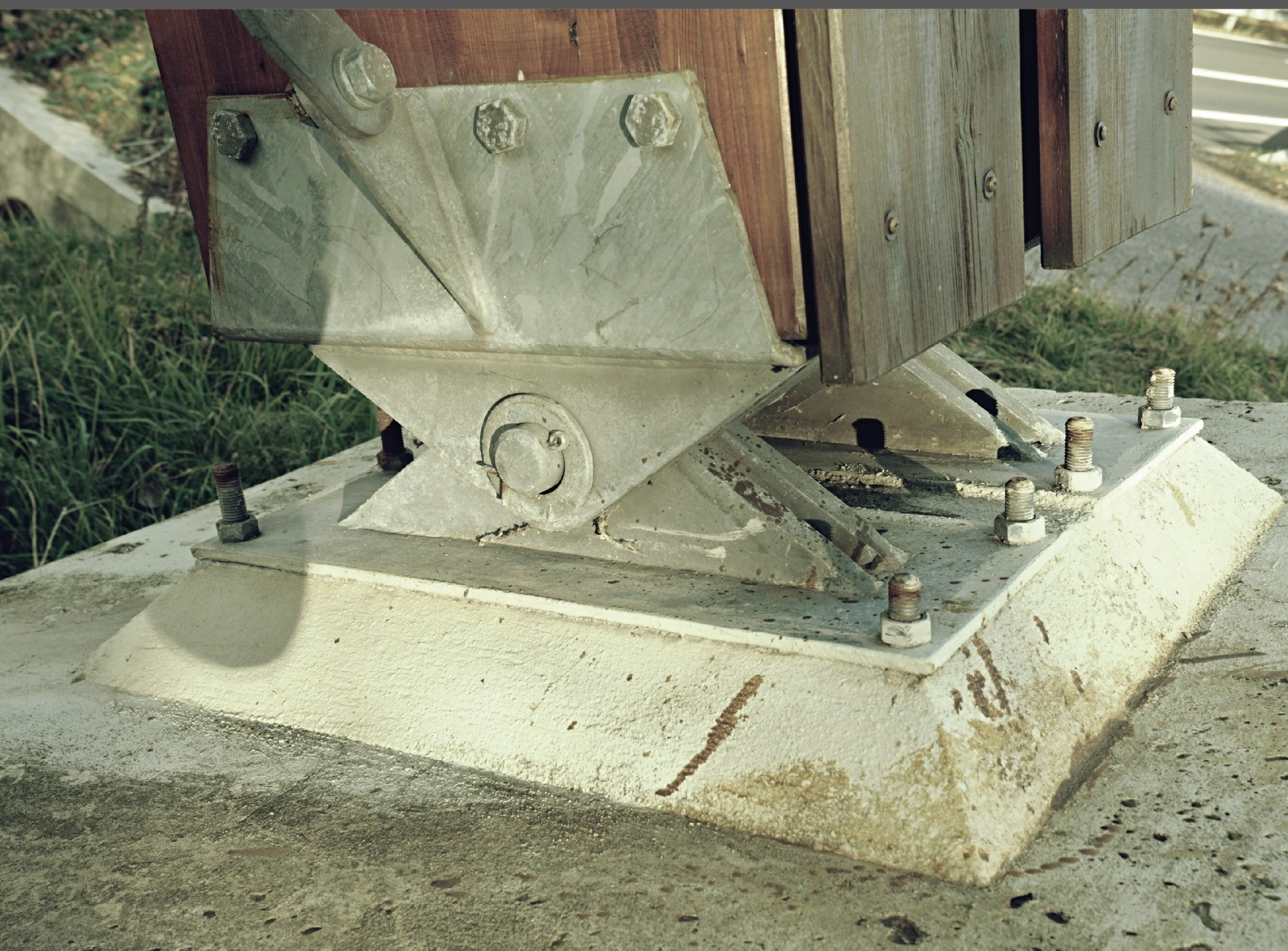


STRUCTURES

Shear Force



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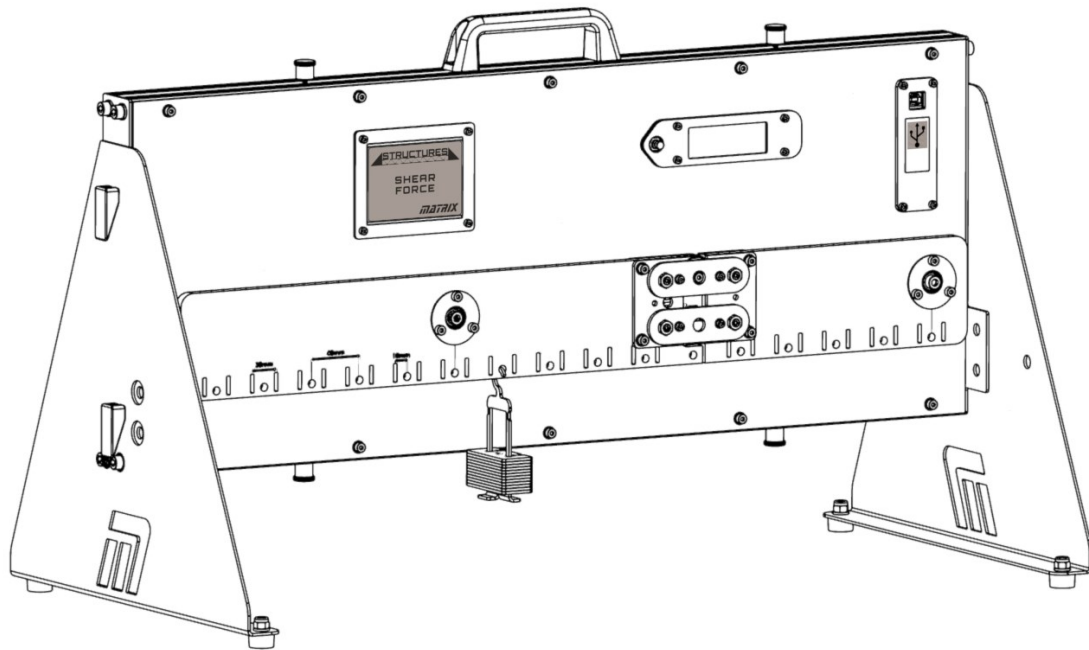
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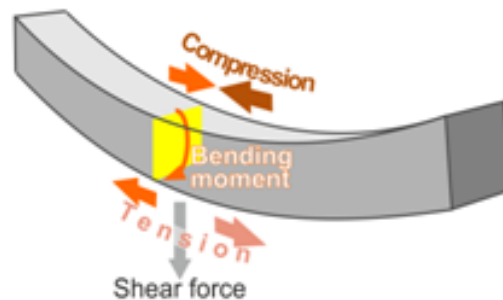
Shear Force

Worksheet 1 -	Changing the load	7
Worksheet 2 -	Moving the load	9
Worksheet 3 -	Multiple loads	11
Worksheet 4 -	Uniformly distributed load	12
Student Handout		14
Notes for the instructor		23



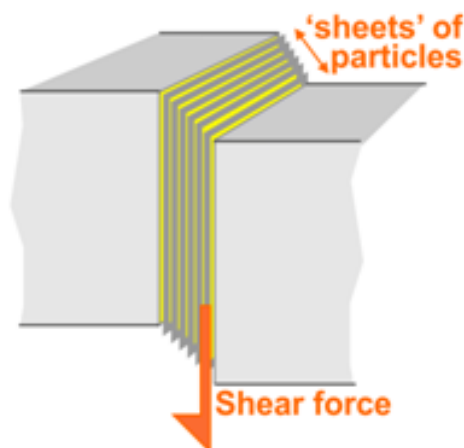
Background:

When a force acts on a structure such as a beam, it can make it bend or even crack. The particles making up the beam are attracted to each other - that is why the beam is a rigid object. Under the action of a downward-acting external force, they are squashed closer together near the top surface and stretched further apart near the lower edge.



Internally, these forces, viewed at a cross-section cut through the beam, can be looked on as a combination of a resultant force and a resultant couple. The resultant internal couple is called the **bending moment**. The resultant internal force is called the **shear force**.

