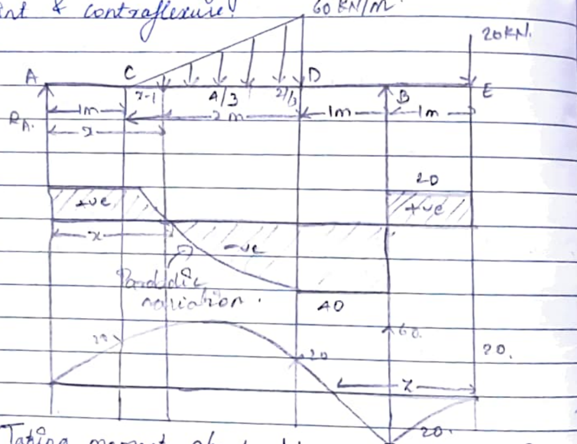
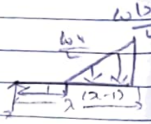
7. Draw SFD & BMD for over hanging beam shown in fig. Indicate all significant values. Including the point & contraflexure.



Taking moment about $M_A = 0$., $R_B = 60\,kN$, $R_A = 20\,kN$

$+20 - \frac{1}{2}(x-1)\left(\frac{60(x-1)}{2}\right) = 0$



$20 - 15(x-1)^2 = 0$

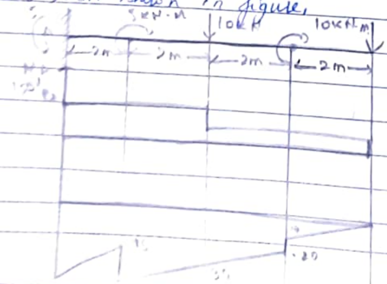
$15(x-1)^2 = 20 \Rightarrow (x-1)^2 = 1.33$

$x - 1 = 1.153 \Rightarrow x = 2.153$

$M = 20x - \frac{1}{2}w(x-1)(x-1)\frac{(x-1)}{3}$

$M = 27.69$

Find the relation at fixed end and SFD & BMD for the cantilever beam shown in figure.



4/9/23.

Module - 4.

Energy Methods.

Conservative Forces:- Forces that are done in moving a particle from one point to another point are called conservative forces.

Eg: Gravitational force, Magnetic force etc..

Strain Energy:- Energy absorbed by the body when it is strained within it's elastic limit.

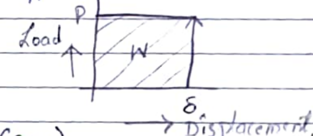
It is denoted by U. Mathematically strain energy stored in the body is equal to workdone by the externally applied load. $\Rightarrow U = W$.

Law of Conservation of Energy.

Work done by the Externally applied load:-

a) Suddenly Applied load.

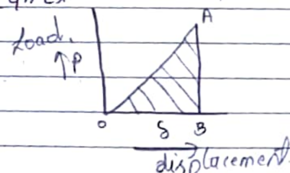
$\boxed{W = P\delta}$



b) Gradually Applied Load. (GAL)

WD by GAL = Area of Load.

$\boxed{W = \frac{1}{2}P\delta}$



c) Strain Energy Due To Axial Load.

(strain Energy Stored in the bar).

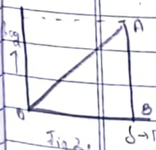


Fig 2.

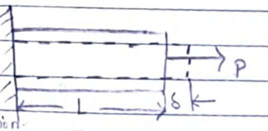


Fig. 1.

Consider a bar of length 'L' cross sectional area 'A' & Youngs Modulus 'E' Subjected to an axial pull 'P' as shown in fig. 1.

Let δ be the deformation due to applied Load and σ be the Stress induced.

Fig 2 Shows load deformation curve for the given bar.

