STEEL STRUCTURE

CIVIL ENGINEERING-CE

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STUDY MATERIAL

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ENGINEERS INSTITUTE OF INDIA

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CONTENT

CHAPTER-1
STRUCTURAL STEEL, LOADS AND STRESSES

Structural Steel:

Main components of steel are: (i) Metallic iron, (ii) Carbon and others like Si, Cr, Mn, Cu etc.

- Generally steel consists of more than 98% of iron and carbon content 0.04% to 2.1%
- Cast iron has high carbon content (2.1% to 4%) which makes it brittle.
- Wrought iron has low carbon content (less than 0.08%). It is tough, malleable, ductile, corrosion resistant and easily welded.
- Steel has carbon content intermediate between cast iron and wrought iron.

- Depending upon chemical composition, steel is classified as:
  - (i) Mild steel
  - (ii) Medium carbon steel
  - (iii) High carbon steel

  } Are Knows as structural steel and is used in steel structure.
  - (iv) Low alloy steel
  - (v) High alloy steel

Note: As carbon content increases, strength, hardness and brittleness increases but the ductility decreases.

- **Mild steel** is used for manufacture of rolled steel section, rivets and bolts.
- **Physical properties** of mild structure are.
  - (i) Mass : 7850 Kg/m^3
  - (ii) Young's modulus of Elasticity (E): 2.04×10^5 N/mm^2 or MPa
  - (iii) Modulus of rigidity (G): 0.785×10^5 N/mm^2
  - (iv) Poisson's ratio (μ) : 0.3 (in elastic range)
    : 0.5 (in plastic range)
  - (v) Co-efficient of thermal expansion or contraction : 12×10^{-6}/ºC

Table : Chemical Composition of Structural Steels

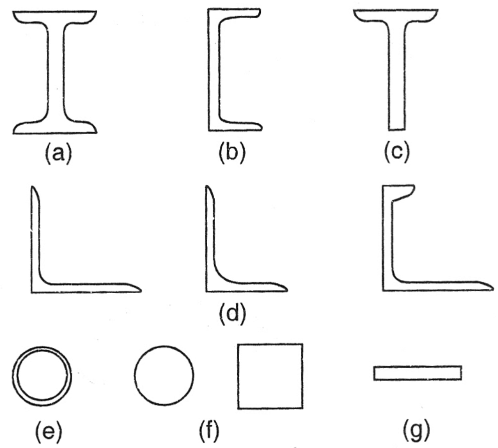
S. No.	Quality of Steel	Designation	I.S. Code	Maximum percentage C	S	P	Mn	Si	Tensile strength (N/mm^2)
1.	Standard structural C = 0.2–0.35%	Fe-410S	226	0.23	0.055	0.055	—	0.10	410
2.	Structural ordinary	Fe 310	1977	0.23	0.07	0.07	—	—	310
		Fe 410-O	1977	0.23	0.07	0.07	—	—	410
3.	Weldable	Fe 410-H	2062	0.20	0.055	0.055	1.0	—	410
		Fe 440 HT	8500	0.25	0.055	0.055	1.5	—	440
		Fe 490 HT	8500	0.25	0.04	0.04	1.5	—	490
		Fe 590 HT	8500	0.25	0.05	0.05	1.5	—	590

Fe = steel, C = carbon, S = sulphur, P = phosphorus, Mn = Manganese, Si = silicon

- **Structural Elements of a Steel Structure :** The steel frame work or the skeleton consists of following elements.
  (*i*) Flexural members – beams or girders
  (*ii*) Tension members – ties
  (*iii*) Compression members – columns, struts

(*iv*) Torsional members

The members of the design are made up of commonly used shapes and built by members – made of the common shapes. Following are the common shapes.



(a.) Rolled steel I-section
(b.) Rolled steel channel section
(c.) Rolled steel T-section
(d.) Rolled steel angle section (equal or unequal)
(e.) Rolled steel circular section (solid or hollow)
(f.) Rolled steel bars (circular or rectangular)
(g.) Rolled steel plates

Flexural members: (Beams and Girders): A beam or girders is a structural component which supports loads normal to its axis. They are both same but girder is primarily used to describe a built up member or a main beam which supports other beams.

