Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2001 Volume V: Bridges: Human links and innovations

The Physics Of Bridges

Curriculum Unit 01.05.08
by Theresa Matthews

Introduction

"The Physics of Bridges" is a curriculum unit that will explain how scientists and engineers utilize physical science concepts when building a bridge. These concepts include Newton's Third Law of Motion (action-reaction forces), forces acting in tension or compression, stresses a material experiences when equal and opposite tension and/or compression forces are exerted on a structure, stress-strain curves, static equilibrium, vibration, and resonance. This unit can be incorporated with eighth to twelfth grade students in either a Physical Science or Physics class. The students should have an understanding of slopes of lines, Newton's Laws of Motion, vector resolution, force and vector diagrams, and equilibrium before teaching this unit. The following are a list of objectives for this curriculum unit.

- To define tension and compression and explain how materials react to these types of forces
- To be able to define the three types of stresses a material experiences when forces are applied to the material
- To understand how scientists test materials to obtain a stress-strain curve
- To understand why Newton's Third Law of Motion should be a concern to engineers when designing a bridge and be able to explain an action and reaction pair of forces
- To grasp the concepts of equilibrium, static and dynamic loads, vibrations, and resonance while studying the different types of bridges
- To be able to identify the following types of bridges: truss, arch, and suspension.

This curriculum unit is divided into class lessons that accommodate a block schedule of 80 minutes. The lessons can be modified for any class schedule. Each lesson is divided into sections so that if you run out of time you can easily continue the lesson in the next class period. The following are a list of activities included in some or all of the lessons:

- lecture/discussion
- pre-lab activity
- lab activity
- post-lab discussion
- homework assignment

The introductory lessons of this unit will concentrate on defining the process of building a bridge and exploring the forces of tension and compression. Students will learn how scientists perform tests on materials to determine the properties of a material which include their tolerance to compressive and tensile forces. They will discover how engineers utilize the results of material tests to select materials used in the components of a bridge. The students will perform experiments that test the amount of stress different types of wood can sustain, discover how abutments of an arch bridge support loads, and utilize computer software to observe how tension forces act on the members of a truss bridge.

Another objective of this unit is for the students to be able to identify a truss, arch, and suspension bridge or the combination of these types. Students will explore the capability of each bridge to withstand tension, compression or both. They will be able to determine why certain bridge designs are suitable for tensile and/or compressive forces. Labor, economics, design constraints, material selection, and methods of construction of each type of bridge will also be discussed.

The final lesson of this unit will give the students an opportunity to apply what they have learned in the previous lessons. They will actually design and build a Trussed or Arched Bridge in the classroom. In this lesson, the students will apply their knowledge of geometry, vectors, compression, and tension to demonstrate how engineers determine that bridges will maintain a state of equilibrium when they are subjected to various static and dynamic loads.

Lesson One

The purpose of this lesson is to introduce the three types of bridges (truss, arch, and suspension) the class will study in this unit. After completing this activity, students should begin to understand how important it is to sketch a plan before building their bridge especially when the supplies are limited. The activity will also help initiate an understanding of the design constraints engineers encounter when building a bridge as well as the disadvantage of not contributing to the material selection.

Lab Activity

Materials

8 feet of string per group, roll of masking tape, a cardboard box, pencil, scissors, and a piece of paper

Procedure

1. Students will break up into groups of four.
2. Each group will obtain their materials.
3. The group must construct a bridge across two tables or desks with the materials listed above.
4. The group must design and sketch the bridge they choose.
5. After the sketch is complete, the group will use the supplies and sketch to build their bridge.

Rules

1. You may not talk to the group across from you.
2. You cannot use any more material than what was given to you.
3. Record any design changes you make when building your bridge and explain why this was necessary.

Post-Lab Activity

The students are to describe what they observed during this activity as well as some principles of physics. The similarities between engineering a bridge and building their model bridge will be noted. The three types of bridges will be described through various books, photos, and their models. Students should keep their notes from this activity so they can compare their methods of building with those of their final project in this unit.

Homework

The following written assignment is to be completed after the lesson: students will be expected to identify through their observations, some similarities and differences among each type of bridge and identify one of each type of bridge located anywhere in the United States with a picture including details of each bridge they have selected.

Lesson Two

This lesson will introduce the concepts of compression, tension, and loads. Students will perform an activity to explore how materials react to compression or tension.

