STRUCTURES

Reactions of a Simply Supported Beam

CP3604

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Contents

Introduction

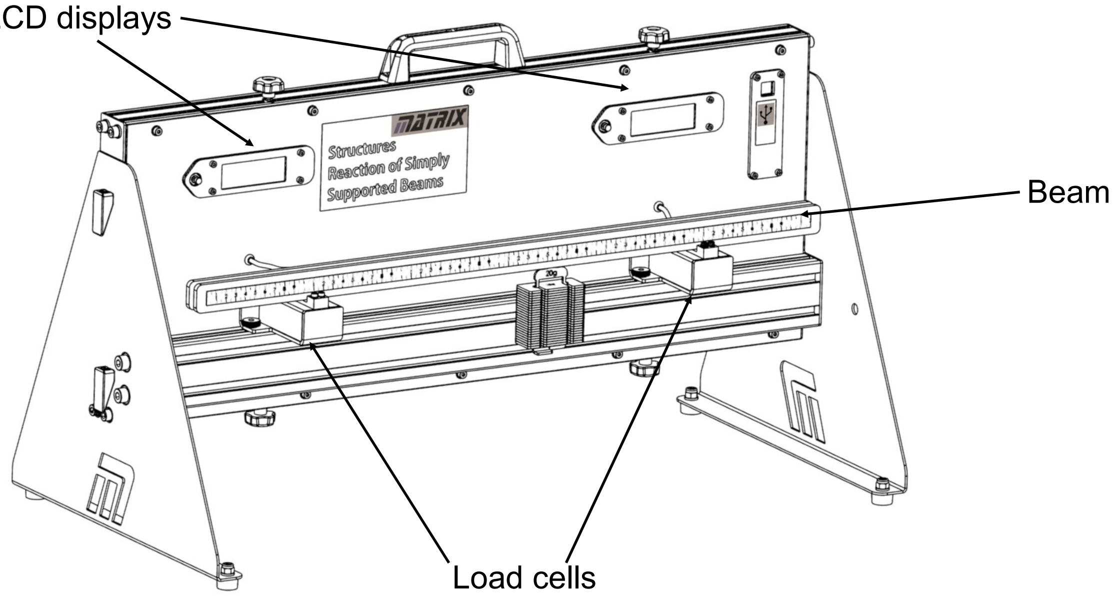
Beams are a vital part of modern structures. They support loads and span gaps - in bridges, door frames, roofs, scaffolding etc....

Their loads are carried on supports, such as the pillars holding up a bridge, which exert opposing reaction forces.

The apparatus:

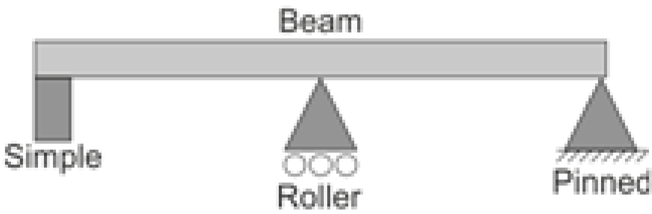
This uses two load cells to convert the forces acting on them into electrical signals. These are processed to indicate the size of these forces.

The beam sits centrally on supports connected to the load cells. The two notches under the beam assist with this. The pegs linking the two sides of the beam are 50mm apart. The load cell supports are 400mm apart.



