UNIT - 2

Problems

(1) A cantilever of length 6 m carries a point load of 48 kN at its centre. The cantilever is propped rigidly at the free end. Determine the reaction at the rigid prop.

Given: $L = 6m$; $W = 48\ kN$,

P - Reaction at rigid prop

$$\boxed{P = \frac{5}{16} \times W}$$

$$= \frac{5}{16} \times 48$$

$$\boxed{P = 15\ kN}$$

(2) A cantilever of length 4 m carries a uniformly distributed load of 1 kN/m run over the whole length. The cantilever is propped rigidly at the free end. If the value of $E = 2 \times 10^5\ N/mm^2$ and $I = 10^8\ mm^4$ then determine.

(i) Reaction at the rigid prop.

(ii) The deflection at the centre of the cantilever.

(iii) Magnitude and position of Maximum deflection

Given: $L = 4m$; $w = 1\ kN/m$. $E = 2 \times 10^5\ N/mm^2$

$= 2 \times 10^5 \times 10^6\ N/m^2$

$= 2 \times 10^{11}\ N/m^2$.

$I = 10^8 mm^4 \Rightarrow 10^8 \times 10^{-12}\ m^4 = 10^{-4} m^4$

(i) Reaction at the rigid prop.

We know; $\boxed{P = \frac{3}{8}\ w.L}$

$$P = \frac{3}{8} \cdot w \cdot L$$

$$= \frac{3}{8} \times 1 \times 4$$

$$P = 1.5 \text{ kN.}$$

(i) The deflection at the centre of cantilever.

y_c = deflection at the centre of cantilever.

$$\boxed{y_c = \frac{wL^4}{192 EI}}$$

($w = 1 \text{kN} = 1000 \text{ N}$)

$$= \frac{1000 \times 4^4}{192 \times 2 \times 10^{11} \times 10^{-4}} \text{ m.}$$

$$= \frac{256}{384 \times 10^4} \text{ m}$$

$$y_c = 0.0667 \text{ mm}$$

(ii) Magnitude and position of maximum deflection.

$$\boxed{x = 0.422 \times \cancel{4}} \Rightarrow \boxed{x = 0.422 \times L}$$

Position of maximum deflection

$$x = 0.422 \times 4 = 1.688 \text{ m.}$$

Hence Maximum deflection will be at a distance 1.688 m from the free end of the cantilever.

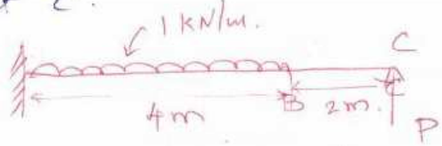
Maximum deflection

$$\boxed{y_{max} = \frac{0.005415\, wL^4}{EI}}$$

$$= \frac{0.005415 \times 1000 \times 4^4}{2 \times 10^{11} \times 10^{-4}}$$

$$y = 0.0693 \text{ mm}$$

(3) A cantilever ABC is fixed at A and rigidly propped at C and is loaded as shown in fig. Find the reaction at C.



Given : $L = 6m$; $w = 1 KN/m$, $L_1 = 4m$. Loaded length.

P = Reaction at the prop C.

To find the reaction P at the prop, the downward deflection due to uniformly distributed loaded on the AB at point C should be equated to the upward deflection due to prop reaction at C.

The downward deflection at point C due to UDL on length AB is given by,

$$\boxed{y = \frac{wL_1^4}{8EI} + \frac{wL_1^3}{6EI}(L - L_1)}$$

$$y = \frac{1 \times 4^4}{8 \times EI} + \frac{1 \times 4^3}{6EI}(6-4)$$

$$= \frac{32}{EI} + \frac{64}{3EI}$$

$$y = \frac{160}{3EI} \longrightarrow (1)$$

The upward deflection at point C due to prop reaction P alone.

$$\boxed{y_{up} = \frac{PL^3}{3EI}} = \frac{P \times 6^3}{3EI} = \frac{72P}{EI} \longrightarrow (2).$$

equating ① & ②.

$$\frac{160}{3EI} = \frac{72P}{EI}$$

$$P = \frac{160}{3\times 72} = 0.741 \text{ KN}.$$

$$\boxed{P = 0.741 \text{ KN}}$$

④. A uniform girder of length 8m is subjected to a total load of 20 KN uniformly distributed over the entire length. The girder is freely supported at its ends. Calculate the B.M and deflection at the centre.
If ~~the~~ a prop is introduced at the centre of the beam so as to nullify this deflection, find the net BM at the centre.

Given: $L = 8$ m, $W = 20$ KN, $w = \frac{W}{L} = \frac{20}{8} = 2.5$ kN/m

(i) The deflection at the centre of a simply supported beam carrying a uniformly distributed load is given by (without prop)

$$\boxed{y = \frac{5wL^4}{384EI}}$$

$$= \frac{5\times 2.5\times 8^4}{384\,EI} = \frac{400}{EI}$$

where EI - stiffness of the grider.