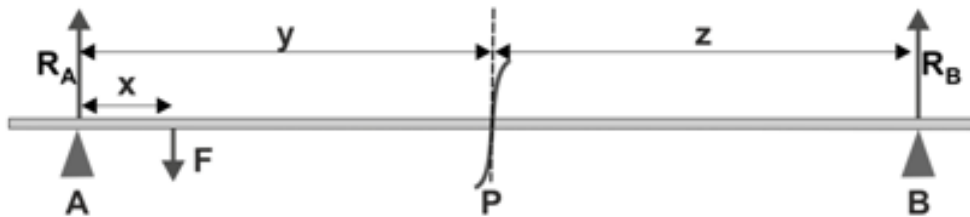
When this shear force is great enough, it can cause sheets of particles in the beam to slip over each other. It is rather like the effect of applying a sideways push to the top card in a pack of playing cards. The pack distorts as each card slides over the one beneath it.



Background

The diagram below shows the **external** forces acting on a beam of negligible weight, resting on simple supports, **A** and **B**, with a point load **F** acting on it. The supports exert reaction forces **R_A** and **R_B**. Looking at these forces, since the beam is in equilibrium:

$$R_A + R_B = F$$



An imaginary cut is made at point **P**. The section labelled **AP** is in equilibrium and so the forces acting on it must cancel out.

These forces are the reaction force **R_A** at support **A**, the force **F** and the shear force **V**.

The shear force is internal. An opposing equal internal shear force, acting just past slice P, cancels it out.



The equation given above shows that the force **F** is bigger than reaction **R_A**. Hence the shear force **V** must act vertically upwards to keep section **AP** in equilibrium.