Work done by the applied load is equal (work done) to area of triangle ΔOAB

$$W = \frac{1}{2} P\delta \rightarrow (1).$$

Since strain energy stored in the bar is equal to work done by the external load. $\rightarrow U = W$.

$$\therefore U = \frac{1}{2} P\delta \rightarrow (2).$$

W.K.T.
$$\left.\begin{aligned} P &= \sigma A \\ \delta &= \frac{\sigma L}{E} \end{aligned}\right\} \rightarrow (3).$$

Substituting (3) in (2)

$$U = \frac{1}{2}(\sigma A)\left(\frac{\sigma L}{E}\right)$$

$$U = \frac{\sigma^2 AL}{2E}$$

$$U = \frac{\sigma^2 V}{2E} \rightarrow (4).$$

(4) is the Exp for strain energy (for) due to Axial Loading

STRAIN ENERGY DUE TO TORSION (Strain E Stored in the Shaft)

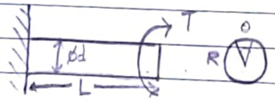


Fig. 1

Consider a shaft of length 'L' dia - 'd' & rigidity modulus 'G'. Subjected to externally applied torque - 'T' as shown in Fig 1.
Let θ be the angle of twist due to applied torque & τ be the shear stress induced.

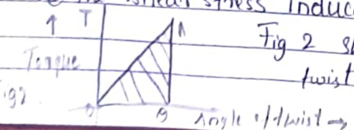


Fig 2

Fig 2 shows torque V.s Angle of twist for the given shaft.

5/9/23.

Work done by the applied torque is equal to Area of triangle OAB.

$$W = \frac{1}{2} T\theta \rightarrow (1).$$

Since strain energy stored in the shaft is equal to work done by the applied torque $U = W$.

$$U = \frac{1}{2} T\theta \rightarrow (2)$$

From torsion Eqⁿ $T = \frac{\tau J}{R}$, $\theta = \frac{\tau L}{GR} \rightarrow (3)$

Where J is polar moment of inertia.
R - maximum radius.
Substituting eq (3) in (2).

$$U = \frac{1}{2} \frac{\tau J}{R} \frac{\tau L}{GR}.$$

$$U = \frac{\tau^2 JL}{2GR^2} \rightarrow (4).$$

WKT.
$$\left. R = \frac{d}{2}, \quad J = \frac{\pi d^4}{32} \right\} \rightarrow (5)$$

$$U = \frac{\tau^2 (\pi d^4/32) L}{2G(d/2)^2}.$$

$$U = \frac{\tau^2 L}{\cancel{2}G} \times \frac{\pi d^4}{\cancel{32}_{16}} \times \frac{\cancel{4}^2}{\cancel{d^2}}$$

$$U = \frac{\tau^2}{4G} \frac{\pi d^2}{4} L.$$

$$\boxed{U = \frac{\tau^2 V}{4G} \rightarrow (6)}$$

Eqⁿ (6) is the exp for Strain Energy due to torsion.

STRAIN ENERGY DUE TO BENDING (STRAIN ENERGY STORED IN THE BEAM).

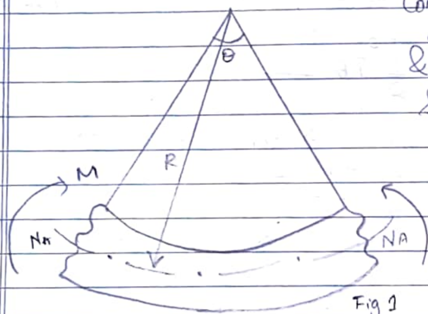
*Note→:- Bending Eqⁿ is given by $\frac{E}{R} = \frac{M}{I} = \frac{\sigma}{y}$.
$\sigma \Rightarrow$ Bending stress.,
Where E is Young's Modulus, R is radius of curvature. M is applied moment, I is Moment of Inertia of beam cross section.
y → distance from neutral axis.

MOI → Moment of Inertia

SURYA Gold

Date______ Page______

Derivation →

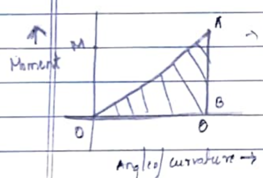


Consider a beam Segment of length 'L', MOI → I. & Young's Modulus - E. Subjected to externally applied Moment 'M' as Shown in fig 1.

Let θ be the angle Subtended by the curvature.

Fig 1

Fig 2 Shows Moment Vs 'θ' curve for the given beam Segment.



Work done by the applied moment is equal to area of Δ^{le} AOB $= W = \frac{1}{2} \times \theta \times M$ → ①

Since Strain energy stored in the beam is equal to work done by the applied moment.

