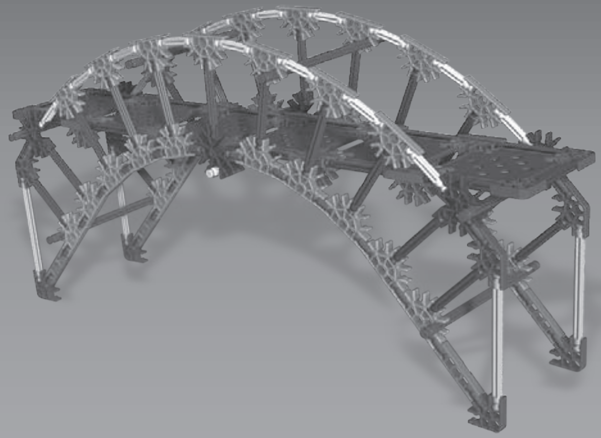
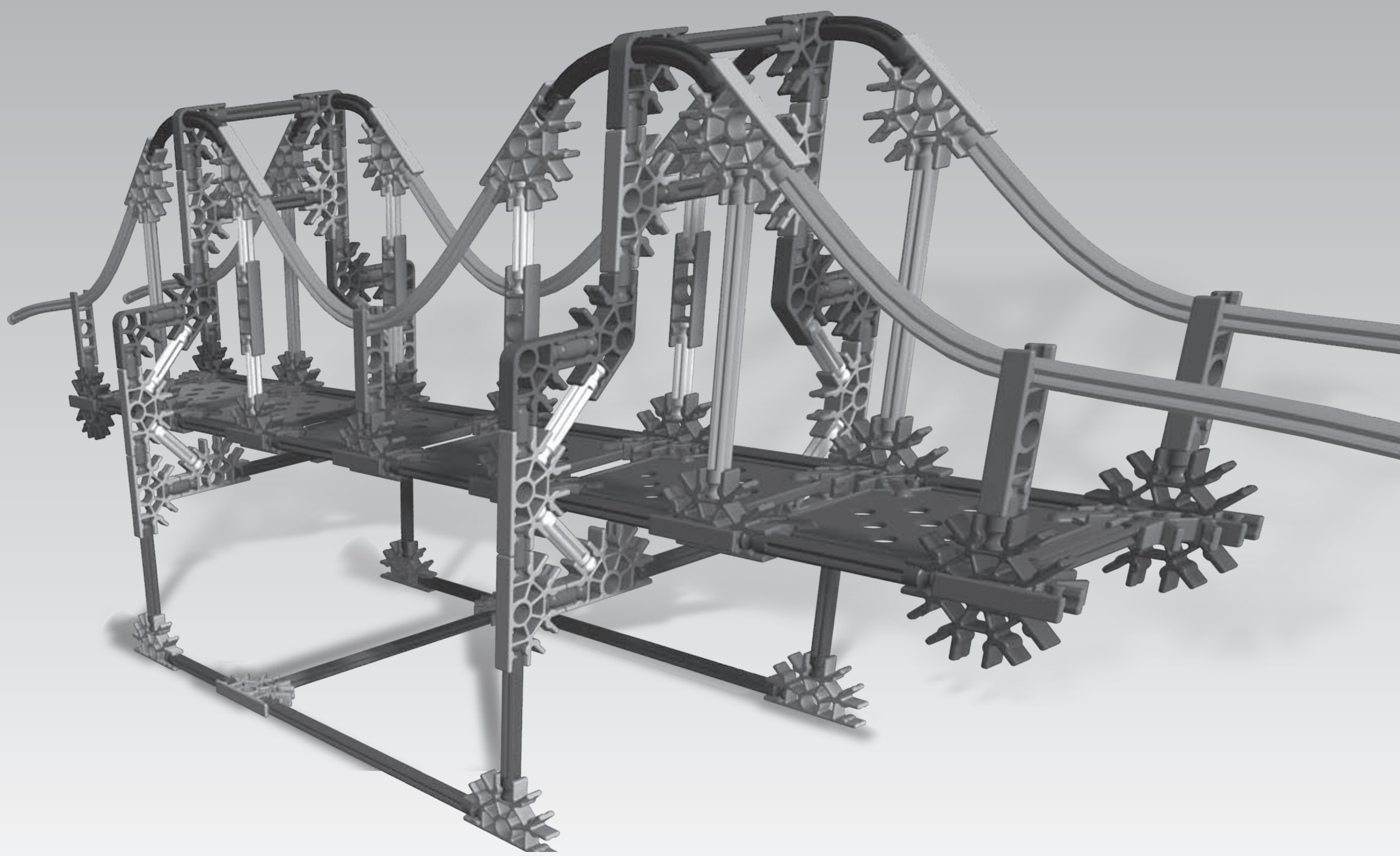
K'NEX Education®

TEACHER'S GUIDE

BRIDGES

INTRODUCTION TO STRUCTURES





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Introduction to Structures:
Bridges Teacher's Guide

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WARNING:

**CHOKING HAZARD - Small parts.
Not for children under 3 years.**

A Note About Safety

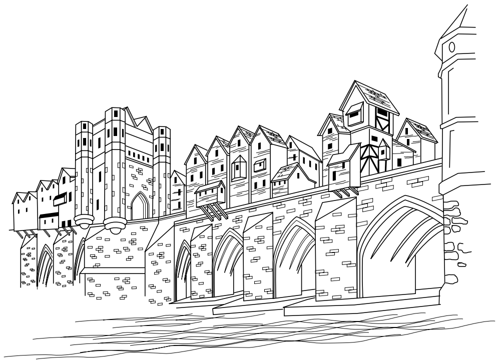
Safety is of primary concern in science and technology classrooms. It is recommended that you develop a set of rules that governs the safe, proper use of K'NEX in your classroom. Safety, as it relates to the use of the elastic bands should be specifically addressed.

PARTICULAR CAUTIONS:
Children should not overstretch or overwind their elastic bands. Overstretching and overwinding can cause the elastic band to snap and cause personal injury. Any wear and tear or deterioration of elastic bands should be reported immediately to the teacher. Teachers and children should inspect elastic bands for deterioration before each experiment.

Caution children to keep hands and hair away from all moving parts. Never put fingers in moving gears or other moving parts.

Contents

TABLE OF CONTENTS



Introduction

This K'NEX Bridges kit is the first in a series called Understanding Structures. An investigation of how bridges work will help children develop a good understanding of the forces affecting structures in general. A successful bridge is the result of balanced forces in action. While bridge building makes use of simple scientific concepts, their application often requires complex engineering solutions. It also demands a knowledge and understanding of the physical properties of materials so that their influence on the design and construction of the bridge can be determined.

The K'NEX Introduction to Structures: Bridges Kit

- Developed to introduce pupils to the 7 main types of bridge design, this construction kit also provides opportunities for learning how structures are made stable and how they are able to support their loads. In addition, it can be used to demonstrate that structures can fail when loaded and to identify the techniques for reinforcing and strengthening them.
- Working in pairs or small collaborative groups, the kit provides opportunities for pupils to explore different bridge designs, and the forces acting on them, through the use of focused practical tasks (FPTs), and investigative, disassembling and evaluative activities (IDEAs). The information gained from these activities will help children develop their own ideas to solve a bridge design problem using sheet and other resistant materials, as well as K'NEX construction kits, where appropriate.

Teacher Support Materials

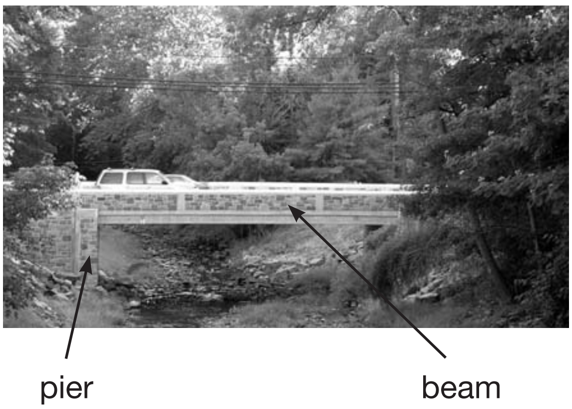
- Developed initially for the non-specialist teacher, the materials included in the Teacher's Guide can also be used as a resource by more experienced teachers as they develop their own lesson plans.
- Implementing the ideas and information contained in the Guide can build your pupils' knowledge and understanding of structures and the forces acting on them.
- Key background information is provided in " A Quick Start Guide" while the Lesson Notes for the K'NEX models provide more detailed information and ideas for possible teaching activities. These teaching activities have been developed primarily to support the DfEE/QCA Scheme of Work for Key Stages 1 and 2 in:
  - **Design and Technology Unit 6A:** 'Shelters' and related units involving structures
  - **Science Unit 6E:** 'Balanced and unbalanced forces' and related units
  - **ICT Unit 5B:** 'Analysing data and asking questions: using complex searches' and related units involving research using Internet search engines.
- A glossary of technical terms is offered as a resource for the teacher.
- Each of the lessons can be completed in approximately 1-2 hours but can be extended using suggested Extension and Research Activities. Useful Internet web sites are listed to help guide the research activities. (Note: these were functioning sites at the time of going to print.)
- A selection of worksheets is provided for your classroom use. These can be used for enrichment and assessment activities.
- The teaching activities are intended to encourage the development of key skills by providing opportunities for whole class and group discussions, observing, evaluating and recording through the use of text and drawings, working with others to solve problems and using ICT within a design and technology context.

A Quick Guide to Structures: Bridges

What is a bridge?
A bridge is a structure that is used to cross some form of barrier, making it easier get to one place from another. Other barriers, such as rivers, have always confronted travellers and traders who wanted to take the shortest, quickest and safest route to complete their journeys. Any study of bridges through time demonstrates the ways in which human ingenuity and resourcefulness have been applied to improve the movement of goods and people from place to place. Today, engineers can design and build bridges that connect countries and cultures, link chains of islands, cross barriers such as wide estuaries, go over busy highways and join one part of a building to another. Elevated sections of motorways can also be thought of as bridges. Bridges carry motor vehicles, trains, pedestrians, animals, pipelines and open channels of water.

The type of bridge that is constructed will be determined by the barrier to be crossed. Some barriers are narrow - a small stream may be only a metre or so wide and requires a simple structure to span the gap. Others barriers, such as river estuaries, may be many kilometres wide and require complex bridge designs.

The earliest bridges were probably fallen tree trunks or stone slabs placed across a small gap – in effect, a simple beam bridge. This type of bridge comprises a horizontal beam supported at each end by vertical supports known as piers.



A wider gap probably did not create too many problems for people travelling on foot – the beam would bend a little in the middle but a person could still cross the barrier.

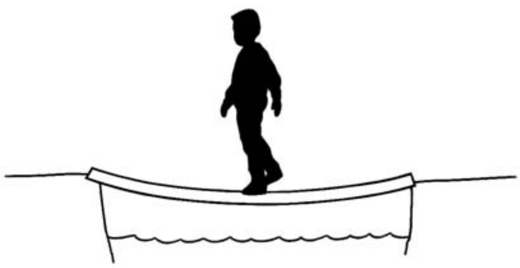


Fig. 1 Long beam bending

When, however, people attempted to cross wider barriers, carrying heavier loads and using wheeled transport, bridges had to be stronger, more stable and made to stay rigid over wider spans. One way to strengthen a beam is to make it thicker.

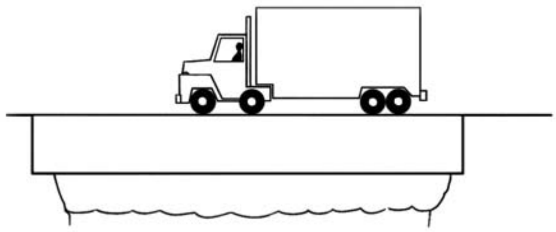


Fig. 2 Strengthening a beam by making it thicker

But will this work over even wider spans?

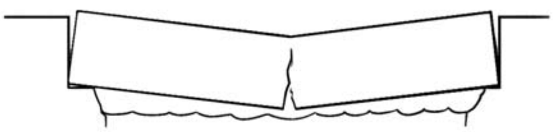


Fig. 3 The bridge itself is too heavy

The problem with the bridge shown in Fig. 3 is that it has been thickened so much that its own weight has become greater than the strength of the materials from which it is made. Although it looks strong, it is unable to support its own weight and it will fail (collapse) or, at best, it will be very weak.

The weight of all the materials used to make a bridge is called the ***dead load*** and this weight must be taken into consideration when designing a bridge. The weight of all the objects carried on a bridge is called the ***live load***.

Additional considerations that engineers must factor into their bridge design calculations include the ***shock load***, which is the result of a sudden high impact, such as that caused by a train or heavy truck crossing a bridge, and the ***environmental load***, resulting from the effects of strong winds, ice and snow build-up, river and tidal currents and earthquakes on the bridge. The Tacoma Narrows Bridge collapsed, for example, because engineers did not fully take into account the effect of wind, (Page 58), while cable-stayed and suspension bridges, (Pages 17-20), are not designed to carry trains because of their susceptibility to shock load.

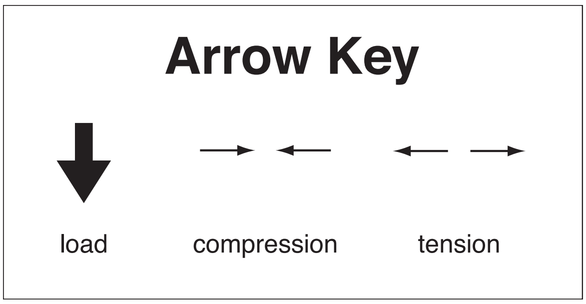
When the total load capacity of the bridge is taken into consideration, the longest **single** span for a beam bridge is approximately 80 – 100 metres.

In order to solve the problem of spanning wider gaps safely, all the **forces** that act on a bridge must be taken into account. A successful bridge is one in which the forces are balanced.

In other words, the action of the load pushing down is balanced by the *reaction* of the bridge structure, and the materials from which it is made, pushing in the opposite direction. If the action is greater than the reaction, movement will take place in the direction of the larger force – the bridge will fail.

Bridge basics

FORCES ACTING ON STRUCTURES



All structures have forces – pushes, pulls, twists – acting upon them. The most important ones affecting bridges are those of compression and tension, although torsion and shear forces can play a role.

A Quick Guide to Structures: Bridges

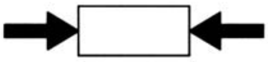


Fig. 4 Compression (squeezing)

- **Compression:** a force that acts to squeeze a material. *Example – squeezing a sponge.*

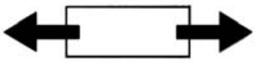


Fig. 5 Tension (stretching)

- **Tension:** a force that acts to stretch a material. *Example – stretching an elastic band.*

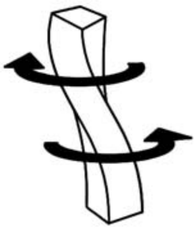


Fig. 6 Torsion (twisting)

- **Torsion:** a force that acts to twist a material. *Example – wringing a wet cloth by hand.*

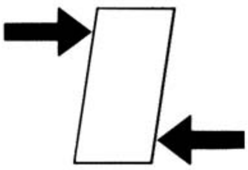
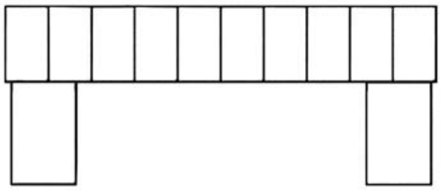


Fig. 7 Shear (sliding)

- **Shear:** a force that acts to move a material in a sideways motion. *Example – cutting action of a pair of scissors.*

When a load presses down on a beam, compression and tension forces are generated: the top edge of the beam is squeezed together by compression, while the bottom edge is stretched by tension. The combination of these forces causes the beam to bend.

The effects of compression and tension on a bridge structure can be modelled by taking a rectangular strip of solid foam rubber and drawing parallel lines with a felt tipped pen along one side, as shown in the diagram below. Place the strip of foam across two blocks (or two books) and push down on the centre. You will notice the effects of compression and tension in the spacing of the lines: they will move closer together at the top edge where compression (squeezing) takes place and move further apart at the lower edge where tension (stretching) occurs.



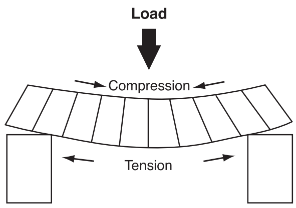


Fig. 8 Forces acting on a beam

How a beam behaves depends on the properties of the materials used to make it. If we compare identically sized beams, one made from steel can support a much greater load than one made from wood or concrete. What is important for structural engineers to know is how the materials behave when put under large compression and tension forces.

We recommend that you visit the 'Force Lab' at:

www.pbs.org/wgbh/buildingbig/bridge/
This interactive site uses simple, clear graphics and animations to demonstrate the

effects of forces on different shapes, as well as addressing building materials, shapes and loads.

MATERIALS USED IN STRUCTURES
As noted above, structural engineers must take into account the properties of the building materials they plan to use for their structures. Some materials are strong under compression - wood, reinforced concrete, steel, and some plastics, for example. Other materials are strong under tension - rope, string, paper, and wood - when it is cut along the grain.

Many bridges are constructed from reinforced concrete. Concrete on its own is strong under compression but weak under tension. Steel is strong under both conditions. Reinforced concrete has steel bars running along its length and so is strong under both tension and compression. This makes it a good choice for many types of structures.

Experimenting with the properties of reinforced concrete is not feasible in the normal classroom. You could, however, test the properties of paper, card and wood under different conditions.

- Can paper be used to make structures? What are its strengths and weaknesses?

Fig. 9a

Paper Forces

Fig. 9b

This test demonstrates how paper is strong under tension but weak under compression.

- Can we change the physical properties of materials?

Fig. 10 Limp paper

When we hold a sheet of A4 paper between our hands it flops down – it is not very rigid/ stiff. When it is folded, however, it has different properties.

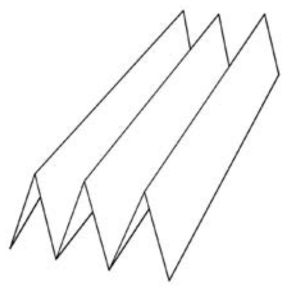


Fig. 11 Making paper stiff

The sheet of paper is now rigid and can support some surprisingly heavy loads. Try testing its load bearing capacity.

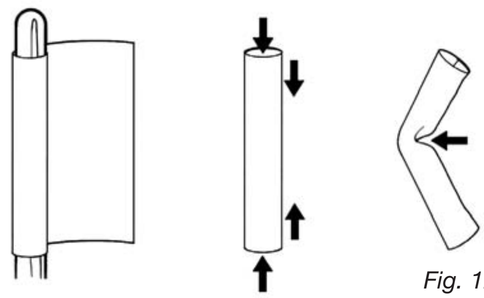


Fig. 12a *Fig. 12b* *Fig. 12c*

Paper columns

A Quick Guide to Structures: Bridges

Roll a sheet of A4 paper to make a tube. Try to compress (squeeze) it along its length (axially). It is surprisingly strong (Fig. 12b).

- What types of load can the tube of paper carry before buckling (failing)?

Tubes, even paper ones, are strong under compression and tension, but not strong in resisting bending forces (See Fig. 12c). Paper tubes, however, when used in the right way, can make quite strong structures. Similarly, hollow steel tubes are often used in structures to give strength, while keeping the amount of steel used, and hence costs, to a minimum.

The ability of a tube or column to support a load depends on a number of things, including the shape of its cross sectional area and its length. For example, a short wide tube will be able to support larger loads than a long thin one; a square column will support a larger load than a narrow rectangular one of the same cross sectional area.

By changing its shape, we can make what at first appears an inappropriate material into one that can be used to make strong structures.