(ii) The B.M at the centre of a simply supported beam due to uniformly load only (ie without prop) is given by

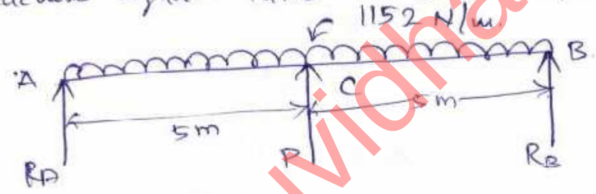
$$M = \frac{wL^2}{8} = \frac{2.5\times 8^2}{8} = 20 \text{ kN.m}$$

(iii) Net B.M at the centre when a prop is introduced at the centre.

Let M_c - Net B.M at centre when a prop is provided

$$M_c = -\frac{wL^2}{32} = -\frac{2.5\times8^2}{32} = -5\ KN.m.$$

⑤ A simply supported beam of span 10m carries a uniformly distributed load of 1152 N per unit length. The beam is propped at the middle of the span. Find the amount, by which the prop should yield, in order to make all the three reactions equal. Take $E = 2\times10^5\ N/mm^2$ & $I = 10^8\ mm^4$.



Solution

Given: $L = 10m$, $w = 1152\ N/m$, $E = 2\times10^5\ N/mm^2$
$= 2\times10^5\times10^6\ N/m^2$
$= 2\times10^{11}\ N/m^2$.

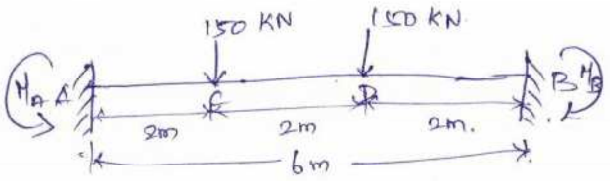
$I = 10^8\ mm^4 = 10^8\times10^{-12}\ m^4 = 10^{-4}\ m^4$.

Total load on beam. $W = w.L$
$= 1152\times10 = 11520\ N$.

If all the three reactions (i.e R_A, R_B & P) are equal then each reaction will be one third of the total load on the beam.

$$R_A = R_B = P = \frac{W}{3} = \frac{11520}{3} = 3840\ N.$$

Let δ = Amount by which the prop should yield if all the three reactions are equal.



Solution :-

The figure shows the fixed beam AB carrying point loads of 150 KN each. The fixed moments M_A and M_B are equal (due to symmetry). Free and fixed B.M diagrams are also shown in Fig.

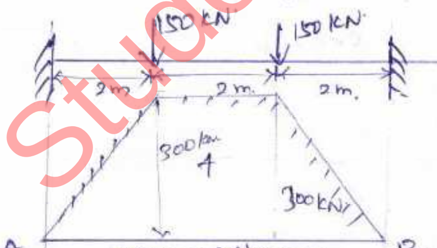
Taking M_C & M_D, for point loads.

$$M_C = 300 \text{ KN.m. } [150 \times 2]$$
$$M_D = 300 \text{ KN.m. } [150 \times 2].$$

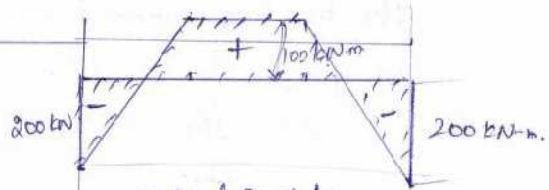
For fixed Moments.

$$M_A = \frac{\Sigma W a b^2}{l^2} = \frac{150 \times 2 \times 4^2}{6^2} + \frac{150 \times 4 \times 2^2}{6^2} = 200 \text{ KN.m}$$

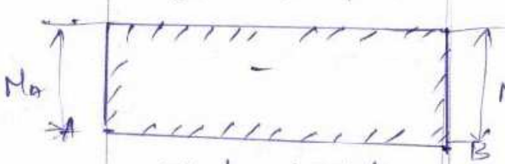
$$M_B = \frac{\Sigma W a^2 b}{l^2} = \frac{150 \times 2^2 \times 4}{6^2} + \frac{150 \times 4^2 \times 2}{6^2} = 200 \text{ KN.m}$$



(b) Free B.M diagram.



(d) Final B.M diagram.



(c) Fixed. BM diagram

By equating the areas of free and fixed B.M diagrams, we have.

$$M_A \times 6 = \frac{1}{2}(6+2) \times 300$$

$$M_A = 200 \text{ kN-m.}$$

$\therefore$ B.M at centre $= 300 - 200 = 100$ kN-m.

Point of Contraflexure.

