STR15
Plastic Bending
of Beams:
Student Guide

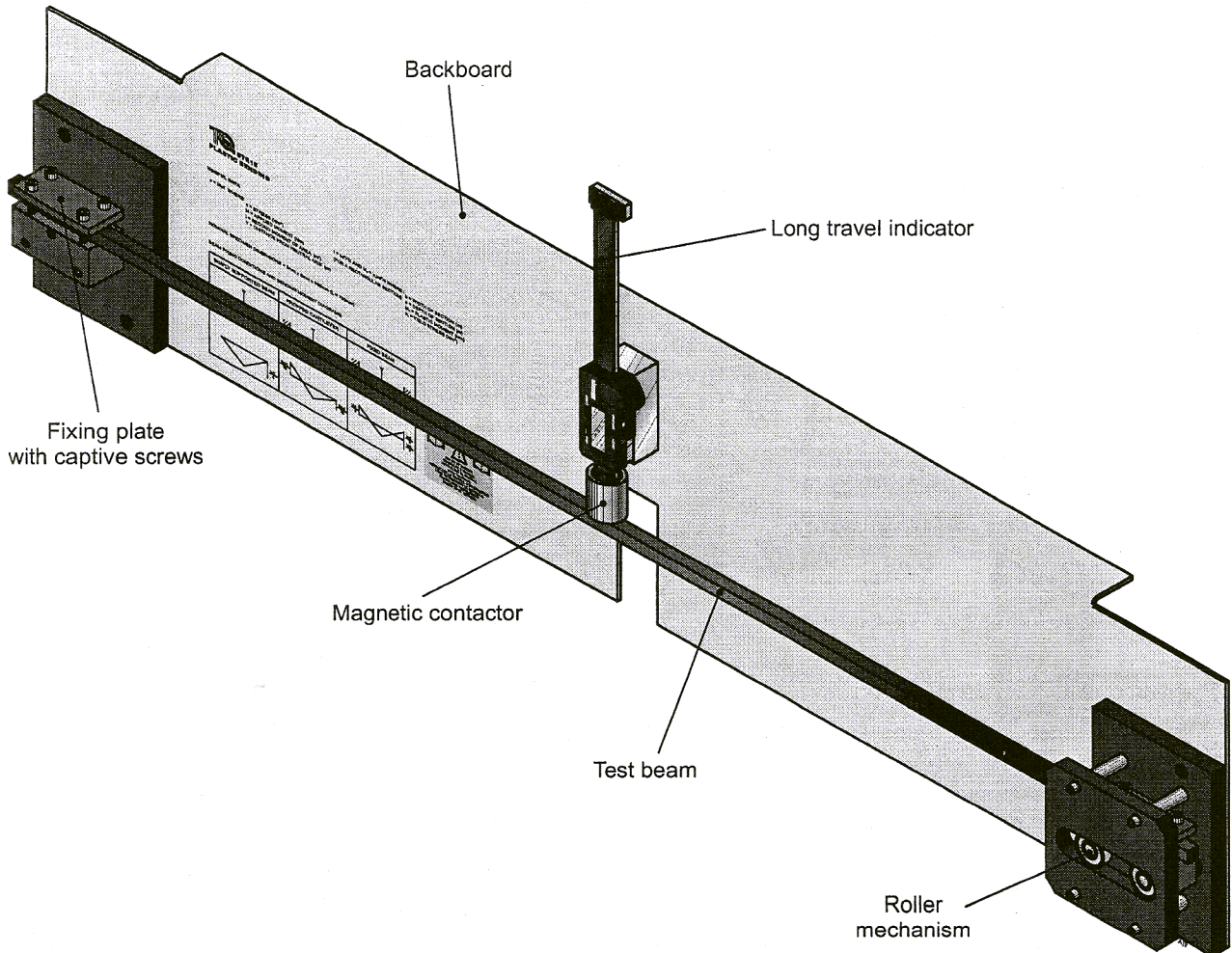**TQ Education and Training Ltd**

Products Division

Figure 1 Plastic Bending of Beams Experiment

Introduction

This guide describes how to set up and perform experiments related to the Plastic bending of beams. The equipment clearly demonstrates the principles involved and gives practical support to your studies.

Description

Figure 1 shows the Plastic bending of beams experiment. It consists of a backboard on which a fixed and rolling chuck is attached, these chucks hold the specimen beams in various configurations during the tests. Also attached to the backboard is a long travel digital indicator, which is used for accurately measuring the deflection of the specimen beams

Look at the reference information on the unit. It is useful and you may need it to complete the experiments in this guide.