Lecture

A force is a push or pull in any direction in which a change is produced. A force can be weight (mass x gravity), wind, air resistance, or even a moving vehicle exerting its weight on the road below. Before we begin to study the design of bridges it is important to understand the forces that are applied to the bridge and that forces never act alone. As stated in Newton's Third Law of Motion, it is not possible for a single force to occur because every action has an equal and opposite reaction. Engineers must consider this law of motion when they design a bridge because the bridge will react to wind, moving vehicles, or even earthquakes although it may not be noticeable to the human eye.

When forces are applied to a structure and added together, the sum of the forces is defined as a load. Two types of load engineers must consider when designing bridges are known as dead and live loads. A dead load, also known as a static load, includes the weight of the bridge or stationary objects on the bridge. A live load, also known as a dynamic load, includes objects in motion as well as natural forces such as the wind (which is typically a lateral or horizontal load) or an earthquake. Live loads are the most difficult to design for because they are always changing. It is crucial that engineers account for all types of loads when designing a bridge because the magnitude of loads will affect the material selection and possibly the type of bridge engineers choose to build. To accommodate for variations of dynamic loads, engineers design for maximum live loads using specialized software which can generate many calculations before building material is even selected.

As stated above, for all forces acting on a bridge, there must be a counter force pushing or pulling in the opposite direction. These forces are defined as either compression or tension forces. A force of tension will lengthen or pull on a material while a compression force will squeeze or push a material together. (Avaikian, 482) Compression and tension forces can act parallel or at an angle to a bridge member's (a member is a segment of a bridge) axis. When two equal and opposite forces in tension or compression (but not both) act parallel or at an angle to the axis of a member, the forces applied are defined as axial forces. Figure 1a clearly demonstrates a pair of compression forces (axial forces) applied to the axis of a member. Figure 1b demonstrates a pair of compression forces applied at some angle to the axis of a member. A pair of equal and opposite tension forces applied to the axis of a member can be seen in

Figure 2a.

Not all members of a structure experience solely tension or compression. Many forces are applied perpendicular to the axis of a member and some forces may not be applied directly across from each other. (Avaikian, 482) In this case, tension and compression forces are both present and are considered non-axial forces. When two forces are not directly opposite each other, engineers must calculate a resultant force (sum of two forces that act at angles to each other) utilizing vector resolution. Refer to Salvadori's *Why Buildings Stand Up* (pages 82-84) for an example of how to solve for a resultant using a 30°-60°-90° triangle.

Activity

The purpose of the following activity is to help students visualize what happens to a material when it is under tension or compression. They should be able to explain what is happening inside the material.

Materials

- 1 container of Play-Doe or Silly Puddy
- 1 Rubber band

Procedure (Part I)

1. Break students into groups of four.
2. Have each group take 1 container of Play-Doe and 1 rubber band.
3. Take the Play-Doe and shape it into a cube.
4. Push down on the Play-Doe

Assessment

Explain what you see and what you think happens to the molecules inside the Play-Doe.

Procedure (Part II)

Select one rubber band and pull with both hands

Assessment

Explain what you observe and what you think happens to the molecules inside the rubber band.

Post Activity Discussion

Students should discover that when they compress the Play-Doe, it becomes shorter and the molecules press together more tightly. When students pull on the rubber band, they should discover that the rubber band gets longer. After this activity students should understand that when a bridge's member is in compression, it will become shorter and when a bridge's member is in tension, it will become longer.

Lesson Three

In continuation of Lesson Two, this lesson will focus on the three types of stress caused by tensile and compressive forces, strain, and the tests that scientists perform on materials so that engineers have accurate data to refer to when selecting the materials for a bridge. Students will also be expected to define and calculate the stress on different samples of wood.

Lecture

A bridge member under tension, compression or both forces at the same time experiences what engineers define as stress. J. E. Gordon states "stress is a measure of how hard the atoms and molecules which make up the material are being pushed together or pulled apart as a result of external forces. Stress is not associated with any particular length or cross-section therefore testing multiple shapes and sizes of the same material will yield the same stress limit. (Gordon, 46) To calculate the stress, you must take the force exerted on a material sample divided by the cross-sectional area of the sample.

