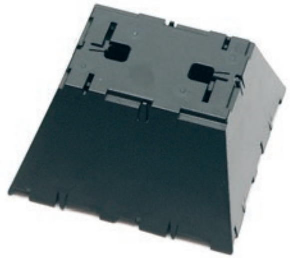
Getting Started

You will need: A Polydron Bridges Set



- ❑ This activity introduces you to the parts in the set and explains what each of them does. A variety of traditional Polydron and Frameworks pieces are used in each of the activities. However, they are coloured to produce more realistic effects. For example, the traditional squares are black and used to represent the road on the bridge deck.

Plinth

- ❑ On the right you can see the plinth or bridge base. All of the bridges use one or two of these. They give each bridge a firm base and allow special parts to be connected easily. Notice the two holes in the top on the plinth. These holes are for long struts. These can be seen in place below.

- ❑ The second picture shows the plinth with two right-angled triangles and a rectangle connected. All three of these parts clip into the plinth.

Struts

- ❑ There are three different lengths of strut in the set. There are 80mm short struts that are used with the pulleys with lugs to carry cables. These are shown on the left. The lugs fit into long struts. On the Drawbridge 110mm short struts are used with ordinary pulleys and a winding handle.

- ❑ Long struts are also used to support the cable assembly of the Suspension Bridge and the Cable Stay Bridge. This idea can be seen in the picture on the right.

- ❑ Long struts are also used to connect the two sections of the Drawbridge.

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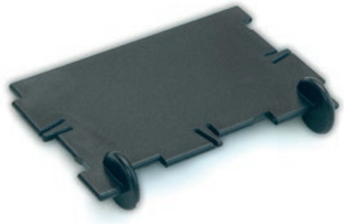
Special Rectangles



- ❑ Special rectangles can be used in a variety of ways. To explain each of them we shall focus on the Drawbridge.
- ❑ The hinge plate shown on the right is used to simulate the hinge of the deck of the Drawbridge as it is raised and lowered.
- ❑ The rectangle with two holes is used to hold long struts. These struts connect the two sections of the bridge and help to keep them a fixed distance apart.

- ❑ The rectangle made from two squares joined together is used to keep a section of bridge rigid.
- ❑ On the left you can see how these double squares fit into a plinth. You will need to make sure that they are secure and inserted correctly, otherwise parts such as the hinge plate, cannot be connected.

Cables and Fixings

- ❑ On the right you can see one of the two towers of the Drawbridge. Notice the double squares in place with the hinge plate.
- ❑ There are two different sets of cables. Those that can be seen in the picture on the front of this card are for the Cable Stay Bridge.
- ❑ The set of cables shown on the left is for the Suspension Bridge.

- ❑ Cables are connected to triangles using the clips, as shown on the right.

Cable Stay Bridge

You will need: 1 plinth, 8 frame squares, 8 equilateral triangles, 6 road squares, 2 long struts, 1 short strut, 2 pulleys with lugs and cables to support the bridge deck.

❑ At first glance a cable stay bridge appears to resemble a suspension bridge since each of them uses cables to support a roadway.

❑ However, whereas the deck of a suspension bridge is supported by cables or rods anchored to a large cable slung between pillars, with a cable stay bridge the supporting cables are anchored directly to the bridge deck.

❑ To begin your bridge fix two supporting struts into a plinth to form the bridge base, as shown on the right.

❑ You now need to make two small platforms like the one on the left. These will support the ends of the bridge. Make sure that each of your platforms are identical and that they are built correctly.

❑ To check that each platform is made correctly create two sections of roadway like the one below. Each section should fit between the central tower and your platform.

❑ If the roadway does not fit onto your platform, then turn your platform inside out and try again.

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- ❑ Push a pulley with a lug onto each end of a short strut, as shown in the picture on the right. Some of the pulleys in the set do not have lugs, so you will need to choose carefully.

- ❑ The assembly of short strut and pulleys is then pushed into the top of each vertical strut, as shown below.

- ❑ Make sure that you have the correct cables. There are four separate cables, two of which are slightly longer than the other two.

- ❑ To fix the cables, pass a longer and a shorter one over each pulley and attach the connectors to the triangle sides of the bridge deck, as shown on the right.

- ❑ Adjust the connectors on each triangle so that the bridge deck sits level.

Extension Activities

- ❑ If you have access to shorter struts you could create a cable stay bridge with a longer deck. Investigate the new problems that arise from using shorter struts.

- ❑ You can create your own, much longer, Cable Stay Bridge. You will need thick, good quality thread for the cables and paper clips for the connectors.

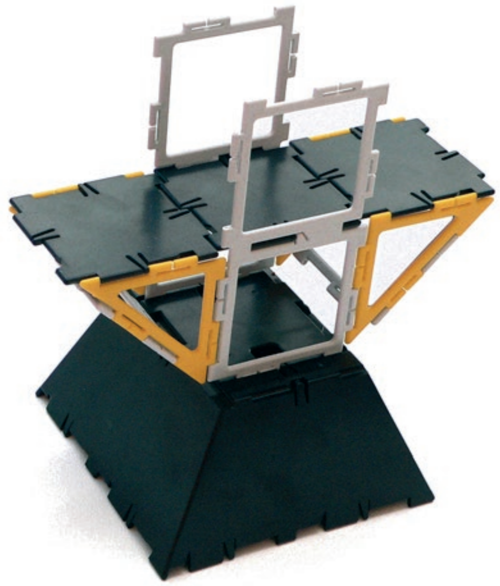
- ❑ You will need some practice to get the cables the right length but, with practice, you can investigate the principles and create a bridge with a very long span.

Cantilever Bridge

You will need: 2 plinths, 4 double squares, 20 frame squares, 16 right-angled triangles and 8 road squares.

