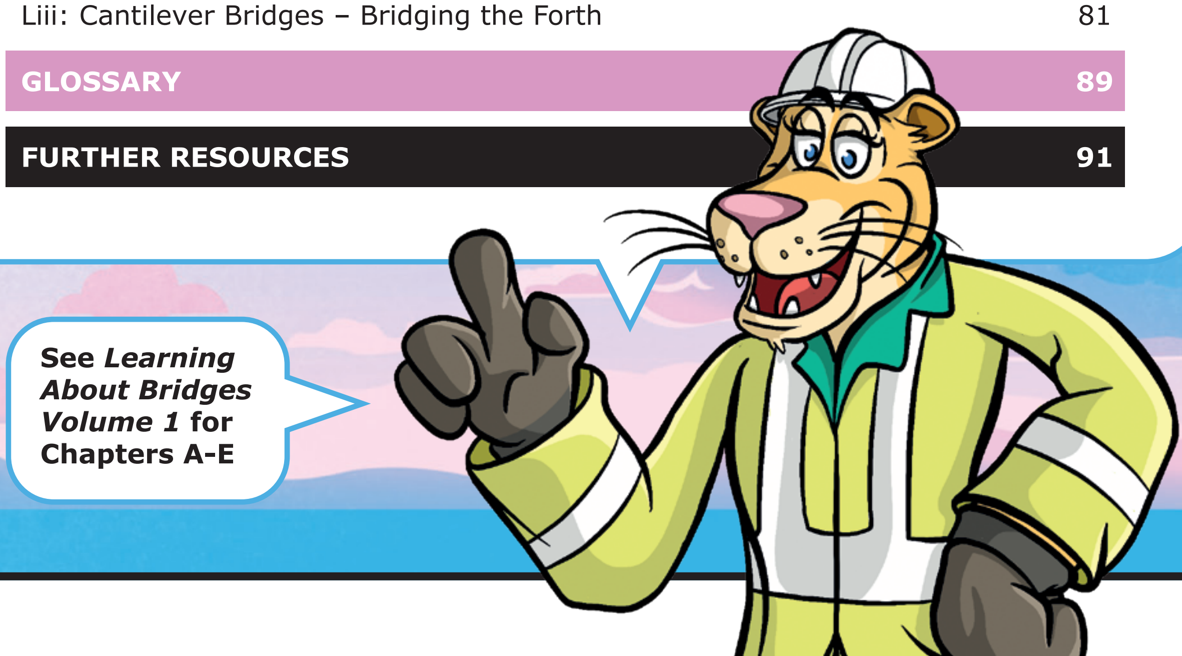
ROCHESTER
BRIDGE TRUST

Learning About Bridges

VOLUME 2



See *Learning About Bridges Volume 1* for Chapters A-E

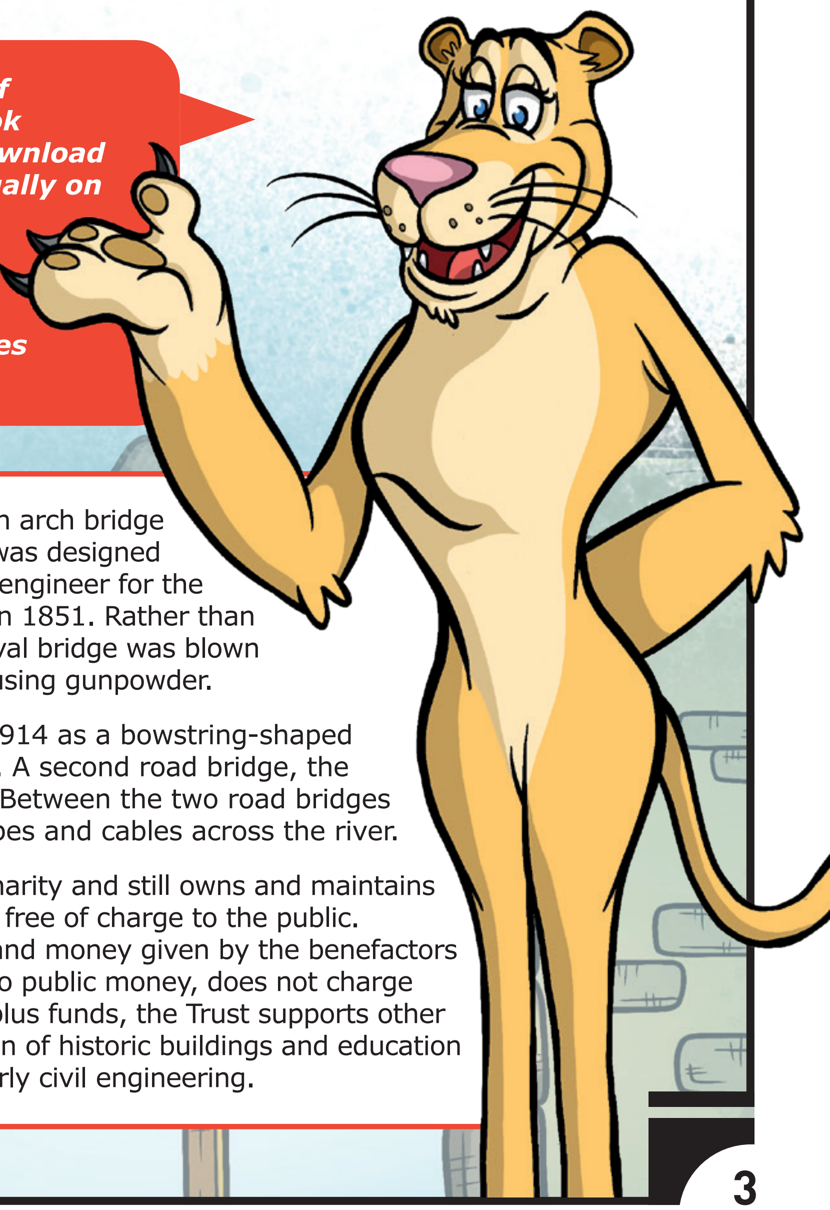
About The Rochester Bridge Trust

The first bridge at Rochester was built by the Romans soon after the invasion of Britain in 43AD. Once the Romans left, their bridge was maintained by the local people of Kent until the 14th century, as outlined in the Bridgeworks List. In 1381, the River Medway froze solid and, when the thaw came, the ice and floodwater swept away the Roman bridge.

Two benefactors built a new stone bridge 100 yards upstream. This was opened in September 1391. Their names were Sir John de Cobham and Sir Robert Knolles. Together, they persuaded their friends and acquaintances to make donations of land and money for the perpetual maintenance of Rochester Bridge. In 1399, King Richard II granted letters patent which allowed the Rochester Bridge Trust to be set up to care for the bridge and its property. Two Wardens were appointed to manage the bridge.

For the next 457 years, the Wardens looked after the medieval bridge. Major improvements were carried out by the civil engineer, Thomas Telford, in 1827. However the increase in road and rail traffic as a result of the industrial revolution meant the stone bridge's days were numbered.

Hello! I'm Leonie the Lion, guardian of Rochester Bridge. Welcome to my book Learning About Bridges 2! You can download each session within this book individually on my website, along with presentations and other resources, as well as many other activities. Simply visit www.rochesterbridgetrust.org.uk. I hope you enjoy the different activities and learning all about bridges!



In 1856, the Trust completed a new cast-iron arch bridge on the line of the original Roman Bridge. It was designed by Sir William Cubitt who had been the civil engineer for the Crystal Palace built for the Great Exhibition in 1851. Rather than a lengthy demolition process, the old medieval bridge was blown up for the Wardens by the Royal Engineers using gunpowder.

The Victorian bridge was reconstructed in 1914 as a bowstring-shaped truss and is today known as the Old Bridge. A second road bridge, the New Bridge, was opened to traffic in 1970. Between the two road bridges there is the Service Bridge which carries pipes and cables across the river.

The Rochester Bridge Trust is a registered charity and still owns and maintains the two road bridges and the Service Bridge free of charge to the public. The Trust's money is derived from the land and money given by the benefactors in the 14th and 15th centuries. It receives no public money, does not charge tolls and does not raise funds. With any surplus funds, the Trust supports other charitable projects, primarily the preservation of historic buildings and education projects in the field of engineering, particularly civil engineering.

How this book works

Learning about Bridges is a Science, Technology, Engineering and Maths (STEM) learning resource that can be used in the classroom, at a club or at home. It is designed to suit 8-12 year olds, with guidance from an adult, but can be adapted to suit a younger or older audience. The book covers a variety of bridge-related topics designed to make civil engineering accessible to everyone.

You can use all of the sessions in order or pick and choose sessions to suit your needs: each chapter of the book covers a separate topic. Although each one is relatively stand alone, each section builds on knowledge from previous chapters.

Each chapter is broken into sections: The Aims and Objectives, Context and You will need… sections, for example, are as you would anticipate.

If you are based in Kent, Medway and some London boroughs, you may be able to borrow some of the equipment used in these activities directly from the Rochester Bridge Trust. Alternatively, you may be eligible for a small grant from the Trust, to enable the purchase of materials to facilitate the use of this book in your school, club or group. Further information about our Bridge in a Box equipment loans and small grants can be found at **www.rochesterbridgetrust.org.uk** – our website which is dedicated to engineering education.

The Language of bridges lists subject-specific vocabulary for that chapter.

The Something to Try and Challenge Time! sections are more hands-on activities to explore.

CHALLENGE

Just for Fun is a more playful activity that relates to the subject of the chapter, such as a game or engineering with food.

Out and About is the opportunity to explore the learning in your local environment.

OUT & ABOUT

Langdon Presents includes further learning materials that relate to the whole chapter. This may be a presentation that is useful in a classroom, or handouts to support the learning.

DID YOU KNOW?

Did You Know? poses a question from our lion friends, Leonie and Langdon, for learners to find out a fact or interesting snippet of information about civil engineering and bridges.

This icon might appear if this section of the chapter relates to another area in the book.

LINK

SCIENCE GEOGRAPHY HISTORY ENGINEERING ART

Hot Topics relates to activities that may link to other non-engineering subject areas or skills, such as literacy, numeracy or the arts. This is not the only place that these skills may be employed – there are logos that identify key skills or subject areas in each activity.

The following logos flag where these key skills or subject areas are particularly developed in the activity.

LITERACY MATHS SCIENTIFIC ENQUIRY THINK LIKE AN ENGINEER

Finally, you might notice Langdon carrying a suitcase. This denotes something that highlights Science Capital. The Rochester Bridge Trust has been working with researchers at King's College London to explore learning through play and learning in more informal settings. This links to helping and encouraging young people to participate in STEM subjects now and in the future. The Science Capital concept helps us to understand patterns in science participation, and why some people engage, while others do not. Wherever you see the Science Capital logo it identifies concepts or activities that relate to the science capital teaching mindset, enabling educators to broaden what counts as science, and hopefully engaging more of their learners with STEM.

We have also included a Glossary to summarise the key words throughout, and a chapter with further resources that we find interesting or helpful for learning more.

Although this resource is not limited to use in the classroom, it can be used to support the National Curriculum for England Programmes of Study in the following ways:

DESIGN AND TECHNOLOGY

The activities can support elements of Design, Make, Evaluate and Technical Knowledge in the KS2 and KS3 Programmes of Study. Each design challenge could be modified or adapted to a longer Design and Technology challenge, by challenging learners to design and model something (e.g. a crossing) for somebody (e.g. pedestrians and vehicles), for a specific purpose (e.g. to link an existing road network to a new village being built on the other side of a river). The learners will then be able to make design decisions to create innovative models which can be tested authentically.

MATHEMATICS

The activities can support elements of Measurement and Geometry in the KS2 and KS3 Mathematics Programmes of Study. Such as:

- Measuring, converting, estimating, comparing and calculating lengths;
- Drawing 2D shapes; making 3D shapes with modelling materials;
- Identifying vertical and horizontal lines;
- Identifying 3D shapes from 2D representations.

With some slight adaptations, the activities could also support the teaching of drawing and measuring angles and use of scale.

SCIENCE

The activities can support elements of Working Scientifically, Everyday Materials and Forces in the KS2 and KS3 Science Programmes of Study, such as:

- Asking questions; observing closely; measuring accurately; making predictions and performing simple, fair tests;
- Helping pupils to identify, name, distinguish between and group materials;
- Comparing material properties and choosing suitable materials for particular uses based on test findings;
- Finding out how gravity, tension, compression and torsion can change the shape of solid materials by squashing, bending, twisting and stretching.

GEOGRAPHY AND HISTORY

Learning about Bridges could supplement elements of the KS2 and KS3 Geography and History Programmes of Study if you choose to study a local bridge or your local river.

The Engineering Process

AIMS & OBJECTIVES

- To know what we mean by civil engineering
- To recognise the engineering design process
- To apply some of the engineering design processes to a task

CONTEXT

Engineering is work that uses science, maths and technology to create products and processes. Engineers work in all types of settings all over the world, sometimes alone and sometimes in a team. The engineering design process is a set of steps an engineer follows to go from an idea or a need, to a product or process.

LANGUAGE OF BRIDGES:

Civil engineering: the type of engineering that helps shape the world around us, helping to design bridges, tunnels, railways, roadways, as well as constructing skyscrapers, dams, power stations, airports and sports stadiums.

Engineering design process: the process engineers use to describe the steps taken to move from a question, idea or need, to designing the product or process required.

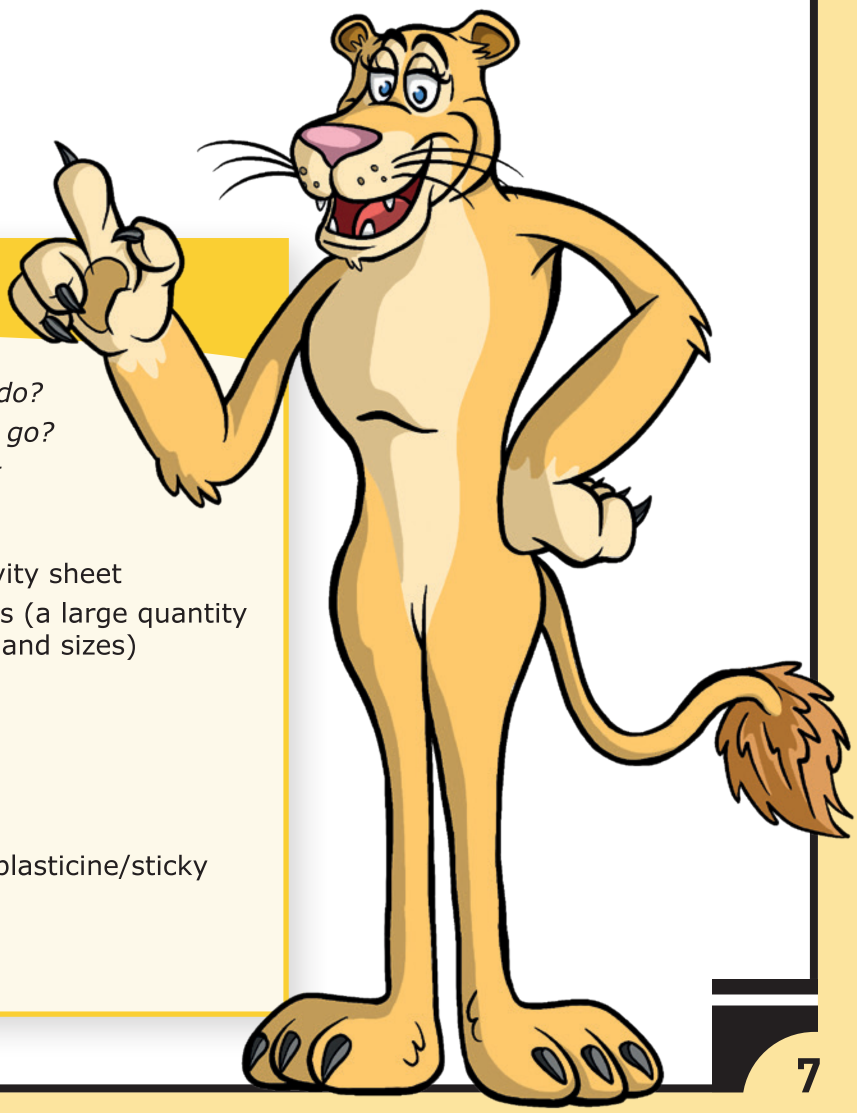
Iron triangle of engineering: a way of showing how three factors in engineering projects affect each other.

You will need...

- Handout: *What do Civil Engineers do?*
- Handout: *Where should the bridge go?*
- Handout: *Bridge builder's checklist*

- Can you build it? (per group)
  - Handout: *Can you build it?* Activity sheet
  - Standard wooden building blocks (a large quantity with a good selection of shapes and sizes)

- Design Challenge (per group):
  - 100 wooden toothpicks
  - 50 jelly sweets
  - Sewing thread
  - A small lump of modelling clay/plasticine/sticky tack, for the base
  - Paper and pens/pencils
  - Handout: *Design Challenge*



There are lots of different types of engineers:

- mechanical engineers, who are experts with all kinds of machines;
- aerospace engineers, who design, build and look after aeroplanes, and/or spacecraft and satellites;
- robotics engineers who create robots and think of new ways for making them work for us;
- energy engineers who work with different power sources to produce energy for our homes, schools, offices, factories and so on;
- alternative energy engineers, who help us capture energy from renewable energy sources, such as the wind, sea and sun;
- materials engineers who study materials, such as metal and plastics, and try to find new ways to use them;
- structural engineers who help design and build structures, such as dams and skyscrapers;

and many more…

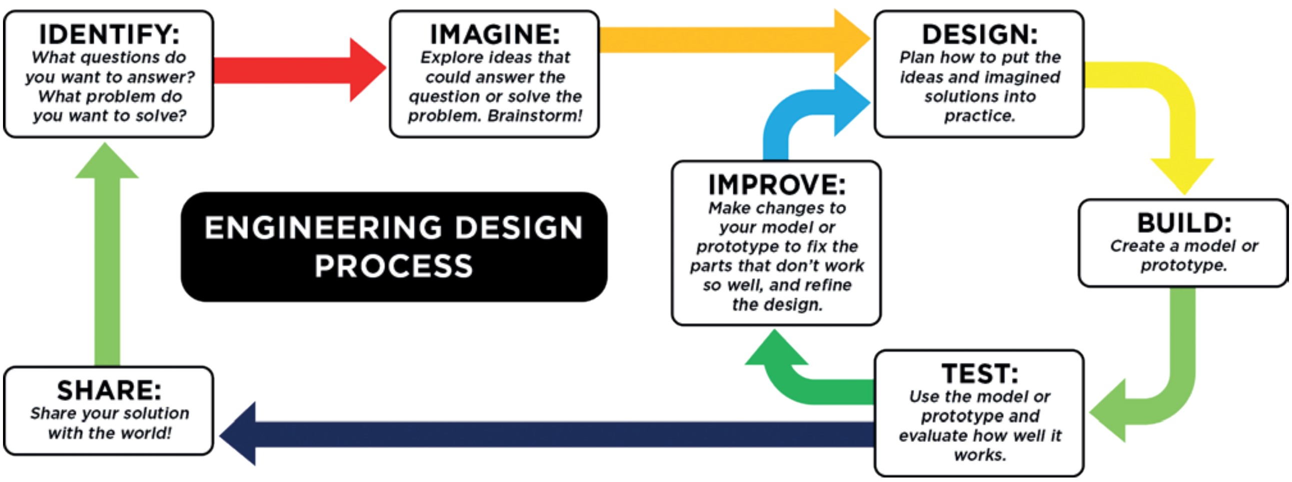
Civil engineers help shape our environment – they have links to material, structural and energy engineers. Civil engineers help design and build bridges, tunnels, railways and various other smaller scale projects, such as drains or sea walls, among others.

Something to Try:

To learn a bit more about the history of the Rochester Bridge Trust and civil engineering, take a look at an introductory video on the Rochester Bridge Trust education website: **www.rochesterbridgetrust.org.uk**

The *What do Civil Engineers do?* handout gives a range of examples of types of projects civil engineers work on, or not, as the case may be.

Whichever field of engineering, engineers use the same type of process to go from an idea or a need, to a manufactured product, plan or process. This is the 'engineering design process'.



It starts with someone asking a question. This identifies the problem or the constraints of the engineering project. Then engineers start to imagine possible solutions, and start to design and plan their project, gathering research and brainstorming ideas. Once an engineer has a plan, they can start to build – this is usually a model or prototype of the project. This can then be tested to check whether the project actually achieves what it set out to do: if it doesn't, the design is refined, re-built and re-evaluated. The final project can then be shared and the cycle starts all over again!

Civil engineers have to consider lots of different factors in their planning and design phase – not just the structural elements of the designs they build, but also how people will be affected by the design or how the environment will affect the design.

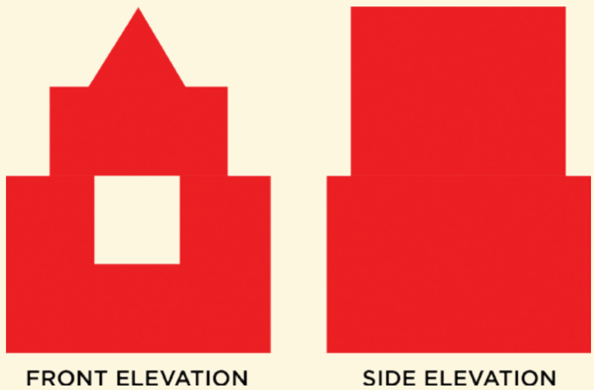
WHERE ARE BRIDGES BUILT?

In this activity, imagine you are a civil engineer trying to plan a crossing. Bridges are built to fit the environment around them. The specific bridge cannot be built anywhere else because bridges are individually designed to match the need in that one place and the specific challenges associated with that location. Challenge the learners to decide where to build a bridge for the specific environment (*Where should the bridge go?* handout).

Ask them to consider where people would most need a bridge, whether there are any environmental factors that might influence the location and whether there are any other issues that might make building a bridge difficult. They can use the *Bridge builder's checklist* handout to help consider all of the issues.

CAN YOU BUILD IT?

Using standard wooden building blocks (such as you might find in an Early Years setting), challenge learners to build the designs shown in silhouette only on the *Can you build it?* handout, using both the front and side elevation plans, to try to work out the bricks needed to create a self-supporting structure.



Discuss whether all the final block designs were the same for each group. Ask learners what they found the hardest part of this challenge? How do they think the process could be improved?

They might consider that having more information, such as the size, shape or number of bricks, would help speed up the build process, or that having clearer plans (not in silhouette) showing the exact nature of the designs would help to reduce the number of 'test' builds required to create the same overall design.

Challenge Time!

Challenge your learners to use the engineering design process with this activity.

Photo by Sid Saxena on Unsplash

Using the materials provided, learners must build a stable structure as tall as possible. The structure has to stand up in the breeze from an electric fan.

Using the *Design Challenge* handout, learners can work through the engineering design process to design and construct their towers. Each tower should be tested and then, if necessary, re-designed and re-tested.

The handout suggests using the Eiffel Tower as inspiration – the design does not have to be limited to only this idea, but might help steer learners in the right direction for completing stable structures.

The main purpose of the challenge is to incorporate the different stages of the engineering process – every group/learner should engage with identifying the problem, carrying out research, developing solutions, constructing and testing designs and finally communicating their ideas. To increase the challenge, a minimum height could be applied to the structures, or to develop other skills, a more detailed presentation about the design and structure testing process could be expected.

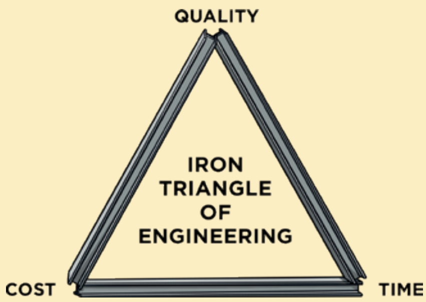
After all the designs have been tested and re-designed as necessary, ask learners to consider the main difficulties they faced during the process and how they overcame them? Did all groups have the same challenges? If the design basically worked the first time/test, were there ways to improve it? For example, could the stability be improved, or could fewer materials be used?

The iron triangle of engineering describes three factors engineers must think about when building a product or implementing a process. They must consider:

Time: how fast does the project have to be completed?

Quality: what features does the finished product have to include, and how good does it have to be?

Cost: how cheap or expensive is the whole project?



These three factors are related and affect each other. It is very unlikely that an engineering project is completed quickly, to a high quality and cheaply! Engineers will often have a number of different design options that meet their clients' needs – whether it is to complete the project quickly, to a small budget or to a very high quality.

Ask learners to consider how their project fits in with the iron triangle concept – did they do it quickly, could they produce it cheaper, or of a better quality? Would they have to adapt their design to make it faster to construct? Or if it needs to be higher quality?

HOT TOPICS!

Research an engineer, for example, Archimedes, George Stephenson, Isambard Kingdom Brunel, Hedy Lamarr, George Carrythers, Roma Agrawal among others... 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.

Engineers try to find solutions to problems, and they often have to visualise a 2D image in three dimensions, or imagine a 3D shape as a two-dimensional diagram.

A geometry net is a two-dimensional shape that can be folded to form a three-dimensional shape or solid. You could try to match nets of different shapes to their 3D diagrams, or even build your own 3D shapes from geometry nets.

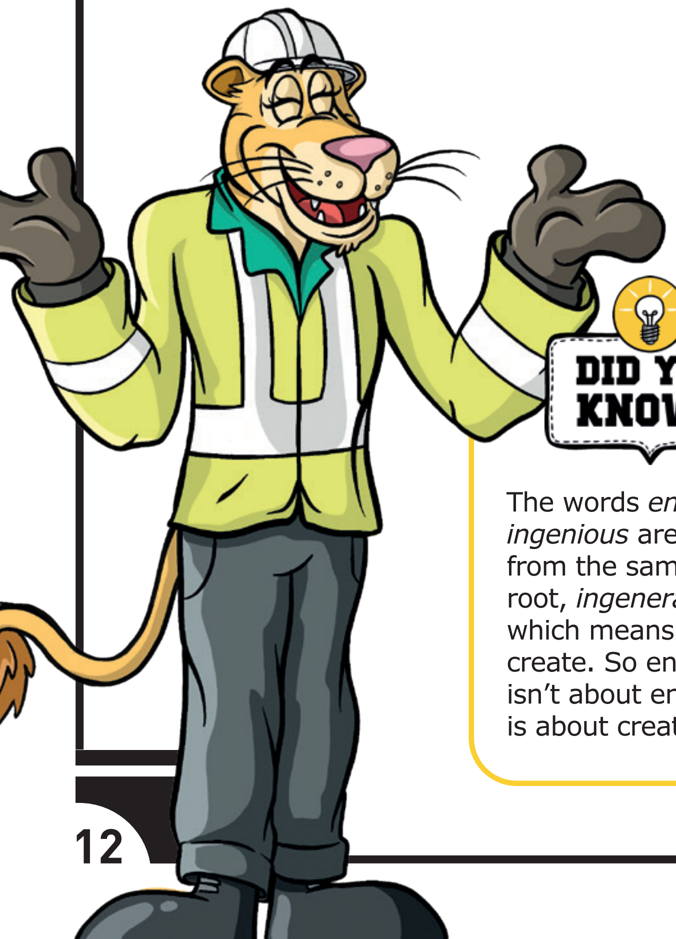
This links to building a template for concrete bars from nets in *Learning About Bridges Vol 1 Chapter Aiii: Materials – Cuboid net* handout.

Photo by Sigmund on Unsplash

Have you ever built a house of cards?

Try to build the tallest tower of playing cards using just an ordinary pack of cards, propping them next to or on to each other.

Can you build a simple structure, like a den, to keep you warm and dry? When you design and test something like this, you are using the engineering process.



DID YOU KNOW?

The words *engine* and *ingenious* are derived from the same Latin root, *ingenerare*, which means to create. So engineering isn't about engines, it is about creating!

Langdon presents:

- *What do Civil Engineers do?* handout
- *Where should the bridge go?* handout
- *Bridge builder's checklist* handout
- *Can you build it?* activity sheet handout
- *Design Challenge* handout
- *Standing on the shoulders of giants* handout

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

Chapter F: Thinking like an Engineer. Different roles in Civil Engineering.

AIMS & OBJECTIVES

- To recognise the different engineering habits of mind
- To demonstrate the different core skills in learning and engineering
- To personally evaluate different engineering habits and skills

CONTEXT

There are lots of different engineering fields, and within these lots of different roles, with each role requiring a range of different habits and skills. However, many of these skills overlap as engineering habits of mind and are reflected in roles across the whole spectrum of engineering, and beyond.

Within civil engineering, there are designers, engineers, supervisors, construction workers, financial managers, surveyors to name but a few... Each role contributes to the success of the project. In short, people make bridges happen.

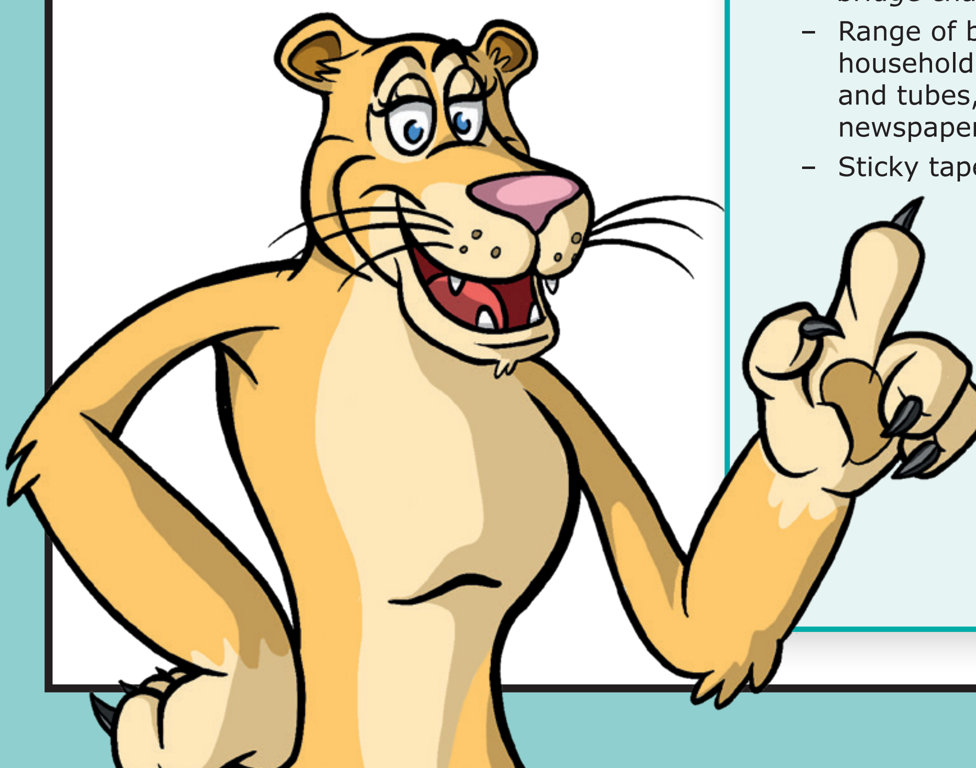
LANGUAGE OF BRIDGES:

Civil engineering: the type of engineering that helps shape the world around us, helping to design bridges, tunnels, railways, roadways, as well, as constructing skyscrapers, dams, power stations, airports and sports stadiums.