B.M (actual) at any section in AC at a distant x from A is given by,

$$M = \text{Free moment} - \text{fixed moment.}$$

$$= 150 \times x \quad - 200$$

To get point of contraflexure equate $M=0$.

$$150x - 200 = 0$$

$$x = 4/3 \text{ m from either end.}$$

Slope & deflection:

The bending moment at any section between A & D distant x from the end A is given by

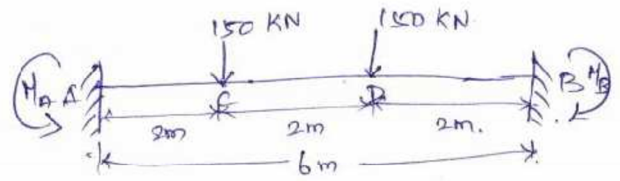
$$EI \frac{d^2y}{dx^2} = 150 - x - 200 - 150(x-2)$$

Integrating on both sides.

$$EI \frac{dy}{dx} = 75x^2 - 200x - 75(x-2)^2 + C_1$$

$\hookrightarrow$ slope eqn.

when $x=0$; $\frac{dy}{dx} = 0 \therefore C_1 = 0$.



Solution :-

The figure shows the fixed beam AB carrying point loads of 150 kN each. The fixed moments M_A and M_B are equal (due to symmetry). Free and fixed B.M diagrams are also shown in Fig.

Taking M_C & M_D, for point loads.

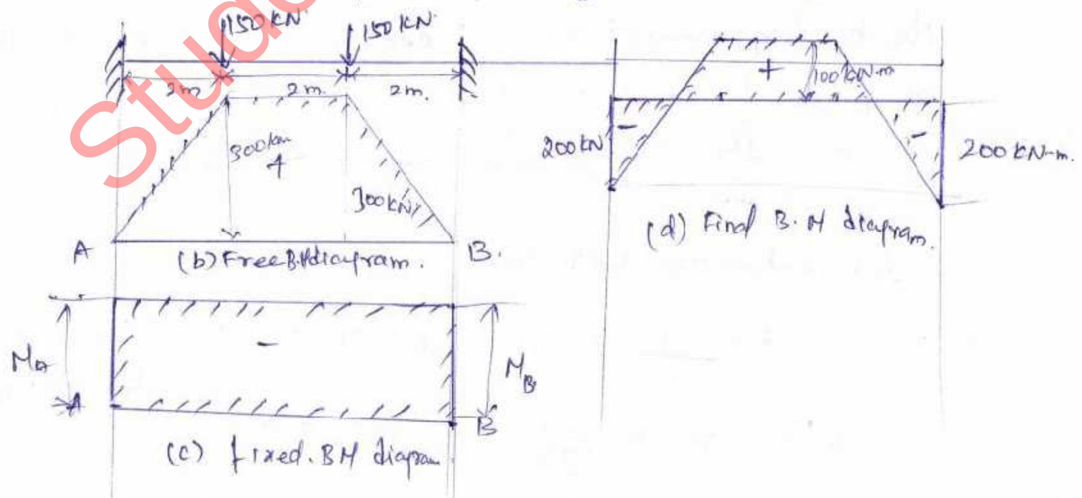
M_C = 300 kN.m. [150 × 2]

M_D = 300 kN.m. [150 × 2].

For fixed Moments.

$$M_A = \frac{\sum Wab^2}{l^2} = \frac{150\times2\times4^2}{6^2} + \frac{150\times4\times2^2}{6^2} = 200 \text{ kN·m}$$

$$M_B = \frac{\sum Wa^2b}{l^2} = \frac{150\times2^2\times4}{6^2} + \frac{150\times4^2\times2}{6^2} = 200 \text{ kN·m}$$



(b) Free B.M diagram.

(c) Fixed. BM diagram

(d) Final B.M diagram.

Integrating again.

$$EI\,y = 25x^3 - 100x^2 + 25(x-2)^3 + C_2$$

$\longrightarrow$ Deflection eqn.

To get Maximum deflection which occurs at the centre in this case, put $x = 3$ m in the deflection eqn.

we get.

$$EI\,y_{max} = 25 \times 3^3 - 100 \times 3^2 - 25(3-2)^3$$

$$EI\,y_{max} = -250.$$

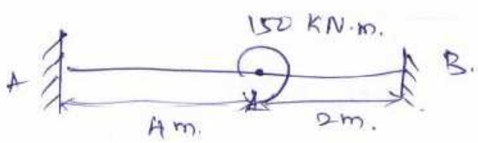
$$y_{max} = \frac{-250}{2 \times 10^8 \times 8 \times 10^8 \times 10^{-12}}\ m.$$

$$= -15.6 \times 10^{-4}\ m.$$

$$= -1.56\ mm.$$

$$\boxed{y_{max} = -1.56\ mm.}$$

(7) A fixed beam of 6 m span is subjected to a concentrated couple of 150 kN-m applied at a section 4 m from the left end. Find the end moments. Draw B.M and S.F diagrams also.



