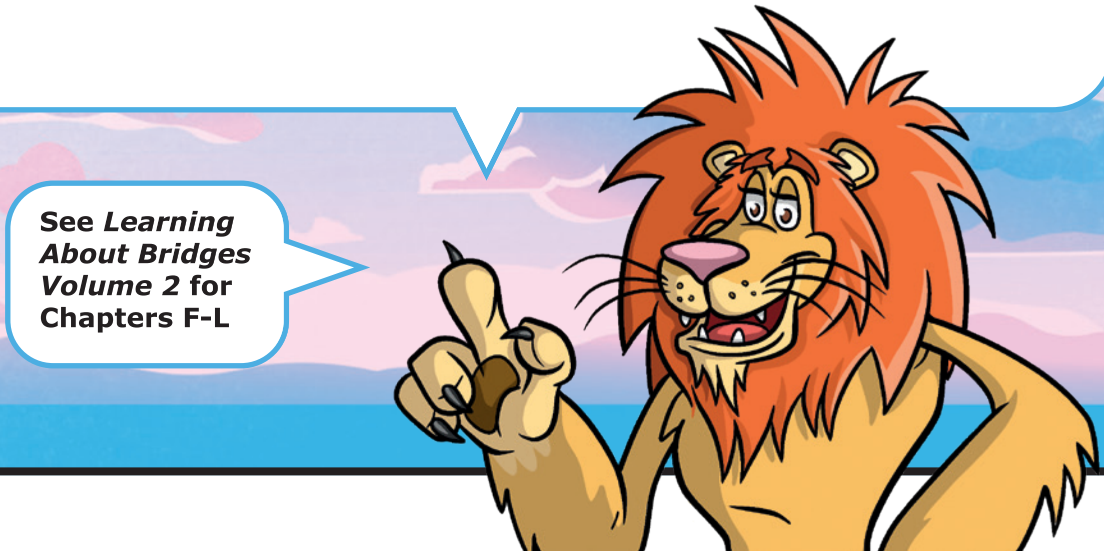
ROCHESTER
BRIDGE TRUST

Learning About Bridges

VOLUME 1


See *Learning About Bridges Volume 2* for Chapters F-L

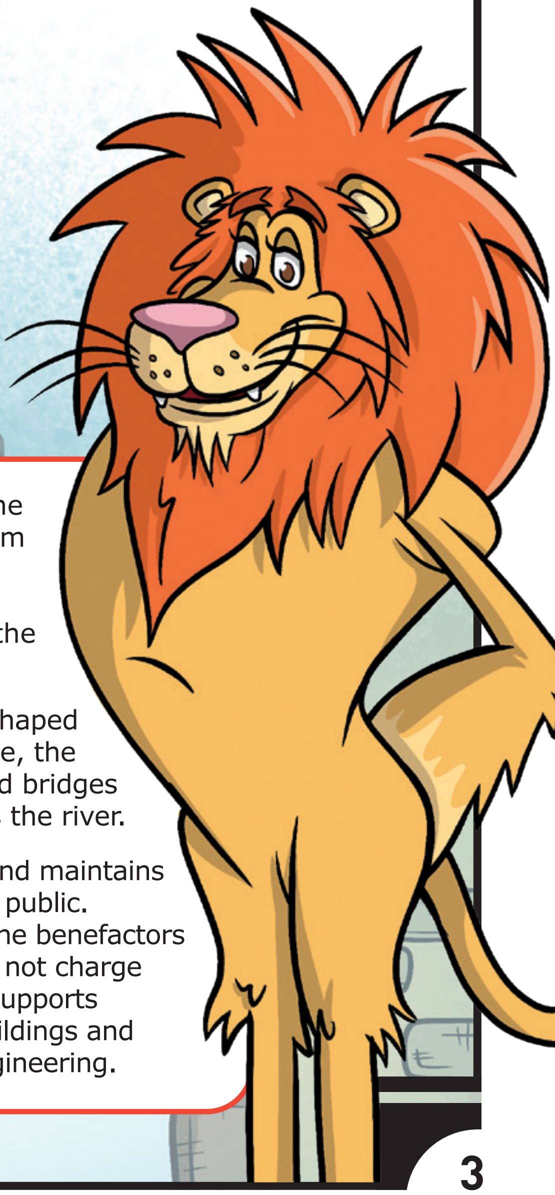
About The Rochester Bridge Trust

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 Langdon the Lion, guardian of Rochester Bridge. Welcome to my book Learning about Bridges! 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 4 FUN

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 mascot, Langdon the Lion, 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.

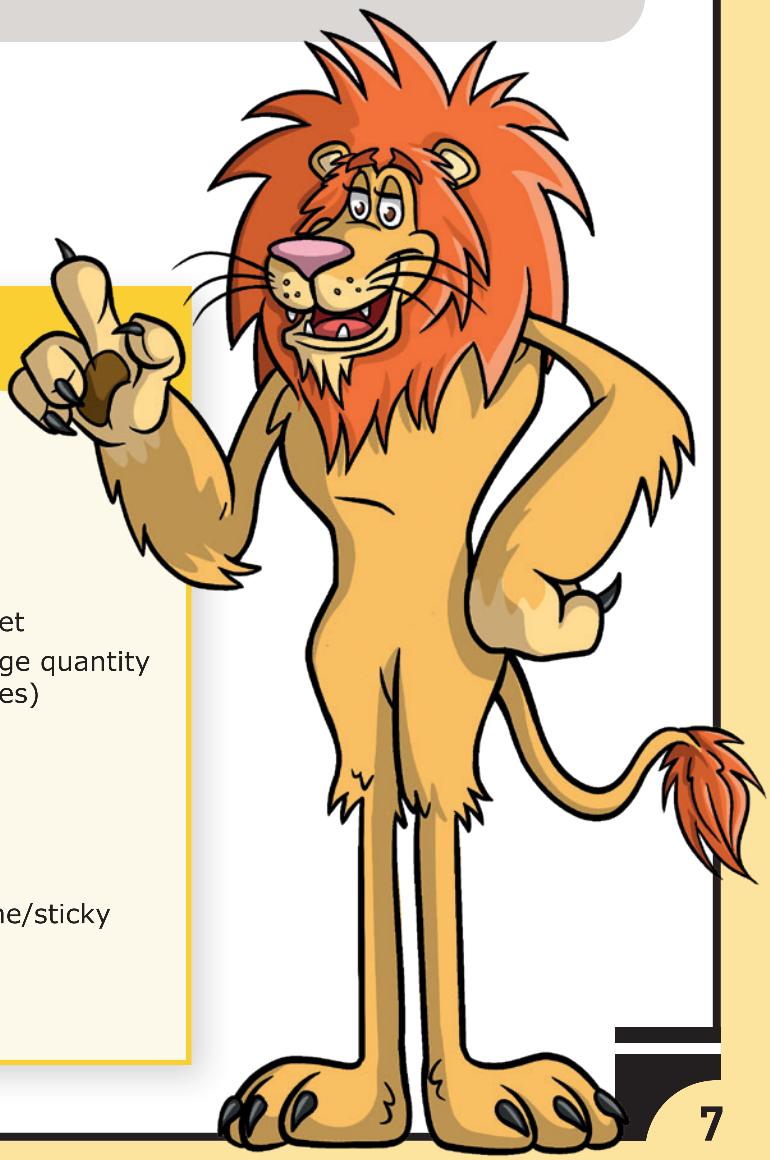
Iron triangle of engineering: a way of showing how three factors in engineering projects affect each other.

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…

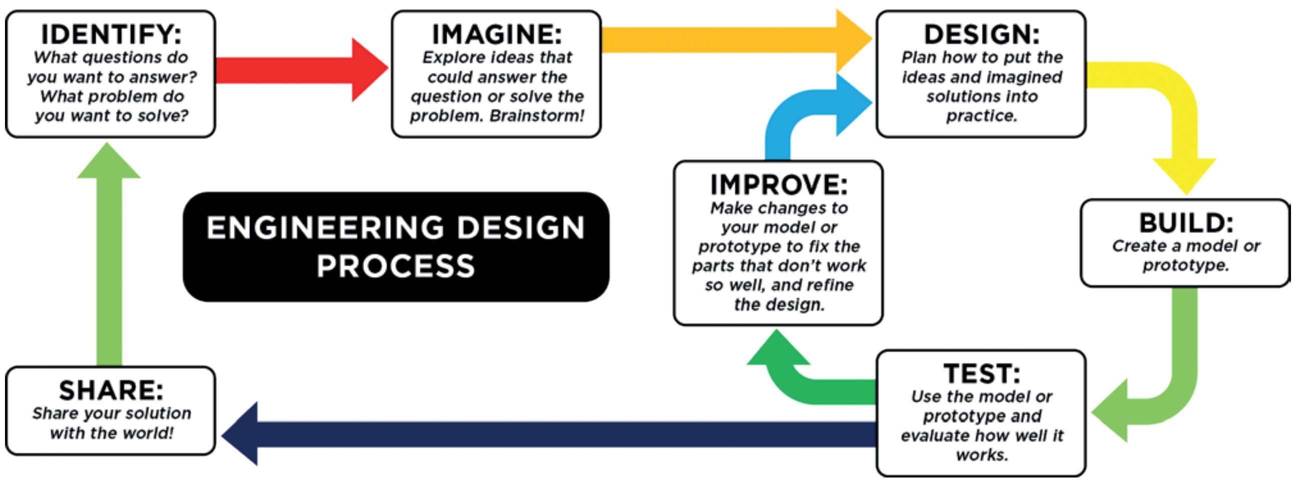
Civil engineers help shape our environment – they have links to material, structural and energy engineers. Civil engineers help design and build bridges, tunnels, railways and various other smaller scale projects, such as drains or sea walls, among others.

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'.



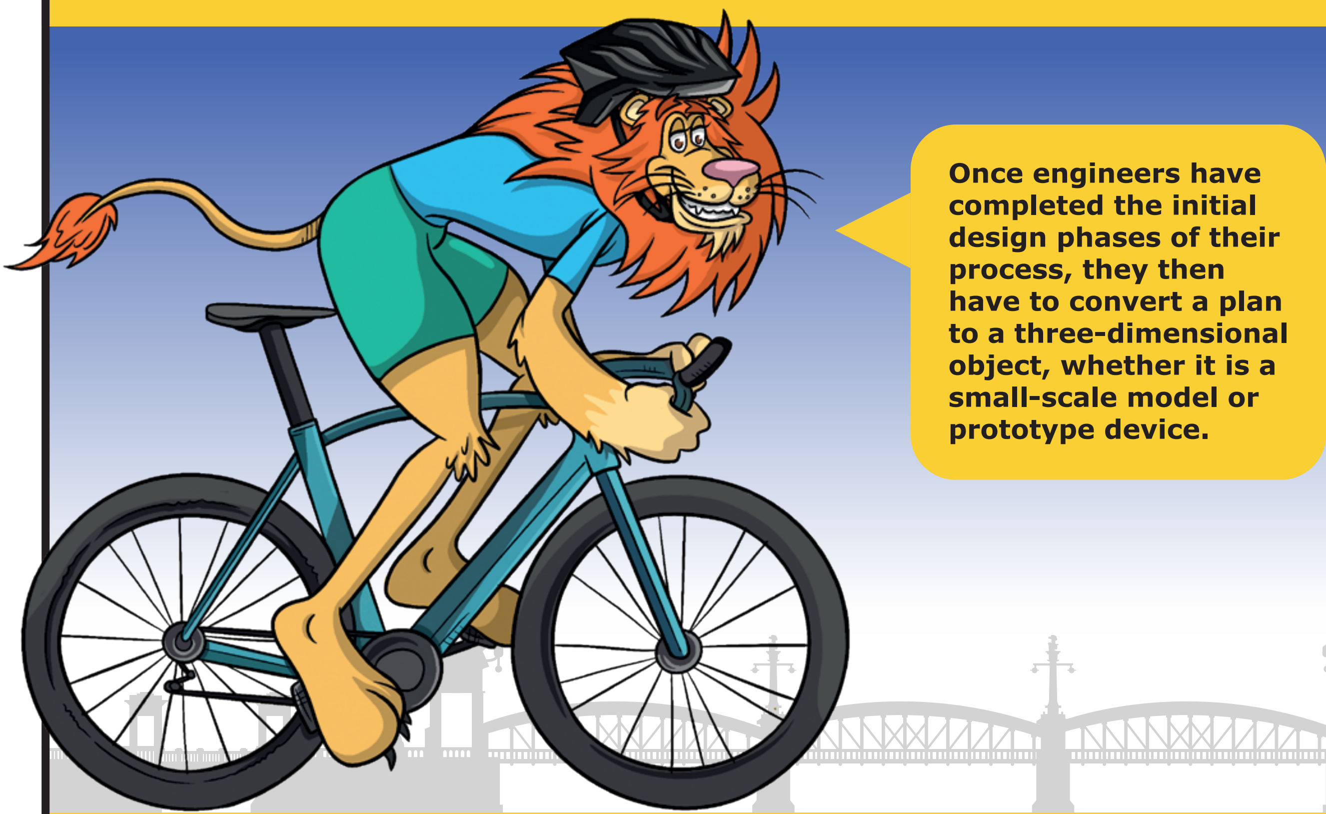
It starts with someone asking a question. This identifies the problem or the constraints of the engineering project. Then engineers start to imagine possible solutions, and start to design and plan their project, gathering research and brainstorming ideas. Once an engineer has a plan, they can start 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?

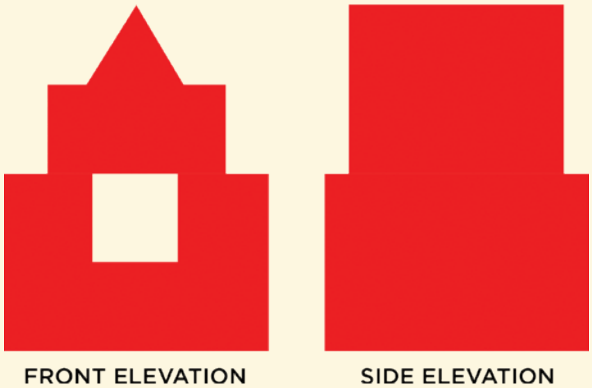
In this activity, imagine you are a civil engineer trying to plan a crossing. Bridges are built to fit the environment around them. The specific bridge cannot be built anywhere else because bridges are individually designed to match the need in that one place and the specific challenges associated with 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.

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.

Photo by Sid Saxena on Unsplash

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.

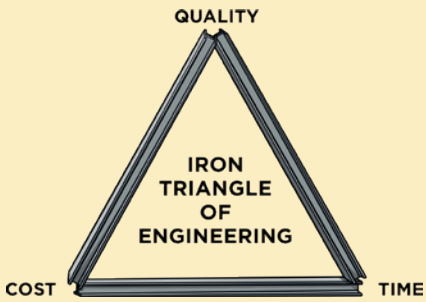
After all the designs have been tested and re-designed as necessary, ask learners to consider the main difficulties they faced during the process and how they overcame them? Did all groups have the same challenges? If the design basically worked the first time/test, were there ways to improve it? For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

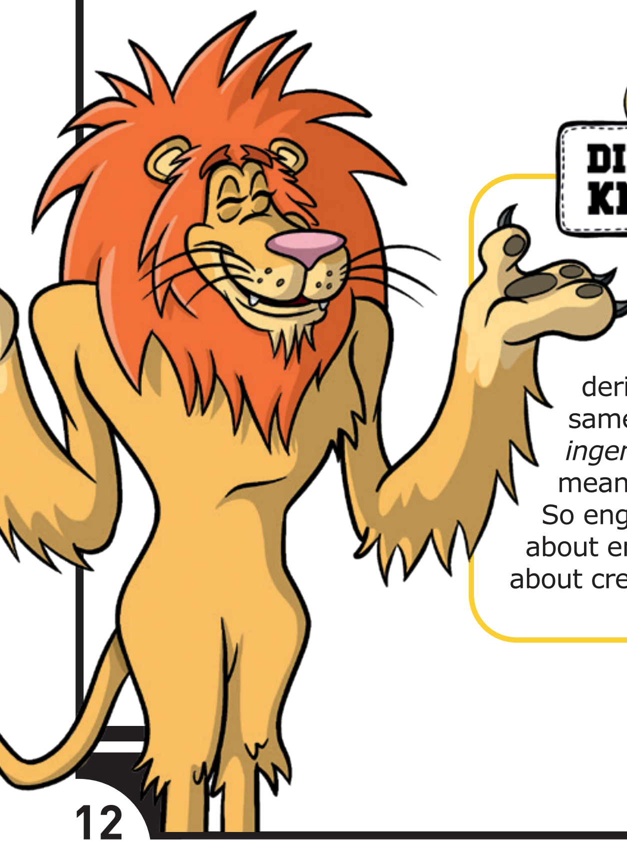
This links to building a template for concrete bars from nets in *Learning About Bridges Chapter Aiii: Materials – Cuboid net* handout.

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?* Handout
- *Design Challenge* handout
- *Standing on the shoulders of giants* handout

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

Chapter Ai: Do we need Bridges?

AIMS & OBJECTIVES

- To understand what makes a bridge
- To consider why we need bridges
- To discuss reasons for bridges being where they are

CONTEXT

Bridges are vital to our way of life. Bridges are unique to their location. Understanding how bridges fail is an important part of learning how to make them stronger.

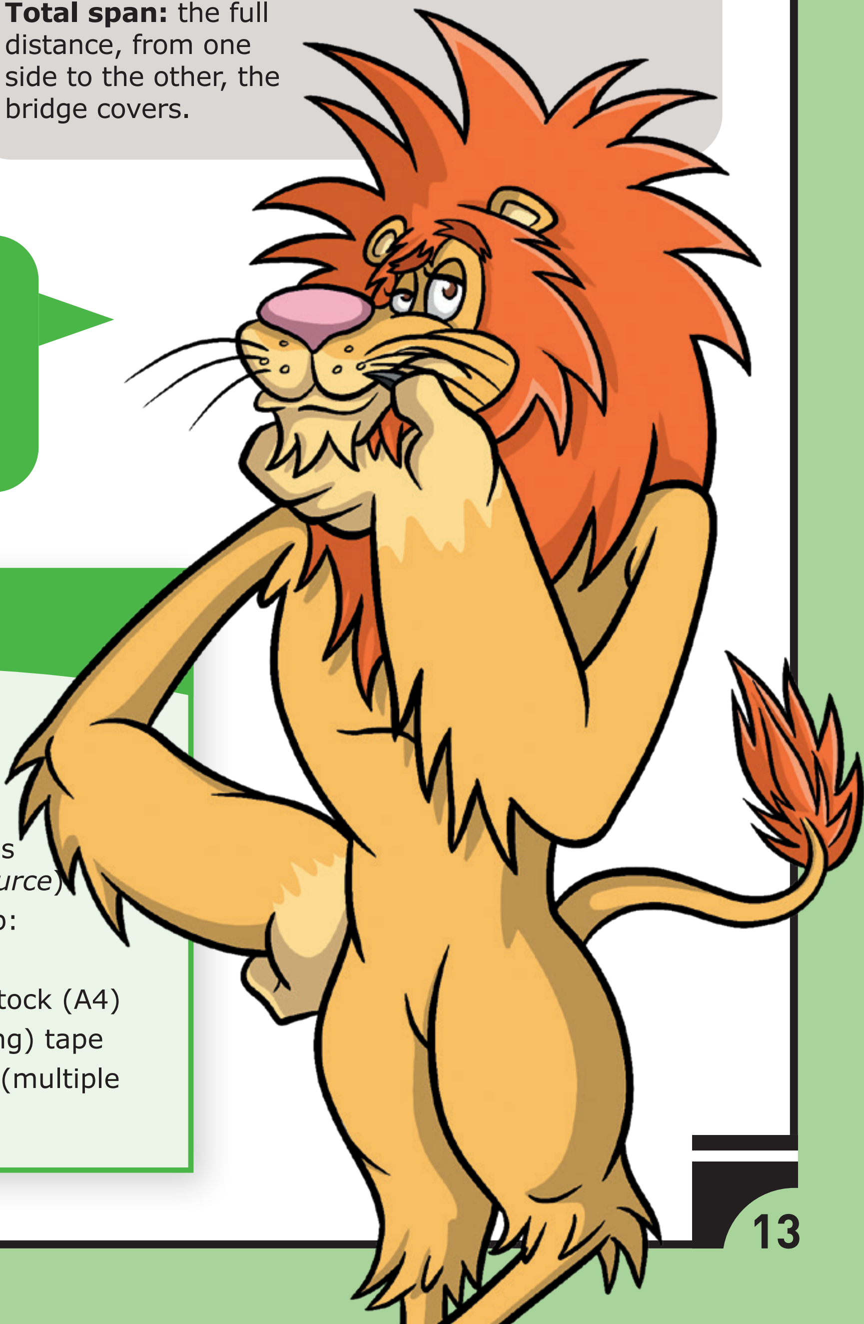
LANGUAGE OF BRIDGES:

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

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).

Span: the distance between bridge supports.

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

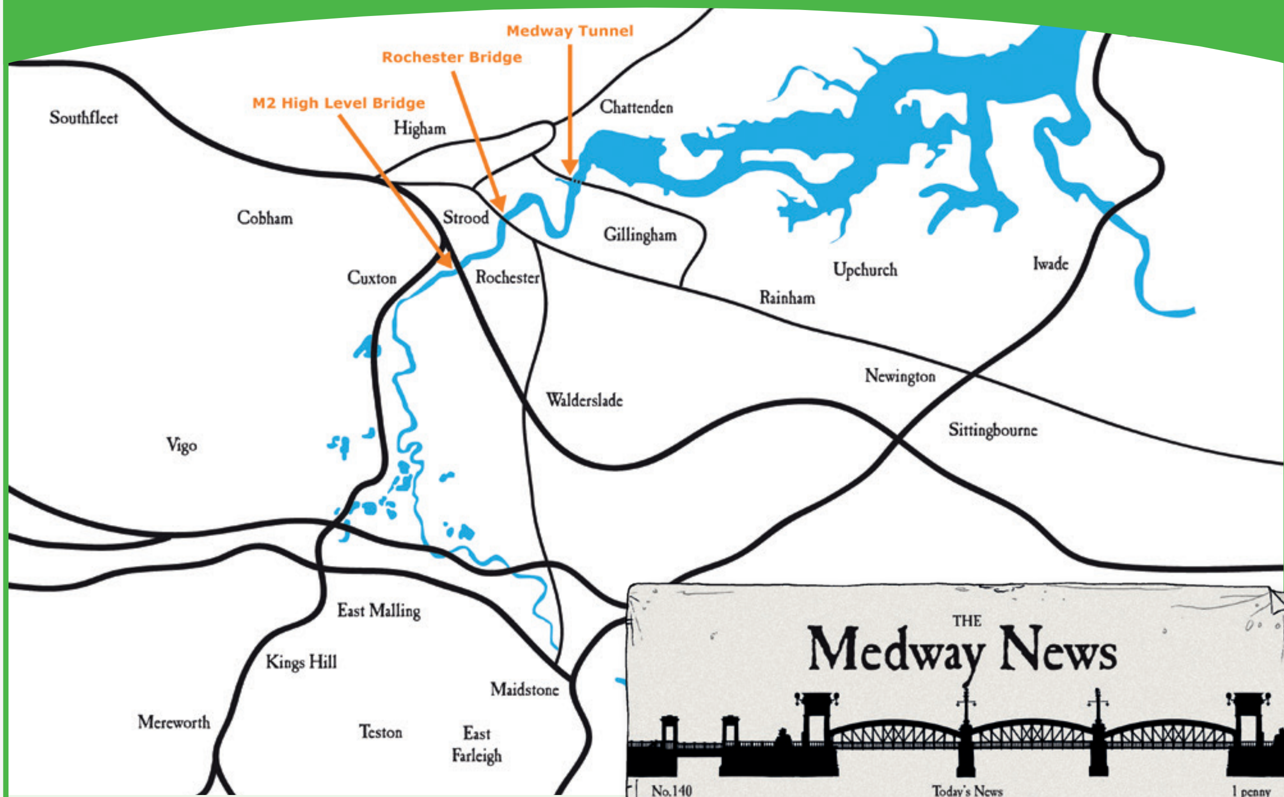


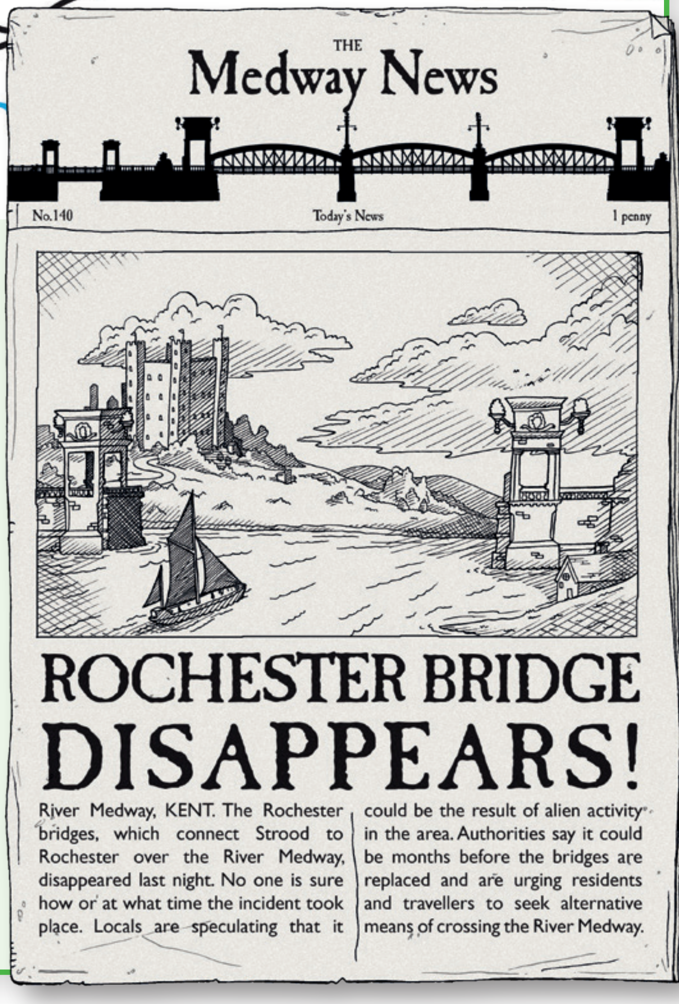
You will need...

- Handout: *Map of the River Medway*
- Handout: *Newsflash!*
- Map of your local area
- Selection of images of different types of bridges (*Classifying Bridges Resource*)
- Bridge Building Challenge, per group:
  - 30 paper art straws
  - 1 piece of thick paper/thin card stock (A4)
  - Roll of Washi (paper-based crafting) tape
  - Masses such as coins or washers (multiple per group) for testing

Something to Try:

Look at the *Map of the River Medway* handout showing the Medway Tunnel, Rochester Bridge, M2 high level motorway bridge and towns.





THE Medway News

No.140 Today's News 1 penny

ROCHESTER BRIDGE DISAPPEARS!

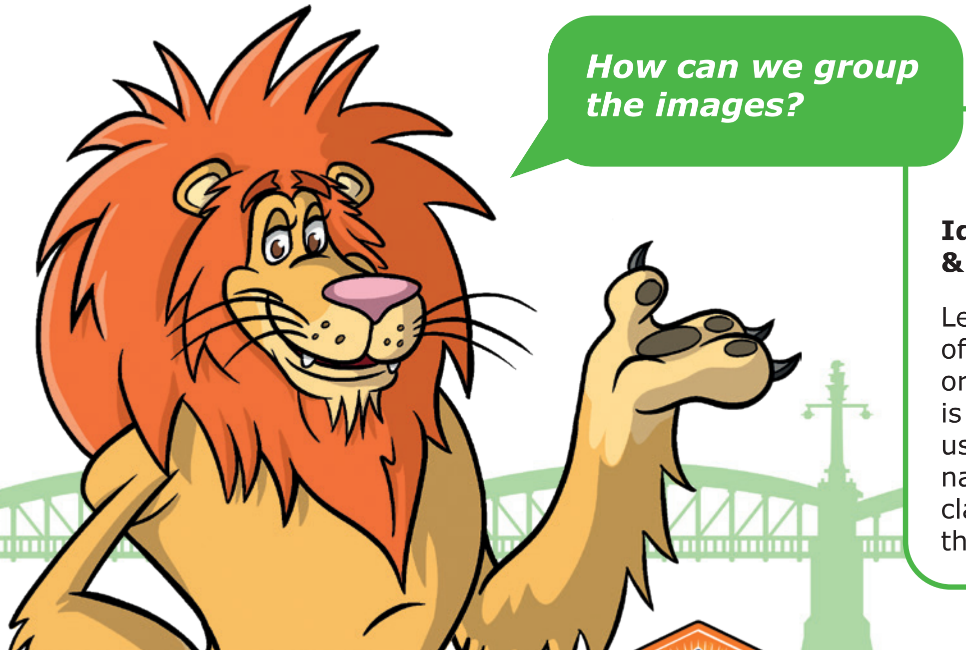
River Medway, KENT. The Rochester bridges, which connect Strood to Rochester over the River Medway, disappeared last night. No one is sure how or at what time the incident took place. Locals are speculating that it could be the result of alien activity in the area. Authorities say it could be months before the bridges are replaced and are urging residents and travellers to seek alternative means of crossing the River Medway.

Talk about all the places that learners might visit if they live locally, and using the *Newsflash!* handout, discuss the outcomes if the Rochester Bridge disappeared overnight.

If you live outside of Medway, try using a map of a more local river, and highlight the different towns and crossings around it.

CLASSIFYING BRIDGES

Give learners various bridge images; you can use the *Classifying bridges* resource. Give groups copies from the various bridge images, each one numbered. There are 60 different images to choose from – you do not need to use all 60 images, simply select a few depending on your particular circumstances. Ask learners to physically group the bridge images, or to write down the numbers of the bridges that they consider go together. When they have done this, ask them to classify each set, for example, "this set of bridges is made of stone", or "these are all road bridges". Ask each group to share their thoughts with the whole group. They can repeat the classification step a number of times, asking learners to classify the bridges in a different way. You might ask them to draw Venn diagrams to categorise their groups.

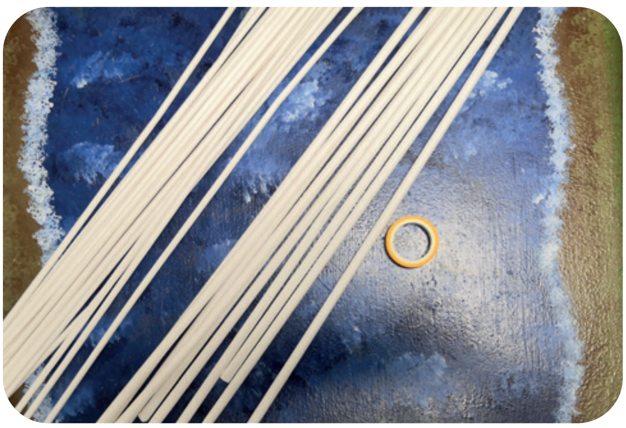


Identifying, classifying & grouping

Learners make sense of how the world is organised. Identification is the process of using differences to name something and classification is organising things into groups.

Challenge Time!

Give each group the art straws, card and 1 roll of tape. Challenge them to build a bridge with the largest capacity, to carry the heaviest load. The gap they have to span should be slightly narrower than the length of the straws – in the picture, we used 40cm straws of two different diameters (6mm and 4mm diameters) and a gap of about 35cm.



To test the bridge, use small masses such as coins or washers which you can balance on the structure, enabling you to identify the bridge that holds the most items and is therefore the winner. In the event of a tie, perhaps choose the one that actually holds the greatest mass or has the most aesthetically pleasing design.

HOT TOPICS!

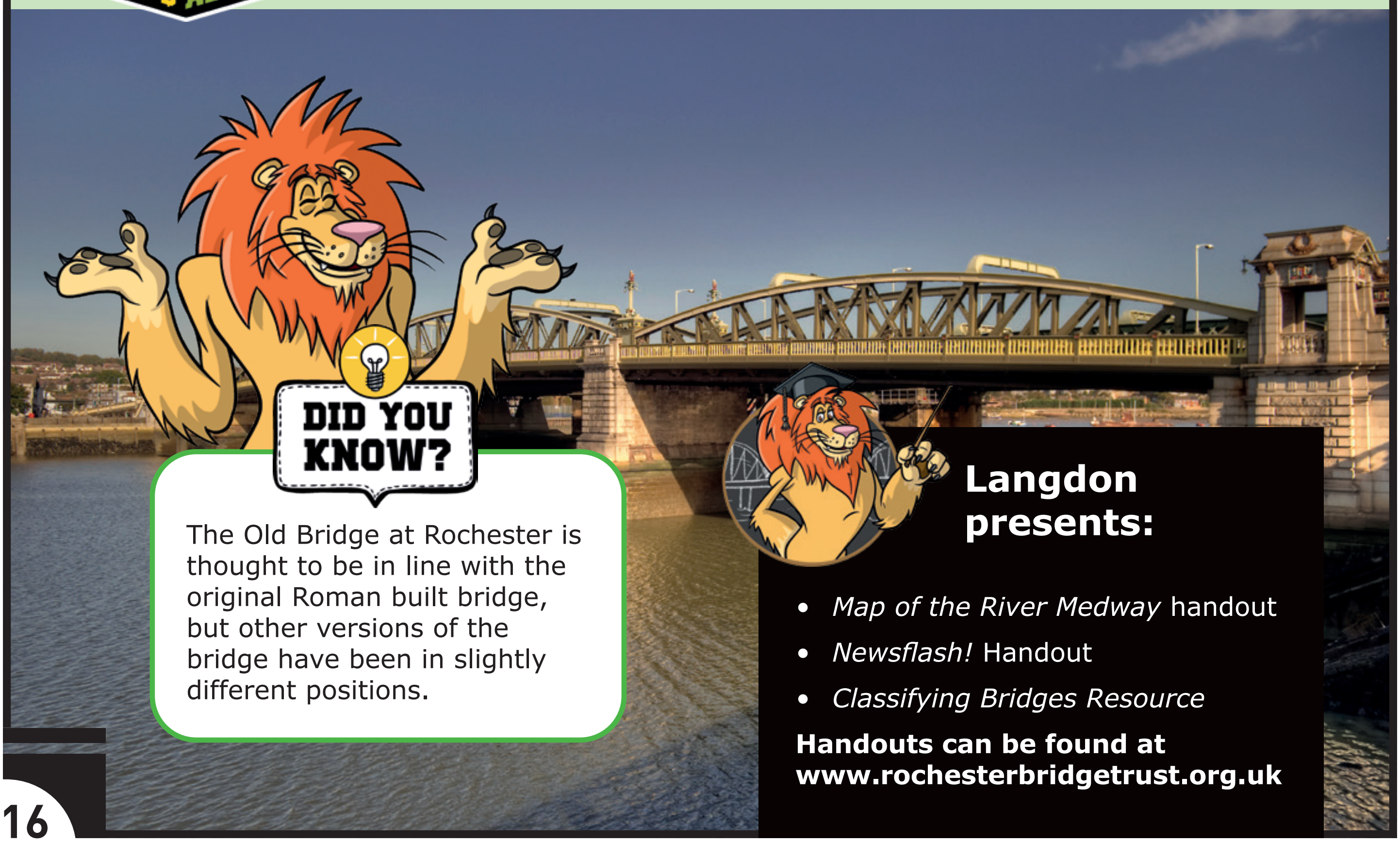
You could write a news article or blog about the disappearance of a bridge. It could be Rochester Bridge, another bridge local to you, or a famous bridge such as Tower Bridge or the Golden Gate bridge. You could think about the disappearance as a result of alien activity, as per the handout, or by a Master Villain as in the film Despicable Me.

