Chapter Hii: Enemies of Bridges – Humans

AIMS & OBJECTIVES

- to know that bridges can collapse due to human activity
- to recognise that resonance is vibrations at a certain speed specific to the material
- to investigate and estimate the maximum live load that a bridge might take before it fails

CONTEXT

Engineers have to consider all loads when designing a bridge. This can include environmental factors, such as wind load, and users of the bridge, such as trains, cars or people. Humans can affect the way a bridge works in different ways – sometimes with devastating consequences.

LANGUAGE OF BRIDGES:

Amplitude: very simplistically, the size of the wave. In sound, the greater the amplitude, the louder the volume.

Dead load: the bridge's own weight which does not change or move.

Distribution: the way a load is spread out, or focussed on a specific point, across a bridge.

Frequency: number of waves per second.

Live Load: mainly the weight of what the bridge is carrying, although wind and snow also have an effect. This moves and changes constantly.

Parapet: a low wall or railing alongside the edge of the bridge deck to protect traffic from falling off.

Point load: a load applied to a single point in a beam bridge.

Resonance: the tendency of an object to move with greater frequency when vibrations match the object's own 'natural' frequency.

Transverse: something at right angles, or crossways, to something else.

Uniformly distributed load: a load spread evenly across the length of the beam bridge.

Weighbridge: a machine installed in the road for weighing vehicles that pass across it.

You will need…

- Distribution of load, per group:
  - 2 stacks of books, or boxes, of equal size, or similar, to create a small gap to bridge
  - 1 piece of A4 paper
  - Paperclips (~50)
- Resonance demonstration, per group:
  - Strips of craft card/heavyweight paper, cut to 20cm, 16cm and 12cm (roughly the width of a ruler)
  - Sticky tape
  - Cardboard tube or narrow box
  - Padlocks on the Pont des Arts
    - Handout: *Padlocks resource*
    - Rulers (to measure the padlocks)
    - Scales (if using your own padlocks)
    - Handout: *Padlocks record sheet 1*
    - Handout: *Padlocks record sheet 2*
    - Handout: *Padlocks record sheet – answers*

Something to Try:

How does the distribution of the load affect the maximum load of a structure?

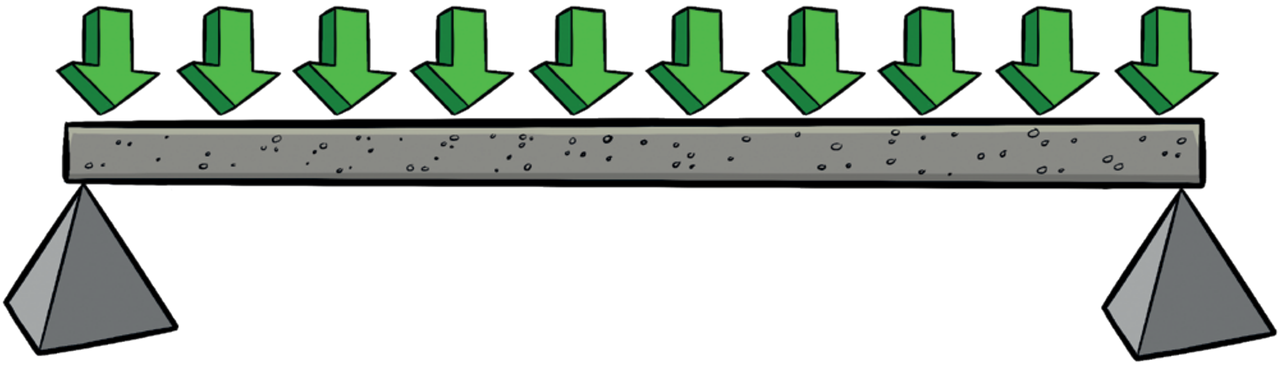
Learners can explore how the distribution of the live load can affect the amount a bridge can support, using this simple demonstration:

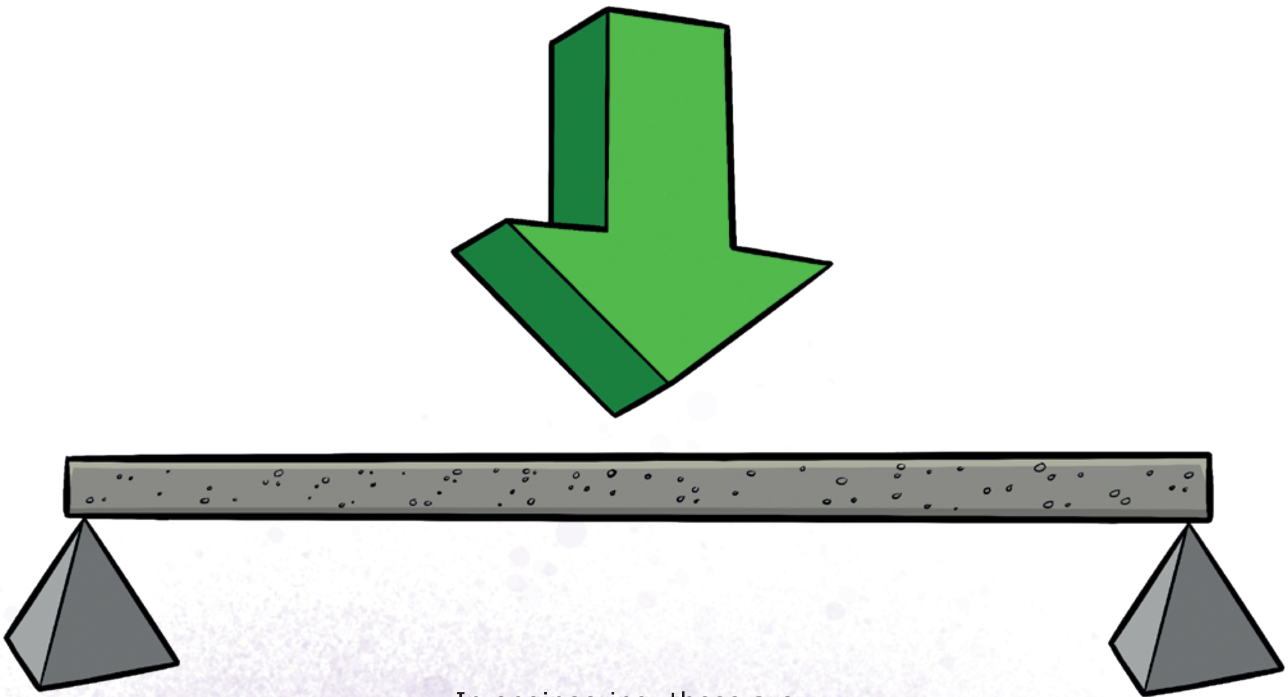
1. Slightly fold a piece of A4 paper, first in half cross-ways and then lengthways, so you end up with a very slight cross in the centre of the paper (this slightly stiffens the paper so this task is easier)
2. Place this paper folded side down on the top of the 2 stacks of books of equal size
3. Place the paperclips on the centre point of the paper (now marked with the folded cross), counting them as you do so
4. Once the bridge has collapsed, make a note of the number of paperclips held as it collapsed and then replace the paper
5. This time, spread the paperclips across the whole surface of the paper, so the entire gap is covered.

Ask learners which way held more paperclips?