$U = W \Rightarrow \therefore U = \frac{1}{2} M\theta$ → ②

θ R

$L = R\theta$

From Geometry of fig 1 angle of curvature $\theta = \frac{L}{R}$ → ③

Substituting ③ in ②

$U = \frac{1}{2} \times M \times \frac{L}{R} \Rightarrow U = \frac{1}{2}\frac{ML}{R}$ → ④

From Bending Eq^n. $\Rightarrow \frac{E}{R} = \frac{M}{I} \Rightarrow R = \frac{EI}{M}$ → ⑤

Subst ⑤ in ④

$U = \frac{1}{2}\frac{ML}{\frac{EI}{M}}$

$U = \frac{M^2 L}{2EI}$ → ⑥

Eq^n ⑥ is the expression for Strain energy due to bending.

If BM is not uniform throughout the beam Segment, Consider a Small strip of length dx, Strain Energy stored in the strip. $\Rightarrow dU = \frac{M^2 dx}{2EI}$

SURYA Gold

Date______ Page______

$$U = \int_0^L \frac{M^2 dx}{2EI} \rightarrow ⑦$$

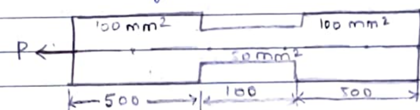
Numerical Problem on Strain Energy Due to Axial Load.

List of formulae:-

1. $U \Rightarrow \frac{\sigma^2 AL}{2E}$
2. $\sigma = \frac{P}{A}$.

1.] The Max Stress produced by a pull in a bar of 1100mm Length is 100 N/mm². The area of Cross Section & Length are shown in fig. Calculate the strain Energy stored in the bar. If E is equal to 2×10^5 N/mm².

$E_1 = E_2 = E_3 = 2 \times 10^5$ N/mm²



$\sigma_2 = 100$ N/mm²

$A_1 = A_3 = 100mm^2$, $A_2 = 50 mm^2$, $L_1 = L_3 = 500mm$, $L_2 = 100mm$

$\sigma_2 = \frac{P}{A_2} \Rightarrow P = 100 \times 50 \Rightarrow P = 5000 N.$

$\sigma_1 = \sigma_3 = \frac{5000}{100} = 50 N/mm^2$

$U_3 = U_1 = \frac{\sigma_1^2 A_1 L_1}{2E_1} = \frac{50^2(100)(500)}{2 \times 2 \times 10^5} = 312.5$ N-mm.

$U_2 = 125$ N-mm.

$= U_1 + U_2 + U_3 = 750$ N-mm.

$\boxed{U = 0.75 J}$

2) STRAIN ENERGY DUE TO TORSION:-

Formula: → $U = \frac{\tau^2 AL}{4G}$, $\tau = \frac{TR}{J}$, For solid shaft. $A = \frac{\pi d^2}{4}$, $R = \frac{d}{2}$

$J = \frac{\pi d^4}{32}$. | For hollow shaft $A = \frac{\pi}{4}(d_o^2 - d_i^2)$, $R = \frac{d_o}{2}$

$J = \frac{\pi}{32}(d_o^4 - d_i^4)$

2) A Solid & hollow shaft of Same material at Same Max Stress are Subjected to Same Max Torque. The ratio of inner to outer diameter for the hollow shaft is 0.75. Find the ratio of Strain Energy in the two Shafts.

Data → $G_s = G_h$, $\tau_s = \tau_h$, $T_s = T_h$.

$\frac{d_i}{d_o} = 0.75$. $\Rightarrow \frac{U_s}{U_h} = ?$

Soln: Let d → diameter of Solid Shaft, d_i & d_o be the inner & outer dia of hollow shaft.

Shear stress induced in the Solid shaft. $\tau_s = \left(\frac{TR}{J}\right)_s$

$$\tau_s = \frac{T\,d/2}{\pi d^4/32} \Rightarrow \tau_s = \frac{16T}{\pi d^3} \rightarrow (1).$$

Shear Stress induced in the hollow Shaft

$$\tau_h = \left(\frac{TR}{J}\right)_h$$

$$\tau_h = \frac{T\,d_o/2}{\frac{\pi}{32}(d_o^4 - d_i^4)} \Rightarrow \tau_h = \frac{16T}{\pi\left(d_o^4 - (0.75d_o)^4\right)/d_o}$$

$$\tau_h = \frac{16T}{0.68\pi d_o^3} \rightarrow (2).$$

from data (1) = (2).