Just 4 Fun

Bridges are featured in lots of stories and nursery rhymes – such as London Bridge is falling down and The Three Billy Goats Gruff. How many more can you find? Could you build a junk model of a bridge from a fairy tale or song, using anything you have lying around?

OUT & ABOUT

Can you spot any bridges near where you live?
What is it going over, and what is using the bridge?



DID YOU KNOW?

The Old Bridge at Rochester is thought to be in line with the original Roman built bridge, but other versions of the bridge have been in slightly different positions.

Langdon presents:

- *Map of the River Medway* handout
- *Newsflash!* Handout
- *Classifying Bridges Resource*

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

Chapter Aii: Loads and Forces

AIMS & OBJECTIVES

- To understand the forces that act in bridges
- To recognise and describe tension and compression
- To show that forces must be balanced for a bridge to stand up

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 bridge to stay standing and functional, the forces and loads exerted on it and within it must be balanced.

LANGUAGE OF BRIDGES:

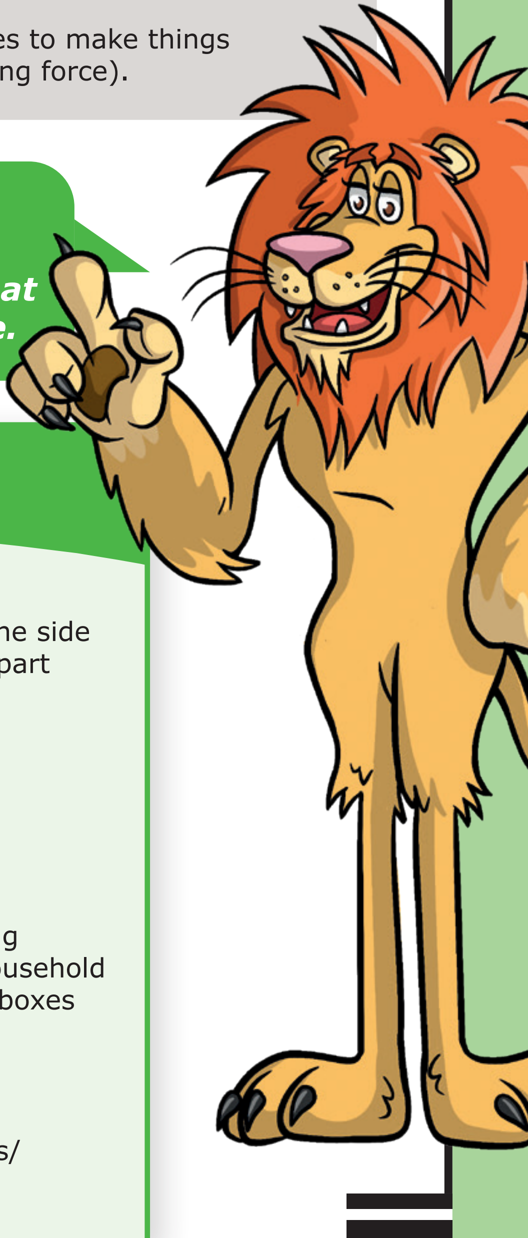
Compression: a force that tries to make things shorter or smaller (a squashing, pushing force).

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

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

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

Here, we will start thinking about the loads and forces that act on every bridge.



You will need...

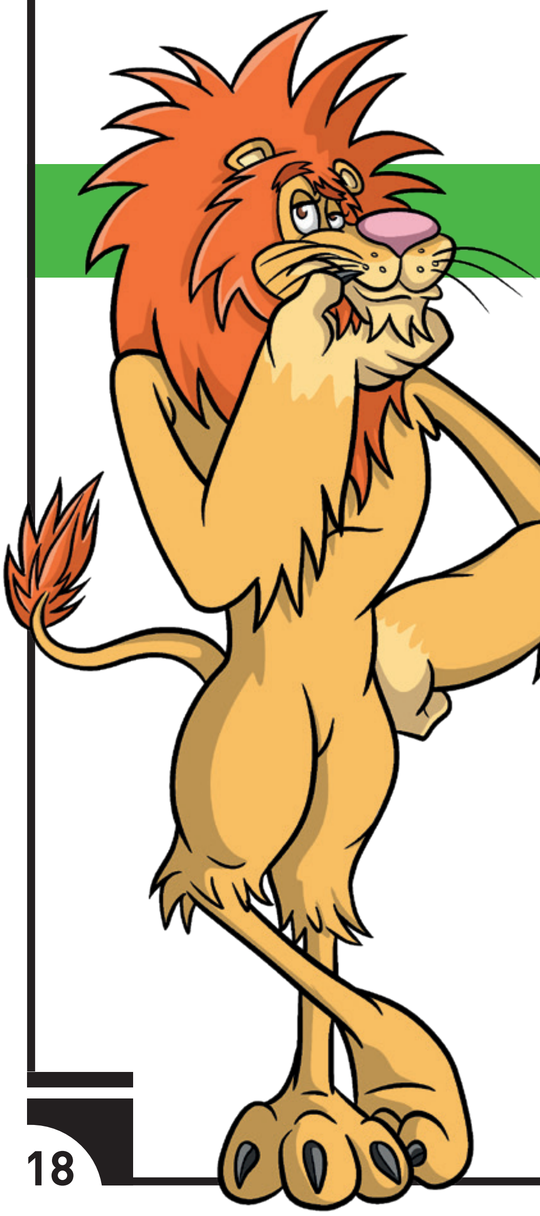
- Slinky spring
- Large sponge (such as used for car cleaning), marked along the side with a marker pen, with vertical lines, approximately 2.5cm apart

Photo by Adam Valstar on Unsplash

- Bridge pier 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*
  - Range of craft building materials, such as household recycling, cardboard boxes and tubes, string
  - Sticky tape
  - Ruler
  - Weights, such as nuts/ washers, thin books

Something to Try:

In the introductory session, we started thinking about why people might need bridges.This picture shows a simple bridge, strong enough to hold up its own weight. The weight of the bridge is called the dead load. This is because once the bridge is built, the dead load stays the same and does not move about.

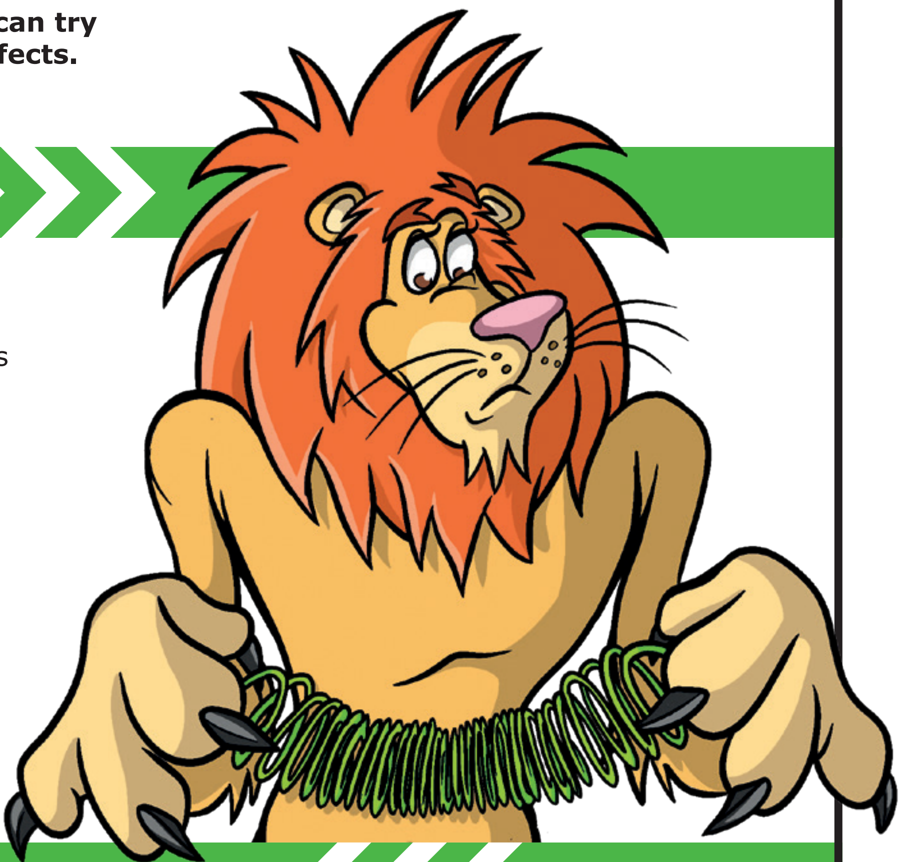


As the person walks across, what do you think happens to the bridge?

The live load, whatever the bridge is carrying, moves and changes constantly.

These loads cause forces inside the bridge.

Here are a series of activities you can try to demonstrate forces and their effects.



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.

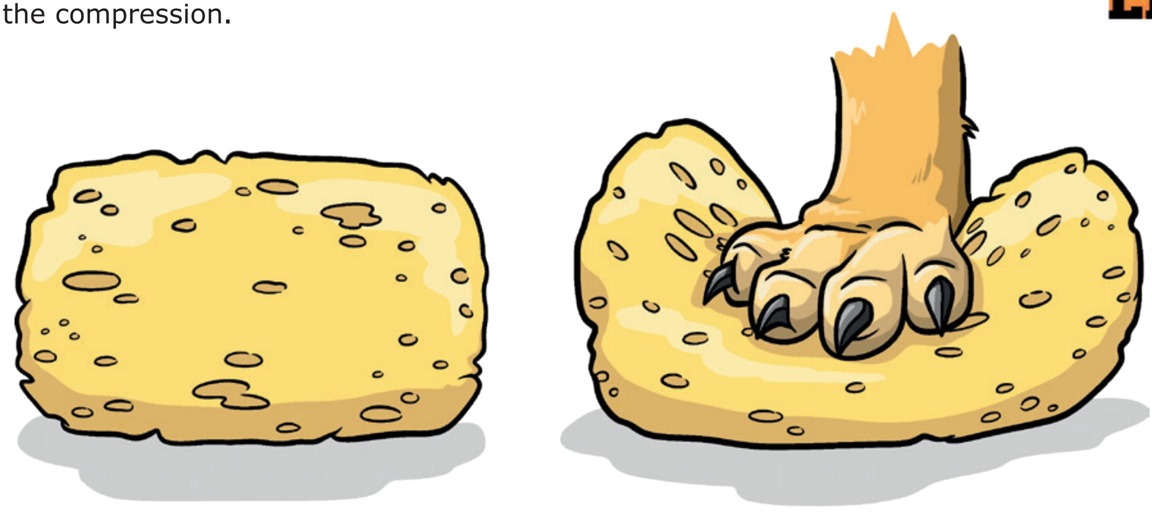
Ask the learners to hold hands in pairs and pull. Feel the tension.

COMPRESSION

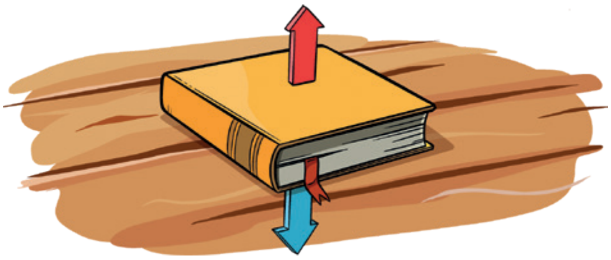
Using the marked-up sponge, push down hard. This force is compression, which always tries to make things shorter or smaller. Think of it as a squashing force. The lines on the sponge help demonstrate the effect of the force: you should notice that as the force is applied, the lines get closer together, 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 *Chapter Bi Beam Bridges, Simple but Strong*.

LINK

Ask the learners, in pairs, to put palms of hands together and push. Feel the compression.



Place a large book on the desk. It is at rest because the gravitational force – the force that pulls objects towards the centre of the Earth – pulls down on it as much as the table pushes up on it. The forces are balanced.



Push the book horizontally across the table. The book moves across the table. It is no longer at rest because the forces are not in balance any more.

How do we get the forces balanced again? Either push with an equal force in the opposite direction; or

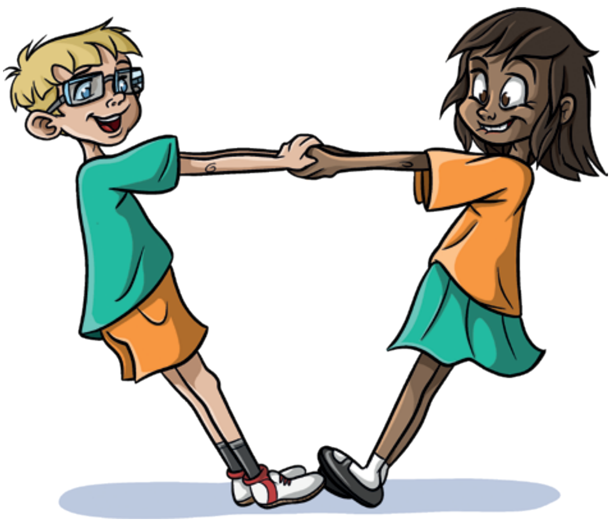
apply a pulling force in the opposite direction to the push (taking care not to allow the book to rotate).

Ask the learners to stand up in pairs facing each other with palms together to form a human bridge. Ask them to feel how much they need to push to make their bridge balanced, strong and steady.

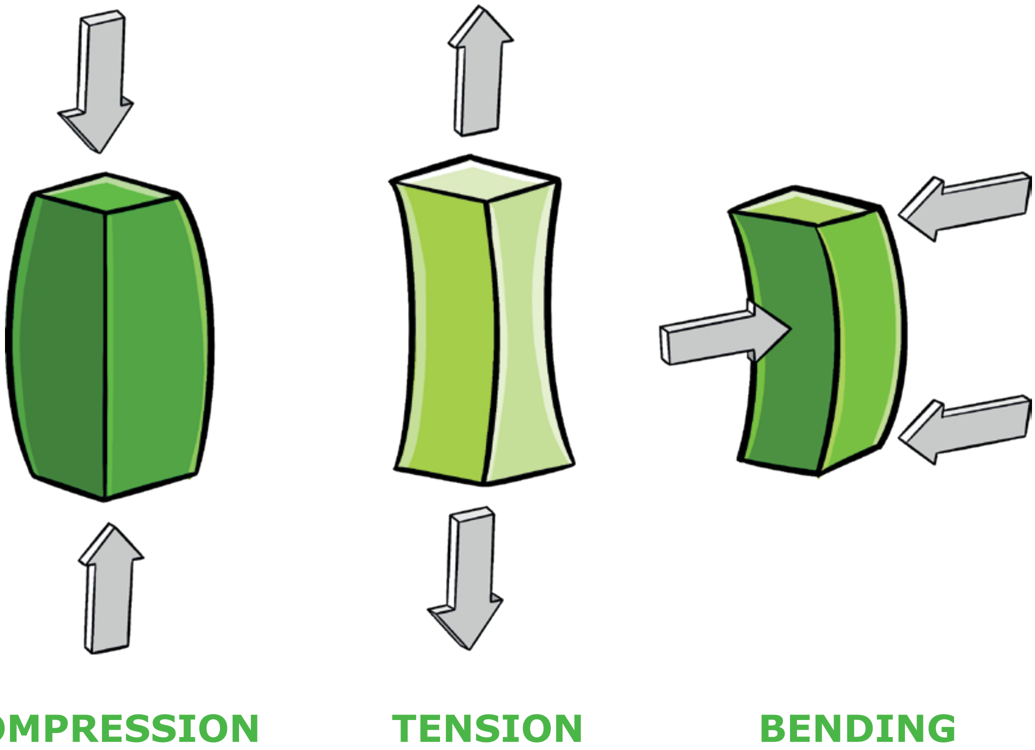
COMPRESSION

Ask them to try this standing back-to-back and leaning their weight against each other. If they can balance their forces, their bridge will stand still and not move. If the forces are NOT in balance, their bridge – and indeed any bridge – will fail!

Ask the learners to hold hands and lean out until they achieve balance. Encourage them to feel the tension in their arms.



TENSION



Challenge Time!

Divide the learners into groups and ask them to examine a series of everyday objects. Are they stronger under tension, compression or both?

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

Using some of the same sorts of everyday materials as those tested to construct a bridge pier, or simple tower, 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 pier, able to hold up the most weight. The pier should be 40cm tall, and no wider than 15cm^2 at the base. To increase the challenge in the task, you could limit the quantity or type of materials and/or sticky tape each group can use.

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.

HOT TOPICS!

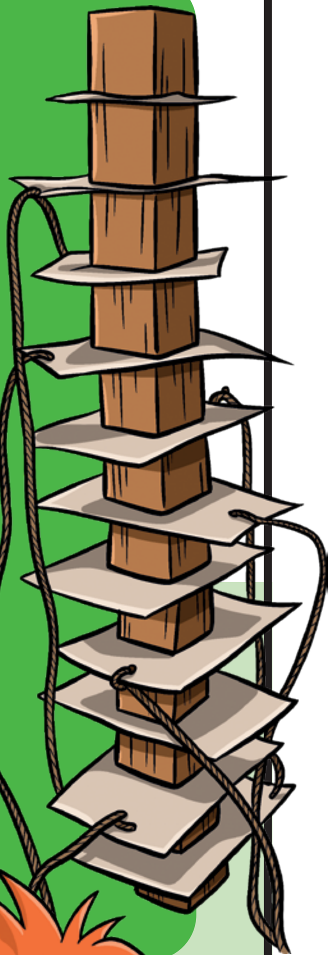
Research Sir Isaac Newton and find out more about how he came up with his Laws of Motion. You could use this to draw a timeline of his life, highlighting his key scientific discoveries. To help you complete your research, you could use the *Standing on the shoulders of giants* resource.

OUT & ABOUT

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?

Just 4 Fun – Science

You can explore one of Newton's Laws of Motion (a series of laws that explain why objects move, or don't move, the way they do). Newton's first law of motion describes something called inertia – the tendency of objects to stay at rest until a force acts upon them. This is easily tested using Inertia Towers: wooden blocks or plastic cups and notecards attached to strings. Stack the blocks in a tower, placing a notecard between each block. Once you have a tower of a number of blocks, test the Newton's law by pulling on the string on the note card. If you pull it fast enough, the tendency of the block is to resist movement and stay where it is.



DID YOU KNOW?

The Goltzschtalbrucke Viaduct in Saxony, Germany, is the largest bridge in the world made of bricks.

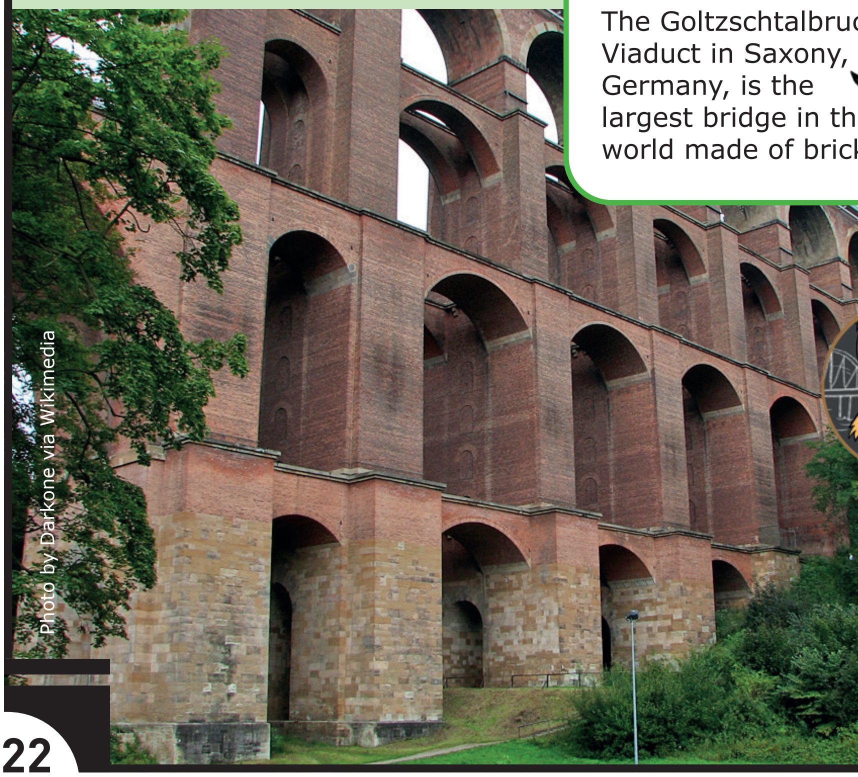


Photo by Darkone via Wikimedia

Langdon presents:

- *Testing everyday objects record sheet* handout
- *Standing on the shoulders of giants* handout

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

Chapter Aiii: Materials

AIMS & OBJECTIVES

- To learn about the materials which are used to build bridges
- To describe ways by which materials can be strengthened
- To understand how concrete is made

CONTEXT

There are many different materials used in bridge engineering. Each material has its own strengths and weaknesses, and can be used in different ways for different designs. Engineers can design a bridge that makes the most of the materials used, and accounts for any weaknesses in the material.

LANGUAGE OF BRIDGES:

Cast iron: iron with additional carbon and other impurities mixed in, and then shaped using a cast, or mould, while 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.

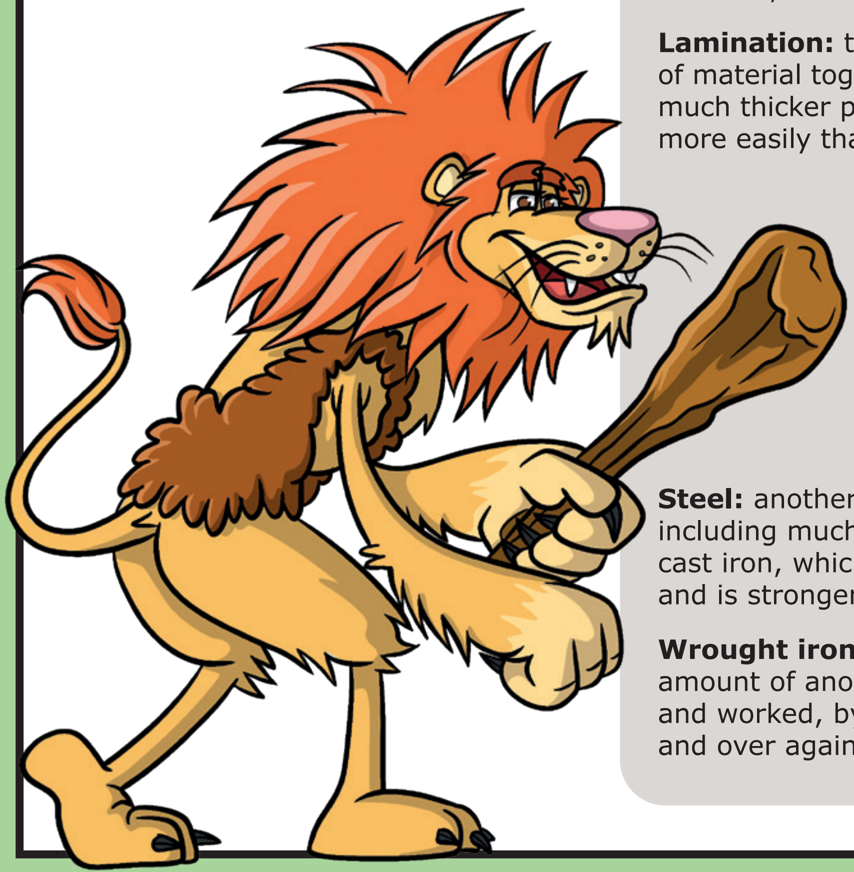
Composite: a material made from two or more different materials combined together.

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.

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

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.

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.



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

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

You will need...

- Various everyday materials: string, toilet paper or paper towel tubes, straws, fabric e.g. towels/t shirts/dusters, elastic bands, uncooked spaghetti, cardboard boxes, sponges, drinking glasses. You will need sufficient for every group to have access to each material.
- Handouts: *Materials and their properties 1 & 2*
- Large bundle of drinking straws held together in two places by elastic bands

- Handout: *Wooden bridges*
- Exploring Lamination, per group:
  - 8 pieces of coloured card, approximately 10x15cm (index card size), ideally at least two different colours
  - 2 large cups or glasses
  - At least 30 flat metal washers (M12 size/24mm diameter)
  - Glue stick
  - Ruler and pencil
- Making concrete, per group:
  - Handout: *Mixing Concrete Instructions*
  - 3x 125g yogurt pots or other sturdy containers
  - Plastic spoons
  - Water in jugs or plastic bottles
  - Sand
  - Cement
  - Fine gravel
  - Large disposable bowls with capacity of at least 1 litre
  - Cardboard mould (2cm x 2cm x 20cm): use the *Cuboid Net* handout and make these from card in advance (making sure the glue is dry before using) – a small toothpaste tube box is a reasonable alternative
  - Safety glasses
  - Dust masks
  - Plastic gloves
  - Newspaper/plastic
  - Slotted masses, or other similar small masses or uniform items such as metal hex nuts

Something to Try:

Ask learners to think of as many different materials as they can that could be used for bridge building, and share with the group.

There are many materials available to engineers, which include wood; stone; bricks; various metals such as cast iron, wrought iron, steel and aluminium; concrete; and modern materials such as glass-reinforced plastic.

Ouse Valley Viaduct made out of brick
(Photo by Viktor Forgacs on Unsplash)

Here are a series of activities you can use to demonstrate the properties and behaviour of a range of materials.

Invite learners to consider the materials used for everyday objects. You could use the *Materials and their properties* handout to guide learners to consider the different properties. Different materials have different strengths and different applications. Once they have a list of everyday objects and their materials, compare and consider why those materials were used. This links to uses in the construction industry.

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

WOOD

Wood was one of the earliest materials used in structures, and it is still in use today. Wood grows in many forms from lightweight balsa wood to very dense iron wood. Properly used and treated, wood can be strong and durable, with a life measured in hundreds of years. Wood can be attacked by insects and fungus unless it is carefully treated. Wood is a natural material.

Historically, engineers had to work with relatively short pieces of wood, limited by the height and straightness of trees. Wood had different strengths in different directions. We can consider the trunk of a tree to be like a bundle of drinking straws. Cells run in tubes along the length of the trunk and support the weight of the tree and carry the sap to the leaves.

You can demonstrate that the bundle of straws is strong if you stand it up and push down hard on the open end (compression) and if you hold both ends and pull it along the length of the straws (tension). Show that it is easy to crush the straws out of shape by pushing on them from the side or pulling the straws apart.

Mathematical Bridge Cambridge
(Photo by Karen Cann on Unsplash)

Wood is weaker when the load is placed on the side of the tubes.

The load causes a hinge and the beam fails.

Wood is stronger when the load is placed on top of the tubes.

The load compresses the tubes.

When engineers are using wood for bridge building they need to make sure the main forces are travelling along the wooden beams.

More recently, engineers have developed the technique of gluing together thin layers of wood to form very long and wide beams, which can even be made into curved shapes. This process is called lamination. Nowadays wood is mainly used only for footbridges with relatively short spans, although laminated wood bridges can be much longer.

EXPLORING LAMINATION

1

Take 8 index cards, or if you don't have index cards, different coloured standard craft card cut into 10cmx15cm rectangles.

2

Glue four index cards together, like a sandwich and leave to dry.

3

Using the ruler, find the centre of the card and draw a circle using one of the washers as a template, around the centre point.

4

Repeat this for both sides of the glued card, and on each side of the unglued cards. (This tells you where the washers should be stacked, to be a fair test).

5

Set the two cups upside down on the table so they are 10cm apart. Take care when using glass beakers. Tape them to the table (particularly if you are using plastic/paper cups) to stop them moving.

6

Stack the unglued cards together and place them across the top of the two cups like a bridge. Carefully stack the washers in the circle on the top card, counting them as they are added. Keep going until the cards collapse.

7

Repeat this step with the glued cards, stacking the washers in the circle on the card.

8

Ask learners to consider which pair of cards held more washers and why?

Look at the *Wooden bridges* handout for some examples of bridges built using wood.

IRON

Iron comes from special rocks in the ground called iron ore. When iron ore is heated with some charcoal to very high temperatures, the metal iron is released.

People have been doing this for thousands of years, but it wasn't until the 18th century that it became a more industrialised process, using coke (coal heated without oxygen) and limestone. This happens inside a blast furnace. The iron produced is called pig iron, due to the shape of the casts used to collect the molten iron. Iron is less brittle than stone. It is less likely to split and crack. Compared to wood, iron is extremely strong. It is easy to shape iron into various forms using quite simple tools. The main disadvantage of iron is rust, but this can be prevented by regular painting or galvanising, which means coating the iron with another metal called zinc.

There are three main types of iron that were used to build bridges:

Wrought Iron is iron mixed with a very small amount of another element called carbon. Carbon is used to make the inside of ordinary writing pencils. The word wrought means worked. To make wrought iron, the mixture of iron and carbon must be heated, squashed and beaten flat over and over again. A blacksmith can then bend the wrought iron into whatever shape is needed because it is very malleable (or flexible).

Cast Iron usually has more carbon and other impurities mixed in. It is shaped by heating the iron until it becomes a liquid and then pouring it into a cast or mould. The Iron Bridge over the River Severn was the first major bridge to be built from cast iron. It was built in 1779, although its history begins earlier with the development of iron production using coke, rather than charcoal, as the source of carbon in a nearby town. The bridge was needed to help transport the iron produced throughout the country, and the grandson of the man who pioneered the iron process actually cast the iron for the bridge.

Photo by Hannah Gibbs on Unsplash

Steel is another metal made from a mixture of iron and carbon. It contains much less carbon than wrought iron or cast iron and this makes it stronger and easier to shape. Before the 1850s, steel was very expensive and difficult to make. It was only produced in small quantities and used mainly for tools, cutlery and swords. Then an English engineer called Henry Bessemer invented a new way of making steel more cheaply. Engineers realised that steel had greater strength and would last longer. The first major bridge made of steel was the Eads Bridge over the Mississippi River in the USA which was completed in 1874. Today, steel is the most common metal used for building bridges.

Photo courtesy of Jasonjsmith via Wikimedia

CEMENT AND CONCRETE

Many people think cement is a modern material invented in the 20th century. However, by the middle of the 1st century AD, the Romans knew how to make cement and used it widely in their bridge building.

The Latin name for cement is opus caementicium.

The Romans made their cement using ash which had been blown out of the volcano Vesuvius. They collected the ash from a town called Pozzuoli and so the cement became known as pozzolana. The amazing thing about pozzolana is that it is waterproof and hardens even when it is wet. It also has a similar strength to the modern version!

Photo courtesy of MM via Wikimedia

Links to *Learning About Bridges Chapter Aiv: Working with Water*

LINK

It wasn't until Joseph Aspdin developed Portland Cement in 1824 that concrete became possible, with reinforced concrete being developed in 1849 by Joseph Monier. This meant the material could be used for larger constructions, such as bridges and industrial buildings.

Concrete is a common construction material, because it is strong, durable, versatile and relatively economical.

Challenge Time!

CHALLENGE

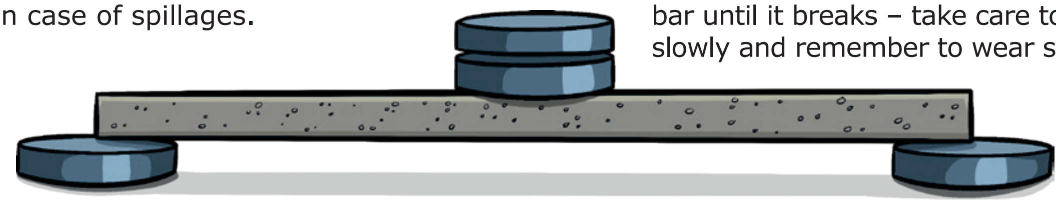
SCIENTIFIC ENQUIRY

Making concrete can be interesting and exciting for primary age learners and is easy to manage safely as long as some basic precautions are followed. (You will also need to consider your own risk assessment procedures.)

- Cement is an alkali which can cause skin burns if not handled carefully.
- Children helping with the mixing should wear safety glasses, masks and plastic gloves.
- Take care when mixing to avoid creating dust.
- Do not wash spare concrete or cement down the sink or into drains as it will harden in the pipes.
- This activity is best done outside in case of spillages.
- Cover benches or tables with newspaper or plastic sheeting.
- Follow the instructions on *Mixing concrete instructions* handout.