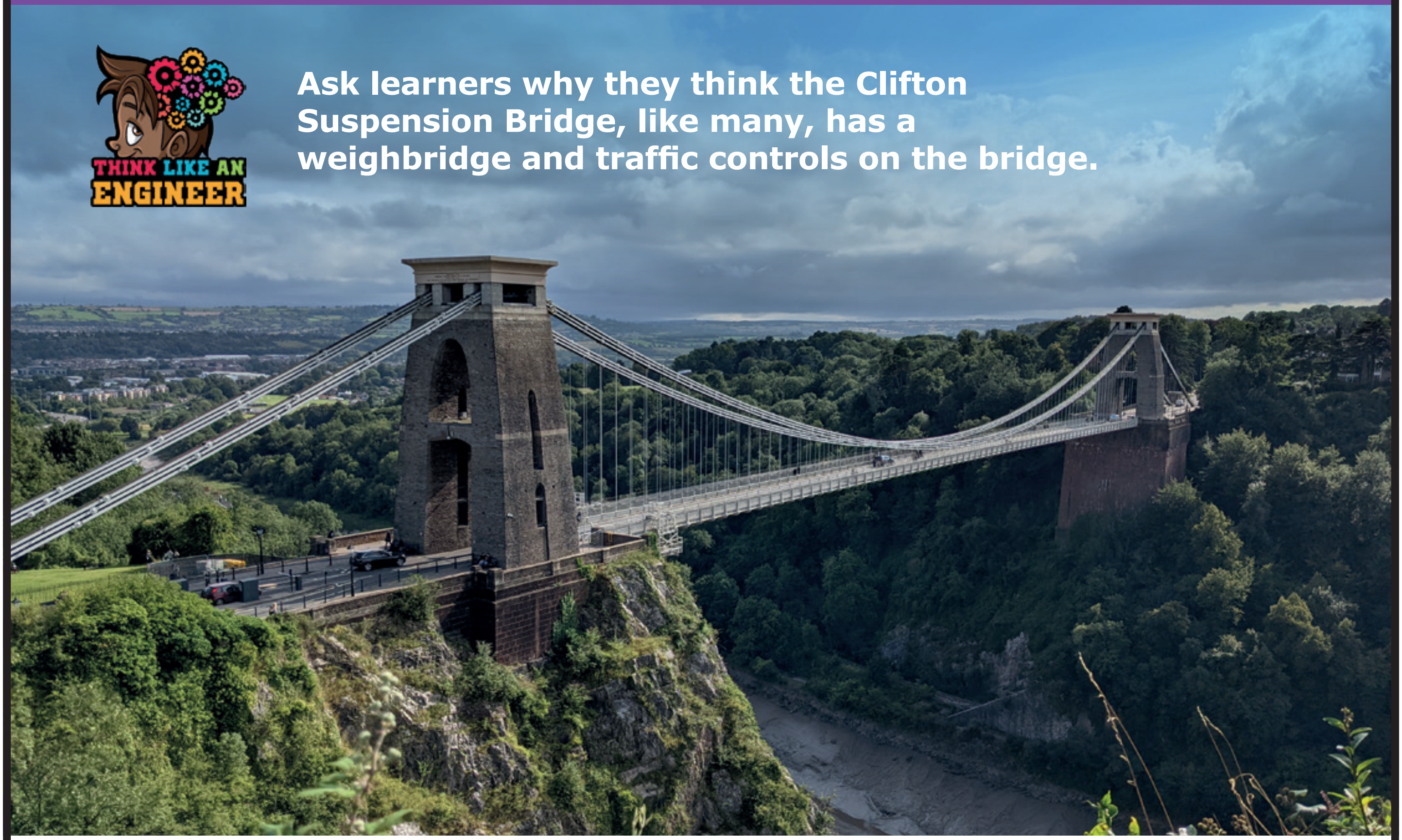
Ask learners to consider why it happened that way?

When a load is placed on a single point, it has a far greater effect than a similar, or larger, load does when spread across the entire surface. This is because the effect of the load can be calculated by the total load divided by the area it is spread over – so in the case of the pile of paperclips, because the mass is all in one spot, the effect is much higher than when the area is much bigger.





In engineering, these are called point loads and uniformly distributed loads.



Ask learners why they think the Clifton Suspension Bridge, like many, has a weighbridge and traffic controls on the bridge.

This is to manage the size of the live load going over them. Many bridges have failed due to poor estimates of the load that they can take, or due to failing materials. The live load and its distribution are something civil engineers must consider when designing a bridge and selecting materials for its construction. It tends to be better for a bridge to carry many smaller loads than a single large load – the weighbridge locks the barrier and prevents over-heavy loads going on to the bridge. The traffic controls prevent too many cars crossing at the same time to make sure the total load upon the bridge does not become too great.

