

# **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,  $\nu$

## **Principal Stress and Strain**

Stresses on a plane at an angle  $\theta$   
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:

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

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

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

## 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:*  $\sigma_1 \geq \bar{\sigma}$

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

$$\lambda = L/r, \text{ slenderness ratio}$$

## Steel Materials and Properties

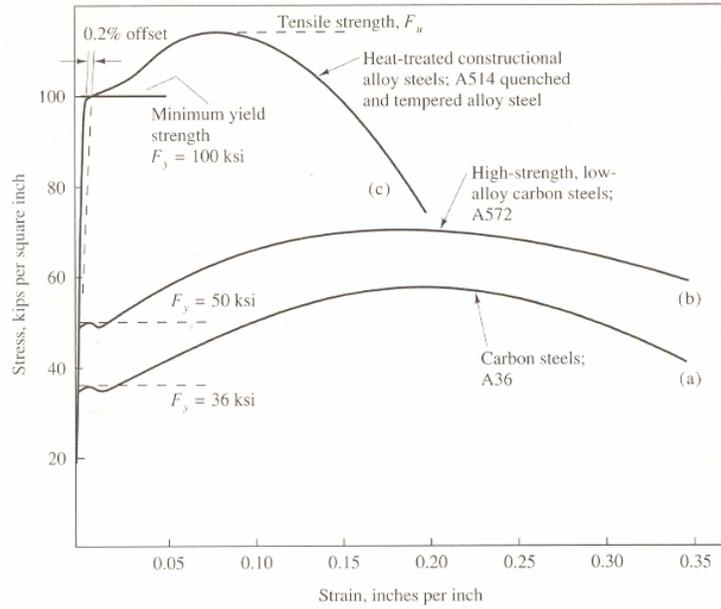
### 1. Steels

- 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.

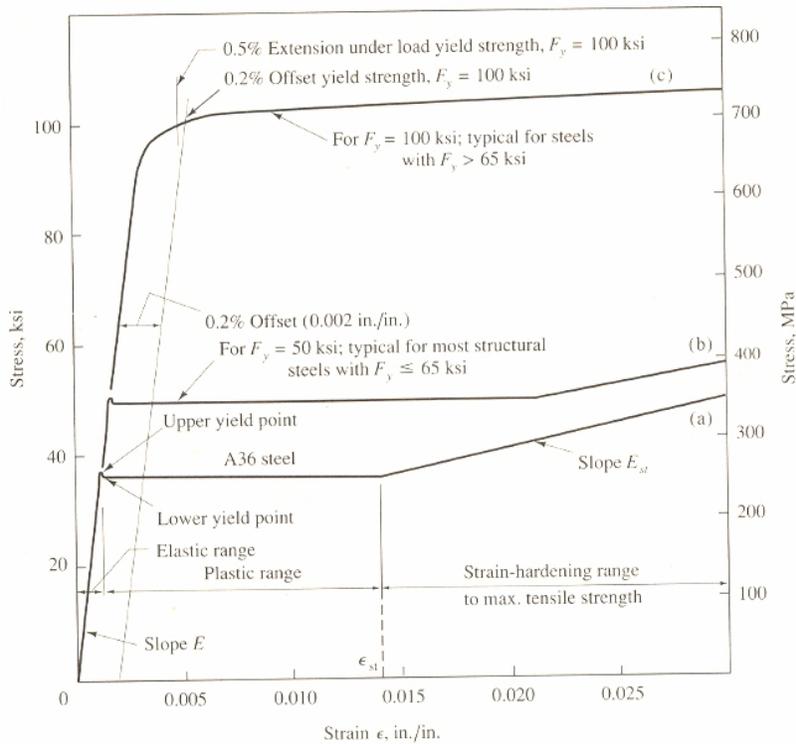
### 2. Mechanical Properties

- Uniaxial stress-strain curve:
  - Modulus of elasticity (Young's modulus):  $E=29,000$  ksi.
  - Yield strength  $\sigma_y$  : 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.