$$\tau_s = \tau_h$$

$$\frac{16T}{\pi d^3} = \frac{16T}{0.68\pi d_o^3} \Rightarrow d_o^3 = 1.47d^3 \quad \boxed{d_o = 1.137d} \rightarrow (3).$$

Strain Energy in Solid Shaft

$$U_s = \left(\frac{\tau^2 AL}{4G}\right)_s \Rightarrow U_s = \frac{\tau^2\pi d^2 L}{16G} \rightarrow (4).$$

Strain Energy in hallow Shaft

$$U_h = \left(\frac{\tau^2 AL}{4G}\right)_h \Rightarrow \frac{\tau^2\pi(d_o^2 - d_i^2)L}{16G} \Rightarrow \frac{\tau^2\pi(d_o^2 - (0.75d_o)^2)L}{16G}.$$

$$U_h = \frac{0.4375\,\tau^2\pi d_o^2 L}{16G} \rightarrow (5).$$

$$\frac{U_s}{U_h} = \frac{\tau^2\pi d^2 L/16G}{\frac{0.4375\,\tau^2\pi d_o^2 L}{16G}} \Rightarrow \frac{d^2}{0.4375\,(1.137d)^2}$$

$$\frac{U_s}{h} = 1.76 \quad //$$

3) STRAIN ENERGY DUE TO BENDING

$$U = \int_0^L \frac{M^2dx}{2EI}, \quad W = \frac{1}{2}W\delta. \quad \delta \rightarrow \text{deflection}$$

3. A Cantilever Beam of uniform cross Section carries a point load at free end. determine i) strain Energy stored by the Cantilever beam & deflection at free end.

ii) If load W is equal to 200 kN. $E = 2\times10^8$ kN/m². $L = 3$m, $I = 10^{-3}$ m⁴. determine the above values.

⇒ U = ? δ = ?

W = 200 kN. L = 3m

$E = 2\times10^8$ kN/m² $I = 10^{-3}$ m⁴

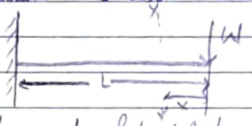


Fig Shows a Cantilever beam of length L Subjected to point load at the free end.

Consider a Section x-x at a distance x from the free end.

Moment at Section at x-x.

$$M = Wx.$$

Strain Energy Stored in the beam $U = \int_0^L \frac{M^2dx}{2EI}$.

$$U = \int_0^L \frac{(Wx)^2dx}{2EI} = \int_0^L \frac{W^2x^2dx}{2EI} = \frac{W^2}{2EI}\int_0^L x^2dx.$$

$$U = \frac{W^2}{2EI}\left[\frac{x^3}{3}\right]_0^L \Rightarrow \boxed{U = \frac{W^2L^3}{6EI}} \rightarrow (1).$$

$$W_d = \frac{1}{2}W\delta. \Rightarrow \frac{1}{2}W\delta = \frac{W^2L}{6EI}$$

$$\boxed{\delta = \frac{WL^3}{3EI}} \longrightarrow (2).$$

ii) Substitute (1) & (2)

$$U = \frac{(200\times10^3)^2 (3)^3}{2\times3(2\times10^8)(10^{-3})}$$

$W = 200\times10^3 N$

$L = 3m$

$E = 2\times10^8\times10^3 \, N/m^2$

$I = 10^{-3}$

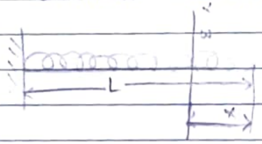
$$U = \frac{6\times10^8}{12\times10^{11}} \Rightarrow U = 900J.$$

$\delta = 9\times10^{-3} m$

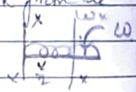
$= 0.009m.$

A Cantilever beam of length L carries UDL of intensity w over it's entire length as shown in fig. Determine i) U strain stored by Cantilever beam.

ii) If $w = 10 KN/m$, $L = 2m$, $EI = 2\times10^3 KN\text{-}m^2$ determine Strain energy stored.



Consider a Section x-x at a distance x from the free end.



U=? Moment at Section x-x

$$M = \frac{wx^2}{2}.$$

Strain energy stored in the beam

$$U = \int_0^L \frac{M^2 dx}{2EI} \Rightarrow \int_0^L \frac{w^2 x^4 dx}{8EI}.$$

$$U = \frac{w^2 L^5}{40EI} = 0.4J.$$

6/9/23

A simply Supported beam of Span L carries a point load F at mid span. Determine strain energy stored by beam and deflection at it's midspan.

