A Handbook on Civil Engineering

Revised & Updated

Contains well illustrated formulae & key theory concepts

For

ESE, GATE, PSUs

& OTHER COMPETITIVE EXAMS

MADE EASY PUBLICATIONS

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Director's Message

B. Singh (Ex. IES)

During the current age of international competition in Science and Technology, the Indian participation through skilled technical professionals have been challenging to the world. Constant efforts and desire to achieve top positions are still required.

I feel every candidate has ability to succeed but competitive environment and quality guidance is required to achieve high level goals. At MADE EASY, we help you to discover your hidden talent and success quotient to achieve your ultimate goals. In my opinion CSE, ESE, GATE & PSUs exams are tool to enter in to main stream of Nation serving. The real application of knowledge and talent starts, after you enter in to the working system. Here in MADE EASY you are also trained to become winner in your life and achieve job satisfaction.

MADE EASY alumni have shared their winning stories of success and expressed their gratitude towards quality guidance of MADE EASY. Our students have not only secured All India First Ranks in ESE, GATE and PSUs entrance examinations but also secured top positions in their career profiles. Now, I invite you to become alumni of MADE EASY to explore and achieve ultimate goal of your life. I promise to provide you quality guidance with competitive environment which is far advanced and ahead than the reach of other institutions. You will get the guidance, support and inspiration that you need to reach the peak of your career.

I have true desire to serve Society and Nation by way of making easy path of the education for the people of India.

After a long experience of teaching in Civil Engineering over the period of time MADE EASY team realised that there is a need of good *Handbook* which can provide the crux of Civil Engineering in a concise form to the student to brush up the formulae and important concepts required for ESE, GATE, PSUs and other competitive examinations. This *handbook* contains all the formulae and important theoretical aspects of Civil Engineering. It provides much needed revision aid and study guidance before examinations.

B. Singh (Ex. IES)
CMD, MADE EASY Group

A Handbook on

Civil Engineering

Contents

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CHAPTER 01

STRENGTH OF MATERIALS

Contents

1 Strength of Materials

PROPERTIES OF MATERIALS

Important Mechanical Properties

- Elasticity : It is the property by virtue of which a material deformed under the load is ***enabled*** to return to its original dimension when the load is removed.

Remember:

☑ If body regains ***completely*** its original shape, then it is called ***perfectly*** elastic body.

☑ ***Elastic limit*** marks the ***partial*** break down of elasticity beyond which removal of load result in a degree of ***permanent deformation***.

☑ Steel, Aluminum, Copper, may be considered to be perfectly elastic ***within certain limit***.

- Plasticity : The characteristics of the material by which it undergoes ***inelastic strain*** beyond those at the ***elastic limit*** is known as plasticity.

Remember:

☑ This property is particularly useful in operation of ***pressing*** and ***forging***.

☑ When large deformation occurs in a ***ductile*** material loaded in ***plastic*** region, the material is said to undergo ***plastic flow***.

- Ductility: ($\sigma_{yt} \geq \sigma_{yc} \geq \tau$) (More fracture strain, more ductility)

  It is the property which permits a material to be drawn out ***longitudinally*** to a reduced section, under the action of ***tensile force***.

Remember:

☑ A ductile material must posses a high degree of plasticity and strength.

☑ Ductile material must have ***low*** degree of elasticity.
This is useful in ***wire drawing***.

- **Brittleness :** ($\sigma_{yc} \geq \tau \geq \sigma_{yt}$) (More ultimate stress, more brittle). It is lack of ductility. Brittleness implies that it can ***not*** be drawn out by tension to smaller section.

Remember:

☑ In brittle material, failure take place under tensile load ***without*** significant deformation.

☑ *Ordinary* ***Glass*** is nearly ***ideal*** brittle material.

☑ Cast iron, ***concrete*** and ceramic material are brittle material.

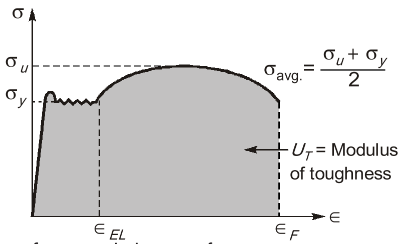
☑ As the percentage of carbon increases in steel (2-5%), fracture strain decreases and strength increases, in other words, brittleness increases.