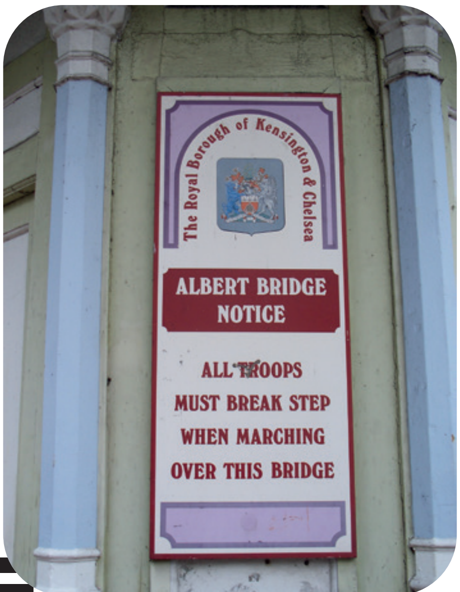


Photo by Iridescent via Wikimedia

Why should troops break step when they cross the Albert Bridge?

The reason troops have been instructed to stop marching in time when crossing bridges is due to the phenomenon of mechanic resonance. It is the result of vibrations that match the natural frequency of the material: if the vibrations caused by the soldiers marching matches the natural frequency of the material of the bridge, it creates resonance, which causes the vibrations to get bigger and bigger.

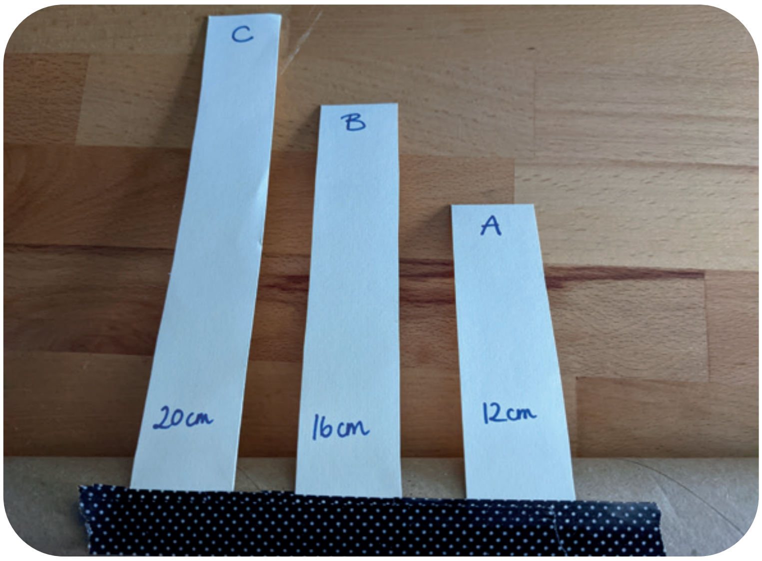
You can see this sort of resonance in action by searching the internet for 32 metronomes resonance or synchronisation of metronomes, which should bring up a number of videos on YouTube.

RESONANCE DEMONSTRATION

1. Cut the card into strips roughly the width of a ruler (around 3cm wide) and into lengths of 20cm, 16cm and 12cm

2. Stick these strips to the tube approximately 2cm apart

3. Move the tube backwards and forwards at different speeds in the transverse direction to the strip width, observing what happens to the strips.



Ask learners what they notice. If you have moved the tube at a range of speeds, it should show how the different lengths of strips move far more than the movement of the tube, at different speeds (their movement is amplified). When the speed of movement is right, the strip will move forwards and backwards far more than the other strips. It should be seen that each strip does this at a different speed.

Photo courtesy of Richerman via Wikimedia

This was first recognised in the Broughton Suspension Bridge, across the River Irwell near Manchester, England. Although there were thought to be construction issues with the bridge, it was found that the soldiers marching across the bridge in 1831 actually created resonance, causing pins securing the chains of the bridge to snap, which led to its collapse. Thankfully, although 40 soldiers fell into the river below, none died. However, it did lead the British Army to order soldiers to break step when crossing bridges.

In 1850, a similar fate befell the Angers Bridge, or Basse-Chain bridge, over the Maine River in France. Although it is suggested that the soldiers had been ordered to break step, the strong winds at the time caused the bridge to sway, forcing the soldiers to walk in step with the bridge's movement, which in turn, caused resonance in the bridge, increasing the movement further. One of the supporting columns broke, leading the bridge to fail and killing over 200 people on it.

