CIVIL ENVIRONMENTAL AND GEOMATIC ENGINEERING

UCL

MEng E&AD

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Mechanics of Buildings – Lab Test – Portals

Basic information for theoretical analysis:

1. The dimension of the portal is *0.3m x 0.2m,* as shown in Figure 1. The cross section has base equal to *12.7 mm* and height equal to *3.1mm*.

2. The yield stress is f_{yk} = 302 MPa.

3. The load ratios are H:V = 2:1, 1:2.5

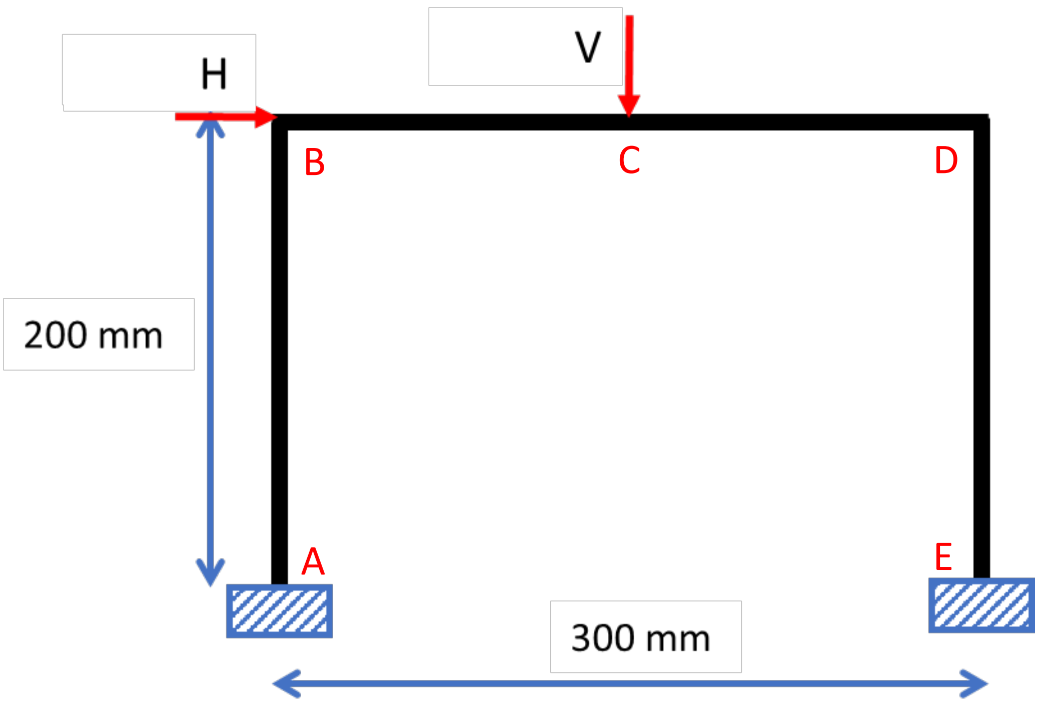

Figure 1 Portal Frame with Vertical and Horizontal Loads

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PRE – EXPERIMENT CALCULATIONS

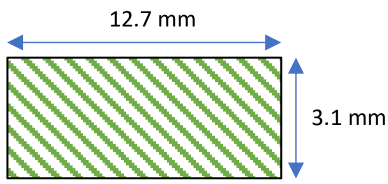

Figure 2 Cross-section of frame

1. We have the cross section of the portal frame with
   b = 12.7 mm
   h = 3.1 mm

   Plastic Section Modulus, Z_p

   $Z_p = bh^2/4$

   ⇨ $Z_p = 30.51\ mm^3 = 3.051 \times 10^{-8}\ m^3$

   We have been given Yielding Strength, $f_{yk} = 302\ MPa = 302 \times 10^6\ Pa$

   Plastic Moment, M_p

   $M_p = f_{yk\ .}\ (Z_p)$

   ⇨ $M_p = 9.21\ Nm$

2. L = 300 mm = 0.3 m , h = 200 mm = 0.2 m

   Case 1 : Beam Mechanism (Application of only vertical load)

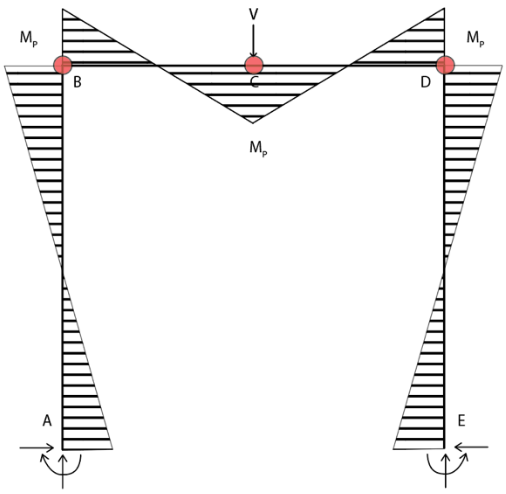

Figure 3 Moment Diagram - Beam Mechanism

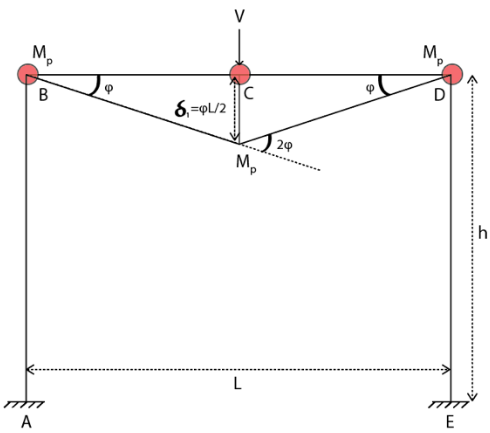

Figure 4 Deformation - Beam Mechanism

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Applying the virtual work principle