Tension Members (Ties) : It is used to resist axial tension. They are usually called ties or hangers. The cross-section of a tension member is important only to the context of its quantity. The shape is immaterial to resist the tensile force.

Compression Members (Columns, Struts): They primarily resist the compressive stress. The shape of a compression member plays an important role in its determination apart from the area required. The material properties also plays an important role in its selection.

Torsional Members: They are primarily provided to resist torsion or twisting forces.

Note: (Important of ESE)

1. ISLB are used as roof beam where loads are relatively less.
2. ISMB are used as floor beam, they have high moment of inertia about *x*-axis as compared with *y*-axis. Lateral buckling strength of these beams is not high (can be overcome by laterally restraining of compression flange of the beam).
3. ISWB have high M.I about *y-y* axis also. So they have higher lateral buckling strength. So they are used as column.

Design methods:

Design of steel structures consists of the design of steel members and their connections. A steel structure can be designed by any one of the following methods:

(*i*) Working stress design: Also known as the elastic design method, it assumes that the acceptable behaviour in a steel member is up to the yield stress. It also takes into account the factor of safety.

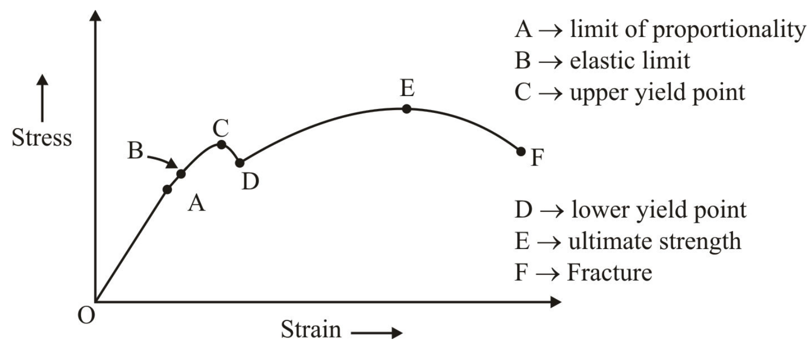
$$\text{Permissible stress} \leq \frac{\text{Yield stress}}{\text{Factor of safety}}$$

(*ii*) Plastic design : In this method, the material is considered acceptable upto the ultimate load. It is mainly used in the analysis and design of statically indeterminate structure. The factor of safety in this method is known by the name of 'load factor.'

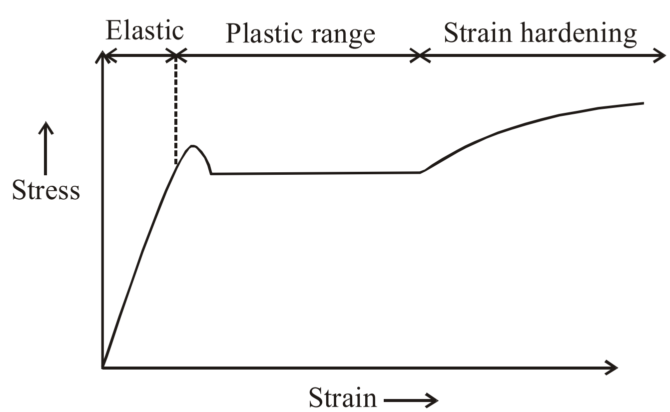
$$\text{Working load} = \frac{\text{Collapse load}}{\text{Load factor}}$$

(*iii*) Limit state method: Limit state method is similar to plastic design which considers most critical limit states of strength and serviceability. Load factors are applied to the service loads and then theoretical strength of member is reduced by application of resistance factor. The criteria to be satisfied in selection of member is factored load ≤ factored strength.

