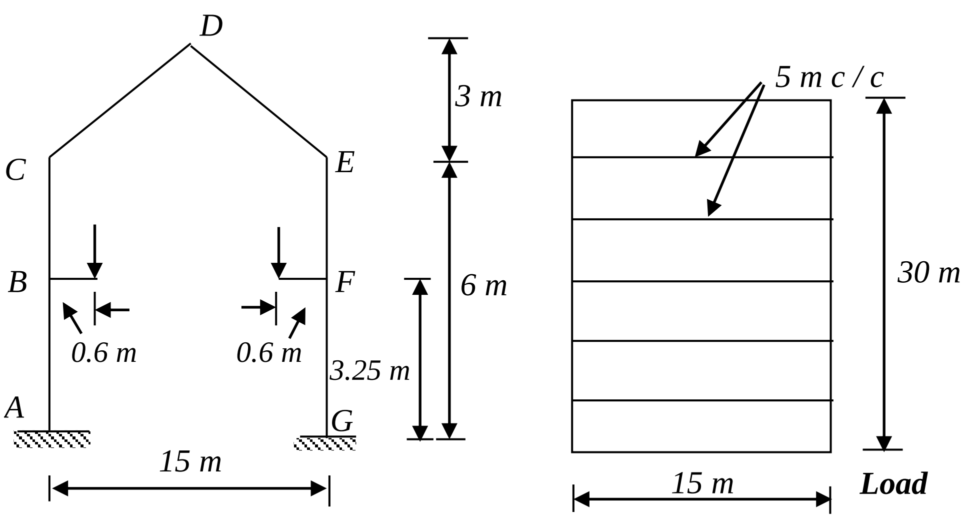
Structural Steel Design Project	Job No:	Sheet ***1** of **30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

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*^{2}
Fixings	=	*0.025 kN/m*^{2}
Services	=	*0.100 kN/m*^{2}
Weight of purlin	=	*0.100 kN/m*^{2}

Total load /m^2	=	*0.395 kN/m*^{2}

Structural Steel Design Project	Job No:	Sheet *2 of 30*	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Dead load/m run = *0.395 * 5*
= *1.975 kN / m*
$\approx$ *2.0 kN/m*

1.2 Live Load

Angle of rafter = tan^{-1} (3/7.5) = 21.8^0

From IS: 875 (part 2) – 1987; Table 2 (cl 4.1),

$$\textbf{Live load / m run} = \{0.75 - 0.02\ (21.8 - 10)\} * 5$$

= *2.57 kN/m*

1.3 Crane Loading

Overhead electric crane capacity = *300 kN*

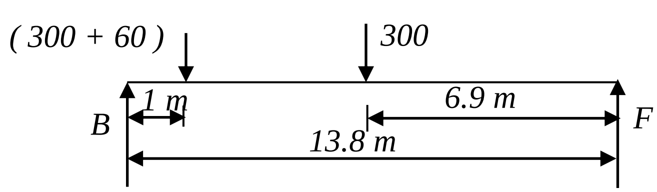
Approximate weight of crane girder = *300 kN*

Weight of crab = *60 kN*

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

1.3.1 Vertical load

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.



$M_B = 0$

<table>
<tr><td rowspan="4">Structural Steel Design Project

Calculation Sheet</td><td>Job No:</td><td>Sheet 3 of 30</td><td colspan="2">Rev</td></tr>
<tr><td colspan="4">Job Title: Portal Frame Analysis and Design</td></tr>
<tr><td colspan="4">Worked Example: 1</td></tr>
<tr><td></td><td colspan="2">Made By PU
Checked By VK</td><td>Date
Date</td></tr>
</table>

$2\,R_F\,(13.8) = (300 + 60) * 1 + 300 * (6.90)$

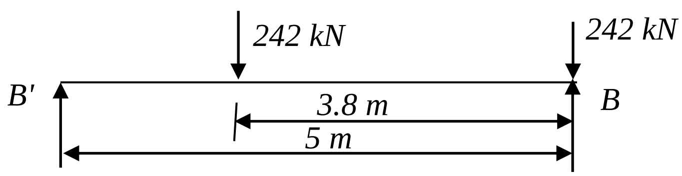
$R_F = 88$ kN

$M_F = 0$

$2\,R_B\,(13.8) = (300 + 60) * (13.8-1) + 300 * (6.9)$

$R_B = 242$ kN

To get maximum wheel load on a frame from gantry girder BB', taking the gantry girder as simply supported.



Centre to centre distance between frames is 5 m c/c.
Assuming impact @ 25%

Maximum wheel Load @ B $= 1.25\,(242\,(1 + (5-3.8)/5)$
$= 375$ kN.

Minimum wheel Load @ B $= (88/242)*375$
$= 136.4$ kN

1.3.2 Transverse Load:

Lateral load per wheel $= 5\%\ (300 + 60)/2 = 9$ kN

(i.e. Lateral load is assumed as 5% of the lifted load and the weight of the trolley acting on each rail).

Lateral load on each column $= \frac{9}{242} * 375 = 13.9$ kN

(By proportion)

<table>
<tr><td rowspan="5">Structural Steel Design Project

Calculation Sheet</td><td>Job No:</td><td>Sheet 4 of 30</td><td>Rev</td></tr>
<tr><td colspan="3">Job Title: Portal Frame Analysis and Design</td></tr>
<tr><td colspan="3">Worked Example: 1</td></tr>
<tr><td rowspan="2"></td><td>Made By PU</td><td>Date</td></tr>
<tr><td>Checked By VK</td><td>Date</td></tr>
</table>

1.4 Wind Load

Design wind speed, $V_z = k_1\, k_2\, k_3\, V_b$

From Table 1; IS: 875 (part 3) – 1987

$k_1 = 1.0$ *(risk coefficient assuming 50 years of design life)*

From Table 2; IS: 875 (part 3) – 1987

$k_2 = 0.8$ *(assuming terrain category 4)*

$k_3 = 1.0$ *(topography factor)*

Assuming the building is situated in Chennai, the basic wind speed is 50 m /sec

Design wind speed,

$$V_z = k_1\, k_2\, k_3\, V_b$$
$$V_z = 1 * 0.8 * 1 * 50$$
$$V_z = 40 \text{ m/sec}$$

