Load & Resistance Factor Design

- Step III. Design the members
  - The failure (design) strength of the designed member must be greater than the corresponding design forces calculated in Step II:

$$\phi R_n > \sum \gamma_i Q_i$$

***R_n* - the calculated failure strength of the member**

ϕ* - the resistance factor used to account for the reliability of the material behavior & equations for *R_n

***Q_i* - the nominal load**

***γ_i* - the load factor used to account for the variability in loading & to estimate the ultimate loading**

Design Strength of Tension Members

- Yielding of the gross section will occur when the stress *f* reaches F_y.

$$f = \frac{P}{A_g} = F_y$$

- Therefore, nominal yield strength = $P_n = A_g F_y$
- Factored yield strength = $\phi_t P_n$

$\phi_t = 0.9$ for tension yielding limit state

Design Strength of Tension Members

- Fracture of the net section will occur after the stress on the net section area reaches the ultimate stress F_u

$$f = \frac{P}{A_e} = F_u$$

- Therefore, nominal fracture strength = $P_n = A_e F_u$
- Where, A_e is the effective net area, which may be equal to the net area or smaller.
- The topic of A_e will be addressed later.
- Factored fracture strength = $\phi_t A_e F_u$

  where: $\phi_t = 0.75$ for tension fracture limit state

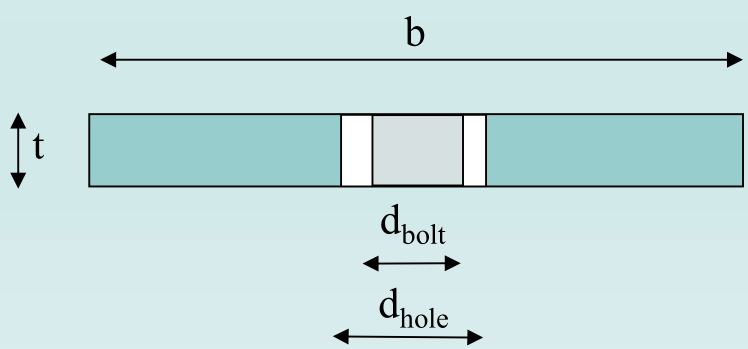
Net Area

- We calculate the net area by deducting the width of the "bolts + some tolerance around the bolt"

- Use a tolerance of 1.6 mm above the diameter hole which is typically 1.6 mm larger than the bolt diameter

- <u>Rule</u>

$$d_{Hole} = d_{bolt} + 3.2\,mm$$



$$A_n = \left[b - (n_{holes}\, d_{hole})\right] t$$

Design Strength

- Tensile strength of a section is governed by two limit states:
  - Yield of gross area (excessive deformation)
  - Fracture of net area
- Thus the design strength is one of the following

Load Effect

$$P_u \leq \begin{cases} \phi_t P_n = \phi_t F_y A_g & \phi_t = 0.9 \quad \textbf{YIELD} \\ \phi_t P_n = \phi_t F_u A_n & \phi_t = 0.75 \quad \textbf{FRACTURE} \end{cases}$$

- The difference in the ϕ factor for the two limit states represent the
  - Seriousness of the fracture limit state
  - The reliability index (probability of failure) assumed with each limit state

Important Notes

- Why is fracture (& not yielding) the relevant limit state at the net section?

  Yielding will occur first in the net section. However, the deformations induced by yielding will be localized around the net section. These localized deformations will *not* cause excessive deformations in the complete tension member. Hence, yielding at the net section will *not* be a failure limit state.

- Why is the resistance factor (ϕ_t) smaller for fracture than for yielding?

  The smaller resistance factor for fracture (ϕ_t = 0.75 as compared to ϕ_t = 0.90 for yielding) reflects the more serious nature & consequences of reaching the fracture limit state.

Important Notes

- What is the design strength of the tension member?

  The design strength of the tension member will be the lesser value of the strength for the two limit states (gross section yielding & net section fracture).

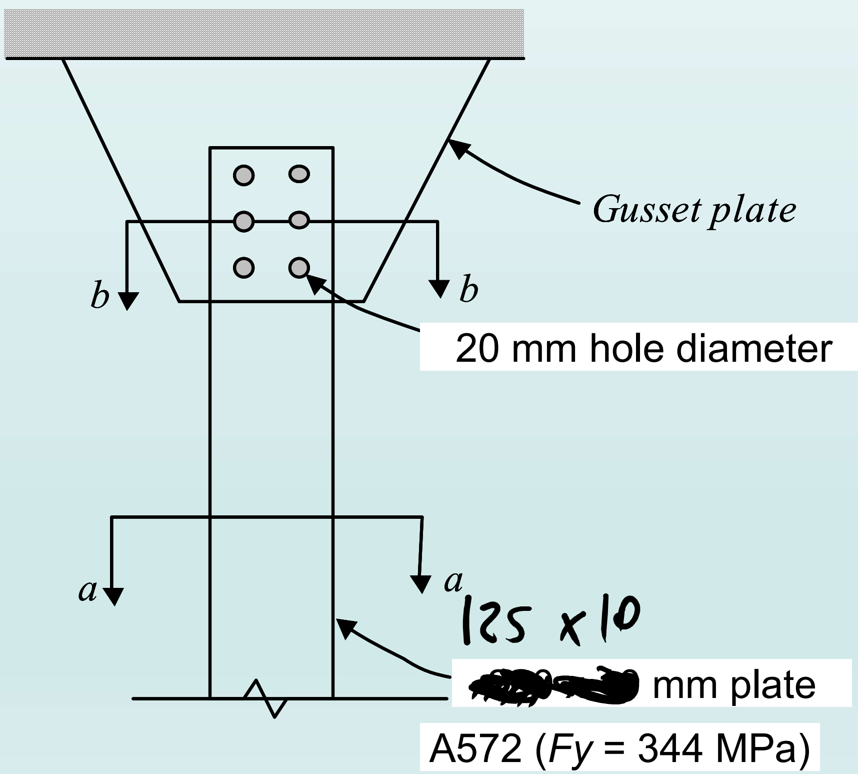
$\bar{y}_p$

- Where are the F_y & F_u values for different steel materials?

  The yield & ultimate stress values for different steel materials are dependent on type of steel.

Ex. 2.1 – Tensile Strength

- A 125 x 10 mm bar of A572 (F_y = 344 MPa) steel is used as a tension member. It is connected to a gusset plate with six 20 mm. diameter bolts as shown below. Assume that the effective net area A_e equals the actual net area A_n & compute the tensile design strength of the member.



Ex. 2.1 – Tensile Strength

- Gross section area = A_g = 125 x 10 = 1250 mm^2
- Net section area (A_n)
  - Bolt diameter = d_b = 20 mm.
  - Nominal hole diameter = d_h = 20 + 1.6 = 21.6 mm
  - Hole diameter for calculating net area = 21.6 + 1.6 = 23.2 mm
  - Net section area = A_n = (125 – 2 x (23.2)) x 10 = 786 mm^2
- Gross yielding design strength = $\phi_t P_n = \phi_t F_y A_g$
  - Gross yielding design strength = 0.9 x 344 x 1250/1000 = 387 kN

Ex. 2.1 – Tensile Strength

- Fracture design strength = $\phi_t P_n = \phi_t F_u A_e$
  - Assume $A_e = A_n$ (only for this problem)
  - Fracture design strength = 0.75 x 448 x 786/1000 = 264 kN
- Design strength of the member in tension = smaller of 264 kN & 387 kN
  - Therefore, design strength = 264 kN (*net section fracture controls*).