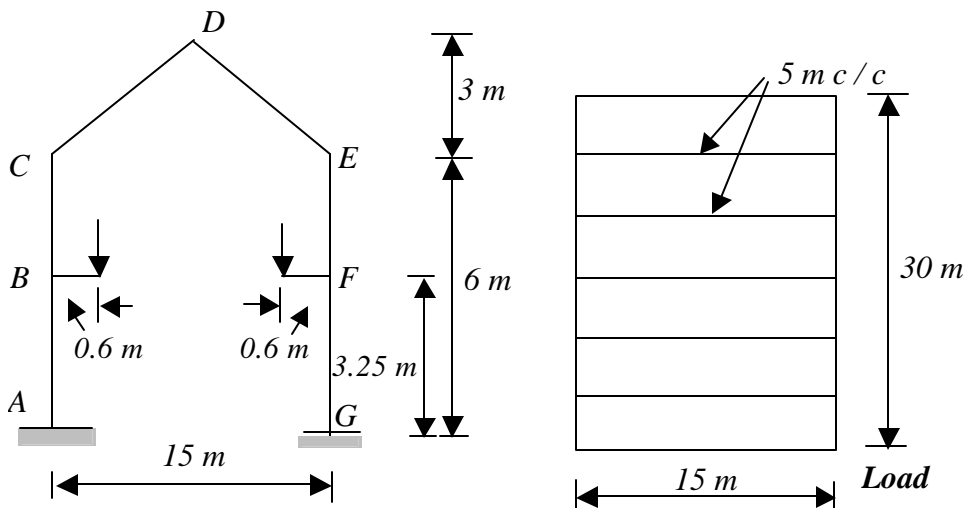


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**Problem**

Analyse and Design a single span portal frame with gabled roof. The frame has a span of 15 m, the column height 6m and the rafter rise 3m. Purlins are provided @ 2.5 m c/c.



**1.0 Load Calculation**

**1.1 Dead Load**

Weight of asbestos sheeting	=	0.17 kN/m <sup>2</sup>
Fixings	=	0.025 kN/m <sup>2</sup>
Services	=	0.100 kN/m <sup>2</sup>
Weight of purlin	=	0.100 kN/m <sup>2</sup>
Total load /m <sup>2</sup>	=	----- 0.395 kN/m <sup>2</sup> -----

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<p>Dead load/m run <math>= 0.395 * 5</math>  <math>= 1.975 \text{ kN/m}</math>  <math>\gg 2.0 \text{ kN/m}</math></p> <p><b>1.2 Live Load</b></p> <p>Angle of rafter <math>= \tan^{-1} (3/7.5) = 21.8^\circ</math></p> <p>From IS: 875 (part 2) – 1987; Table 2 (cl 4.1),  <b>Live load / m run</b> <math>= \{0.75 - 0.02 (21.8 - 10)\} * 5</math>  <math>= 2.57 \text{ kN/m}</math></p> <p><b>1.3 Crane Loading</b></p> <p>Overhead electric crane capacity <math>= 300 \text{ kN}</math></p> <p>Approximate weight of crane girder <math>= 300 \text{ kN}</math></p> <p>Weight of crab <math>= 60 \text{ kN}</math></p> <p>The extreme position of crane hook is assumed as 1 m from the centre line of rail. The span of crane is approximately taken as 13.8 m. And the wheel base has been taken as 3.8 m</p> <p><b>1.3.1 Vertical load</b></p> <p>The weight of the crane is shared equally by four wheels on both sides. The reaction on wheel due to the lifted weight and the crab can be obtained by taking moments about the centreline of wheels.</p> <div style="text-align: center;"> </div> <p><math>M_B = 0</math></p>			

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<p> <math>2 R_F (13.8) = (300 + 60) * 1 + 300 * (6.90)</math>  <math>R_F = 88 \text{ kN}</math> </p> <p> <math>M_F = 0</math> </p> <p> <math>2 R_B (13.8) = (300 + 60) * (13.8-1) + 300 * (6.9)</math>  <math>R_B = 242 \text{ kN}</math> </p> <p> <i>To get maximum wheel load on a frame from gantry girder BB', taking the gantry girder as simply supported.</i> </p> <div style="text-align: center;"> <p>The diagram shows a horizontal beam labeled B'B. At the left end B', there is an upward reaction arrow. At the right end B, there is an upward reaction arrow. Two downward point loads of 242 kN are applied to the beam. The first load is 3.8 m from the left end. The second load is 5 m from the left end. The distance between the two loads is 3.8 m.</p> </div> <p> <i>Centre to centre distance between frames is 5 m c/c.</i>  <i>Assuming impact @ 25%</i> </p> <p> <i>Maximum wheel Load @ B = 1.25 (242 (1 + (5-3.8)/5))</i>  <math>= 375 \text{ kN.}</math> </p> <p> <i>Minimum wheel Load @ B = (88 /242)*375</i>  <math>= 136.4 \text{ kN}</math> </p> <p> <b>1.3.2 Transverse Load:</b> </p> <p> <i>Lateral load per wheel = 5% (300 + 60)/2 = 9 kN</i> </p> <p> <i>(i.e. Lateral load is assumed as 5% of the lifted load and the weight of the trolley acting on each rail).</i> </p> <p> <i>Lateral load on each column { EMBED Equation.3 } = 13.9 kN</i>  <i>(By proportion)</i> </p>			