Stress Strain Relationship for Mild Steel:



The curve starts from the origin showing that there is no initial stress or strain upto point A, Hooke's law is obeyed and stress is proportional to strain. Point A is called the limit of proportionality.
Point B is called the elastic limit. Upto this point if the load is removed, the material returns to its original shape and size, *i.e.,* no strain is left in the specimen.
Beyond point B, the material behaves as a plastic material until point C which is the upper yield point.
After point C the cross-sectional area of the material starts decreasing and the stress decreases to a lower value to point D, called the lower yield point.
Beyond D, the specimen elongates without a considerable increase in stress and reaches a maximum value of stress called the ultimate strength. This is denoted by point E.
After point E, necking of the material starts and the cross-sectional area decreases at a rapid rate. At last, the material fractures at point F.



This figure is an enlarged view of a part of the graph given above. It shows that the range of working stress design is only upto the proportional limit while the range for plastic design is large and upto a strain 10 times than what occurred upto the proportional limit. Beyond plastic range is the strain hardening for which a structure is not designed.

Example: Which of the following statements is incorrect regarding steel?
(*a*) It can be reused.
(*b*) Being heavy, it is quite hard to transport.
(*c*) Steel has a very long life when maintained properly.
(*d*) Steel is a ductile material.
Sol. **(*b*)** Being light, steel can be handled conveniently thus it offers ease in transportation.

The primary purpose of any structure is that it should be strong enough to carry all types of foreseeable loads. For the purpose of designing any element or a structure as a whole, the following loads and their effects should be taken into account, where applicable, with partial safety factors and combinations.
(*i*) Dead loads ; IS 875 (Part I)
(*ii*) Live loads : IS 875 (Part II/IV)
(*iii*) Wind loads ; IS 875 (Part III)
(*iv*) Earthquake loads ; IS 1893
(*v*) Erection loads
(*vi*) Accidental loads such as those due to blast
(*vii*) Secondary effects due to contraction or expansion resulting from temperature changes, differential settlement of structure as a whole or of its components, eccentric connections, rigidity of joints differing from design specifications.

(*i*) Dead loads: It is the weight of the walls, partitions, roofs, etc. and other permanent construction in the building. Dead loads do not change their position and do not vary in magnitude.
(*ii*) Live loads: It consists of variable loads, due to people, furniture, stores, machinery etc. It is also known as the super-imposed loads. In broader sense, it includes.
- Movable machinery
- Snow load
- Earth pressure
- Earthquake forces
- Thermal forces.

(*iii*) Wind loads: Wind produces wind pressure on the exposed vertical surfaces of wall, towers, etc. and acts horizontally. The wind velocities are measured with the help of anemometers which are installed at a height of 10 to 30 meters.

Load combinations: The following combination of loads with appropriate load factors specified in the code may be considered.
(*a*) Dead load + Imposed load
(*b*) Dead load + Imposed load + Wind or earth quake load
(*c*) Dead load + Wind or earthquake load
(*d*) Dead load + Erection load

Permissible Stresses:

1. Axial tensile stress:

Permissible axial tensile stress (σ_{at}):

$\boxed{\sigma_{at} = 0.6 f_y}$ Where $f_y =$ yield stress of steel (N/mm^2)

2. Axial Compressive Stress:

Permissible axial compressive stress

$\boxed{\sigma_{ac} = 0.6 f_y}$ For direct stress in compression of a axially loaded column

Or, According to Rankine's formula:

$$\sigma_{ac} = 0.6 \frac{f_{cc} . f_y}{\left[(f_{cc})^n + (f_y)^n\right]^{1/n}}$$

Where, $f_{cc} =$ elastic critical stress in compression $= \dfrac{\pi^2 E}{\lambda^2}$

$\lambda =$ Slenderness ratio $= \dfrac{l}{r}$

$n = 1.4$

E = Young's modulus

The value of σ_{ac} shall exceed neither of the above two values.

