CE 388 – FUNDAMENTALS OF STEEL DESIGN

CHAPTER 2: TENSION MEMBERS

Types of Tension Members

- Any member subjected to two pulling forces applied to its ends is called ***a tension member***
- Types of tension members:
  - Wires, strands, ropes and cables
  - Rods and bars
  - Single structural shapes
  - Built-up members

Types of Tension Members

- Wires, Strands, Ropes and Cables
  - Some applications:
    - Cable-stayed bridges
    - Suspension bridges
    - Guyed Towers

cable

Types of Tension Members

A cable-stayed bridge

Types of Tension Members

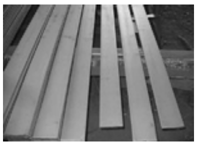
A guyed tower

Types of Tension Members

- Advantages:
  - The ultimate strength of high strength cable in tension is 4 to 6 times that of carbon steel
  - Provide more economical solutions than conventional steel bridges
- Disadvantages:
  - Unable to resist compression
  - Require special connecting devices
  - Low elasticity modulus, which causes excessive elongation when the strength is fully utilized

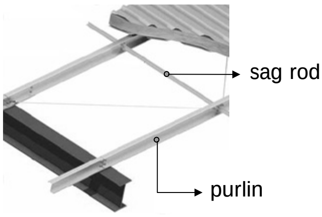
Types of Tension Members

- Rods and Bars
  - Hot rolled square and round bars or flat bars
  - Usually secondary members where design stress is small
  - Some applications are
    - Sag rods to support purlins in industrial buildings
    - Vertical ties to support girts in industrial building walls
    - Tie rods to resist the thrust of an arch



Rods and bars

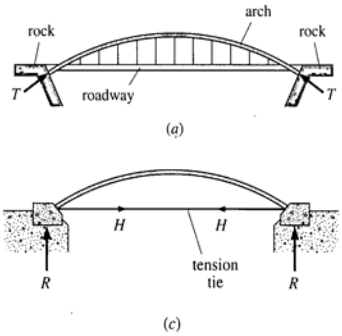
Types of Tension Members



Sag rods to support purlins in industrial buildings)

Types of Tension Members

Vertical ties to support girts in industrial buildings



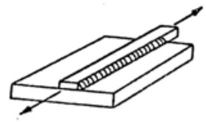
Tie rods to resist thrust of an arch

Types of Tension Members

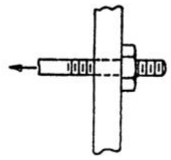
- Disadvantages:
  - Inadequate stiffness which results in noticeable sag under their own weight
  - Negligible compressive strength (slender members)
  - Difficulties in connection details

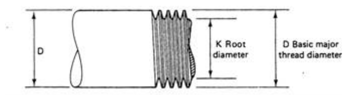
Types of Tension Members

- Connection details:
  - Welding (flat or rod bars)



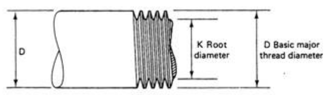
  - Bolting (rod bars)



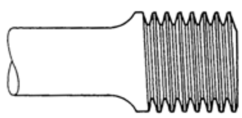


Types of Tension Members

- Threading has the disadvantage that the net section of the rod is reduced



- Alternatively, the rod can be upset at the ends and then threaded



upset rod

Types of Tension Members

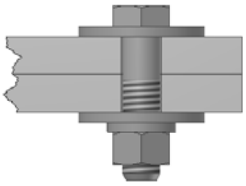
- Single Structural Shapes
  - When some amount of rigidity is required or when the tension member may be subjected to compression, rolled shapes must be employed as tension members
  - The rolled shapes:
    - Angle sections
    - Channel sections
    - Tee sections
    - I sections
    - Hollow structural shapes

Types of Tension Members

- Connections to adjoining parts are done by riveting, bolting or welding

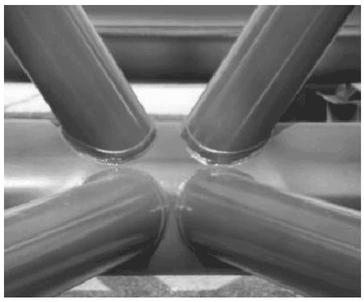
riveting

Types of Tension Members



bolting

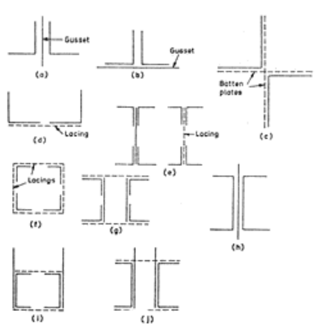
Types of Tension Members



welding

Types of Tension Members

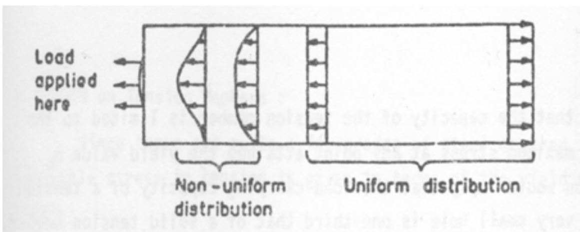
- Built-up members
  - Consist of two or more rolled sections properly connected which acts as a single member
  - Used when:
    - The tensile capacity of a single rolled section is not sufficient
    - The slenderness ratio does not provide sufficient rigidity