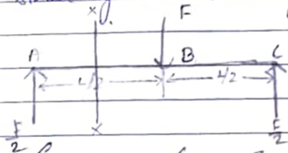


fig shows a simply supported beam of span 'L' Subjected to point load F at mid span.

Considering beam Segment AB. Let x-x be the Section at a distance at a distance x from A.

Moment at Section x-x.

$$M = \frac{Fx}{2} \Rightarrow U_{AB} = \int_0^{L/2} \frac{M^2 dx}{2EI}.$$

$$U_{AB} = \int_0^{L/2} \frac{(Fx/2)^2 dx}{2EI}$$

$$U_{AB} = \int_0^{L/2} \frac{F^2x^2 dx}{8EI} \Rightarrow U_{AB} = \frac{F^2}{8EI}\int_0^{L/2} x^2 dx.$$

$$U_{AB} = \frac{F^2}{8EI}\left[\frac{x^3}{3}\right]_0^{L/2}$$

$$U_{AB} = \frac{F^2}{24EI}\left[\frac{L}{2}\right]^3 \Rightarrow U_{AB} = \frac{F^2L^3}{192EI}.$$

from Symmetry of the beam.

$$U_{AB} = U_{BC} = \frac{F^2L^3}{192EI}.$$

Total Strain energy in the beam $U = U_{AB} + U_{BC}$.

$$\boxed{U = \frac{F^2L^3}{96EI}}$$

Work done by the applied load, $W = \frac{1}{2}\times F\delta$.

$\because U = W$ Since Strain Energy = Work done.

$$\frac{1}{2}F\delta = \frac{F^2L^3}{96EI} \Rightarrow \boxed{\delta = \frac{FL^3}{48EI}}$$

Energy Theorems -

Castigliano's I Theorm :-

Statement → In an elastic member, partial derivative of strain energy w.r.t to deflection is equal to load acting at that point, deflection being measured in the direction of load.

To prove → $\frac{\partial U}{\partial \delta_i} = P_i$

Consider a simply supported beam subjected to point loads P_1 & P_2 as shown in the figure. Let δ_1 & δ_2 be the corresponding deflections. Strain Energy stored in the beam,

$$U = \frac{1}{2} P_1 \delta_1 + \frac{1}{2} P_2 \delta_2 \longrightarrow (1)$$

Let ∂P_1 & ∂P_2 be the additional loads applied in such a proportion that additional deflection is produced at point 1 alone.

Additional strain energy due to loads ∂P_1 & ∂P_2.

$$\partial U = \frac{1}{2} \partial P_1 \partial \delta_1 + P_1 \partial \delta_1$$

Neglecting higher order terms. $\partial U = P_1 \partial \delta_1$

$$\frac{\partial U}{\partial \delta_1} = P_1 \text{ (or) in general } \frac{\partial U}{\partial \delta_i} = P_i$$

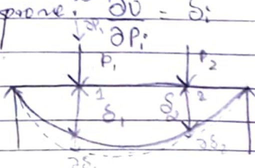
Hence Castiglian's first theorem is proved.

Castigliano's Second (II) Theorem :-

Statement :- In an elastic member, partial derivative of strain energy with respect to load at a point is equal to deflection at that point deflection being measured in direction of load.

→ To prove : $\frac{\partial U}{\partial P_i} = \delta_i$

Proof :-



Consider a simply supported beam subjected to point load P_1 & P_2 as shown in the fig.

Let δ_1 & δ_2 be the corresponding [illegible] Strain Energy in the beam

$$U = \frac{1}{2} P_1 \delta_1 + \frac{1}{2} P_2 \delta_2 \rightarrow (1)$$

Let ∂P_1 → additional load at 1 → [illegible] deflection $\partial \delta$ [illegible]

Additional strain energy due to ∂P_1

$$\partial U = \frac{1}{2} \partial P_1 \partial \delta_1 + P_1 \partial \delta_1 + P_2 \partial \delta_2 \rightarrow (2)$$

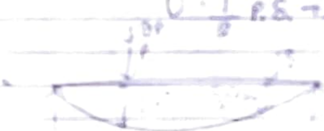
Neglecting the higher order terms

$$\partial U = P_1 \partial \delta_1 + P_2 \partial \delta_2 \longrightarrow (3)$$

