Chapter Liii: Cantilever Bridges – Bridging the Forth

AIMS & OBJECTIVES

- To recall the historical engineering context for the Forth Bridge
- To describe the advantages of cantilever bridges in certain contexts, over other bridges
- To understand the forces that act in a cantilever bridge

CONTEXT

The Firth of Tay disaster is hugely significant in the development of bridge engineering, specifically cantilever bridges. In order to understand why cantilever bridges were needed, and indeed why we have a cantilever Forth Bridge at all, it is necessary to appreciate the events that happened in the recent history of the region. Benjamin Baker designed a new type of bridge that would support such loads whilst spanning the great distance of the Firth of Forth. However, understandably, there was nervousness about attempting such a massive undertaking in the context of the Tay Bridge disaster.

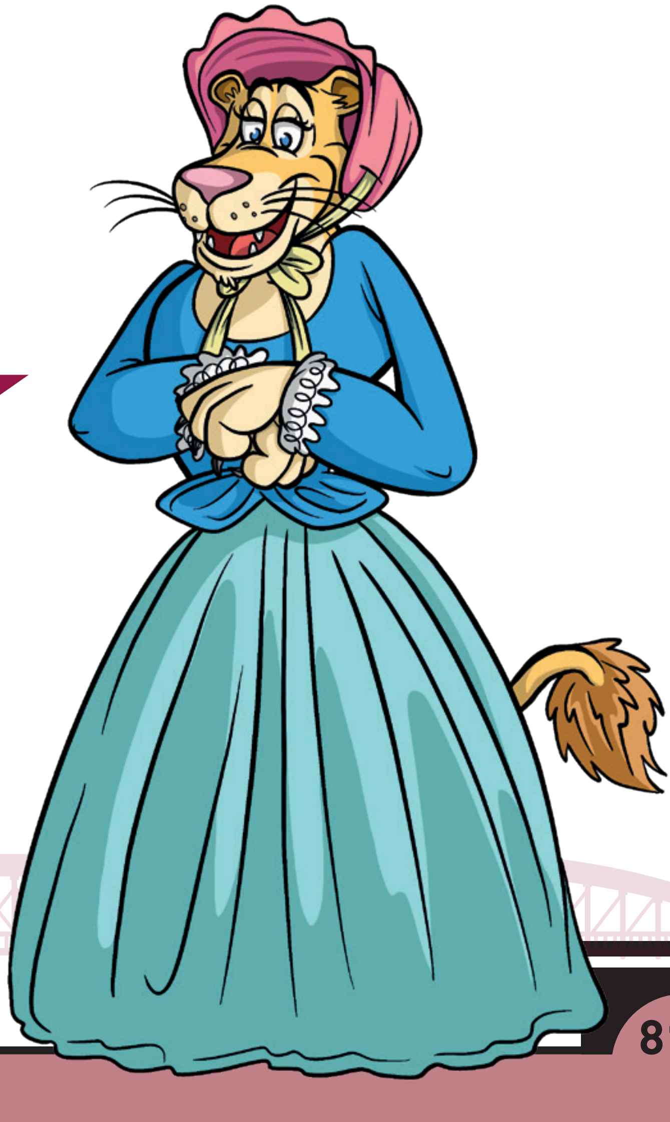
LANGUAGE OF BRIDGES:

Cantilever: A horizontal structure that projects into space at right angles (perpendicularly) to its supporting structure, supported or fixed at only one end.

Compression: a force that tries to make things shorter or smaller (a squashing, pushing force).

Tension: a force that tries to make things longer (a stretching, pulling force).

In this session we will find out more about a number of Victorian engineers and how they changed bridge engineering!



