3. Steel (2 courses)

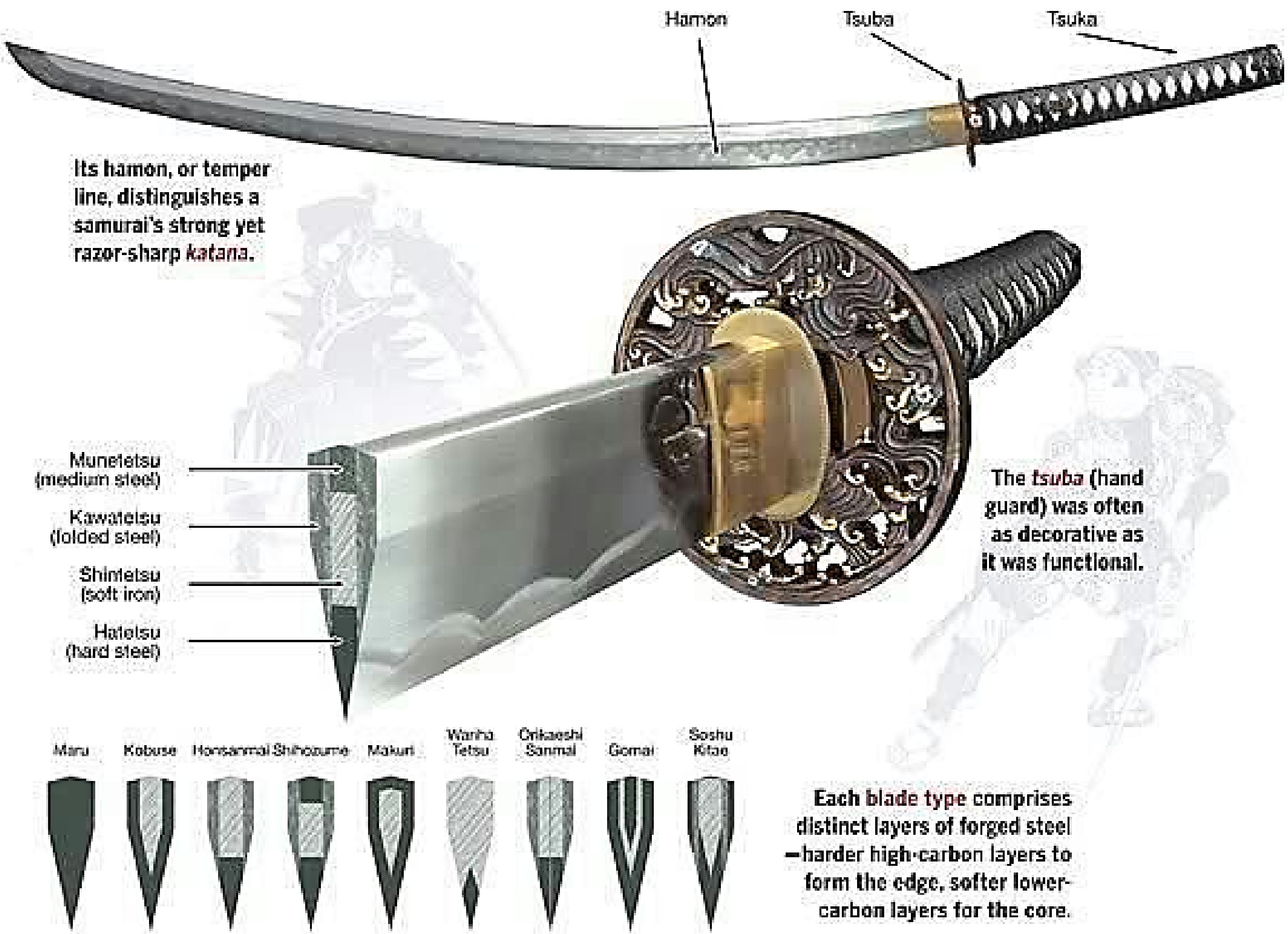
- Definition
- Steel behavior, stress-strain response
- Sections properties
- Production: hot rolled and cold-formed
- Fasteners
- Tensile and compression behavior
- Local buckling and residual stresses
- Composite structures

Definitions

What is steel ?

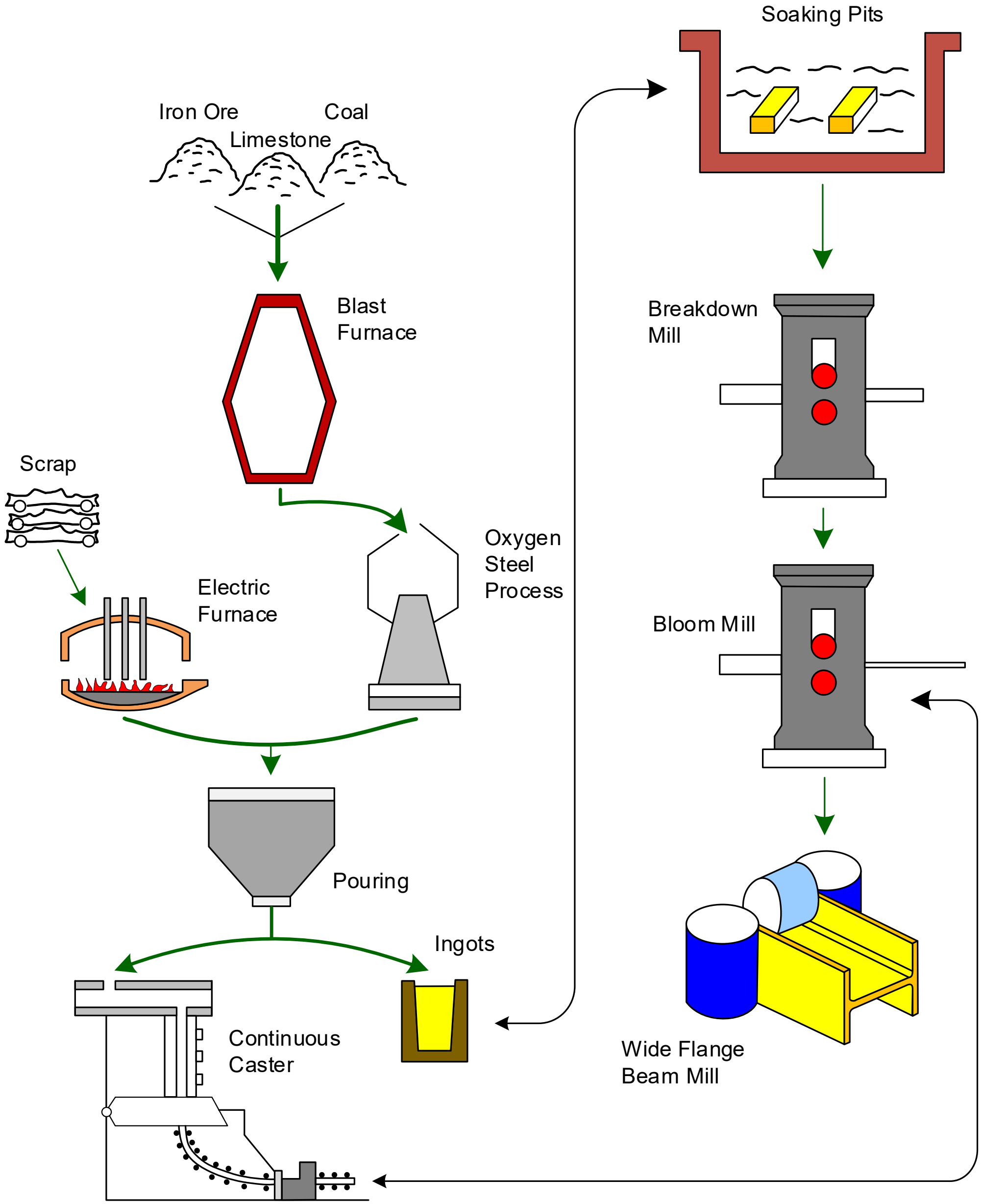
Steel is an *iron* alloy with additional carbon for enhancing its strength and fracture resistance. Additional elements can be added to modify its behavior

The beauty of a Japanese sword



https://www.pinterest.com/pin/562175965963798622/

Steel making process



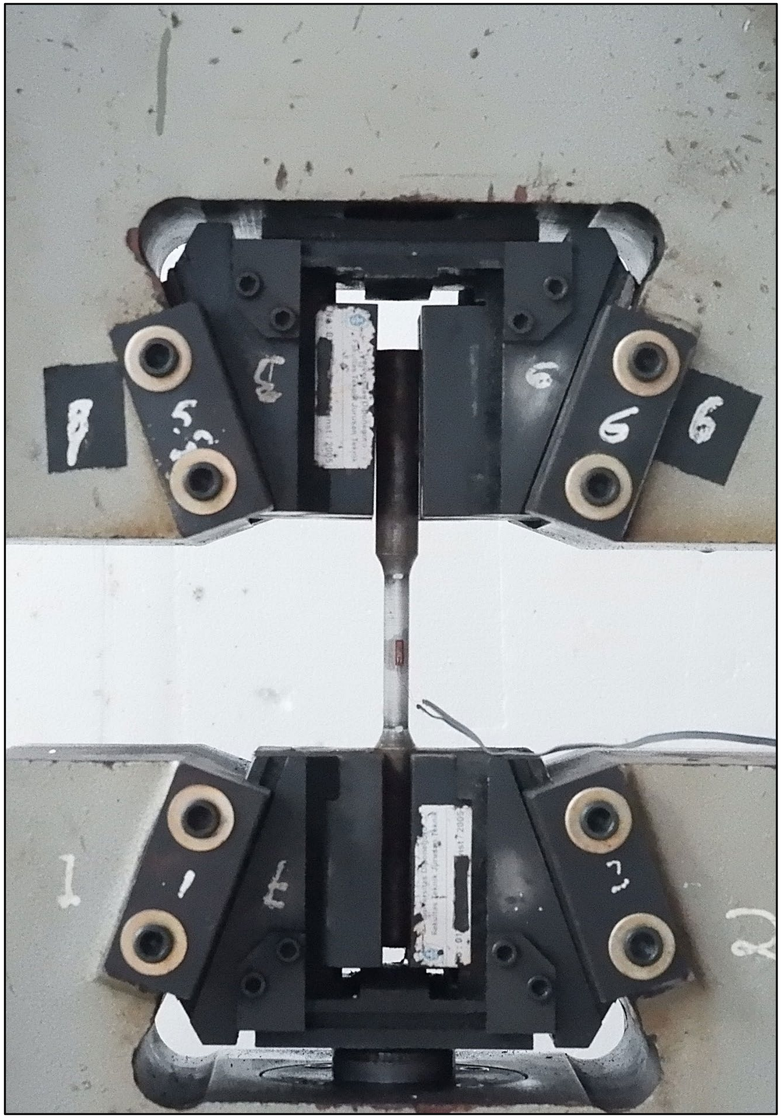
Strength and Ductility

The *strength* and *ductility* properties are the major advantages of steel.

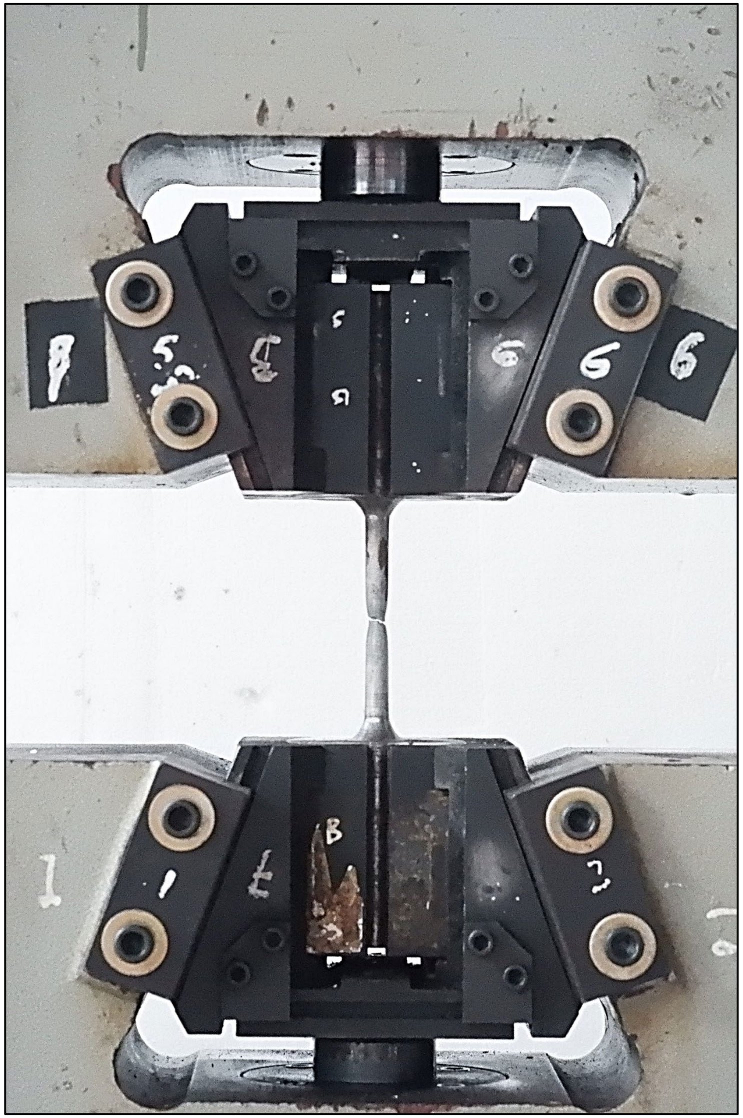
Other points are: ease in fabrication and erection and relative low cost and low self-weight

The *strength* and *ductility* are determined based on the stress-strain behavior.

