ROMAN ARCHITECTURAL MARVEL – AN ARCH	
Respective blueprint	Roman Arch
Description	Pupils will learn how to build an arch and how the arch can stand by itself. They will get familiar with the forces affecting the arch and why it is an important architectural achievement, not only in ancient times, but also nowadays.
Learning Objectives	Learn about the physics of arches, distribution of forces, and strength. Understand the historical meaning of Roman architectural inventions and the importance of arch. Present the use of arches nowadays. Improve engineering skills with the creation of the arch presented in the blueprint.
Related curricular subject(s)	Engineering, Physics, History, Art (Architecture)

Prerequisites / preparatory actions for teachers	Prepare the materials for implementing the associated blueprint. Prepare the online video to present to the pupils the basics of the Roman Arch and architecture: Roman Arch - online video Prepare some photos of ancient Roman buildings (you can find them at the end of the pedagogical sequence). The teacher can print them or show them on the screen. Prepare the material for an additional experiment to introduce the physical concept of arch construction. The teacher will need two heavy books, one or more pieces of thin cardboard, which can be curved, and a weight (wood cube or similar).
Prerequisites / preparatory actions for students	None
Age of students	10-15 years old
Duration	1-2 hours
Level of difficulty	Medium

Step by step description of the tasks

1. The teacher invites the pupils to look at the pictures and guides a discussion with the following questions:

- What do you see?
- Do you know any of these buildings?
- To which era do they belong?
- What do they have in common?

The teacher shows the pupils pictures from constructions made by ancient Romans (you can find them at the end of this document). The teacher guides the pupils to find answers to the questions. The discussion has to lead to the arches used in the building shown in the photos.

2. Why are arches used? Why are so important for architecture? In which era were invented and then studied in detail to create the most impressive buildings?

Again, the teacher waits to get the answers from the pupils.

The arch was first used in the Mediterranean world by those in Mesopotamia, Greece, Persia, and ancient Italy. While these cultures had the arch, they rarely used it except for underground tunnels and

drainage systems, where the force of the earth around it provided natural buttressing, or reinforcement.

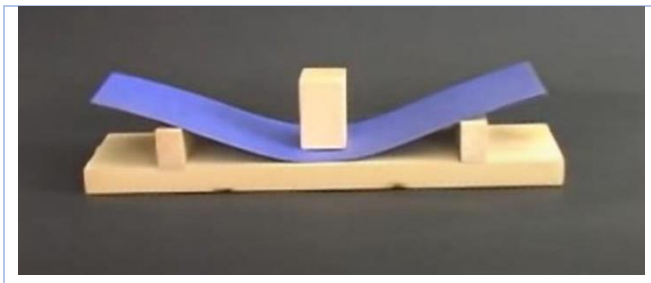
The Romans were the first people in the world to really figure out how to use it in the construction of bridges, aqueducts and buildings. The Roman arch is largely responsible for the expansion of infrastructure across the Roman Empire. It was the Romans who first found a way to set an arch on top of two tall pedestals such that it would span a walkway (and in many cases, even highways). Many bridges were built upon these arches, and so were the aqueducts, sewers, amphitheaters, and even the great Colosseum. Roman arches were later used in the Middle Ages when some of the most magnificent cathedrals in history were built. In fact, it was the only known method for putting a roof on a building without the use of support beams.

3. The teacher does an additional experiment to present how strong the arch bridge can be in contrast to a plain bridge.

The teacher needs two heavy books (or a wood tool like in the picture below), two pieces of thin cardboard, which can be curved, a weight (for example a wood cube) and tape.

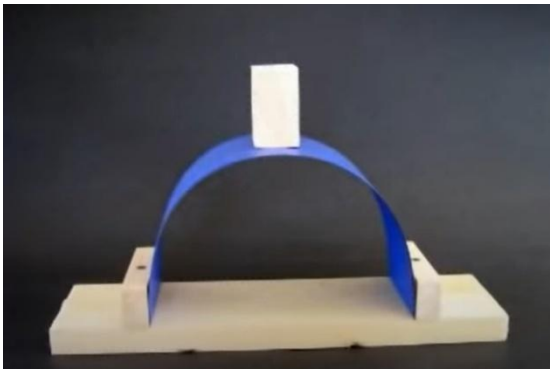
Pupils can gather around the teachers' table to see the experiment.

First, the teacher places two books on the table and places the cardboard on the books to create the plain bridge. Then the teacher adds the weight on the cardboard – the bridge collapses.