$W_e = W_i$

⇨ $\sum_i P_i \varphi_i = \sum_j M_{P_j} \varphi_j$

⇨ $\lambda_{BEAM}.(\frac{L}{2}\varphi.V) = \varphi M_p + 2\,\varphi M_p + \varphi M_p$

⇨ $\lambda_{BEAM} = 8\frac{M_p}{VL}$

⇨ λ_{BEAM} = 245.6/V

Case 2 : Sway Mechanism (Application of only horizontal load)

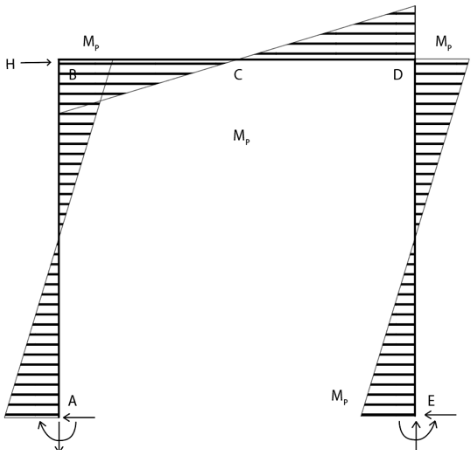

Figure 6 Moment Diagram - Sway Mechanism

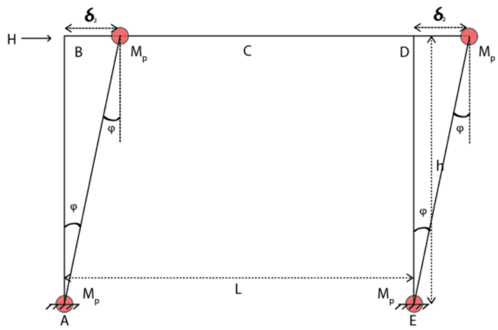

Figure 5 Deformation - Sway Mechanism

Applying the virtual work principle

$W_e = W_i$

⇨ $\sum_i P_i \varphi_i = \sum_j M_{P_j} \varphi_j$

⇨ $\lambda_{SWAY}.(h.\varphi.H) = 4.(\varphi M_p)$

⇨ $\lambda_{SWAY} = 4\frac{M_p}{Hh}$

⇨ λ_{SWAY} = 184.2/H

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Case 3 : Combined Mechanism (Application of both loads)

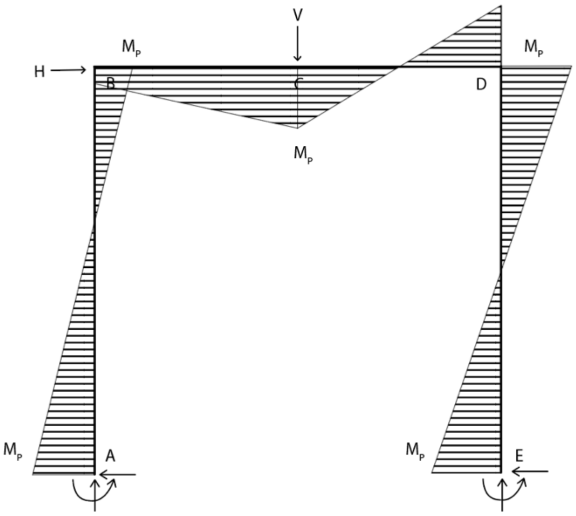

Figure 7 Moment Diagram - Combined Mechanism

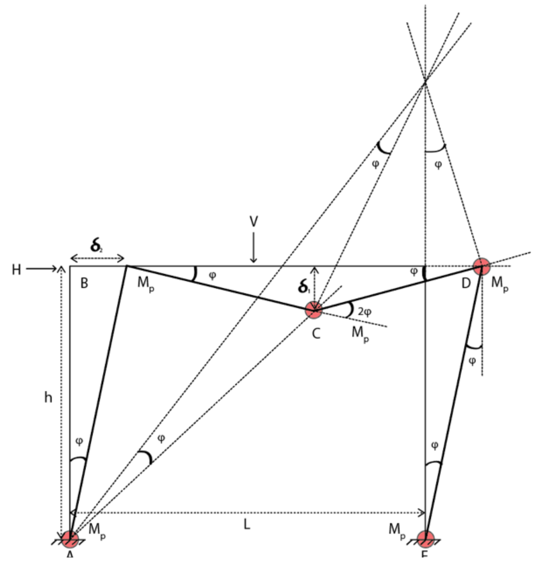

Figure 8 Deformation - Combined Mechanism

Calculating the deflections

$\delta_1 = L\frac{\varphi}{2}$, $\delta_2 = H\,\varphi$

Applying the virtual work principle

$W_e = W_i$

⇨ $\sum_i P_i \varphi_i = \sum_j M_{P_j} \varphi_j$

⇨ $\lambda_{COMBINED}.\left((h.\varphi.H) + \left(V.L.\frac{\varphi}{2}\right)\right) = \varphi M_p + 2\varphi M_p + 2\varphi M_p + \varphi M_p$

⇨ $\lambda_{COMBINED}.(H.h + V.\frac{L}{2}) = 6M_p$

⇨ $\lambda_{COMBINED}$.(0.2H + 0.15V) = 55.26

⇨ $\lambda_{COMBINED}$ = 55.26 / (0.2H + 0.15V)