Basic design wind pressure,

$$P_d = 0.6 * V_z^2$$
$$= 0.6 * (40)^2$$
$$= 0.96 \text{ kN/m}^2$$

1.4.1. Wind Load on individual surfaces

The wind load, W_L *acting normal to the individual surfaces is given by*

$$W_L = (C_{pe} - C_{pi})\, A * P_d$$

(a) Internal pressure coefficient

Assuming buildings with low degree of permeability

$$C_{pi} = \pm 0.2$$

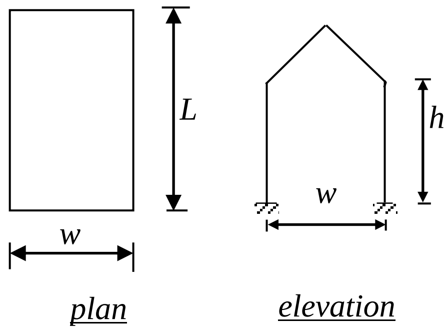
Structural Steel Design Project	Job No:	Sheet ***5 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

(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
$A = 5 * 6 = 30\ m^2$

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

Table 1 (a): Total wind load for wall

Wind Angle θ	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

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

Calculation Sheet		Checked By **VK**	Date

For roof, Ap_d *= 38.7 kN*

Table 1 (b): Total wind load for roof

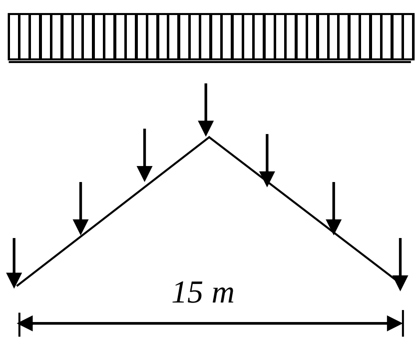
Wind angle	Pressure Coefficient			$C_{pe} - C_{pi}$		Total Wind Load(kN) $(C_{pe} - C_{pi}) Ap_d$	
	C_{pe} Wind	C_{pe} Lee	C_{pi}	Wind ward	Lee ward	Wind ward Int.	Lee ward Int.
0^0	-0.328	-0.4	0.2	-0.528	-0.6	-20.4	-23.2
	-0.328	-0.4	-0.2	-0.128	-0.2	-4.8	-7.8
90^0	-0.7	-0.7	0.2	-0.9	-0.9	-34.8	-34.8
	-0.7	-0.7	-0.2	-0.5	-0.5	-19.4	-19.4

2.0 Equivalent Load Calculation

2.1 Dead Load

Dead Load = 2.0 kN/m

Replacing the distributed dead load on rafter by equivalent concentrated loads at two intermediate points on each rafter,



$$W_D = \frac{2.0*15}{6} = 5kN$$

2.2 Superimposed Load

Superimposed Load = 2.57 kN/m

$$\text{Concentrated load},\ W_L = \frac{2.57*15}{6} = 6.4\,kN/\,purlin$$

Structural Steel Design Project	Job No:	Sheet ***7*** *of* ***30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		

Calculation Sheet		Made By *PU*	Date
		Checked By *VK*	Date

2.3 Crane Load

Maximum Vertical Load on columns = 375 kN (acting at an eccentricity of 600 mm from column centreline)

*Moment on column = 375 *0.6 = 225 kNm.*

Minimum Vertical Load on Column = 136.4 kN (acting at an eccentricity of 600 mm)

*Maximum moment = 136.4 * 0.6 = 82 kNm*

3.0 Partial Safety Factors

3.1 Load Factors

For dead load, γ_f *= 1.35*
For major live load, γ_f *= 1.5*
For minor live load, γ_f *= 1.05*

3.2 Material Safety factor

γ_m *= 1.15*

4.0 Analysis

In this example, the following load combinations are considered, as they are found to be critical.

Similar steps can be followed for plastic analysis under other load combinations.

(i) 1.35D.L + 1.5 C .L + 1.05 W.L

Structural Steel	Job No:	Sheet ***8 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		

Design Project		Made By *PU*	Date
Calculation Sheet		Checked By *VK*	Date

(ii) $1.35\ D.L + 1.5\ C.L + 1.05\ L.L$

4.1. $1.35\ D.L + 1.5\ C.L + 1.05\ W.L$

4.1.1Dead Load and Wind Load

(a) Vertical Load

w @ intermediate points on windward side

$w = 1.35 * 5.0 - 1.05 *(4.8/3) \cos 21.8$

$= 5.2\ kN.$

$$\frac{w}{2} @\ eaves = \frac{5.2}{2} = 2.6\ kN$$

w @ intermediate points on leeward side

$w = 1.35 * 5.0 - 1.05 * 7.8/3 \cos 21.8$
$= 4.2\ kN$

$$\frac{w}{2} @\ eaves = \frac{4.2}{2} = 2.1\ kN$$

Total vertical load @ the ridge = 2.6 + 2.1 = 4.7 kN

b) Horizontal Load

H @ intermediate points on windward side

$H = 1.05 * 4.8/3 \sin 21.8$

$= 0.62\ kN$

Structural Steel	Job No:	Sheet ***9 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

H/2 @ eaves points = 0.62/2 = 0.31 kN

H @ intermediate purlin points on leeward side
*= 1.05 * 7.8 /3 sin 21.8*
= 1 kN
H/2 @ eaves = 0.5 kN

Total horizontal load @ the ridge = 0.5 - 0.31 = 0.19 kN

Table 3: Loads acting on rafter points

	Vertical Load (kN)		*Horizontal Load (kN)*	
	Windward	*Leeward*	*Windward*	*Leeward*
Intermediate Points	*5.2*	*4.2*	*0.62*	*1.0*
Eaves	*2.6*	*2.1*	*0.31*	*0.5*
Ridge	*4.7*		*0.19*	

4.1.2 Crane Loading

*Moment @ B = 1.5 * 225 = 337.5 kNm*
*Moment @ F = 1.5 * 82 = 123 kNm*
*Horizontal load @ B & @ F = 1.5 * 13.9 = 20.8 kN*

Note: To find the total moment @ B and F we have to consider the moment due to the dead load from the weight of the rail and the gantry girder. Let us assume the weight of rail as 0.3 kN/m and weight of gantry girder as 2.0 kN/m