Solution:

Assuming A as origin, the unknowns are the reaction R_A and the end moment M_A, Let their directions be shown

The bending at any section at a distance x from the end A, is given by

$$EI\frac{d^2y}{dx^2} = R_A x + M_A + 150$$

Apply Macaulay's Method,

$$EI\frac{d^2y}{dx^2} = R_A x + M_A + 150(x-4)^0 \longrightarrow (1)$$

Integrating on both sides.

$$EI\frac{dy}{dx} = R_A\frac{x^2}{2} + M_A x + C_1 + 150(x-4)$$

$\longrightarrow$ slope eqn. (2)

when $x=0$; $\frac{dy}{dx}=0$; $\therefore C_1 = 0$.

Integrating again, we get

$$EIy = R_A\frac{x^3}{6} + M_A\frac{x^2}{2} + C_2 + 75(x-4)^2$$

$\hookrightarrow$ Deflection eqn (3)

$x=0$; $y=0$; $C_2=0$

when $x=6$, $\frac{dy}{dx}=0$. ; $\left[\text{At } B, \frac{dy}{dx}=0\right]$

Sub this in (2).

$$0 = \frac{R_A \times 6^2}{2} + M_A \times 6 + 150(6-4)$$

$$18R_A + 6M_A + 300 = 0$$

$$3R_A + M_A = -50 \longrightarrow (4)$$

At B, the deflection is zero.

∴ when $x = 6$ m ; $y = 0$.

sub in ③,

$$0 = \frac{R_A \times 6^3}{6} + \frac{M_A \times 6^2}{2} + 75(6-4)^2$$

$$0 = 36 R_A + 18 M_A + 300.$$

$$6R_A + 3M_A = -50 \longrightarrow ⑤$$

solving ④ & ⑤

$$R_A = -\frac{100}{3} \text{ kN} ; \quad M_A = 50 \text{ kN.m}$$

B.M Calculation

$M_A = +50$ kN.m (sagging)

$M_C^A = 50 - \frac{100}{3} \times 4$

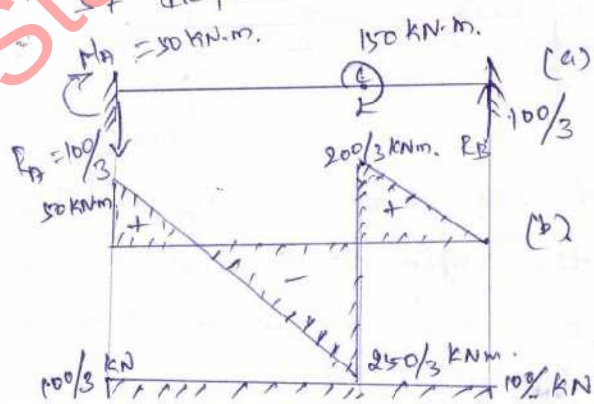
$= -\frac{250}{3}$ kN.m (Hogging)

$M_C^B = -\frac{250}{3} + 150$

$= \frac{200}{3}$ (sagging)

$M_B = 50 - \frac{100}{3} \times 6 + 150 = 0.$

S.F diagram at any section of beam $= \frac{100}{3}$ kN.



(a) Fixed beam.

(b) B.M diagram

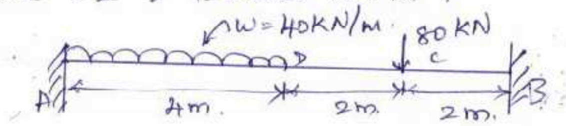
(c) S.F diagram.

8) A fixed beam of 8m span carries a uniformly distributed load of 40 kN/m run over 4 m length starting from left hand end and a concentrated load of 80 kN at a distance of 6m from the left hand end. Find,

(i) Moments at the supports

(ii) Deflection at centre of the beam.

Take $EI = 15000\ kN\ m^2$.



Solution :

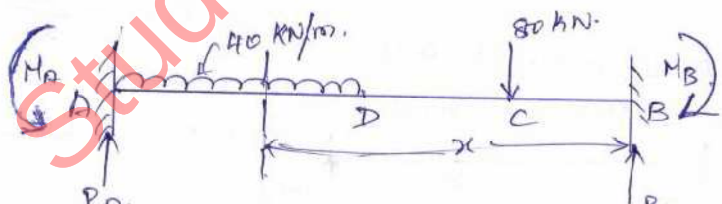
Fig shows the fixed beam AB of 8m span and carrying uniformly distributed load and a concentrated load.

Let, R_A - Reaction at A.

R_B = " " B

M_A = Moment at Support A.

M_B = " " " B.



(i) Moments at the Supports, M_A and M_B.

Taking the origin at B and x positive towards left, consider a section XX at a distance x from the end B in the position DA.