The symbols:

A simply supported beam is represented by the symbols shown in the following diagram:



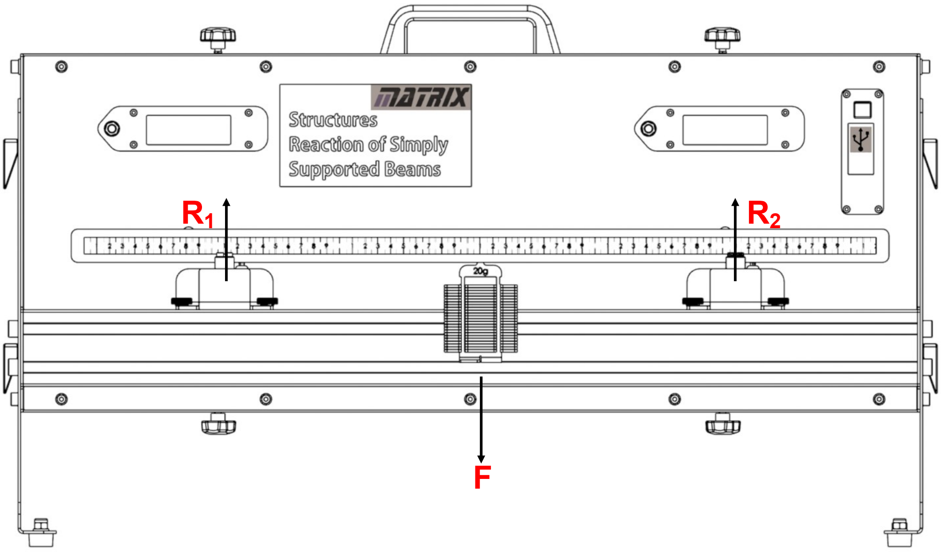
Introduction

The apparatus is designed to work off 5v power supply. This means that a USB cable plugged into either a computer or a plug will be sufficient. The data acquisition software only works through the computer, therefore the recommended setup is to have the USB plugged into the computer which is running the software. However, if you'd like to run the experiment without the software, a USB plug will need to be sourced for the correct local plug style.

Investigation A

Single weight applied at centre

Over to you:



- Place the beam on the load cell supports as shown in the diagram.
- Press the 'zero' button on each LCD display to remove the weight of the beam from the readings.
- Position a 100g mass hanger at the centre of the beam, mid-way between the supports.
- Record forces R_1 and R_2, shown on the LCD displays, in Table 1 of the Student Handout.
- Increase the load on the beam by adding a further 100g to the hanger.
- Again, record the load cell readings.
- Continue in this way up to a total mass of 500g and complete Table 1.

So what:

Since the beam is in equilibrium:

- the load cell supports provide upward forces that balance the weight on the beam;
- the clockwise moments of the forces are balanced by the anticlockwise moments.

  In other words:
- the two reaction forces always add up to the total load, F, applied, i.e. $F = R_1 + R_2$
- since the load is positioned at equal distance, D, from the supports,

  equating clockwise and anticlockwise moments about the centre of the beam:

$$R_1 \times D = R_2 \times D$$

and so

$$R_1 = R_2$$

The load itself has no moment (turning effect) about the centre of the beam.

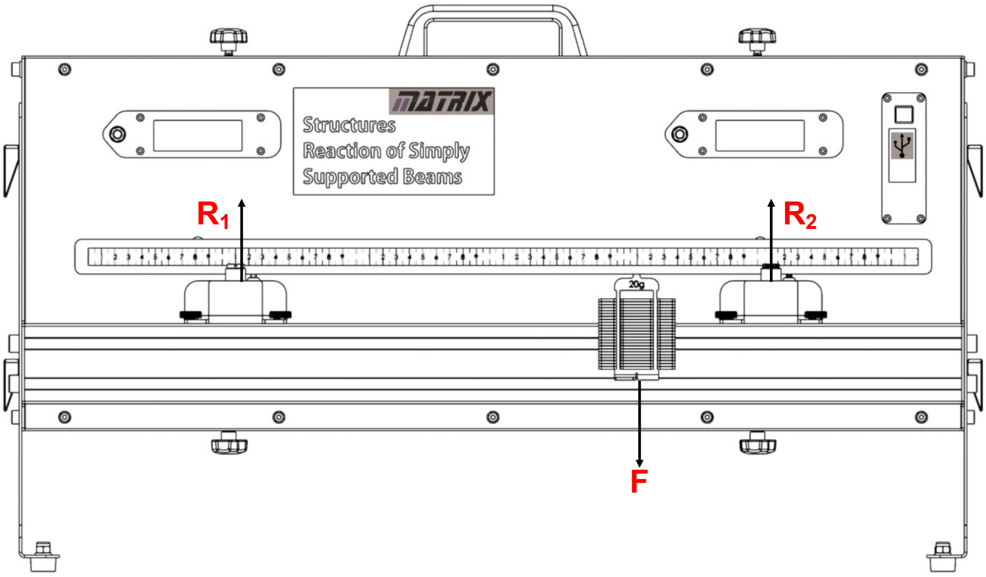
Challenge!

