PART IB EXPERIMENTAL ENGINEERING

SUBJECT: STRUCTURES — EXPERIMENT S1
LOCATION: INGLIS MEZZANINE — (SHORT)

PLASTIC COLLAPSE

OBJECTIVES

1. To measure the load-deflection response of simply-supported beams of different lengths, up to collapse. To define the plastic moment, corresponding to a plastic hinge.
2. To verify that plastic collapse of a structure occurs when a sufficient number of plastic hinges have formed.
3. To set up a work balance, based on the actual collapse mechanism — if it is known — or on a hypothetical collapse mechanism, to relate plastic moment and collapse load.
4. To verify that the work balance can provide useful upper bound estimates of the collapse load of a complex structure.

1. INTRODUCTION

It is important for engineers to understand the way in which structures fail, and to be able to estimate failure loads. This experiment is concerned with the plastic collapse of beams and framed steel structures. The structural layouts shown in Fig. 1, below, are investigated.

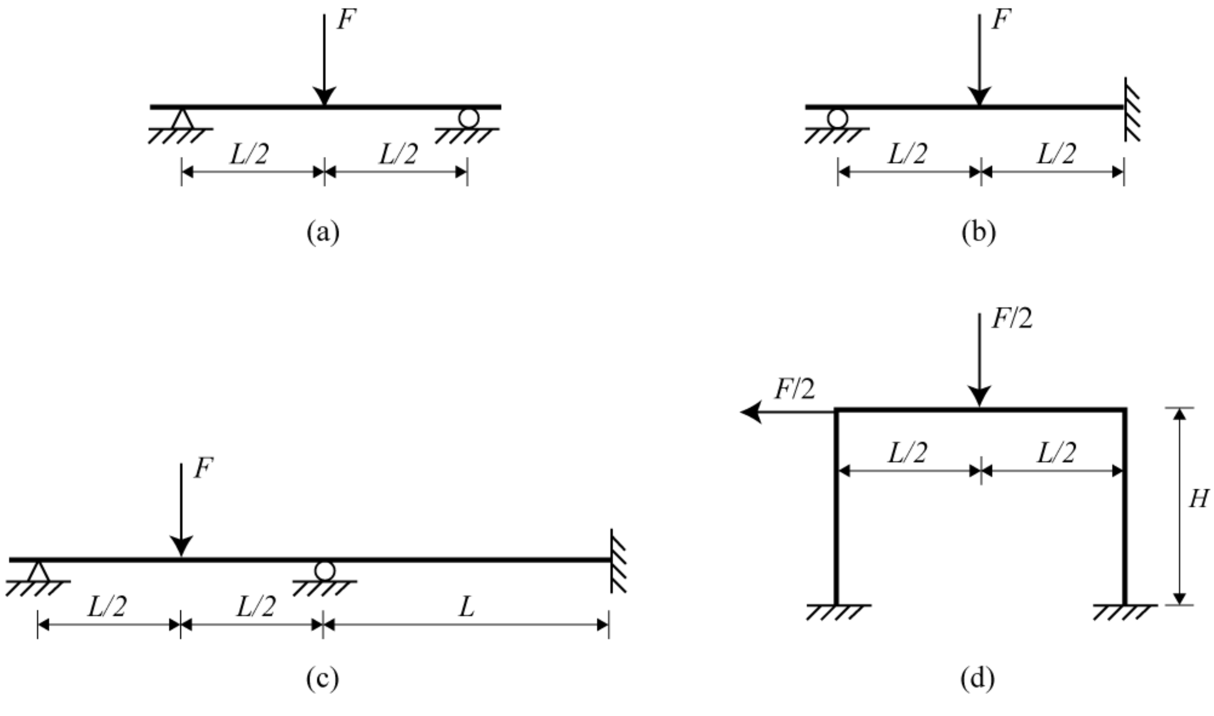

Figure 1

2. APPARATUS

- Annealed mild steel strips of uniform cross-section.
- Supports for beams: rollers, knife-edge, and full support. Base clamp for portal frame.
- Loading cell.
- Loading beam, links, etc. to apply horizontal and vertical forces of equal magnitude on the portal frame.
- Displacement transducer.