various built-up sections

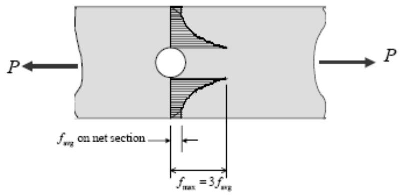
Stress Distribution in Tension Members

- Stress distribution in solid members



Stress Distribution in Tension Members

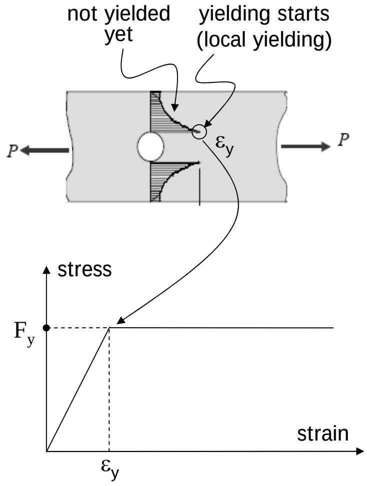
- Stress distribution in tension member with a hole



  - Stress concentration is observed around the holes
    - The theory of elasticity indicates that the stress around the hole is about three times the average stress ($\sigma_{max}/\sigma_{ave}$ = 3)

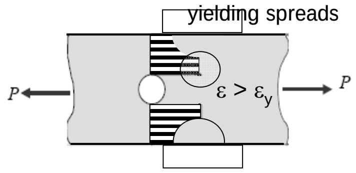
Stress Distribution in Tension Members

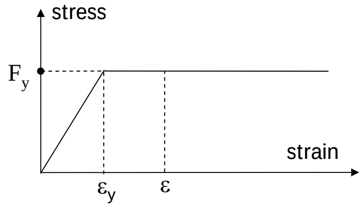
- Does ($\sigma_{max}/\sigma_{ave}$ = 3) imply that the load carrying capacity of the member is reduced by one-third?
  - No!!! Experiments indicate that the presence of a hole decreases strength only by 10-15 %.
- This phonomenon can be expressed by *plasticity theory*



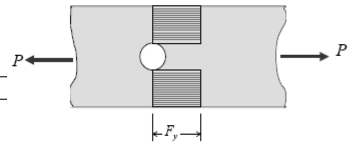
Stress Distribution in Tension Members

- Local yielding does not imply failure!!!
- What happens if the load is increased further





- At some load level, the entire width is subjected to F_y (failure)



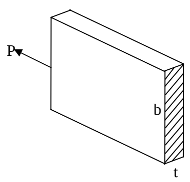
Gross Cross Section, Net Section and Staggered Holes

- For tension member analysis, direct stress formula is used

$$\sigma = \frac{P}{A}$$

Computed tensile stress → σ; Applied axial force → P; Cross-section area of the member → A

- For solid members:

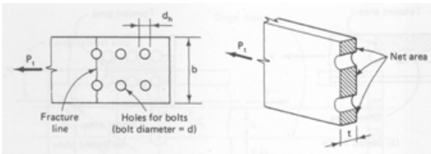


$$A = bt$$

Gross cross sectional area (A_g)

Gross Cross Section, Net Section and Staggered Holes

- For members having holes:



Net area   Gross area

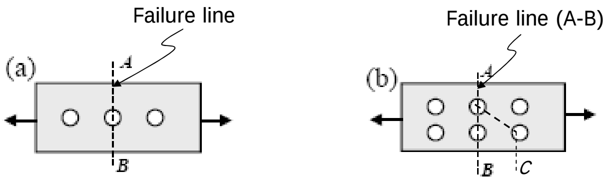
$A_n = A_g$-(area of holes)

$$= bt - 2(d_h t)$$

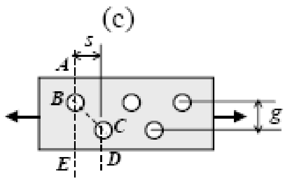
  - Hole diameters are punched a little larger then diameter of the fastener (bolt, rivet)
  - The hole diameters (d_h) are calculated as follows:
    - For bolts, d_h = bolt diameter + 1 mm
    - For rivets, d_h = rivet diameter + 2 mm

Gross Cross Section, Net Section and Staggered Holes

- Staggered holes:
  - Failure line: the line which yields the minimum net section (critical net section). It is the section at which the failure is likely to occur.