- **Malleability :** It is the property of a material which permits the material to be ***extended*** in ***all direction*** without rupture. (turn into v sheets).

Remember:

☑ A malleable material posses a ***high degree*** of plasticity, but ***not*** necessarily ***great strength***.

- **Toughness:** It is the property of material which enables it to absorb energy ***without fracture***.
- Toughness is equal to area under load deflection curve upto fracture.



Modulus of toughness

U_T = Area under ***stress-strain*** curve of material upto fracture.

$$= \left(\frac{\sigma_u + \sigma_y}{2}\right) \epsilon_f .$$

Remember:

☑ It is desirable in material which is subjected to ***cyclic*** or ***shock loading***.

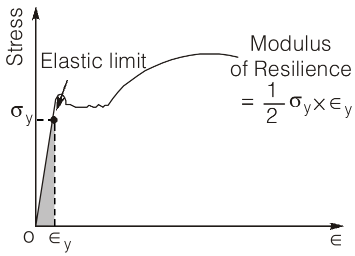
☑ ***Bend test*** used for common comparative test of toughness.

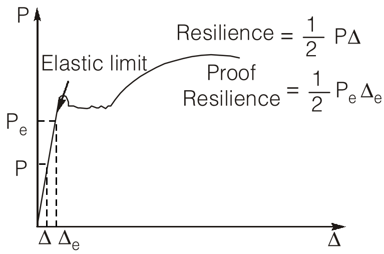
- **Resilience**

  It is the total elastic strain energy which can be stored in the given volume of metal and can be released after unloading.

  It is equal to area under load deflection curve within ***elastic limit.***
- **Resilience:** Ability of a material to absorb energy in the ***elastic region*** when it is strained.

$$= \text{Area under P-}\delta\text{ curve} = \frac{1}{2} P \times \delta$$





- **Proof Resilience:** ***Maximum*** energy absorbing capacity of a material in the ***elastic region*** is called proof resilience. It is equal to the area of the load deflection curve upto elastic limit. In other words, when the resilience becomes maximum, it is said to be proof resilience.

$$= \text{Area under P-}\delta\text{ curve} = \frac{1}{2}P_{EL} \times \delta_{EL}$$

Here P_{EL} = Load at elastic limit
δ_{EL} = Elongation upto elastic limit

$$\text{Modulus of Resilience} = \frac{\text{Proof Resilience}}{\text{Volume}} = \frac{\sigma_{EL}^2}{2E}$$

Here σ_{EL} = Strain at elastic limit
E = Modulus of elasticity

- **Modulus of Resilience:** It is the maximum strain energy that can be stored i a unit volume of material upto elastic limit. It is equal to the area of the stress-strain curve under elastic limit. It is the property of material.
- **Hardness :** It is the ability of a material to resist ***indentation*** or ***surface abrasion***.

Remember: ....

☑ Brinell hardness test is used to check hardness.

☑ Brinnell hardness number = $\dfrac{P}{\dfrac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$

where, P = Standard load; D = Diameter of steel ball (mm);
d = Diameter of indent (mm)

....

- **Strength :** This property enables material to resist fracture under load.

Remember: ....

☑ Load required to cause fracture, divided by area of test specimen, is termed as ***ultimate strength***.

☑ This is most important property from ***design*** point of view.

☑ Design stress for ductile material is yield stress, whereas for brittle material it is ultimate stress.

....

- **Creep** : Creep is a permanent deformation which is recorded with passage of time at constant loading. It is plastic deformation (permanent and non-recoverable) in nature.

Note:

☑ The temperature at which creep is uncontrollable is called *Homologous Temperature.*