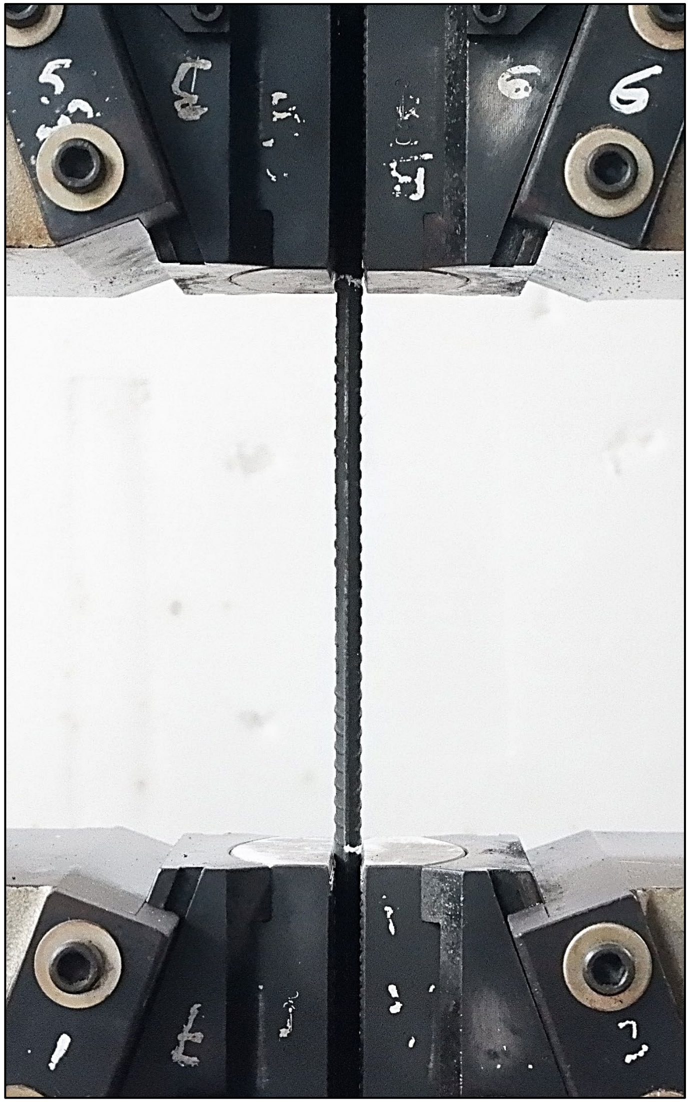
A standard test specimen is pulled in the Laboratory until failure



Prior to testing



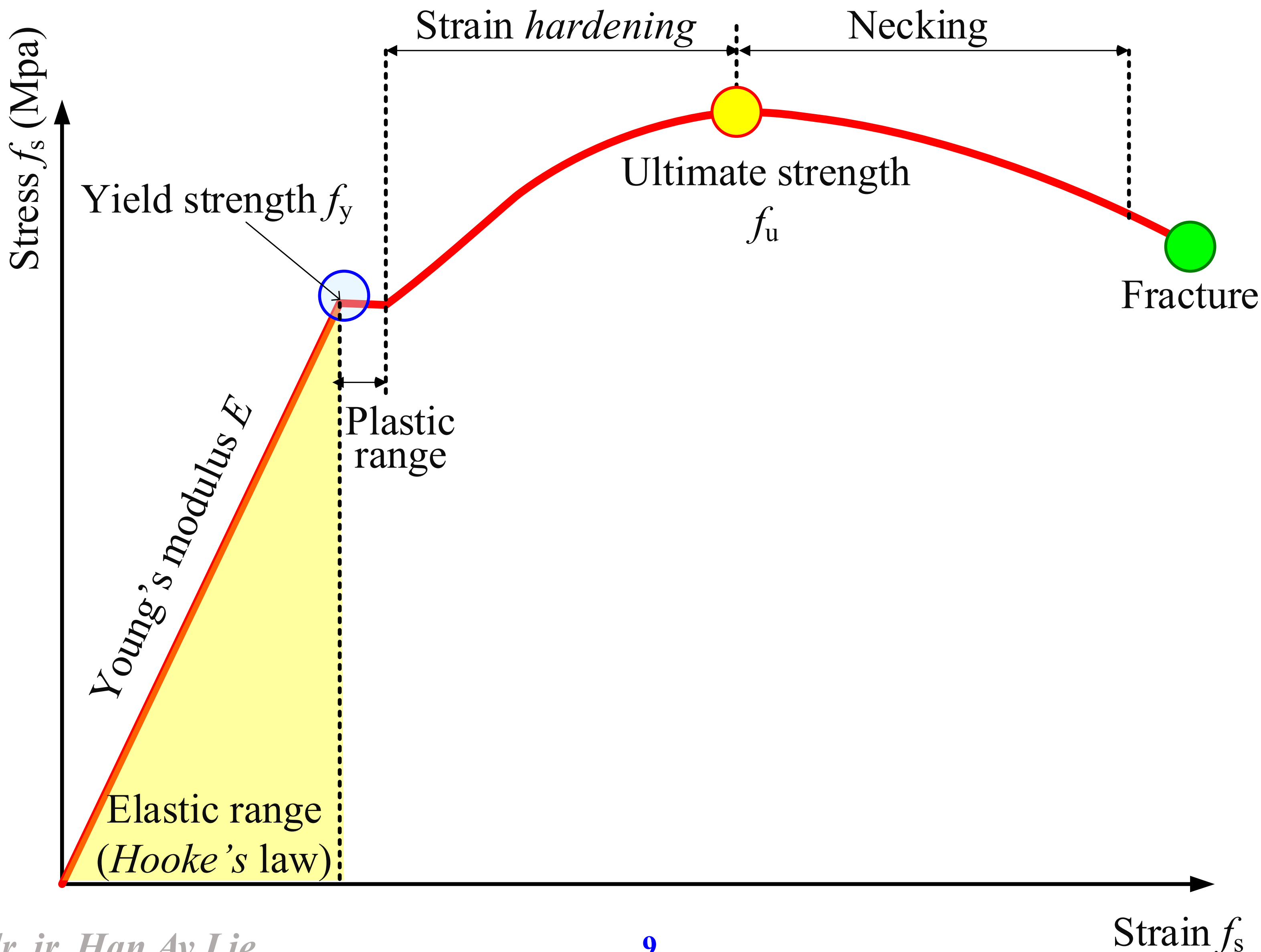
After testing



Prior to testing

After testing

Stress-strain behavior

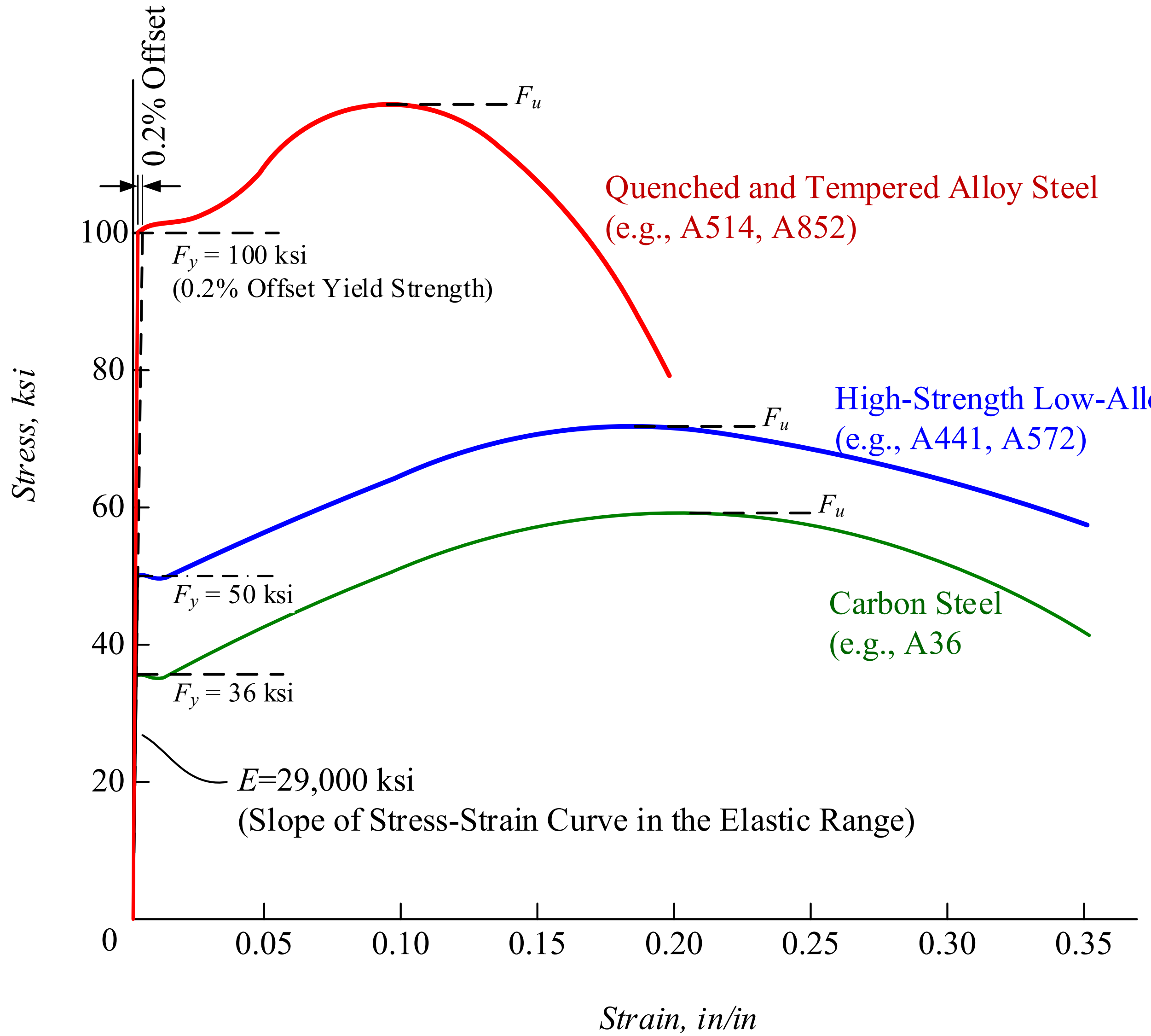


Stress-strain behavior

- The steel behaves linearly until its proportional limit (elastic limit)
- Yielding occur, the strain increases without an increase in stress (*long, flat plateau*)
- Strain hardening, in-elastic behavior
- The maximum stress is reached, the specimen's cross-section decreases

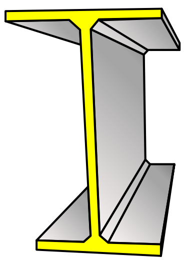
- Not all steels exhibit a yielding plateau (*for exp. high-strength steel*)
- The maximum stress that the material can carry is mandates as the *strength* f_u of the material
- The ability to undergo large plastic deformations is defined as the *ductility* of the material

