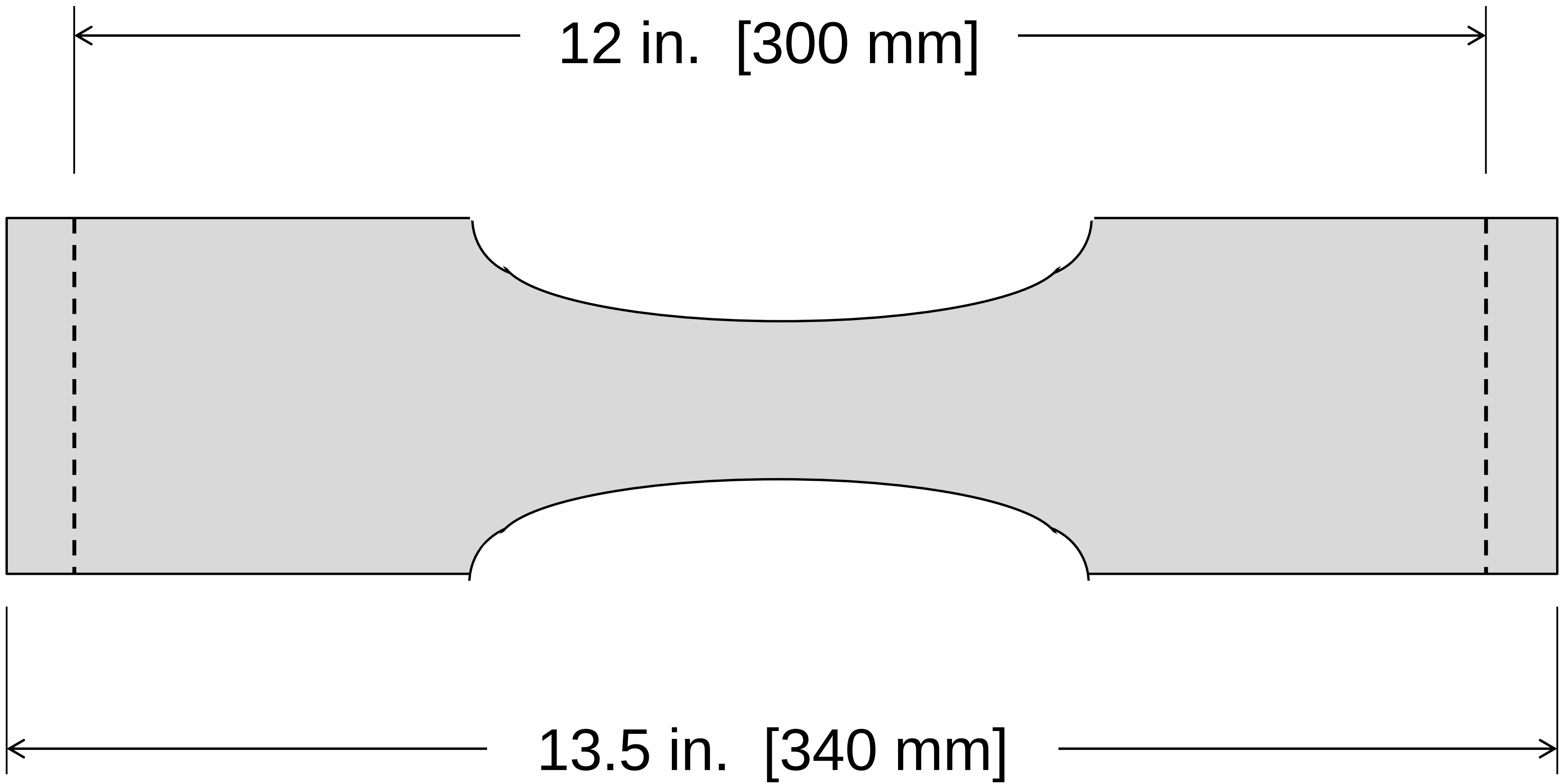

13 17"/32 = 13.531"
[redacted]
=1.531"
=.406"
12 13"/32 = 12.406"

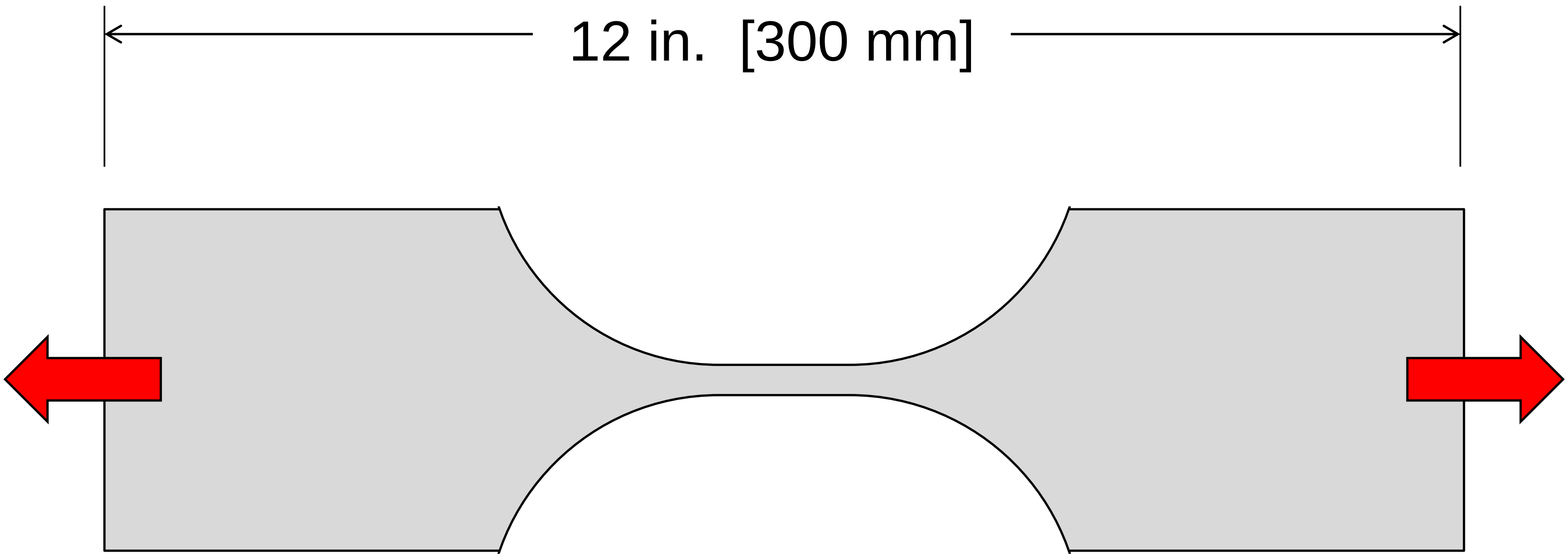

12 in. [300 mm]
3 in. [75 mm]
0.2 in. [5 mm] thick

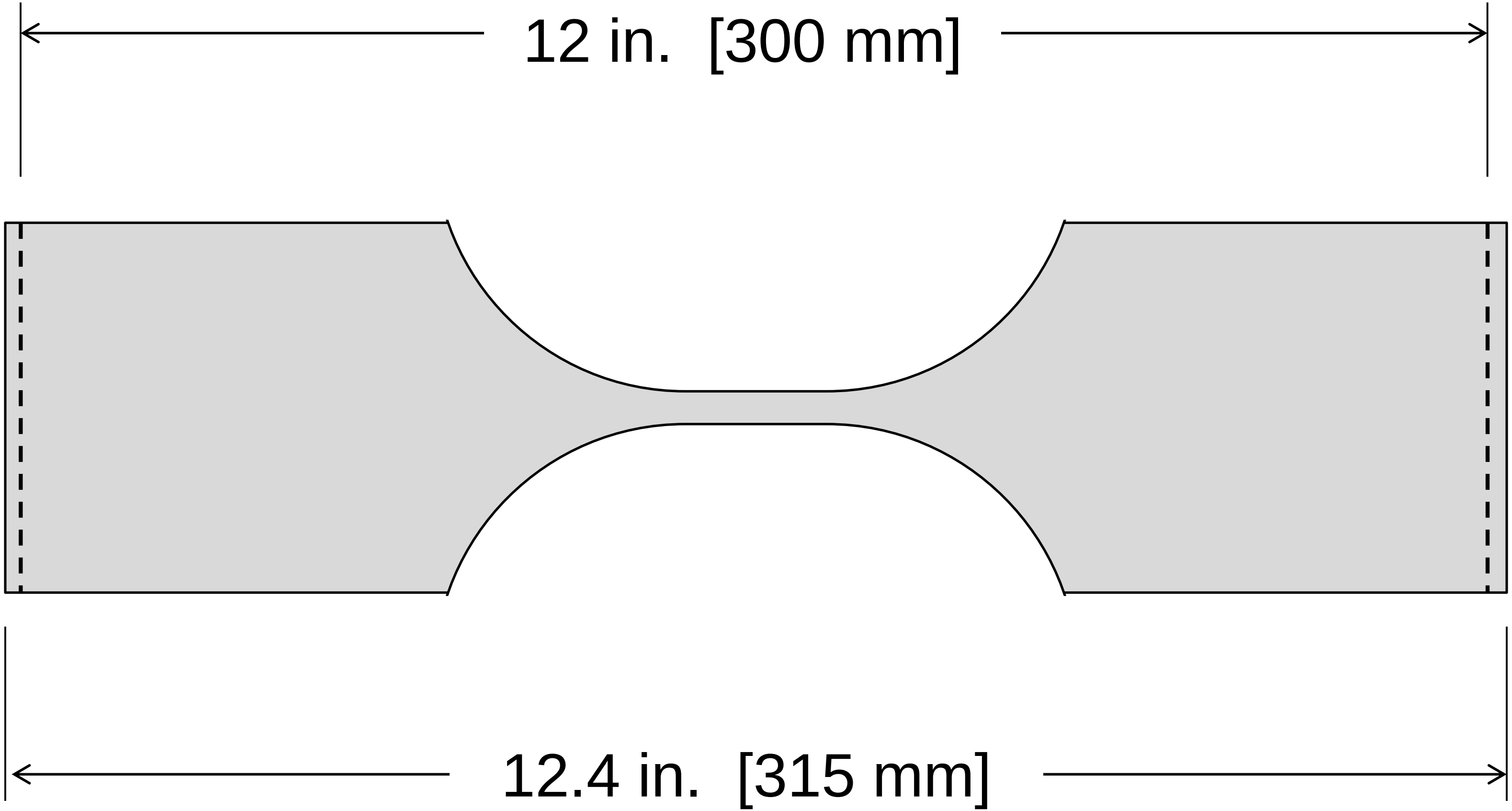

approximately
2.5 in. [64 mm]

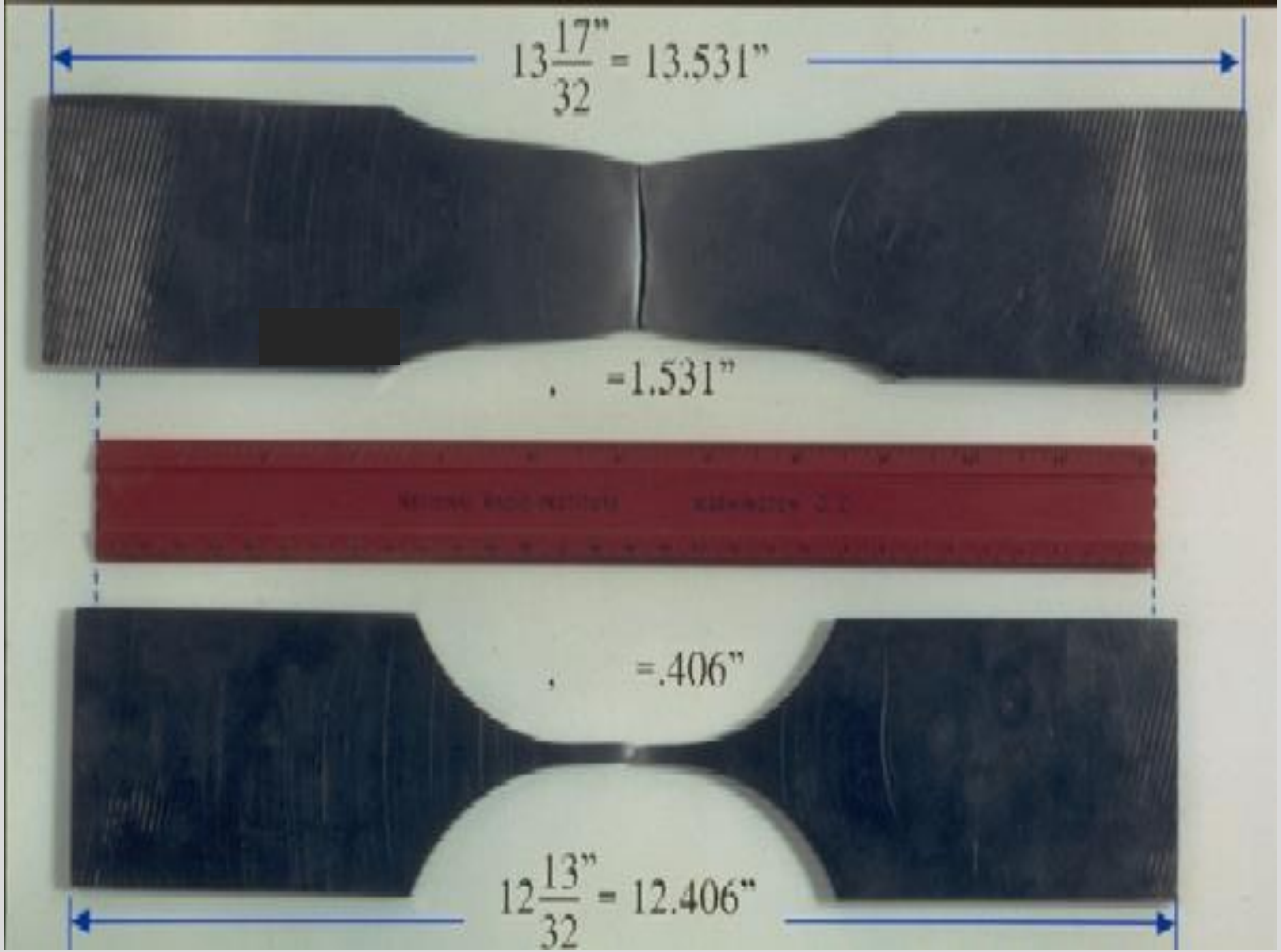

approximately
0.2 in. [5 mm]

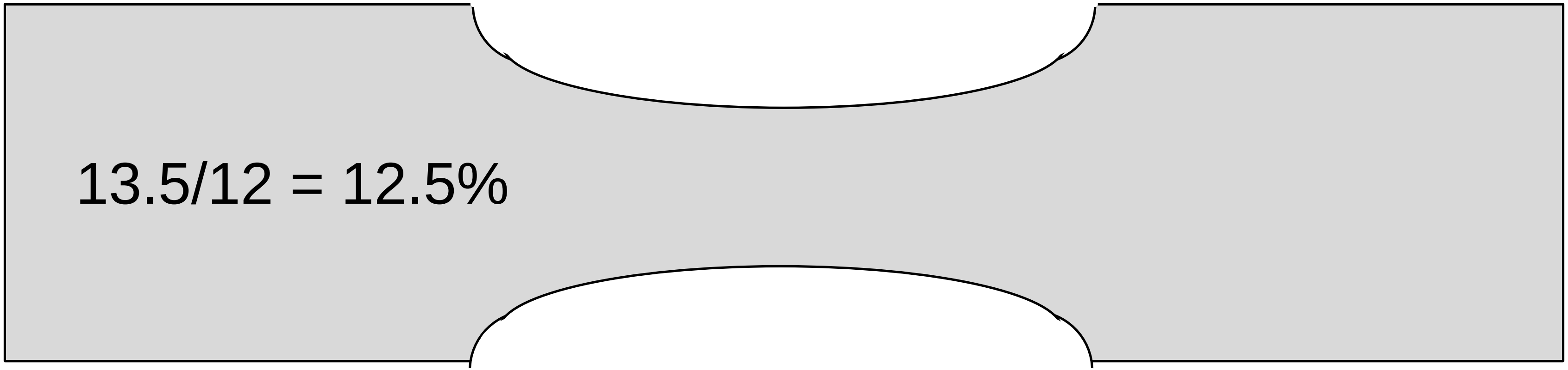

12 in. [300 mm]