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<p><b>1.4 Wind Load</b></p> <p><i>Design wind speed, <math>V_z = k_1 k_2 k_3 V_b</math></i></p> <p><i>From Table 1; IS: 875 (part 3) – 1987</i></p> <p><i><math>k_1 = 1.0</math> (risk coefficient assuming 50 years of design life)</i></p> <p><i>From Table 2; IS: 875 (part 3) – 1987</i></p> <p><i><math>k_2 = 0.8</math> (assuming terrain category 4)</i></p> <p><i><math>k_3 = 1.0</math> (topography factor)</i></p> <p><i>Assuming the building is situated in Chennai, the basic wind speed is 50 m/sec</i></p> <p><i>Design wind speed, <math>V_z = k_1 k_2 k_3 V_b</math></i>  <math display="block">V_z = 1 * 0.8 * 1 * 50</math> <math display="block">V_z = 40 \text{ m/sec}</math></p> <p><i>Basic design wind pressure, <math>P_d = 0.6 * V_z^2</math></i>  <math display="block">= 0.6 * (40)^2</math> <math display="block">= 0.96 \text{ kN/m}^2</math></p> <p><b>1.4.1. Wind Load on individual surfaces</b></p> <p><i>The wind load, <math>W_L</math> acting normal to the individual surfaces is given by</i>  <math display="block">W_L = (C_{pe} - C_{pi}) A * P_d</math></p> <p><i>(a) Internal pressure coefficient</i></p> <p><i>Assuming buildings with low degree of permeability</i></p> $C_{pi} = \pm 0.2$			

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*(b) External pressure coefficient*

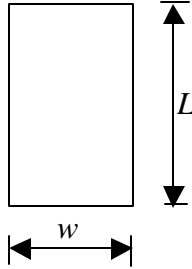
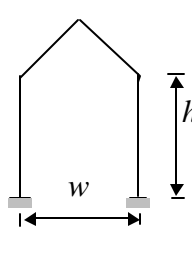
External pressure coefficient for walls and roofs are tabulated in Table 1 (a) and Table 1(b)

1.4.2 Calculation of total wind load

*(a) For walls*

$h/w = 6/15 = 0.4$   
 $L/w = 30/15 = 2.0$

Exposed area of wall per frame @ 5 m c/c is  
 $A = 5 * 6 = 30 \text{ m}^2$

*plan*                      *elevation*

For walls,  $A p_d = 30 * 0.96 = 28.8 \text{ kN}$

*Table 1 (a): Total wind load for wall*

Wind Angle <b>q</b>	$C_{pe}$		$C_{pi}$	$C_{pe} - C_{pi}$		Total wind(kN) $(C_{pe}-C_{pi})Ap_d$	
	Wind-ward	Lee-ward		Wind ward	Lee ward	Wind ward	Lee ward
$0^0$	0.7	-0.25	0.2	0.5	-0.45	14.4	-12.9
			-0.2	0.9	-0.05	25.9	-1.4
$90^0$	-0.5	-0.5	0.2	-0.7	-0.7	-20.2	-20.2
			-0.2	-0.3	-0.3	-8.6	-8.6