SHAPES USED IN STRUCTURES
3 basic shapes are commonly used in structures: ***rectangles, triangles and arches***.

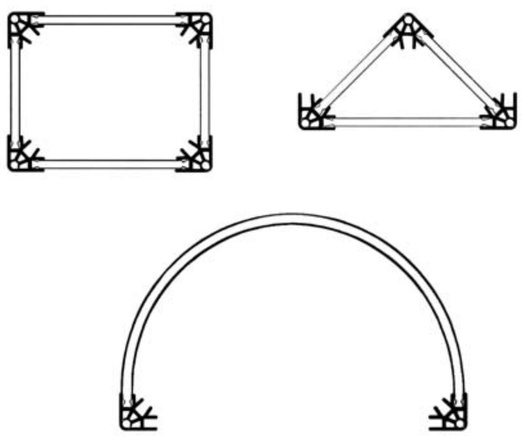


Fig. 13 Shapes commonly used in structures

What happens to these shapes when forces are applied to them?

Rectangles
When you push one corner of a rectangle its shape changes. The rectangle now becomes a parallelogram. Rectangles are therefore unstable shapes to use in structures on their own.

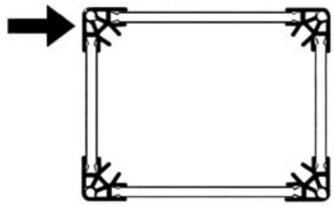


Fig. 14

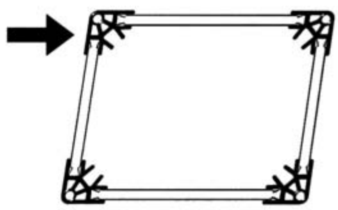


Fig. 15

Fig. 14 & 15 Pushing at a corner - using K'NEX models.

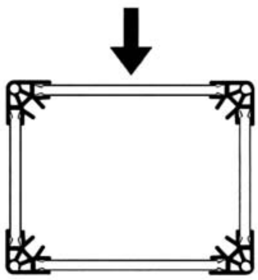
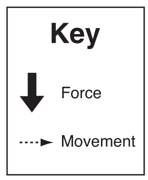


Fig. 16



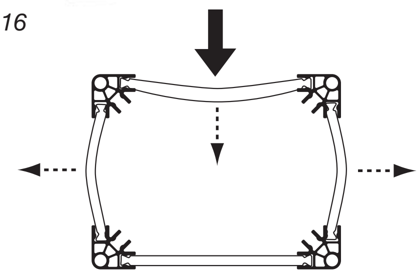


Fig. 17

Fig. 16 & 17 Loading the top - using K'NEX models

The force or load causes both the top and the sides to bend, with the sides bending outwards.

Using strengthening triangles
By adding a *diagonal brace* to a rectangle, however, so that the forces act along its length, the rectangle can be strengthened and reinforced. It is now a rigid, stable structure. ***A brace is a strengthening or reinforcing component of a structure.***

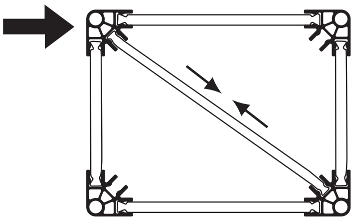


Fig. 18 Strengthening triangles

The shape does not change when the corners are pushed or pulled because the forces are now transmitted along the length of the diagonal brace, which is strong under compression. The addition of a diagonal brace also creates two triangles. **Braces** that resist compression are called **struts**.

If the rectangle is pushed from the opposite corner, the diagonal brace will be under tension. In this case the brace is call a ***tie***. Steel is strong under tension, which makes it a useful construction material for ties.

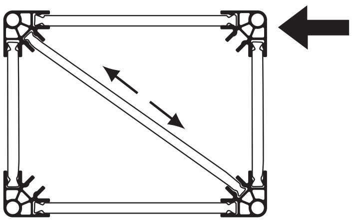


Fig. 19 Tension acting on the tie

You can also demonstrate the forces acting in a rectangular structure by using elastic bands instead of K'NEX rods. When they stretch they are under tension and when relaxed compression forces can be identified at work.

Safety Note: Please refer to Page 1 of this Guide and undertake a risk assessment and safety precautions when using stretched elastic bands.

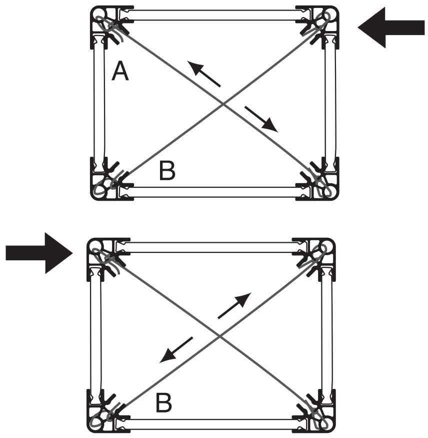


Fig. 20 Using string to create a stable rectangular structure

As demonstrated in Fig. 20, two strings under tension are needed to do the job of one strut. Add the strings diagonally from one corner to the opposite one. The end result is similar to using a single K'NEX connecting Rod as a strut.

Triangles
If a load or force is applied to one of the sides of a triangle, the side may bend inwards. The side is the weakest point in a triangular structure.

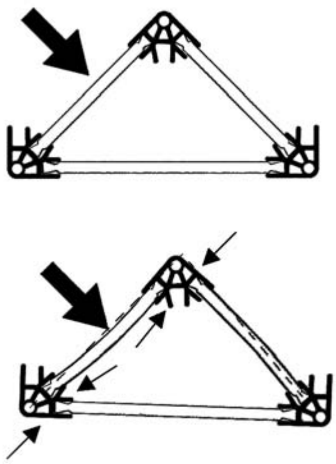


Fig. 21 Forces applied to the sides of triangles

If, however, a load or force is applied at one of the angles, the triangle does not bend because the two sides are squeezed and the base is stretched. The forces are distributed around the whole structure and not just on one side.

A Quick Guide to Structures: Bridges

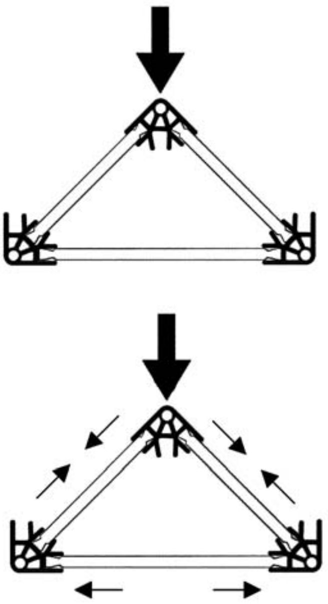


Fig. 22 Force applied at the angle of a triangle

Used in the right way, triangles are the most stable and rigid shapes that can be incorporated into a structure.

Arches
Arches have been used in structures for thousands of years. Many arched bridges and aqueducts built by the Romans are still in use today – a testimony to their strength.

When a load is applied to the top of an arch, the top moves down, while the sides will tend to move outwards.

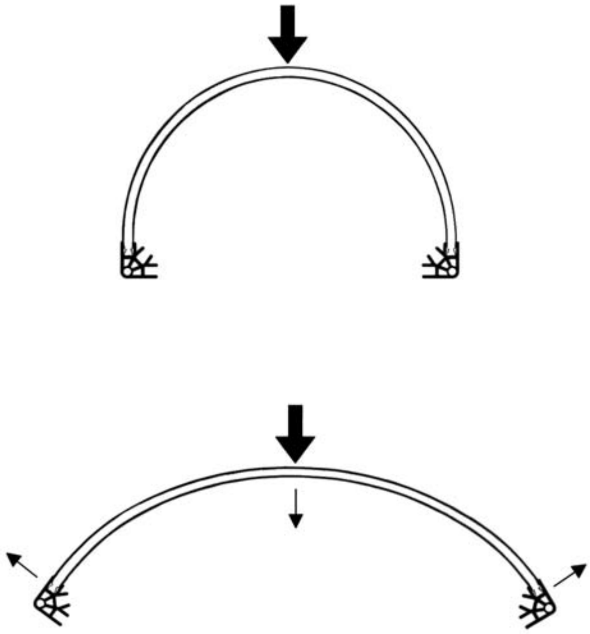


Fig. 23 Forces acting on an arch

Using supporting structures to push back against the sides, however, will strengthen an arch as all the forces now act to squeeze the whole structure together. This additional support creates a very strong structure.

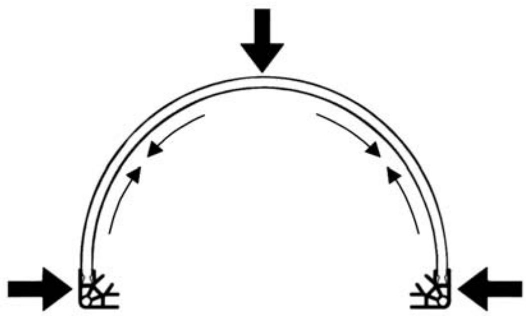


Fig. 24 Strengthening an arch

When a load is subsequently applied to a supported arch, the arms of the arch attempt to move sideways, but the external supports push back, stopping this movement. The external supports are called ***abutments.***

Arches, however, do have their limitations. If the arch span is too large, it is weakened. The largest single span arches today are approximately 250 metres wide.

Not all arches are made from stone. Modern arches are made from steel frames and this material allows longer arches to be constructed, as can be seen in the Sidney Harbour Bridge, Australia.

Different types of bridges

BEAM BRIDGES

- Construction and materials:
  The beam bridge supports its own weight and its load on upright, or vertical, piers. This type of bridge is typically used to span narrow distances over streams or small rivers, or over highways. While wood and stone were commonly used for this type of bridge construction in the past, modern beam bridges are usually constructed from steel and reinforced concrete.

- Forces acting on the bridge:
  The forces acting on a beam bridge tend to compress the top but stretch (place under tension) the bottom of the beam. The piers supporting the weight of the bridge are under compression.

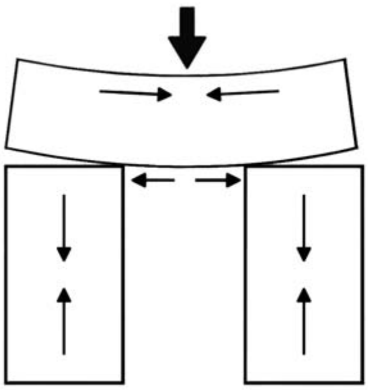
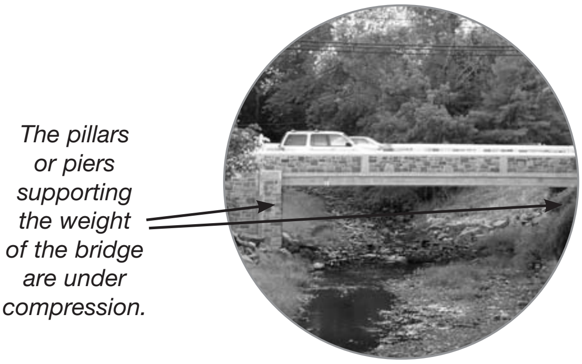


Fig. 25 Forces in a beam bridge

A Quick Guide to Structures: Bridges



Long beams are much weaker than short beams of the same thickness.

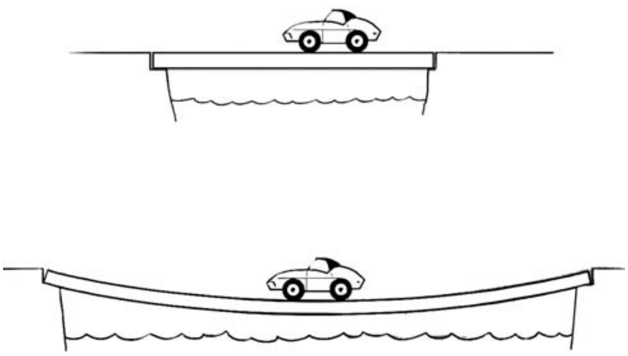


Fig. 26 Long beams are weaker than short ones

Increasing the thickness of the beam can make this type of bridge stronger and more rigid. This, however, will not only increase the cost, but will also make the bridge much heavier. A point will eventually be reached when the bridge cannot support its own weight and will fail (Fig. 3). As bridge building evolved, a different solution, to help carry heavier loads over longer distances, had to be found.

TRUSS BRIDGES

- Construction and materials
  A truss bridge is a version of the beam bridge, in which the beam is constructed from a lattice of straight sections that are joined together to form a series of triangles. This allows the beam to become thicker without significantly increasing the weight. The use of triangles produces a strong, rigid structure because they prevent the structure from bending, twisting or pulling out of shape. Early truss bridges included few triangles and were made from wood (see Figs. 27 & 28).

Fig. 27 King Post truss design

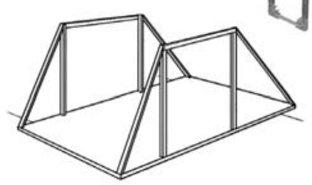


Fig. 28 Queen Post truss design

As better materials and designs were developed, trusses became more complex, using larger and larger numbers of triangles in their designs. Today, trusses are usually made from steel. In some cases the beam is "arch shaped". These are thicker in the middle, to provide greater strength where a simple beam would bend the most, and thinner at either end, where it bends least.

While the addition of trusses can increase the strength of a beam, truss bridges also have limits on their maximum practical length.

Longer Bridges

Let's investigate the problem of spanning a wider barrier

As noted above, a long beam bridge will bend in the middle when weight is applied. Engineers have attempted to overcome this problem in two ways. They have designed bridges so that the weak point in the structure (where it bends) is either pushed up from below by a pier or pulled up from above by cables. The use of these 2 techniques has resulted in a variety of bridge designs. The discussion that follows explores variations on the beam bridge, as well as reviewing the main features of the arch bridge, as a means to span wider barriers.

Fig. 29a: Problem: The bridge bends and is weak

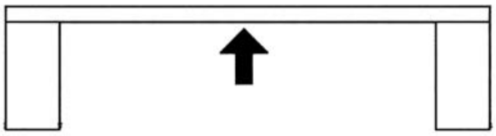


Fig. 29b: Solution 1: Push up from below

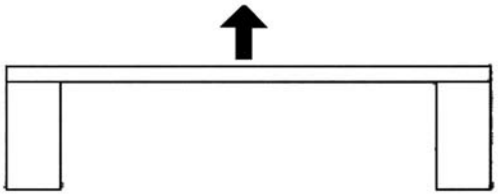
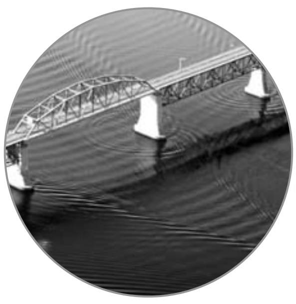


Fig. 29c: Solution 2: Pull up from above

Available options
1. Using multiple spans and supporting piers

Photo Courtesy of the Chesapeake Bay Bridge-Tunnel

Instead of using a long, single span with its inherent problems of bending in the middle, engineers have built bridges from what are effectively hundreds of small beam bridges joined together. The regularly spaced piers prevent the bridge from sagging. The Chesapeake Bay Bridge -Tunnel in the U.S.A. is constructed in this way and is known as a continuous span bridge. The bridge (together with the tunnel), crosses the shallow estuary of the Chesapeake Bay, and is about 26 kilometres long, but the largest single span is only 30 metres.



A Quick Guide to Structures: Bridges

2. Using arches
ARCH BRIDGES
The arch was used in structures built by ancient Egyptian and Chinese engineers, as well as in the buildings, bridges and aqueducts constructed by the Romans.

The arch draws its strength from the ability of blocks of stone, (concrete, bricks, wood, or steel), to withstand very large forces of compression. In the arch bridge, the forces of compression are dissipated along the curve of the arch towards its ends (abutments) and into the ground. The ground, in turn, pushes back on the ends of the arch, creating a resistance that is transferred from one block to the next until the keystone, or central block, is reached. These forces hold the stones together between the abutments of the bridge. When the arch bridge is made from masonry blocks, their shape is critical. Blocks (called **voussoirs**) must be wedge-shaped, as it is this shape that makes it possible for the arch to hold itself up. The wedge-shape ensures that each block is caught between its neighbouring blocks, preventing it from falling. If the blocks were rectangular, they could slip out of place, causing the bridge to collapse.

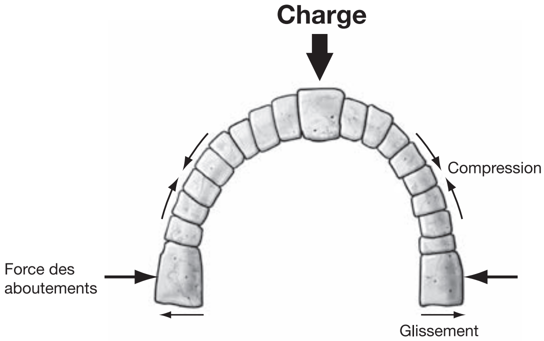
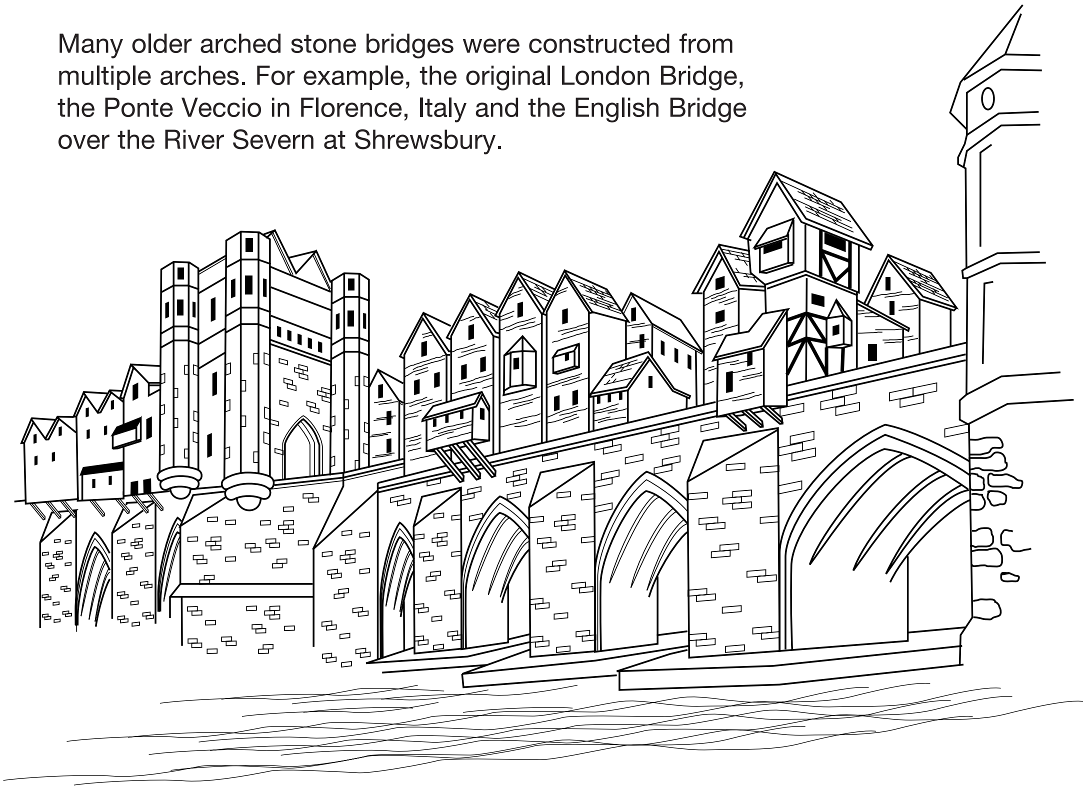


Fig. 30 Forces acting on an arch

All parts of an arch bridge are under compression – from the weight of the bridge deck pushing out along the curve of the arch and from the resistance of the ground pushing back on the abutments. Tension, by comparison is a minor force in an arch, even on its underside, although the steeper the curve of the arch, the more tension is likely to be present.