3. EXPERIMENTAL PROCEDURE

Test two simply-supported beams of different lengths, loaded in the middle; use the beam lengths defined on your loading rig. It is suggested that in each step the load be increased by 10 N, or the displacement by 2 mm, whichever occurs first (except for the 100 mm beam, where 20N steps should initially be taken). **Do not stop loading once the load reaches a peak**; we are interested in the behaviour of the beam as it collapses. Start unloading once the load on the beam has remained approximately constant over a few steps — **make sure that a large kink** (a *plastic hinge*) **has formed in the beam**. Take two or three readings while unloading.

At the end of each test, write down the steady state value of the load F_p under which the beam deforms plastically (not the peak load), and calculate the value of the corresponding bending moment M_p at the plastic hinge.

Finally, plot the load/deflection response for one of the two beams.

L = ... mm

Force (N)	Deflection(mm)

F_p = ... N

M_p = = ... N mm

L = ... mm

Force (N)	Deflection(mm)

F_p = ... N

M_p = = ... N mm

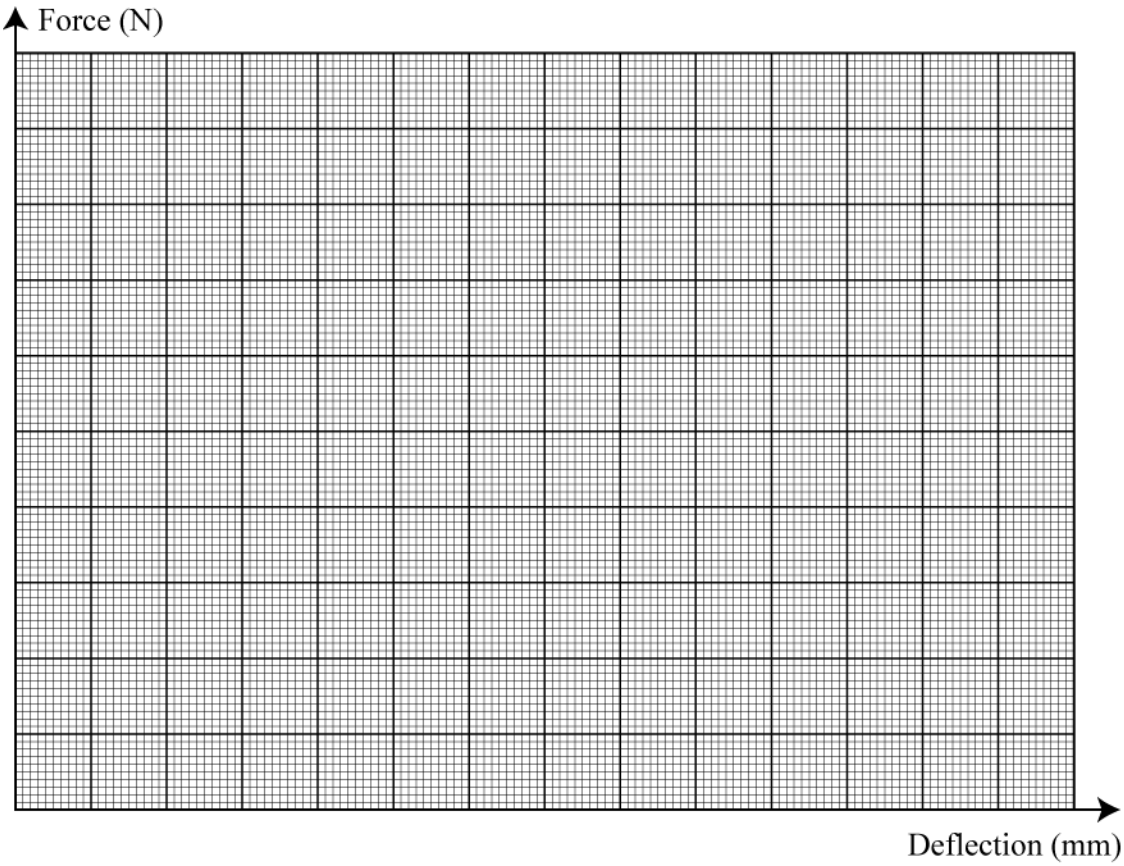

Figure 2

4. PLASTIC MOMENT

4.1 Comparison of plastic moments

Collect data from other groups and complete the table below.

L (mm)	100	150	200	250	300	350	400
M_p (N mm)							

Average M_p = ... N mm

4.2 Calculation of plastic moment by work balance

In Section 3 you calculated M_p from L and the measured F_p by equilibrium, which was possible because the beam was *statically determinate*. In this section you will calculate M_p by a *plastic method*, which can be generalized for *statically indeterminate* structures.

Take one of the two beams which you tested earlier. During plastic collapse the plastic hinge in the middle of the beam rotated through θ (rad) while the force applied to the beam, F_p (N), moved downwards by δ (mm).

During plastic collapse, since loads and moments remain constant, the work done by the load is $F_p\delta$ and the energy dissipated in the plastic hinge is $M_p\theta$. Hence, the following work balance has to be satisfied

$$F_p\,\delta = M_p\,\theta. \qquad (1)$$

For this particular beam F_p is known. Now measure δ and θ on the unloaded beam itself (trace the shape of the beam on a sheet of paper and take measurements with a ruler) and substitute these values into equation (1):

$$M_p = \frac{F_P \delta}{\theta} =$$