- ❑ Your bridge is made from two identical towers and some additional sections of road to join them together. Notice that this bridge uses two squares fixed rigidly together, on either side of the tower. This is to improve the strength and rigidity of the bridge.

- ❑ The tower at each end of the bridge needs a base unit. Insert 2 double squares into the slots in each base to make two copies of the picture shown on the right. Notice the arrangement of the central slots in the double squares.



- ❑ To build each tower of your bridge add right angled triangles to the bottom of the double squares and then clip some sections of road in place. This is shown in the picture on the left.

- ❑ You will notice that your bridge section can twist and move. To strengthen it add squares to each section of the underside. This is shown on the right.

- ❑ Notice that squares have been added to long edges of right-angled triangles and not rectangles as you normally expect. Can you see why this is?

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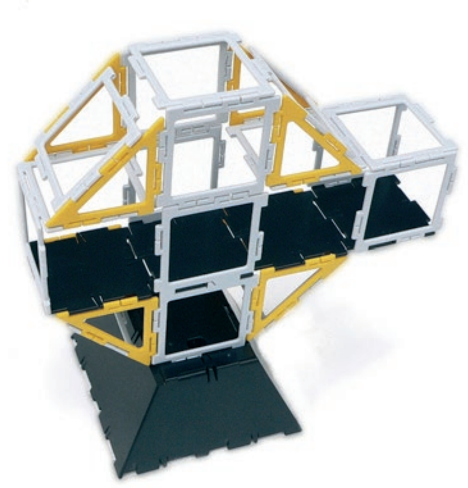
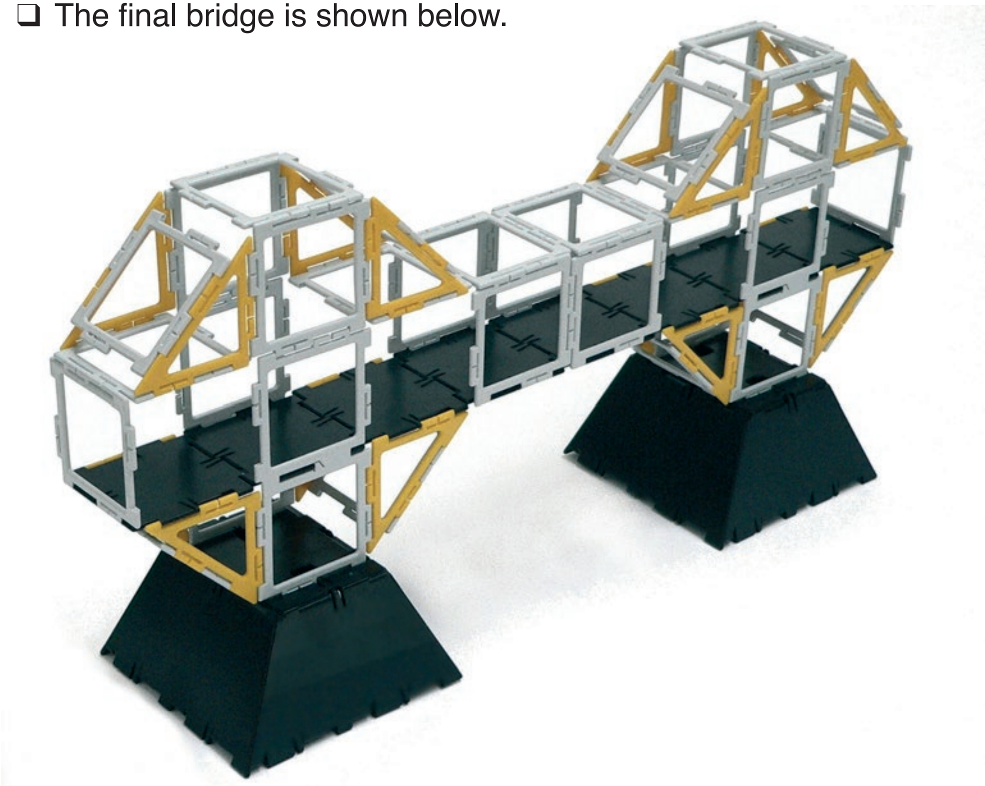
- ❑ Add the top part of each tower. This is very similar to the bottom half and gives each tower a very satisfying symmetrical appearance.

- ❑ Notice that squares rather than rectangles are used to strengthen the long edges of the right-angled triangles. This allows squares to be used at each end of the road deck to add strength.

- ❑ The model shown on the right shows one complete tower and the connecting roadway. It requires only the second tower for completion.



- ❑ The final bridge is shown below.



Extension Activities

- ❑ Make your cantilever bridge longer by adding more road sections in the centre.

- ❑ Add a third cantilever tower. As the middle tower of this new bridge supports the road in both directions it is called a double cantilever.

- ❑ Investigate the use of cantilever bridges around the world. The Forth Bridge in Scotland is a good place to start.

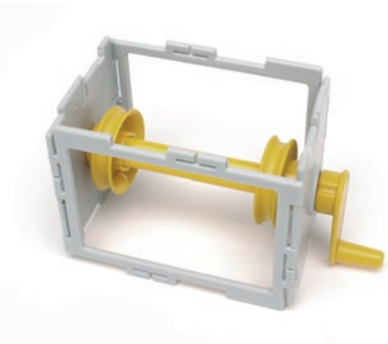
- ❑ There are more ideas in the Advanced Topics part of this pack.

Drawbridge

You will need: 2 plinths, 4 double squares, 8 frame squares, 2 large equilateral triangles, 2 isosceles triangles, 10 rectangles, 6 equilateral triangles, 4 pulleys, 4 road squares, 2 long struts, 2 winders, 2 rectangles with holes and 4 short lengths of cord.