Bending moment at the section.

$$M = -M_B + R_B \times x - 80(x-2) - \frac{w(x-4)^2}{2}$$

$$= -M_B + R_B \times x - 80(x-2) - \frac{40(x-4)^2}{2}$$

$$= -M_B + R_B \times x - 80(x-2) - 20(x-4)^2.$$

(or)

$$EI\frac{d^2y}{dx^2} = -M_B + R_B \cdot x - 80(x-2) - 20(x-4)^2. \rightarrow (1)$$

Integrating both sides, we get.

$$EI\frac{dy}{dx} = -M_B \cdot x + R_B\frac{x^2}{2} - 40(x-2)^2 - \frac{20(x-4)^3}{3} + C_1 \rightarrow (2)$$

when $x = 0$; $\frac{dy}{dx} = 0$; at fixed end B.

$$\boxed{C_1 = 0}$$

Again integrating,

$$EI\frac{dy}{dx} = -M_B x + R_B \cdot \frac{x^2}{2} - 40(x-2)^2 - 20\frac{(x-4)^4}{12} + C_2.$$

Where C_2 = constant of integration

$x = 0$; $y = 0$. at fixed end D

$$\boxed{C_2 = 0.}$$

$$EIy = -M_B\frac{x^2}{2} + R_B \cdot \frac{x^3}{6} - \frac{40(x-2)^3}{3} - \frac{20(x-4)^4}{12}. \rightarrow (3)$$

when $x = 8m$ (at the end A) $\frac{dy}{dx} = 0$; $y = 0$.

Sub in (2) & (3).

$$0 = -8M_B + 32R_B - 1440 - \frac{1280}{3}.$$

$$- M_B - 4R_B + 180 + \frac{160}{}$$

$$M_B - 4R_B + \frac{700}{3} = 0. \longrightarrow (4)$$

$$0 = -32M_B + \frac{512}{6}R_B - 2880 - \frac{1280}{3}$$

$$0 = M_B - 8/3\, R_B + 90 + 40/3.$$

$$M_B - 8/3\, R_B + \frac{310}{3} = 0. \longrightarrow (5)$$

solving (4) & (5).

$$R_B = 97.5 \text{ kN}.$$

$$M_B = -156.6 \text{ kNm}.$$

Also;

$$R_A + R_B = 40 \times 4 + 80$$

$$= 240 \text{ kN}.$$

$$R_A = 240 - 97.5$$

$$= 142.5 \text{ kN}.$$

equation for B.M,

$$M = -M_B + R_B \cdot x - 80(x-2) - 20(x-4)^2.$$

$$= -156.6 + 97.5x - 80(x-2) - 20(x-4)^2$$

$$x = 8\text{m}, \quad M = M_A$$

$$M_A = -156.6 + 97.5 \times 8 - 80(8-2) - 20(8-4)^2$$

$$M_A = -176.6 \text{ kNm}$$

(ii) Deflection at the centre y_D:

Put $x = 4$ in (3),

$$EI\, y_D = -M_B \times \frac{4^2}{2} + R_B \times \frac{4^3}{6} - 40\frac{(4-2)^3}{2} - 0$$

$$= -156.6 \times 8 + \frac{97.5 \times 64}{6} - \frac{320}{3}$$

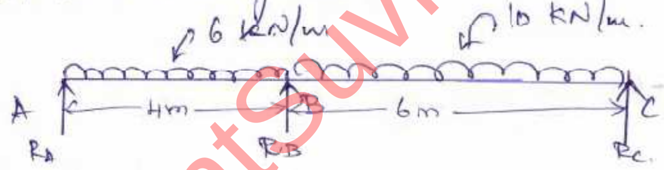
$$= -1252.8 + 1040 - 106.66$$

$$EI\,y_D = -319.46$$

$$y_D = \frac{-319.46}{EI} = \frac{-319.46}{15000} = -0.02129\ m$$

$$\boxed{y_D = -21.29\ mm}$$

(9) A continuous beam ABC covers two consecutive span AB and BC of length 4m and 6m, carrying uniformly distributed load of 6 kN/m and 10 kN/m respectively. If the ends A and C are simply supported, find the supports moments A, B and C, Draw also BM & S.F diagrams.



Given :-

$L_1 = 4m$; $L_2 = 6m$;

$w_1 = 6\ kN/m$ $w_2 = 10\ kN/m$.

At ends in simply supported beam,

$M_A = M_C = 0$.

To find M_B, using clapeyron's equation of three moments.

$$M_A L_1 + 2M_B(L_1 + L_2) + M_C L_2 = \frac{6a_1\bar{x}_1}{L_1} + \frac{6a_2\bar{x}_2}{L_2}$$

$$0 \times 4 + 2M_B(4+6) + 0 \times L_2 = \frac{6a_1\bar{x}_1}{4} + \frac{6a_2\bar{x}_2}{6}$$

$$20 M_B = \frac{3a_1\bar{x}_1}{2} + a_2\bar{x}_2 \longrightarrow (1)$$

B.M for simply supported. Carrying UDL.

$$= \frac{wL^2}{8}$$

Area of B.M diagram $= \frac{2}{3} \times$ span $\times$ Altitude.

distance of CG of this area $= \frac{\text{span}}{2}$.