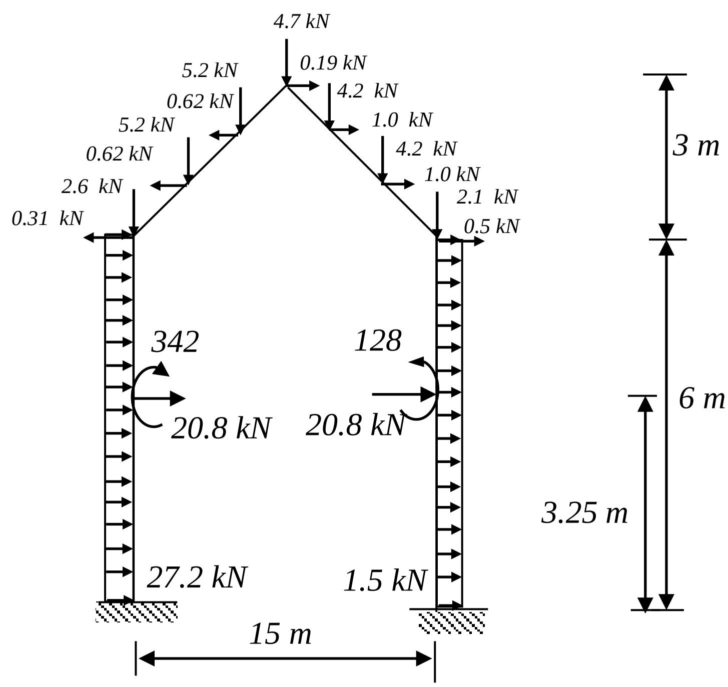
Dead load on the column $= \left(\frac{2+0.3}{2}\right) * 5 = 5.75\,kN$

*Factored moment @ B & F = 1.35 * 5.75 * 0.6 = 4.6 kNm*

Structural Steel	Job No:	Sheet ***10 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

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 ≈ 6.8 kN.

Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

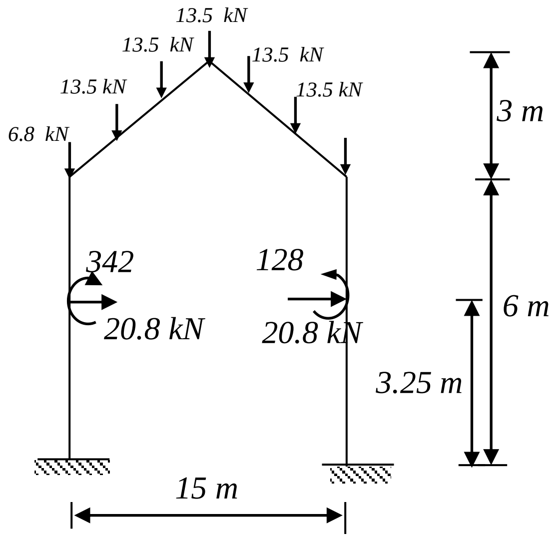
4.2.2 Crane Load

Moment @ B = 342 kNm

Horizontal load @ B = 20.8 kN

Moment @ F = 128 kNm

Horizontal load @ F = 20.8 kN



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

4.3 Mechanisms

We will consider the following mechanisms, namely

(i) Beam mechanism
(ii) Sway mechanism
(iii) Gable mechanism and
(iv) *Combined mechanism*

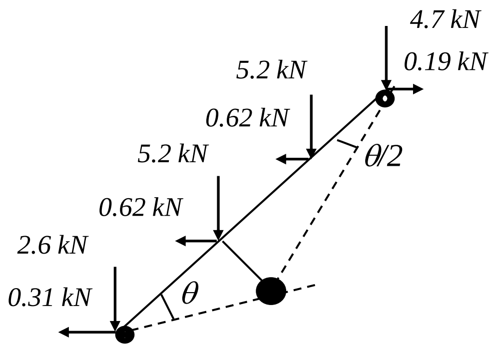
Structural Steel	Job No:	Sheet ***12 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

4.3.1 Beam Mechanism

(1) Member CD

Case 1: 1.35 D.L + 1.5 C.L + 1.05 W.L



Internal Work done, Wi $= M_p\theta + M_p(\theta/2) + M_p(\theta + \theta/2)$
$= M_p(3\theta)$

External Work done, $W_e = 5.2 * 2.5\theta - 0.62 * 1 * \theta + 5.2 * 2.5 * \theta/2 - 0.62 * 1 * \theta/2$
$= 18.6\theta$

Equating internal work done to external work done

$W_i = W_e$
$M_p(3\theta) = 18.6\theta$

$M_p = 6.2$ *kNm*

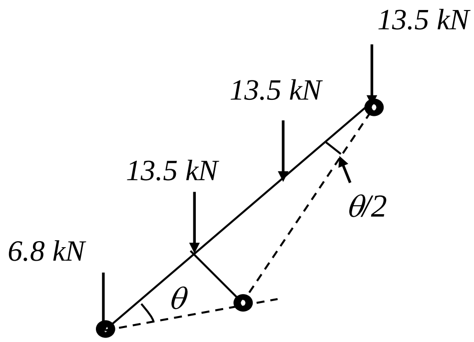
Case 2: 1.35 D.L + 1.5 C.L + 1.05 W.L

Internal Work done, $W_i = M_p(\theta + \theta/2 + \theta + \theta/2)$

$W_i = M_p 3\theta$

Structural Steel	Job No:	Sheet ***13 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date



External work done, $W_e = 13.5 * 2.5\ \theta + 13.5 * 2.5\theta/2$
$= 50.6\theta$

Equating $W_i = W_e$,

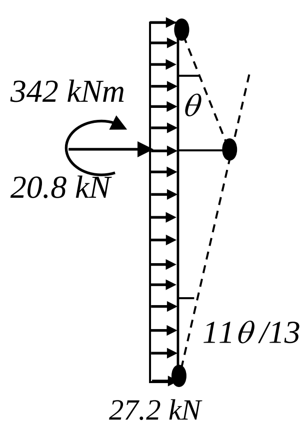
$$M_p\,(3\theta) = 50.6\ \theta$$

$$M_p = 16.9\ kNm$$

Note: Member DE beam mechanism will not govern.