Since this section is in equilibrium:

$$R_A + V = F$$

The force **F** is known. The reaction force **R_A** can be calculated by applying the principle of moments about support **B**.

Hence the shear force **V** can be calculated.

(Alternatively, looking at the segment **PB**, which is also in equilibrium:

$$V = R_B$$

Reaction force **R_B** can be calculated by applying the principle of moments about support **A**.)

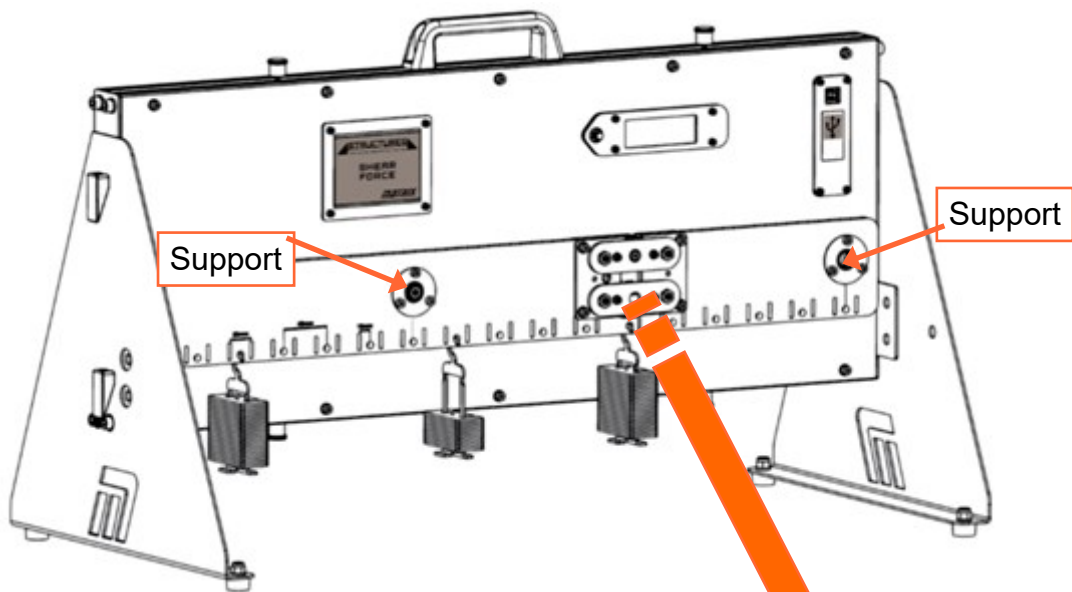
The apparatus:

The 'Structures - Shear Force' apparatus allows us to investigate this internal shear force. It consists of a beam, supported at two points, divided into two sections linked by a pivot.

A load cell, spanning the gap between the sections, measures the force between the two sections. From this, the shear force at that slice can be calculated.

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.

Detail of load cell assembly:



These two bars are part of the linkage system that ensures that the two sections of the beam move parallel to each other, reflecting the effect of the shear force.

Worksheet 1

Changing the load

The design of a structure determines the loads it is capable of carrying. It can be dangerous to exceed the maximum load.

For a bridge like the one in the photograph, the weakest point is usually at the centre of the span.

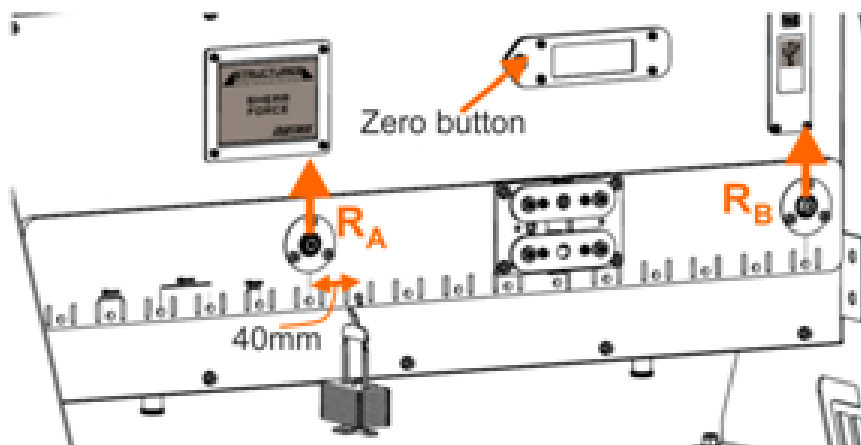
The structural engineer must be able to predict the effects of different loads on the structure.

This experiment explores the effect that changing the load on a beam has on the resulting shear force.



Over to you:

- Make sure that the device is level.
- Press the button on the LCD display to zero the equipment.
This eliminates the weight of the beam and load cell in later calculations.
- Place an empty mass hanger 40mm (one hole) away from the left-hand support, as shown in the diagram below.
- Record the load measured by the load cell, either in a spreadsheet or in the table in the Student Handout.
- Increase the mass on the hanger in 40g steps, to a maximum of 300g and record the measured load each time.