- ❑ Drawbridges have been used for hundreds of years. They can be raised and lowered quickly and are useful for the defence of a moat or a castle entrance.

- ❑ Our drawbridge is the type that has two sections that can be raised or lowered. This type of bridge is used for river crossings, where it can be raised to allow boats to pass.



- ❑ You need to make two towers. Begin each of them by fixing double squares into a base and then attach the special hinge shown above. The tower has been started on the left.

- ❑ You may need to experiment to make sure that both of the double squares have been fixed the correct way round and that the hinge is clipped in securely.

- ❑ Continue the tower with the winding gear shown on the left. It is much easier to get the bridge deck level if you if you arrange for the notches on each pulley to be facing the same way.

- ❑ One of the two towers is shown completed on the right. Notice the placing of the rectangle with two holes. These holes will accept long struts when the bridge is finally assembled.

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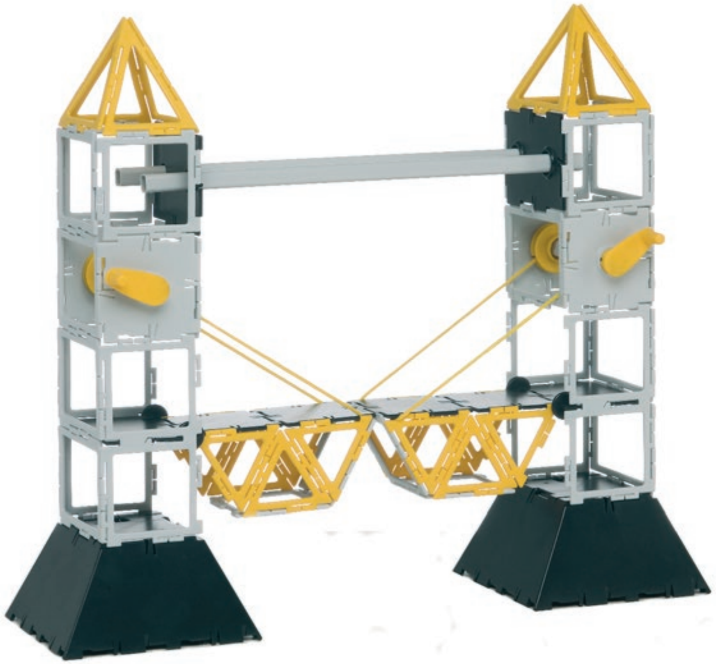
❑ One half of the bridge deck is shown on the right. Notice that only two Frameworks squares are used on the underside to strengthen each deck. This leaves one road square free to join onto the hinge. Make sure that the deck will clip into the hinge. If it will not do so then turn the deck inside out.

❑ You need four short lengths of cord for the lifting cables. To thread these and to complete the assembly requires some patience.

❑ Tie a small knot near the end of each cable and push the knot into the notch in the pulley, so that it is trapped, as shown in the detail on the left.



❑ Thread the free end of each cord into the corner between the road and support structure. When the pieces are clipped together they will hold the cord in place, but will allow enough freedom for you to adjust its length.

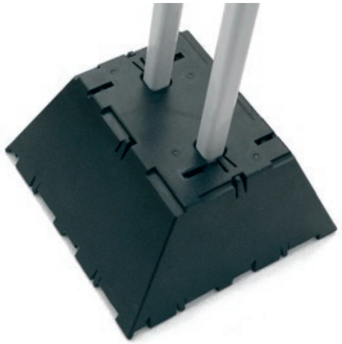
❑ In the final bridge shown on the right, you can see how two long struts have been used to connect the two halves of the Drawbridge.

Extension Activities

❑ Connect the two towers together by using squares to join the plinths together.

❑ Try moving the winding gear to the bottom of the bridge. You will need longer cables that rise through the tower and over.

Suspension Bridge



You will need: 2 plinths, 8 frame squares, 12 equilateral triangles, 4 pulleys with lugs, 2 short struts, 2 long struts, 8 road squares and suspension cables to support the bridge deck.

- ❑ A suspension bridge is a complex construction. The bridge deck is supported by vertical cables or rods that connect to a long, strong cable, suspended between two towers.
- ❑ To begin your bridge make the two towers by fixing two supporting struts into each of the two bridge bases. One of these bases is shown on the right.

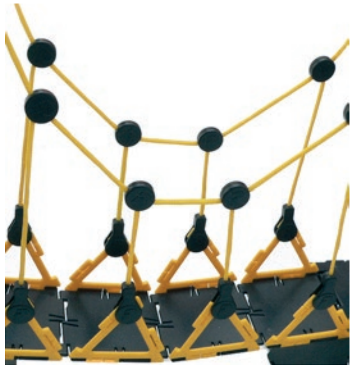
- ❑ You now need to make two small platforms like the one on the left. These will support the ends of the bridge deck. Make sure that each of your platforms are identical and that they are built correctly.
- ❑ To check that each platform is made correctly connect a square between each one and a bridge base. If the square does not fit, turn your platform inside out and try again.
- ❑ The road deck is made from four squares and eight equilateral triangles, connected as shown on the right.
- ❑ Check that you have the two suspension cables. One of them is shown on the left.

❑ The short sections of cable will be connected to each of triangles as shown on the right.
It is worth practising clipping the cable connector in place a few times with a spare triangle.
Clip it over the thinnest part of the triangle as shown.

❑ Make up two copies of the cable support pulleys you see below, using the special pulleys with lugs, and a short strut. Once you have constructed them, insert the lugs into the struts at the top of each tower

❑ You now have everything you need to complete the assembly of your suspension bridge.

❑ Arrange the cables over the pulleys that you have just made. Attach a free end to each of the spare triangles at the ends of the bridge.



❑ The final bridge is shown on the left. Take care to adjust the clips so that the deck is level and each of the cables sits over the pulleys.