The use of abutments is a critical design feature of the arch bridge. Note how both ends of the Victoria Falls Bridge, which spans the Zambezi River and links Zambia and Zimbabwe, abut against the rock face of the ravine. These abutments prevent the ends of the bridge from pushing outward.

Many older arched stone bridges were constructed from multiple arches. For example, the original London Bridge, the Ponte Veccio in Florence, Italy and the English Bridge over the River Severn at Shrewsbury.



With time, bridge materials improved and arch bridges were made with cast iron, steel and, more recently, with concrete.

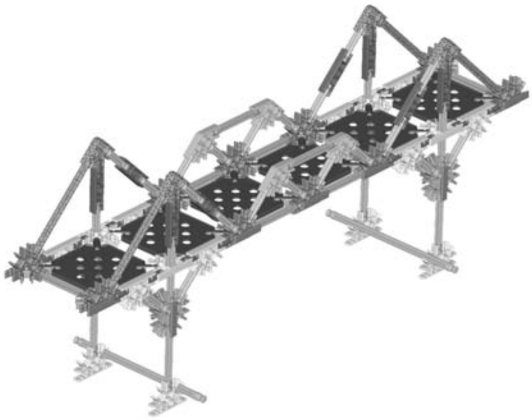
3. Using Cantilevers

CANTILEVER BRIDGES

A cantilever bridge is another variation of a beam bridge. In this type of bridge there are usually two beams extending out from opposite sides of a barrier, each supported by one pier only. Often an additional beam is placed over a gap between the two cantilevered beams to form an even longer span. Weight on a cantilever bridge system is transferred to the piers and then to the bedrock. Each pier is firmly embedded in bedrock and the deck extends out on either side of the supporting pier. In the cantilever system, the weight of the deck (and/or the anchors/counterweights) on the landward side of the pier balances the weight of the deck extending over the water. The balance of the forces involved allows the deck to extend far over the water with a minimal amount of additional support. Keeping the beam balanced can be accomplished either by:

1. Extending each span backwards, away from the pier to make a T-shaped structure.
2. Adding counterweights, or anchors, at the ends of the cantilevers, where they meet the shore. These anchors serve as weights at one end of the system, so the part of the deck extending beyond the pier, over the barrier, can be longer.

A Quick Guide to Structures: Bridges



The cantilever concept can be easily demonstrated using 5 books of an equal size (or wood blocks). Stand two books vertically - these represent the supporting piers. Lay a book, horizontally, on each of the piers – these represent the cantilevers. Each pier and cantilever should look like a letter T. Connect the two cantilevers by balaning another book across the gap or by moving the two cantilevers together so that they meet.

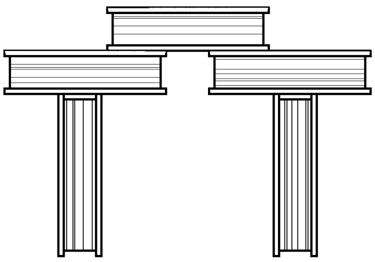


Fig. 31

Adding struts below the cantilever will provide additional support. The struts are joined to the bridge pier and are subject to compression. If, however, the struts are long and thin they might bend and buckle and so additional support could be needed. (See Fig. 34 showing the structure of the Firth of Forth Railway Bridge.)

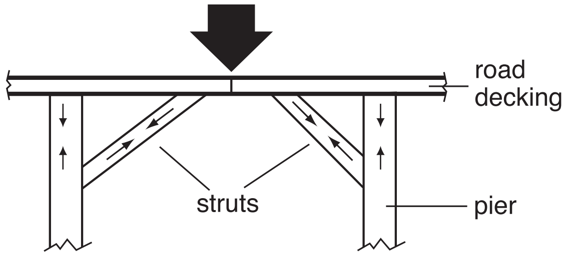


Fig. 32

Even more strength could be added by pulling up the road deck. The supports above the decking are subject to tension and so balance the compression forces acting on the lower supporting struts. This is the basis of the design for the Forth Railway Bridge.

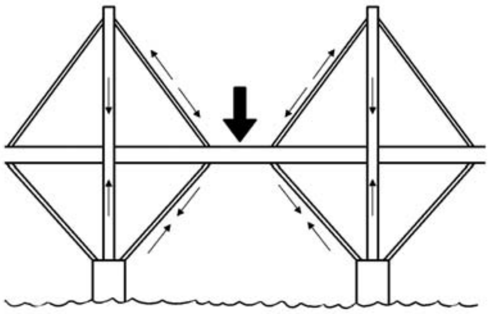


Fig. 33

Jacques-Cartier Bridge, Montreal, Canada: a cantilever bridge that incorporates a supporting steel truss structure.

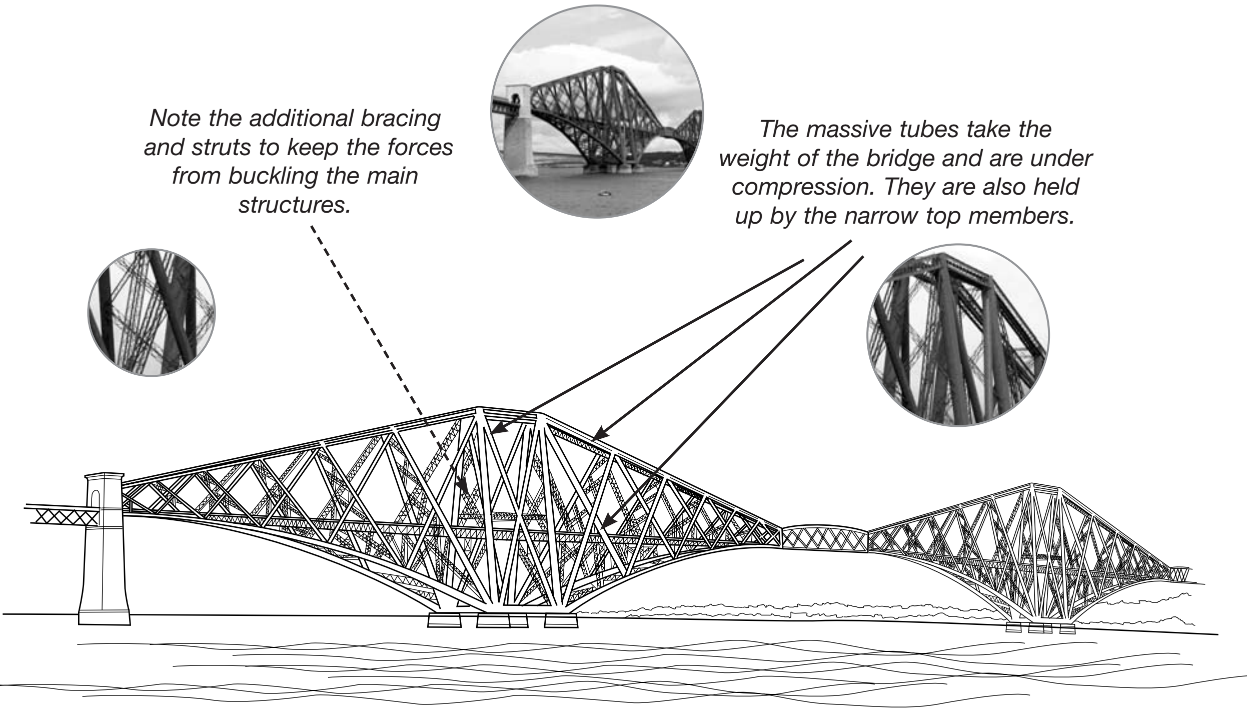


Fig. 34

The Forth Railway Bridge, crossing the wide estuary of the Firth of Forth near Edinburgh, Scotland is one of the world's largest cantilever bridges. It was constructed of steel in 1890 and has a length of approximately 2500 metres. Its central span between the two cantilevers, however, is only 100 metres wide.

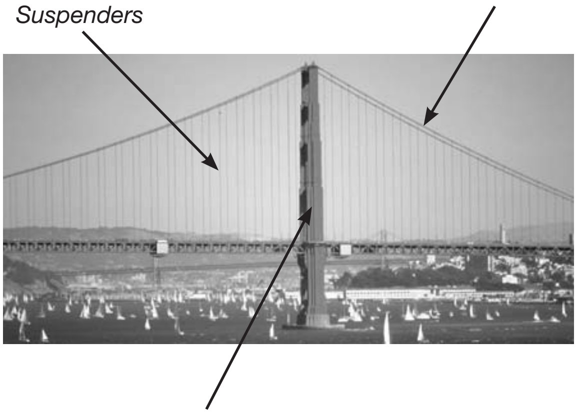
In this example the rail decking is supported from below by struts and from above by ties. Additional support is provided by a latticework of triangles above and below.

Like the Forth Rail Bridge, many cantilever structures have a triangular shape. These include roofs for railway stations, sports stadiums, some carports and even bookshelves.

4. Using cables to pull up from above
4A. SUSPENSION BRIDGES
The concept of a suspension bridge quite possible dates back to pre-history – vines in forested areas may have been used to construct footbridges across narrow valleys. Today, suspension bridges form some of the longest bridges in the world.

A Quick Guide to Structures: Bridges

- Constructions and Materials
  Modern suspension bridges use cables strung between two towers, (the cables pass over the tops of the towers), which support the weight of the bridge. The ends of the cables are anchored in the bedrock. The decking is suspended from vertical cables, called suspenders, which hang down from the main cables. The road decking itself may be gently arched, with a truss structure to provide additional strength and rigidity.



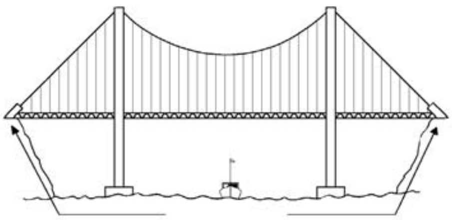
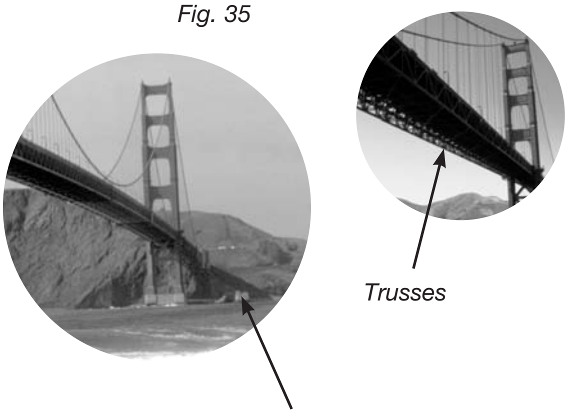


Fig. 35



- Forces acting on the bridge
  The design of suspension bridges, like any other type of bridge, must ensure that the forces acting on the structure are balanced and are working together in harmony. With a suspension bridge, the cables and the suspenders are under tension as they are always being pulled, while the towers are under compression because the cables push down on them.

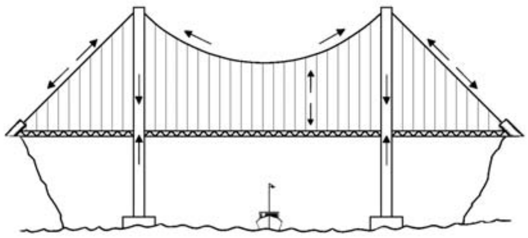


Fig. 36 Forces acting on a suspension bridge.

The Humber Bridge: Total length - 2220 metres

The very longest bridges built today are suspension bridges, capable of spanning lengths of 4000metres. The Akashi Bridge, linking the Japanese Islands of Shikoku and Honshu, for example, has a length of 3,911 metres.

4B. CABLE-STAYED BRIDGES
Cable-stayed bridges include design elements from both cantilever and suspension bridges: the road decking of the bridge is the cantilever structure and this is suspended by cables from a tower. Each tower supports a balanced portion of the deck by way of its cables. While the design idea is not new, this type of bridge became increasingly popular from the mid-20th Century onwards, largely due to developments in construction materials (pre-stressed concrete). It is also a relatively inexpensive design to build because, unlike a tower-to-tower suspension bridge, it does not require anchorages. As a result, this type of bridge is now selected for many locations where, formerly, a medium sized (under 1000 metres) suspension bridge would have been built. It is also worth noting that advances in technology have resulted in the construction of cable-stayed bridges with lengths of over 2500 metres.

- Construction and Materials
  Cables, attached to a tall tower, are used to support the bridge road decking. The cables run directly from the tower to the deck. Towers are typically constructed from concrete or steel, while the cables exhibit great variety in their design.

- Forces acting on the bridge
  All the cables are under tension and the tower, which is under compression, supports the total weight of the bridge and everything on it.

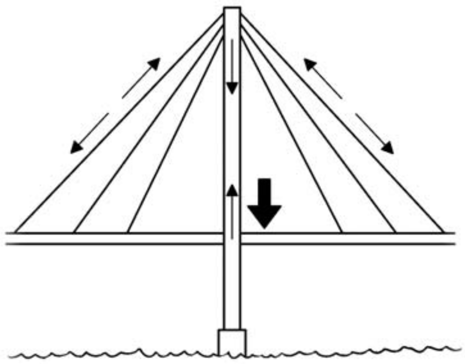


Fig. 37 Forces acting on a cable-stayed bridge

A Quick Guide to Structures: Bridges



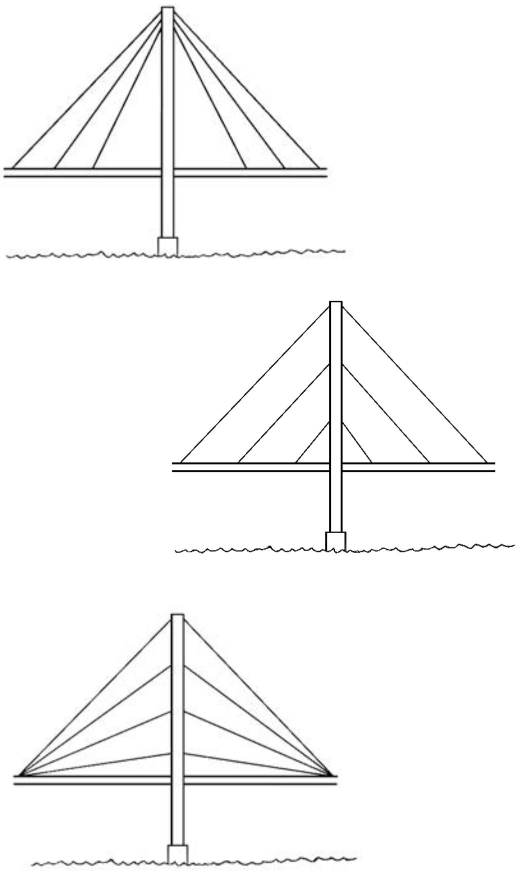


Fig. 38 Cable designs

NOTE: We encourage you visit www.brantacan.co.uk/cable_stayed.htm where you will find a helpful summary comparing the features of cable-stayed bridges with those of suspension bridges. This site also provides information on the new Severn Bridge (cable-stayed) carrying the M4 motorway over the River Severn and compares it with the older suspension bridge carrying the M48 motorway across the river further upstream.

Moving Bridges
BASCULE BRIDGES

The word BASCULE is French and means ‘seesaw’. A bascule bridge is one that opens to allow the passage of ships. Its central span is divided into two sections called leaves. The ends of the leaves must be counterbalanced to reduce the effort needed to raise them. These movable sections rotate upward to open the bridge and are operated by a system of counterweights, gears and motors. The counterweights themselves are typically made from concrete and are normally located below the roadway. A motor operates the opening mechanism; it turns the gears that move the counterweights down, while the leaves pivot up and open a passage for shipping. Tower Bridge, crossing the River Thames in London is a bascule bridge. Each bascule is approximately 33 metres (100 feet) long and each has a 422-ton counterweight attached at one end.

A bascule bridge opening for shipping

Tower Bridge, London, England.

A castle drawbridge
A drawbridge is a variation of a bascule bridge. Both types of bridges use the principle of the lever to operate.

Useful web sites:
http://www.brantacan.co.uk/ A valuable resource site with detailed information on all aspects of bridge design and construction. Offers an excellent selection of photos and diagrams that can be used in the classroom.

http://www.icomos.org/studies/bridges.htm This site is an excellent library of bridge designs from all over the world. Heavy on text and very detailed, but a good reference source.

http://eduspace.free.fr/bridging_europe/index.htm A very good educational web site with links to other sites. Has informative ideas for lessons and activities.

www.pbs.org/wgbh/buildingbig/bridge/. This web site offers an excellent interactive section on bridges where Forces, Loads, Shapes and Materials can be investigated.

http://www.pbs.org/wgbh/nova/bridge/. A companion web site to the US television series, “Super Bridge.” A useful source of information on bridge building, with interactive sections.

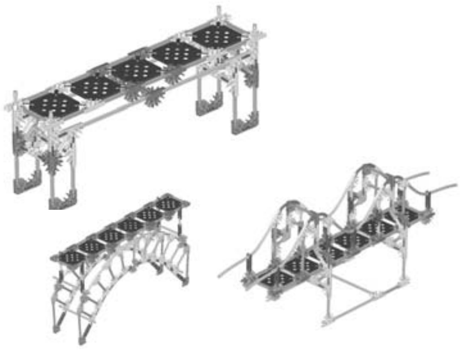
http://www.bbc.co.uk/history/society_culture/architecture/ This site offers animated and interactive sections on building an arch and the construction of the Iron Bridge at Coalbrookdale. You may need to download a free VRML plug-in or QuickTime to view these pages. Easy-to-follow directions are provided.

http://www.bbc.co.uk/history/society_culture/architecture/launch_vr_london_bridge.shtml This site provides a 3-D virtual tour of London Bridge as it was around 1500. You may need to download a free VRML plug-in to take the tour (directions provided).

Lesson 1: An Introduction to Bridges
OPTIONAL Preparatory Activities

Time: 2 hours

Objectives - Children should learn:
- to identify the forces that act on structures
- to demonstrate the ways in which selected materials respond to forces acting on them
- to explore the ways in which selected shapes respond to forces acting on them



Materials
Each group of 2-3 children will need:
- *Sheets of A4 paper*
- *Elastic bands*
- *Long K'NEX rods*
- *Selection of K'NEX corner Connectors*

You will need:
- *A piece of solid foam rubber approx. 30 x 6 x 6 cm*
- *Felt-tipped pen*

Teachers Notes
The activities described and referenced below are intended for children with no prior knowledge of structures. Your judgment will determine which of these activities are appropriate for your pupils.

Introduction
Begin by asking the children what they understand by the words: STRUCTURE or STRUCTURES.

Answers may include the following: Buildings including skyscrapers, stadiums, domes; roads/motorways; bridges; tunnels; dams; harbours; breakwaters; jetties; cooling towers for power stations; transmission towers; pipelines; oil rigs and oil platforms; pyramids; amusement park rides.

- Encourage the children to describe the largest structure they have visited. Ask them to describe their feelings while in the structure. Probe to discover why they had the feelings they described.

- *Possible answers: excited, anxious, amazed.*

- Ask them if they can tell you the name given to the specialists who design structures such as buildings, roads, and bridges.

- Ask the children the following question: "If you were an engineer designing a large building, bridge, etc., what would you need to take into consideration as you planned the structure?"

- Use probing, questioning strategies to help the class with this brainstorming activity.

- List their responses on the board and use a mapping or webbing diagram to help the children realize how many of their ideas are related.

Teachers Notes
Possible answers: Strength, beauty, safety, etc.