3. Number of Plastic Hinges = 4

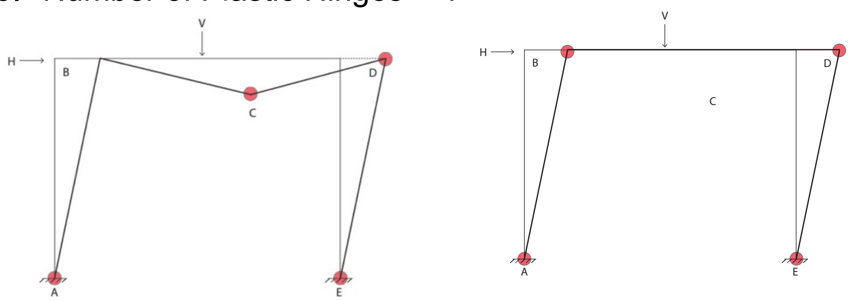

Figure 9 Location of Plastic Hinges (right) for V>H and (left) for H>V

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For H:V = 2:1, we consider H = 2V
For H:V = 1:2.5, we consider H = 0.4V

Load ratio	**λ**		
H:V	**BEAM**	**SWAY**	**COMBINED**
2:1	245.6 / V	92.1 / V	100.47 / V
1:2.5	245.6 / V	460.5 / V	240.26 / V

For the ratio 2:1 we have :
$\lambda_{SWAY} < \lambda_{COMBINED} < \lambda_{BEAM}$
⇨ The sway mechanism will develop.

For the ratio 1:2.5 we have :
$\lambda_{COMBINED} < \lambda_{BEAM} < \lambda_{SWAY}$
⇨ The combined mechanism will develop.

4. For Load Ratio 2:1

The mechanism that will develop is the sway mechanism

We have
$\lambda_{SWAY} = 92.1 / V$
⇨ $\lambda_{SWAY} . V = 92.1$ N
And,
⇨ $\lambda_{SWAY} . H = 184.2$ N

For Load Ratio 1:2.5

The mechanism that will develop is the combined mechanism

We have
$\lambda_{COMBINED} = 240.26 / V$
⇨ $\lambda_{COMBINED} . V = 240.26$ N
And,
⇨ $\lambda_{COMBINED} . H = 96.10$ N

EXPERIMENTAL DATA 1 : '2:1'

Table 1

PORTAL FRAME H:V = 2:1				
From the Wizard (*i.e.,* Theoretical results)				
Take values of the Horizontal and Vertical Loads and Displacements corresponding to the formation of the plastic hinges.	H (N)	V (N)	δ_H (mm)	δ_V (mm)
1st Hinge at E	137.47	68.73	11.2	2.6
2nd Hinge at A	158.13	79.07	14.2	3.3
3rd Hinge at D	163.12	81.56	16	3.4
4th Hinge at B	184.29	92.15	39.4	7.9
From Experiment (*i.e.,* Experimental results)				
Record the observed values of the Horizontal and Vertical Loads and Displacements	H (N)	V (N)	δ_H (mm)	δ_V (mm)
	0	0	0	0
	19.4	10.8	1.48	0.42
	39.7	19.6	3.5	0.63
	59.6	30	5.65	0.91
	79.1	40	6.83	1.35
	99.6	49.9	8.4	1.87
	119.1	59.6	9.66	2.57
	128.8	63	12.16	2.93
	139.1	70.5	12.77	3.22
	148.4	66.5	15.07	3.51
	144	79.3	18.59	5.02
	164.3	82	22.89	6.30
	170	87.1	28.31	8.09
	173.9	89.2	31.83	9.38
	177.3	98.4	34.63	10.68

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POST–EXPERIMENT ANALYSIS 1: ‘2:1’

1. Horizontal Load (H)
   Comparing theoretical and experimental values for ultimate load capacity

Theoretical Result $P_{H,T}$	Experimental Result $P_{H,E}$
184.29 N	177.3 N

   Vertical Load (V)
   Comparing theoretical and experimental values for ultimate load capacity

Theoretical Result $P_{V,T}$	Experimental Result $P_{V,E}$
92.15 N	98.4 N

2. The difference between the theoretical and experimental values are as follows.

   For Horizontal Load:
   $\Delta P_H = 6.99$ N where $P_{H,E} < P_{H,T}$

   For Vertical Load:
   $\Delta P_V = 6.25$ N where $P_{H,E} > P_{H,T}$

3. For horizontal load (H) we have:

Theoretical Displacement $\delta_{y,T}$	Experimental Displacement $\delta_{y,E}$
39.5 mm	34.63 mm

   For vertical load (V) we have:

Theoretical Displacement $\delta_{y,T}$	Experimental Displacement $\delta_{y,E}$
7.9 mm	10.68 mm

4. The frame reached full local plasticity but not full global plasticity. It can be said that the frame reached plasticity because the formation of four hinges was visually observed, which fulfils the criterion for local plasticity and hence, the hinge is considered to have reached plasticity. However, it can be argued that the hinge hasn’t reached global plasticity as in order for that to occur, there needs to be a deformation in the cross-section at every point of the frame which is practically not possible.

5. The formation of all four hinges can be seen visually. However, when the results of load-deformation are plotted onto a graph, the points of hinge formation cannot easily be identified. However, this could also be because the load increments taking while experimentation were too large, which caused us to miss the specific data-

point of hinge formation. Hence, it cannot be ascertained that all hinges were formed other than just from visual observation.

6. If the frame would not have reached full plasticity it could have been caused due too several reasons. One of these could have been a manufacturing defect in the material of the frame i.e., the material steel did not have the yielding strength f_{yk} that was assumed of the material initially. It could also be due to experimental errors such as faulty calibration and fixing of the supports.

7. According to the WIZARD simulation, hinges formed at the points E, A, D and B in this specified order. The order of formation of hinges during the experiment could not be clearly observed as due to the nature of the frames deformation it seemed as though they were forming around the same time. However, due to the theoretically assumed order, because of a pre-conceived bias the hinges were formed in the same order.

