STRUCTURES

Simple Suspension Bridge

CP9503

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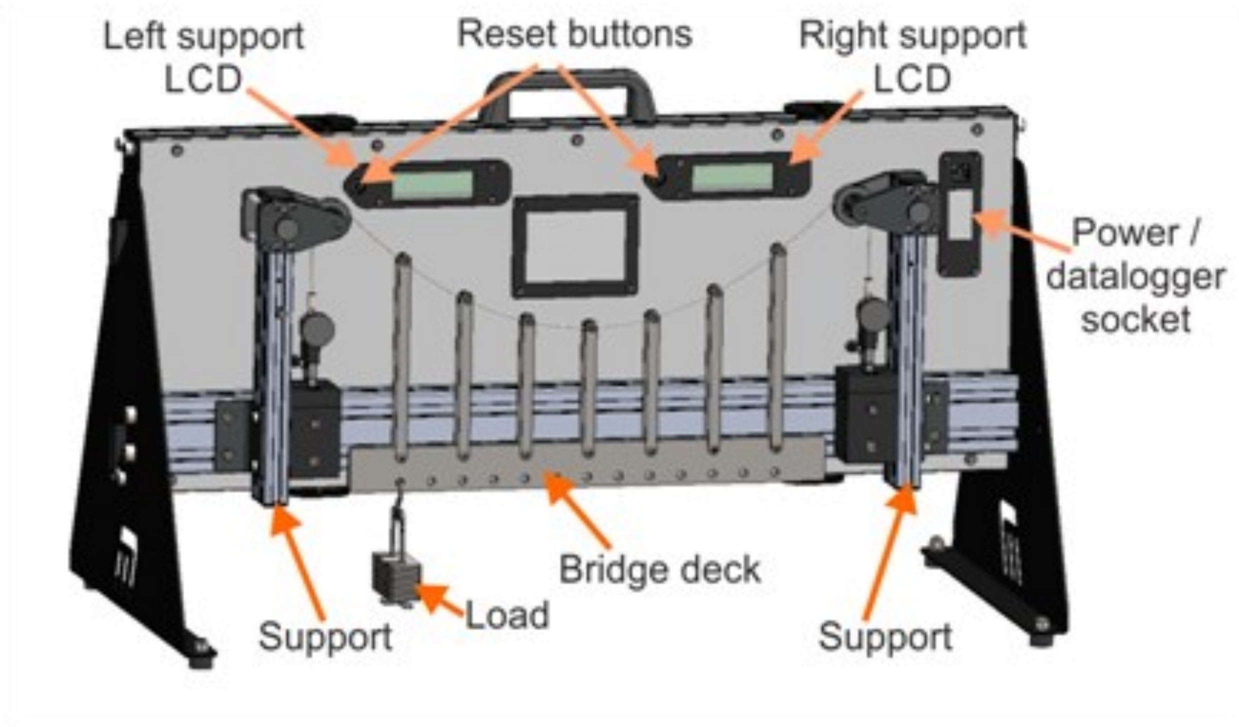
Contents

Introduction

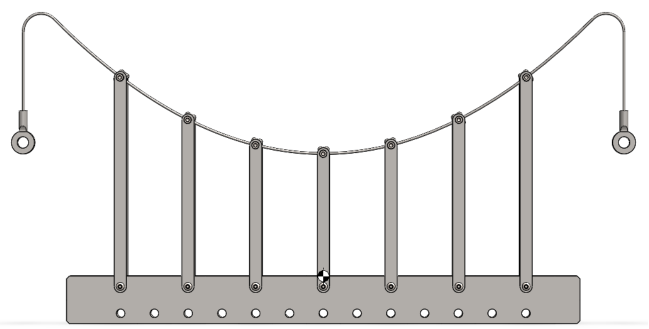
Suspension bridge

This kit allows students to apply concentrated loads or uniformly distributed loads (UDL) to the bridge deck of two types of **suspension bridge** to explore the resulting tension in the cable at both ends.
In one configuration, the two guided pulley supports sit at the same height. In the other, the pulley support on one side is lowered to create an asymmetric arrangement with supports at different heights.

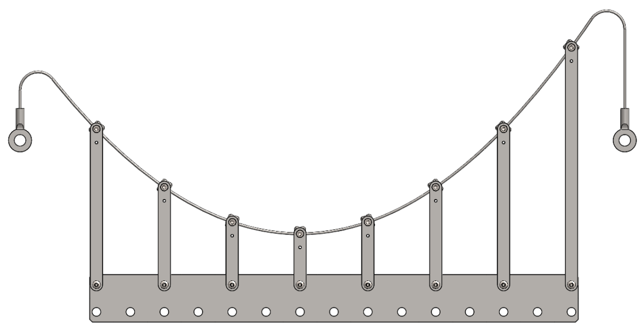
The following diagram identifies the main components in the equipment.