3. Bending Stress:

- Permissible bending stress in tension or in compression:

$$\boxed{\sigma_{bt} \ or \ \sigma_{bc} = 0.66 f_y}$$

- Permissible bending compressive stress in beams and plate girders:

$$\sigma_{bc} = 0.66 \frac{f_{cb} \cdot f_y}{\left[(f_{cb})^n + (f_y)^n\right]^{1/n}}$$

Where, f_{cb} = Elastic critical stress in bending.

n =1.4

4. Shear Stress:

- Permissible shear stress, $\boxed{\tau_{vm} = 0.45 f_y}$

5. Bearing Stress:

- Permissible bearing stress, $\boxed{\sigma_p = 0.75 f_y}$

Factor of safety (F.O.S.)F:

- It is defined as the ratio of yield stress to maximum expected stress.

$$\boxed{F = \frac{f_y}{\sigma_{max}}}$$

- I.S. Code permits the value of F as 1.67.

Key Points

1. As carbon content increases, strength, hardness and brittleness increases but ductility decreases.
2. For mild steel, Mass = 7850 kg/m^3

   $E = 2.04 \times 10^5 \text{ N/mm}^2$ $G = 0.785 \times 10^5$ MPa

   $\mu = 0.3$
3. Permissible stresses:

- Axial tension, $\sigma_{at} = 0.6 f_y$
- Axial compressive, $\sigma_{ac} = 0.6 f_y$

or, by Rankine's formula, $\sigma_{ac} = \dfrac{0.6 f_{cc} \cdot f_y}{[(f_{cc})^n + (f_y)^n]^{\frac{1}{n}}}$

- Bending stress, $\frac{\sigma_{bt}}{\sigma_{bc}} = 0.66 f_y$
- Shear stress, $\tau_{VM} = 0.45 f_y$
- Bearing stress, $\sigma_P = 0.75 f_y$

SOLVED EXAMPLES

1. What will be the working stress for a mild steel specimen whose yield strength is $250\ \text{N/mm}^2$ with factor of safety of 2.5?

(*a*) $75\ \text{N/mm}^2$ (*b*) $100\ \text{N/mm}^2$

(*c*) $125\ \text{N/mm}^2$ (*d*) $625\ \text{N/mm}^2$

Ans. **(*b*)**

Exp. Working stress = $\dfrac{\text{Yield strength}}{\text{Factor of safety}}$

$$= \frac{250}{2.5} = 100\ \text{N/mm}^2$$

2. What should be the impact factor (in %) to be adopted for installed machinery?

(*a*) 20% (*b*) 30% (*c*) 40% (*d*) 50%

Ans. **(*a*)**

Exp. Impact load can be computed by multiplying live loads with the impact factor. Impact factor for installed machinery as per code is 20%.

3. A tie bar 60 mm × 8 mm is to carry a load of 100 kN. A specimen of the same quality steel of cross-sectional area $300\ \text{mm}^2$ was tested in the laboratory. The maximum load carried by specimen was 150 kN. Find the factor of safety in the design.

Ans: 2.4

Exp. Yield strength for steel = $\dfrac{\text{Maximum load}}{\text{Cross-sectional area}}$

$$= \frac{150 \times 1000}{300} = 500\ \text{N/mm}^2$$

Working stress = $\dfrac{100 \times 1000}{60 \times 8} = 208.33\ \text{N/mm}^2$

Factor of safety = $\dfrac{\text{Yield strength}}{\text{Working stress}} = \dfrac{500}{208.33} = 2.4$

4. A steel chimney 3.0 m in diameter is situated in a region where the intensity of wind pressure is $1500\ \text{N/m}^2$. Assuming the intensity of wind pressure to be uniform, estimate the shear due to wind load at a level 15 m below top of chimney.

Ans: 47.25

Exp. Design wind load = $K\ P_1\ A_1$

Where, K = Shape factor = 0.7

P_1 = Intensity of wind pressure $= 1500\ \text{N/m}^2$

A_1 = Projected area = 3 × 15

So, wind load, P = 0.7 × 1500 × (3 × 15) = 47250 N = 47.25 kN

PRACTICE SET

1. What is the permissible axial tensile stress for the grade of steel having $f_y = 250\ \text{N/mm}^2$?

(*a*) $150\ \text{N/mm}^2$ (*b*) $100\ \text{N/mm}^2$ (*c*) $200\ \text{N/mm}^2$ (*d*) $250\ \text{N/mm}^2$