Draw the free-body diagram of this setup.

Investigation B

Single weight offset from centre

Over to you:



- Centre the beam on the load cell supports as before.
- Press the 'zero' buttons to eliminate the weight of the beam from the readings.
- Add the 100g mass hanger on the second peg from the right-hand support (i.e. 100mm from the right-hand support and 300mm from the left-hand support) .
- Record forces R_1 and R_2, shown on the LCD displays in Table 2 of the Student Handout.
- Increase the load on the beam by adding a further 100g to the hanger.
- Again, record the load cell readings.
- Continue in this way up to a total mass of 500g.
- Complete Table 2.

So what:

Once again, the beam is in equilibrium and so:

- the vertical forces cancel out;
- the clockwise and anticlockwise moments cancel out.

Hence: $$F = R_1 + R_2$$

and equating moments about the position of the load:

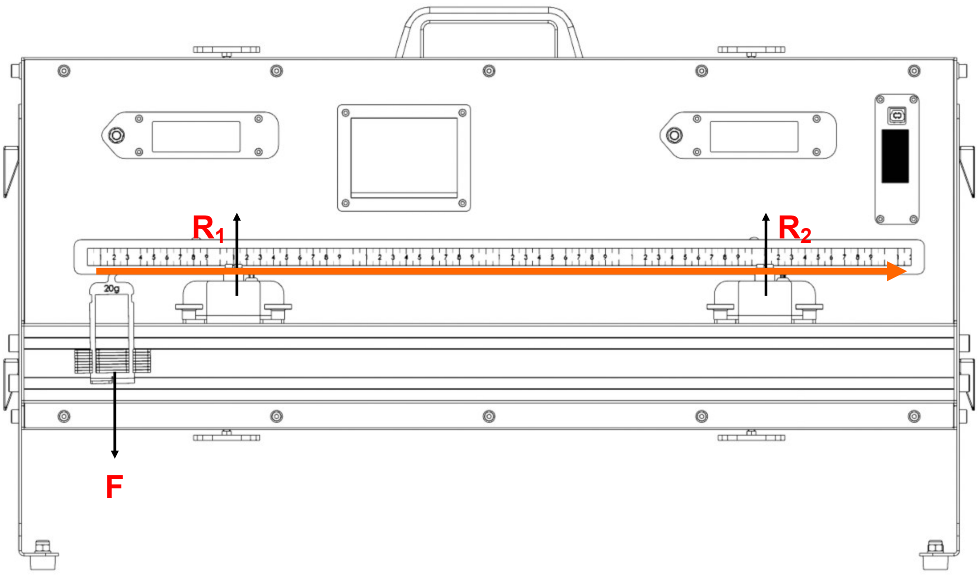
$$R_2 \times 100 = R_1 \times 300$$

$$R_2 = 3 \times R_1.$$

Investigation C

Single weight moving across beam

Over to you:



- Centre the beam on the load cell supports as before.
- Press the ‘zero’ buttons to eliminate the weight of the beam from the readings.
- Add the 100g mass hanger on the left most position
- Record forces R_1 and R_2, shown on the LCD displays in Table 3 of the Student Handout.
- Move the hanger along 1 position to the right
- Again, record the load cell readings.
- Continue in this way up along the beam.
- Complete Table 3

So what:

Once again, the beam is in equilibrium and so:

- the vertical forces cancel out;
- the clockwise and anticlockwise moments cancel out.