Possible Inquiry Activities
The **www.pbs.org/wgbh/buildingbig/bridge/** web site provides a **'Forces Lab'** that demonstrates the effects of FORCES on different shapes, as well as addressing building MATERIALS, SHAPES and LOADS. It uses simple, clear graphics and animations. We highly recommend that you and your pupils explore the resources offered at this site.

*Information and suggested classroom activities for **FORCES, MATERIALS** and **SHAPES** are provided in the Quick Guide to Structures: Bridges section on Pages 5-11 of this Guide.*

- You may want to discuss, for example, the **forces** that act on structures:
  - Squeezing/compression
  - Stretching/tension
  - Twisting/torsion
  - Sliding/shear

For additional information please refer to A Quick Guide to Structures: Bridges and the web site we have referenced above.

- You may also want to explore the following with the children:
  - some of the characteristic features of different types of **building materials**
  - the ways in which different **shapes** respond to different forces
  - the **loads** that structures are required to bear

All these concepts are clearly and simply demonstrated at the web site we have referenced above.

Suggested Procedure
Explain to the class that they will explore some of the factors that engineers must consider as they develop their designs.

1. If they appeared as responses in the earlier discussion, highlight the following factors that engineers must consider as they design structures. If they were not mentioned earlier, use questioning techniques to elicit them from the children and add them to the list/map:
- **FORCES** acting on the structure
- **MATERIALS** used for the structure
- **SHAPES** used in the structure
- **LOADS** to be carried by the structure

Lesson 1: An Introduction to Bridges
OPTIONAL Preparatory Activities

2. To introduce your pupils to these concepts **please refer to the activities described in the Quick Guide section on Page 5-11 of this Guide.** Resource materials for these activities are listed above on Page 22.

The activities you may want the children to undertake might include:

- Demonstrating the effects of forces using a piece of foam rubber or visiting the Forces Lab at **www.pbs.org/wgbh/buildingbig/bridge/**
- Activities demonstrating the ways in which the properties of materials can be changed, using sheets of A4 paper.
- Investigating the strength of various shapes using K'NEX Rods and Connectors.
- Using the Forces Lab at **www.pbs.org/wgbh/buildingbig/bridge/** to investigate ways to strengthen shapes used in structures.

Arrow Key

A wide, downward pointing arrow represents the LOAD.

Arrows along the bridge cables, beam, or arch represent compressions and tensions:

COMPRESSION

TENSION

Arrows at abutments or piers represent the transfer of weight to the ground.

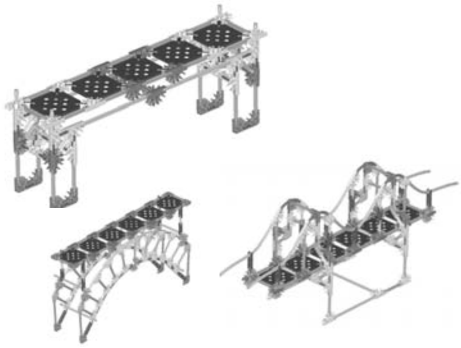
For example: All the arrows on an arch bridge represent compression, while most on a beam or truss bridge represent a combination of compression and tension.

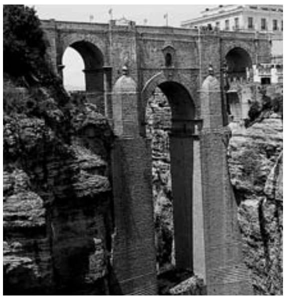
Lesson 2: What do bridges do?

Time: 2 hours

Learning Objectives - Children should learn:

- to form an operational definition of a bridge
- to use a range of sources to find information about bridges and how they support loads
- to relate the way bridges are designed and constructed to their intended function and to the materials used in their construction





Vocabulary
bridge, barrier, obstacle, valleys, estuaries, ravines, stepping-stones, span

Resources
Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges Building Instructions Booklet for photographs of bridges*

You will need:

- *Large scale map of the local area*

Useful Internet Web Sites
www.freefoto.com

www.brantacan.co.uk

www.howstuffworks.com/bridge

www.pbs.org/wgbh/buildingbig/bridge/

These web sites allow free use of their images for educational purposes.

Possible Teaching and Learning Activities

Introduction
In this lesson the children will learn about some of the key concepts used in the design and construction of structures. They will do this by researching some different bridge designs. They could also undertake a study of bridges in their local area.

Teachers Notes
This should be regarded as an introductory activity to help the children begin to appreciate that not all bridges are the same. Their later investigations, using the K'NEX materials, will deepen their understanding of the ways in which bridge designs differ from one another. You may want to have the children focus on beam, arch and suspension bridges in this activity. Alternatively, suggest a comprehensive survey that also includes truss, cantilever, cable-stayed and bascule bridges.

Lesson 2: What do bridges do?

Teachers Notes
*As noted in Lesson 1, the web site at **www.pbs.org/wgbh/buildingbig/bridge/** provides much of the basic information you will need to help children understand how bridges work. This site covers some of the main bridge types, the forces acting on them, explains compression/squeezing, stretching/tension, twisting and sliding forces using simple clear graphics. It also explores the effect of forces on different shapes.*

Other contexts might include stories about bridges, bridges in poems, or bridges in pictures, bridges featured in nursery rhymes, or bridges with which they are familiar. Examples: William McGonagall's,'Tay Bridge Disaster'; London Bridge is Falling Down; The Three Billy Goats Gruff.

*Some links to other sites can be found at the **www.brantacan.co.uk site.***

Whole Class

- Ask the children, " What is a bridge?" Record their comments on the board (or on large sheets of paper that can be displayed). You will refer the children back to these ideas.

A bridge is a structure that allows people/animals/vehicles to cross a barrier/obstacle of some form. Some children may also mention that bridges carry pipelines and also channels of water – aqueducts.

- You may want to use mapping strategies for this activity. Help the children form a definition of a bridge as a structure that provides a way for people, animals or vehicles to cross over a barrier.
- Encourage the children to use their imaginations and describe what they think the earliest bridges might have been like. Again, record their suggestions.

Answers will vary: fallen logs across streams; stones or boulders used as stepping-stones; vines to swing across a stream; combinations of all of these.

- Ask the children to identify:
  * **3 reasons why we use bridges today.**

  * **To cross busy roads safely; to cross rivers without getting wet; to move safely from one building to another; to drive cars across valleys.**

  * **3 barriers/obstacles that prevent people from getting from place to place.**

  * **Rivers; valleys; estuaries; roads; ravines; stretches of water between islands.**

* **How people crossed such barriers without bridges.**

- You may want to refer the children to the photographs of bridges shown in the Building Instructions booklet, and the barriers they have been designed to cross.

- Encourage them to look carefully at the shape of the bridges and ask them to notice differences. At this stage it may be helpful to focus on just 3 types of bridge: beam (Pages 2-3), arch (Page 10) suspension (Page 12).

- Ask the children to cite examples of bridges in your community.

- If there is a bridge near to the school you could begin your pupils' inquiries into bridges by visiting it and exploring its characteristics.

- Talk about how bridges have evolved from the simple stone slabs that may have been placed to cross a stream to massive bridges with spans thousands of metres long. The children should be made aware, however, that while modern bridges are usually great feats of engineering skill and design, in many parts of the world simple bridges of stone slabs or logs or vines continue to be constructed.

Working in Groups of 2-3

- Ask the children to investigate bridges using photographs and other sources. For example:
  www.brantacan.co.uk
  www.howstuffworks.com/bridge
  www.pbs.org/wgbh/buildingbig/bridge/

- Possible questions to ask:
  * **How many different types of bridges can the children find?**
  * **What types of barriers do the bridges cross?**
  * **Which types of bridges are the longest/shortest?**

Teachers Notes

* **Waded across fords in rivers; used stepping-stones; travelled up a valley or ravine to find a place to cross.**

Lesson 2: What do bridges do?

Alternative Activity

- Each group could choose a bridge from the local area to investigate and include some of the following information in a short, written report:
  - What type of bridge is it?
  - Where is the bridge located?
  - What is the purpose of the bridge – who/what/where does it link?
  - What type of barrier does the bridge cross?
  - What are the key measurements of the bridge? What is its approximate span, height…etc.?
  - What types of materials have been used to build the bridge?
  - What are the different parts of bridges called?
  - What do the different parts do?
- Ask each group to include labelled drawings, or photographs taken using a digital camera, of the bridge they have investigated.
- If the study of a local bridge is not feasible, children should select a well-known bridge and research answers to the questions identified above. They could download images from web sites to illustrate their report.
- Provide a local map and help the children locate the bridges they have identified, together with bridges in the community that they may not have mentioned.
- Ask them to imagine what travel would be like in the local area without these bridges.
- Encourage them to trace routes on the map for getting from one point to another without using any bridges.
- Suggest that the children count and list the bridges they cross as they walk, ride, or drive to school.

Teachers Notes
The children may not have this knowledge at this stage – a simple description will be sufficient.

Extension Activity 1
Do bridges fail?
Ask the children to investigate the Tay Bridge disaster.

Information about bridge disasters can be found at: ***http://eduspace.free.fr/bridging_europe/index.htm***

Plenary

- Provide each group with time to present their findings on the bridges they have investigated. Refer back to their original thoughts about bridges.
- Compile a table of the bridges presented by the children – is there any pattern? For example: bridge type/length/use.

Lesson 3: Beam Bridges

Time: 2 hours

Learning Objectives - Children should learn:

- the basic characteristics of a simple beam bridge structure
- that structures can fail when loaded
- to identify the need for a fair test and how to devise and carry one out

Vocabulary
stable, unstable, beam, pier, support, ramp, road deck, guard rail, beam, span, force, weight, load, splay, tension, girder

Resources
Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges set with Building Instructions booklet*
- *Hooked/slotted masses or other weights (10-1000 grams)*

You will need:

- *1 Pre-built K'NEX beam bridge*
- *A piece of solid foam rubber approx. 30 x 6 x 6cm*
- *Felt-tipped pen*

Useful Web Sites for children's research
Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

Possible Teaching and Learning Activities

Introduction
Explain that in this lesson the children will investigate a beam bridge. This is the simplest of all bridges and may have been the first type of bridge used – most likely a fallen tree trunk spanning a stream.

Whole Class
Review the results of the class investigation into different types of bridges from the previous lesson.

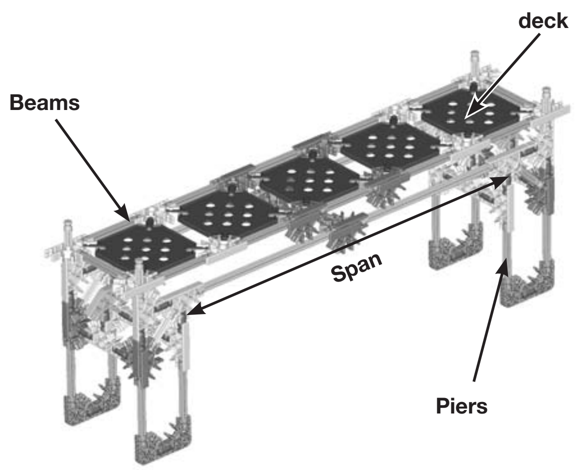
Teachers Notes
The main influence on bridge design is the distance to be crossed in a single span – the span being the distance between two bridge supports or piers. The supports can be constructed or can be natural rock.

Modern beam bridges can span a distance of 80 - 100m, while arch bridges may have spans of 250m; the longest spans are found in suspension bridges, some of which now span distances of 4000m.

Lesson 3: Beam Bridges

- Talk about how a beam bridge is one of the oldest and simplest types of bridge. The earliest example of a beam bridge was probably a tree trunk that had fallen across a stream. Modern beam bridges, often called girder bridges, are made from steel beams and can be quite complex structures, but all beam bridges are alike in the way they support their own weight and their loads on upright or vertical supports.

- Demonstrate the key parts of a beam bridge using a pre-made K'NEX beam bridge model.



- Write any terms used on the board, or create a word board using cards, with simple explanations on the reverse side as a reference for the children. For example: span, beams, piers or supports, ramp, roadway, deck, guardrails.

Teachers Notes
A glossary of terms is provided on Page 68 of this Guide.

- Explain that a beam bridge is simply a horizontal beam resting on piers at either end. The weight of the bridge, and any load it carries, pushes down onto the piers. The piers must support the total weight.

Teachers Notes
For information on the forces acting on beam bridges refer to A Quick Guide to Structures: Bridges section of this Guide.

Working in Groups of 4-6
Inquiry Activity 1: How long can a beam bridge be before it fails?

- Organize the class into groups of 4-6 children and distribute 2 K'NEX Intro to Structures: Bridge sets to each group.

- Before making the K'NEX beam bridge models allow the children time to investigate what happens to a simple beam structure the longer it becomes.
  - What do they think will happen to the load carrying ability of the bridge, as it gets longer?
  - How might they test their ideas?
  - What measurements will they need to make?
  - Where on the bridge will they actually take the measurements?
  - Where are the weak points in the structure?

SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Invite each group to construct a bridge between 2 desks/chairs, or large boxes, using the materials from 2 K'NEX sets. There should be enough room below the bridge to hang weights.

As each section of the bridge is added the load bearing capacity of the 'bridge' can be measured. If conventional weights are not available the children could be encouraged to develop an alternative method for measuring the bridge's load bearing capacity.

The simplest place to load the bridge is in the centre of the span.

- Encourage the groups to plot the load against bridge length and to record their observation through notes and/or annotated drawings. They could use the number of Rods as non-standard measurements for the bridge length.

The most likely place for the K'NEX bridge to fail is at the joints (the Connectors). This is also likely to be the case when children make structures from other materials.

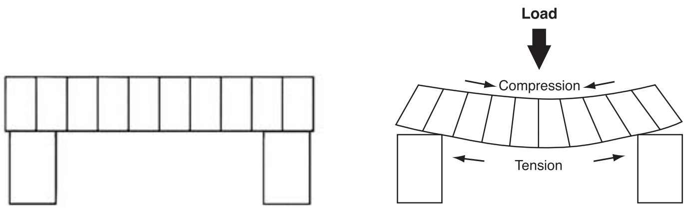
Lesson 3: Beam Bridges

Whole Class

- Discuss the children's findings.
  As its span increases, the weaker the beam bridge becomes. The beam will begin to bend under its own weight and may even break without any load being placed on it.

- These findings will provide an opportunity for you to review the effects of compression and tension on a structure.

- Remind the children of the activity - or undertake it now - that demonstrates the bending effect of compression and tension on a beam. Use a rectangular strip of solid foam rubber and draw parallel lines with a felt tipped pen along one side, as shown in the diagram below. Place the strip of foam across two blocks (or two books) and have two children hold the ends in place. Push down on the centre. The children should notice the effects of compression and tension in the spacing of the lines: they will move closer together at the top edge where compression (squeezing) takes place and move further apart at the lower edge where tension (stretching) occurs.



Forces acting on a beam.

Working in Groups of 2-3

- Ask each group to build the K'NEX Beam bridges shown on Pages 2 and 3 of the K'NEX Building Instructions booklet. They should investigate the effect of loading their bridges and find answers to the following questions:
  - What happens to the bridge parts and the piers as the load increases on each bridge?
  - Which bridge will have the greater load bearing ability?
  - What effect does the roadway or decking have on the load bearing capacity of each bridge?
  - Why do the K'NEX beam bridges not behave like the beam bridges in the photographs?
- Results can be recorded in a data table.

Teachers Notes

Careful observation of how the beam fails shows that the joints snap open at the bottom. This demonstrates that the beam is being stretched at the bottom i.e. put under tension. The top of the beam will be under squeezing forces or compression. Eventually even the plastic Connectors will unsnap if enough weight is put on them.
CAUTION: DO NOT ALLOW THE LOADING TO PROCEED THIS FAR.

As the bridge gets longer it will start to bend under its own weight.

Increasing the load on the bridges will cause the green Rods and Connectors to move and bend. The two K'NEX piers will also start to splay out. The children can measure the distances that the piers move as the load increases and the amount of sagging that occurs in the decking. They should discover that the bending (sagging) of the bridge components is greater at the centre of the Long Span bridge and the piers move further apart than they do in the Short Span version. They should also find that the bridge fails when it is carrying less weight than the Short Span beam bridge.

Teachers Notes
The decking gives additional strength to the structure by adding another layer that helps to resist the bending forces acting on it.

When loaded, the two K'NEX piers will start to splay out as the beam bends. In the photographs of real beam bridges, both ends of the bridges are firmly anchored. By preventing the base of the K'NEX piers from moving, the rigidity and strength of the K'NEX beam bridge can be greatly increased.

Plenary
Discuss how structures can fail when loaded and how the weight of the structure must also be considered because, in bridges, this can also cause a beam to bend. You may want to discuss this in terms of **dead load** and **live load**.

Discuss how their investigations demonstrate that if longer bridges are to be constructed, some method of reinforcing the structure will be required. In preparation for the next lesson ask the children to think about how they might reinforce their beam bridge.

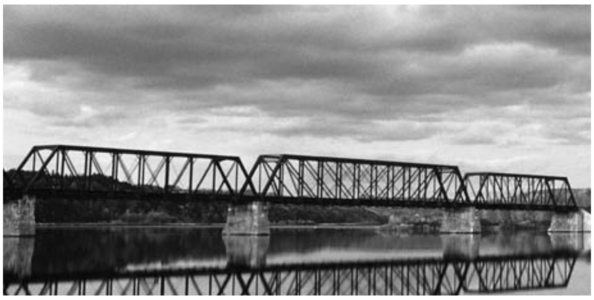
Suggested Worksheet: Beam Bridges

Lesson 4: Truss Bridges

Time: 2 hours or 2 x one-hour lessons

Learning Objectives - Children should learn:

- how structures can fail and explore methods used for strengthening and reinforcing them
- to understand the need for an experimental design that includes a fair test
- to apply what they have learnt by carrying out a simple design and make task
- to work as part of a team



Vocabulary

reinforce, strengthen, diagonal, stable, unstable, stability, framework, lattice, truss, arch, section, square section, ties, strut, beam, horizontal, vertical, model, load, loading, span, triangle, rectangle, force, weight

Resources

Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges set with Building Instructions booklet*
- *Slotted masses or other weights in designated amounts (actual weights: 10-1000grams; books etc.)*
- *String/cord to suspend the weights*
- *Different sizes of square section wood or dowelling*
- *Ruler, pencil, crayons*
- *Paper*

You will need:

- *A dictionary to use as the load for the Design and Build assignment (optional)*

Useful Internet Web Sites

Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

Possible Teaching and Learning Activities

Whole Class
Introduction

- Refer to the investigation carried out in the previous lesson into the strength of beam bridges.

- Discuss possible ways of making a beam bridge stronger/more stable so that it will not bend/fail when heavier loads are carried across wider spans.

Teachers Notes
The children may suggest adding more piers to support the beam, using more rigid materials or making the beam thicker. The optional activity below suggests one way to investigate their suggestions.

*The Forces Lab at **www.pbs.org/wgbh/buildingbig/bridge/** provides some very useful background information on this topic.*

You could take this opportunity to introduce the term stability as it relates to bridges. Stability is the ability to resist being deformed or buckled when a force or load is applied.

See: A Quick Guide to Structures: Bridges for additional information.

Optional Activity 1
Whole class demonstration or small group work
Depending on time available, either demonstrate or allow the children to investigate the effect of thickening a beam with respect to its ability to resist bending.

- Provide each group with supplies of different thickness squared section wood, or doweling, a ruler and weights and ask the children to devise a fair test to investigate how thickening a beam affects its ability to resist bending.

Teachers Notes
Possible variables the children may need to think about when devising their test include:
- *The length of beam they will test*
- *The thickness of the beam*

- The following are some questions for the children to consider:
  - How many different thickness sections of wood will be needed to get the information they need to answer the question? Will two thickness sections be enough?
  - How will they measure the ‘bending effect’?
  - How will they record and report their results?
- Discuss their findings.