You will need…

- Handout: *Two types of cantilever bridge*
- Simple vs balanced, per group:
  - Stiff card, to cut into strips of 20cm and 10cm
  - 5 small cardboard tubes (such as paper towel inners cut into 3) or paper cups
  - 20p in pennies or two pence pieces
- Alternative cantilever demonstration:
  - Two chairs
  - Four brooms/mops with wooden handles
  - Large bedsheet or sturdy blanket
  - 4 large buckets and/or bricks
  - Thin rope
- Bridge design challenge, for example:
  - Range of building materials, such as household recycling, cardboard boxes and tubes, string, craft card, paper, newspaper, art straws
  - Sticky tape, washi tape, masking tape
  - Paperclips, treasury tags, bulldog clips (as available)
  - Scissors/craft knife and cutting mat (as appropriate)
  - Glue/hot glue gun (as appropriate)
  - Mars bars, exercise books or masses for testing the bridges
  - Ruler
  - Paper and pencils
- Handout: *Standing on the shoulders of giants*

Something to Try:

You may have noticed the Tay Bridge was not a cantilever… So why was it, and the unfortunate incidents that befell it in 1879, included in a chapter on cantilever bridges?

Image courtesy of Wikimedia Commons

Sir Thomas Bouch was originally intended to design the crossings at both the Tay and Forth.

Learners can consider why the Forth Bridge is threatened: reputation of the engineer, greater likelihood that a longer bridge would be more susceptible to environmental factors, for example. You could also watch the BBC Victorian Scotland clip (search for Thomas Bouch Tay Bridge Disaster BBC) that dramatizes a hypothetical conversation between Bouch and his assistant, Charles Meik. Whilst it is highly unlikely that the conversation played out the way it is dramatized, learners could consider the approach of Bouch, and whether this was in keeping with the attitudes of the time.

Image courtesy of Wikimedia Commons

In light of the Tay Bridge disaster, Benjamin Baker was appointed as one of the engineers to construct a bridge at the Firth of Forth. He was already highly regarded after helping to develop the London Underground and had been used as an expert witness to give testimony at the inquiry into the Tay Bridge disaster.

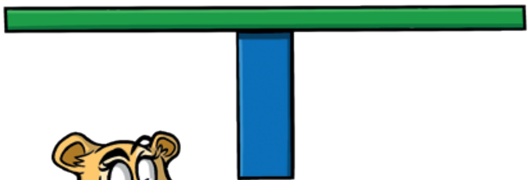
Benjamin Baker's design was a cantilever bridge. In *Chapter Li: Cantilever Bridges – Introduction*, learners were introduced to the idea of levers and balancing forces to construct a cantilever bridge.

LINK

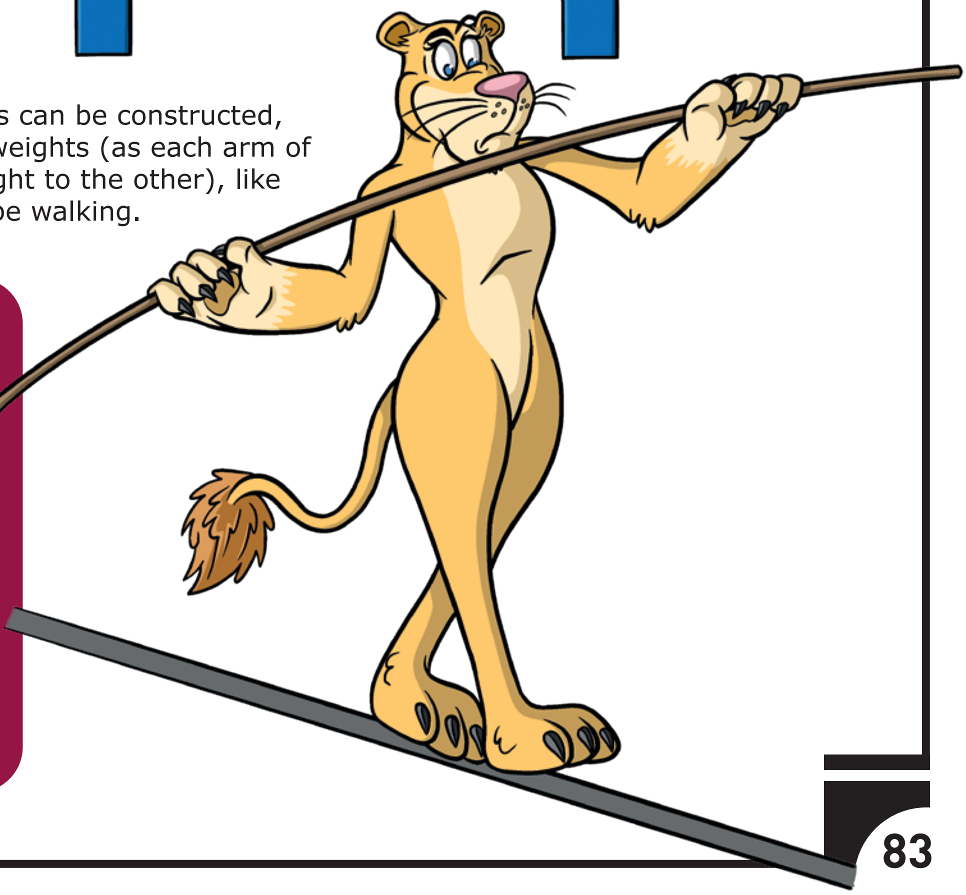
Remind learners of what a cantilever is using a ruler. Ask them where does a ruler need to be for it to balance on your finger? They should recognise that it needs to be in the middle. Ask them to try to balance a ruler near one of it's ends: what do they need to do to get the ruler to balance this time? They need to apply a counterweight – another finger or a weight at the short end. The longer end of the ruler is the cantilever.