STRENGTH TESTING THE CONCRETE

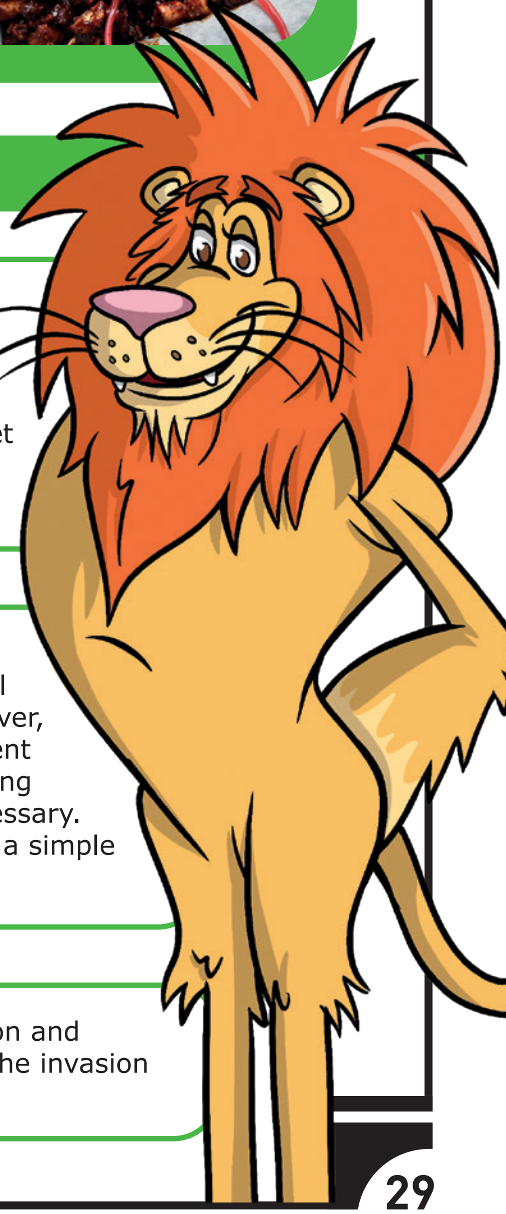
- Once the concrete has cured for at least a week, the strength of the various mixtures can be tested using slotted masses, or small weights if you do not have slotted masses available.
- Place each bar on a slotted mass (or two identical books) so it is slightly raised above the surface of the table.
- Then place the masses in the centre of the bar until it breaks – take care to do this slowly and remember to wear safety glasses.



You can demonstrate concrete and reinforced concrete using food! Rocky road is a type of cake, made up of biscuit and marshmallow pieces stuck together with a chocolate and syrup mixture. Easy recipes can be found via a quick internet search.

This mimics concrete, which is cement, with other aggregates such as gravel and sand, all mixed together and left to set. You can model reinforced concrete by using the rocky road mixture and layering the mixture with a network of strawberry laces in the pan, so you have a criss-cross pattern.

HOT TOPICS!

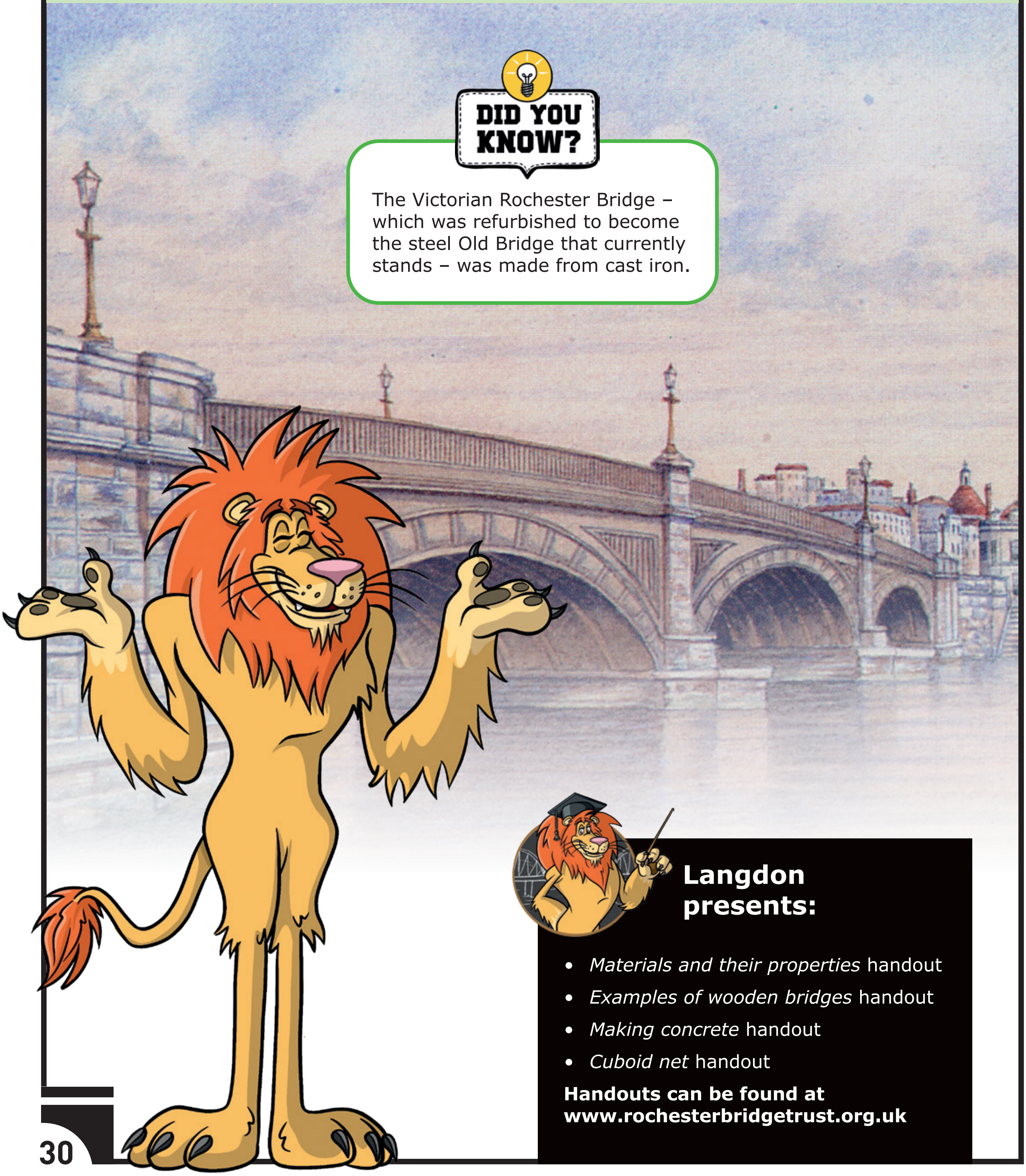


"As useful as a chocolate teapot" usually means that the something is useless or not suited to the purpose suggested. However, Nestle UK found a way to challenge this. You could find out a bit more about this by searching the internet for "Nestle chocolate teapot" – you may even find a video explaining how it's made.

Plastics and their uses are a popular topic in the media. You could consider why we use a material that lasts (as far as humans are concerned) forever, for single-use products. You could explore different ways of overcoming our plastics problem, including development of Ecobricks and why they are necessary. You can find lots of information about them with a simple internet search.

You could explore more about Roman construction and civilisation, including Roman life in Britain after the invasion in 43AD.

What different construction materials can you spot on your journey to and from school? Are there any unusual construction materials? Can you see or guess why each material has been chosen for that particular place or structure?



DID YOU KNOW?

The Victorian Rochester Bridge – which was refurbished to become the steel Old Bridge that currently stands – was made from cast iron.

Langdon presents:

- *Materials and their properties* handout
- *Examples of wooden bridges* handout
- *Making concrete* handout
- *Cuboid net* handout

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

Chapter Aiv: Working with Water

AIMS & OBJECTIVES

- To learn about some of the techniques civil engineers use for building structures under water
- To consider some of the challenges faced by civil engineers when designing bridges

CONTEXT

Most bridges will require some sort of building in water, whether that is developing the abutments or constructing piers to support the deck. The longer or bigger the bridge, the more complex this will be. The Romans were the first to build a bridge at Rochester, in 43AD, because they were the first to have the technical skills to be able to do so.

LANGUAGE OF BRIDGES:

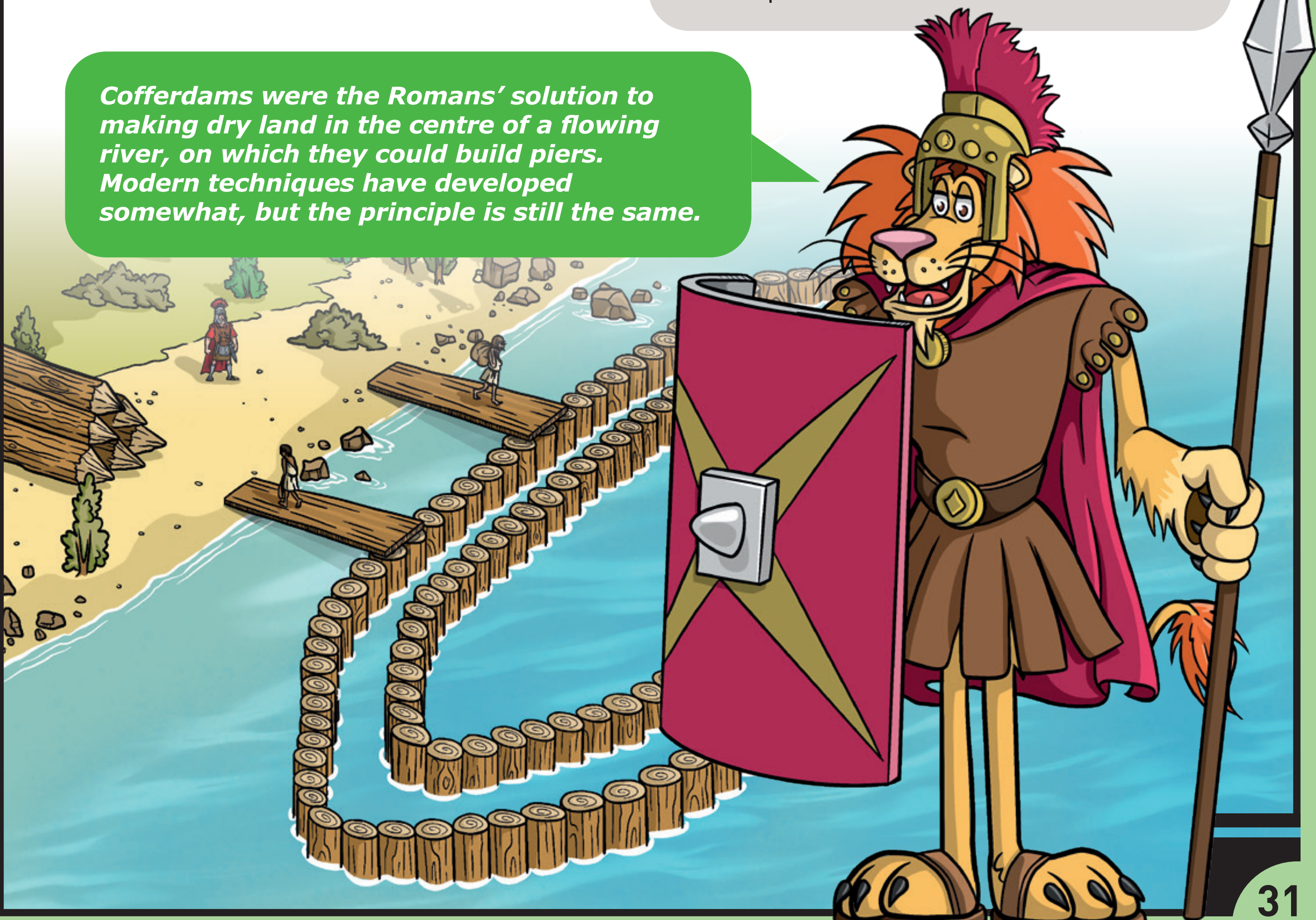
Cofferdam: a temporary box, built in the water, from which the water is removed, leaving a dry space for building.

Piers: the upright columns that support the bridge.

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

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

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



Something to Try:

If we think about how early humans built their bridges, the very first bridges were simply logs across small streams. The spans of these bridges were limited by the length of the logs available.

Then people worked out they could pile rocks and stones in shallow rivers and streams to make piers in the centre to allow their bridges to be longer. But these only worked when the flow of the river was gentle enough not to wash away the rocks. If the water was gentle and shallow, it might just be easier to wade across the river! So early humans usually found an easier place to cross, even if it meant they had to go a long way round. The problem was, people needed to cross rivers, even when the water was rushing past. How could they build a pier in the middle of a river?

The Romans were not going to be put off by this challenge. They liked to build their roads straight and if there was a rushing river in the way they would just have to find a way to build piers in the water. The solution was a cofferdam.

A cofferdam is a temporary box, built in the water, from which the water is removed leaving a dry space for building. In other words, a cofferdam blocks the water on all sides and makes a dry place in the middle of the river where the pier can be built.

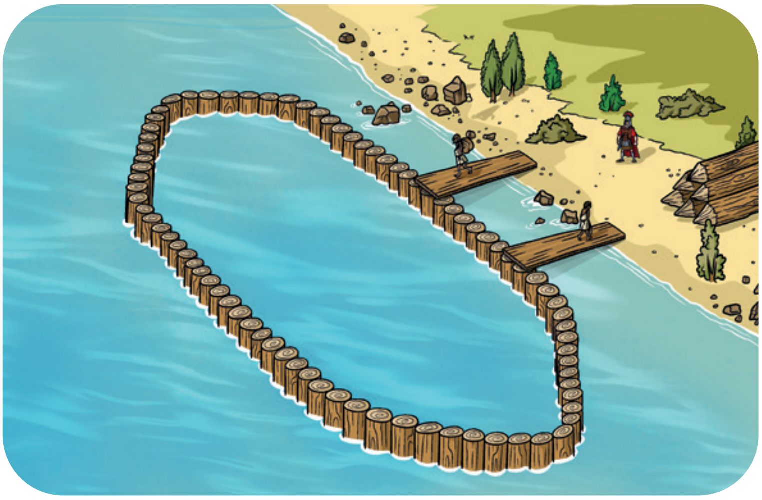
First the Romans collected large logs and sharpened the ends. These logs are called piles. Then they pushed the piles into the river bed near where they wanted to build the pier of the bridge.

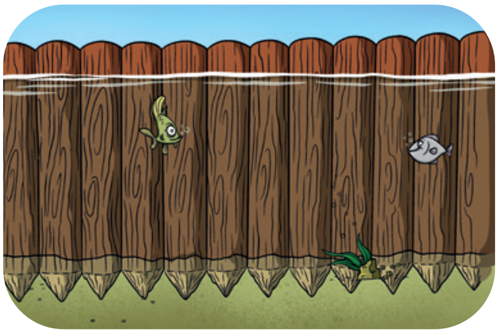
To get the logs into the river bed they invented a machine called a pile-driver. This used a large weight on the end of a rope which hammered the pile into the soft river bed.

You will need...

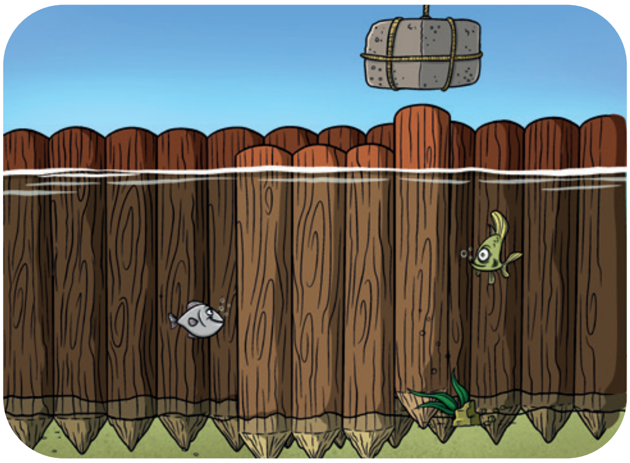
- Cofferdam Activity, for each group or demonstration:
  - Deep waterproof tray (e.g. Large roasting tin or seed tray without drainage holes)
  - Empty 2 litre plastic bottle
  - Empty 500ml plastic bottle
  - Sand
  - Water
  - Scissors
  - Plastic syringe (for example, the type used for children's medication) or a pipette
  - Bowl or jug
  - Sheet of A4 paper
  - Handout: *Building a model cofferdam*
- Working under water demonstration:
  - Sticky tack/modelling clay/ plasticine/PlayDoh®
  - Plastic milk bottle lid
  - Large bowl/container/bath containing water
  - Wide-necked drinking glass or jar
- Diver Challenge, per group:
  - Approximately 20 Lego®, Duplo® or similar sized building bricks
  - A tray or shallow box
  - Optional: a towel or blanket

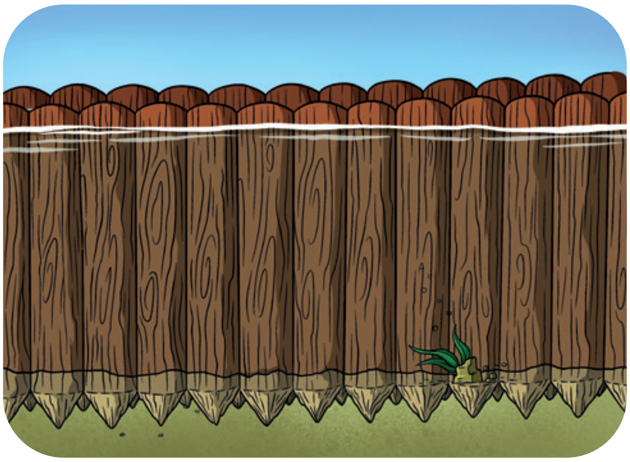
The Romans repeated this until they had made a ring of logs very close together and much bigger than the pier they needed to build.



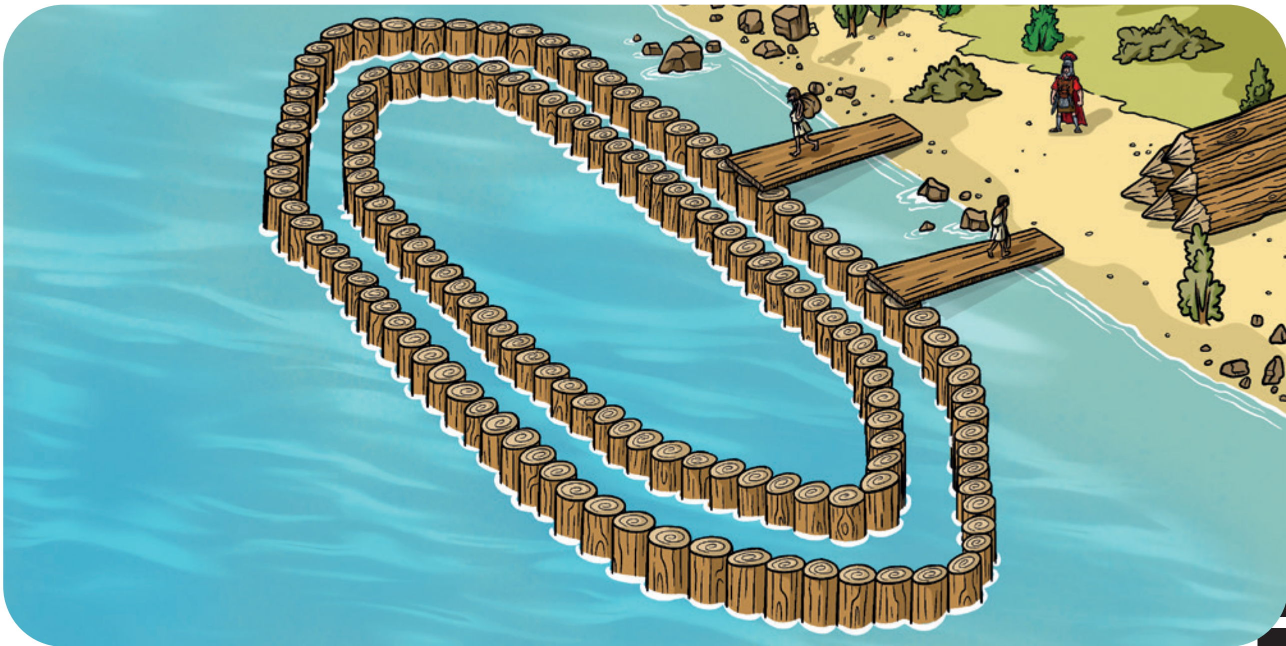


Then they started again and made another ring of logs outside the first one.

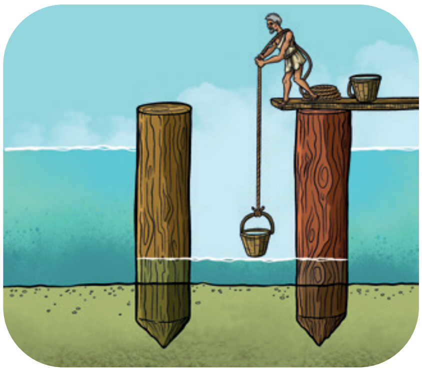


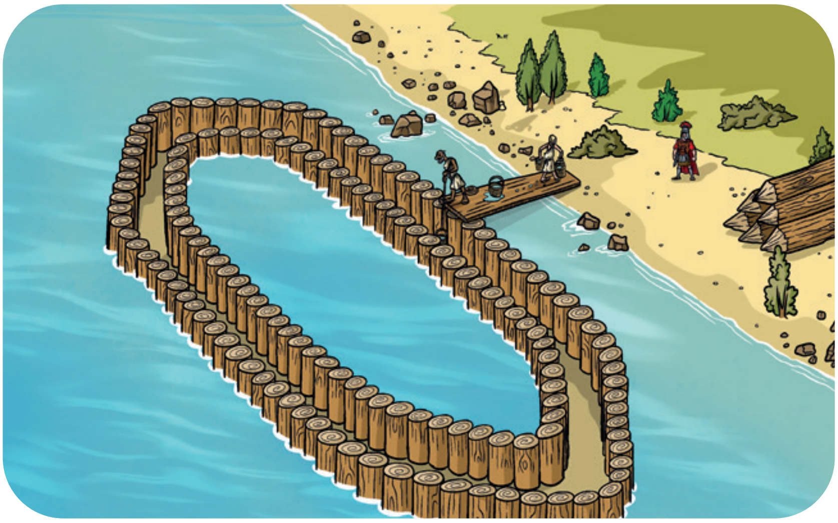


When they were finished, they had made concentric rings of piles.



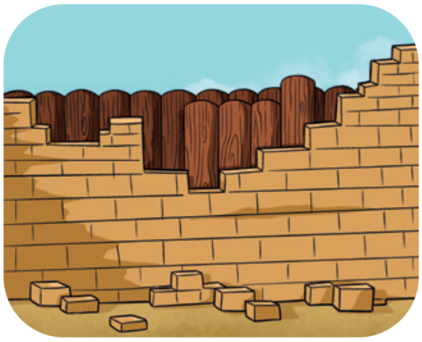
They would then bail out the water between the two rings, likely using a bucket.



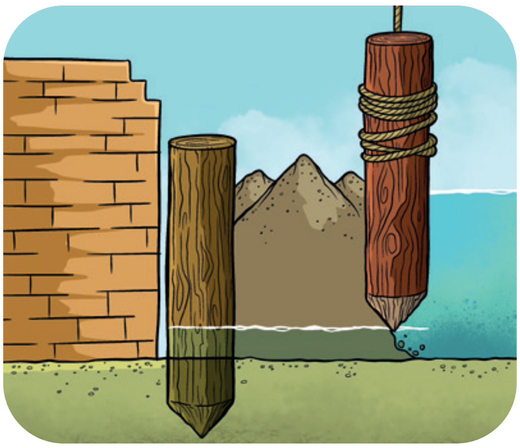


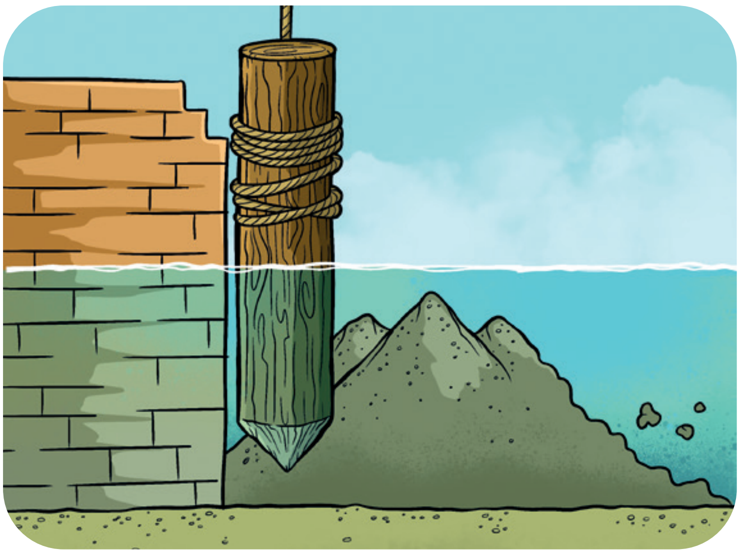
Next they filled the space between the two rings with clay, packing it down as tightly as they could to push all the water out of the gap. They were trying to make the space as waterproof as they could.

When this was done they bailed out the water from inside the middle ring, leaving themselves with a fairly dry space.



Now the Roman engineers could work in the dry ring and dig out the river bed until they reached the rock underneath. Then they built their bridge piers as high as they needed and added the deck.

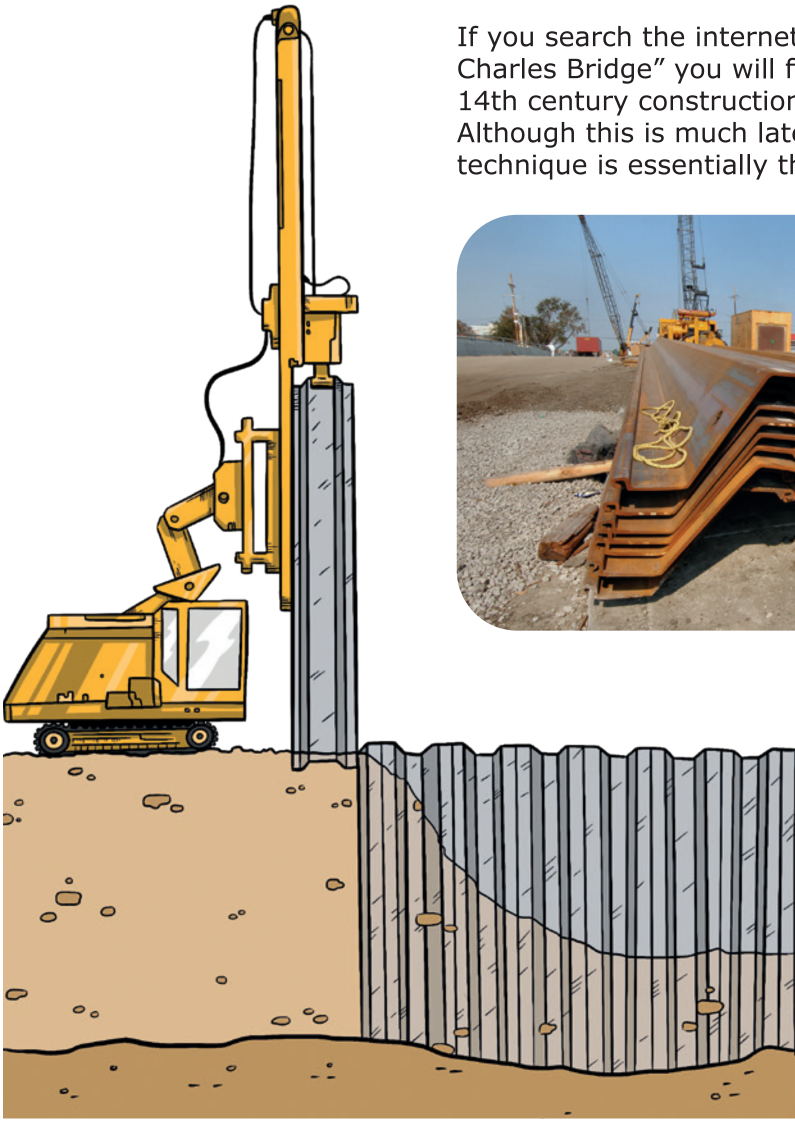




Once the bridge was finished they could take away the cofferdam.

If you search the internet for “Engineering and architecture Charles Bridge” you will find an animation depicting the 14th century construction of the Charles Bridge in Prague. Although this is much later than the Roman period, the technique is essentially the same.

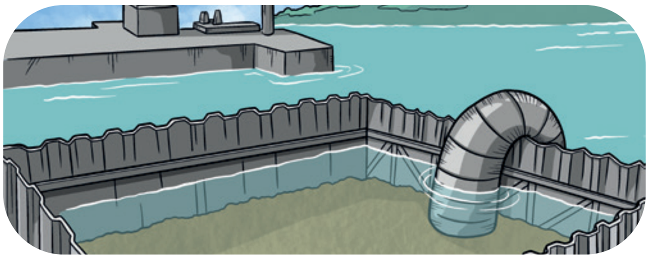
Photo by Alan Dooley of the US Army Corps of Engineers via Wikimedia

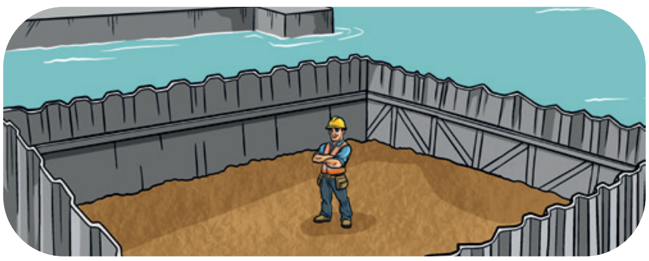


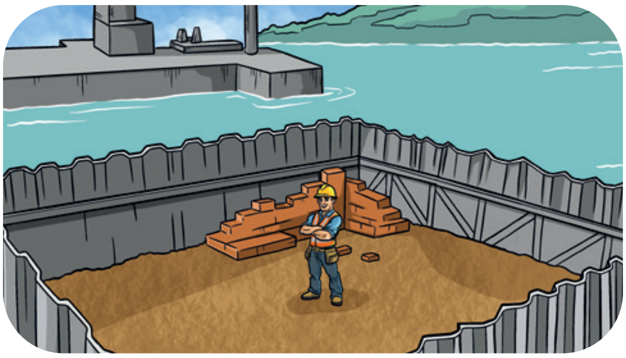
Today civil engineers still use cofferdams and the technique for building them is very similar to the Roman method. Instead of sharpening logs, however, modern engineers tend to use sheet piles. These are made of steel and bent into a special shape.

A modern-day pile-driver is used to push the sheet piles into the ground or the river bed.

Large pumps are used to remove the water from inside the cofferdam.







Once the space is dry, work can begin. Sometimes water needs to be continuously pumped out of the cofferdam, to keep the working area dry and safe for the workers.

BUILD A MODEL COFFERDAM:

Follow the instructions here or use the *Building a model cofferdam* handout.

1

Cut off the top and bottom of the bottles to create two cylinders about 12cm high.

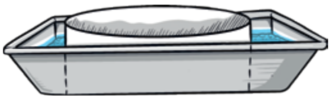
2

Fill the tray with sand up to a depth of about 4cm.

3

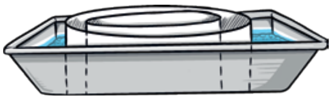
Add water until the level is about 3cm above the sand.

4



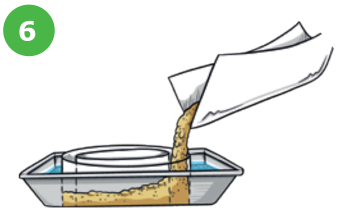
Insert the larger cylinder in the sand and water until it is flush with the bottom of the tray.

5



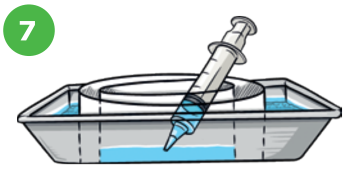
Insert the smaller cylinder into the centre of the first until it is also flush with the bottom of the tray.

6



Fold a piece of paper down the centre and use it as a chute to pour sand into the space between two cylinders.

7



Use the syringe or pipette to remove the water from the centre section into the small bowl until the water level inside the ring is significantly lower than the outside.

Since there will not be a true, water-tight seal around the bottom of the cylinders, it will probably not be possible to remove all of the water from the inner ring. This is not a problem: the Romans were not able to achieve a completely dry cofferdam either and would have had to bail out water throughout their construction process. However, it should be possible to get the water level in the inner ring significantly lower than the rest of the water in the tray.

The bottles used in this activity can be replaced by parts of drainpipe, which can be re-used a number of times.

The important thing is to understand how civil engineers use structures like cofferdams to make building bridge piers possible in water.

Vauxhall bridge cofferdam

Challenge Time!

DIVER CHALLENGE: BRICK INSPECTION

Bridges need to be maintained to ensure they stay strong enough to support their loads. The piers underwater need to be inspected to make sure nothing is damaged and needs repairing. To do this, divers enter the water at low tide and inspect the masonry in the piers. The visibility is very poor, so they do this by touch – they have to feel for any bricks that are missing or damaged, or mortar that is missing, to ensure the masonry won't fail. This activity mimics that process.

Use Duplo® or similar toy construction blocks to build a wall with several gaps between the bricks, representing cracks in the structure. Aim for a wall which is 5 rows high and approximately 3-4 long bricks wide. This can be laid on its side in the tray/shallow box.

Keep it hidden from the learners using the towel/ blanket if you have one.

Learners should take on the role of an underwater diver who must gather information on the state of the wall, whilst working in poor light. They should be blindfolded, and have to use only touch, to work out where the gaps are in the wall and report this to a partner, who must make notes of what they say.