Worksheet 1

Changing the load



Over to you

- Use the formulae given in the Student Handout to determine:
 - the reaction force R_B ;
 - the measured and calculated values of shear force, V .
- Use the axes provided to plot graphs of measured shear force vs suspended load and calculated shear force vs suspended load.
- In the Student Handout, answer the question on how to obtain the value of the reaction force R_A .

So What?

The calculated and the experimentally measured shear force produce very similar traces on the graphs, showing that the equations used to obtain the calculated value are robust and can be used to predict beam behaviour.

Challenge:

- Use the free body diagram provided in the Student Handbook to complete the shear force diagram for this set-up when the applied load is at its maximum (2.94N).

Worksheet 2

Moving the load

The job of a crane, like the tower crane shown opposite, is to move heavy loads from one location to another.

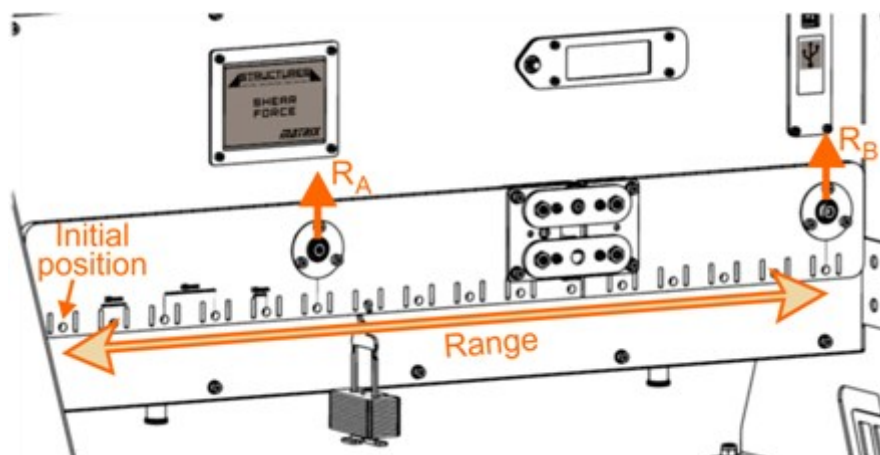
In the process, as the load moves, the stresses it produces on the structure of the crane change. The crane must be designed to withstand the maximum stress. The design engineer must be able to predict what that maximum will be.

This experiment explores the effect of moving a fixed load along the beam on the resulting shear force.



Over to you:

- Make sure that the device is level.
- Press the button on the LCD display to zero the equipment and eliminate the weight of the beam and load cell.
- The experiment uses a fixed load of 300g (2.94N). Place a 300g mass hanger initially at the left-hand end of the beam, as shown in the diagram below.
- Record the load measured by the load cell either in a spreadsheet or in the table in the Student Handout.
- Move the 300g mass hanger along to the next hole on the right (i.e. 40mm from the initial position,) and record the new load cell reading.



Worksheet 2

Moving the load



Over to you.....

- Continue in this way, moving the 300g load along the beam, hole by hole, and recording the load cell readings.
- Use these readings to calculate the reaction forces at supports **A** and **B** for each position. Hence determine the measured and calculated values of shear force.
- Plot graphs of measured shear force vs distance and calculated shear force vs distance. Suitable axes are provided in the Student Handout.
Choose a suitable scale for the vertical axis and add appropriate labels to show your choice.

So What?

The shear force produced by the load depends on exactly where the load is applied. When the load is directly below a support, there is no shear force at the load cell slice. When the load reaches the slice, the shear force there changes sign. The load cell is initially under tension and then suddenly under compression as the load moves past.

Challenge:

- Confirm these findings by repeating the process using a different load. To streamline the investigation, move the new load in steps of 80mm (two holes).
As in the first part, record the results either in a spreadsheet or in the table in the Student Handout.

Worksheet 3

Multiple loads

The first two investigations looked at the effect of a single load on the beam.

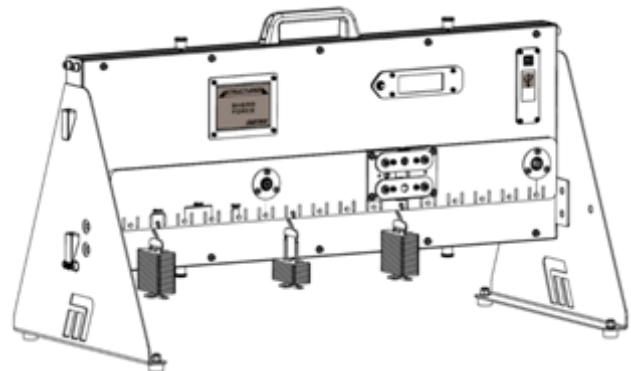
In real life, structures have to withstand many loads simultaneously. However, the principle of superposition of forces says that the overall effect of many loads is simply the sum of their individual effects.

