CE 388 – FUNDAMENTALS OF STEEL DESIGN

CHAPTER 1: GENERAL CONCEPTS IN DESIGN AND PROPERTIES OF STEEL

Types of Steel Structures

- In general, the amount of steel used in construction industry is proportional with the degree of industrial development.
- In developed countries, steel is in competition with reinforced concrete for almost all types of structures.

Types of Steel Structures

- Types of steel structures:
  - Framed structures
  - Tensile structures
  - Thin-plate structures

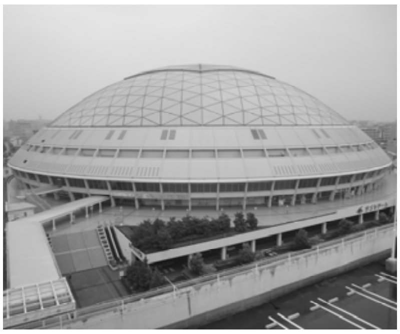
Types of Steel Structures

- Framed Structures:
  - Multi-story frames
  - Industrial buildings
  - Towers
  - Space structures (domes, barrel vaults)
  - Bridges
  - Stadiums, etc.

Types of Steel Structures

A multi-story steel frame (Bank of China Building, Hong Kong)

Types of Steel Structures



A steel dome in Nagoya, Japan

A barrel vault structure

Space structures

Types of Steel Structures

A steel tranmission tower structure

Types of Steel Structures

A steel industrial building

Types of Steel Structures

A steel bridge (Sdyney Harbour Bridge, Australia)

Types of Steel Structures

A steel stadium

Types of Steel Structures

- Tensile Structures:
  - Also referred to as cable structures or suspension-type structures
  - Examples of bridge tensile structures:
    - Suspension bridges
    - Cable stayed bridges

Types of Steel Structures

A cable-stayed bridge

Types of Steel Structures

A suspension bridge

Types of Steel Structures

- In the design tension cables play an important role
- Very light structures can be built using high-strength cables

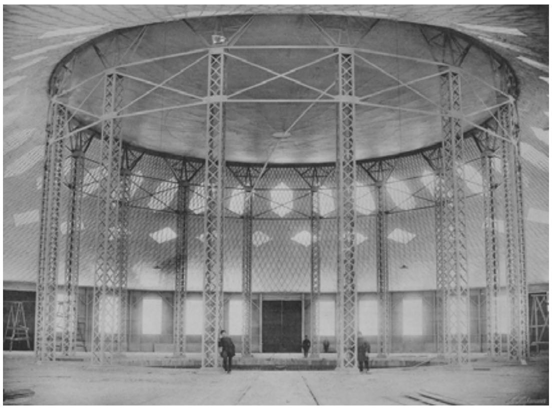
Types of Steel Structures

- Thin-plate Structures:
  - Examples of these structures are
    - Liquid storage tanks
    - Shell roofs

Types of Steel Structures

Liquid storage tanks

Types of Steel Structures



A steel shell roof

Advantages and Disadvantages of Steel

- Advantages:

  1. High strength $\rightarrow$ less dead load and smaller dimensions (more preferable for bridges, high-rise buildings and poor foundation conditions).

Advantages and Disadvantages of Steel

2. Ductility: steel can undergo large plastic deformation before failure.

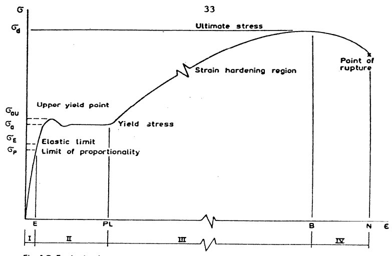


Fig. 1.7 Typical stress-strain diagram for steels having a yield plateau (Not drawn to scale)

A typical stress-strain diagram

Advantages due to ductility:

i) High impact resistance (such as blast or earthquake
ii) High energy absorption capacity
iii) Exhibition of sample warning by excessive deflections (sudden failure does not occur)

Advantages and Disadvantages of Steel

3. Predictable material properties
   - Homogeneity and isotropy
   - Perfectly elastic up to yield stress
   - Steel properties do not change considerably with time
4. Speed of erection
5. Ease of repair