Bridges involving cantilever can have slightly different designs. Learners can see these in the *Two types of cantilever bridge* handout. For example, it could be two cantilevers like the ruler put together:

Alternatively, a cantilever bridge can be what we call a 'balanced cantilever' that resembles a see-saw:



In this way, much longer bridges can be constructed, without requiring large counterweights (as each arm of the bridge acts as a counterweight to the other), like using a balance pole for tightrope walking.



Additionally, this allows the bridges to be built without the need for falsework, the additional supports that are built and then dismantled when the bridge is completed, such as the centring for arch bridges (see *Learning About Bridges Vol 1 Chapter Di: The Science of Arches*).

LINK

SIMPLE VS. BALANCED CANTILEVERS

Learners can explore both types of bridges using cardboard and cardboard tubes or paper cups.

1

Cut five long strips of stiff card of 20cm and two shorter 10cm strips of the same width.

2

Place two cardboard tubes/cups 30cm apart.

3

Try to balance the longer strips of card between the two tubes, as a simple cantilever bridge, with the pieces meeting in the middle, and projecting from the tubes/cups similarly to a diving board, using the coins as counterweight.

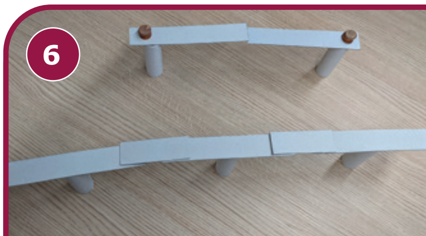
4

Take three more cardboard tubes and place these 20cm apart.

5

Take the remaining long strips of card and balance them on the tubes, so that they are balanced, with both sides of equal length.

6



Take the short strips and balance those between the arms of the cantilever strips.

Ask learners what do they notice about the two different forms of cantilever bridge? They may identify that you don’t need extra materials to counterbalance the balanced cantilever bridges, as you do with the simple ones, or that the balanced cantilever bridge can be much longer, as the structure can be repeated.

