FREE NOTES · NCERT + JEE/NEET LEVEL

Mechanical Properties of Solids

Elasticity, stress, strain, Hooke's law, stress-strain curve, Young's, shear aur bulk modulus, Poisson's ratio aur stored elastic energy. Roz ki zindagi ke examples aur solved numericals ke saath.

01 Elasticity & plasticity
02 Stress
03 Strain
04 Hooke's law
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01 Elasticity & plasticity

Elasticity: force hatane pe body apni purani shape aur size me wapas aa jaaye (rubber band, spring).
Plasticity: wapas na aaye, permanently badal jaaye (geeli mitti, putty, chewing gum).

ANDAR KYA HOTA HAI

Solid ke atoms aapas me springs jaise bandhe hain. Kheencho toh doori badhti hai aur andar ek **restoring force** paida hota hai jo wapas kheenchta hai.

INTERESTING FACT

Steel rubber se zyada elastic hai. Elastic hone ka matlab "zyada khinchna" nahi, balki "deformation ka zyada virodh karna" hai. Same stress pe steel me strain bahut kam hota hai, isliye uska Young's modulus bada hai. Quartz ko lagbhag perfect elastic maana jaata hai.

02 Stress

Deform karne pe andar paida hone wala restoring force per unit area.

$$\text{Stress} = F / A$$

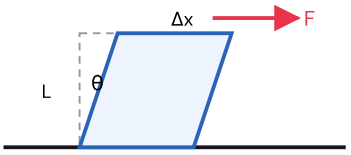
Unit N/m² = Pa. Dimensions $[ML^{-1}T^{-2}]$ (pressure jaise).

Type	Force kaise laga	Kya badalta hai
Longitudinal (tensile / compressive)	Surface ke ⊥, kheencha ya dabaya	Length
Shearing (tangential)	Surface ke parallel	Shape (cube tirchha ho jaata)
Hydraulic (volume)	Chaaron taraf se barabar dabaav (paani me doobi body)	Volume

03 Strain

Deformation ka fraction (kitna badla / pehle kitna tha). Ratio hai, isliye **unit aur dimension nahi**.

$$\text{Longitudinal strain} = \Delta L / L$$
$$\text{Shearing strain} = \Delta x / L = \tan\theta \approx \theta$$
$$\text{Volume strain} = \Delta V / V$$



Shear: upar ki surface Δx khiski

04 Hooke's law

STATEMENT

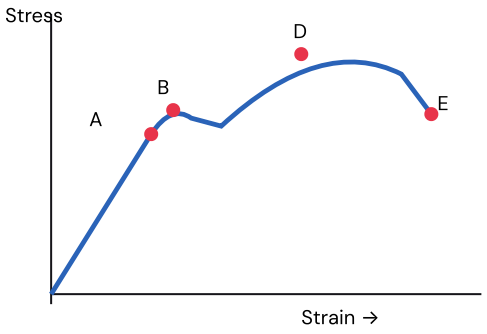
Chhote deformation (elastic limit ke andar) me **stress ∝ strain**.

Stress = k × Strain

k = **modulus of elasticity**. Unit aur dimensions stress jaise (Pa), kyunki strain ka koi unit nahi.

Modulus **material** pe depend karta hai, uske size ya shape pe nahi. Temperature badhne pe modulus aam taur pe ghatta hai.

05 Stress-strain curve



Metal (jaise steel) ka typical graph

Point	Matlab
O–A	Seedhi line: Hooke's law (proportional limit)
A–B	Elastic par proportional nahi; B = **elastic limit / yield point**
B–D	Plastic region: permanent set
D	**Ultimate tensile strength** (max stress)
E	**Fracture point** (toot gaya)

Material	Graph ki pehchaan
Ductile (copper, aluminium)	D aur E ke beech zyada doori: taar kheench ke patla kar sakte hain
Brittle (kaanch, cast iron)	D aur E bahut paas: thoda zyada hote hi toot jaata
Elastomer (rubber, aorta)	Hooke's law follow nahi karta, par bahut zyada khinch ke bhi wapas aata

06 Young's modulus (Y)

$$Y = (F/A) / (\Delta L/L) = F\,L / (A\,\Delta L)$$

Taar (radius r) ke liye $\Delta L = FL/(\pi r^2 Y)$. Sirf **solids** ka hota hai. Steel ≈ 2 × 10^{11} Pa, aluminium ≈ 7 × 10^{10} Pa.

