Chapter Eii: Suspension Bridges – Tacoma Narrows Case Study

AIMS & OBJECTIVES

- To know what happens if bridges don't transfer loads well
- To consider why the Tacoma Narrows bridge failed

CONTEXT

The Tacoma Narrows Bridge over the Puget Sound was the third longest suspension bridge in the world when it was opened in 1940. It was not a radically new or different design, but incorporated relatively new ideas of bridge design from the previous ten years. Just four months after the bridge was opened, it collapsed. The introduction of a light, more flexible design meant it was too flexible and became known as Galloping Gertie, this is what led to its failure.

LANGUAGE OF BRIDGES:

Aeroelastic flutter: vibrations or movement, caused by fluids (such as wind) on a flexible material, these can lead to a positive feedback loop – feeding into their own movement and increasing the flutter even more.

Anchor: acts to secure the bridge to the ground.

Deck: the main surface of the bridge, the traffic crosses here.

Hanger: the cables that hang the deck from the main cable.

Main cable: the cables that hold up the bridge, anchored at either end and suspended from the towers.

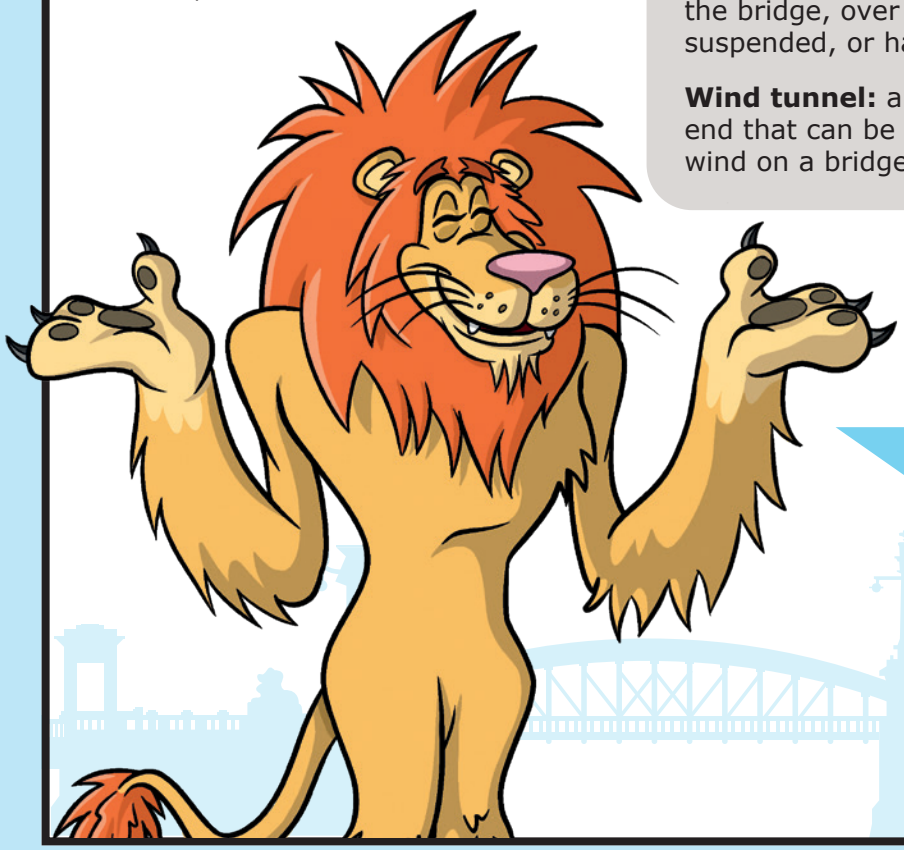
Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

Total span: the full distance, from one side to the other, the bridge covers.

Tower: the main structure that supports the bridge, over which the main cables are suspended, or hanging.

Wind tunnel: a tunnel with a large fan at one end that can be used to simulate the effects of wind on a bridge or other structure.



People actually made journeys to ride Galloping Gertie and see the extreme movement of the bridge. In this session, you can start to think about why it collapsed.

You will need...

- The effect of wind (per group):
  - Hair dryer
  - Paper
- Modelling the Tacoma Narrows bridge deck:
  - Clamp stands, bosses and clamps (if you do not have these in school, or in sufficient quantities, it may be possible to borrow these from a local secondary school science department)
  - String
  - Hole punch
  - Ruler
  - Card
  - Glue/sticky tape
  - Fan/hair dryer
  - Modelling/craft materials, such as card, paper, paper straws, string, lollipop sticks

Something to Try:

The longest beam bridge span in the world is about 300 metres long, and most beam bridge spans are less than 75m long. In contrast, a suspension bridge's span can be nearly 2km long! The spans of suspension bridges have increased in length over the years as civil engineers have learned more about the best way to build them.

University of Washington Libraries Digital Collections, Public domain, via Wikimedia Commons

The first Tacoma Narrows bridge over the Puget Sound was the third longest suspension bridge in the world when it was opened in 1940, and the designer, Leon Moisseiff, had aimed to create a slender, elegant but innovative bridge, that used materials economically. This led to a design that had plate girders forming a shallow deck that was also incredibly slender (less than 12m wide). The plate girder design was novel for a bridge of this span, as it had only been used for much shorter spans in the past: and thus, it appeared to be a steel ribbon across the Puget Sound. During construction, workers nicknamed it Galloping Gertie because it moved so much in even slight winds, due to the flexible nature of the design. Just four months after opening, the moderate wind speeds on the day, combined with the design of the bridge, caused the bridge to fail. The design of the deck caused vortices or areas of lower pressure from the wind swirling around the bridge, which increased the twisting movement of the deck. This led to the bridge twisting itself apart.

