Chapter I: Bridge Work

AIMS & OBJECTIVES

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

CONTEXT

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

LANGUAGE OF BRIDGES:

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

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

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

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

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

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

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

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

LANGUAGE OF BRIDGES:

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

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

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

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

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

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

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

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

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

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

You will need...

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

Something to Try:

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

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

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

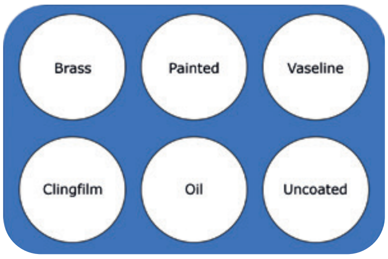
LINK

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

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

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

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



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

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

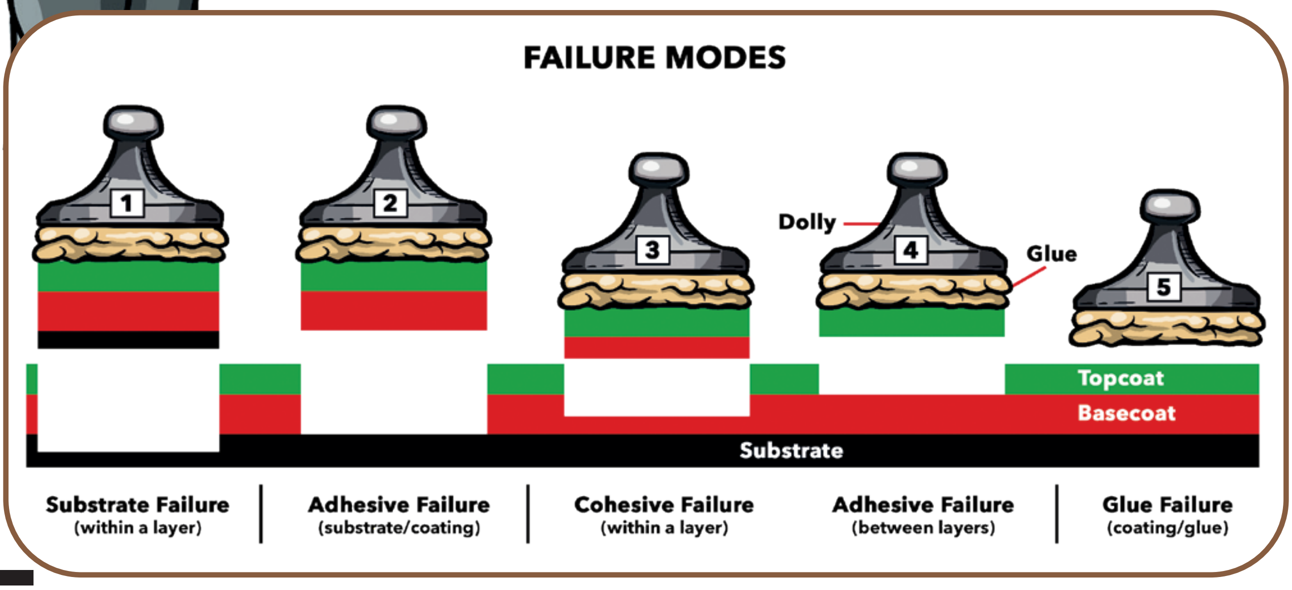
PAINTING

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

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

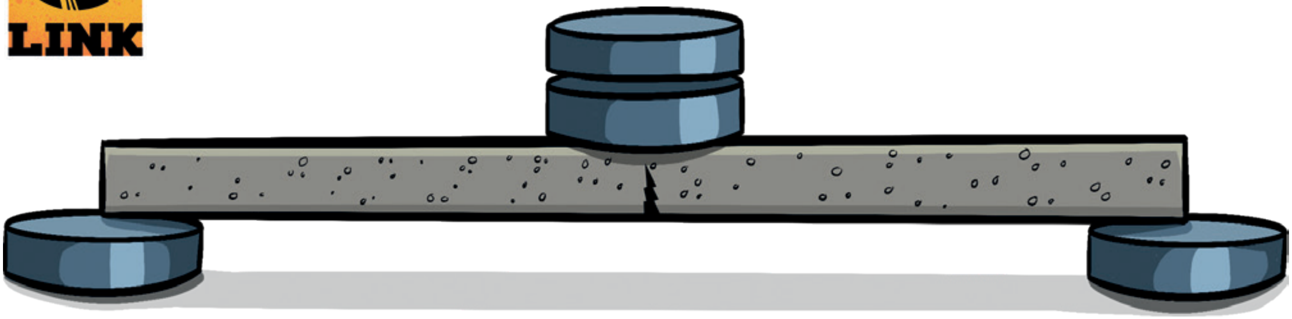
Painting needs to be regularly renewed as any gaps can lead to patches of rust, which may cause significant structural problems.