Two load cells, connected to LCD displays, measure the tension at the ends of the bridge, allowing students to explore a variety of loading scenarios, such as moving a concentrated load across the bridge span, or applying a UDL to it. The resulting measured tensions can then be compared to theoretical values.



Symmetric bridge



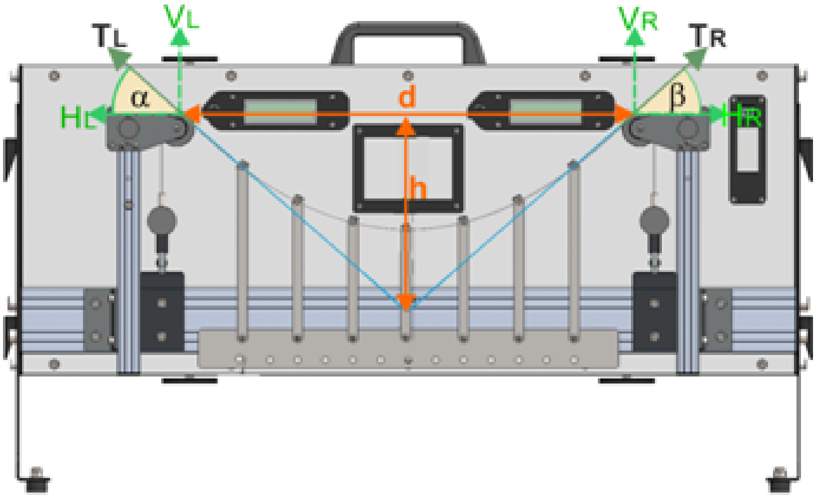
Assymmetric bridge

Introduction

Suspension bridge

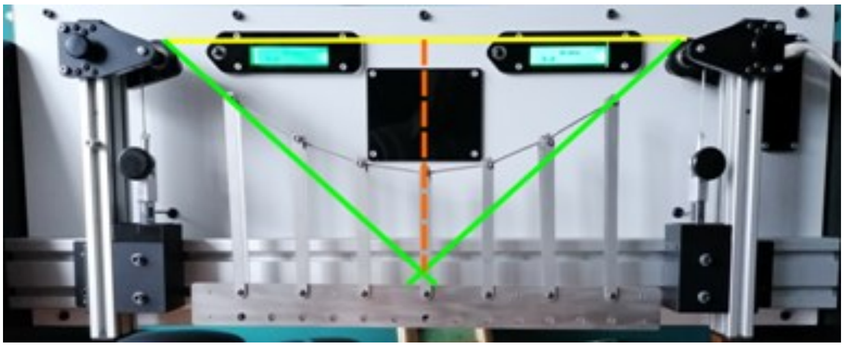
Measuring the geometry

Several calculations in this module require students to know the angles α and β, between the cable that supports the bridge and the horizontal.



There are a number of ways to find these:

For example, you could take a photograph of the equipment, and add lines to the image, as shown below:



The angles can then be obtained either by direct measurement or by using trigonometry.

The image shows a close-up used to measure angle α directly, using a digital protractor.

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.

Worksheet 1

Unloaded bridge

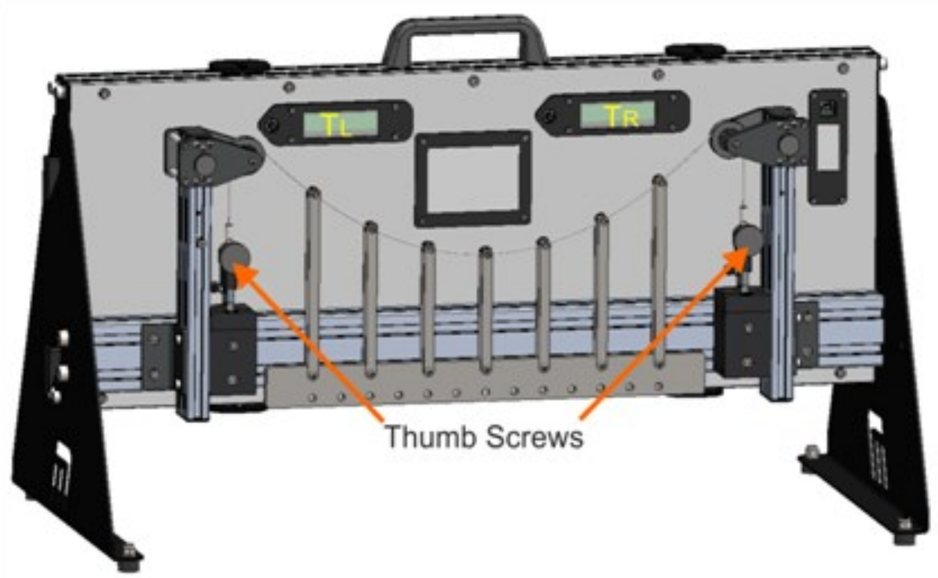
Suspension bridge

A bridge structure has considerable weight, even without the extra loading due to traffic.

