STRUCTURES

Trusses

CP1673

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Contents

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Check the loading!

The engineer designing a frame structure must analyse the loading of each member in it, over the full range of loads expected.

Some members will be in compression while others are in tension.
Some are zero force members, with no internal forces at all, used to increase the stability and rigidity of the structure.

Different materials have different properties. Some perform better under compression, while others are better under tension. This analysis helps to select appropriate materials and determine suitable dimensions.

The experiments in this module allow us to compare calculated values of the forces in the beams and columns with measured values. The aim is to validate the techniques used in the calculations.

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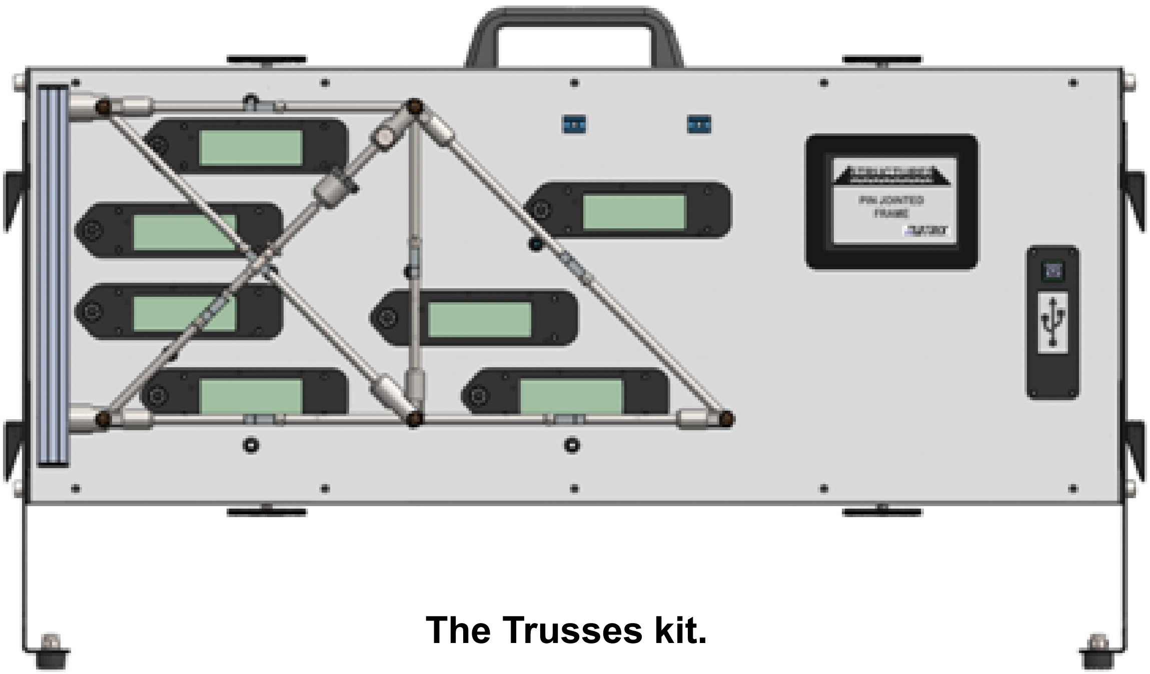
Introduction

In this module, students investigate the load distribution within perfect and redundant trusses, consisting of members linked by pin joints.

They check their measured values against forces calculated from theory, to confirm the validity of the theory.



The Trusses kit.

The framework is fixed at its left-hand end to a beam, simulating a reaction wall.

Each of the stainless steel members has, at its mid-point, a load cell linked to a LCD display, measuring the tension / compression force within each member. A positive LCD reading indicates compression in the member and a negative reading tension.

There are two hanging positions, allowing students to explore the effects of redundancy in frameworks. A magnetic pulley allows students to apply angled loads as well.

The kit includes one removable redundant member, enabling students to convert between the truss types. This incorporates a twisting mechanism to adjust its length.

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.

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Introduction...

Pin joint:

A pin joint can resist both vertical and horizontal forces but not a moment. It has only one degree of freedom, allowing rotation about a single axis but no translational motion.

Types of truss:

A truss can be classified as being either:

- a perfect truss;
- an imperfect truss;
- or a redundant truss.

depending on the number of members, **m**, compared to the number of joints, **j**.

Perfect truss: fulfils the condition: $m = 2j - 3$

Every member is essential for the stability and load-bearing capacity of the structure. This ensures an efficient distribution of loads throughout the truss, maximizing its strength-to-weight ratio.

Imperfect truss: fulfils the condition: $m < 2j - 3$

The number of members in the structure is less than that required for stability. An imperfect truss collapses when a load is applied to it.

Redundant Truss: fulfils the condition: $m > 2j - 3$

A redundant truss more members than needed to be a perfect truss.

Redundant trusses do not collapse when loaded.

Redundant truss members allow the structure to distribute loads in different ways, producing a number of load paths. This provides a safety margin against changes in loading conditions or the failure of individual members.

With the redundant member disengaged, students learn to analyse forces in the other truss members using the ‘Method of Joints’ and ‘Method of Sections’ and Bow’s notation.

With the redundant member engaged, they learn to analyse the forces using the ‘Method of Virtual Work,’ in addition.

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Introduction...

Perfect vs redundant:

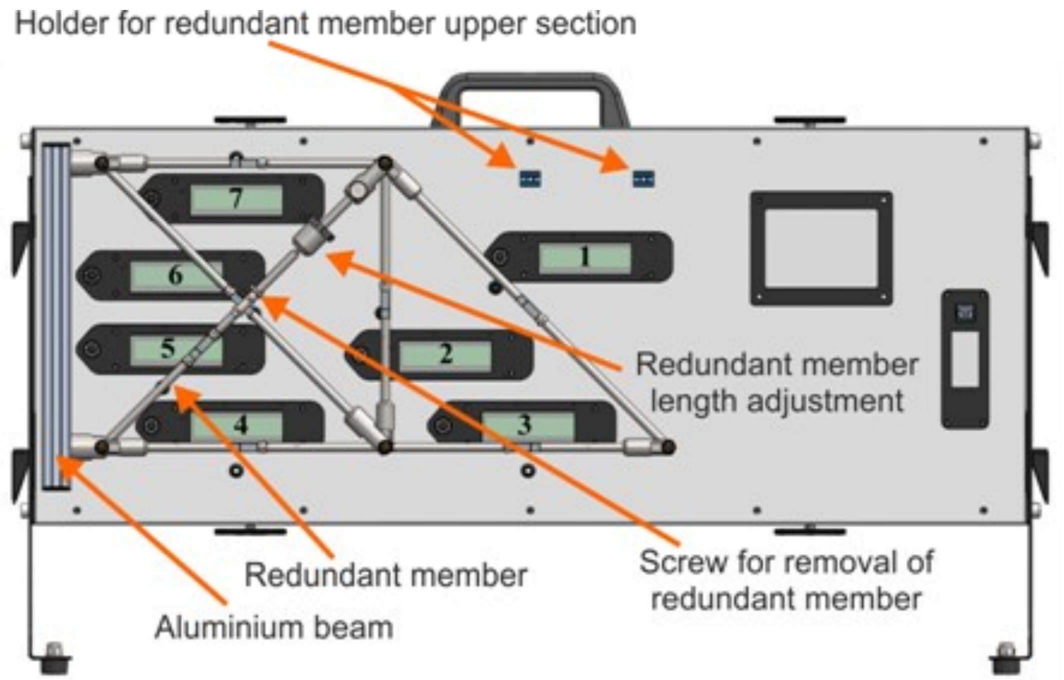
With all seven members in place, the framework acts as a redundant truss. There are eight members, including the reaction wall, and five joints, so that