Engineering habits of mind: a concept developed to characterise the range of skills usually found in those people that think like an engineer.

You will need...

- Cup pyramid teamwork challenge, per group:
  - 4-6 lengths of string/yarn
  - Rubber band
  - 6 large plastic cups
- Think like an engineer bridge building challenge, per group:
  - Handout: *Thinking like an engineer bridge challenge order form*
  - 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
  - Scissors/craft knife and cutting mat (as appropriate)
  - Glue/hot glue gun (as appropriate)
  - Ruler
  - Paperclips, treasury tags, bulldog clips (as available)
  - Mars bars, exercise books or masses for testing the bridges



Something to Try:

Meet the Future You is a careers quiz developed by EngineeringUK in partnership with UCL Engineering with the support of Tomorrow's Engineers Careers Working Group and takes learners through a series of questions designed to think about their skills and interests, to help identify the area of engineering they might enjoy working in. Aimed at 7-19 year-olds, it can be accessed through a web browser or is available as an app. It is based on profiles of real-life engineers and showcases a diverse range of engineers from different backgrounds. This could be used to inspire interest in engineering, and demonstrate that anyone can become an engineer.
https://mtfy.org.uk/

The Centre for Real-World Learning (at the University of Winchester) and the Royal Academy of Engineering have developed a series of Engineering Habits of Mind that are key skills found in those people that think like an engineer.

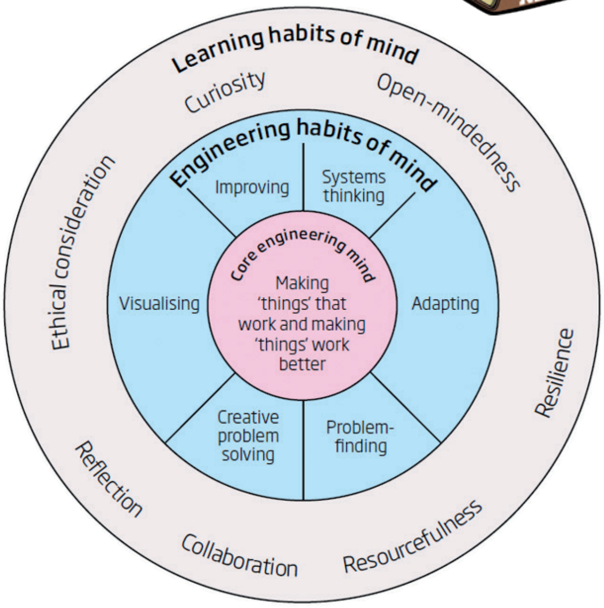
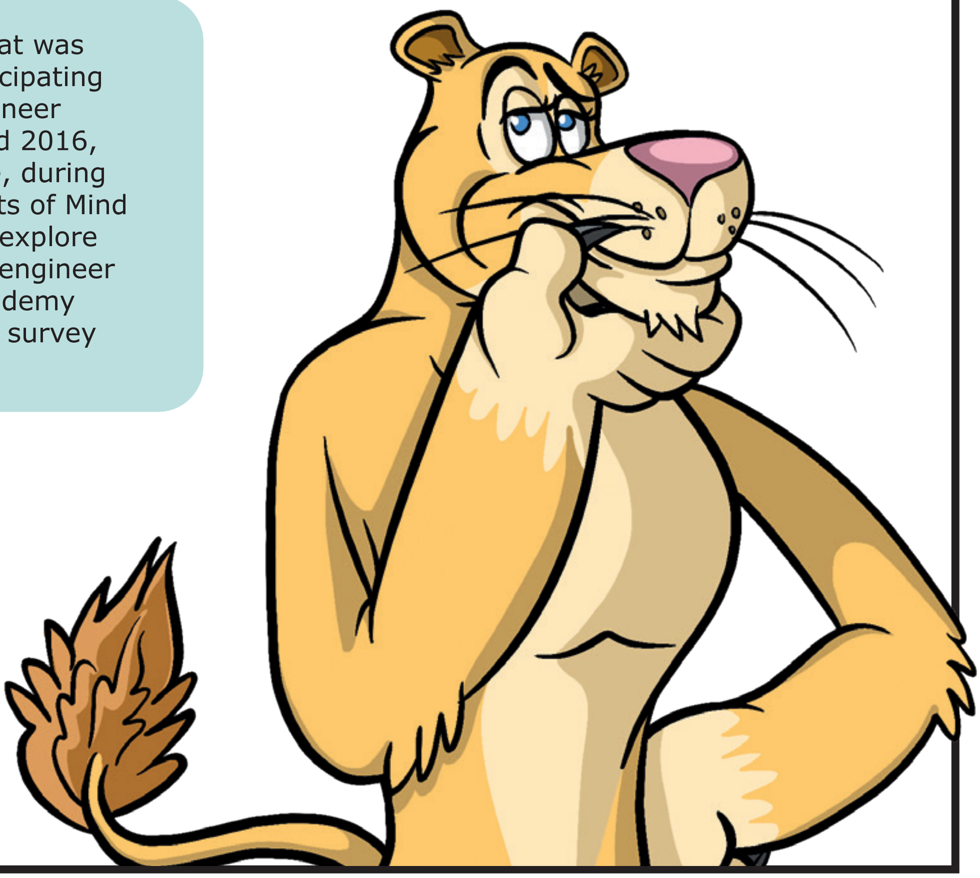


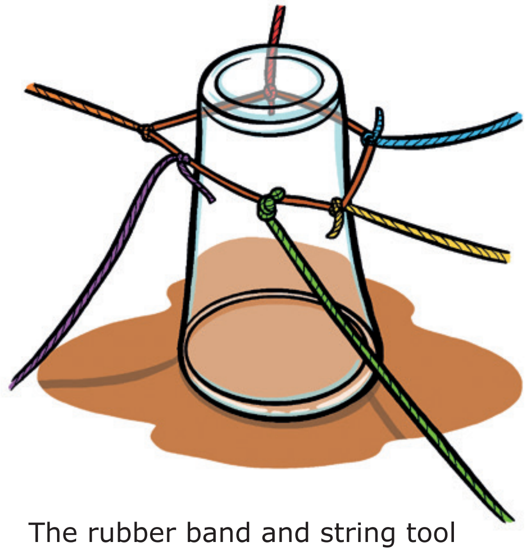
Image taken from Thinking like an engineer Implications for the education system – the May 2014 report for the Royal Academy of Engineering Standing Committee for Education and Training
https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report

There is a questionnaire that was developed for schools participating in the Thinking like an engineer research between 2014 and 2016, designed to be used before, during and after Engineering Habits of Mind intervention. Learners can explore whether they think like an engineer if you search for 'Royal Academy of Engineering EHOM short survey Winchester school'.



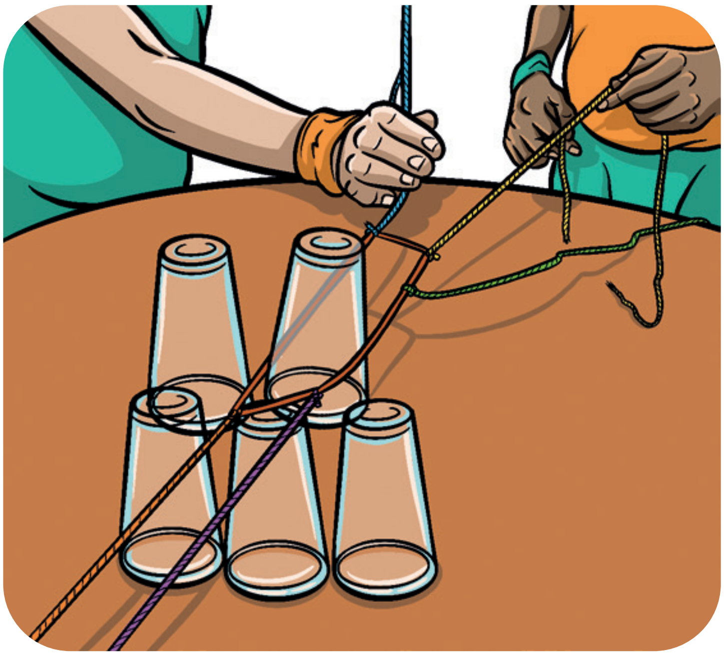
Teamwork is an essential skill in a variety of roles and careers, not least in engineers. Learners can develop their own teamworking skills by taking part in this activity.

Learners should be in groups of 4-6 people. The first challenge is to make a rubber band and string tool. This could be done in advance, to focus the activity more on developing teamwork, but making the tool can also be part of developing the engineering and scientific enquiry mindset.



The rubber band and string tool is the only means of moving the plastic cups to build a pyramid of cups – nobody should touch the cups with any part of their body.

The tool is created by tying 4-6 lengths of string (depending on the number of participants in the group) to the rubber band. This can then be used to lift and place the plastic cups. The team must work together to adjust the tension in the string to allow the cups to be picked up and then deposited in the correct position.

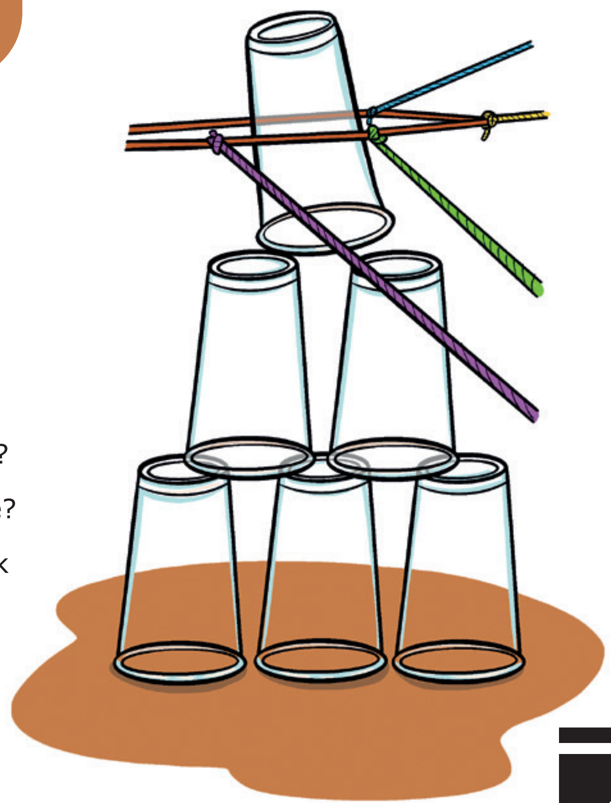


The object of the game is to construct a pyramid of all 6 cups in the shortest time possible.

To encourage learners to think like an engineer, ask them to reflect on the activity:

1. Was the challenge easy or hard?
2. What problems arose, and did you solve them?
3. How would you rate the teamwork in your group?
4. What were important skills used in this challenge?

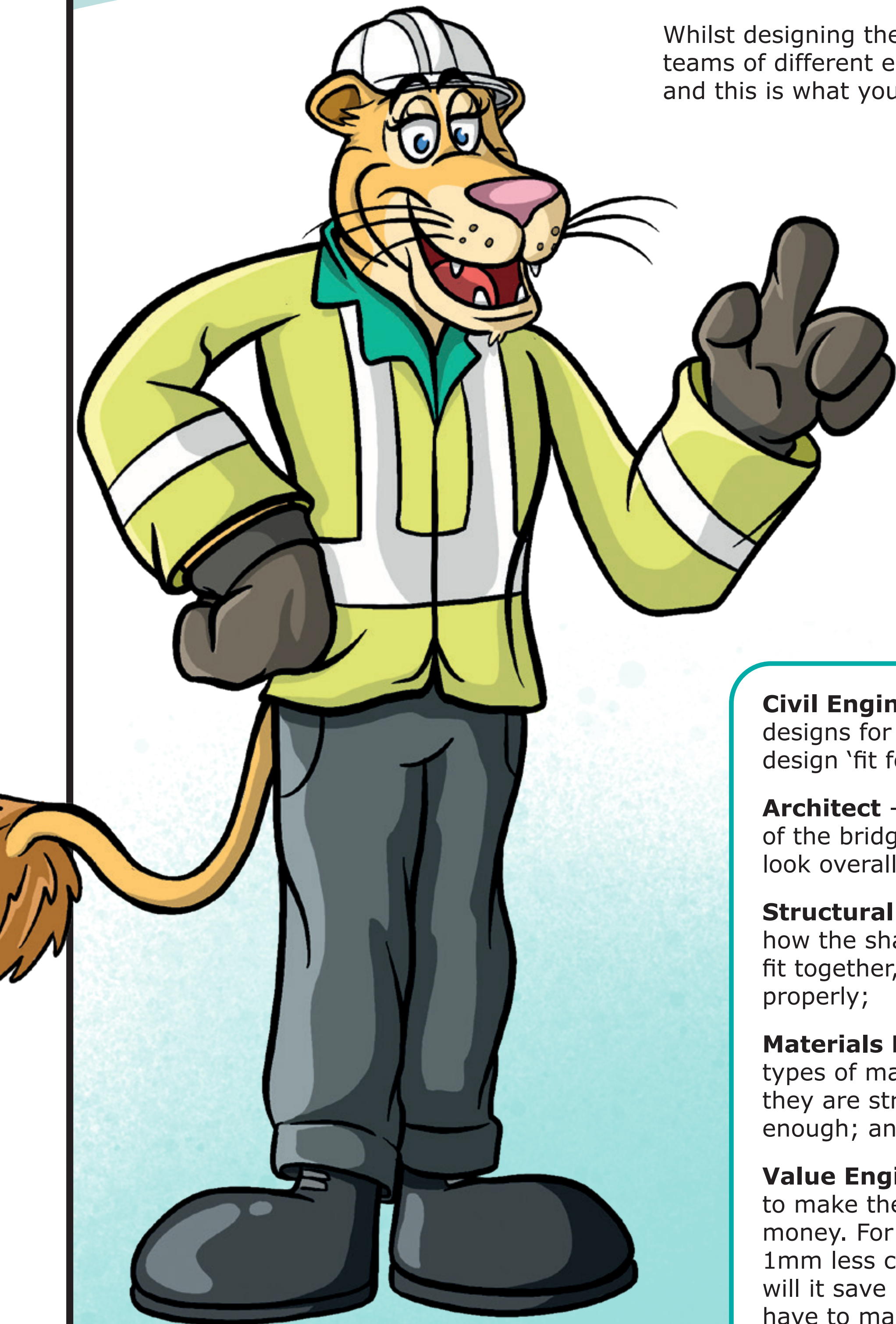
To make the activity more challenging you could ask learners to complete the task without talking, or by blindfolding one (or more) of the group.



Challenge Time!

CHALLENGE

Whilst designing these large one-off structures, teams of different engineers must work together and this is what you are going to be doing today.



But what does it mean to work in a team?

What different types of engineers might work together in a team to design something like an airport, bridge or rollercoaster?

What do you think each type of engineer does within the team?

Civil Engineers – choose the best designs for the job, they call this design 'fit for purpose';

Architect – considers the appearance of the bridge and how the design will look overall;

Structural Engineers – work out how the shapes of materials might fit together, to look right and join properly;

Materials Engineer – work out what types of materials to use and whether they are strong, flexible, rigid or soft enough; and

Value Engineer – work out how to make the design better value for money. For example, if builders use 1mm less concrete all over a structure, will it save money? But they also have to make sure if they use less concrete that the design is still safe, and fit for purpose.

In this challenge, learners will work together in teams to design and build a load-bearing bridge that spans a 40-cm gap and is entirely self-supporting. This can be based on junk modelling, using recycling, or using craft/construction materials, such as art straws, paper, card and so on. Part of the challenge is to set a budget for the design and construction of the bridge. For example, you could set a budget of £5,000 and construct a price list based on the materials to be used, such as £350 per sheet of paper, £750 per sheet of card, £50 per thin art/paper straw, £80 per thick art/paper straw, £200 per 50cm length of sticky tape, £15 per paperclip and so on (included in the resources is an order form for learners to use).

- Give the groups a short time (10 minutes) to discuss and plan how they are going to make their load-bearing bridge, including how they are going to spend their budget.
- The groups then have 30 minutes to build the strongest bridge they can. Do not give the learners any guidance at this stage; let them explore the possibilities for themselves.
- When the time is up, invite each team to bring their bridge to the testing zone. Load the bridges up with Mars Bars/exercise books/masses. When the bridge collapses, count the number of Mars Bars/exercise books/masses it was carrying just before it fell (i.e. do not count the last one).
- Record the scores for comparison. Ask the learners to observe the way the bridge failed: it is important that learners consider the weaknesses of their bridges. Encourage them to think of solutions to how they could be improved. Did it fold? At which part? What could be done to reinforce that point?
- After the learners' first attempts have been tested and discussed, give the teams the opportunity to improve their designs (15 minutes) by making modifications and test them again to see if they can better their scores. This is important as learning from experience is an important engineering process.

Learners can demonstrate their engineering habits of mind through creative problem-solving and collaborative teamwork, adapting their designs and being resourceful around using materials, and being resilient if the design doesn't work first time.

Just 4 Fun

Could you dress like a civil engineer on site, wearing PPE? Perhaps you could make a DIY civil engineer outfit for your soft toy or doll, to be part of your team?

HOT TOPICS!

Tinkering is a good way to introduce engineering concepts and habits of mind. There are lots of different resources available to encourage learners to tinker but a good introduction is the activity where learners try to help Rosie Revere from the book "Rosie Revere: Engineer" overcome her 'failure' to design a hat to keep the snakes off Uncle Fred's head. Learners can design and construct their own ideas using junk, and then communicate their ideas to the rest of the group at the end (all part of the engineering design process).

This can be found if you search for 'tinkering for learning snakes uncle Fred'.

You could design a plan for a local park or play area that would be easily accessible for everyone, and fun for children to enjoy. You could then present this to your class, group or family. This uses basic engineering principles in considering the problem, plan drawing skills and communication to explain how and why you have designed it the way you have.

Photo by Charles J. Sharp, CC BY-SA 3.0 via Wikimedia Commons

DID YOU KNOW?

The first engineer is thought to be Imhotep, who designed the Step Pyramid at Ṣaqqārah, Egypt, probably about 2550BC.

Langdon presents:

- *Thinking like an engineer bridge challenge order form* handout

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

Chapter G: More Loads and Forces

AIMS & OBJECTIVES

- To understand the **forces** that act in bridges and structures
- To recognise and describe **shear** and **tension**
- To show that forces must be balanced for a structure to stand

CONTEXT

You cannot see a force, but you can see the effect of a force. When a force is acting on an object, it can change its shape, speed or direction of movement. For a structure to stay standing and functional, the forces and loads exerted on it and within it must be balanced.

LANGUAGE OF BRIDGES:

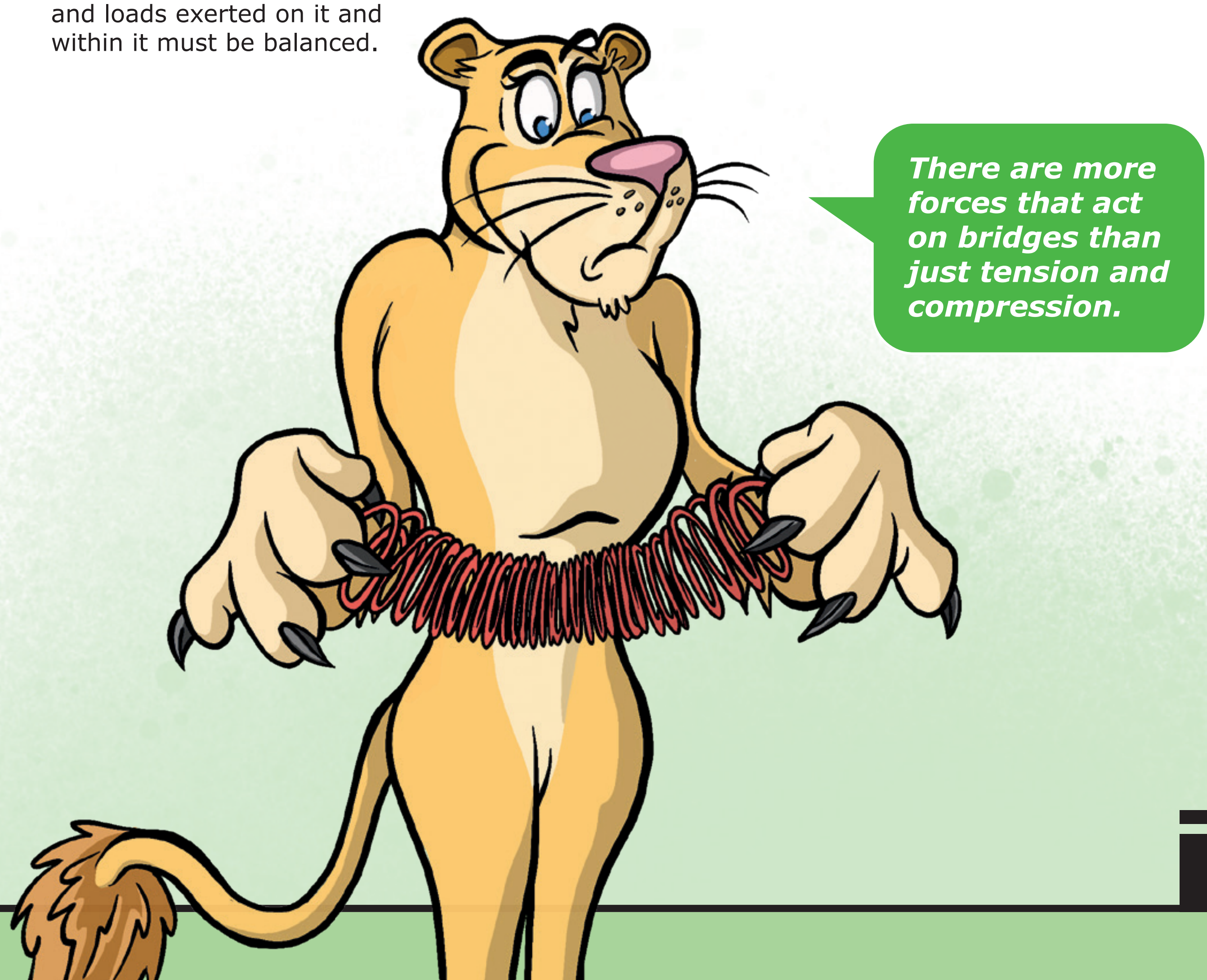
Compression: a force that tries to make things shorter or smaller (a squashing, pushing force).

Shear: a sliding force which occurs when an object is being pulled in two different directions.

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

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

Torsion: a twisting force. This is caused when either end of the object is being moved in opposite directions.



You will need...

- Slinky spring
- Large sponge (such as used for car cleaning), marked along the side with a marker pen, with vertical lines, approximately 2.5cm apart
- Scissors with long strips of thin card
- Deck of playing cards
- Piece of paper

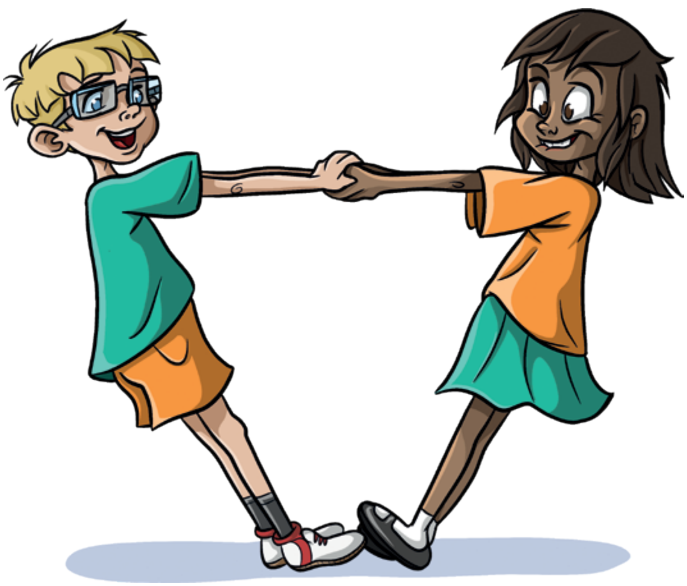
Photo by Adam Valstar on Unsplash

- Towel/cloth, bowl of water
- Bridge building challenge, per group:
  - Range of every day materials: for example, string, Lego® bricks, uncooked spaghetti, cardboard tubes, bread rolls, cardboard boxes
  - Handout: *Testing everyday objects record sheet 2*
  - Range of 'building' materials, such as household recycling, cardboard boxes and tubes, string
  - Sticky tape
  - Ruler
  - Weights, such as nuts/ washers, thin books
  - Desk fan

Something to Try:

In Learning about Bridges, the loads that cause forces inside the bridge were explored. The following activities you can try to demonstrate the forces of tension and compression:

Tension: Using a "Slinky" spring, pull from each side. This force is tension which always tries to make things longer. Think of it as a stretching force. Ask the learners to hold hands in pairs and pull. Feel the tension.

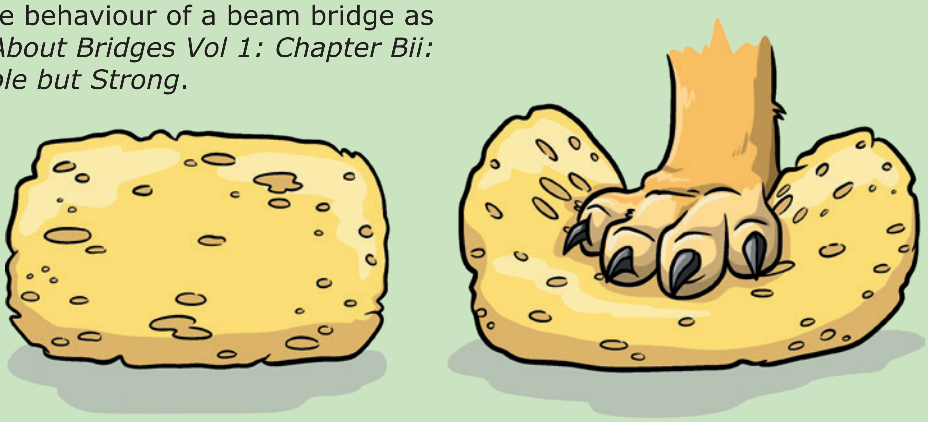


TENSION

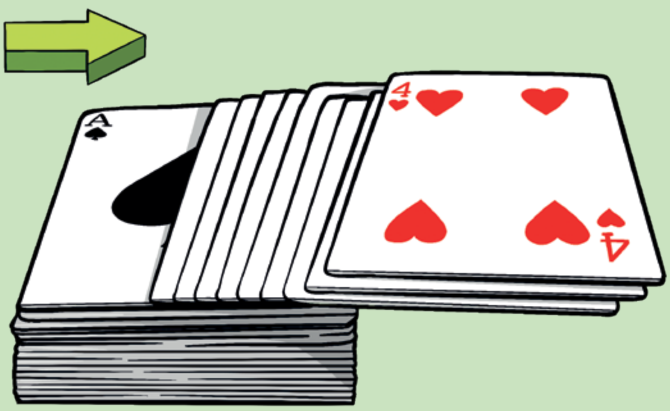
Compression: Using a sponge, push down hard. This force is compression which always tries to make things shorter or smaller. Think of it as a squashing force. The lines on the sponge help demonstrate the effect of the force: you should notice that as the force is applied, the lines get closer together, at the top of the sponge particularly. If the sponge is firm and large enough, you might notice the lines spread out a little along the bottom, although get closer together along the top edge.

This demonstrates the behaviour of a beam bridge as covered in *Learning About Bridges Vol 1: Chapter Bii: Beam Bridges – Simple but Strong*.

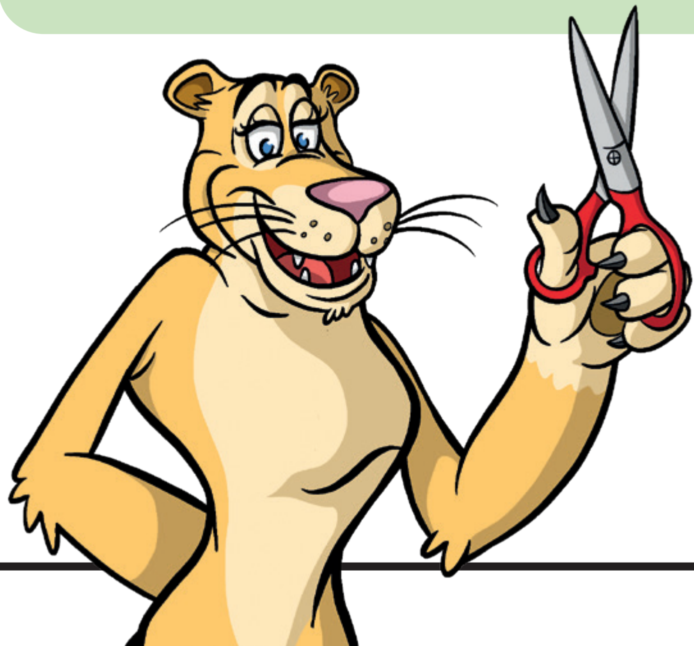
LINK



Shear force happens when an object is being pulled in two different directions, when part of the object slides across another part. This can be caused in bridges by high winds or floods, when one part of the bridge is affected by the force in one direction, and another in a different direction.



This can be demonstrated with a pack of cards. Simply stack the cards in a single pile, and then gently, just using a finger, push sideways on the top part of the stack. Ask learners what they notice happening.

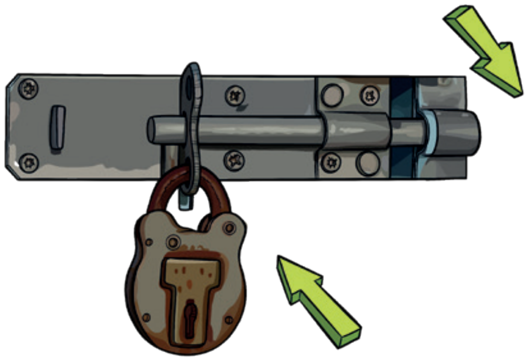


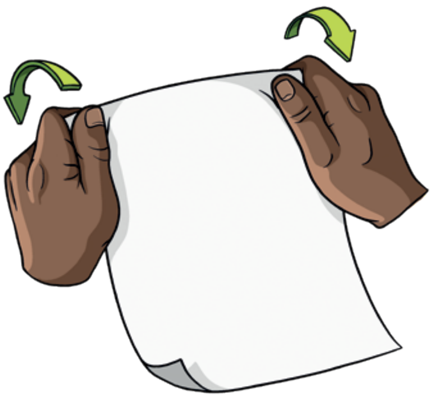
When scissors are used to cut a sheet of paper, this is using shear force. The handles of the scissors move in opposite directions. They place force on the screw that joins the handles together. The blades slide to cut the paper.