Total strain energy

$$U' = U + \partial U$$

$$U' = \frac{1}{2} P_1 \delta_1 + \frac{1}{2} P_2 \delta_2 + P_1 \partial \delta_1 + P_2 \partial \delta_2 \rightarrow (4)$$



Let the loads P_1, P_2 & ∂P_1 simultaneously applied on the beam. Total Strain energy U'

$$U' = \frac{1}{2}(P_1 + \partial P_1)(\delta_1 + \partial \delta_1) + \frac{1}{2} P_2 (\delta_2 + \partial \delta_2)$$

$$U' = \frac{1}{2} P_1 \delta_1 + \frac{1}{2} P_1 \partial \delta_1 + \frac{1}{2} \partial P_1 \delta_1 + \cancel{\frac{1}{2} \partial P_1 \partial \delta_1}$$

$$+ \frac{1}{2} P_2 \delta_2 + \frac{1}{2} P_2 \partial \delta_2 \rightarrow (5)$$

Equating (4) & (5)

$$P_1 \partial \delta_1 + P_2 \partial \delta_2 = \frac{1}{2} P_1 \partial \delta_1 + \frac{1}{2} P_2 \partial \delta_2 + \frac{1}{2} \partial P_1 \delta_1$$

$$\Rightarrow \frac{1}{2} P_1 \partial \delta_1 + \frac{1}{2} P_2 \partial \delta_2 = \frac{1}{2} \partial P_1 \delta_1 \longrightarrow (6)$$

Substituting eq (3) in (6)

$$\partial U = \partial P_1 \delta_1$$

$$\boxed{\frac{\partial U}{\partial P_1} = \delta_1}$$

Hence Castigliano's II theorem is proved.

Problems On Castigliano's Theorem.

1. $U = \int_0^L \frac{M^2 dx}{2EI}$

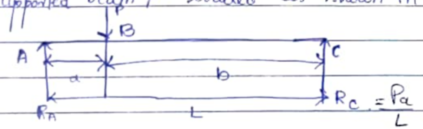
2. $\delta = \frac{\partial U}{\partial P}$.

1. Determine the deflection at the free end of cantilever beam subject to point load at it's free end. Using Castigliano's theorem.

$U = \frac{P^2 L^3}{6EI}$ $\qquad \delta = \frac{\partial U}{\partial P}$

$$\delta = \frac{\partial}{\partial P}\left(\frac{P^2L^3}{6EI}\right) = \frac{2PL^3}{6EI} \Rightarrow \boxed{\delta = \frac{PL^3}{3EI}}$$

- A simply supported beam is loaded as shown in the figure.



Moment at A.

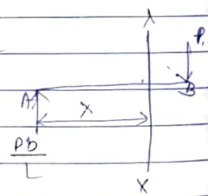
$M_A = 0$.

$R_C L - Pa = 0$.

$R_C = \frac{Pa}{L} \Rightarrow R_A + R_C = P, \Rightarrow R_A = P - \frac{Pa}{L}$

$= P\left(1 - \frac{a}{L}\right) = P\left(\frac{L-a}{L}\right) = \frac{Pb}{L}$

Considering Section A - B of the beam. Let x - x be the section at a distance x from A.



Moment at section x - x

$M = \frac{Pb}{L}$

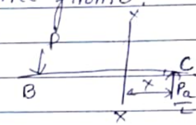
Strain energy in section AB.

$U_{AB} = \int_0^a \frac{M^2 dx}{2EI}$

$$= \int_0^a \frac{P^2b^2x^2}{2EIL^2} = \frac{P^2b^2a^3}{6EIL^2} = \frac{P^2b^2a^3}{2EIL^2}.$$

Considering segment BC of the beam. Let x - x be the section at a distance from C.

Moment at section x - x.



$M = \frac{Pax}{L} \Rightarrow U_{BC} = \int_0^L \frac{M^2 dx}{2EI}$.

$U_{BC} = \frac{P^2a^2b^3}{6EIL^2}$

Total strain energy.

$U = U_{AB} + U_{BC}$.