*(b) For roofs*

Exposed area of each sloping roof per frame @ 5 m c/c is

$$A = 5 * \sqrt{(3.0)^2 + (7.5)^2} = 40.4 \text{ m}^2$$

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<p>For roof, <math>A_{pd} = 38.7 \text{ kN}</math></p> <p style="text-align: center;"><i>Table 1 (b): Total wind load for roof</i></p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr> <th rowspan="3">Wind angle</th> <th colspan="3">Pressure Coefficient</th> <th colspan="2"><math>C_{pe} - C_{pi}</math></th> <th colspan="2">Total Wind Load(kN) <math>(C_{pe} - C_{pi}) A_{pd}</math></th> </tr> <tr> <th><math>C_{pe}</math></th> <th><math>C_{pe}</math></th> <th rowspan="2"><math>C_{pi}</math></th> <th>Wind ward</th> <th>Lee ward</th> <th>Wind ward</th> <th>Lee ward</th> </tr> <tr> <th>Wind</th> <th>Lee</th> <th></th> <th></th> <th>Int.</th> <th>Int.</th> </tr> </thead> <tbody> <tr> <td rowspan="2"><math>0^\circ</math></td> <td>-0.328</td> <td>-0.4</td> <td>0.2</td> <td>-0.528</td> <td>-0.6</td> <td>-20.4</td> <td>-23.2</td> </tr> <tr> <td>-0.328</td> <td>-0.4</td> <td>-0.2</td> <td>-0.128</td> <td>-0.2</td> <td>-4.8</td> <td>-7.8</td> </tr> <tr> <td rowspan="2"><math>90^\circ</math></td> <td>-0.7</td> <td>-0.7</td> <td>0.2</td> <td>-0.9</td> <td>-0.9</td> <td>-34.8</td> <td>-34.8</td> </tr> <tr> <td>-0.7</td> <td>-0.7</td> <td>-0.2</td> <td>-0.5</td> <td>-0.5</td> <td>-19.4</td> <td>-19.4</td> </tr> </tbody> </table> <p><b>2.0 Equivalent Load Calculation</b></p> <p><b>2.1 Dead Load</b></p> <p>Dead Load = 2.0 kN/m</p> <p>Replacing the distributed dead load on rafter by equivalent concentrated loads at two intermediate points on each rafter,</p> <div style="display: flex; align-items: center;"> <div style="flex: 1;"> <p>{ EMBED Equation.3 }</p> <p><b>2.2 Superimposed Load</b></p> <p>Superimposed Load = 2.57 kN/m</p> <p>Concentrated load , { EMBED Equation.3 }</p> </div> <div style="flex: 1; text-align: center;"> </div> </div>				Wind angle	Pressure Coefficient			$C_{pe} - C_{pi}$		Total Wind Load(kN) $(C_{pe} - C_{pi}) A_{pd}$		$C_{pe}$	$C_{pe}$	$C_{pi}$	Wind ward	Lee ward	Wind ward	Lee ward	Wind	Lee			Int.	Int.	$0^\circ$	-0.328	-0.4	0.2	-0.528	-0.6	-20.4	-23.2	-0.328	-0.4	-0.2	-0.128	-0.2	-4.8	-7.8	$90^\circ$	-0.7	-0.7	0.2	-0.9	-0.9	-34.8	-34.8	-0.7	-0.7	-0.2	-0.5	-0.5	-19.4	-19.4
Wind angle	Pressure Coefficient				$C_{pe} - C_{pi}$		Total Wind Load(kN) $(C_{pe} - C_{pi}) A_{pd}$																																															
	$C_{pe}$	$C_{pe}$	$C_{pi}$		Wind ward	Lee ward	Wind ward	Lee ward																																														
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<p><i>2.3 Crane Load</i></p> <p><i>Maximum Vertical Load on columns = 375 kN (acting at an eccentricity of 600 mm from column centreline)</i></p> <p><i>Moment on column = 375 * 0.6 = 225 kNm.</i></p> <p><i>Minimum Vertical Load on Column = 136.4 kN (acting at an eccentricity of 600 mm)</i></p> <p><i>Maximum moment = 136.4 * 0.6 = 82 kNm</i></p> <p><b>3.0 Partial Safety Factors</b></p> <p><i>3.1 Load Factors</i></p> <p><i>For dead load, <math>g = 1.35</math></i>  <i>For major live load, <math>g = 1.5</math></i>  <i>For minor live load, <math>g = 1.05</math></i></p> <p><i>3.2 Material Safety factor</i></p> <p><i><math>g_n = 1.15</math></i></p> <p><b>4.0 Analysis</b></p> <p><i>In this example, the following load combinations are considered, as they are found to be critical.</i></p> <p><i>Similar steps can be followed for plastic analysis under other load combinations.</i></p> <p>(i) <i>1.35D.L + 1.5 C.L + 1.05 W.L</i></p>			
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<p>(ii) <math>1.35 D.L + 1.5 C.L + 1.05 L.L</math></p> <p>4.1. <math>1.35 D.L + 1.5 C.L + 1.05 W.L</math></p> <p>4.1.1 Dead Load and Wind Load</p> <p>(a) Vertical Load</p> <p><math>w</math> @ intermediate points on windward side</p> $w = 1.35 * 5.0 - 1.05 * (4.8/3) \cos 21.8$ $= 5.2 \text{ kN.}$ $\frac{w}{2} @ \text{ eaves} = \frac{5.2}{2} = 2.6 \text{ kN}$ <p><math>w</math> @ intermediate points on leeward side</p> $w = 1.35 * 5.0 - 1.05 * 7.8/3 \cos 21.8$ $= 4.2 \text{ kN}$ $\frac{w}{2} @ \text{ eaves} = \frac{4.2}{2} = 2.1 \text{ kN}$ <p>Total vertical load @ the ridge = <math>2.6 + 2.1 = 4.7 \text{ kN}</math></p> <p>b) Horizontal Load</p> <p><math>H</math> @ intermediate points on windward side</p> $H = 1.05 * 4.8/3 \sin 21.8$ $= 0.62 \text{ kN}$		

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*Total moment @ B = 337.5 + 4.6 = 342 kNm*  
*@ F = 123 + 4.6 = 128 kNm*

**Factored Load (1.35D.L+1.5 C.L +1.05 W.L)**

4.2  $1.35 D.L + 1.5 C.L + 1.05 L.L$

4.2.1 *Dead Load and Live Load*

@ intermediate points on windward side =  $1.35 * 5.0 + 1.05 * 6.4$   
 = 13.5 kN

@ ridge = 13.5 kN

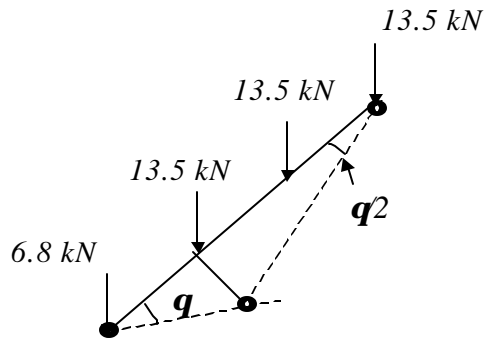
@ eaves =  $13.5 / 2 \gg 6.8 \text{ kN}$ .

