Plastic Collapse of Portal Frame Lab
Group T05

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March 22, 2023

1 Introduction

The purpose of this experiment is to investigate the behaviour of a mild steel portal frame model when subjected to increasing loads.

The rig consists of a loading system that applies a vertical load at the center of the beam and a horizontal load at the top of one column.

2 Experiment

The frame is made of mild steel and has a uniform rectangular cross-section. Also, The rig is equipped with two gauges to monitor the horizontal deflection of the beam and its central vertical deflection. The yield strenth of the steel is 250MPa.

The experimental parameters are shown in the following table Table 1.

Data type	Height	Length	Thickness	Width
Theory	200	300	3.3	13
Actual	200	304	3.27	12.97

(Unit: mm)

Table 1: Experiment parameters

The experiment entails the following steps:

1. Measure and record the dimensions of the frame and its cross-section.
2. Ensure the loading rig is in proper working condition and inspect cables for damage.
3. Zero the force and displacement readings while the rig is still unloaded.
4. Gradually apply increasing horizontal and vertical loads to the frame in increments of 10 N. The relationships between P and W are $yx = x$.
5. Record the applied forces and corresponding deflections for each increment.
6. Continue the process until a plastic failure occurs, and observe the formation of plastic hinges and position.
7. Unload the frame and identify the locations of plastic hinges by observing permanent rotation in the joints.

Here are the recorded data Table 2.

Force(N)	Vertical	10	20	30	40	50	60	70	80	90	100	110	120	130
	Horizontal	10	20	30	40	50	60	70	80	90	100	110	120	130
Distance(mm)	Vertical	0.06	0.05	0.1	1.42	2.13	2.26	2.8	3.22	3.62	4.28	5.23	7.46	12.88
	Horizontal	0.88	1.58	2.15	2.99	4.04	4.44	5.06	6.48	7.63	8.55	9.31	15.05	23.08

Table 2: Record data

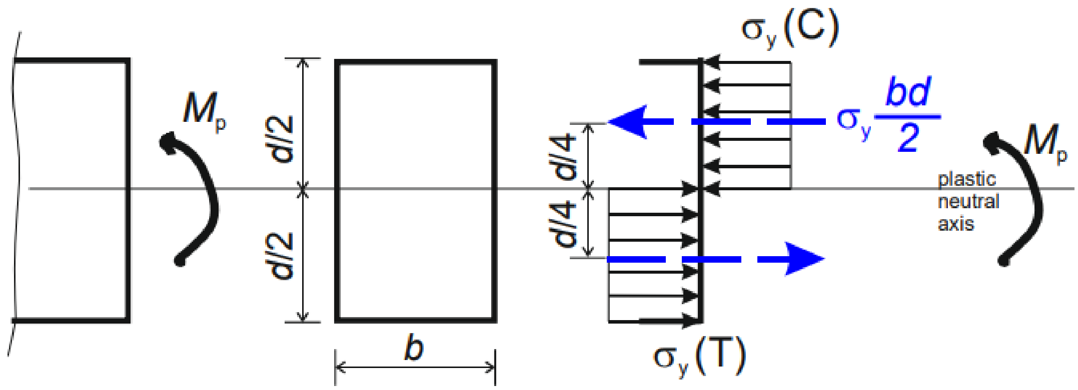

Figure 1: plastic modules of rectangular section

3 Theory

The method of calculating the plastic moment is introduced in the powerpoint of the Week 6 lecture. As shown in the figure below Figure 1.

The plastic moment M_p when all points in the section reached yield stress σ_y is caculated by:

$$M_p = \sigma_y \frac{bd}{2}(\frac{d}{4} + \frac{d}{4}) \tag{1}$$

Calculated from the data from Table 1, we get $M_p = 8.67N \cdot m$.

There are three cases of collapse of plasticity of portal frame. We use virtual work method to caculate it.

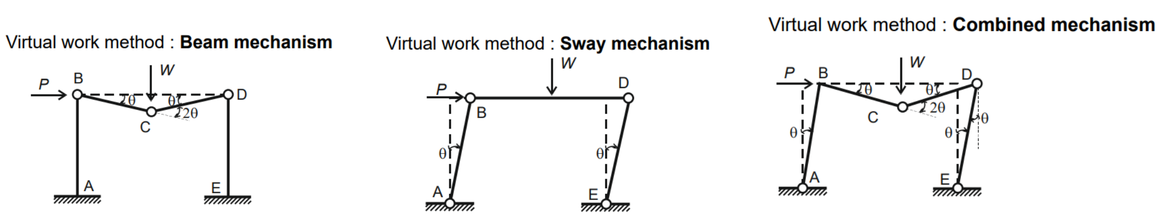

Figure 2: Three cases of collapse of plasticity of portal frame

- Beam mechanism: If $W >> P$, the hinges are likely to appear in B, C and D.