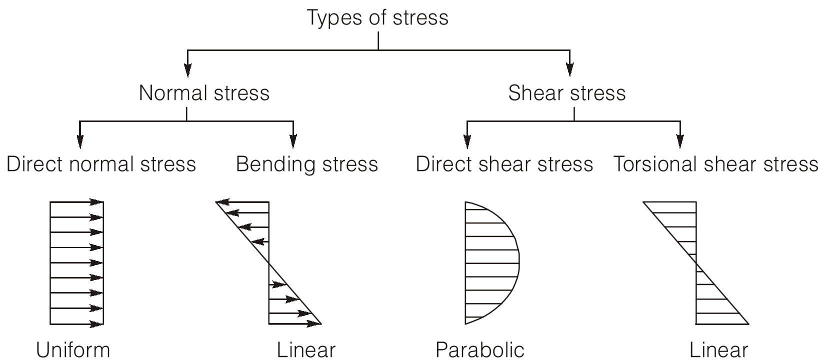
- **Fatigue** : Due to cyclic or reverse cyclic loading fracture failure may occur if total accumulated strain energy exceeds the toughness. Fatigue causes rough fracture surface even in ductile metals.
- **Endurance Limit**: It is the stress level below which even large number (10^5) of stress cycle can not produce fatigue failure.
- **Tenacity**
  It is the ability of a material to resist fracture under the action of tensile load.

STRESS AND STRAIN

Stress (N/mm^2)

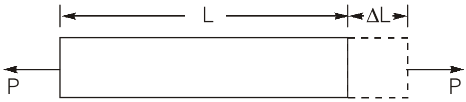
It is the resistance offered by the body to deformation.

- Nominal stress (Engineering stress) = $\dfrac{\text{Load}}{\text{Original Area of cross section}}$
- Actual/True stress = $\dfrac{\text{Load}}{\text{True (Actual) Area of cross section}}$
- Stress develops only if strain is resisted.

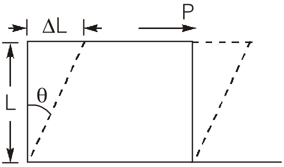


Strain

- Strain is the deformation of a material from stress.Deformation that are applied perpendicular to the cross-section are normal strains, which deformation applied parallel to the cross-section are shear strain.



Normal strain = $\frac{\Delta L}{L}$



Shear strain, $\tau = \tan\theta$; $\theta = \frac{\Delta L}{L}$

Remember: ....

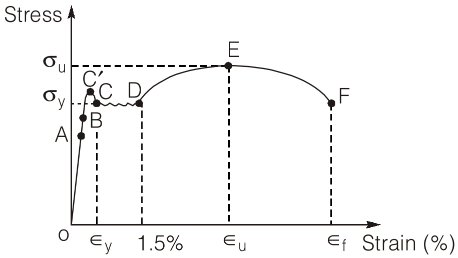
☑ It is a ***dimensionless*** quantity.

☑ Strain is the measured quantity whereas stress can not be measured directly.

....

Engineering Stress-Strain curve of mild steel for tension under static-loading

OA -Straight line proportional region,



OB - Elastic region

BC - Elasto plastic region

CD - Perfectly plastic region

DE - Strain hardening

EF - Necking region

A - Limit of proportionality

B - Elastic limit

C - Lower yield point

F - Fracture point

C′- Upper yield point

D - Strain hardening starts

E - Ultimate or maximum stress point

- Limit of Proportionality: It is the stress at which the stress-strain curve ***ceases*** to be a straight line.

Remember: ....

☑ ***Hooke's law*** is valid upto proportional limit.

....

- Elastic Limit : It is the point on the stress-strain curve upto which the materials remains elastic.

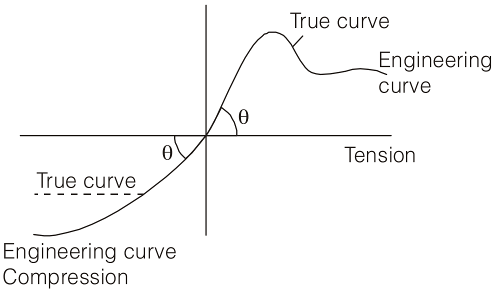
Remember: ....

☑ Upto this point there is ***no permanent*** deformation after removal of load.

....

- **Plastic Range:** It is the region of the stress-strain curve between the elastic limit and point of rupture.
- **Yield Point:** This point is just beyond the elastic limit, at which the specimen undergoes an appreciable increase in length ***without*** further increase in the load.
- **Rupture Strength:** It is the stress corresponding to the failure point 'F' of the stress-strain curve.
- **Proof Stress:** It is the stress necessary to cause a ***permanent extension*** equal to defined percentage of gauge length.