In other words, the approach used in earlier investigations, for a single load, is equally valid here.



Outline:

Investigate the overall effect on shear force of placing three different loads at three different places on the beam.



Over to you:

Challenge:

- Set up three different loads in different positions on the beam.
- Record their weights, their positions and the resulting load cell reading.
- Calculate the resulting shear force at the slice using the measured load cell force.
- In the Student Handout, draw the free body diagram for this system.
- Apply the principle of moments to derive the reaction forces generated by the supports.
- Calculate the theoretical shear force at the slice using one of these reaction forces.
- Check this value by calculating it again, using the other reaction force.
- Using either tables drawn in the Student Handout or a spreadsheet, record the results and your calculations.
- Repeat the same process for three different loading arrangements.

Worksheet 4

Uniformly distributed load

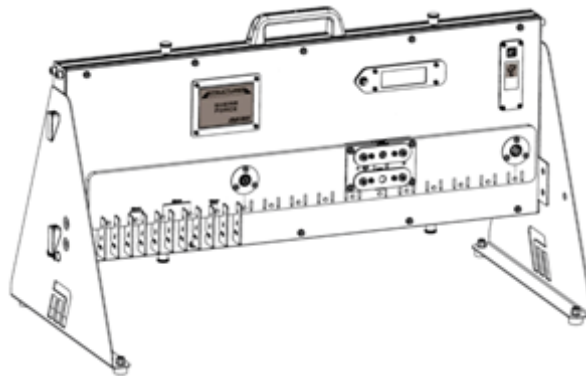
So far, we have considered only point loads, whose effects are concentrated at specific points in the structure. Very often, real-world loads are distributed, i.e. spread out over a region.

A uniformly distributed load (UDL) is a load which is spread in such a way that each unit length of the structure is loaded to the same extent.



Outline:

The aim is to investigate the effect on shear force of a uniformly distributed load situated on the left-hand end of the beam.



Over to you:

Challenge:

- Create the uniformly distributed load by placing eleven 20g masses in adjacent holes at the left-hand end of the beam, as shown in the diagram, creating a load of 2.16N.
- Record the resulting load cell reading.
- Calculate the shear force at the slice using this measured load cell force.
- In the Student Handout, draw the free body diagram for this system.
- Use the principle of moments to derive the reaction forces generated by the supports.
- Hence, calculate the theoretical shear force at the slice .
- Check this value by calculating it again, using the other reaction force.
- Using either tables drawn in the Student Handout or a spreadsheet, record the results and your calculations.

Worksheet 4

Uniformly distributed load



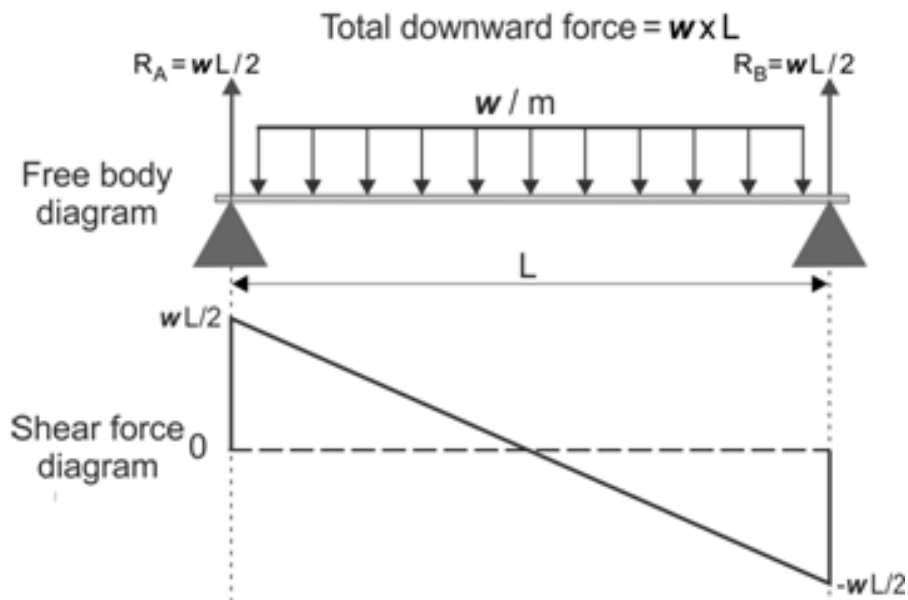
So what:

The last investigation looked at three point loads.

Imagine a huge number of point loads sitting next to each other - this is a distributed load.

The fact that it is a distributed load does not affect the resulting reaction forces at the supports but does affect the shear forces produced.

The diagram shows the effect of a uniformly distributed load on the resulting shear force. One consequence of this is that UDLs are less likely to cause a structure to bend or fail than are point loads.