$$\mathbf{m} > 2\mathbf{j} - 3$$

With the redundant member removed, the framework acts as a perfect truss, with only seven members, including the reaction wall, and five joints, so that

$$\mathbf{m} = 2\mathbf{j} - 3$$

To convert it to a perfect truss (ie. Pin Jointed Frame) :



- Slacken and remove the thumb screws holding the redundant member in place.
- Clip the upper sections of the redundant member into the holder provided.
- Turn the lower section so that it leans against the aluminium beam at the left-hand end.

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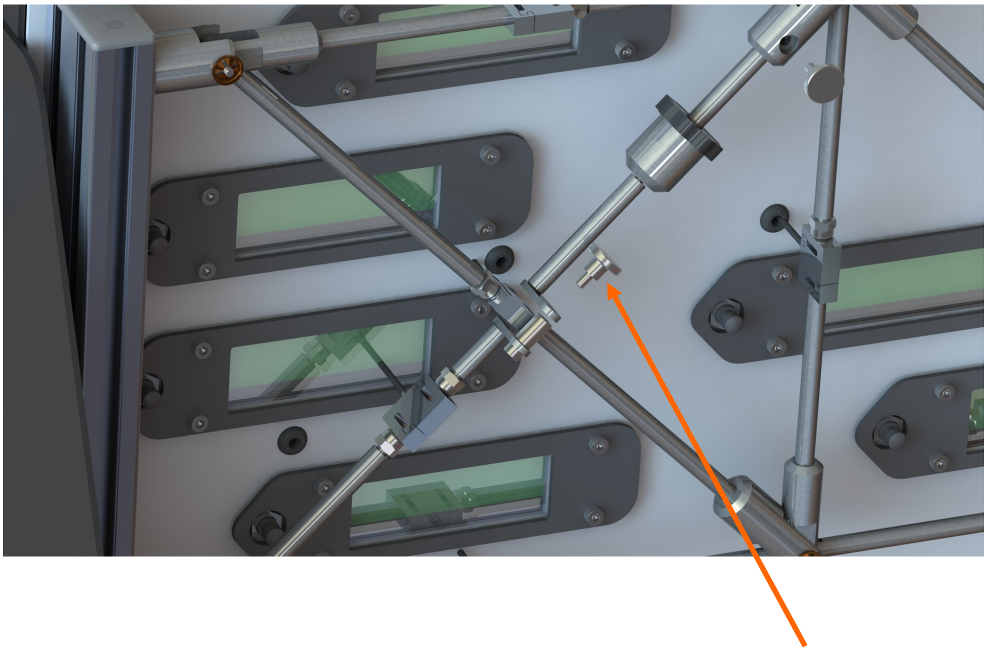
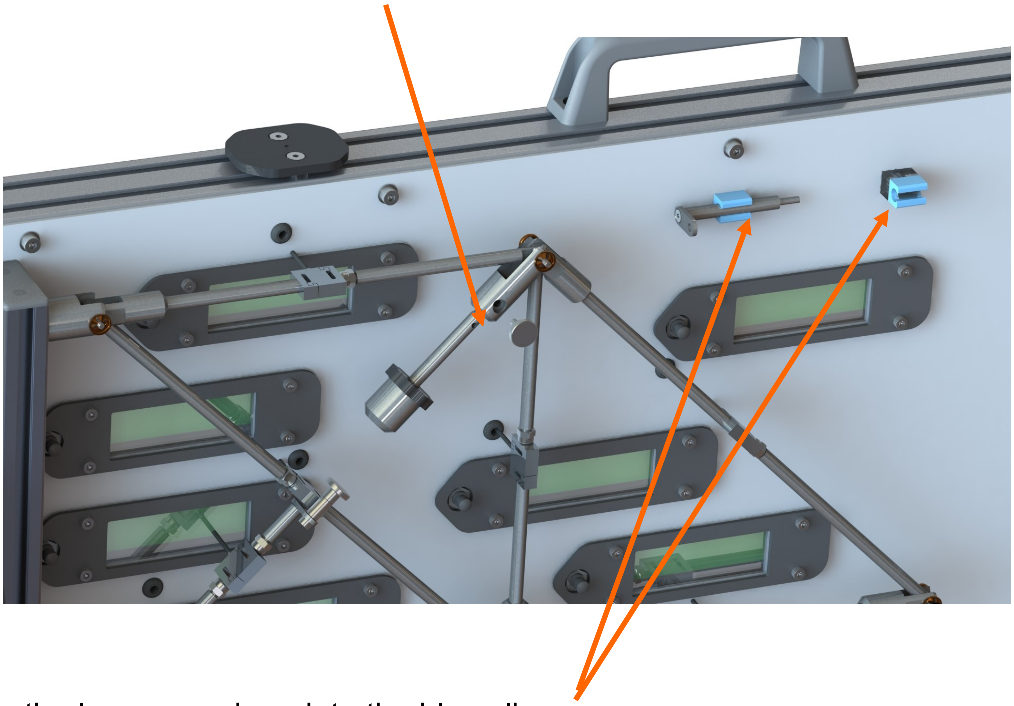
Introduction...

- Slacken the thumbscrew used to adjust the length of the redundant member.



- Screw out the top section of the redundant trusses member from the pivot



- Clip the loose members into the blue clips

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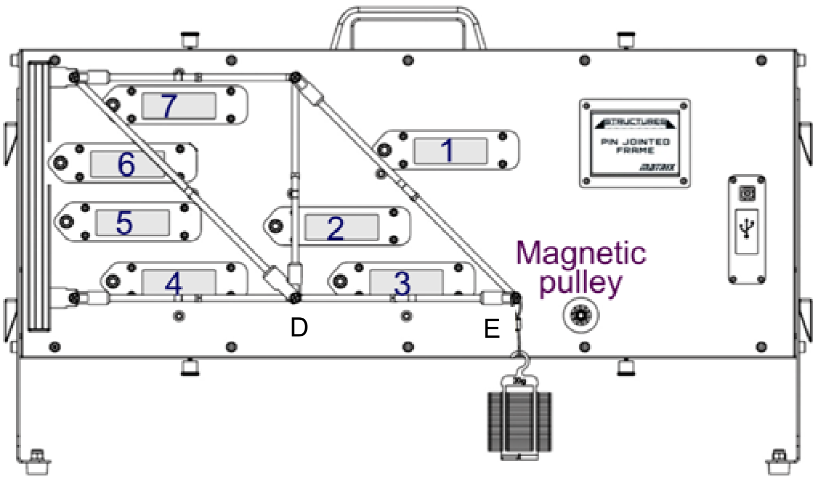
Perfect truss

In each investigation:

- Make sure that the device is level.
- Disconnect the redundant member.
- The diagram shows numbers for each of the LCD displays to allow you to record their readings in the Student Handout.