Does this value agree with the calculation of Section 3?

The work balance can also be used to estimate the collapse load of a statically indeterminate structure loaded by one or more forces. A possible collapse mechanism is chosen: in general, this will involve more than one plastic hinge. The hinge rotations θ_i and the displacements of the points of application of the loads, δ_j, can be related by kinematics, and the collapse load can then be estimated from a work balance equation

Work done by loads = Energy dissipated in hinges

$$\sum_{\text{all loads}} F_j \delta_j = \sum_{\text{all hinges}} M_p \theta_i \qquad (2)$$

It will be shown in the Structures lectures that any estimate of the collapse load obtained by this method is either equal to or greater than the correct value.

5. COLLAPSE OF A STATICALLY INDETERMINATE BEAM

In this section you will estimate the collapse load of a statically indeterminate beam whose plastic moment is equal to the value estimated in Section 4.1, and then verify the accuracy of your prediction by a test.

Choose a statically indeterminate beam from Fig. 1, i.e. either the propped cantilever (b) or the continuous beam (c). Then, guess a possible collapse mechanism for your chosen structure (at least two plastic hinges are required) and find geometric relationships between the plastic hinge rotations θ_i the deflection of the point of application of the load δ, and the beam length L. Finally, choose a value for L and obtain an estimate for F_p from equation (2).

Sketch of hypothetical collapse mechanism

Calculation of collapse load

F_p = ... N for L = ... mm

Now, test this beam to see if your prediction is accurate. Follow the experimental procedure of Section 3. Do not forget that your estimate of the collapse load may well be higher than the actual value.

Force (N)	Deflection(mm)

Predicted collapse load = ... N

Sketch of statically indeterminate beam and actual collapse mechanism

Actual collapse load = ... N

6. COLLAPSE OF A PORTAL FRAME

In this section you will estimate the collapse load of a portal frame, and then verify your prediction by a test.

First, estimate the collapse load of the portal frame shown in Fig. 1(d), for general L and H: all possible collapse mechanisms have 3 or 4 plastic hinges. Then, substitute L = 150 mm, H = 100 mm into this expression and find the corresponding value of F_p.