Whole Class
- Ask the class to think of other types of structures that are strong and rigid. What shapes are used in these structures?

Remind the children about the way in which rectangular structures can be made stronger by reinforcing them with diagonal braces (triangulation).

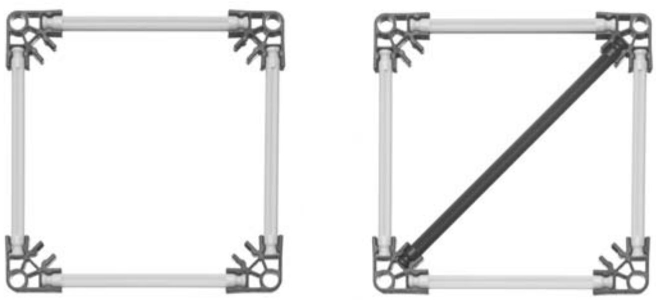
Lesson 4: Truss Bridges

Optional Activity 2
Working in Groups of 2-3

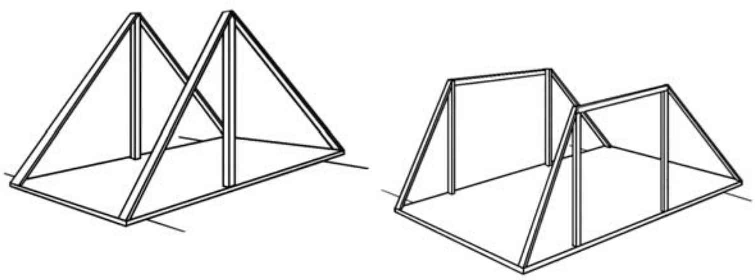
- Children could be allowed the opportunity of investigating this point for themselves by constructing a square from 4 K'NEX Rods (blue) and 4 dark grey 90-degree Connectors.

- Encourage them to gently twist and bend the square, then ask them to add one Rod to their square and notice what happens. (They can use a dark grey Rod as a diagonal.)

- Ask what shape was formed when they added a Rod to the square.



- Explain how engineers used the strength of triangles to create a framework called a TRUSS. Trusses can be used to build long spans and enhance strength without adding to the weight of the bridge, as a thicker beam would do. The use of triangles helps to keep a structure from bending, twisting or pulling out of shape. The truss bridge was designed as a latticework of triangles and other stable shapes.



- Introduce the ideas of **stable** and **stability** when applied to structures - the ability of structures to be able to resist being deformed significantly, or collapsing, when a load is applied.

- Explain to the children that they will build a number of versions of the truss bridge and will investigate the strength of truss systems.

- Ask the entire class what they think would be a fair test for measuring the strength of the bridges they build. Help them to understand that a fair comparison of the different versions can only be made if testing methods are the same throughout the series of experiments.

Teachers Notes
It is likely that the children will suggest adding weights to measure the strength of the bridges. Ask them to consider how and where they will place the weights. You may want to introduce the term "variable" at this point. Help them to understand that the way in which they place the weights should be the same in every test. In this way, the only variable is the amount of weight and not the way in which the weight is distributed. Hanging the weight underneath the bridge is a more consistent test than placing the weight on the deck or rails. If, however, the weights are hung, the children should ensure that the bridge is spanning a gap between two desks or 2 chairs.

Working in Groups of 2-3
How strong is the bridge without its truss structure?

SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Ask each group to build STEP 1 of the K'NEX Warren Truss bridge on Page 4 of the Building Instructions booklet. Explain that they should not build STEPS 2 and 3 until they have tested the load bearing capacity of the basic beam bridge. Questions for the children to consider:
  - Where are the weak points in the bridge structure?
  - What is the maximum weight the bridge can hold before it fails?

- Record the results for each bridge on the board. Ask the children, " Do you see any information that is not consistent with the other groups in the class? Can you offer any explanations for any data that seems to be different from the other groups?"

How strong is the bridge with its truss structure?
- Ask the children to make any necessary repairs to their bridge and then continue with STEPS 2 and 3 in the Building Instructions booklet to complete the Warren Truss bridge design.

- When completed the children should re-test their structure, using the same experimental design as before.

Lesson 4: Truss Bridges

- Ask the children to:
  - Predict the weight their bridge might support.
  - Record and explain their findings using labelled drawings and notes.
  - Explain the effect of using triangles in their bridge structures.

Other Truss Bridges

- To investigate the other examples of truss bridges, shown on Page 5, teams of 4-6 children could build 2 variations of the Warren Truss bridge: the Howe Truss and the Baltimore Truss bridges.
- They should be encouraged to make predictions about the number of triangles built into the structure and the strength of the bridge.
- Ask each team to test their new designs and record their findings in a table such as the one shown below. They should add their results from their investigations into the Warren Truss bridge to the table.

Bridge Design	Maximum Load (Weight)	Number of triangles in structure
Warren Truss		
Howe Truss		
Baltimore Truss		

- Review the findings. Ask the question, "If you had included the K-Truss in your investigations would it have been a fair test?" Ask them to look very carefully at the Building Instructions for the K-Truss design and compare this bridge with the other three bridges shown on Pages 4 and 5.

Whole Class

- Discuss how the height of the beam, (its thickness), has been increased by the addition of the trusses which form a latticework of triangles. The addition of triangles has the effect of increasing the stability of the structure by adding strength and rigidity to the existing beam.
- Talk about the possible limitations of a truss bridge design when increasing the span.

Teachers Notes

This would not have been a fair test because the K-Truss model is a different length from the other bridge models.

Other advantages of the design: The trusses dissipate, or spread out, the compression and tension forces through the structure when a load is applied. This is important, especially as heavy loads are moved across the bridge. (This type of bridge was developed to carry heavy trains with their problem of SHOCK Load.) The open framework of the truss design allows the bridge to withstand the effects of strong winds. The wind passes though the structure and reduces its effect - known as an ENVIRONMENTAL Load.

Limitations of the design:
As the span increases the weight of the bridge will also increase until its own weight will be so large it will not be able to support itself.

Remind the children about some of the effects they observed in the previous lesson.

Extension Activity 1
Working in Groups 2-3
Ask the children to design and make plans for their own truss bridge pattern. Each group may either make their own truss bridge or ask another group to build to their plans.

Design Task
Build a truss bridge that spans 50cms. and can bear the weight of a dictionary (or other designated load)

- 2 groups combine as a bridge design team.
- They have 10 minutes planning time and a further 20 minutes to complete the building activity.
- They may use the contents of 2 K'NEX kits.
- Before constructing their bridge, ask each group to decide what form of truss they might use.

Plenary
Each group tests their bridge, while the remaining groups observe.
Ask the children to:

- Share any problems they had with their structure and describe how they overcame them.
- Suggest ways in which their designs could be improved.
- Use correct terminology and vocabulary.

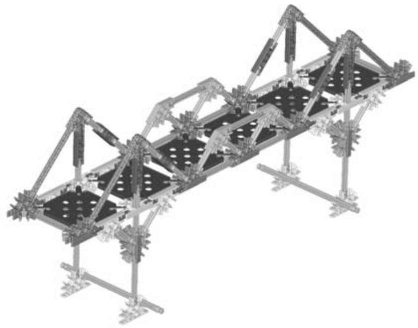
Suggested Worksheet: Truss Bridges
Ask the children to identify, by name, as many truss designs as they can. Use library or Internet research to identify those that are unfamiliar.

Lesson 5: Cantilever Bridges

Time: 2 hours

Learning Objectives - Children should learn:

- to relate the way things work to their intended purpose and to how materials have been used
- how to find information on bridges and the ways in which they support their loads
- to record their research findings using drawings and labels
- to work as part of a team



Possible Teaching and Learning Activities

Whole Class
Introduction

- Discuss how engineers have been called upon to design and build bridges that can carry heavy loads over longer and longer distances. Previously, the children learnt how the **truss** bridge overcame some of the engineers' problems, but when faced with crossing a wide estuary, like the Firth of Forth in Scotland, with its busy shipping lanes, a new solution had to be found. Beam and truss bridges, supported by many piers, are a problem for ships, and while in some locations a tunnel could be built, that solution is not always practical or cost effective. One alternative is to use a bridge design known as a **CANTILEVER** bridge. This bridge design is not new – small wooden cantilever bridges were built in China and Tibet more than 2,000 years ago – but longer cantilever bridges, capable of handling heavy rail traffic, could not be built until steel beams became available for bridge building in the 19th Century. The Firth of Forth Railway Bridge is probably the greatest cantilever bridge in the world and at one time held the record for the longest bridge.

Optional Research Activity

- To obtain background information, the children could be encouraged to carry out a research project and write a report on the Forth Railway Bridge.

What is a cantilever?

- Explain that the cantilever bridge is another variation of a truss bridge. Unlike the truss, or the simple beam bridge, however, the beams in the cantilever do not require two piers for support, just one. Bridges using this design are made from multiple cantilevers and often include an additional beam that is supported by the cantilever structure.

Vocabulary
cantilever, symmetrical, compression, tension, reinforcing, strengthening, diagonal, stable, unstable, stability, framework, lattice, truss, section, ties, brace, strut, beam, horizontal, vertical, model, load, loading, span, triangle, rectangle, force, weight

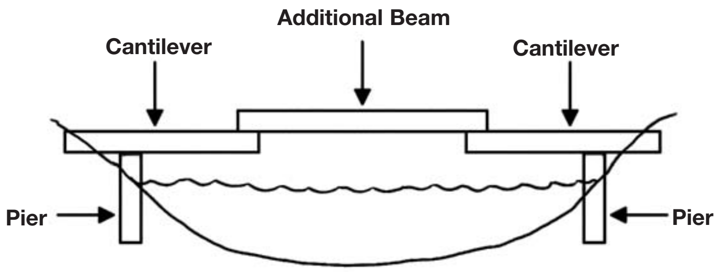
Resources
Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges set with Building Instructions booklet*
- *Slotted masses or other weights (10-1000 grams)*
- *5 (or 9) similar sized books or blocks of wood*

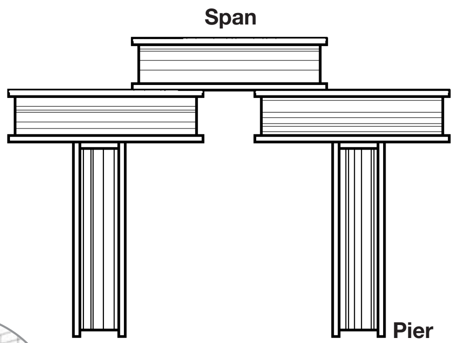
Useful Web sites for children's research:
Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

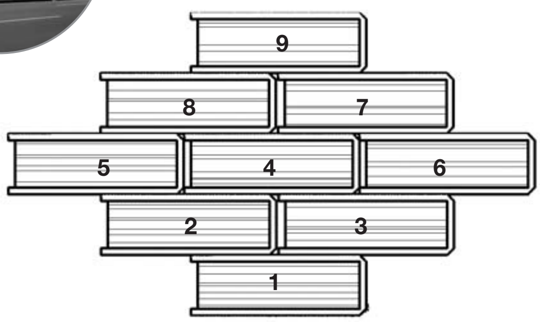
- Ask the children to imagine two diving boards, built on either side of a river. The ‘boards’ extend out over the river and either meet in the middle, or have an additional beam suspended on the two boards to close the span.

- You may want to draw a sketch on the board to demonstrate the principle.



- Demonstrate the concept by making a cantilever from books or blocks of wood.





- Ask the children to compare the shape produced, using the 9 books, with the photograph of the Forth Railway Bridge in their Building Instruction booklet. Both are very similar. Can they identify the cantilevers in the real bridge?

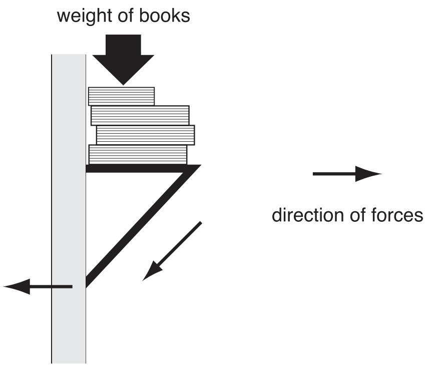
Teachers Notes
This can be demonstrated in 2 ways:

(i) Ask the children to use 5 books of an equal size (or blocks of wood). Arrange two books, a small distance apart, standing so that their spines are vertical. These will represent the piers of the bridge. On top of each pier balance a book horizontally – these represent the cantilevers. Each pier and cantilever should look like a letter T. Next, connect the two cantilevers by balancing a book across the gap. Encourage the children to experiment by moving the cantilevers closer together or further apart to see how the whole structure balances.

(ii) Alternatively, a symmetrical stack of 9 books, arranged horizontally, can represent the cantilever. The children will see that the stack needs support during construction - as the stack is built sideways it will begin to topple over. This is the cantilever action. The structure has become unstable, yet on completion, the whole structure is stable.

Lesson 5: Cantilever Bridges

- Talk about how cantilevers are not only used in bridges but can also be found at home or in school e.g. bookshelves. The shelf is the cantilever and the books the load. The weight of the shelf is supported by a triangular bracket, which transfers some of the weight of the books to the wall.



What might happen if a rectangular bracket was used instead of a triangular one?

Teachers Notes
It would probably collapse because rectangles are not strong shapes.

Working in Groups of 2-3

- To further their understanding of the cantilever concept ask the children to build STEP 1 (the road decking) of the K'NEX cantilever bridge model shown on Page 6 of the Building Instructions booklet.

- Two children should each build exactly one half of the decking.

- To enable them to feel the forces involved in the cantilever:
  - Ask each child in turn to hold one end of the decking in a horizontal position above their desktop. What do they notice?
  - Add small weights to the outer end to simulate a load on the bridge. What do they feel now?
  - Ask how they might reinforce/support their bridge decking to make it easier to hold.

Inform the class they cannot support at the non-holding end. Ask them to consider the techniques they have used to support and reinforce weak structures in previous investigations. For example, where do they need to push or pull up? Could they use diagonal braces, triangles… how might they be used in this instance? How is a bookshelf supported?

- Ask the children to record their ideas on the board.

Whole Class

- Bring the whole class together to discuss their findings and possible solutions to support the cantilever structure.
- Suggest the children place the decking on an upright book so that most of the decking is unsupported (as it was when they held one end of it.) Ask them to add weight to the end of the decking that rests on the book. Can they balance the decking with this added weight?
- Talk about how the cantilever has to balance – then it can stand on its own. Review the ways in which they could accomplish this.

Teachers Notes

There are two options available:
(i) Extend each span back, away from the centre of the tower/pier to make a T-shaped structure.

(ii) Add counterweights, or anchors, to the ends of the cantilevers, where they meet the shore/riverbank/wall etc.

Optional activity

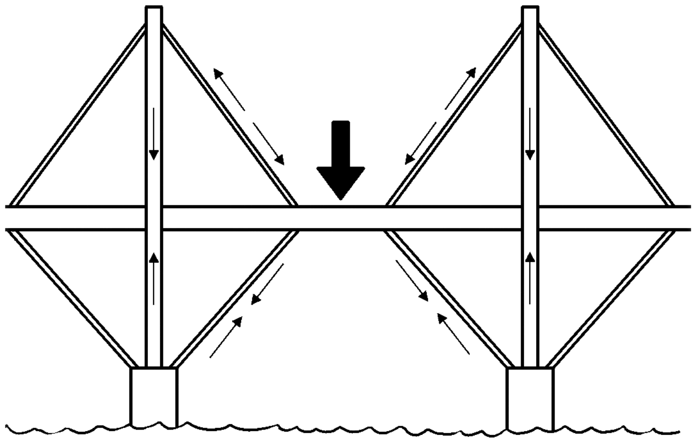
If time is available the children could make use of the Internet and the school library to carry out research on different structures that use the cantilever concept in their design. For example, the roofs of many football stadiums, railway stations, bus stations and carports make use of the cantilever design.

Working in Groups of 2-3
SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Ask the children to complete the building of the K'NEX Cantilever bridge model and investigate how it functions. Possible questions for the children to consider:
  - Why does their model bridge extend back from the supporting piers?
  - What happens to the supporting piers when you add a weight (load) to the centre span to simulate a train crossing the bridge?
  - How is the road decking supported so that it remains rigid and strong enough to support the load?
  - What parts of the bridge are under compression?
  - What parts of the bridge are under tension?

Lesson 5: Cantilever Bridges

- Do they think their cantilever bridge is a stable or unstable structure? Why or why not?



- Ask the children to record and explain their findings using labelled drawings, notes and the correct technical vocabulary.

Design Task – A large span

- 2 groups combine as a bridge design team.
- They have 10 minutes for planning and a further 20 minutes to complete the building activity.
- Using the contents of two kits, allow the children time to design a cantilever bridge that can carry a load of 2 dictionaries over a span of 60cms.
- Before constructing their bridge, ask each group to decide the method they will use to support the cantilever – where will the greatest support be needed?

Plenary

- Test the bridge structures.
- Ask the children to:
  - Share any problems they had with their structure and describe how they overcame them.
  - Suggest ways in which their designs could be improved.
  - Use correct terminology and vocabulary.

Teachers Notes

See A Quick Guide to Structures: Bridges for additional information. The children should recognize that the bridge extends back from the piers in order to balance the cantilever structure.

The base of the piers in the model bridge will splay outwards when weight is added to the deck.

There is a network of trusses to keep the bridge rigid and strong.

The supporting piers/towers and the triangular trusses beneath the deck are under compression, while the struts above the deck are under tension as the load presses down.

The children should be encouraged to use technical terms correctly when describing and reporting the results of their investigations.

Lesson 6: Bascule or Movable Bridges

Time: 1- 2 hours

Learning Objectives - Children should learn:
- to relate the way things work to their intended purpose and to how materials have been used
- how to find information on bridges and the ways in which they support loads
- to record their research findings using drawings and labels

Possible Teaching and Learning Activities

Whole Class
Introduction
- Review the functions and locations of the bridges the children have investigated so far. They all have in common the fact that they have been designed to allow water traffic to pass underneath them. Not all bridges, however, can be static. In medieval castles movable bridges – drawbridges - formed part of the castle's defence system.

- Bridges spanning more conventional barriers, such as rivers and canals, have also been required to open in order to accommodate tall masts or large hulls. Display pictures and ask the children to look at the photograph in the Building Instructions booklet on Page 8.
- Explain that this lesson will investigate one type of movable bridge – a **bascule** bridge. The word *bascule* is French and means seesaw.

Vocabulary
reinforcing, strengthening, diagonal, stable, unstable, stability, framework, lattice, truss, arch, section, ties, strut, beam, horizontal, vertical, model, load, loading, span, triangle, rectangle, force, weight, counterbalanced, counterweight, pier, bascule

Resources
Each group of 2-3 children will need:
- *1 K'NEX Introduction to Structures: Bridges set with Building Instructions booklet*
- *Slotted masses or other weights (10-1000 grams)*
- *Force meter (optional)*
- *Plasticene (optional)*

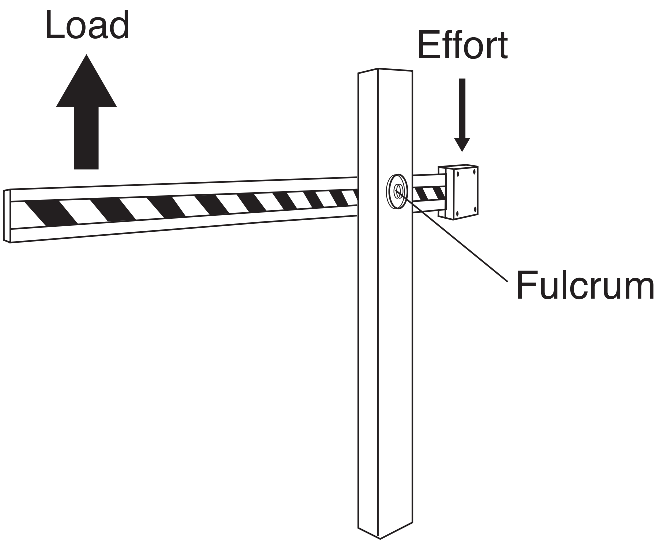
You will need:
- *Pictures of bascule bridges, such as Tower Bridge, London*
- *Pictures of sailing ships with tall masts and large ships such as container ships or oil tankers*

Useful Web sites for children's research:
Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

Lesson 6: Bascule or Movable Bridges

- Ask the children to consider ways to make a bridge move so that it can accommodate ships using a river.