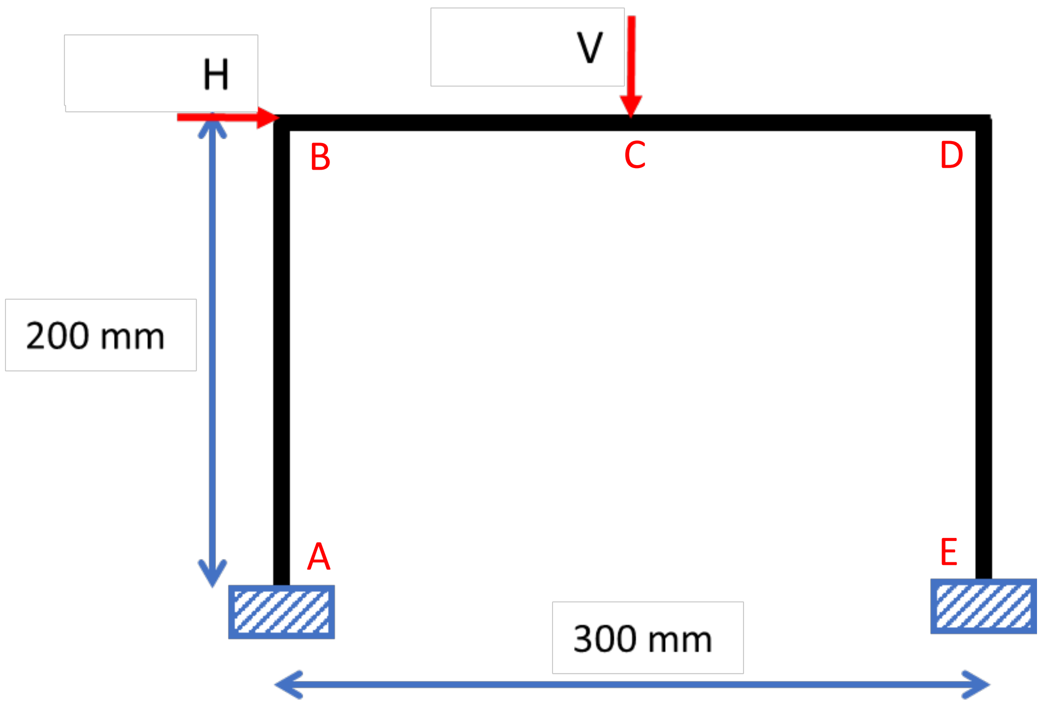
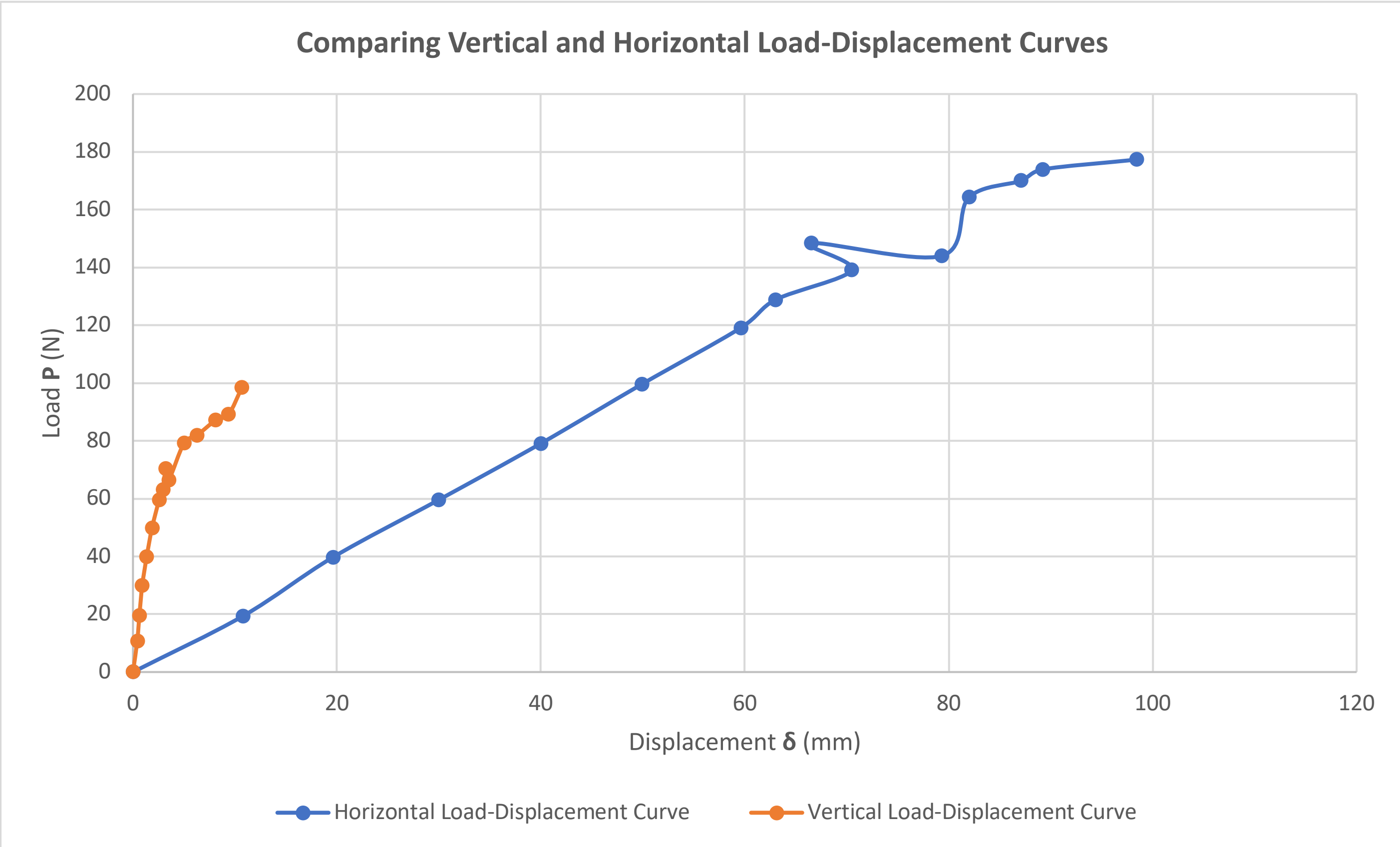