The aim is to accurately and systematically record where all the gaps are from touch alone.

The activity can be repeated several times, with the wall being rebuilt many times with the cracks in different positions each time.

HOT TOPICS!

The construction of the Brooklyn Bridge in New York, USA, was riddled with set-backs as a result of accident or illness. One of the issues was something called Caisson's Disease. In fact, the first ever identified cases of Caisson's Disease occurred at the building of the Victorian Rochester Bridge. You could research what is Caisson's Disease and why labourers suffered from this during the construction of the Brooklyn Bridge. You could also explore why Emily Warren Roebling's involvement in this bridge's construction was so remarkable.

Photo by Alexander Rotker on Unsplash

Just4Fun

EXPLORING ENGINEERING UNDER WATER:

This demonstration helps to show your learners how engineering work can be carried out under water.

a) Take a piece of sticky tack or PlayDoh® and make a small person.

b) Balance them on the inside of a lid from a plastic milk bottle. This represents your engineer, who is going to be working under water.

c) Float the lid containing your engineer, on the surface of a large bowl or bath of water.

d) Take a glass with a wide opening, such as a pint glass, and carefully place it over the top of the plastic lid/engineer.

e) When you gently push the glass down under the water, what do you notice happens? Keep the glass vertical and with the opening pointing downwards as you move it up and down in the water. Is the engineer wet when they return to the surface?

OUT & ABOUT

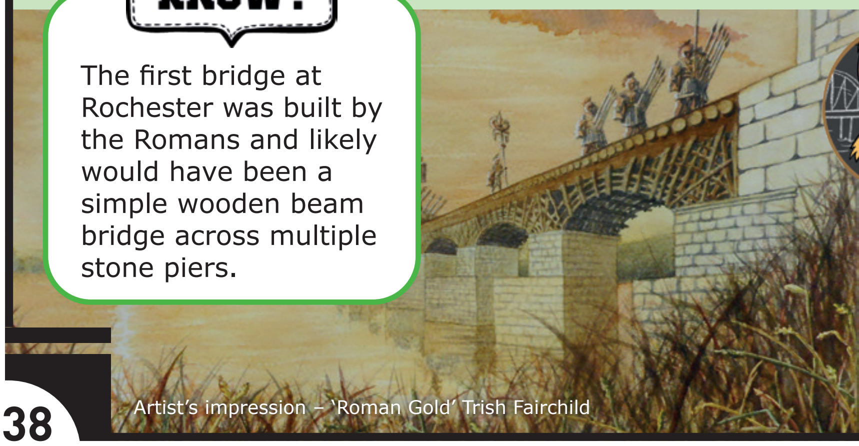
The first Roman bridge over the River Medway was built to allow Roman forces to travel directly to London without deviating to the nearest alternative crossing point. Many towns grew up around fords or bridges and are named after them, Stratford, Bradford, Cambridge and Tonbridge are examples. Some places have a name ending in -brook, -burn, -bourne or -beck. These are all other names for a stream. Can you use a local map and list as many places as possible, named after river crossings?

Also, in some places, people used to have to pay a fee, called a toll, to cross the bridge. Some tollhouses, where the toll collectors lived, still exist. Are there any near where you live?

GEOGRAPHY

DID YOU KNOW?

The first bridge at Rochester was built by the Romans and likely would have been a simple wooden beam bridge across multiple stone piers.



Artist's impression – 'Roman Gold' Trish Fairchild

Langdon presents:

- *Building a model cofferdam* handout

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

Chapter Bi: Beam Bridges – The First Bridge

AIMS & OBJECTIVES

- To learn key terms for beam bridges
- To understand how bridges developed

CONTEXT

The earliest form of bridge was a beam bridge, constructed from a log or wooden plank. The word bridge is itself derived from an ancient word for log or beam.

LANGUAGE OF BRIDGES:

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

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

Corrugated: folded into small furrows or ridges.

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

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

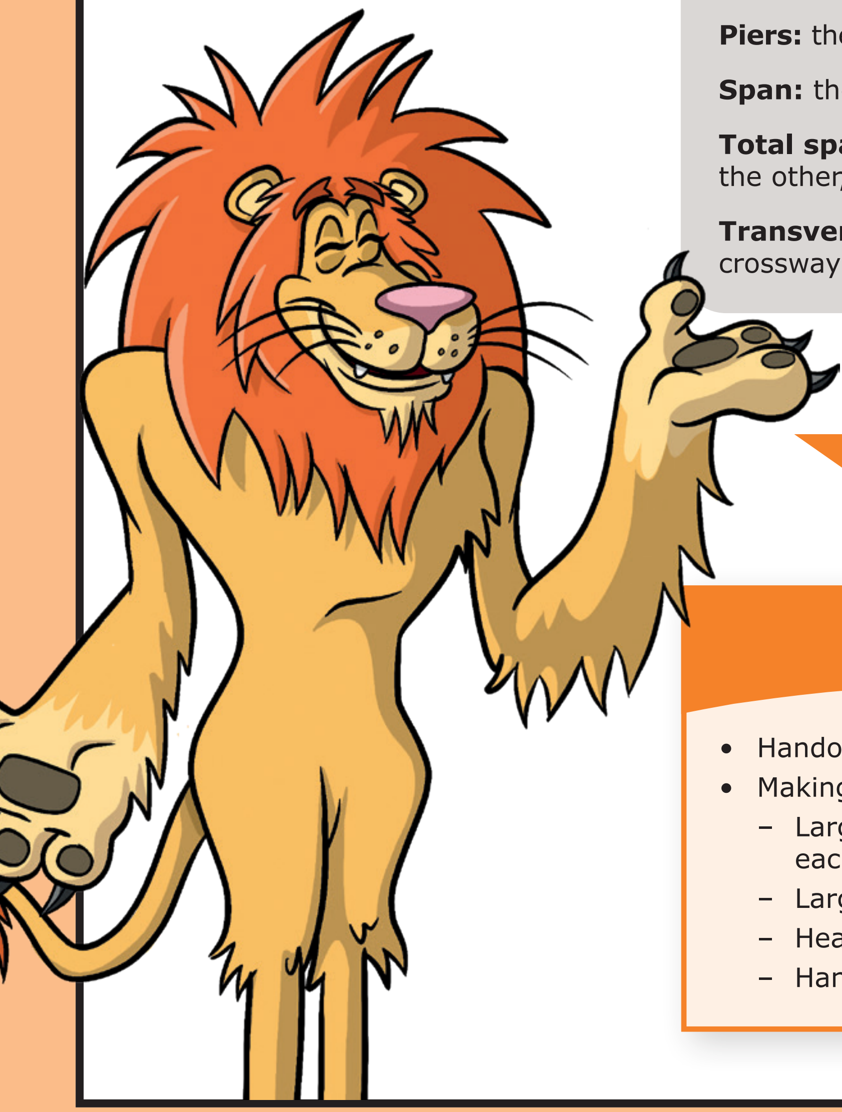
Parapet: a low wall or railing alongside the edge of the bridge deck to protect traffic from falling off.

Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

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



We are going to think more about simple bridges and why they're so important…

You will need…

- Handout: *Beam bridge terminology*
- Making bridges stronger challenge, per group:
  - Large books to build two 30cm high piles for each group of learners (optional)
  - Large cardboard sheets or old boxes
  - Heavy weights, such as dumbbell weights
  - Handout: *Beam bridge record sheet*

Something to Try:

Anyone who has ever placed a log over a stream so they didn't get their feet wet has built a bridge. Possibly the earliest structure ever built by humans is a bridge – early humans probably used the simplest form of bridge to cross narrow streams and gorges long before they built houses or settlements. The simplest and oldest type of bridge is the beam bridge.

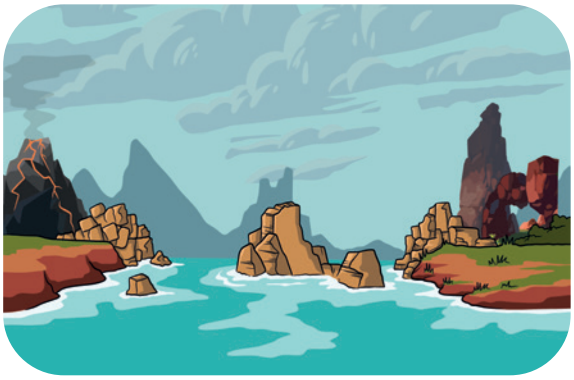
- The caveman puts a log over a stream – he has built a bridge but it is wobbly and precarious.

- He turns the log into a plank (i.e. beam) – it is more stable and easier to walk over but it sinks into the mud in wet weather.

- He piles up stones under the ends of his beam – he has made abutments. His bridge is steadier but now it is much higher up and can be scary to cross in the wind.

He makes simple parapet rails out of sticks and vines.

Now he knows how to build a good, strong bridge but when he wants to cross a wider river the trees are too short. So he piles up stones in the middle of the river to make a pier.



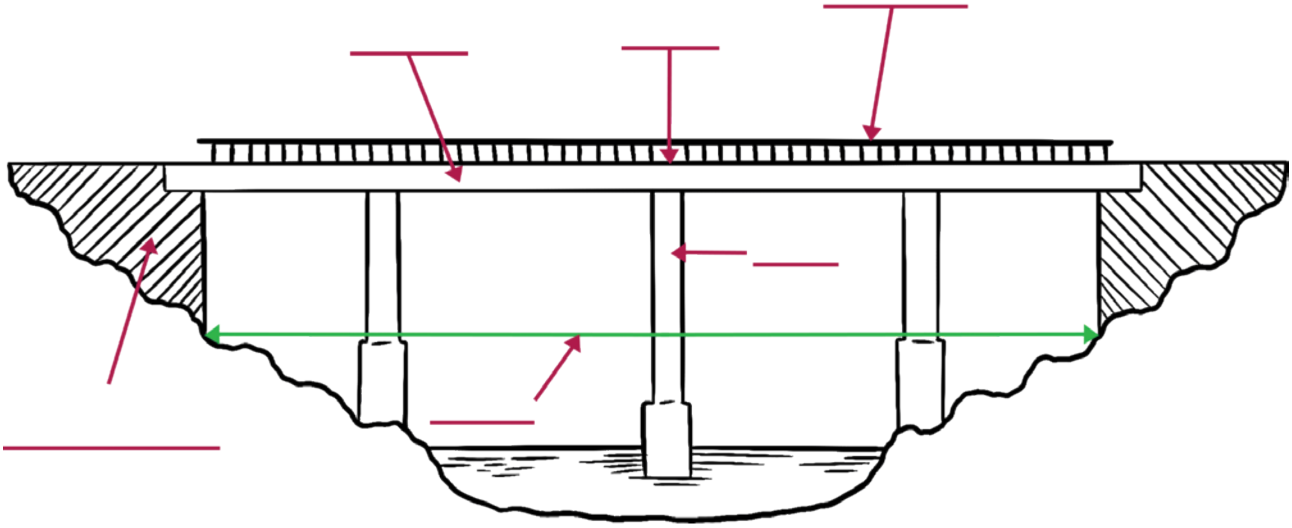
By adding a beam on each side he has doubled the length of his bridge.

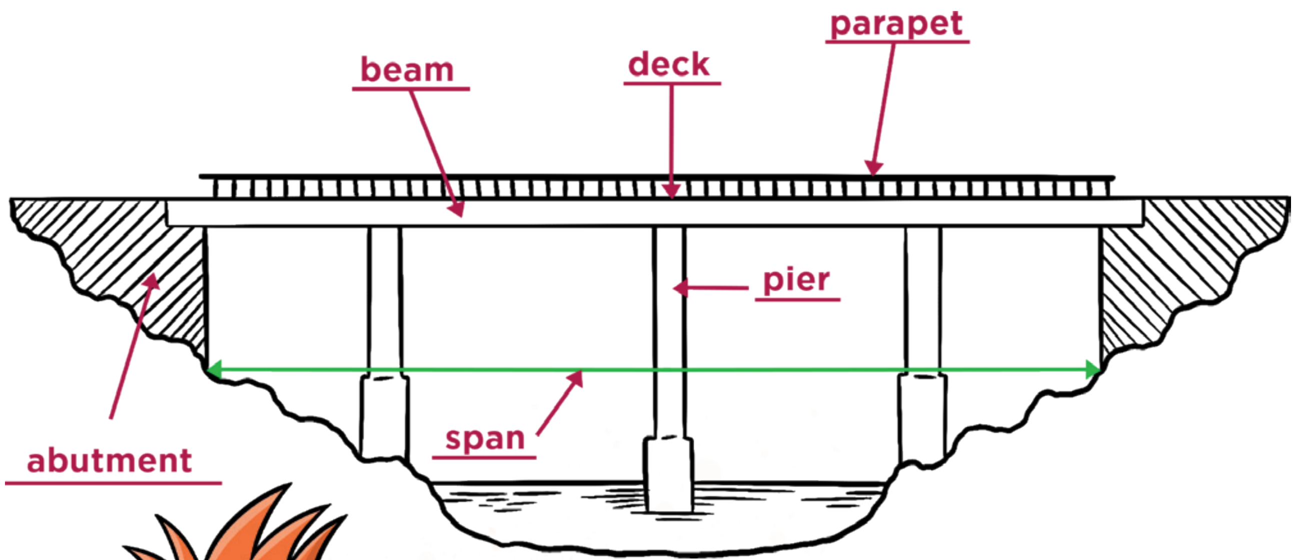
One of the longest beam bridge spans in the world – and currently the longest in the Southern Hemisphere – is 300 metres and is part of the Rio-Niteroi Bridge in Brazil.

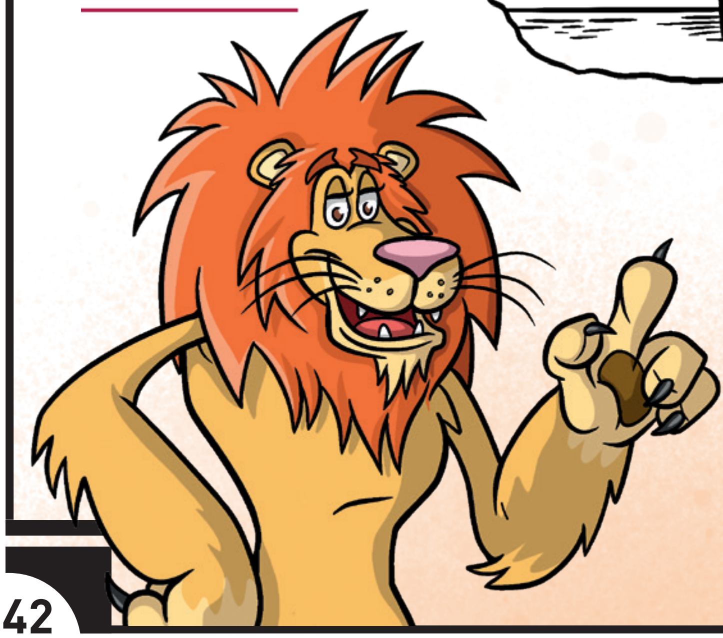
Photo by Halley Pacheco de Oliveira via Wikimedia

LABELLING THE BEAM BRIDGE

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





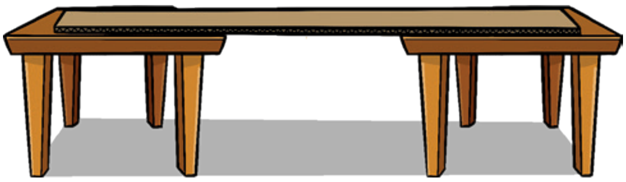


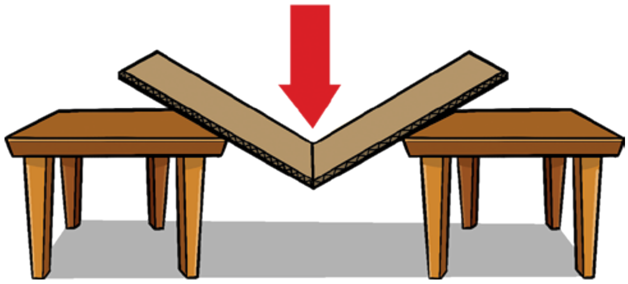
Challenge Time!

Place two tables or desks 40 centimetres apart, and place a sheet of A3 card across the gap. This has made a simple beam bridge. This cardboard bridge is strong enough to hold up its own weight. In a real bridge the weight of the bridge is called the dead load. This is because once the bridge is built the dead load stays the same and does not move about.

Now walk your fingers across the cardboard bridge leaning hard enough to make the bridge bend and even collapse. That represents the live load. On a real bridge this might be the traffic or a train going across. It could also be the wind blowing across the bridge, or snow falling. The live load moves and changes all the time.

A bridge engineer needs to work out what the dead load and live load will be and make sure the bridge is strong enough to carry both of those loads.





TESTING BEAM BRIDGES

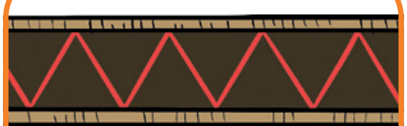
There is an illustrated step-by-step guide on the following pages.

Brief the learners on the safety rules for this activity:

- Weights must be added one at a time, slowly and carefully.
- Make sure each weight is securely balanced before the next one is added.
- The weights must be removed one at a time and not allowed to fall.
- Care should be taken to keep fingers and feet clear of the pile of weights.
- For each small group, set up desks or tables with a gap of about 50 to 60 centimetres between the abutments.

For safety reasons, it may be preferable to use a pile of large books or blocks of solid wall insulation on a carpeted floor to reduce the risk of the heavy weights falling from any height. If this option is used, make sure there is a clearance of about 30 centimetres under the bridge to ensure the experiment works properly.

Taking each cardboard beam in turn, discuss the way they are described and explain the meaning of the terms used. Discuss the terms corrugated, transverse and longitudinal.



Corrugated: folded into small furrows or ridges

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

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

Add weights until the beam bridge fails by collapsing or bending so much in the middle it cannot carry any more weight and almost touches the river beneath the bridge. Record on the *Beam bridge record sheet* handout the final weight each beam carried just before it failed.

Encourage the learners to observe how the bridge failed. Did it just keep bending more and more? Did it fail by creating a straight line in the cardboard – engineers might describe this as a hinge forming – compare it to the hinge on the classroom door. What condition is the beam in after failure? Does it spring back to its original shape so that it could be used again? Or has it failed completely so that it could not carry so much weight again?

STEP-BY-STEP INSTRUCTIONS FOR TESTING BEAM BRIDGES

Create the abutments using blocks of wall insulation, or a pile of large books, on a carpeted floor.

Add a cardboard beam with transverse corrugation (in the direction shown by the ruler).

The cardboard bridge has failed because a "hinge" has formed.

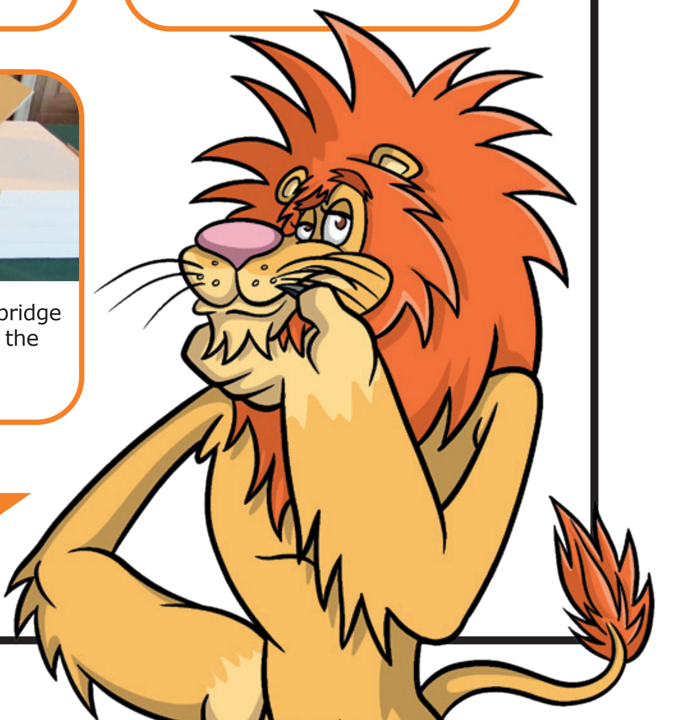
Add a cardboard beam with longitudinal corrugation (in the direction shown by the ruler).

The cardboard bridge has failed but a "hinge" has not formed in this case. This bridge should be able to carry more load than the first one.

Add a cardboard beam with an arched piece of cardboard underneath.

The arch-beam combo holds the load. Should be able to carry more load than either of the other bridges.

But with a heavier load the bridge fails. Hinges have formed in the arch and the beam.



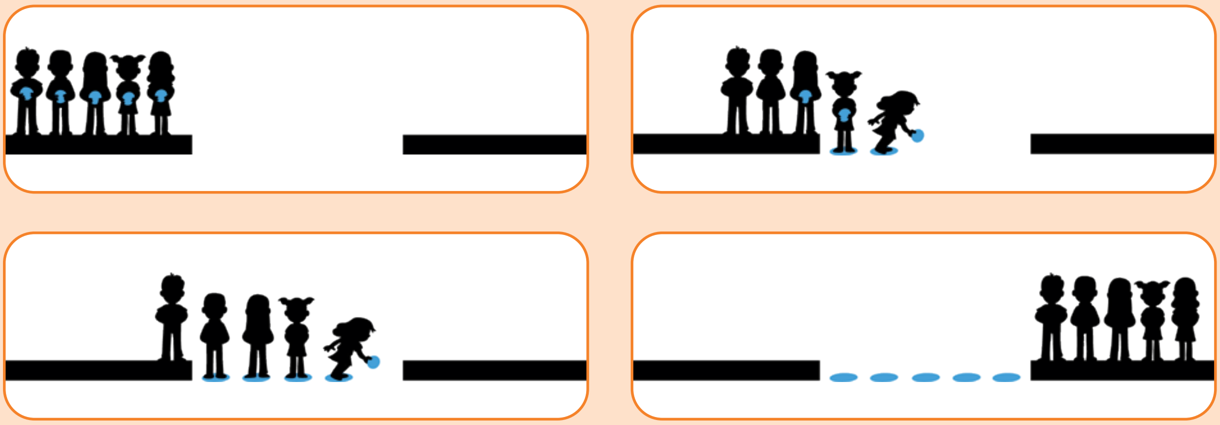
Why did the cardboard bridge fail?

The earliest bridges were felled trees or piles of stones that developed beyond simple stepping stones. In this game, we return to the ancient way of crossing a stream...

In an outdoor space, use some round spot markers (such as those used in PE) in a selection of colours, challenge the teams to get all the way across the river without touching the water in the quickest time possible.

Divide the group into small teams, no more than 5 in a team. Give each team a set of 5 coloured spot markers, with each team getting a different colour if possible. Using either lines marked out already on the ground, or ropes to indicate the sides of the river bank (making the river as big as the area will allow), get the teams to travel from one side of the river to the other, using only the stepping stone spots. They must not step in the river, and they must pick up the markers as they go. The stepping stones will also get washed away if someone isn't touching them; the teams cannot just throw their markers out into the river and wait until they need them – they must carry them with them and have someone collect them as they go.

Challenge them to see how quickly they can get across. Reduce the number of stepping stones and repeat the challenge.

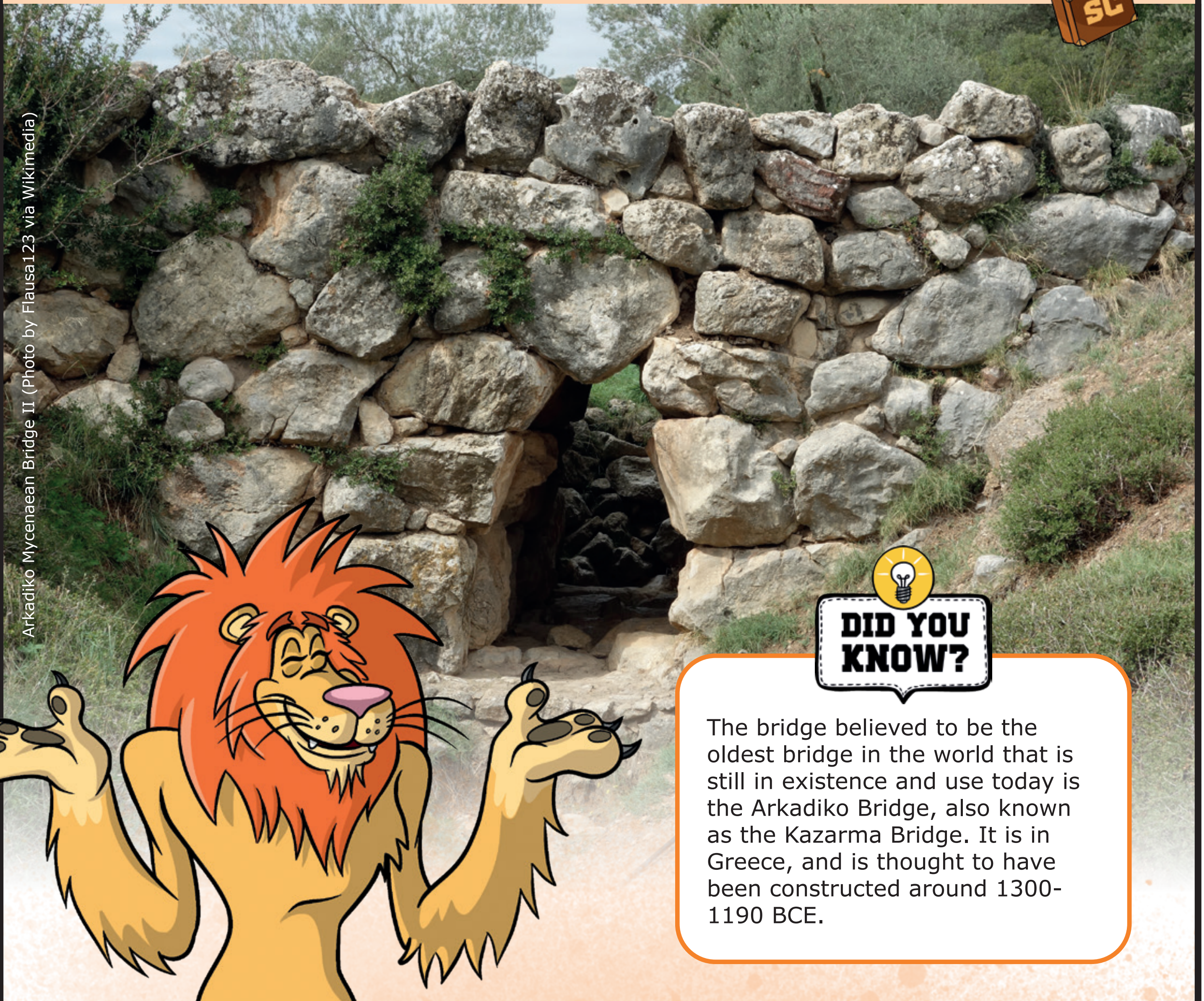


HOT TOPICS!

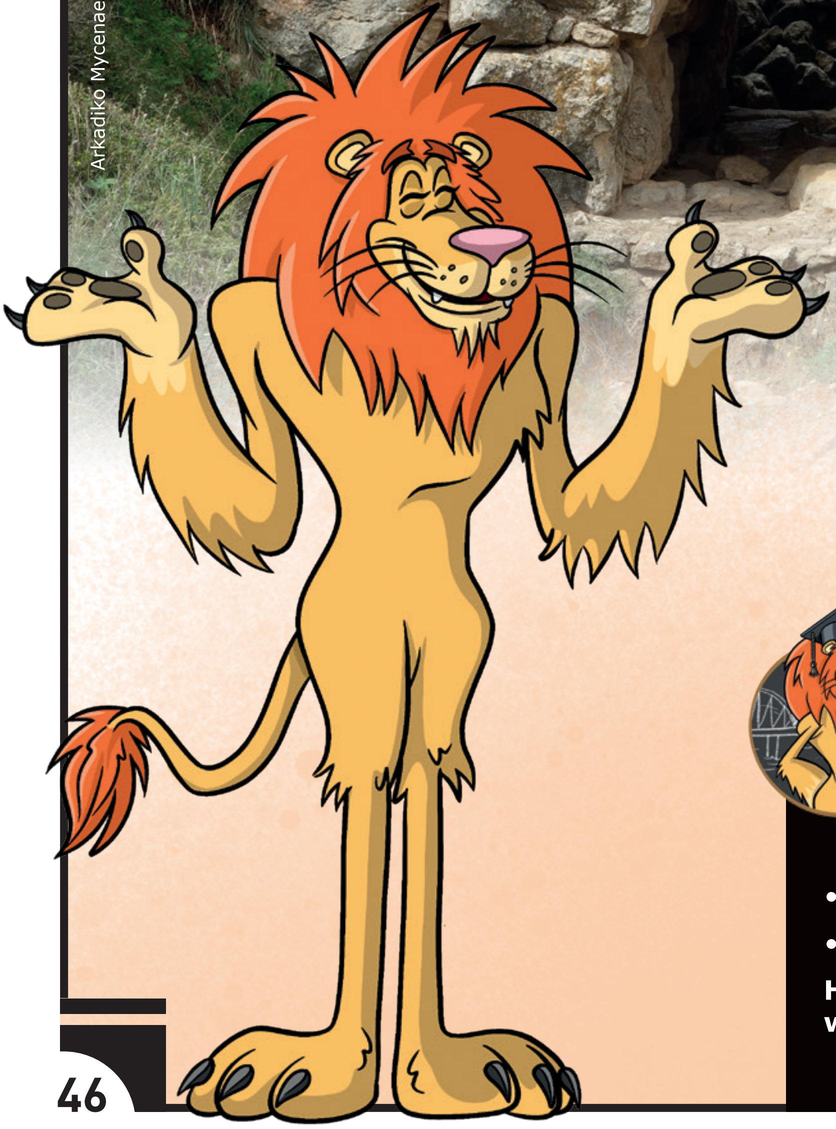
The earliest stone bridges were likely to be clapper bridges – piles of stones that were laid with larger, flat stones between them. The name is derived from the Anglo-Saxon word, cleaca, which means bridging the stepping stones: it is obvious why they were given this name when viewing images of such bridges!

This could link to Anglo-Saxons in history, or perhaps develop sketching and painting skills in art by reviewing different scenes in a similar location, or over time.

Can you spot a beam bridge in your local area? Take a photo and identify the parapet, abutments, deck and piers, if it has any.



Arkadiko Mycenaean Bridge II (Photo by Flausa123 via Wikimedia)



DID YOU KNOW?

The bridge believed to be the oldest bridge in the world that is still in existence and use today is the Arkadiko Bridge, also known as the Kazarma Bridge. It is in Greece, and is thought to have been constructed around 1300-1190 BCE.

Langdon presents:

- *Beam bridge terminology* handout
- *Beam bridge record sheet* handout

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

Chapter Bii: Beam Bridges – Simple but Strong

AIMS & OBJECTIVES

- To apply knowledge of forces and loads to a beam bridge
- To explain the limitations of beam bridges

CONTEXT

The earliest and simplest form of bridge was a beam bridge, but as human civilisation has developed, so has the need for longer and stronger bridges. The load of the bridge is entirely supported by the piers, and the deck is susceptible to bending: for this reason, beam bridges are used to span relatively small gaps.

LANGUAGE OF BRIDGES:

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

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

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

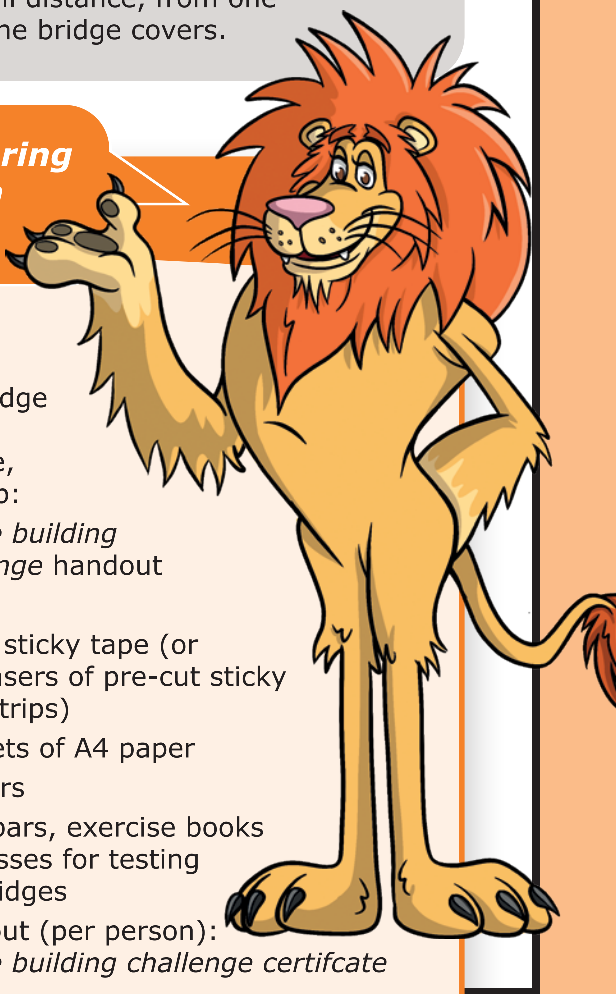
Parapet: a low wall or railing alongside the edge of the bridge deck to protect traffic from falling off.

Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

We will start exploring forces and loads in beam bridges.