- Before you start, press the buttons on the LCD displays to zero the load cells. (This subtracts the weight of the frame from later readings.)

  The displays turn green when they have done so.

  Readings can either be taken manually or using data transfer via the USB port direct to a spreadsheet

  The displays show the loads in grammes.

  To obtain the load as a force, in newtons:
    - divide the reading by 1000 to convert it into kilogrammes;
    - multiply the result by 9.81, the gravitational field strength.

  You now have the load expressed as a force.

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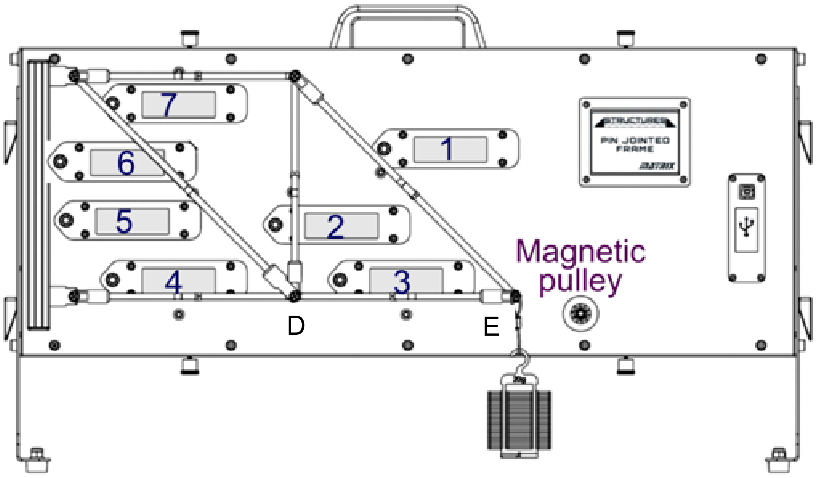
Perfect truss

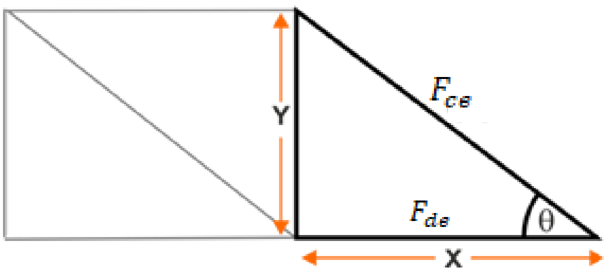
Investigation A - Load applied to joint **P**

Over to you:

- Suspend a total 100g from joint **E** on the frame, using a loop of string. The empty hanger has a mass of 20g.



- Take each load cell reading.
  Convert it into the force within that member, as described earlier.
- Record it in table in the Student Handout.
  The table uses Bow's notation (see 'Reference section',) to identify frame members and its corresponding load cell.
- Increase the load by adding a 40g mass to the mass hanger and record the new force readings.
- Continue in this way until the mass hanger carries a total of 300g.
- Next, measure:
  - angle θ between frame members at joint **E**, it should be 45deg
  - lengths **X** and **Y** of members **CE** and **DE**.
- Record them in the Student Handout.



So what:

- Calculate the theoretical value of the forces in each member, using one of the methods described in the Reference section.
- Record your results in the second table in the Student Handout.

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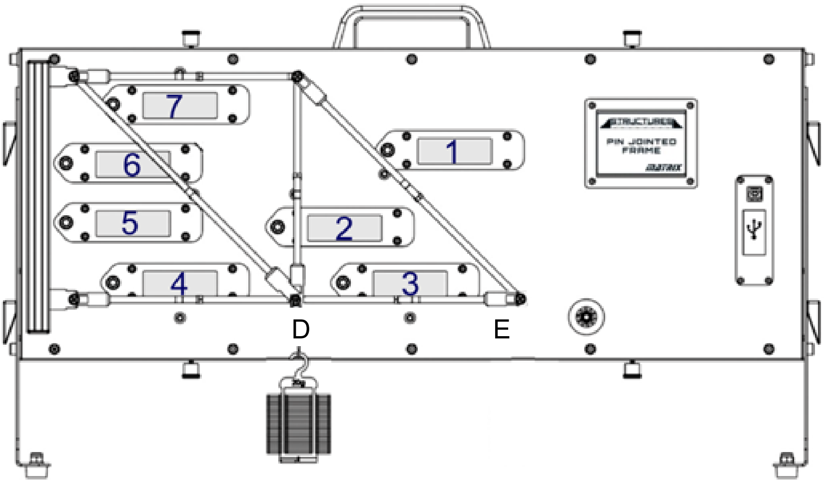
Perfect truss

Investigation B - Load applied to joint **D**

Over to you:

- Move the mass hanger from joint **E** to joint **D** on the frame.



- With the mass hanger with total load of 100g take each load cell reading and convert it into the equivalent force.
- Record it in the first table in the Student Handout.
- As before, increase the load in 40g steps until the total mass of the load is 300g.
- Record the load cell readings as forces in the Student Handout each time.

Challenge:

- Use the method of joints analysis to obtain equations for the forces in the six members of the frame with the load at joint **D**.
- Give your analysis in the space provided in the Student Handout.
- Hence, calculate the forces in each member.
  (Hint - you will find that there are some zero force members.)
- Record your results in the second table in the Student Handout.

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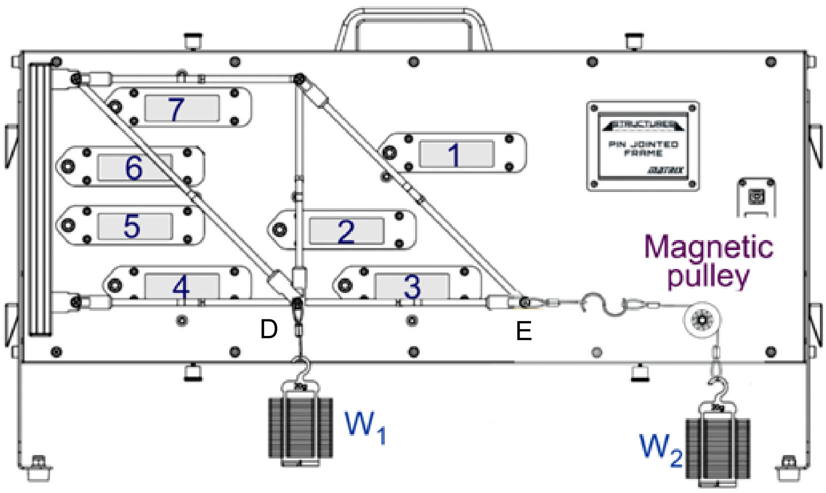
Perfect truss

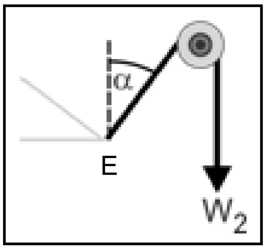
Investigation C - Multiple loads

Over to you:

- This time, one mass hanger is still attached to joint **D** with a second one attached to joint **E** using the magnetic pulley to apply the load at an angle α, as shown in the diagram.