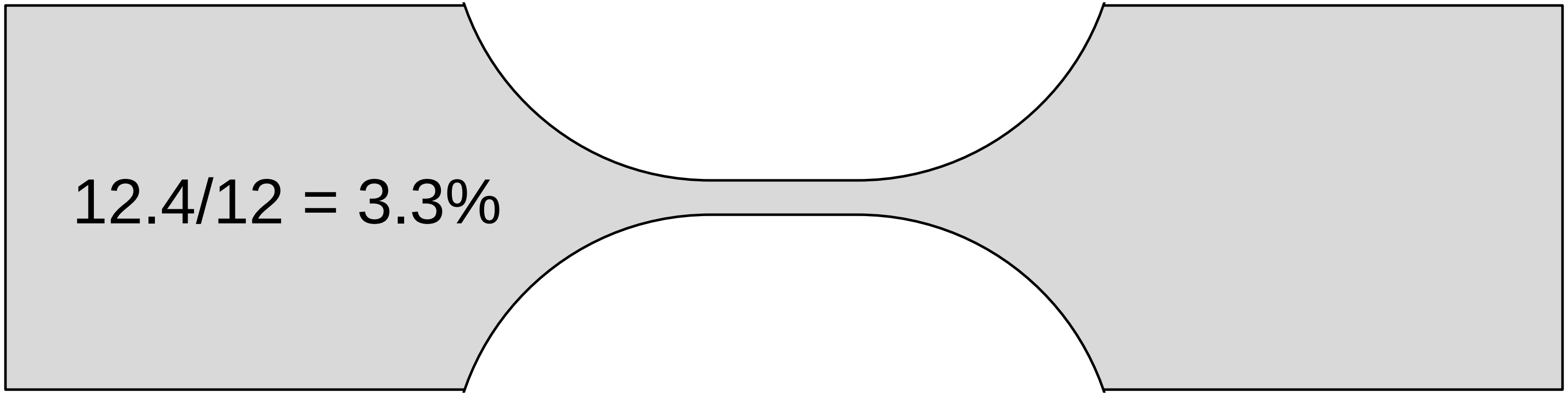

12 in. [300 mm]
13.5 in. [340 mm]


12 in. [300 mm]

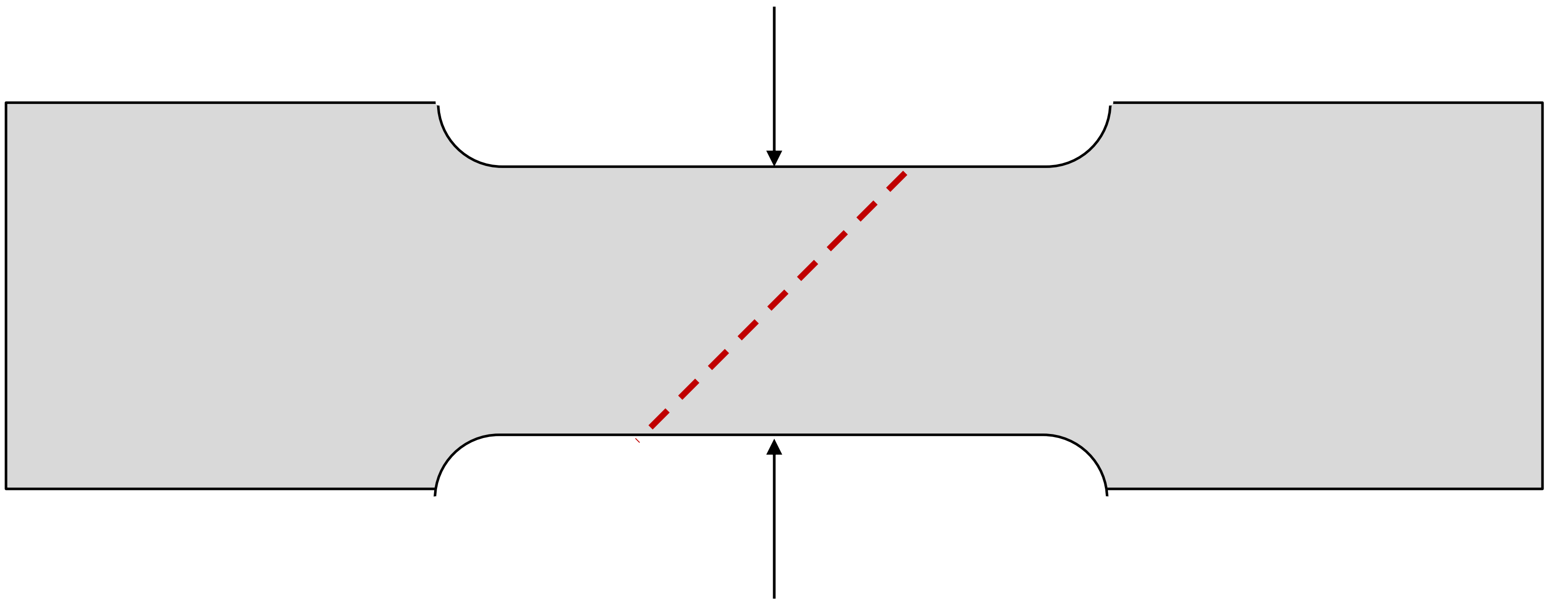

12 in. [300 mm]
12.4 in. [315 mm]

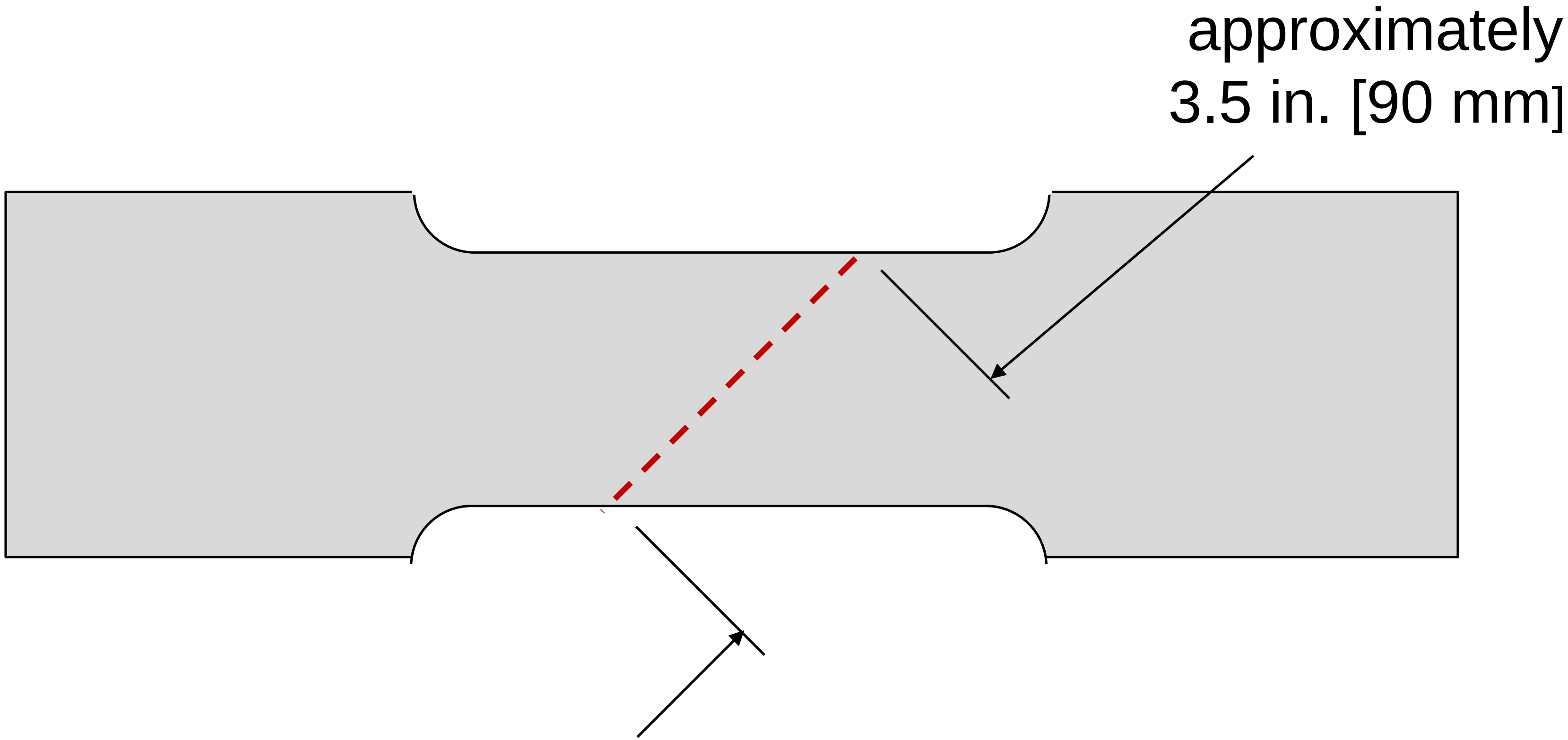

13 17/32" = 13.531"
[redacted]
=1.531"
=.406"
12 13/32" = 12.406"

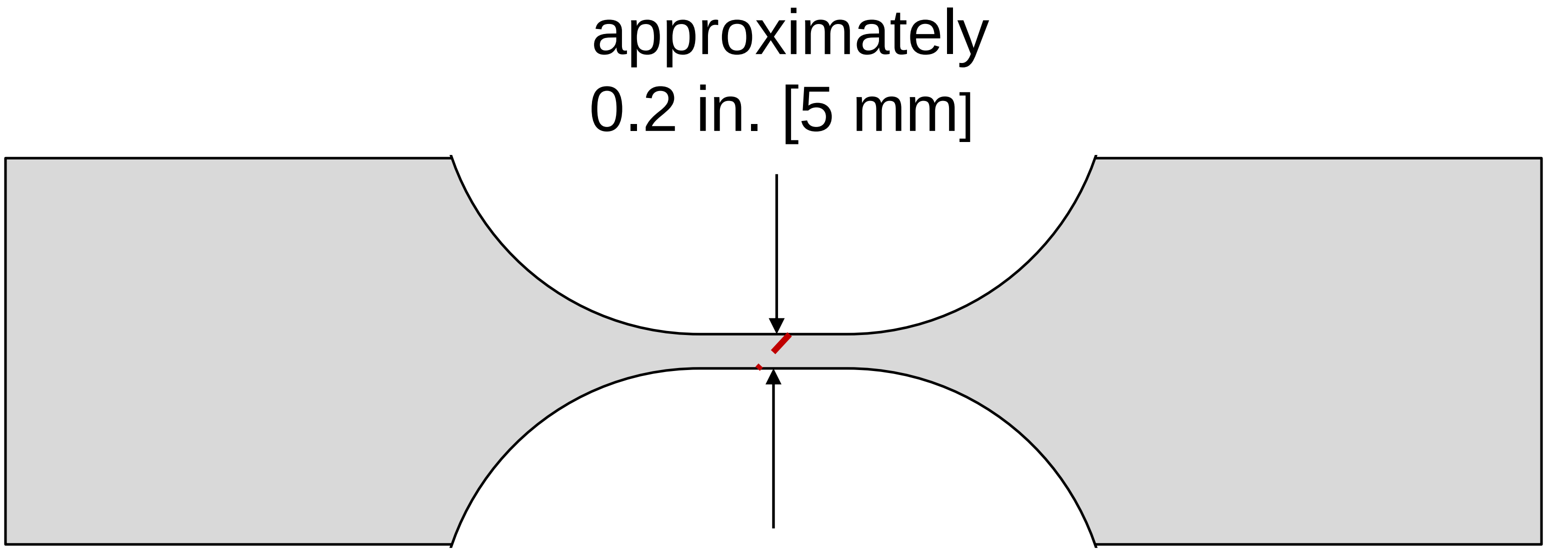

13.5/12 = 12.5%

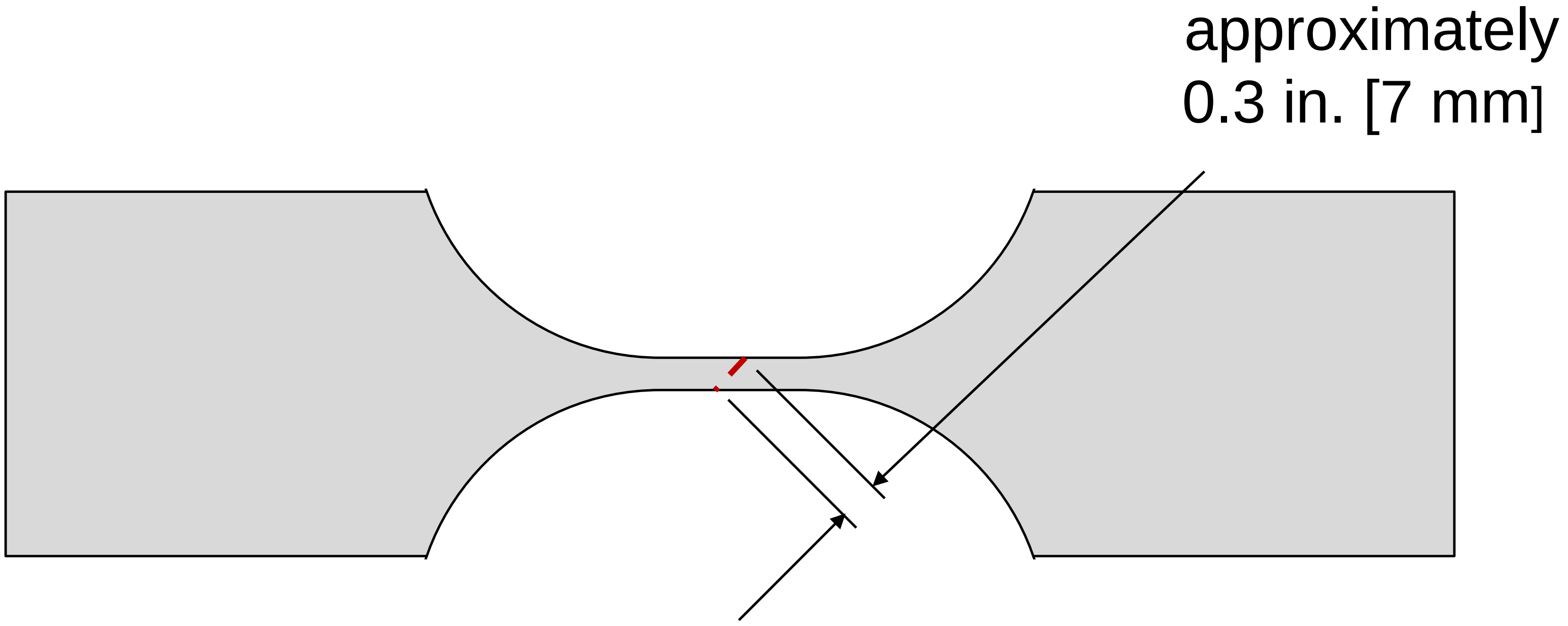

12.4/12 = 3.3%

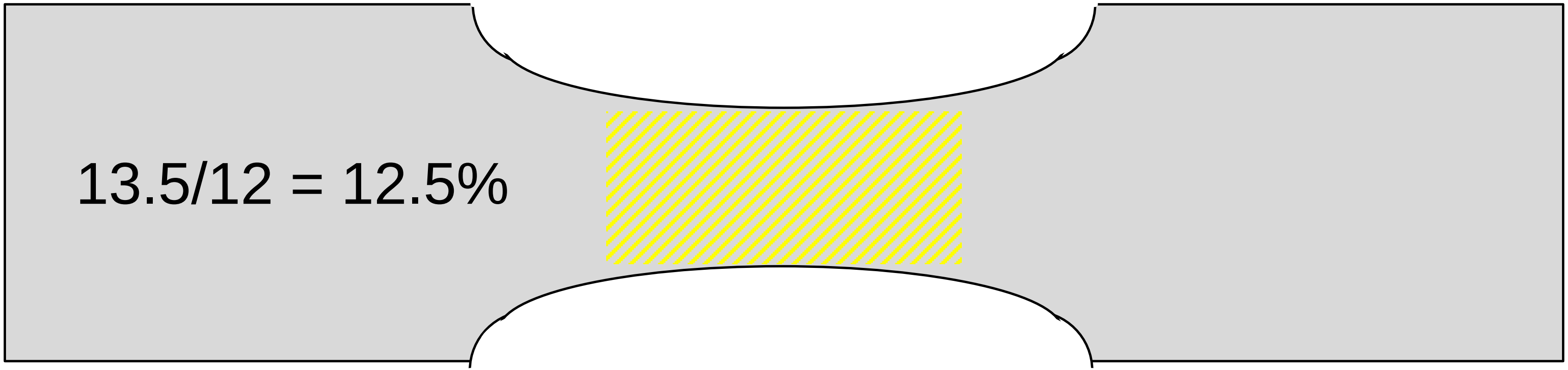
approximately
2.5 in. [64 mm]

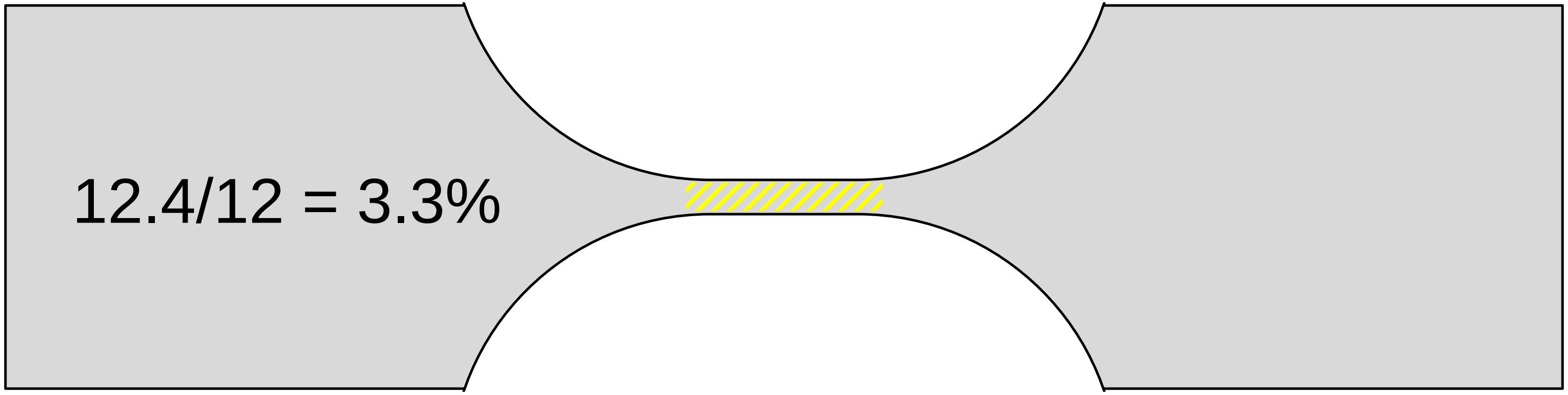



approximately
3.5 in. [90 mm]