Extension Activities

❑ Make a much larger suspension bridge using your own cables.
You need thick, good quality thread, and paper clips in place of the cable clips.

❑ Test the strength of the deck by placing objects in the middle and observing the way the bridge changes.

Truss Bridges 1

You will need: Each Truss 2 plinths, 20 right-angled triangles, 4 frame squares, 2 frame rectangles and 4 black squares. Double the parts if you can, to make both bridges at once.

- ❑ Truss bridges are essentially a rigid platform, whose strength and rigidity comes from the surrounding framework.
- ❑ In this activity you are going to build two truss bridges that look similar. The differences will be explained at the end.

Pratt Truss

- ❑ Start by making two copies of the bridge pier shown on the right. Notice that the right-angled triangles and the rectangle snap into the black plinths.
- ❑ The deck of the bridge is made from four black squares. If you insert these squares between the bridge piers the road will not be rigid. To hold the deck rigid and horizontal you need a framework of squares and rightangled triangles, as shown on the left below.

- ❑ Look carefully at the framework on the left. Notice how the long edges of the right-angled triangles slope down towards the middle of the bridge. This is important.
- ❑ The complete Pratt Truss is shown on the right.

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Howe Truss

- ❑ The Howe Truss begins in the same way as the Pratt Truss. You need two copies of the bridge pier shown on the right.

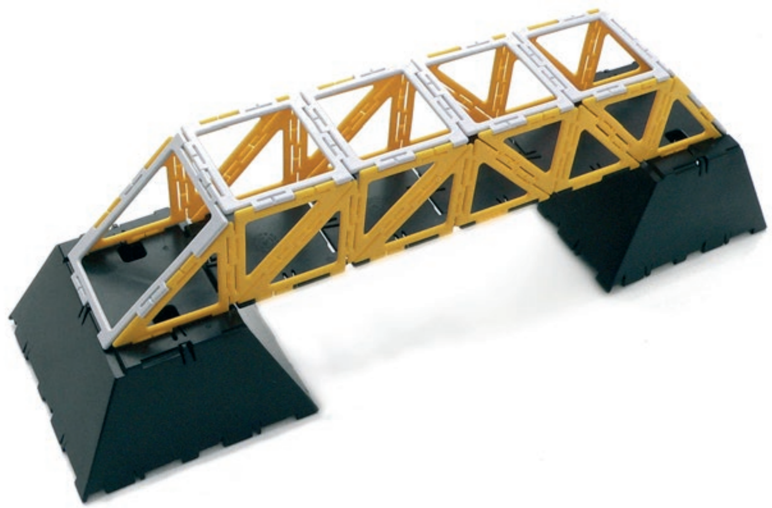
- ❑ The bridge deck for the Howe Truss is shown below. Notice how the long edges of the right-angled triangles slope up towards the middle. This is important.

- ❑ The completed Howe Truss can be seen on the right below.

- ❑ When made from Polydron Frameworks there is no real difference between the strength of these two Truss bridges. However, if you were to make these bridge decks from straws you would notice that the diagonals of the Pratt Truss are under tension when the bridge is loaded. This makes this style of bridge suitable for modern materials, such as steel.

- ❑ The diagonals of the Howe Truss are under compression when the bridge is loaded.

- ❑ This makes it unsuitable for construction with materials such as steel. It is sometimes used when the diagonal struts are made of wood, for example, in a rural foot bridge.



Extension Activities

- ❑ Use the pieces from these two bridges to make one very long truss bridge.

- ❑ Build a truss bridge with a central plinth.

Truss Bridges 2

You will need: Warren Truss – 2 plinths, 22 equilateral triangles, 7 frame squares, 4 road squares
Deck Truss – 2 plinths, 14 equilateral triangles, 9 frame squares, 6 road squares

❑ The two truss bridges you built in 'Truss Bridges 1' use right angled triangles to give them strength and rigidity. The two bridges in this activity use equilateral triangles.

Warren Truss

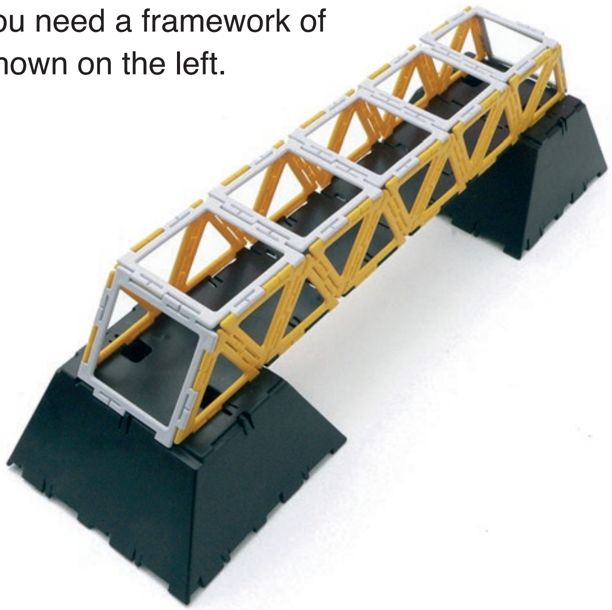
❑ Start by making two copies of the bridge pier shown on the right. Notice that the equilateral triangles and the squares snap into the black plinths.

❑ The deck of the bridge is made from four black squares. If you insert these squares between the bridge piers the road will not be rigid.

❑ To hold the deck rigid and horizontal you need a framework of squares and equilateral triangles, as shown on the left.

❑ The completed bridge on the right has an elegant simplicity about it.

❑ Engineers like this bridge because it is fairly easy to build but it is also very strong.