• Sway mechanism: If $P >> W$, the hinges are likely to appear in A, B, D and E.

• Combined mechanism: If P $\approx$ W, the smallest moment is at B (as moments due to P and W oppose each other), so hinges form at other possible locations. (The angle between ABC is 90°)

The virtual work method is:

$$\sum_i P_i \delta_i = \sum_j M_j \theta_j \tag{2}$$

We noticed that the height (200mm) is equal to $\frac{2}{3}$ length (300mm). i.e. $H = \frac{2}{3}L$.

By using Equation 2, we can get

$$\begin{cases} W\frac{\theta L}{2} = M_p\theta + M_p 2\theta + M_p\theta \rightarrow W = \frac{8M_p}{L}(Beam) \\ P\frac{2L}{3}\theta = M_p\theta + M_p\theta + M_p\theta + M_p\theta \rightarrow P = \frac{6M_p}{L}(Sway) \\ P\frac{2L}{3}\theta + W\frac{\theta L}{2} = M_p\theta + M_p 2\theta + M_p 2\theta + M_p\theta \rightarrow 4P + 3W = \frac{36M_p}{L}(Combined) \end{cases}$$

Plot the relationships P-W on a graph

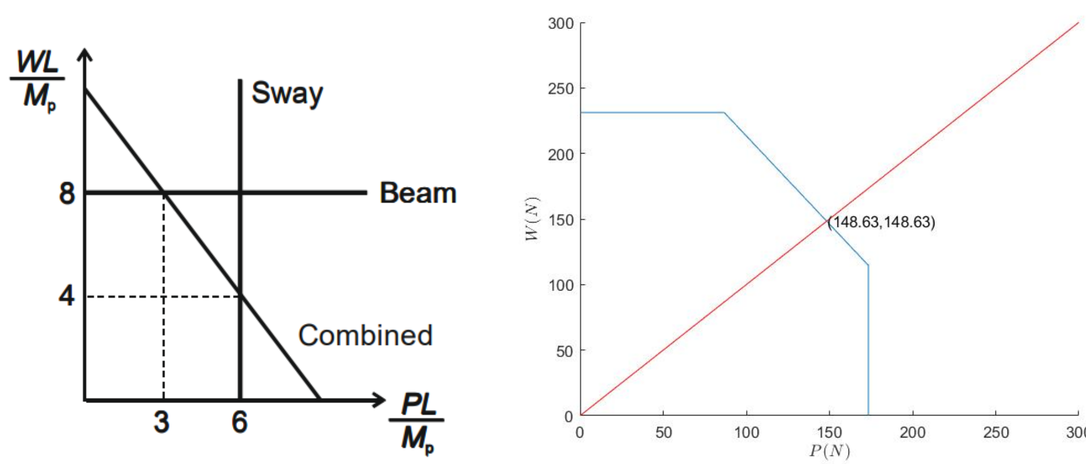

Figure 3: P-W graph

Substitude data from Table 1 and Equation 1, We have $\frac{M_p}{L} = 28.9$ and the boundary of the graph is

$$\begin{cases} W = \frac{8M_p}{L} = 231.2 \\ P = \frac{6M_p}{L} = 173.4 \\ 4P + 3W = \frac{36M_p}{L} = 1040.4 \end{cases}$$

Plotting the three boundary lines with the applied load lines ($y = x$) on the graph, the following figure is obtained.

where the coordinates of the load line and the boundary line are (148.63,148.63).

4 Analysis

a

Using the data in Table 2, the force vs deformation plot can be derived as Figure 3. Also, from the lecture in week 7, we can learn that the total bending moment diagram is as follows