For example, the Golden Gate bridge, shown in the photograph has a weight of over 150 000 tonnes. This creates enormous forces in its supports and in the cables that carry the bridge deck.

Over to you:

The first investigation relates the tension in the cable to the forces in the supports.



- Remove the bridge from the supporting frame by unscrewing the two thumb screws.
- Press the ‘zero’ button on each LCD display to initialise the readings.
- Measure the weight of the bridge.
- Replace the bridge on the frame as shown in the diagram above.
- Observe the values of the tensions $\mathbf{T_L}$ and $\mathbf{T_R}$.
- Obtain the values of the angles α and β.
- Record all measurements in the Student Handout.
- Complete the calculations outlined in the Student Handout and comment on the results.

Challenge:

Compare the weight of the bridge and the sum of the vertical components. Comment on the tension

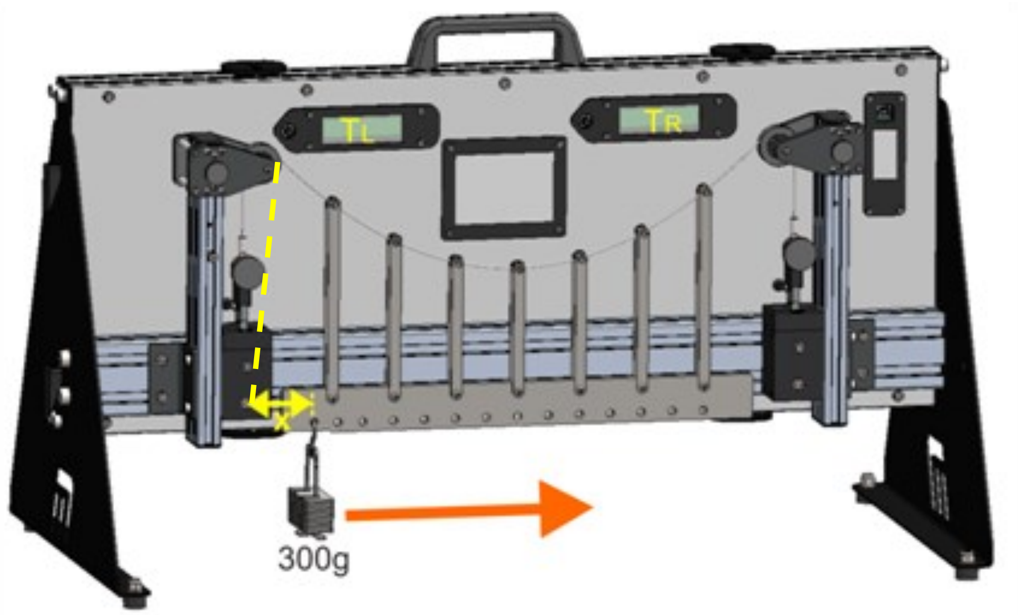
Worksheet 2

Concentrated load

Suspension bridge

In addition to carrying the weight of the bridge, the cables and supports are subject to additional loads due to traffic crossing the bridge.
The effect of this changes as the loads move across the bridge. This investigation looks at the effect of moving just one load.

Over to you:



- Remove the bridge from the frame by unscrewing the two thumb screws.
- Press the ‘zero’ button on each LCD display to initialise the readings.
- Set up the hardware as shown with the symmetric bridge, with a 300g load, a concentrated load, suspended from the first suspension point, at the left-hand end of the bridge.
- Measure the distance, **x**, from the left-hand point where the cable leaves the pulley to the suspension point. Each hole should be 25mm apart.
- Measure tensions $\mathbf{T_L}$ and $\mathbf{T_R}$.
- Measure the angles α and β, between the cable and the horizontal, using the method developed in the Introduction.
- Move the 300g load further along the bridge deck to the next suspension point and repeat this procedure.
- Continue in this way until the load reaches the centre of the bridge deck.
- Record all measurements in the Student Handout.

So what:

Use your results to plot a graph showing how both $\mathbf{T_L}$ and $\mathbf{T_R}$ vary with distance **x** as the load moved to the centre of the bridge deck.