- Load the mass hangers and move the magnetic pulley to the set up the first set of values for loads $\mathbf{W_1}$ and $\mathbf{W_2}$, and angle α given in the Student Handout table.



- Record the resulting load cell readings in the table.
- Repeat the process for the other values given in the table.
- Each time, record the results in the table in the Student Handout.

Challenge:

- Using one of the methods outlined in the Reference section, and free body diagrams obtain equations for the forces in the six members of the frame when loaded in this way.
- Record your diagrams and analysis in the space provided in the Student Handout.
- Hence, calculate the forces in each member.
- Record your results in the second table in the Student Handout.

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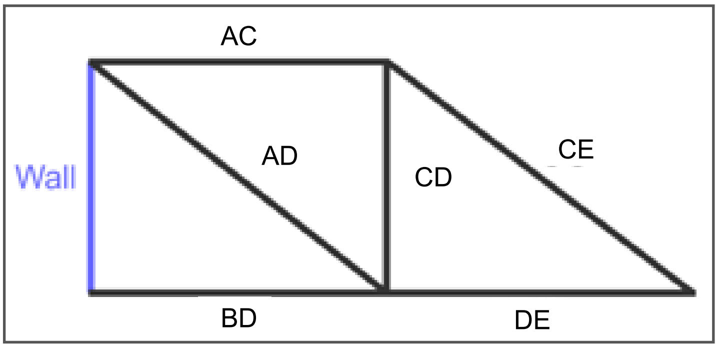
Perfect truss

Summary so far:



- Triangulated frameworks like this are often used in structures such as bridges and roof supports. Their analysis and design can be greatly simplified by treating the joints as pin joints.

- The positions and sizes of external forces such as loads and reaction forces determine the loading pattern across a structure. Analysis like that shown earlier can be used to optimise designs and identify zero force structural members.

- Topology optimization is the mathematical technique used to refine the design of a structure within specified boundary conditions. For example, it could be used to reduce the number of beam elements in the truss, depending on the loading conditions.

- The loading pattern can have a big effect on the force within a structural member. The angle at which a load is applied can determine whether a member is in tension or compression, which can then influence the choice of material for that member. For example, wood is 30% stronger under compression than in tension.

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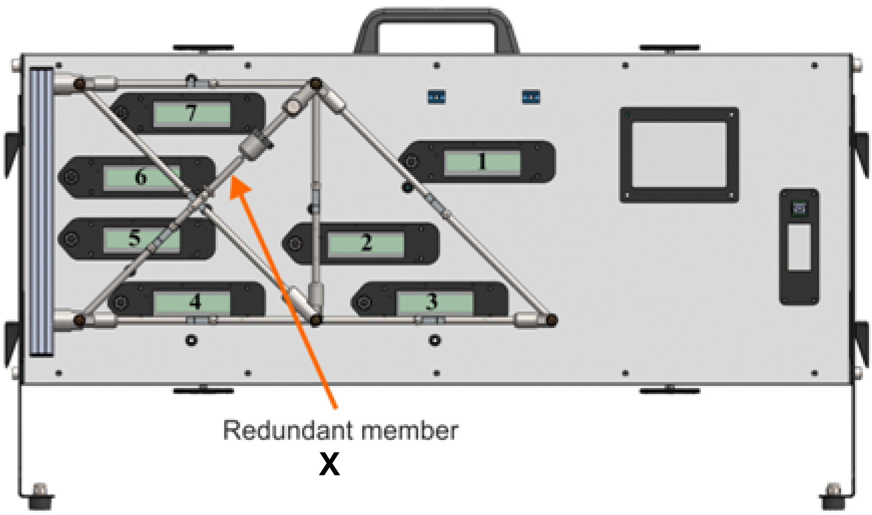
Redundant truss

In each investigation:

- Make sure that the device is level.
- Reconnect the redundant member, labelled **X**.



A reminder - the displays show the loads in grammes.

To obtain the load as a force, in newtons:

- divide the reading by 1000 to convert it into kilogrammes;
- multiply the result by 9.81, the gravitational field strength.

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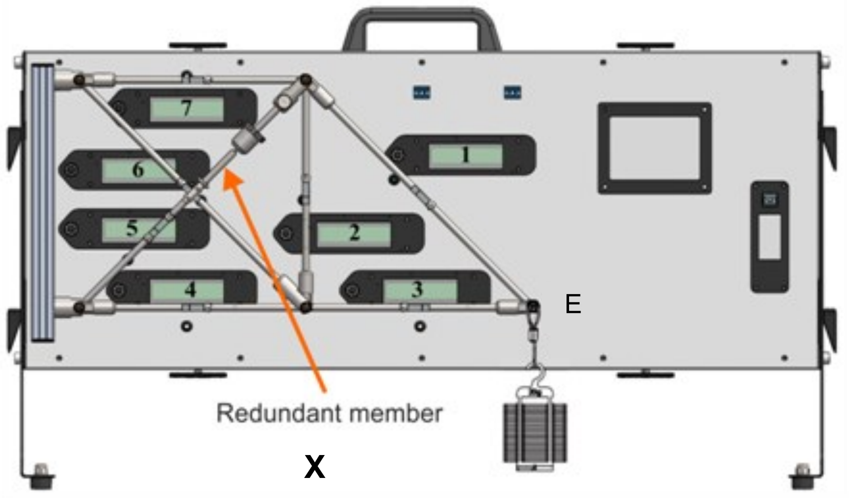
Redundant truss

Investigation D - Load applied to joint **E**



Over to you:

- Zero all the load cells.
- Suspend an 100g load, from joint **E** on the frame.
- Look at LCD 7, twist the black thumbnut on the redundant member, until the readout matches previous result for perfect truss
- Take each load cell reading and convert it into the force within that member.
- Record it in the Student Handout.
- Increase the load by adding a 40g mass to the mass hanger.
- Record the new force readings in the Student Handout.
- Continue in this way until the mass hanger carries a total of 300g.

So what:

Compare these results with those for the perfect truss (investigation A).

Comment on this comparison in the Student Handout.