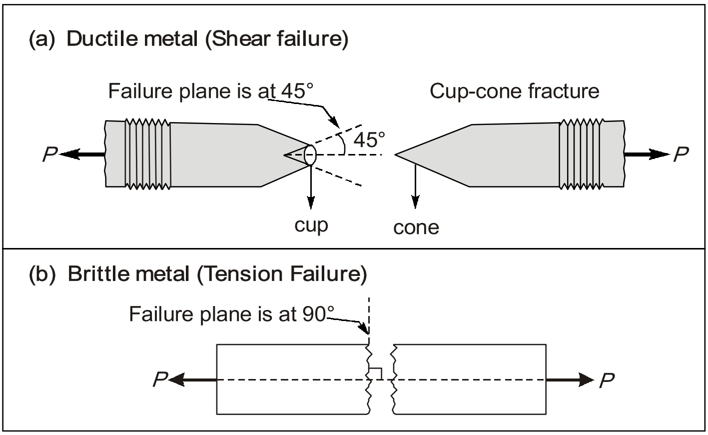
Relation between True stress and Engineering stress



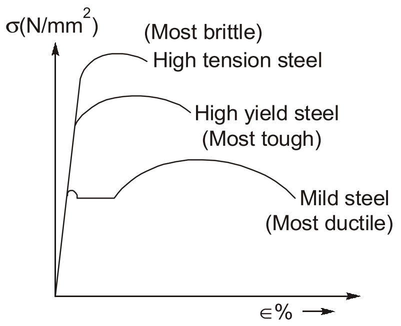
$$\text{Engineering stress} = \frac{P}{A_0}, \text{ Engineering strain} = \frac{\delta}{L_0}$$

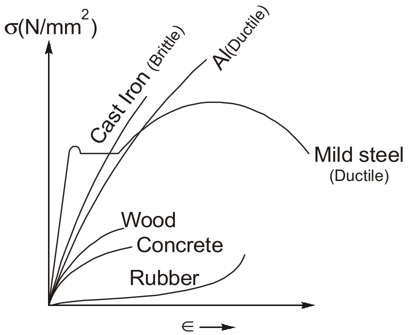
$$\text{True stress} = \frac{P}{A}, \text{ True strain} = \frac{\Delta L}{L}, (L = L_0 \pm \Delta L)$$

Type of Tension failure in Metal



Stress-Strain Diagram for Various type of Steel/Material





All grades of steel have same young's modulus but different yield stress.

Ductile material

If post elastic strain is greater than 5%, it is called ductile material.

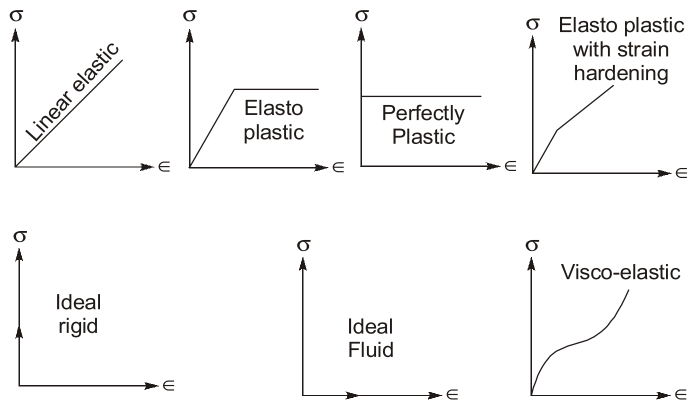
It undergoes large permanent strains before failure.

Large reduction in area before fracture,e.g. ***lead***, mild steel, copper

Brittle Material

- If post elastic strain is less than 5%, it is called brittle material.
- It fails with only little elongation after the proportional limit is exceeded.
- Very less reduction in area before fracture, e.g. Bronze, ***Rubber***, Glass.

Behavior of Various Material



Where σ= Stress, ∈ = Strain

Remember:

☑ ***'Mild steel'*** is ***more*** elastic than ***'Rubber'***.

Hooke's Law

When a material behaves elastically and exhibits a linear relationship between stress and strain, it is called linearly elastic. For homogeneous and isotropics materials, stress (σ) is directly proportional to strain ($\in$).

$$\sigma \propto \in \rightarrow \sigma = E . \in$$

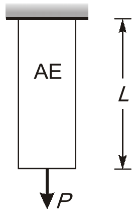
where, σ = Stress; $\in$ = Strain; E = Young modulus of elasticity

- $E_{\text{cast iron}} \approx \frac{1}{2} E_{\text{steel}}$.
- $E_{\text{Aluminium}} \approx \frac{1}{3} E_{\text{steel}}$
- **Homogeneous:** Same property at any point in one direction.
- **Isotropic:** Same property in all direction at a given point.