SHORTCUT RATIOS

- Same material, same force: $\Delta L \propto L/r^2$.
- Taar ka volume same rakh ke length 2 guna kheencho: area aadha ⇒ ΔL 4 guna.
- Apne hi weight se latakti rassi: $\Delta L = \rho g L^2/(2Y)$ (aadha weight maano).

Searle's apparatus se lab me Y naapte hain: ek reference taar aur ek test taar, spirit level aur micrometer se chhota extension.

07 Shear & bulk modulus

SHEAR MODULUS (RIGIDITY, G OR H)

$$G = (F/A) / \theta$$

Shape badalne ka virodh. Aam taur pe G ≈ Y/3. Liquid aur gas ka G = 0 (unki koi fixed shape nahi).

BULK MODULUS (B)

$$B = -p / (\Delta V/V)$$

Minus kyunki dabaav badhe toh volume ghatta. Compressibility k = 1/B. Solid > liquid > gas (B ka order). Gas sabse aasaani se dabti hai.

State	Y	G	B
Solid	Hai	Hai	Hai
Liquid	Nahi	Nahi	Hai
Gas	Nahi	Nahi	Hai (isothermal B = p, adiabatic B = γp)

08 Poisson's ratio (σ)

Rubber ko lamba kheencho toh wo patla bhi hota hai. Lateral (side wala) strain aur longitudinal strain ka ratio:

$$\sigma = -(\Delta d/d) / (\Delta L/L)$$

Unitless. Theory me -1 se 0.5 tak, practically 0 se 0.5. σ = 0.5 matlab volume nahi badla (incompressible, jaise rubber ≈ 0.5). Metals ke liye ≈ 0.3.

MODULI KA RISHTA (JEE)

$$Y = 2G(1+\sigma) = 3B(1-2\sigma)$$

09 Elastic potential energy

Taar kheenchne me kiya work andar **elastic PE** ban ke store hota hai.

$$U = \tfrac{1}{2} \times F \times \Delta L = \tfrac{1}{2} \times \text{Stress} \times \text{Strain} \times \text{Volume}$$

Energy density (per unit volume) $u = \tfrac{1}{2} \times \text{stress} \times \text{strain} = \text{stress}^2/(2Y) = \tfrac{1}{2}\, Y\, \text{strain}^2$

Stress-strain graph ke neeche ka area = energy density.

THERMAL STRESS

Dono sire fix rod ko ΔT garam karo, wo phail nahi sakti, toh andar stress: $\text{stress} = Y\,\alpha\,\Delta T$, force = $YA\alpha\Delta T$. Railway patri ke beech gap isi liye rakhte hain.

10 Applications (NCERT)

- **Crane ki rassi:** load ka stress yield strength se kam rakhna, safety factor ke saath. Ek mota taar ki jagah kai patle taar milake rassi banate hain (lacheeli aur mazboot).
- **Pul aur building ka beam:** beech me load W se jhukaav (sag) $\delta = WL^3/(4bd^3Y)$. Depth d badhane ka sabse zyada asar (d^3), isliye beam ka cross-section **I-shape** rakhte hain: kam material, kam jhukaav, kam weight.
- **Pahaad ki max height:** neeche ki chattan pe $h\rho g$ ka stress uski elastic limit se zyada nahi ho sakta, isliye Earth pe pahaad ≈ 10 km se zyada oonche nahi.
- **Khokhla (hollow) shaft** utne hi material ke solid shaft se zyada mazboot hota hai (twist ka virodh).

11 JEE Extra + Tricks

JEE LEVEL

- Elastic constants ka sambandh: $Y = 3K(1 - 2\sigma) = 2\eta(1 + \sigma)$; Poisson's ratio σ -1 se 0.5 (asal me 0 se 0.5).
- Per unit volume elastic PE = ½ × stress × strain = ½ Y $(\text{strain})^2$.
- Dono sire fixed rod me thermal stress: $Y\,\alpha\,\Delta T$ (lambai aur area se independent).
- Apne weight se latki rod ka khinchav: $\Delta L = MgL/(2AY)$ (sire pe load ka aadha).
- Steel rubber se zyada elastic (zyada Y). Compressibility = $1/K$.