Student Handout

Worksheet 1 - Changing the load

Mass m of load in g	Weight F of load in N	Reaction force R_B in N	Calculated shear force V in N	Load cell reading c in g	Load cell reading L in N	Measured shear force V in N
20						
60						
100						
140						
180						
220						
260						
300						

Complete the table using the following formulae:

Weight = mass x gravitational field strength.

where gravitational field strength = 9.81 N.kg^{-1} .

(Notice, all masses must be in kg.)

Hence: $F = m / 1000 \times 9.81$ and $L = c / 1000 \times 9.81$

Applying principle of moments to **external** forces exerting moments about support **A**:

$$R_B \times 0.4 = F \times 0.04 \Rightarrow R_B = (F \times 0.04) / 0.4$$

Looking at the segment **PB**, which is in equilibrium:

$$V = R_B$$

How would you use the above results to obtain values of the reaction force R_A at support **A**?

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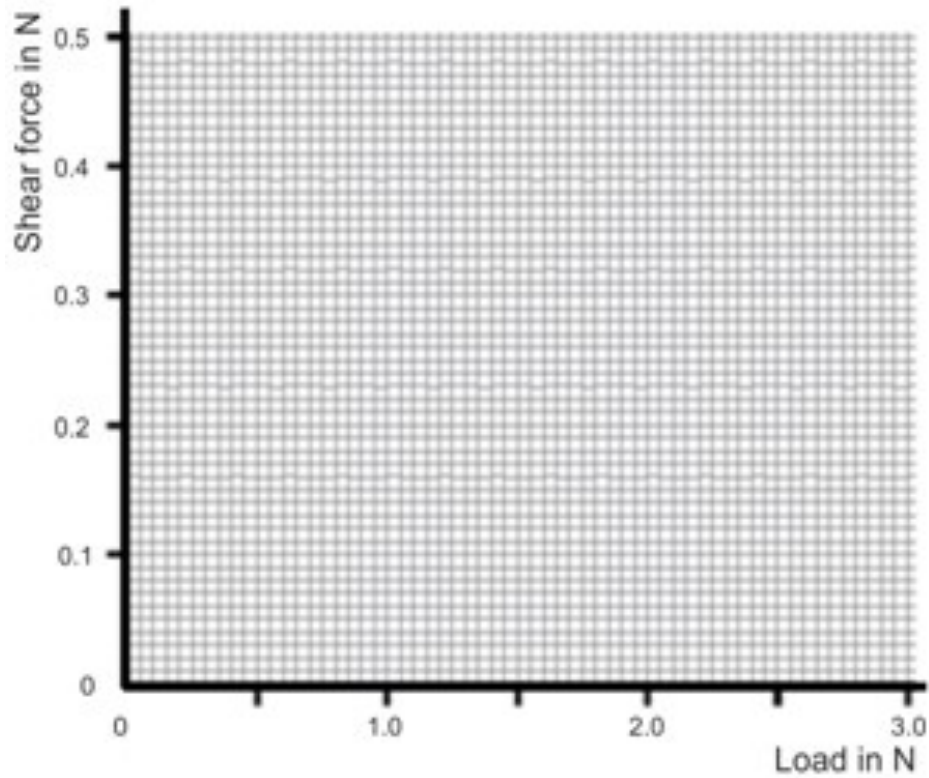
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Worksheet 1

Graphs of shear force vs suspended load for both measured and calculated values:

Show your measurements as small crosses.

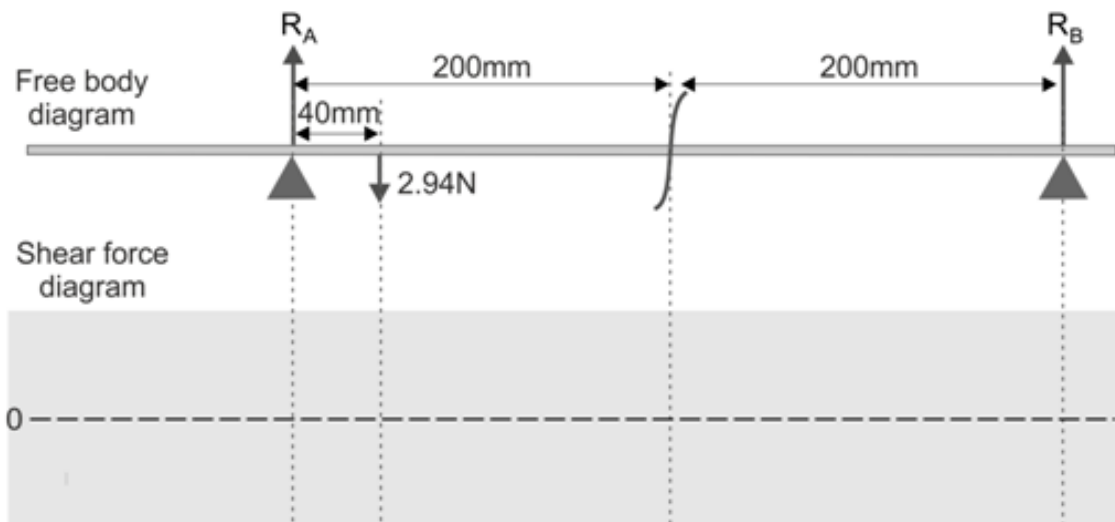
Use different colours for the two traces so that you can distinguish between them easily.