Advantages and Disadvantages of Steel

6. Adaptation to prefabrication
7. Repetitive use
8. Expanding existing structures

Advantages and Disadvantages of Steel

- Disadvantages:

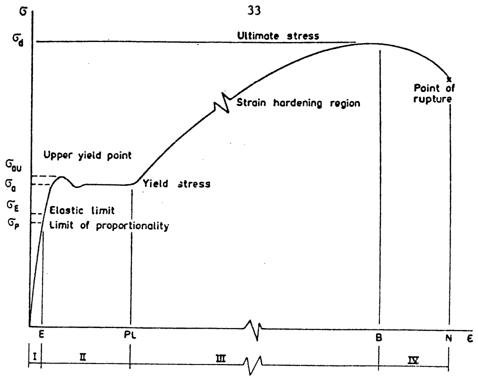
1. General cost (more costly than others)
2. Fireproofing
   - At about 600ºC, steel strength completely vanishes.
   - Encasing steel members (fire proofing technique) → increases cost and dead load

Advantages and Disadvantages of Steel

3. Maintenance
   - Steel tends to corrode when exposed to air.
   - Should be painted regularly → increases maintenance cost
4. Susceptibility to buckling
   - Steel members are more susceptible to buckling due to relatively smaller sizes

Mechanical Properties of Structural Steel

- Stress-strain diagram for steels having a yield plateau:



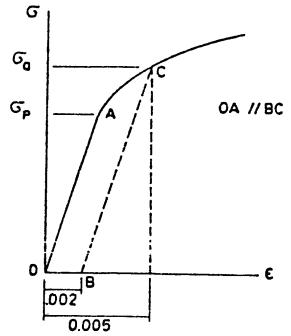
σ_p : Proporional limit
σ_E : Elastic limit
σ_{au} : Upper yield point
σ_a : Yield stress (point)
σ_d : Ultimate stress ($\cong$ 1.5-2.0σ_a)

Region 1: Elastic range [0-ε_E]
Region 2: Plastic range [ε_E- ε_{PL}]
($\varepsilon_{PL} \cong$ 10-15 ε_E)
Region 3: Strain-hardening [ε_{PL}- ε_B]
Region 4: Necking [ε_B- ε_N]
($\varepsilon_N \cong$ 150-200 ε_E)

Elasticity modulus (E) → slope of the region 1 = 2.1x10^6 kgf/cm2

Mechanical Properties of Structural Steel

- Stress-strain diagram for steels without a yield plateau:



- ❑ Do not exhibit a yield plateau.
- ❑ The yield stress is generally defined as the stress corresponding to 0.002 permanent strain or 0.005 strain.

Chemical Composition and Types

- Structural steel

$\underbrace{\text{Iron} + \text{Carbon}}_{\text{primary elements}}$ + Other elements (silicon, nickel, manganese, copper)

- Addition of carbon increases steel strength, but decreases ductility
- Steel types used in constructurion industry:
  - ❑ Structual carbon steels
  - ❑ High-strength low-alloy steels
  - ❑ Heat treated low-alloy or carbon steels

Chemical Composition and Types

- Structural carbon steels:
  - carbon content between 0.15-0.29 %
  - exhibits a marked yield plateau
  - has yield stress between 2400-3500 kg/cm^2
- High-stregth low alloy steels:
  - has yield stress between 2800-5000 kg/cm^2
  - exhibits a marked yield plateau
- Heat-treated low alloy and carbon steels
  - obtained by quenching and tempering of low-alloy or carbon steels
  - has yield stress between 5500-7000 kg/cm^2
  - do not have a definite yield point

Structural Shapes

- Structural shapes:
  - Standard shapes
  - Built-up shapes

Structural Shapes

- ❑ Standard shapes in ASTM:
  - ❑ W-Shapes
  - ❑ S-Shapes
  - ❑ HP-Shapes
  - ❑ C-Shapes
  - ❑ L-Shapes
  - ❑ Circular tube or pipe
  - ❑ Square tubing
  - ❑ Rectangular tubing