In fact, shears is another name for scissor-like cutting tools.

Photo by Belinda Fewings on Unsplash

Looking at this picture of a bolt lock on a gate, ask learners to imagine what would happen if someone pushed really hard on the gate, and someone pushed really hard on the other section.

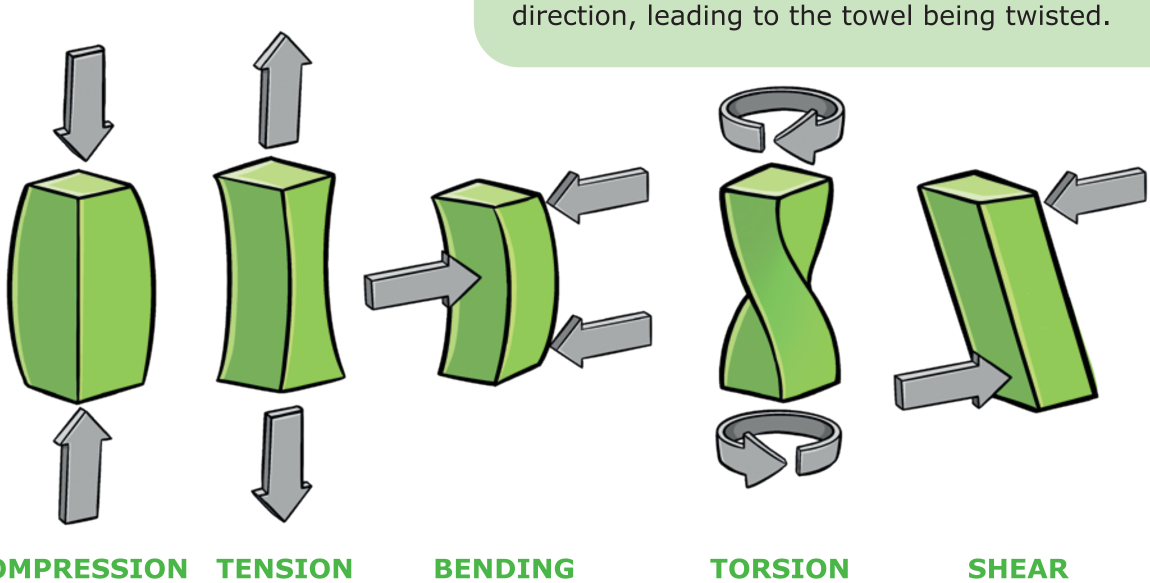




Another demonstration of this force uses a single piece of paper. Take the top two corners in your hands. Quickly push one forward and pull one back. What happens to the paper?

When the shear force (which is effectively pushing in two directions across the bolt) is applied to the gate lock, it is possible that the bolt would shear or break. This is what happens in engineering and structures: if bolts are used to fix two parts of the structure together, and a load is applied to the structure (such as high winds) that creates the shear force, the bolts can shear or break.

Torsion is a twisting force. An every day example of this is when you wring out a wet towel – each end of the towel is being moved in a different direction, leading to the towel being twisted.



Challenge Time!

Divide the learners into groups and ask them to examine a series of everyday objects, by twisting, stretching, squashing, pulling or pushing the objects. Are they stronger under tension, compression, torsion or shear?

Try string, elastic bands, a small tower made of Lego® bricks, uncooked spaghetti, bread rolls, building blocks, stickle bricks and cardboard boxes tubes for example, alongside some general 'recycling' such as cardboard boxes. Use the *Testing everyday objects record sheet handout 2* to record the outcome.

Links to *Learning About Bridges Vol 1: Chapter Aii Loads and Forces*

Use some of the same sorts of every day materials as those tested to construct a bridge. Encourage learners to think about the forces the structure will have to resist and choose the materials that will have the correct properties to withstand these forces. The aim is to build the strongest bridge, able to hold a set mass (choose a mass that most of the bridges can withstand depending on what you have available – it just has to be equal for all bridges) whilst withstanding the environmental pressure of the wind (which creates increased live load).

The bridge should span a 40cm gap. To increase the challenge in the task, you could limit the quantity or type of materials and/or sticky tape each group can use.

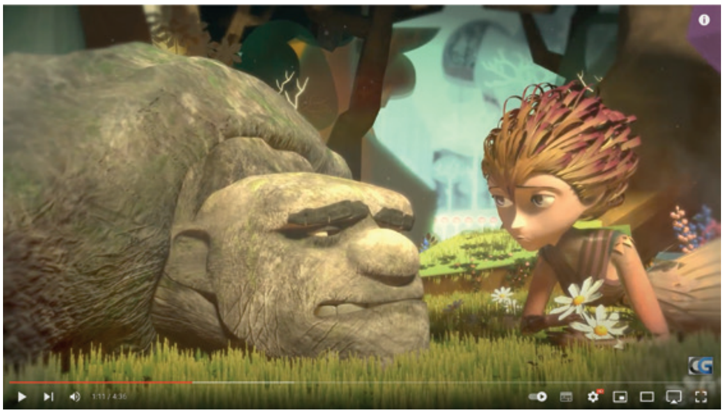
To test the bridges, position a fan to one side of the bridge, so that the air flows across the bridge. The position should be fixed, with the same wind speed, for all bridges to keep the conditions for all bridges as consistent as possible.

There is no one 'right' solution to this challenge, instead the outcome is to identify the forces applied to the structure and consider the appropriate materials and their properties for construction of the pier.

Get learners to 'think like engineers' by testing their designs and improving them to test again. This is the 'engineering design process'. **This links to page 7.**

HOT TOPICS!

In this section, we talk about shear force, and properties of materials. The Broken Team from CG Bros have produced a CGI animated short, which creates personalities for the traditional 'Rock, Paper, Scissors' game. This links to visual literacy skills, as it doesn't have any dialogue, and can be used to inspire creative projects.

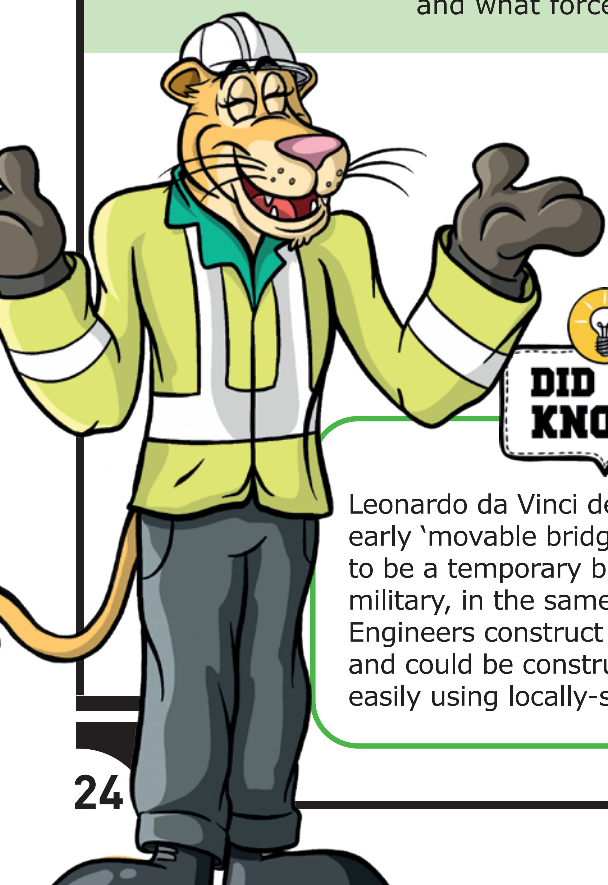


Just 4 Fun

To explore how forces balance as well as exploring the idea of the centre of gravity, you could attempt to make a balancing butterfly. Draw a butterfly on a piece of paper or thin card, and then, try to balance it on top of a pencil or small stick (use a blob of sticky tack or clay to keep the pencil standing upright). Tape a penny or attach a paperclip to the front of each wing and then repeat balancing the butterfly on top of the pencil. What do you notice about how the butterfly balances?

OUT & ABOUT

In this session, we added torsion and shear to compression and tension as forces in bridges. As you go about your daily activities, start thinking about times when you notice the forces that are acting on you or objects around you, and the effects they have. Can you identify when forces are acting and what forces they are?



Here's a model version we have at Rochester Bridge Trust.

DID YOU KNOW?

Leonardo da Vinci designed a very early 'movable bridge'. It was designed to be a temporary bridge for the military, in the same way the Royal Engineers construct temporary bridges, and could be constructed quickly and easily using locally-sourced wood.

Langdon presents:

- *Testing everyday objects record sheet 2* handout

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

Chapter Hi: Enemies of Bridges – The Environment

AIMS & OBJECTIVES

- To know factors that affect a bridge
- To recognise the impact 'thermal expansion' has on a bridge
- To consider the impact rusting has on materials and bridges

CONTEXT

Weather, such as rain, salt water and animals, such as pigeons, all negatively affect the materials from which bridges are made. The result can often be a reduction in strength or function, with time. In this session, we explore the different environmental factors that affect bridges.

LANGUAGE OF BRIDGES:

Chemical weathering: the weathering of materials due to chemicals – including rain water which is slightly acidic due to carbon dioxide from the atmosphere being dissolved in it.

Corrosion: the chemical change in metal due to environmental factors.

Physical weathering: the effect of temperature change on materials, causing them to break apart over time.

Thermal expansion: the change in a material (getting longer, deeper, wider) as a result of heating.

Weathering: the breakdown of materials as a result of the weather, such as rainwater or temperature changes.

You will need...

Demonstrations:

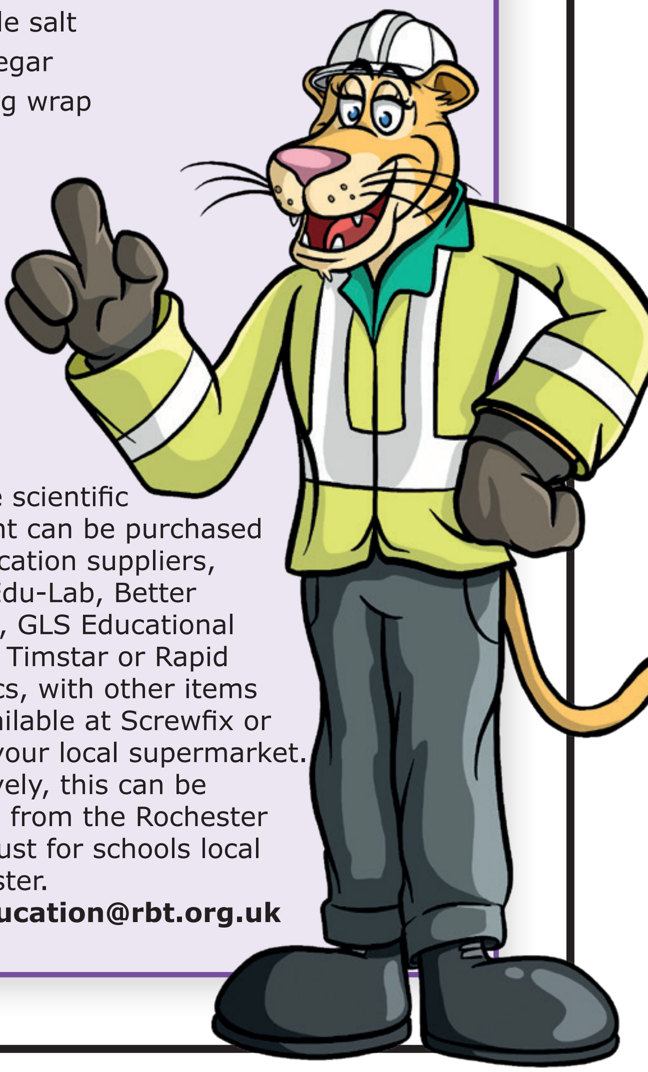
- Expansion of water:
  - Rigid plastic (NOT silicon) ice cube tray (e.g. from Wilkinson's, John Lewis or any other supermarket or similar retailer, eBay or Amazon)

  - Freezer
- Expansion of water causing weathering:
  - Egg
  - Safety pin
  - Bowl
  - Wax (from a candle)
  - Matches/lighter/tealight
  - Egg box/egg sixed container
  - Syringe – a single use 10ml plastic one, without needle (available through retailers such as Amazon, eBay, or via TTS group, and other healthcare suppliers)

  - Freezer
- Expansion due to heat:
  - Spirit burner and methylated spirits, or kitchen blow torch
  - Ball and ring demonstration equipment and/or bar and gauge demonstration equipment
  - Heat proof (bench) mat, or similar item, such as a heavy wooden chopping board, to protect the work surface
  - Matches/lighter
  - Safety glasses

Experiments:

- Rusting Iron experiment – per group:
  - Handout: *Exploring rusting*
  - Steel wool (you can use iron nails if you have them instead, but ungalvanized iron nails are difficult to acquire)
  - Gloves – slightly thick ones, such as garden gloves, construction gloves, or heavy duty kitchen gloves, to protect the hands when handling the steel wool
  - Plate/container/paint palette – we used a set of paint pots in a tray from Baker Ross, to keep them all together, but a standard paint palette, or small individual plastic tubs, such as clean yogurt pots, would also be fine
  - Cooking oil
  - Water
  - Table salt
  - Vinegar
  - Cling wrap



The more scientific equipment can be purchased from education suppliers, such as Edu-Lab, Better Equipped, GLS Educational Supplies, Timstar or Rapid Electronics, with other items being available at Screwfix or B&Q, or your local supermarket. Alternatively, this can be borrowed from the Rochester Bridge Trust for schools local to Rochester.
Email **education@rbt.org.uk**

Something to Try:

Ask learners to imagine a bridge, where specifically is not important. Invite them to share ideas about what might happen to that bridge throughout the day, week, month or year. Ask them to imagine what might be different in the summer compared to the winter.

Ask learners to consider the impact of weather on the bridge: the aim is not to get too complicated, but just to start to appreciate that weather will affect materials outside. So rain will get it wet, wind may cause it to move/tip over, sunshine will cause it to heat up.

By Dominicus Johannes Bergsma - Own work, CC BY-SA 4.0

Weather has a chemical or physical effect on materials, including rock, concrete and metal.

Learners may not appreciate that water expands as it freezes. Using an inflexible, hard ice cube tray, you can demonstrate that ice cubes bulge slightly at the top after freezing.

Freeze-Thaw "wedge" weathering – when water gets into cracks and freezes, expanding as it does so.

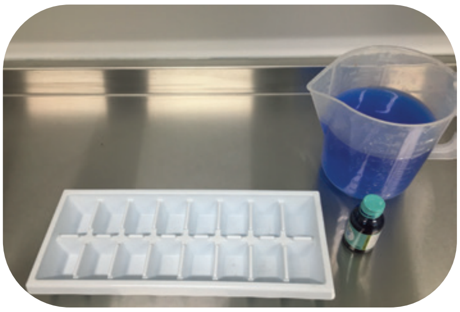
You can also use an egg to demonstrate the destructive power that is generated by the expanding water, and shows how rocks can be weathered by the 'freeze-thaw' process.

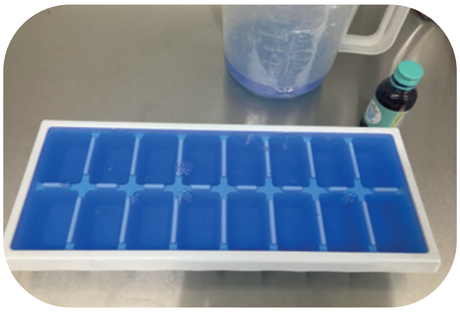
DEMONSTRATION: EXPANSION OF WATER

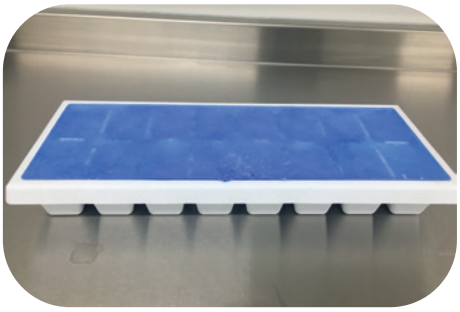
Frozen ice cubes in a rigid ice cube tray: fill the ice cube tray with water right up to the brim.

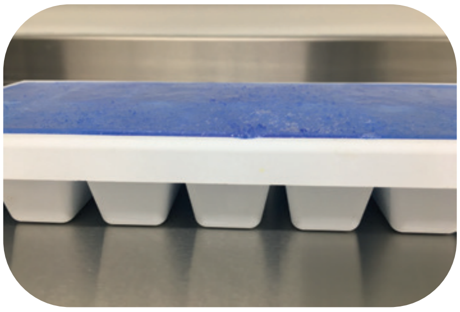
You might like to add food colouring, to colour the water a contrasting shade, to make it stand out in comparison.

Place this in the freezer until fully frozen and then examine what has happened.









HOT TOPICS!

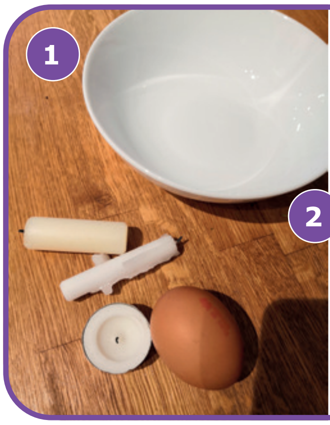
Take inspiration from the artist Andrew Goldsworthy and create some art from natural/outside materials. Take photos over a period of time, and then review how the weather and environment have changed the art work.

Play Jenga. As the pieces are removed from the stack, it weakens the whole pile. This is similar to how the rusting process weakens iron.

Photo by Michał Parzuchowski on Unsplash

DEMONSTRATION: EXPANSION OF WATER CAUSING WEATHERING

This is a bit fiddly, so is probably best shown as a demonstration, but can be carried out by learners too.



1 Using a pin, put a small hole in each end of an egg. These should be big enough to fit the syringe into at a later stage.

2 Blow through one of the holes, until the contents of the egg are removed (collect these in the bowl), taking care not to damage the eggshell as far as possible.

3 Using the candle or wax, seal one of the holes. If you have a tealight, the candle/wax can be melted over the tealight more easily.

4 Using the syringe, refill the egg shell with water.

5 Carefully, seal the second hole using the wax.

7 Place this egg either in a small freezer-safe container, or 'glue' using the candle/wax back into an eggbox section.

8 Place the egg in the container into the freezer for at least four hours (depending on the temperature and efficiency of the freezer).

The freeze-thaw process can also cause deterioration or damage to concrete– when water inside the concrete freezes, it expands and then causes the concrete to 'flake' away.

If you leave the egg to defrost, the water will obviously melt and run away (make sure you leave it somewhere water-proof!), you can more clearly show how rock, stone or concrete can 'flake' away after water has penetrated it. You could invite learners to consider what would happen if water got into the egg again somehow, and froze: this would mimic the repeated exposure of structures to the freeze-thaw process in winter.

DEMONSTRATION: BALL AND RING/BAR AND GAUGE

Although quite straight forward and an effective demonstration, it will require a risk assessment and the purchase of some specific equipment. The technique is simple, but when using any sort of heat source or open flame, care should be taken. Safety glasses are included in the equipment list as a precaution. This demonstration is also available to view as short videos on the Rochester Bridge Trust's education website **www.rochesterbridgetrust.org.uk**

1

Check the equipment – if the ball fits relatively easily through the ring, the ball needs to be heated for this demonstration (often referred to as Gravesande's ring, or Gravesande's experiment). If the ball is too large to fit through at room temperature, the ring must be heated. Demonstrate this for the learners.

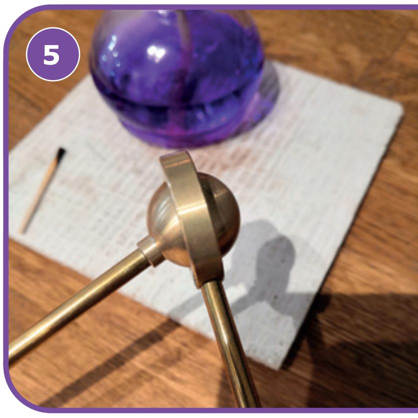
2 Place the spirit burner on the heat proof mat, allowing room to lay the ball and ring equipment with the metal ends on the mat also.

3 Light the burner.

4

Heat the metal ball in the flame for a few minutes, taking care to move it around and warming the surface as evenly as possible.

5



Carefully try to push the ball through the ring – if it is heated sufficiently, it will no longer fit: the metal has expanded with the heat.

Expansion of metal, and other materials, with heat is a problem faced in structures, including bridges. Engineers have had to develop ways of dealing with this.

Links to *Learning About Bridges Vol 2 Chapter Ii: Protecting the Bridge*

Bridges are made from metal: in fact, since the Industrial Revolution, and the possibility of transportation of such useful materials across the country, more bridges were built from iron (cast iron originally) and later steel.

Ask learners how do you think rusting affects metal bridges?

Water encourages metal to rust and, over time, fatigue (or damage) to the metal. Rusting is when the outer layer of the metal reacts with oxygen (oxidises) and turns red. This new material is weaker than the original iron, and more easily flakes away from the metal. This then leaves the iron exposed to more rusting.

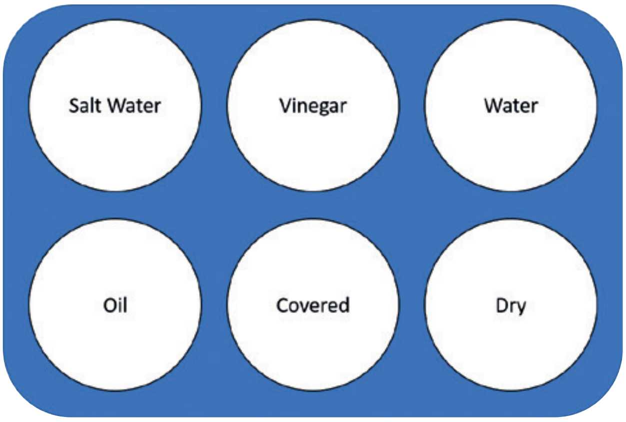
Challenge Time!

This will need to be set up in advance if you wish to view this within the same session. However, it can be used as an introduction to the 'Bridge Work' chapter too.

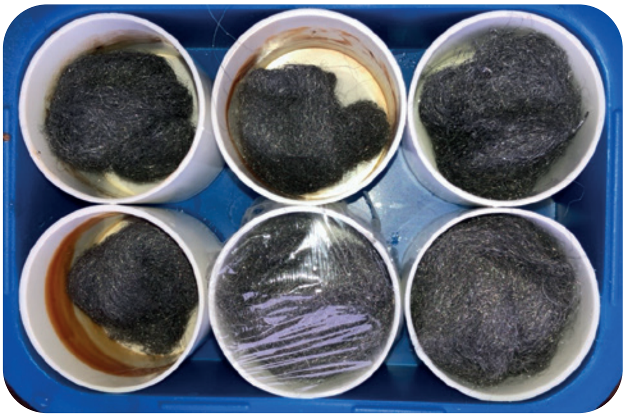
LINK

Learners will explore how rusting happens, by setting up an experiment with different conditions for the steel wool, to see if the steel rusts. You can use the *Exploring rusting* handout to guide learners through the process.

Label your pots, or draw a diagram to show which pot will contain which substance:



1. Using separate containers for each fluid, put some fresh, clean cold water in one. Approximately 150ml, to ensure that all samples have the same volume.
2. Add about a tablespoon of salt to approximately 150ml of water in a second container, stir.
3. Add the same volume of malt vinegar or distilled vinegar to another container.
4. Pour the same volume of oil to a fourth container.
5. Add a small ball of steel wool, roughly the same size to each other, to each container.
6. Leave them to soak for a few minutes, turning them over in the container, until they are fairly saturated.
7. Add a small ball of steel wool to one of the clean labelled pots, and use the cling wrap to cover the dry steel wool in the container.
8. Place all 6 containers together to one side, where they can be left undisturbed for a few days or so. You may find you need to return to the experiment sooner, depending on the temperature and humidity of the location.
9. Ask learners what they notice has happened to the steel wool.



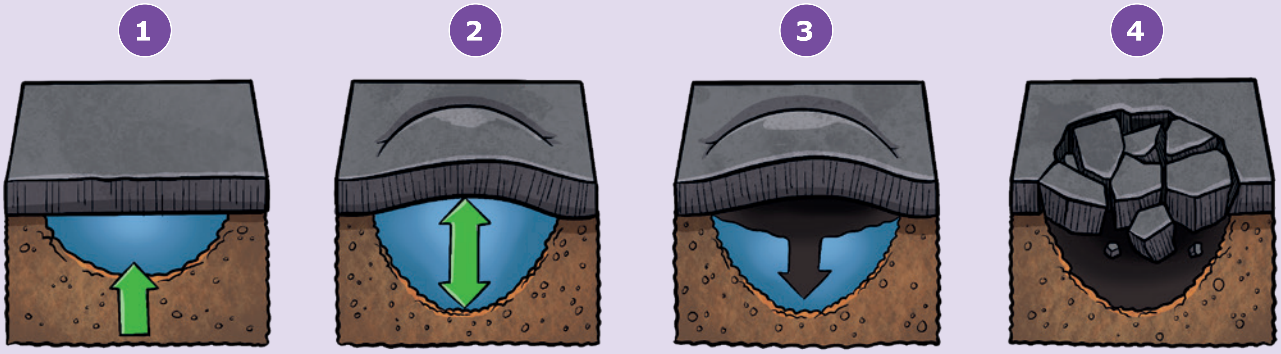
The BBC Bitesize website offers some Science clips on changing materials, if you search for rust, or what is rust.

You could explore rusting and weathering in your local environment – you could take photos of statues that have been changed over time, or perhaps take pictures of structures that have rusted.

DID YOU KNOW?

Pot holes in the roads are examples of every-day freeze-thaw weathering in action. When water gets underneath the road surface and freezes, it expands and pushes the road surface up. When the ice melts again, the 'hole' under the road surface makes it weak, so it can get broken by vehicles going over the top. This creates small holes and cracks in the road surface, which allows more water to get in, and in turn, freeze, expand and make even bigger holes!

HOW IS A POTHOLE FORMED?



1. Water accumulates between the asphalt and the subgrade under the road.
2. Cold freezes the water, causing it to expand and form a bump in the road.
3. Above-freezing temperatures thaw the ice, creating a cavity under the road.
4. Weight from passing vehicles causes asphalt to collapse, creating a pothole.

Langdon presents:

- *Exploring rusting* handout

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

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?

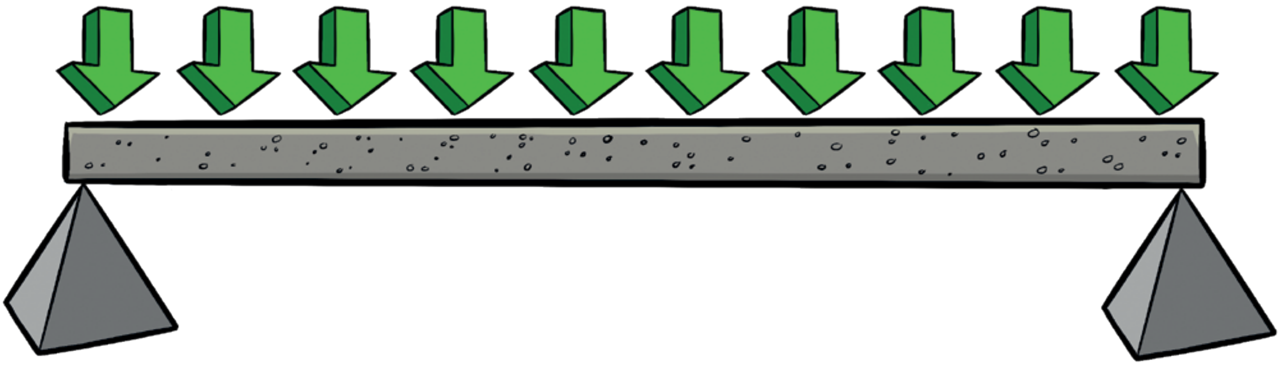
Learners can explore how the distribution of the live load can affect the amount a bridge can support, using this simple demonstration:

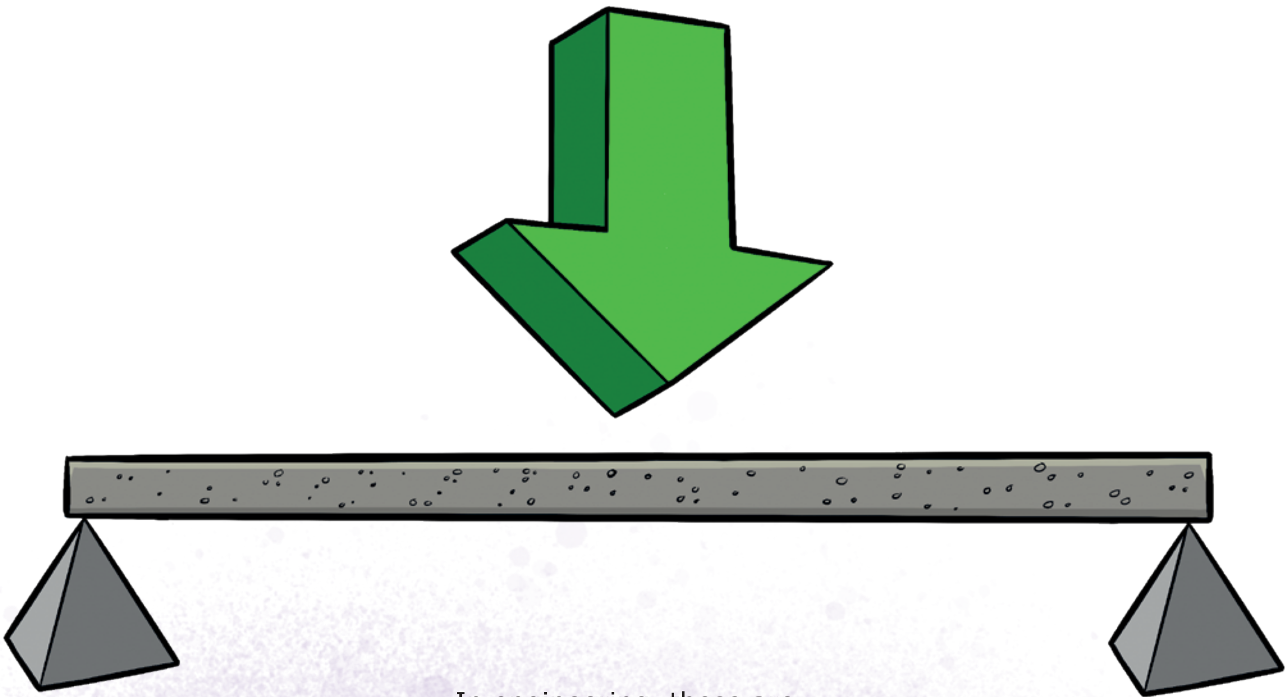
1. Slightly fold a piece of A4 paper, first in half cross-ways and then lengthways, so you end up with a very slight cross in the centre of the paper (this slightly stiffens the paper so this task is easier)
2. Place this paper folded side down on the top of the 2 stacks of books of equal size
3. Place 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.