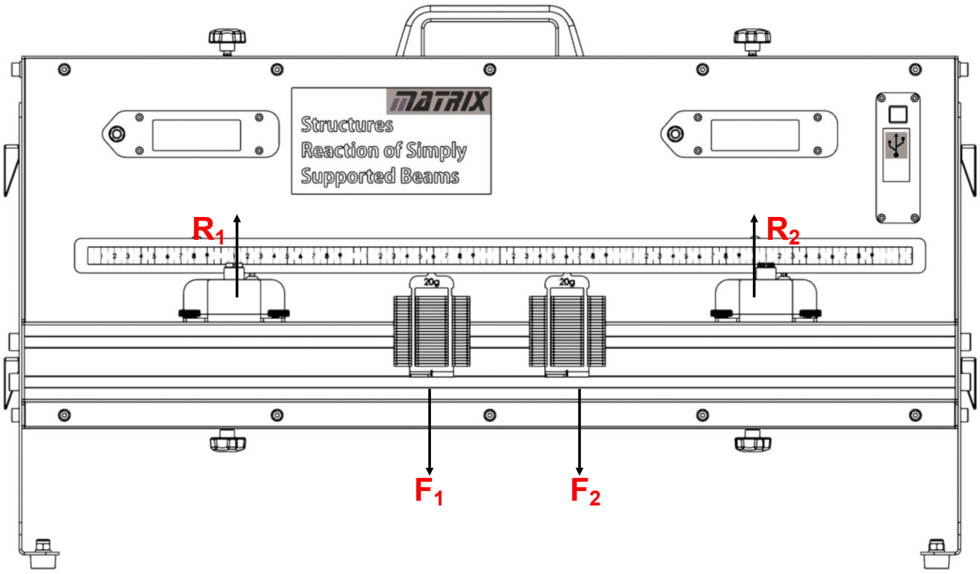
Hence: $F = R_1 + R_2$

The transfer of negative and positive reaction forces are shown as the weight moves inside and outside of the supports.

Investigation D

Two weights

Over to you:



- Centre the beam on the load cell supports as before.
- Press the 'zero' buttons to eliminate the weight of the beam from the readings.
- Add one 100g mass hanger on the second peg from the right-hand support (i.e. 100mm from the right-hand support) and a second hanger on the third peg from the left-hand support, (i.e. 250mm from the right-hand support) .
- As before, record forces R_1 and R_2, in Table 4 of the Student Handout.
- Increase the load on the beam, 100g at a time up to a maximum of 500g.
- Again, record all load cell readings and complete Table 4.

So what:

Once again, the beam is in equilibrium and so:

- the vertical forces cancel out;
- the clockwise and anticlockwise moments cancel out.

Hence: $F_1 + F_2 = R_1 + R_2$

Taking moments about the right-hand load cell support:

$$R_1 \times 400 = F_1 \times 250 + F_2 \times 100$$

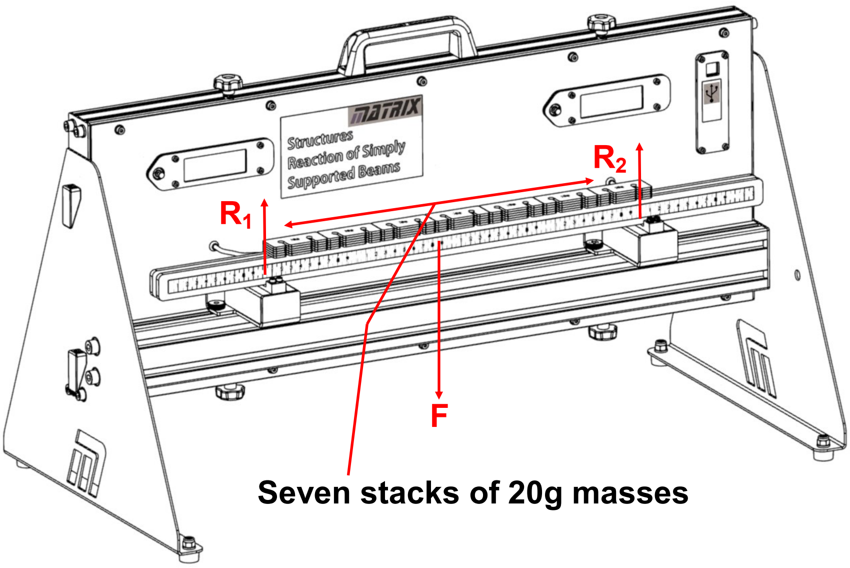
Challenges!

- Draw the free-body diagram for this arrangement.
- Test these equations for a different pair of forces F_1 and F_2 and for these two forces placed at different distances. Record your readings in Tables 5 and 6.
- What happens when you position the hangers outside the supports?

Investigation E

Uniformly distributed load at centre

Over to you:



- Centre the beam on the load cell supports as before.
- Press the 'zero' buttons to eliminate the weight of the beam from the readings.
- Spread seven individual 20g masses in a line along the beam between the two supports. This creates a uniformly distributed load (UDL).
- As before, record forces R_1 and R_2, in Table 6 of the Student Handout.
- Add seven more 20g masses to make seven stacks each 40g in mass.
- Again, record the load cell readings.
- Repeat this process until each stack contains five masses and has a mass of 100g. The total load is now 700g.
- Complete Table 7.

So what:

So far, the weight of the beam has been neglected, (by 'zeroing' the load cells before adding weight). When the beam weight needs to be considered, it can be represented in this way. The uniformly distributed load is spread evenly across the beam and can be represented by a point load situated at its centre, at the centre of the beam in this case.

As a result, the reaction forces are equal, as in the first setup and so $R_1 = R_2$

Taking moments about the right-hand support: $R_1 = F \times 200$

as the centre of the beam is 200mm from the support.

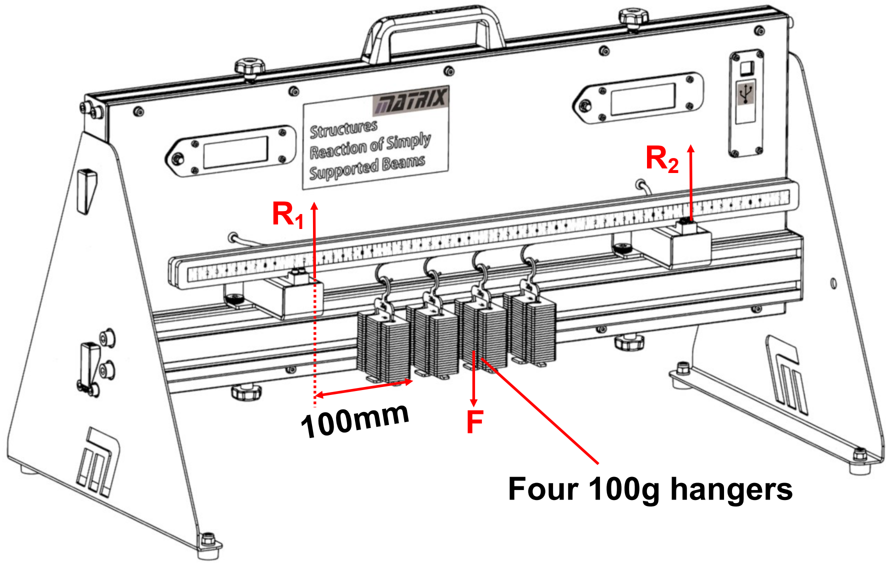
Challenge!