$= \frac{P^2b^2a^3}{6EIL^2} + \frac{P^2a^2b^3}{6EIL^2}$

$= \frac{P^2a^2b^2}{6EIL^2}(a+b). \Rightarrow \frac{P^2a^2b^2}{6EIL^2}(L)$

$U = \frac{P^2a^2b^2}{6EIL}$.

Deflection for the given beam.

$\delta = \frac{\partial U}{\partial P}$

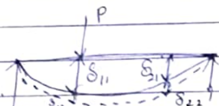
$\delta = \frac{\partial}{\partial P}\left(\frac{P^2a^2b^2}{6EIL}\right) \Rightarrow \delta = \frac{Pa^2b^2}{3EIL}$.

Maxwell Reciprocal Theorem.

Statement :- In an elastic member, deflection at point i due to load applied at point j is equal to deflection at point j due to load applied at i.

To prove: $\delta_{ij} = \delta_{ji}$

Proof :- Case 1:-



Consider a SPB subjected to load P at point 1. Let δ_{11} & δ_{21} be the deflections at point 1 & 2 respectively.

Strain energy stored in the beam $U_1 = \frac{1}{2}P\delta_{11}$. → (1).

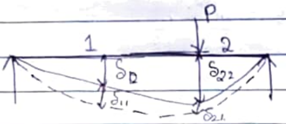
Let Load P be applied at point 2, δ_{12} & δ_{22} are the corresponding deflections at point 1 & 2 respectively.
Additional strain energy due to this load.

$$U_2 = \frac{1}{2} P\delta_{22} + P\delta_{12} \rightarrow (2)$$

Total strain energy :- $U = U_1 + U_2$.

$$U = \frac{1}{2} P\delta_{11} + \frac{1}{2} P\delta_{22} + P\delta_{12} \rightarrow (3)$$

Case II :-



Consider the same beam subjected to load P at Point 2,
Let δ_{12} & δ_{22} be the deflections at point 1 & 2 respectively.
Strain energy stored in a beam.

$$U_2 = \frac{1}{2} P\delta_{22} \rightarrow (4).$$

Let Additional strain energy due to this load.

$$U_1 = \frac{1}{2} P\delta_{11} + P\delta_{21} \rightarrow (5).$$

Total strain energy. ⇒ $U = U_2 + U_1$.

$$U = \frac{1}{2} P\delta_{22} + \frac{1}{2} P\delta_{11} + P\delta_{21} \rightarrow (6).$$

Since strain energy is same in both the cases equating (3) & (6).

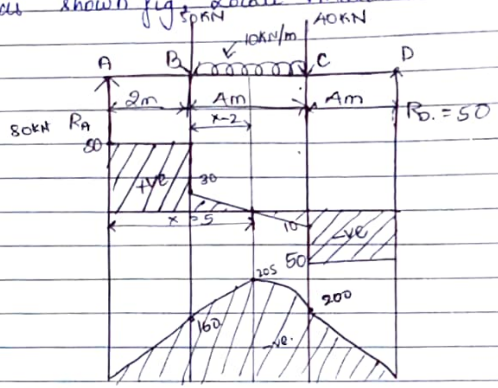
$$\frac{1}{2} P\delta_{11} + \frac{1}{2} P\delta_{22} + P\delta_{12} = \frac{1}{2} P\delta_{11} + \frac{1}{2} P\delta_{22} + P\delta_{21}.$$

$$P\delta_{12} = P\delta_{21}$$

$$\delta_{12} = \delta_{21}.$$

or in general ⇒ $\delta_{ij} = \delta_{ji}$.
hence maxwells Reciprocal theorem is proved

QP. Draw the SFD & BMD of the Simply Supported beam as shown fig, Locate maximum bending Moment.



$M_A = 0$

$R_D(10) - 40(6) - 40(4) - 50(2) + R_A(0) = 0.$

$R_D = 50KN.$

$R_A + R_D = 50 + 40 + 40 \Rightarrow R_A + 50 = 130 \Rightarrow R_A = 80KN$

$SF_x = +80 - 50 - 10(x-2) = 0.$ ⇒ $30 - 10x + 20 = 0$, $50 - 10x = 0 \Rightarrow 50 = 10x$

$x = 5.$

$M_A = 0 = M_D \Rightarrow M_B = 160KN\text{-}m.$

$M_x = 80(5) - 50(3) - 10(x-2)\frac{(x-2)}{2}$ $x = 5 : 205$

*