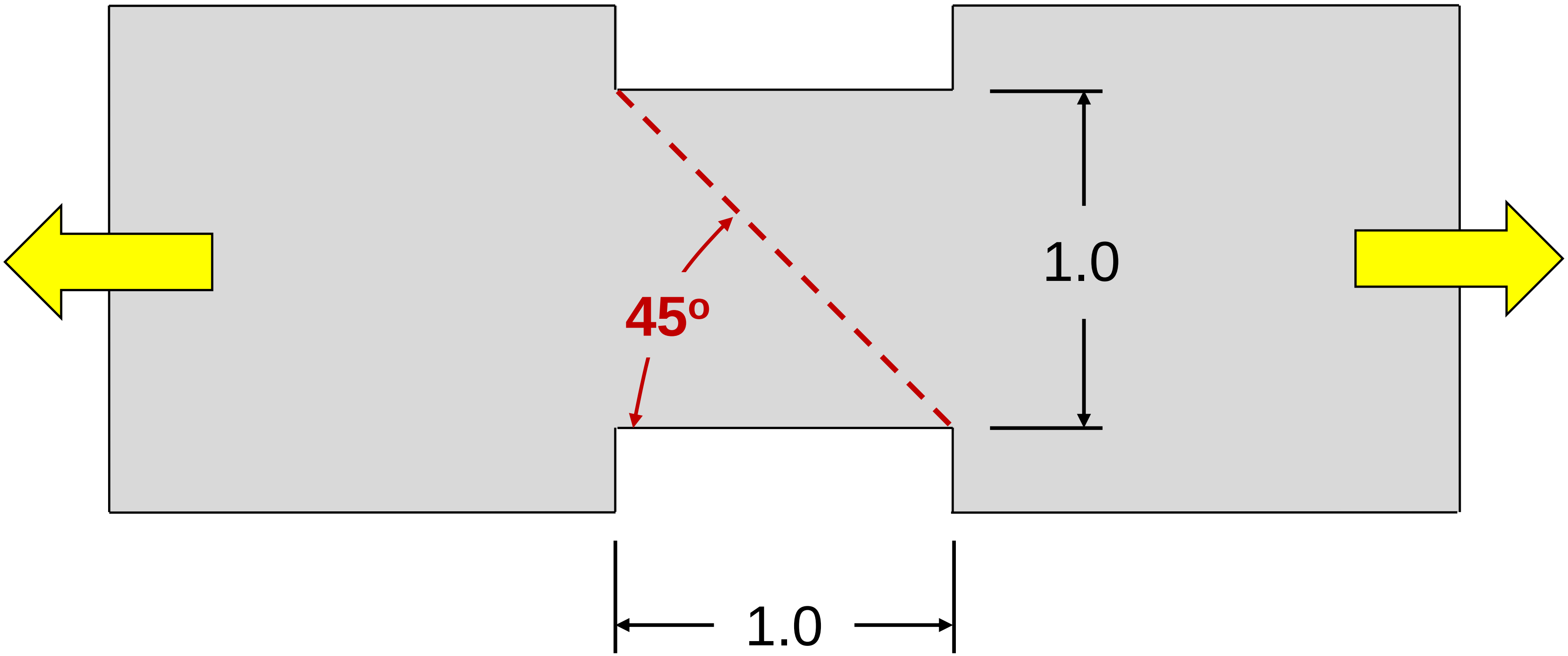

approximately
0.2 in. [5 mm]


approximately
0.3 in. [7 mm]

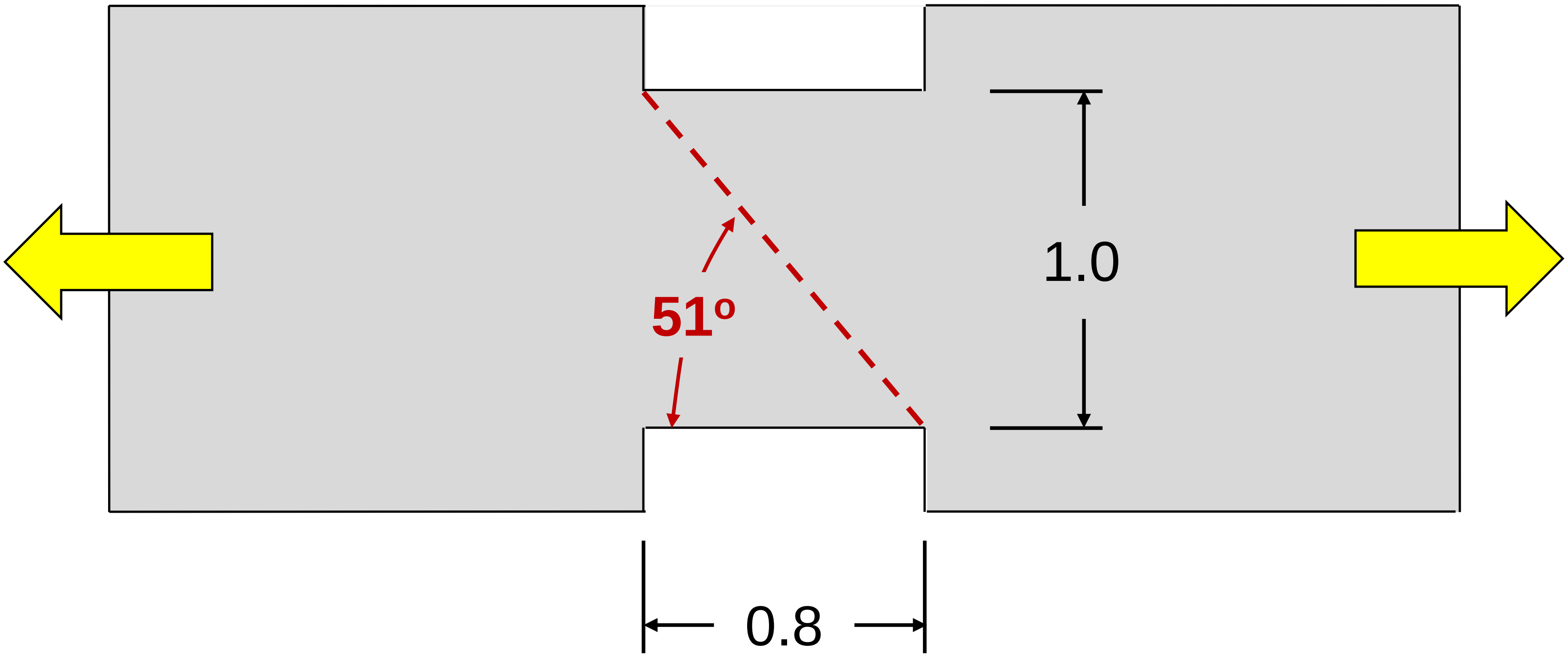

13.5/12 = 12.5%


12.4/12 = 3.3%

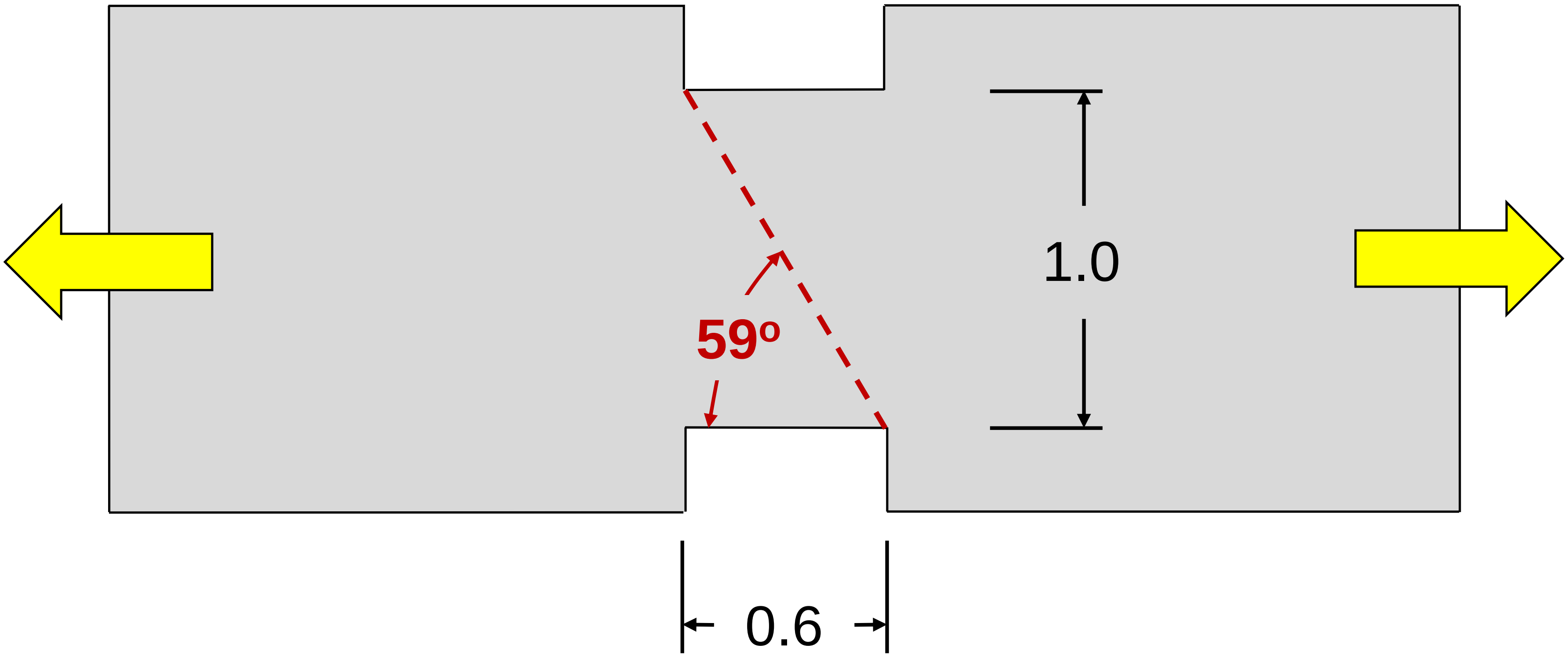
F_y = 35.0 Ksi [242 MPa]



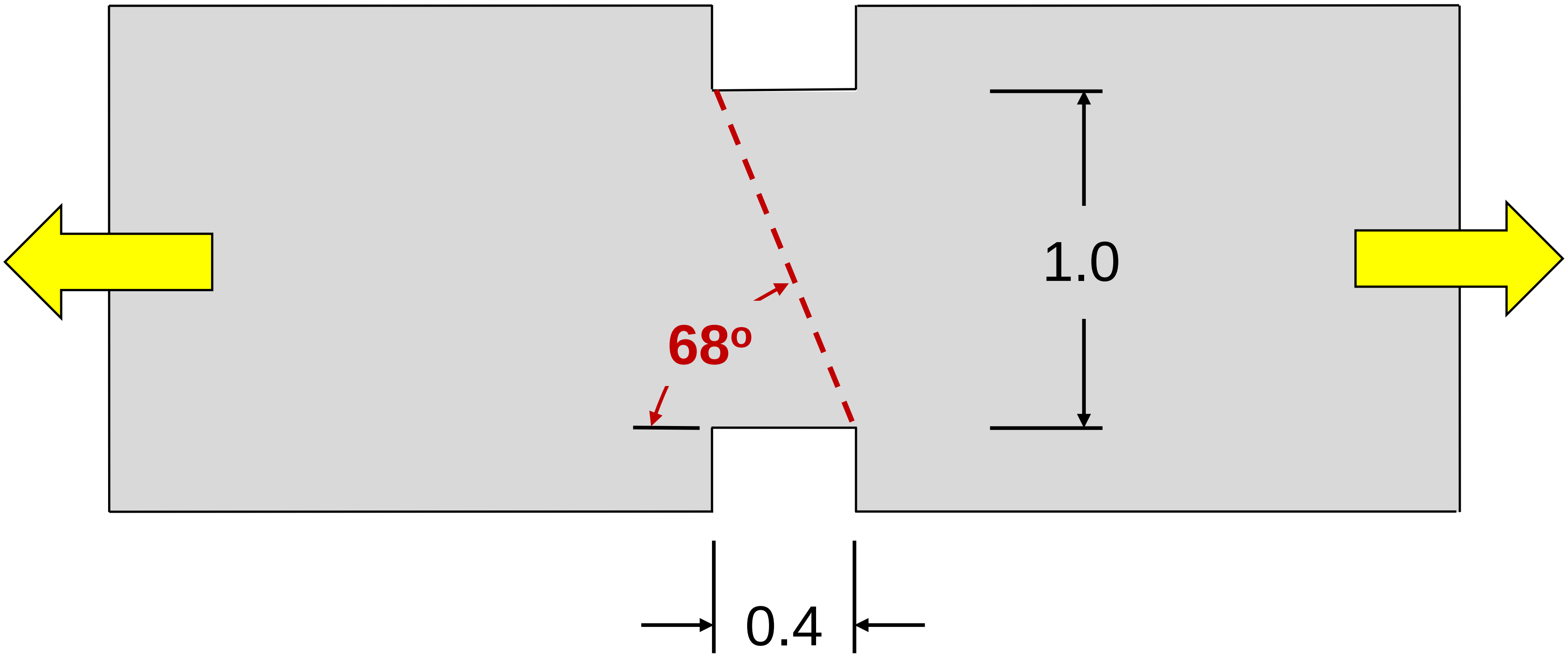
F_y = 35.9 Ksi [248 MPa]



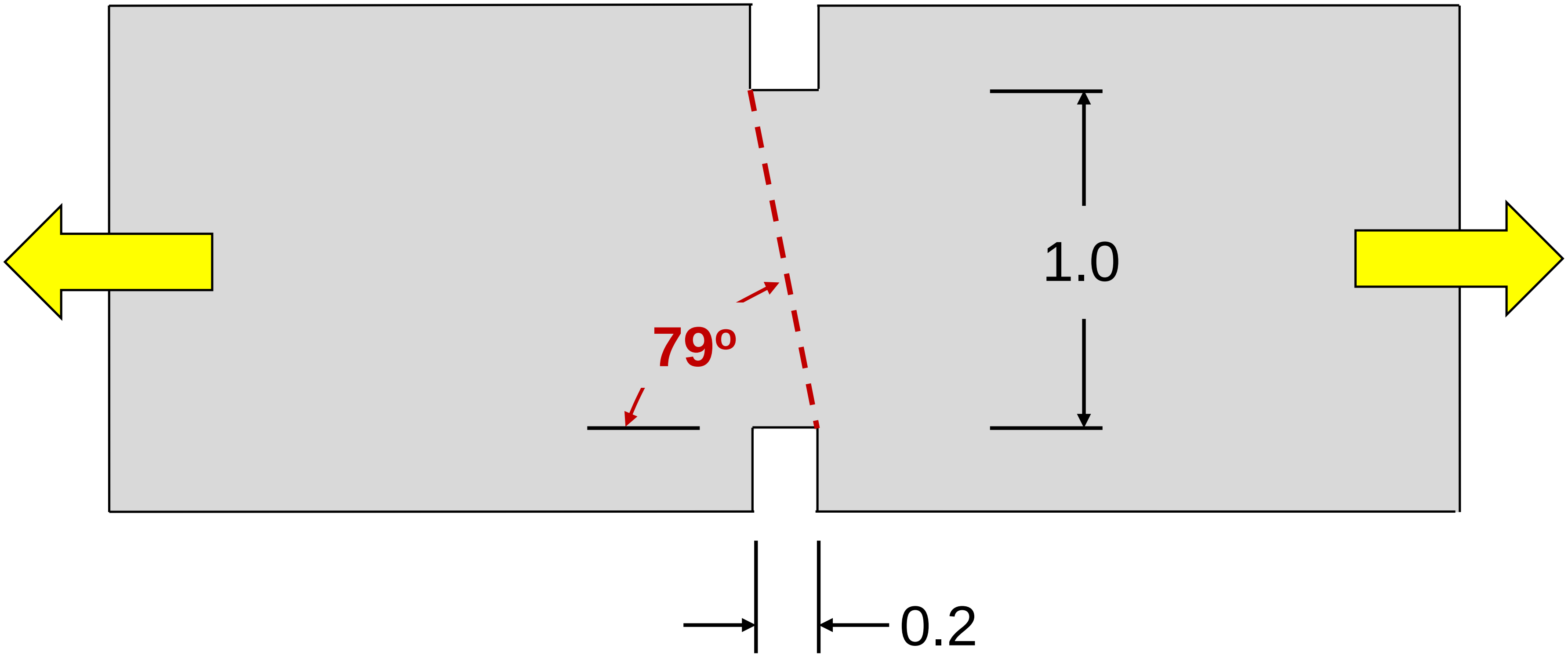
F_y = 39.7 Ksi [274 MPa]