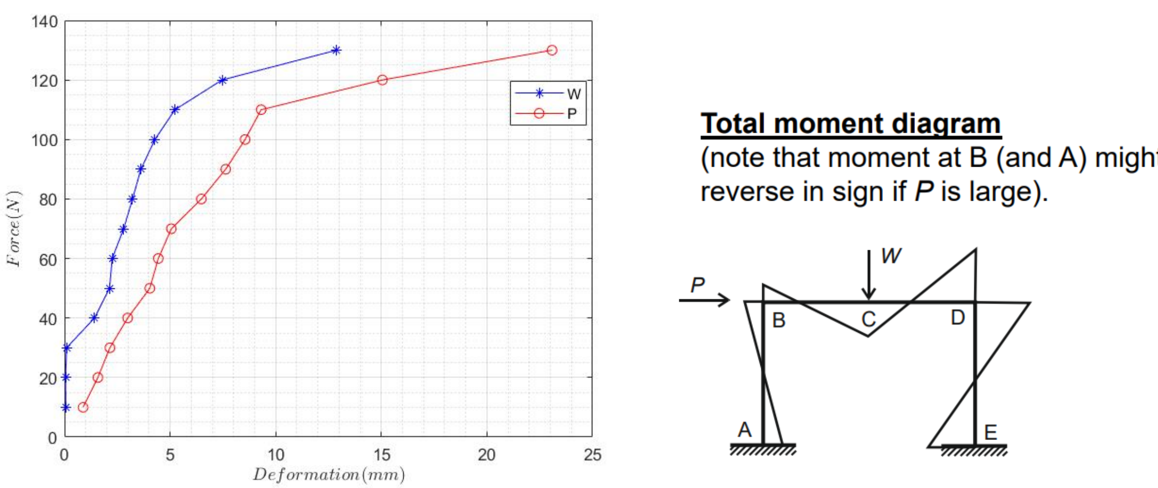

Figure 4: Force vs deformation and total moment diagram

The chart illustrates the relationship between the strength and deformation of steel, which can be discussed in two different situation.

- W<110N,P<110N: Elastic deformation: The relationship between the elastic deformation variable and the external force is linear.

- W≥110N,P≥110N: Plastic deformation: The relationship between force and deformation is nonlinear, i.e., the strain shows a rapid increase with the increase of stress.

From the total moment diagram (Figure 3), it can be seen that the bending moment at point D is the largest, and this point will be the first point in the experiment to achieve plastic deformation.

In Figure 2, The P-W graph is piecewise and if the combination of the P and W exceeds the closed figure on the left, The collapse will happen. In this case($y = x$), the collapse load for the frame was $W = 148.63N, P = 148.63N$.

Can you identify at which load each plastic hinge formed?

b

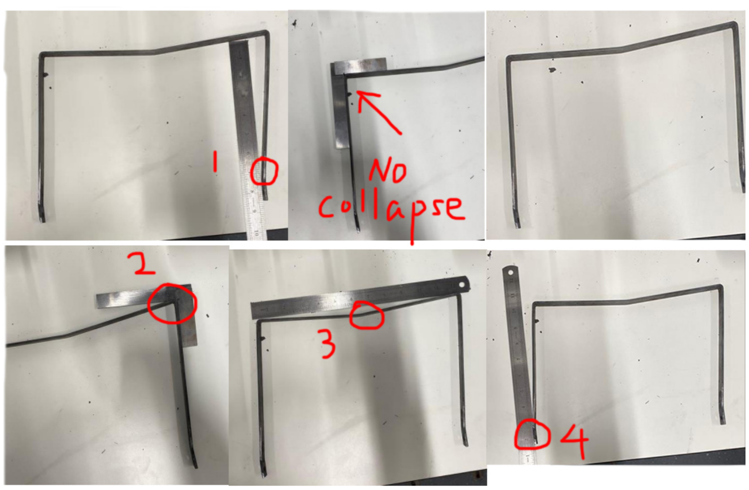

Figure 5: Experimental results

There are 4 plastic hinges at the moment of the collapse of the frame. Compare Figure 2 and Figure 5 we can find:

- After the force load, the upper left corner of the frame did not rotate, and the angle between the beam and column was still degrees.

- The angle of rotation of the plastic collapse occurring at points 1,4 is θ(in Figure 2).

- The angle of rotation of the plastic collapse occurring at points 2,3 is 2θ(in Figure 2).

c

i

The theoretical plastic collapse load derived from Section 2 is 148.63N, while the actual collapse load is in the region of 110N.

The comparison leads to the conclusion that the actual collapse load will be less than the theoretical value for these possible reasons:

- Material inhomogeneity: there are microscopic defects, grain boundaries, organisation and other factors in the actual material, which can lead to differences in the mechanical properties of the material, thus affecting the plastic deformation and strength of the material.

- Differences in test conditions: The plastic collapse load of a material often needs to be determined experimentally, and differences in experimental conditions (e.g. temperature and humidity) can also affect the difference between the actual plastic collapse load and the theoretical value.

ii

iii

5 Conclusion