Gross Cross Section, Net Section and Staggered Holes



- It is not immediately evident whether ABE or ABCD is the critical section
- ABE is shorter, yet one hole is deducted from the path
- ABCD is longer, yet two holes are deducted from the path

Gross Cross Section, Net Section and Staggered Holes

- Accurate checking of strength along ABCD is very complex
- Design codes use a simple method:
  - The net width is obtained by deducting from the grosss width the diameters of all the holes along the fracture line, and adding for each digonal line the quantity $s^2/4g$.

$$w_n = w_g - \sum d_h + \sum \frac{s^2}{4g}$$

Spacing between holes

Gage distance between rows

Net width

Gross width

Hole diameter

Gross Cross Section, Net Section and Staggered Holes

- If the thickness is uniform

$$A_n = w_n t = w_g t - \sum d_h t + \sum \frac{s^2 t}{4g}$$

- If the thickness is not uniform

$$A_n = A_g - \sum d_h t + \sum \frac{s^2 t}{4g}$$

- An additional constraint is imposed by TS648

$$A_n \leq 0.85 A_g$$

Gross Cross Section, Net Section and Staggered Holes

Example Problem

Design of Tension Members

- In TS648
  - Stress Limitations:

$$\text{Computed stress} \longrightarrow \sigma \leq \sigma_{cem} \longleftarrow \text{Allowable stress}$$

- Computed stress σ :

  σ = P/A_g (for solid sections)

  σ = P/A_n (for sections with holes), $A_n \leq 0.85\ A_g$

- Allowable Stress $\sigma_{çem}$:

$$\left.\begin{array}{l} \sigma_{çem} = \dfrac{\sigma_a}{1.67} = 0.6\sigma_a \quad \text{(F.S = 5/3=1.67)} \\ \sigma_{çem} = \dfrac{\sigma_d}{2.0} = 0.5\sigma_d \quad \text{(F.S = 2.0)} \end{array}\right\} \text{smaller of the two}$$

Design of Tension Members

- Stability Limitation:
  - It is necessary to limit the length of a tension member in order to prevent it from
    - becoming too flexible
    - sagging excessively under its own weight
    - vibrating excessively
  - A stifness criterion based on slenderness ratio, λ, is established

Effective length factor (K=1 for pin-ended members)

$$\lambda = \frac{KL}{i}$$

Length

Radious of gyration

- $\lambda \leq 250$ for all members (tension and compression)

Design of Tension Members

- In AISC-ASD
  - Stress Limitations:
    - Same as TS648
  - Stability Limitations:
    - $\lambda \leq 300$ for tension members
    - $\lambda \leq 200$ for compression members

Design of Tension Members

Example Problem

Design of Cables

- In American practice, ultimate strength of a cable is approximated by the equation

$$\underbrace{P_u}_{\text{Ultimate strength (kips)}} = 80\underbrace{D^2}_{\text{Nominal rope diameter (inches)}}$$

- Metric equivalence of this equation

$$\underbrace{P_u}_{\text{(tons)}} = 5.6\underbrace{D^2}_{\text{(cm)}}$$

- Factory of safety is usually between 3 and 5

Design of Cables

- Elongation check is necessary. Elastic elongation (Δ_e) is checked using the conventional formula

$$\Delta_e = \frac{PL}{AE}$$

  - P : Force in the cable
  - L : Length of the cable
  - A : cross-sectional area of the metallic part of the rod ($0.35D^2$-$0.60D^2$)
  - E : Elasticity modulus ($6.32x10^5$ – $16.87x10^5$ kgf/cm2)

Design of Cables

- In addition to elastic strech, the cable undergoes plastic deformation, Δ_p

$$\Delta_p \cong 0.0025L \text{ to } 0.01L$$

- Total elongation (Δ_T) = $\Delta_e + \Delta_p$

Design of Cables

Example Problem

Design of Rods and Bars

- Rods and bars are simply welded at their ends or they may be threaded and held in place with nuts
- $\lambda \leq 2000$ for rods and bars
- For threaded rods, 4D and 5D types of steels are used.

Type	Allowable stress (kgf/cm^2)
4D	1120
5D	1500

Allowable stresses for 4D and 5D Steels

Design of Rods and Bars

Rod diameter (mm)	Rod net diameter (mm)	Cross-sectional area (cm^2)	Net cross-sectional area (cm^2)
6	4.7	0.283	0.173
8	6.376	0.503	0.319
10	8.052	0.785	0.509
12	9.726	1.13	0.743
16	13.402	2.01	1.41
20	16.752	3.14	2.20
22	18.752	3.80	2.76
24	20.102	4.52	3.17
27	23.102	5.73	4.19
30	25.454	7.07	5.09
33	28.454	8.55	6.36
36	30.804	10.2	7.45
42	36.154	13.9	10.27
48	41.504	18.1	13.53

Threaded rod bars

Design of Rods and Bars

Example Problem