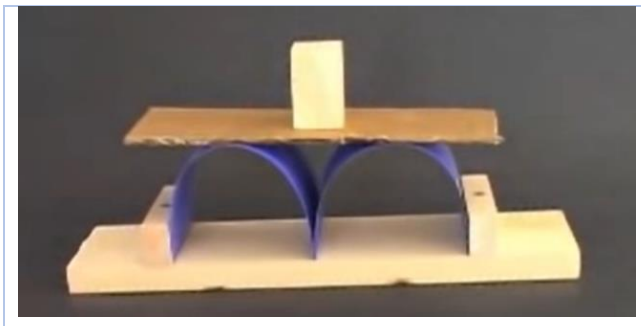
Source: Structures - The Arch video

The teacher tries to build a bridge again by creating the arch – the piece of cardboard is curved between the books. The books are called buttresses. When the teacher put the weight on it, the bridge is still standing.



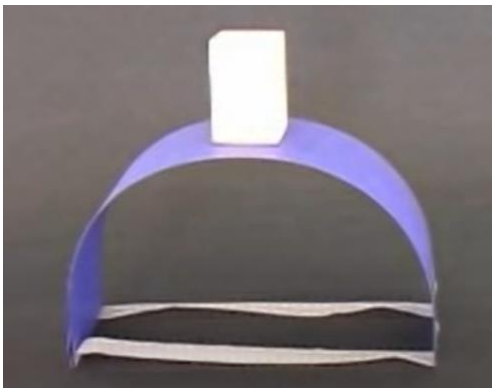
Source: Structures - The Arch video

Teachers can also present a bridge made of two or more arches. Also, these arches can be loaded without crashing.



Source: Structures - The Arch video

Another type of arch bridge can be presented, an arch connected by attaching a strong rope on the base of the arch instead of the buttresses. This can be achieved by putting two pieces of tape on the base of the cardboard arch. Does the arch still stand strong when the teacher adds weight to it? It should. Arch bridges made from steel are usually made in this way.



Source: Structures - The Arch video

4. Ask the pupils what they think about the experiment – why is the arch stronger than a plain structure? What forces are actually involved in the first or the second type of bridge?

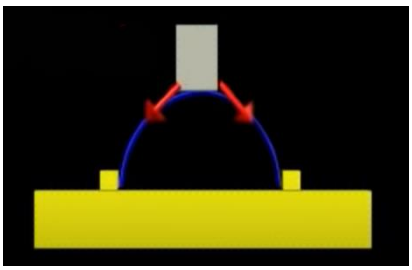
The answer is in the distribution of forces.

For better understanding, the teacher can show the video about the Roman Arch to the pupils. If they need a translation, the teacher should provide it simultaneously.

The Impressive Engineering of the Roman Arch - YouTube

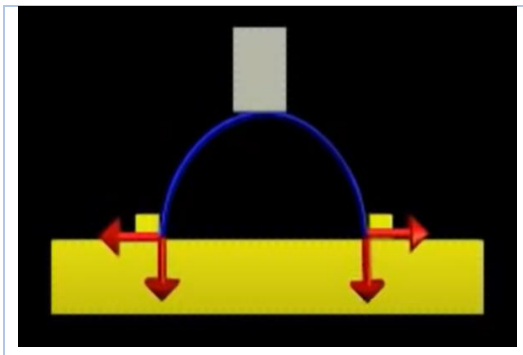
Picture 1 – Gravity forces distribution.

The force from a load transfers down the arch to the base.



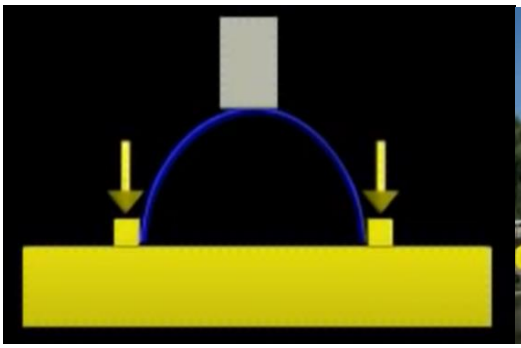
Source: Structures - The Arch video

Picture 2: There are two components of the forces on the base. One is vertical, pushing down on the base. The other is horizontal, pushing to the side.



Source: Structures - The Arch video

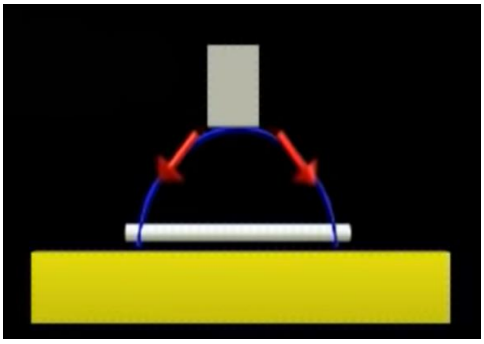
Picture 3 and 4: The structure that resists the horizontal force is a buttress. In the arch bridge in the picture, you can see its stone wall buttresses on both sides of the bridge arch.



