Rajan's Book Chapter 3: Structural Design Fundamentals

What is Design?

Design – a process by which an optimum solution is obtained.

-- Emphasizing minimum weight (minimum cost).
-- Mixture of art and science.

Material Behavior

Stress and strain
Shear stress and strain

Material Properties

Linearly elastic range
Initial yielding – perfectly plastic rang
Strain hardening phase
Ultimate stress
Fracture

Stress-Strain Relationship

Young's modulus (modulus of elasticity), E
Shear modulus, G
Poisson's ration, ν

Principal Stress and Strain

Stresses on a plane at an angle θ
Maximum direct stress
Maximum shear stress
Mohr's circle to represent state of stress at a point

Stress and Strain Computations

Need cross-sectional properties: centroid, area, moment of inertia
Axial force: stress = force /area = N_x/A
Bending moment:

$$\sigma_x = -\frac{M_z y}{I_z};\quad (\sigma_x)_{max} = \frac{M_z}{S};\quad Section\ modulus,\ S = \frac{I_z}{y_{max}}$$

Shear force: $\tau_{xy} = \frac{V_y Q}{I_z t};\quad (\tau_{xy})_{max} = \frac{V_y}{SF};\quad Shear\ factor,\ SF = \frac{I_z}{(t/Q)_{min}}$

Combined stress: $\sigma_x = \frac{N_x}{A} \mp \frac{M_z y}{I_z}$

Theories of Failure

Some causes of structural failure:
yielding
low stiffness
buckling
crushing
fracture.

Failure criteria:
Von Mises Criterion: Octahedral shearing, strain energy density of distortion

$$\tau_{oct} \geq \frac{\sqrt{2}}{3}\bar{\sigma}$$

Maximum Principal Stress Criterion: $\sigma_1 \geq \bar{\sigma}$

Buckling: $\sigma_{cr} = \frac{\pi^2 EI}{A(KL)^2} = \frac{\pi^2 E}{(KL/r)^2};\ r = radis\ of\ gyration,\ r^2 = I/A$

$\lambda = L/r$, *slenderness ratio*

Steel Materials and Properties

1. Steels

- Steels for structural use may be classified as:

  -- Carbon steels:
  * Increased carbon percent raises the yield stress but reduces ductility.
  * Typical: A36, general structural purpose, mainly for buildings.

  -- High-strength low-alloy steels:
  * Yield strength ranging from 40 to 70 ksi.
  * Typical: A572, structural shapes

  -- Alloy steels:
  * Yield strength ranging from 80 to 110 ksi, no well-defined yield point.
  * Typical: A514, primarily for welded bridges.

2. Mechanical Properties

- Uniaxial stress-strain curve:

  -- Modulus of elasticity (Young's modulus): E=29,000 ksi.

  -- Yield strength σ_y : yield point, or stress at an offset strain of 0.2%.

  -- Plastic range (plateau) and strain hardening.

  -- Ductility: permanent strain (plastic strain) up to the point of fracture.