I-shape

HSS

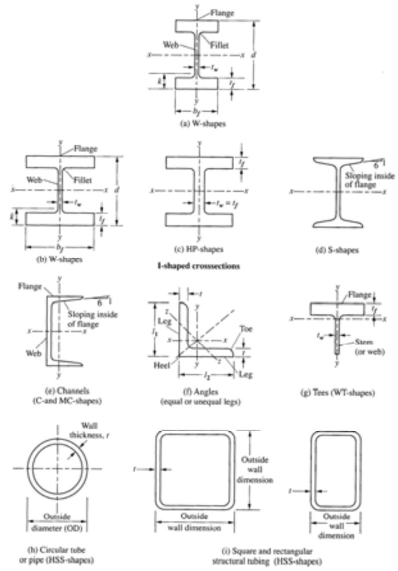


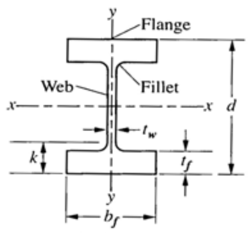
Figure 3.4 Structural Shapes.

Structural Shapes

- W-Shapes (IPBv or IPE Sections):
  - ❑ Wide-flange sections
  - ❑ Primarily used as beam and column members in framed structures
  - ❑ Standard designation

W 36 x 300

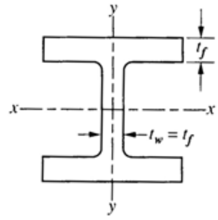
wide-flange | nominal depth (in) | weight per foot (lb/ft)



(a) W-shapes

Structural Shapes

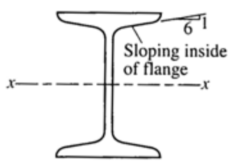
- HP-Shapes:
  - Wide-flange shapes with square cross-section
  - Often used as driven piles for foundation support



(c) HP-shapes

Structural Shapes

- S-Shapes (I-Sections):
  - Have relatively narrow flanges compared to their depth
  - Infrequently used in construction
  - Used in cases where heavy point loads are applied to the flanges, such as in monorails for the support of hung cranes



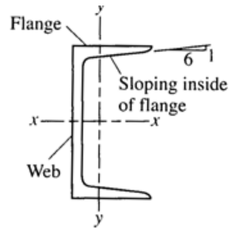
(d) S-shapes

Structural Shapes

- C-Shapes (Channel Sections):
  - Used as bracing or tie members, components of built-up cross sections or members that frame openings
  - Standard designation

C 15 x 50

channel section | nominal depth (in) | weight per foot (lb/ft)



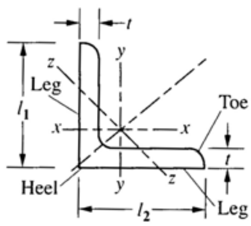
(e) Channels (C-and MC-shapes)

Structural Shapes

- L-Shapes (Angle Sections):
  - Commonly used singly or in pairs as bracing members and tension members
  - Standard designation

L 6 x 4 x 7/8

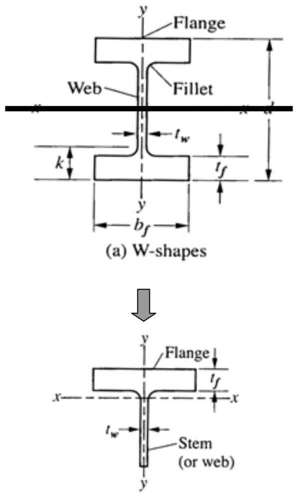
angle section | dimensions of the legs (in) | leg thickness (in)



(f) Angles (equal or unequal legs)

Structural Shapes

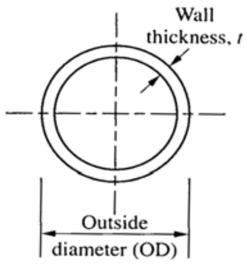
- WT-Shapes (T Sections):
  - Tees that are produced by cutting wide-flange sections from the half (e.g., WT18x105 ← W36x210)
  - Used for special beam applications and as components in connections and trusses