Now, a_1 = Area of B.M diagram due to udl on AB.

$$= \frac{2}{3} \times AB \times \text{Altitude}.$$

$$= \frac{2}{3} \times 4 \times \frac{w_1 L^2}{8}.$$

$$= \frac{2}{3} \times 4 \times \frac{6 \times 4^2}{8}$$

$$= 32.$$

$$\bar{x}_1 = \frac{L_1}{2} = \frac{4}{2} = 2\text{ m}.$$

a_2 = Area of B.M diagram due to udl on BC.

$$= \frac{2}{3} \times BC \times \frac{w_2 L_2^2}{8}$$

$$= \frac{2}{3} \times 6 \times \frac{10 \times 6^2}{8}.$$

$$= 180$$

$$\bar{x}_2 = \frac{L_2}{2} = \frac{6}{2} = 3\text{ m}.$$

Sub in (1).

$$20 M_B = \frac{3 \times 32 \times 2}{2} + 180 \times 3.$$

$$M_B = \frac{636}{} = 31.8\text{ KN.m}.$$

Now BM diagram due to supports moments is drawn.

$M_A = 0$; $M_C = 0$; $M_B = 31.8$ kN·m.

The B.M diagram due to vertical loads (UDL) on span AB and span BC are also parabola of altitudes.

$$M_{AB} = \frac{w_1 L_1^2}{8} = \frac{6 \times 4^2}{8} = 12 \text{ kN·m.}$$

$$M_{BC} = \frac{w_2 L_2^2}{8} = \frac{10 \times 6^2}{8} = 45 \text{ kN·m.}$$

S.F Diagram:

Take span AB, $M_B = ?$

$$R_A \times 6 - 4 \times 6 \times \frac{4}{2} = M_B.$$

$$= -31.8 \quad (-ve \rightarrow \text{hogging})$$

$$4R_A - 48 = -31.8$$

$$R_A = \frac{-31.8 + 48}{4} = 4.05 \text{ kN.}$$

Similarly for span BC. $M_B = ?$

$$R_C \times 6 - 6 \times 10 \times \frac{6}{2} = M_B$$

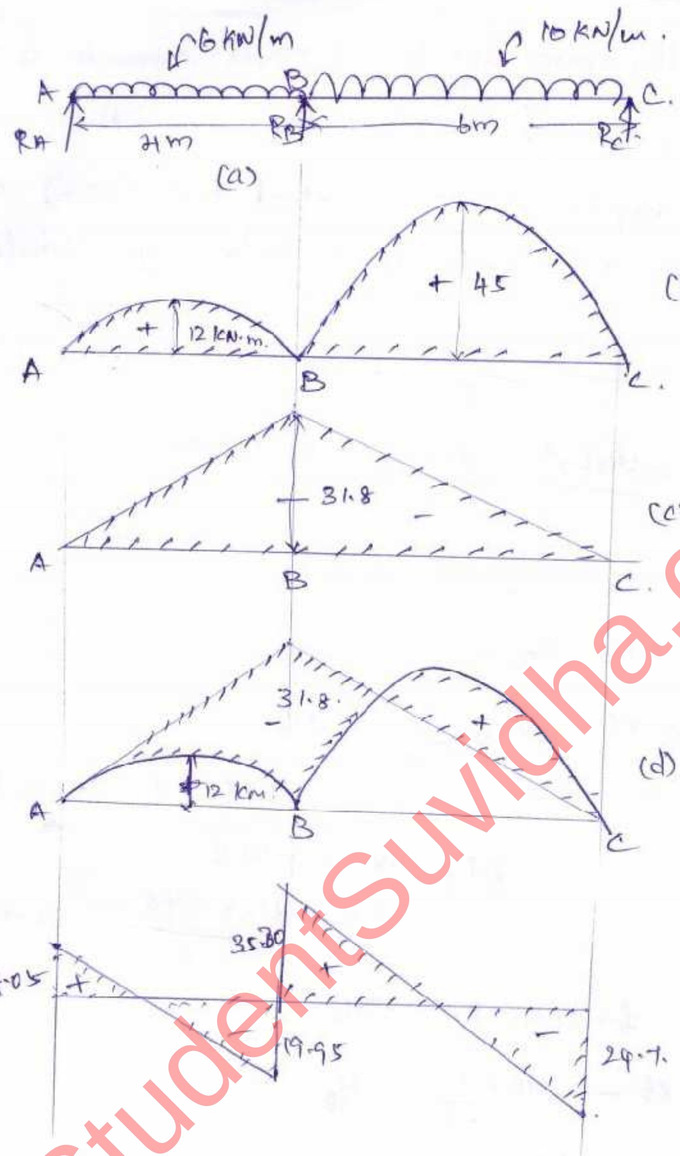
$$6R_C - 180 = -31.8$$

$$R_C = \frac{180 - 31.8}{6} = 24.7 \text{ kN.}$$

$R_A + R_B + R_C$ = Total load on ABC.