Stress-strain behavior

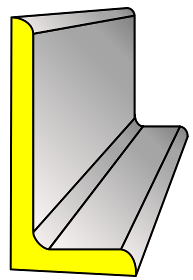


Cross-section Properties

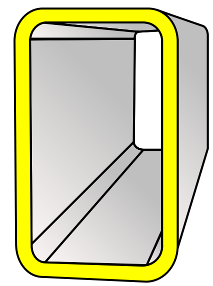
The strength of steel is relatively high as compared to concrete and timber. This will result in generally *slender* sections



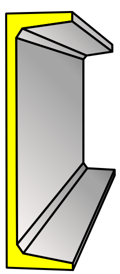
BEAM



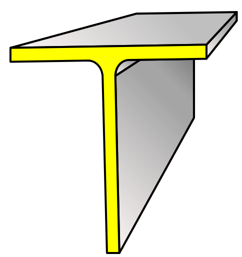
ANGEL



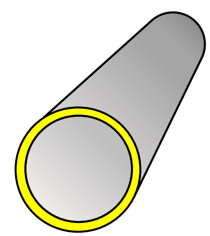
HOLLOW



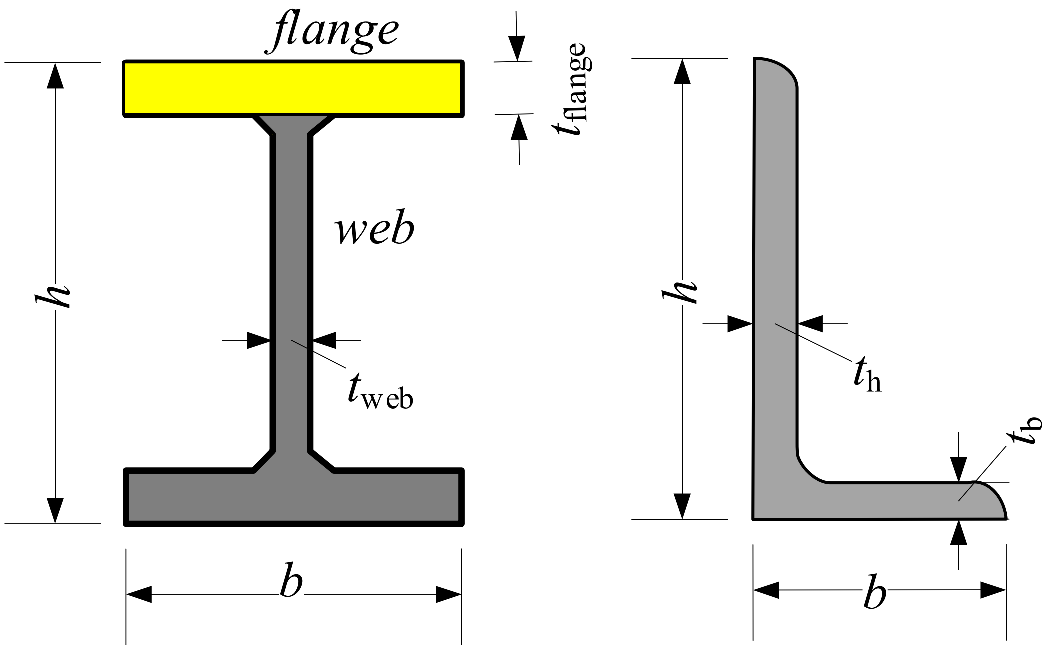
CANAL



TEE



Cross-section Properties

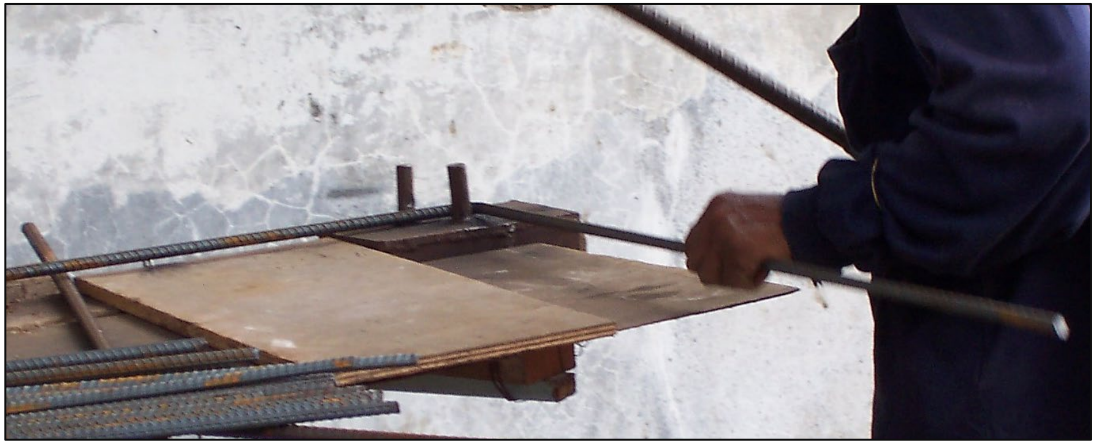


- Hot rolled section can have variation in thicknesses for the flange and the web, whereas cold-formed sections have the same thickness throughout the entire section

Cold-formed and hot rolled sections

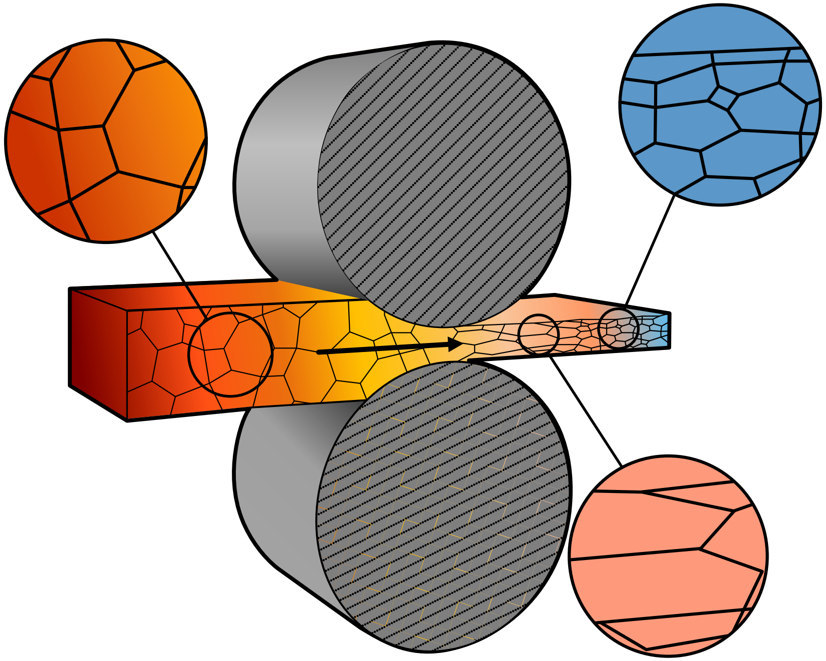
- Hot rolling is a process of rolling steel at a high temperature (925^0 C). This is above the crystallization temperature of steel so that the steel can be molded (shaped and formed)
- Cold formed sections are mechanically formed at room temperature