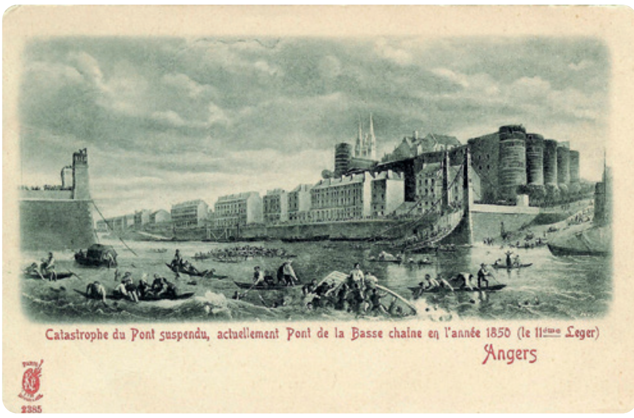


Image courtesy of Photographie Officielle on Wikimedia Commons

Challenge Time!

Photo by Guillaume QL on Unsplash

Will the padlocks cause the bridge to collapse?

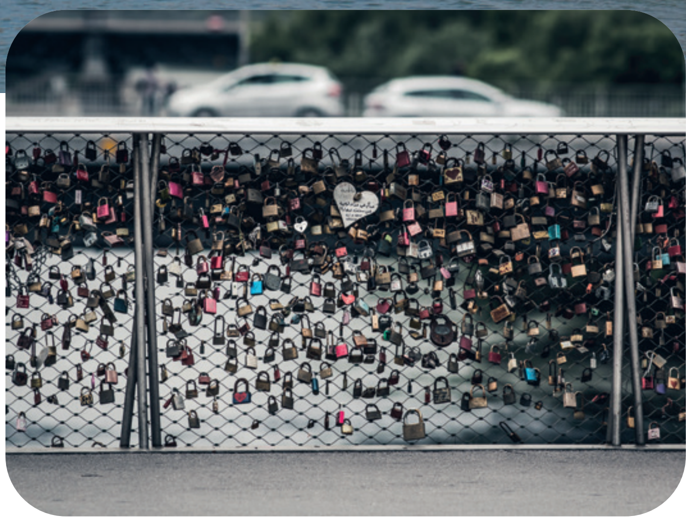


Photo by Quaritsch Photography on Unsplash

The Pont des Arts bridge is a pedestrian bridge that crosses the Seine in Paris, France. It is 155m long, made up of seven arches. It was built to match the previous Napoleon version of the bridge at the spot ‘identically’ (although the number of arches was reduced from nine to seven) in the early 1980s.

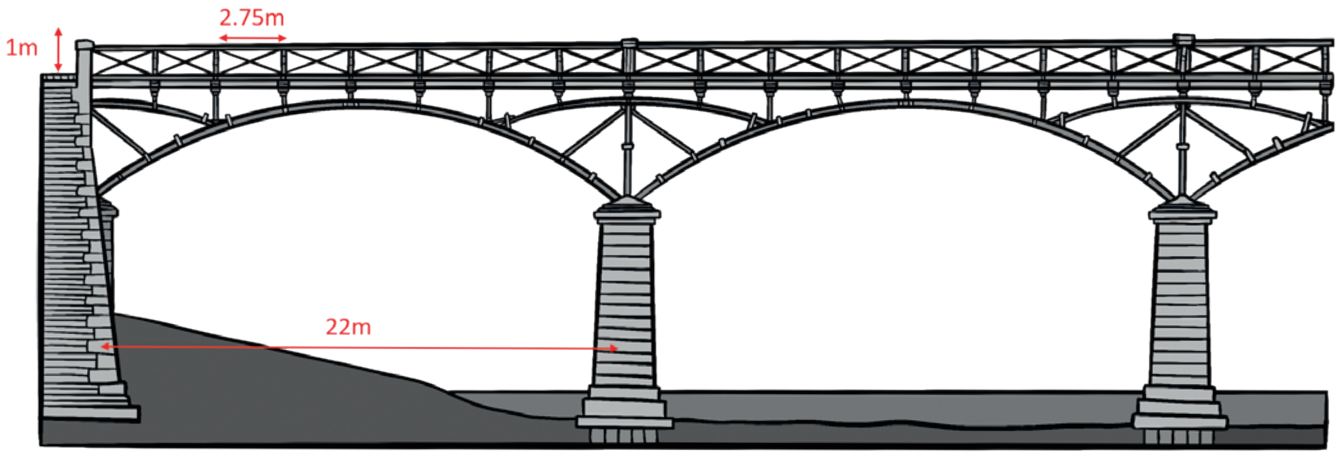
Putting padlocks on bridges has become a popular tourist activity, but how does it affect the load a bridge can take?