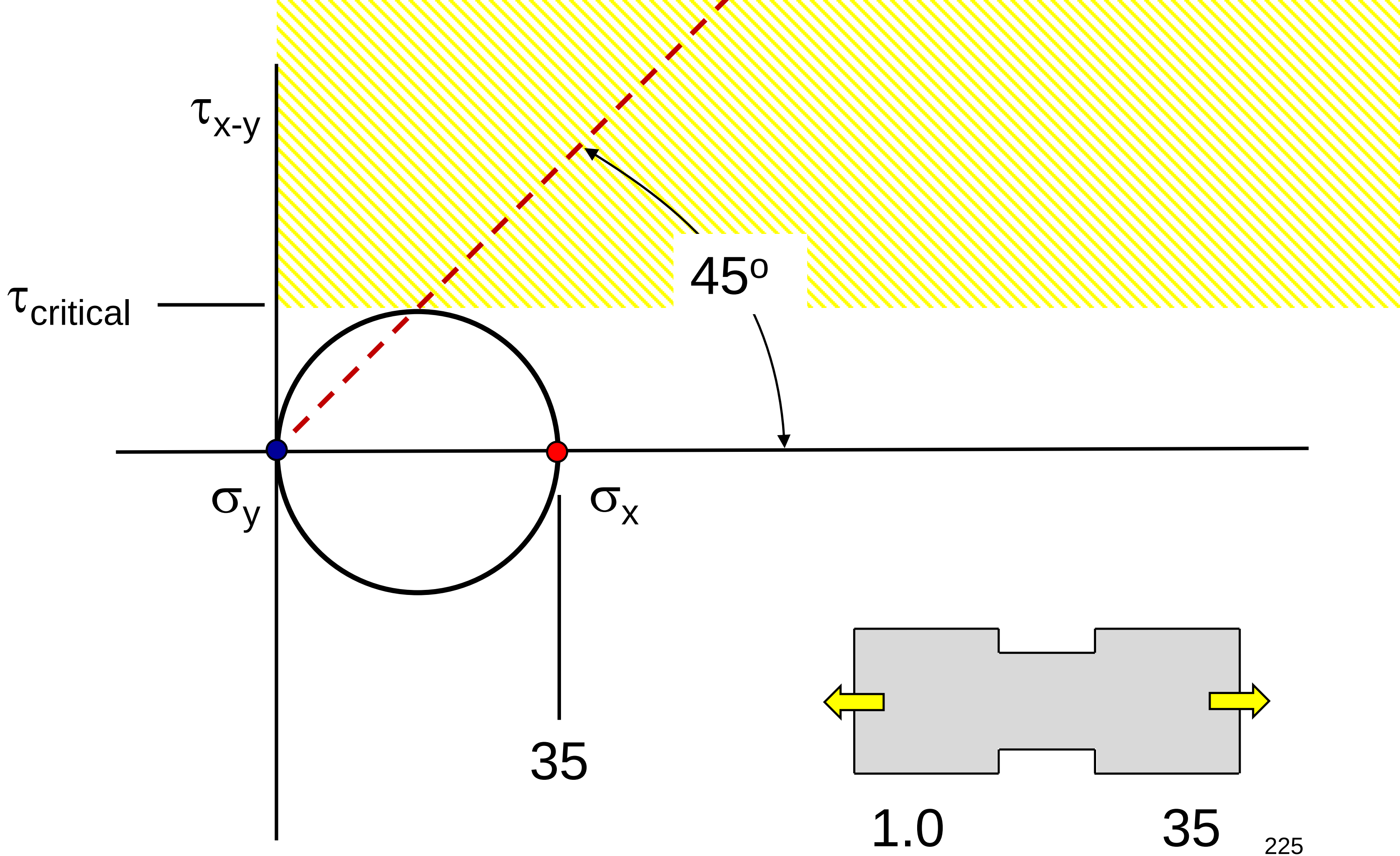
F_y = 50.7 Ksi [350 MPa]



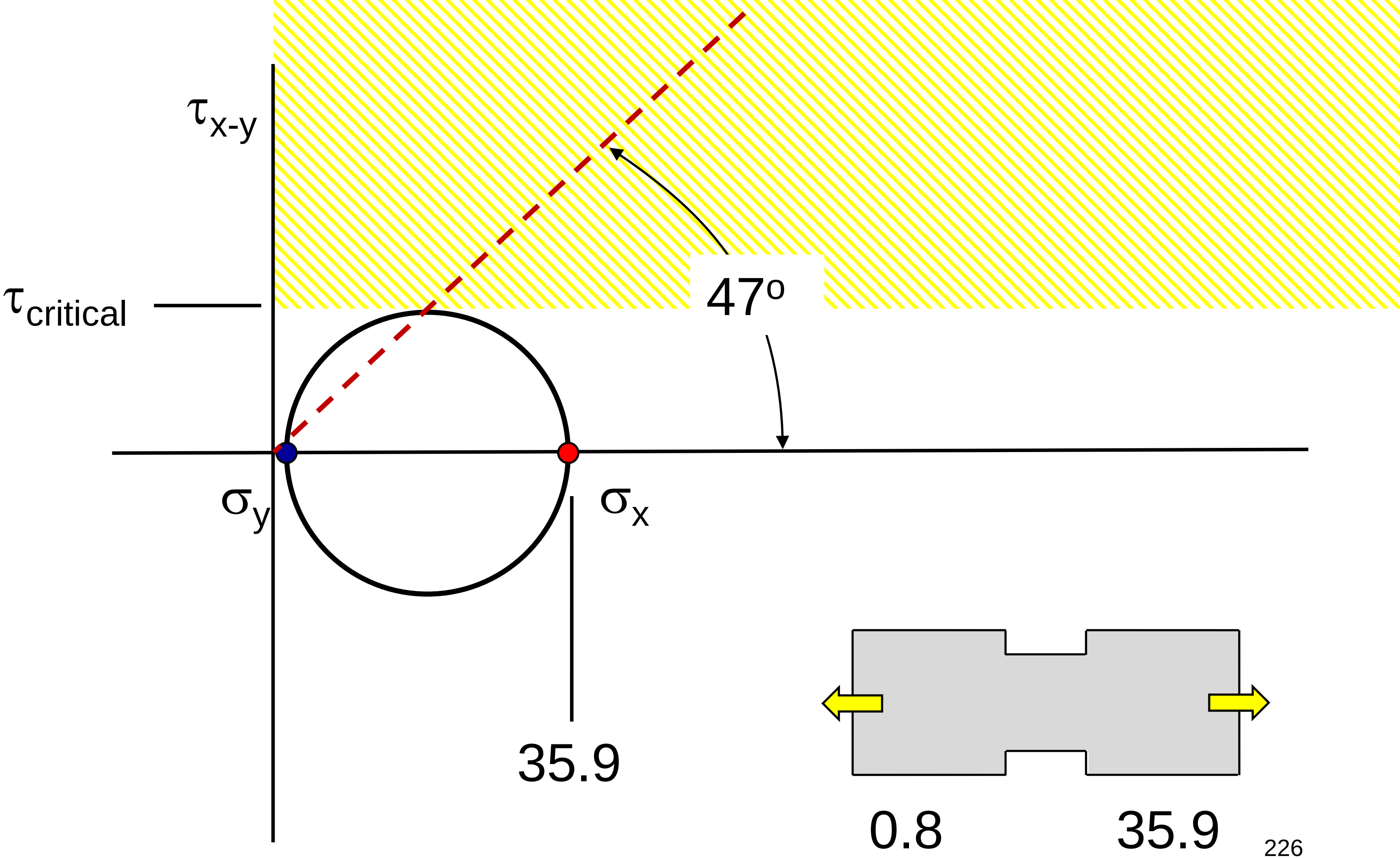
F_y = 91.0 Ksi [628 MPa]



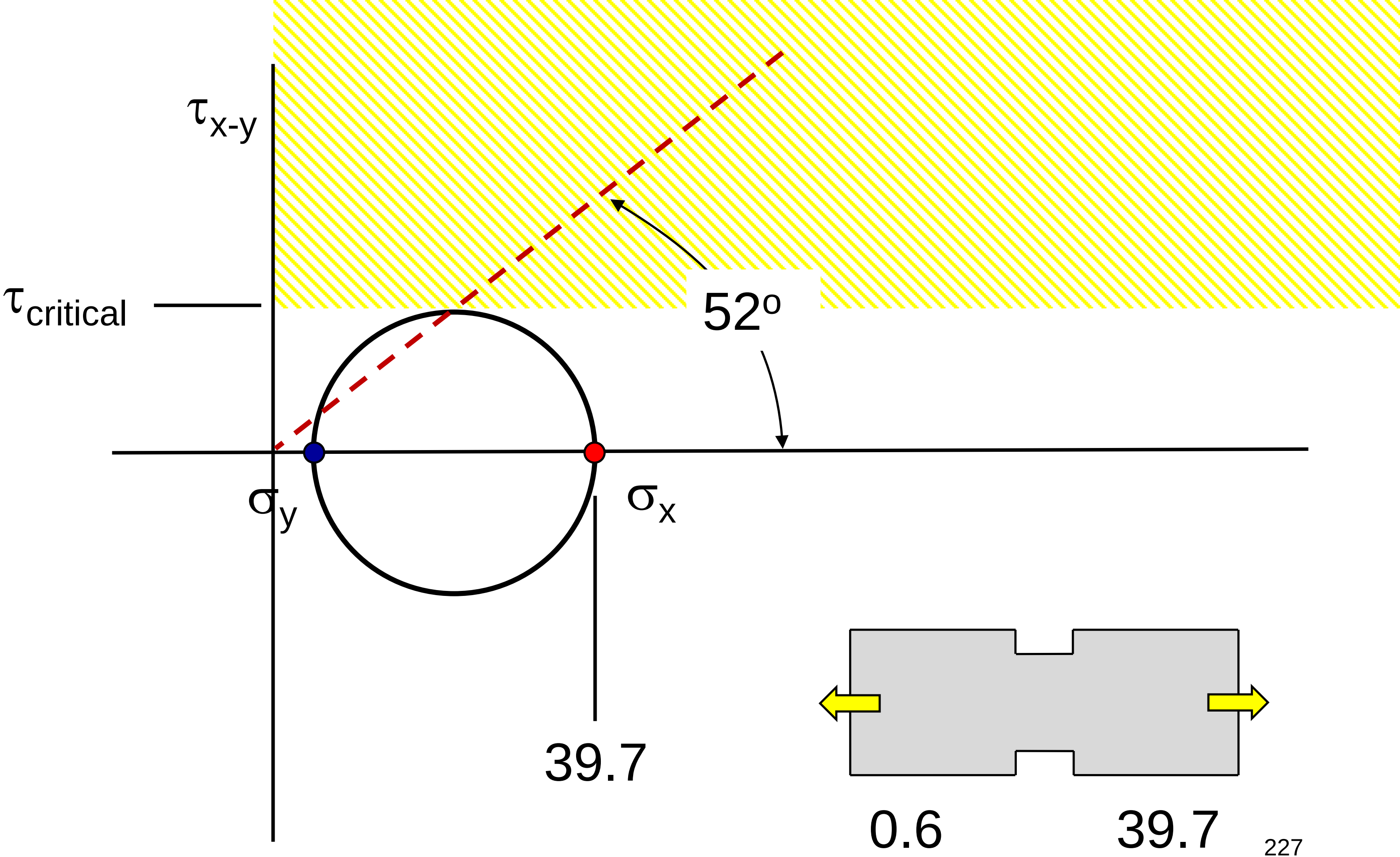
Width	Length	Angle	Yield Stress (ksi)	Yield Stress (MPa)
1.0	1.0	45^o	35.0	242
	0.8	51^o	35.9	248
	0.6	59^o	39.7	274
	0.4	68^o	50.7	350
	0.2	79^o	91.0	628



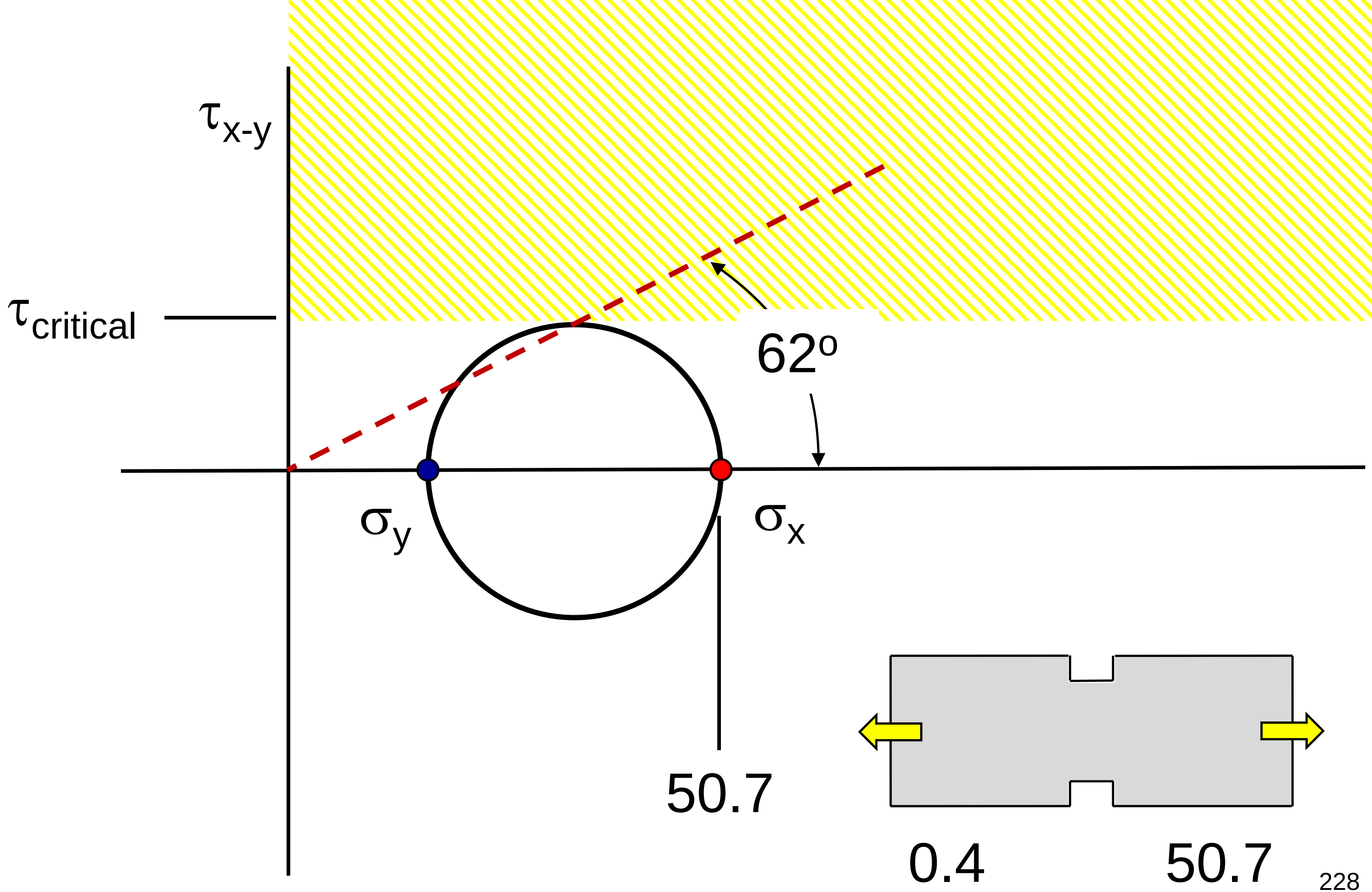
τ_{x-y}
$\tau_{critical}$
45°
σ_y
σ_x
35
1.0
35