Figure 10 Portal Frame Analysed

8. The Load-Displacement curves for the Horizontal and Vertical Loads have been plotted.



9. The following information has been plotted on the load displacement curves, wherever possible

i. the elasto-plastic phase (*i.e.*, before reaching the full formation of first plastic hinge);
ii. the values at turning point (*i.e.*, the load is stable, and the displacement is increasing, and the first plastic hinge has formed);
iii. the values between the first and second hinge formation (*i.e.*, the load is increasing slightly, and the displacement is increasing);
iv. the values at turning point (*i.e.*, the load is stable again and the displacement is increasing: the second plastic hinge has formed);
v. the values between the second and third hinge formation (*i.e.*, the load is increasing slightly, and the displacement is increasing);
vi. the values at turning point (*i.e.*, the load is stable again and the displacement is increasing: the third plastic hinge has fully formed);
vii. values between the third and fourth hinge formation (*i.e.*, the load is increasing slightly, and the displacement is increasing).

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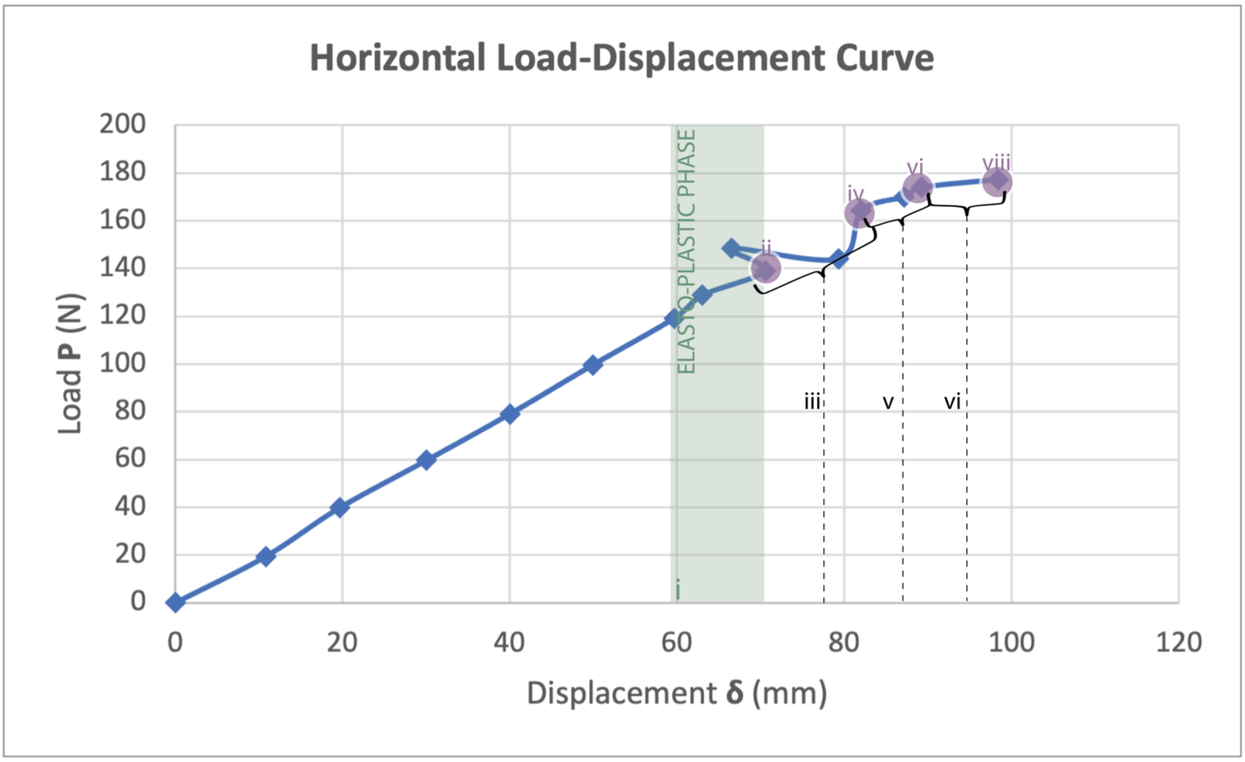