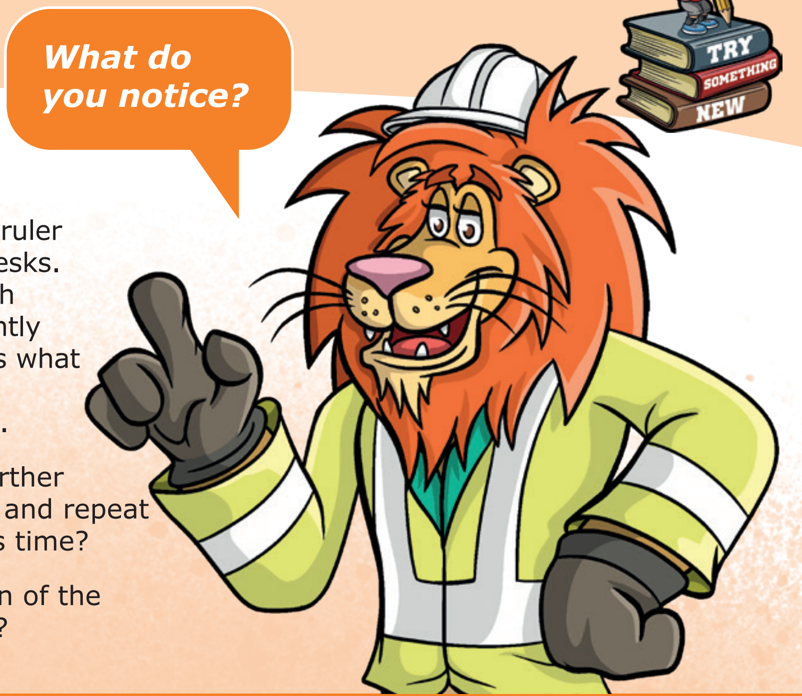


You will need...

- Ruler Beam bridge
  - Metre ruler
  - Books – enough to create two stacks/abutments, alternatively two desks that can be moved apart would work.
- Exploring beam bridges, per group:
  - Wooden building blocks (4 per group)
  - Strips of thin card (3 per group)
  - Masses (such as coins or washers, multiple per group)
- Handout: *Forces in a beam bridge*
- Large sponge (such as used for car cleaning), marked along the side with a marker pen, with vertical lines, approximately 2.5cm apart

- Paper bridge building challenge, per group:
  - *Bridge building challenge* handout
  - Ruler
  - 1m of sticky tape (or dispensers of pre-cut sticky tape strips)
  - 6 sheets of A4 paper
  - Scissors
  - Mars bars, exercise books or masses for testing the bridges
  - Handout (per person): *Bridge building challenge certifcate*

Something to Try:



RULER BEAM BRIDGE

Create a beam bridge by resting a metre ruler on two stacks of books or between two desks. Keep the gap relatively small to begin with (20cm or so). Then test the bridge by gently pushing down on the middle. Ask learners what they notice. Ask learners what they think would happen if more force/load is added.

Pull the stacks of books/desks slightly further apart, increasing the span of the bridge, and repeat the test. What do the learners notice this time?

Repeat several times, increasing the span of the bridge slightly each time. What happens?

EXPLORING BEAM BRIDGES

Each team needs to be given 4 large building blocks, 3 strips of card, and some small masses (coins, washers for example).

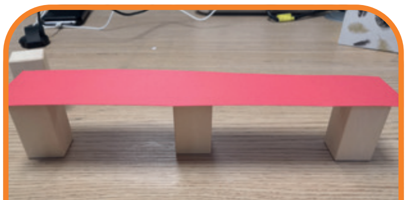
They can then explore which type of bridge is the strongest: which bridge holds the greatest mass.

Some options for this might be:

A simple beam bridge, with 2 blocks at either end.

A beam bridge with reinforcement.

Or an arch support.



A beam bridge with an additional pier.

Encourage learners to explore all the different combinations of supports and card uses, testing them as they go. You could get each group to demonstrate their strongest bridge design and ask them to explain why they think it was the strongest.

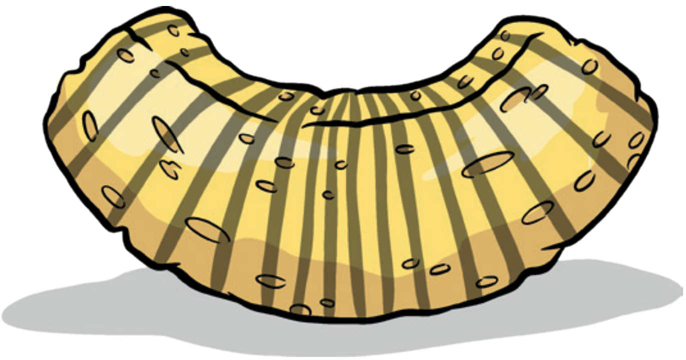
Learners are encouraged to make scientific observations and to think about how to set up comparative and fair tests. They can then use scientific language to describe their observations.

FORCES IN A BEAM BRIDGE:

Place two tables or desks about 40 centimetres apart and place a sheet of A3 card across the gap to make a simple beam bridge. Place a toy car in the centre to act as the live load. Ask the learners whether there is any tension in the beam bridge. If so, where is it coming from?

The forces in a beam bridge can be demonstrated visually using a large sponge, marked along the sides.

Take the sponge with vertical lines on. Bend it like a beam bridge carrying a heavy live load.



Observe that the lines at the top are closer together – so what is the force?

Compression.

Observe that the lines at the bottom get further apart – so what is the force?

Tension.

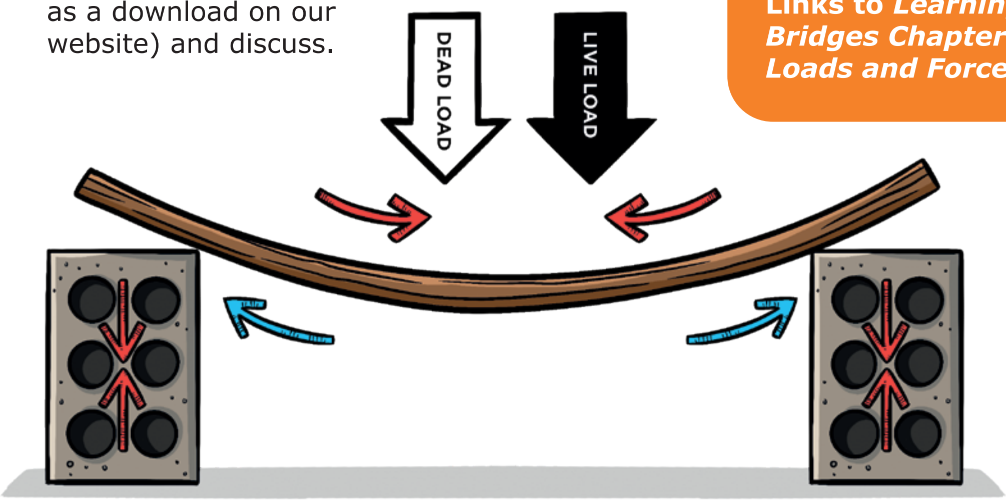
So there is tension in the beam of a beam bridge.

When a force is applied from above, the top of the sponge shows compression and the bottom of the sponge shows tension.

Look at *Forces in a beam bridge* handout (available as a download on our website) and discuss.

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

LINK



The forces in a beam bridge.

Given what has been explored in this section (and the previous chapters), discuss how an engineer might try to cope with these forces to make a beam bridge really strong.

Challenge Time!

What is the strongest bridge you can create with paper and sticky tape? Will you receive my certificate of bridge building mastery?

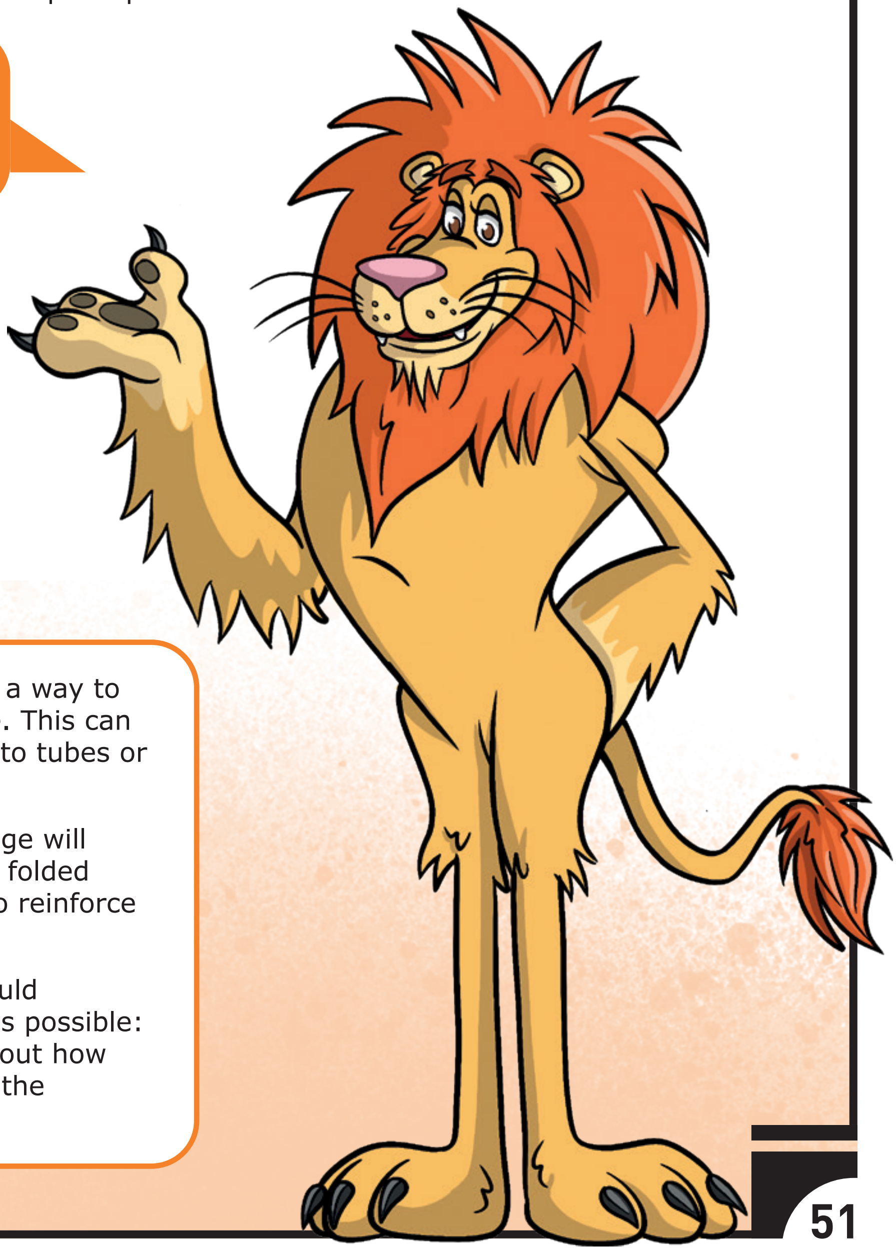
PAPER BRIDGE CHALLENGE

For your convenience, there is an illustrated step-by-step guide on the following pages.

1. Set up a testing zone by placing two chairs or tables 40cm apart.
2. Divide the learners into small groups of 2-3 people, if possible. Each group needs a ruler, 1 metre of sticky tape, 6 sheets of A4 paper, scissors and a *Bridge building challenge* handout. No other materials should be used, but you may wish to provide some pens/pencils and paper to help the groups design and test their initial ideas. Instead of 1 metre of sticky tape, you may find it more convenient to use dispensers of pre-cut sticky tape strips.
3. Give the groups a short time (10 minutes) to discuss and plan how they are going to make their bridge the strongest.
4. 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.
5. 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 items it was carrying just before it fell (i.e. do not count the last one).
6. 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?

Links to *Learning About Bridges Chapter Aii: Loads and Forces* and *Chapter Bi: Beam Bridges – The First Bridge*

7. After the learners' first attempts have been tested and discussed, you can then lead them, step-by-step, through one possible solution which gives a good result. See the following pages for an example solution, either using the resources or by hand. Reinforce that this is not the only solution; learners should try to apply what they have learnt rather than entirely copying the example.
8. Give the teams 3 more sheets of paper and a very short time (5 to 10 minutes) to make 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.
9. The winning team is the one whose bridge holds the highest number of items.
10. Certificates available in the Handouts pack at **www.rochesterbridgetrust.org.uk** can be printed and presented to participants.



The key to this challenge is to find a way to make the paper as stiff as possible. This can be achieved by rolling the paper into tubes or folding into a concertina.

The weakest part of the paper bridge will be the joints between the tubes or folded sections. Encourage the learners to reinforce the joints as much as possible.

Every part of the paper bridge should contribute to making it as strong as possible: encourage the learners to think about how each piece of paper contributes to the strength of the bridge.

A STEP-BY-STEP SOLUTION FOR THE BRIDGE BUILDING CHALLENGE

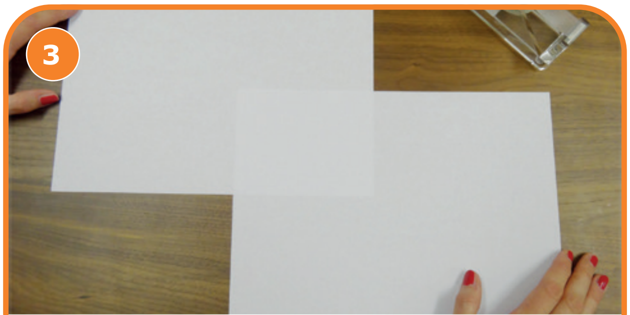
1

Set up a testing zone by placing two chairs or tables 40cm apart.

2

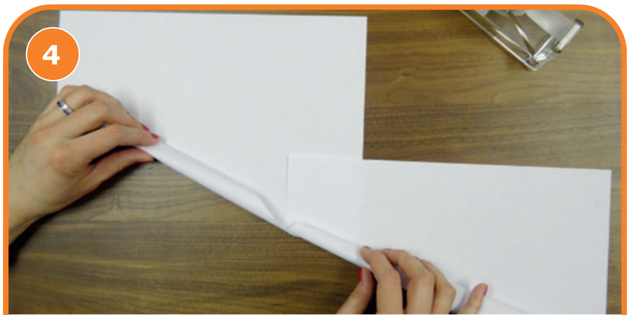
Materials: 6 sheets of A4 paper, 1 metre of tape, scissors and a ruler.

3



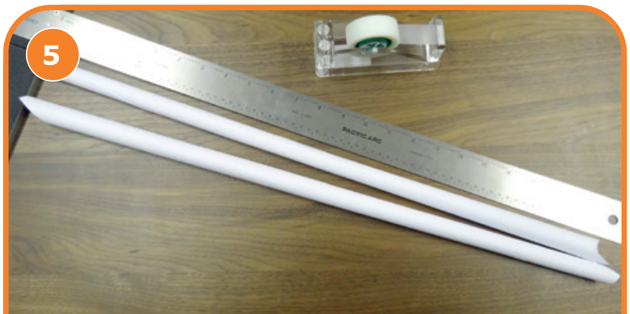
To make two beams: Place 2 sheets of paper over each other so the corners overlap.

4



Roll the sheets into each other, ensuring that the total length of the tube is 55cm.

5



Repeat the process to make 2 tubes (beams) which are each 55cm in length.

6

Bend each beam approximately 5cm from each end.

7

Tuck the ends of one beam into the ends of the other beam. Tape together.

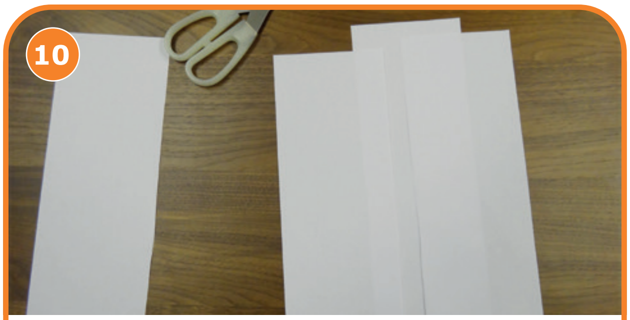
8

The result is a rectangle made of your beams.

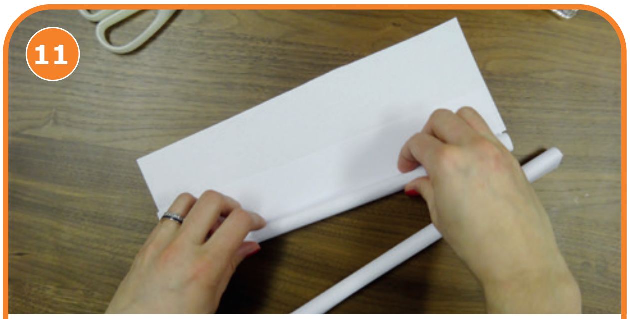
Photos courtesy of Guy Fox Limited

A STEP-BY-STEP SOLUTION FOR THE BRIDGE BUILDING CHALLENGE

9 Take the remaining 2 sheets of paper and cut in half lengthwise.

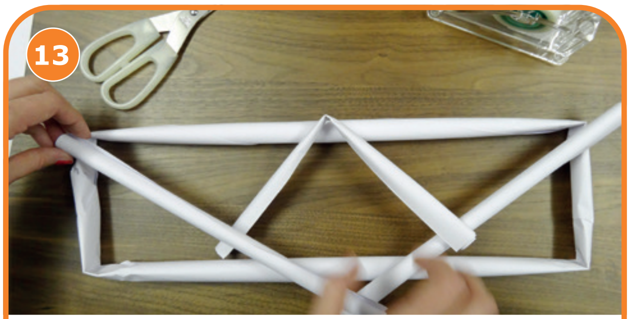


10 Set aside 1 strip to use as the deck; the other 3 strips will be used for secondary beams.



11 Make 3 secondary beams: Roll up each strip to make a tube. Tape to secure each beam.

12 Fold one beam in half; leave the other 2 beams straight.



13 Attach the secondary beams to the main beam and secure with tape.

14 Attach the secondary beams to the main beam and secure with tape.

15 Attach the secondary beams to the main beam and secure with tape.

16 Your beam is almost ready!

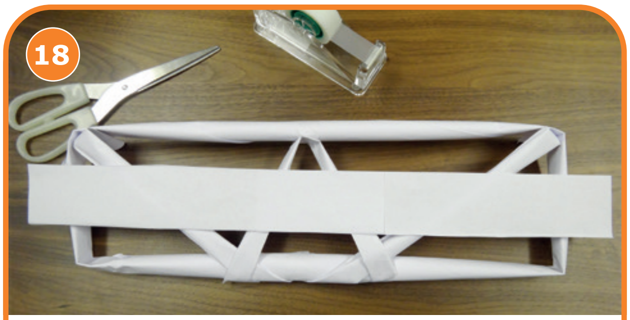
Photos courtesy of Guy Fox Limited

A STEP-BY-STEP SOLUTION FOR THE BRIDGE BUILDING CHALLENGE

17

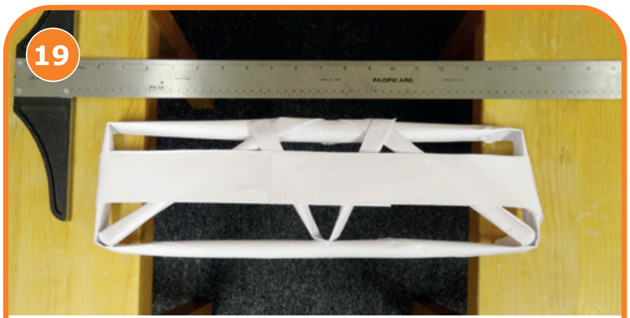
Find the strip that set you aside in Step 10 and cut it lengthwise. It's going to be the deck.

18



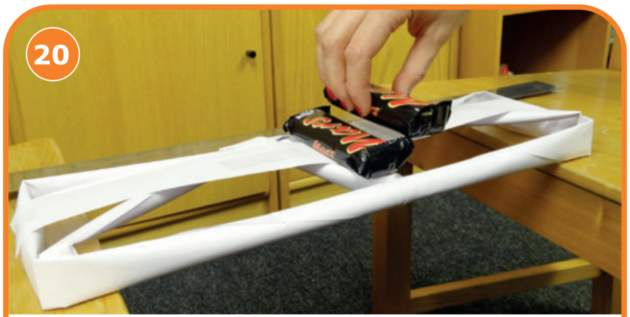
Tape the strip to the beam.

19



Now it's time to test your bridge! Place it in your testing zone.

20



Load your bridge with Mars Bars (or other masses), placing them evenly on your deck.

21

See how many Mars Bars you can put onto your bridge before it collapses.

22

When it collapses, you can see the weak points and make adjustments by adding more tape.

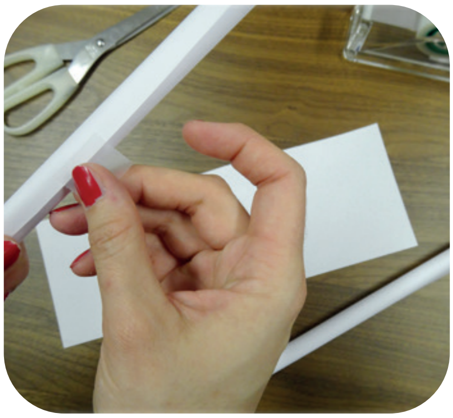
23

Make adjustments and then try again. See if you can build a stronger bridge!

Photos courtesy of Guy Fox Limited

Why are circular tubes so strong?

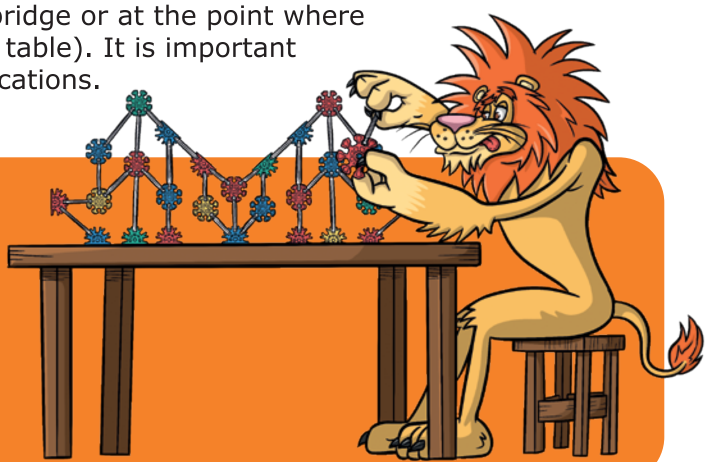
Tubes are strong because they are difficult to bend. Try folding one piece of A4 paper like a fan and rolling another piece of A4 paper into a tube. Which one is more difficult to bend?



The rolled piece of paper is much more difficult to bend. This is because tubes have both rigidity and depth. As you increase the diameter of the tube it gets weaker/easier to bend. This is because the paper becomes less curved or flatter and the number of layers of paper decreases.

Why is the type and location of each connection important?

Connections are often the weakest point in a bridge. The highest forces in a bridge are generally at the centre of the bridge or at the point where they meet the abutment (in this example, the table). It is important that weak connections are avoided at these locations.



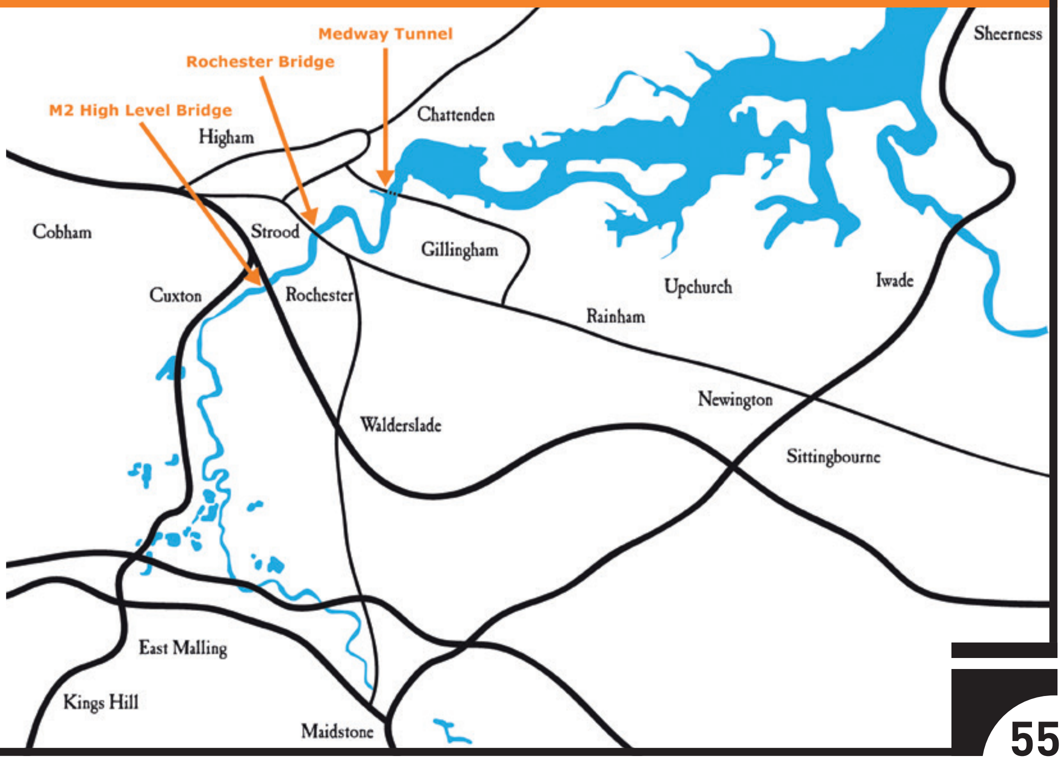
Just 4 Fun

You could also try building a real life beam bridge in an outside space. If you can get a plank of wood, some old car tyres or bricks, you can demonstrate the simplest beam bridge. Ask learners to consider how they could make it more stable or safer in any way.

HOT TOPICS!

You could find out about the history of Rochester, including reasons why the town built up at this part of the River Medway.

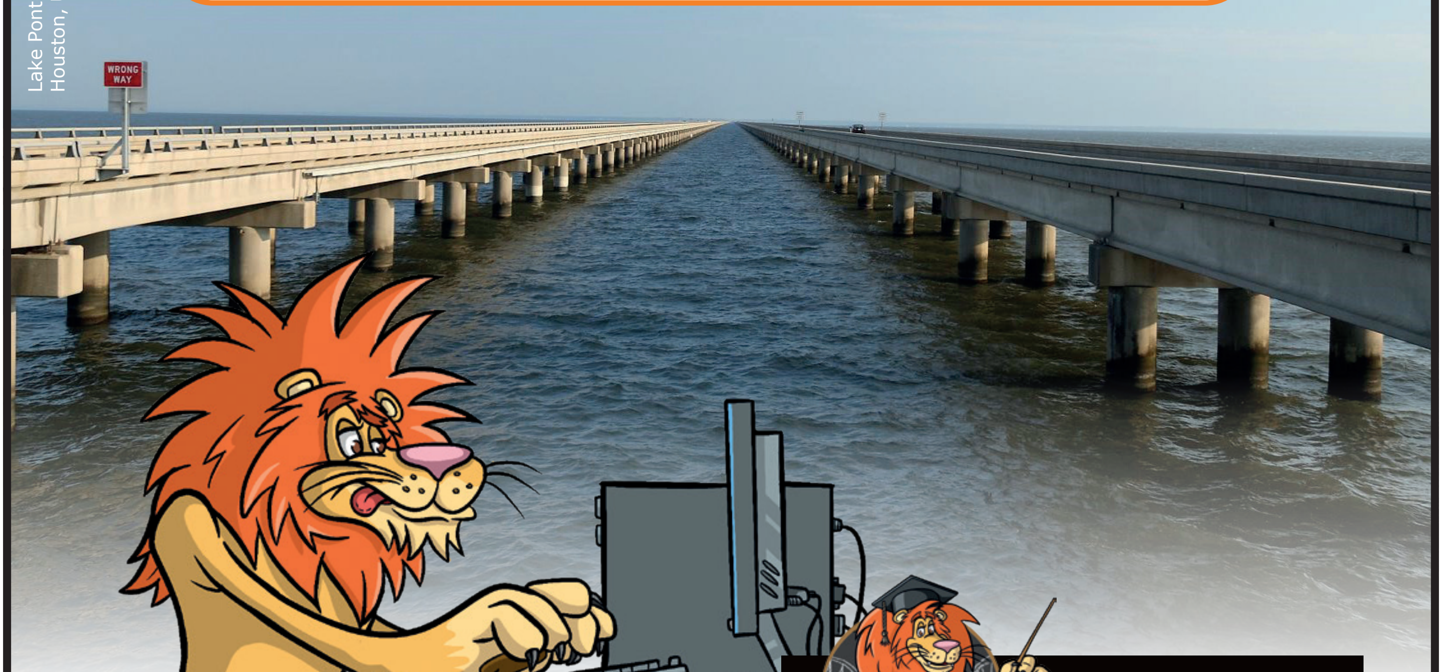
Perhaps you could research a local town or area around a river near to you, if you live elsewhere.



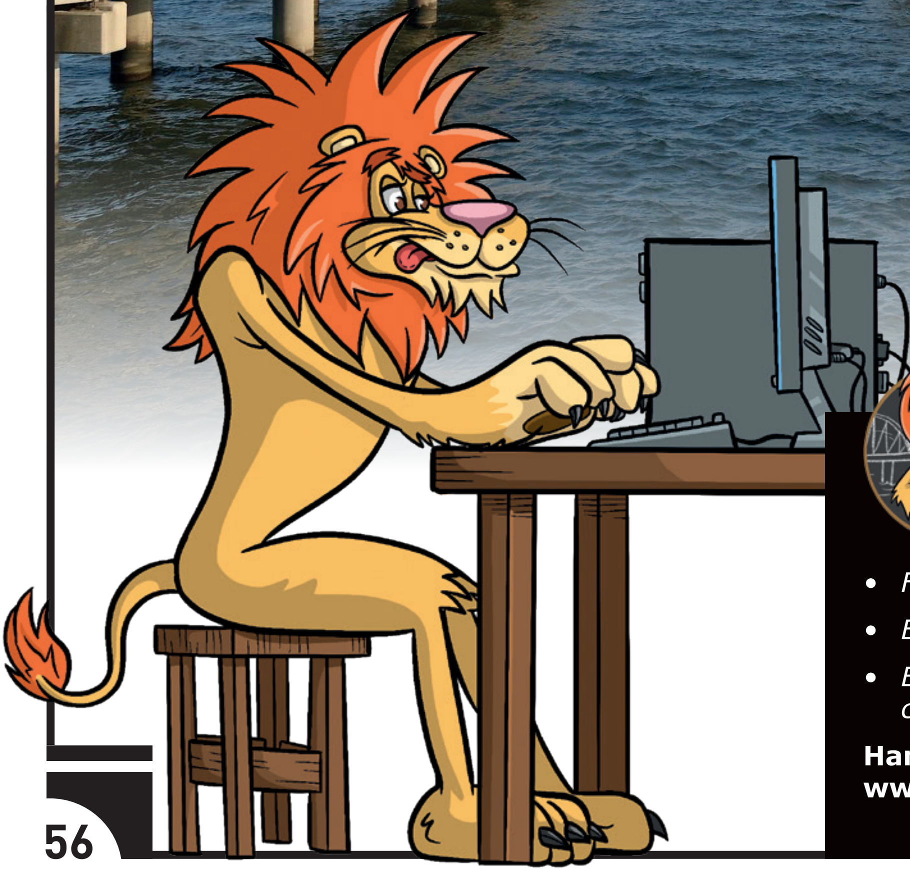
Beam bridges are simple, but strong: they balance the loads and forces to stay standing. When you are in your local area, take a look at structures around you – it could be bridges, but perhaps they are tall buildings, tunnels or famous landmarks? Think about how the structures stay standing: what forces are acting on them, how do they balance those forces? Remember, forces are found in pairs.

DID YOU KNOW?

The Guinness Book of World Records had to clarify their definition of 'world's longest bridge over water' in 2011, when the Jiaozhou Bay Bridge was opened, and China claimed that this was longer than the previous world record holder, the Lake Pontchartrain Causeway in southern Louisiana. The organisation decided to split the title into separate categories: the world's longest continuous bridge over water, and the world's longest aggregate bridge over water – the Jiaozhou Bay Bridge is actually made up of land bridges and sea tunnels. The world's longest continuous bridge over water remains as the Lake Pontchartrain Causeway.



Lake Pontchartrain Causeway (Photo by Glenn from Houston, USA via Wikimedia)



Langdon presents:

- *Forces in a beam bridge* handout
- *Bridge building challenge* handout
- *Bridge building challenge certificate*

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

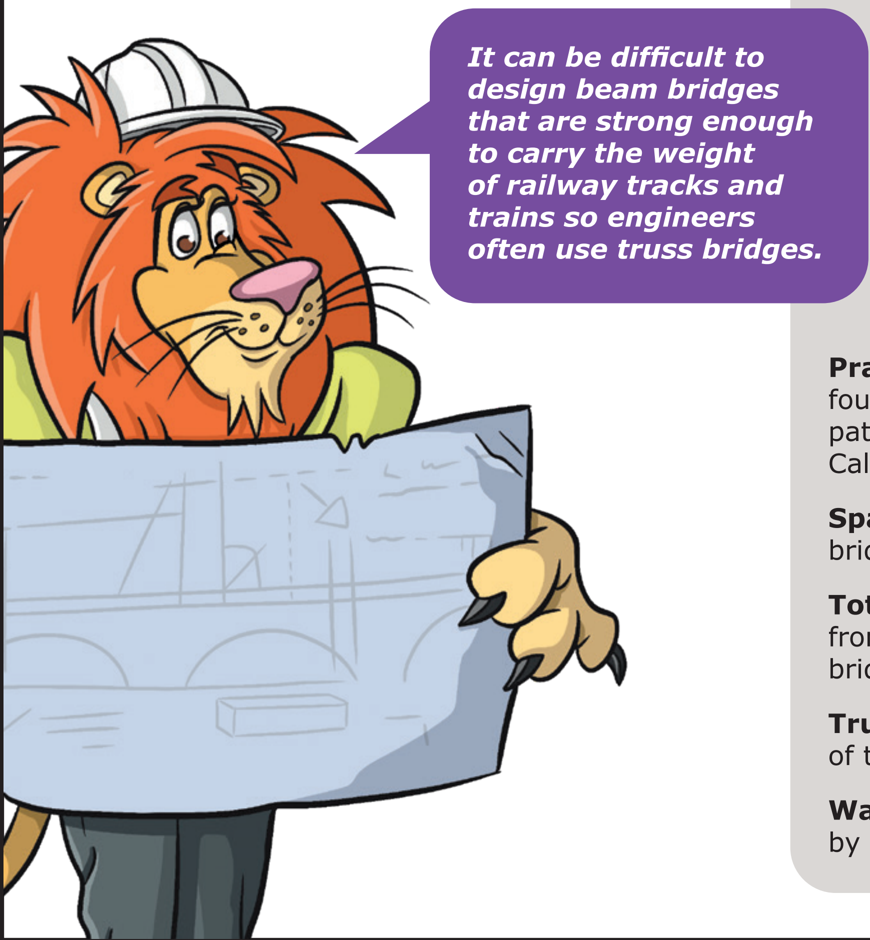
Chapter C: Truss Bridges – What is a Truss?