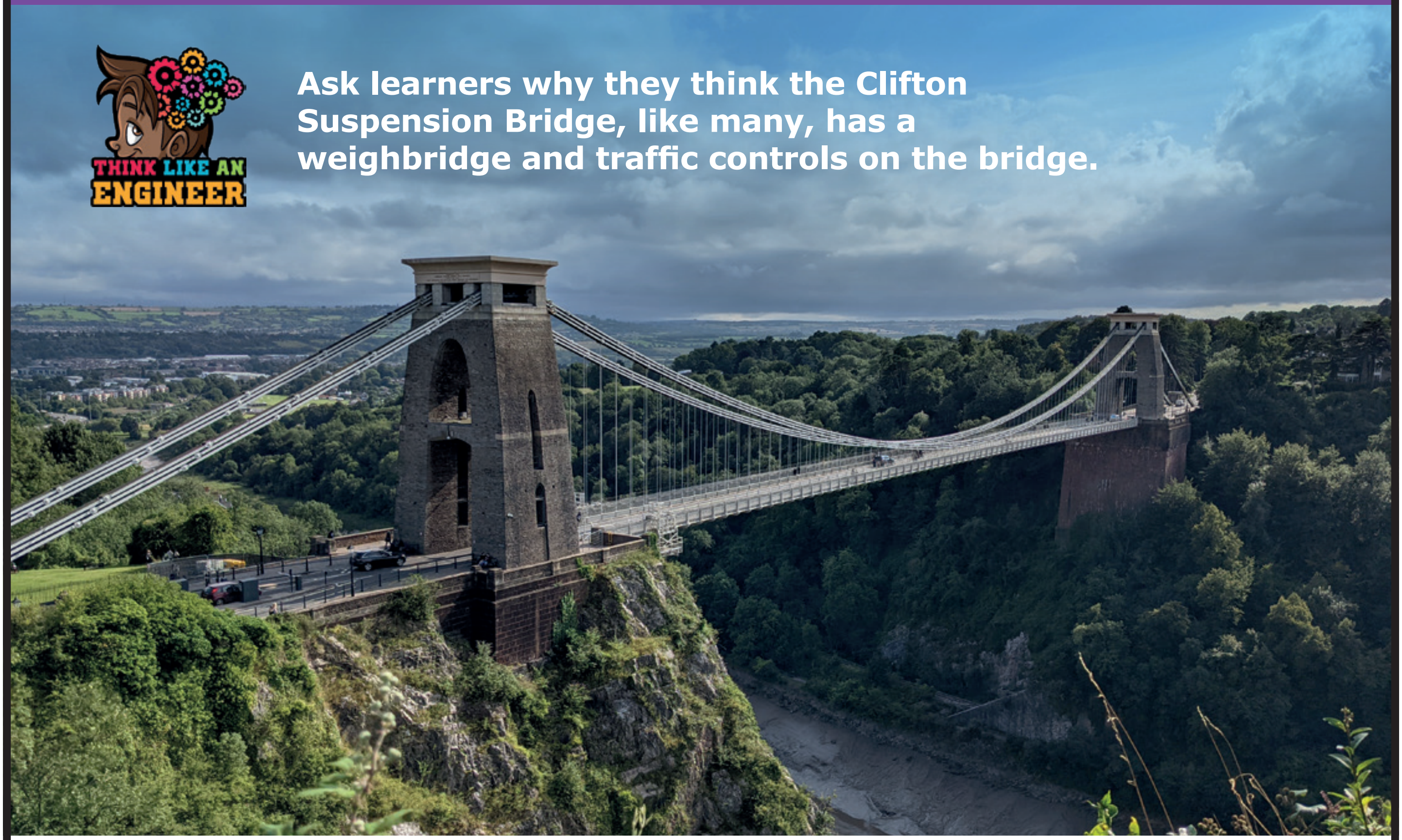




In engineering, these are called point loads and uniformly distributed loads.

THINK LIKE AN ENGINEER

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.

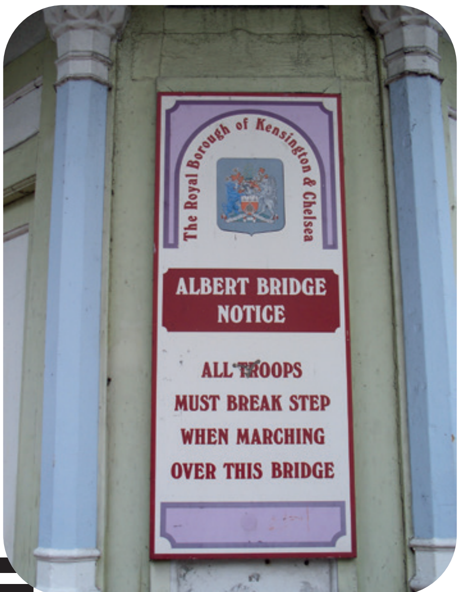


Photo by Iridescent via Wikimedia

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

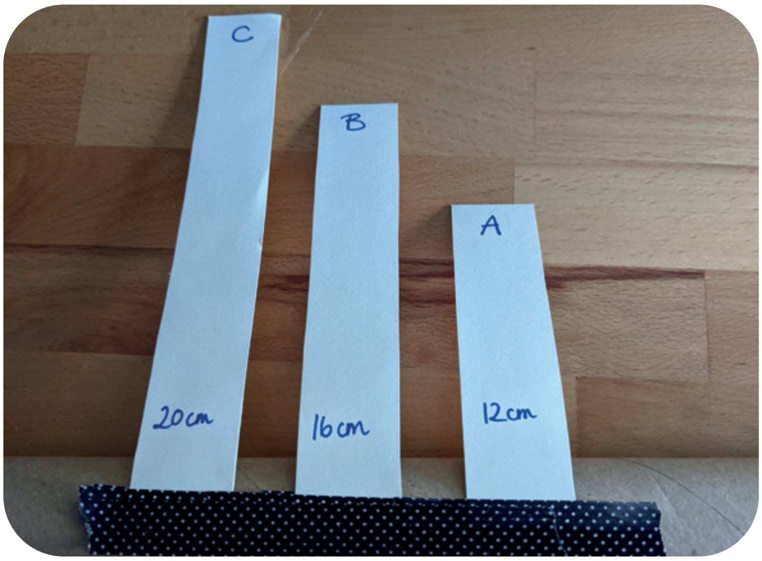
The reason troops have been instructed to stop marching in time when crossing bridges is due to the phenomenon of mechanic resonance. It is the result of vibrations that match the natural frequency of the material: if the vibrations caused by the soldiers marching matches the natural frequency of the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

SCIENTIFIC ENQUIRY

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.

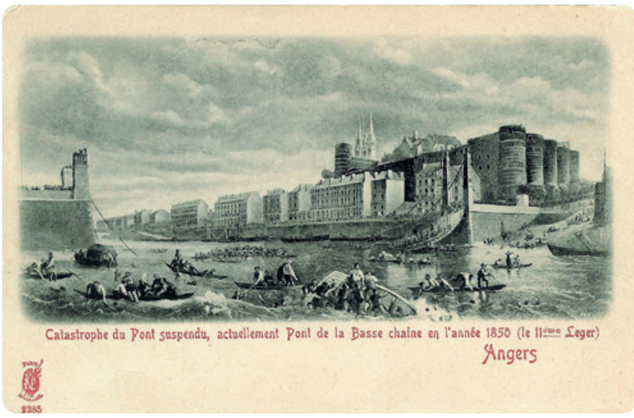


Image courtesy of Photographie Officielle on Wikimedia Commons

Challenge Time!

Photo by Guillaume QL on Unsplash

Will the padlocks cause the bridge to collapse?

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.

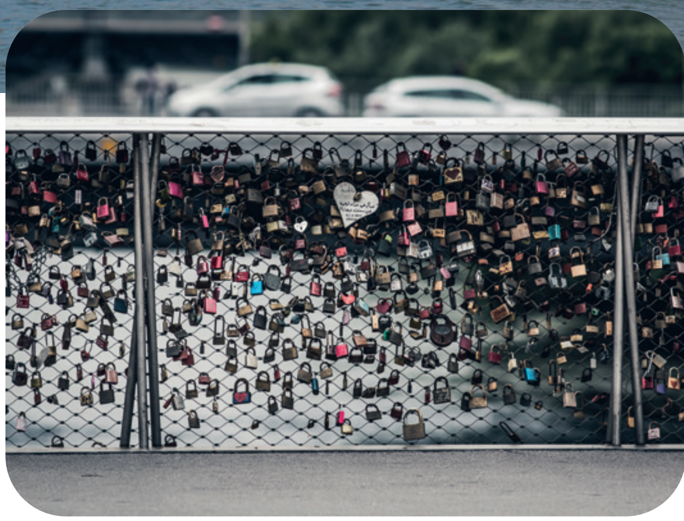


Photo by Quaritsch Photography on Unsplash

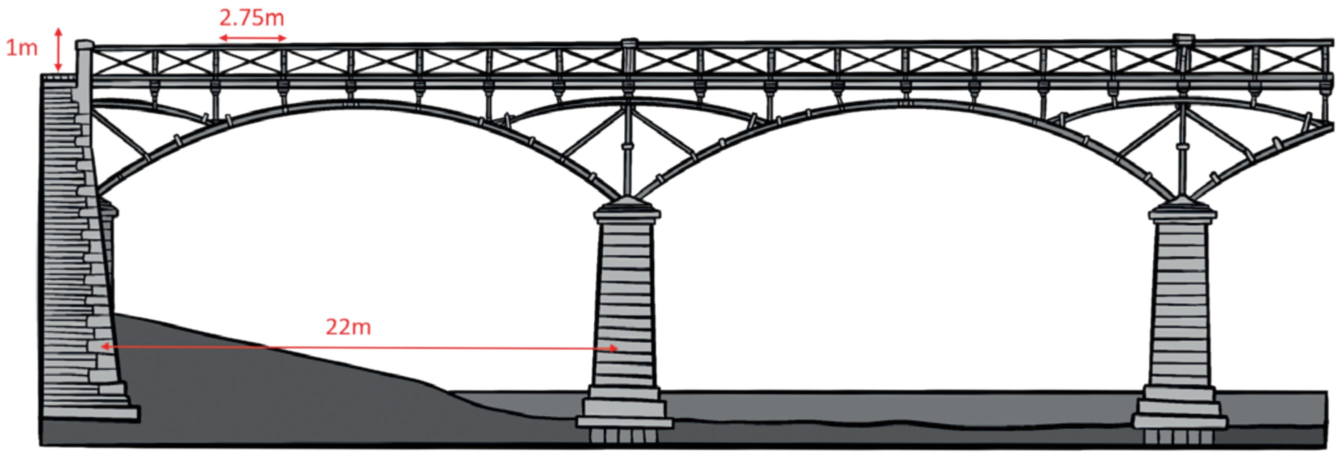
Putting padlocks on bridges has become a popular tourist activity, but how does it affect the load a bridge can take?

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.

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

Chapter I: Bridge Work

AIMS & OBJECTIVES

- To introduce a range of real-life challenges that engineers face in bridge design, construction and maintenance
- To investigate what causes different materials to create different angles of slope when forming mounds
- To demonstrate engineering skills by designing a bridge to meet a client's needs

CONTEXT

There are a number of different types of bridges that are designed to overcome difficulties caused by a range of challenges, from the location, to the materials and the forces within, to the external factors, such as the weather and the users of the bridge. The environment causes wear on a bridge, and without proper care and maintenance, the bridge can collapse. Engineers have developed many ways to protect a bridge, so it is a safe and useful crossing for a long time. In this chapter, we're going to learn about other important factors that engineers have to consider when designing, constructing or maintaining bridges.

LANGUAGE OF BRIDGES:

Chemical weathering: the weathering of materials due to chemicals – including rain water which is slightly acidic due to carbon dioxide from the atmosphere being dissolved in it.

Client: This the generic name for the people or organisation who have asked for a job to be done. In this session, it is the organisation who has asked for some moving bridge solutions.

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

Corrosion: the chemical change in metal due to environmental factors.

Elevation: In a technical drawing, this is the view from the side. This view is used on engineering plans to show how a bridge design will look from the side, almost as if you're standing in a boat on the water, looking at the bridge over the span of the river.

Engineering design process: the process engineers use to describe the steps taken to move from a question, idea or need, to designing the product or process required.

Functionality: This is about how something works. If a bridge is primarily designed to be functional, the engineers are more concerned with how it works.

There's a cliché that anyone can build a bridge that stays up, but it takes an engineer to build one that just about stands. It doesn't mean engineers make mistakes – just that there are lots of things for engineers to think about when building or looking after a bridge.

LANGUAGE OF BRIDGES:

Iron triangle of engineering: a way of showing how three factors in engineering projects affect each other.

Maintenance requirements / to maintain: This is a list of things that are needed to keep the bridge looked after once it has been built, so it is still safe and lasts a long time.

Physical weathering: the effect of temperature change on materials, causing them to break apart over time.

Rust: a particular form of corrosion or chemical weathering, when iron metal reacts with oxygen in the air in the presence of water, forming an oxide which is red in colour.

Shear: a sliding force which occurs when an object is being pulled in two different directions.

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

Thermal expansion: the change in a material (getting longer, deeper, wider) as a result of heating.

Torsion: a twisting force. This is caused when either end of the object is being moved in opposite directions.

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

Weathering: the breakdown of materials as a result of the weather, such as rainwater or temperature changes.

You will need...

- Preventing rusting experiment – per group:
  - Handout: *Preventing rusting*
  - Paperclips – 5 standard metal paperclips
  - 1 brass or brass-plated paperclip
  - Plate/container/paint palette – we used a set of paint pots in a tray from Baker Ross, to keep them all together, but a standard paint palette, or small individual plastic tubs, such as clean yogurt pots, would also be fine
  - Acrylic or oil-based paint, or nail polish
  - Cooking oil
  - Water
  - Vaseline
  - Cling wrap
  - Table salt
  - Spray bottle
- Slippery Slope activity – per group:
  - Scissors
  - Plastic cup, 16oz
  - Plain paper, 1 sheet per material tested
  - Baking dish or tray
  - Pen
  - Lentils (2 cups)
  - Icing sugar (2 cups)
  - Table salt (2 cups)
  - Rice (2 cups)
  - Flour (2 cups)
  - Protractor
- Mechanically Reinforced Earth demonstration – per group:
  - 2 plastic cups
  - Sand
  - Water
  - Paper towel, cut into circles that fit into the cup
  - Something to tamp down the sand (the handle of a trowel or the back of a dessert spoon)
  - Small masses (such a coins, slotted masses, hex nuts)
- Challenge
  - A3 paper
  - Pencils
  - Rulers
  - Card – at least 250gsm
  - String
  - Holepunch
  - Scissors
  - Either: Glue, double sided tape or sellotape
  - Handout: *Challenge task sheet*

Something to Try:

In the 'Enemies of Bridges – The Environment' chapter, we were introduced to the effect the environment has on bridges, including causing iron to rust. Ask learners what they recall about the conditions needed to cause corrosion, specifically rusting, and the outcome of the experiments.

Rusting is when the outer layer of iron reacts with oxygen (oxidises) and turns red. This new material is weaker than the original iron, and more easily flakes away from the metal. This then leaves the iron exposed to more rusting.

Links to Chapter *Hi: Enemies of Bridges – The Environment*

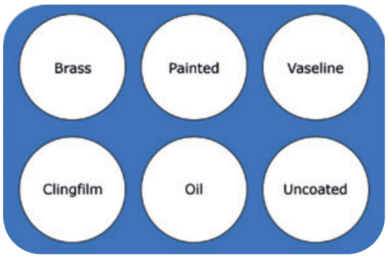
LINK

One way of protecting the bridge is to paint or waterproof the material.

In the previous challenge, steel wool was used to show that salt, water and oxygen caused rusting to happen. In the case of many bridges, there is salt water in the form of the sea flowing under, or salt-water formed from ice-melt and de-icing salts used in the winter on the roadways, so rusting is a big problem!

You can explore different methods to prevent rusting by trying the following activity. This will need to be set up in advance if you wish to view this within the same session.

1. Label your pots, or draw a diagram to show which pot will contain which substance:



2. In a spray bottle, dissolve salt and water so you have a salt water solution ready.
3. Place one brass or brass plated paperclip in the first labelled pot.
4. Using acrylic or oil-based paint, or nail polish, cover one paperclip, and when it is dry, place it in the pot labelled 'painted'.
5. Cover one paperclip in Vaseline, and place in the correct pot.
6. Wrap a 4th paperclip in clingfilm and then place in the pot.
7. Coat another paperclip in oil (any kind, standard vegetable cooking oil is suitable) and then place in the pot.
8. Finally, place the 6th paperclip in the remaining empty container as it is.
9. Using the salt solution you made earlier, lightly spray the paperclips, just enough so they are damp.
10. Place all 6 containers together to one side, where they can be left undisturbed for a few days or so. You may find you need to return to the experiment sooner, depending on the temperature and humidity of the location.
11. Ask learners what they notice has happened to the paperclips.

Ask learners which method of preventing rusting worked the most effectively. If several of them look to be a similar condition, ask learners which way do they think would be the easiest to apply to paperclips for using normally, for example. They might consider Vaseline or oil as too messy when using paperclips to hold their worksheets together, for example.

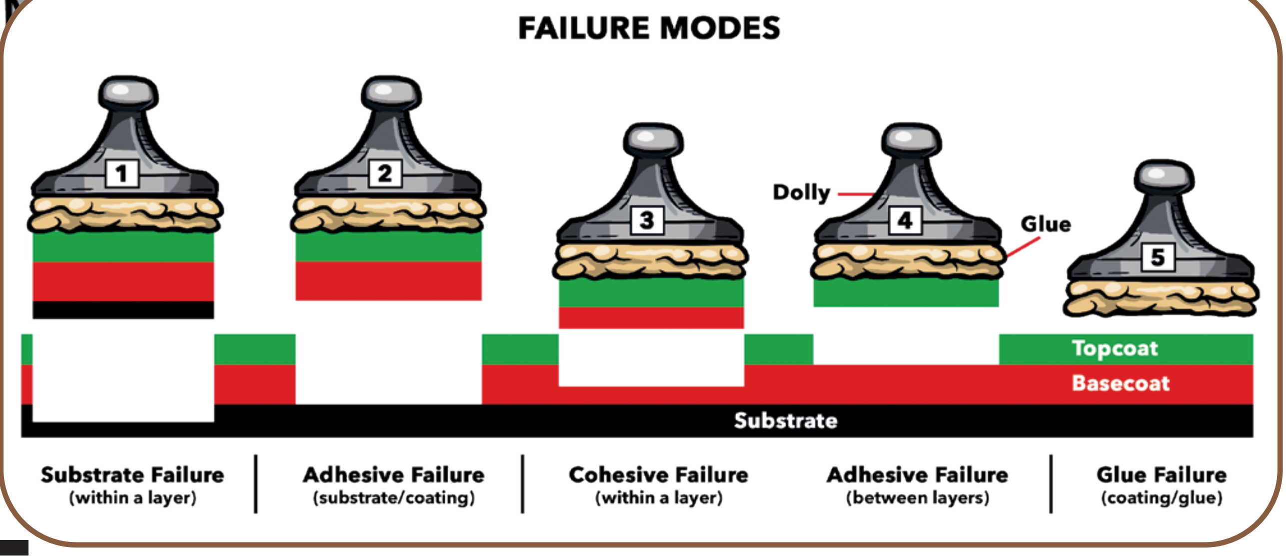
PAINTING

Painting is a common method of protecting structures from rusting. This is because it is a relatively cheap product, it can be easily applied and renewed regularly.

Once the bridge is painted, people looking after the bridges need to make sure the bridge stays fully painted. Ask learners why they think that might be.

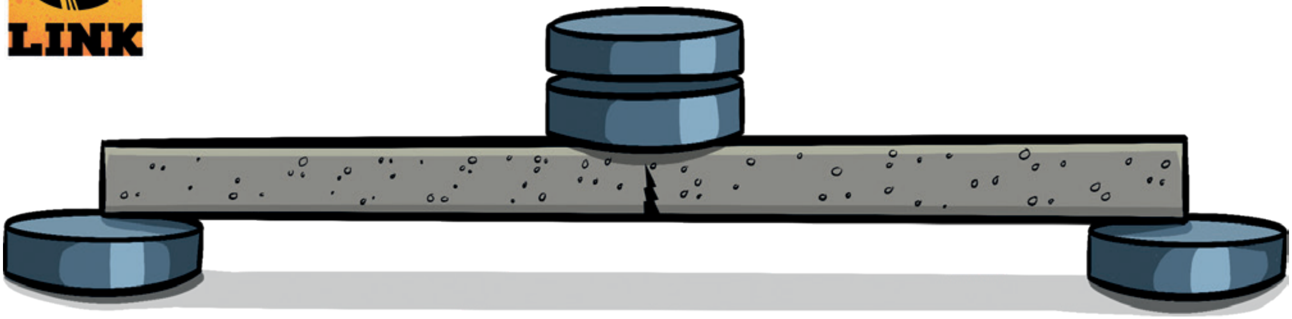
Painting needs to be regularly renewed as any gaps can lead to patches of rust, which may cause significant structural problems.

One way of testing the painted surface is to use a pull-off adhesion meter. This is a special piece of equipment that measures the force it takes to pull off a stuck-on 'dolly' or pin from a surface. By finding how much force it takes to pull the dolly off, and by looking at the material still stuck to the dolly itself, it tells the technician or engineer a lot about how good condition the coating of the structure is. In the diagram, you can see the different types of failure – if the dolly only has glue still on it, the glue for the test has failed, for example, whilst if the dolly and the surface have the same colour coating on them, the failure has happened within one of the coating layers. In this way, engineers can determine if the surface can simply be sanded down and repainted, or whether the all coatings need to be totally removed and the surface re-coated. This means that maintaining the bridge can be more efficient.

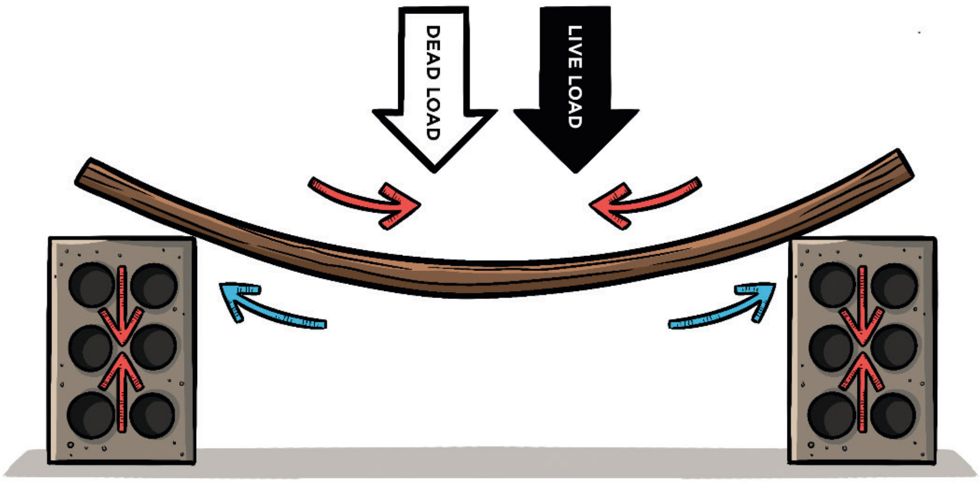


CONCRETE

In *Chapter Aiii Materials in Learning about Bridges Volume 1*, we talked about concrete. If you managed to test the bars, you might have noticed that the concrete tended to crack on the bottom first.



As we saw in *Chapter Bii Beam Bridges – Simple but Strong in Learning about Bridges Volume 1*, adding a load to a bridge creates forces within the deck – a squashing or squeezing force at the top, compression, and the stretching force along the bottom, tension. Concrete is weak under tension, so when the load is too great, the tension produced is too large for the concrete to resist, cracks are produced.



One way to prevent these cracks from getting bigger and causing the concrete to break apart is to use fibre-reinforced concrete.

This concrete has small fibres, such as small lengths of fine steel, glass or other materials, mixed into it. These short length fibres are spread evenly within the concrete as it is poured. If the concrete experiences tension and starts to crack, the fibres are spread throughout the concrete and can 'hold' across the gap, in a similar way to how laces hold each side of a shoe together.


Photo by Nathan Dumlao on Unsplash

SLIPPERY SLOPES

Links to *The Engineering Process*

The cost of materials is important when engineering structures. The least costly material to use is dirt, or more accurately, earth.

However, materials that make up soil, such as sand, silt, gravel and clay, rely on friction between the material particles themselves, rather than another material, to keep them together. If you have ever built a sandcastle, you will know that sometimes this isn't enough: attempting to build a sandcastle with dry sand versus wet sand shows how important this friction can be.

When materials pile up, they often reach a point before they start sliding down. The slope created by materials is called the 'angle of repose': this is the steepest angle the material can rest at before it starts sliding down. This angle is created as a result of the load caused by the material's weight being equal to the strength caused by the internal friction of the material. We can carry out an exploration into the different angle of repose for different materials using a simple demonstration.

1. Cut a small hole in the bottom of the plastic cup. Its diameter should be about 2cm.
2. Place a sheet of paper into the baking dish or tray and label it with the material that you want to test.
3. Pour the first material into the plastic cup you have prepared with the hole, covering the hole with your hand or fingers so it doesn't pour out yet. Fill the cup to the same level each time, at least half way.
4. Keeping the hole covered, hold the cup over the centre of the paper in the tray, before removing your hand and allowing the material to be released.
5. Once all the material has poured from the cup, using a pen, carefully draw a line around the edge of the pile. Try not to disturb the material too much.
6. Using a protractor, measure the angle of the slope made by the material. Try to find the highest point of the pile and line up the normal line for the protractor with that centre point.
7. Remove the material and repeat all of the steps with the other materials you have.

Which material has the greatest angle of repose? Why do you think this happened? Is there a pattern to the angles of repose and the size of the material grains? Is there any other factor that might affect the pattern of angles of repose, other than the size of the grain?

It is likely that the lentils or rice have the smallest (lowest) angle of repose, whilst the highest is probably icing sugar. This is due to the variation in the size and shape of the grains of the material. The smaller the grain, broadly speaking, the higher the pile created, the greater the angle of repose. This is because the friction between the grains is greater than the load generated by the material. However, this pattern can be disrupted when the grains are particularly irregularly shaped, causing them to interlock, creating greater friction between the grains.

MECHANICALLY REINFORCED (STABILISED) EARTH

Knowing the angle of repose for materials is helpful for engineers to ensure that they can build structures and the angle of the slope that will be stable. However, this does mean that the usable space for a structure is much less for a slope than if we could use the same material and build vertically. For this, we need a force that can balance out the gravitational pull of the materials as they slide down (and out) for a slope.

Engineers can do this by 'mechanically reinforcing' the earth: reinforcing elements are added in layers within the soil or sand. This can be demonstrated very simply, using a cup, sand and some paper towel circles.

1. Dampen the sand so it sticks together and is the ideal texture for making sandcastles.
2. Take one of the two plastic cups, fill it completely with sand, tamping it down with the trowel handle/spoon, so the cup is entirely full.
3. In the second cup, add some sand then place a piece of the paper towel into the cup.
4. Add more sand and more paper towel in alternate layers, tamping down the sand each time.
5. When both cups are completely full and the sand is fully compacted, turn them over to create sandcastles on a flat surface.
6. Carefully add the small masses to each sandcastle.

SCIENTIFIC ENQUIRY

What happens to the sandcastles? Is there a difference between them? How does this happen?

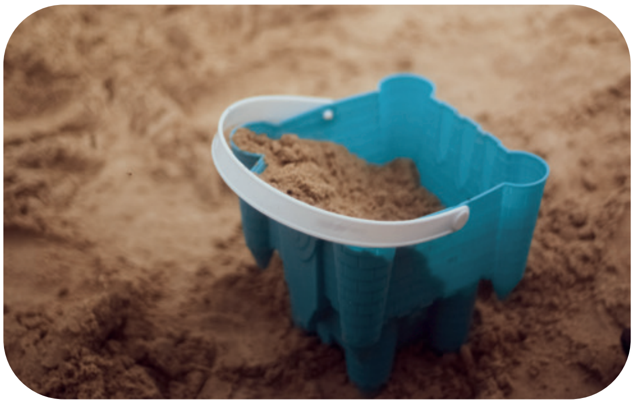
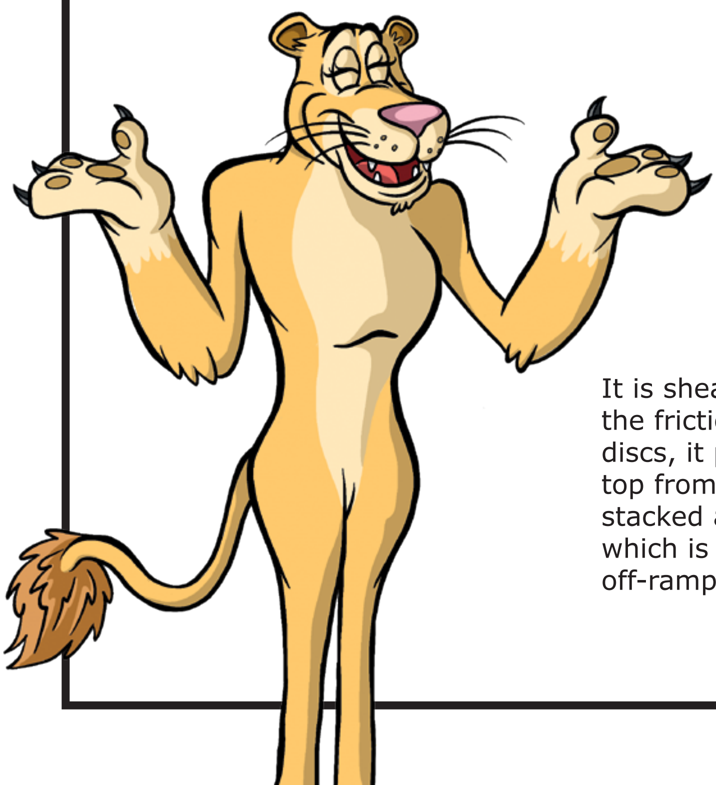


Photo by Jaye Haych on Unsplash

If you search the internet for the Practical Engineering video on Mechanically Stabilized Earth, it demonstrates how sand can actually support a car!