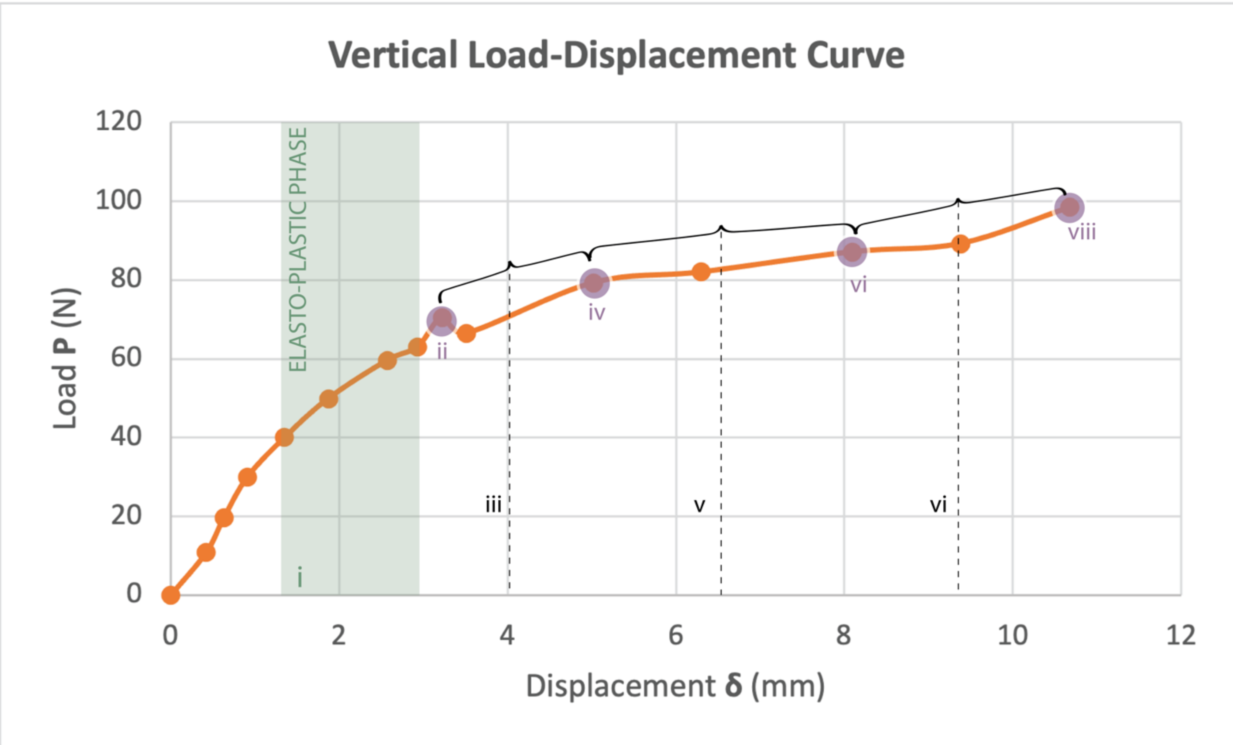

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EXPERIMENTAL DATA 2 : ‘1:2.5’

Table 2

PORTALFRAME H:V = 1:2.5				
From the Wizard (*i.e.,* Theoretical results)				
Take values of the Horizontal and Vertical Loads and Displacements corresponding to the formation of the plastic hinges.	H (N)	V (N)	δ_H (mm)	δ_V (mm)
1st Hinge at C	78.63	196.58	6.4	7.4
2nd Hinge at D	81.01	202.52	6.6	8.4
3rd Hinge at E	84.59	112.48	9.4	14.7
4th Hinge at A	96.15	240.38	27.4	44.9
From Experiment (*i.e.,* Experimental results)				
Record the observed values of the Horizontal and Vertical Loads and Displacements	H (N)	V (N)	δ_H (mm)	δ_V (mm)
	0	0	0	0
	9.9	27.5	0.56	0.78
	19.6	49.2	1.25	1.69
	29.5	75	1.89	2.70
	39.7	100.2	3.08	3.97
	49.9	124.8	4.31	4.80
	59.3	149.9	5.30	5.82
	69.8	174.7	6.33	6.97
	74.5	187.7	6.46	7.60
	77.9	189.5	6.82	8.43
	83.9	199.4	8.45	11.56
	90.2	212.2	10.39	17.52
	94	218.6	11.64	22
	100.3	238.9	14.50	31.19

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POST–EXPERIMENT ANALYSIS 1: ‘1:2.5’

1. Horizontal Load (H)
   Comparing theoretical and experimental values for ultimate load capacity

Theoretical Result $P_{H,T}$	Experimental Result $P_{H,E}$
96.15 N	100.3 N

   Vertical Load (V)
   Comparing theoretical and experimental values for ultimate load capacity

Theoretical Result $P_{V,T}$	Experimental Result $P_{V,E}$
240.38 N	238.9 N

2. The difference between the theoretical and experimental values are as follows.

   For Horizontal Load:
   ΔP_H = 4.15 N   where $P_{H,E} > P_{H,T}$

   For Vertical Load:
   ΔP_V = 1.48 N   where $P_{H,E} < P_{H,T}$

3. For horizontal load (H) we have:

Theoretical Displacement $\delta_{y,T}$	Experimental Displacement $\delta_{y,E}$
27.4 mm	14.5 mm

   For vertical load (V) we have:

Theoretical Displacement $\delta_{y,T}$	Experimental Displacement $\delta_{y,E}$
44.9 mm	31.19 mm

4. The frame reached full local plasticity but not full global plasticity. It can be said that the frame reached plasticity because the formation of four hinges was visually observed, which fulfils the criterion for local plasticity and hence, the hinge is considered to have reached plasticity. However, it can be argued that the hinge hasn’t reached global plasticity as for that to occur, there needs to be a deformation in the cross-section at every point of the frame which is practically not possible.