Chal-

enge:

Free body diagram for an applied load of 2.94N (maximum load).



Worksheet 2 - Moving the load

1. Load = 300g:

Distance x from left in m	Load cell reading c in g	Load cell reading L in N	Reaction force R_A in N	Reaction force R_B in N	Measured shear force V in N	Calculated shear force V in N
0						
0.04						
0.08						
0.12						
0.16						
0.20						
0.24						
0.28						
0.32						
0.36						
0.40						
0.44						
0.48						
0.52						
0.56						
0.60						

Challenge:

2. Load =:

Distance x from left in m	Load cell reading c in g	Load cell reading L in N	Reaction force R_A in N	Reaction force R_B in N	Measured shear force V in N	Calculated shear force V in N
0						
0.08						
0.16						
0.24						
0.32						
0.40						
0.48						
0.56						
0.60						

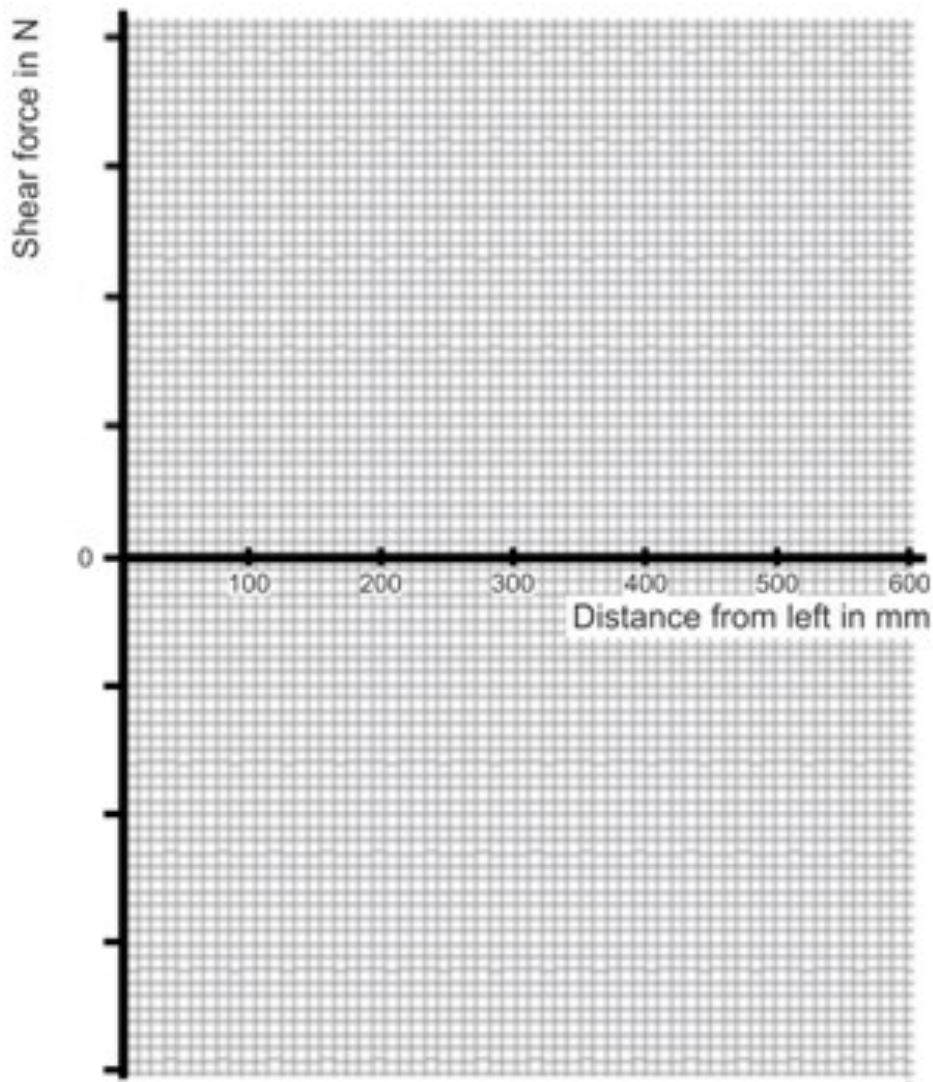
Worksheet 2

For the load of 300g, plot graphs of **measured** shear force vs distance **x** and **calculated** shear force vs distance **x** on the same axes

Graph of shear force vs distance along the beam:

Show your measurements as small crosses.

Use different colours for the two traces so that you can distinguish between them easily.



Student Handout



Worksheet 3 - Multiple loads

Use the following space to draw tables for your results if you wish.