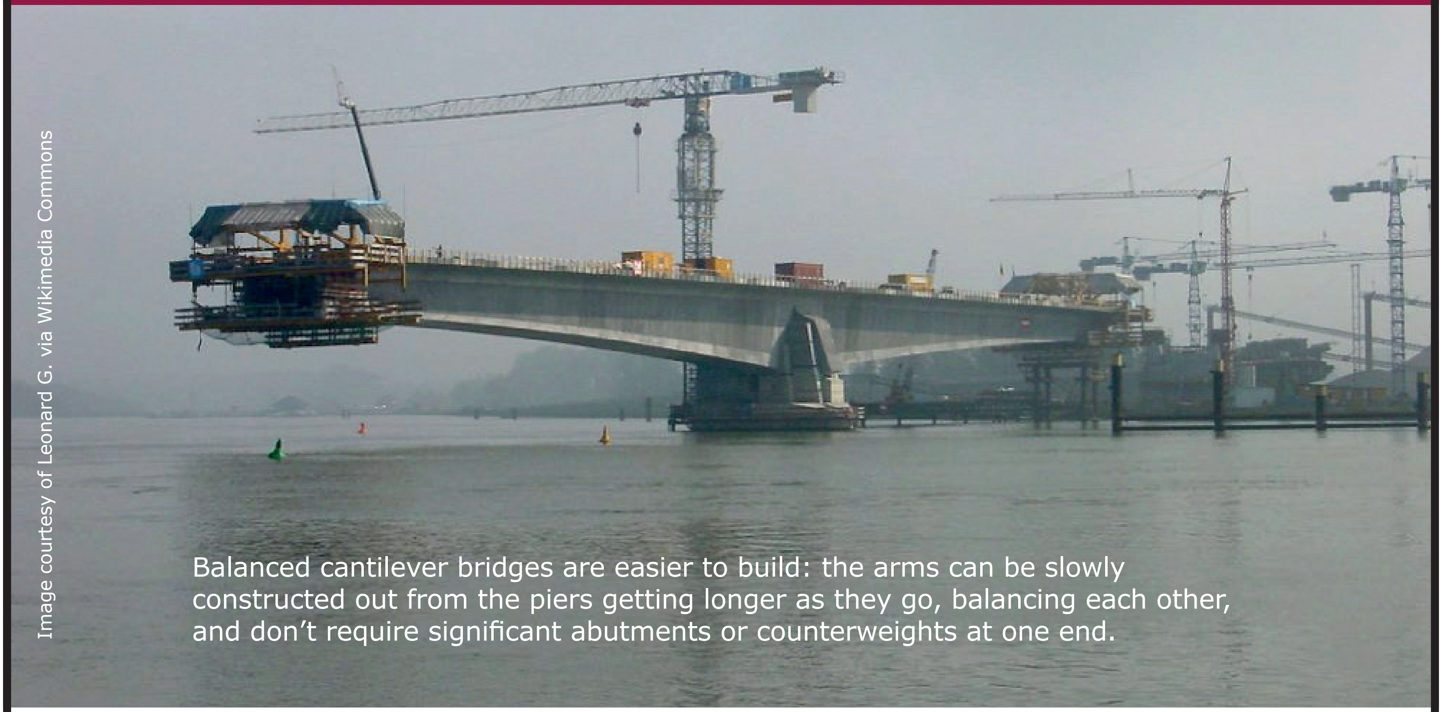


Image courtesy of Leonard G. via Wikimedia Commons

Balanced cantilever bridges are easier to build: the arms can be slowly constructed out from the piers getting longer as they go, balancing each other, and don't require significant abutments or counterweights at one end.