Source: Structures - The Arch video

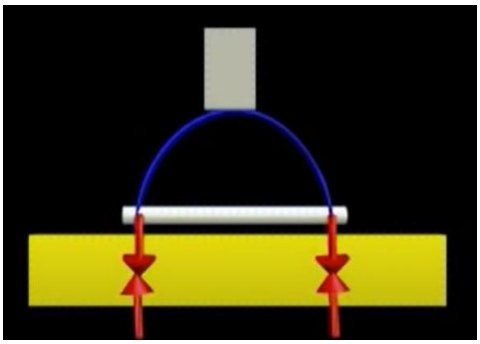
Source: Structures - The Arch video

Picture 5: Another type of arch, without buttresses but with strong rope in the base of the arch.

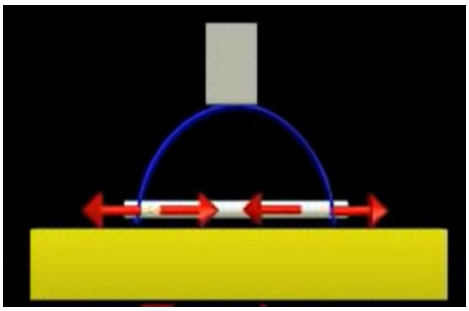


Source: Structures - The Arch video

Picture 6 and 7: The forces components affecting the arch are compression vertically and tension horizontally.



Source: Structures - The Arch video



Source: Structures - The Arch video

5. Hypothesis – Can the arch stand by itself without glue, using sugar cubes as the construction elements?

6. Creation of an arch from sugar cubes – blueprint implementation.

7. Confirming the hypothesis and discussion about building our arch

Can it stand by itself? Does it need a buttress?

We confirm our hypothesis - the arch can stand by itself. This can be achieved with buttresses.

Why do we put the popsicle sticks between?

The ancient Romans used not only rectangular elements in constructing arches, but also precisely measured trapezoids. The Romans used an even number of rectangular bricks on each side of the arch and an odd number of trapezoidal bricks. For this reason, the popsicle sticks are

added between the elements to create a trapezoid shape in connection with the sugar cube.

What has a role in the length and height of the arch – can you create a different arch with the same shape of bricks?

The length and height are dependent on the shape of the elements used. When the Romans planned to make the arch bridge or a big arched building, they calculated how many rectangular or trapezoid-shaped bricks they needed and then formed trapezoids to be the most appropriate structure for the constructed building.

Is the order of steps important for successfully creating the arch?

In building arches, the order of the steps of creation is important. We have to start at the base on both sides of the arch and proceed to the top, where the arch is connected with the keystone – the stone at the middle, usually bigger and differently shaped as others. Moreover, the law of forces in physics permits us to create an arch without a keystone, instead using just the trapezoid-shaped elements, with the same strength characteristics.

How can the arch control the pressure from the weight in large and more complex buildings? The arch directs pressure downwards and outwards, creating a strong passage underneath it that has the ability to support heavy structures. This is called compressive stress, because the pressure of the weight is compressed by the shape of the arch. Because the stress is directed both down and outwards, walls or other structures-buttresses were often required to reinforce the arch. All of these forces act together to create a strong and sturdy structure. It nevertheless withstands the strong downward forces acting on it

because of both its overall shape and the shape of its individual blocks. Precisely cut, wedge-shaped blocks are used for construction. The arch allowed ancient builders to make larger, more complex buildings that could hold more space and people.

The central feature of a Roman arch is the keystone - the wedge-shaped stone at the top of the arch. It is the last stone placed during construction, and it locks all the other stones of the arch into position. The keystone bears almost no weight, but is the center of redirecting the weight of the structure down and outwards. The Romans used arches with circular tops, called rounded arches, which were made of stone. A series of rounded arches side by side is called an arcade.

Assessment activities

Who invented the arch?

Name the forces that act on the arch with a buttress or a base rope.

What is a keystone?

How are the arch's bricks shaped?

Why are arches so important for architecture?

Where are arches used? Give a few examples used in ancient times or nowadays.

What plays a role in the length and height of the arch?

Sources:

- The Impressive Engineering of the Roman Arch - YouTube

- The Roman Arch: Definition, Construction & History - Video & Lesson Transcript | Study.com
- Roman Arch - hoffnerphysics
- Structures - The Arch - YouTube

Appendix – Photos of ancient constructions (Source: Stock images)