Structural Shapes

- Circular tubes or pipes (Circular sections):
  - Produced by bending and welding flat plates
  - Standard designation

$$\underbrace{\text{HSS}}_{\text{hollow str. section}}\ \underbrace{5.563}_{\text{diameter (in)}}\ \text{x}\ \underbrace{0.258}_{\text{nominal thickness (in)}}$$



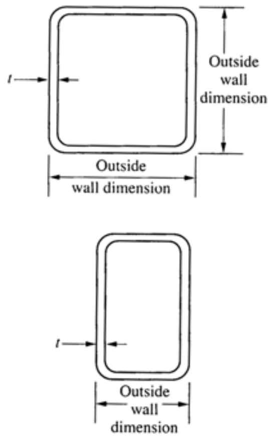
(h) Circular tube or pipe (HSS-shapes)

Structural Shapes

- Square/rectangular tubes (Square/rectangular sections):
  - Hollow sections make excellent compression members
  - Standard designation

HSS 12 x 8 x 1/2

hollow str. section | height (in) | width (in) | nominal thickness (in)



Structural Shapes

- Built-up shapes:
  - Obtained from combinations of standard shapes
  - Over the years, have been found to be useful to the designer

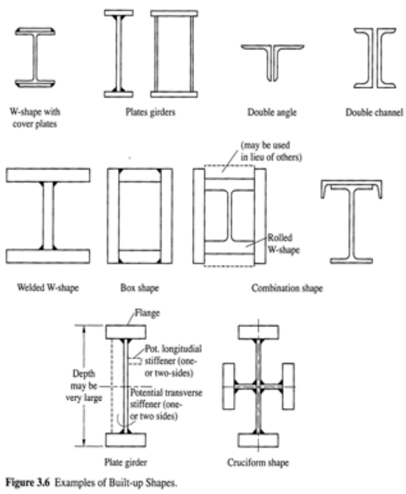
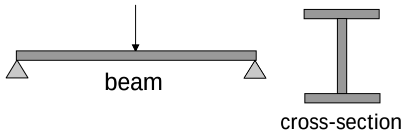


Figure 3.6 Examples of Built-up Shapes.

Elastic and Inelastic Behaviour of Steel

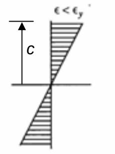
- For nominal loads, the beam behaves elastically
  - Flexural formula:



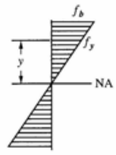
Applied moment

Stress $\rightarrow \sigma = \frac{My}{I}$ ← Distance from neutral axis

Moment of inertia

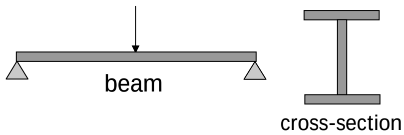


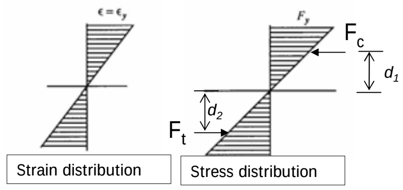
Stress in the extreme fiber $\rightarrow \sigma_b = \frac{Mc}{I} = \frac{M}{W}$ ← Elastic section modulus



Elastic and Inelastic Behaviour of Steel

- Yielding:
  - If the loading is increased further, the strain in the extreme fiber reaches the yield strain and the stress in the extreme fiber reaches yield stress



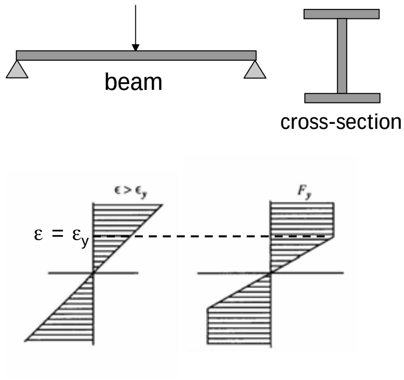


$$M_e = F_c * d_1 + F_t * d_2$$

Elastic moment capacity (M_e = F_y.W)

