Course Content

INTRODUCTION TO STRUCTURAL STEEL DESIGN

Introduction

- A Structural component must possess both **Strength** and **Ductility**
- Steel gets its strength by shearing of its layers
- Unit weight of steel is 78.5 KN/m^3
- Steel has high strength to weight ratio
- Steel has **ferrite** (ductility) **+ Pearlite** (mechanical strength) micro-structure
- Steel stress- strain graph has elastic region, plastic region and strain hardening region. Yield strain of steel is around **0.0012**
- **Strain hardening** is the increase of strength of hardness due to the changes in micro-structure
- From Von Mises yield criterion,
- In state of pure shear, $\tau_{xy} = \frac{f_y}{\sqrt{3}}$
- For normal stress, $\sigma_x = f_y$

Limit State

- Limit states are failure states. Two limit states; Strength and Serviceability
- Strength limit states; ultimate, buckling and fatigue
  Serviceability limit states; deflection, vibration and corrosion
- Limit state assumes **variable safety** and it follows **probabilistic approach**
- **Characteristic Load –** Value of load above which not more than 5% of the test results may be expected fall
- **Characteristic Strength –** Value of resistance, below which not more than 5% of the test results may be expected fall
- In limit state the material is expected to go till the ultimate strength. The load is increased and the strength reduced by multiplying characteristic load and strength by partial safety factors
- **Partial Safety Factor-** To account for the possibility of deviation

Tension Members

Examples of tension members

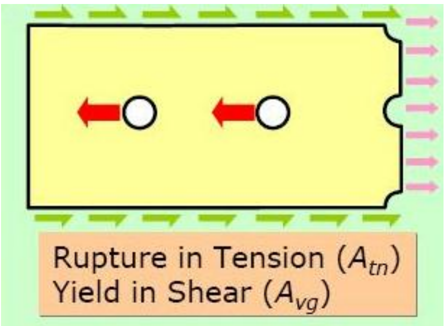
1. Braces
2. Sag rods in roof purlin system
3. Tie rods in a roof truss

Important fact: Tension must be anchored

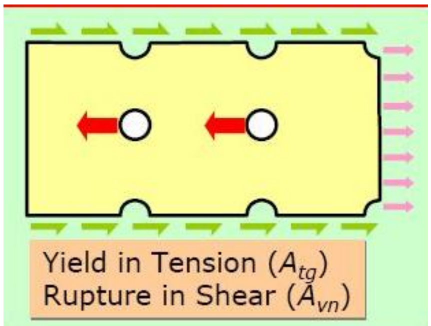
Plates in tension

- Possible limit states
    1. **Yielding of gross section** $T_{dg} = A_g \frac{f_y}{\gamma_{mo}}$
    2. **Rupture of net section** $T_{dn} = 0.9 A_n \frac{f_u}{\gamma_{m1}}$ (0.9 factor to take of the non-uniformity of stress along the net section)
    3. **Block shear** – combined failure of shear and tension
- Design Strategy for Block Shear

Rupture in tension, Yield in shear



Yield in tension, rupture in shear



Minimum of the above two cases is the block shear strength.

- **Shear Lag**- non-uniform stress distribution

Angles in tension

The rupture strength of an angle connected through one leg is affected by shear lag.

Part of the cross-section not effectively used.

Factors causing shear lag:

1. More outstand or thin/slender outstand
2. Flexible connection – more shear lag

Connections

Bolting

- Minimum of **two bolts** per connection is required for basic stability
- Grade of bolts: **Class X.Y**

  Tensile Strength = X *100 MPa

  Yield Strength = 0.Y *Ultimate strength MPa

- Bolts are never in compression. The forces that the bolts take are
  1. Tension
  2. Shear
  3. Friction
  4. Bearing
- Two types of bolt : Bearing bolt and Friction bolt

Bearing Type

- Load resistance by **bearing** and **shear**
- **Spacing-**Minimum -2.5 D where D is nominal diameter
  Maximum-32t 0r 300mm (to minimize unconnected length)
- **Pitch –** Distance along the direction of application of load
  Maximum – 16t or 200mm (tension members)
  12t 0r 200mm (compression members)
- **End and Edge Spacing**
  Minimum – 1.5d where d is the diameter of the hole (to prevent end rupture)
  Maximum – 12tε
- Reduction of shear strength because of the following
  1. **Long joints** results in a non-uniform distribution of shear
  2. **Large Grip Length** results in the bending of bolts
  3. **Packing Plates**

Important Assumptions:

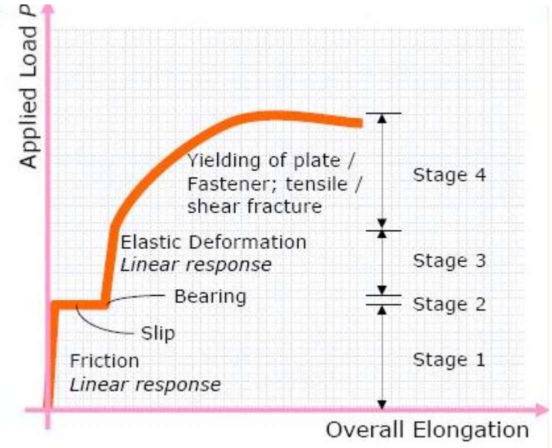
- **Connection elements are assumed to be rigid than connectors**
- **Connection behaviour is linear elastic**