Links to *Chapter G: More Loads and Forces*

LINK



It is shear force that causes the sand to slide – by increasing the friction within the sandcastles with the paper towel discs, it prevents the shear force created by the loads on the top from pulling the sandcastle apart. It allows earth to be stacked at a steeper angle than it would naturally withstand, which is more practical when designing and building on- and off-ramps for bridges and tunnels, for example.

As we found in *Chapter Hi: Enemies of Bridges – The Environment*, when materials are heated, they can expand. This is true of bridges. However, as bridges are often made of a range of materials, not only do they expand and contract at different rates, but they also do so in different directions.

This sketch shows the loads and the resulting forces exerted in the bridge in an exaggerated manner – the concrete abutments should never bend like that in real life!

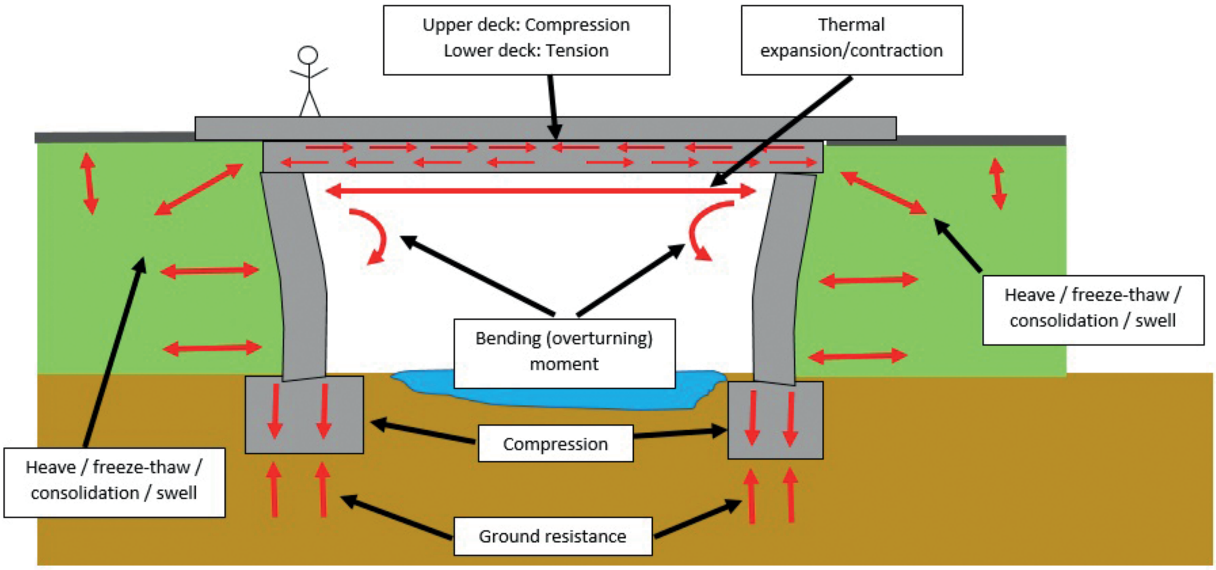


Image courtesy of Alex Romankiw via Twitter

The ground expands and contracts with the weather too, so over time, all of the different movements in different directions would cause the bridge to fall apart.

To avoid the movement of the deck causing abutments to become damaged, or vice versa, bearings can be used. These are ways of separating the deck and the abutments, leaving them connected but permitting the transfer of loads and small movements within the different parts of the bridge.

To allow for smaller movements within the deck materials, expansion joints can be installed. These are small gaps within the deck, which leave space for the deck to get bigger or smaller.

Photo by Charles Cheng on Unsplash

Bearings are placed between the bridge deck and the bridge piers. As the loads change on the deck, it causes the deck to move unevenly on the piers (which, in turn, can change how they move on or in the ground, which can create unstable foundations). By putting bearings between the piers and the deck, it means the deck can move but this isn't transferred directly to the piers – there is a buffer between them. The bearings act like the springs around the edge of a trampoline: allow it to move around, but stay attached to the main frame.

Challenge Time!

Bridges can often get damaged in use – whether because people do not read signs (for examples of this, visit the 11 foot 8 bridge website for videos of drivers failing to note the signs about the very low bridge) or by simply making mistakes.

This happened to the Victorian Bridge at Rochester, when often vessels sailing under the arches misjudged the clearance height and would hit the cast iron structure.

In this activity, learners are challenged to design a replacement bridge. The Challenge task sheet handout summarises the activity and the steps learners should take.

Links to *The Engineering Process*

What, who and why:

A local bridge used by pedestrians and vehicles has a problem.

The bridge has metal arches underneath the bridge to support the deck.

The bridge crosses an estuary which is tidal.

When the river rises it lifts boats up and sometimes lifts them so high the boats are hitting the underside of the bridge.

Design Brief:

Design and model changes to the current bridge.

The new bridge designs must allow boats to pass underneath even if the tide is high and must provide the best value for money solution in the long term.

Design Specification:

- To design and model one solution for the bridge problem.
- The design must allow for boats even at high tide.
- The design needs to be high quality then best value for money.
- The design needs to offer the least disruptive solution, allowing the river still to be crossed as much as possible.

Your first step is to consider how you can meet your clients' needs. Think about your designs using these themes ready to present your model:

- quality
- time the bridge would be disrupted
- cost
- aesthetics and
- environmental impact

HOT TOPICS!

Paper coding treasure hunt. More and more frequently technology is being used to assist in bridge construction and maintenance, and software engineers are designing programmes to help monitor structures. In this activity, you can explore simple coding techniques.

- You need 16 note cards or small pieces of paper. On one card, write 'treasure' or use a picture of a treasure chest. On another card, write the word 'start'.
- Place all of the cards in a square 4 by 4 cards at random.
- Now work out a simple set of directions, or code, to get from the start card to the treasure card, using arrows to represent one card up, down, left or right.
- At the end of the code or instructions, write stop.
- Hide the treasure card and then give the code to someone else to try.

Can they find the hidden treasure?

Just 4 Fun

Desiccated coconut flakes in chocolate mimics fibre-reinforced concrete. You could make chocolate coconut clusters if you do an internet search for a recipe – and while you're making the treat, explore how the fibres change the behaviour of the melted chocolate and what happens when the chocolate sets.

Photo by Pure Julia on Unsplash

OUT & ABOUT

You could explore if weather-proofing of materials has happened on any of the structures in the local area.

When civil engineers are on site, working to maintain the bridge, they have to wear lots of PPE – Personal Protective Equipment. What do you think they have to wear and why? You could dress up as on-site civil engineers and explain why you need to wear the different pieces of equipment.

DID YOU KNOW?

Many bridges around the world are painted a similar red-orange colour.

The official colour is known as 'International Orange'

These bridges are often built over waterways that have a lot of fog. Red and orange colours stand out particularly well in fog. Additionally, steel rusts to a red-brown colour. By painting the metal, the bridge is protected and it doesn't stand out if there is rust.

The Forth Bridge is famous for its huge structure and red colour: the phrase 'like painting the Forth Bridge' was meant to mean a job that would be never-ending or always needing repeating. However, in 2011, a special coating was applied to the bridge which means that the paint should last at least 25 years before needing to be re-done!

Langdon presents:

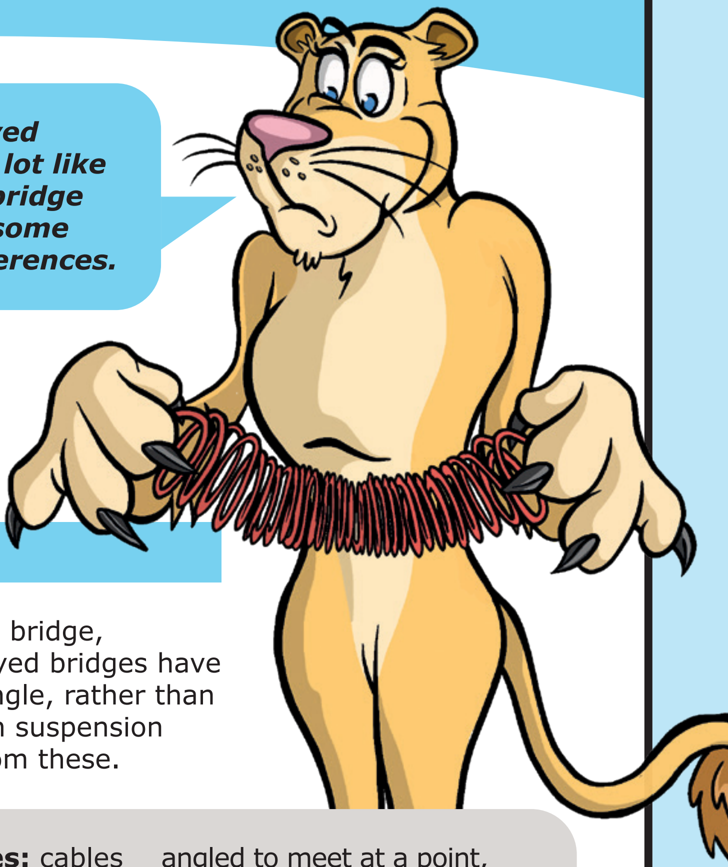
- *Preventing rusting* handout
- *Challenge task sheet* handout

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

Chapter J: Cable-Stayed Bridges

AIMS & OBJECTIVES

- To introduce the cable-stayed bridge
- To appreciate the differences and similarities between cable-stayed and suspension bridges
- To understand how cable-stayed bridges can be used with beam spans to make very long bridges



CONTEXT

The cable-stayed bridge looks a lot like a suspension bridge, but there are some important differences. Cable-stayed bridges have cables attached to towers or pylons directly, at an angle, rather than the main cable going over the top of the towers as in suspension bridges, where secondary cables then hang down from these.

LANGUAGE OF BRIDGES:

Anchor: acts to secure the bridge to the ground.

A-Shaped Pylon: pylon that looks like the letter A when viewed from the end of the bridge, as it has two upright members that meet at the top.

Cable-stayed bridge: bridge where the cables attach directly to the towers or pylons at an angle.

Column Pylon: single vertical pylon.

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

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

Fan shaped cables: cables that are attached to the pylon at the same point, or very nearly, but attach at further intervals on the deck, creating a triangular shape that resembles a traditional hand-fan.

H-Shaped Pylon: pylon that looks like the letter H when viewed from the end of the bridge, as it has two upright members and a horizontal member between them.

Harp shaped cables: cables that are attached to the pylon and the deck at regular intervals, so they run parallel to each other.

Inverse Y Shaped Pylon: pylon that looks like the letter Y upside down, when viewed from the end of the bridge, as it has two upright members angled to meet at a point, and continues vertically up as a single column.

Piers: the upright columns that support the bridge.

Pylon: the tower or vertical part of the bridge to which the cables are attached.

Span: the distance between bridge supports.

Suspension bridge: bridge in which the deck is hung from main cables on vertical hangers.

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

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

You will need...

- Handout: *Comparing Cable-stayed and Suspension bridges*
- Handout: *Cable-stayed bridge examples*
- Handout: *Cable-stayed bridge terminology*
- Handout: *Describing cable-stayed bridges 1 – pylons*
- Handout: *Describing cable-stayed bridges 2 – cables*
- Handout: *Name the cable-stayed bridge*
- Forces in a cable-stay bridge demo:
  - Two shopping bags
  - Various lightweight items to put in the bags – the load should be noticeable but not excessive
- Exploring cables:
  - Lengths of string

Something to Try:

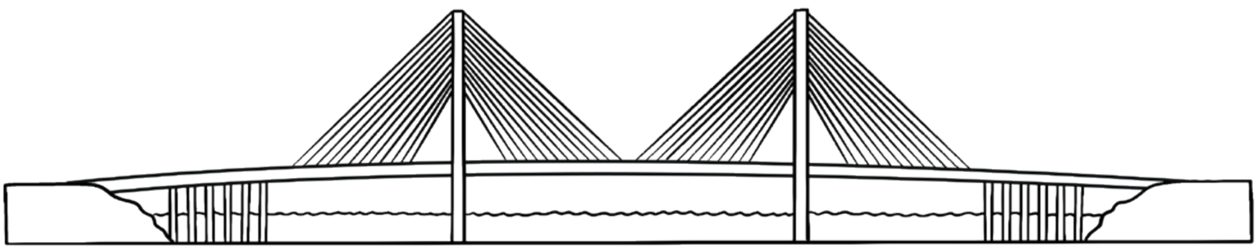
What's the difference between a suspension bridge and a cable-stayed bridge?

Links to *Learning About Bridges Vol 1 Chapter Ei: Suspension Bridges – Hanging Tough*

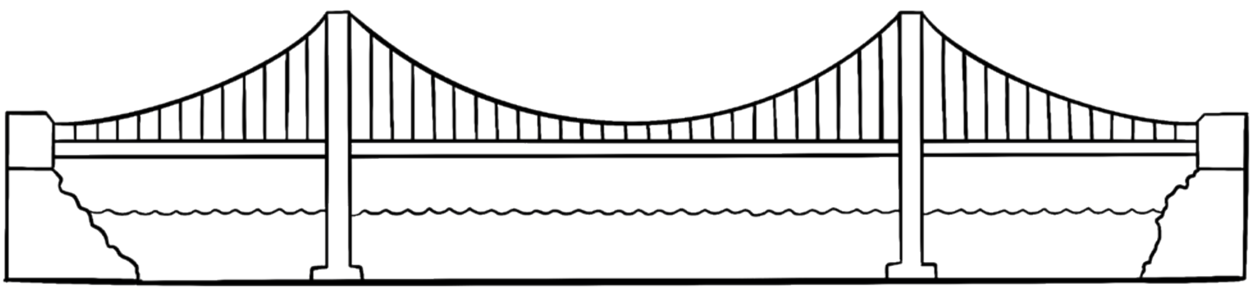
In the section on suspension bridges in book 1, there were a number of activities that demonstrated how suspension bridges are able to bridge wide gaps, and why they need to be well anchored to support the load.

Ask learners to compare the two designs and notice the differences and similarities.

Learners might notice that the cables are attached to the towers or pylons in different ways – in a cable-stayed bridge the cables attach directly to the tower at an angle; in a suspension bridge, the main cable runs over the top of the tower, with the secondary cables, or hangers, hanging vertically from the main cable.



Cable-stayed bridge



Suspension bridge

HERE ARE SOME EXAMPLES OF CABLE-STAYED BRIDGES

Clockwise from top left:

Prince of Wales Bridge, River Severn near Bristol, UK. Photo by mfjordan via Wikimedia;

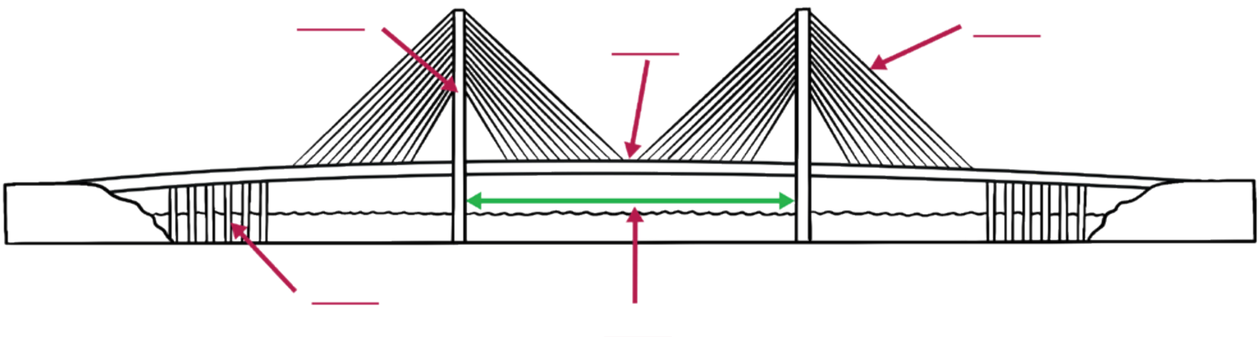
Los Fundadores Bridge, Envigado, Colombia. Photo by chilangoco via Wikimedia;

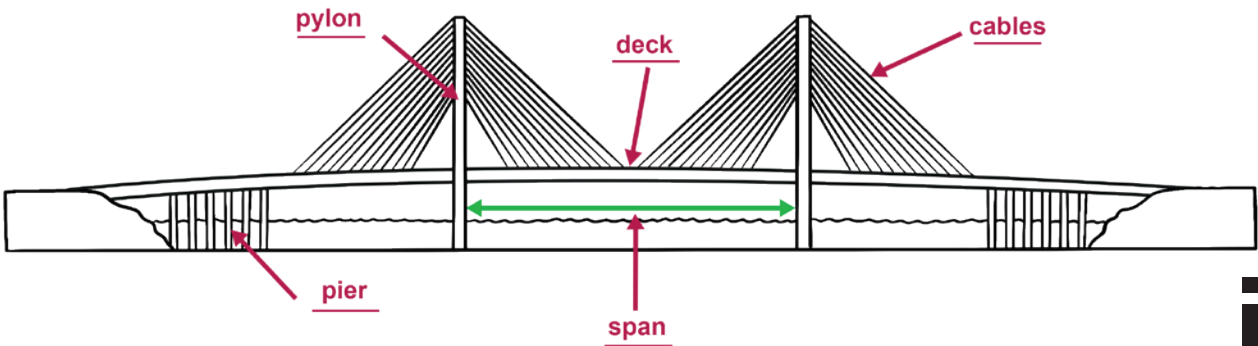
Anzac Bridge, Sydney, Australia. Photo by Adam J.W.C via Wikimedia;

Zakim Bridge, Boston Massachusetts, USA. Photo courtesy of the Boston Airport Express via Wikimedia

THE LANGUAGE OF BRIDGES

Give learners a copy of Cable-stayed bridge terminology handout, and ask them to try to label the different parts of the bridge. Some of the words they might already be familiar with from other bridges, but perhaps not all.

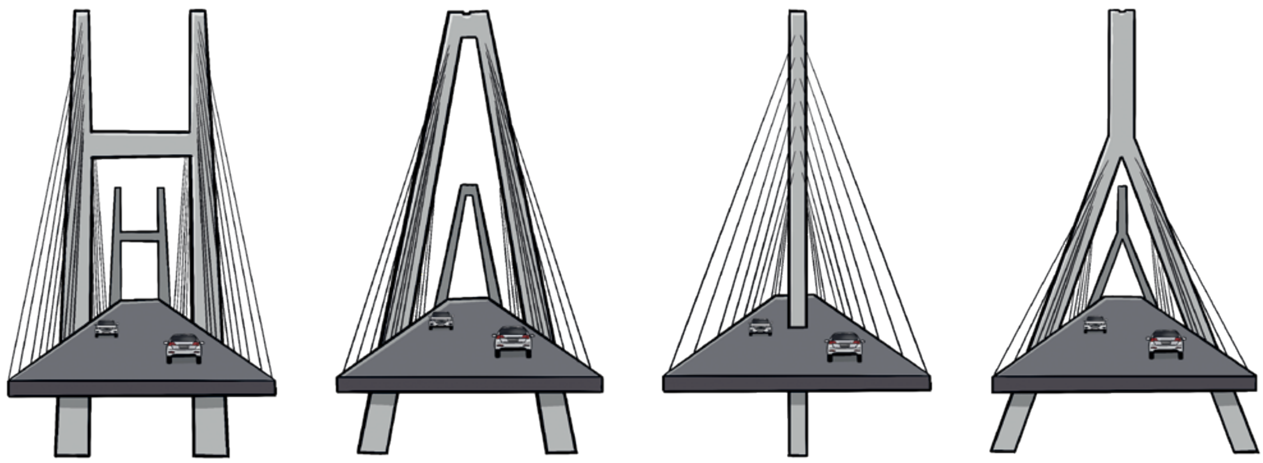


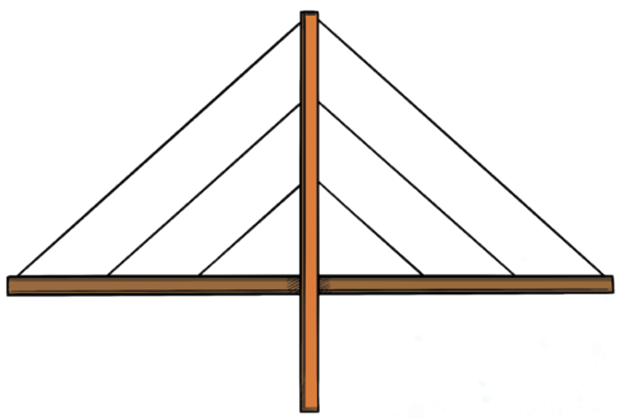


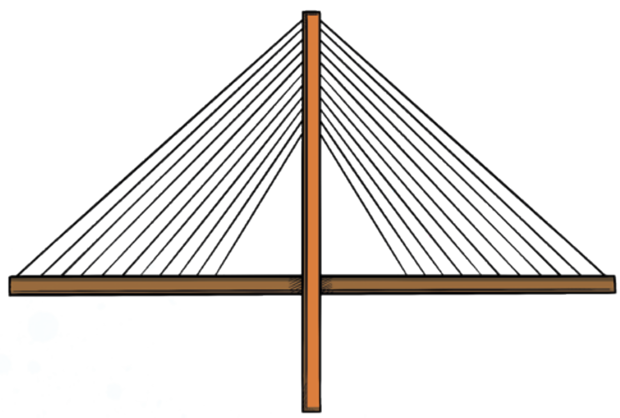
Cable-stayed bridges are described by:

- The number of pylons they have
- The shape of the pylons, and
- The arrangement of the cables.

The following diagrams show the different shapes of pylons and arrangements of cables. Ask learners to try to explain why each shape has the name it has. The handouts *Describing cable-stayed bridges 1 – pylons*, and *Describing cable-stayed bridges 2 – cables* show these diagrams.







In addition to the images here, learners could search on the internet for images of the following bridges and try to identify and name the different features of the bridges using the correct terminology.

- Stonecutters Bridge
- Pont de Normandie
- Jingyue Yangtze River Bridge
- Øresund Bridge
- Helgeland Bridge
- Can Tho Bridge
- Queen Elizabeth II Bridge

You could alternatively use the handout *Name the cable-stayed bridge*.

WHY BUILD CABLE-STAYED BRIDGES?

Although they are expensive, cable-stayed bridges are easier and cheaper to build than suspension bridges. They have stiffer decks so don't tend to bounce and sway in the wind as much as suspension bridges. They can be built where the ground on each side is not as suitable for constructing large anchor blocks.

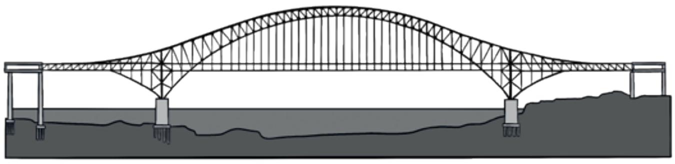
Carry out an internet search for the National Geographic documentary Impossible Bridges: Denmark to Sweden (some sections are on YouTube) – in this video, engineers are deciding between the main types of bridge for a new crossing between Denmark and Sweden.

Cable-stayed bridges can't be as long as suspension bridges. The maximum span is about 1,100 metres (compared to 2000 metres for a suspension bridge). The Russky Bridge in Vladivostock, Russia has the longest cable-stayed span in the world at 1,104m metres. Remember this is the distance between the towers not the total length of the bridge.

The longest bridge over water in the world is the Jiaozhou Bay bridge in China which opened in 2011. The main span is a cable-stayed bridge. The total length of the bridge is about 42.3kilometres – long enough to run a full marathon on – and it could span the English Channel at its narrowest point, with about six miles to spare. The bridge cost £1.4billion.

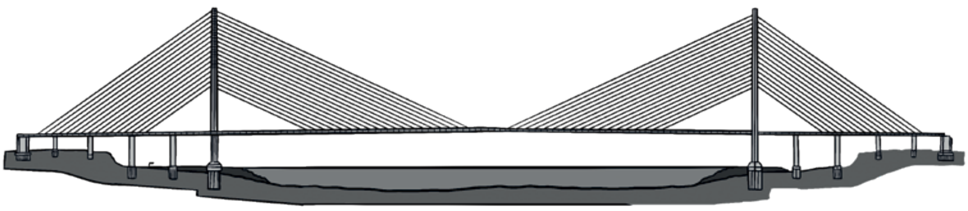
This compares the longest spans of the main bridge types:

Rio-Niteroi, Brazil (Beam) – 300m



Ciaotianmen, China (Arch) – 552m

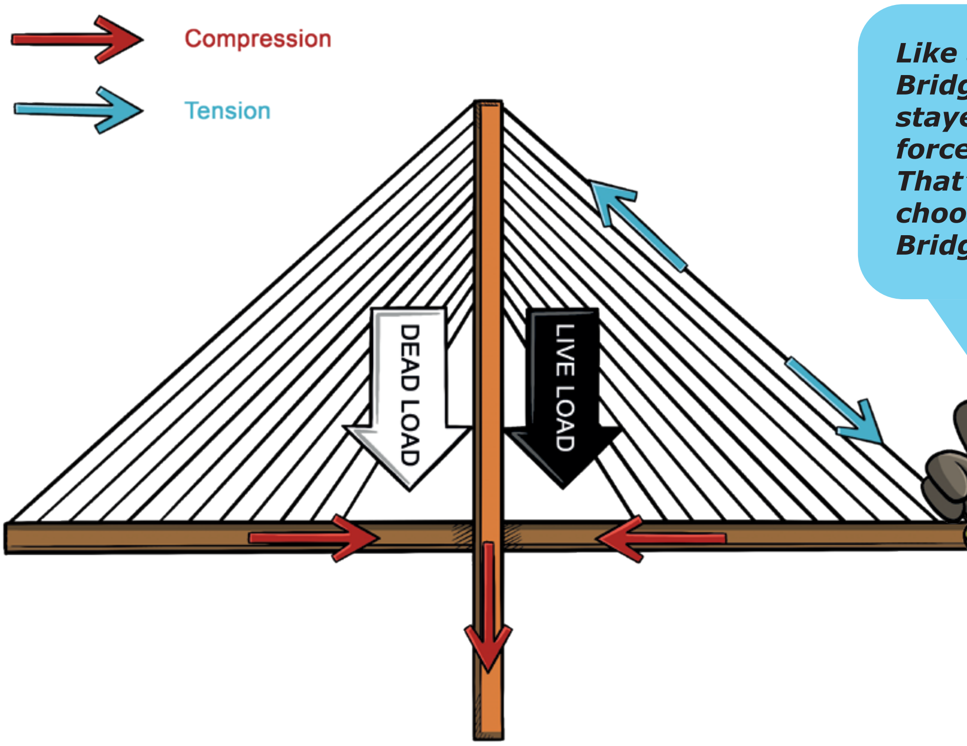
Akashi-Kaikyo, Japan (Suspension) – 1,991m



Russky, Vladivostock Russia (Cable-stayed) – 1,104m

UNDERSTANDING THE FORCES ON A CABLE-STAYED BRIDGE

This diagram shows how the forces in the cable-stayed bridge are transferred.



A really simple way of demonstrating how the forces change in the cables of the bridge is to use shopping bags. Ask the learners to hold two bags, containing some items, straight down and close to their body. Ask them to gradually lift their arms to the sides, at an angle away from the body, mimicking the way the cables move out away from the pylon on the bridge. Ask learners to describe what they notice.

As the bag moves further out/up, learners should report that the bag feels heavier (despite it not actually gaining any mass). This reflects the distribution of the forces in the cables of the bridge – the further the cable is from the pylon, the greater the force exerted.

EXPLORING CABLES

Cables are obviously key components of both suspension and cable-stay bridges. Give learners lengths of string. Ask them to split it down to the component fibres.

Ask learners to apply tension (remember this is a pulling force) and observe what happens. Encourage them to test their observations with one strand, two strands and so on. Discuss what they find. They should notice that each individual strand snaps easily when some tension is applied, however, even just 6 strands wound together becomes much stronger and "unsnappable". This is why the cables found in bridges are made of steel wires wound together to make strong steel cable, which are then wound together to make even stronger cables.

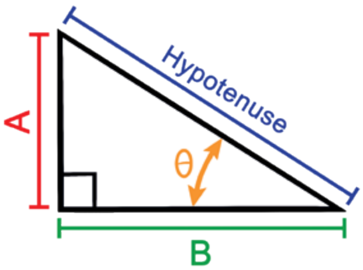
Challenge Time!

Build a cable-stayed bridge. You could construct a cable-stay bridge out of cardboard tubes, or use 6mm square section wood as often used in Design and Technology activities to create the pylon, and card for deck. Challenge learners to build a working bridge using one of the string arrangements detailed above, and test the bridge using small masses, such as coins or hex nuts. If they use the wood to construct the pylons, they may need to have assistance in creating holes with which to thread the cables.

Challenge learners to bridge a gap of 50cm – you should be able to demonstrate that the card bridge deck alone across the gap sags and cannot support a large load. Once learners have constructed a string-cable stayed bridge, they should be able to demonstrate that the load the bridge can withstand is larger.

HOT TOPICS!

The cables of a cable-stayed bridge form a series of triangles with the tower and the deck. You could use trigonometry and Pythagorus' theorem to calculate the length and angles of the various cables in the different configurations in the cable-stayed bridge.