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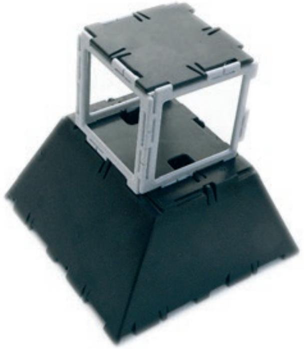
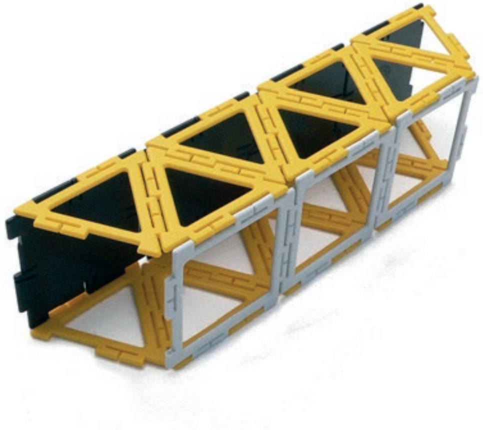
bridges

Deck Truss

❑ This is an unusual bridge in that its strength comes from a frame of triangles and squares underneath the deck.

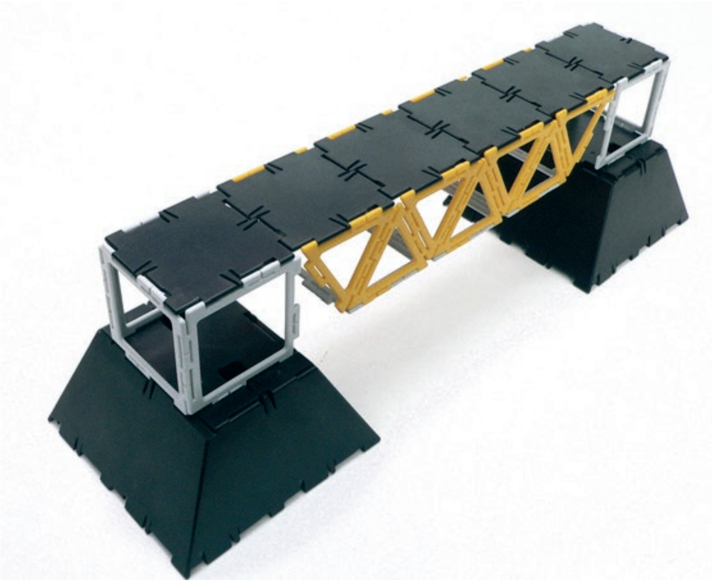
❑ You need two copies of the base shown on the right. Notice that to achieve the extra height needed to accommodate the frame beneath the deck, the bridge deck is raised.





❑ The deck of this bridge is built from a frame of equilateral triangles and squares. The picture on the left shows the view from beneath the deck. Notice that there are no squares on the ends of the deck. Before constructing your deck make sure that the black squares are the correct way round to join onto the base.

❑ The final Deck Truss is shown below. This style of bridge is used when there is a need to keep the deck as clear as possible.



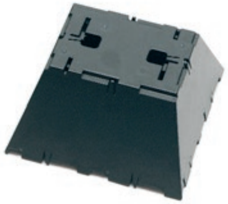
❑ Both the Warren and the traditional Deck Truss were used extensively in the United States Railway Industry.

Extension Activities

❑ Use the pieces from both bridges to make one long example of each bridge.

❑ Try to make a long Deck Truss with a central pier. Explain why it is not very stable. Find a way to improve its stability.

Working with Plinths



- ❑ The plinth forms the foundation of every bridge. It has been designed to make it easy to connect other pieces to it, with holes for struts as recesses for polygons. Here are some imaginative ways to use this versatile component.

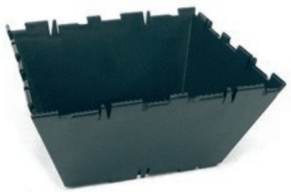
- ❑ Plinths can be raised off the ground on a framework of squares as shown in the second picture on the left. This will allow you to build a taller tower for a cable stay bridge or a suspension bridge.

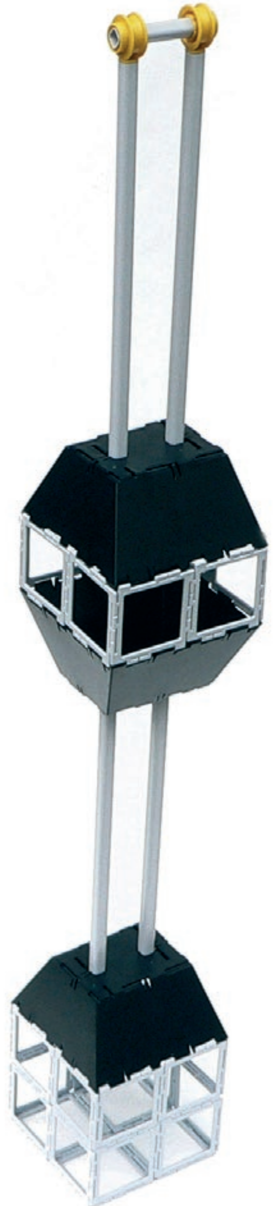
- ❑ A raised plinth can be the foundation for a high level road deck.

- ❑ Using plinths with other pieces allows us to extend upwards a long way. The striking picture on the right is of a structure over a metre high. This tower shows you what is possible and it would make a wonderful attraction for your own bridge. The central section looks like a viewing gallery for spectators.

- ❑ A plinth can be used upside down. If one of your projects requires a double width road then the upside down plinth below can be used as a central platform.