## 53:134 Structural Design II



**Figure 2.1.1** Typical stress-strain curves.



**Figure 2.4.1** Enlarged typical stress-strain curves for different yield stresses.

## 53:134 Structural Design II

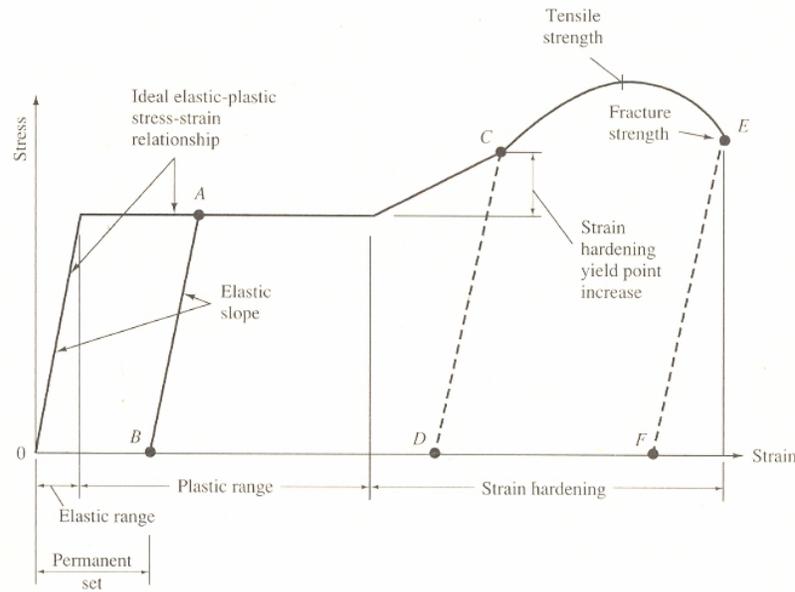


Figure 2.8.1 Effects of straining beyond the elastic range.

## Modeling the Structure and the Loads

Truss model

Frame model

Loads: dead, live, snow, wind, earthquake (ASCE 7-02)

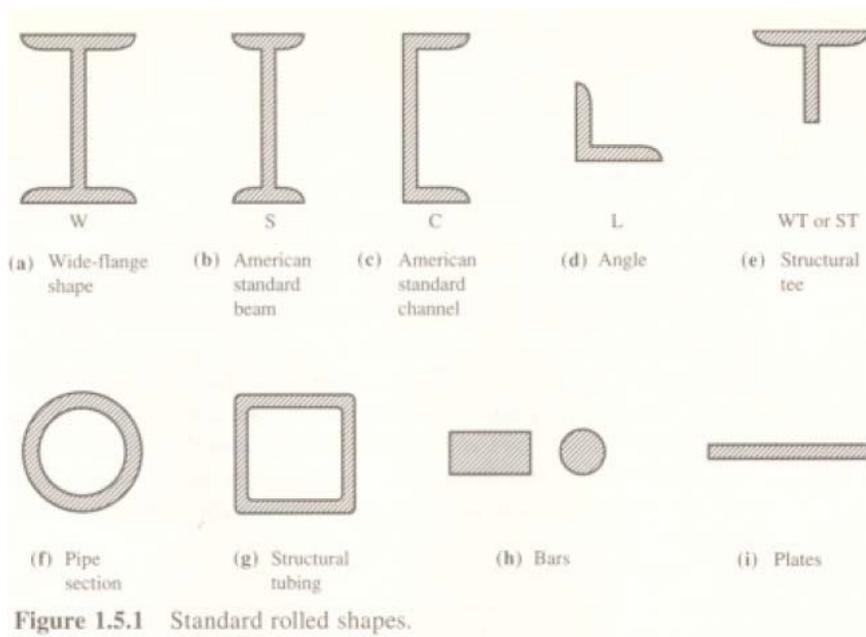
### 1. Loads

- *Dead load*: a fixed-position gravity service load.
  - Weight of the structure
  - Attachments to the structure (pipes, suspended ceilings, lighting fixtures, etc.)
- *Live load*: gravity loads acting when the structure is in service, but varying in magnitude and location.
  - For example, human occupants, furniture, movable equipment.
  - Difficult to determine; need empirical and conservative estimation.
  - Typical live loads (from ASCE 7 Standard, 2002):

Hotel guest rooms, school classrooms:	40 psf.
Office:	50 psf.
Library reading rooms:	60 psf.
Library stack rooms:	150 psf.
- *Snow load*: live loading for which roofs are designed.
  - Basic snow load used in design varies 30 ~ 40 psf in the northern/eastern states.
  - Basic snow load used in design is about 20 psf in southern states.
- *Wind load*: all structures are subject to wind load, but it is usually only those more than three or four stories high, as well as long bridges, for which special consideration of wind is required.
- *Earthquake load*: the effect of horizontal motion of the ground during earthquake is thought of as earthquake load.

## 2. Steel Structures and Their Members

- Structures may be divided into three general categories:
  - Framed structures: beams and columns, most typical building construction.
  - Shell-type structures: axial forces predominate. (e.g., water tanks)
  - Suspension-type structures: tension cables are major supporting elements. (bridges)
- Steel members: tension members, compression members, beams, and columns.
- Standard steel rolled shapes: (cross section)



- Wide-flange shape: most commonly used section.
  - For example, W18x97: nominally 18 in. deep (18.59 in.) and 97 lb/ft weight.