Axial elongation (Δ) of prismatic bar due to external load

$$\Delta = \frac{PL}{AE}$$

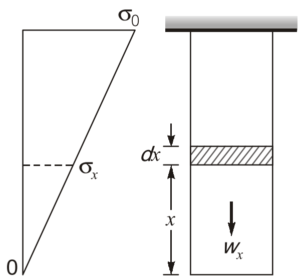
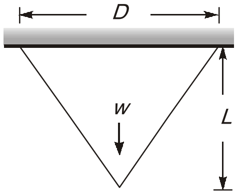
Here, P = Load applied
L = Length of bar
A = Area of bar
E = Young modulus



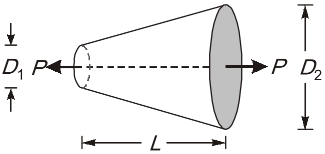
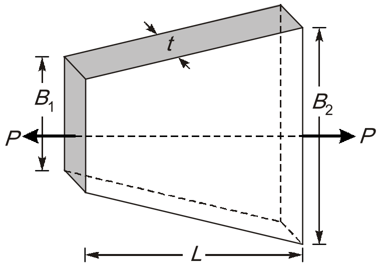
$$\Delta = \frac{P}{\frac{EA}{L}} = \frac{P}{K}$$

$K = AE/L$ = Axial stiffness of bar
AE = Axial rigidity
EI/L = Flexural stiffness
EI = Flexural rigidity

Deflection of bar (Δ) due to self-weight

Prismatic bar	Conical bar
$\Delta = \frac{WL}{2AE} = \frac{\gamma L^2}{2E}$ Here, W = Total Self weight  Stress diagram	$\Delta = \frac{\gamma L^2}{6E} = \frac{WL}{2AE}$ Here, γ = Specific weight L = Length of bar E = Young's modulus A = Base area of cone = $\frac{\pi}{4} D^2$ 

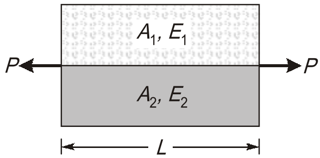
Deflection (Δ) of Tapered Bar

Circular tapering bar	Rectangular tapering bar with constant thickness
$\Delta = \dfrac{4PL}{\pi E D_1 D_2}$	$\Delta = \dfrac{PL \log_e \left(\dfrac{B_2}{B_1}\right)}{E \times t(B_2 - B_1)}$
	

Equivalent Young's Modulus of Parallel Composite Bar

$$E_{equivalent} = \frac{A_1 E_1 + A_2 E_2}{A_1 + A_2}$$

where, A_1=Area of first bar; A_2 = Area of second bar; E_1 = Young's modulus of first bar; E_2 = Young's modulus of second bar



ELASTIC CONSTANTS

Elastic constants are those factor which determine the deformation produced by a given stress system acting on material.

- Modulus of elasticity (E) = $\dfrac{\text{Longitudinal stress}}{\text{Longitudinal strain}}$

  Modulus of rigidity (G) = $\dfrac{\text{Shear stress}}{\text{Shear strain}}$

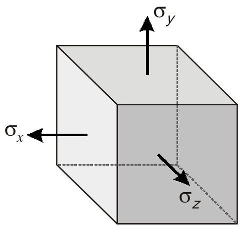
  Bulk modulus (K) = $\dfrac{\text{Direct stress}}{\text{Volumetric strain}}$

Poisson's Ratio, $\mu = \dfrac{-(\text{Lateral strain})}{(\text{Longitudinal Strain})}$

Under uniaxial loading,

Material	μ
For cork	0
For perfectly plastic body (Rubber)	0.5
For elastic metals	0.25 to 0.42
For concrete	0.1 to 0.2
Mild steel	0.286