There are lots of videos showing the movement and collapse, search Tacoma Narrows Bridge collapse on the internet.

MODELLING THE EFFECT OF THE WIND ON THE BRIDGE

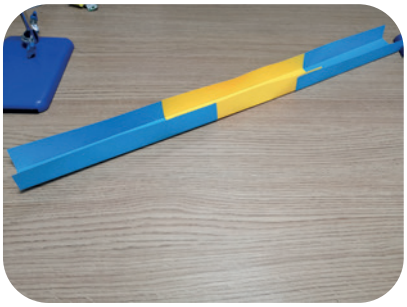
Using an A4 piece of paper and a hairdryer, learners can observe the way the design of the bridge created a barrier effect to the wind and resulted in the galloping motion. Hold the A4 piece of paper vertically on its side, so that the largest area is angled towards the hairdryer. Start the hairdryer and observe what happens to the paper.

MODELLING THE BRIDGE DECK

The Practical Engineering YouTube channel has a great video that explains how the bridge collapsed as a result of aerodynamic flutter, search for "Why the Tacoma Narrows Bridge Collapsed".

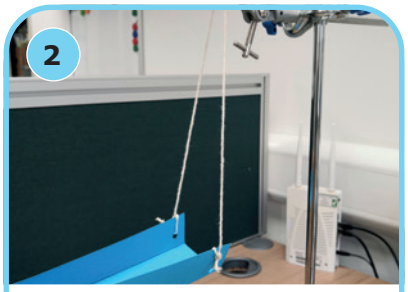
We can recreate this using a model made from cardboard:

This is constructed from three pieces of thin craft card, glued together and then cut in half lengthways. Each side is folded to form a channel.



1

Using a hole punch, create holes at the same distance from the end, and at the same height up the side.



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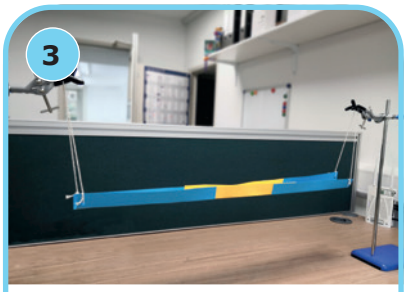
Take a 60cm length of string, and tie it through the holes at each end, creating a hanger for the bridge.



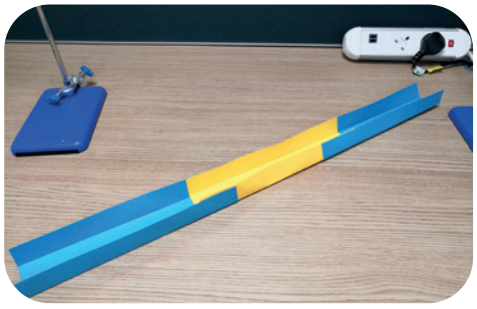
3

Hang the bridge from the two clamp stands

Challenge Time!

Having seen the problems with the Tacoma Narrows bridge, challenge learners to redesign the bridge to resist the loads from the wind.

The deck of the Tacoma Narrows bridge was very shallow and flexible, with a solid-sided parapet. This is a model made from cardboard:

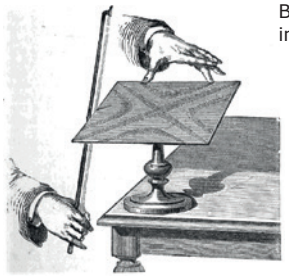


Can learners make changes to the design to make it less flexible and less likely to gallop in the wind?

When you're out and about, can you spot anything that is affected by wind currents in a similar way to Galloping Gertie? Can you see how structures are designed to avoid the effects of the wind? What do designers and engineers do to make sure structures are aerodynamic?

HOT TOPICS!

Resonance has often been blamed for Galloping Gertie's collapse. You could explore how we can 'see' sounds waves using an experiment based around the idea of Chladni Plates. Search the internet for "salt vibrations sound you can see" for an experiment to try. When the sound hits a certain frequency, it will cause the salt to vibrate at a higher rate and demonstrate the natural resonance of the equipment.



Bowing chladni plate, image via Wikimedia

The way the air flowed across the Tacoma Narrows bridge contributed to its collapse. Aerodynamics can easily be tested using paper planes. You could test different designs of paper planes and explore which glides the furthest. This gives you a good opportunity for developing your scientific enquiry skills, such as controlling variables and making accurate measurements.

CAN YOU PRETEND TO WALK ON THE MILLENNIUM BRIDGE?

In a big space, form a line of as many people as possible, standing very closely to each other, with their hands on the shoulders of the person in front – as if you were about to do the conga!

Get the front person to take a step out with their left foot, and then their right: it should be quite an exaggerated step, with a larger stride than they would normally use, and slightly out to the side each time. Each person behind should walk in time with the front person, using the movement of their hands on the person in front's shoulders to guide how far and how fast their steps will be. As the front person leads the group around, it should become obvious that the steps of anybody further back become more exaggerated, and that everybody starts to sway more and more.

This was the same issue for London's Millennium Bridge, which was also known as the wobbly bridge. The unconventional design of the suspension bridge was meant to have some sway, but as the volume of foot traffic swelled, so did the sway. As the sway increased, more people started to walk in time with the bridge's movement – which caused the wobble to increase even more.

Millenium Bridge, London (Photo by Jean-Luc Benazet on Unsplash)

DID YOU KNOW?

The Severn Bridge was completed in 1966, but the design is different to its first plan. Originally it was meant to have a truss deck design, like many other suspension bridges around the world, but after the model was destroyed in a wind tunnel test, the design was re-worked to become a more aerodynamic hollow-box deck.

Severn Bridge (Image via Wikimedia)