PENSACOLA BAY BRIDGE
REPLACEMENT PROJECT

Popsicle Stick Bridge Lesson Plan – Unit V

ARCH BRIDGE

Objective: "Arch Bridges." After this lesson, students should be able to do the following:

- discuss different types of arch bridge designs;
- understand how the arch bridge supports load (dead and live) and how the forces are applied; and
- determine the elements of an arch bridge.

Summary: Through a PowerPoint presentation, students will learn about arch bridges and how they manage the natural forces of compression and tension. They will also find out about the elements important to arch bridge construction.

Materials: PowerPoint presentation, 2 2" x 12" strips of cardboard per student, and a stack of books (to test bridge strength).

ACADEMIC STANDARDS

Objectives:

SC.6.P.13.1

Investigate and describe types of forces including contact forces and forces acting at a distance, such as electrical, magnetic, and gravitational.

SC.6.P.13.2

Explore the Law of Gravity by recognizing that every object exerts gravitational force on every other object and that the force depends on how much mass the objects have and how far apart they are.

SC.7.P.11.2

Investigate and describe the transformation of energy from one form to another.

SC.7.P.11.3

Cite evidence to explain that energy cannot be created nor destroyed, only changed from one form to another.

SC.8.N.1.1

Define a problem from the eighth grade curriculum using appropriate reference materials to support scientific understanding, plan and carry out scientific investigations of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

SC.8.N.1.5

Analyze the methods used to develop a scientific explanation as seen in different fields of science.

SC.8.N.1.6

Understand that scientific investigations involve the collection of relevant empirical evidence, the use of logical reasoning, and the application of imagination in devising hypotheses, predictions, explanations and models to make sense of the collected evidence.

s. 1003.41, Florida Statutes
Rule 6A-1.09441, F.A.C

Vocabulary:

Abutment: a structure built to support the lateral pressure of an arch or span, e.g., at the ends of a bridge.

Cantilever: a long projecting beam or girder fixed at only one end, used chiefly in bridge construction.

Aqueduct: an artificial channel for conveying water, typically in the form of a bridge across a valley or other gap.

Viaduct: a long bridge like structure, typically a series of arches, carrying a road or railroad across a valley or other low ground.

Procedure:

The arch bridge is one of the most popular types of bridges. This design came into use over 3,000 years ago and remained popular until the development of advanced materials enabled engineers to create bridge structural designs. However, arch bridges remain in use today.

Show students the Unit 5 presentation of the arch bridge. Using PowerPoint, go through the introduction to the lesson with students. The PowerPoint will also contain all of the vocabulary as well as the types of bridges with vocabulary and captions. This PowerPoint can be used for the entire lesson, or it can be used as an introduction to activities 1 or 2.

Activity One

After the presentation, ask the following questions: (Use the discussion questions provided below as an icebreaker prior to beginning the activity.)

Discussion Questions:

- What are the different types of arch bridges?
  (Possible answers: Corbel arch bridge, Aqueducts and canal viaducts, Deck arch bridge, Through arch bridge, and Tied arch bridge.)
- What are some of the common materials or elements used in arch bridges?
  (Possible answers: stone, keystone, abutment, etc.)

Procedure Continued:

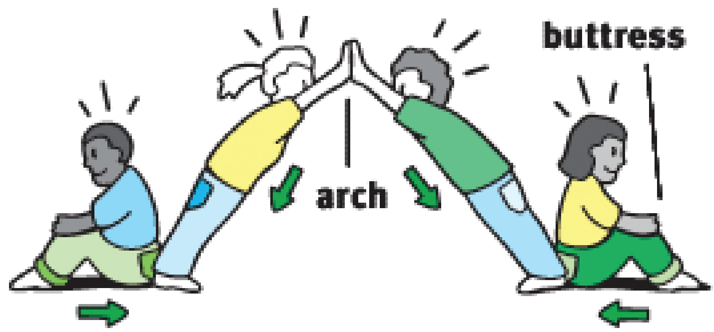
Main Activity — Human Arch Bridge

1. Have two students form an arch by placing their palms together and leaning toward each other, sliding their feet as far back as they can. Caution them not to lose their balance. Ask: Where do you feel a push or a pull? (Push on their hands.)

2. Have a third student gently pull down on the top of the arch to test its strength. Ask: How difficult is it to break the arch? (It is not difficult.)

3. Have the group brainstorm ways for two more students to join the arch and make it stronger, but without breaking up the space beneath the arch.

Guide them to the idea of adding buttresses by asking the arch-makers how stable their legs feel. Then repeat Step 2 and compare the results. (The buttresses exert an inward force on the sides of the arch that balances the outward force created by the load pressing down on the top of the arch.)



Main Activity obtained from http://www.pbs.org/wgbh/buildingbig/educator/act_mini_arch.html

Supplemental Activity – *Students will work in small groups.*

How do the abutments support an arch bridge?

1. Get a 2-inch by 12-inch strip of cardboard. Bend the strip gently, forming an arch.

2. Place both ends on a table in the fashion of an inverted U.

3. Press down gently on the top of the arch and notice the effect on the ends. (The likely outcome is the spreading outward of the ends of the arch.)

4. Place two stacks of books about six inches apart (the stacks must be lower than the height of the arch).

5. Place the arched strip between the stacks of books in the inverted U fashion.

6. Apply a gentle force to the top of the arch and notice how the stacks of books act as abutments, preventing the ends of the arch from spreading apart.