Just 4 Fun

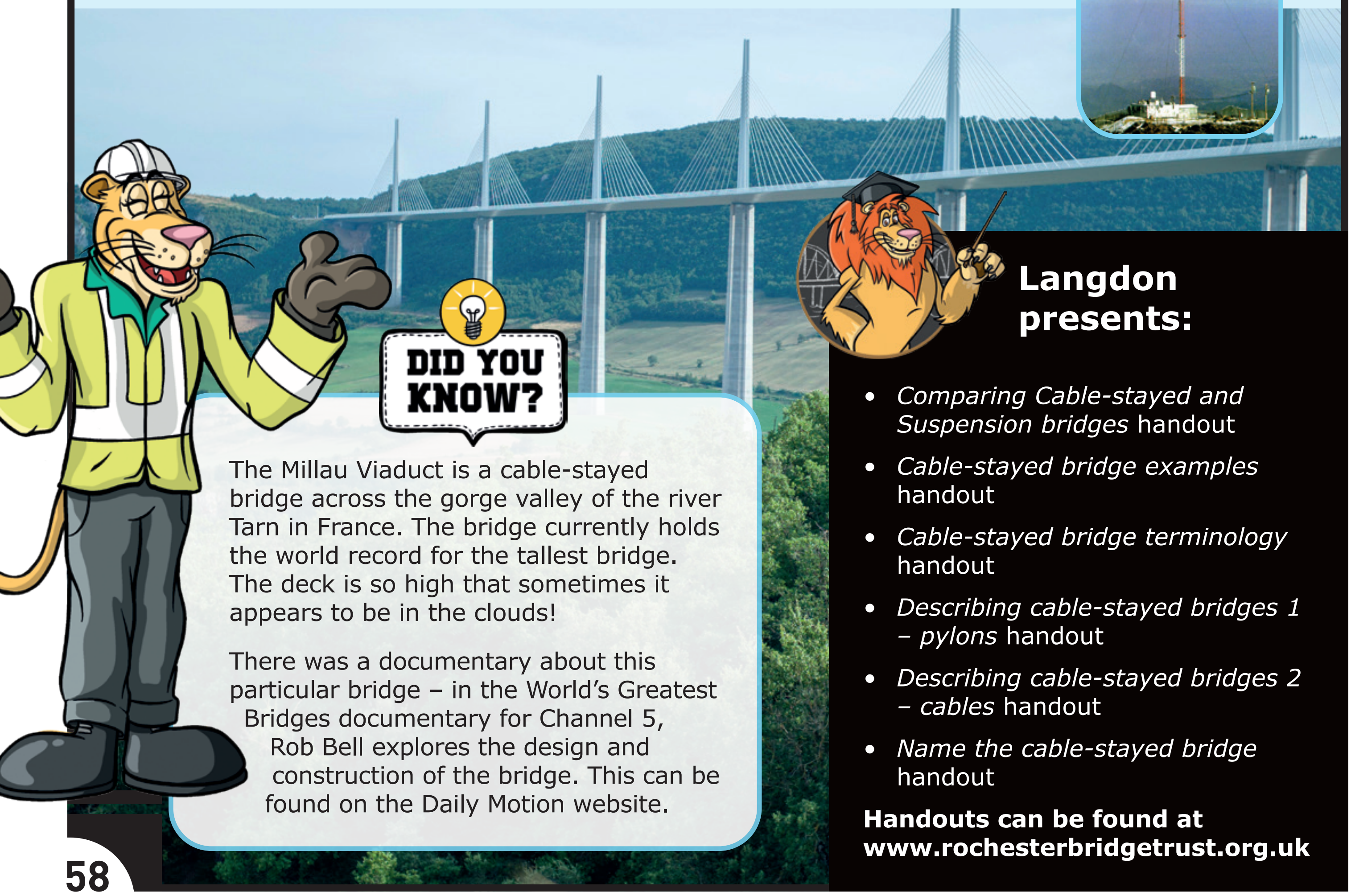
Cable-stayed bridges are one way of bridging a gap using wires or cables – a zip wire is another way!

You could make your own zipline out of smooth string or thread, attaching one end to something very sturdy and the other end at least 60cm lower. Make sure nobody can walk into it by accident though! Then you can design and build a container to transport something, like a small toy, Lego® or action figure, down the zip wire. You can then investigate how heavy you could make the carrier, or whether you can make the journey faster or slower.

THINK LIKE AN ENGINEER

OUT & ABOUT

When you are outside in your local area, or even further afield, look out for cables that help make structures stronger or more stable. These could be guy-lines on a tent, a temporary flag pole that you might see at a Scout camp, or even securing a telecommunications mast.



DID YOU KNOW?

The Millau Viaduct is a cable-stayed bridge across the gorge valley of the river Tarn in France. The bridge currently holds the world record for the tallest bridge. The deck is so high that sometimes it appears to be in the clouds!

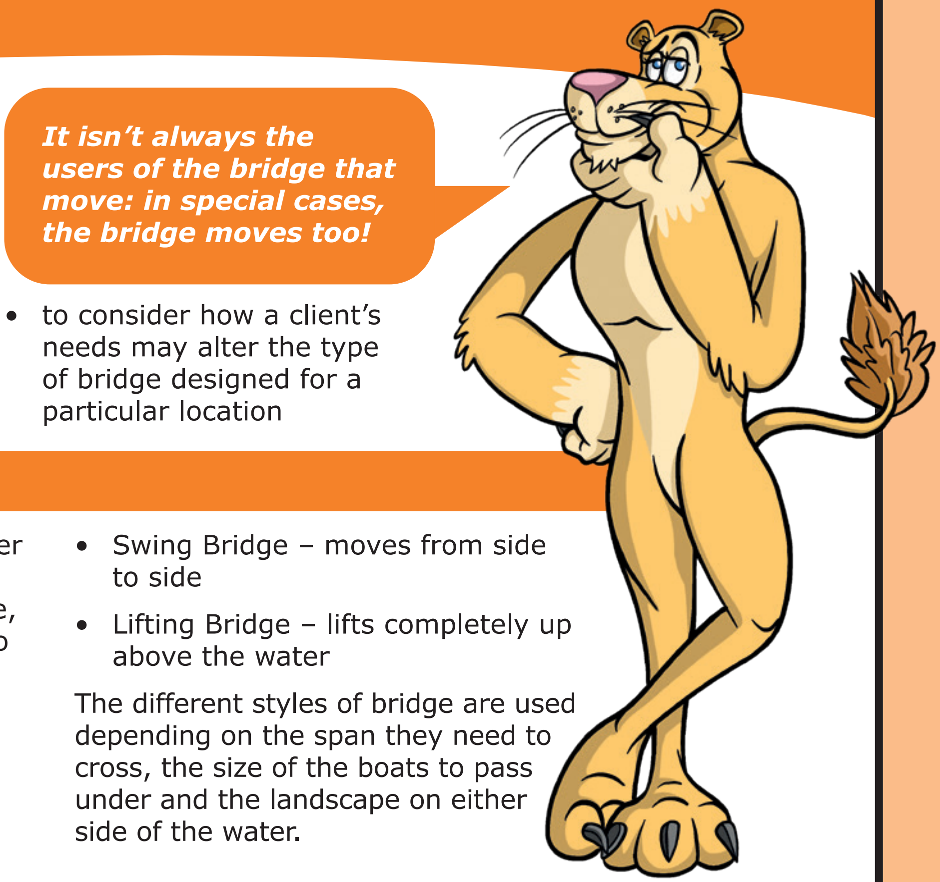
There was a documentary about this particular bridge – in the World's Greatest Bridges documentary for Channel 5, Rob Bell explores the design and construction of the bridge. This can be found on the Daily Motion website.

Langdon presents:

- *Comparing Cable-stayed and Suspension bridges* handout
- *Cable-stayed bridge examples* handout
- *Cable-stayed bridge terminology* handout
- *Describing cable-stayed bridges 1 – pylons* handout
- *Describing cable-stayed bridges 2 – cables* handout
- *Name the cable-stayed bridge* handout

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

Chapter K: Moving Bridges



AIMS & OBJECTIVES

- to recognise the three main types of moving bridge
- to explore how bridges move and how this affects things around them
- to consider how a client's needs may alter the type of bridge designed for a particular location

CONTEXT

Moving bridges are usually used over water to allow fast following traffic to keep moving on top of the bridge, while occasionally stopping traffic to allow tall boats to pass underneath.

There are three main types of moving bridge:

- Bascule Bridge – moves up and down vertically in an arc
- Swing Bridge – moves from side to side
- Lifting Bridge – lifts completely up above the water

The different styles of bridge are used depending on the span they need to cross, the size of the boats to pass under and the landscape on either side of the water.

LANGUAGE OF BRIDGES:

Aesthetics: This is about how something looks. If a bridge is primarily designed to be aesthetically pleasing, the engineers are more concerned with how it looks. It may be the public and the architects who view the appearance of the bridge as of equal importance to how it works.

Bascule Bridge: Bascule is a French word meaning to tip over or seesaw. Bascule bridges move up and down vertically in an arc shape.

Client: This the generic name for the people or organisation who have asked for a job to be done. In this session, it is the organisation who has asked for some moving bridge solutions.

Functionality: This is about how something works. If a bridge is primarily designed to be functional, the engineers are more concerned with how it works.

Elevation: In a technical drawing, this is the view from the side. This view is used on engineering plans to show how a bridge design will look from the side, almost as if you're standing in a boat on the water, looking at the bridge over the span of the river.

Lifting Bridge: This moves the bridge up, above the river like a lift. They tend to have towers on either side that the bridge moves between on its way up and down.

Maintenance requirements / to maintain: This is a list of things that are needed to keep the bridge looked after once it has been built, so it is still safe and lasts a long time.

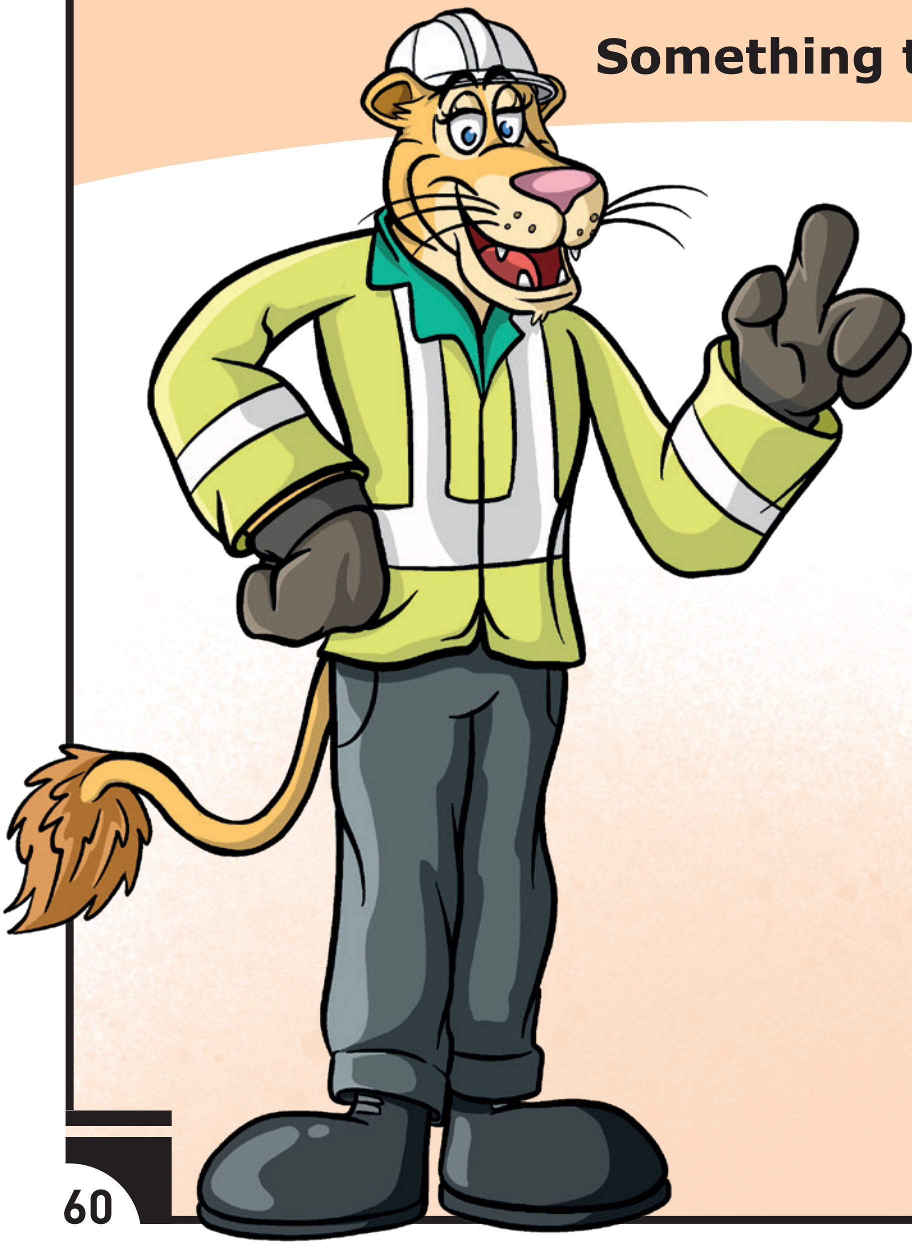
Plan view: In a technical drawing, this is the view from above or a bird's-eye view. This view is used in maps and on engineering plans for a new bridge design, showing how the bridge and landscape look from above.

Swing Bridge: This moves horizontally from side to side or around a central pivot to open and close the bridge.

You will need...

- Drawbridge demonstration, per group:
  - Empty cereal box
  - Scissors
  - Hole punch
  - String
- Lift bridge demonstration, per group:
  - 2 empty cereal boxes
  - Hole punch
  - Scissors
  - String
  - Thin piece of card, roughly the same size as the cereal boxes (A4 was used here)
  - 2 straws (wider milkshake type straws are ideal but not essential)
- Handout: *Moving bridges*
- Moving bridges challenge, per group:
  - Handout: *Moving bridges challenge*
  - Craft card e.g. 150-250gsm
  - Scissors
  - Split pins

Something to Try:



Moving bridges are usually used over water to allow fast following traffic to keep moving on top of the bridge, while occasionally stopping traffic to allow tall boats to pass underneath. In situations where land space is limited, or the river is relatively narrow, other bridge designs would not work: a beam bridge is too low to allow ships to pass under, an arch bridge can only get tall enough for tall vessels to pass under when the river (or bridge) is very wide, and other options (such as suspension bridges) require long approaches on either side.

There are three main types of moving bridge:

BASCULE BRIDGE:

Bascule bridges move up and down vertically in an arc shape. This is similar to how a drawbridge works. Learners can explore the way a drawbridge works using this simple demonstration.

CEREAL BOX DRAWBRIDGE:

1

Cut the top flaps from the cereal box.

2

Using a holepunch, make four holes on the back and front panels of the box, near the corners. Try to space them symmetrically – this could be a little tricky for some learners, so might require adult assistance, especially if using a standard desk hole punch.

3

Thread the string through the holes: starting from one of the back panel holes, bring the string forward and thread through one of the front panel holes. Then bring the string across the front of the cereal box, and thread it through the front panel hole, before returning through the remaining back panel hole. You should now have a loop of string that runs from the back and across the front.

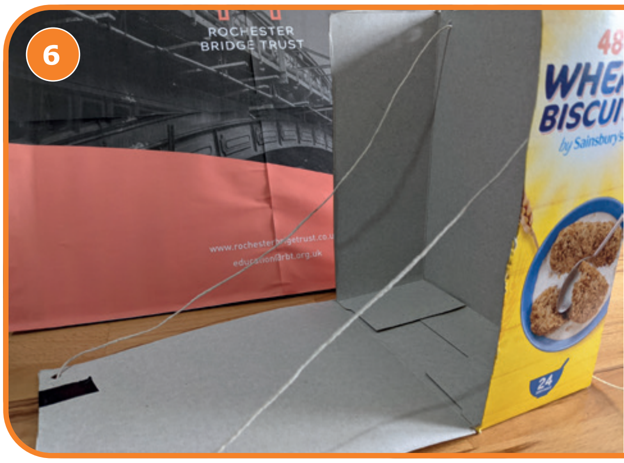
4

Thread the string through, leaving a good amount hanging equally from both of the rear holes.

5

Cut down the sides of the front section of the box, to create the drawbridge – take care not to cut the string as you do this!

6



You can now draw it up!

Ask learners what they notice about how the bridge moves – where does it get stuck, or where does it move easily? How hard do they have to pull on the string? Is it the same all the way through? If the string is very short and they pull more closely to the back of the box, do they pull more firmly or more gently than if the string is longer and can be held further away?

Ask learners what they notice about how the bridge moves – where does it get stuck, or where does it move easily? How hard do they have to pull on the string? Is it the same all the way through? If the string is very short and they pull more closely to the back of the box, do they pull more firmly or more gently than if the string is longer and can be held further away?

Bascule is a French word meaning to tip over or seesaw, which helps to explain how they work. They're counterbalanced by huge weights, that equal the weight of the bridge deck being lifted. Mechanical means can be used to move the weights, such as hydraulics or electric motors. These are attached to a series of cogs and gears, that allow the bridge to move up and down at a slow, managed rate, so the bridge doesn't slam shut.

Image courtesy of Sung Shin on Unsplash

A famous Bascule bridge is Tower Bridge in London.

If you search on YouTube for 'bascule bridge opening' there are a number of different videos showing the process, including Tower Bridge, Pegasus Bridge in Normandy and Erasmus Bridge in Rotterdam. There are also various videos about the bascule chambers of Tower Bridge online, as well as an episode of London's Greatest Bridges on My5, Channel 5's on demand service. A slightly different type of Bascule bridge can be seen in videos of the Johnson Street Blue Bridge in Victoria, British Columbia (Canada). This has a single bascule leaf, rather than two such as Tower Bridge. Other two-leaf bascule bridges can be found if you search for Poole (in Dorset, England) harbour bridges – here there are two very different lifting bridges. One is named the Twin Sails bridge, as when opened, the leaves of the bridge resemble sailing boat sails.

Technically Tower Bridge isn't a straight-forward bascule bridge: it is a suspension bridge, with a double-leaf bascule section for the central deck. This was needed because both the river and the crossings in London were very busy.

In the early period of the bridge, sailors merely had to honk their horn to alert the operator to open the bridge. Now vessels must book the opening in advance.

LIFTING BRIDGE:

A lifting bridge moves the deck up straight up and down, above the river like a lift. They tend to have towers on either side that the bridge moves between on its way up and down. They're suited for wide water ways, where a small section of a low beam bridge can be moved up and out of the way to allow ships to pass, or where railways need to cross the river: the counterweights required to lift the deck vertically are much smaller than those required for a Bascule bridge, for example, as the deck is moving vertically up rather than being lifted at an angle. The main disadvantage of a lifting bridge is that the height beneath the deck is restricted for vessels passing underneath, as the deck remains above the passage (whilst in alternative moving bridge types, the deck moves out of the way almost entirely).

Photo courtesy of "Stuart" 74009 via Wikimedia

An example is the Kingsferry Bridge over the Swale between the Isle of Sheppey and Kent. If you search YouTube for 'Kingsferry lifting bridge Kent' there are a number of videos showing the bridge working.

THIS ACTIVITY DEMONSTRATES THE WAY LIFTING BRIDGES WORK:

1 Make holes in the corners of the thin piece of card, which will be the deck of the bridge, using a hole punch.

2 Cut the flaps from the top of both of the cereal boxes.

3 Punch holes in the front and back of the top of the box.

4 Then also make holes in the front bottom corners.

5 Cut a length of string just over twice as long as the cereal box is tall – for example this cereal box is 25cm tall, so the string used was 55cm. This allows sufficient excess to knot it.

6 Thread the string into the bottom hole that aligns with the card. Loop this up inside the box and bring it out of the top hole. Then bring the string down to towards the deck. Thread the string from the bottom hole in the cereal box up through the hole in the corner of the thin deck card, so it meets the other end of the string, and knot them together. You should end up with something that looks like this.

7 You now need to cut two lengths of string about 1m long. This will be the lifting mechanism for the bridge deck. Loop this through one hole on one side of the deck and knot it. Pass the loose end up through the front hole on the cereal box, then across to the rear hole.

8 Taking your straw, cut it so it fits neatly between the two holes on the back of the box.

9 Pass the string through the straw and then bring it forward through the other rear hole in the box.

10 Make sure the straw is hanging around 4cm below the top of the box, and then loop the string through the hole at the front of the box and then loop it through the deck hole and knot it securely.

11 Repeat this process with the second length of string and straw on the other side of the deck.

12 At this point, you should have a final lifting bridge model. If you carefully pull on the straws and bring them down the back of the boxes, you should see your deck rise! You might wish to add a small weight in the bottom of the box, such as a food tin, some bean bags or a small book, to ensure the boxes don't move too much.

SWING BRIDGE:

This bridge moves horizontally from side to side or around a central pivot to open and close the bridge. The bridge may be attached to the land on one side and when it opens, it moves in an arc out over the river providing a large space across the river for boats.

Original image courtesy of the Royal Engineers Museum collection

The Victorian version of the Rochester Bridge was built to have a swing bridge. The Admiralty (the British governing body at the time responsible for overseeing the Navy and marine affairs) insisted that Sir William Cubitt's design incorporated a ship's passage: a swing bridge that would allow ships with fixed masts to move upriver. It was not powered, but was said to be so well-balanced that two men could easily rotate it around 90 degrees in five minutes.

Some bridges move from a central pivot providing two channels for boats on either side such as the Tyne River Swing Bridge in Newcastle. If you search on YouTube for 'Newcastle swing bridge' there are a number of videos showing the bridge moving. Many of the videos feature the other bridges over the Tyne in Newcastle as well, which may be thought-provoking for learners, to consider why there is a swing bridge at all, or what is different about the swing bridge to the other bridges that allow the vehicles and shipping to pass.

Photo courtesy of Oliver Newbury via Wikimedia

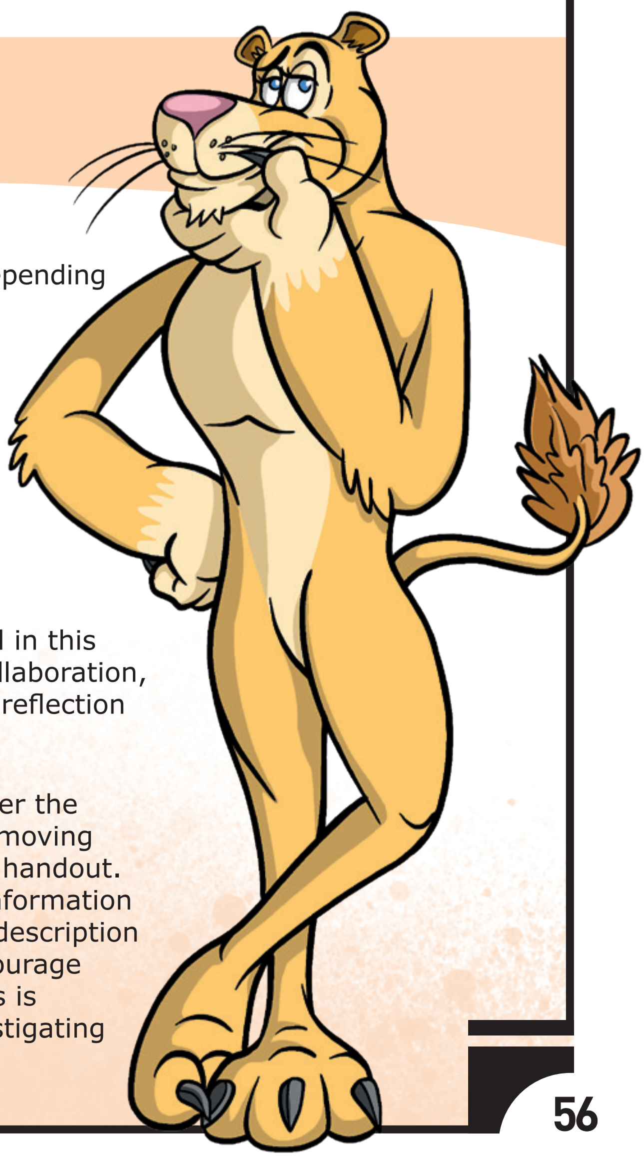
Using the *Moving bridges* handout, learners can compare and contrast the key aspects of each of the bridges from the images and video links shared in this chapter.

Ask learners to consider the different bridges and answer the following questions:

- Why do these bridges need to move?
- What do you notice about how these bridges move?
- What space is needed to allow them to move?
- If this bridge was not available, what other ways might have been used to allow vehicles and pedestrians to cross the water while still allowing boats to sail?

Engineers only use moving bridges when absolutely necessary because they are hard to design, build and maintain. Engineers work out what might work best and Value Engineers work out how to make the project the best value for money. Moving bridges cost a lot to maintain because of the moving parts which can get damaged by use as well as the water and weather. Maintenance of a bridge is a big factor in considering the cost of a bridge.

Challenge Time!



The different styles of the three types of bridge are used depending on the span they need to cross; the size of the boats to pass under and the landscape on either side of the water. Engineers need to spend time testing, designing and modelling their ideas. This includes considering where a bridge might be best placed and the bridge styles that might be suitable, before offering a client some solutions.

Clients have to weigh up what will be the best solution for their water crossing based on functionality, cost, time, maintenance requirements and aesthetics.

Learners can demonstrate their engineering habits of mind in this activity – it is a really good opportunity to demonstrate collaboration, open-mindedness, resourcefulness in problem-soling, and reflection upon the design at the end of the process.

This challenge requires learners to consider the context and brief to select a design for a moving bridge using the Moving bridge challenge handout. The context provides some background information about this challenge. The brief is a short description about what you need to do and why. Encourage learners to use the tips to help them. This is designed to be an enjoyable activity investigating possibilities, not a competition or test.

CONTEXT: You have been given the 'plan' and 'elevation' view of a river where a client thinks they need a bridge.

The client needs vehicles and pedestrians to frequently cross the water at this point on the landscape. The plan view is from above as if you are a bird looking down at the land and water. The elevation view is from the side as if you are in the water looking at the span of the river banks.

The client wants a vehicle and pedestrian crossing here but also needs to allow boats to pass through the water at times.

BRIEF (WHO, WHAT AND WHY):

The client requests that you make some recommendations about which type of crossing could be most suitable. Using your knowledge of moving bridges and looking at the plans you have been given, consider which types of crossing you might recommend.

TIPS:

- As a group you can help each other. Engineers work together in teams to get the best results for their client.
- Consider each possible solution separately and discuss what the benefits and issues of each would be.
- You can use the cardboard and split pins provided to add to the plan and elevation views map and model some ideas.
- Prepare to share your ideas with the other teams at the end of this activity.

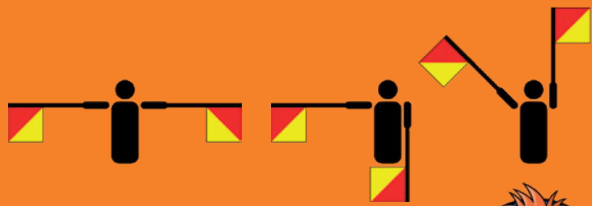
Once the learners have completed their task, it is time for each team to share their ideas and models while explaining what they considered. You could do this with presentations in front of everyone or you could have groups pair up and present to each other. Ask learners to make sure they explain what they thought would work well (or not) and why.

Photo by Andrey Metelev on Unsplash

SOME EXAMPLES OF QUESTIONS YOU MIGHT ASK DURING THIS FEEDBACK:

- Where does the bridge go when it moves? Will space be needed on the land for it when it moves (such as with a Swing Bridge that pivots from one side or the mechanisms of the Bascule Bridge that need space either behind or below the bridge).
- Which bridge styles would least affect the view of the landscape?
- On a narrow river like this how well would a Swing Bridge that pivots in the middle work?
- What other solutions to traffic and pedestrians crossing might there be, other than building a moving bridge here?

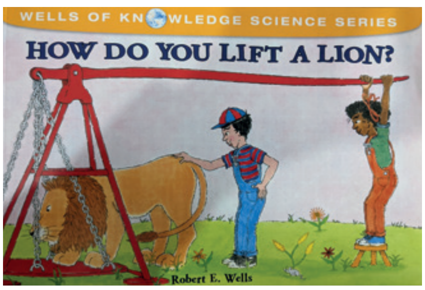
When pilots want to signal for bridges to be opened, nowadays they will likely use radio. However, many moving bridges existed before radios were in common use, so mariners would use semaphore, a signalling system using flags, where the position of hand-held flags mean different letters. These can be found online.



You could learn to send messages to friends, family, classmates – you don't even need flags, you can just use your arms. See what's the longest message you can send!

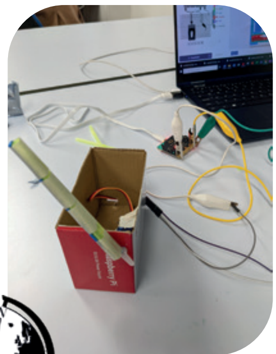
HOT TOPICS!

You could read the book 'How do you lift a lion?' by Robert E Wells. In it the reader gets to find out how simple machines, such as a wheel, lever or pulley, are used to help the children move an amusing assortment of animals.



Tower Bridge is a famous landmark in London, and across the world, as well as being a moving bridge. If you visit the website, there are lots of activities to do including finding out when the lifts are going to happen, reading all about iconic occasions when the bridge has opened, or even do some creative activities, such as making your own moving Tower Bridge picture. You can then use it to make a stop motion film.

If developing basic programming skills, you could use a BBC Micro:bit or Raspberry Pi, servo motor and some basic crafting materials to create a voice activated drawbridge. By creating a simple code to recognise the sound level and respond by moving the motor by a defined number of degrees, it can lift a crafted bridge up and down on command. You could ask learners why this wouldn't be a good idea in real life.



OUT & ABOUT

Moving bridges are quite unusual, so you probably won't see one near where you live… However, maybe when you go out in your local area, you might see other structures that move something from place to place. Can you find out how it moves?

There is an unusual moving bridge in the Paddington area of London. This is called the Heatherwick's Rolling Bridge: more details can be found in the *Interesting Bridge* chapter of this book (online only). Perhaps when you're out and about, you might notice some other unusual moving bridges.

LINK

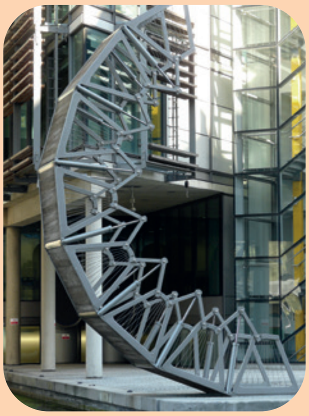
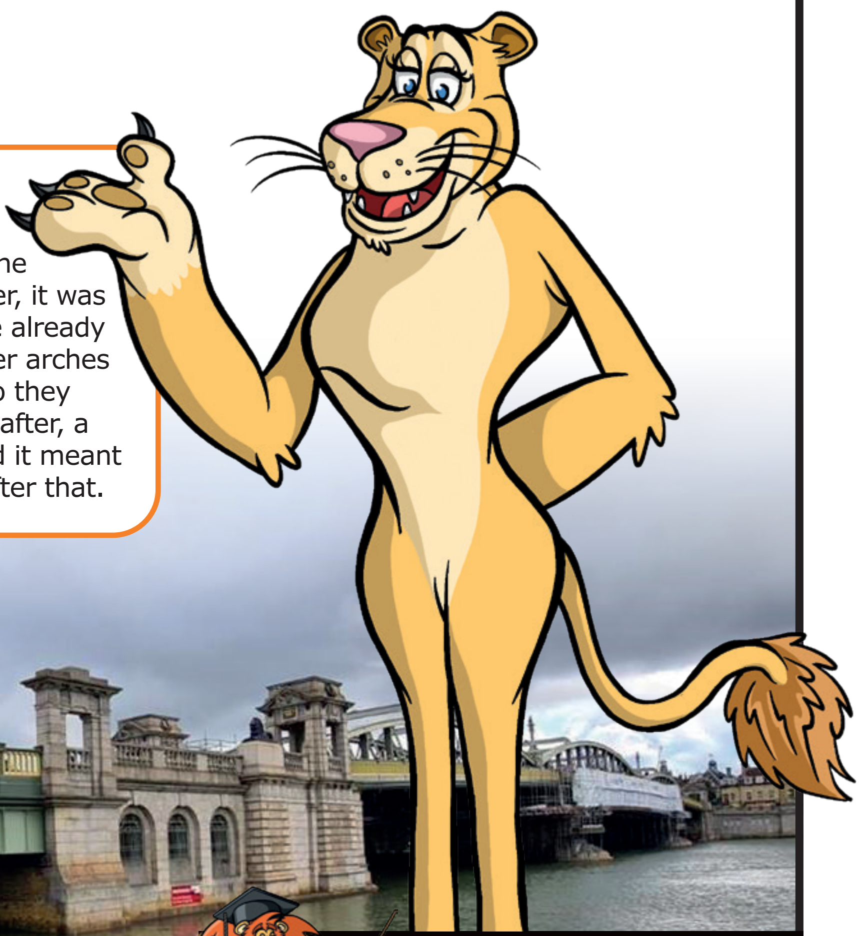


Photo by Thomas Heatherwick via Wikimedia

DID YOU KNOW?