- Ask the children if they have ever seen movable bridges operating. Ask where they are found and how they think they might work. For example, the children may have noticed that the road deck can be raised or it may rotate. Explain how castle drawbridges and even car park barriers use the same principle.



Teachers Notes
Drawbridges, car park barriers and bascule bridges are all forms of levers. Unlike the seesaw type of lever, they are asymmetrical. They need a weight at the shorter end to counterbalance the weight of the bridge, or the barrier, at the opposite end.

- Talk about the bridge in the photograph in the K'NEX Bridges Building Instruction Booklet and compare the way it works with Tower Bridge in London.

This lesson could be linked to the previous lesson on Cantilever Bridges. Essentially the bascule bridge in the photograph consists of two movable cantilever bridge arms.

This also presents an opportunity to include the children's knowledge and understanding of levers. The principle involved is similar to the car park barrier, where a long arm is counterbalanced by a weight at the operator's end.

In a bascule bridge the weight of the roadway is counterbalanced by a heavy weight under the short end of the bridge. This weight slots into an opening in the support pier – just like the mechanism in a castle drawbridge. Without the counterbalancing of the weight of the roadway, it would be almost impossible for the motors and gears in the raising mechanism to lift the arm.

- Arrange for the children to see photographs of movable bridges or encourage them to use the Internet to find out about the locations of bascule bridges, what they are used for and how their lengths compare to other bridges they have investigated.

Teachers Notes
The following Internet sites are useful sources of free photographs of bridges
www.freefoto.com
www.FreeImages.co.uk
www.brantacan.co.uk

Working in Groups of 2-3

SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Ask the children to build the K'NEX bascule bridge model.

- Provide time for them to investigate the model, then ask for volunteers to describe how the bridge functions. Suggest that they begin their description using the phrase: "To raise the K'NEX bascule bridge you first….."

The following should be included in their descriptions:
- *Apply a downward force to both blue Rods (levers) that extend horizontally at each end of the bridge.*
- *The K'NEX model has no counterweight and so it is necessary to use additional force on the opening lever to overcome the entire weight of the road deck.*
- *The bridge deck pivots on another blue Rod and moves into a vertical position.*
- *The deck is prevented from turning completely over on itself by the blue Rod (the lever) which stops at the pier.*
- *To lower the bridge, apply an upward force to the blue Rod (lever). The deck will pivot and return to a horizontal position.*
- *The green Rod, extending between the piers, prevents the deck from rotating any further.*

- Invite the children to discuss and investigate in their groups:
  - How they will measure the force needed to open the bridge.
  - Why the bridge roadway is narrower at one end than at the other.
  - The functions of the different shapes used in the real bridge design.
  - Why they think bascule bridges have only short spans.

Some children may decide to use weights attached to the ends of the roadway; others may attach a force meter to measure the 'pull' on the blue opening lever.

The children should be helped to understand that:

(i) if the spans of the two parts of the bascule bridge are too long they could sag in the middle

Lesson 6: Bascule or Movable Bridges

(ii) if the span is too long it will be harder to lift, or take too long to move.

Design Task 1: To reduce the force needed to open the bascule bridge

- 2 groups combine as a bridge design team.
- They have 10 minutes planning time and a further 20 minutes to complete the building activity.
- Before constructing their bridge, ask the children to suggest two alternative solutions and give their reasons for selecting the one they will use.
- Ask the children to record and explain their findings using labelled drawings and notes. They should adopt the correct technical vocabulary.

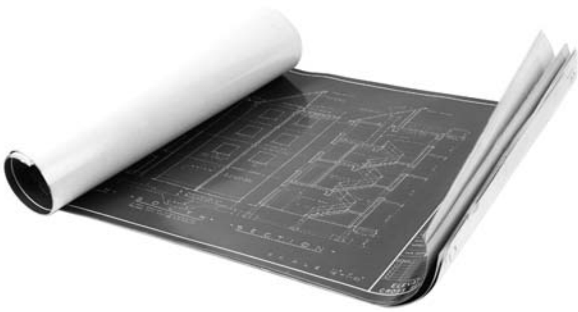
Teachers Notes

Slotted weights or Plasticene could be made available as counterweights.

The children should be encouraged to use technical terms correctly when describing and reporting the results of their investigations.

Design Task 2: Research how castle drawbridges may have worked.

- Design and make a working model of a castle drawbridge using a K'NEX kit and any other appropriate materials.
- The teams should draw plans of their proposed drawbridge before they begin construction.



Plenary

- Test the bridge structures.
- Ask the children to:
    - Share any problems they had and explain how they overcame them.
    - Suggest ways in which their designs could be improved.
    - Use the correct terminology and vocabulary.
- Discuss the children's findings about bascule and other movable bridges.

Lesson 7: Arch Bridges

Time: 1 hour

Learning Objectives - Children should learn:

- to relate the way things work to their intended purpose and to the way materials have been used
- how to find information on bridges and the ways in which they support their loads
- to record their research findings, making use of labelled drawings

Vocabulary
arch, abutment, span, reinforcing, strengthening, diagonal, stable, unstable, stability, framework, splay, keystone, horizontal, vertical, model, load, loading, resistance force, weight

Resources
Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges set with Building Instruction booklet*
- *Slotted masses or other weights (10-1000 grams)*

Useful Internet Web Sites
Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

Possible Teaching and Learning Activities

Whole Class
Introduction

- Remind the children of their previous investigations into strength and stability in structures and of the knowledge they have gained about engineering strategies to address problems with bridges that must span long distances.
- Explain how this lesson will be about a bridge design that has been used for thousands of years and is still used today.
- Arrange for the children to see photographs of structures that use arches. For example: Roman buildings, aqueducts and bridges, medieval river bridges, Victorian railway bridges.

Lesson 7: Arch Bridges

How strong is an arch?

- Demonstrate an arch shape using a green K'NEX flexi-rod and show how it can be used to make stable structures.

Teachers Notes

Teacher's notes: For more information on arches please refer to A Quick Guide to Structures: Bridges or visit the "Forces Lab' at **www.pbs.org/wgbh/buildingbig/bridge/.**

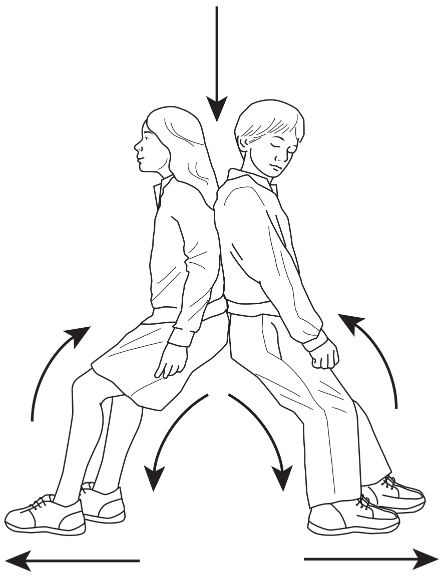
The web site at **www.bbc.co.uk/history/society_culture/architecture/** *offers an interactive section on building a stone arch.*

Demonstration or Working in Groups of 4

- Organize the class into teams of 4 children - similar heights and weights work best.

- Explain that they are going to make a human-body arch.

- Instruct two children from each team to stand back-to-back, a little bit apart and lean back against each other. Their feet should be planted one large stride in front of their bodies – they will need to bend their legs. They have now formed an arch. The two remaining team members should prevent the feet of the arch participants from sliding out from under them during the activity. They can place their feet in front of the experimenters' feet.



- Ask the children what it felt like to be part of an arch.
    - **Where did they feel the greatest forces?**

On their backs as they pushed against each other.

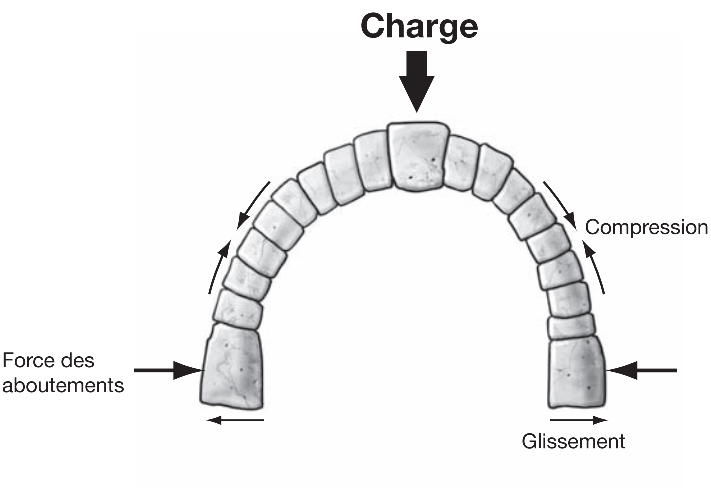
-
    - **What stopped their feet from sliding away?**

Friction and the feet of the other team members.

- Team members should switch roles so that everyone has the chance to experience being part of an arch structure.

- Show the class a picture of a stone arch bridge and compare it to the human arch bridges they have just made. Point out that the top centre stone in the arch, called the KEYSTONE, has a similar location to the place where their upper backs pressed together. All the other stones in the bridge push, or squeeze, against this stone, in the same way that all the weight of the children's bodies pressed against their upper backs.

- You may want to discuss the shape of the stones used in arch bridges and talk about why wedge shaped, rather than rectangular shaped, stones are used.
- Ask the children if their feet felt as if they were going to slide forward when they made their arches. Explain that the same thing happens in arch bridges as the weight of the bridge pushes downward and outward. The arch will only hold together if strong **abutments** are placed at the end of the bridge to keep the stones from pushing to the side.
- Ask what/who acted as the abutments in their human-body arch.



- Talk about how an arch can also be used in buildings because it is a very strong shape. Some Roman arch bridges are still in use today, 2000 years after they were built. Many multi-arch medieval bridges also continue to be used - the famous Ponte Veccio in Florence, Italy is one example.
- Explain how the children will investigate the stability of arch structures for themselves using a K'NEX model. They will be expected to record and report their findings through labelled drawings and notes.

Lesson 7: Arch Bridges

Working in Groups 2-3

- Before beginning construction of the K'NEX Arch Bridge model, you may want to draw the children's attention to the 3 versions (Pages 10-11 of the Building Instruction booklet) and explain that an arch can be a very versatile structure. Ask the children to identify the differences between the 3 versions of the bridge.

- Ask each group to construct Steps 1-4 of the K'NEX Arch Bridge shown on Page 10 of their Building Instructions booklet.

- Ask the children to test the stability of the arch at this stage of the construction.
    - What happens when they press down on the top of the arch?

- Ask the children to look at the photograph on Page 10 again and notice how the arch is built against the rock face. Arches need to be built against structures that prevent the ends from splaying outwards. These structures are called abutments; they can be constructed or they can be the natural rock on the side of a valley. Talk about how the rock prevents the arch sides from moving sideways.

- What happens when the sides of the arch are prevented from moving sideways? The arch now becomes a stable structure.

- You may want to organize the class into teams of 6-9 children and explain that each group of 2-3 children within the team will complete a different version of the K'NEX Arch Bridge model shown on Pages 10-11 and carry out a series of investigations. Results will be compared.

- Ask the teams to develop a fair test for investigating the strength of each version of the bridge. Measurements should be included. This information could be recorded in a table.

Teachers Notes

When completing STEP 1 suggest that the children work from left to right, connecting top and bottom rims of the arch with blue Rods as they proceed. They will find this easier than first building the entire top and bottom rows and then joining the two components with the blue Rods. Assembling the two sides of the arch (Steps 2, 3, 4) must be a shared activity as more than one pair of hands will be required to attach the green connecting Rods.

The centre is depressed and the ends of the arch move outward. This does not appear to be a stable structure.

Please refer to A Quick Guide to Structures: Bridges for further information.

Teams will probably decide to add the same load/weight in the same location on each of the bridges and notice the effect on the deck and on the sides of the arch.

Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Ask if adding the decking has affected the strength of the structure.

Teachers Notes
The completed bridge is more stable but a force will still need to be applied against the sides to give the bridge its overall stability.

- You may want the teams to investigate and discuss the following:
  - How is the road decking supported so that it remains rigid and strong enough to support the load?
  - What parts of the bridge are under compression?
  - What parts of the bridge are under tension?
  - Explain why they think their arch bridge is a stable or unstable structure.

The road decking is made rigid and strong enough to support a load by using a reinforcing framework.

The entire arch structure is under compression.

The decking on top of the arch is under tension.

You may want to help the children understand that the curved shape of an arch spreads out – dissipates – the compression forces toward the abutments. This is the natural strength of an arch shape. For additional information visit the 'Forces Lab' at **www.pbs.org/wgbh/buildingbig/bridge/**

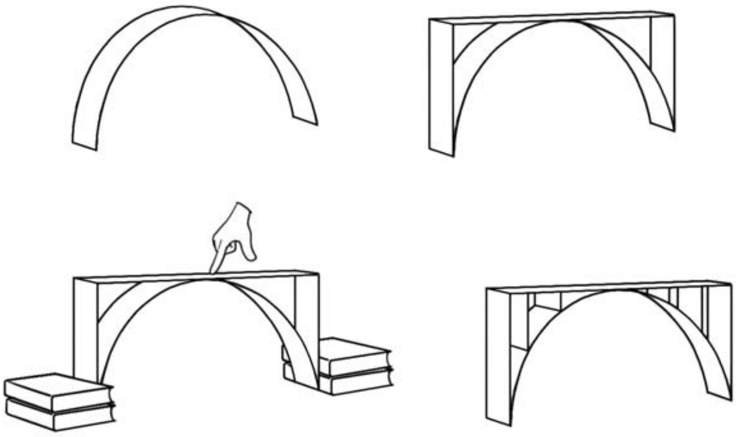
Extension Activity 1

- Invite each group to use the Internet, or school library, to research information about real-world examples of their type of arch bridge. They may want to investigate size, location and function.

Extension Activity 2

- The following activity allows children to put the arch concept into action by making an arch bridge out of flexible cardboard, as shown in the drawing below. They can form the curved piece by allowing a strip of wet cardboard to dry while wrapped around a can. Then the deck and side supports can be glued in place. Suggest they press gently on the bridge as they complete each stage to see where the bridge gets its strength. The children could also experiment with different sized spans and even build multi-arch structures.

Lesson 7: Arch Bridges



Plenary
Discuss the children's findings about arch bridges and how this arch bridge model uses similar structures to truss bridges to increase its stability.

Suggested Worksheet: Arch Bridge

Lesson 8: Suspension Bridges

Time: 90 minutes - 2 hours

Learning Objectives - Children should learn:

- to relate the way things work to their intended purpose and to how materials have been used
- how to find information on bridges and the ways in which they support loads
- to record their research findings using drawings and labels

Vocabulary

supporting towers, cables, roadway, deck, compression, tension, anchorage, reinforcing, strengthening, stable, unstable, stability, framework, truss, arch, suspension, horizontal, vertical, model, load, loading, span, force, weight

Resources

Each group of 2-3 children will need:

- *1 K'NEX Introduction to Structures: Bridges set with Building Instruction booklet*
- *Slotted masses or other weights (10-1000 grams)*

You will need:

- *A length of rope or strong cord (see illustration on Page 56)*
- *Plastic bucket with weights*
- *Large elastic band (optional)*
- *Block of foam rubber (optional)*
- *Props such as chairs, large sheets of coloured paper, rugs (optional)*

Useful Web sites for children's research:

Please refer to the list provided on Page 21 of this Guide. Many of the sites allow the free download of images for educational purposes.

Possible Teaching and Learning Activities

Whole Class
Introduction

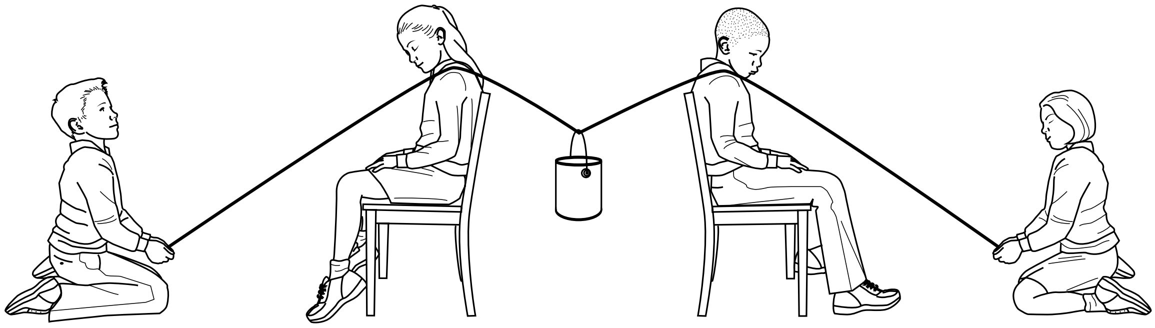
- Explain that this lesson will be about investigating suspension bridges. Display a large picture of a suspension bridge and ask the children to think of the ways in which this type of bridge differs from the ones they have explored so far. How is it the same? Record their answers on the board.

- String a length of rope over the shoulders of two children placed a few metres apart. Ask the class to suggest ways in which the rope could be used to make a bridge.

Teachers Notes

The children may suggest using it to swing "hand over hand" or as a simple rope bridge.

Lesson 8: Suspension Bridges



Teachers Notes
To help children understand the different parts of a suspension bridge and to experience the forces that are at work on it you could ask for volunteers to act out the roles of the different bridge elements. See drawing above.

- Place a rug or a large piece of paper on the floor and explain to the class that this represents a large river that has to be crossed by a suspension bridge.

- Refer back to the photo of the suspension bridge, or have them look at the photo of the Golden Gate Suspension Bridge shown on Page 12 of the Building Instructions booklet. Explain that there will be 2 chairs with a person sitting on each. Ask what the children think these will represent.

  *** Towers**

  Ask if they should be located on the banks of the river or in the river.

  *** Either location.**

- Seat the children on the chairs and drape the rope/cord over their shoulders. Discuss what the rope represents.

  *** The main cables.**

- Arrange for a plastic bucket to hang from the middle of the rope. What does the bucket represent? If necessary tell the children that weight will be added to the bucket.

  *** The weight of the road deck.**

- Ask how the ropes will be kept tight/taut so that the "bucket" does not slip down into the river. Help the children understand that the cables will have to be anchored into the banks of the river. Ask two more children to sit on the floor in locations that will represent the banks of the river. Hand the ends of the rope to these two children.

- Explain that weight will be added to the bucket and the aim is to keep the bucket at the same height above the level of the river. As weight is added the 4 pupils should describe their experiences.

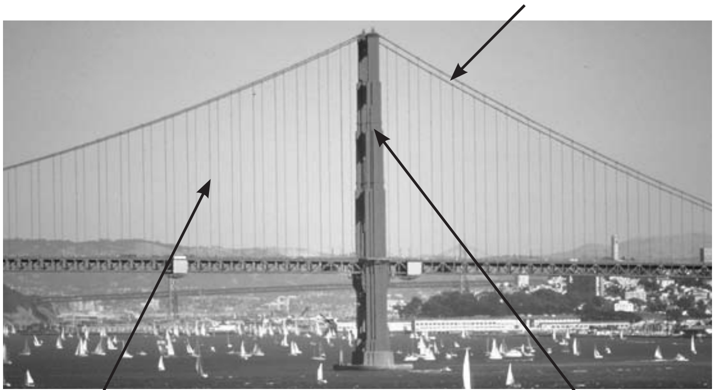
- Ask what would happen if one person were to release the end of the rope.