12 Solved numericals (g = 10 m/s²)

Q1. 2 m lambi, 1 mm² area wali steel taar pe 100 N. Y = 2 × 10^{11} Pa. Extension?
$\Delta L = FL/(AY) = 100 \times 2/(10^{-6} \times 2 \times 10^{11}) = 200/(2 \times 10^{5}) = 10^{-3}$ m = 1 mm. **Ans: 1 mm**

Q2. Same material ki do taaren: lengths 1 : 2, radii 2 : 1. Same load pe extension ka ratio?
$\Delta L \propto L/r^2 \Rightarrow (1/4) : (2/1) = 1 : 8$. **Ans: 1 : 8**

Q3. Paani ko 1% dabaane ke liye kitna pressure? (B = 2.2 × 10^{9} Pa)
$p = B \times \Delta V/V = 2.2 \times 10^{9} \times 0.01 = 2.2 \times 10^{7}$ Pa (≈ 220 atm). **Ans: 2.2 × 10^{7} Pa**

Q4. 10 cm side ka cube, upar ki surface pe 10^{4} N parallel force. G = 2.5 × 10^{10} Pa. Upar ki surface kitna khiskegi?
Stress = $10^{4}/0.01 = 10^{6}$ Pa. $\theta = 10^{6}/(2.5 \times 10^{10}) = 4 \times 10^{-5}$. $\Delta x = \theta L = 4 \times 10^{-6}$ m. **Ans: 4 µm**

Q5. Q1 wali taar me stored energy?
$U = \frac{1}{2} F \Delta L = \frac{1}{2} \times 100 \times 10^{-3} = 0.05$ J. **Ans: 0.05 J**

Q6. Steel rod (Y = 2 × 10^{11}, α = 1.2 × 10^{-5} /°C) dono sire fix, 50 °C garam. Thermal stress?
Stress = $Y\alpha\Delta T = 2 \times 10^{11} \times 1.2 \times 10^{-5} \times 50 = 1.2 \times 10^{8}$ Pa. **Ans: 1.2 × 10^{8} Pa**

13 Common mistakes

- Rubber ko steel se zyada elastic maan lena.
- Strain ki unit likh dena. Ye unitless hai.
- Liquid ka Young's modulus nikaalne ki koshish. Liquid ka sirf bulk modulus hota hai.
- mm² ko m² me galat badalna (1 mm² = 10^{-6} m²).
- Bulk modulus formula me minus sign bhool jaana.
- Modulus ko taar ki length ya area pe depend maan lena. Sirf material pe depend.

14 Formula sheet

Stress, strain	F/A, $\Delta L/L$
Young's modulus	$Y = FL/(A\Delta L)$
Shear modulus	$G = (F/A)/\theta$
Bulk modulus	$B = -p/(\Delta V/V)$, $k = 1/B$
Poisson's ratio	$\sigma = -(\Delta d/d)/(\Delta L/L)$
Relations	$Y = 2G(1+\sigma) = 3B(1-2\sigma)$
Elastic energy	$U = \frac{1}{2}F\Delta L = \frac{1}{2}$ stress $\times$ strain $\times$ V
Energy density	$u = \text{stress}^2/2Y$
Thermal stress	$Y\alpha\Delta T$
Beam sag	$\delta = WL^3/(4bd^3Y)$

15 Practice questions

1. Taar ki length aur radius dono 2 guna kar do (same load). Extension?
2. Stress 2 guna karo (elastic limit me), energy density kitni?
3. Perfectly rigid body ka Young's modulus?
4. Rubber ka Poisson's ratio 0.5 ka matlab?
5. 4 m taar, area 2 mm², 200 N load pe 2 mm badhi. Y?

ANSWERS

1) $\Delta L \propto L/r^2 \Rightarrow$ 2/4 = aadha · 2) 4 guna · 3) Infinite · 4) Kheenchne pe volume nahi badalta · 5) $Y = 200 \times 4/(2 \times 10^{-6} \times 2 \times 10^{-3}) = 2 \times 10^{11}$ Pa

16 Quick revision: exam se pehle 5 minute

BASICS

- Stress = F/A (Pa); strain unitless.
- Hooke: stress ∝ strain.
- Steel > rubber (elasticity).

MODULI

- $Y = FL/A\Delta L$; $\Delta L \propto L/r^2$.
- $G \approx Y/3$; liquid me $G = 0$.
- $B = -p/(\Delta V/V)$; gas me $B = p$ (isothermal).
- $Y = 2G(1 + \sigma) = 3B(1 - 2\sigma)$.

CURVE

- Proportional → elastic/yield → ultimate → fracture.
- Ductile: D–E door; brittle: paas.
- Elastomer: Hooke nahi.

ENERGY & USES

- $U = \frac{1}{2}F\Delta L$; $u = \text{stress}^2/2Y$.
- Thermal stress $Y\alpha\Delta T$.
- I-beam: sag ∝ $1/d^3$.

Doubt hai? padhaiadda.netlify.app pe AI Doubt Solver se poocho, ya is chapter ka mock test do.