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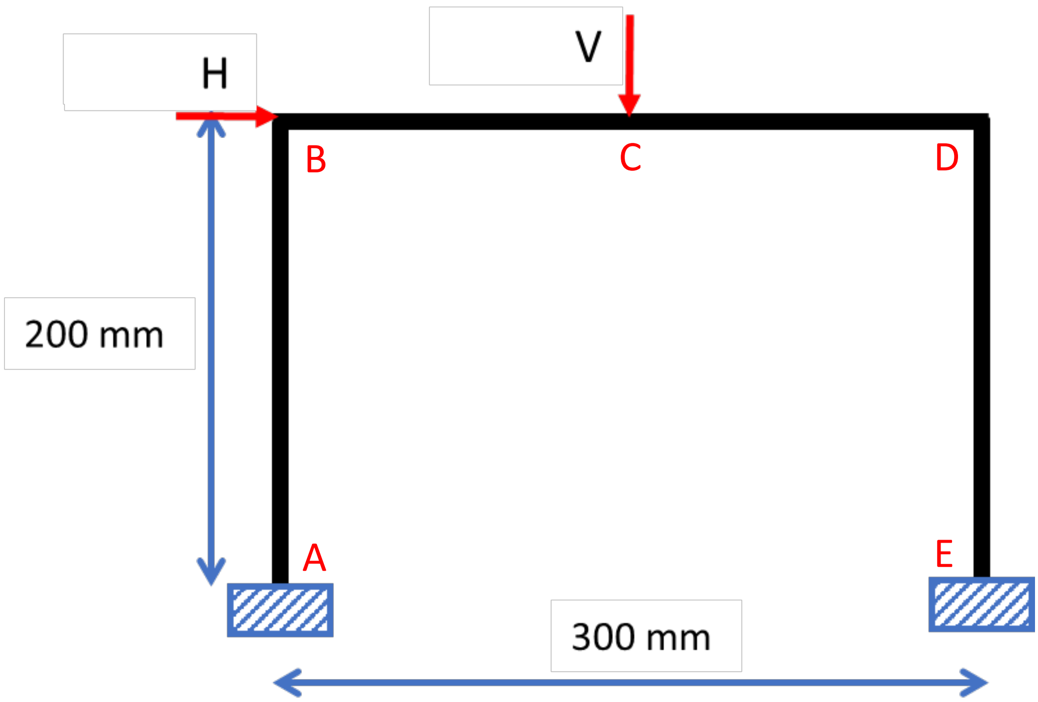
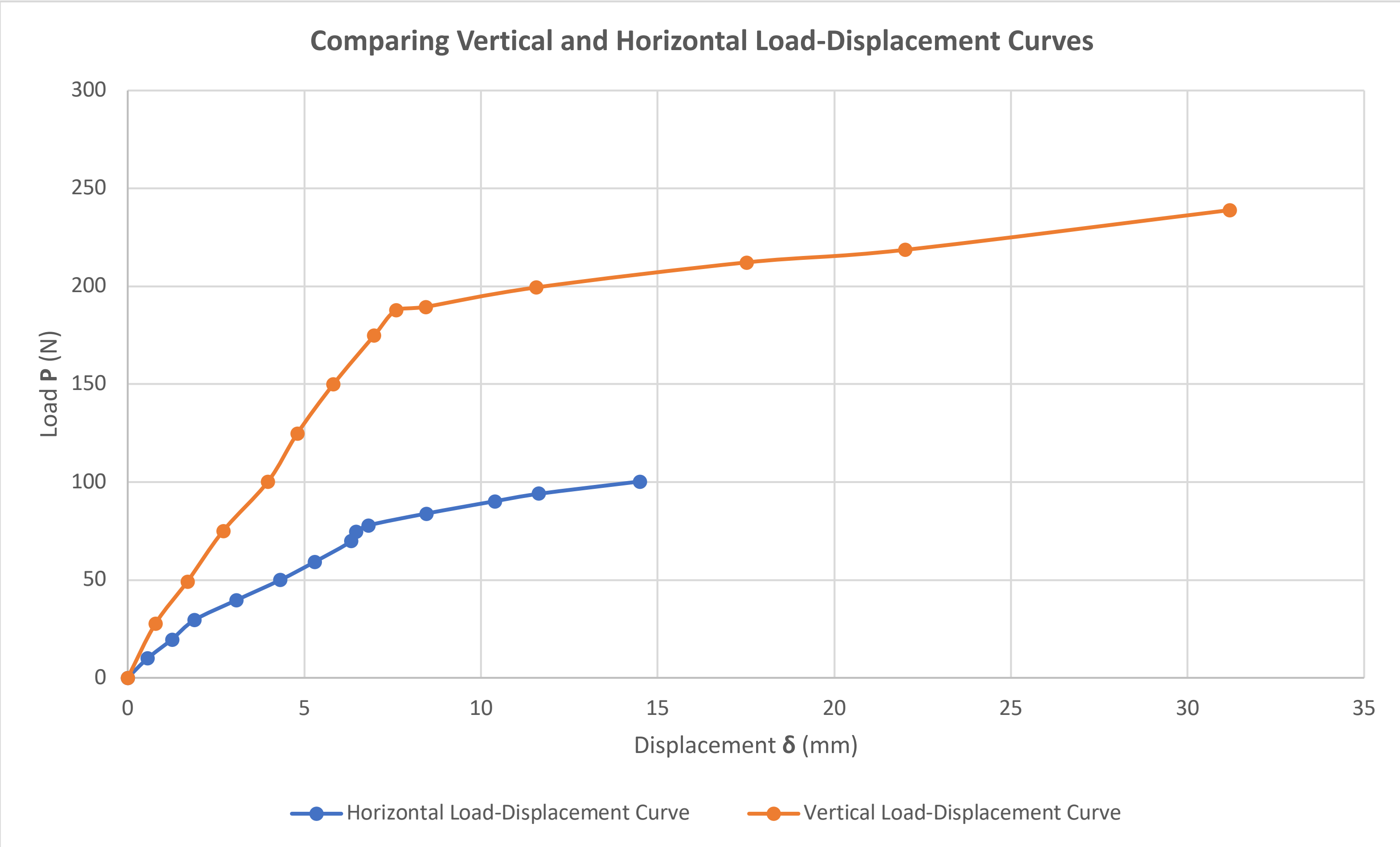