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	<p>4.2.2 Crane Load</p> <p>Moment @ B = 342 kNm</p> <p>Horizontal load @ B = 20.8 kN</p> <p>Moment @ F = 128 kNm</p> <p>Horizontal load @ F = 20.8 kN</p> <div style="text-align: center;"> </div> <p><b>Factored Load (1.35 D.L + 1.5 C.L + 1.05 L.L)</b></p>		
4.3 Mechanisms	<p>We will consider the following mechanisms, namely</p> <ul style="list-style-type: none"> <li>(i) Beam mechanism</li> <li>(ii) Sway mechanism</li> <li>(iii) Gable mechanism and</li> <li>(iv) Combined mechanism</li> </ul>		
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<p>4.3.1 <i>Beam Mechanism</i></p> <p>(1) <i>Member CD</i></p> <p>Case 1: <math>1.35 D.L + 1.5 C.L + 1.05 W.L</math></p> <div style="text-align: center;"> </div> <p>Internal Work done, <math>W_i = M_p \mathbf{q} + M_p (\mathbf{q}/2) + M_p (\mathbf{q} + \mathbf{q}/2)</math>  <math>= M_p (3\mathbf{q})</math></p> <p>External Work done, <math>W_e = 5.2 * 2.5\mathbf{q} - 0.62 * 1 * \mathbf{q} + 5.2 * 2.5 * \mathbf{q}/2 - 0.62 * 1 * \mathbf{q}/2</math>  <math>= 18.6\mathbf{q}</math></p> <p>Equating internal work done to external work done</p> $W_i = W_e$ $M_p (3\mathbf{q}) = 18.6\mathbf{q}$ $M_p = 6.2 \text{ kNm}$ <p>Case 2: <math>1.35 D.L + 1.5 C.L + 1.05 W.L</math></p> <p>Internal Work done, <math>W_i = M_p (\mathbf{q} + \mathbf{q}/2 + \mathbf{q} + \mathbf{q}/2)</math></p> $W_i = M_p 3\mathbf{q}$			
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External work done,  $W_e = 13.5 * 2.5 q + 13.5 * 2.5 q^2$   
 $= 50.6 q$

Equating  $W_i = W_e$ ,

$$M_p (3q) = 50.6 q$$

$$M_p = 16.9 \text{ kNm}$$

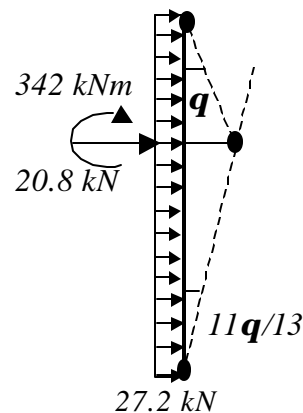
Note: Member DE beam mechanism will not govern.

(2) Member AC

Internal Work done,

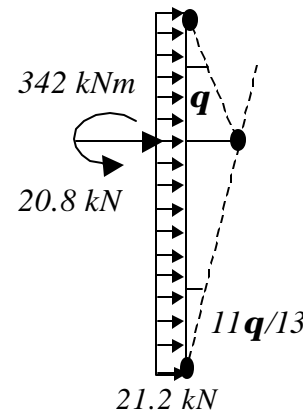
$$W_i = M_p \theta + M_p \frac{2}{3} \theta + \frac{11}{13} \theta \frac{11}{13} + M_p \frac{2}{13} \theta \frac{11}{13}$$