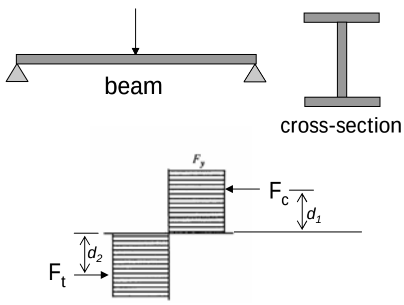
Elastic and Inelastic Behaviour of Steel

- Inelastic behaviour:
  - If the loading is increased further, the fibers adjacent to the extreme fiber also reaches yield stress, that is, yielding spreads throughout the section



Elastic and Inelastic Behaviour of Steel

- Plastic moment capacity:
  - The entire section reaches the yield stress



$$M_p = F_c * d_1 + F_t * d_2$$

Plastic moment capacity

Plastic section modulus → $Z_P = \frac{M_p}{F_y}$ or $M_p = Z_p . F_y$

Elastic and Inelastic Behaviour of Steel

Example: section properties

Design Approaches

- Design approaches:
  - Allowable Stress Design (ASD) – Working Stress Design
  - Load and Resistance Factor Design (LRFD)

Design Approaches

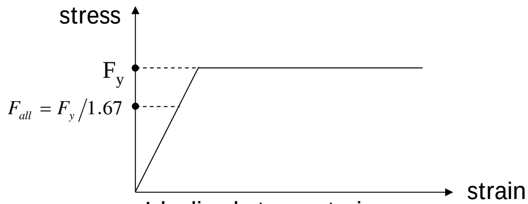
- Allowable Stress Design (ASD)
  - Under actual loads the stress in a member is not to exceed an allowable value F_{all}

Stress → $\sigma \le F_{all} = \dfrac{F_y}{F.S}$

Nominal strength (yield stress)

Factory of satefy

Allowable stress



Idealized stress-strain curve

Design Approaches

- Load and Resistance Factor Design (LRFD)
  - Both the load effect (Q, member force) and resistance (R, strength) are assumed to have a normal distribution

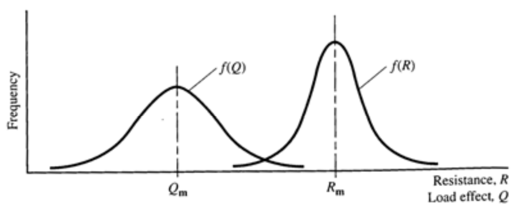
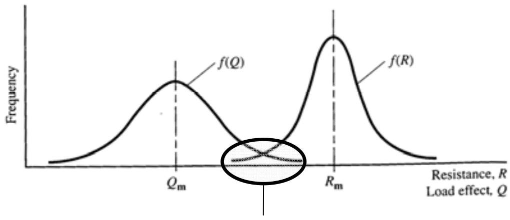


Figure 1.10 Probability Distribution, R and Q.

  - If Q ≤ R, the structure is safe

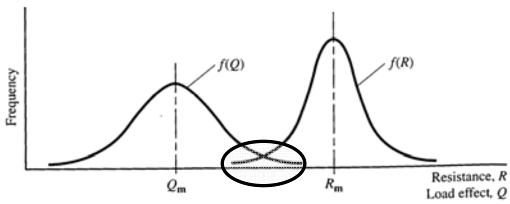
Design Approaches



Overlapping area
(Q>R)
Occurences of failure

- Safety of the structure is a function of the size of this overlapping area

Design Approaches



Factored (increased) load effects $= \sum \gamma_i Q_i$

Reduced strength (resistance,capacity) $= \phi R_n$

Factored load effects ≤ Reduced strength

$$\sum \gamma_i Q_i \le \phi R_n$$

Design Approaches

- ϕ (the resistance or capacity reduction factor) takes into account the uncertanities in the calculation of resistance.
  - ϕ = 0.85 (for columns)
  - ϕ = 0.75 or 0.90 (for tension members)
  - ϕ = 0.90 for bending and shear in beams

Design Approaches

- γ_i (load factor for load effect i) takes into account the uncertanities in the calculation of load effect i.
- Load combinations in LRFD:
  - 1.4D
  - 1.2D + 1.6L +0.5S
  - 1.2D + 1.6S + (0.5W or 0.8W)
  - 1.2D + 1.6W + 0.5L +0.5S