(2) Member AC

Internal Work done,



$$\boldsymbol{W_i = M_p\theta + M_p\left(\theta + \frac{11}{13}\theta\right) + M_p\left(\frac{11}{13}\theta\right)}$$

$$\boldsymbol{= 3.69\ M_p\theta}$$

Structural Steel	Job No:	Sheet ***14 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project Calculation Sheet	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

External Work done,

$$W_e = 20.8*3.25*\frac{11}{13}\theta + 342*\frac{11}{13}\theta + \frac{1}{2}*27.2*3.25\left(\frac{11}{13}\theta\right)$$

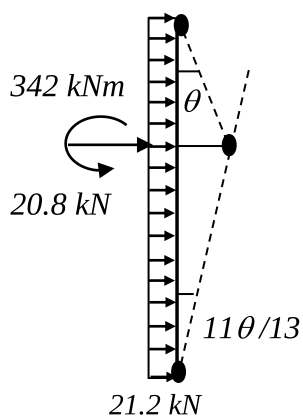
$$= 383.9\theta$$

Equating $W_i = W_e$*, we get*

$$3.69\,M_p\theta = 383.9\,\theta$$

$$M_p = 104.1 \text{ kNm.}$$

(3) Member EG



Internal Work done,

$$W_i = M_p\theta + M_p\left(\theta + \frac{11}{13}\theta\right) + M_p\left(\frac{11}{13}\theta\right)$$

$$= 3.69\,M_p\theta$$

External Work done,

$$W_e = 20.8*3.25*\frac{11}{13}\theta + 342*\theta + \frac{1}{2}(21.2)*3.25\left(\frac{11}{13}\theta\right)$$

$$= 428.3\theta$$

Equating $W_i = W_e$*, we get*

$$3.69\,M_p\theta = 428.3\theta$$

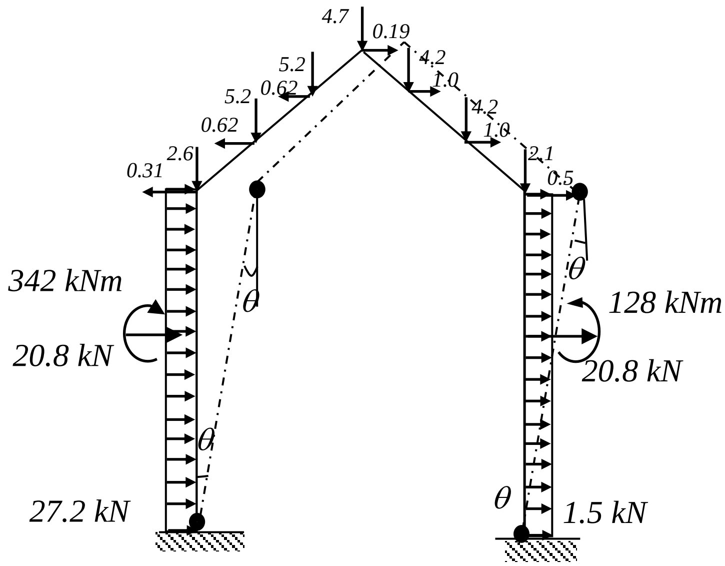
Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

$M_p = 116.1\ kNm$

For members AC & EG, the 1st load combination will govern the failure mechanism.

4.3.2 Panel Mechanism

Case 1: 1.35 D.L + 1.5 C.L + 1.05 W.L



Internal Work done, $W_i = M_p(\theta) + M_p(\theta) + M_p(\theta) + M_p(\theta)$

$= 4M_p\theta$

External Work done, W_e

$W_e = 1/2\,(27.2) * 6\theta + 20.8 * 3.25\theta + 342\theta - 0.31 * 6\theta - 0.62 * 6\theta - 0.62\,(6\theta) + 0.19 * 6\theta + 1.0 * 6\theta + 1.0 * 6\theta + 0.5 * 6\theta + 1/2\,(1.5) * 6\theta + 20.8 * 3.25\theta - 128 * \theta$

$= 442.14\theta$

Structural Steel	Job No:	Sheet ***16 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Equating $W_i = W_c$, we get

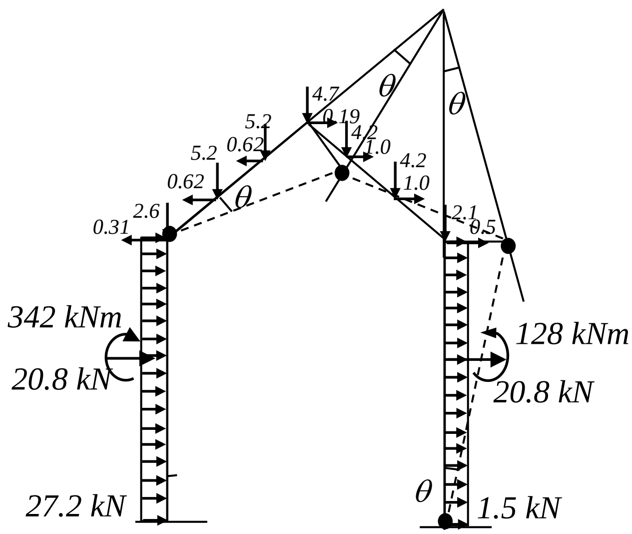
$4M_p\theta = 442.14\theta$

$M_p = 110.5$ *kNm*

The second load combination will not govern.

4.3.3 Gable Mechanism

Case 1: 1.35 D.L + 1.05 W.L + 1.5 C.L



Internal Work done $= M_p\theta + M_p2\theta + M_p(2\theta) + M_p\theta = 6M_p\theta$

External Work done, $W_e =$

$-0.62 * 1 * \theta - 0.62 * 2 * \theta + 0.19 * 3 * \theta + 1.0 * 4 * \theta + 1.0 * 5 * \theta + 0.5 * 6 * \theta + 5.2 * 2.5 * \theta + 5.2 * 5 * \theta + 4.7 * 7.5 * \theta + 4.2 * 5 * \theta + 4.2 * 2.5 * \theta + ½ * 1.5 * 6\theta + 20.8 * 3.25 * \theta - 128*\theta$

$W_e = 60.56\theta$

Structural Steel	Job No:	Sheet ***17 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

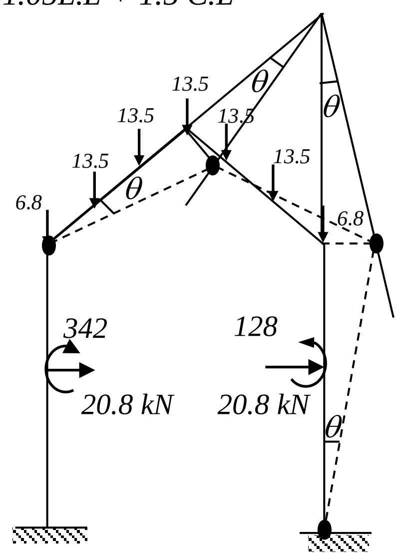
Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Equating $W_i = W_e$*, we get*