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

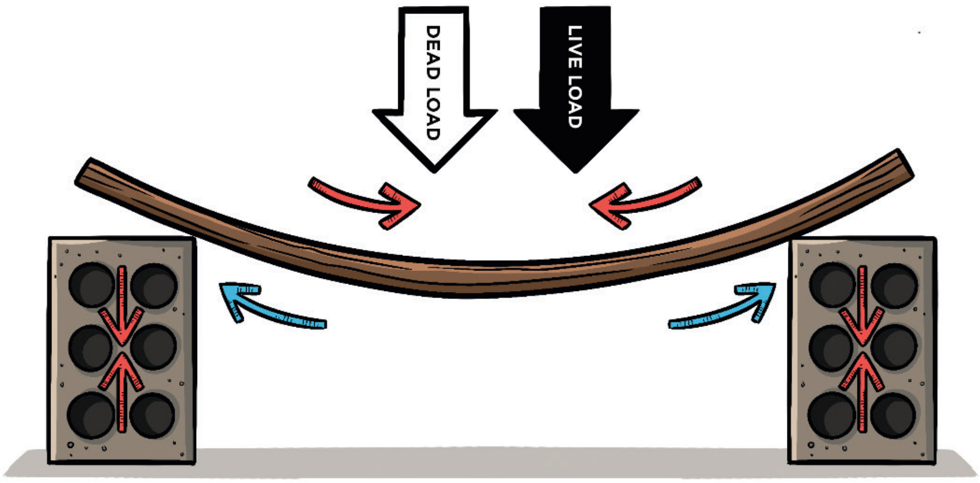


CONCRETE

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



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



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

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


Photo by Nathan Dumlao on Unsplash

SLIPPERY SLOPES

Links to *The Engineering Process*

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

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

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

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

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

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

MECHANICALLY REINFORCED (STABILISED) EARTH

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

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

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

SCIENTIFIC ENQUIRY

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

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

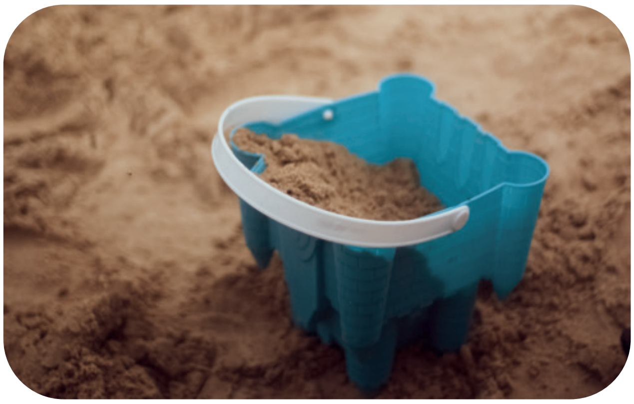
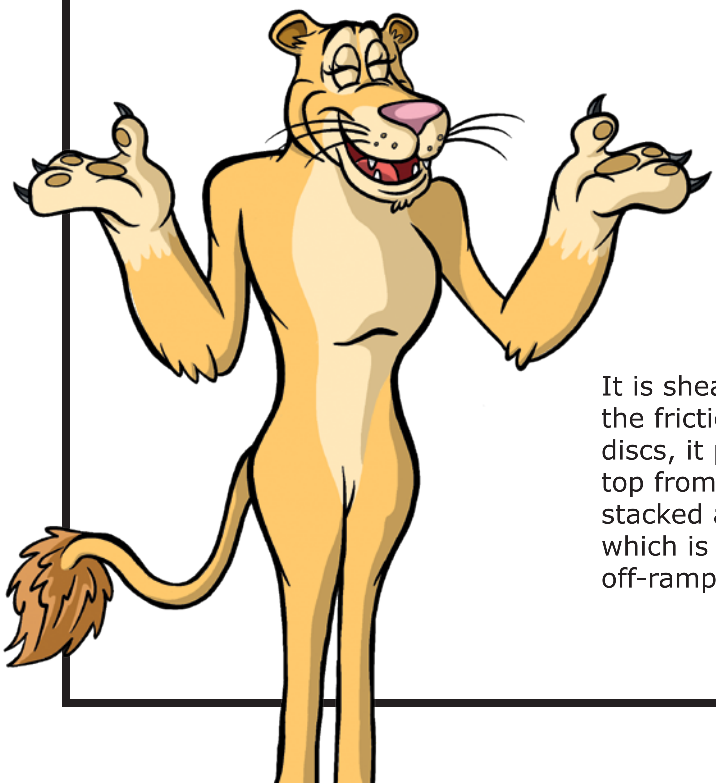
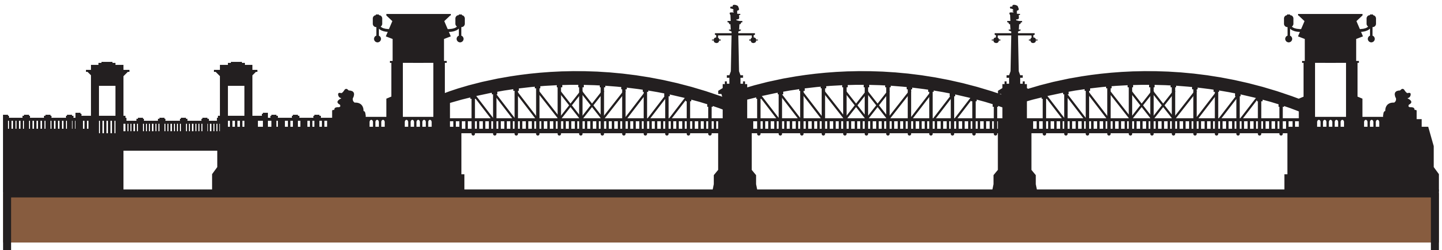