Sketch of hypothetical collapse mechanism

Calculation of collapse load

F_p = ... N

Next, test the portal frame to collapse while measuring the horizontal deflection of the beam. Take two or three readings on unloading. Plot the measured load/deflection response.

Force (N)	Deflection(mm)

Predicted collapse load = ... N

<u>Sketch of portal frame and actual collapse mechanism</u>

Actual collapse load = ... N

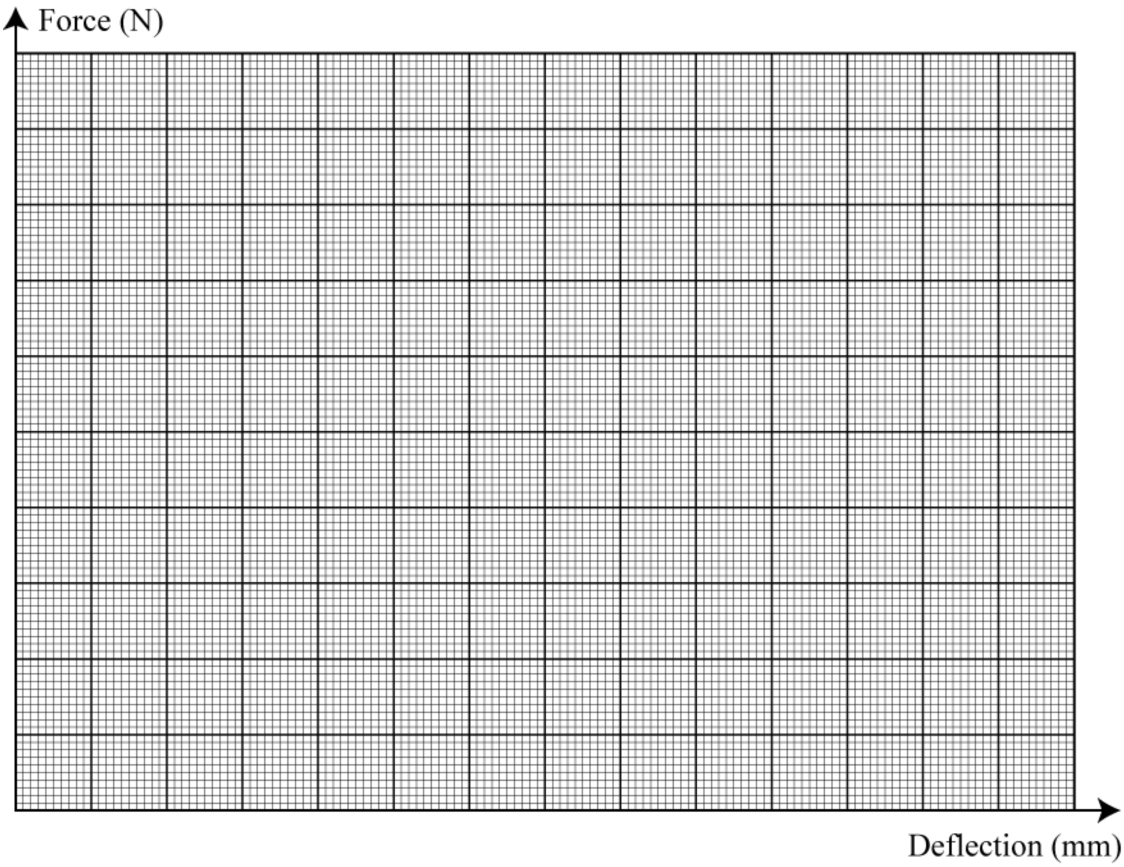

Figure 3

7. COMMENTS

Compare the load/deflection responses in Figures 2 and 3. Write short comments on the key similarities and differences between the response of the statically determinate beam and the response of statically indeterminate structures.

Did your guessed collapse mechanisms turn out to be the actual ones? If not, use the actual mechanisms to produce new estimates of the collapse load.

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