$6M_p = 60.56\theta$

$M_p = 10.1$ *kNm.*

Case 2: 1.35 D.L + 1.05L.L + 1.5 C.L



Internal Work done, $W_i = M_p\theta + M_p(2\theta) + M_p(2\theta) + M_p\theta = 6M_p\theta$

External Work done, W_e

$= 13.5 * 2.5*\theta + 13.5 * 5 * \theta + 13.5 * 7.5\theta + 13.5 * 5 * \theta + 13.5 * 2.5\theta - 128 * \theta + 20.8 * 3.25\theta$

$= 243.4\theta$

Equating $W_i = W_e$*, we get*

$6M_p\theta = 243.4\theta$

$M_p = 40.6$ *kNm*

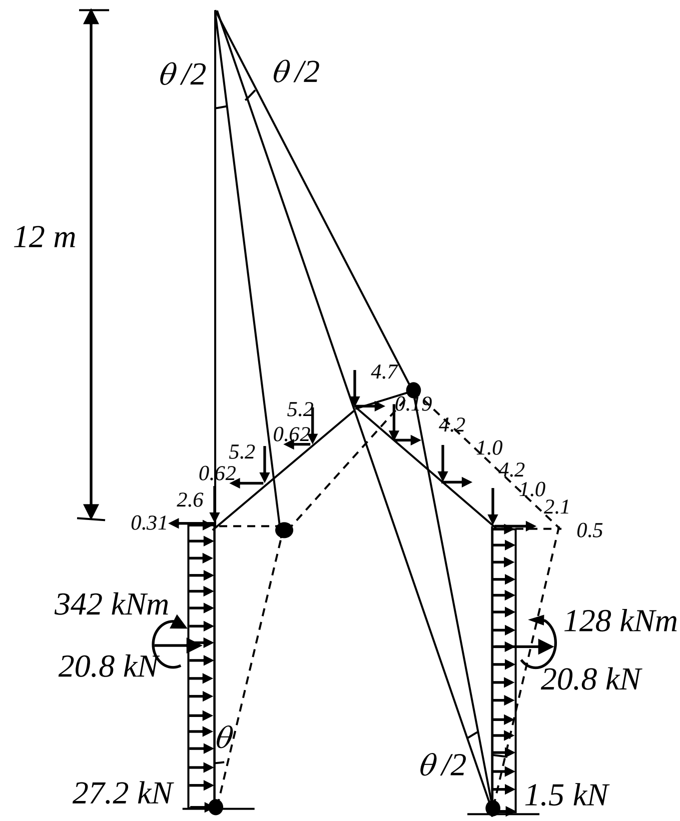
Structural Steel	Job No:	Sheet ***18 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

4.3.4 Combined Mechanism

Case1: 1.35 D.L + 1.05 W.L + 1.5 C.L

(i)



Internal Work done, $W_i = M_p\,(\theta) + M_p\,(\theta + \theta/2) + M_p\,(\theta/2 + \theta/2) + M_p\,(\theta/2)$

$= M_p\,(\theta + \theta + \theta/2 + \theta/2 + \theta/2 + \theta/2 + \theta/2)$

$= 4\,M_p\theta$

External Work done, $W_e =$

$1/2 * 27.2 * 6\theta + 20.8 * 3.25 * \theta + 342\theta - 0.31 * 12 * \theta/2 - 0.62 * 11 * \theta/2 - 0.62 * 10 * \theta/2 + 0.19 * 9 * \theta/2 + 1.0 * 8 * \theta/2 + 1.0 * 7 * \theta/2 + 0.5 * 6 * \theta/2 + 1/2\ (1.5) * 6\theta/2 + 20.8 * 3.25 * \theta/2 - 128 * \theta/2 - 5.2 * 2.5 * \theta/2 - 5.2 * 5.0 * \theta/2 - 4.7 * 7.5 * \theta/2 - 4.2 * 5 * \theta/2 - 4.2 * 2.5 * \theta/2$

$= 411.86\theta$

Structural Steel	Job No:	Sheet ***19 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

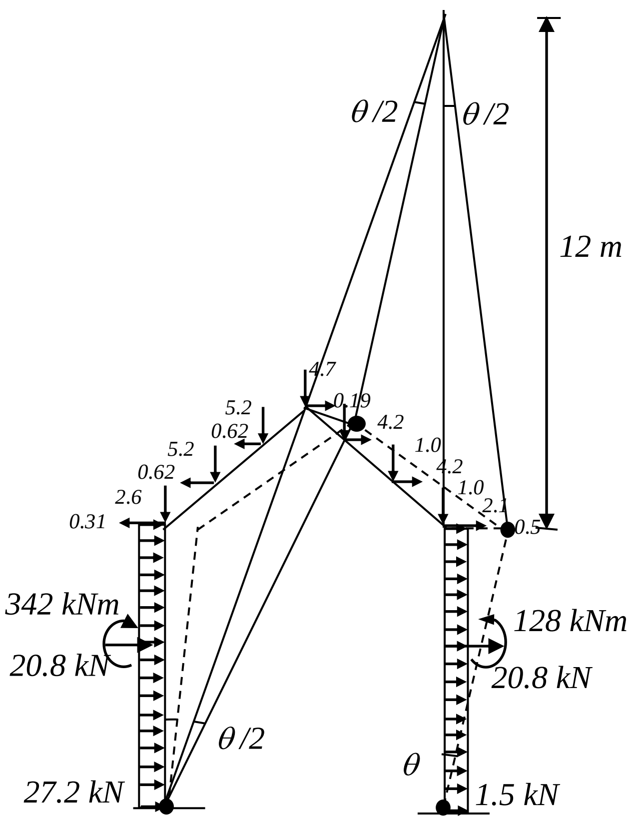
Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Equating $W_i = W_e$

$4M_p\theta = 411.86\theta$

$M_p = 102.9$ *kNm*

(ii) Internal work done, $W_i = M_p\,\theta/2 + M_p(\theta/2 + \theta/2) + M_p(\theta/2 + \theta)$
$+M_p\theta$
$W_i = 4M_p\theta$



Structural Steel	Job No:	Sheet ***20 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

# Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

External Work done,

$$W_e = 20.8*3.25*\frac{\theta}{2} + 342*\frac{\theta}{2}+ \frac{1}{2} * 27.2*6\left(\frac{\theta}{2}\right) - 0.31*6*\frac{\theta}{2} - 0.62*7*\frac{\theta}{2}$$

$$-0.62*8*\frac{\theta}{2}+0.19*9*\frac{\theta}{2}+5.2*2.5*\frac{\theta}{2}+5.2*5.0*\frac{\theta}{2}+4.7*7.5*\frac{\theta}{2}+1.0*10*\frac{\theta}{2}$$

$$+1.0*11*\frac{\theta}{2}+0.5*12*\frac{\theta}{2}+4.2*5.0*\frac{\theta}{2}+4.2*2.5*\frac{\theta}{2}+20.8*3.25\theta-128*\theta$$

$$+\frac{1}{2}*1.5*6\theta$$

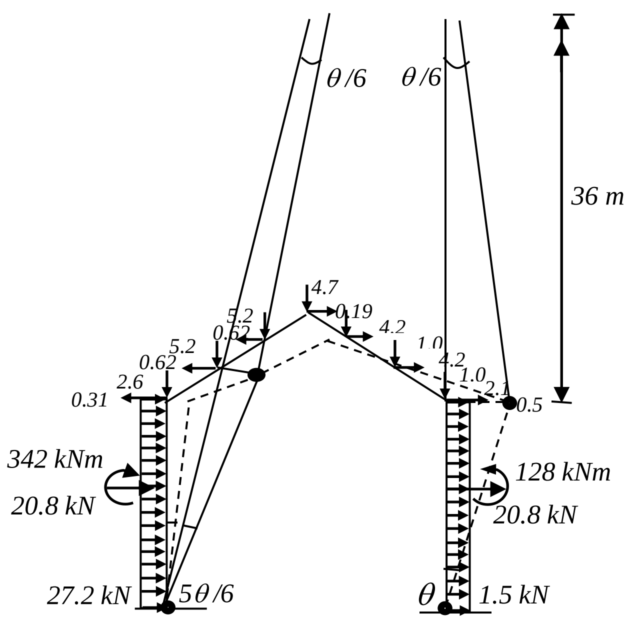
$= 251.35\theta$

Equating $W_i = W_e$*, we get*

$4M_p\theta = 251.35\theta$

$M_p = 62.84$ *kNm*

(iii)



# Structural Steel	Job No:	Sheet ***21 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Internal work done, W_i

$$= M_p\left(\frac{5\theta}{6}\right)+M_p\left(\frac{\theta}{6}+\frac{5\theta}{6}\right)+M_p\left(\frac{\theta}{6}+\theta\right)+M_p(\theta)$$

$$= 4M_p\theta$$

External Work done, W_e =

$$20.8*3.25*\left(\frac{5\theta}{6}\right)+342*\frac{5\theta}{6}+\frac{1}{2}*27.2*6*\frac{5\theta}{6}-0.31*6*\frac{5\theta}{6}-0.62*35*\frac{\theta}{6}$$
$$-0.62*34*\frac{\theta}{6}+0.19*33*\frac{\theta}{6}+1.0*34*\frac{\theta}{6}+1.0*35*\frac{\theta}{6}+0.5*36*\frac{\theta}{6}$$
$$+5.2*12.5*\frac{\theta}{6}+5.2*10*\frac{\theta}{6}+4.7*7.5*\frac{\theta}{6}+4.2*5.0*\frac{\theta}{6}+4.2*2.5*\frac{\theta}{6}$$
$$+20.8*3.25*\theta-128*\theta+\frac{1}{2}(1.5)(6*\theta)$$

$W_e = 390.92\theta$

Equating $W_i = W_e$, we get

$4M_p\theta = 390.92\theta$

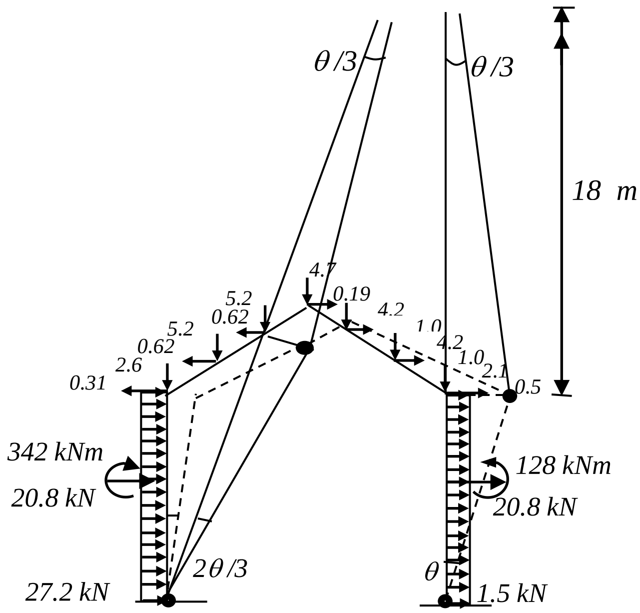
$M_p = 97.7$ kNm

(iv) Internal Work done,

$$W_i = M_p\left(\frac{2}{3}\theta\right)+M_p\left(\frac{2}{3}\theta+\frac{\theta}{3}\right)+M_p\left(\frac{\theta}{3}+\theta\right)+M_p(\theta)$$
$$= 4M_p\theta$$

Structural Steel	Job No:	Sheet ***22 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date



External Work done, W_e =

$$20.8*3.25*\left(\frac{2}{3}\theta\right)+342*\frac{2}{3}\theta+\frac{1}{2}*27.2*6*\left(\frac{2}{3}\theta\right)-0.31*6*\left(\frac{2}{3}\theta\right)$$

$$-0.62*7*\left(\frac{2}{3}\theta\right)-0.62*16*\frac{\theta}{3}+0.19*15*\frac{\theta}{3}+5.2*2.5*\frac{2}{3}\theta+5.2*5*\frac{2}{3}\theta$$

$$+4.7*7.5*\frac{\theta}{3}+0.19*15*\frac{\theta}{3}+1.0*16*\frac{\theta}{3}+1.0*17*\frac{\theta}{3}+0.5*18*\frac{\theta}{3}+4.2*5.0*\frac{\theta}{3}$$

$$+4.2*2.5\left(\frac{\theta}{3}\right)+20.8*3.25*\theta-128*\theta+\frac{1}{2}(1.5)*6\theta$$