AIMS & OBJECTIVES

- To understand that triangles are the strongest shape for building bridges
- To explore truss bridges
- To learn the terminology for truss bridges

CONTEXT

Truss bridges are one of the oldest type of modern bridge and were widely used throughout the 19th century, especially for railway bridges. They are economical to construct because they make efficient use of materials. Initially they were made of timber but gradually iron and steel came to be used. It is relatively straightforward for engineers to calculate the forces in a truss bridge.



LANGUAGE OF BRIDGES:

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

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

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

Bowstring Truss: this was patented in 1841 by Squire Whipple. The Old Bridge at Rochester is a bowstring shaped truss.

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

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

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

Piers: the upright columns that support the bridge.

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

Span: the distance between bridge supports.

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

Truss: a bridge designed with lots of triangle shapes.

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

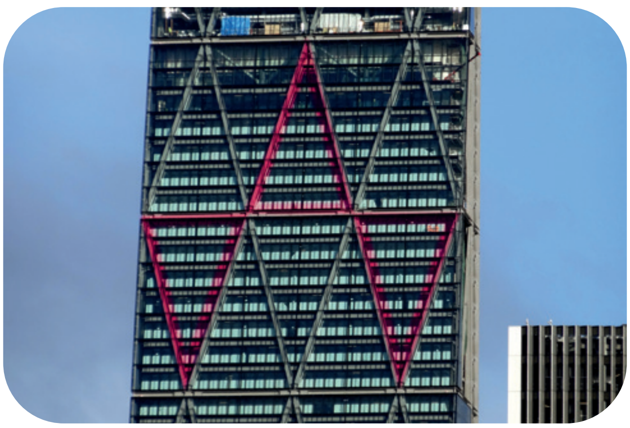
You will need...

- Strong shapes, for each learner/pair:
  - 7 identical lengths of card with a hole punched in each end (30cm x 3cm)
  - 1 longer piece of card which will fit across the diagonal (43cm x 3cm)
  - 7 paper fasteners
- Exploring truss bridges, for each group:
  - K'Nex® Education Introduction to Structures – Bridges set
  - Handout: *Truss bridge terminology*
  - Handout: *Describing truss bridges*
  - Handout: *What is this truss?*
- Truss construction challenge, for each group:
  - Art straws (minimum 12 in total per group)
  - Washi (paper-based crafting) tape
  - Masses (such a coins or washers)
  - Handout: *Truss bridge challenge order form (optional)*

Something to Try:

How can shapes make a bridge strong?

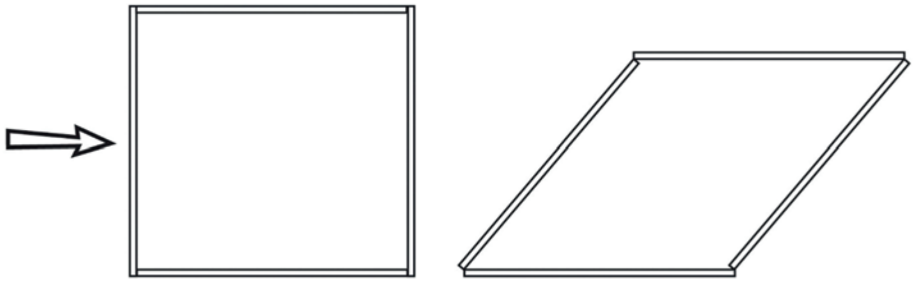
Ask the learners if there are any similarities between the structures in the following images:



Photos courtesy of Guy Fox Limited

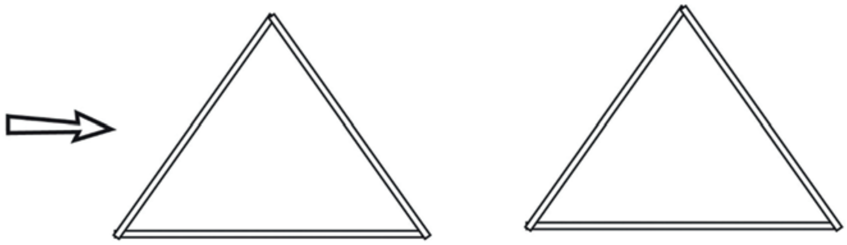
All of the structures include a combination of triangle shapes.

With learners working in pairs, if possible, make a square from four strips of card of the same length and some paper fasteners. When completed, ask learners to hold the square with one side resting on the table and test it by pushing and pulling on any side of it. They will see that the square immediately loses its shape and becomes a diamond. It is not a rigid shape.



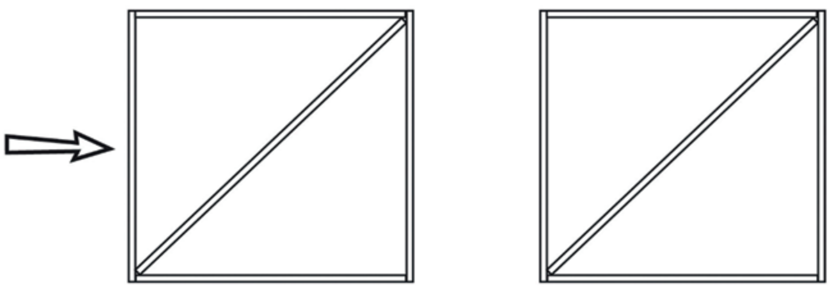
Next, ask learners to make a triangle (with equal sides) in the same way. When they push or pull the sides, they will see that the triangle holds its shape.

Triangles do not twist, bend or collapse easily in comparison with rectangles or other shapes. A triangle is the only shape that cannot be pushed or pulled out of shape without changing the length of one of the sides. This is because the load/force applied is distributed equally to all of the points, and the points cannot rotate: it is a rigid shape.

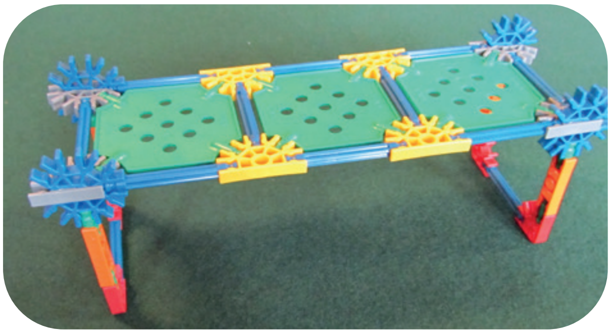


Ask learners how they could make the square stronger.

Encourage learners to add one strip of card across the diagonal of the square and fasten it with the paper fasteners. Again, test the shape to see how much stronger it has become by making it into two triangles.



EXPLORING TRUSS BRIDGES

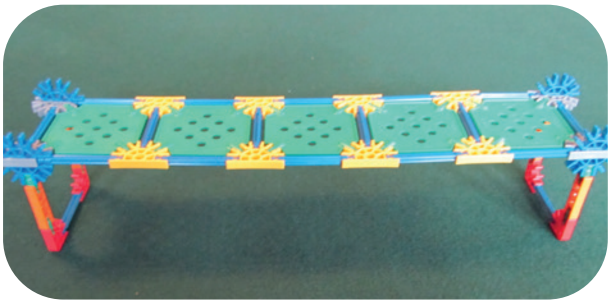


In small groups of 3 or 4, ask learners to construct a simple beam bridge using 3 deck slabs of K'Nex®.

Push gently on the centre and show that this is a strong structure.

Links to *Learning About Bridges Chapter Bii: Beam Bridges – Simple but Strong*

LINK



Extend each beam bridge to 5 deck slabs.

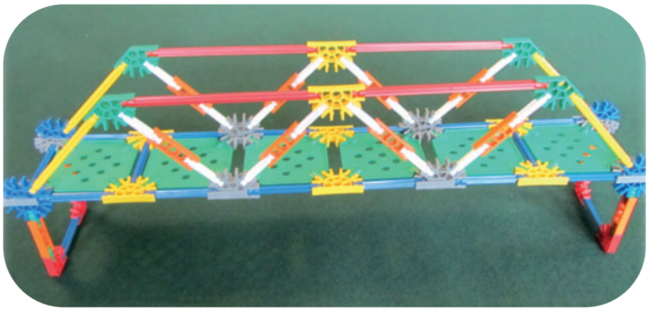
Again, push gently on the centre. Notice that the long bridge is much more bendy in the middle and not as strong as the short bridge.

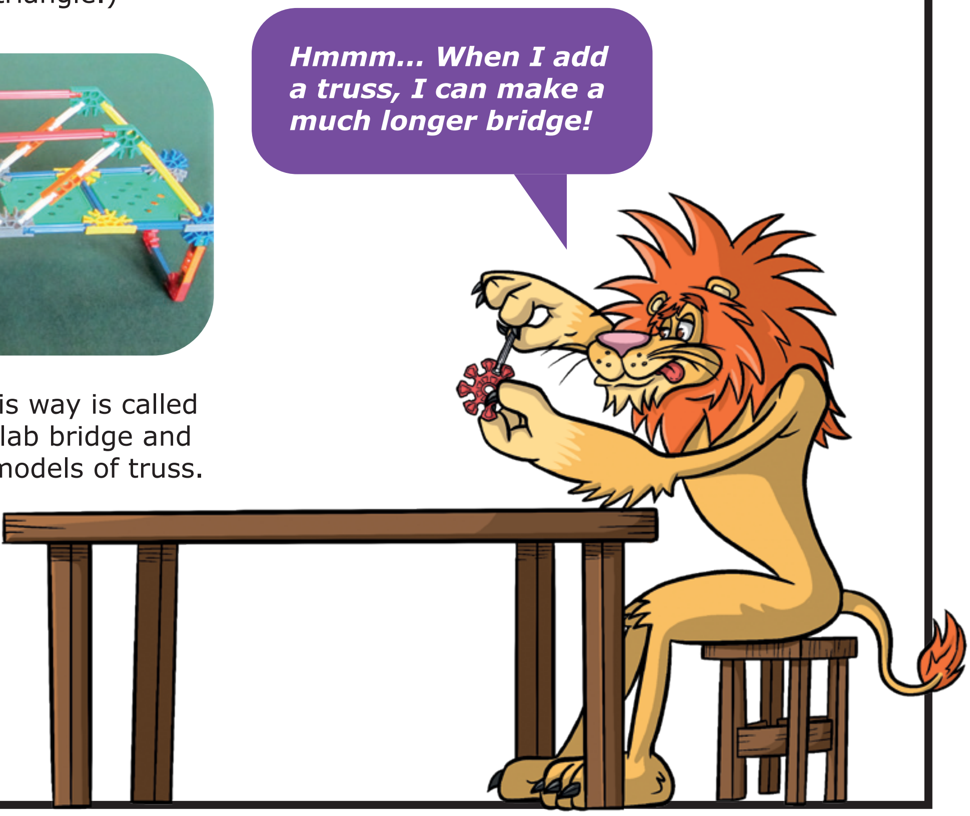
Ask learners to consider the problems this might cause, and the limitations of beam bridges. The beam bridges are great for short distances, but what if you want to span a longer distance? As they get longer, beam bridges get weaker.

Ask learners how they might make the bridge stronger?

One way would be to make the deck thicker/to stiffen the deck. What would be the problem with doing this? It could make the deck very heavy and increase the load on the bridge.

Is there anything else we know that could increase the strength of a structure? What is the strongest shape? (Answer: the triangle.)



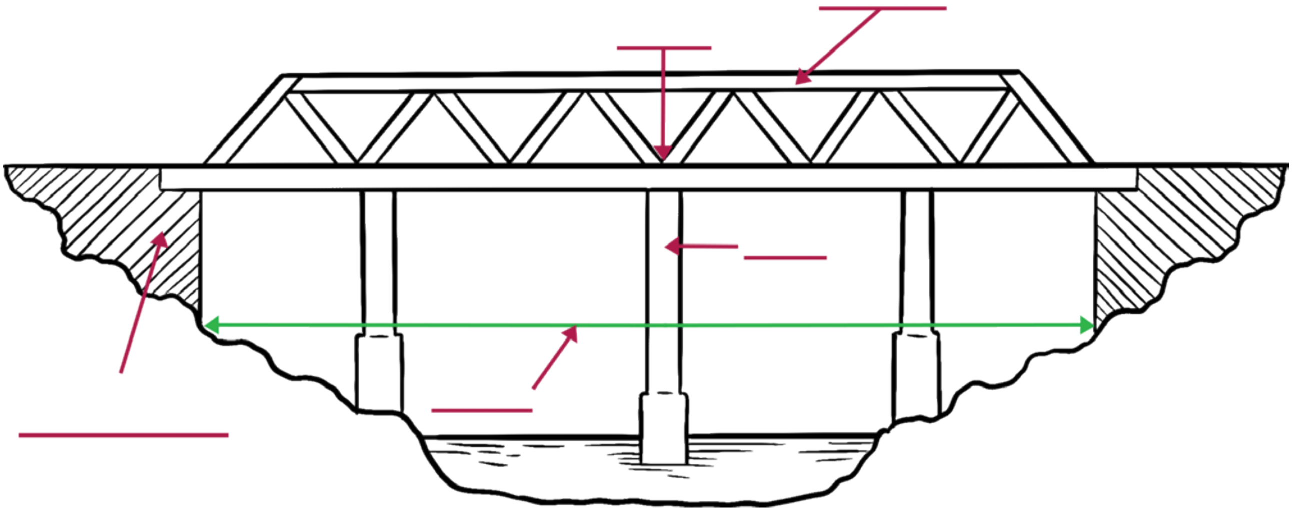


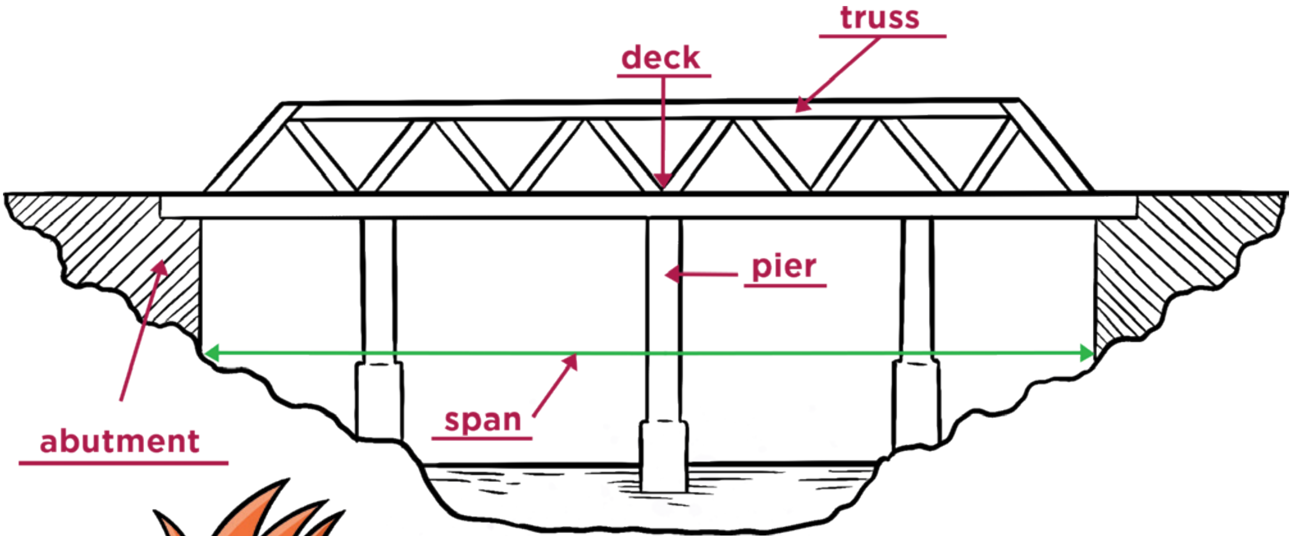
A bridge made of triangles in this way is called a truss bridge. Use the 5 deck slab bridge and add triangles to build different models of truss.

There are lots of different ways to arrange the triangles. Some ideas are provided in the K'Nex® kit, or you could experiment.

LABELLING THE TRUSS BRIDGE

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





TYPES OF TRUSS BRIDGE

Almost every combination of triangles was used in truss bridges from 1800 to 1900. The *Describing truss bridges* handout has lots of examples. Each design has a name, usually after the first person to design that shape, or the place where it was first tried or sometimes using a description of the shape itself. The way engineers describe a truss bridges is based on the arrangement of the parts of the truss.

Challenge learners to identify the type of truss used in some real bridges, using proper terminology, with the *What is this truss?* handout.

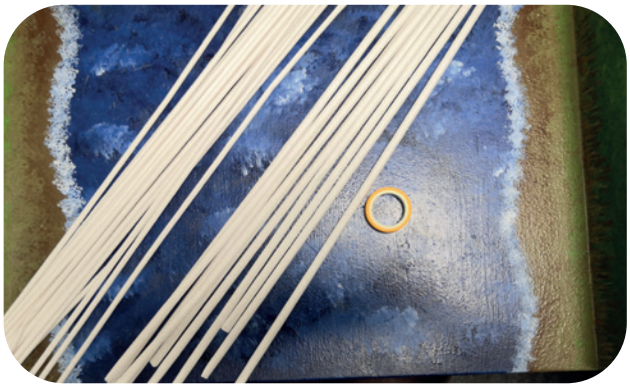
Answers:
A - Baltimore Truss
B - Warren Truss
C - Pratt Truss
D - Warren Truss

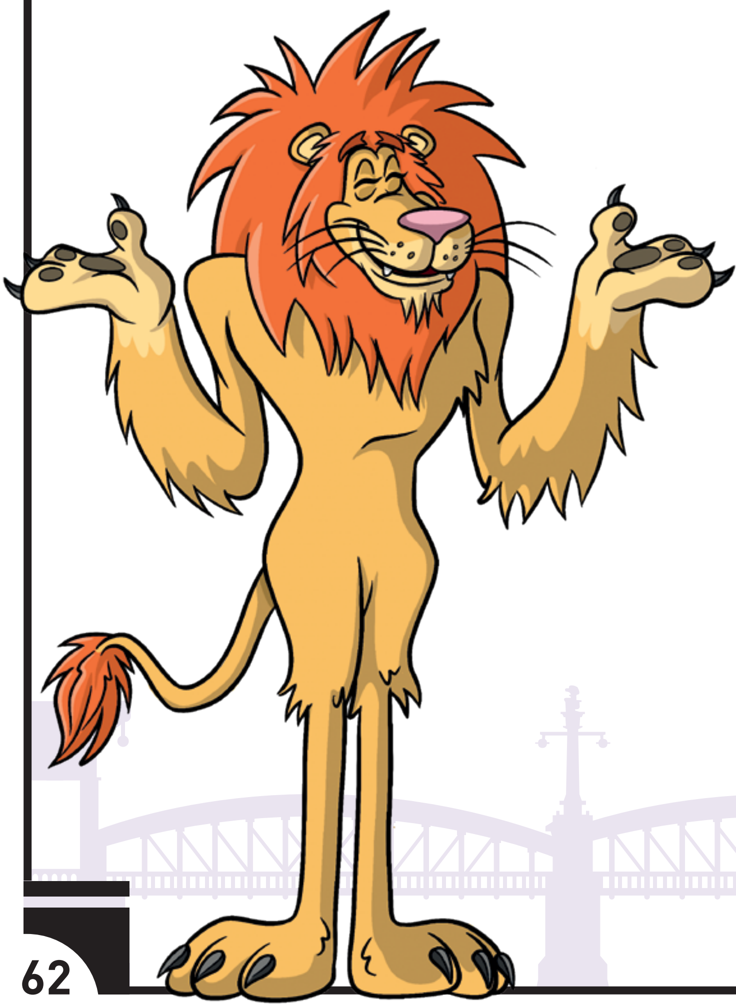
Challenge Time!

CHALLENGE

TRUSS BRIDGE CONSTRUCTION

Give each group the art straws and Washi tape. Challenge them to build a bridge using one of the main truss types from the *Describing truss bridges* handout. The bridges can then be tested with the masses.





Your learners will need to think about how the loads and forces are distributed and how the trusses work.

THINK LIKE AN ENGINEER

For an additional challenge, you could set them a budget and create a materials price list for the paper straws and lengths of tape. They then need to think like an engineer and make sure they purchase sufficient materials to create a strong truss bridge, without going over their budget. You could use the *Truss bridge challenge order form* handout for this.

SCIENTIFIC ENQUIRY

As your learners build, invite them to consider how they communicate their ideas using the correct scientific language. Help them to see that making observations about the way their structure behaves is developing scientific enquiry skills.

You could invite learners to build a truss bridge by gluing wooden lollipop sticks together to form equilateral triangles. Once the glue has fully dried, you can test the strength of the bridge using masses.

Triangles form a particular type of fractal called a Sierpinski Triangle. You could use this repeating pattern of triangles to build a tree. Search the internet for "How to make a Sierpinski Christmas Tree" to find out how.

HOT TOPICS!

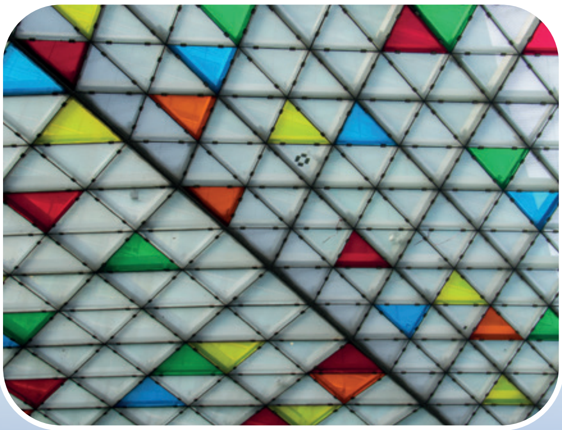


Photo by Nick Fewings on Unsplash

A tessellation (or tiling) is when a surface is covered with a pattern of flat shapes so there are no overlaps or gaps. Triangles are one of the few shapes that form a regular tessellation pattern (squares and hexagons are the others). Tessellation is found repeatedly in architecture. You could explore forming tessellations with different shape combinations, or instead be inspired by tessellations from great works of architecture, the art of MC Escher or in nature to create your own art.

Photo by Andrés Yves on Unsplash

Photo by Safdar-Hussain on Unsplash

HOT TOPICS! MATHS

A geodesic dome is a combination of triangles to form a sphere – arches are parts of spheres and are strong shapes in bridges. You could explore geodesic domes and even build a model, either using toothpicks and marshmallows to form the triangles, or make triangles out of paper straws, before joining them together.

Once you start looking for truss bridges, it's surprising how many you'll see!

OUT & ABOUT

Try to spot a truss bridge in your local area. Take a photo (if it is safe to do so) and identify the parts using the correct terms. What type of truss bridge is it? What is the bridge used for?

If you can't find one locally, try looking on the internet to see if you can find truss bridges around the world. Can you identify the type of truss bridge?

DID YOU KNOW?

There is actually a truss bridge that doesn't have any triangles! Called a Vierendeel truss, it relies on having a very rigid frame instead of the diagonal bracing in the usual trusses.

Vierendeel Truss (Photo by Ben Titze via Wikimedia)

Langdon presents:

- *Truss bridge terminology* handout
- *Describing truss bridges* handout
- *What is this truss* handout
- *Truss bridge challenge order form* handout

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

Chapter Di: Arches – The Science of Arches

AIMS & OBJECTIVES

- To introduce the arch bridge
- To learn that one way to make bridges stronger is to dissipate the forces

CONTEXT

Arches can be seen all around us. Gates, doors and windows are often shaped like arches. This is because an arch is considered to be one of the most beautiful shapes to build with and it is certainly one of the strongest. When the arch was first introduced in ancient times it was a great leap forward. Before the arch, there were mostly beam bridges but building the necessary piers in water was hard and it could be difficult for boats to pass underneath. Arch bridges solved this problem because they can be built higher than beam bridges, allowing tall boats to pass underneath.

LANGUAGE OF BRIDGES:

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

Arch: semi-circular curved structure.

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

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

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

Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

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

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

You will need...

- Handout: *Arch bridge terminology*
- Handout: *Forces in an arch bridge*
- Handout: *Arch bridge shapes template*
  - Scissors
  - Pens/pencils
- Exploring arch strength, per group:
  - Thick card (enough to cut into at least one 5x35cm strip, one 5x25cm strip and two 5x10cm strips as a minimum)
  - Scissors
  - Sticky tape
  - Ruler
  - Heavy books/supports, to act as abutments
  - Coins/washers/small masses as loads for testing

Something to Try:

INTRODUCING ARCH BRIDGES

Ask the learners to hold hands and lean out until they achieve balance. Encourage them to feel the tension in their arms.

TENSION

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

Ask the learners to stand up in pairs facing each other with palms together to form a human bridge. Ask them to feel how much they need to push to make their bridge balanced, strong and steady.

Now ask them to (carefully) gradually increase the span by moving their feet further apart until failure occurs. Encourage them to express the view that there is a limit to how long the span of the bridge can be.

COMPRESSION

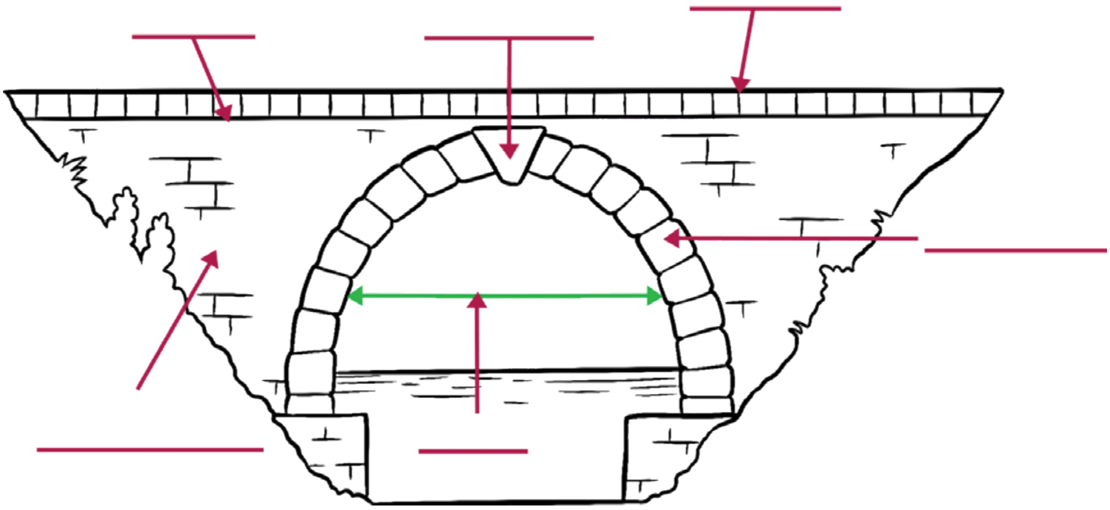
Now ask the pairs to join another pair, forming a group of four. Ask one pair to continue to create a human arch, by standing facing each other with their palms together, making the arch span as wide as possible without failing, while asking the other pair acts as abutments either side.

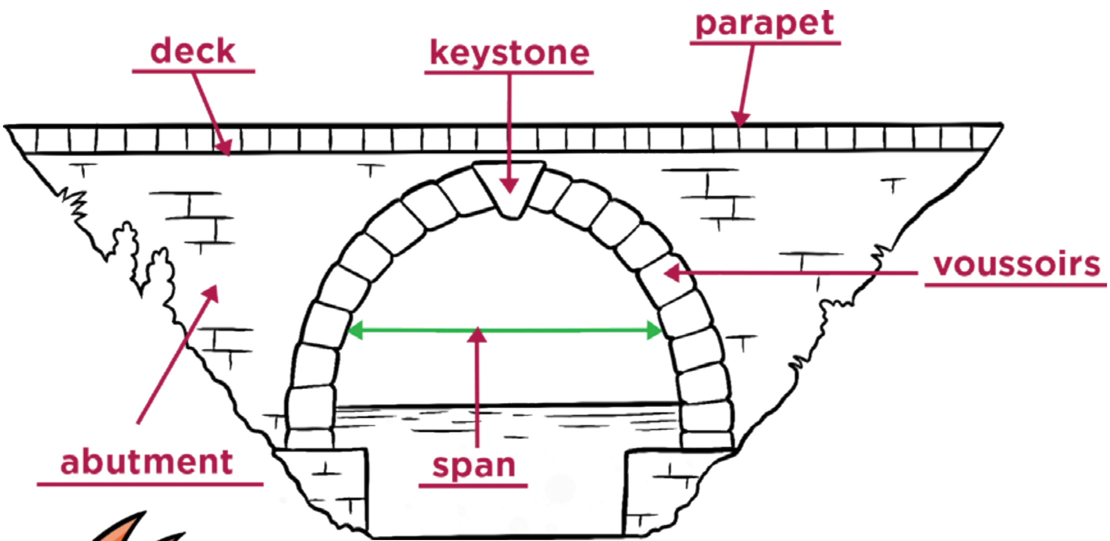
Ask the learners what they notice – can they make their arch bridge span even further?

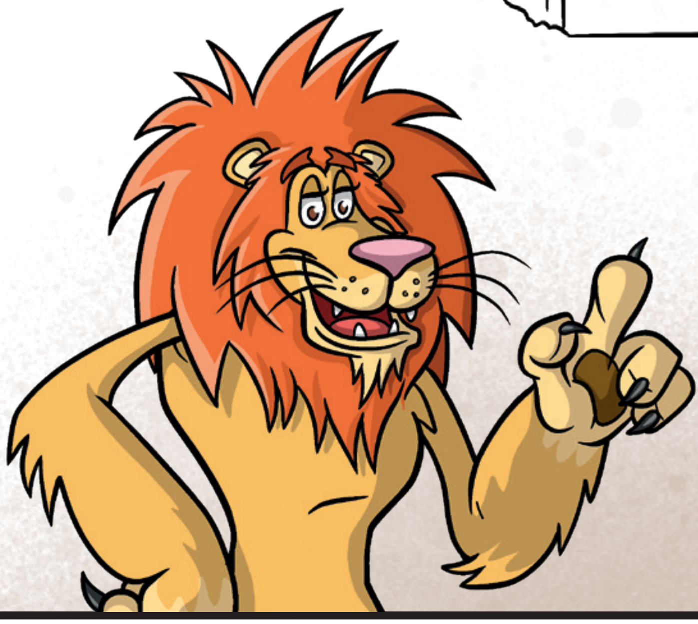
They should realise that by placing a firm object at the base of the arch, such as an abutment, the arch is able to reach further.

THE LANGUAGE OF BRIDGES

Give learners a copy of *Arch bridge terminology* handout, and ask them to try to label the different parts of an arch bridge.



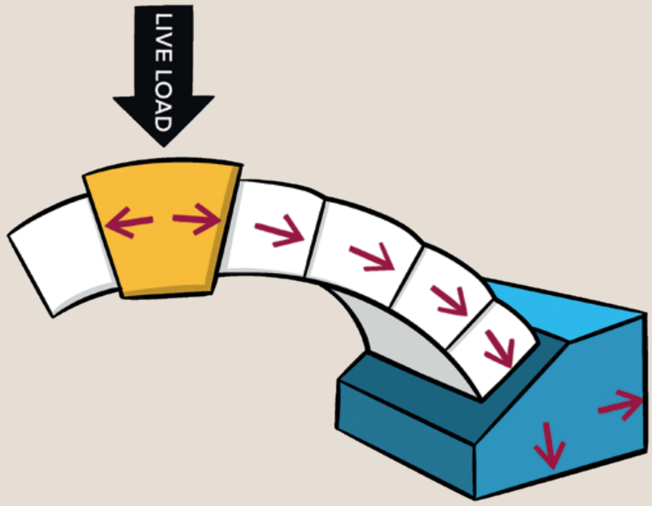




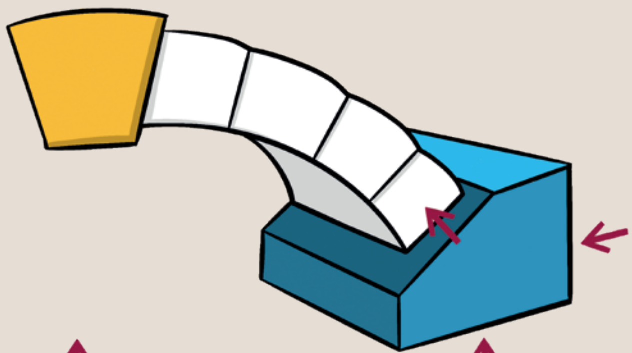
THE FORCES IN AN ARCH BRIDGE

Ask learners what they think is the main force in the arch. Explain that an arch bridge is always in compression. An arch bridge is stronger than a beam bridge because instead of pushing straight down, the load in an arch bridge is carried along the curve of the arch to the strong supports (abutments) at each end. The force is spread out or dissipated through the structure of the bridge (as shown in the *Forces in an arch bridge* handout).