2. What is slenderness ratio, λ is terms of efficiency length and radius of gyration ?

(*a*) $\lambda = \frac{l_e}{r}$ (*b*) $\lambda = \frac{l_e^2}{r}$ (*c*) $\lambda = \left(\frac{l_e}{r}\right)^2$ (*d*) $\lambda = \sqrt{\frac{l_e}{r}}$

3. What is the value of factor of safety permitted by the code for steel structure ?

(*a*) 1.5 (*b*) 1.15 (*c*) 1.67 (*d*) 1.8

4. In what category of load world a machinery fall?

(*a*) Dead load (*b*) Live load (*c*) Wind load (*d*) None of the above

5. Till which point, a material remains elastic in nature (not necessarily obeying Hooke's law) ?

(*a*) upper yield point (*b*) Lower yield point

(*c*) Proportional limit (*d*) Ultimate load

6. How much additional thickness should be provided in steel sections in contact with water and those subjected to alternate wetting and drying?

(*a*) 1 mm (*b*) 1.5 mm (*c*) 2 mm (*d*) 3 mm

7. Which of the following is the heaviest for same depth?

(*a*) ISHB (*b*) ISWB (*c*) ISMB (*d*) ISLB

8. For a moment-resisting frame building, fundamental natural period T_a is given as:

(*a*) $\frac{4h}{d}$ (*b*) $\frac{2h}{d}$ (*c*) $\frac{0.09\,h}{d}$ (*d*) $\frac{0.045\,h}{d}$

9. Choose the correct statement regarding compact sections?

(*a*) The stress distribution for such sections is parabolic

(*b*) These can develop plastic moment of resistance but have inadequate plastic hinge rotation capacity for formation of a plastic mechanism before buckling.

(*c*) These can develop plastic hinges and have rotation capacity required for failure

(*d*) All of the above

10. Modulus of elasticity and unit mass of steel (as per IS 800 : 2007) are respectively

(*a*) $2\times10^5\ \text{N/mm}^2$ and $7850\ \text{kg/m}^3$ (*b*) $2.1\times10^5\ \text{N/mm}^2$ and $7500\ \text{kg/m}^3$

(*c*) $2.1\times10^5\ \text{N/mm}^2$ and $7850\ \text{kg/m}^3$ (*d*) $2\times10^5\ \text{N/mm}^2$ and $7500\ \text{kg/m}^3$

11. In the context of ultimate load theory for steel, the stress-strain curve for steel is idealized as

(*a*) a circular are (*b*) A quadratic parabola

(*c*) a single straight line (*d*) bi linear

12. The code used to calculate earthquake load on structure is

(*a*) IS 875 Part IV (*b*) IS 1893

(*c*) IS 875 Part III (*d*) IS 1839

13. What will be the permissible bending stress, shear stress and bearing stress for yield stress of $250\ \text{N/mm}^2$?

Answers with Explanations

1. **(*a*)** $\sigma_{at} = 0.6\, f_y$

$\Rightarrow \sigma_{at} = 0.6 \times 250 = 150 \text{ N/mm}^2$

2. (*a*) **3.** (*b*) **4.** (*b*) **5.** (*c*)

6. **(*b*)** **7. (*a*)**

8. **(*c*)** Fundamental natural period for a moment resisting frame building is given as,

$$T_a = \frac{0.09\, h}{d}$$

Where, h = height of building (in m)

d = base dimension of building at plinth level, in meters, along the considered direction of lateral force.

9. **(*b*)** Stress distribution of compact sections is rectangular

10. **(*a*)** **11. (*d*)** **12. (*b*)**

13. Yield stress, $f_y = 250 \text{ N/mm}^2$

So, permissible bending stress, $\sigma_b = 0.66\, f_y = 0.66 \times 250 = 165 \text{ N/mm}^2$

Permissible shear stress, $\sigma_{VM} = 0.45\, f_y = 0.45 \times 250 = 112.5 \text{ N/mm}^2$

Permissible bearing stress, $\sigma_P = 0.75\, f_y = 0.75 \times 250 = 187.5 \text{ N/mm}^2$

Published Books