$$W_e = 328.3\theta$$

Equating $W_i = W_e$*, we get*

$$4M_p\theta = 328.3\theta$$

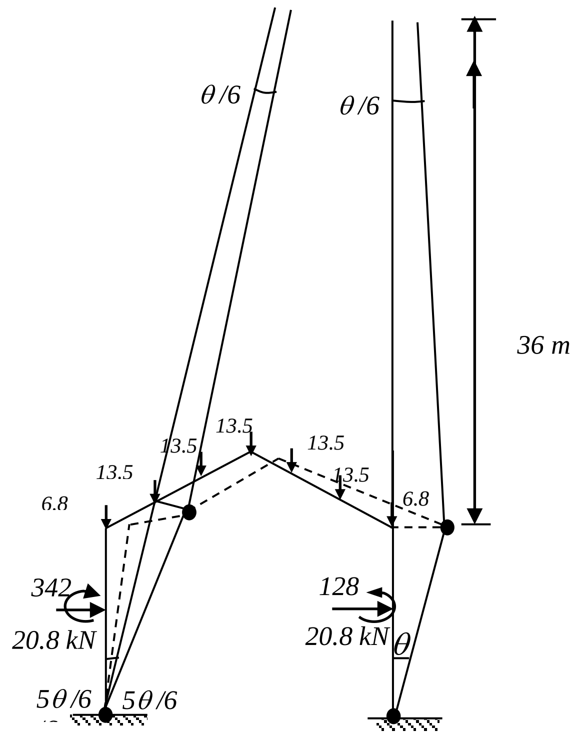
M_p = 82.1 kNm

Structural Steel	Job No:	Sheet ***23 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Case 2: 1.35 D.L + 1.05 L.L + 1.5 C.L

(i) Assuming plastic hinge is formed @ purlin point 2 and 7 and at fixed supports.



$$\text{Internal Work done} = M_p\left(\frac{5\theta}{6}\right) + M_p\left(\frac{5\theta}{6} + \frac{\theta}{6}\right) + M_p\left(\frac{\theta}{6} + \theta\right) + M_p\theta$$

$$= 4M_p\theta$$

Structural Steel	Job No:	Sheet ***24 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

External Work done = W_e

$$20.8*3.25*\left(\frac{5\theta}{6}\right) + 342*\left(\frac{5\theta}{6}\right) + 13.5*12.5*\left(\frac{\theta}{6}\right) + 13.5*10*\left(\frac{\theta}{6}\right) +$$

$$13.5*7.5*\left(\frac{\theta}{6}\right) + 13.5*5.0*\frac{\theta}{6} + 13.5*2.5*\frac{\theta}{6} + 20.8*3.25*\theta - 128\theta$$

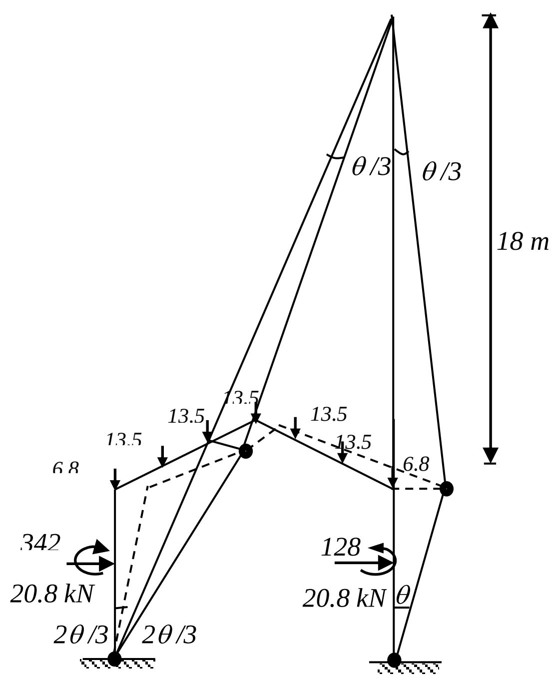
$$= 365.3\theta$$

Equating $W_i = W_e$*, we get*

$4M_p\theta = 365.3\theta$

$M_p = 91.3\ kNm$

(ii) Plastic hinge is formed @ 3 and 7



Structural Steel	Job No:	Sheet ***25 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

Internal work done,

$$W_i = M_p\left(\frac{2}{3}\theta\right) + M_p\left(\frac{2}{3}\theta + \frac{\theta}{3}\right) + M_p\left(\frac{\theta}{3} + \theta\right) + M_p(\theta)$$

$$= 4M_p\theta$$

External Work done, W_e=

$$20.8*3.25*\left(\frac{2}{3}\theta\right) + 342*\frac{2}{3}\theta + 13.5*2.5*\frac{2}{3}\theta + 13.5*5.0*\frac{2}{3}\theta + 13.5*7.5*\frac{\theta}{3} +$$

$$13.5*5.0*\frac{\theta}{3} + 13.5*2.5*\frac{\theta}{3} + 20.8*3.25\theta - 128\theta$$

$$=347.7\theta$$

Equating $W_i = W_e$, we get

$4M_p\theta = 347.7\theta$

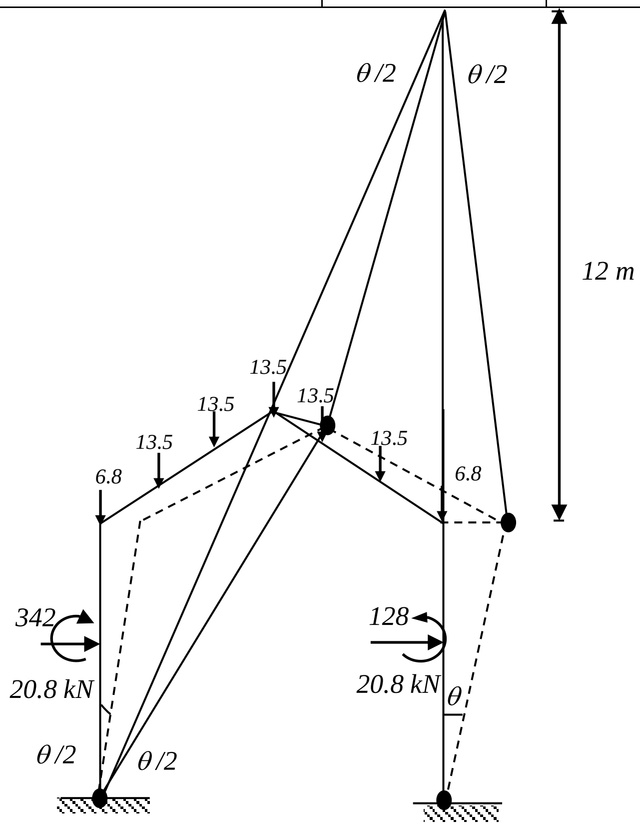
$M_p = 86.9$ *kNm*

(iii) Plastic hinged is formed at 4 and 7

Internal Work done $= \boldsymbol{M_p\left(\frac{\theta}{2}\right) + M_p\left(\frac{\theta}{2} + \frac{\theta}{2}\right) + M_p\left(\frac{\theta}{2} + \theta\right) + M_p\theta}$

$$= \boldsymbol{4M_p\theta}$$

Design Project **Calculation Sheet**	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date