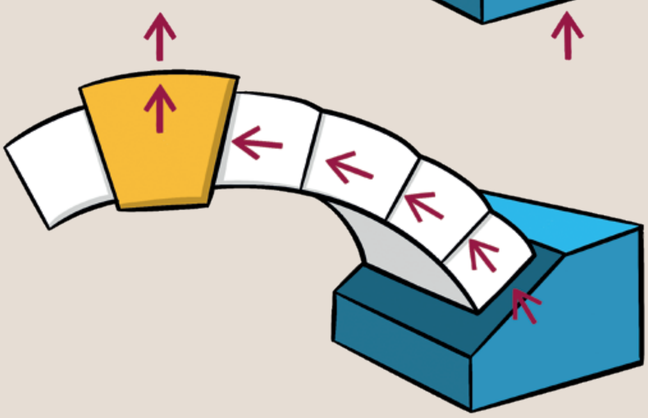
The load on the top of the **keystone** makes each **voussoir** on the **arch** of the bridge push on (**compress**) the **voussoir** next to it. This happens until the forces reaches the end **abutments** which are built into the ground.



The ground around the **abutments** is squeezed and pushes back (**compresses**) the **abutments**.

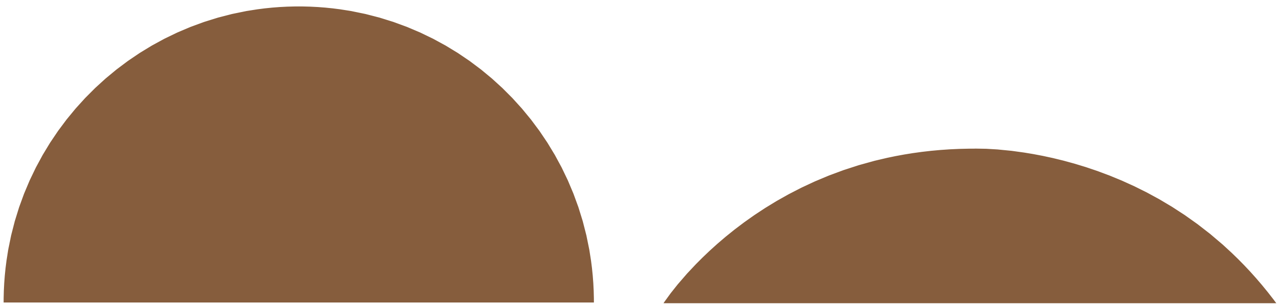


The **abutments** push back onto the **voussoirs** which pass the force back along the **arch** to the **keystone** which supports the load.

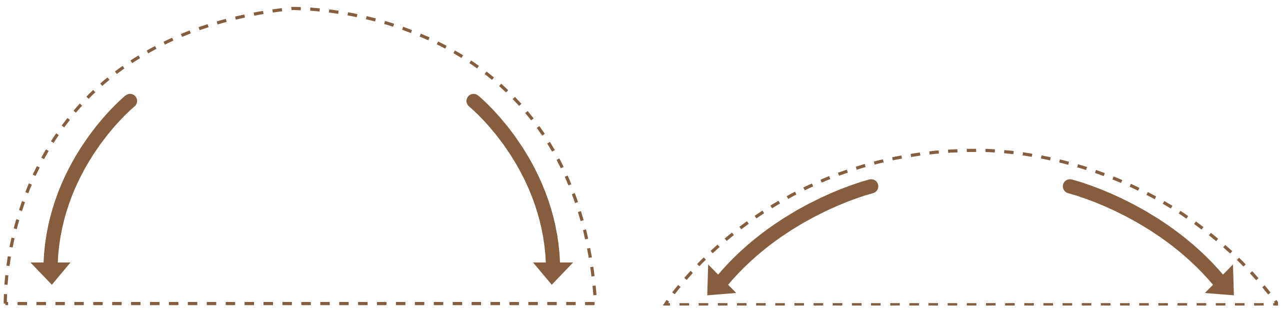


The earliest arches tend to be semi-circular. However, this limits the span of the bridge without building piers – if, for example, the river is too fast flowing for construction of piers, a semi-circular arch that crosses the wider span would have to be very tall and, as a result, very heavy. The weight could potentially put too much load on the abutments, and cause a collapse.

Using the *Arch bridge shapes template* handout, ask the learners to cut out the shapes and compare. If you compare the size and shape of the semi-circular arch and the shallower arch below, they both span the same distance, but the first arch is much taller.

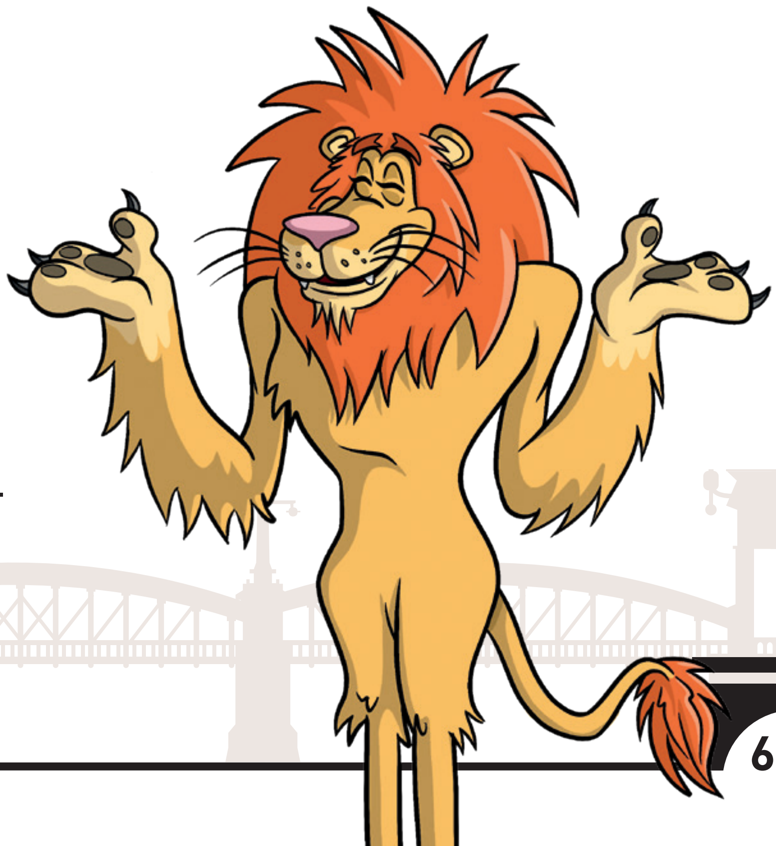


Ask the learners to draw force arrows on the shapes, as in the diagrams in the previous section.



Once learners have drawn their arrows, ask them what they notice about the pairs of arrows. They should identify that the semi-circular arrows are pointing downwards, but the shallow arch arrows are pointing out to the side.

Ask learners whether this would affect the abutments needed for the two types of arches. Which arch would need more support on the sides? The shallower arch. This is because some of the force is distributed to the sides, so the abutments would need to push back and resist this, stopping the arch from spreading outward.



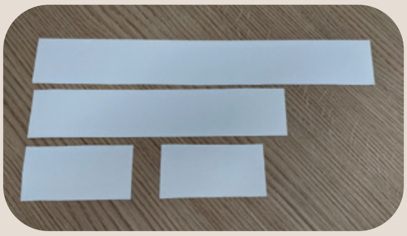
Challenge Time!

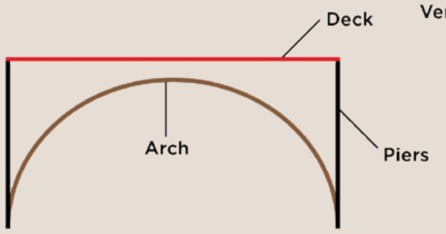
EXPLORING THE STRENGTH OF ARCHES

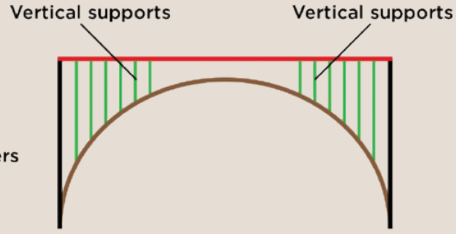
In this challenge, learners will explore the use of vertical supports in arches to strengthen bridges. Older masonry bridges usually have a series of stones creating the arch, with walls of stone to each side of them and up towards the deck and then filled. Modern bridges, of concrete or steel, often have a more open framework.

Each group should have sufficient materials to make at least one arch bridge.

For each arch bridge, the group needs one strip of card 5x35cm long, to form the arch; one strip 5x25cm long to form the deck, and two strips 5x10cm long to form two piers. Each group should either test the basic bridge, using only these components, or add a specific number of supports to test whether the supports increase the load-bearing strength of the bridge, and whether the number of supports increases the strength of the bridge proportionally.

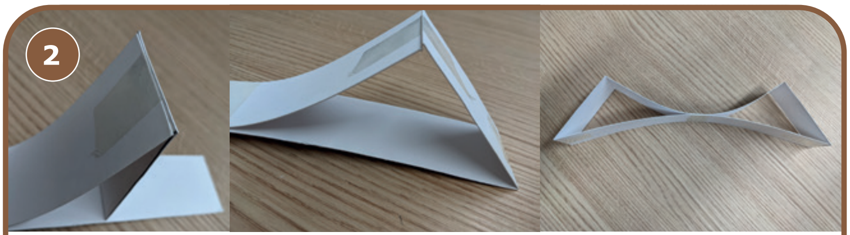




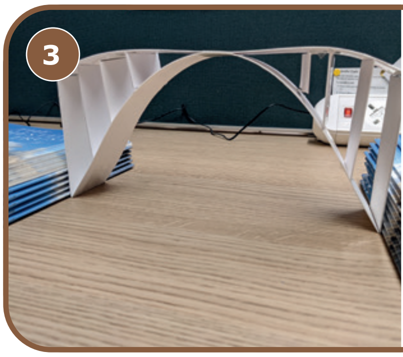


Depending on the number of groups you have, and the equipment available, you can increase the number of vertical supports to as many as can physically fit into the model.

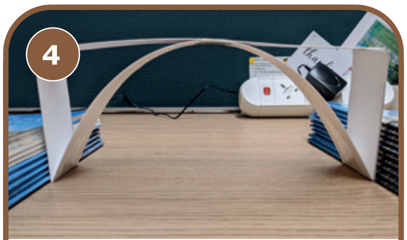
Tape the centre of the deck strip to the centre of the arch strip.



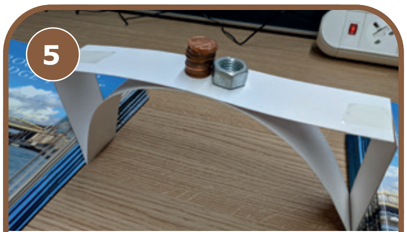
Tape a pier between the ends of the deck and arch at both sides. This will cause the longer strip to bend to form an arch shape.



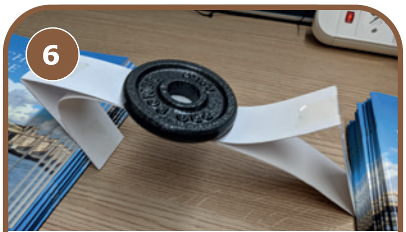
If vertical supports are to be added, tape the appropriate number of supports into position, parallel to the piers, and between the deck and arch strips. These should be symmetrical: if adding one each side, they should be as close to the same length and same position either side of the centre. If adding more than one support each side, they should be evenly spaced, and again symmetrical on both sides.



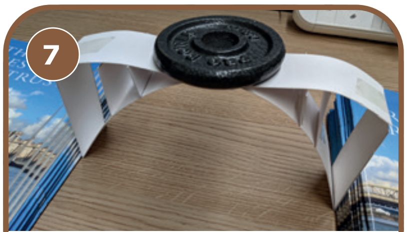
Place the arch between two large books on a table about 25cm apart (wide enough to fit the deck).



Add the small masses (coins, washers, paper clips) to the bridge, one by one, counting as they are added.



Take note of the number of masses in total required for the bridge to collapse.

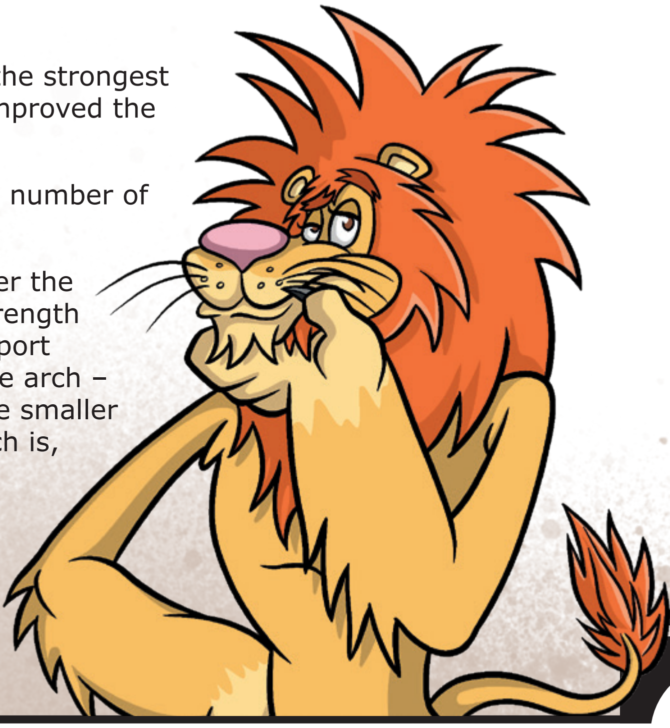


Now test each bridge with vertical supports added, recording the number of masses required to collapse each bridge in turn.

Ask the learners to describe which bridge was the strongest and why? Can they explain why the supports improved the strength of the bridge?

You could plot the results as a line graph of the number of supports on one side against the mass held.

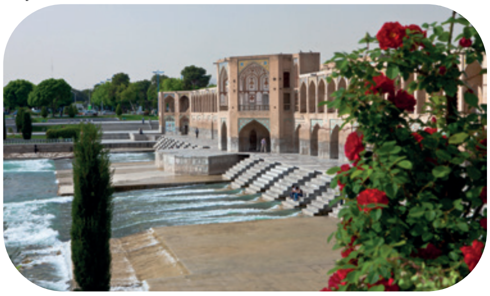
This demonstration should show that the greater the number of vertical supports, the greater the strength of the bridge. This is because each vertical support distributes the load from the deck down into the arch – the greater the number of vertical supports, the smaller each individual load on each support on the arch is, so it is spread out more. This is then dispersed into the abutments more effectively.



HOT TOPICS!

This is the Khaju Bridge, in Isfahan in Iran. It was constructed in around 1650.

It is a stone and brick arch bridge spanning the Zayandeh Rood. It is adorned with brightly coloured tiles and 17th century artwork. This could be used as inspiration for creating geometric shape mosaics or similar artwork.



Khaju Bridge (Photo by Ninara via Wikimedia)

MAKING EDIBLE ARCHES

Using bitesize cake pieces from the supermarket, or making your own, can you build an arch?

Try using a whole peeled banana, cut it into voussoir shapes. You can then use toothpicks to try to secure the pieces together.

When walking around, can you spot any arches or domes which are a form of arch in other structures, not just bridges? Can you research different arch-containing structures from around the world? How old are they and who built them?

DID YOU KNOW?

The term voussoir comes from the Old French word which means to turn and was likely related to stone masonry.

Langdon presents:

- *Arch bridge terminology* handout
- *Forces in an arch bridge* handout
- *Arch bridge shapes template* handout

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

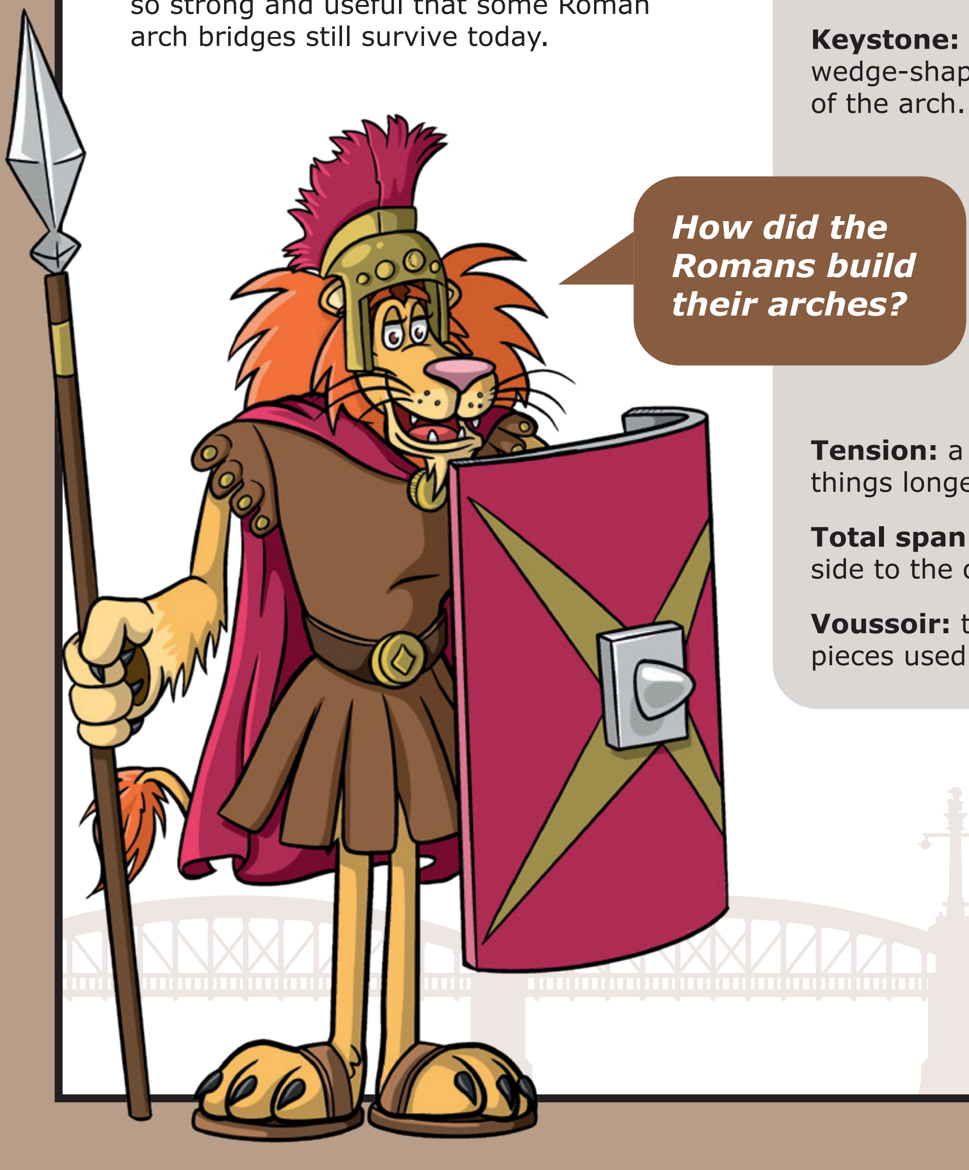
Chapter Dii: Arches – Ancient and Strong

AIMS & OBJECTIVES

- To recognise that centring was an important part of Roman arch building
- To demonstrate understanding by building an arch bridge

CONTEXT

The Romans specialised in the use of arch bridges. They joined them together to make long road bridges called viaducts and sometimes placed them on top of each other to make aqueducts to carry water over the valleys. Their arches were so strong and useful that some Roman arch bridges still survive today.



LANGUAGE OF BRIDGES:

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

Arch: semi-circular curved structure.

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

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

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

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

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

Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

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

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

You will need...

- Handout: *Roman bridges*
- Arch Building Kit(s)
  - Large Arch Bridge Demonstration Kit (This can be borrowed from the Rochester Bridge Trust for schools local to Rochester. Email education@rbt.org.uk)
  - Small Arch Bridge kits (These can be borrowed from the Rochester Bridge Trust by local schools by emailing education@rbt.org.uk, or can be purchased online, search for Montessori Roman arch kits)
- Roman bridge building, per group:
  - Large cylinder (such as a Pringles® crisp tube)
  - Play-doh®, plasticine, modelling clay, or air-drying clay
  - Stones or pebbles of a similar size
  - Newspaper or covering to protect the work surface
  - Cardboard (optional, to act as a base if using air-drying clay)

Something to Try:

Arches are incredibly strong and were one of the earliest types of bridges constructed. They can often be found naturally occurring, with rock having been worn away by the elements. The earliest human-made arch structures can be found in ancient stone structures, such as tombs, where two large stones are placed diagonally against each other, creating an opening beneath.

The Romans were gifted engineers and built structures unrivalled for many centuries...

EXPLORING ROMAN ARCHES

The Romans realised that to build an arch bridge they would first have to build some wooden supports called centring. The centring was a bit like modern scaffolding. Once the centring was complete, they could start to add the specially shaped stones called voussoirs. Each voussoir is shaped like a wedge. The stone in the middle of the arch is called the keystone and is the most important part. It acts like a key to lock the other stones together. Without the keystone the arch would collapse. Only once the keystone had been put in place could the Romans remove the centring.

To see an animation depicting the 14th century construction of the Charles Bridge in Prague, search "Charles Bridge construction" on YouTube. Although this is much later than the Roman period, the technique is essentially the same.

Links to *Learning About Bridges Chapter Di: Arches – The Science of Arches, Forces in arches*

LINK

Ask learners to look at the *Roman bridges* handout. Ask them to name the different features in some of the famous arch bridges, using the correct terminology.

Pont Flavien, France (Photo by Tanis13 via Wikimedia)

Alcantara Bridge, Spain (Photo by Dantla via Wikimedia)

Pont du Gard, France (Photo by Beth Lieu Song via Wikimedia)

Using the arch kits, encourage learners to work out how to build a strong and stable bridge using the pieces provided. Test the strength of the bridge by applying a load to the top, and test its weakness by removing a piece from underneath. Learners may realise that an arch bridge is very weak until it is complete. The centring is vital to hold it all up during construction, which means engineers have to build this type of bridge twice – once for the centring/falsework and again in the final material for the bridge. You might like to challenge learners to see which group can construct a stable arch bridge most quickly.

BUILDING AN ARCH BRIDGE WITH THE ARCH BUILDING KIT

The arch building kit with centring.

Stand the widest piece up on a flat surface. Add the supports for the centring between the two sides.

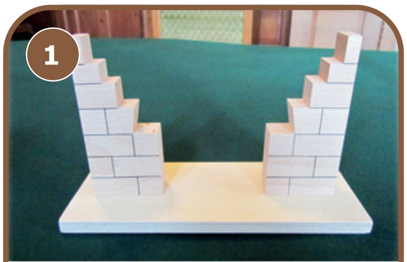
Place the arched piece on top of the supports. This will act as the centring.

Place the individual voussoirs on top of the centring one-by-one from the outside-in.

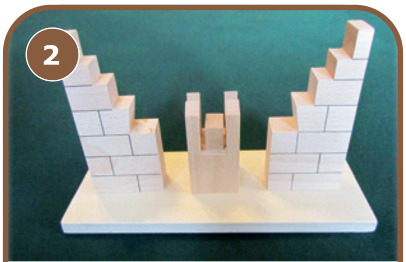
Add the final middle piece. This is the keystone.

Remove the centring and the supports. You now have a freestanding arch bridge!

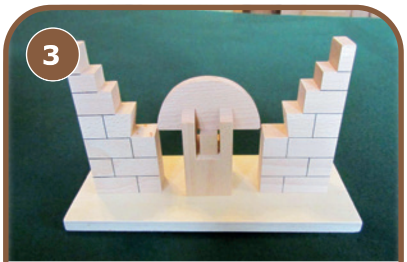
BUILDING AN ARCH BRIDGE WITH THE MONTESSORI ARCH BUILDING KIT



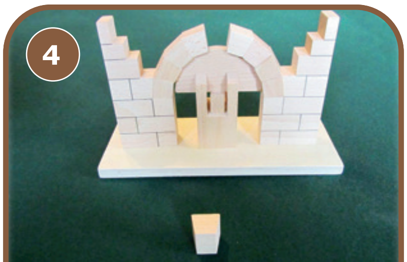
Stand the Montessori arch building kit base on a flat surface.



Add the support for the centring in the centre of the gap.



Place the arched piece on top of the support. This will act as the centring.



Place the individual voussoirs on top of the centring one-by-one from the outside-in.

Add the final middle piece. This is the keystone.

Remove the centring and the supports. You now have a freestanding arch bridge!

Challenge Time!

ROMAN BRIDGE BUILDING

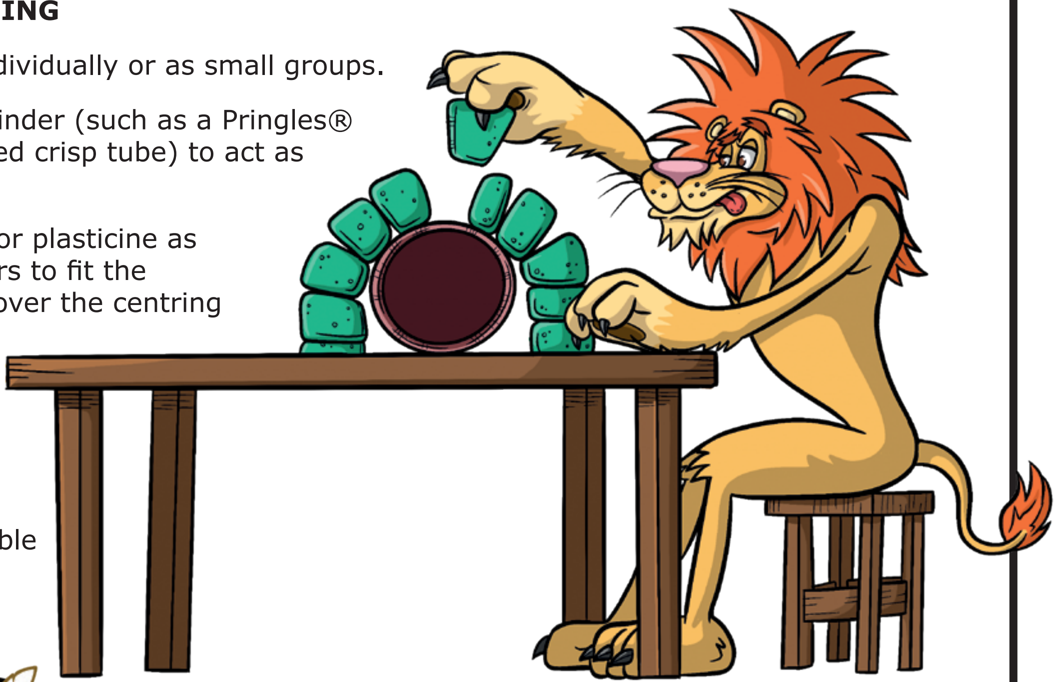
This can be completed individually or as small groups.

Learners need a large cylinder (such as a Pringles® tube, or other non-branded crisp tube) to act as the centring.

Using the modelling clay or plasticine as mortar, encourage learners to fit the pebbles/stones together over the centring to form the arch bridge.

When firmly in place, remove the centring.

If air-drying clay and a cardboard base are used, the bridges should be stable enough to be displayed.

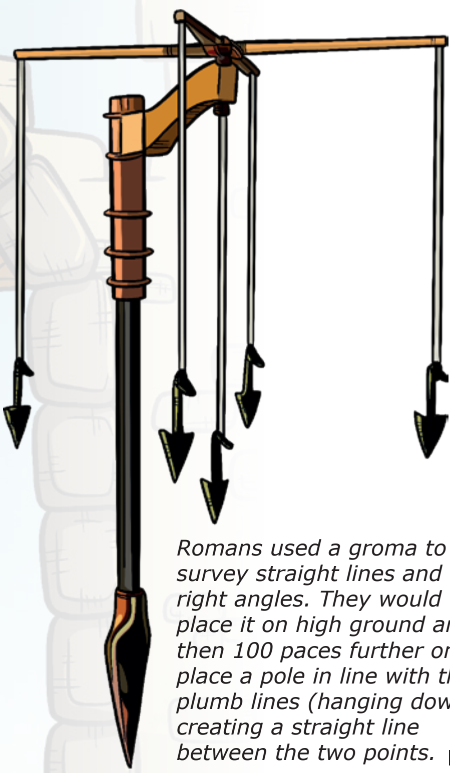


HOT TOPICS!

The first bridge built at Rochester was Roman. Although it was a beam bridge, the more common form of bridge built in the northern European settlements, Roman arch bridges are very common in southern Europe.

The Romans built a network of roads across their empire to move their troops and goods across long distances. They were built very straight to form the most direct route, and therefore be the shortest, quickest way to get anywhere, and safely!

You could explore how Romans built their roads, building models using rocks, pebbles and sand. Perhaps you could find out how Roman surveyors made sure the route was straight, using a groma – a type of surveying equipment. You could even build a model groma.



Romans used a groma to survey straight lines and right angles. They would place it on high ground and then 100 paces further on, place a pole in line with the plumb lines (hanging down), creating a straight line between the two points.

BUILDING A BRIDGE WITH LEGO®

Can you build an arched bridge with Lego®? Using some standard Lego® or Duplo® bricks, is it possible to form a Roman-style arch?

DID YOU KNOW?

The Pont du Gard is an ancient Roman aqueduct, built in the first century AD to carry water to the Roman colony, over the river Gard in southern France. It is the highest of all Roman aqueducts and one of the best preserved, and was added to the UNESCO list of World Heritage Sites in 1985 because of its historical importance.

OUT & ABOUT

If you look at a map of Britain, can you spot any Roman roads? How will you know which ones are Roman roads? Are there any Roman roads near you?

Pont Du Gard Moritz-Kindler on Unsplash

Langdon presents:

- *Roman bridges* handout

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

Chapter Ei: Suspension Bridges – Hanging Tough

AIMS & OBJECTIVES

- To show how transferring loads can make a bridge stronger
- To introduce the suspension bridge

CONTEXT

A suspension bridge is a type of bridge in which the deck is hung from main cables on vertical hangers. The suspension bridge was developed by engineers to cross long distances without needing extra piers, such as a beam bridge would require. Although suspension bridges are spectacular and beautiful structures, they are expensive and complex to build.

LANGUAGE OF BRIDGES:

Anchor: acts to secure the bridge to the ground.

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.

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

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

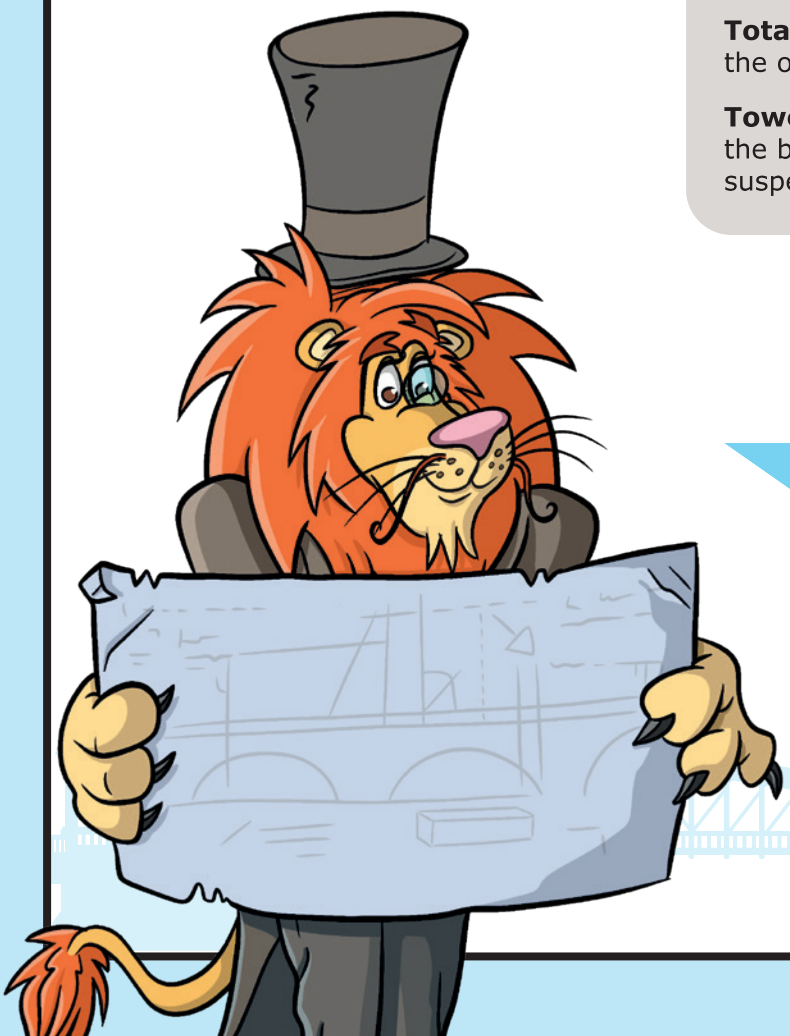
Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

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.



As a budding civil engineer, you will learn all about how suspension bridges transfer forces really well. This means they can span very long distances compared to other types of bridges.

Something to Try:

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)

Photo by Adam Valstar on Unsplash

- For the long K'Nex bridge demonstration, per group:
  - K'Nex® Education Introduction to Structures – Bridges set
  - Two 70cm lengths of string
  - Safety glasses
  - Heavy books/supports/desks, to act as abutments (at least 10cm tall, 40cm gap)
  - Small masses/washers/coins, to act as the load on the bridge
- Handout: *Suspension bridge terminology*
- For the simple suspension bridge demonstration, per group:
  - Two large, heavy books
  - Ball of string
  - Two drawing pins
  - Handout: *Forces in a suspension bridge*
- For the human suspension bridge:
  - Two ropes, each 4m long (or one 6m long rope)
  - Four towels/cushions/rolled up jumpers or similar cushioning material for the shoulders of the four 'towers'
- For the rope bridge activity, per group:
  - Two clamp stands, clamps and bosses (if you do not have these in school, or in sufficient quantities, it may be possible to borrow these from a local secondary school science department)
  - String – at least 12m ball, to be cut into 26 lengths of at least 45cm.
  - Range of small objects to test the bridge
- For the friendship bracelet (per bracelet):
  - At least three different colours of embroidery thread (these can be bought from a local craft supply shop)
  - Scissors
- Handout: *Card wheel method for making friendship bracelets*
- Handout: *Famous suspension bridges*
- Local area map

Links to *Learning About Bridges Chapter Aii – Loads and Forces*

In the earlier section of this book, the chapter on Loads and Forces includes a series of activities you can use to demonstrate forces and their effects. You can re-visit these to remind learners of loads and forces on the bridge.

