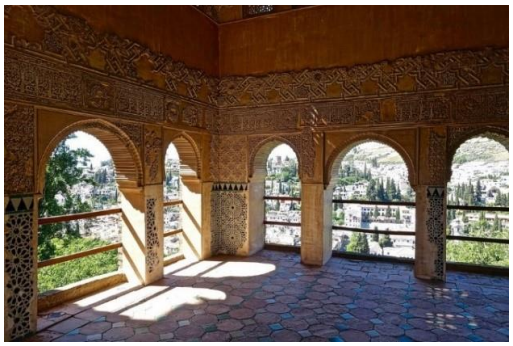
ARCHES IN ARCHITECTURE AND ENGINEERING



What is an **arch**? In architecture, an arch is an opening in a structure that is curved on top and designed to distribute weight. Arches are used in **structural engineering** (a branch of civil engineering that deals with large buildings and similar structures) because they can support a very large mass placed on top of them. You may see arches over doors and windows. They are frequently used to construct bridges. There are even arches in your body. The arches in your feet help to support your entire weight!

In an arch that is made of stones or bricks, the stone at the very top of the arch is called the **keystone**. This keystone keeps the rest of the arch from falling down. The load on top of the keystone causes each stone of the arch to push against the stone next to it. This continues until the force is applied to the **abutment**, or **end support**. The ground around the abutment pushes back on the abutments.

Men placing the keystone in the center of a stone arch.

There are many forms of arches, but they can be grouped into three main categories:

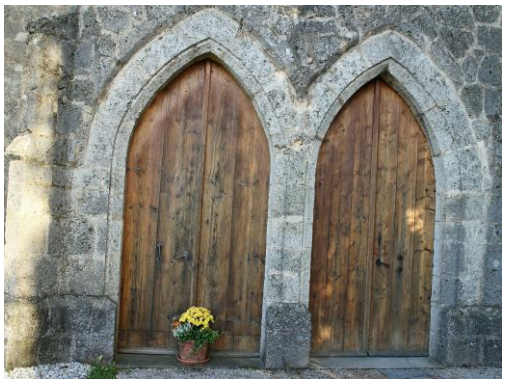
- **Circular,** or **rounded arches** were often used by the ancient Romans to build bridges, large buildings, and **aqueducts**. Aqueducts are structures used to transfer water from a stream or creek across a valley. With the use of arches to build aqueducts, the ancient Romans were able to bring water to people far

away from the natural sources of water. Many stone-arched structures built by the Romans are still standing and remain strong today.

Roman Colosseum

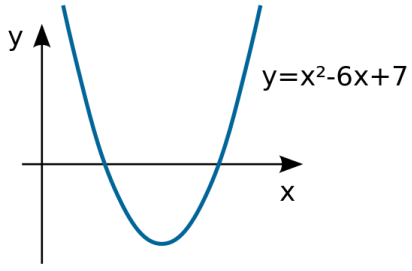
Roman Aqueduct

- **Pointed arches** were often used in **Gothic** architecture, a particular style common in Europe from the mid-12th century to the 16th century. With a pointed arch, buildings could be taller because they produced less thrust force at the base.



Pointed arches used in a cathedral and in doorways.

- **Parabolic arches**, used mostly in bridges, have the shape of a **parabola**. In mathematics, a parabola is a special curve, shaped like an arch.



Parabola from a mathematical function

Parabolic arch

An **arched bridge** has a curved arch with **abutments** at each end, which are structures that keep the ends of the bridge from spreading out and also carry the load. An arched bridge has great natural strength. Instead of pushing straight down, the arches transfer the weight of the bridge outward to the abutments. A **viaduct** is a long bridge made from a series of arches.

Arched bridge

Viaduct

Forces on arched bridges:

- **Compression**: Compression is a force that squeezes something. In an arched bridge it is an outward force along the curve of the bridge toward the abutment
- **Tension**: Tension is a force that stretches something. There is very little tension in an arched bridge because the arch transfers the force outward. Tension forces increase as the span of the bridge increases, and they can overtake the natural strength of the arch if the span is too great.
- **Dissipation**: The shape of the arch **dissipates** (transfers or moves) the weight from the center to the abutments.

Here are two activities to help you explore the strength of an arch.

ACTIVITY #1: Build a simple model of an arched bridge from paper and books

Materials**:**

- Two sturdy books
- Strip of paper approximately 2 inches wide and 11 inches long
- A small lightweight object of your choice, like the basket used below, or a small cardboard box

1. Place the books about 5 - 6 inches apart (see images below).
2. Create a paper bridge by placing the strip of paper on top of the books. Place the basket or other object on top of your paper bridge. Oops!