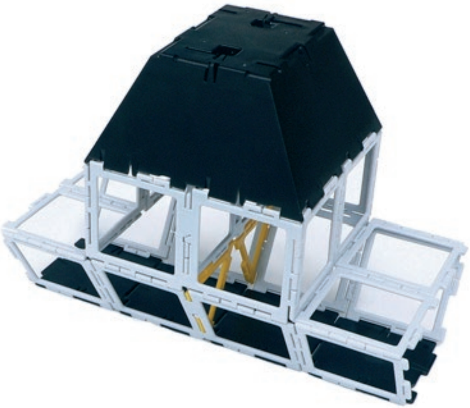
- ❑ Consider a plinth as a counter balance for a much larger bascule bridge. It has the advantage of looking like a large mass of the type you might expect to see balancing a bridge deck.





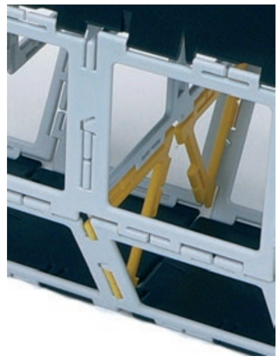
❑ Plinths can also be used to make towers taller but allow the road to pass underneath. On the right you can see how to alter the structure under a plinth to provide space for the road.

❑ The picture below shows a plinth that has been altered in several ways. Firstly, the use of the double square allows triangles to be used to brace the inside of the structure. A special property of these double squares is that they allow three Frameworks pieces to meet along a single edge. This can be seen in the detail on the right below.



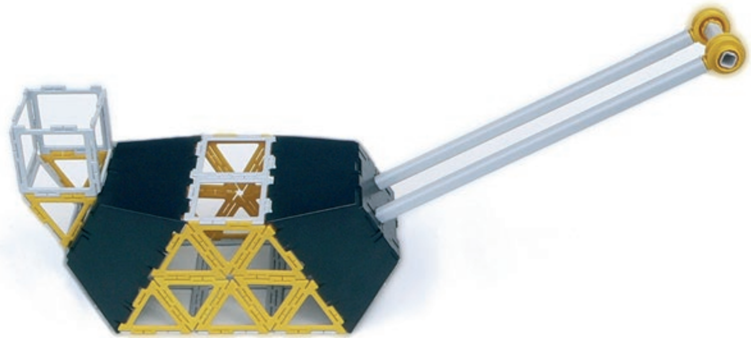
❑ A second feature of this design is that the road deck is supported while it passes below the plinth. This makes it very suitable for the central plinth of a suspension bridge or a cable stay bridge. This structure could also be used in a very long truss bridge.

❑ The plinths below have been used to extend cable supports at an angle. This design could be adapted for use with either the cable stay bridge or the suspension bridge. For example it could be used at the end of a self anchoring suspension bridge, to supply forces along the deck.



❑ Equilateral triangles are used to create the angle of slope of the plinths. You can replace these with right-angled triangles to make the angle between the struts and the vertical 45° instead of 60°.

❑ Notice that on the other side of the structure a small platform has been started. This could be used to support another tower.



Bascule Bridges

Advanced Topics

You will need: A wide variety of materials. In particular you need lots of equilateral triangles to build the first bridge.

- ❑ This bridge shares some of the properties of the draw bridge, shown on the right, but it works on a different principle. The main bridge deck is supported with a counter-weight.

- ❑ This bridge presents a number of challenges, such as building a secure frame to counter the mass of the bridge deck. The aim is to reduce the forces needed to lift the deck and to allow a larger deck to be lifted safely.

- ❑ We shall be aiming to lift a deck almost identical to the Warren Truss, so it may be worth studying that bridge first.

- ❑ The picture on the right shows a Warren Truss with some pieces removed from one end. This end will hinge upwards. Where the pieces have been removed we shall build a counter balance. The left hand end of the deck in the picture has been separated from the plinth to allow it to lift.

- ❑ While the bridge is in this form, use a force meter to test the force required to lift the deck. Note this force down so that you can compare it with the force required to lift the deck of the final bridge.

- ❑ The counter balance shown on the left is the critical part of a bascule bridge.

- ❑ It is quite tricky to make this section. It has been designed so that it sits over the plinth once the bridge has been raised and provides just enough counter weight to support the bridge.

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- ❑ The final Bascule Bridge is shown on the right.

- ❑ Notice that in the raised position it requires no additional force to keep it stable. This minimises the energy needed to run the bridge and also makes it safer to operate.

- ❑ The addition of the square with hole was to increase the mass of this part of the bridge and to provide a place to add additional masses if needed.

- ❑ Measure the lift force required to raise the deck and compare it with the measurement made without the counter weight in place.

- ❑ You might like to make a winding mechanism to lift the deck. You will need to give some thought to placing the pulleys and the cable.

Extension Activities

- ❑ Add small masses to the counter weight, until the bridge just balances. Now raise the deck by pressing down on the counter weight. You will find that once started, the deck will continue to raise on its own. Try to explain why this happens.

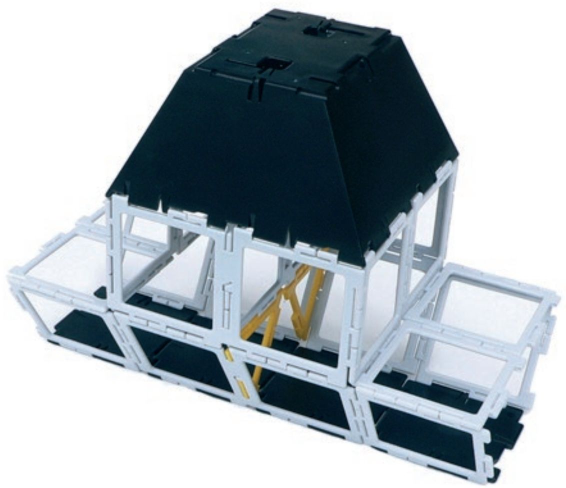
- ❑ Try to create a similar sort of bascule bridge based upon the Pratt Truss. This uses right-angled triangles instead of equilateral triangles and so will present a different range of problems to solve.