How to Set Up the Equipment

The Plastic bending of beams experiment fits into a Test Frame. Figure 2 shows the Plastic bending of beams experiment in the Frame with a load cell and force display used to bend the beams and measure the force applied.

Before setting up and using the equipment, **always:**

- Visually inspect all parts, including electrical leads, for damage or wear.
- Check electrical connections are correct and secure.
- Check all components are secure and fastenings are sufficiently tight.
- Position the Test Frame safely. Make sure it is on a solid, level surface, is steady, and easily accessible.

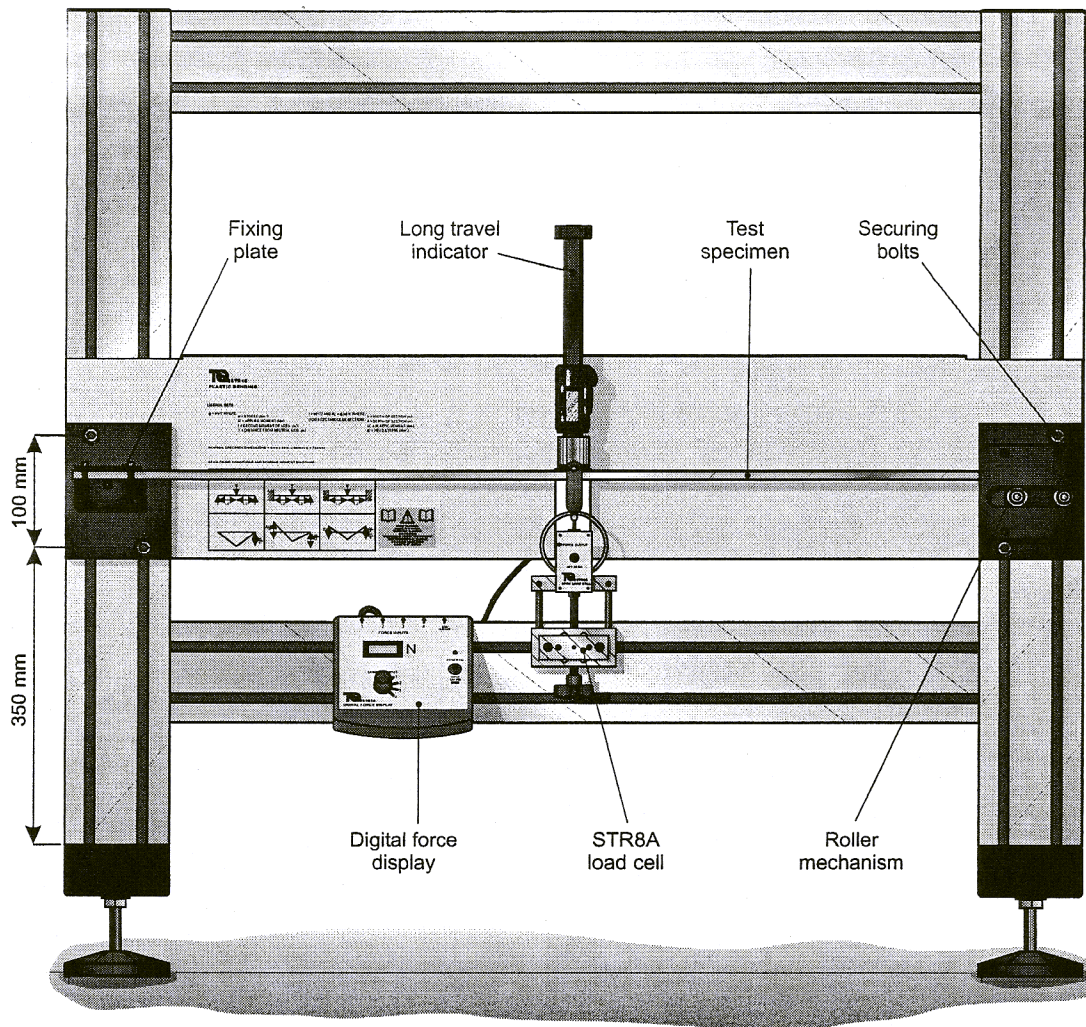**Never** apply excessive loads to any part of the equipment.

Figure 2 Plastic bending of beams experiment in the structures frame

The following instructions may already have been completed for you.

1. Place an assembled Test Frame (refer to the separate instructions supplied with the Test Frame if necessary) on a workbench. Make sure the 'window' of the Test Frame is easily accessible.

2. There are two securing nuts in each of the side members of the frame (on the inner track). Move one from each side to the outer track (see STR1 instruction sheet) then slide all four nuts to approximately the positions shown in Figure 2.