When an engineer is designing a bridge, they must first understand how different loads will put forces on the bridge. Then they must find a way to balance them. Where the load is likely to exceed the strength, the bridge will fail.

An example would be when an engineer needs to build a bridge across an estuary which is more than 1km wide. The water is very deep and is used by large boats to reach a port upstream.

What are the different options for the bridge?

The length of each span in a beam bridge is limited to about 300m – the addition of extra spans requires more piers. These would be challenging to build and obstruct the shipping lanes.

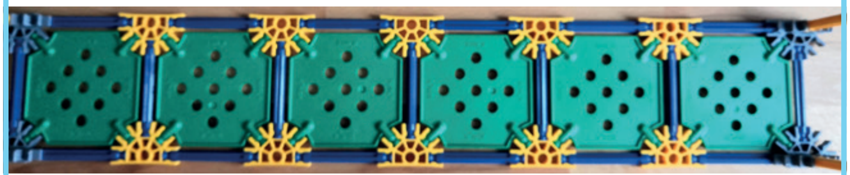
An arch bridge has a maximum span of about 500m – the same issue as a beam bridge then arises, with the need for more piers etc.

In the truss bridge section of this book, learners explored how making a beam bridge longer weakened the bridge. Ask learners what they think happens when bridges become even longer. If we want a very long bridge, we need to find a way to transfer the load away from the middle of the bridge.

Links to Learning About Bridges Chapter C: Truss Bridges – What is a Truss?

LINK

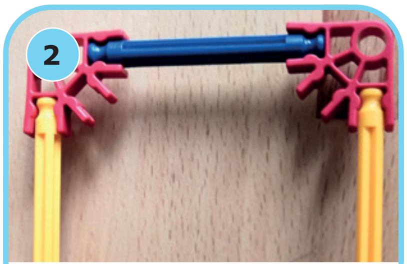
1 Create a K'Nex bridge span using the full six deck plates:



This isn't in the instruction book, so it needs to be created using:

- 6 green deck plates,
- 10 yellow half cog pieces
- 19 blue rods
- 8 grey half cogs fitted together at right angles

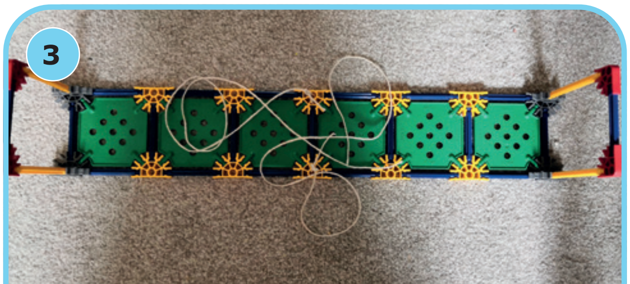
2



Then add two upright sections, one at each end

- 4 yellow rods
- 4 red right angled cogs
- 2 blue rods

3



Tie two 70cm lengths of string on each side of the middle of the bridge.

4

Place this K'Nex bridge across the 40cm gap created by the books/desks.

While wearing safety glasses, add the small masses until the bridge collapses. This demonstrates the maximum load the bridge can support.

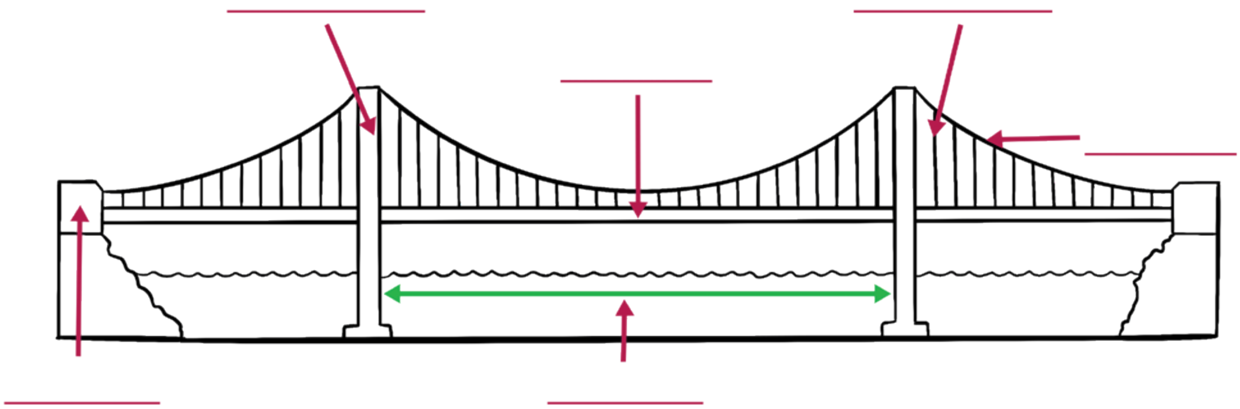
5

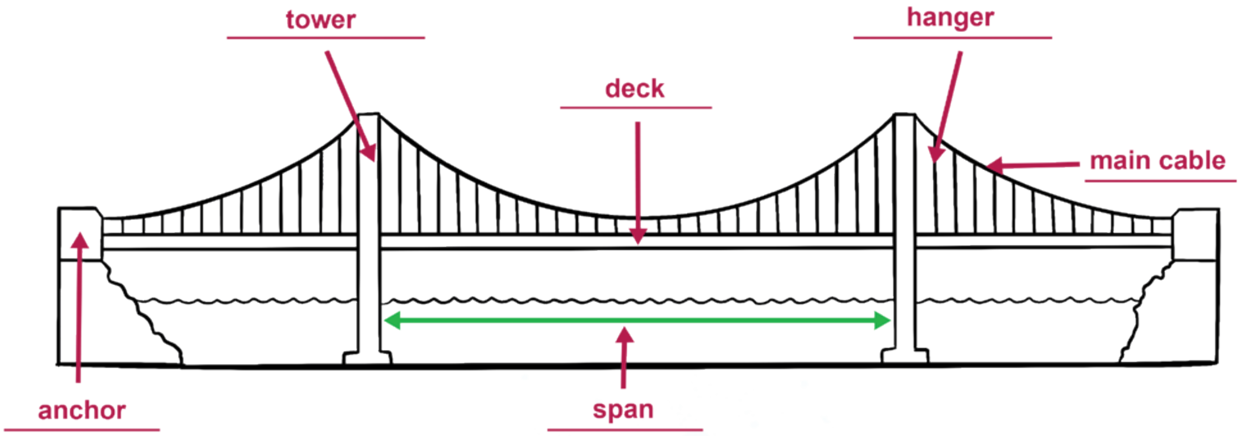
Remove the maximum load from the bridge. Bring one length of string over the upright on the right side of the bridge, and bring the other length over the upright on the left. Using some more of the small masses, weigh down the strings on either end of the bridge. Now return the original maximum load to the centre of the bridge. What do you notice?

Can you add extra load to the centre of the bridge to see how much greater the load now needs to be to collapse the bridge? Why does this happen?

INTRODUCING THE SUSPENSION BRIDGE

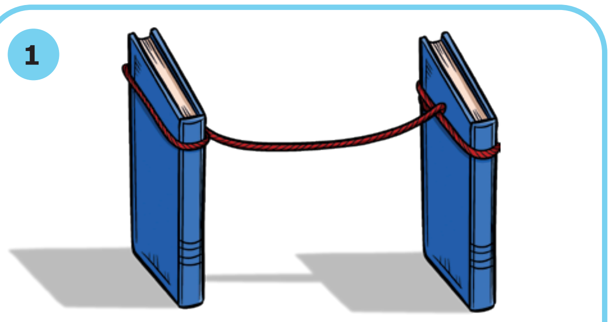
Using the *suspension bridge terminology* handout, learners can identify the different parts of the suspension bridge. Ensure learners understand the meaning of suspend, to hang something, which then explains the suspension bridge: the deck hangs from hangers which are joined to a long main cable strung between towers and anchored into the ground.





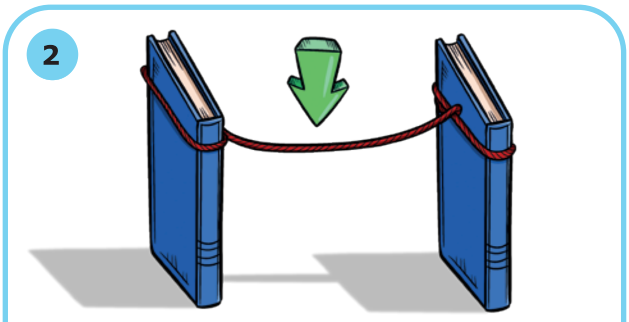
To give a simple demonstration explaining why the towers on a suspension bridge need to be anchored, you need two large books, some string and drawing pins.

1



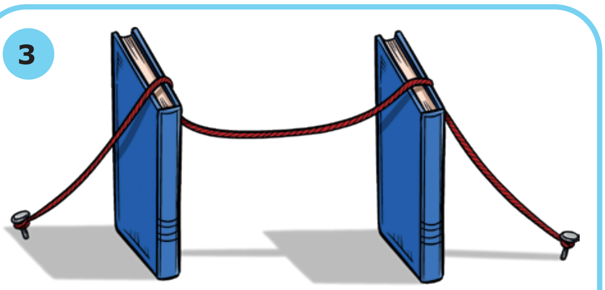
Tie string around two large books, so a 20cm (minimum) length of string acts as a bridge between the books when they are stood on end:

2



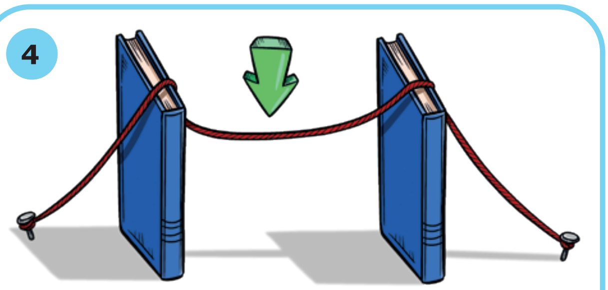
Push down gently on to the middle of the string. What do you notice?

3



Instead of tying the string around the books, fasten the ends of the string using the drawing pins, and rest the string on the top of the books:

4

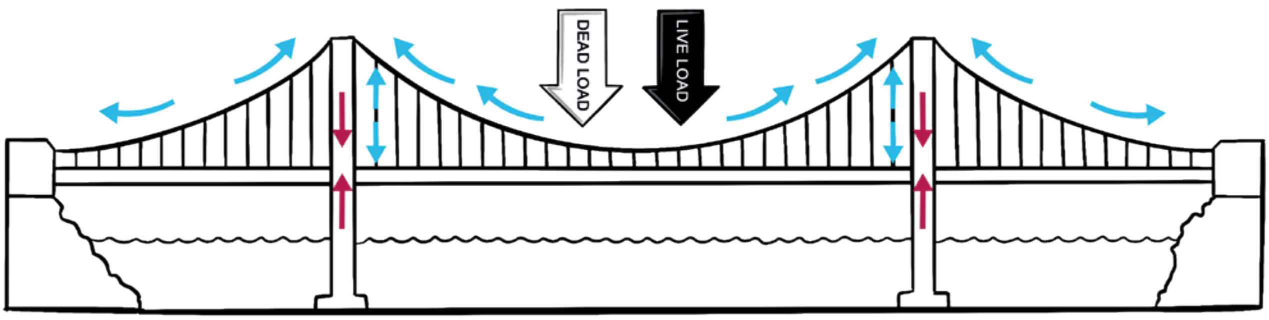


Again, push down on the centre of the string. What do you notice?

When the string is fastened, or anchored, the load in the centre of the bridge is re-distributed to the anchors.

Search the internet for "PBS learning media Clifton Suspension Bridge" for a short video explaining how the forces in a suspension bridge work.

You could use the *forces in a suspension bridge* handout to help visualise the forces.



HUMAN SUSPENSION BRIDGE

This activity requires 12 children.

It is important that no-one pulls too hard on the ropes, as this could hurt the children acting as towers or could pull someone over.

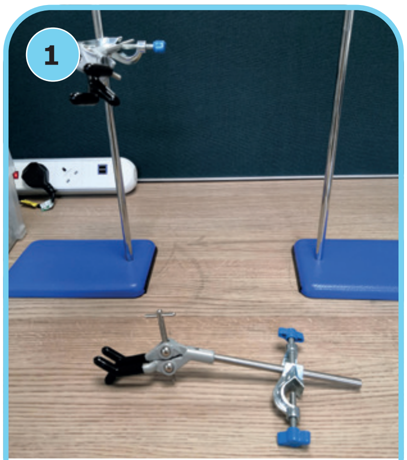
1. Select four of the taller children and get one pair to stand facing the other, they should be roughly 2m apart. These children represent the two towers of the suspension bridge.
2. Place the rope across the shoulders of each pair (using the cushioning material underneath) – this represents the main cable.
3. Select four more children to act as anchors, getting each one to sit on the floor facing the back of each tower. They should each hold the end of the main cable. Remind them not to pull on the rope!
4. Select four more children to act as the hangers. They should kneel or sit on the floor, facing each other and holding on to the main cable. They represent the parts holding on to the deck of the bridge (the floor).
5. The four hangers can now pull gently on the main cable. They should feel the tension pulling on their arms. The towers should feel the compression pushing down on their shoulders, and the anchors should feel the tension in the main cable pulling against their arms.
6. Ask the learners to notice that all the parts have to balance the forces for the bridge to stay up and be stable (even without pulling hard).
7. You could invite the children to consider what would happen if there were no anchors, or to consider what might happen if the hangers failed? They might appreciate that a suspension bridge has lots more parts than most other types of bridge. This makes them complicated and expensive to build.

If there are additional participants in the group, ask them to act as cars and move through the centre of the suspension bridge (carefully!), between the two lines of children, remaining on the floor/deck of the bridge. Ask the learners to imagine how the forces in their parts of the bridge would change as this live load travels across.

Challenge Time!

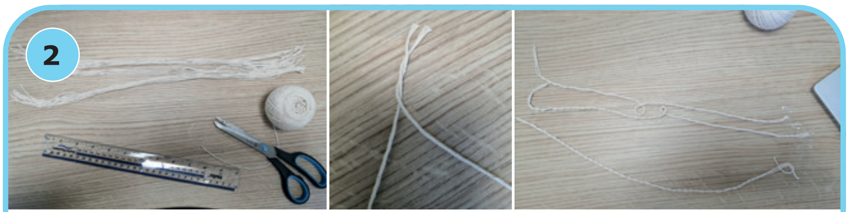
TRY MAKING A ROPE BRIDGE

1



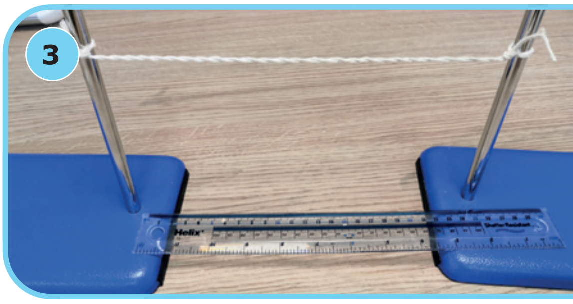
Using two clamp stands, clamps and bosses, fix the clamps at right angles to the clamp stand upright pole. Ensure both are at the same height. Set the stands 20-25cm apart.

2



Cut the string into 26 pieces of at least 45cm length. Weave two pieces together to form one strip, by twisting them around each other. Do this three times, so you end up with three double-thickness lengths.

3



Take one double-thickness piece and tie it a third of the way up the uprights of the clamp stands. Make sure this string is tight.

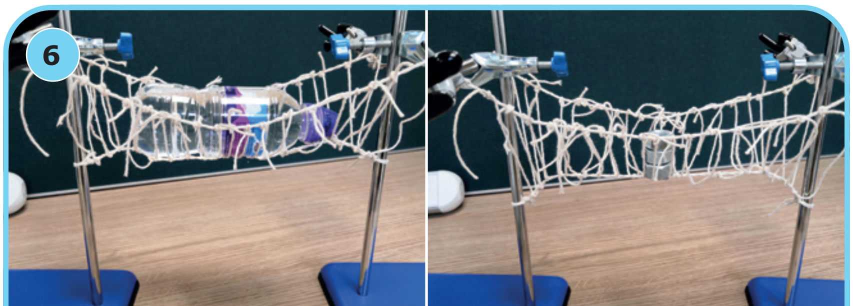
4

Take the other two double-thickness lengths and tie them between clamps so they're horizontal and parallel to the first piece. Again, make sure they are tight.

5

Take a string and tie it to one of top double strings. Tie the middle of it to the bottom one and then tie the other end to the opposite top string. Repeat this for all the strings. The challenge here is to ensure all the strings remain as tight as possible. There is an excess of string in the lengths to help make it easier to tie them – the extra string can be cut off when the length is knotted in position.

6



Test the bridge with your objects.

Rope doesn't seem like a strong material, and it isn't rigid so it will move when in use, but it is lightweight, easy to make and transport, and easily replaced if needed. How could the rope bridge be improved?

Weaving friendship bracelets: although the process of spinning the suspension bridge cables is slightly different, weaving your own friendship bracelet using embroidery thread or yarn is still fun!

Here is a simple way of making a friendship bracelet, and just like a suspension bridge, the strands have to be anchored at the starting end.

1

Choose the colours you want to use for the friendship bracelet. You will need a minimum of three different colours, but you can use as many as you want.

2

Cut each thread to at least 75cm long; 1m should be sufficient for most wrist sizes.

3

Gather all the threads together and then fold them in half. Knot together all of the strands in the middle.

Anchor this knot – you can use a pin on a cushion or a branch on a tree for example.

4

Choose one strand of embroidery thread hanging from the knot. Take this in your dominant hand. Cross it over to your other hand to create a 4 shape, then loop the loose end around the remaining embroidery threads in your non-dominant hand. Then pull the knot you have just created up to the top by the main knot with your dominant hand.

5

Repeat this knotting process with the same strand of thread a few times.

Choose another colour strand and repeat steps 4 and 5.

6

When the bracelet is long enough, knot all of the strands together as you did at the start.

You can explore using more coloured threads, or changing how many knots you tie with each strand. You could also try a completely different method, described here: *Card wheel method for making friendship bracelets* handout.

HOT TOPICS!

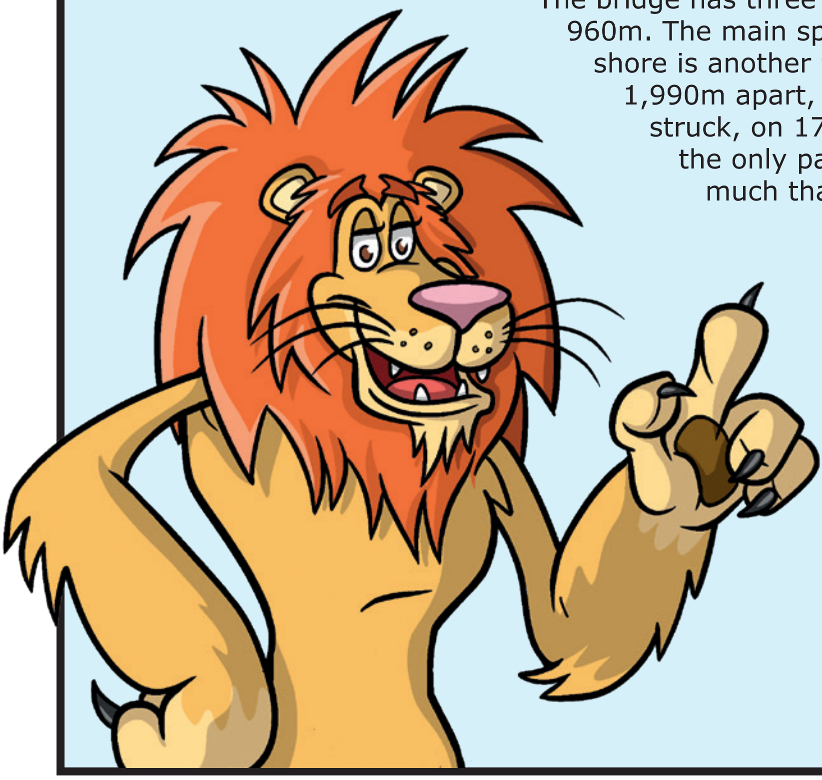
Take a look at the *Famous suspension bridges* handout. Can you discover where these bridges are in the world, and why they might have needed to be built?

OUT & ABOUT

The Akashi Kaikyo Bridge, also known as the Pearl Bridge, has the longest main span of any bridge in the world. It was finished in 1998. It links the city of Kobe on the mainland of Japan to Awaji Island.

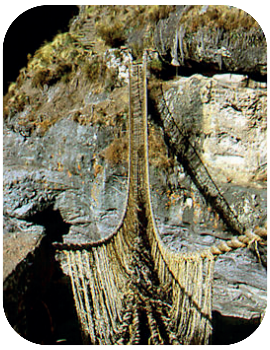
Before the Pearl Bridge was built, ferries carried passengers across the Akashi Strait in Japan. This dangerous waterway often experienced severe storms and, in 1955, two ferries sank in the strait during a storm, killing 168 people, most of them children. The resulting shock and public outrage convinced the Japanese government to develop plans for a suspension bridge to cross the strait.

The bridge has three spans. From the shore, the first span is 960m. The main span is 1,991m and the final span back to shore is another 960m. The two towers were originally 1,990m apart, but when the Great Hanshin earthquake struck, on 17th January 1995, the towers, which were the only parts constructed at the time, moved so much that the span had to be increased by a metre!



Look at a local area map. Measure how far the main span of the Pearl Bridge would carry you from your home or school.

The cables used in suspension bridges are made up of many, many smaller strands that have been spun together. The cables in the Pearl Bridge have 300,000km of wire – enough to go around the Earth almost eight times! When you are out and about, see if you notice any other materials that are like this – made up of lots of smaller parts to become a much larger, stronger object.



Photos courtesy of Rutahsa Adventures
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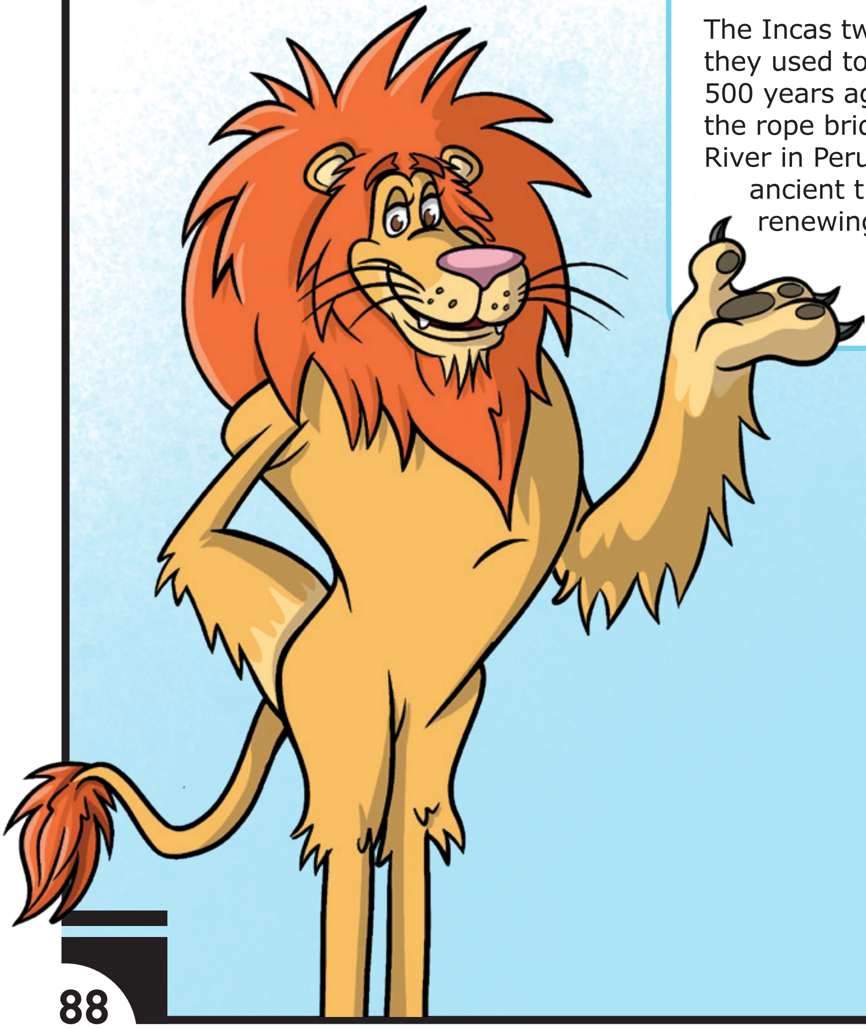


DID YOU KNOW?

The Incas twisted grass to create ropes, which they used to build suspension type-bridges around 500 years ago. One still remains: Q'iswa Chaka, the rope bridge spanning over the Apurimac River in Peru. The locals keep this ancient tradition and skill alive by renewing the bridge every June, even though there is a modern bridge nearby.

GEOGRAPHY

Langdon presents:

- *Language of suspension bridges* handout
- *Suspension bridge terminology* handout
- *Famous suspension bridges* handout
- *Card wheel method for making friendship bracelets* handout

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

Chapter Eii: Suspension Bridges – Tacoma Narrows Case Study

AIMS & OBJECTIVES

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

CONTEXT

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

LANGUAGE OF BRIDGES:

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

Anchor: acts to secure the bridge to the ground.

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

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

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

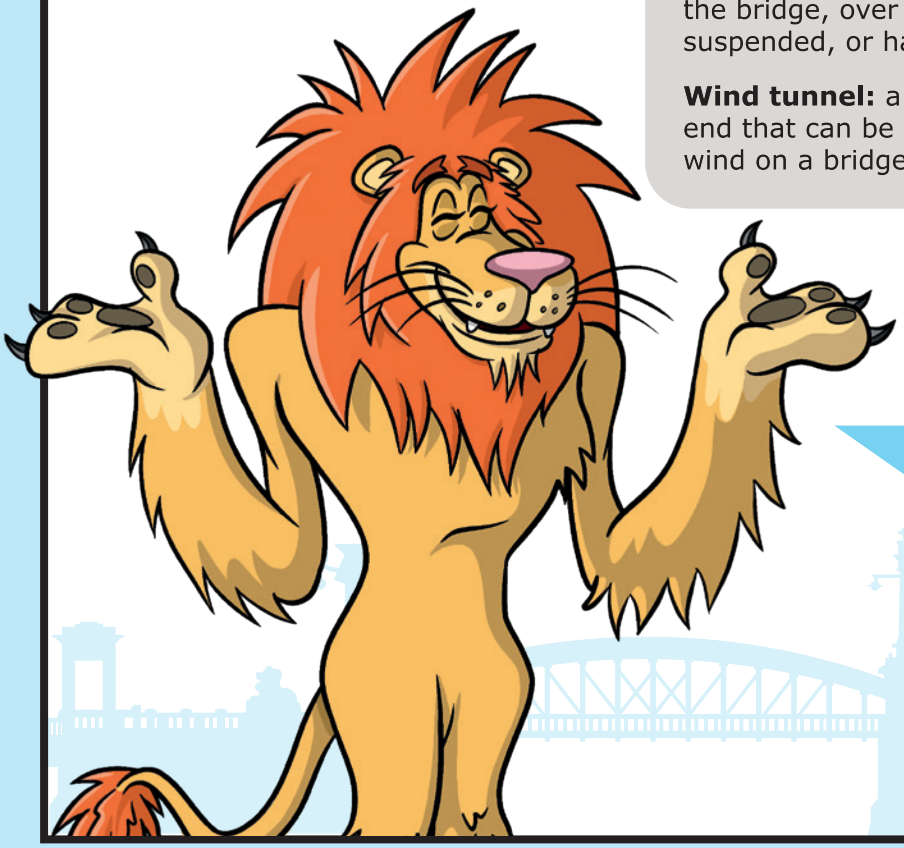
Piers: the upright columns that support the bridge.

Span: the distance between bridge supports.

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

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

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



You will need…

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

Something to Try:

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

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

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

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

MODELLING THE EFFECT OF THE WIND ON THE BRIDGE

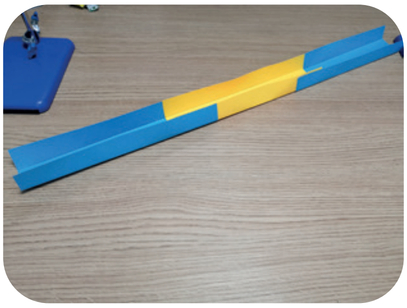
Using an A4 piece of paper and a hairdryer, learners can observe the way the design of the bridge created a barrier effect to the wind and resulted in the galloping motion. Hold the A4 piece of paper vertically on its side, so that the largest area is angled towards the hairdryer. Start the hairdryer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

MODELLING THE BRIDGE DECK

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

We can recreate this using a model made from cardboard:

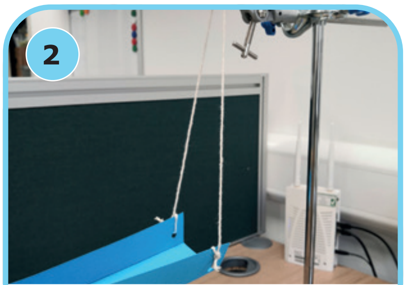
This is constructed from three pieces of thin craft card, glued together and then cut in half lengthways. Each side is folded to form a channel.



1

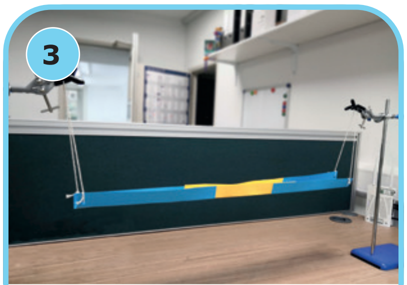
Using a hole punch, create holes at the same distance from the end, and at the same height up the side.

2



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

3

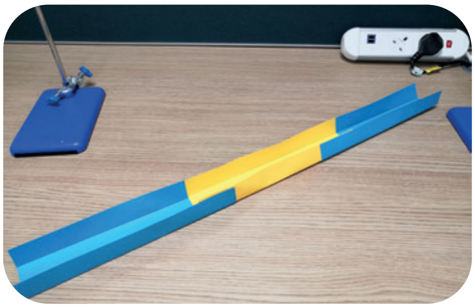


Hang the bridge from the two clamp stands

Challenge Time!

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

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



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

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

HOT TOPICS!

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

Bowing chladni plate, image via Wikimedia

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

CAN YOU PRETEND TO WALK ON THE MILLENNIUM BRIDGE?

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

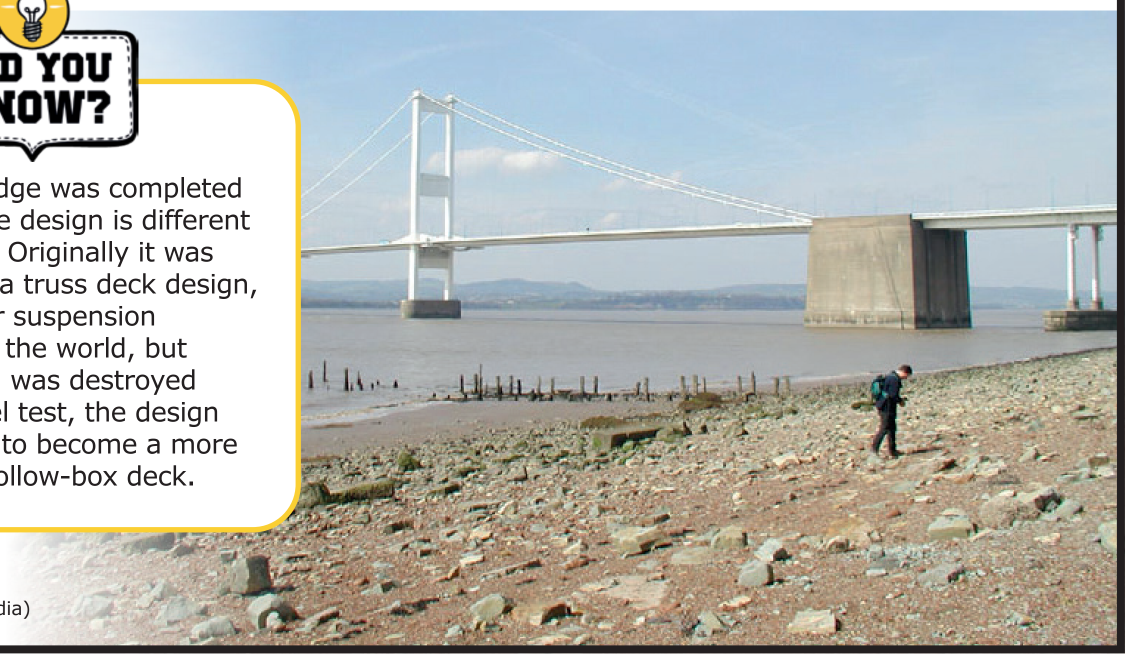
Get the front person to take a step out with their left foot, and then their right: it should be quite an exaggerated step, with a larger stride than they would normally use, and slightly out to the side each time. Each person behind should walk in time with the front person, using the movement of their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

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

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

DID YOU KNOW?

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



Severn Bridge
(Image via Wikimedia)

Glossary

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

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

Anchor: acts to secure the bridge to the ground.

Arch: semi-circular curved structure.

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

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

Bowstring Truss: this was patented in 1841 by Squire Whipple. The Old Bridge at Rochester is a bowstring shaped truss.

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

Cast iron: iron with additional carbon and other impurities mixed in, and then shaped using a cast, or mould, while 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.

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.

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

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.

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.

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.

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

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.

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

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.

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.

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

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

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).

Piers: the upright columns that support the bridge.

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

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

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

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

Span: the distance between bridge supports.

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

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

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.

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

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

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, 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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ISBN 978-1-7391077-0-3