The Victorian Bridge at Rochester on the River Medway has a moveable section, the Old Ships Passage shown below. However, it was never used! Ship pilots on the river were already used to lowering their masts for the lower arches in the previous Medieval stone bridge, so they just continued to do that. Then not long after, a railway bridge was built downstream and it meant there was no room to open the bridge after that.



Langdon presents:

- *Moving bridges* handout
- *Moving bridges challenge* handout

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

Chapter Li: Cantilever Bridges – Introduction

AIMS & OBJECTIVES

- To know what we mean by 'cantilever'
- To start to recognise cantilever structures
- To use the correct terminology for a cantilever bridge
- To build a simple model cantilever bridge

CONTEXT

Cantilever bridges can span long distances, often over water, whilst carrying heavy loads. In contrast to suspension bridges (covered in *Learning About Bridges Vol 1*) which may be able to span the same distances (if not greater), cantilever bridges are less flexible and therefore able to carry a heavier load.

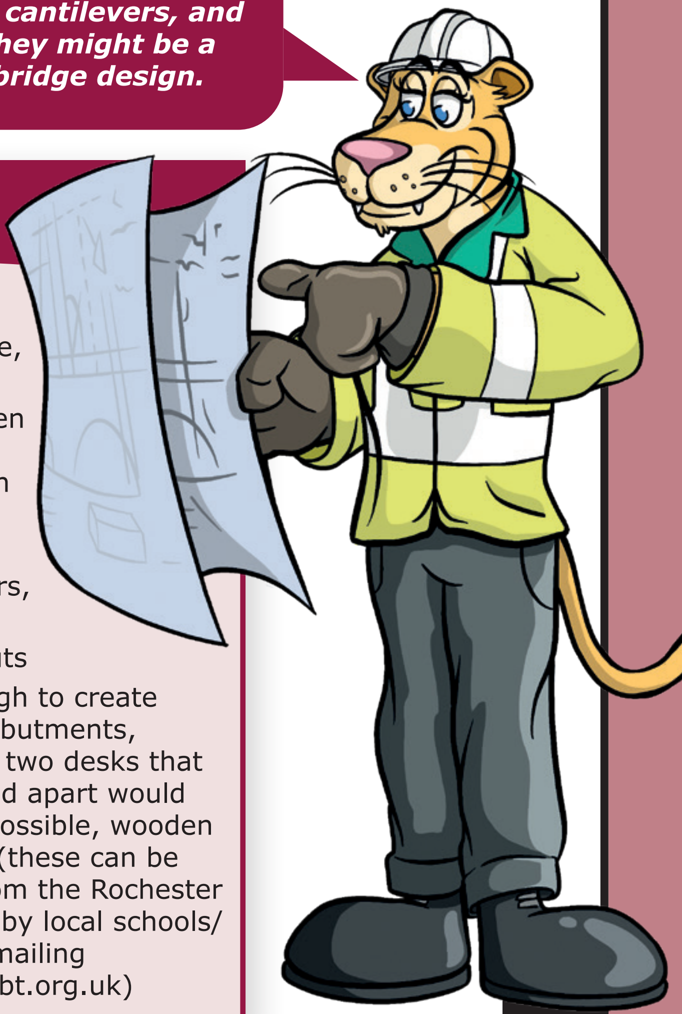
LANGUAGE OF BRIDGES:

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).

We are learning about a different type of bridge, cantilevers, and when they might be a useful bridge design.



You will need...

- Handout: *Common structures*
- Resource: *Common Structures*
- Handout: *Cantilever Bridge Terminology*
- Handout: *Cantilever Bridge Challenge*
- Experimenting with levers, per group:

  1st demonstration:
  - A heavy book and a bag with straps, OR
  - 2 dumb bell masses/weight plates of different sizes (e.g. 0.5kg and 2kg)

  2nd demonstration:
  - A ruler
  - A hardback book
  - 9 pennies
  - Paper/note pad and pencil
- Cantilever bridge challenge, per group:
  - Tub of wooden planks, or large wooden craft/jumbo lolly sticks
  - Metal washers, or coins
  - Metal hex nuts
  - Books, enough to create two stacks/abutments, alternatively two desks that can be moved apart would work, or, if possible, wooden bridge base (these can be borrowed from the Rochester Bridge Trust by local schools/groups by emailing education@rbt.org.uk)

Something to Try:

What is a cantilever?

Give groups copies of the various common structure images from the *Common Structure* resource and/or *Common structures* handout.

Ask learners to see if they can identify a common feature, something they all have in common.

There may be lots of different reasons given, but draw out the ideas that all show they have a structure supported at only one end. This is essentially a cantilever.

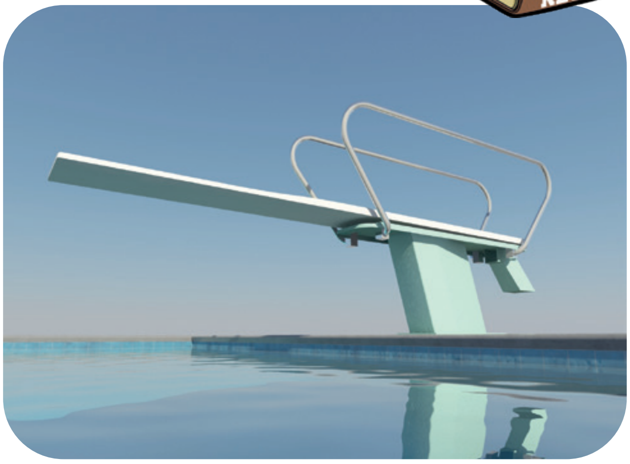


Photo by Lehmer and Associates via Shutterstock

Photo by Seighean via Wikimedia

Photo by Darren Richardson on Unsplash

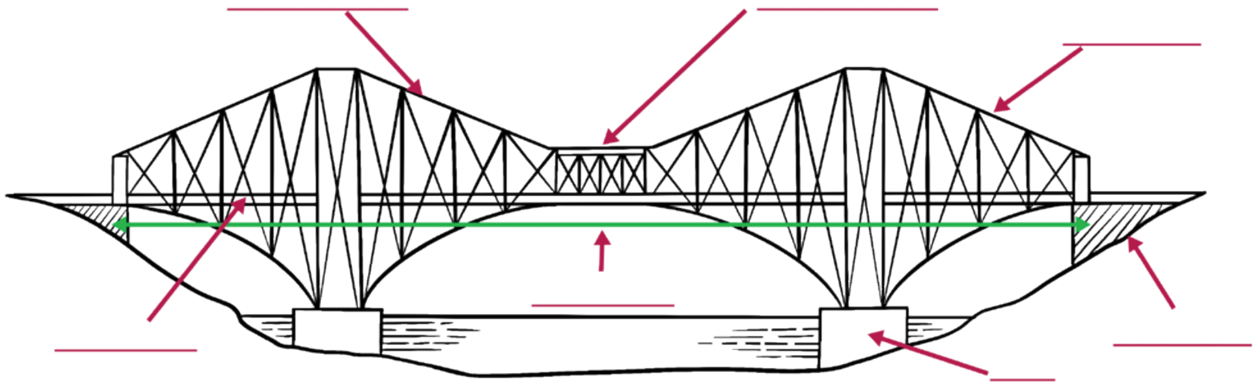
Photo by Holger Ellgaard via Wikimedia

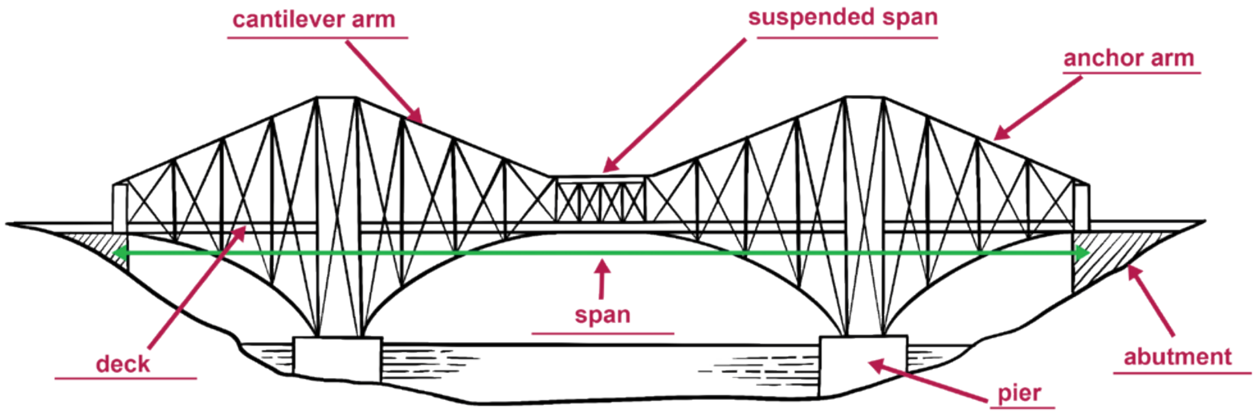
Photo by Finlay McWalter via Wikimedia

Photo by Laurenz Grabosch on Unsplash

LABELLING THE CANTILEVER BRIDGE:

Give learners a copy of the *Cantilever bridge terminology* handout. Get learners to identify the different parts of the cantilever bridge.





Ask learners what they notice about the bridge – do they recognise any similar structures that relate to their previous bridge sessions?

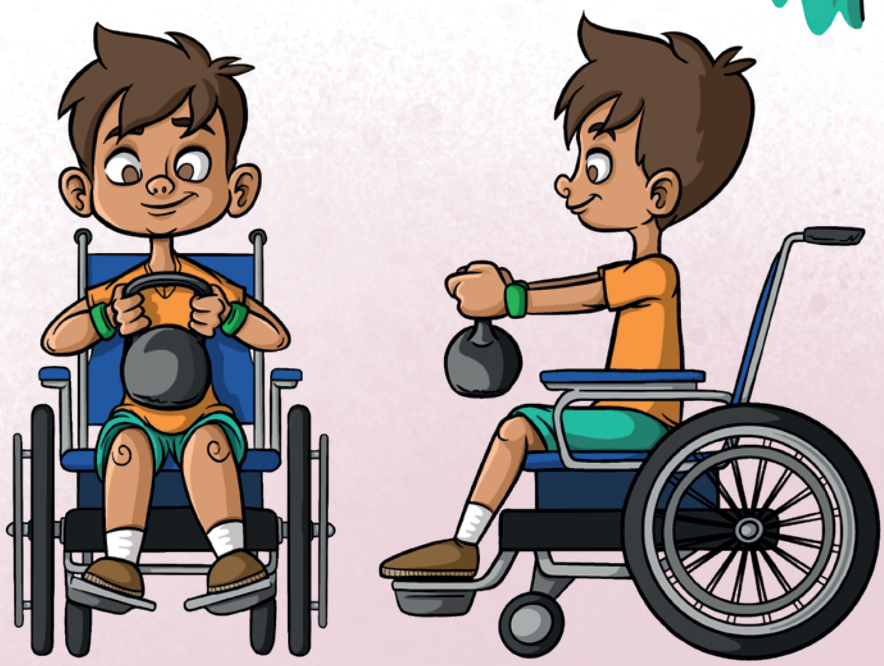
EXPERIMENTING WITH LEVERS:

Learners can do a simple demonstration to show the effect of a lever.

Place the heavy book in the bag with straps, if these are being used instead of the weight plates.

Ask learners if they think they would be able to hold the bag. Those that say 'yes', instruct them to slide the straps over their hand and along their arm, as far as their elbow and hold their arm straight out. Then repeat with the bag over the tips of their fingers.

Ask those taking part, which position was easiest?

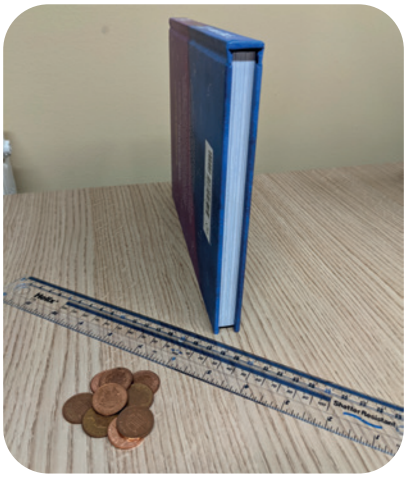


If using weight plates, a similar process applies, but this time, ask one learner to hold the large weight close in to their chest, with both hands, while another learner holds the smaller mass in their hands at full arm's length (with straight arms).

Ask them how long they think they can hold it for. Monitor both learners, asking them whether it is easy; it is likely the learner holding the smaller mass at full length will tire first. Ensure that they can put the mass down (safely) before they get too tired.

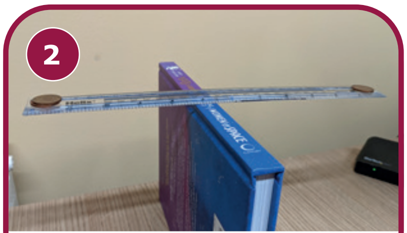
Ask learners why they think there is a difference?

Learners can further explore levers and balancing using some simple materials.



1 

Balance the ruler on the book with a penny on each end.

2 

Put a second penny, so you have two pennies on one end and slide the ruler along until it balances.

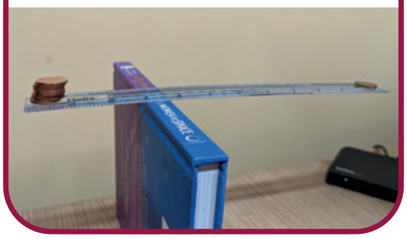
3 Make a note of where the top of the book is, using the centimetre marks on the ruler and write this down.

4 

Repeat the same process, but adding two pennies to the end with two pennies, so you now have four pennies on one end.

5 

Repeat with six pennies and eight pennies.



This links to science and forces; moments and levers.

Learners should find that the single penny gets further away from the balancing point (fulcrum) as the number of pennies at the other end increases.

Challenge Time!

Who can build the longest span cantilever? Here's a hint: be very gentle with the wooden planks as you move them so you can find their balance point.

CANTILEVER BRIDGE CHALLENGE:

Photo by Mikael Häggström via Wikimedia Commons

This picture shows an early cantilever bridge.

Each group is challenged to build a cantilever bridge using the wooden planks and metal hex nuts, using the *Cantilever bridge challenge* handout.

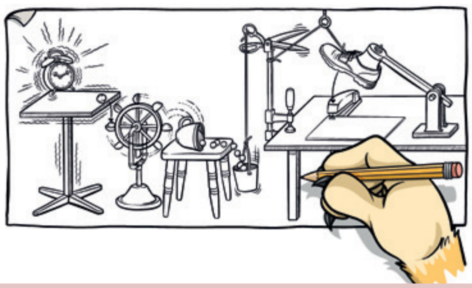
This offers the chance for learners to experiment with an iterative design process – trying ideas out, testing them watching to see if they fail or succeed, changing their design to improve it, testing again.

HOT TOPICS!

The concept of moments (and levers) relates to simple machines, such as pulleys. This links to Science and Design and Technology. You could ask learners to identify some simple machines – look for scissors, can openers, screwdrivers and even a doorstop/wedge for example. You could explore how levers work to make things easier to do, such as using a screwdriver to open a can of paint.

You could also link to art with work by Rube Goldberg or Heath Robinson. They designed machines that are sometimes described as over-complicated machines for completing simple tasks.

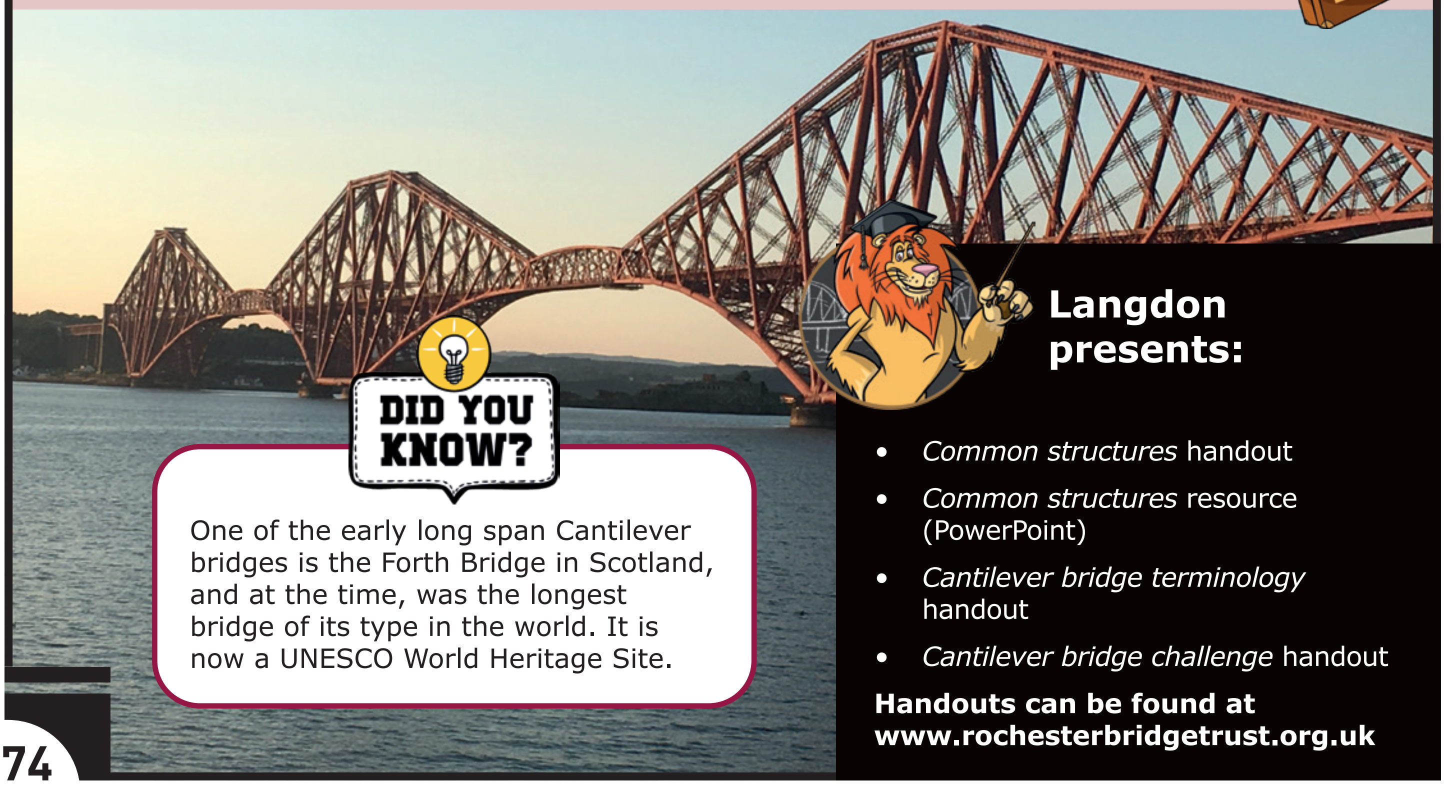
Could you build a cantilever bridge using biscuits or flapjacks? How could you counterbalance them?



There are lots of examples of these machines if you search for 'Rube Goldberg machines for kids', and many videos showing them in action.

You could design your own 'Rube Goldberg machine' to turn on a light, turn off an alarm, or to water a plant, or if you see any online, you could build a 'chain reaction' type process using your toys.

Can you spot any cantilevers? They don't have to be bridges, although we often use cantilever bridges for longer spans, as cantilevers can be found in all sorts of everyday objects! See how many you can find. Can you take a picture and explain how it works?



DID YOU KNOW?

One of the early long span Cantilever bridges is the Forth Bridge in Scotland, and at the time, was the longest bridge of its type in the world. It is now a UNESCO World Heritage Site.

Langdon presents:

- *Common structures* handout
- *Common structures* resource (PowerPoint)
- *Cantilever bridge terminology* handout
- *Cantilever bridge challenge* handout

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

Chapter Lii: Cantilever Bridges – The Tay Bridge Disaster

AIMS & OBJECTIVES

- To recognise some key features of cantilever bridges
- To apply a historical context to engineering
- To understand how environmental factors can play a role in engineering

CONTEXT

Cantilever bridges can span long distances, often over water, whilst carrying heavy loads. The Forth 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.

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

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.

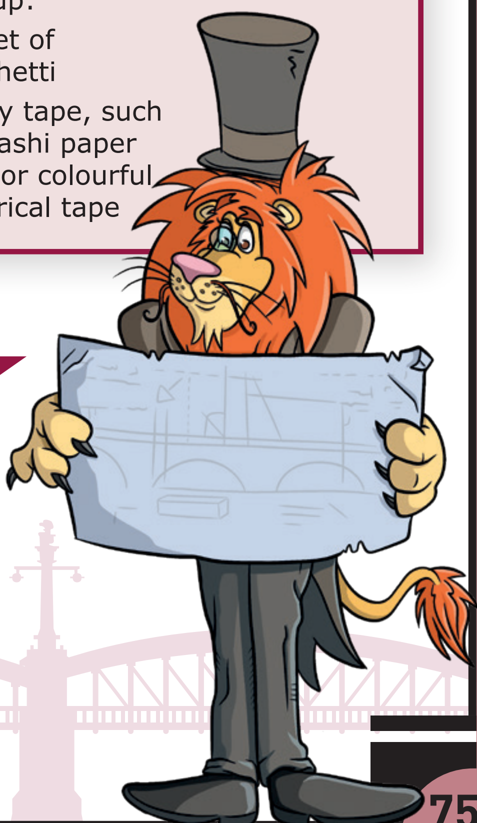
Compression: a force that tries to make things shorter or smaller (a squashing, pushing force).

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

You will need...

- Handout: *Spot the cantilever!*
- Resource: *Spot the cantilever!*
- Handout: *Tay and Forth rivers map*
- Handout: *Social Media Post*
- Per group:
  - Packet of spaghetti
  - Sticky tape, such as Washi paper tape or colourful electrical tape

Queen Victoria once said 'We will not have failure – we will have success and new learning': it may not have been that easy!



Something to Try:

Which ones are cantilevers?

Give groups copies of the various bridge images from the *Spot the cantilever!* resource and/or handout. Ask learners to see if they can identify which bridges are cantilevers and the common features of cantilever bridges.

BRIDGING THE RIVER TAY:

At the start of the Victorian era, there were few railway lines built in Scotland. Ask learners why they think this might have been a problem for people living in Scotland during this period.

Railway companies were eager to build more and more railway lines, to allow people and products to be moved across the country, following the industrial revolution. To compete with rail lines built from Glasgow that dominated north of the Tay, the North British Railway Company decided to bridge both the Tay and the Forth.

Show learners the Tay and Forth rivers map resource, showing the area around the River Tay (Firth of Tay). Ask them why a bridge might be useful.

This links back to Do we need bridges chapter in *Learning About Bridges Vol 1*.

Ask the learners to consider why a railway bridge might be more useful than a road or foot bridge, for example: they should consider it was during the Victorian era, after the Industrial revolution.

You might ask them to consider what type of bridge they might build, and where exactly, across the Tay they would build it. They might consider the span of the bridge required, depth/speed of the river flowing beneath it, where the bridge is more needed by the local population, for example.

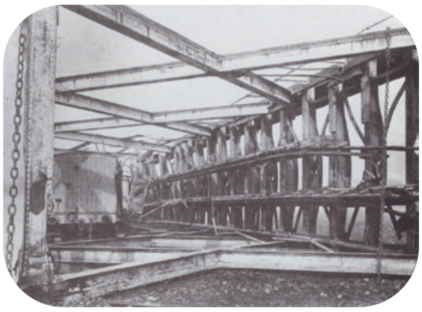
Sir Thomas Bouch

Sir Thomas Bouch was born on 25 February 1822. He became a well-known and renowned British engineer who developed the first roll-on/roll-off rail ferry (across the Forth). This saved railway companies lots of time as they didn't need to unload and reload the train carriages when the train arrived at the river, they could transfer the carriages to the ferry directly.

Bouch was highly regarded for his work on railways, using a lattice girder design for a number of bridges he designed. He was selected as engineer to cross the Tay and Forth rivers.

Bouch used his trusted lattice girder design and as shown in the photo, the lattice girders ran underneath the railway track, and then the track ran through the girders when the height of the bridge had to be raised in the centre, to allow ships to pass.

Photo from the National Library of Scotland via Wikimedia Commons



Photos from the National Library of Scotland via Wikimedia Commons

The bridge was supported on a total of 85 piers – the first 14 of which are brick and masonry, and although it was intended that the remaining piers be built in the same construction method, it was found that the bedrock was too deep (despite surveys that suggested the contrary), finding only gravel, and as such the piers were instead cast-iron columns braced with wrought iron struts and ties, mounted on a concrete base, so as to reduce the mass of the structure supported. The number of piers was also reduced, and the span between them in the central sections therefore increased. The bridge was opened on the 1st June 1878.

An internet search for Tay bridge disaster should produce some short Open University videos that explain what took place in the evening of 28th December 1879, only 6 months after the bridge was opened.

This is an illustration by an unknown author showing the search for passengers on the train.

The photographs are originals taken in 1879: apparently the images are incredibly high resolution, particularly notable for the time.

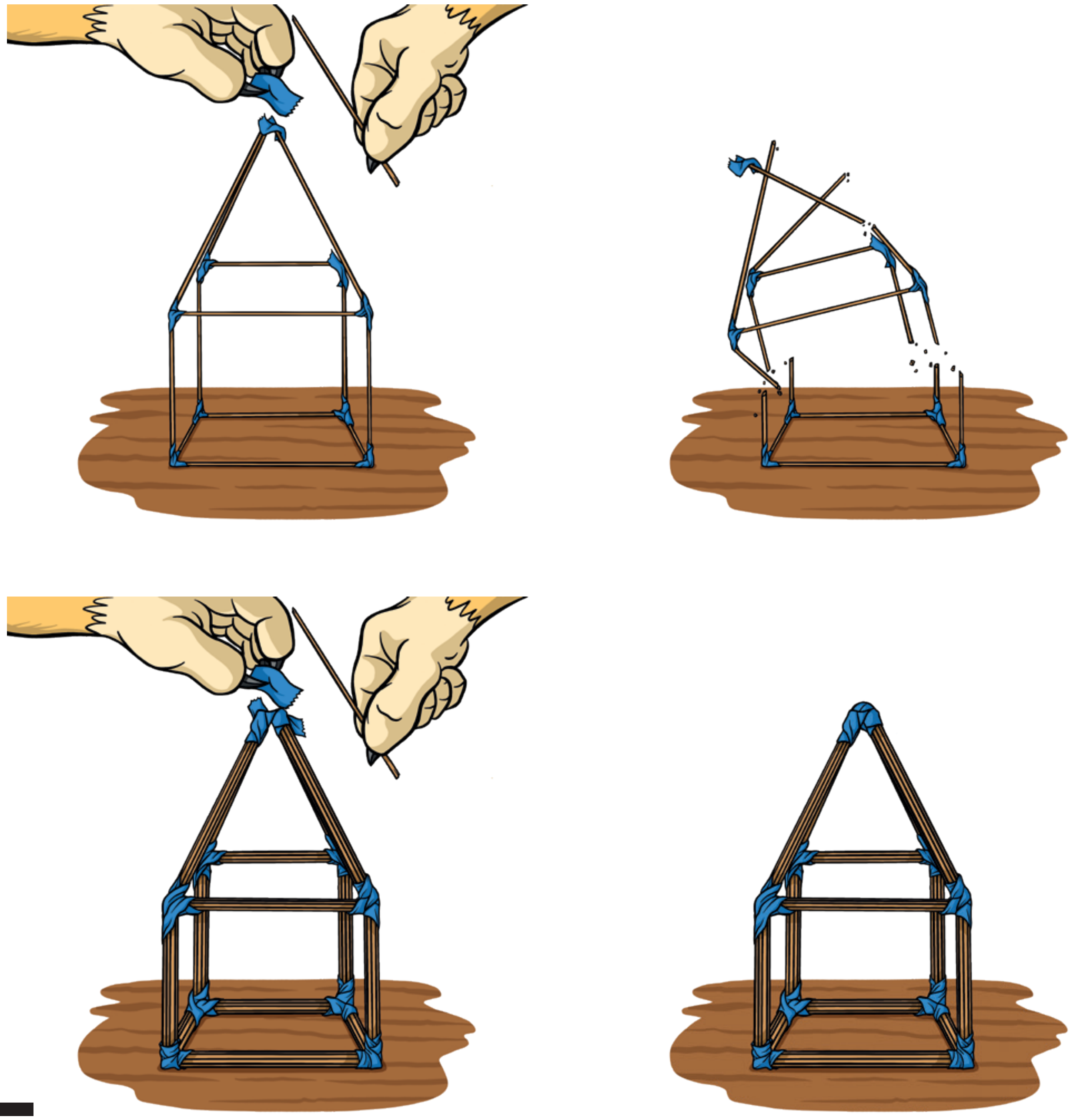
Various sources suggest the bridge was still there as the train approached, and it was the train on the bridge that caused the bridge to fail.