External Work done, W_e =

$$20.8*3.25*\frac{\theta}{2}+342*\frac{\theta}{2}+13.5*2.5*\frac{\theta}{2}+13.5*5.0*\frac{\theta}{2}+13.5*7.5*\frac{\theta}{2}$$

$$+13.5*5.0*\frac{\theta}{2}+13.5*2.5*\frac{\theta}{2}+20.8*3.25\,\theta-128\,\theta$$

$$=296.3\theta$$

Equating $W_i = W_e$

$4M_p\theta = 296.3\theta$

$M_p = 74$ *kNm*

Structural Steel	Job No:	Sheet ***27 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

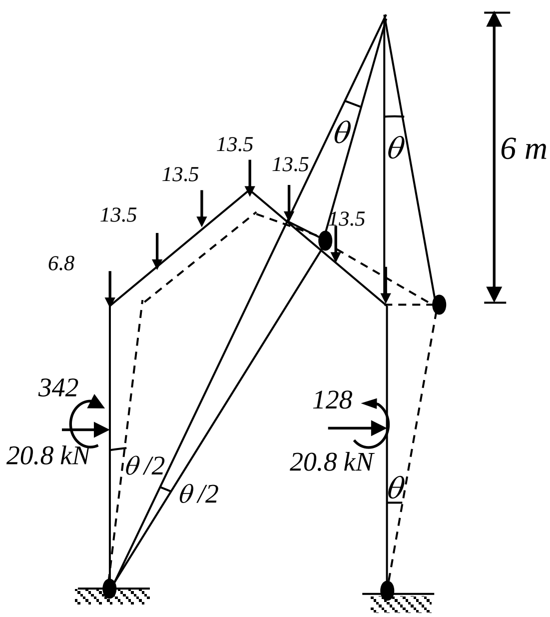
Design Project Calculation Sheet	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

(iv) Plastic hinge is formed @ 5 and 7

Internal Work Done, W_i =

$$= M_p\left(\frac{\theta}{2}\right) + M_p\left(\frac{\theta}{2} + \theta\right) + M_p(\theta + \theta) + M_p(\theta)$$

$$W_i = 5 M_p \theta$$



External Work done, W_e=

$$20.8*3.25*\left(\frac{\theta}{2}\right) + 342*\left(\frac{\theta}{2}\right) + 13.5*2.5*\left(\frac{\theta}{2}\right) + 13.5*5.0*\left(\frac{\theta}{2}\right) +$$

$$13.5*7.5*\left(\frac{\theta}{2}\right) + 13.5*5.0*\theta + 13.5*2.5\theta + 20.8*3.25*\theta - 128\theta$$

$$W_e = 346.9\theta$$

Design Project Calculation Sheet	Worked Example: ***1***		
		Made By ***PU***	Date
		Checked By ***VK***	Date

Equating $W_i = W_e$

$5M_p\theta = 346.9 * \theta$

$M_p = 69.4$ kNm

Design Plastic Moment = 116.1 kNm.

5.0 DESIGN

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.

5.1 Selection of section

Plastic Moment capacity required= 116 kNm

Required section modulus, $Z = M_p / f_{yd}$

$$= \frac{\left(116*10^6\right)}{250/1.15}$$

$$= 533.6 * 10^3 \text{ mm}^3$$

From IS: 800-1984 (Annexure F)

ISMB 300 @ 0.46 kN/ m provides

$Z_p = 683 * 10^{-3}$ mm^3
$b = 140$ mm
$T_i = 13.1$ mm
$A = 5.87 * 10^3$ mm^2
$t_w = 7.7$ mm
$r_{xx} = 124$ mm
$r_{yy} = 28.6$ mm

Structural Steel	Job No:	Sheet ***29 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		

Design Project	Worked Example: ***1***		
		Made By ***PU***	Date
Calculation Sheet		Checked By ***VK***	Date

5.2 Secondary Design Considerations

5.2.1 Check for Local buckling of flanges and webs

<u>Flanges</u>

$$\frac{b_f}{T_1} = \frac{136}{\sqrt{f_y}}$$

$b_f = 140/2 = 70\ mm$

$T_1 = 13.1\ mm$

$t = 7.7\ mm$

$$\frac{b_f}{T_1} = \frac{70}{13.1} = 5.34 < 8.6$$

<u>Web</u>

$$\frac{d_1}{t} \le \left[\frac{1120}{\sqrt{f_y}} - \frac{1600}{\sqrt{f_y}}\left(\frac{P}{P_y}\right)\right]$$

$$\frac{300}{7.7} \le \left[\frac{1120}{\sqrt{250_y}} - \frac{1600}{\sqrt{250_y}}(0.27)\right]$$

$38.9 \le 68, Hence\ O.K$

5.2.2 Effect of axial force

Maximum axial force in column, P = 40.5 kN

Structural Steel	Job No:	Sheet ***30 of 30***	Rev
	Job Title: ***Portal Frame Analysis and Design***		
	Worked Example: ***1***		

Design Project **Calculation Sheet**		Made By ***PU***	Date
		Checked By ***VK***	Date

Axial load causing yielding, $P_y = f_{yd} * A$

$$= \frac{250}{1.15} = 5.87*10^3$$
$$= 1276\,kN$$

$$\frac{P}{P_y} = \frac{40.5}{1276} = 0.03 < 0.15$$

Therefore the effect of axial force can be neglected.

5.2.3 Check for the effect of shear force

Shear force at the end of the girder = P- w/2
= 40.5 -6.8 kN
= 33.7 kN

Maximum shear capacity V_{ym}, of a beam under shear and moment is given by

$V_{ym} = 0.55\, A_w * f_{yd} / 1.15$

$= 0.55 * 300 * 7.7 * 250/1.15$
$= 276.2\ kN >> 33.7\ kN$

Hence O.K.