- Draw a diagram of the demonstration on the board and discuss how it represents a suspension bridge and the forces acting on it. Review how:
  - The rope acts as one of the bridge cables holding the weight of the roadway.
  - The children supporting the cables and the load are the ‘supporting towers’.
  - The children holding each end of the rope are ‘anchorages’.
  - The bucket handle suspending the weight from the cable is one of the bridge ‘suspenders’.

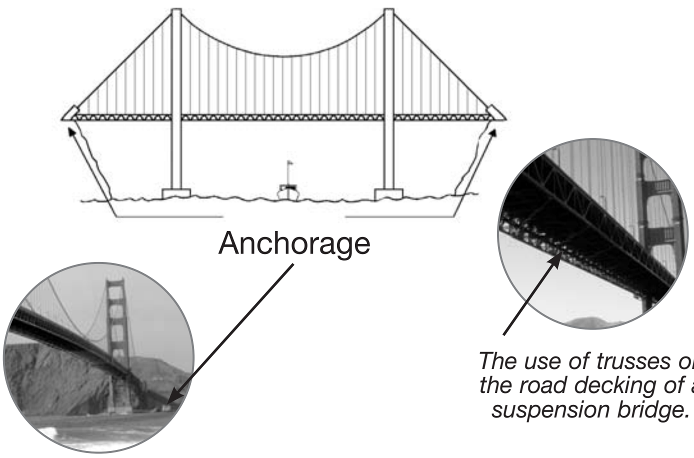
Teachers Notes

* **Those holding the ends of the rope should find that they must pull harder, while the seated pupils will find that more weight is pressing down on their shoulders.**

* **The rope would slip and the bucket would fall.**



Golden Gate Bridge, USA



The use of trusses on the road decking of a suspension bridge.

Lesson 8: Suspension Bridges

Working in Groups of 2-3

- Arrange for the children to see other photographs of suspension bridges. You may want to have the children use some of the web sites listed in this Guide. Encourage them to:
  - Identify the main components of suspension bridges.
  - Find out about the locations of suspension bridges.
  - Discover what types of traffic use them.
  - Compare their lengths to those of other bridges they have investigated.

Whole Class

- Ask the groups to report back on their suspension bridge research.
- Refer back to previous work on the strength and stability of bridge structures. Talk about the possible problems engineers may have had to solve when designing and making such long bridges. For example, the main span may be 2000m in length. How can such a long beam be supported and still retain its rigidity and strength? Record any suggestions they may have.

Working in Groups of 2-3
SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Explain how the children will investigate this problem starting with the K'NEX model suspension bridge on Pages 12 and 13 of the Building Instructions booklet.
- Ask the children to build the bridge up to and including STEP 4. They should then:
  - Observe what happens when a load is placed on the centre of the structure (or they press down on the structure).
  - Identify the weakest parts of the bridge.
  - Determine whether the bridge is a stable or unstable structure.
  - Explain their observations.
- Continue building STEPS 5-7 and connect the cables to the road decking. Test the structure again.
- How has the addition of the cables increased the stability of the bridge?

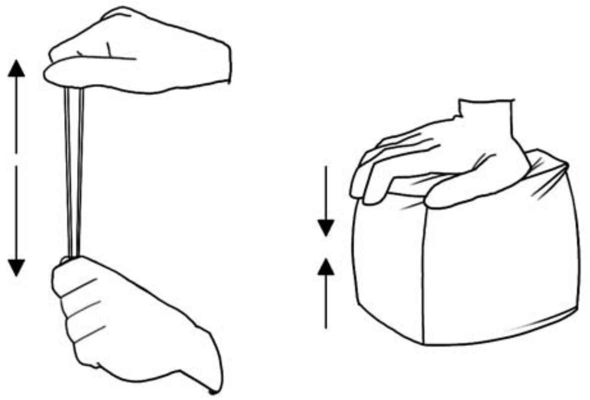
Teachers Notes
The following Internet sites are useful sources of free photographs of bridges:
www.freefoto.com
www.FreeImages.co.uk
www.brantacan.co.uk

See: A Quick Guide to Structures: Bridges for further information.

The entire structure is weak and unstable - the deck bends in the centre and sways from end to end, the towers move and also bend in towards each other. Explanation: As built, there are insufficient support structures for the bridge.

The weight of the load is taken up by the resistance of the cables, which are now under tension. The weight, however, will also pull the towers towards the middle. This force has to be balanced by pulling back on *the outer cables. In real suspension bridges the ends of the cables would be embedded in concrete or bedrock anchorages. If the ends of the Flexi-rods on the K'NEX model are pulled tight, the load carried by the bridge can be greatly increased.*

- Review their findings by asking:
  - What is the function of the towers?
  - What is the function of the cables that are laid across the towers?
  - Why do these main cables need to be anchored at either end?
  - What is the function of the vertical cables?
  - How is the road decking made strong and rigid?



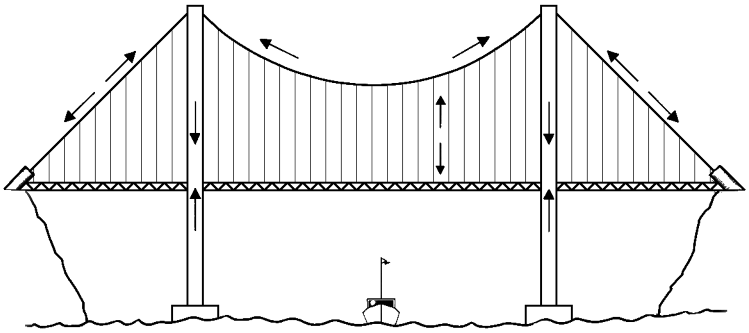
Tension and Compression or Pull and Push forces

- Refer the children back to their observations when acting out the different parts of a suspension bridge. Discuss the way in which all the cables are under tension and the towers are under compression. You may want to draw a sketch on the board to illustrate the location of the different forces acting on the suspension bridge. Identify tension and compression forces through the use of different coloured chalk/markers.

Teachers Notes

The towers carry the total weight of the bridge. The main cables, laid across the towers in 'saddles', carry the weight of the decking. This weight causes the cables to sag. To stop the whole structure from being pulled inwards, the main suspension cables must be anchored at both ends.The vertical cables, known as suspenders or hangers, connect the deck to the main cables. The road decking is arched and has a truss bridge construction. The arching of the road decking helps to reduce tension in the structure.

Lesson 8: Suspension Bridges



Forces acting on a suspension bridge.

- Ask the children to record and explain their findings.They should identify the forces involved in the bridge structure using labelled drawings and notes. They should also make use of the correct technical vocabulary.

Teachers Notes
The children should be encouraged to use technical terms correctly when describing and reporting the results of their investigations.

Extension Activity 1: When things go wrong

- Talk about how sometimes, even though engineers spend a great amount of time planning and testing the designs of their bridges before they are constructed, things do not always go according to plan.

- Ask the children to use the Internet to investigate the Tacoma Narrows (Washington, USA) suspension bridge collapse.

Photographs of this event can be obtained from ***http://eduspace.free.fr/bridging_europe/index.htm****. It also includes short film footage of the disaster. While modern suspension bridges are designed to sway to some extent, a slight wind could cause the Tacoma Narrows Bridge, crossing the Puget Sound in Washington State, to whip, bounce and ripple. It soon became a tourist attraction and was given the name “Galloping Gertie.” In November 1940, however, a moderate wind (40 m.p.h.) caused the bridge to twist and sway excessively until it failed. The design error lay in the shape of the bridge decking. It produced eddies of air that caused the bridge to oscillate. Had the designers first tested a model in a wind tunnel and then chosen decking with an aerofoil shape so that crosswinds could pass around and through the bridge, the oscillations would have been reduced. Ten years later the bridge was rebuilt using new specifications.*

Extension Activity 2

- Invite the children to act out an imaginary story about building a suspension bridge. Set the scene by describing two high cliffs on either side of a wide river. Ask them to set up chairs, tables, a rug and other props to represent the scene. Describe how a bridge is needed so that people and goods can cross from one side to the other. Explain that the only material available is rope. How can they make a simple bridge from this and what are the steps in the process?

- Ask the children to research how modern suspension bridges are constructed and present a report to the class. Suggest they use the following terms in their account: air-spinning, towers, suspenders, cable, catwalk, pilot rope, and anchorages.

Plenary
Discuss the children's findings about suspension bridges.

Suggested Worksheet: Suspension Bridges

Teachers Notes

A possible sequence might be:

1. *Find a good site for the bridge, with trees that can be used to attach the ropes for anchorage.*
2. *Construct several ropes from vines.*
3. *Attach the end of one of the ropes to a tree. Climb down the cliff, swim across the river with the other end of the rope and attach it to a second tree.*
4. *Travel hand-over-hand on the rope, carrying more vine ropes to be part of the bridge.*
5. *Lash the ropes together to make a walkway with handrails.*

Lesson 9: Cable-stayed Bridges

Time: 1 hour

Learning Objectives - Children should learn:
- to relate the way things work to their intended purpose and to the way materials have been used
- how to find information on bridges and the ways in which they support loads
- to record their research findings, making use of labelled drawings

Possible Teaching and Learning Activities

Whole Class
Introduction
- Explain that this lesson will involve investigating cable-stayed bridges using a K'NEX model. The children will also use the Internet to search for information about this type of bridge design.
- Arrange for the children to see photographs of cable-stayed bridges. You could use the photo on Page 14 of the K'NEX Building Instructions booklet. They could also use the Internet to find out about the locations of cable-stayed bridges, what types of traffic use them and how their lengths compare to other bridges they have investigated.
- After examining the photos of cable-stayed bridges explain to the children that this bridge design combines elements from 2 types of bridges they have already investigated. Can they name one bridge design it resembles?

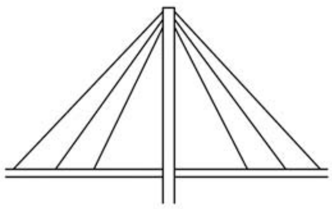
Vocabulary
cable-stayed, tension, compression, suspension bridge, tower, road decking, reinforcing, stable, unstable, stability, balanced and unbalanced, beam, horizontal, vertical, model, load, loading, span, triangle, rectangle, force, weight, similar, difference, compare

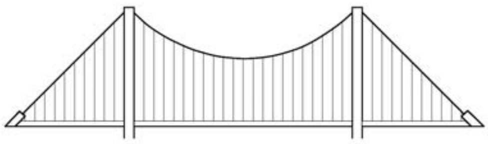
Resources
Each group of 2-3 children will need:
- *1 K'NEX Introduction to Structures: Bridges set with Building Instructions booklet*
- *Slotted masses or other weights (10-1000 grams)*
- *String or cord*
- *Paper, pencil, scissors*

Useful Web sites for children's research:
Please refer to the list provided on Page 21 of this Guide as well as the note below. Many of the sites allow the free download of images for educational purposes.

Teachers Notes
The cable-stayed bridge is a relatively new design. The first bridge using this design was constructed in the 1950s. These bridges are usually of medium size and are a combination of a cantilever structure and a suspension bridge, in which the tower supports a balanced portion of the road deck by its cables.

- Draw simple sketches of a suspension bridge and a cable-stayed bridge on the board and/or create a worksheet and ask the children to compare the design features of the bridges.
  - In what ways are the two designs similar and how do they differ?





- Refer back to previous work on the strength and stability of bridge structures and talk about the possible problems engineers may have had to solve when designing and making cable-stayed bridges. What, for example, might happen to the road deck as they build it outwards from the single tower?

Working in Groups of 2-3

SAFETY NOTE: Please have the children wear safety glasses as they test their bridges. This is sound safety practice for activities in the science classroom or lab.

- Explain how the children will investigate this problem using the K'NEX cable-stayed bridge model shown on Page 14 of the Building Instructions booklet.

- Ask the children to build STEPS 1-3 of the Single Tower K'NEX cable-stayed bridge.

The following Internet sites are useful sources of free photographs of bridges
www.freefoto.com
www.FreeImages.co.uk
www.brantacan.co.uk

See: A Quick Guide to Structures: Bridges for further information.

Teachers Notes
Similarities: Both have decks suspended from cables.

Differences: In a suspension bridge the cable runs from tower to tower and the road deck is suspended from the cable, whereas in a cable-stayed bridge there is usually only a single tower from which the cables run directly to the road deck.

NOTE: Some cable-stayed bridges do employ two towers to accommodate long spans.

Lesson 9: Cable-stayed Bridges

- The children should observe and explain what happens when they place a load at the end of either arm or press down on the arms.

- Is this model bridge a stable or unstable structure?

Teachers Notes
In this case the bridge is like a large seesaw – it is balanced in the middle but when a load is placed at one end, the opposite end rises. In a real cable-stayed bridge both ends would have supporting piers - just like a cantilever bridge. Ask the children to look at photos of real cable-stayed bridges to confirm this.

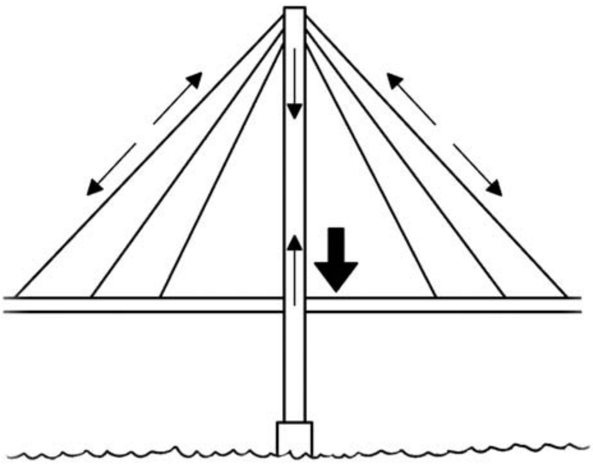
- To demonstrate the forces and support given by the cables, ask each group to remove the cables from one side of the bridge, place a small load on both ends and observe what happens.

  *** The end without the cables attached will collapse.**

- Discuss with the groups how both cable-stayed bridges and suspension bridges mainly rely on tension to create a stable structure. Ask them to infer from their models the parts of the bridge that will be under tension and the parts that will be under compression.

- What do they notice about the shape of the road decking?

The children should be helped to see that, if the bridge is carrying a live load, the tower and the deck are under compression, while the cables are under tension. You may want to develop this further by explaining that in a cable-stayed bridge, the resistance of the cables, now under tension, matches the load of the decking, while the towers support the weight of the bridge and are under compression. The road decking is slightly arched. This arching helps to reduce tension in the road decking beam.



Forces acting on a cable-stayed bridge.

- Ask the children to record and explain their findings using labelled drawings, notes and correct technical vocabulary. Their findings should include answers to the following questions:
  - *** What is the function of the tower(s)?**
  - *** What is the function of the cables?**

Teachers Notes
- *** To support the weight of the bridge**
- *** To support the weight of the road deck**

* **Which parts of the bridge are under (i) compression (ii) tension**

* **How is the road decking made strong and rigid?**

Teachers Notes

* **i. tower, ii. cables**

* **The cables pull on it to make it slightly arched. The children may find from their research that the deck on some cable-stayed bridges include a truss system to add to its strength and rigidity.**

Extension Activity
Working in Groups of 2-3
Ask the children to build the Double Tower Cable-stayed Bridge and investigate the Second Severn Crossing Bridge.

Each group should prepare an illustrated report to include bridge 'facts and figures' and an explanation of why this site was selected for the bridge. Would the children have used a cable-stayed bridge design for this site? They should be prepared to explain their answers.

Plenary
Discuss the children's findings about cable-stayed bridges. Talk about how both cable-stayed bridges and suspension bridges mainly rely on tension to create a stable structure.

Suggested Worksheet: Cable-stayed Bridges

Lesson 10: Design and Make Assignment

Time: 2 hours

The Design Task
To design and make a bridge that can span a 40cms gap and be able to support a 50g load in the middle of its span. The bridge must have a roadway designed to accommodate vehicles.

Introduction
Discuss how the children will be set a task of building a bridge to carry a specific load. They will work as company design teams comprised of 4-6 children. Each group can decide on their company name.

Every member of the company will be assigned a role. Roles might include drawing the design plans, overseeing the operations to see that the work is done according to plan and using the designated materials, purchasing materials and tracking the costs, or serving as spokesperson for the group. Everyone should play a part in the actual construction process.

The project requires their bridge to be constructed from any, or all, of the following materials: A4 paper, paper clips, sellotape, pipe cleaners and straws. The companies decide which materials to use for their design.

Talk about how, once they have developed the preliminary design drawings, engineers use small models to test bridges for design, safety and strength. From the models, special building instructions called blueprints are made. Bridge builders follow these plans when constructing an actual bridge. Display an example of a blueprint so the children can see the kind of information that is typically provided on such a document.

Teachers Notes
You may need to draw the children's attention to the fact that, like all plans and maps, the blueprint (or construction drawings) can only show 2 dimensions at a time. The plan can show the length and the width of the structure, while the elevation shows the height and either the length or the width (not both). You may want to make sketches on the board to illustrate this.

Conditions
- The bridge must span 40cms.
- It must be able to carry a load of 50g.
- It must have a roadway designed to accommodate vehicle traffic.
- The companies will be allowed 1 hour designing time, during which they will draw and try out their design and estimate and purchase the materials for their bridge.
- They cannot use K'NEX construction kit parts in their final model, but ***they can use the kits to try out and test their ideas.***

Remind the children about developing their ideas first and that the K'NEX kits are available for this purpose.

Encourage the children to record all their design ideas on paper together with the reasons for rejecting and accepting them. They should make notes and comments on any modifications made to their design during the construction process.

- The materials can be purchased from the teacher's store at the following prices.

A4 paper	£5 per sheet
Sellotape	£1 per 10cm strip
Paper Clips	£0.50 each
Straws	£1 each
Pipe cleaners	£2 each

- No materials can be left at the end.

- Any over-purchases will be bought back by the teacher's store at half the original cost.

- If any additional materials need to be purchased to complete the bridge they will cost twice the original price.

- The companies will have 45 minutes to construct their bridges.

- A drawing that looks like a blueprint should be made of the structure. Children can use graph paper or A4 paper. Accuracy is important.

Presentations
Invite the children to present their bridge designs to the rest of the class. Companies should describe the type of bridge they built, how they decided which type of bridge to build, and point out the components from which the bridge is made. Each bridge should be tested using the 50-gram weight. The total cost of the bridge should be noted and the blueprint/construction drawing should be displayed. When evaluating their design ask questions such as:

- How can we make it stable?
- How can we make it stronger?
- What are the weak points in the design?
- How can we reinforce it?

On completion of their presentations ask the children to:

- Share any problems they had and the ways in which they overcame them

- Say how they might improve their design – where the weak points were located and techniques they might use to strengthen them.

- Say how they might make their bridge stronger, using fewer materials

Teachers Notes
You may wish to present this activity as a competition, in which case the company who will be assigned the contract for the project will be the one whose bridge meets the design specifications at the lowest cost.

Alternatively, present this as a problem-solving activity involving cooperative teamwork - one in which everyone is a winner.

Glossary

The following is intended as a glossary for the teacher. The age of your pupils, their abilities, their prior knowledge, and your curriculum requirements will determine which of these terms and definitions you introduce into your classroom activities. These items are not presented as a list for children to memorize. Rather, they should be used to formalize and clarify the operational definitions your pupils develop during their investigations.

BRIDGE
A structure that provides a way across a barrier. Something that connects, supports, or links one thing to another.