Comment on what members to the forces in the redundant member , when the mechanism is twisted so that the member is elongated and when the mechanism is twisted so that the member is shortened.

Challenge:

- Calculate the theoretical value of the forces in each member.
- Record your results in the second table in the Student Handout.

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Redundant truss

Investigations E and F

Repeat this procedure:

- for a load suspended from point **D**;
- for a multiple load configuration with a load at **D** and a second load applied at an angle to **E**.
- Record your results in the Student Handout.

So what:

Compare these results with those for the equivalent configuration with the perfect truss.

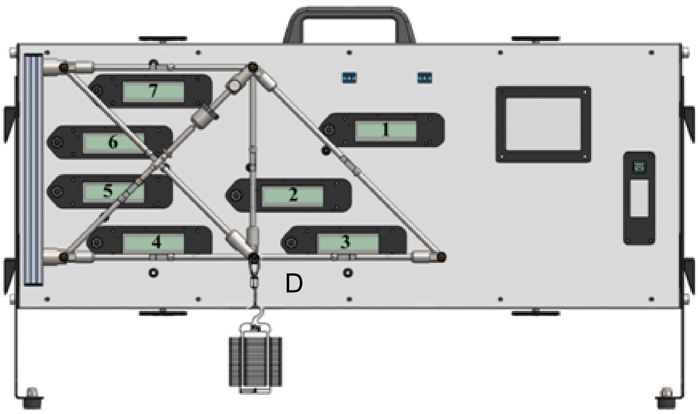
Comment on this comparison in the Student Handout.

Challenge:

- For each set up, calculate the theoretical value of force in each member.
- Record the results in the Student Handout.

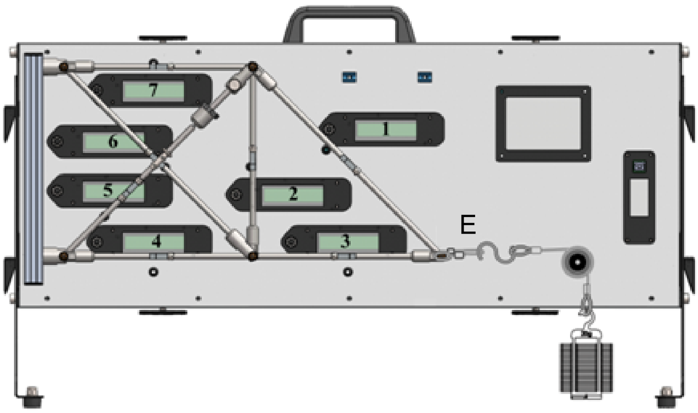
Investigation E -

Load applied to joint **D:**



Investigation F -

Multiple loads, using the values for loads $\mathbf{W_1}$ and $\mathbf{W_2}$, and angle α given in the Student Handout table.



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Reference section

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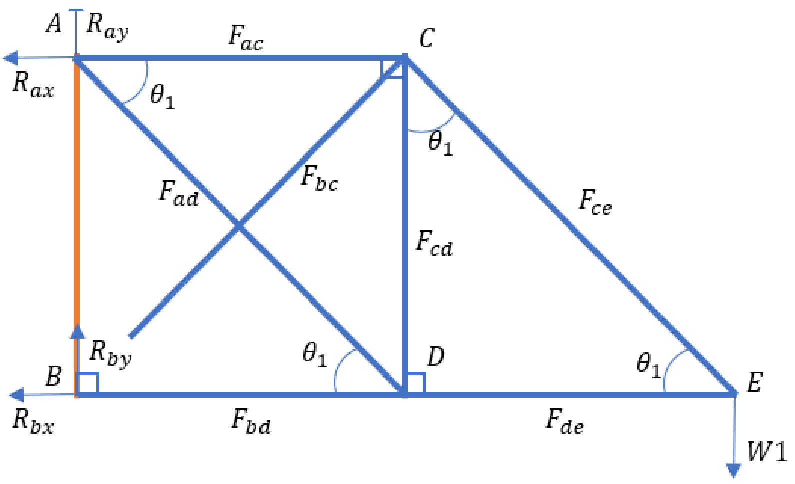
Bow's notation

Bow's notation, a labelling convention, is used to label the free body diagrams. The spaces around the members are labelled **A** to **E**. The members, and the forces within them, have labels that indicate the spaces that they separate.

The first diagram applies this convention to the labelling of a framework of six members.

In addition, it shows the external forces:

- added load **W**;
- reaction forces $\mathbf{R_a}$ and $\mathbf{R_b}$ generated at the reaction wall. These are shown resolved into horizontal and vertical components, e.g. $\mathbf{R_{aX}}$ and $\mathbf{R_{bY}}$.



Member	Length (mm)
$F_{ac} = load\ cell\ 7$	200
$F_{bc} = load\ cell\ 6$	200*sin(45)
$F_{ad} = load\ cell\ 5$	200*sin(45)
$F_{bd} = load\ cell\ 4$	200
$F_{de} = load\ cell\ 3$	200
$F_{cd} = load\ cell\ 2$	200
$F_{ce} = load\ cell\ 1$	200*sin(45)

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Calculating the forces

Calculating the forces

Two approaches to finding theoretical values of the forces in the members, the method of sections and the method of joints, rely on the same basic physics:

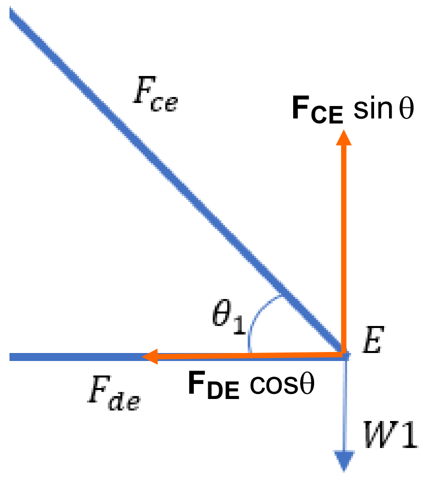
In a body that is equilibrium:

1. the total horizontal force is zero;
2. the total vertical force is zero;
3. the sum of the moments of forces about any point is zero.

Method of joints:

This looks at the forces acting on a particular joint.

For example, first of all, concentrate on the forces acting on the joint labelled **E**.



The second diagram assumes that:

- force $\mathbf{F_{CE}}$ is a tension force;
- force $\mathbf{F_{DE}}$ is compressing joint P.

These assumptions are not significant as the maths will identify the true directions by adding a '+' or a '-' sign.

The diagram shows force $\mathbf{F_{CE}}$ resolved into horizontal and vertical components.

The analysis

1. Sum of vertical forces = 0:

$$F_{CE} \sin\theta - W = 0$$

$$F_{CE} = W / \sin\theta$$

2. Sum of horizontal forces = 0:

$$F_{DE} - F_{CE} \cos\theta = 0$$

$$\text{so } F_{DE} = F_{CE} \cos\theta$$

3. Sum of the moments of forces is zero:

No useful equation will be obtained by taking moments about point **E** as both $\mathbf{F_{CE}}$ and $\mathbf{F_{DE}}$, pass through that point and so exert no moment about it.