Figure 11 Portal Frame Analysed

8. The Load-Displacement curves for the Horizontal and Vertical Loads have been plotted.



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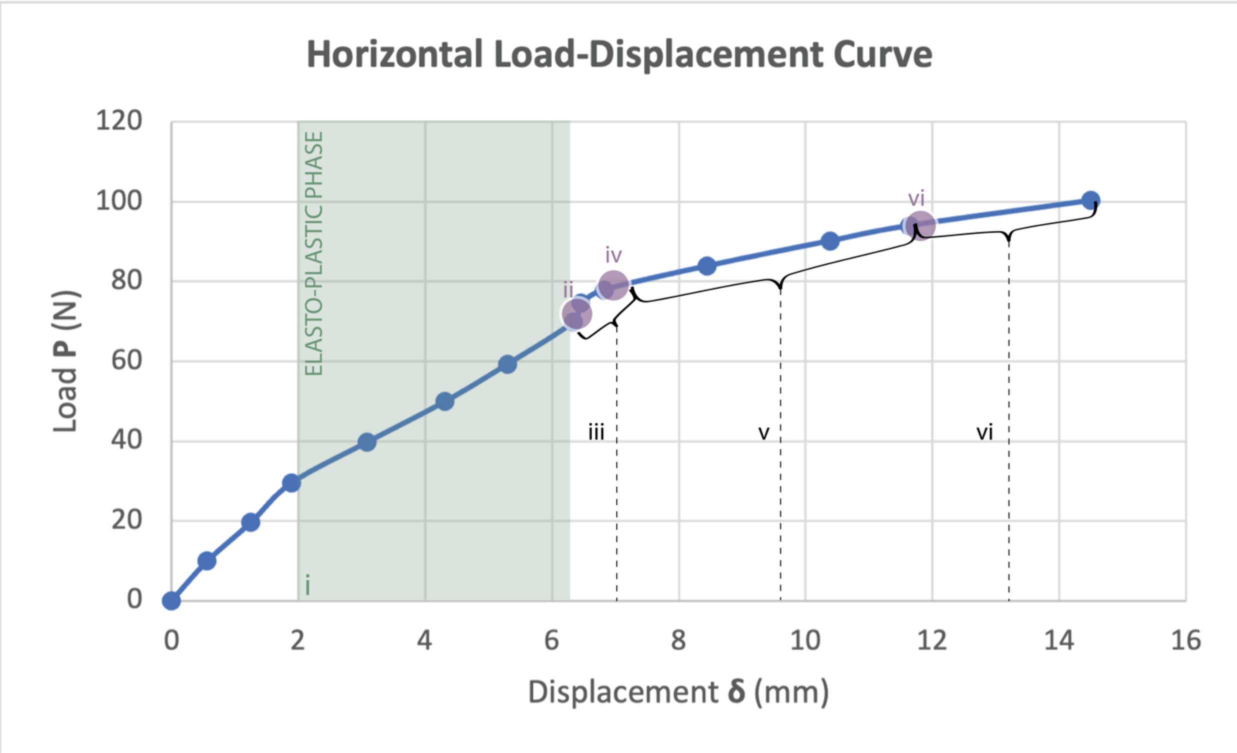

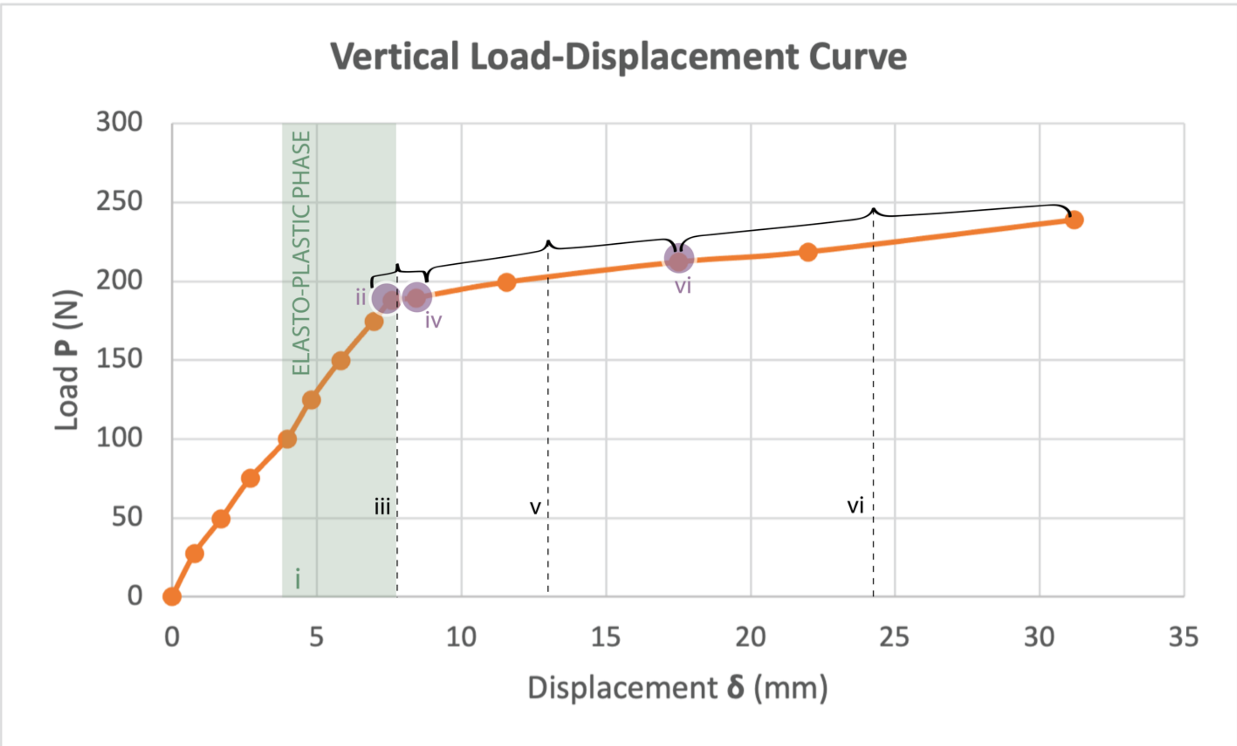

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