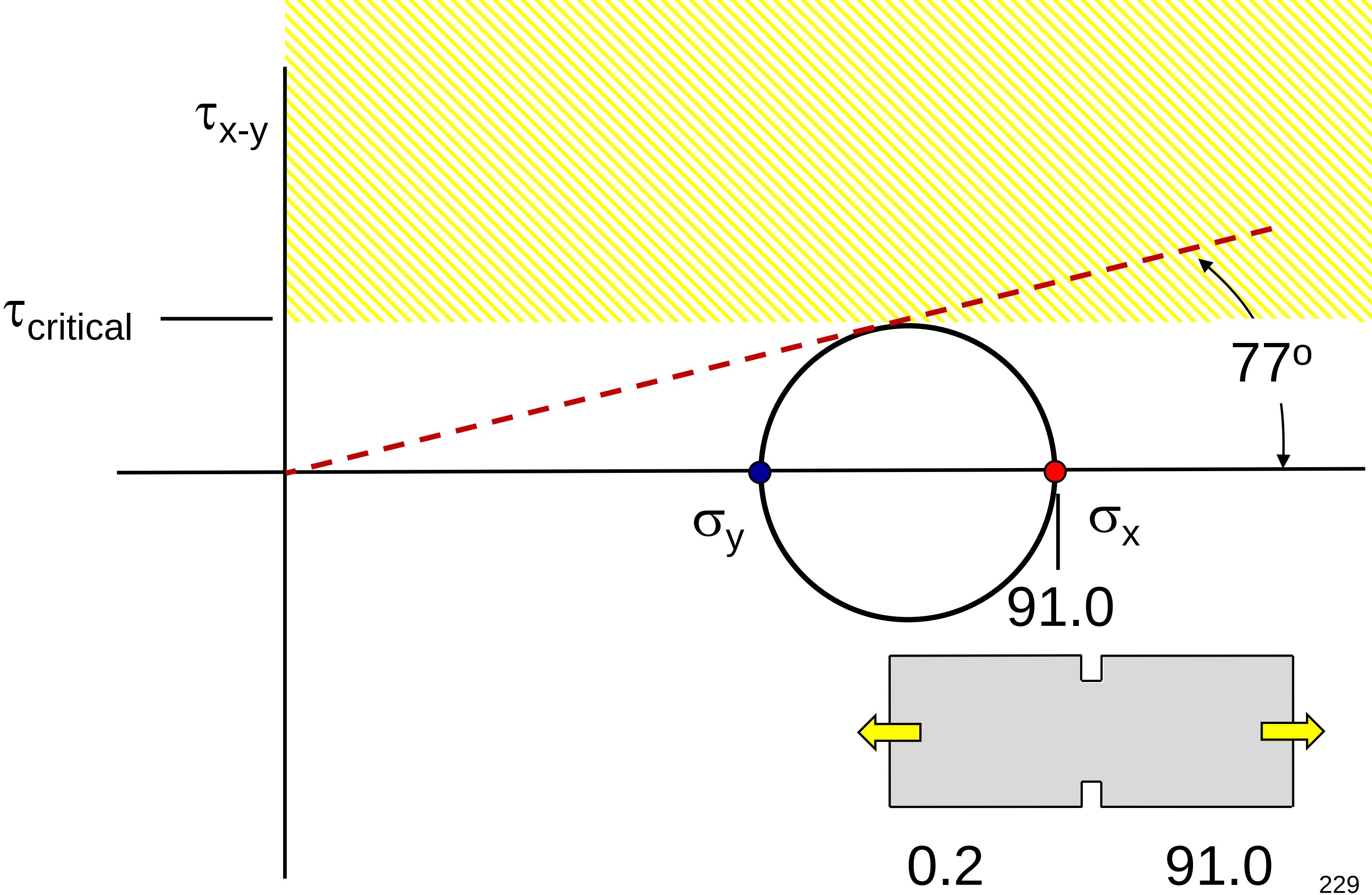


$\tau_{x\text{-}y}$
$\tau_{critical}$
47°
σ_y
σ_x
35.9
0.8
35.9



τ_{x-y}
$\tau_{critical}$
52º
σ_y
σ_x
39.7
0.6
39.7


τ_{x-y}
$\tau_{critical}$
62°
σ_y
σ_x
50.7
0.4
50.7



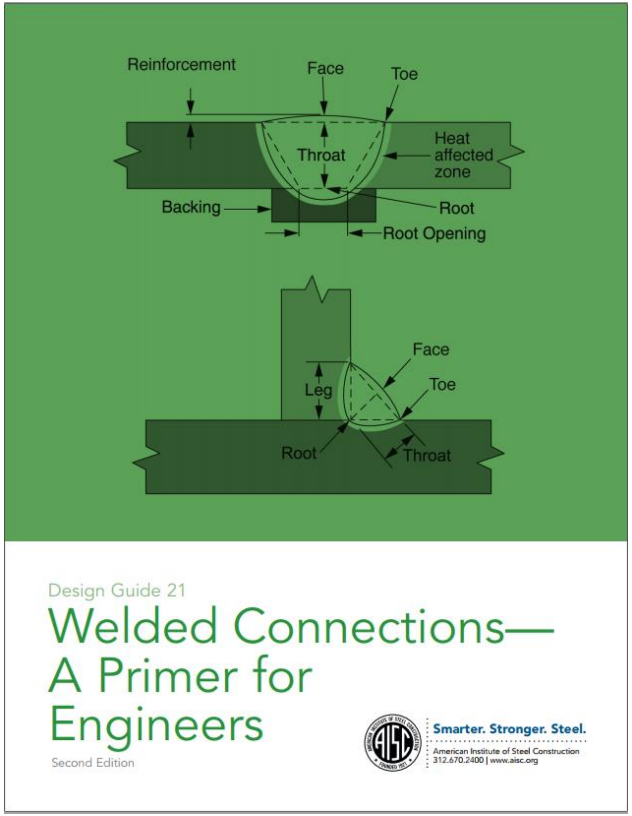
$\tau_{x\text{-}y}$
$\tau_{critical}$
77°
σ_y
σ_x
91.0
0.2
91.0