Knowing the load **W** and the angle θ, the two forces $\mathbf{F_{CE}}$ and $\mathbf{F_{DE}}$ can be determined.

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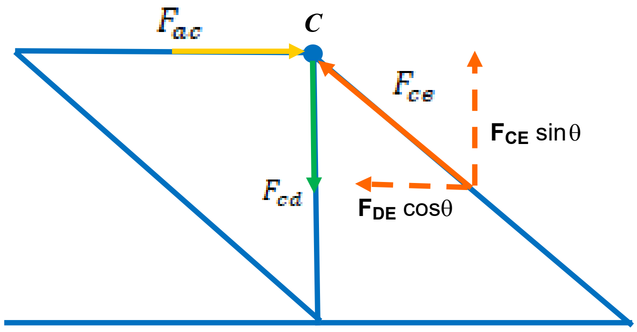
Calculating the forces:

1. Method of joints

Joint C:

Next, look at the forces acting on joint **C**.



Force $\mathbf{F_{CE}}$ is again resolved into horizontal and vertical components.

The analysis

1. Sum of vertical forces = 0:

$$F_{CE} \sin\theta - F_{CD} = 0$$

$$F_{CD} = F_{CE} \sin\theta$$

2. Sum of horizontal force= 0:

$$F_{AC} - F_{DE} \cos\theta = 0$$

$$F_{AC} = F_{DE} \cos\theta$$

3. Sum of the moments of forces is zero:

Once again, as all three forces pass through point **C**, no useful equation results from taking moments about point **C**.

Knowing force $\mathbf{F_{CE}}$ and the angle θ, the two forces $\mathbf{F_{CD}}$ and $\mathbf{F_{AC}}$ can be found.

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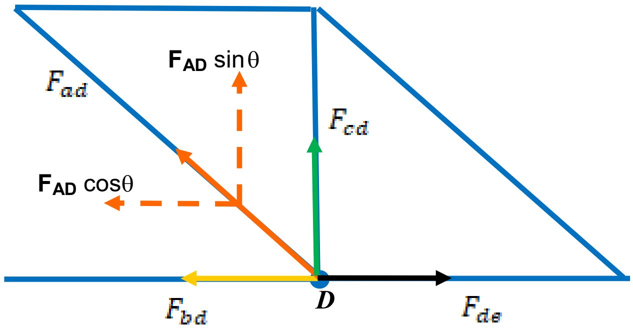
Calculating the forces:
1. Method of joints...

Joint D:



This time, force $\mathbf{F_{AD}}$ is resolved into horizontal and vertical components.

The analysis

1. **Sum of vertical forces = 0:**

$$F_{AD} \sin\theta - F_{CD} = 0$$
$$F_{AD} = F_{CD} \; / \sin\theta$$

2. **Sum of horizontal forces = 0:**

$$F_{DE} - F_{AD} \cos\theta - F_{BD} = 0$$
$$F_{BD} = F_{DE} - F_{AD} \cos\theta$$

3. **Sum of the moments of forces is zero:**
   Again, all forces pass through point **D** and so no useful equation results from taking moments about point **D**.

Knowing forces $\mathbf{F_{CD}}$ and $\mathbf{F_{DE}}$ and the angle θ, the two forces $\mathbf{F_{EF}}$ and $\mathbf{F_{DE}}$ can be found.

Summary

By analysing the situations at the joints, **E**, **C** and **D**, all six forces have been calculated.

Notice that at each joint the analysis yields only two equations, as taking moments was pointless. Nevertheless, the analysis of each joint worked because there were only two unknown forces involved each time.

This method **is not appropriate when more than two unknown forces act on the joint.**

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Calculating the forces:
2. Method of sections

Method of sections:

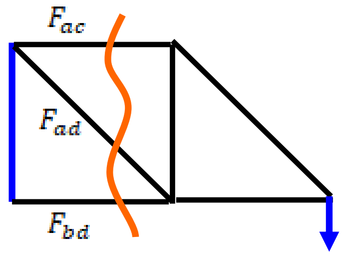
This approach examines the forces acting on a particular section of the structure.

A cut through the structure creates that section. Like the whole structure, the section is in equilibrium and so in that section:

- the sum of the vertical forces is zero;
- the sum of the horizontal forces is zero
- and the sum of the moments of the forces around any point is zero.

This time, each of these aspects will generate a useful equation, meaning that we can cope with **three** unknown forces within the section we choose.

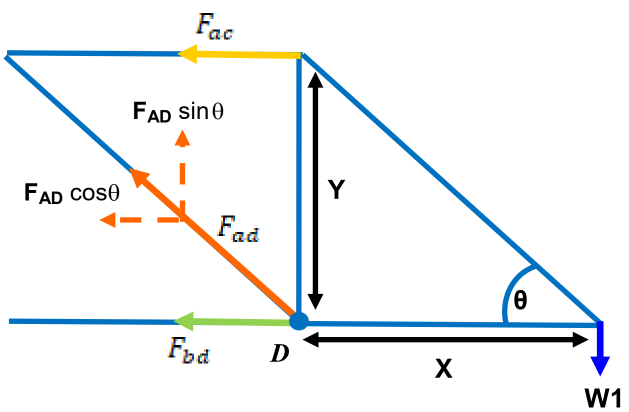
For example, look at the section created by cutting through members **AC**, **AD** and **BD**, as shown opposite. This will allow us to determine the forces $\mathbf{F_{AC}}$, $\mathbf{F_{AD}}$ and $\mathbf{F_{BD}}$.



Step 1 - draw the free body diagram for the section:

All the forces have been drawn in tension. Again the maths will sort out whether that is true or not.

Force $\mathbf{F_{AD}}$ is shown resolved into its horizontal
and vertical components.



Step 2 - apply the equilibrium criteria:

Looking at the vertical forces: $\mathbf{F_{AD}} \sin\theta - \mathbf{W} = 0$

and so $\mathbf{F_{AD}} = \mathbf{W} / \sin\theta$

Taking moments about joint **D**: $(\mathbf{F_{AC}} \cdot Y) - (\mathbf{W} \cdot X) = 0$

and so $\mathbf{F_{AC}} = \mathbf{W} \cdot X / Y$

Looking at the horizontal forces: $-\mathbf{F_{BD}} - \mathbf{F_{AC}} - \mathbf{F_{AD}} \cos\theta = 0$

and so $\mathbf{F_{BD}} = -\mathbf{F_{AC}} - \mathbf{F_{AD}} \cos\theta$

Knowing **W**, θ and the lengths X and Y allows us to calculate the three forces.