Friction Bolts

- The bolts used as friction bolts are called HSFG bolts i.e **High Strength Friction Grip Bolts**
- Load transfer by **friction** before slip which is developed because of the pre-tension equal to 0.7 -0.8f_u .Shank is in tension only till slip occurs

- After slip (ultimate load level), shank is in **tension**, **bearing** and **shear**

- There can be tension coming because of **prying, the effect because of eccentricity.**



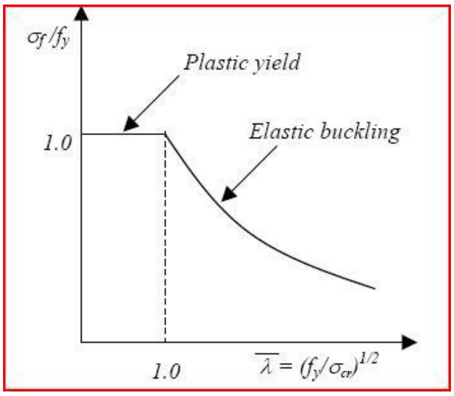
By using friction bolts the pinching effect can be reduced. Pinching effect is the elongation of the hole because of the slip and also the energy dissipation decreases as the slip increases every time the elongation takes place.

<u>Welding</u>

- There are different types of welds; **Lap** and **Butt** weld
- In case of lap joints – lap length should not be greater than 4t or 40mm whichever less is
- Size of fillet weld ≥ 3mm or thickness of thinner plate
- Effective throat thickness is 0.7t
- The shear strength of weld = 0.7t w $\frac{f_u}{\sqrt{3}\,\gamma_{m1}}$, w is width of weld

<u>Columns</u>

- In columns, it is the **slenderness ratio** that affects the capacity
- Column can fail in two ways; yielding of the section and loss of stability
- Structure looses stability when potential of external load equals strain energy. It involves a phenomenon in which the displacement of structure occurs perpendicular to the load
- **Buckling**
  Un-symmetric section – P_x+ P_y+ P_T
  Singly symmetric section – P_x+ P_T or P_y
  Doubly symmetric section - P_x or P_y or P_T
  In cruciform section, **torsional buckling** is predominant
- Euler Buckling curve is for **Ideal column** which shows symmetric buckling



- Critical buckling stress for plate $\sigma_{cr} = \frac{k\pi^2 E}{12\,(1-\gamma^2)\left(b/t\right)^2}$

  Value of k depends on the support conditions. k = 4 (hinged-hinged)

  = 0.43(hinged –free)

  Stiffened element is 10 times stronger than un-stiffened element

P_x buckling about major axis, P_y buckling about minor axis, P_T torsional buckling

- Local buckling erodes the axial capacity of short column

- $b/t < 16$, no local buckling

  b is width of plate

  t is thickness of plate
- Factors that affect column behaviour are **radius of gyration** and **effective length**
- Effective length factor is > 1 for a sway frame

  < 1 for non-sway frame
- Factors affecting ultimate strength in real columns
  1. Initial Imperfection
  2. Eccentricity of loading
  3. Residual Stresses
- There are **four** buckling classes based on which column curve is. The buckling class is assigned to a section based on the imperfection.

Section Classification

1. **Plastic –** cross section which can develop plastic hinges and the redistribution of moment occurs
2. **Compact-** cross section which develops plastic hinges but no redistribution of moment
3. **Semi-compact-** extreme fibre in compression can reach yield stress but not plastic moment of resistance
4. **Slender-** elements buckle locally even before reaching yield stress

- Section classification should be done for columns before starting with the design process. If the section is not slender then the entire section contributes to the axial strength of the column.

Beams

- In beam, load is applied perpendicular to the axis
- Load is transferred by **bending** and **shear**
- Every section should be able to take shear and moment
- In I-section it is assumed that the **moment** is carried by the **flanges** and **shear** by **web.**
- If **(span/depth)**< **16**, then the beam is **deep** beam. In deep beam, load transfers by shear. In thin beam, flexure dominates.
- Modes of Failure; flexure, shear, crushing failures and lateral torsional buckling
- Beam can be laterally restrained or un-restrained. Lateral torsional buckling occurs in un-restrained beam.
- **Lateral torsional Buckling**
    1. It is the buckling due to the compression flange
    2. To avoid it, compression flange has to be restrained
    3. Each restraint should carry at least 1% of the force in the compression flange and a total of 2.5% all restrained combined.
- In a plastic section, as the moment increases, the section reaches plastic moment capacity and plasticisation starts. Till plastic hinges form, it acts as a flexure member but after hat it behaves as a truss member.
- Full capacity is achieved only if local buckling doesn't occur.
- **Shape factor = M_p/M_y** .If more area is near the neutral axis, shape factor is high
- Beam is designed for moment and is checked if it is experiencing low shear or high shear. If $V < 0.6V_d$ where$V_d = \frac{A_s}{\sqrt{3}}\frac{f_y}{\gamma_{m0}}$, then low shear. For high shear, the web length for carrying shear has to be increased. The reduced moment capacity is giving in clause 9.2.2 in IS 800:2007
- Beam has to be checked for web crippling and web buckling