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

AISC Design Guide 21, 2nd Edition

Welded Connections–

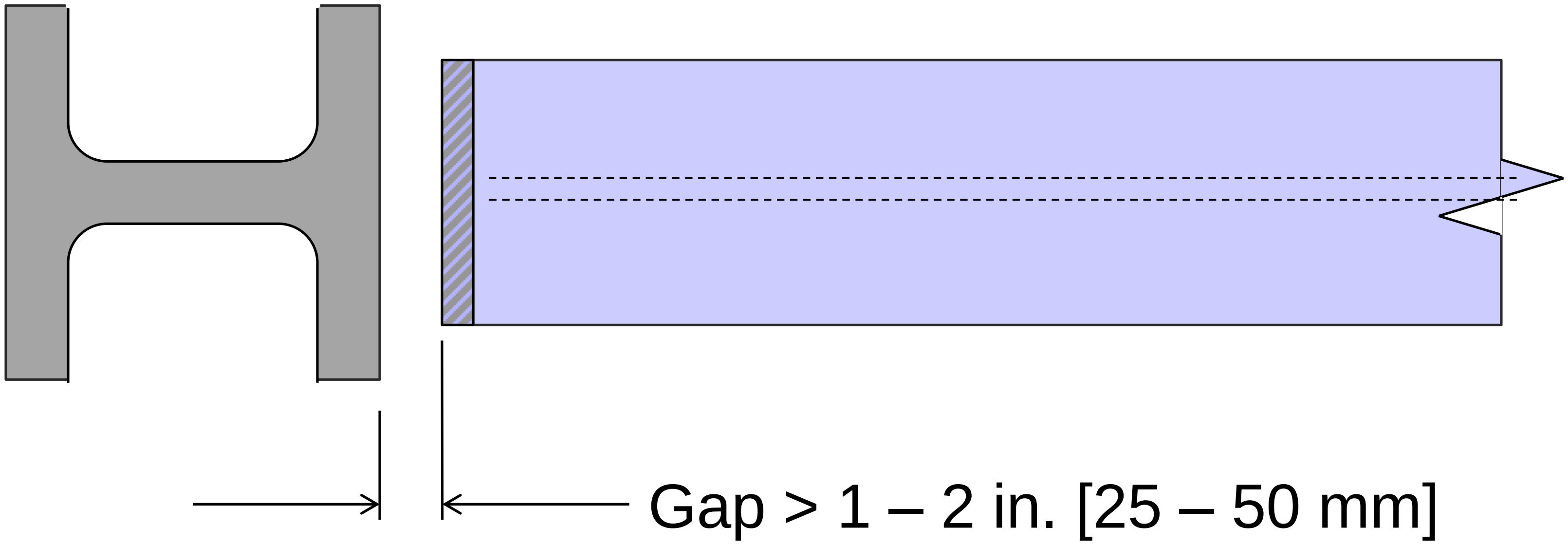
A Primer for Engineers



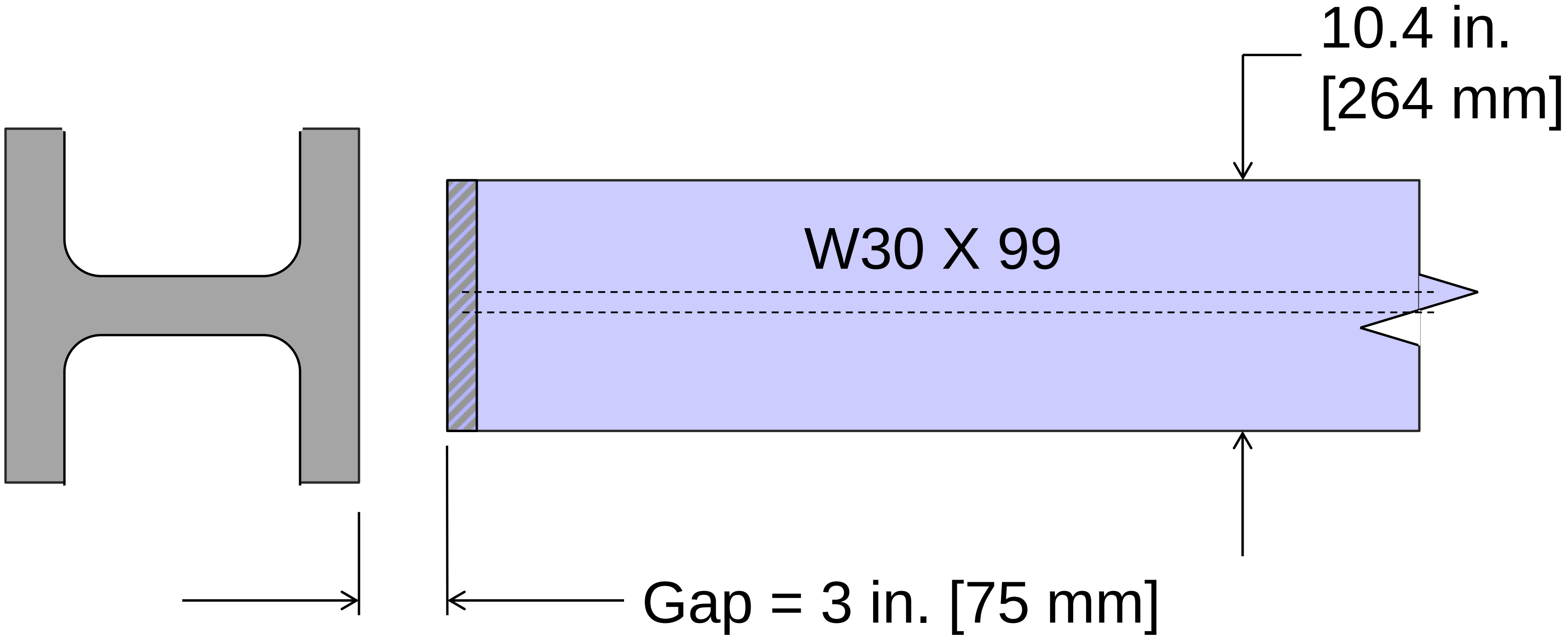
15.5 Fixing Members That Are Cut Short

15.5 Fixing Members That Are Cut Short

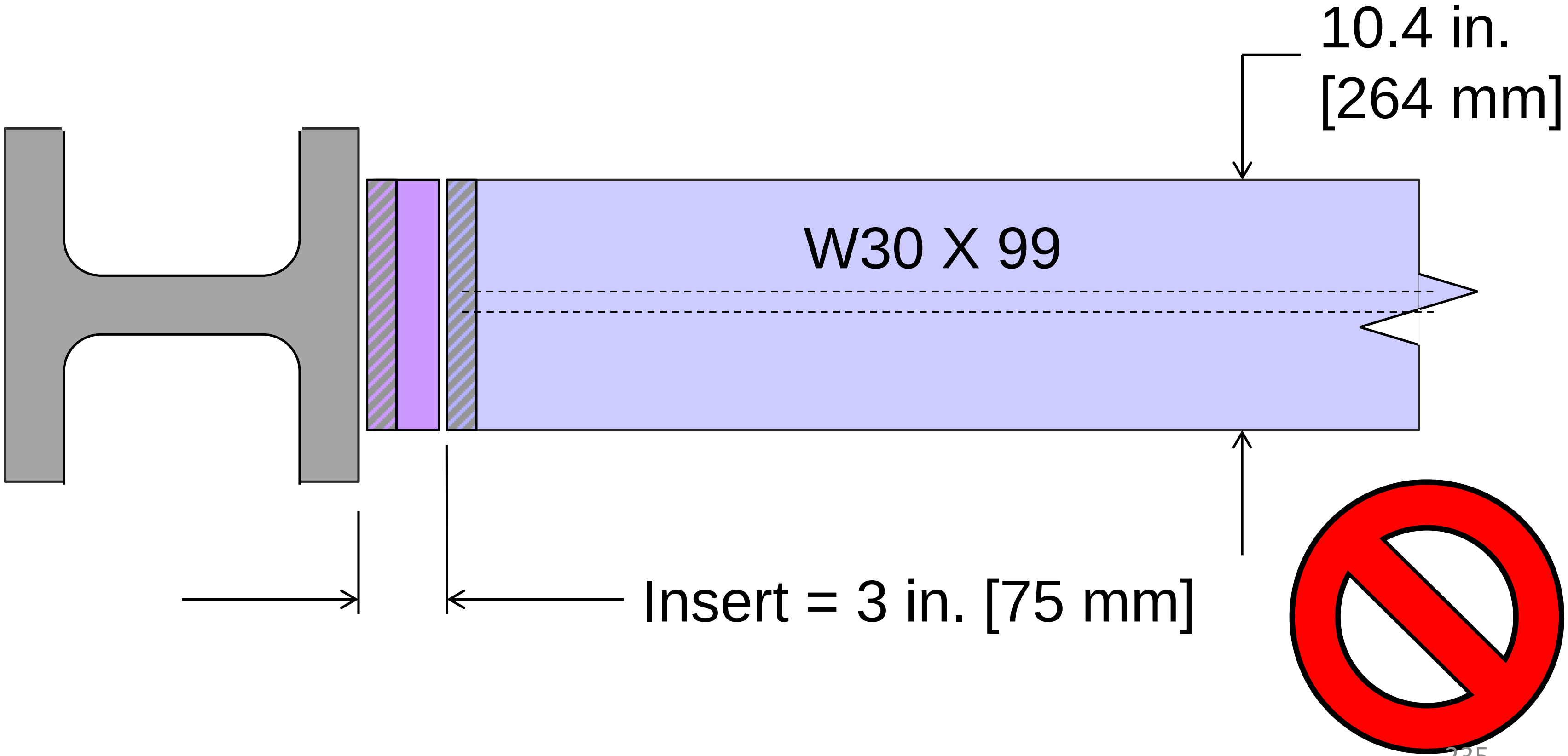
Buttering may be a good solution



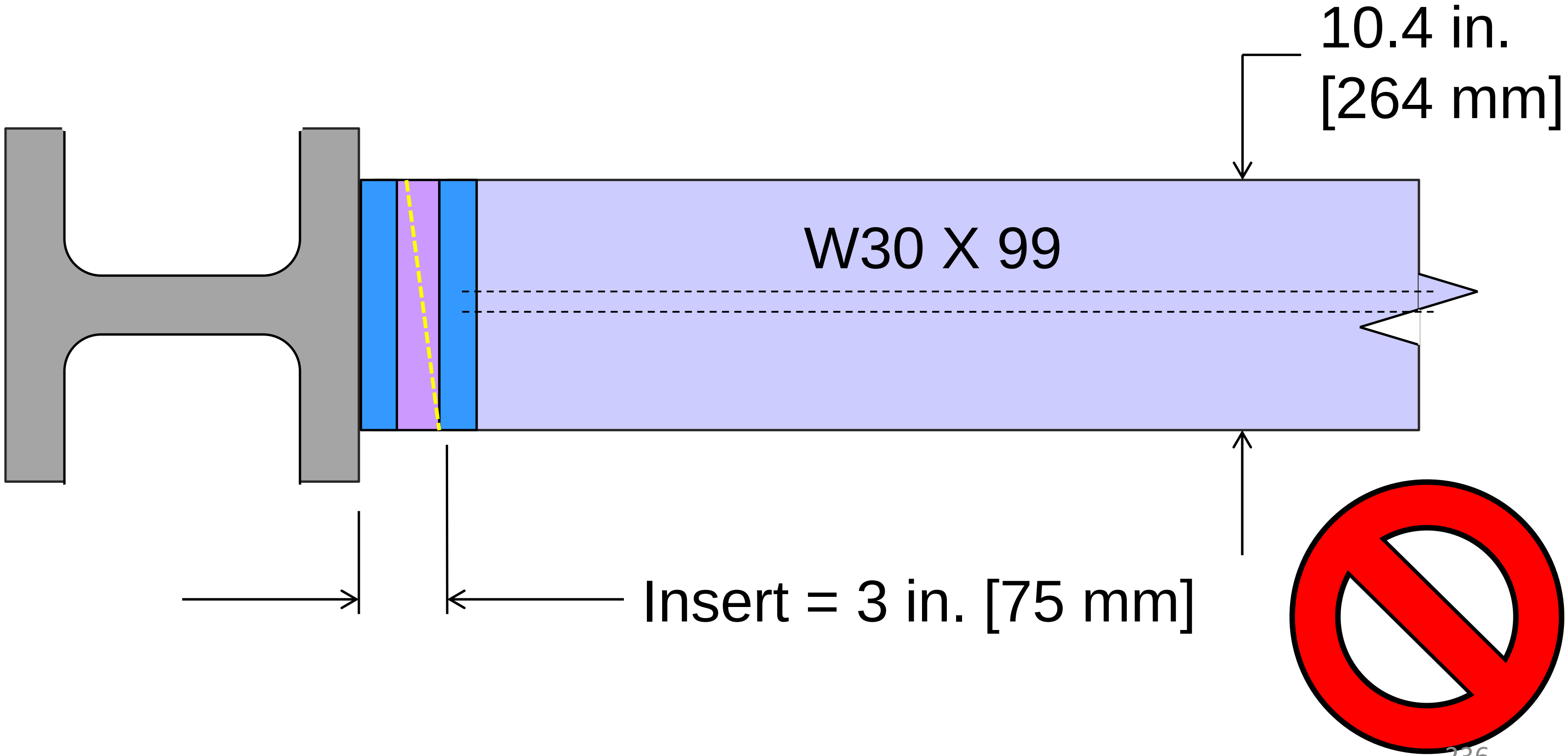
15.5 Fixing Members That Are Cut Short



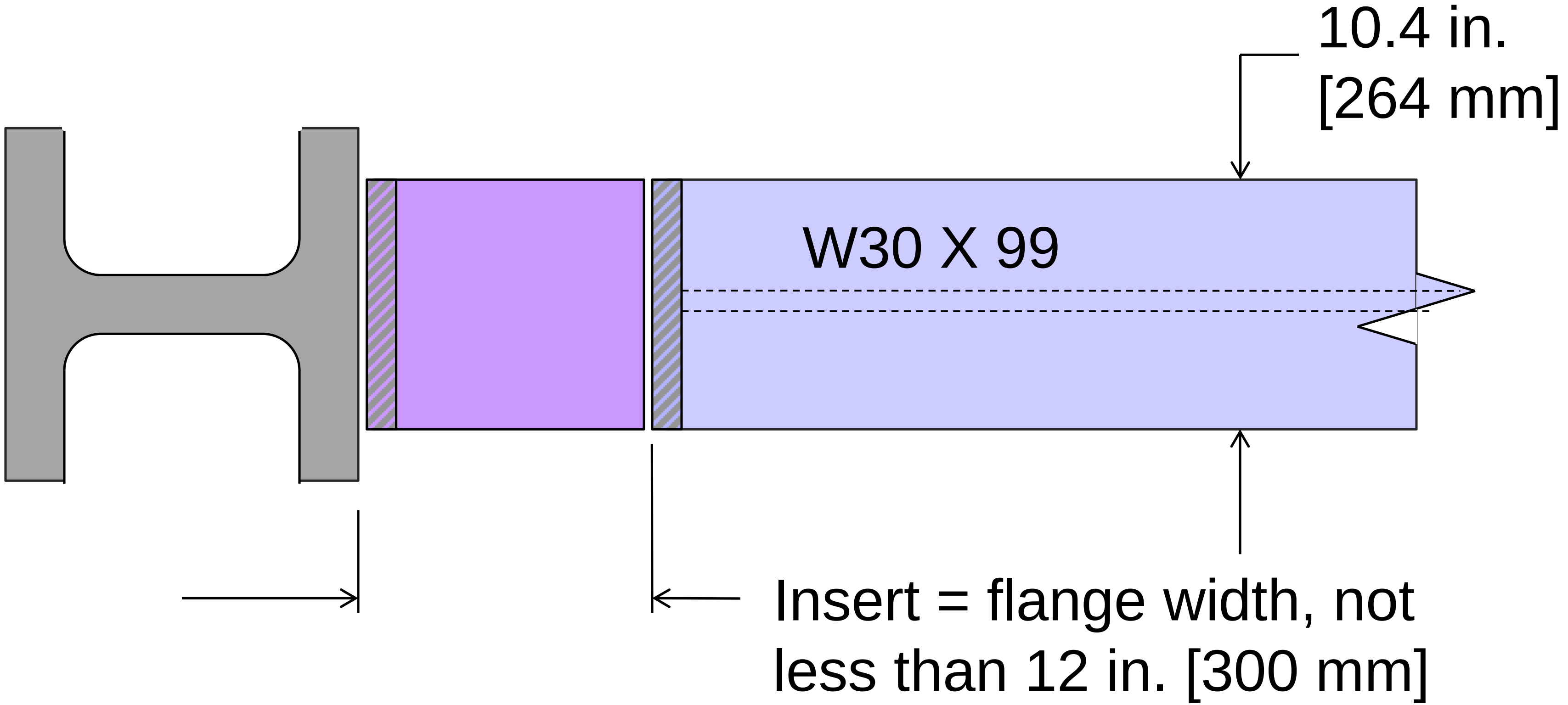
15.5 Fixing Members That Are Cut Short



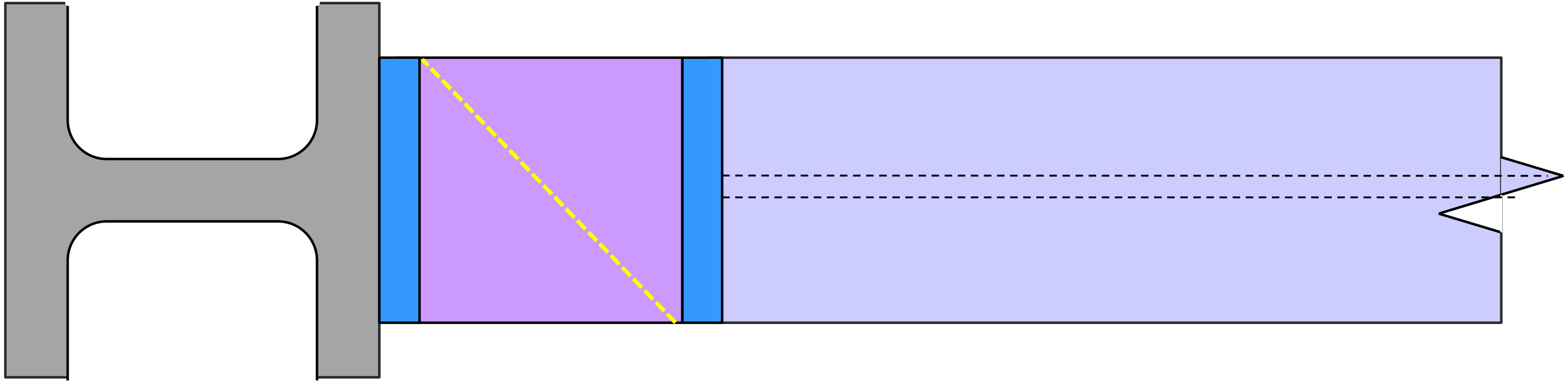
15.5 Fixing Members That Are Cut Short



15.5 Fixing Members That Are Cut Short



15.5 Fixing Members That Are Cut Short

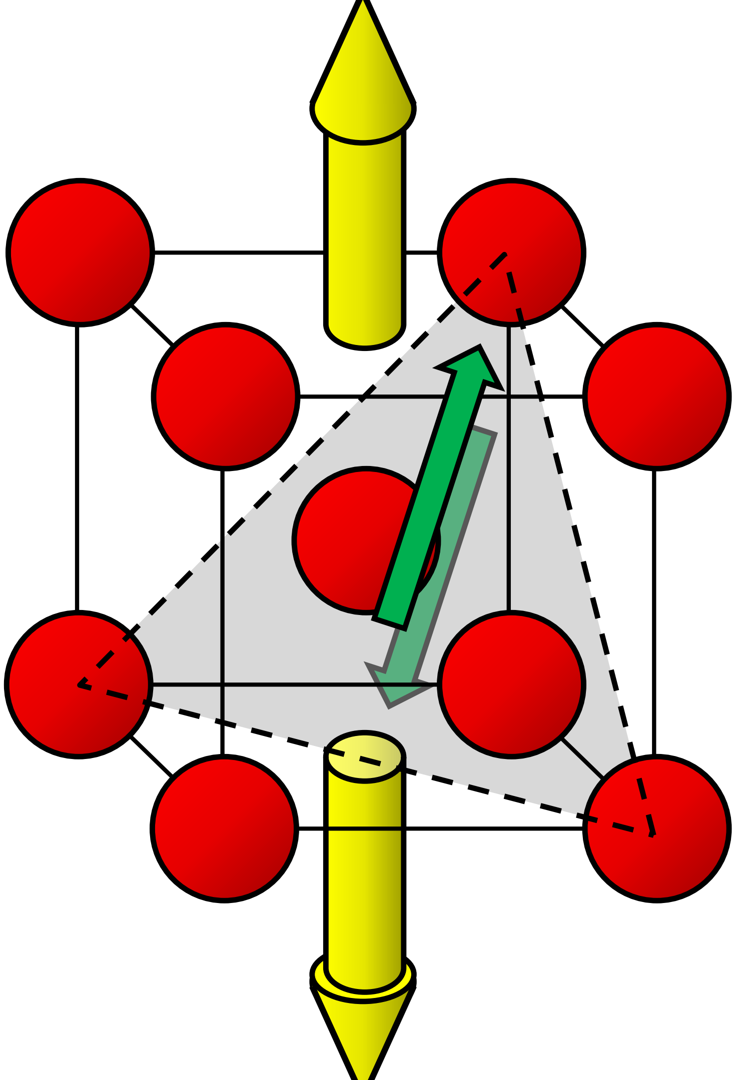


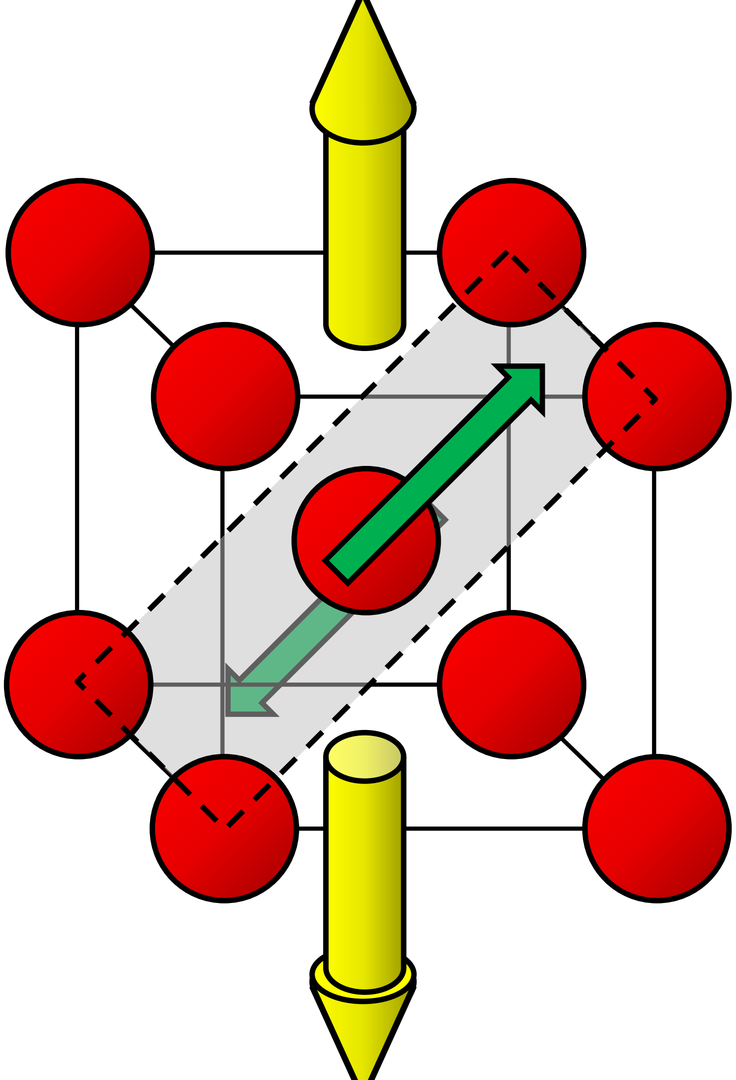
The additional material between the two parallel welds accommodates weld shrinkage strains.

How to Achieve Controlled Inelastic Deformations

- Select a ductile material
- Avoid conditions that prompt brittle fracture

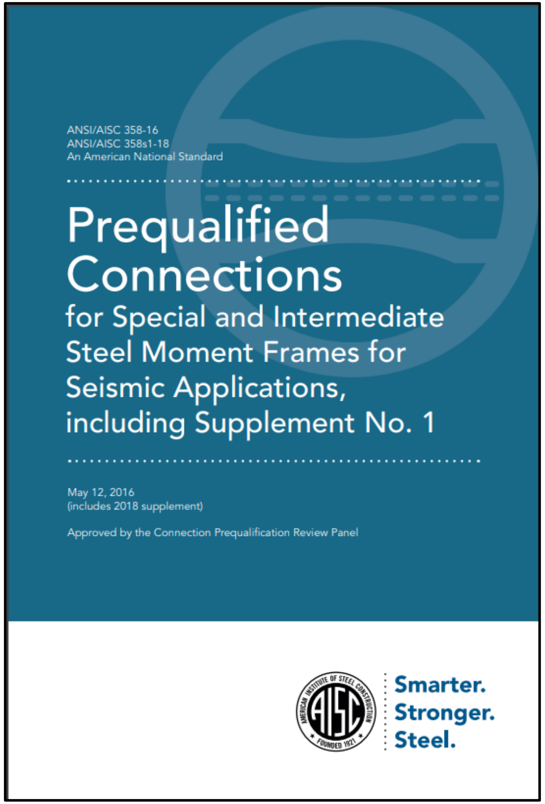
  (triaxial stress, constraint, notches, low temperatures, high strain rates)
- Encourage shear stresses
- Applied shear stress > critical shear strength
- Ensure enough material is present to create meaningful displacements
- Ensure movement is in a meaningful direction