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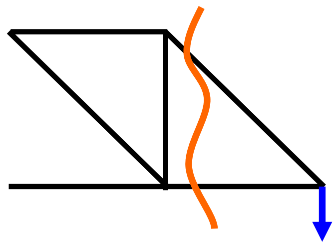
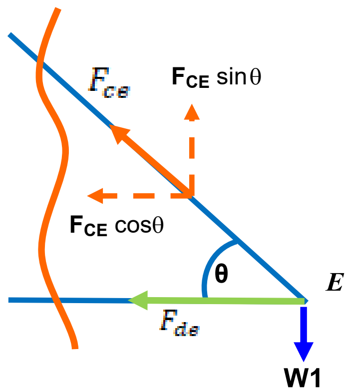
Calculating the forces:
2. Method of sections...

Next, look at the section created by cutting through members CG and **DG**.
This allows us to determine the forces $\mathbf{F_{CG}}$ and $\mathbf{F_{DG}}$.



Step 1 - draw the free body diagram for the section:

Force $\mathbf{F_{CG}}$ is shown resolved into its horizontal and vertical *components.*



Step 2 - apply the equilibrium criteria:

Looking at the vertical forces: $\mathbf{F_{CE}}\sin\theta - \mathbf{W} = 0$

and so $\mathbf{F_{CE}} = \mathbf{W} / \sin\theta$

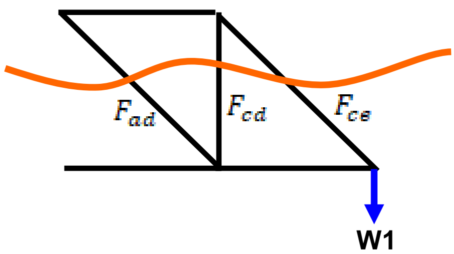
Looking at the horizontal forces: $\mathbf{F_{DE}} - \mathbf{F_{CE}}\cos\theta = 0$

and so $\mathbf{F_{DE}} = \mathbf{F_{CE}}\cos\theta$

There is no need for a third equation as there are only two unknown forces.

Knowing **W** and θ, these forces can be determined.

That leaves only one unknown force, $\mathbf{F_{CD}}$. This can be obtained using the method of joints, looking at joint **C** or **D**, or by applying another cut as shown below:



Although this shows that there are three forces involved, two, $\mathbf{F_{AD}}$ and $\mathbf{F_{CE}}$, are already known. The remaining one, $\mathbf{F_{CD}}$, can be determined by looking at the vertical forces.

Summary

The method of sections generates a maximum of **three** equations and so cannot be used for a cut involving more than **three** unknown forces.

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Calculating the forces:
3. Method of virtual work

The principle of virtual work states that if a body is in equilibrium, then the algebraic sum of the virtual work done by all forces acting on it is zero for any virtual displacement.
(A virtual displacement is a possible displacement of a system of particles that is possible - but actually does not exist.)

The starting point - energy cannot be created or destroyed, just changed from one form to another. Whenever, this happens, work is done. For example, to push a wooden block across the floor, you need to apply a force to overcome friction. In doing so, you do work and lose chemical energy, which is converted into heat and sound energy.

Sometimes it is not obvious that work is done. When you place (not drop) a block onto the floor, a reaction force keeps the block in equilibrium. Although it cannot be seen, at the atomic level, floor particles have moved slightly and in the process have created an upward reaction force that balances the weight of the block, (we hope!) The weight of the block has done a small amount of work, (*virtual*ly zero,) in re-arranging the floor particles, which has increased their potential energy, known as strain energy.

Now consider stretching a metal rod. The significant factor is its axial stiffness, **K**, a measure of its resistance to stretching or compression in response to an applied force.

It is defined as:

$$\mathbf{K} = \mathbf{F} / \delta$$

where **F** is the applied force and δ is the resulting displacement (extension or compression).

Axial stiffness depends on the elastic modulus (Young's modulus, **E**) of the material the rod is made from.

The definition of Young's modulus is:

$$\mathbf{E} = \text{tensile stress} / \text{tensile strain} = \frac{\mathbf{F} / \mathbf{A}}{\delta / \mathbf{L}}$$

where **A** = cross-sectional area of the rod and **L** is its original length.
Re-arranging this:

$$\delta = \frac{\mathbf{F} \times \mathbf{L}}{\mathbf{E} \times \mathbf{A}}$$

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Calculating the forces:
3. Method of virtual work...

Sample calculation

Using the virtual work method to calculate deformation in a member.

The table shows data on the lengths of the members and a set of possible forces.

Member number	Length **L** in m	**Real** Force $\mathbf{F_R}$ in N	**Real** Deformation δ in m	**Virtual** Force $\mathbf{F_V}$ in N	Work **W** in Nm
1	0.283	+6.9			
2	0.200	-4.9			
3	0.200	-4.9			
4	0.200	-9.8			
5	0.283	0			
6	0.283	+6.9			
7	0.200	+4.9			

The next step is to calculate the Real Deformation, **δ,** of each member, using the formula:

$$\delta = (\mathbf{F_R} \times \mathbf{L}) / \mathbf{E} \times \mathbf{A}$$

and complete the fourth column with the results.

The cross-sectional area, **A**, of the members is 20×10^{-6} m^2.

The Young's modulus, **E**, for mild steel is 200×10^9 Pa.

Member number	Length **L** in m	**Real** Force $\mathbf{F_R}$ in N	**Real** Deformation δ in m	**Virtual** Force $\mathbf{F_V}$ in N	Work **W** in Nm
1	0.283	+6.9	4.9×10^{-7}		
2	0.200	-4.9	-2.5×10^{-7}		
3	0.200	-4.9	-2.5×10^{-7}		
4	0.200	-9.8	-4.9×10^{-7}		
5	0.283	0			
6	0.283	+6.9	4.9×10^{-7}		
7	0.200	+4.9	2.5×10^{-7}		

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Calculating the forces:

3. Method of virtual work...

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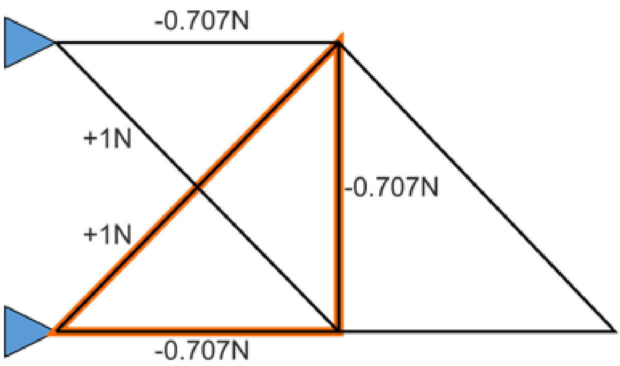
Trusses

At this point, we introduce a virtual force of +1N, acting to stretch member 5.
Using a rule such as the ‘triangle of forces’ and the fact that the structure contains a number of right-angled isosceles triangles, like that outlined in orange, the virtual forces in the other members can be calculated. These are shown in the following diagram.