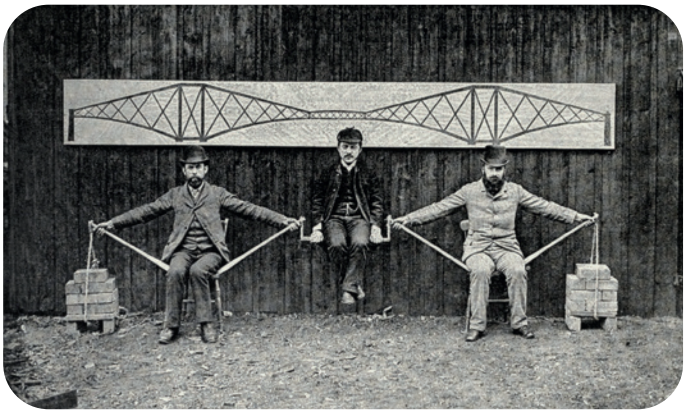


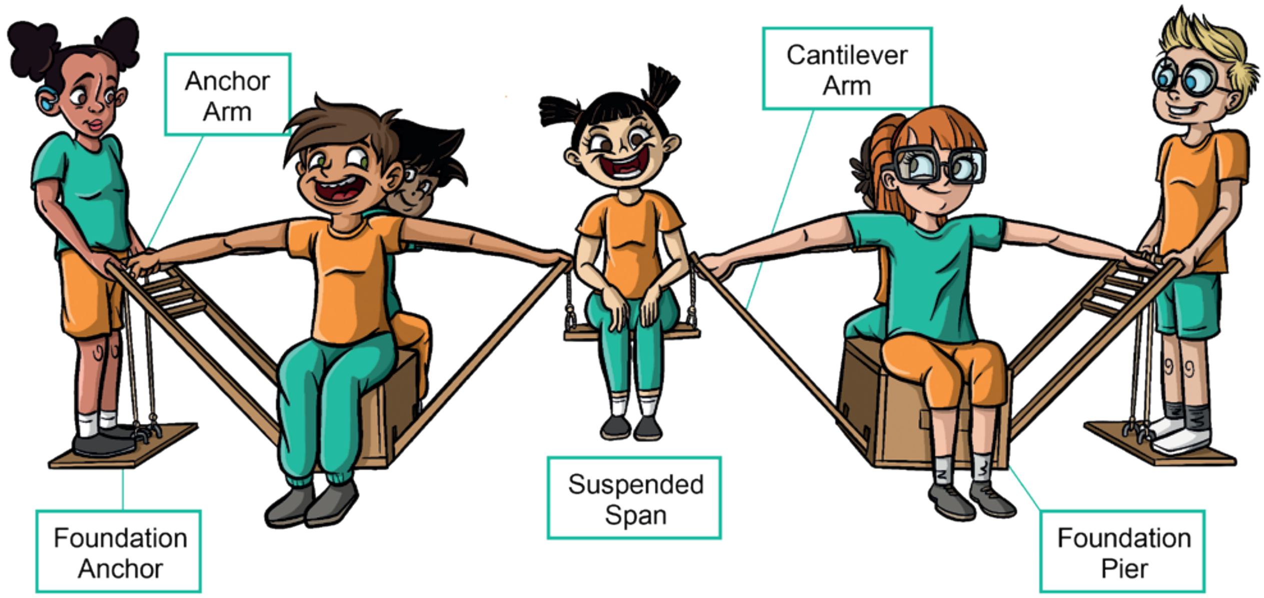
Image courtesy of Wikimedia Commons

Although cantilever bridges have been used for a long time, Benjamin Baker's bridge over the Forth was to be the first of its kind, and the longest in the world. After what had happened with the Tay crossing, people were understandably nervous about this new type of construction!

As a result, Benjamin Baker and his collaborating engineer, Sir John Fowler devised a demonstration, shown at the Royal Institution in 1887.

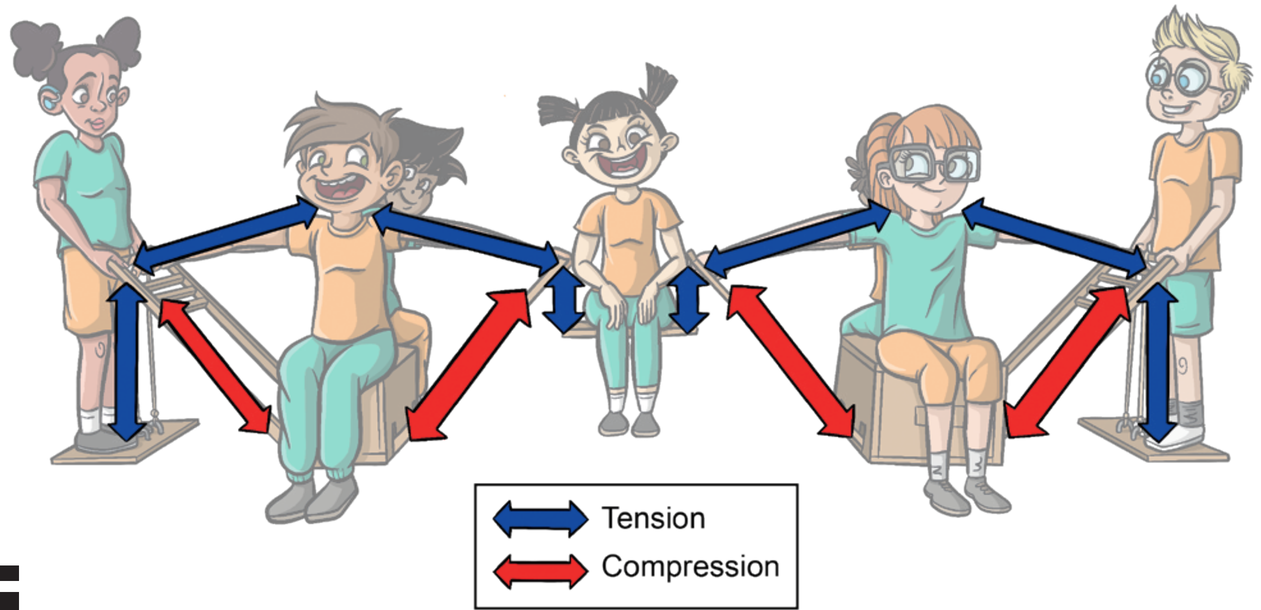
Note the scale diagram of the Forth Rail Bridge – Sir Benjamin Baker drew it to the same size as his demonstration to directly relate the model to the structure design.