Photo by Jaye Haych on Unsplash



Links to *Chapter G: More Loads and Forces* LINK

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



BEARINGS AND EXPANSION JOINTS

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

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

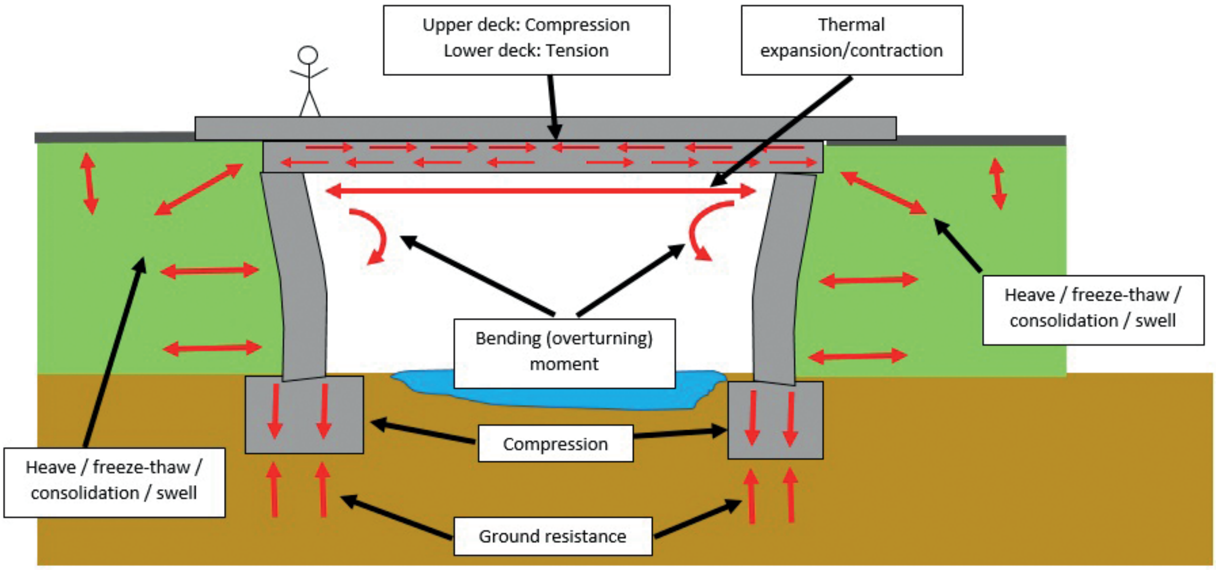


Image courtesy of Alex Romankiw via Twitter

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

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

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

Photo by Charles Cheng on Unsplash

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

Challenge Time!

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

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

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

Links to *The Engineering Process*

What, who and why:

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

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

The bridge crosses an estuary which is tidal.

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

Design Brief:

Design and model changes to the current bridge.

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

Design Specification:

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

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

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

HOT TOPICS!

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

- You need 16 note cards or small pieces of paper. On one card, write 'treasure' or use a picture of a treasure chest. On another card, write the word 'start'.

- Place all of the cards in a square 4 by 4 cards at random.
- Now work out a simple set of directions, or code, to get from the start card to the treasure card, using arrows to represent one card up, down, left or right.
- At the end of the code or instructions, write stop.
- Hide the treasure card and then give the code to someone else to try.

Can they find the hidden treasure?

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

Photo by Pure Julia on Unsplash

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

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

DID YOU KNOW?

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

The official colour is known as 'International Orange'

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

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

Langdon presents:

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

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