When the arch bridge is supporting its dead load (its own weight) and the load of the traffic crossing the bridge (the live load), every part of the arch is under compression. Given this situation, arch bridges must be constructed from materials that can withstand considerable compression force.

Supplemental Activity obtained from http://teachersinstitute.yale.edu/curriculum/units/2001/5/01.05.06.x.html

TEACHER BACKGROUND INFORMATION

Essentials of Arch Bridges

The arch bridge is one of the world's most popular styles of bridges, and it has been in use for well over a millennium. The invention of advanced materials enabled architects and engineers to create very different bridges, but ancient Romans and Greeks built aqueducts and arch bridges that are still standing and in use today. This classic design, aided by modern materials, can be created on a much larger scale than ever before.

During the Roman Empire, architects built over 1,000 stone and wood arch bridges as well as long, multi-arched aqueducts across Europe, Asia, and North Africa. Even today, many of these wonders of ancient architecture remain standing. The Roman design usually consisted of semicircular arches—though under Roman rule, numerous segmented arch bridges were also constructed. Unlike ordinary semicircular bridges, segmental arch bridges have the advantage of allowing the arch of the bridge to be much higher and to distribute the mass of the whole structure lower. Thus, bridges were much better equipped to survive powerful rivers and flooding. (A nice example is the Ponte Vecchio in Florence, Italy, the predecessor of which allowed the ancient Roman road to cross the narrowest point of the Arno. As the only crossable point in the river for a long way, in essence, the city only exists due to the protection of the rivers and the commerce allowed by the bridge.) Among Roman, Baroque, and Renaissance arch bridges, there's quite a bit of cosmetic variety in construction (for instance, flood openings on the piers). However, the basic structure doesn't change; all of them are architecturally different but structurally consistent.

As time went on, the designs of ancient Romans were improved upon by medieval architects. They made thinner arch barrels, narrower piers, pointed arches, lower span-to-rise ratios, and increased the arch spans. (The bridge at Trezzo sull'Adda was the most famous of these, with arch spans measuring over 70 meters.)

Arch bridges were infused with the fashion of their time by Renaissance architects, in addition to sound engineering. They created some of the most famous, wondrous bridges of modern human civilization (for instance, the Grand Canal's Rialto Bridge in Venice, Italy).

In the last century and a half, modern materials such as iron, steel, and prestressed concrete have supported even more ambitious arch bridges in every country in the world. Contemporary arches typically span 200 to 800 feet (61 to 244 meters). Meanwhile, to support a bridge over 3,000 feet long, the steel arch of West Virginia's New River Gorge Bridge spans an astounding 1,700 feet (518 meters)—the longest arch bridge span in the United States.

TEACHER BACKGROUND INFORMATION CONTINUED

Corbel arch bridge

The Corbel arch is not a true arch bridge (no forces are conveyed across the arch). By layering masonry or stone, it is built to look very similar to a true arch bridge.

Aqueducts and canal viaducts

To cross long distances, ancient Romans created viaducts by building a series of supports that were ultimately connected by stone arches. These viaducts were not made in one layer like typical bridges but were constructed using several stacked layers allowing them to reach impressive heights.

Deck arch bridge

This is a common type of arch bridge where the bridge deck is placed on top of the arch.

Through arch bridge

A through arch bridge is a bridge in which the deck is not situated completely above the arch, but rather travels in one part below it and is suspended to it via cables or tie bars.

Tied arch bridge

Also known as a bowstring arch bridge, the tied arch uses ties to hold the ends of the arch rather than abutments. The Pensacola Bay Bridge main span is a tied arch.

Forces of arch bridges

The curved design is the defining characteristic of an arch bridge. The strength of arch bridges comes from the arches themselves. The arch is under compression so materials such as stone, brick and mortar or concrete are good materials. They don't need to rely on any technology other than stone; they don't even need mortar. Arch bridges are not so simple to assemble, however. Building an arch generally requires additional scaffolding to support the arch until the two sides are connected in the middle and it can support itself.

The curve of the structure conveys the compressive forces of the loads from traffic and the bridge materials along the arch in each direction to the supports at the base, rather than pushing straight down. These structures—called abutments—carry the bridge's whole load. The abutments must not move or the arch will fail. This is why very hard stone works well for the abutments. This precise, immovable achievement is accomplished thanks to a central keystone at the top of the arch. Carefully and perfectly balanced, the keystone is designed to push its weight down and outward into the adjacent rocks, each of which does the same to the next.

These very elements are what make ancient arch bridges, domed ceilings, and similar structures so rigid and strong. The arch's natural curve and ability to dissipate forces outward virtually negates the

TEACHER BACKGROUND INFORMATION CONTINUED

effects of tensional force on the underside. However, just like beams and trusses, the laws of physics cannot be broken, even by the mighty arch. The more the semicircle (i.e., the degree of curvature) of the arch is increased, the greater the tension effects become on the bridge's underside. Tension will eventually overtake the natural structural strength of a big enough arch.

The primary forces exerted on the load-bearing foundations of arch bridges are vertical and horizontal compression. Therefore, arch foundations must address vertical settling and horizontal sliding.

ASSESSMENT UNIT 5

Students should be able to distinguish an arch bridge from other types of bridges as well as complete basic identification of vocabulary included in the PowerPoint.