D: dead load, L:live load, W:wind load, S: snow load

Design Approaches

Example: comparison of ASD and LRFD design approaches

Design Specifications

- National:
  - TS648 : Building Code for Steel Structures
- International:
  - AISC-ASD : American Institute of Steel Construction – Allowable Stress Design
  - AISC-LRDF : American Institute of Steel Construction – Load and Resistance Factor Design

Steel Grades

- In TS648:
  - St37 or Fe37 :
    - Ordinary structural steel
    - Ultimate strength: σ_d = 3700-4500 kgf/cm^2
    - Yield stress: σ_a = 2400 kgf/cm^2
  - St52 or Fe52 :
    - High stregth steel
    - Ultimate strength: σ_d = 5200-6200 kgf/cm^2
    - Yield stress: σ_a = 3600 kgf/cm^2
  - Material properties:
    - $\sigma_p = 0.8\ (\sigma_a)$,
    - $\rho_w = 7.85\text{x}10^{-3}$ kg/cm^3,
    - $\upsilon = 0.3$

Table I.4 Properties of Steel (From TS 648)

Type of Steel	Tensile Strength σ_d kgf/cm^2 (N/mm^2)	Yield Stress* σ_a kgf/cm^2 (N/mm^2)	Modulus of Elasticity E kgf/cm^2 (N/mm^2)	Shear Modulus G kgf/cm^2 (N/mm^2)
Fe 33	3300-5000 (324-490)	1900 (186)	2100 000 (206182)	810 000 (79434)
Fe 34	3400-4200 (333-412)	2100 (206)		
Fe 37	3700-4500 (363-491)	2400 (235)		
Fe 42	4200-5000 (412-490)	2600 (255)		
Fe 46	4400-5400 (431-530)	2900 (284)		
Fe 50	5000-6000 (490-588)	3000 (294)		
Fe 52	5200-6200 (510-608)	3600 (353)		
Fe 60	6000-7200 (588-706)	3400 (333)		
Fe 70	7000-8500 (686-834)	3700 (363)		

*These values are for sections with thicknesses equal to or
If $16 < t \leq 40$ mm, decrease the yield stress values by 100 (9.8 N/mm^2). If $40 < t \leq 100$ mm, decrease the yield stress v
(19.6 N/mm^2).

Steel Grades

- In AISC:
  - Classification:
    - Carbon Steel (A36, A53, A500, A501, A529)
    - High-strength low alloy steel (A572, A618, A913, A992)
    - Corrosion resistant high-strength low alloy steel (A242, A588, A847)
  - A36:
    - Ordinary structural steel
    - Ultimate strength: σ_d = 58-80 ksi
    - Yield stress: F_y = 36 ksi

Table 2-3
Applicable ASTM Specifications for Various Structural Shapes

Steel Type	ASTM Designation		F_y Min. Yield Stress (ksi)	F_u Tensile Stress[a] (ksi)	W	M	S	HP	C	MC	L	HSS Rect.	HSS Round	Pipe
Carbon	A36		36	58-80[b]		■	■		■	■	■			
	A53 Gr. B		35	60										■
	A500	Gr. B	42	58									■	
			46	58								■		
		Gr. C	46	62										
			50	62										
	A501		36	58										
	A529[c]	Gr. 50	50	65-100										
		Gr. 55	55	70-100										
High-Strength Low-Alloy	A572	Gr. 42	42	60										
		Gr. 50	50	65[d]				■						
		Gr. 55	55	70										
		Gr. 60[e]	60	75										
		Gr. 65[e]	65	80										
	A618[f]	Gr. I & II	50[g]	70[g]										
		Gr. III	50	65										
	A913	50	50[h]	60[h]										
		60	60	75										
		65	65	80										
		70	70	90										
	A992		50-65[i]	65[i]	■									
Corrosion Resistant High-Strength Low-Alloy	A242		42[j]	63[j]										
			46[k]	67[k]										
			50[l]	70[l]										
	A588		50	70										
	A847		50	70										