$$= 3.69 M_p \theta$$



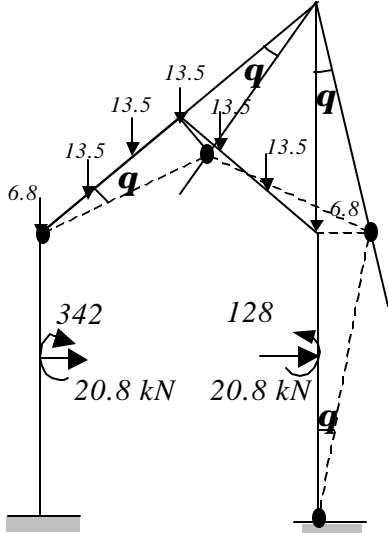
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<p><i>External Work done,</i></p> $W_e = 20.8 * 3.25 * \frac{11}{13} \delta + 342 * \frac{11}{13} \delta + \frac{1}{2} * 27.2 * 3.25 \left( \frac{11}{13} \delta \right)$ $= 383.9 \delta$ <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $3.69 M_p q = 383.9 q$ $M_p = 104.1 \text{ kNm.}$ <p>(3) Member EG</p> <p><i>Internal Work done,</i></p> $W_i = M_p \delta + M_p \frac{2}{3} \delta + \frac{11}{13} \delta \frac{\delta}{13} + M_p \frac{2}{3} \frac{11}{13} \delta \frac{\delta}{13}$ $= 3.69 M_p \delta$ <p><i>External Work done,</i></p> $W_e = 20.8 * 3.25 * \frac{11}{13} \delta + 342 * \delta + \frac{1}{2} (21.2) * 3.25 \frac{2}{3} \frac{11}{13} \delta$ $= 428.3 \delta$ <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $3.69 M_p q = 428.3 q$		
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<p><math>M_p = 116.1 \text{ kNm}</math></p> <p>For members AC &amp; EG, the 1<sup>st</sup> load combination will govern the failure mechanism.</p> <p>4.3.2 Panel Mechanism</p> <p>Case 1: 1.35 D.L + 1.5 C.L + 1.05 W.L</p> <p>Internal Work done, <math>W_i = M_p(q) + M_p(q) + M_p(q) + M_p(q)</math>  <math>= 4M_p q</math></p> <p>External Work done, <math>W_e</math></p> $W_e = 1/2 (27.2) * 6q + 20.8 * 3.25q + 342q - 0.31 * 6q - 0.62 * 6q - 0.62 (6q) + 0.19 * 6q + 1.0 * 6q + 1.0 * 6q + 0.5 * 6q + 1/2 (1.5) * 6q + 20.8 * 3.25q - 128 * q$ $= 442.14q$		
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	<p>Equating <math>W_i = W_e</math>, we get</p> <p><math>6M_p = 60.56q</math></p> <p><math>M_p = 10.1 \text{ kNm}</math>.</p> <p>Case 2: <math>1.35 \text{ D.L} + 1.05 \text{ L.L} + 1.5 \text{ C.L}</math></p>  <p>Internal Work done, <math>W_i = M_p q + M_p (2q) + M_p (2q) + M_p q = 6M_p q</math></p> <p>External Work done, <math>W_e</math></p> <p><math>= 13.5 * 2.5 * q + 13.5 * 5 * q + 13.5 * 7.5 * q + 13.5 * 5 * q + 13.5 * 2.5 * q -</math>  <math>128 * q + 20.8 * 3.25 q</math>  <math>= 243.4 q</math></p> <p>Equating <math>W_i = W_e</math>, we get</p> <p><math>6M_p q = 243.4 q</math></p> <p><math>M_p = 40.6 \text{ kNm}</math></p>		
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<b>Design Project</b>	Worked Example: <b>I</b>		
		Made By <b>PU</b>	Date
<b>Calculation Sheet</b>		Checked By <b>VK</b>	Date
<p>4.3.4 Combined Mechanism</p> <p>Case1: 1.35 D.L + 1.05 W.L + 1.5 C.L</p> <p>(i)</p> <p>Internal Work done, <math>W_i = M_p (q) + M_p (q + q/2) + M_p (q/2 + q/2) + M_p (q/2)</math>  <math>= M_p (q + q + q/2 + q/2 + q/2 + q/2)</math>  <math>= 4 M_p q</math></p> <p>External Work done, <math>W_e =</math>  <math>1/2 * 27.2 * 6q + 20.8 * 3.25 * q + 342q - 0.31 * 12 * q/2 - 0.62 * 11 * q/2</math>  <math>- 0.62 * 10 * q/2 + 0.19 * 9 * q/2 + 1.0 * 8 * q/2 + 1.0 * 7 * q/2 + 0.5 * 6 * q/2</math>  <math>+ 1/2 (1.5) * 6q/2 + 20.8 * 3.25 * q/2 - 128 * q/2 - 5.2 * 2.5 * q/2 - 5.2 * 5.0 * q/2 - 4.7 * 7.5 * q/2 - 4.2 * 5 * q/2 - 4.2 * 2.5 * q/2</math>  <math>= 411.86q</math></p>			
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*Equating  $W_i = W_e$*

$4M_p \mathbf{q} = 411.86 \mathbf{q}$

$M_p = 102.9 \text{ kNm}$

(ii) *Internal work done,  $W_i = M_p \mathbf{q}/2 + M_p (\mathbf{q}/2 + \mathbf{q}/2) + M_p (\mathbf{q}/2 + \mathbf{q}) + M_p \mathbf{q}$*