3. Slide two nuts into position for the load cell and fix the load cell leaving the screws slightly loose at this point.

4. Temporarily remove the long travel indicator from the unit and lift the unit into position, secure with the screws provided, level the ends of the unit with the frame.

5. Temporarily remove the fixing plates from the unit and rest a straight specimen across the chucks.

6. Adjust the position of the load cell until it is in the vertical position. Lock the load cell in the vertical

position using the locking pin provided into one of the securing screw holes. Tighten the load cell using the 6mm A/F Allen key.

7. Adjust the height of the load cell using the mechanism until the loading pin can pass through the holes in the load cell fork above the specimen. Adjust the height of the load cell until the pin is just about to touch the specimen *do not apply a load to the specimen at this point*.

8. Remove the specimen beam and replace the indicator on the backboard. Check that there is at least 40mm of downward travel available on the load cell before it hits the bottom stops; if there is not then move the back board up in the frame by the required amount.

9. Make sure the Digital Force Display is 'on'. Connect the mini DIN lead from 'Force Input 1' on the Digital Force Display to the socket marked 'Force Output' on the left-hand side of the load cell.

10. With no load on the load cell zero the reading using the knob on the front of the load cell.

Experiment 1: Plastic Bending of a Simply Supported Beam

During the design process for beams it would not be unreasonable for one to assume that no part of the beam should experience a stress greater than that allowable for the working material. However it can be found that there a beam will withstand much larger forces before collapse than simple elastic theory predicts. Why? To explain this consider the following diagram and the bending equation:
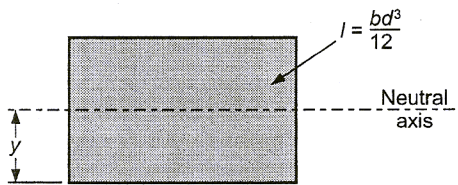
$$I = \frac{bd^3}{12}$$

Neutral axis

y

Figure 3 Section Through a Beam

M/I = σ/y (the bending equation)
M = Bending moment (Nm)
I = Second moment of area of the section (m^4)
σ = Stress (Nm^{-2})
y = Distance from the neutral axis (m)

When the beam is bent around the neutral axis, the stress through the beam section varies with the distance from the neutral axis, from the greatest at the extreme fibres (y = maximum) to zero at the neutral axis (y = 0).

Yield Stress (6y)

Extreme fibre plastic

y

Neutral Axis

Extreme fibre plastic
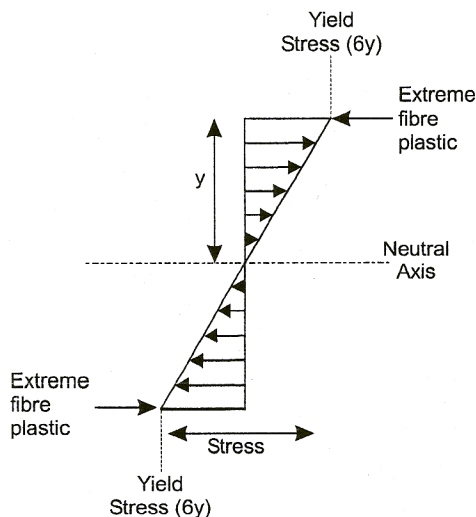
Stress

Yield Stress (6y)

Figure 4a Beam Just Reaching Plastic Condition

If we were to subject the beam to an increasing bending moment the stress will build up through the section to a maximum at the extreme fibres. If we continue to increase the bending moment the outer fibres would begin to yield (Figure 4a) This means that although the outer parts of the beam may well have yielded and are behaving plastically, the inner parts may still be behaving elastically and resisting the load.

6y

Plastic Portion

y

Neutral Axis
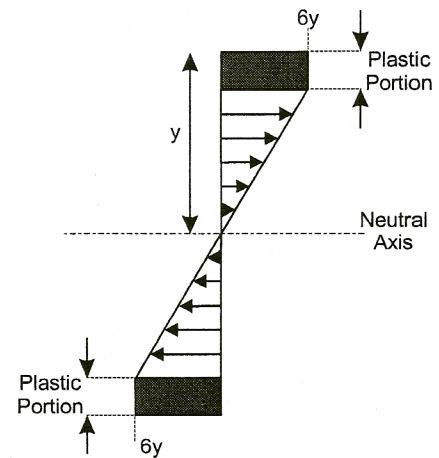
Plastic Portion

6y

Figure 4b Beam in the Partially Plastic Condition

If we continue to increase the bending moment, the plastic portion will move further into the beam leaving a smaller elastic core (Figure 4b). This is called the partially plastic condition. The beam will continue to resist the bending moment although with an increasing rate of deflection as the plastic portion moves further toward the neutral axis.