Cold formed section

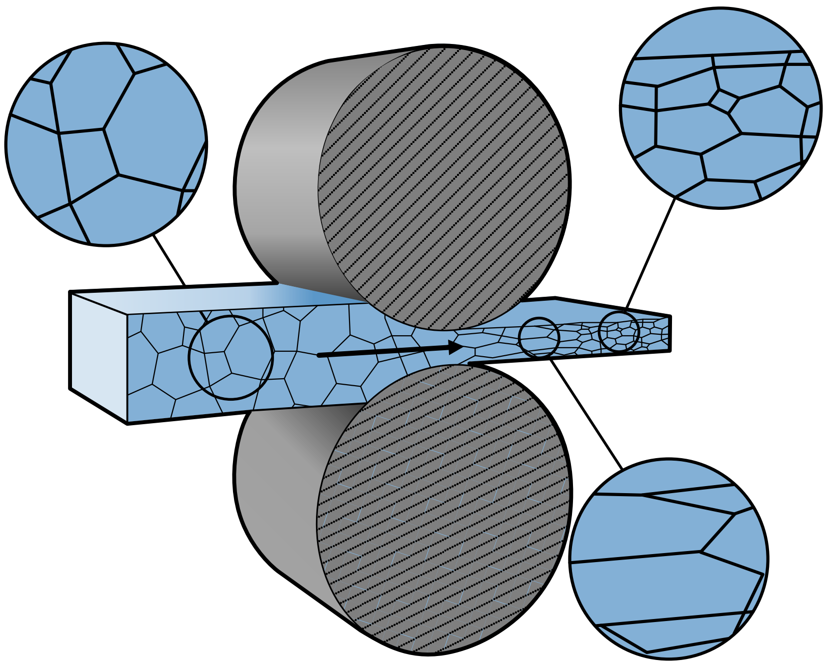


Hot rolled section

https://fscutlery.com/about/

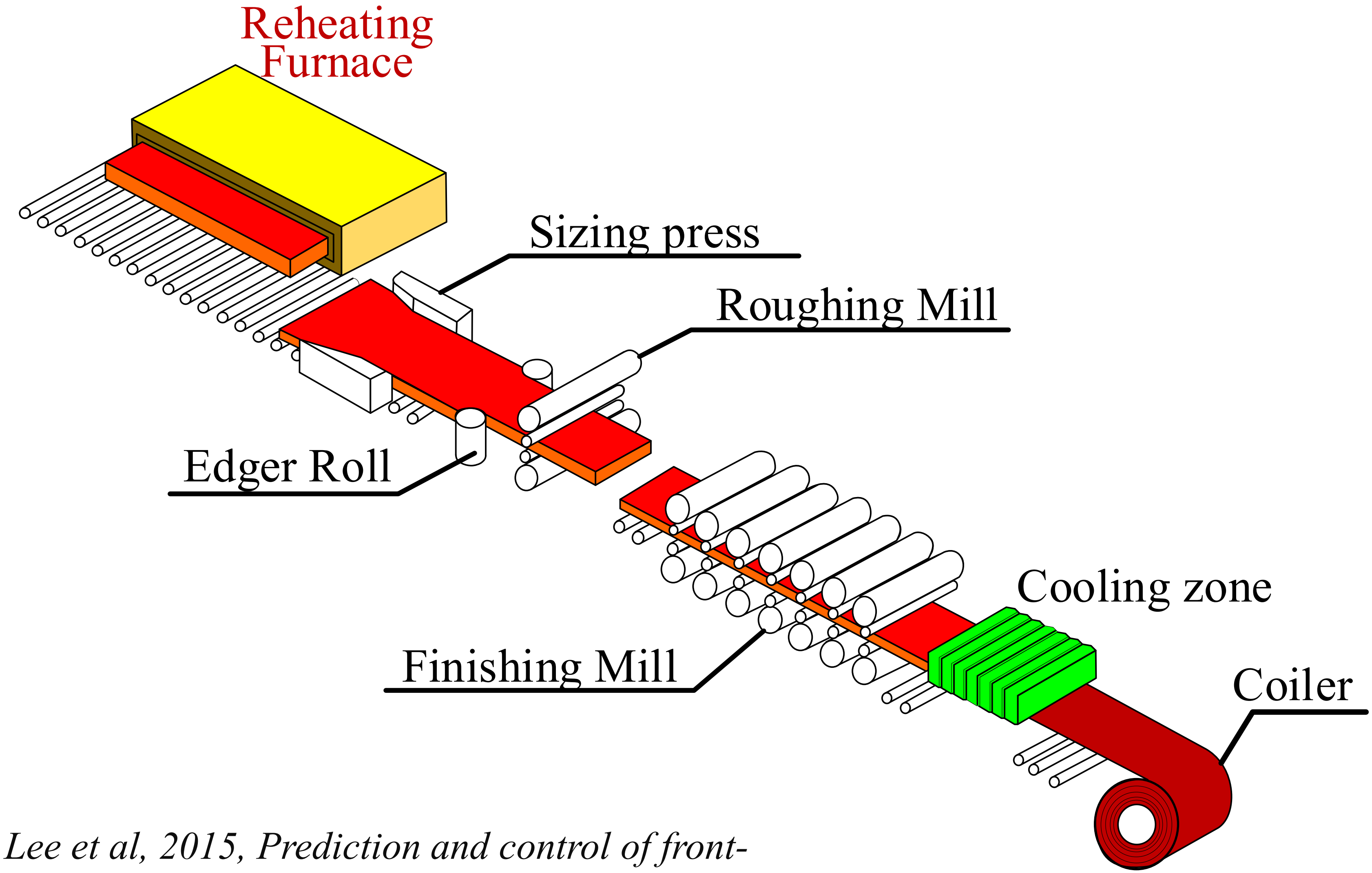


Hot rolled section



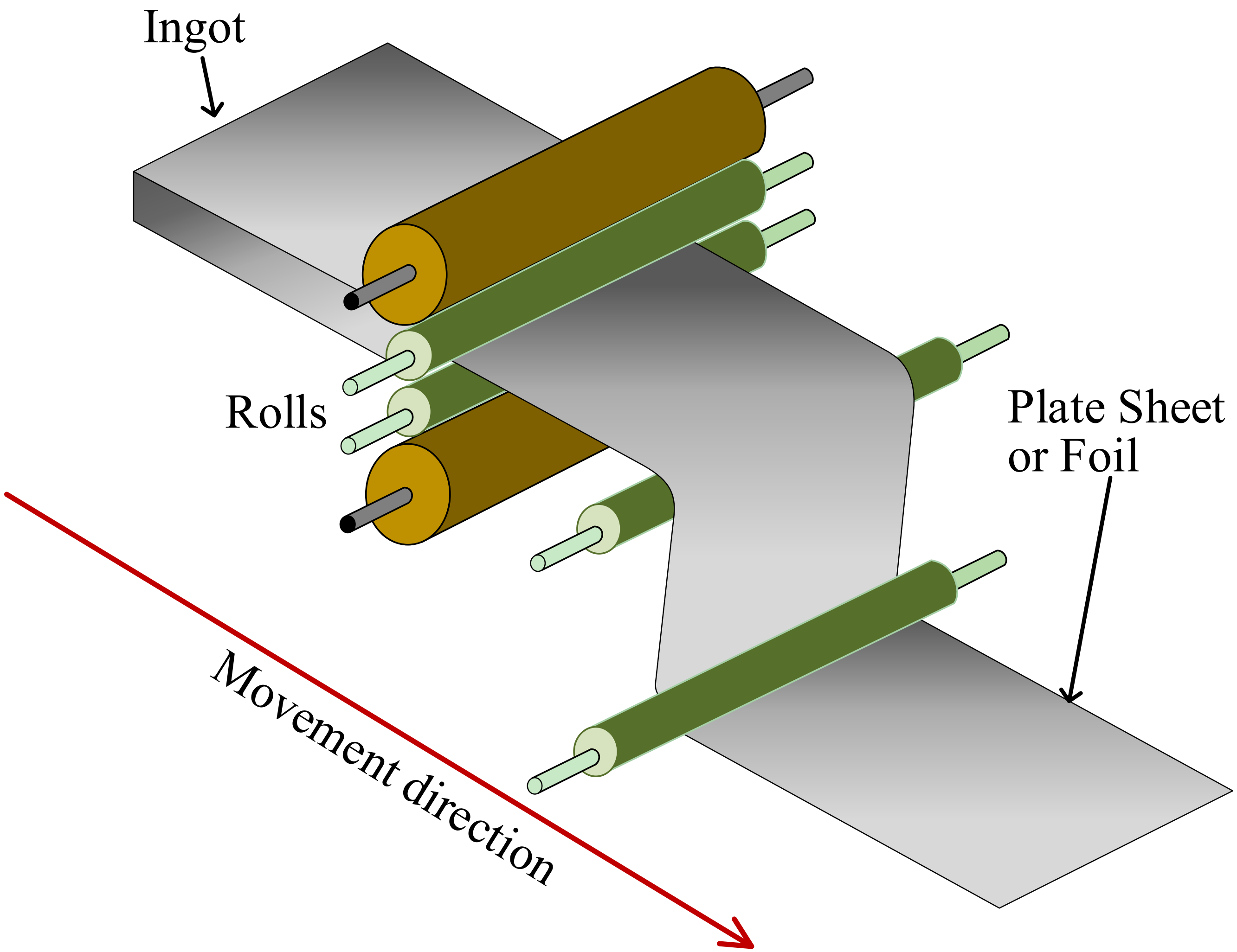
Cold formed section

Hot rolled sections



Lee et al, 2015, Prediction and control of front-end curvature in hot finish rolling process

Cold formed sections



http://www.themetalcasting.com/cold-forming-process.html

Structural fastening

Mechanical fastening

1. High strength bolts (*heavy hexagon-head with hexagon nuts*)
2. Ribbed bolts (*rounded head and ribs parallel to the shank*)
3. Rivets (unthreaded fastener that uses expansion for fastening)

Welding

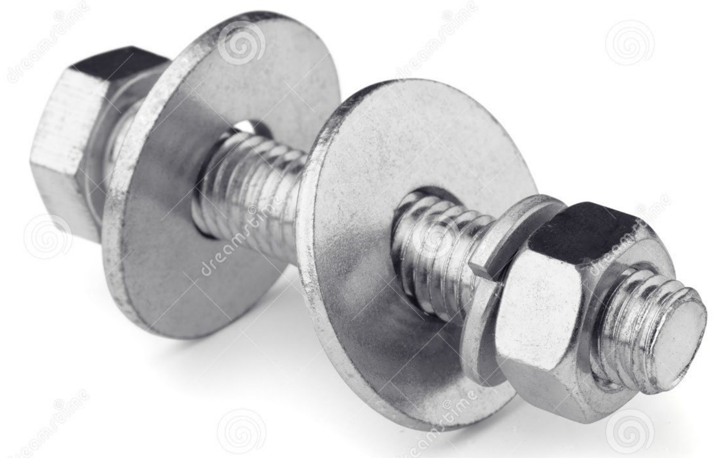
Welding is the process of joining metal by heating to a plastic or fluid state

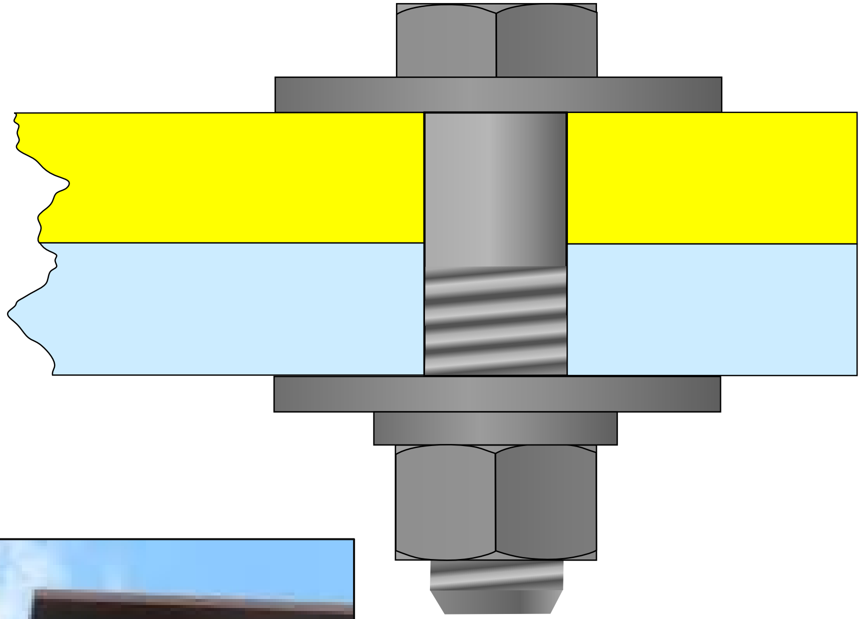
High strength bolts

Ribbed bolts

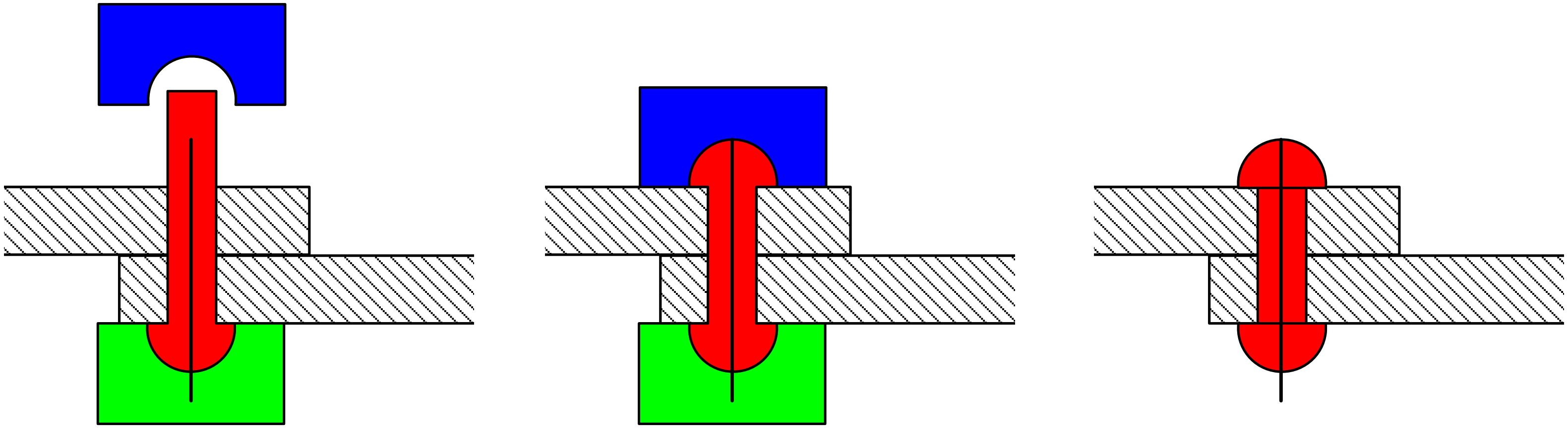
Rivets

High strength bolts

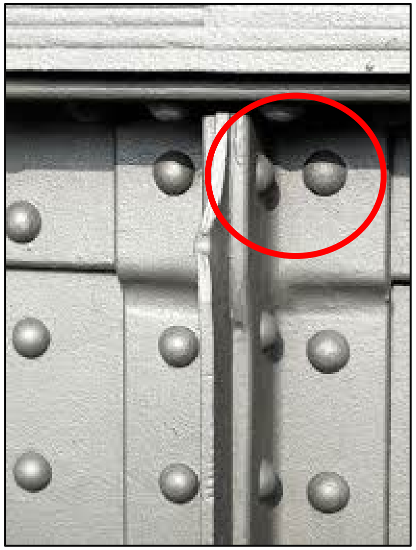




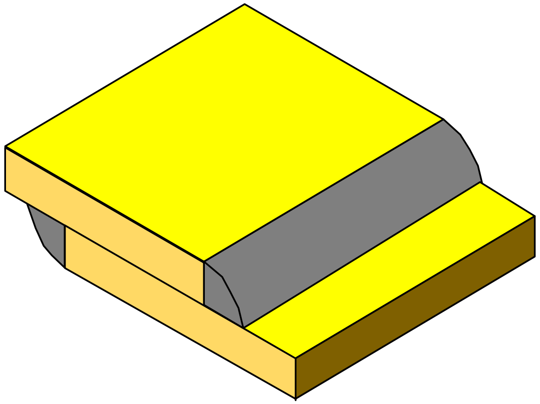
Rivets



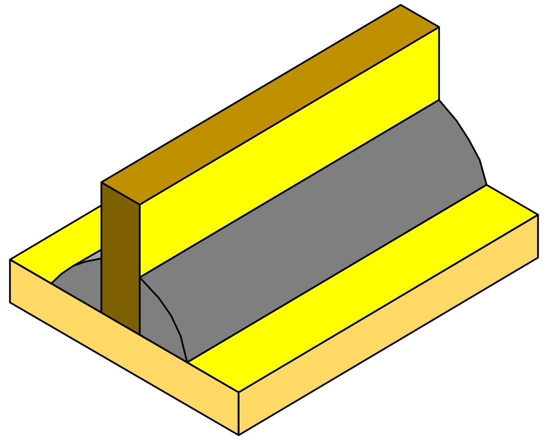
material heating *rivet forming* *final product*