$$R_B = (6 \times 4 + 10 \times 6) - (4.05 + 24$$

$$R_B = 55.25 \text{ kN}$$

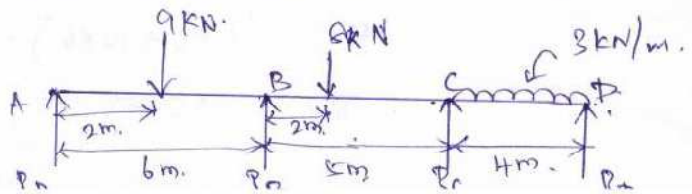


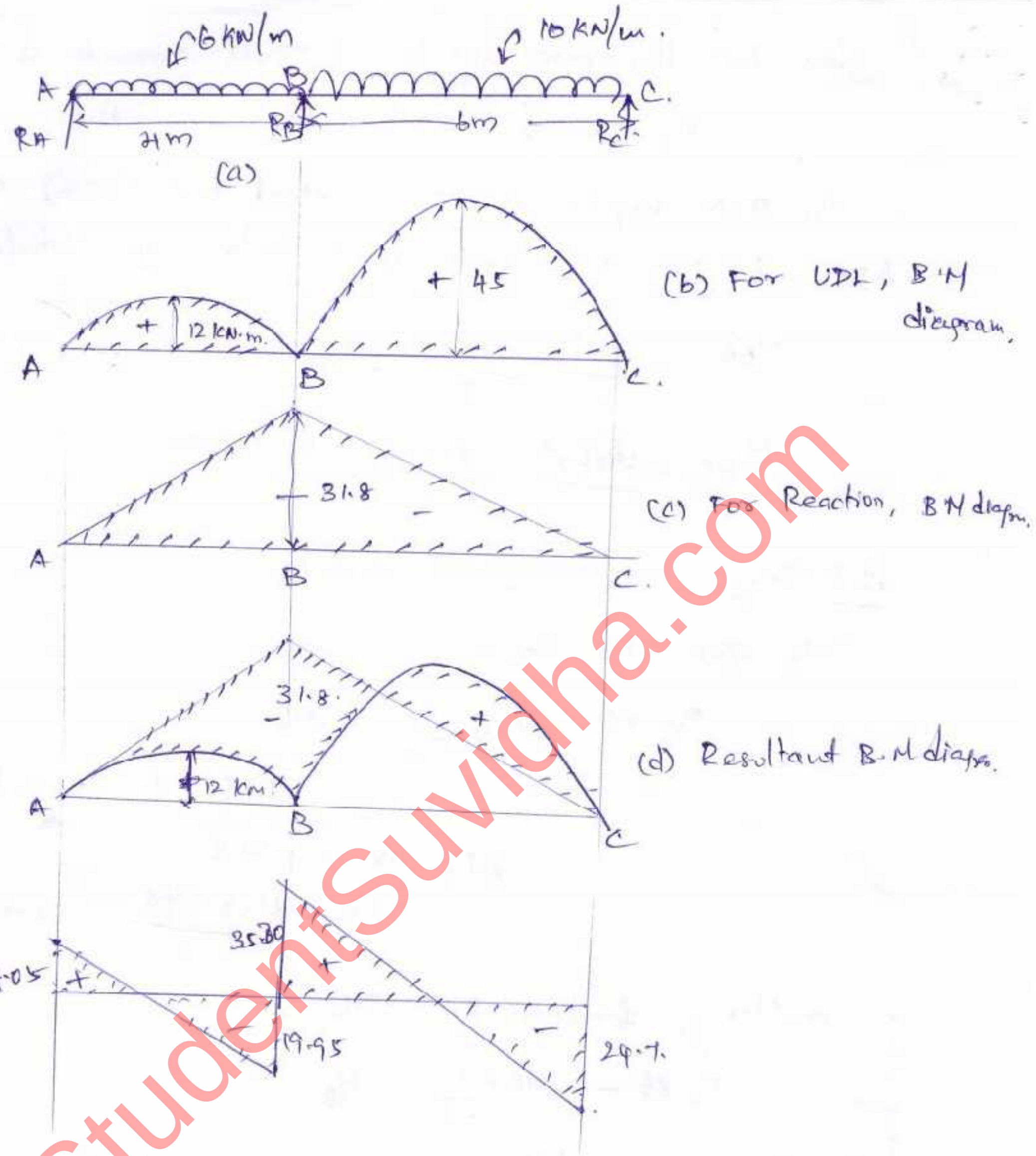
(b) For UDL, B.M diagram.

(c) For Reaction, B.M diagm.

(d) Resultant B.M diagm.

(10) A continuous beam ABCD, simply supported at A, B, C & D is loaded as shown in figure. Find the moments over the beam and draw the B.M and S.F diagram.





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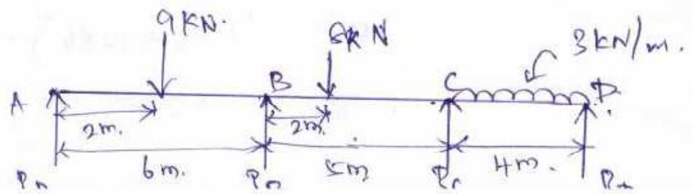


UNIT – 2

INDETERMINATE BEAMS.