Add these virtual forces to the table, column five, and use them to calculate the virtual work done (using δ x $\mathbf{F_V}$).
These results are then added to the sixth column.

Member number	Length **L** in m	**Real** Force $\mathbf{F_R}$ in N	**Real** Deformation δ in m	**Virtual** Force $\mathbf{F_V}$ in N	Work **W** in Nm
1	0.283	+6.9	4.9 x 10^{-7}	0	0
2	0.200	-4.9	-2.5 x 10^{-7}	-0.707	1.8 x 10^{-7}
3	0.200	-4.9	-2.5 x 10^{-7}	0	0
4	0.200	-9.8	-4.9 x 10^{-7}	-0.707	3.5 x 10^{-7}
5	0.283	0		+1.000	
6	0.283	+6.9	4.9 x 10^{-7}	+1.000	4.9 x 10^{-7}
7	0.200	+4.9	2.5 x 10^{-7}	-0.707	-1.8 x 10^{-7}

Total internal virtual work done = 8.4 x 10^{-7} Nm

According to the virtual work principle:

$$W_{ext} = W_{int}$$

where W_{ext} = total external virtual work done and W_{int} = total internal virtual work.

In this case:

$$1 \times \Delta = 8.4 \times 10^{-7}$$

where Δ = deformation of member 5.

Hence:

$$\Delta = 8.4 \times 10^{-7}\text{m}$$

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Student Handout

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Investigation A - Load applied to joint E

Measurements

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) **F_{CE}** in N	**CD** (LCD 2) **F_{CD}** in N	**DE** (LCD 3) **F_{DE}** in N	**BD** (LCD 4) **F_{BD}** in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) **F_{AD}** in N	**AC** (LCD 7) **F_{AC}** in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Angle θ between the frame members at joint **E =** ....

Length of member **DE**, **X** = ...

Length of member **CD**, **Y** = ...

Calculations

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) **F_{CE}** in N	**CD** (LCD 2) **F_{CD}** in N	**DE** (LCD 3) **F_{DE}** in N	**BD** (LCD 4) **F_{BD}** in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) **F_{AD}** in N	**AC** (LCD 7) **F_{AC}** in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

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Investigation B - Load applied to joint D

Measurements

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) **F_{CE}** in N	**CD** (LCD 2) **F_{CD}** in N	**DE** (LCD 3) **F_{DE}** in N	**BD** (LCD 4) **F_{BD}** in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) **F_{AD}** in N	**AC** (LCD 7) **F_{AC}** in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Challenge:

Use the free body diagrams and the method of joints to obtain equations for the forces in the six members.

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Investigation B - Load applied to joint D

Cal- culated

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Investigation C - Multiple loads

Measured

Load					Member						
1 Mass in g	**1** Weight W_1 in N	**2** Mass in g	**2** Weight W_2 in N	**2** angle α	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98	300	2.94	45							
100	0.98	300	2.94	45							
300	2.94	100	0.98	90							
300	2.94	100	0.98	45							

Calculated

Load					Member						
1 Mass in g	**1** Weight W_1 in N	**2** Mass in g	**2** Weight W_2 in N	**2** angle α	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) **Not in USE**	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98	300	2.94	45							
100	0.98	300	2.94	45							
300	2.94	100	0.98	90							
300	2.94	100	0.98	45							

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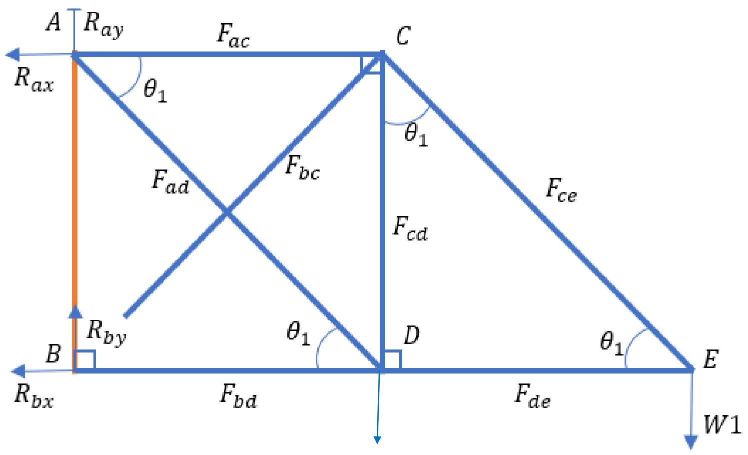
Investigation C - Multiple loads .....

Challenge:

Draw free body diagrams and use either the method of joints or of sections to obtain equations for the forces in the six members.



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Investigation D - Redundant truss - load applied to joint E

Measurements

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) F_{BC} in N	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Calculations

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) F_{BC} in N	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Comment on the comparison between these results and those for the perfect truss.

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Investigation E - Redundant truss - load applied to joint D

Measurements

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) **F_{CE}** in N	**CD** (LCD 2) **F_{CD}** in N	**DE** (LCD 3) **F_{DE}** in N	**BD** (LCD 4) **F_{BD}** in N	**BC** (LCD 5) **F_{BC}** in N	**AD** (LCD 6) **F_{AD}** in N	**AC** (LCD 7) **F_{AC}** in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Calculations

Load		Member						
Mass in g	Weight **W** in N	**CE** (LCD 1) **F_{CE}** in N	**CD** (LCD 2) **F_{CD}** in N	**DE** (LCD 3) **F_{DE}** in N	**BD** (LCD 4) **F_{BD}** in N	**BC** (LCD 5) **F_{BC}** in N	**AD** (LCD 6) **F_{AD}** in N	**AC** (LCD 7) **F_{AC}** in N
100	0.98							
140	1.37							
180	1.77							
220	2.16							
260	2.55							
300	2.94							

Comment on the comparison between these results and those for the perfect truss.

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Investigation F - Redundant truss - Multiple loads

Measured

Load					Member						
1 Mass in g	**1** Weight W_1 in N	**2** Mass in g	**2** Weight W_2 in N	**2** angle α	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) F_{BC} in N	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98	300	2.94	90							
100	0.98	300	2.94	45							
300	2.94	100	0.98	90							
300	2.94	100	0.98	45							

Calculated

Load					Member						
1 Mass in g	**1** Weight W_1 in N	**2** Mass in g	**2** Weight W_2 in N	**2** angle α	**CE** (LCD 1) F_{CE} in N	**CD** (LCD 2) F_{CD} in N	**DE** (LCD 3) F_{DE} in N	**BD** (LCD 4) F_{BD} in N	**BC** (LCD 5) F_{BC} in N	**AD** (LCD 6) F_{AD} in N	**AC** (LCD 7) F_{AC} in N
100	0.98	300	2.94	90							
100	0.98	300	2.94	45							
300	2.94	100	0.98	90							
300	2.94	100	0.98	45							

Comment on the comparison between these results and those for the perfect truss.

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