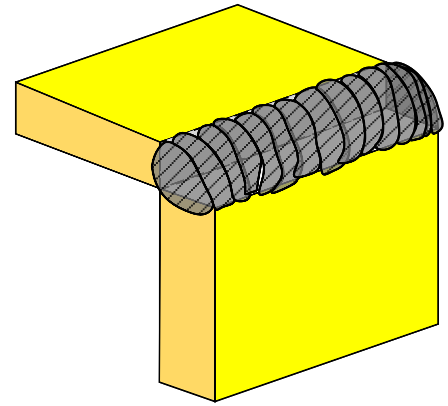
Welding



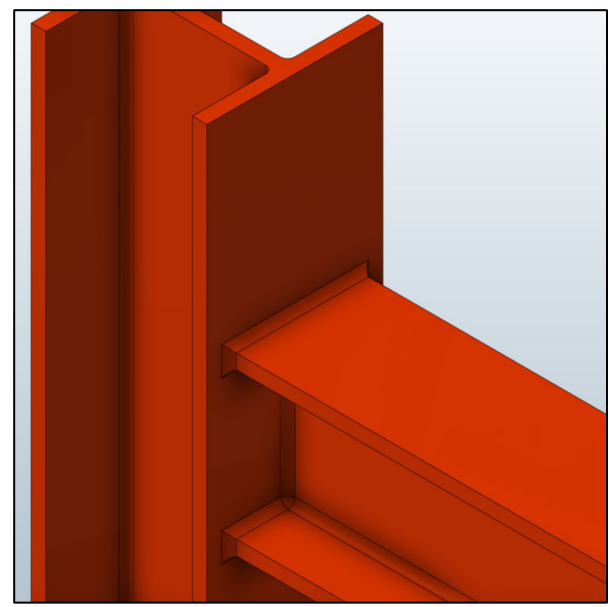
lap joint



tee joint

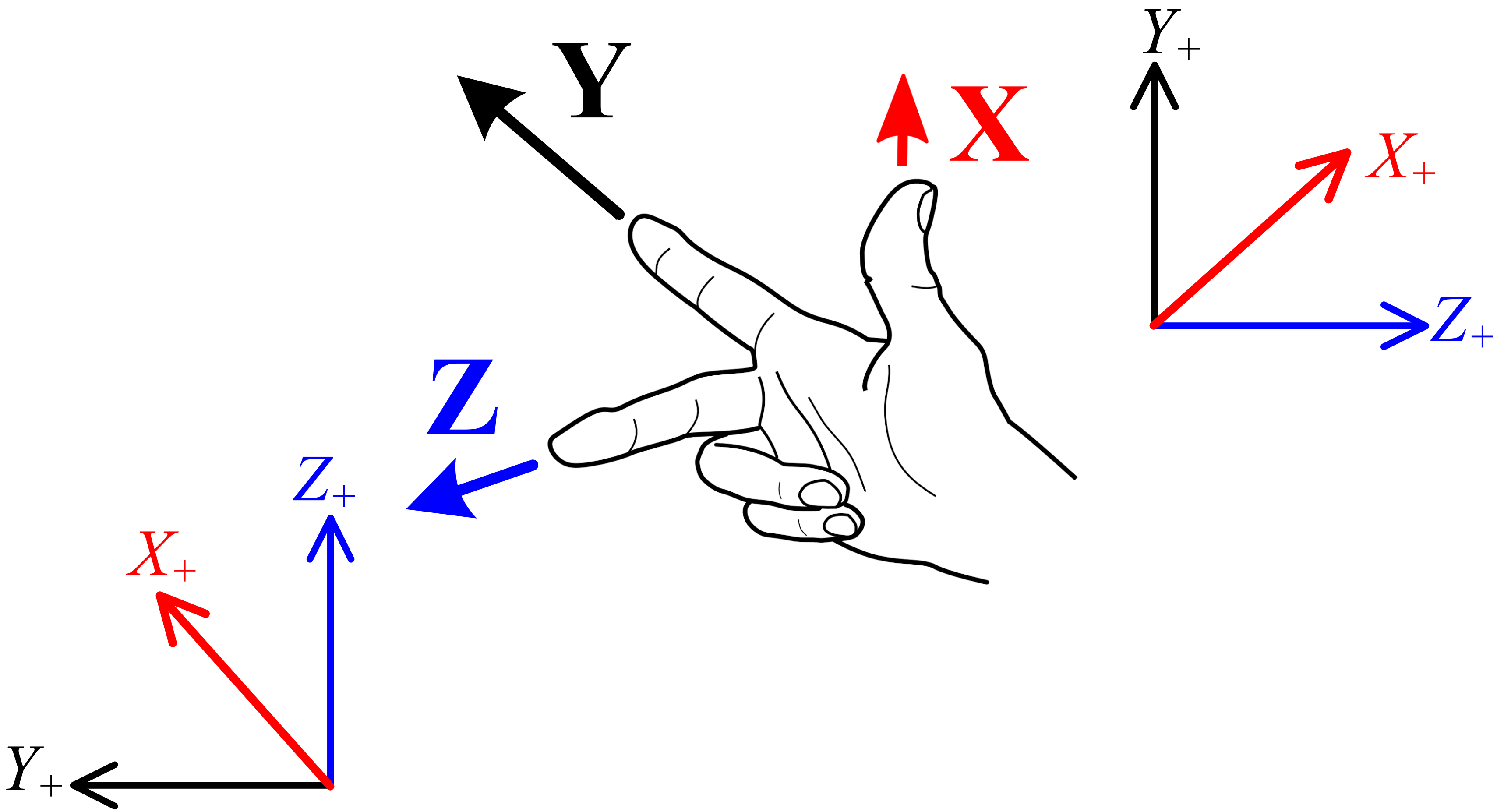


corner joint



Tensile and compression response

The Cartesian right-hand rule

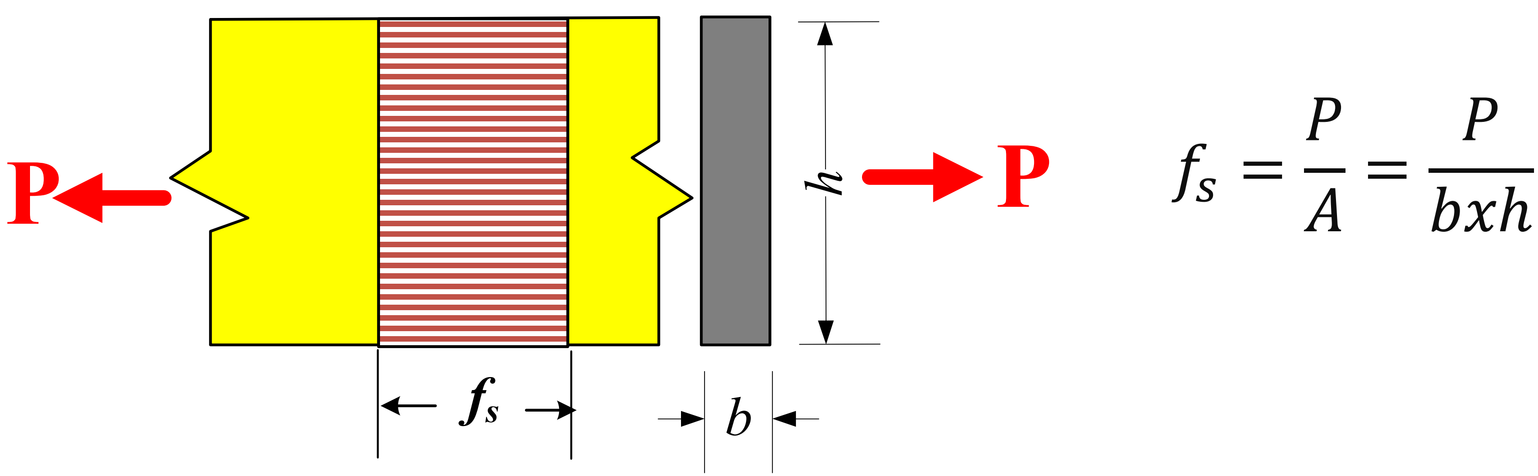


Tensile stresses

The tensile stresses can be easily calculated from the basic formula:

$$f_{s\ actual} = \frac{P}{A} = \frac{P}{bxh}$$

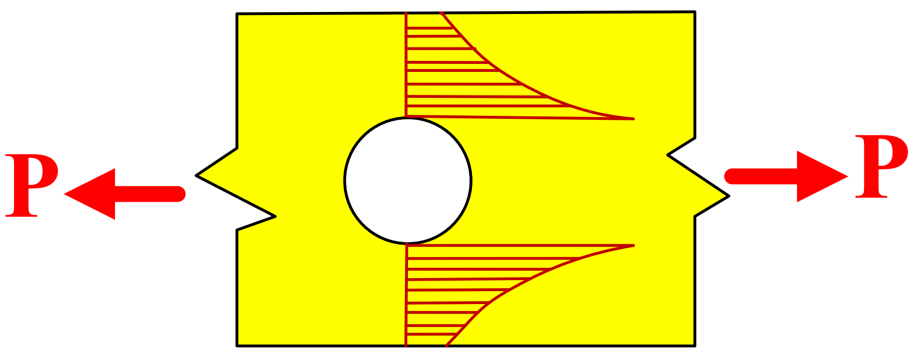
Where: P is the tensile load (N), and A is the area where the load is acting (mm^2)



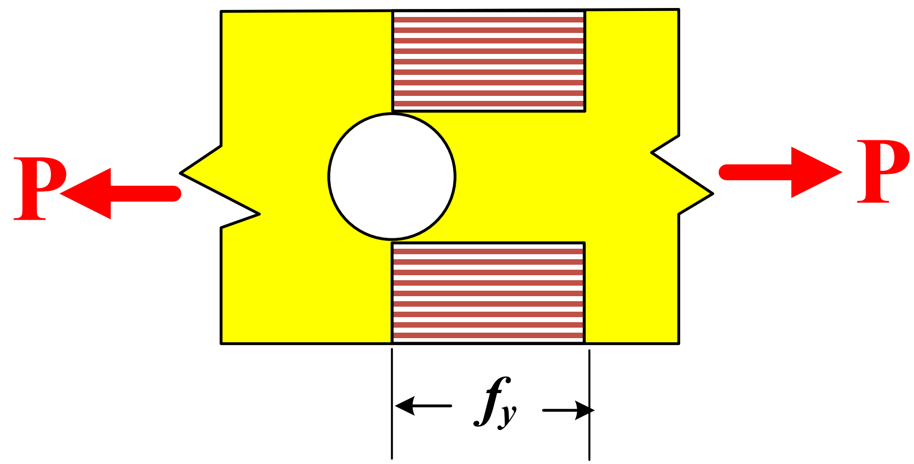
In the case of holes (for connectors)

$$f_{s\ actual} = \frac{P}{A_{nett}}$$

Where: P is the tensile load (N), and A_{nett} is the net area where the load is acting (mm^2)



Elastic stresses



Ultimate condition

Compression stresses

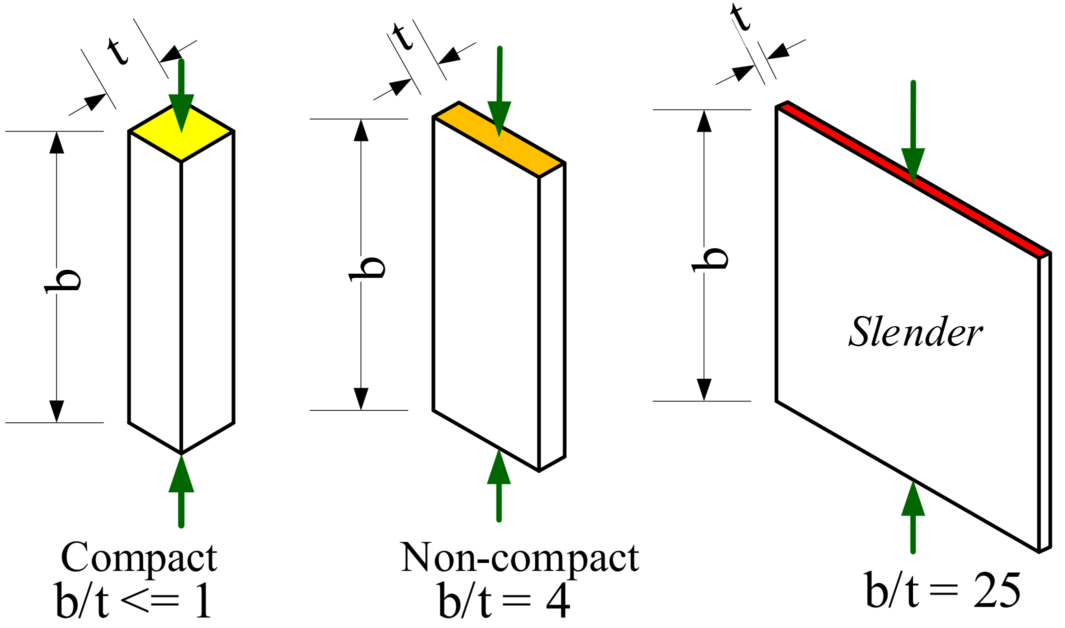
The compression stresses are also calculated from the basic formula:

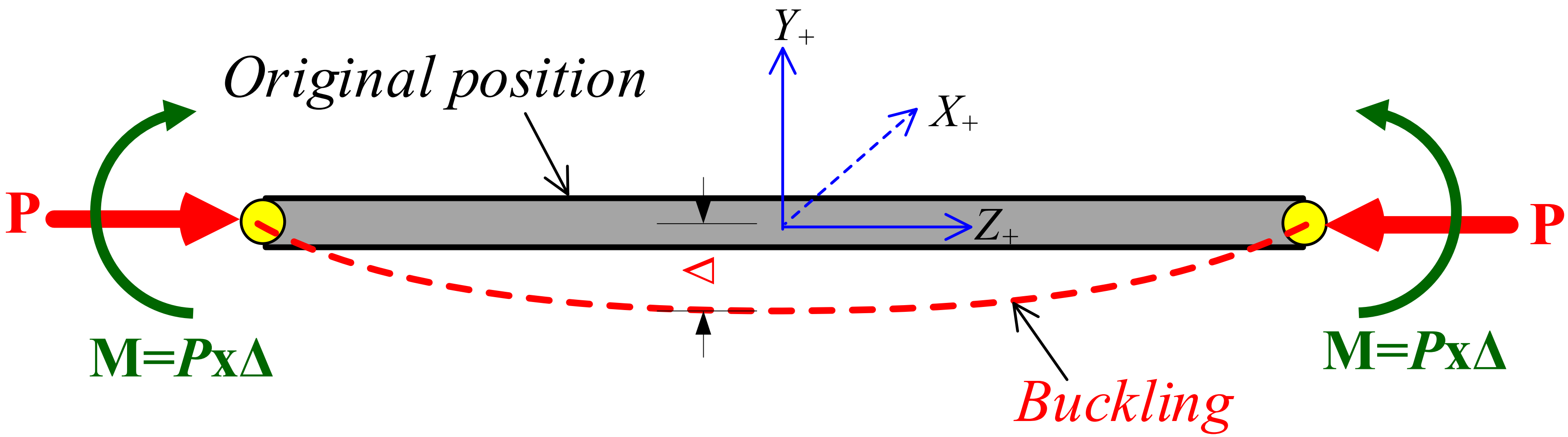
$$f_{s\,actual} = \frac{P}{A}$$

Where: *P* is the compression load (N), and *A* is the area where the load is acting (mm^2)

But buckling becomes a problem

Thin plates may buckle before the full strength is attained if the thin plates are too slender.


t
b
Compact
b/t <= 1
t
b
Non-compact
b/t = 4
t
b
Slender
b/t = 25



Due to buckling, a deviation of Δ creates an additional moment in the element. Now the element carries a compression load ***P*** and a moment **M = *P* x Δ**

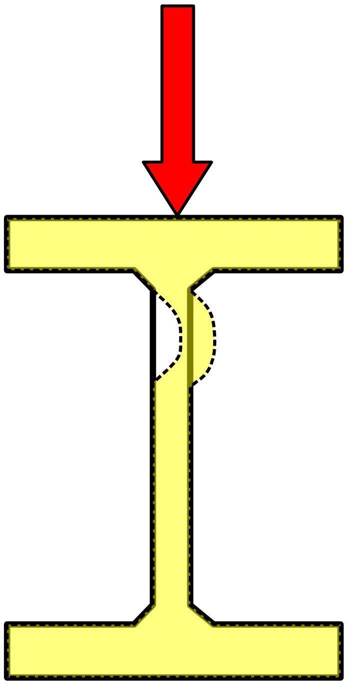
This is called the *P*-Δ effect

The steel sections are sensitive to:

- *Local buckling*. When a part of a cross-sectional element fails in buckling, the member capacity is reached.

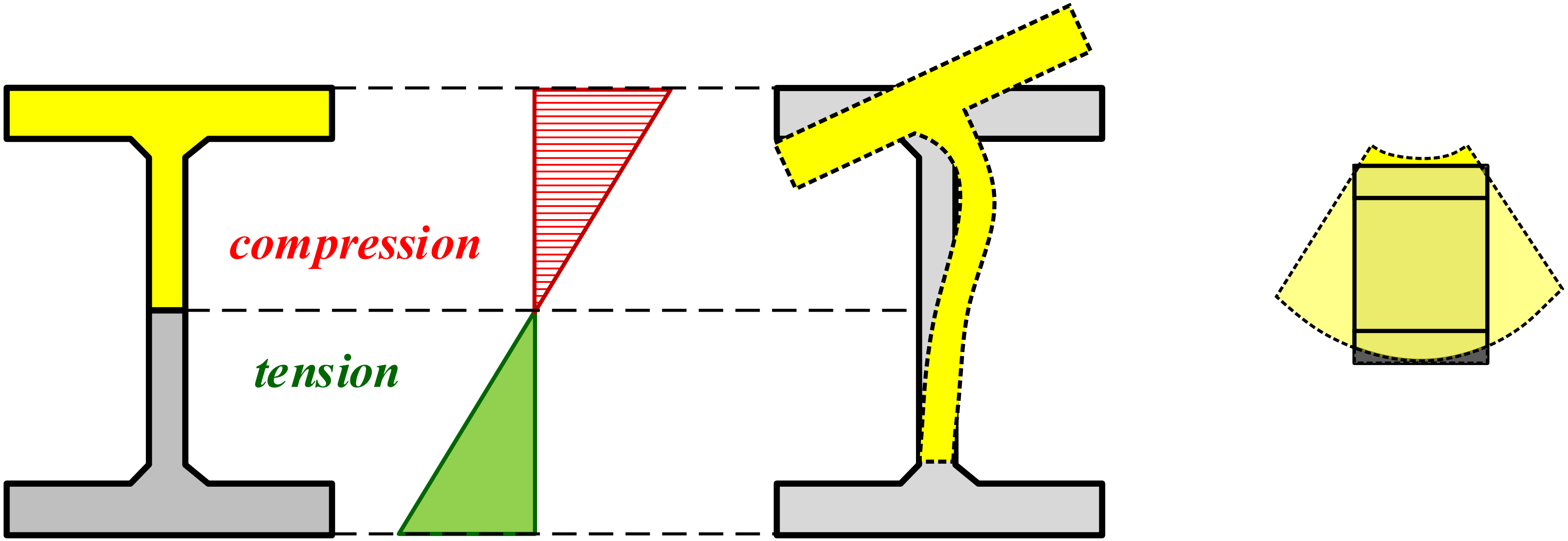
- Local buckling it the phenomenon of *partial buckling* within a section

- Types of WF sections local buckling
- *Web crippling*. The *web buckles* under large direct loading.



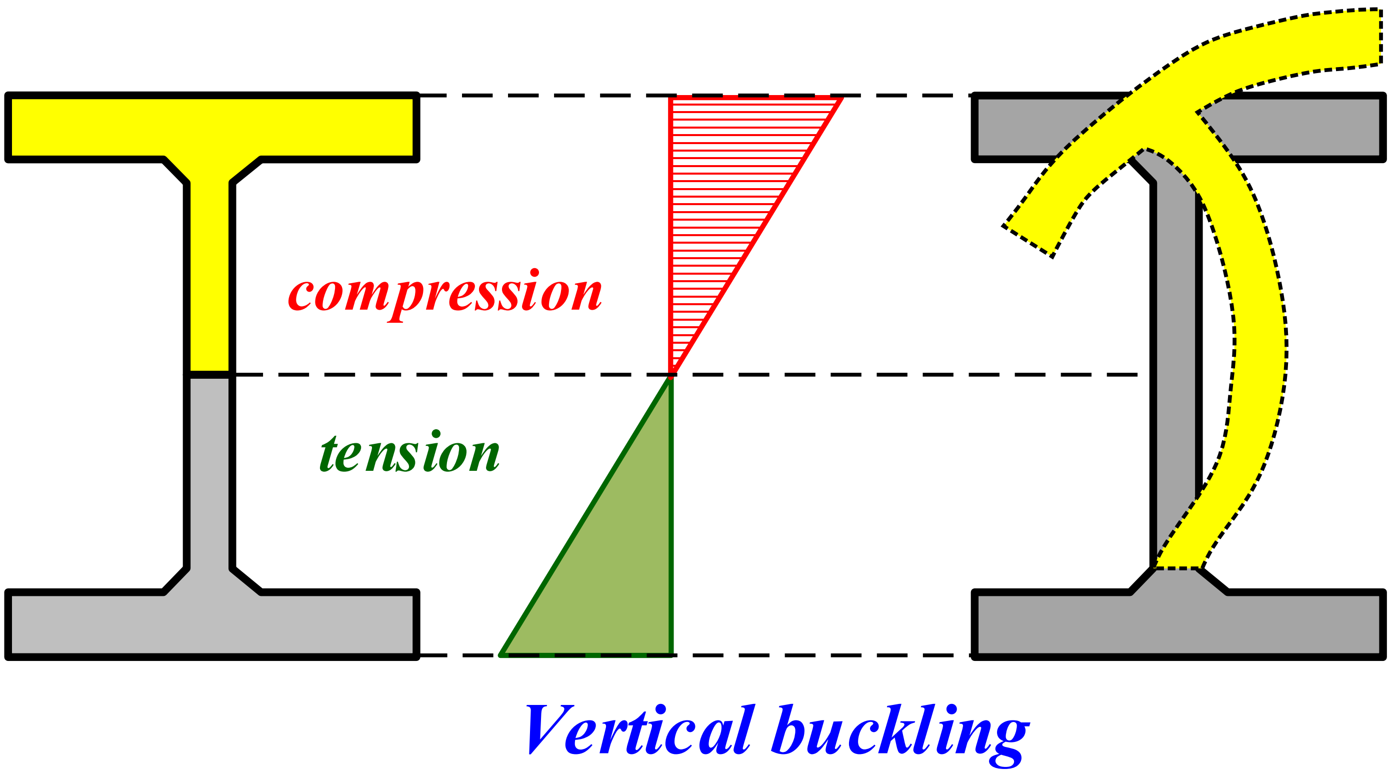
Web crippling

- *Bend buckling.* The web of a section fails due to *high compression* stresses (*in flexure*).