Volumetric Strain under Tri-Axial Loading



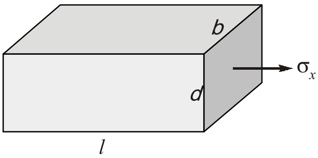
$$\epsilon_V = \epsilon_x + \epsilon_y + \epsilon_z = \frac{\sigma_x + \sigma_y + \sigma_z}{E}(1-2\mu)$$

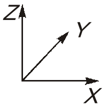
Under hydrostatic loading,

$$\sigma_x = \sigma_y = \sigma_z = \sigma$$

$$\therefore \quad \epsilon_V = \frac{3\sigma}{E}(1-2\mu)$$

Uni-axial Loading on Rectangular Parallel pipe



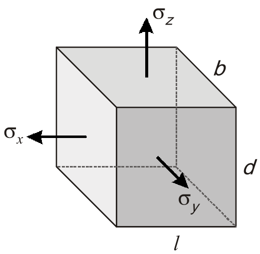


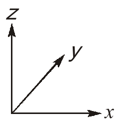
$$\epsilon_x = \frac{\Delta l}{l} = \frac{\sigma_x}{E}$$

$$\epsilon_y = \frac{\Delta b}{b} = -\frac{\mu\sigma_x}{E} \qquad \epsilon_z = \frac{\Delta d}{d} = -\frac{\mu\sigma_x}{E}$$

Here, ϵ_x, ϵ_y and ϵ_z are strain in x, y and z directions respectively.
Δl, Δb and Δd are change in length, width and depth respectively.
l, b and d are original length, width and depth respectively.

Tri-axial loading on Rectangular Parallelopipe





$$\epsilon_x = \frac{\sigma_x}{E} - \frac{\mu\sigma_y}{E} - \frac{\mu\sigma_z}{E} = \frac{\delta l}{l}$$

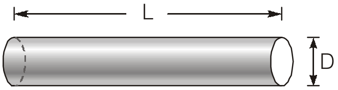
$$\epsilon_y = \frac{\sigma_y}{E} - \frac{\mu\sigma_x}{E} - \frac{\mu\sigma_z}{E} = \frac{\delta b}{b}$$

$$\epsilon_z = \frac{\sigma_z}{E} - \frac{\mu\sigma_x}{E} - \frac{\mu\sigma_y}{E} = \frac{\delta d}{d}$$

Remember:

☑ **Sign convention:** Tensile is positive, and Compressive is negative.

Volumetric Strain of Cylindrical Bar



$$\in_V = \text{Longitudinal Strain} + (2 \times \text{Diametric strain})$$

Volumetric Strain of Sphere

$$\in_V = 3 \times \text{Diametric strain}$$

Matrix Representation of Stress and Strain

3-D stress matrix

$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{bmatrix}$$

3-D strain matrix

$$\begin{bmatrix} \in_{xx} & \frac{\phi_{xy}}{2} & \frac{\phi_{xz}}{2} \\ \frac{\phi_{yx}}{2} & \in_{yy} & \frac{\phi_{yz}}{2} \\ \frac{\phi_{zx}}{2} & \frac{\phi_{zy}}{2} & \in_{zz} \end{bmatrix}$$

Relation between *E*, *G*, *K*, μ

- $E = 3K(1-2\mu)$
- $E = 2G(1+\mu)$
- $E = \dfrac{9KG}{3K+G}$
- $\mu = \dfrac{3K-2G}{6K+2G}$

Here, E = Young's modulus, G = shear modulus
K = Bulk modulus, μ = Poisson ratio

-

Material	Number of Independent elastic constant
Homogeneous & Isotropic	2
Orthotropic (Wood)	9
Anisotropic	21

Strain Energy

It is the ability of material to absorb energy when it is strained

$$U = \frac{1}{2}P \times \delta = \frac{1}{2}T \times \theta$$

Here, P = Applied load
δ = Elongation due to applied load
T = Applied torque
θ = Angle of twist due to applied torque

Thermal Stress and Strain

$$\Delta = L\alpha T$$

$$\text{Strain} = \frac{L\alpha T}{L} = \alpha T$$

$$\sigma_{Th\text{-}stress} = E\alpha T$$

where, σ = Thermal stress
α = Coefficient of thermal expansion
T = Temperature change
Δ = Change in length