(From symmetry, the behaviour of these tensions when the load is located on the right hand half of the bridge deck would produce a mirror image of this graph.)

Challenge:

The bridge is in static equilibrium.

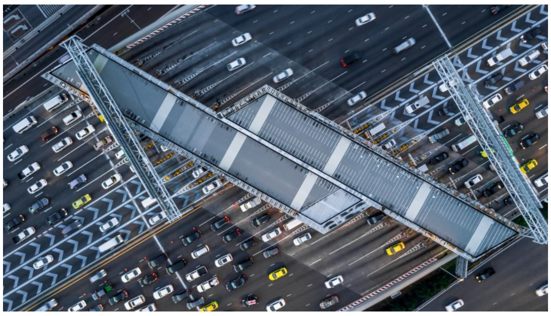
This means that all vertical forces cancel out, all horizontal forces cancel out and the total moment of all forces about any point on the bridge is zero.

In the Student Handout:

- use this information to obtain formulae allowing you to calculate the *theoretical* values of the tension in the cable for the different load positions;
- add these values to the graph produced from your results and draw smooth curves through them to show the theoretical variation of $\mathbf{T_L}$ and $\mathbf{T_R}$ with distance **x**.

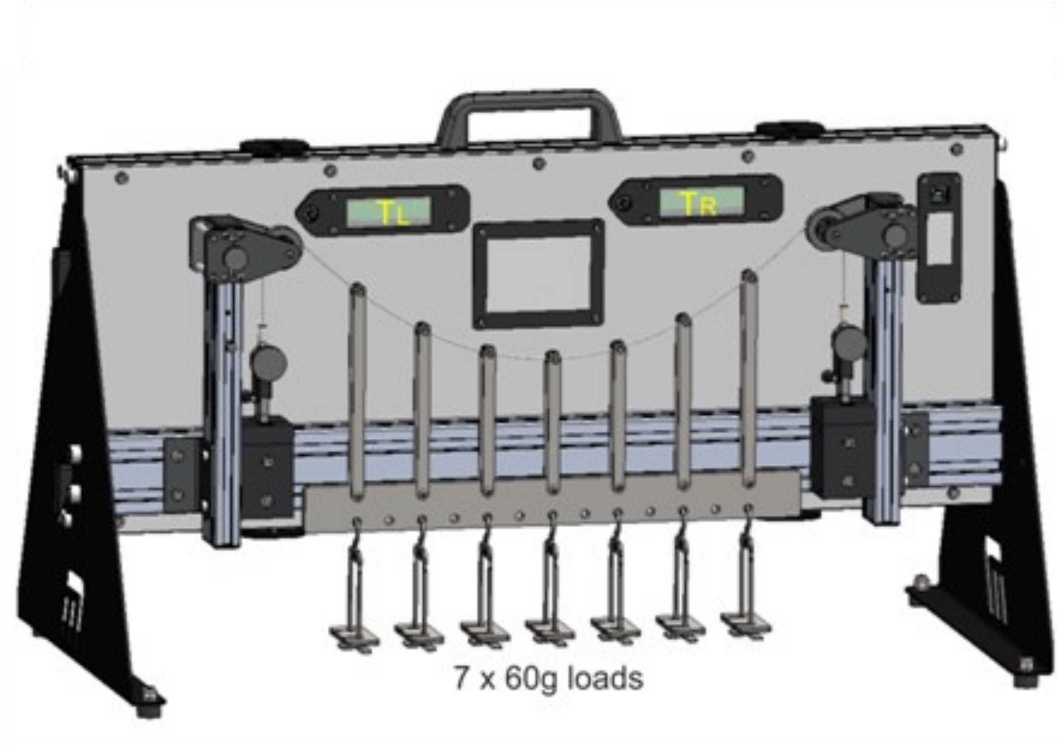
Worksheet 3
UDL

Suspension bridge



Often, bridges are built to carry large volumes of traffic. They must also withstand forces caused by wind and other weather events.
Distributed loads, like these, cause forces acting over an extended area rather than at a single point.
This activity examines a load of this kind, known as a uniformly-distributed load (UDL).

Over to you:



- Remove the bridge from the frame by unscrewing the thumb screws.
- Press the 'zero' button on each LCD display to initialise the readings.
- Set up the hardware as shown in the diagram above. The seven load hangers, spread across the length of the bridge deck, simulate a uniformly distributed load.
- Observe the values of the tensions $\mathbf{T_L}$ and $\mathbf{T_R}$.
- Measure angles α and β, between the cable and the horizontal.
- Record all values in the Student Handout.