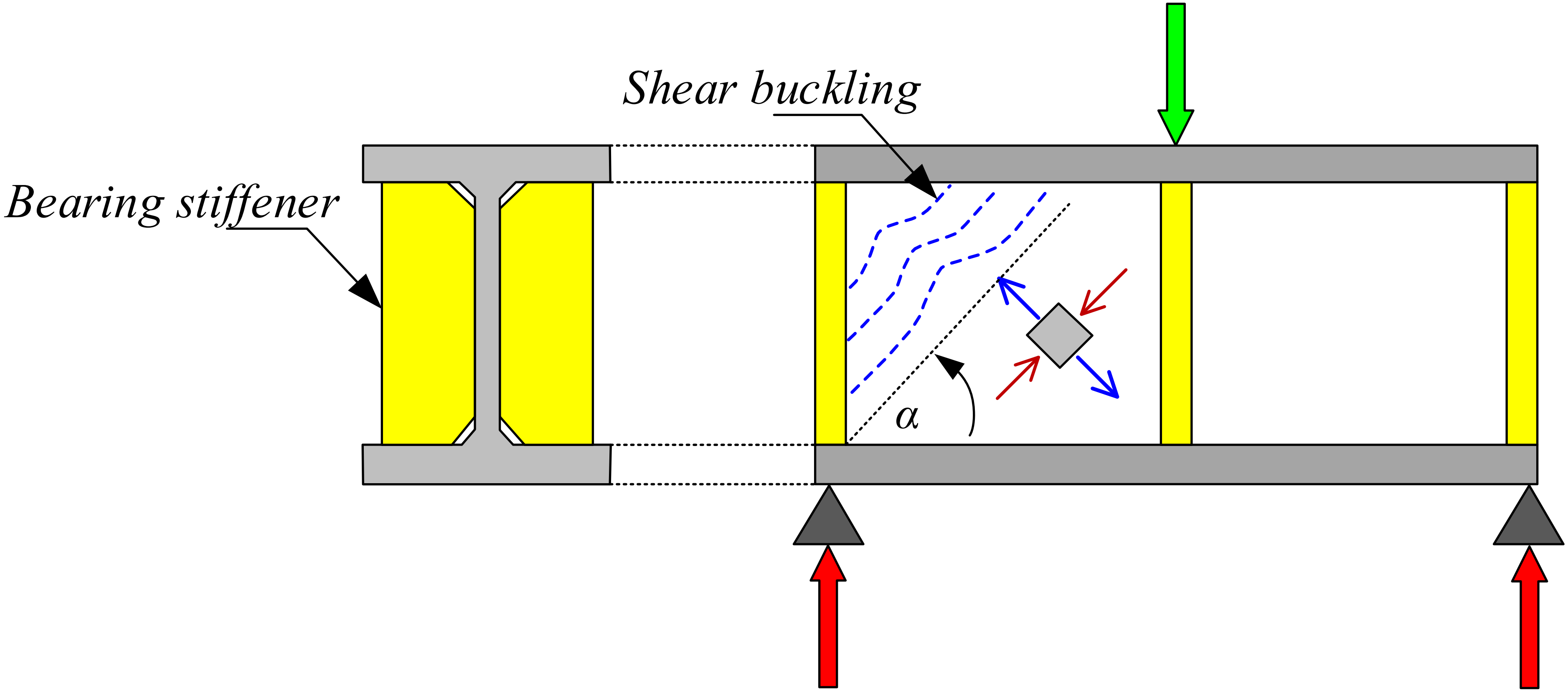


Bend buckling

- *Vertical buckling. Yielding in the flange.*



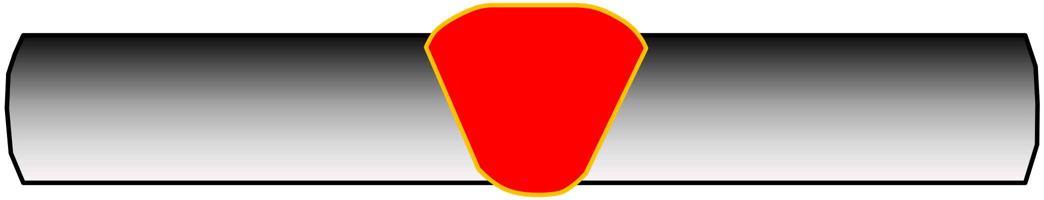
- *Shear buckling.* Buckling in the *web* due to high *shear* stresses



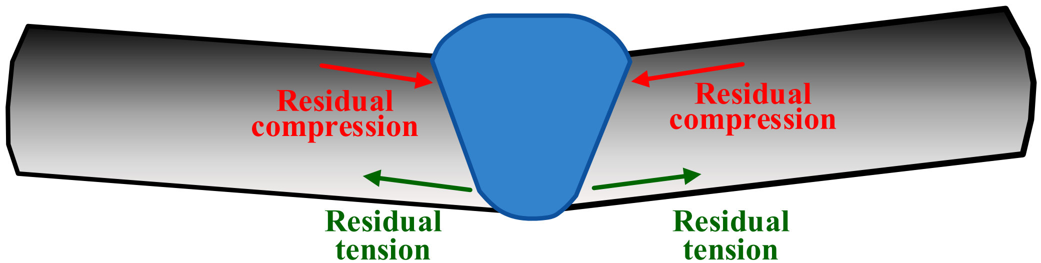
2. *Residual stresses*. Residual stresses are stresses that are present in an *unloaded* section due to the production process. Examples are those induced by *cold bending, cooling, and welding*

The stresses are in *self-equilibrium*, but their presence will influence the behavior of the member under loading

Welding

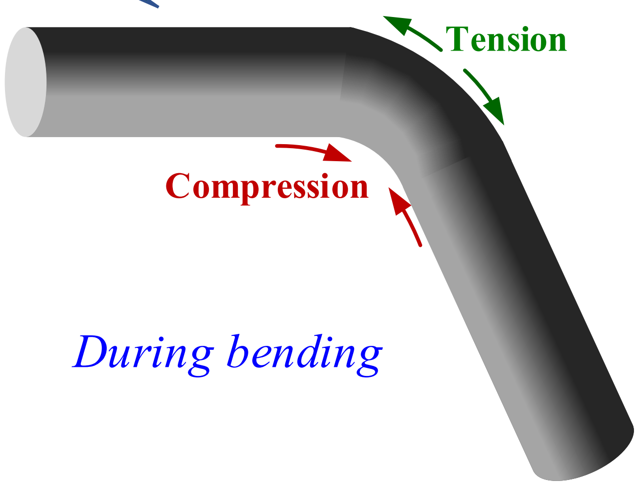


Immediately after welding

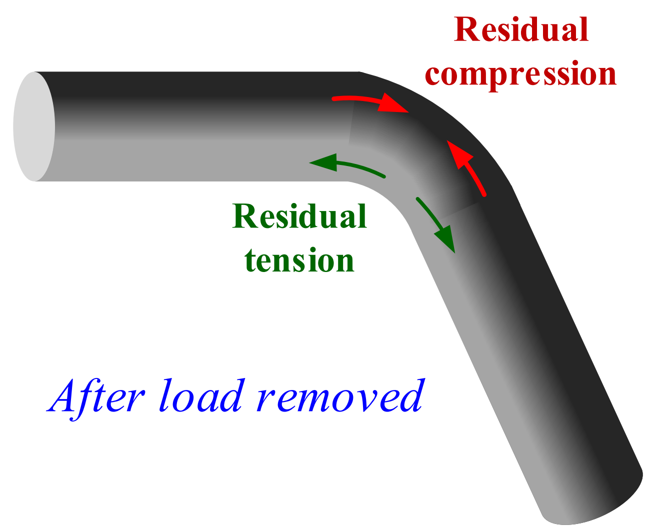


Weldment cooled to room temperature

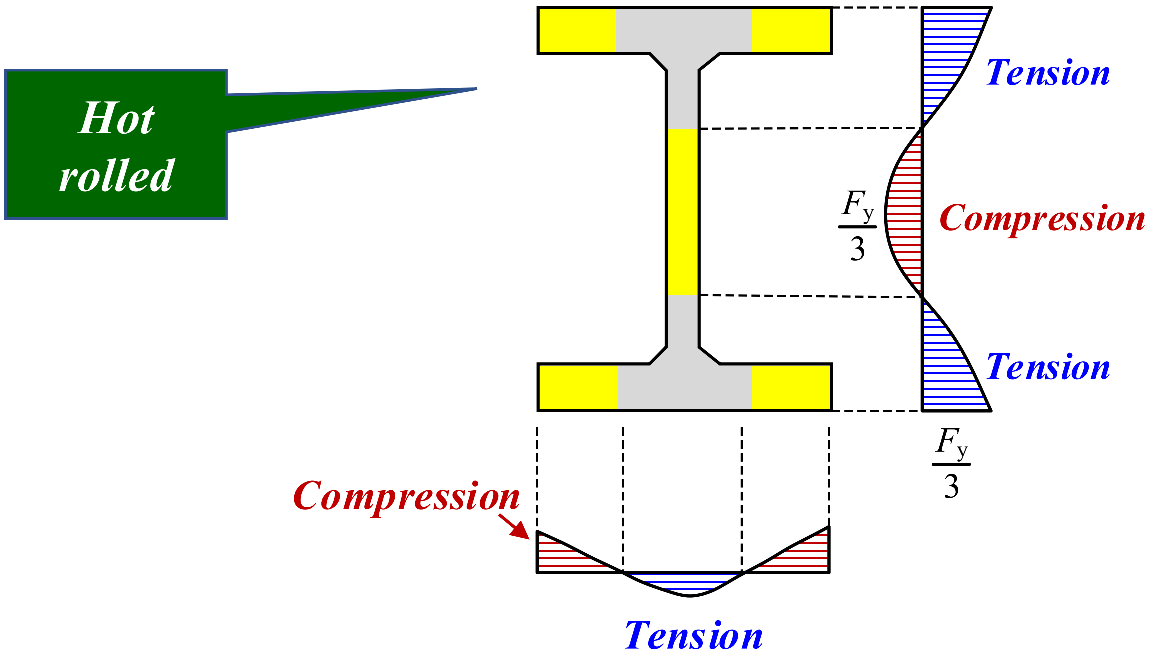
Cold formed



During bending

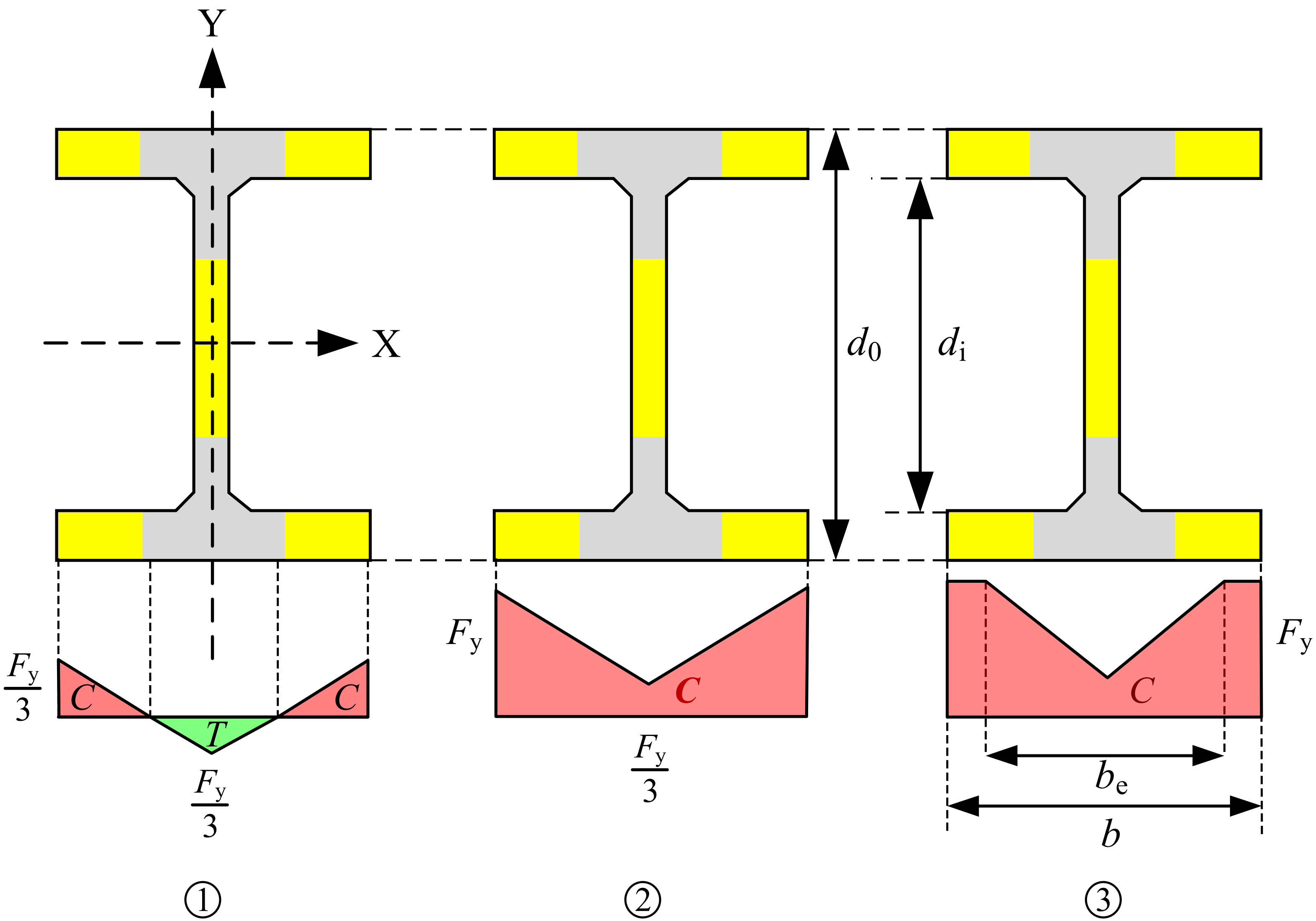


After load removed



Residual Stresses

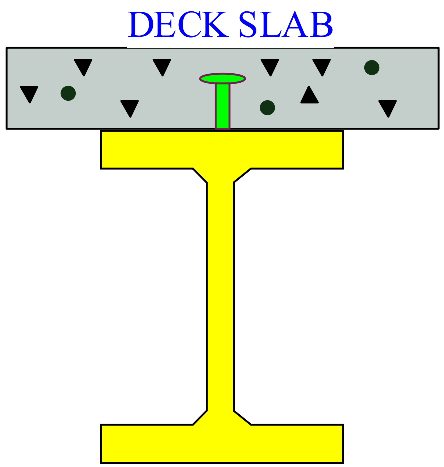
Residual stresses are important especially for *columns* since it will result in premature yielding of part of the section