$W_i = 4M_p \mathbf{q}$

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<b>Design Project</b>	Worked Example: <i>I</i>	
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<b>Calculation Sheet</b>	Checked By <i>VK</i>	Date
<p><i>External Work done,</i></p> $W_e = 20.8 * 3.25 * \frac{\delta}{2} + 342 * \frac{\delta}{2} + \frac{1}{2} * 27.2 * 6 * \frac{\delta}{2} - 0.31 * 6 * \frac{\delta}{2} - 0.62 * 7 * \frac{\delta}{2}$ $- 0.62 * 8 * \frac{\delta}{2} + 0.19 * 9 * \frac{\delta}{2} + 5.2 * 2.5 * \frac{\delta}{2} + 5.2 * 5.0 * \frac{\delta}{2} + 4.7 * 7.5 * \frac{\delta}{2} + 1.0 * 10 * \frac{\delta}{2}$ $+ 1.0 * 11 * \frac{\delta}{2} + 0.5 * 12 * \frac{\delta}{2} + 4.2 * 5.0 * \frac{\delta}{2} + 4.2 * 2.5 * \frac{\delta}{2} + 20.8 * 3.25 \delta - 128 * \delta$ $+ \frac{1}{2} * 1.5 * 6 \delta$ $= 251.35 q$ <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $4M_p q = 251.35 q$ $M_p = 62.84 \text{ kNm}$ <p>(iii)</p>		
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Design Project	Worked Example: <i>I</i>	
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Calculation Sheet	Checked By <i>VK</i>	Date
<p><i>Internal work done, <math>W_i</math></i></p> $= M_p \left[ \frac{25\delta}{6} + M_p \left[ \frac{2\delta}{6} + \frac{5\delta}{6} \right] + M_p \left[ \frac{2\delta}{6} + \delta \right] + M_p (\delta) \right]$ $= 4M_p \delta$ <p><i>External Work done, <math>W_e =</math></i></p> $20.8 * 3.25 * \frac{25\delta}{6} + 342 * \frac{5\delta}{6} + \frac{1}{2} * 27.2 * 6 * \frac{5\delta}{6} - 0.31 * 6 * \frac{5\delta}{6} - 0.62 * 35 * \frac{\delta}{6}$ $- 0.62 * 34 * \frac{\delta}{6} + 0.19 * 33 * \frac{\delta}{6} + 1.0 * 34 * \frac{\delta}{6} + 1.0 * 35 * \frac{\delta}{6} + 0.5 * 36 * \frac{\delta}{6}$ $+ 5.2 * 12.5 * \frac{\delta}{6} + 5.2 * 10 * \frac{\delta}{6} + 4.7 * 7.5 * \frac{\delta}{6} + 4.2 * 5.0 * \frac{\delta}{6} + 4.2 * 2.5 * \frac{\delta}{6}$ $+ 20.8 * 3.25 * \delta - 128 * \delta + \frac{1}{2} (1.5) (6 * \delta)$ <p><math>W_e = 390.92q</math></p> <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $4M_p q = 390.92q$ <p><math>M_p = 97.7 \text{ kNm}</math></p> <p><i>(iv) Internal Work done,</i></p> $W_i = M_p \left[ \frac{2\delta}{3} + M_p \left[ \frac{2\delta}{3} + \frac{\delta}{3} \right] + M_p \left[ \frac{2\delta}{3} + \delta \right] + M_p (\delta) \right]$ $= 4M_p \delta$		
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	Rev	