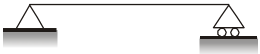
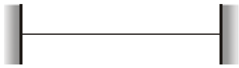
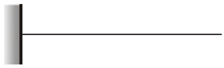
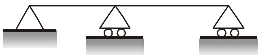
$$\alpha_{steel} = \alpha_{concrete} = 12 \times 10^{-6}/°C$$

$$\alpha_{Aluminium} > \alpha_{Brass} > \alpha_{Copper} > \alpha_{Steel}$$

Remember:

- ☑ When bar is ***free*** to expand then there will be ***no thermal*** stress due to change in temperature.
- ☑ To calculate thermal stress following relation can be used. (Increase in length due to temperature change) = (Decrease in length due to reaction force)

SHEAR FORCE AND BENDING MOMENT

Types of Beam	Supporting conditions	
Simply supported beam	One end hinged other end supported on rollers.	 Determinant Beam
Fixed Beam	Both ends fixed	 Indeterminant Beam
Cantilver Beam	One end fixed other end free	 Determinant Beam
Continuous Beam	More than 2 supports	 Indeterminant Beam
Propped Cantilever Beam	One end fixed, other end supported by rollers.	 Indeterminant Beam
Overhanging Beam	Some portion of beam overhangs.	 Determinant Beam

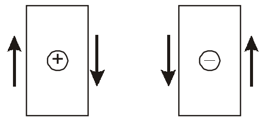
Remember:

- ☑ **Displacement resisted:** Reaction force develops.
- ☑ **Rotation resisted:** Reaction moment develops.

Shear Force

It is the internal resistance developed at any section to maintain ***free body equilibrium of either*** left or right part of the section.

- Sign Convention : Shear force having an upward direction to the left hand side of ***section*** or downward direction to the right hand side of section will be taken positive and vice-versa.



Remember:

☑ It may be horizontal or vertical. Shear force at any section is ***algebraic*** sum of all transverse forces ***either*** from left or right of that section.

Bending Moment

Bending moment at any section is the internal reaction due to all the ***transverse*** force ***either*** from left side or from right side of that section.

Remember:

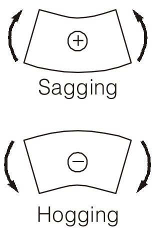
☑ It is equal to ***algebraic*** sum of moments at that section either from left or from right side of that section.

☑ Bending moment is different from twisting moment.

- Sign convention of Bending moment

A bending moment causing ***concavity upward*** will be taken as positive and called ***sagging*** bending moment.

A bending moment causing ***convexity upward*** will be taken as ***negative*** and will be called a ***hogging*** bending moment.



Relationship Between Bending Moment (*M*), Shear Force (*S*) and Loading Rate (*w*)

- Rate of change of shear force for a section of beam is equal to load intensity for that section of beam.

$$\frac{dS}{dx} = -w$$

Here, w = Load per unit length

Remember:

☑ Negative slope represents downward loading.

- Rate of change of bending moment ***along the length*** for a section of beam is equal to shear force for that section of beam.

$$\frac{dM}{dx} = S_x$$

Remember:

☑ At hinge, bending moment will be zero.

☑ Bending moment is maximum or minimum when shear force is zero or changes sign at a section.

☑ If degree of loading curve = n then
degree of shear force curve = $n + 1$
and degree of bending moment curve = $n + 2$

☑ Point of contra-flexure/inflexion is that point where bending moment ***changes its sign***.

☑ If concentrated load acts at a section on loading diagram, then in shear force diagram a jump is observed on that section. Similarly, if concentrated moment acts then there is a jump in bending moment diagram.
For maximum positive bending moment to be minimum possible, the magnitude of maximum bending moment on the positive side is equal to the magnitude of maximum bending moment on negative side. (Such that it is equally distributed on both sides).

PRINCIPAL STRESS-STRAIN

Principal Stress

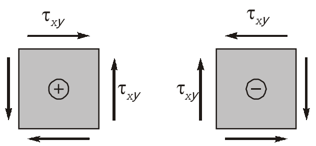
Principal stress is maximum or minimum ***normal*** stress which may be developed on a loaded body.

Remember:

☑ The plane of principal stress carry ***zero shear stress***.

Sign Conventions

- ***Tensile*** stress is considered ***positive*** and ***compressive*** stress is ***negative***.



Positive shear stress Negative shear stress