- Draw the free-body diagram for this arrangement.

Investigation F

Uniformly distributed load offset from centre

Over to you:



- Centre the beam on the load cell supports as before.
- Place four 'S' hooks on consecutive pegs, starting 100mm from the left support.
- Press the 'zero' buttons to eliminate the weight of the beam and hooks.
- Add mass hangers each with a total of 100g onto each 'S' hook.
- Record the load cell readings for R_1 and R_2 in Table 8 in the Student Handout.
- Add 100g masses to each hanger and record the resulting forces R_1 and R_2 in the table.
- Repeat this process until each hanger has a mass of 500g and complete Table 8.

So what:

This investigation shows what happens when the forces of the UDL act as a point load, in the centre of the uniform distributed load, but not at the centre of the beam.

Taking moments about the left-hand support: $R_2 \times 400 = F \times (100 + 75)$

as the UDL extends over 150mm and acts as a point load located at its centre.

Taking moments about the right-hand support: $R_1 \times 400 = F \times 225$

as the UDL acts as a point load located 225mm from the right-hand support.

Challenges!

- Draw the free-body diagram for this arrangement.
- Modify the arrangement to combine elements from previous setups. Draw the free-body diagram for the modified arrangement.
- Use it to calculate the expected values for the reaction forces.
- Compare these results with the measured values on the LCD displays and comment on the comparison.

Student Handout

Student Handout

A. Single weight applied at centre

Table 1:

A. Point Load at centre				
Load (g)	Load F (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
100	1			
200	2			
300	3			
400	4			
500	5			

Challenge!

Free-body diagram for setup **A**:

B. Single weight offset from centre

Table 2:

B. Point Load at 100mm from right support				
Load (g)	Load F (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
100	1			
200	2			
300	3			
400	4			
500	5			

C. Single weight moving across beam

Table 3:

C. Point Load Moving Across Beam				
Position	Distance from left (mm)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
1	-100			
2	-50			
3	0			
4	50			
5	100			
6	150			
7	200			
8	250			
9	300			
10	350			
11	400			
12	450			
13	500			

D. Two weights

Table 4:

D. Point Loads at 100mm and 250mm from right support						
Load 1 (g)	Load 2 (g)	Load F_1 (N)	Load F_2 (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
100	100	1	1			
200	200	2	2			
300	300	3	3			
400	400	4	4			
500	500	5	5			

Challenge!

Free-body diagram for setup **D**:

Table 4:

D. Point Loads at 100mm and 250mm from right support						
Load 1 (g)	Load 2 (g)	Load F_1 (N)	Load F_2 (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)

Table 5:

D. Point Loads at .... mm and ....mm from right support						
Load 1 (g)	Load 2 (g)	Load F_1 (N)	Load F_2 (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)

When you position the hangers outside the supports:

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E. Uniformly distributed load at centre

Table 7:

E. UDL at centre				
Total load (g)	Total load F (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
140	1.4			
280	2.8			
420	4.2			
560	5.6			
700	7.0			

Challenge!

Free-body diagram for setup **E**:

F. Uniformly distributed load offset from centre

Table 8:

F. UDL off-centre										
Load 1 (g)	Load 2 (g)	Load 3 (g)	Load 4 (g)	Load 1 (N)	Load 2 (N)	Load 3 (N)	Load 4 (N)	R_1 (N)	R_2 (N)	R_1+R_2 (N)
100	100	100	100	1	1	1	1			
200	200	200	200	2	2	2	2			
300	300	300	300	3	3	3	3			
400	400	400	400	4	4	4	4			
500	500	500	500	5	5	5	5			

Challenges!

Free-body diagram for setup **E**:

Free-body diagram for modified setup:

Calculations to determine $\mathbf{R_1}$ and $\mathbf{R_2}$:

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Comment on the comparison with the measured values:

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Notes for the Instructor

About this course

Introduction

This module allows students to investigate the effects of forces generated in simple beam structures through a structured sequence of practical investigations.