So what:

A prediction:

The simulated UDL just tested behaves like a concentrated point load of 7 x 60 = 420g placed at the centre of the bridge.

Challenge:

1. Test the prediction

- Remove the bridge and zero the LCDs in the usual way.
- Set up the hardware as shown in the diagram with a single load of 420g placed at the centre of the bridge.

- Observe the values of the tensions $\mathbf{T_L}$ and $\mathbf{T_R}$.
- Measure angles α and β, between the cable and the horizontal.
- Record all measurements in the Student Handout.
- Comment on how well your results support the prediction.
- Suggest likely sources of error.

2. Repeat the investigation with other values of UDL.

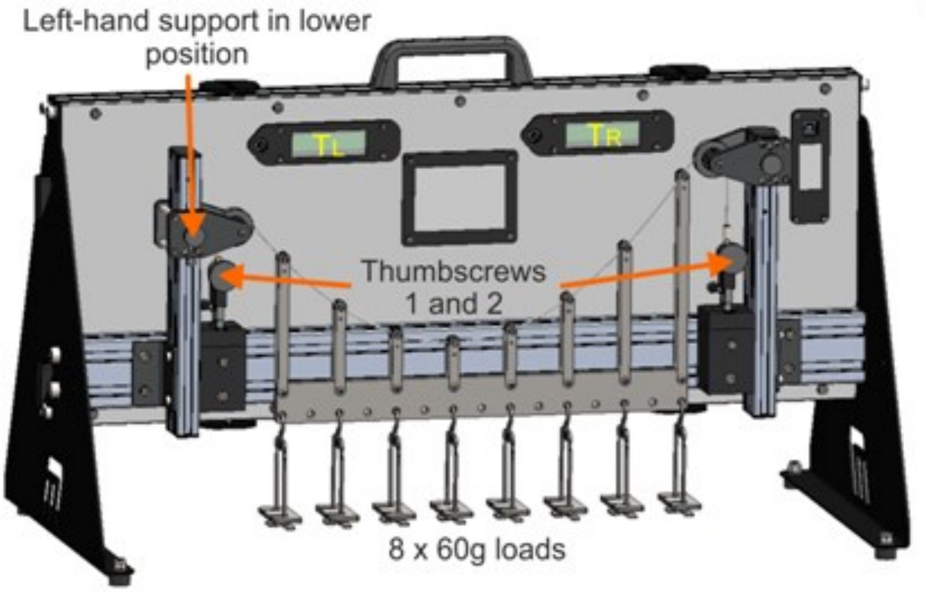
- Record all measurements in the Student Handout.

Worksheet 4
Asymmetric bridge

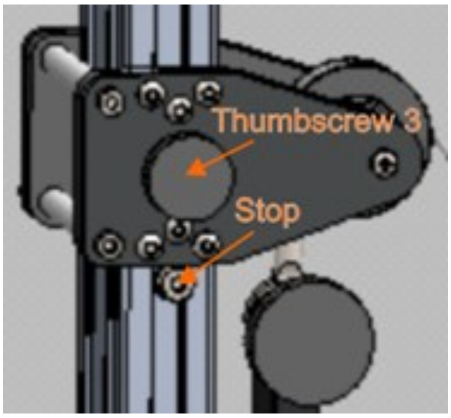
Suspension bridge

Geography or local geology often impact the design of bridges and may require an asymmetric solution. The towers supporting the Clifton Suspension bridge, for example, are unequal in height. In addition, the one shown on the left in the picture sits on a larger sandstone structure. This worksheet investigates the result of this asymmetry

Over to you:



Make the following changes to the hardware:



1. Remove the symmetric bridge:
   - Unscrew and remove thumbscrews 1 and 2.
   - Detach the symmetric bridge.
2. Lower the left-hand support:
   - Loosen and lower the stop.
   - Remove thumbscrew 3 and lower the support.
   - Fasten the thumbscrew in the hole left by the stop.
3. Connect the asymmetric bridge to the supports:
   - Reset the LCD displays;
   - Holding the asymmetric bridge in position, thread thumbscrews 1 and 2 through the eyes at the ends of the bridge cable and screw them into position.

Over to you.....

1. Unloaded bridge:

- Measure and record the tensions $\mathbf{T_L}$ and $\mathbf{T_R}$ and the angles α and β between the cable and the horizontal, at the two ends.