<b>Design Project</b>	Worked Example: <i>I</i>		
		Made By <i>PU</i>	Date
<b>Calculation Sheet</b>		Checked By <i>VK</i>	Date
<p>External Work done, <math>W_e =</math></p> $20.8 * 3.25 * \frac{2\bar{\theta}}{3} + 342 * \frac{2}{3}\bar{\theta} + \frac{1}{2} * 27.2 * 6 * \frac{2\bar{\theta}}{3} - 0.31 * 6 * \frac{2\bar{\theta}}{3}$ $- 0.62 * 7 * \frac{2\bar{\theta}}{3} - 0.62 * 16 * \frac{\bar{\theta}}{3} + 0.19 * 15 * \frac{\bar{\theta}}{3} + 5.2 * 2.5 * \frac{2}{3}\bar{\theta} + 5.2 * 5 * \frac{2}{3}\bar{\theta}$ $+ 4.7 * 7.5 * \frac{\bar{\theta}}{3} + 0.19 * 15 * \frac{\bar{\theta}}{3} + 1.0 * 16 * \frac{\bar{\theta}}{3} + 1.0 * 17 * \frac{\bar{\theta}}{3} + 0.5 * 18 * \frac{\bar{\theta}}{3} + 4.2 * 5.0 * \frac{\bar{\theta}}{3}$ $+ 4.2 * 2.5 * \frac{2\bar{\theta}}{3} + 20.8 * 3.25 * \bar{\theta} - 128 * \bar{\theta} + \frac{1}{2} (1.5) * 6\bar{\theta}$ <p><math>W_e = 328.3\bar{\theta}</math></p> <p>Equating <math>W_i = W_e</math>, we get</p> <p><math>4M_p q = 328.3q</math></p> <p><math>M_p = 82.1 \text{ kNm}</math></p>			
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	Made By <b>PU</b>	Date
<h2>Calculation Sheet</h2>	Checked By <b>VK</b>	Date
<p>Case 2: <math>1.35 D.L + 1.05 L.L + 1.5 C.L</math></p> <p>(i) Assuming plastic hinge is formed @ purlin point 2 and 7 and at fixed supports.</p> <div style="text-align: center;"> </div>		
<p>Internal Work done = <math>M_p \left( \frac{5\theta}{6} + \frac{\theta}{6} \right) + M_p \left( \frac{5\theta}{6} + \frac{\theta}{6} \right) + M_p \left( \frac{\theta}{6} + \theta \right) + M_p \theta</math></p> <p style="text-align: center;"><math>= 4M_p \theta</math></p>		
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<b>Design Project</b>	Worked Example: <b>I</b>		
		Made By <b>PU</b>	Date
<b>Calculation Sheet</b>		Checked By <b>VK</b>	Date
	<p><i>External Work done = <math>W_e</math></i></p> $20.8 * 3.25 * \left(\frac{5\dot{\epsilon}}{6}\right) + 342 * \left(\frac{5\dot{\epsilon}}{6}\right) + 13.5 * 12.5 * \left(\frac{\dot{\epsilon}}{6}\right) + 13.5 * 10 * \left(\frac{\dot{\epsilon}}{6}\right) + 13.5 * 7.5 * \left(\frac{\dot{\epsilon}}{6}\right) + 13.5 * 5.0 * \frac{\dot{\epsilon}}{6} + 13.5 * 2.5 * \frac{\dot{\epsilon}}{6} + 20.8 * 3.25 * \dot{\epsilon} - 128\dot{\epsilon}$ $= 365.3\dot{\epsilon}$ <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $4M_p \mathbf{q} = 365.3 \mathbf{q}$ $M_p = 91.3 \text{ kNm}$ <p>(ii) <i>Plastic hinge is formed @ 3 and 7</i></p>		
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<b>Design Project</b>	Worked Example: <b>I</b>	
	Made By <b>PU</b>	Date
<b>Calculation Sheet</b>	Checked By <b>VK</b>	Date
<p><i>Internal work done,</i></p> $W_i = M_p \left( \frac{2}{3} \mathbf{q} \right) + M_p \left( \frac{2}{3} \mathbf{q} + \frac{\mathbf{q}}{3} \right) + M_p \left( \frac{\mathbf{q}}{3} + \mathbf{q} \right) + M_p (\mathbf{q})$ $= 4M_p \mathbf{q}$ <p><i>External Work done, <math>W_e =</math></i></p> $20.8 * 3.25 * \left( \frac{2}{3} \dot{\epsilon} \right) + 342 * \frac{2}{3} \dot{\epsilon} + 13.5 * 2.5 * \frac{2}{3} \dot{\epsilon} + 13.5 * 5.0 * \frac{2}{3} \dot{\epsilon} + 13.5 * 7.5 * \frac{\dot{\epsilon}}{3} +$ $13.5 * 5.0 * \frac{\dot{\epsilon}}{3} + 13.5 * 2.5 * \frac{\dot{\epsilon}}{3} + 20.8 * 3.25 \dot{\epsilon} - 128 \mathbf{q}$ $= 347.7 \dot{\epsilon}$ <p><i>Equating <math>W_i = W_e</math>, we get</i></p> $4M_p \mathbf{q} = 347.7 \mathbf{q}$ $M_p = 86.9 \text{ kNm}$ <p>(iii) <i>Plastic hinged is formed at 4 and 7</i></p> <p><i>Internal Work done</i></p> $= M_p \left( \frac{\dot{\epsilon}}{2} + \frac{\dot{\epsilon}}{2} \right) + M_p \left( \frac{\dot{\epsilon}}{2} + \frac{\dot{\epsilon}}{2} \right) + M_p \left( \frac{\dot{\epsilon}}{2} + \frac{\dot{\epsilon}}{2} \right) + M_p \dot{\epsilon}$ $= 4 M_p \dot{\epsilon}$		