Arch Bridge: A bridge having a curved structure. The arch design provides strength by exerting force downwards and sideways against the abutments.

Bascule Bridge: A hinged bridge that acts like a seesaw. Sections can be lifted using weights as a counterbalance.

Beam Bridge: The simplest type of bridge. It is made from a rigid, straight structure resting on supports at either end.

Cable-Stayed Bridge: A modern design of bridge in which the deck is supported by cables directly attached to towers.

Cantilever Bridge: Similar to the beam bridge, this design gets its support from counterbalanced beams meeting in the middle of the bridge rather than from supports at either end. The two arms of the beam are called cantilevers.

Suspension Bridge: A type of bridge in which the deck hangs from wires attached to thick cables. The cables themselves pass over towers and are securely anchored in concrete anchorages.

Truss Bridge: A type of beam bridge, reinforced by a framework of girders that form triangular shapes.

LOADS AND FORCES:

Load: The distributions of weights on a structure. (See also Dead Load and Live Load below).

Force: A push or pull. In the case of bridges, force is applied to the bridge in the form of a load.

Stress: A force that tends to distort the shape of a structure.

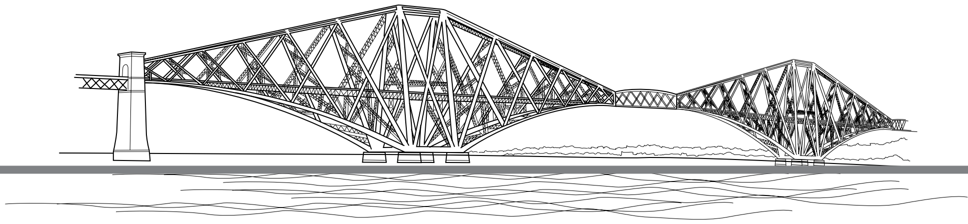
Compression: A force that tends to shorten, push or squeeze a structure.

Tension: A force that tends to lengthen or stretch part of a structure.

Torsion: The strain produced when a material is twisted.

Shear: A force that acts to move a material in a sideways motion.

Symmetry: An arrangement that is balanced and equal on opposite sides of a central dividing line.



Buckle: A condition that occurs when structures bend under compression.

Dead Load: The weight of the bridge's structure.

Live Load: The weight of traffic using the bridge.

BRIDGE FEATURES:

Abutment: The mass of rock or concrete at either end of an arch bridge that keeps the ends of the arch securely in place.

Anchorage: Foundations/concrete blocks into which the cables of a suspension bridge are secured.

Beam: A rigid, horizontal component of a bridge.

Brace: A support used to strengthen and stiffen structures.

Cable: A bundle of wires used to support the decking of a suspension bridge or a cable-stayed bridge.

Caisson: A temporary structure used to keep out water during construction of the piers' foundations.

Decking: The surface of the bridge that serves as a walkway, roadway or railway.

Engineer: A professional who researches and designs bridges and other structures. There are many types, including civil, structural, and environmental engineers.

Framework: A skeletal arrangement of materials that give form and support to a structure.

Girder: A strong, supporting beam.

Hand or Guardrail: A safety feature added to the sides of the bridge's deck to prevent people, animals or vehicles from falling from the bridge.

Keystone: The final wedge-shaped piece placed in the centre of an arch that causes the other pieces to remain in place.

Obstacle: Something that stands in the way or acts as a barrier.

Pier: A vertical support for the middle spans of a bridge – a column, tower or pillar, for example.

Pulley: A wheel used for hoisting or changing the direction of a force.

Ramp: An inclined section connecting the shore/banks/approach route to the deck of the bridge.

Roadway: The area of the bridge along which traffic travels; it rests on the decking.

Span: The section of the bridge between two piers.

Support: An object that holds up a bridge and serves as a foundation.

Suspender: A supporting cable for the deck; it is hung vertically from the main cable of the suspension bridge. Also known as a **Hanger.**

Strut: A structural support under compression.

Glossary

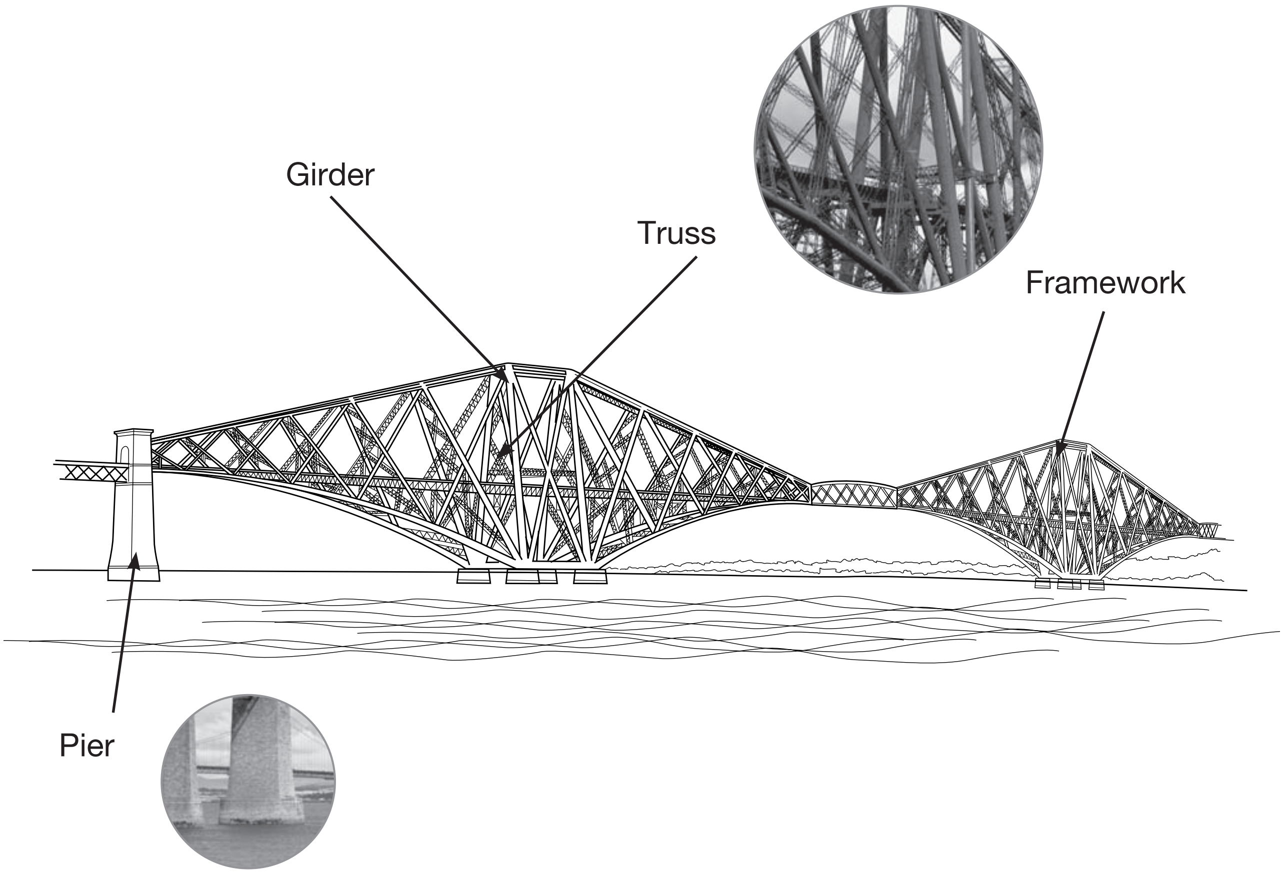
Tie: A structural support under tension.

Tower: A tall, vertical support that carries the main cables of a suspension bridge and cable-stayed bridge.

Triangulation: A building concept, using triangles, made from squares, to enhance the strength of a structure.

Truss: A framework of girders, some in tension and some in compression, comprising triangles and other stable shapes.

Voussoir: A wedge-shaped stone block used in an arch. (French: ‘arch-stone.’)



Cantilever Bridge - The Forth Railway Bridge, Scotland

Worksheet 1

WORKSHEET 1

BEAM BRIDGES

Write short sentences to describe what each of these parts of a beam bridge do.

1. PIERS ______________________________________

____

2. BEAM ______________________________________

____

3. SPAN ______________________________________

____

4. DECK ______________________________________

____

5. RAMP ______________________________________

____

6. GUARDRAILS ________________________________

____

ANSWER KEY:

WORKSHEET 1: BEAM BRIDGES

PIERS: Vertical supports that hold up the beam bridge.

BEAM: Horizontal framework that rests on piers.

SPAN: Distance between the piers.

DECK: Foundation on which roadway/walkway is built on top of the beam.

RAMP: Inclined section that connects land to beam.

GUARDRAILS: Protective barriers along the deck which keep things from falling from the bridge.

Worksheet 2

WORKSHEET 2

TRUSS BRIDGES

Match the pictures of different truss bridge designs with their correct names. Draw a line from the name of the bridge to its matching diagram.

BALTIMORE (PRATT)

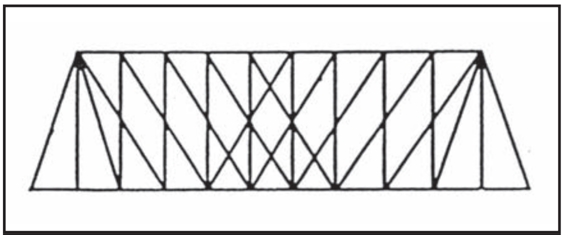
WARREN

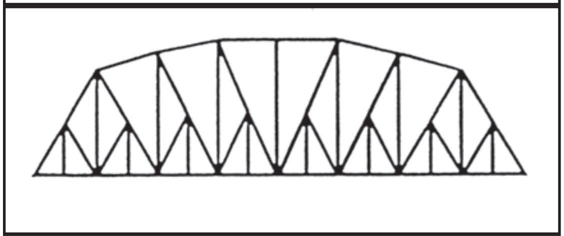
PENNSYLVANIA (PRATT)

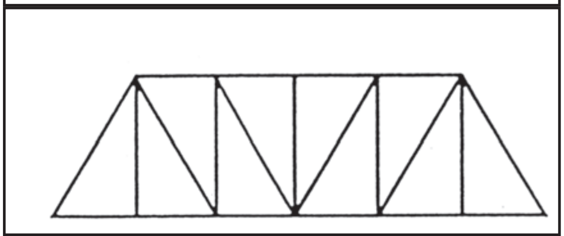
LATTICE

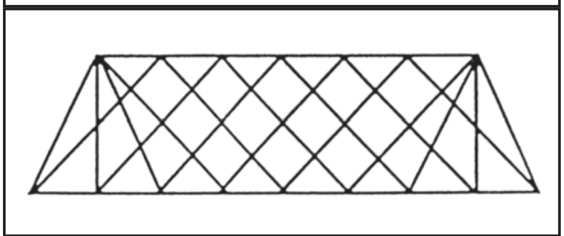
PRATT

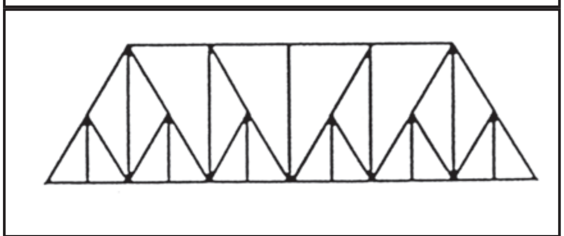
WHIPPLE

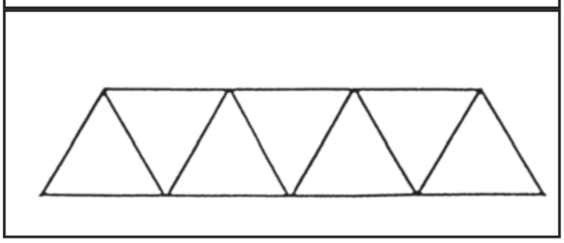












Worksheet 2

ANSWER KEY:
WORKSHEET 2: TRUSS BRIDGES

BALTIMORE (PRATT)

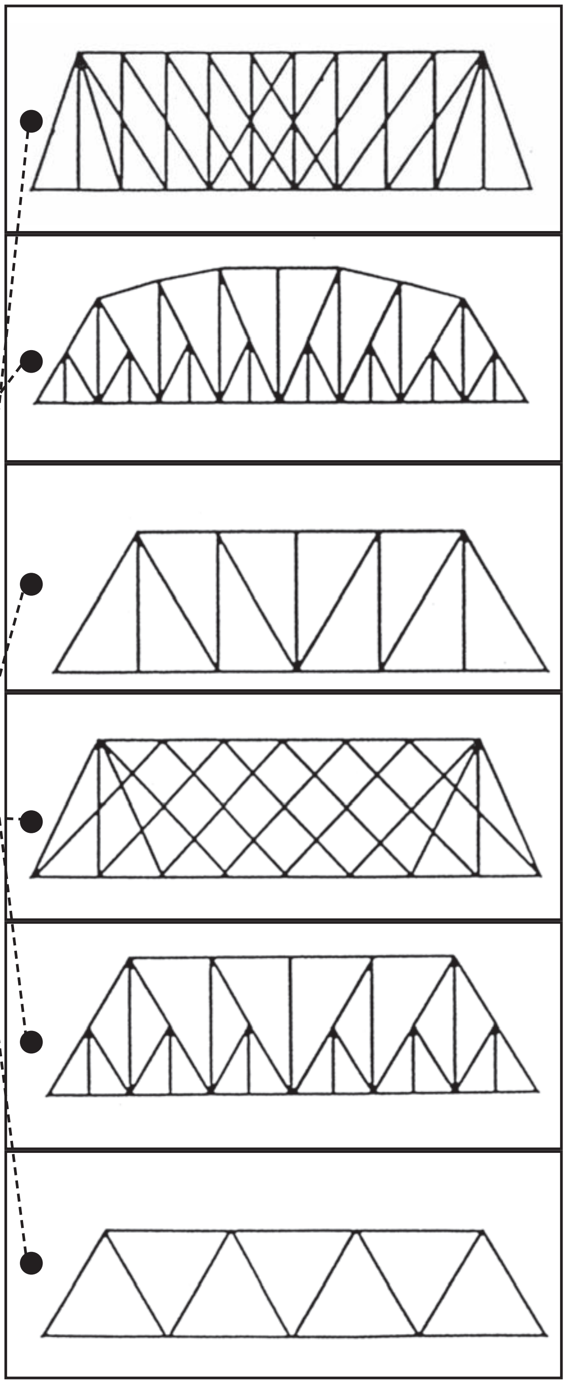
WARREN

PENNSYLVANIA (PRATT)

LATTICE

PRATT

WHIPPLE



Worksheet 3

WORKSHEET 3

ARCH BRIDGES

Can you complete the following sentences about ARCH bridges using the words fromthe box? When you have filled in the missing letters for all the sentences, use the ones from the bolded spaces to answer the following question:

What were arches used for before bridge building?

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

STEEL
COMPRESSION
KEYSTONE
ROMANS
CONCRETE
AQUEDUCTS
ABUTMENTS
STONE

1. The sides of the bridge, where they are attached to the land, which support the arch:

   _ _ _ _ _ _ _ _ t _

2. Three materials from which arch bridges are typically made:

   _ _ o _ _

   _ _ _ _ _ _ _ e

   _ _ _ _ l

3. Special long arches that carry water from rivers to towns that need it:

   _ _ _ e _ _ _ _ _

4. The force that has the most impact on arch bridges:

   _ _ _ _ _ _ s _ _ _ _

5. The group of people responsible for developing the arch bridge:

   _ _ m _ _ _

6. The top, centre stone that all other stones in the arch bridge lean on, or push against, for support:

   _ _ _ _ _ _ n _

ANSWER KEY:

WORKSHEET 3:
ARCH BRIDGES

1. Abutments
2. Stone, Concrete, Steel
3. Aqueducts
4. Compression
5. Romans
6. Keystone

Arches were used for decoration.

Worksheet 4

WORKSHEET 4

SUSPENSION BRIDGES

Here are some statements about suspension bridges. Determine if they are true or false.

If a statement is false, change it so it becomes true.

_______1. All suspension bridges have three things in common: two very tall towers; strong anchorages; cables made of many wires.

_______2. The deck is hung from the cables.

_______3. Suspension bridges usually have the longest single span of all bridges.

_______4. The longer the suspension bridge, the shorter the towers need to be.

_______5. The worst enemy of a suspension bridge is the rain because it can rust the steel cables.

_______6. Some of the most famous bridges in the world are suspension bridges.

_______7. The cables on a suspension bridge are not in a state of tension.

_______8. One of the last steps in building a suspension bridge is anchoring the cables.

Worksheet 4

ANSWER KEY:

WORKSHEET 4: SUSPENSION BRIDGES

1. True
2. True
3. True
4. False: The longer the suspension bridge, the taller the towers need to be.
5. False: The worst enemy of a suspension bridge is the wind, because it can cause the bridge to sway and twist.
6. True
7. False: The cables on a suspension bridge are in a state of tension
8. False: One of the last steps in building a suspension bridge is suspending the deck.

Worksheet 5

WORKSHEET 5

CABLE-STAYED BRIDGES

The following are characteristics of bridges. Mark with a tick the statements that apply to cable-stayed bridges.

______ Cables are strung from the tower to the deck.

______ This type of bridge easily spans distances under 1000 meters.

______ A tower supports a balanced portion of the deck.

______ Anchorages are not necessary at the ends of the cables.

______ The deck lifts up to allow boats to pass safely.

______ Abutments are always found in this type of bridge.

______ Tension is the force acting on the cables.

______ A keystone helps keep the other pieces of the bridge in place.

ANSWER KEY:

WORKSHEET 5: CABLE-STAYED BRIDGES

The following principles apply to cable-stayed bridges:

- ✔ Cables are strung from the tower to the deck.
- ✔ These bridges easily span distances under 1000 meters.
- ✔ A tower supports a balanced portion of the deck.
- ✔ Anchorages are not necessary at the ends of the cables.
- ✔ Tension is the force acting on the cables.

Worksheet 6

WORKSHEET 6

NAME THAT BRIDGE

Below are facts about the different types of bridges you have investigated. Match the fact with the name of a bridge from the list provided. You may use the bridge names more than once.

ARCH BEAM TRUSS BASCULE
CANTILEVER SUSPENSION CABLE-STAYED

1. Because bridges like me are long, light in weight, and high in the air, our greatest enemy is the wind. ________________________________

2. Builders made the original versions of me out of wedge shaped stones that fitted snugly together. They were held in place with the pressure from the weight of the bridge. ________________________________

3. My bridge design is popular when the span is less than 1,000 meters, mainly because I do not need anchorages or many piers. ________________________________

4. My name means "seesaw" in French and the English dictionary describes me as a lever – something that is counterbalanced, so that when one end is lowered, the other is raised. ________________________________

5. In the past I was commonly used to cross narrow obstacles like streams or small rivers. ________________________________

6. The strength of my design lies in the use of triangles. ________________________________

7. Bridges like me are usually made from two beams, each supported by one pier. ________________________________

8. I am a new bridge design that includes elements from a cantilever and a suspension bridge, I am easier to build than either of those but I am limited to spanning shorter distances. ________________________________

9. Two bridges that are like me are the Humber Bridge and the Golden Gate Bridge. They both have decks that hang from cables made of hundreds of steel wires. ________________________________

10. I am one of the oldest and simplest bridge designs. Today I can be quite a complex bridge, but like my ancestors, I support my own weight and the loads I have to bear, on vertical piers. ________________________________

ANSWER KEY:

WORKSHEET 6: NAME THAT BRIDGE

1. Suspension
2. Arch
3. Cable-stayed
4. Bascule
5. Beam
6. Truss
7. Cantilever
8. Cable-stayed
9 Suspension
10. Beam