Y
X
F_y
3
C
T
C
F_y
3
F_y
C
F_y
3
d_0
d_i
F_y
C
b_e
b
①
②
③

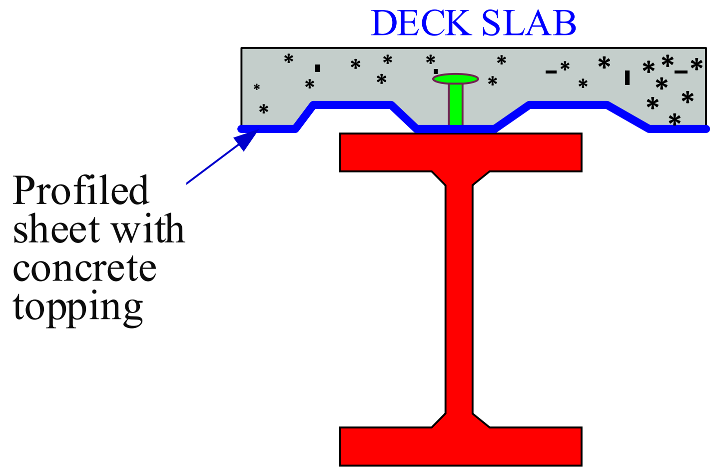
Composite steel-concrete structures

Composite structures discussed in this course are the solid *cast-in-place* concrete slabs placed and interconnected to a WF, I-shaped, or box beam or girder.

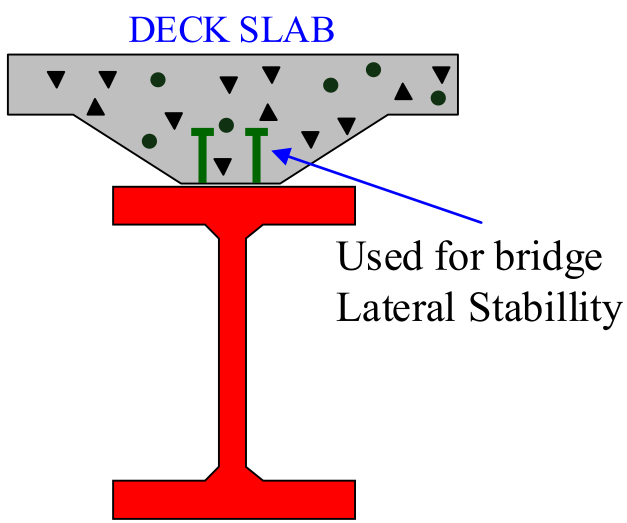
Shear connectors are used to create an integrated structure



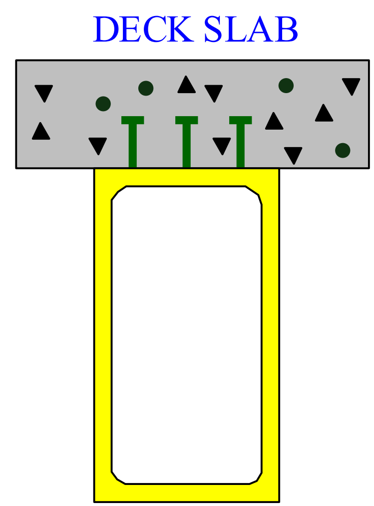
(a) Steel Beam with Solid Slab



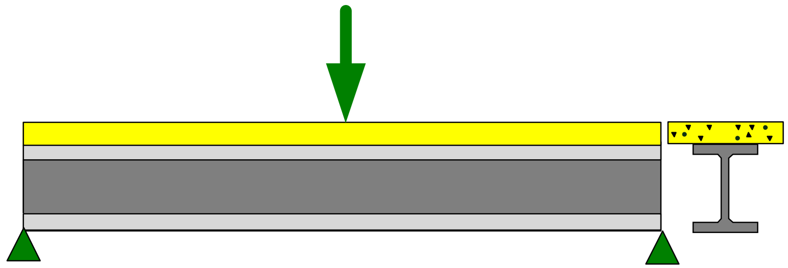
(a) Steel Beam with Deck Slab

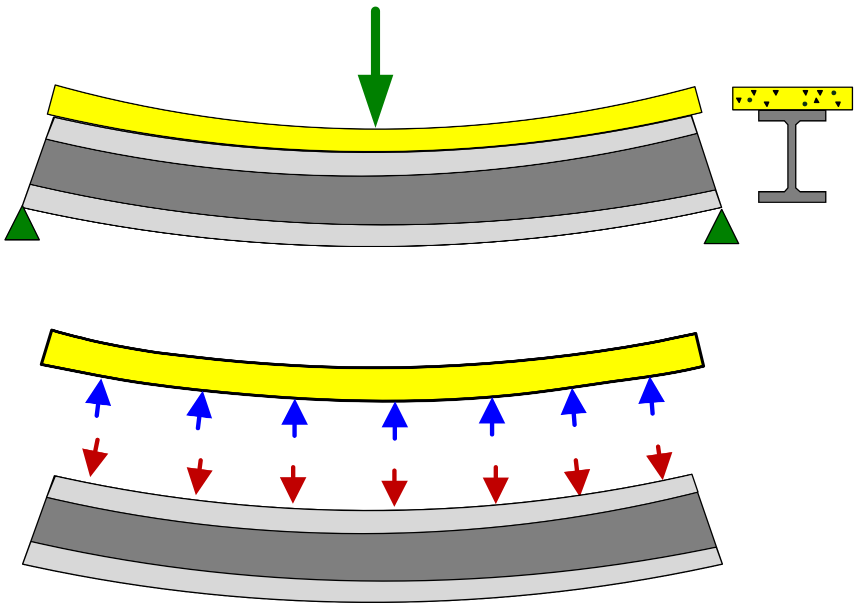


(c) Beam with Haunched Slab

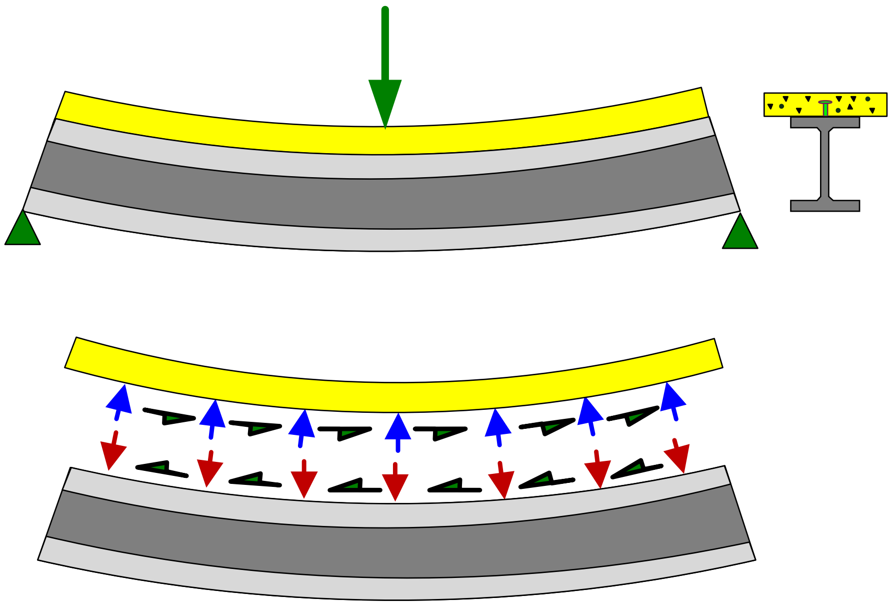


(d) Steel Box Girder



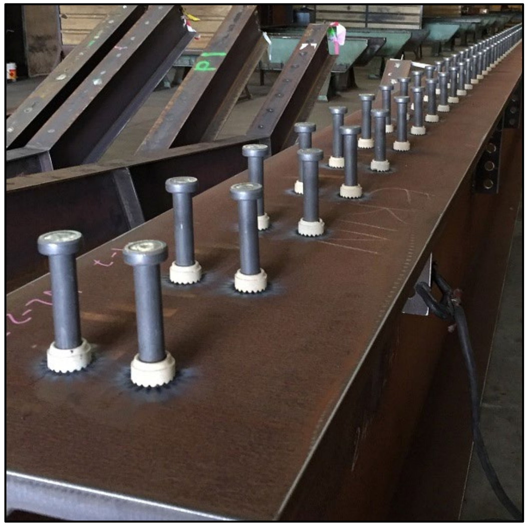


Deflected non-composite beam



Deflected composite beam

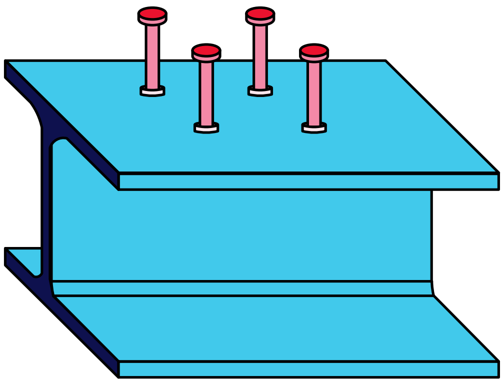
Shear connectors



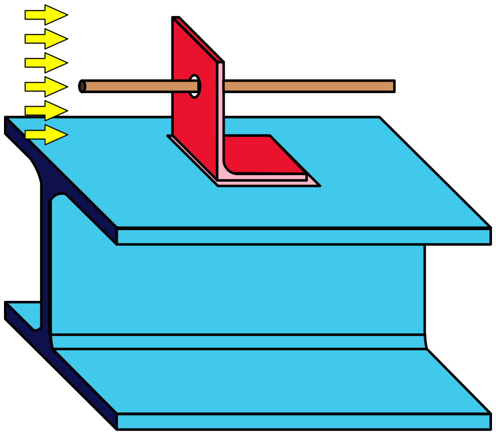
https://studweldingmelbourne.com.au/

https://smdltd.co.uk/tgn-online/6.8_-_Alternative_Shear_Connectors

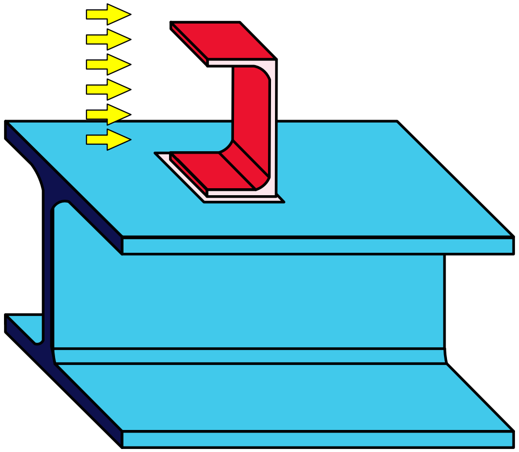
Shear connectors



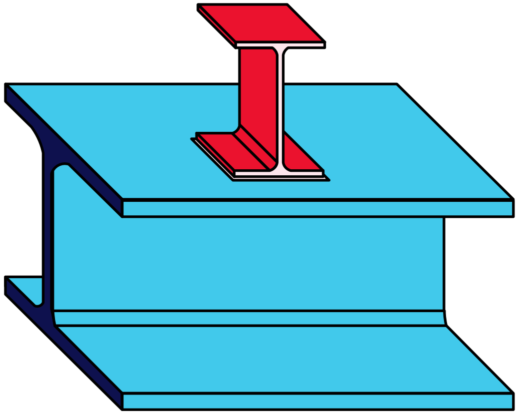
(a) Stud connector



(b) Angle connector



(c) Channel connector



(d) I-shape connector

End of Session 11 and 12

More in-depth and detailed material on the design and analyses of concrete and steel structures will be covered in the courses on these particular topics