❑ Make sure you have built the Cable Stay Bridge shown on the right. Notice that the cables are exactly the right length for this particular bridge.

❑ Make a longer Cable Stay Bridge by using your own cables. Use paperclips in place of the connectors. Choose large paperclips and open each one up a little before starting the bridge.

❑ To make the bridge longer consider raising the tower. There are some ideas for this in the activities on using plinths. However, one way is to use a special platform for the plinth, as shown on the left below.

❑ Make sure you put the plinth on the correct way round or the long struts will face the wrong way.



❑ You will need longer strings to attach to the deck and possibly a different way to attach each cable. One way to do this is to tie a small knot at the end of each length of string and pass it between two sections of road, as shown on the right.

❑ Notice that the tower shown on the left allows the road to be supported while is passes underneath.

❑ Try extending this support out from the tower using a truss framework. That way the cable stays will have less of a load to support and you will need fewer of them.

Suspension Bridges — Advanced Topics

- ❑ Many of the things you need to think about when extending the suspension bridge are similar to those for the Cable Stay Bridge, on the other side of this card.

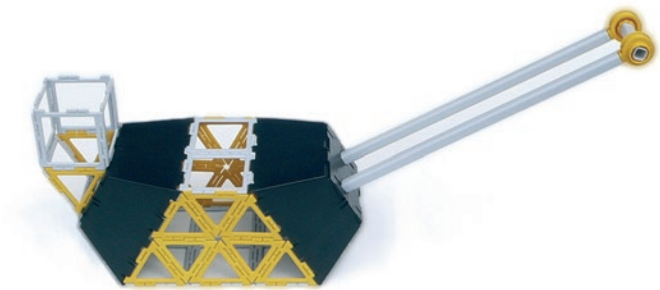
- ❑ But to make a suspension bridge longer you have an extra problem to solve; how to anchor the end of the long cable that carries the load. One way to do this is to build your bridge on a plank of timber, about 2.4m long. That way you can anchor then ends using a staple gun and use the Polydron Bridge Set to construct the bridge itself.

- ❑ You will need to find a way to raise the tower that holds the long struts. There are several ideas in the activity called ‘Working with Plinths’.

- ❑ The picture on the right shows how paper clips may be used to connect the bridge deck to the cable. In practice you will want to use a length of cord between the two paper clips, or use the method shown on the other side of the card.

Extension Activities

- ❑ Investigate self anchoring suspension bridges. These anchor the suspension cable to the road deck itself. The original bridge above does this in a very simple way. However, the method used above would place excessive upward forces on this part of the bridge.



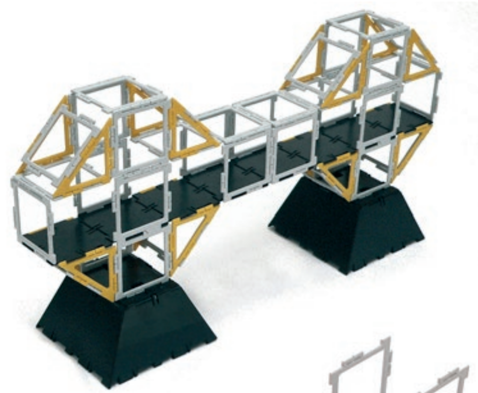
- ❑ A self anchored suspension bridge has its cables anchored to the deck in such a way that the forces are mainly along the bridge. The picture on the left shows a structure that could be used to do this. You will need to adapt the idea to suit your bridge.

- ❑ In addition, you might build part of the bridge deck as a truss.

POLYDRON® bridges

Large Cantilever Bridge

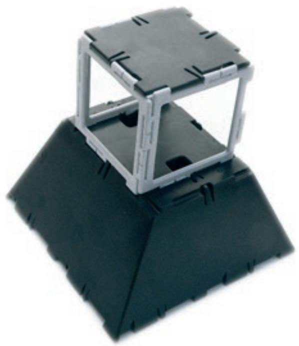
❑ Before starting this activity make sure that you have built the Cantilever Bridge. The completed bridge is shown on the right.



❑ Start by making the span between the bridge plinths larger. You may be surprised at how long you can make the span before there are problems.

❑ Some of the strength of each tower comes from the use of the double squares, shown on the right. Try replacing each of these double squares with two ordinary squares.

❑ Notice how the bridge can be more easily twisted out of shape. If you remove the squares at each end of the bridge deck, you will notice that the bridge becomes much weaker.