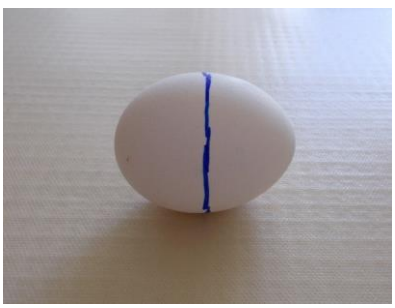

3. Without moving the books, place the paper strip between the books forming an arch, as seen in the picture below. The books will serve as abutments. Once again, place your object on top of the arch bridge. Wow!


ACTIVITY #2: Discover how much weight a few eggshells can support

Materials:

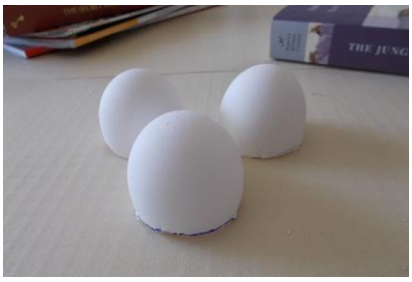
- Three raw eggs
- Small bowl
- Cuticle scissors
- Ruler
- Marking pen
- A few books (one that's hardcover) and magazines
- Scale (optional)

1. Use the ruler and marker to divide the eggs in half.

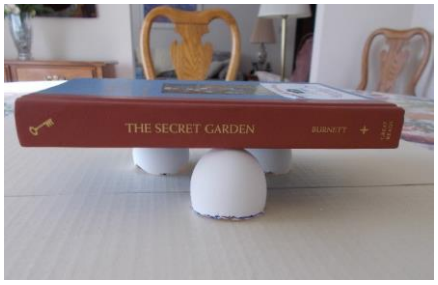



2. Crack a small opening in the pointy end of the egg and empty the egg into a bowl. Remember to wash your hands with soap and water after handling the raw eggs!

3. Before the eggshells dry out, use the cuticle scissors to gently snip the egg shell in half along the line that you have drawn. You may want to have an adult helper do this for you. It's okay if the edges aren't perfectly straight, but if there is a large crack or big chips in the eggshell, you will need to start again.
4. Place the eggshells on a flat surface in the shape of a triangle.



5. Gently place a hardcover book on top of the eggshells, centered, so the weight is evenly distributed.



6. Carefully add more books and magazines, one at a time, to see how much weight the eggshells can support before they crack.

7. Weigh your books and magazines after the eggshells finally crack!

Were you surprised by how many books and how much weight the eggshells could support?

In building, the force on top of an arch is distributed along the sides of the arch. This allows it to withstand a large mass that is placed on top. The natural arch of an eggshell allows it to support a surprising amount of weight!

To further explore the strength of the natural arch of an eggshell, try to squeeze an egg lengthwise to break it. Wear a glove and do this over a sink or bucket! It will be messy! You will be surprised by how much force you can apply before it breaks!

Arches are everywhere! Look around your house, your neighborhood, and your town to see how many arches you find.

ADDITIONAL RESOURCES

Books available from the Washoe County Library System

13 Architects Children Should Know by Florian Heine

Architecture According to Pigeons by Speck Lee Tailfeather and Stella Gurney

Bridges: An Introduction to Ten Great Bridges and Their Designers by Didier Cornille

Bridges: From My Side to Yours by Jan Adkins

Building Big by David Macaulay

Buildings in Disguise : Architecture That Looks Like Animals, Food, and Other Things by Joan Marie Arbogast

From Mud Huts to Skyscrapers : Architecture for Children by Christine Paxmann

The Illustrated Atlas of Architecture and Marvelous Monuments by Sarah Tavernier and Aleandre Verhille

Let's Try it Out with Towers and Bridges: Hands-on Early-learning Science Activities by Seymour Simon and Nicole Fauteux

The Medieval Cathedral by William W. Lace

Roman Amphitheaters by Don Nardo

Videos

Easy Architecture, "What is Gothic Architecture?" https://youtu.be/vrdkL7Y8Who

PBS, Building Big, "Arch Bridge"
https://knpb.pbslearningmedia.org/resource/phy03.sci.phys.mfw.bbarch/arch-bridge/

SciShow Kids, "What Makes Bridges So Strong?" https://youtu.be/oVOnRPefcno

Websites

Dublin City Council, Bridges of Dublin, Arch http://www.bridgesofdublin.ie/bridge-building/types/arch

Khan Academy, Gothic Architecture: An Introduction https://www.khanacademy.org/humanities/medieval-world/gothic-art/beginners-guide-gothic-art/a/gothic-architecture-an-introduction

Nova, Super Bridge https://www.pbs.org/wgbh/nova/bridge/