Now compare effect of the two load types:

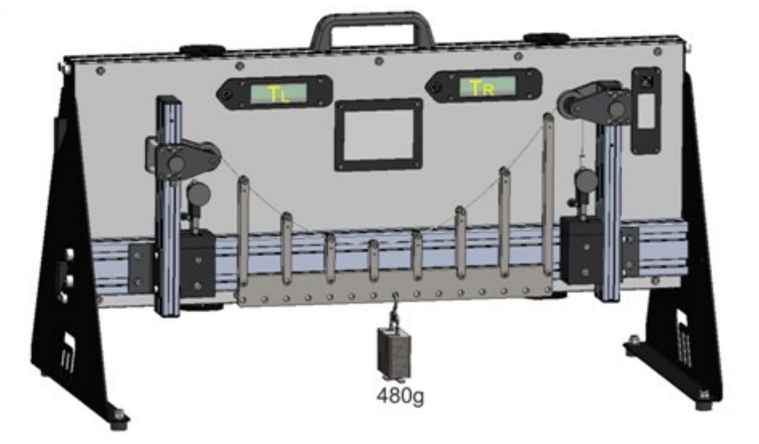
2. UDL:

The eight load hangers, spread across the length of the bridge deck, simulate a uniformly distributed load.

- Measure tensions $\mathbf{T_L}$ and $\mathbf{T_R}$ and the angles α and β, between the cable and the horizontal.
- Record these measurements in the Student Handout.

3. Concentrated load:

- Remove the eight load hangers and the bridge.
- 'Zero' the LCD displays.
- Replace the asymmetric bridge and suspend a single load of 480g at its centre.
- Once again, measure tensions $\mathbf{T_L}$ and $\mathbf{T_R}$ and the angles α and β, between the cable and the horizontal and record them in the Student Handout.



Challenges:

In the Student Handout:

1. perform calculations to show how these readings can be used to calculate the weight of the bridge and comment on your result;
2. compare the results for the UDL and the concentrated load and comment on the comparison.

Student Handout

Worksheet 1 - Unloaded bridge

Weight of unloaded bridge = ………………..

Tension $\mathbf{T_L}$ measured at left-hand end of supporting cable = ………………..

Tension $\mathbf{T_R}$ measured at right-hand end of supporting cable = ………………..

Angle α between left-hand end of cable and horizontal = ………………..

Angle β between right-hand end of cable and horizontal = ………………..

Vertical component $\mathbf{V_L}$ of cable tension at left-hand end = $\mathbf{T_L}$ x sin α

= ....

Vertical component $\mathbf{V_R}$ of cable tension at right-hand end = $\mathbf{T_R}$ x sin β

= ....

$\mathbf{V_L} + \mathbf{V_R}$ = ………………..

Challenge:

Comment on the comparison between the weight of the bridge and the sum of these vertical components.

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What are likely sources of error?

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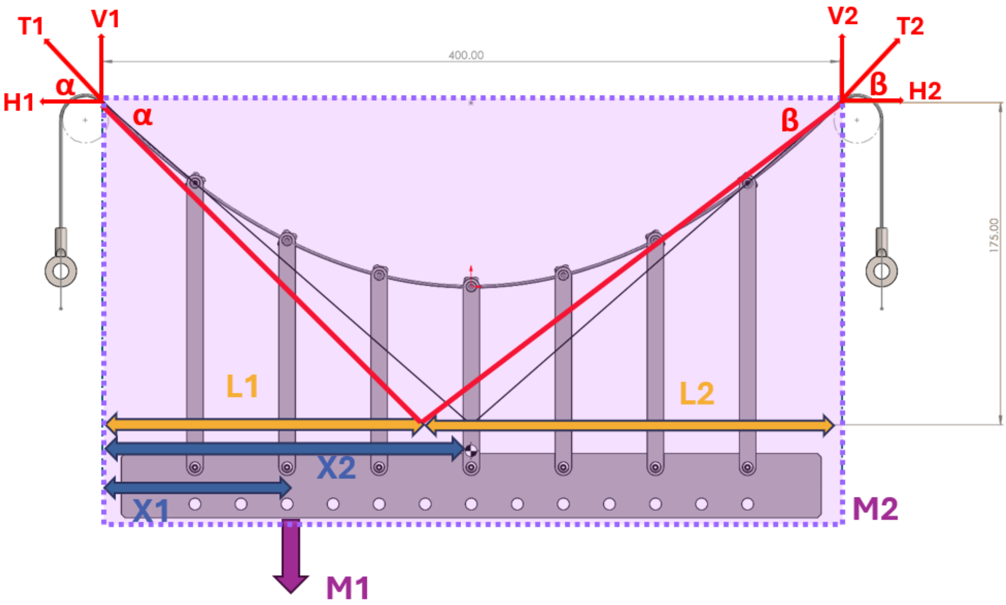
Worksheet 2 - Concentrated load