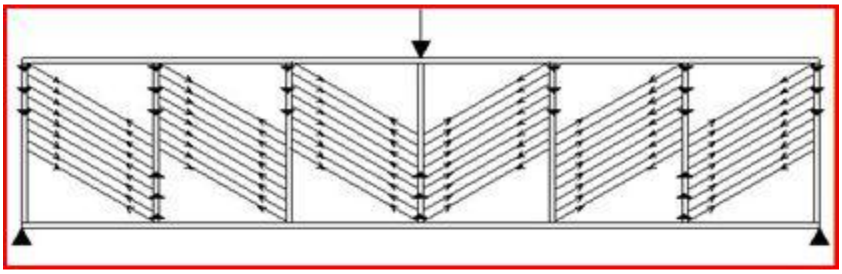
Laterally Un-restrained Beam

- Three situations when Lateral Torsional Buckling is absent
    1. Stiffer plane in the lateral direction
    2. Closed section
    3. Short beam, $\lambda_{LT} \leq 0.4$ where $\lambda_{LT} = \sqrt{\frac{M_y}{M_{cr}}}$
- In column, buckling is due to the axial forces but in beams buckling is because of bending moment.
- There are two components of critical moment; Pure torsion or St. Venant's torsion and Warping torsion or Vlasov torsion
- **Pure torsion** is predominant in **hot rolled section** and **warping torsion** in **cold formed section**
- If displacement is arrested, stresses develop

- The beam stability depends on the level of loading i.e the vulnerability is high when load is applied on compression flange than at neutral axis or tension flange.
- Effective length of the beam depends on the support conditions. There are three kinds of support; flexure, torsion and warping supports
- Unlike columns only two strength curves are used. One for **rolled section** and the other for **welded section**

Plate Girder

- **Post buckling strength** is the ability to take larger stress beyond the critical stress. It is predominant in thin plate elements. It develops only after buckling occurs.
- In plate girder the web is similar to a plate and the post bucking capacity is taken advantage of.
- If $d/t_w > 67\varepsilon$, web buckling occurs. After buckling post buckling strength develops
- In plate girder web buckling occurs. Web is generally stiffened using stiffeners placed at intervals to enhance the critical stress.
- **Assumption** : Flanges- flexure
  Web- shear
  Stiffener- prevents buckling
- Two methods used for design : Simple post critical method and tension field method
- In tension field method, truss action of web in post buckled state is used. Anchorage is provided by stiffeners

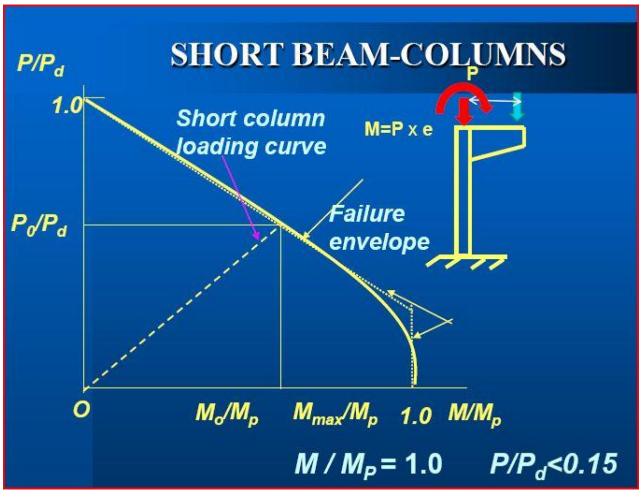


Tension Field

- **Behaviour of transverse web stiffener**
  1. Increases web buckling stress
  2. Supports tension field after buckling
  3. Prevents tendency of flanges to get pulled into each other
- **Longitudinal Stiffener**
  1. Provided in compression zone
  2. Increases buckling resistance of web

Combined Forces

- Beam column – member subjected to both bending and axial forces
- Axial load reduces the stiffness of the member. It reduces moment capacity.
- As axial load acting increases, moment capacity decreases. The figure shows the relation between axial force and moment
  I



- Unity checks should be satisfied by the members. See clause 9.3 of IS 800:2007
- **In long columns**,
  1. P-Δ and P-δ effect should be considered
  2. P-Δ is due to the swaying action of beam and P-δ is due to small buckling effect in non-sway frame
  3. Axial load amplifies the moment