6y

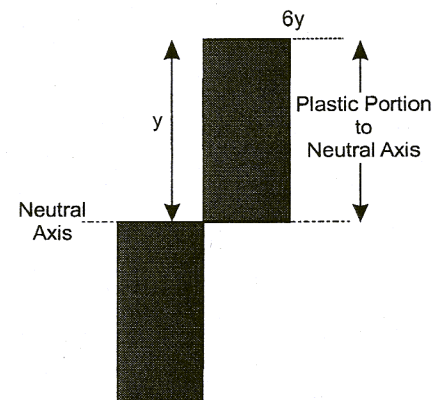Plastic Portion to Neutral Axis

y

Neutral Axis

Figure 4c Beam in the 'Fully' Plastic Condition

Eventually the elastic portion will be far enough into the beam (Figure 4c) and the beam will be "fully" plastic. It will form a plastic hinge and be unable to resist any further bending moment.

The ratio of the "fully" plastic bending moment to the "just" plastic bending moment is called the *Form*

factor. A more mathematical approach will be found in most standard texts. It should be noted from the mathematical derivation that form factor is entirely dependent on the shape of the beam: not the size, material or fixing condition.

In the following experiment we will test a simply supported beam to find the form factor and examine the load deflection relationship for a beam which is taken to the point of plastic collapse.

Take a specimen beam and measure the cross section, calculate the second moment of area for the specimen.

Ensure the clamp plates are removed, and place the specimen beam across the chucks of the unit. Push the roller mechanism outwards to its stops. Put the pin through the load cell fork and wind the load cell down until the pin *just* touches the specimen beam, zero both the load cell and the indicator.

Wind the load cell down to cause a measured deflection of 3mm and take a reading of the force required. Continue to wind the load cell down in 3mm steps until there is no or very little increase in load for each increment of deflection. Enter your results into Table 1.

Deflection (mm)	Force (N)
0	0
3	
6	
9	
12	
15	
18	
21	
24	
27	
30	
33	
36	

Table 1 Results for Experiment 1

Plot a graph of force versus deflection from your results, comment on the shape of the resulting plot Note the collapse load, and using the bending mom diagrams calculate the plastic collapse moment (M_p) Release the load and remove the beam. Sketch shape of the collapsed beam

To find the form factor we need the yield stress of the material. Your lecturer will provide you with data for the specimen material.

Using the yield stress calculate the bending moment to just cause yielding of the extreme fibres (M_y) of the beam and calculate the ratio of M_p/M_y (the form factor). Compare this to textbook derived value of form factor for a rectangular beam. Does the

experimental form factor compare favourably to the theoretical value?

Discuss the advantages of considering the extra available strength due to the plastic beam theory when designing structures.

Experiment 2: Comparison of Collapse Loads for Various Beam Fixing Conditions

Clamp a *new* specimen beam into the fixed specimen chuck at the left-hand end of the unit leaving the other end resting on the rolling chuck to produce a propped cantilever. Ensure the rolling chuck is pushed outward towards its stops. Repeat the test in experiment 1 for the propped cantilever. Entering the results into Table 2

Deflection (mm)	Force (N)
0	0
3	
6	
9	
12	
15	
18	
21	
24	
27	
30	
33	
36	

Table 2 Results for Experiment 2 (propped cantilever)

Remove the beam once collapse has occurred and sketch the final shape of the beam

Repeat the experiment for a fixed beam ensuring that the moving chuck is fully outward and the specimen ends are clamped firmly in both chucks using the clamp plates. Note that the rolling chuck will move inward with the beam during the test to compensate for the bending in the beam. Enter your results in Table 3. *NB: for the fixed beam use increments of deflection of 2 mm.*

Enter your results in Table 3

Deflection (mm)	Force (N)
0	0
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	
22	

Table 3 Results for Experiment 2 (fixed beam)

Plot force versus deflection for both sets of results and read off the maximum force for each. Calculate the

plastic moments and form factor for both beams and compare with the theoretical values.

Compare the ratio of collapse loads for the three beam fixing conditions to theoretical values, ie

Simply supported beam: propped cantilever: fixed beam = 1:1.5:2

Do the experimental results confirm these ratios? Examine the bending moment diagrams for all three fixing conditions and comment on the ratios and the sketched shapes of the collapsed beams. Why does the propped cantilever differ from the simple and fixed beams in terms of the formation of plastic hinges?

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