Using the kit, students complete a series of worksheets that focus on a number of topics found in BTEC Higher National and equivalent courses.

Aim

The course teaches students about the relationships between and effects of the forces arising in simple beam structures and their supports.

Prior Knowledge

It is expected that students have followed an introductory science course, enabling them to take, record and analyse scientific observations and appreciate the errors inherent in them.
Some mathematical capability is required.

Using this course:

It is expected that the Worksheets and Student Handout are printed / photocopied, preferably in colour, for the students' use.

Each worksheet includes:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows.

The Student Handout is a record of measurements taken in each worksheet and questions relating to them. Students do not need a permanent copy of the worksheets but do require their own copy of the Student Handout

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with progress through the worksheets. One way to do this is to 'sign off' each worksheet, as the student completes it, and in the process have a brief chat to assess the student's grasp of the ideas involved in the exercises it contains.

We realise that you as a subject area practitioner take the lead in determining how and what students learn. The worksheets are not meant to supplant this or any other supporting underpinning knowledge you choose to deliver. For subject experts, the 'Notes for the Instructor' are provided simply to reveal the thinking behind the approach taken.

For staff whose core subject knowledge is not in the field covered by the course, these notes can both illuminate and offer guidance.

Time:

It will take students between three and five hours to complete the worksheets. It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Notes for the instructor

Learning Objectives

On successful completion of this course, the student will be able to:

- describe three applications that involve the use of beams;
- state the function of a load cell;
- draw the symbols for simple, roller and pinned supports;
- calculate the moment of a given force about a point at a known distance from the force;
- explain what is meant by the term *‘equilibrium’* in terms of the forces acting on an object and their moments;
- calculate reaction forces for a simple beam of known weight in equilibrium on two supports;
- draw a free-body diagram for a body subject to a number of coplanar forces;
- explain what is meant by the term *uniformly distributed load (UDL)*;
- calculate the reaction forces for a uniformly distributed load in equilibrium on two supports;
- compare calculated and measured values for reaction forces and account for any differences in terms of systematic errors.

Notes for the instructor

Worksheet	Notes
Introduction Timing 10 - 20 mins	Concepts involved: load cell LCD display simple support roller support pinned support reaction force Instructors should offer a quick guide to the equipment, pointing out the load cells, their reset buttons and corresponding LCD displays. Depending on the previous experience of the students, the instructor may need to describe the difference between different types of support in terms of the reaction forces they can offer.
A Single weight applied at centre Timing 20 - 30 mins	Concepts involved: equilibrium moment of a force free-body diagram This is a good point at which to distinguish between free-body diagrams (FBD) and space diagrams. The instructor could lead a class discussion as to why the weight of the unloaded beam is eliminated at the outset of the investigation. There may be a need with some students to go through the calculations outlined in the ‘So what’ section. These are pivotal for the remainder of the module.
B Single weight offset from centre Timing 20 - 30 mins	This follows the same procedure and uses the same arguments as the previous section but for a point load that is displaced from the centre of the beam.
C Two weights Timing 20 - 30 mins	The procedure and arguments are the same but for a beam that supports two loads. Students then carry out their own variations using different loads at different distances. Faster, more able groups could be encouraged to investigate the effect of three or more loads. A class discussion could focus on the effect of placing the weights outside the supports.
D UDL offset from centre Timing 20 - 30 mins	Concepts involved: uniformly distributed load The aim is to show that the UDL has the same effect as a point load at the centre. This result shows how to manage a beam whose weight cannot be ignored.
E UDL at centre Timing 20 - 30 mins	Concepts involved: systematic and random errors Students investigate the effect of a UDL placed off-centre. Part of the plan here is to calculate the expected reaction forces and then compare the results with the measured values. It is hoped that the results are comparable but this creates a setting in which to discuss the effect of errors on the readings, both systematic and random.