Load position	Distance x	Angle α	Angle β	Measured		Theoretical	
				Tension T_L	Tension T_R	Tension T_L	Tension T_R
1							
2							
3							
4							
5							
6							
7							

Theoretical values:

- Use formulae below to allow you to calculate theoretical values for $\mathbf{T_L}$ and $\mathbf{T_R}$ for the different load positions:



$$L_1 = \frac{x_1 m_1 + x_2 m_2}{m_1 + m_2}$$

$$\alpha = \tan^{-1}\left(\frac{y}{L_1}\right)$$

$$\beta = \tan^{-1}\left(\frac{y}{L_2}\right)$$

$$V_1 = (m_1 + m_2)\frac{L_2}{L_1 + L_2}$$

$$V_2 = (m_1 + m_2)\frac{L_1}{L_1 + L_2}$$

$$T_1 sin\alpha = V_1$$

$$T_2 sin\beta = V_2$$

$$T = \frac{\left(\frac{w}{L_0}\right)L}{2}\sqrt{1 + \left(\frac{L}{4h}\right)^2}$$

Worksheet 2 - Concentrated load

Challenge:

- Obtain formulae to allow you to calculate theoretical values for $\mathbf{T_L}$ and $\mathbf{T_R}$ for the different load positions:

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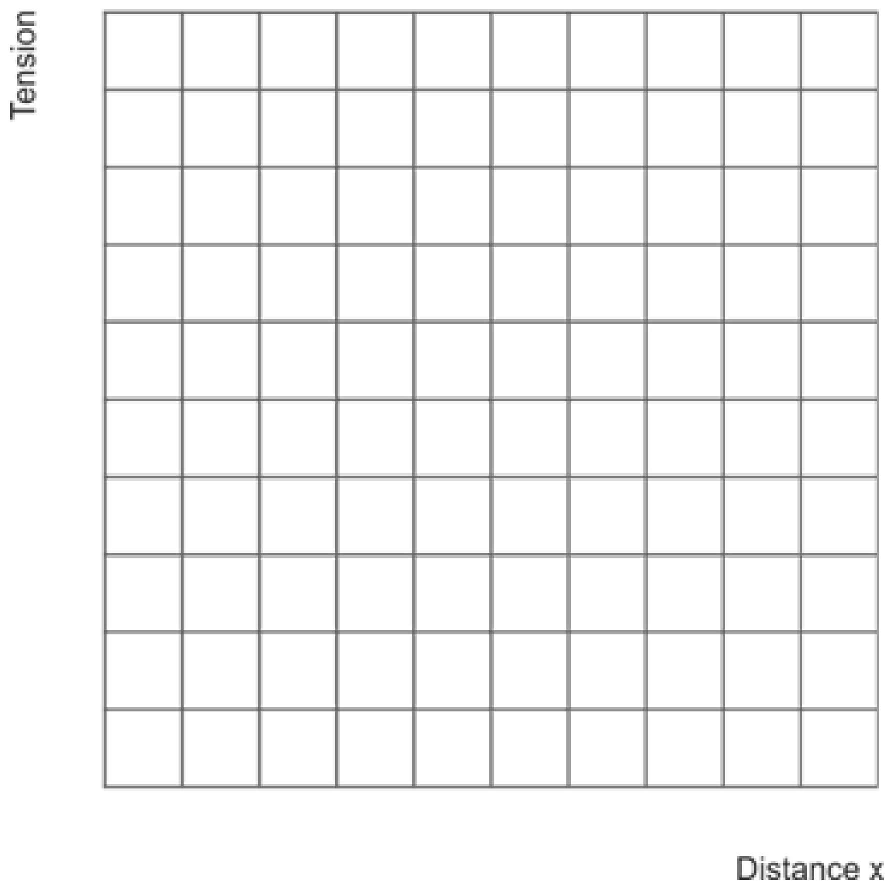
- Enter these calculated values in the last two columns of the table above.

Worksheet 2 - Concentrated load …..

- Use your measurements to plot a graph showing how $\mathbf{T_L}$ and $\mathbf{T_R}$ vary with the distance **x** as the load moved to the centre of the bridge deck.
- Add suitable scales.
- Label the curves clearly to identify $\mathbf{T_L}$ and $\mathbf{T_R}$.



Challenge .....

- Add the theoretical values of tension to the graph and draw smooth curves through them to illustrate the variation of the calculated values of tension with distance.
- Label these curves as $\mathbf{T_L}$**’** and $\mathbf{T_R}$**’**.

Worksheet 3 - UDL

With UDL:

Tension $\mathbf{T_L}$ measured at left-hand end of supporting cable = ………………..

Tension $\mathbf{T_R}$ measured at right-hand end of supporting cable = ………………..