If you are based in Kent, Medway and some London boroughs, you may be able to borrow our bespoke Baker cantilever equipment. However, you can recreate this demonstration using chairs or footstools, broom handles, bricks or buckets of water, and having someone small for the middle suspended-span made out of a sheet! If you search on the internet for Baker's cantilever demonstration, you should find a number of demonstrations to help with this.



Learners can do a simple demonstration to show the effect of using a support for a cantilever arm. Place the heavy book in the bag with straps as in *Chapter Fi – Cantilever Bridges – Introduction*. Repeat the activity with the bag over the tips of their fingers. Ask learners how their arm could be strengthened. They might suggest that having someone else hold up the arm holding the book, the arm can hold more weight.

To build a cantilever bridge you need to balance the tension and compression forces; 'channelling' the weight of the bridge itself (dead load) and all that it carries (live load) into the abutments and piers.



Challenge Time!

In groups, challenge the learners to use all of the knowledge and skills they have developed over the course of Learning about Bridges book 1 and 2, to build a strong bridge.

As in *Chapter F: Thinking like an Engineer*, challenge learners to bridge a gap of your choosing, using materials suitable for that task, such as recycling materials, art straws, craft sticks and so on. Set them a short time to design and then build the structure, before testing it. You can add extra challenge by creating a budget and price list for the items, or by making the design and development time shorter. The best bridge might be the strongest, but it could also be the most aesthetically pleasing, the most interesting engineering, or the cheapest.

LINK

Just 4 Fun

Could you construct a structure out of people?! Could you try making a human table, that was popular on social media in 2020? Place four chairs in a square, facing each other, then four people sit on the chairs, turning around to sit sideways on their chair (all facing the same way), and then they lie back, so their shoulders and heads are on the knees of the person behind them. Take away the chairs, and you have a human table!

Return the chairs before they get tired and collapse!

If that's too easy, how about a fan-shaped structure, with people leaning at different angles?

Image courtesy of Amotoki via Wikimedia Commons

HOT TOPICS!

A UNESCO World Heritage Site

The Forth Rail Bridge is a UNESCO World Heritage site. To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of ten selection criteria. The Forth Rail Bridge meets at least 2 of the selection criteria: (i) to represent a masterpiece of human creative genius; and (iv) to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history.

Learners could research the bridge design further, and consider why the bridge meets these criteria – think about the 'oversized' structural components, that are not hidden or adorned in any way, the striking colour, the brave engineering at the time when a similar bridge had failed, the record-breaking span, the use of a new material that stretched the boundaries of engineering thus far…

Learners could also look at local structures or notable sites, and present their own argument for why they should be nominated as a 'UNESCO World Heritage Site' using the criteria (which can be found with an internet search).

OUT & ABOUT

Research a civil engineer, for example, William Cubitt, Thomas Telford, Joseph Bazalgette, Nora Stanton Barney, Mary Fergusson, Roni Savage, or many more that can be found on the Institution of Civil Engineers website. To help you complete your research, use the *Standing on the shoulders of giants* resource. You could then complete a profile of your chosen engineer, to share their life and work with others.

DID YOU KNOW?

£20 notes issued by the Bank of Scotland feature a series of famous engineering structures, including the Forth Bridge.

Langdon presents:

- *Two types of cantilever bridge* handout
- *Standing on the shoulders of giants* handout

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