Free body diagram of the arrangement:

Student Handout



Worksheet 4 - Uniformly distributed load

Use the following space to draw tables for your results if you wish.

Free body diagram of the arrangement:

Notes for the Instructor

About this course

Introduction

The 'Structures - Shear force' module introduces students to the concept of shear force, one result of applying a load to a beam.

Using the kit, students complete a series of worksheets that focus on a number of topics found in BTEC Higher National and equivalent courses. Initially, these worksheets provide full details of the investigations. Eventually, that 'scaffolding' is reduced, encouraging students to demonstrate their knowledge and understanding to new situations.

Aim

The course teaches students about the relationships between applied loads and the resulting shear forces.

Prior Knowledge

It is expected that students have followed an introductory science course, enabling them to take, record and analyse scientific observations. Some mathematical capability is required - ability to take readings from an analogue scale, ability to understand the transposition of formulae, ability to use a calculator to perform calculations and ability to plot a graph.

Using this course:

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

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 are 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 Instructors' 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.

A similar length of time will be needed to support the learning that takes place as a result.

Learning Objectives

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

- describe how compressive and tensile forces in a loaded beam give rise to a shear force;
- calculate the moment of a given force around a specified point;
- apply the principle of moments to a beam in equilibrium;
- use data about the forces acting on a beam in equilibrium and their positions to calculate the shear force generated at a particular slice through the beam;
- describe the function of a load cell;
- 'zero' a load cell;
- use a load cell to obtain a measured value of shear force;
- given data about the forces acting on a beam and their positions, draw:
 - a free-body diagram;
 - and a shear force diagram.

to represent the arrangement;

- investigate how the shear force produced by a point load changes as the point at which the load is applied moves along the beam;
- devise an experiment to investigate the principle of superposition of forces on a beam subjected to several simultaneous forces;
- apply the principle of superposition of forces to obtain the overall effect of multiple point forces acting simultaneously on a beam;
- distinguish between a point load and a uniformly distributed load;
- devise an experiment to investigate the effect of a uniformly-distributed load on the resulting shear force in a beam.

Worksheet	Notes
<p>Introduction</p> <p>Timing 15 - 20 mins</p>	<p>Concepts involved: compressive force tensile force shear force moment bending moment couple equilibrium load cell</p> <p>The introduction seeks to show how the process causing a beam to bend can be described as the result of a bending moment and a shear force. The instructor may choose to develop further the ideas outlined here.</p> <p>In particular, depending on the previous experience of the students, it may be thought advantageous to explore the implications of 'equilibrium' for a body subjected to a system of forces and moments. It is important that they understand the formulae given on page 5.</p>
<p>1 Changing the load</p> <p>Timing 30 - 45 mins</p>	<p>Concepts involved: mass weight gravitational field strength free body diagram shear force diagram</p> <p>As this is the first time students have used this equipment, some may need guidance.</p> <p>Depending on their mathematical ability and experience, students may need help in understanding the argument given in the Student Handout which leads to a formula for the theoretical value of shear force.</p> <p>The measurements are used to plot graphs that should justify the validity of the formulae used to calculate the theoretical value of shear force.</p> <p>Where students are unfamiliar with the procedure for drawing free body and shear force diagrams, the instructor should support them through a number of exercises before they tackle the challenge here.</p>
<p>2 Moving the load</p> <p>Timing 30 - 45 mins</p>	<p>There are no new concepts.</p> <p>The techniques used here mirror those in the previous investigation. Previously, a varying load was applied at a fixed location. Here, a constant load is moved to a variety of locations. The students need to be aware of this comparison to help them in later investigation designs.</p> <p>The measurements are processed in the same way as before.</p>

Worksheet	Notes
<p>3 Multiple loads</p> <p>Timing 40 - 60 mins</p>	<p>There are no new concepts.</p> <p>The students design their own investigation into the effect of multiple loads on the shear force produced. An initial discussion on factors to consider in designing the investigation could help to distinguish between what is relevant and what is not.</p> <p>The instructor could allocate different loads and load positions to different groups. They could later share their findings and be asked to justify their approach to other groups in a class discussion.</p> <p>The techniques they require are those practised in the previous investigations.</p>
<p>4 Uniformly distributed load</p> <p>Timing 40 - 60 mins</p>	<p>Concepts involved: uniformly distributed load</p> <p>Depending on the students' experience, an initial discussion might be needed to compare point loads and distributed loads, with examples of each. The instructor could give an overview into the different types of distributed load to avoid the misapprehension that all distributed loads are uniformly distributed.</p> <p>Once again, the students design their own investigation, this time, on the effect of a uniformly distributed load on shear force. The results could be shared via group presentations.</p> <p>As an extension, students could explore the effects of other forms of load distribution.</p> <p>In the 'So what' section, diagrams show the relationship between the UDL and the resulting shear force. This may not be immediately apparent to students without further support from the instructor.</p>