Angle α between left-hand end of cable and horizontal = ………………..

Angle β between right-hand end of cable and horizontal = ………………..

Challenge 1:

With concentrated point load of equal total weight placed at centre of bridge :

Tension $\mathbf{T_L}$ measured at left-hand end of supporting cable = ………………..

Tension $\mathbf{T_R}$ measured at right-hand end of supporting cable = ………………..

Angle α between left-hand end of cable and horizontal = ………………..

Angle β between right-hand end of cable and horizontal = ………………..

Comment on the comparison between these two situations.

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Identify some likely sources of error.

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Challenge 2:

Describe further investigations you carried out and comment on the results.

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Student Handout

Suspension bridge

Worksheet 4 - Asymmetric bridge

Weight of unloaded asymmetric bridge = ………………..

Unloaded:

Tension $\mathbf{T_L}$ at left-hand end of bridge = ………………..

Tension $\mathbf{T_R}$ at right-hand end of bridge = ………………..

Angle α = ……………….. Angle β = ………………..

UDL:

Tension $\mathbf{T_L}$ at left-hand end of bridge = ………………..

Tension $\mathbf{T_R}$ at right-hand end of bridge = ………………..

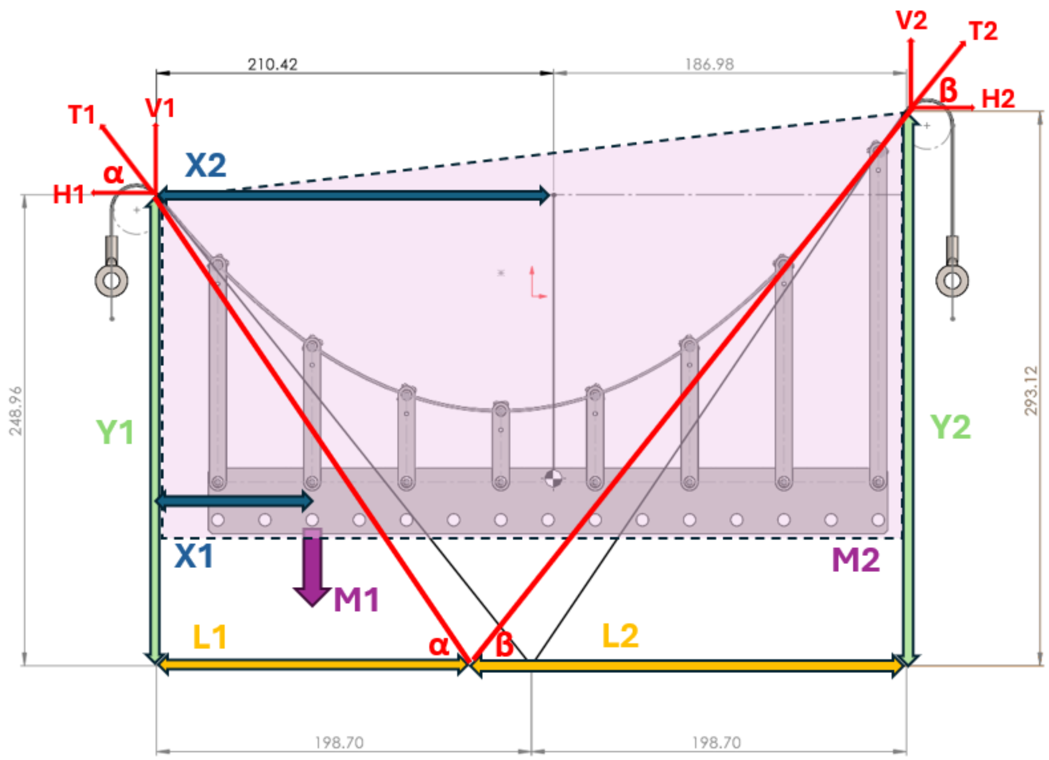
Angle α = ……………….. Angle β = ………………..

Concentrated load:

Tension $\mathbf{T_L}$ at left-hand end of bridge = ………………..

Tension $\mathbf{T_R}$ at right-hand end of bridge = ………………..

Angle α = ……………….. Angle β = ………………..



$$T_1 = \left(\frac{w}{L_0}\right) L_1 \sqrt{1 + \left(\frac{L_1}{2h_1}\right)^2}$$

$$T_2 = \left(\frac{w}{L_0}\right) L_2 \sqrt{1 + \left(\frac{L_2}{2h_2}\right)^2}$$

Challenges:

1. Use your readings to calculate the weight of the bridge and comment on the result:

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2. Compare results for the UDL and the concentrated load and comment on this comparison:

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