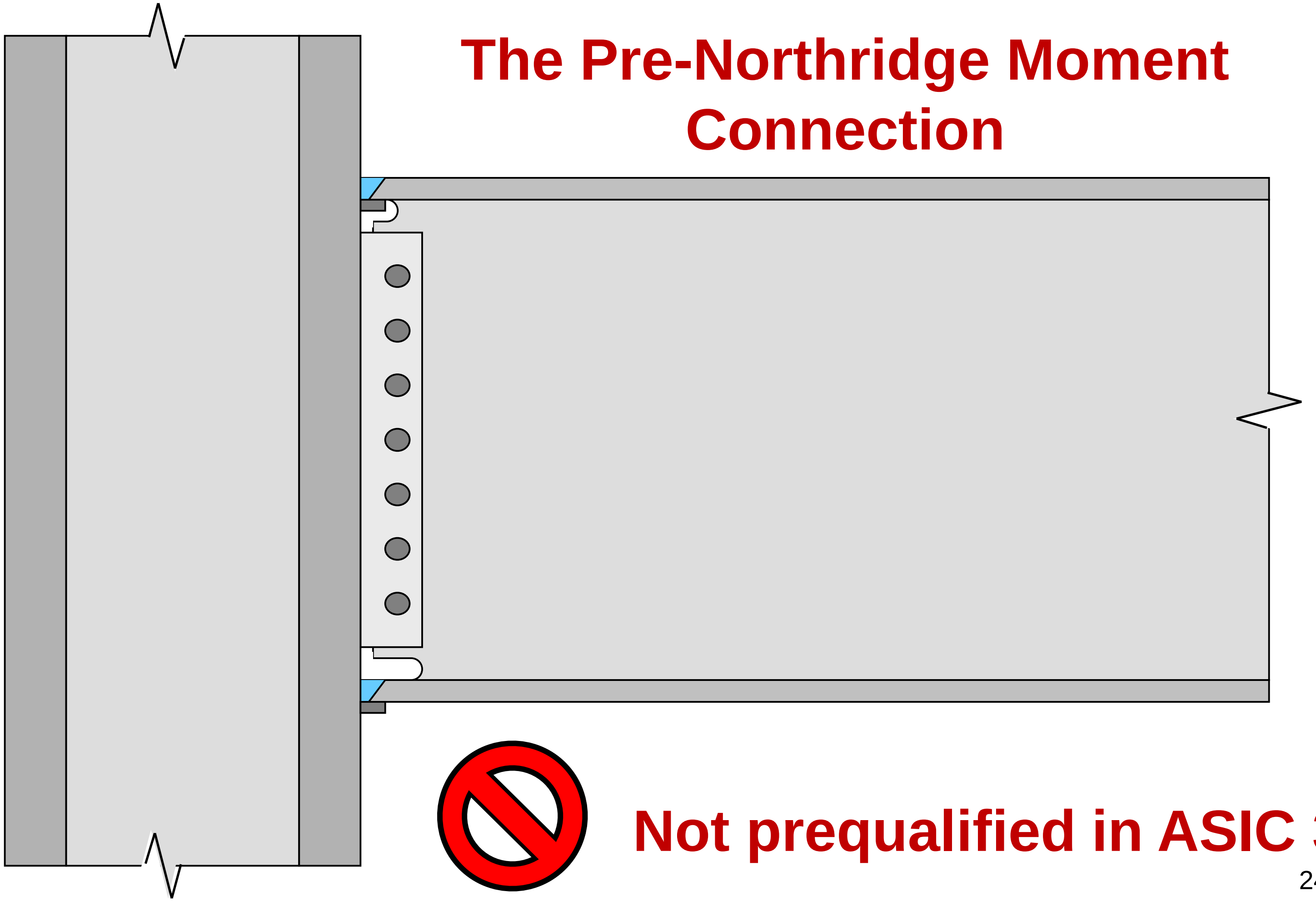


ANSI/AISC 358-16
An American National Standard

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

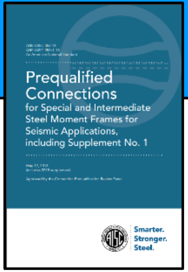


The Pre-Northridge Moment Connection

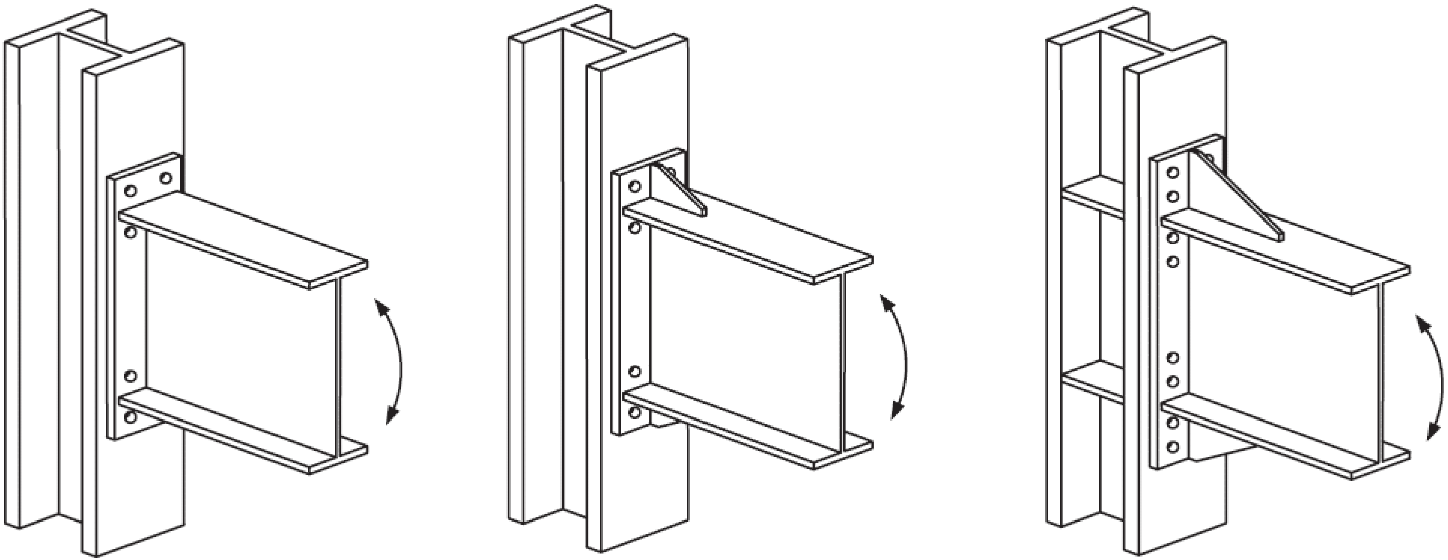


Not prequalified in ASIC 358

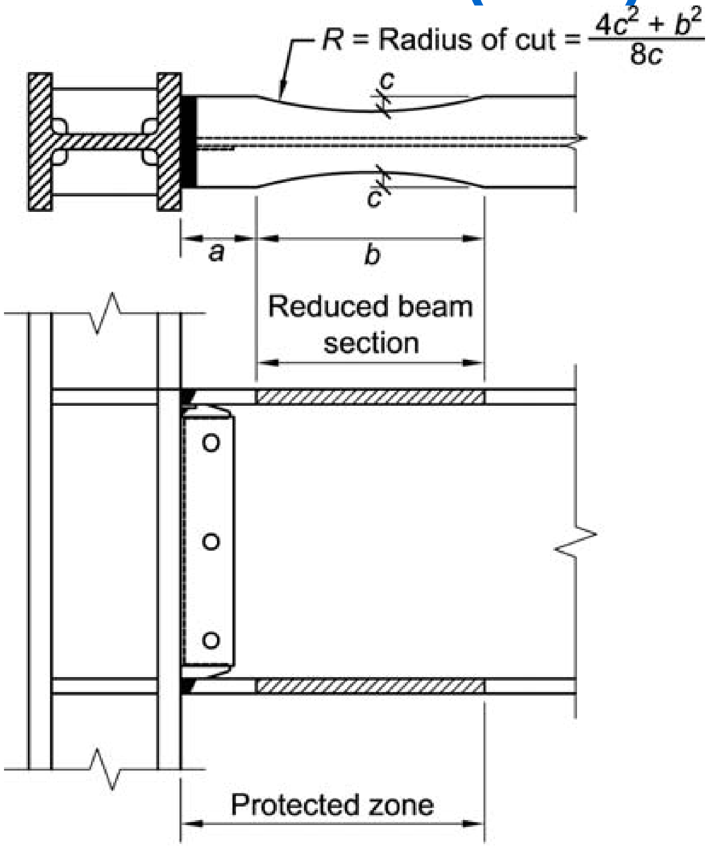
AISC 358-16 Prequalified Connections

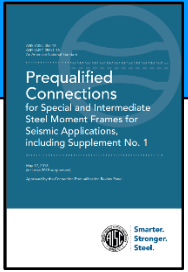


Bolted End Plate Moment Connection

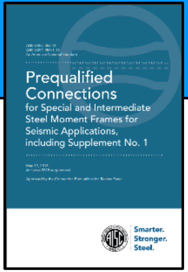


Reduced Beam Section (RBS) Moment

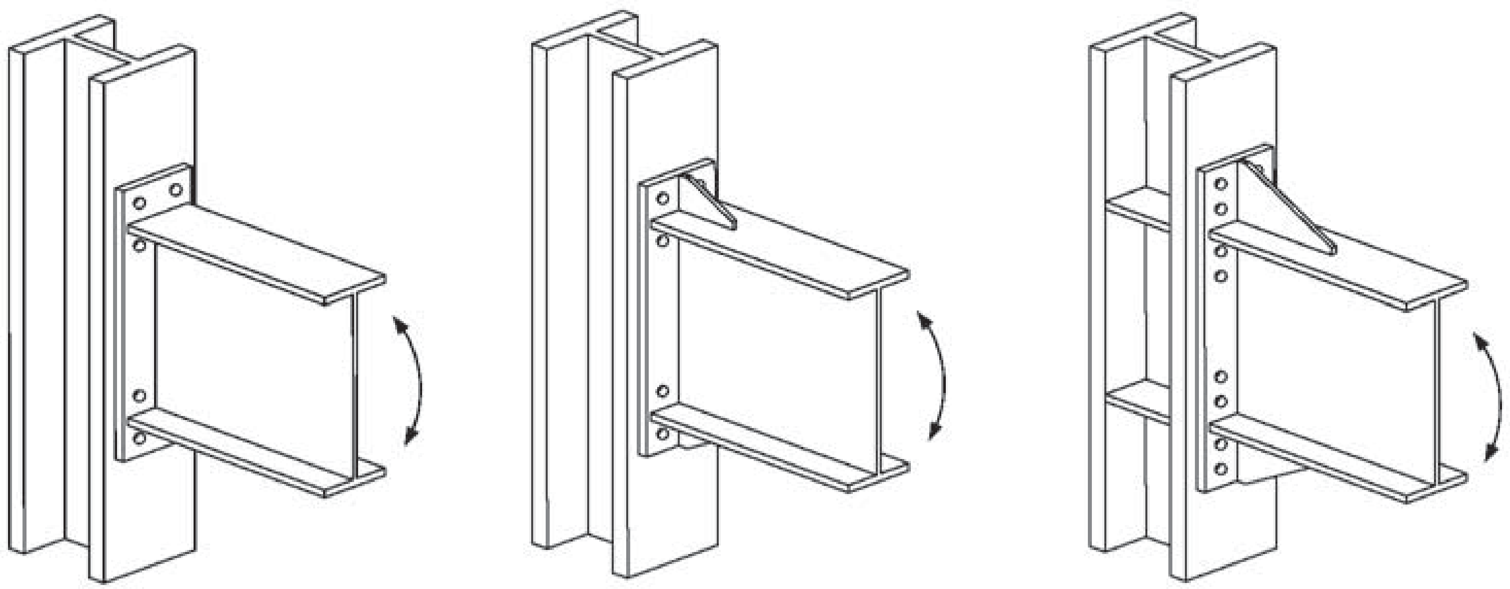




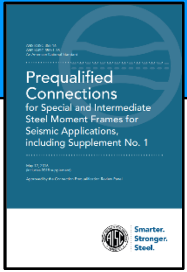
AISC 358-16 Prequalified Connections



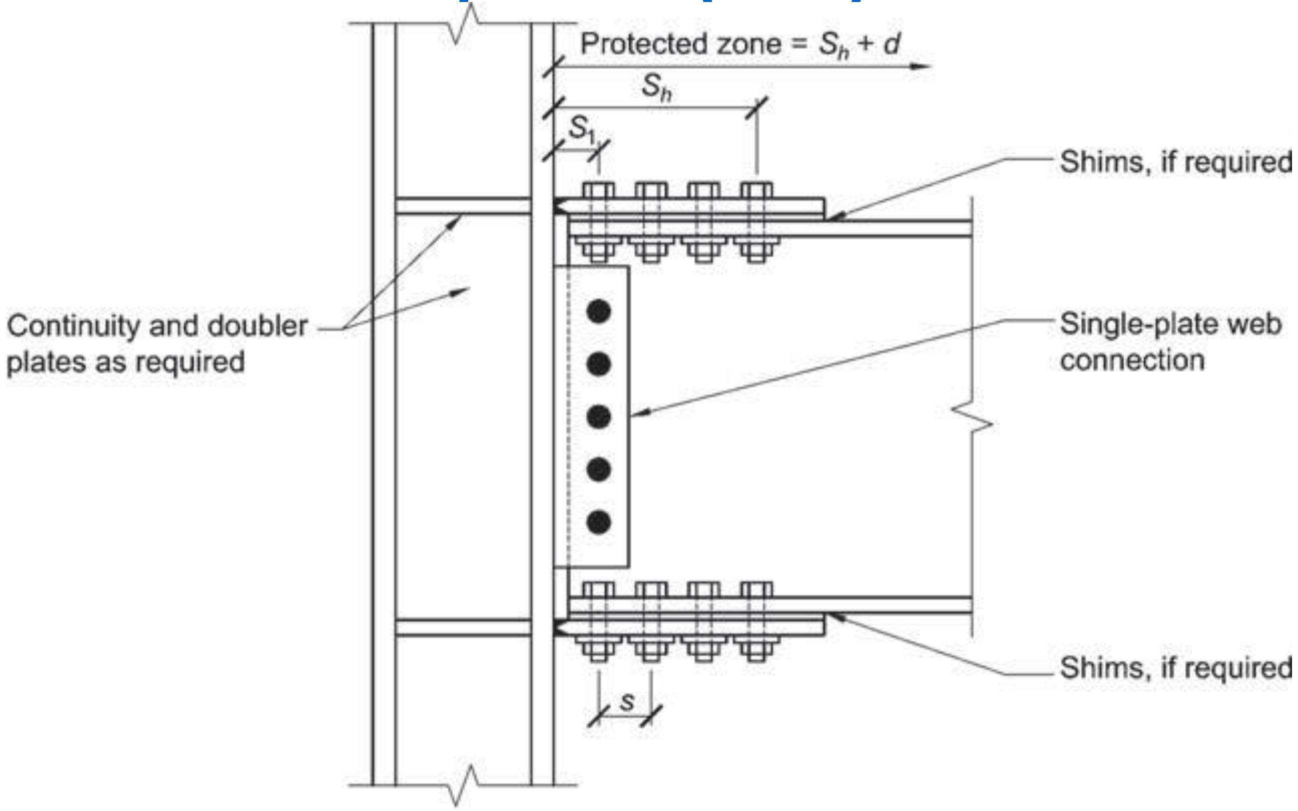
Bolted Unstiffened and Stiffened Extended End-Plate moment connections (BUUEP, BSEEP)



AISC 358-16 Prequalified Connections

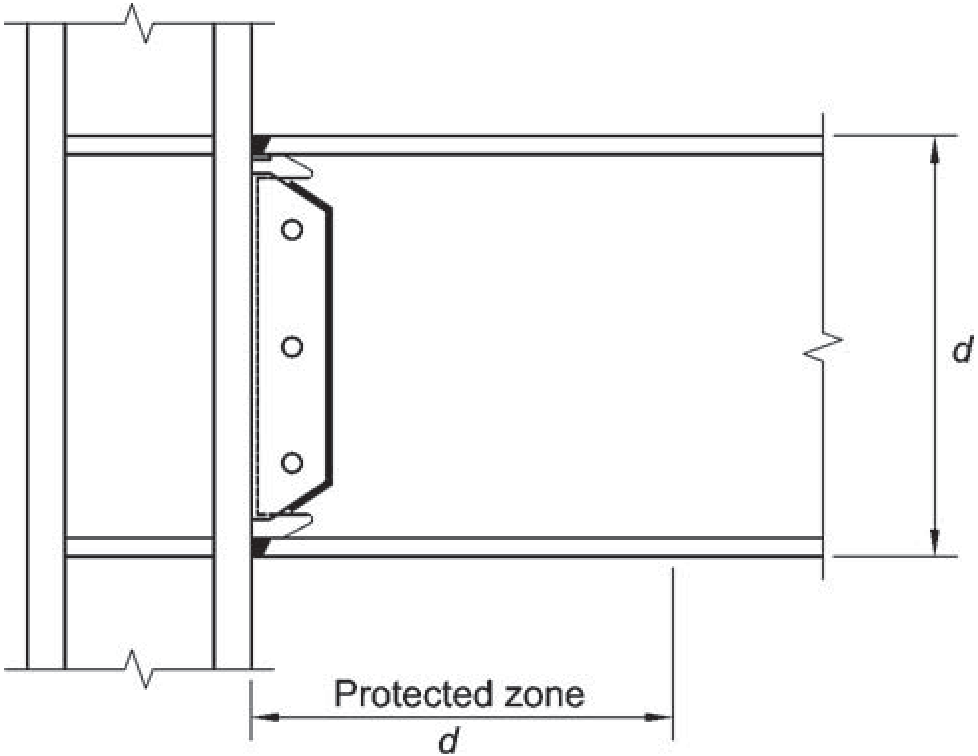


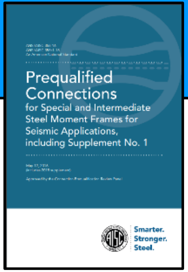
Bolted Flange Plate (BFP) Moment

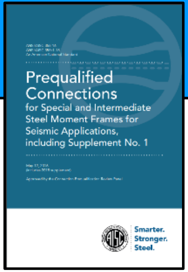


AISC 358-16 Prequalified Connections

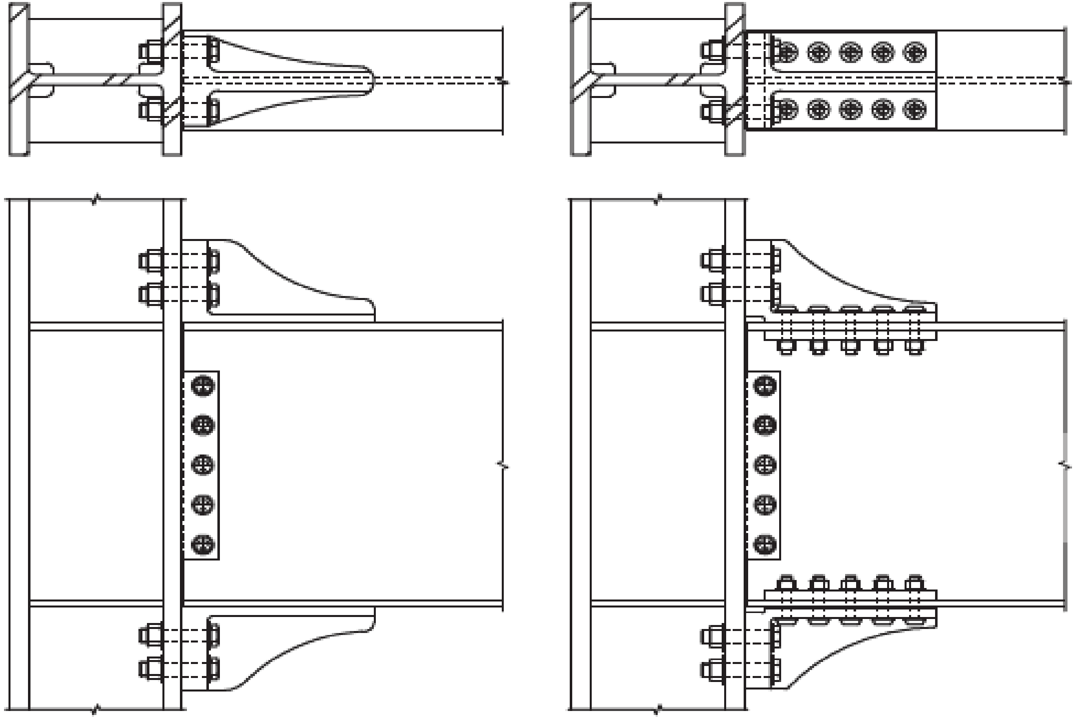
Welded Unreinforced Flange-Welded Web (WUF-W) Moment Connection