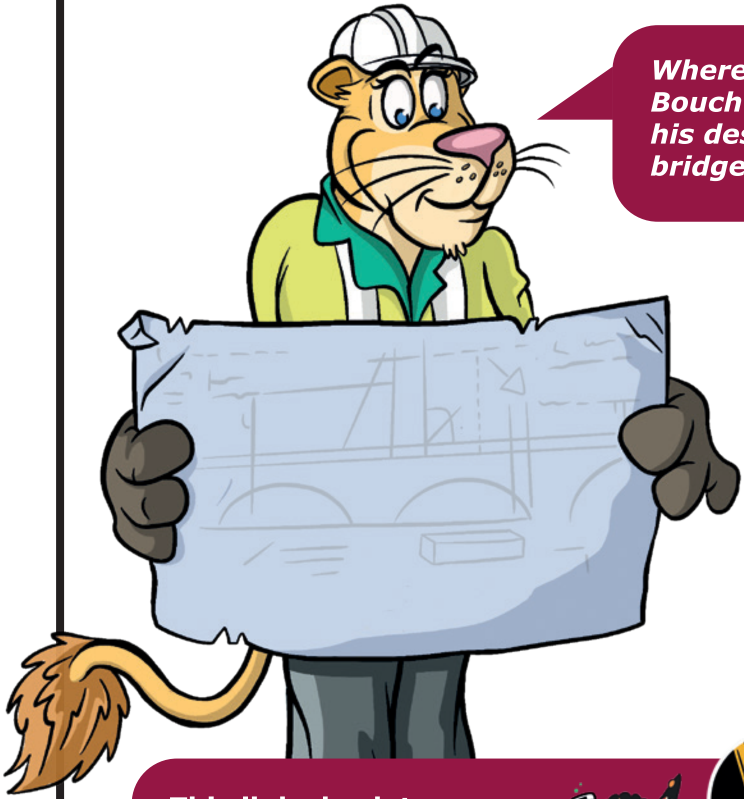
Using the *Social Media Post* Handout, challenge learners to write a post to explain the disaster as if the learners were there. What would they say? What do they think the response would be from people on social media if this happened now?

Challenge Time!

BOUCH'S TAY BRIDGE

Cast iron is a brittle material no longer used in modern constructions. Challenge learners to build a pier like those of Bouch's using just spaghetti and tape. Ask them to explore how tall and narrow they can make their towers. You can then test them to destruction! Learners will no doubt find spaghetti a very brittle difficult material to work with, and find it challenging to construct a strong, tall tower from.





Where did Thomas Bouch go wrong?

The following information is a summary of numerous sources and a number of the suggested reasons for the failure.

The Court of Inquiry found that Bouch's design was insufficient to withstand the wind – there were too few cross-bracings or fastenings.

It has been estimated that the gale that came in late that evening was a force 11. The bridge design had not been tested at such wind speeds.

Under such winds, the types of materials used also become a factor. It seems that cast iron bolts, not expected to be under tension in the structure, may have been under tension due to the movement of the bridge due to the high winds. If the cast iron bolts had been made of wrought iron, they would have been more able to withstand the forces caused by the loads on the bridge.

This links back to the Loads and Forces chapter in *Learning About Bridges Vol 1*.

SCIENCE LINK

Additionally, the design of the columns was altered to make them easier to build, making the fixings slightly weaker than usual. Therefore, as the wind, rain and loads of the trains acted on the bridge, the fixings couldn't withstand the forces. Photographs suggest that the cast iron column piers broke at these points.

Bouch had the reputation of building 'modestly priced' bridges and probably was under pressure, from this and his clients, to continue building the bridge cheaply, making decisions that kept the cost low but also may have weakened the bridge. This may have led to a rather hasty, poor quality build; girders which had accidentally been dropped into the (salt) water beneath were re-used, rather than replaced, the cast iron itself may have been of poor quality and joints poorly completed.

Additionally, the larger Edinburgh locomotive may have contributed to the bridge failure. An earlier train that was a smaller load on the bridge, with the same winds, had been seen to produce sparks as it crossed: these sparks are thought to be from the iron wheels rubbing against the lee (sheltered) side of the track as the train has been pushed over slightly. A larger train would have added a greater load to a weakened bridge, as well as provided greater resistance to the wind.

The fact that the initial surveys had been wrong about the depth of the bedrock, leading to the central piers being redesigned, may have also contributed to the weakness, and therefore reduced the load that the bridge could carry.

A worker maintaining the bridge had also given testimony to the Inquiry that a number of the ties had been working loose. Whether this was due to the design of the tie fixings alone (as mentioned earlier) or by the fact that the wind and/or movement of the train across the bridge had worked it loose, isn't known. However, it is clear that he carried out repair work by hammering small lengths of iron into the holes to ensure that the fastenings were tightened.

HOT TOPICS!

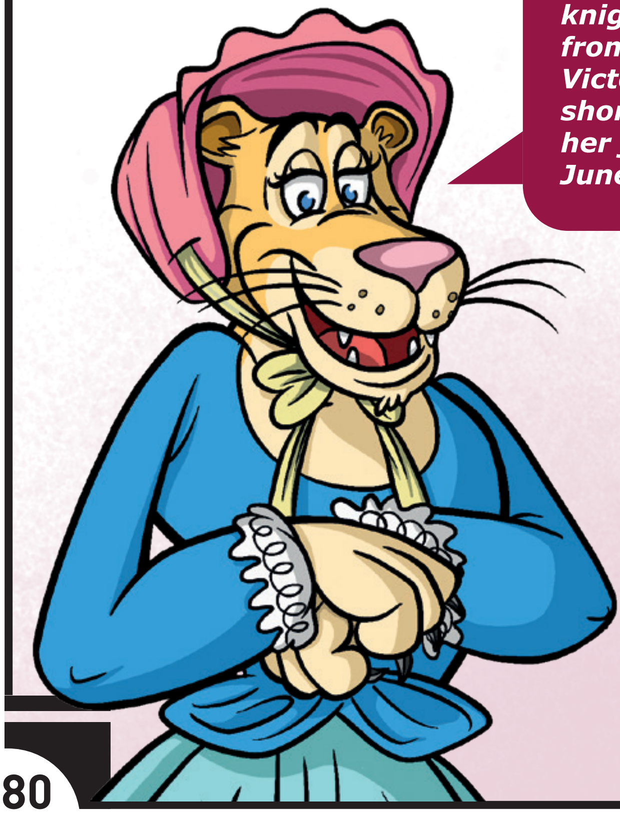
Leaners could write newspaper articles or present a news report on a factual or fictional bridge disaster.

Learners could research more about the industrial revolution and find out why more railway lines, canals and indeed bridges, needed to be built as a result.

You could try writing a poem about the Tay Bridge Disaster. William McGonagall, dubbed Scotland's 'best worst poet' wrote a poem about the Tay Bridge Disaster (if you search online, you may be able to find the poem itself and more information about William McGonagall himself).

Can you find out about any other accidents that have happened with bridges? What has happened to the bridge, why and when? It might be that a local bridge has been washed away in a flood, or had a vehicle drive into it…

There are some well-known bridges that are always getting crashed into on the internet – in fact, there is a bridge famous for the way trucks are always crashing into it because it is only 11ft 8 tall (about 3.5m tall, so a double decker bus is taller…) and videos appear on YouTube often (search for '11foot8 bridge' to find out more).



Thomas Bouch received his knighthood from Queen Victoria shortly after her journey in June 1879.

DID YOU KNOW?

Queen Victoria crossed the Tay Bridge just a year after it was opened, on her way south from Balmoral. Not long after that, in December 1879, it collapsed.

Langdon presents:

- *Spot the cantilever!* handout
- *Spot the cantilever!* resource
- *Tay and Forth rivers map* handout
- *Social Media Post* handout

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

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.

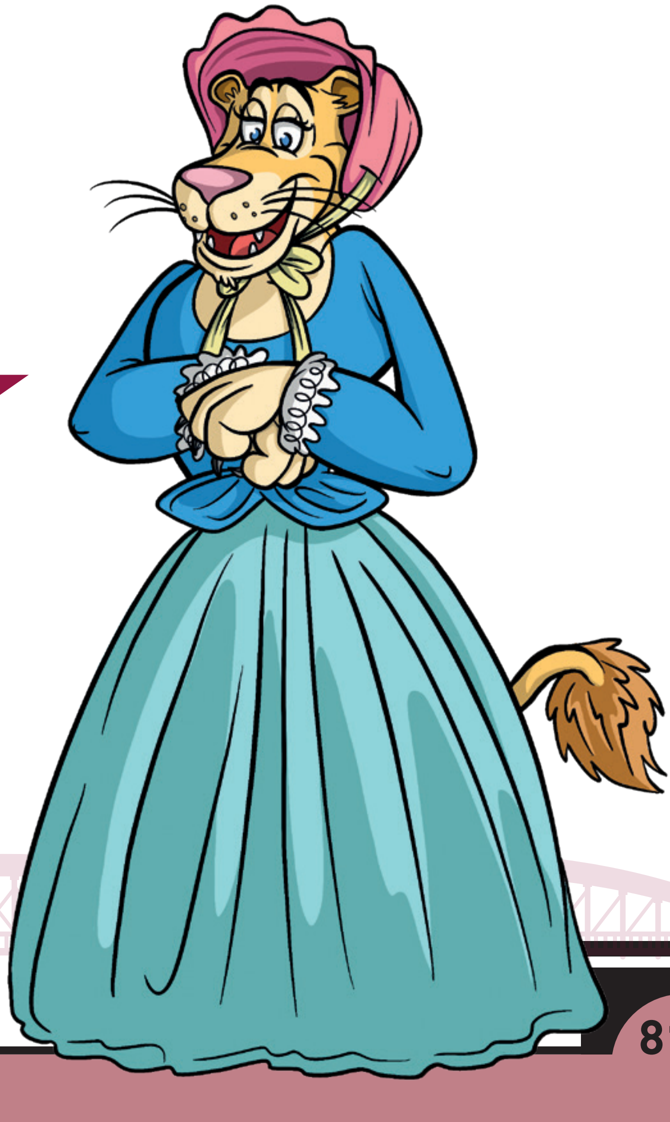
LANGUAGE OF BRIDGES:

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.

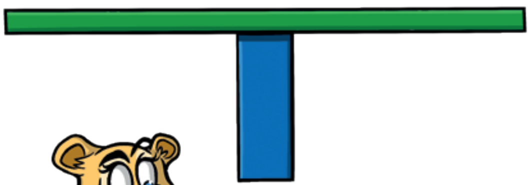
Benjamin Baker's design was a cantilever bridge. In *Chapter Li: Cantilever Bridges – Introduction*, learners were introduced to the idea of levers and balancing forces to construct a cantilever bridge.

LINK

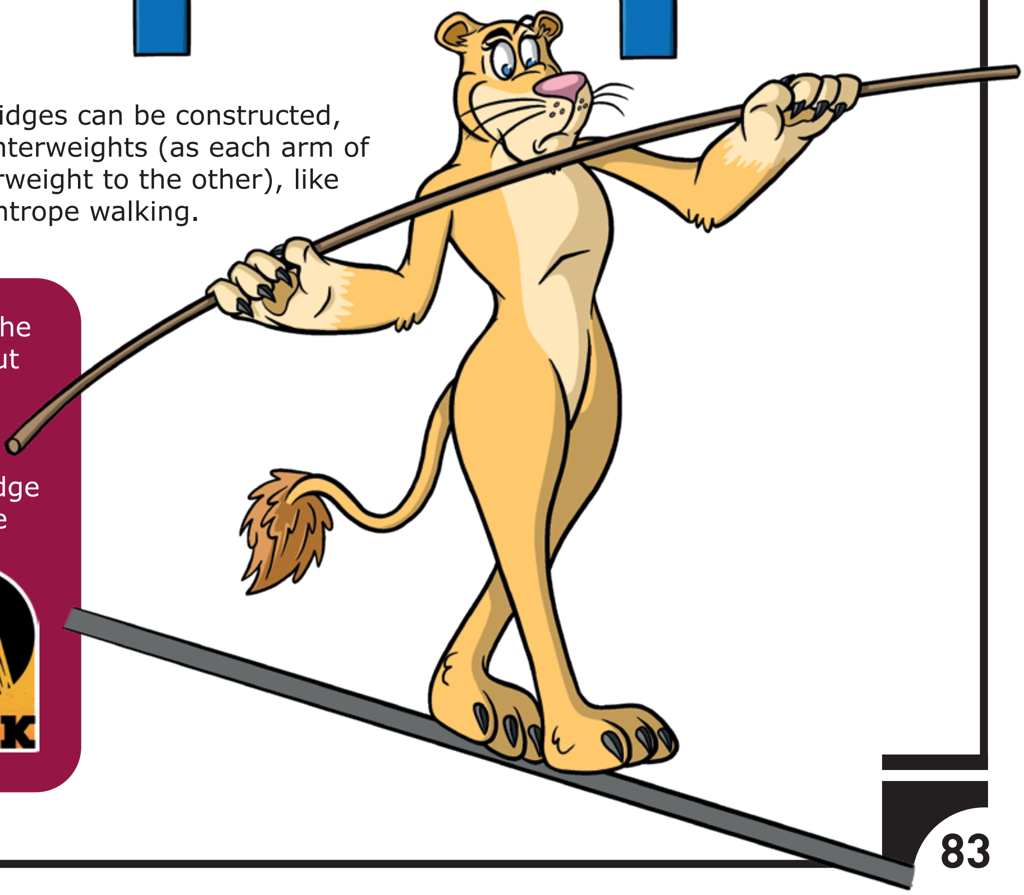
Remind learners of what a cantilever is using a ruler. Ask them where does a ruler need to be for it to balance on your finger? They should recognise that it needs to be in the middle. Ask them to try to balance a ruler near one of it's ends: what do they need to do to get the ruler to balance this time?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

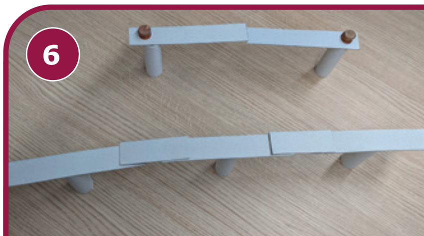
Take three more cardboard tubes and place these 20cm apart.

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.

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.

6



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

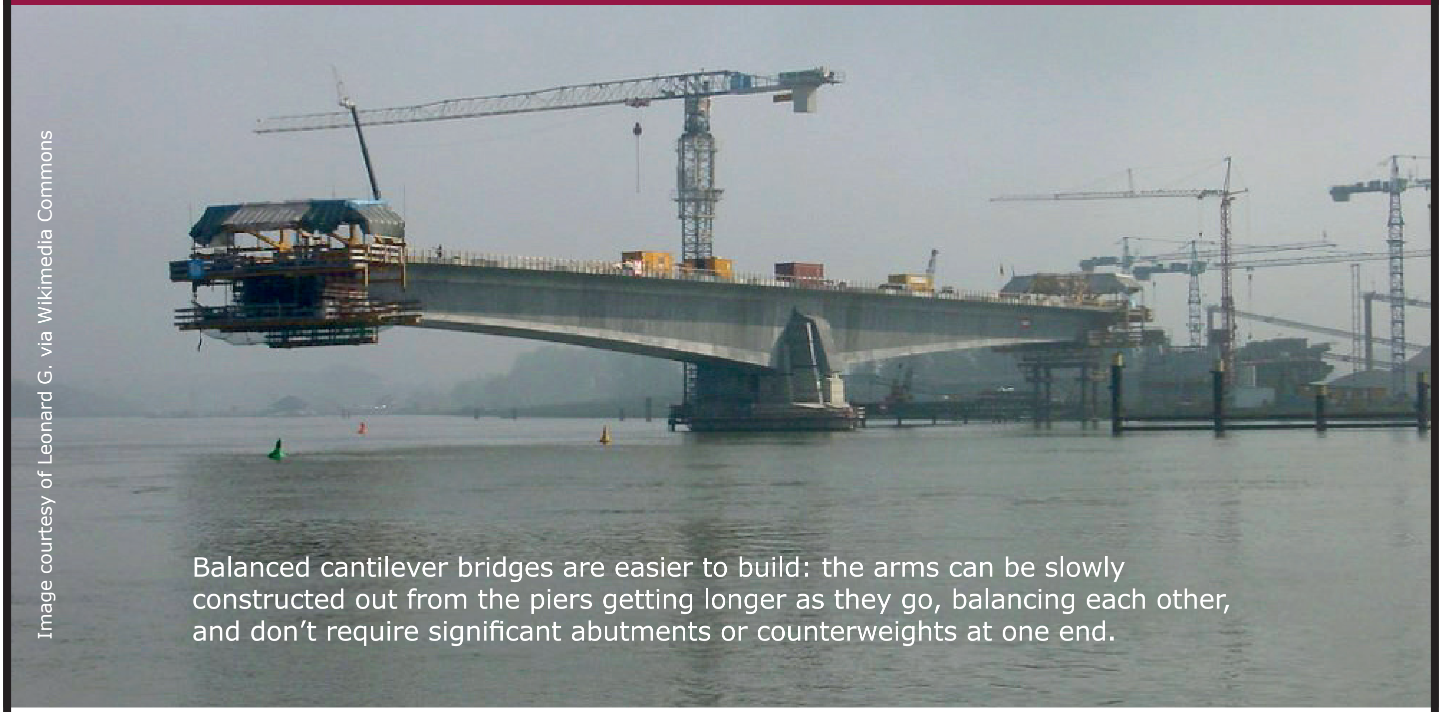


Image courtesy of Leonard G. via Wikimedia Commons

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.

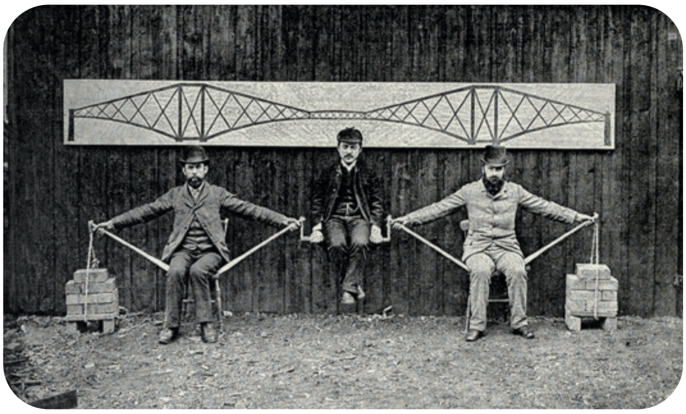


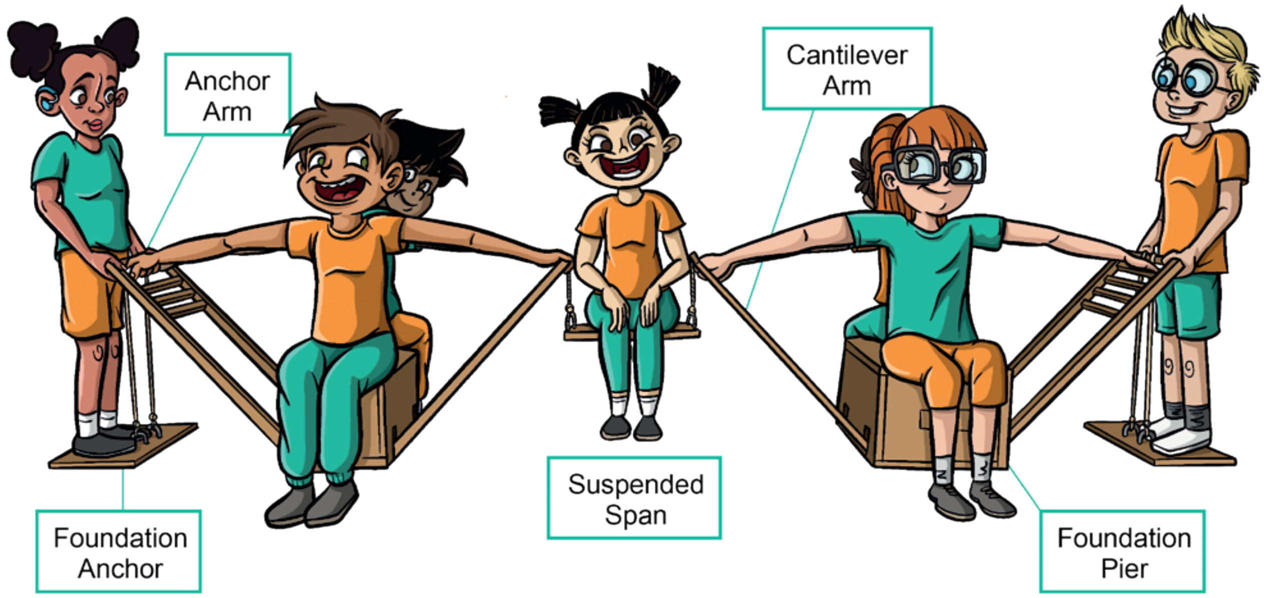
Image courtesy of Wikimedia Commons

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.

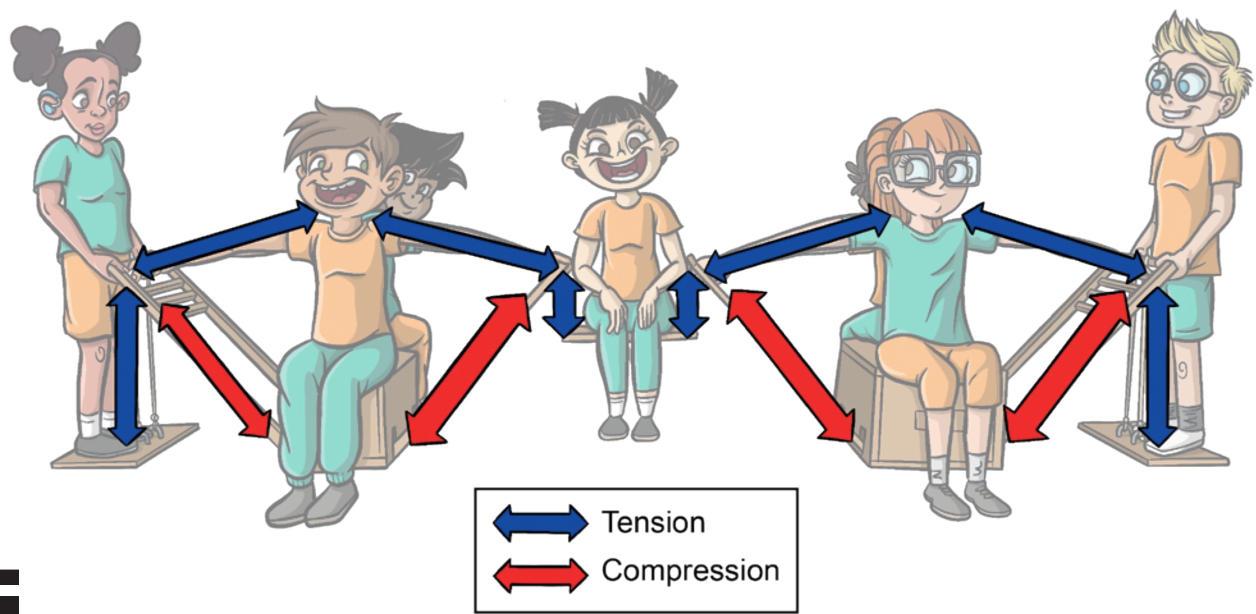
Note the scale diagram of the Forth Rail Bridge – Sir Benjamin Baker drew it to the same size as his demonstration to directly relate the model to the structure design.

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

Glossary

Abutment: the structure that the ends of the bridge rests and can be anchored by.

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

Aesthetics: This is about how something looks. If a bridge is primarily designed to be aesthetically pleasing, the engineers are more concerned with how it looks. It may be the public and the architects who view the appearance of the bridge as of equal importance to how it works.

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

Anchor: acts to secure the bridge to the ground.

Arch: semi-circular curved structure.

A-Shaped Pylon: pylon that looks like the letter A when viewed from the end of the bridge, as it has two upright members that meet at the top.

Baltimore Truss: a type of truss bridge developed in the 1870s in Baltimore, USA. It is mainly used for railway bridges.

Bascule Bridge: Bascule is a French word meaning to tip over or seesaw. Bascule bridges move up and down vertically in an arc shape.

Beam: the simplest form of bridge, consisting of a single span resting on abutments.

Bowstring Truss: this is the form of truss used in the Rochester Old Bridge, patented in 1841 by Squire Whipple.

Bridge: a structure that goes over an obstacle to carry or support something else.

Cable-stayed bridge: bridge where the cables attach directly to the towers or pylons at an angle.

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

Cast iron: iron with more carbon and other impurities mixed in, and then shaped using a cast, or mould, whilst hot.

Cement: a fine power that hardens when water is added and used as the binding material in concrete. It is most commonly 'Portland Cement', produced by heating limestone and clay in a kiln, and then adding gypsum.

Centring: the temporary structure originally used by the Romans to support the arch during construction.

Chemical weathering: the weathering of materials due to chemicals – including rain water which is slightly acidic due to carbon dioxide from the atmosphere being dissolved in it.

Civil engineering: the type of engineering that helps shape the world around us, helping to design bridges, tunnels, railways, roadways, as well, as constructing skyscrapers, dams, power stations, airports and sports stadiums.

Client: This the generic name for the people or organisation who have asked for a job to be done. In this session, it is the organisation who has asked for some moving bridge solutions.

Cofferdam: a temporary box, built in the water, from which the water is removed, leaving a dry space for building.

Column Pylon: single vertical pylon.

Composite: a material made from two or more different materials combined together.

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

Concrete: a construction material that could be described as 'artificial rock' made up of fine and coarse aggregates, such as sand or gravel, and cement.

Corrosion: the chemical change in metal due to environmental factors.

Corrugated: folded into small furrows or ridges.

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

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

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

Elevation: In a technical drawing, this is the view from the side. This view is used on engineering plans to show how a bridge design will look from the side, almost as if you're standing in a boat on the water, looking at the bridge over the span of the river.

Engineering design process: the process engineers use to describe the steps taken to move from a question, idea or need, to designing the product or process required.

Engineering habits of mind: a concept developed to characterise the range of skills usually found in those people that think like an engineer.

Fan shaped cables: cables that are attached to the pylon at the same point, or very nearly, but attach at further intervals on the deck, creating a triangular shape that resembles a traditional hand-fan.

Frequency: number of waves per second.

Functionality: This is about how something works. If a bridge is primarily designed to be functional, the engineers are more concerned with how it works.

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

Harp shaped cables: cables that are attached to the pylon and the deck at regular intervals, so they run parallel to each other.

Hinge: a fold that allows movement to swing open and closed from that point.

Howe Truss: a type of truss bridge patented in 1840 by Millwright William Howe.

H-Shaped Pylon: pylon that looks like the letter H when viewed from the end of the bridge, as it has two upright members and a horizontal member between them.

Inverse Y Shaped Pylon: pylon that looks like the letter Y upside down, when viewed from the end of the bridge, as it has two upright members angled to meet at a point, and continues vertically up as a single column.

Iron ore: a type of rock found in the Earth's crust from which iron can be extracted: when the iron ore is heated to a very high temperature with charcoal, iron is produced.

Iron triangle of engineering: a way of showing how three factors in engineering projects affect each other.

Iron: a type of metal, and one of the most commonly found in the Earth's crust, found in iron ore.

Keystone: the most important, wedge-shaped stone in the very centre of the arch.

Lamination: the process of gluing very thin layers of material together, such as wood, to form a much thicker piece, which can be bent or shaped more easily than a similar single piece of wood.

Lifting Bridge: This moves the bridge up, above the river like a lift. They tend to have towers on either side that the bridge moves between on its way up and down.

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

Longitudinal: running lengthwise, along the material, not across it.

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

Maintenance requirements / to maintain: This is a list of things that are needed to keep the bridge looked after once it has been built, so it is still safe and lasts a long time.

Mortar: a clay-based type of 'glue' used to stick the stones together in an arch.

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

Pedestrian: a person walking, rather than travelling in a vehicle, and for bridges, can refer to a bridge made solely for people to walk across, or for part of the deck that people are able to walk safely across (for example, the pavement).

Physical weathering: the effect of temperature change on materials, causing them to break apart over time.

Piers: the upright columns that support a bridge.

Pile-driver: a large weight at the end of a rope, used by Romans to drive the piles in the river bed. There are modern-day versions of this to drive in sheet piles.

Piles: the large logs with sharpened ends used by Romans to make cofferdams.

Plan view: In a technical drawing, this is the view from above or a bird's-eye view. This view is used in maps and on engineering plans for a new bridge design, showing how the bridge and landscape look from above.

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

Pratt Truss: This is a bridge type found commonly in the USA, that was patented in 1844 by Thomas and Caleb Pratt.

Pylon: the tower or vertical part of the bridge to which the cables are attached.

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

Rust: a particular form of corrosion or chemical weathering, when iron metal reacts with oxygen in the air in the presence of water, forming an oxide which is red in colour.

Shear: a sliding force which occurs when an object is being pulled in two different directions.

Sheet Piles: modern versions of piles, made of steel and shaped into a specific 'M' shape.

Span: the distance the bridge, or a part of the bridge, covers.

Steel: another iron and carbon mixture, although much less carbon than either wrought or cast iron, which means it is much easier to shape and is stronger.

Suspension bridge: bridge in which the deck is hung from main cables on vertical hangers.

Swing Bridge: This moves horizontally from side to side or around a central pivot to open and close the bridge.

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

Thermal expansion: the change in a material (getting longer, deeper, wider) as a result of heating.

Torsion: a twisting force. This is caused when either end of the object is being moved in opposite directions.

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.

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

Truss: a bridge designed with lots of triangle shapes.

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

Voussoir: the special wedge-shaped pieces used in stone arches.

Warren Truss: patented in 1848 by its designer James Warren.

Weathering: the breakdown of materials as a result of the weather, such as rainwater or temperature changes.

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

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

Wrought iron: iron mixed with a very small amount of another element, called carbon. It is heated and 'worked', by being squashed and beaten over and over again, by a blacksmith.

Further Resources

At the Rochester Bridge Trust we often tell people about our free education resources because we believe they are a great way to introduce children to engineering in the real world. And because they are free, even if they aren't for your child or class, you've nothing to lose by giving them a try!

However, we fully admit there's more to engineering education than our resources can offer. We also appreciate it's not always easy to find resources when there are so many other topics and ideas clamouring for your attention.

So, we've drawn up a couple of shopping lists to help. While these are not exhaustive lists, we believe they are a good start for the development of equipment libraries for schools, youth groups and at home. Each leaves plenty of scope for adding your own ideas to create bespoke collections for your setting. The kits are similar or the same as equipment we use to run our own hands-on activities for children. These are great for encouraging children to put classroom learning into practice without even realising it.

The book list aims to encourage wider reading among children of all ages. Some of the books directly identify engineering principles, whereas others incorporate the applications of engineering through the narratives or themes of the story.

The lists contain a broad range of resources to give people the opportunity to select the things that are most suited to their audience. We also appreciate that the costs of these items add up. To help with this, grants are available from the Trust for the purchase of materials for use in STEM learning activities run by school and community groups.

You can find out more about these grants, view the regularly updated lists and download individual chapters from this book at **www.rochesterbridgetrust.org.uk**

Scan for the resources:

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