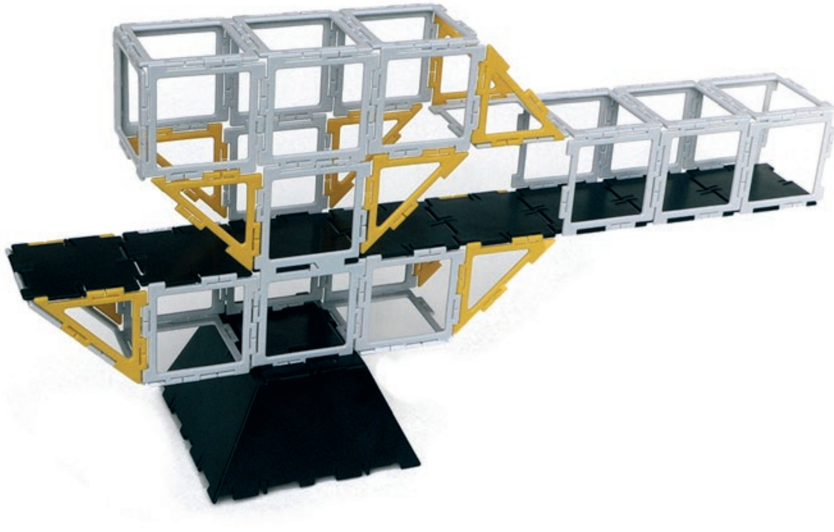


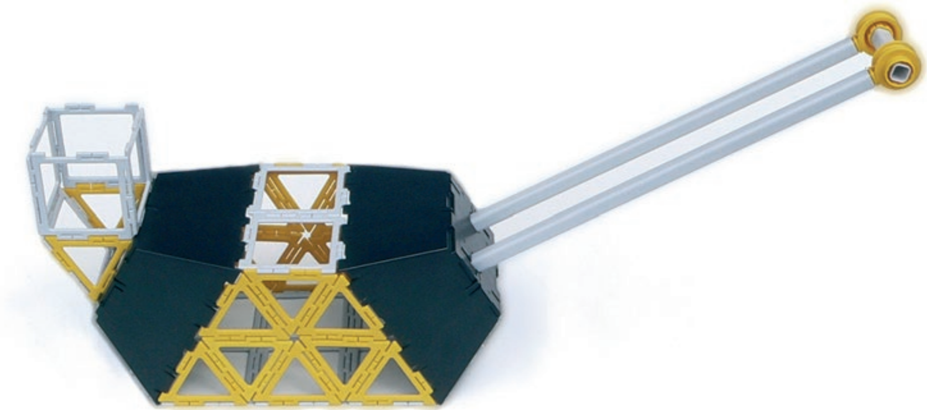
❑ Construct a new central section to sit beneath a very long span such as the simple one own on the left.

❑ Investigate different ways to create your central support, such as the one shown on the right. This is called a double cantilever as it supports the bridge deck in both directions.

❑ Try putting all of the ideas above together to make one very large bridge, with several spans and large supporting structures.

- ❑ A cantilever bridge uses the structure around each plinth to strengthen the bridge deck. Investigate making larger structures on each plinth. One method of doing this is shown on the right.
- ❑ This deign has weaknesses and does not function well as a cantilever. See if you can you find the weaknesses and improve the structure.
- ❑ Research the principles behind the cantilever. You may like to consider building a demonstration model to show others how it works. One way to do this is to use materials such as lollypop sticks and string. Use split pins to create the joints.
- ❑ Examine some famous cantilever bridges, such as the Forth Rail Bridge in Scotland. These are usually designed to make use of trusses as well as cantilevers.





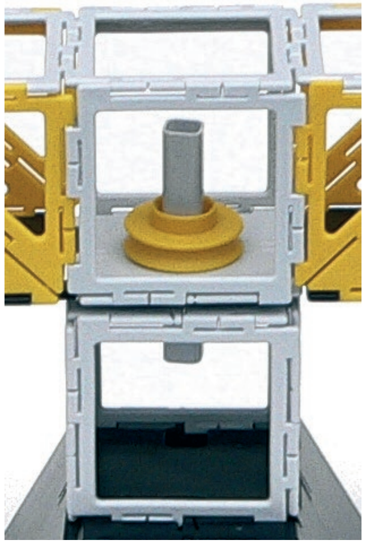
- ❑ Find a way to use the long struts as cantilevers. There are some ideas on the card called 'Working with Plinths'.
- ❑ The picture on the left shows a structure that can be adapted to work as a cantilever.

Swing Bridges

- Swing bridges are used in a variety of ways, but one of the main ones is to allow ships to pass either side.

- The special feature of swing bridges are that they rotate about a vertical axis and they must be very easy to move, even when heavily laden.

- Our bridge will be based upon an elongated truss such as a long version of the one shown on the right. You are free to make the truss any way that you like so long as it is perfectly symmetrical. This allows it to rotate freely balanced only on a central joint.

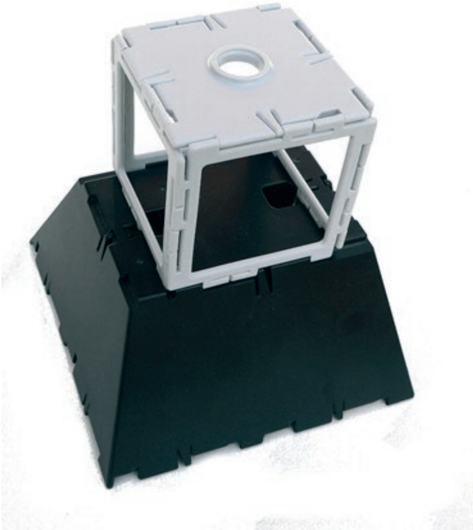


- Our bridge is going to revolve on a joint made from two squares with holes. In the detail shown on the left you can see the entire joint. The pulley is used to prevent the short strut from falling through.

- Notice the small gap between the bridge deck and the supporting platform. The entire bridge is balanced on a small central ring between these two.

- This pivot ring can be seen around the hole in the square in the picture on the right.

- The pivot ring on the bridge centre faces down, to sit on the one in the picture.



❑ The final bridges are shown here, closed on the right and open below.

Extension Activities

❑ Make your bridge longer but take care to make bridge symmetrical, or it will not balance correctly. If you keep the bridge symmetrical, you may be surprised at how long you can make it.

❑ Experiment with how the bridge behaves when it is not symmetrical. For example, extend the bridge deck until the structure becomes unstable, or add an extra piece to upset the symmetry.

❑ Create a revolving bridge in the shape of a +. To do this you will need to make another deck identical to the existing one. Your new deck will be at right-angles to the old one.

❑ Such a design may not be very practical to use over a river but it would make an interesting structure.

❑ Try to create a dual carriageway swing bridge. The deck will to need be three lanes wide overall, with the central lane empty or used for framework.

❑ You will need to give some thought to planning the plinths or bases at each end.