You will need to measure a selection of padlocks or use the Padlocks resource. Learners will need to measure the padlocks and determine the average size of the padlocks.

Once the average padlock has been determined, they are challenged to determine how many padlocks could actually fit on the Pont des Art.

This model shows two of the arches in the bridge and gives approximate measurements for key parts of the bridge. This should help learners to estimate the number of average sized padlocks that could physically fit on the parapets of the bridge.

Photo by Markus Spiske on Unsplash



Having calculated the number of padlocks, challenge learners to calculate the load these padlocks would exert on the bridge.

Ask learners whether they think this would be a worrying load as far as the bridge engineers that look after the Pont des Arts would be concerned.

Photo by Guilhem Vellut on Wikimedia Commons

Challenge learners to devise a way to prevent padlocks being attached to the bridge again once they were removed.

THINK LIKE AN ENGINEER

After a number of years of the fad, it was estimated that some 700,000 padlocks had been attached to the bridge. In 2014, when part of the balustrade collapsed under the weight, the Mayor of Paris decided that it was time for action. The padlocks were removed and auctioned off for charity, and engineers were given the task of coming up with a padlock-free design for the balustrade. The outcome was that the mesh panels were replaced with shatter-proof, graffiti-resistant glass.

HOT TOPICS!

Resonance links to the Sound topic in Science, particularly amplitude, or volume. This could link to the use of personal protective equipment or PPE to protect the ears, or perhaps how sound waves change with increased volume.

You could explore making art using sound, which links to the Chladni plates experiments in *Learning About Bridges Vol 1 Chapter Eii: Suspension Bridges – The Tacoma Narrows Case Study*, or carry out an internet search for cymatics or cymatics art for inspiration.

There are two activities you can do to demonstrate resonance.

First, create a 'singing glass' – using a wine glass, add some water and then dip your finger into the water. Run your damp finger around the rim of the glass until the glass 'sings' – the vibrations created by the friction between your finger and the glass match the natural vibrations in the glass, causing it to vibrate more and create the humming sound. You can change the volume of water in the glass, and change the note the glass sings!

Second, you can amplify a tuning fork, using a tumbler of water and a hollow tube (the tube is ideally water proof, so a length of water pipe or similar works well). Holding the tube vertically, so one end is in the tumbler of water, start the tuning fork vibrating. Hold the tuning fork over the end of the hollow tube, and move the tube up and down until the sound produced by the tuning fork gets louder. This is the vibrations resonating in the hollow tube, amplifying the sound.

Bridges often display lots of different information – whether notices for traffic or advertisements. When out and about, look at how adverts are displayed on local bridges. Do you recognise any bridges in TV adverts? In fact, the Old Bridge at Rochester featured in a well-known car brand's advert!

DID YOU KNOW?

The Victorian Bridge at Rochester had to be replaced because ships were sailed into the cast-iron arches during high tides, causing considerable damage, despite there being a specially-requested swing bridge to allow ships to pass. The barge captains were so used to dropping their masts to pass under the previous bridge that they continued to do so after the Victorian Bridge was constructed, but sometimes got it a little bit wrong!

Langdon presents:

- *Padlocks* resource
- *Padlocks record sheet 1* handout
- *Padlocks record sheet 2* handout
- *Padlocks record sheet – answers* handout

Handouts can be found at www.rochesterbridgetrust.org.uk