1. Propped Cantilever:

Propped cantilever means cantilevers supported on a vertical support at a suitable point. The vertical support is known as prop.

2. To find the reaction at the prop:

The reaction of the prop is calculated by equating the downward deflection due to load at the point of prop to the upward deflection due to prop reaction.

3. Fixed beam:

A beam whose both ends are fixed is known as fixed beam.

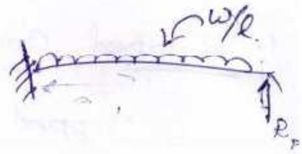
4. Continuous beam:

A beam which is supported on more than ~~two~~ two supports is known as a continuous beam.

5. Advantage of Fixed beam.

* The beam is more stable and stronger.
* The slope at both ends of a fixed beam is zero
* The fixed beam is subjected to a lesser maximum Bending moment.
* The maximum ~~bending moment~~ deflection of a fixed beam is less than that of a simply supported beam.

(6) For a cantilever carrying a uniformly distributed load over the entire span and propped rigidly at the free end.



* Prop Reaction, $P = \frac{3}{8} w.L$
* B.M at fixed end; $M = \frac{wL^2}{8}$
* Point of contraflexure, $x = \frac{3L}{4}$
* Deflection at the centre, $y_c = \frac{wL^4}{192 EI}$
* Maximum deflection, $y_{max} = \frac{0.005415\, wL^4}{EI}$

Where; w = Uniformly distributed load
x = Distance from free end.

(7) For a simply supported beam, carrying a uniformly distributed load over the entire span and propped at the centre.

* Prop reaction; $P = \frac{5}{8} W$
* Support Reaction, $R_A = R_B = \frac{3W}{16}$
* B.M at centre, $M = -\frac{wL^2}{32}$
* Point of contraflexure, $x = \frac{3L}{8}$

* Deflection.

$$y = \frac{wL^4}{384\, EI}$$

Where W = Total load on beam.
$= w.L$
w = Uniformly distributed load on beam.
x = Distance from the support.

(8) The deflection at the centre of a fixed beam carrying a point load at the centre.

$$y_c = \frac{WL^3}{192\,EI}$$

W - Point load. ; L - length of beam.

(9) The deflection at the centre of a fixed beam carrying a point load at the centre is one fourth of the deflection of a simply supported beam.

(10) To find deflection of a fixed beam with an eccentric load, under the point load is given by.

$$y_c = \frac{W a^3 b^3}{3\,EI\,l^3}$$

(11) Fixed beam carrying Uniformly Destributed load over a whole length.

End Moments $= \frac{WL^2}{12}$ Deflection $= y_c = \frac{wL^4}{192\,EI}$

Max deflection $= \frac{wL^4}{384\,EI}$

(12) Clapeyron's Theorem of Three Moments for continuous beam

$$M_A L_1 + 2M_B(L_1+L_2) + M_C \times L_2 = \frac{6\,a_1\bar{x}_1}{L_1} + \frac{6\,a_2\bar{x}_2}{L_2}$$

a_1 - area of B.M diagram due to vertical loads on span AB

a_2 = area of B.M diagram due to vertical loads on span BC

$\bar{x}_1$ - Distance of CG of BM diagram due to vertical loads on AB from Point A.

— . . . BM diagram due to vertical loads

Formulae to Remember:

* $\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$

Moment area Method

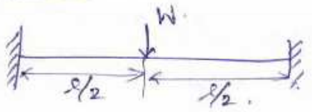
* Slope $= \frac{A}{EI}$

* Deflection $= \frac{A\bar{x}}{EI}$

(B) Point of contraflexure:

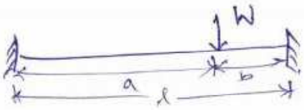
The point where Bending moment is zero after changing its sign, is known as point of contraflexure

Fixed End Moments:

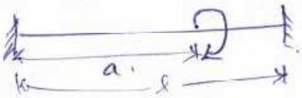
1. 

$M_A = \frac{-Wl}{8}$

$M_B = \frac{-Wl}{8}$

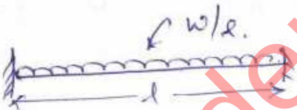
2. 

$M_A = \frac{-Wab^2}{l^2}$ $M_B = \frac{-Wa^2b}{l^2}$

3. 

$M_A = \frac{M}{l^2}(l-a)(l-3a)$

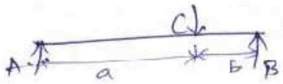
$M_B = \frac{M}{l^2}a(2l-3a)$

4. 

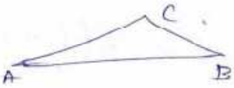
$M_A = M_B = \frac{-wl^2}{12}$

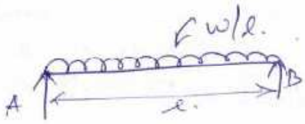
Bending Moment

$M_c = \frac{WL}{4}$



$M_c = \frac{Wab}{L}$





$M_c = \frac{wl^2}{8}$