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<h1>Design Project</h1> <h2>Calculation Sheet</h2>	Worked Example: <i>I</i>		
		Made By <i>PU</i>	Date
		Checked By <i>VK</i>	Date
<p>External Work done, <math>W_e =</math></p> $20.8 * 3.25 * \frac{q}{2} + 342 * \frac{q}{2} + 13.5 * 2.5 * \frac{q}{2} + 13.5 * 5.0 * \frac{q}{2} + 13.5 * 7.5 * \frac{q}{2}$ $+ 13.5 * 5.0 * \frac{q}{2} + 13.5 * 2.5 * \frac{q}{2} + 20.8 * 3.25 q - 128 q$ $= 296.3q$ <p>Equating <math>W_i = W_e</math></p> $4M_p q = 296.3q$ $M_p = 74 \text{ kNm}$			
<h1>Structural Steel</h1>	Job No:	Sheet 27 of 30	Rev
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<b>Design Project</b>	Worked Example: <b>I</b>		
		Made By <b>PU</b>	Date
<b>Calculation Sheet</b>		Checked By <b>VK</b>	Date
<p>(iv) Plastic hinge is formed @ 5 and 7</p> <p>Internal Work Done, <math>W_i =</math></p> $= M_p \frac{\delta \bar{\theta}}{\frac{\delta}{2}} + M_p \frac{\delta \bar{\theta}}{\frac{\delta}{2}} + \delta \frac{\bar{\theta}}{\frac{\delta}{2}} + M_p (\delta + \delta) + M_p (\delta)$ <p><math>W_i = 5 M_p \delta</math></p> <div style="text-align: center;"> </div> <p>External Work done, <math>W_e =</math></p> $20.8 * 3.25 * \left(\frac{\delta}{2}\right) + 342 * \left(\frac{\delta}{2}\right) + 13.5 * 2.5 * \left(\frac{\delta}{2}\right) + 13.5 * 5.0 * \left(\frac{\delta}{2}\right) +$ $13.5 * 7.5 * \left(\frac{\delta}{2}\right) + 13.5 * 5.0 * \delta + 13.5 * 2.5 \delta + 20.8 * 3.25 * \delta - 128 \delta$ <p><math>W_e = 346.9 \delta</math></p>			
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<b>Calculation Sheet</b>		Checked By <b>VK</b>	Date
<p><i>Equating <math>W_i = W_e</math></i></p> <p><math>5M_p \mathbf{q} = 346.9 * \mathbf{q}</math></p> <p><math>M_p = 69.4 \text{ kNm}</math></p> <p><i>Design Plastic Moment = 116.1 kNm.</i></p> <p><b>5.0 DESIGN</b></p> <p><i>For the design it is assumed that the frame is adequately laterally braced so that it fails by forming mechanism. Both the column and rafter are analysed assuming equal plastic moment capacity. Other ratios may be adopted to arrive at an optimum design solution.</i></p> <p><b>5.1 Selection of section</b></p> <p><i>Plastic Moment capacity required= 116 kNm</i></p> <p><i>Required section modulus, <math>Z = M_p / f_{yd}</math></i></p> $= \frac{116 * 10^6}{\frac{250}{1.15}}$ $= 533.6 * 10^3 \text{ mm}^3$ <p><i>From IS: 800-1984 (Annexure F)</i></p> <p><i>ISMB 300 @ 0.46 kN/ m provides</i></p> <p><math>Z_p = 683 * 10^3 \text{ mm}^3</math></p> <p><math>b = 140 \text{ mm}</math></p> <p><math>T_i = 13.1 \text{ mm}</math></p> <p><math>A = 5.87 * 10^3 \text{ mm}^2</math></p> <p><math>t_w = 7.7 \text{ mm}</math></p> <p><math>r_{xx} = 124 \text{ mm}</math></p> <p><math>r_{yy} = 28.6 \text{ mm}</math></p>			
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<b>Design Project</b>	Worked Example: <i>I</i>		
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<b>Calculation Sheet</b>		Checked By <i>VK</i>	Date
	<p><b>5.2 Secondary Design Considerations</b></p> <p><b>5.2.1 Check for Local buckling of flanges and webs</b></p> <p><b><u>Flanges</u></b></p> $\frac{b_f}{T_1} = \frac{136}{\sqrt{f_y}}$ $b_f = 140/2 = 70 \text{ mm}$ $T_1 = 13.1 \text{ mm}$ $t = 7.7 \text{ mm}$ $\frac{b_f}{T_1} = \frac{70}{13.1} = 5.34 < 8.6$ <p><b><u>Web</u></b></p> $\frac{d_l}{t} \leq \left[ \frac{1120}{\sqrt{f_y}} - \frac{1600}{\sqrt{f_y}} \left( \frac{P}{P_y} \right) \right]$ $\frac{300}{7.7} \leq \left[ \frac{1120}{\sqrt{250_y}} - \frac{1600}{\sqrt{250_y}} (0.27) \right]$ $38.9 \leq 68, \text{Hence O.K}$ <p><b>5.2.2 Effect of axial force</b></p> <p>Maximum axial force in column, <math>P = 40.5 \text{ kN}</math></p>		
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	Worked Example: <i>I</i>		

<b>Design Project</b>		Made By	Date
		<i>PU</i>	
<b>Calculation Sheet</b>		Checked By	Date
		<i>VK</i>	
<p><i>Axial load causing yielding, <math>P_y = f_{yd} * A</math></i></p> $= \frac{250}{1.15} = 5.87 * 10^3$ $= 1276 \text{ kN}$ <p><math>\frac{P}{P_y} = \frac{40.5}{1276} = 0.03 &lt; 0.15</math></p> <p><i>Therefore the effect of axial force can be neglected.</i></p> <p><b>5.2.3 Check for the effect of shear force</b></p> <p><i>Shear force at the end of the girder = <math>P - w/2</math></i></p> $= 40.5 - 6.8 \text{ kN}$ $= 33.7 \text{ kN}$ <p><i>Maximum shear capacity <math>V_{ym}</math>, of a beam under shear and moment is given by</i></p> $V_{ym} = 0.55 A_w * f_{yd} / 1.15$ $= 0.55 * 300 * 7.7 * 250 / 1.15$ $= 276.2 \text{ kN} \gg 33.7 \text{ kN}$ <p><i>Hence O.K.</i></p>			