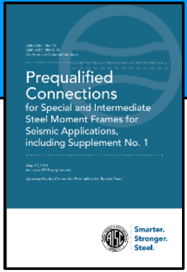




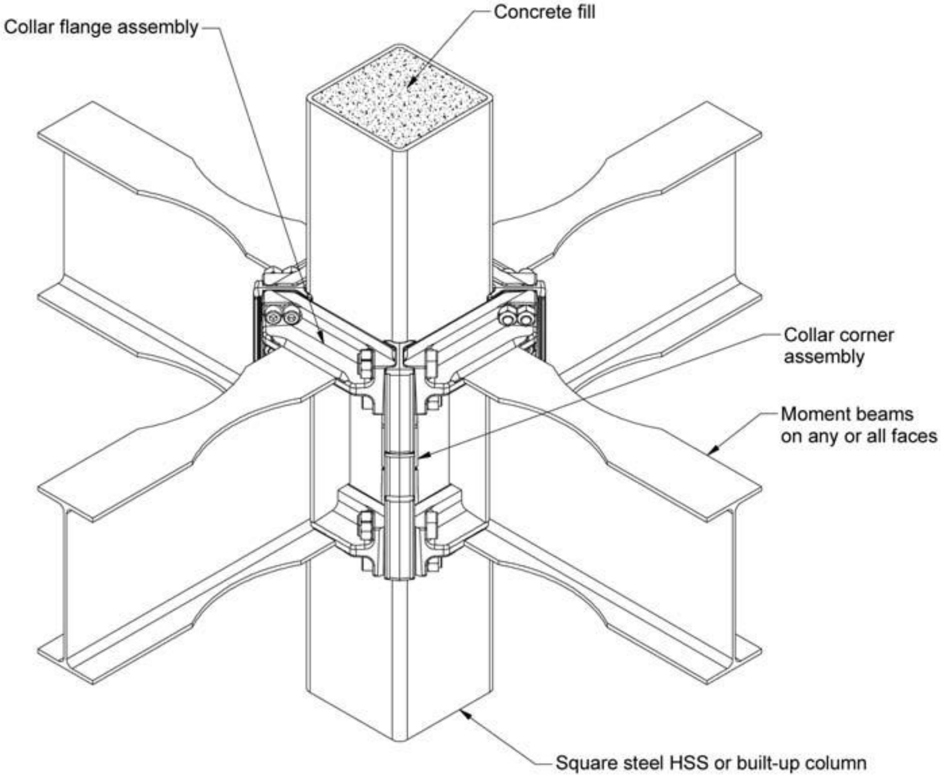
Kaiser Bolted Bracket (KBB) Moment Connection



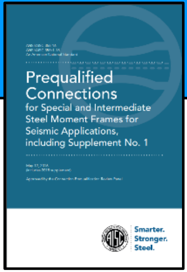
AISC 358-16 Prequalified Connections



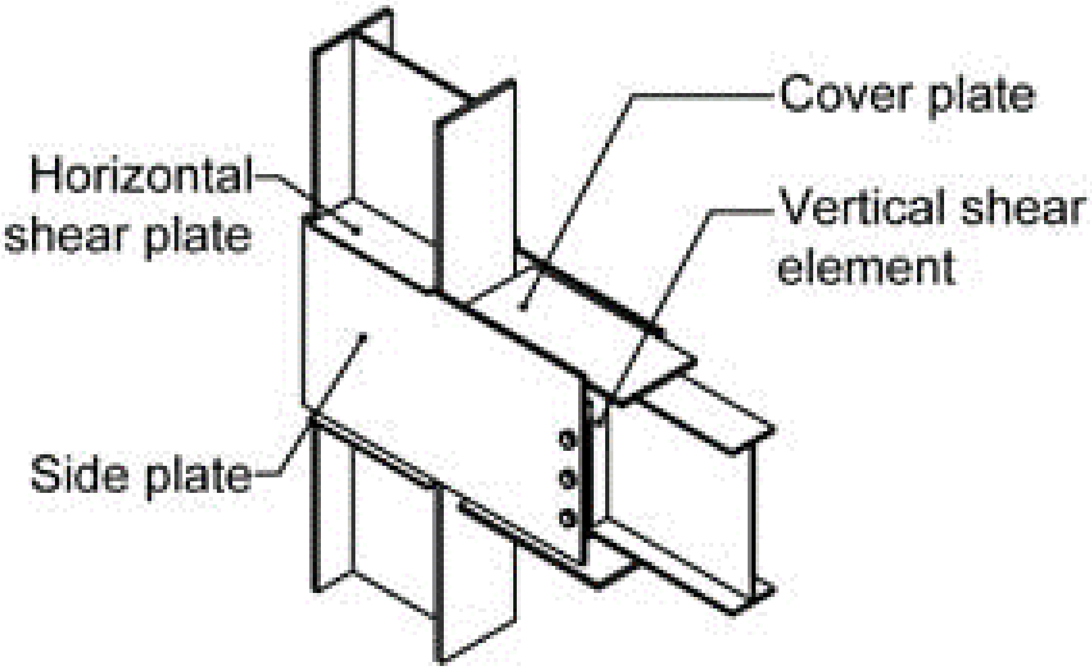
CONXTECH ® CONXL™ Moment Connection



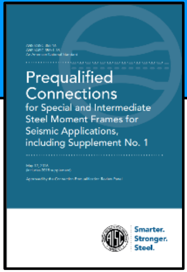
AISC 358-16 Prequalified Connections



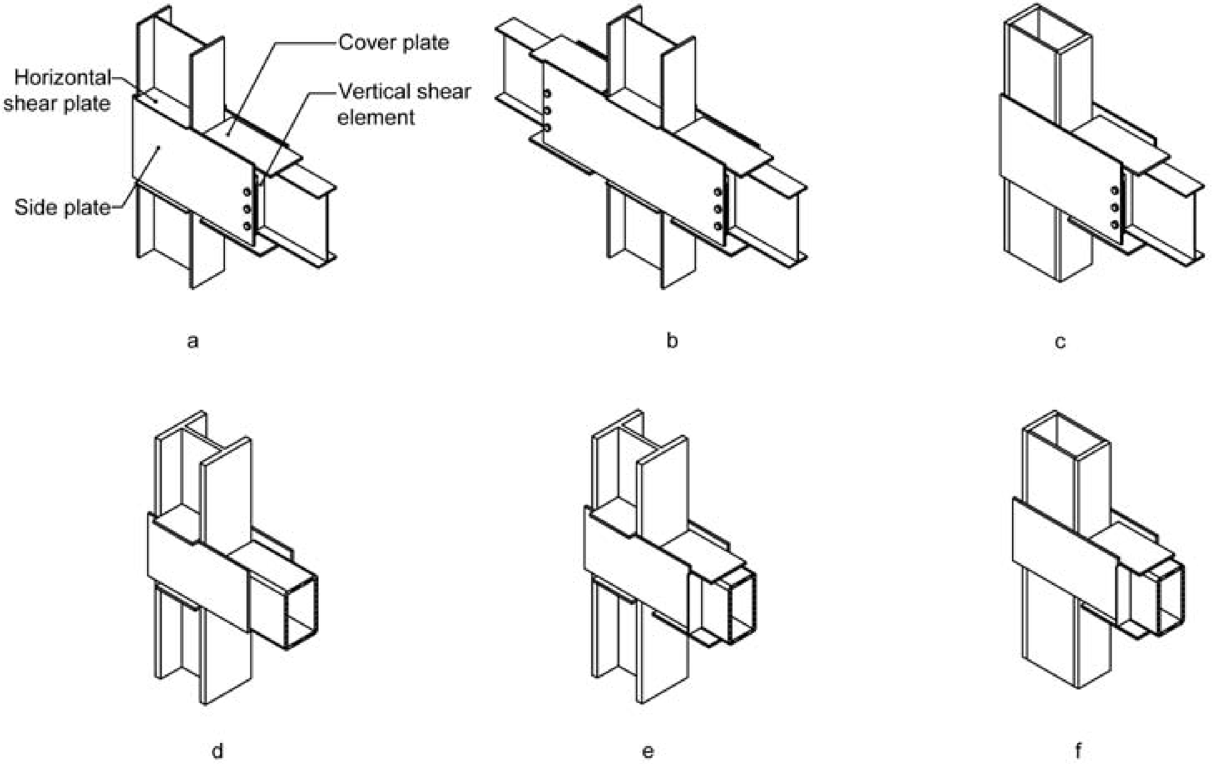
SidePlate® Moment Connection

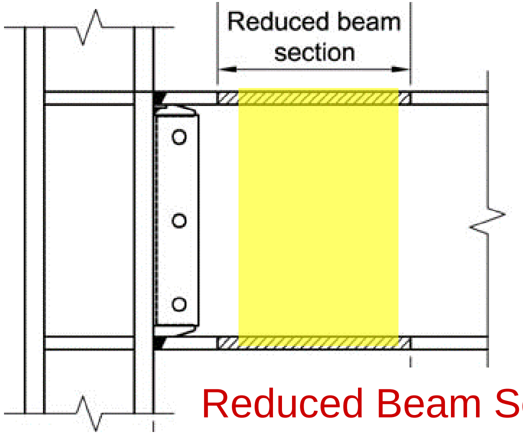


AISC 358-16 Prequalified Connections

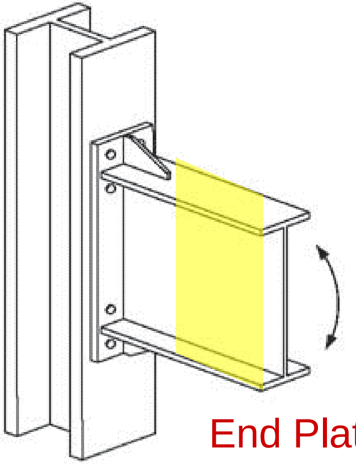


SidePlate® Moment Connection

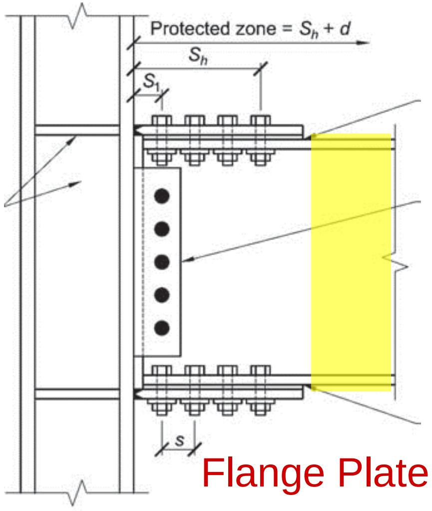




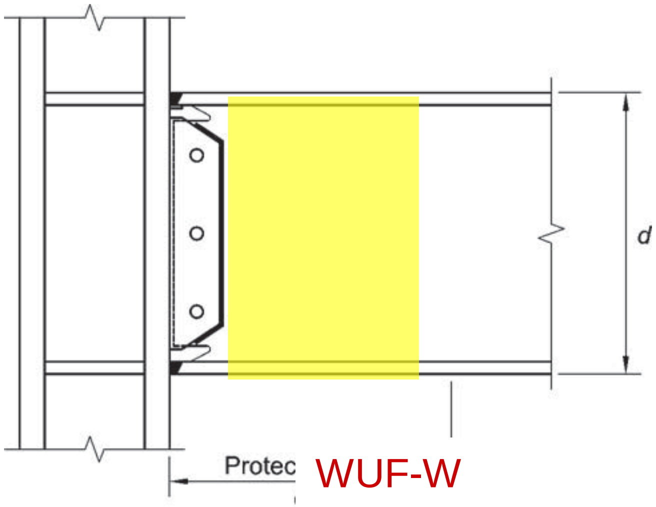
Reduced Beam Section



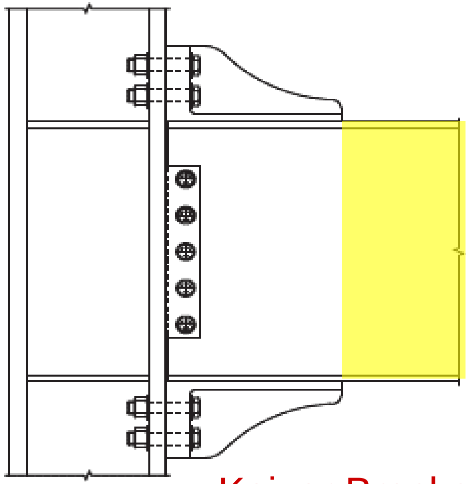
End Plate



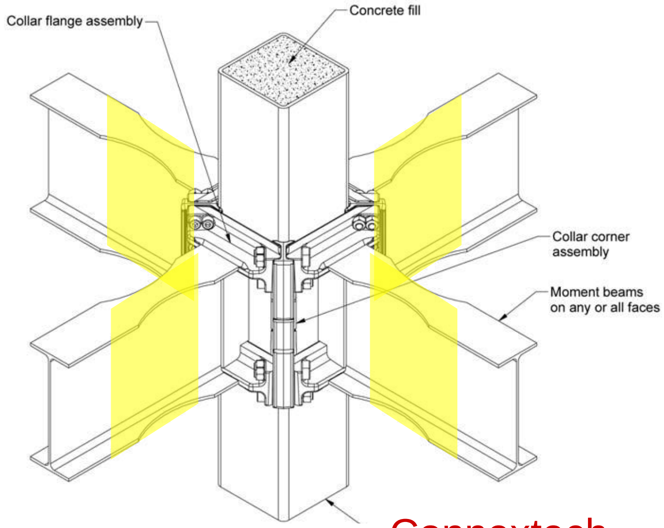
Flange Plate



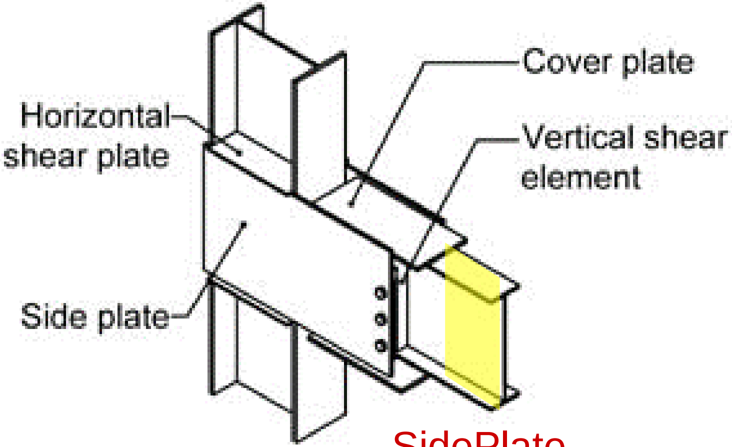
WUF-W



Kaiser Bracket



Connextech

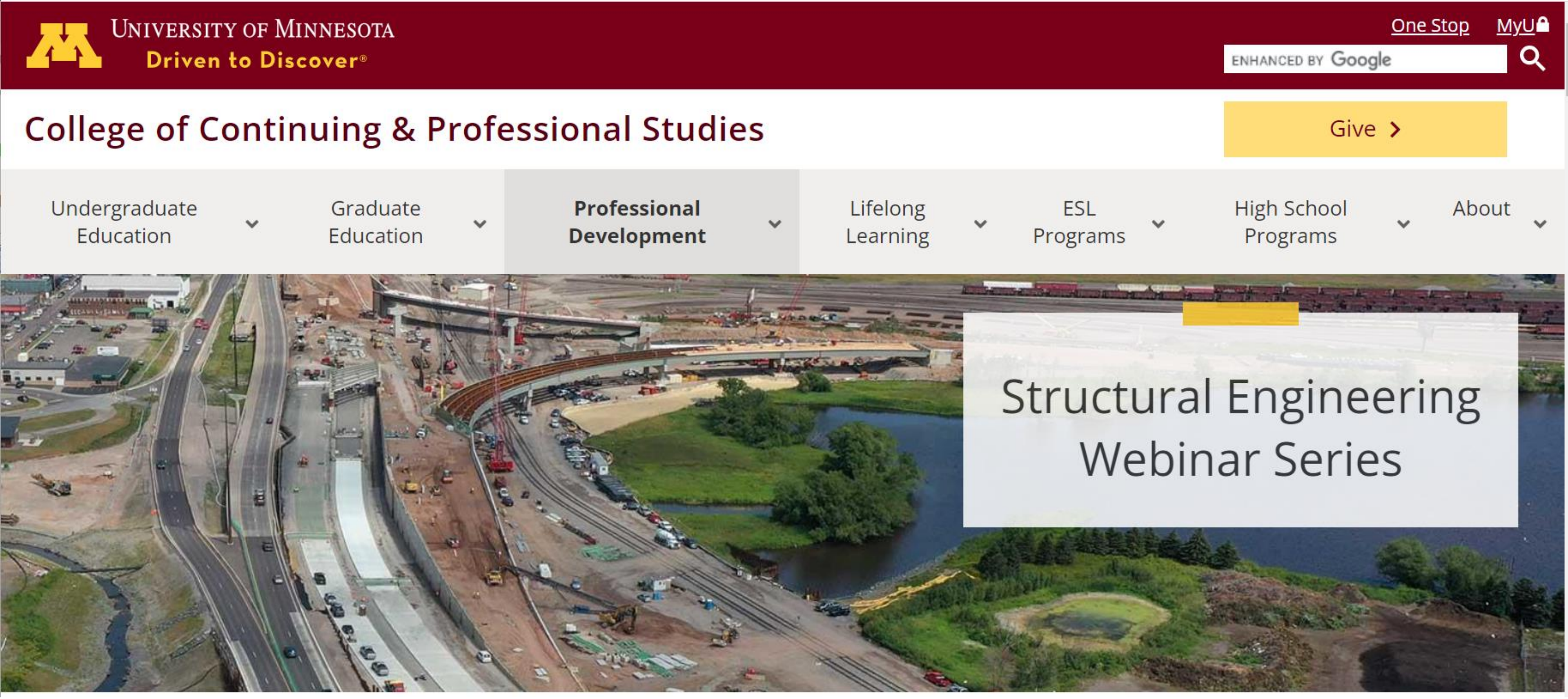


SidePlate

Ductility: Another View

Outline

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



LISTEN to the STEEL

Ductility: Another View

LINCOLN® ELECTRIC