The elongation or shortening of a material under stress is defined as strain. Strain is a measure of how far a material is being pulled apart or pushed together and like stress, it is not associated with any particular length or cross-section of a material. (Gordon, 49-50) Strain is calculated using the following formula:

(Strain) e = (Change in Length) D L / (Original Length) L

To be of use to engineers, the values of stress and strain are plotted on a graph. The stress is plotted on the y-axis and strain is plotted on the x-axis. Gordon explains the stress-strain curve as follows: "The slope of this curve is usually a straight line and when this happens it is said that the material is 'obeying Hooke's Law'. The slope of the line varies for different materials. Engineer's use the slope of a stress-strain curve to measure how readily a material strains elastically (deforms temporarily and returns to its original shape after a load has been removed) under a given stress."(Gordon 1978, pg. 52) Hooke's Law is the amount of restoring force needed to bring a spring back to it's original position after a force has been applied to it. It is important that a material behave much like a spring because engineers do not want permanent deformation of a structure to occur every time a load is applied. Therefore, the slope (Ds/De), also known as the Young's Modulus of Elasticity of a stress-strain curve measures the elastic stiffness of a material or the point at which the maximum elastic deformation will occur. Engineers might desire a material with a low Modulus of Elasticity such as rubber or a material with very high Modulus of Elasticity such as steel depending upon the designed application of the member.

When referring to stresses, materials can experience different types. Forces pulling on a member will cause tensile stress, forces pushing on a member will result in compression stress, and when both forces push and pull on a member and the lines of forces are not directly across from each other, a shear stress is produced. (Avaikian, 482) Figure 2b explains how compression and tension affect a member to cause shearing. This type of stress can cause bending or twisting of a material.

The amount of stress a member can tolerate is crucial when selecting materials for a bridge. Engineers analyze every component of a bridge to determine what members will be in tension, compression, or both. Engineers must keep in mind that certain materials are better under compression rather than tension. These include concrete, brick, hard woods, and steel. Some materials such as steel, flexible yet strong can carry tensile forces. There are also materials that can carry both tensile and compressive forces. Pre-stressed concrete is one of these materials. Pre-stressed concrete has steel rods running through it so it can withstand not only a compression force but a tension force as well.

After engineers have determined the forces acting on members of a bridge, they refer to engineering reference books for the stress-strain limits of specific materials. As stated above, the required stiffness of a material will depend on the function of the member.

The following lab activity is designed to help students understand how scientists perform tests on materials to obtain stress limits. This particular test is a compression test in which they can calculate the stress of a material utilizing the formula:

(Stress) s = (Force) F / (Cross Sectional Area) A (Units of Measure are lb/in2 or N/m2)

Today, scientists can test materials with a test machine. When an engineer wants a particular material tested, they create a test piece that is put into a testing machine. This machine can simulate a load of tension or compression. The machine measures the strain with an extensometer. From this data, a stress-strain curve can be obtained.

Lab Activity

Objectives

To help students understand how scientists test materials, calculate stress, determine maximum compression loads of different types of wood, and understand why different wood can tolerate more stress.

Materials: 2 pieces of pre-cut balsa wood (4" x 4" x ¼" and 4" x 4" x 5/32")
2 pieces of pre-cut pine wood (4" x 4" x ¼" and 4" x 4" x 5/32") 2 pieces of pre-cut oak wood (4" x 4" x ¼" and 4" x 4" x 5/32") 20 Bricks or Weights of 50 N or more Procedure:

1. Record the weight of 1 brick in Newtons.
2. Calculate the cross-sectional area of the two different samples of wood. (Multiply the length x height)
2. To begin the test, place 2 bricks on a table.
3. Lay one specimen of wood at a time across the two bricks.
4. Slowly add a weight or brick on top of the wood and observe what happens. Students will be expected to continue until the material begins to deform or fail.
5. Record the maximum amount of weight before a failure or deformation in the material occurs.
6. Calculate the stress of that particular sample.
7. Repeat with the other samples.

Assessment: Students should draw a force diagram to illustrate what forces are acting on the wood. They should compare the values of stress for each pair of wood and explain what they have observed.

Post-Lab Discussion

Students should discuss their observations, hypothesize why certain materials can withstand more stress than others, and realize that the different cross-sectional areas of the same material do not affect the amount the material can tolerate. You can discuss the molecular structure of hardwood versus softwood to explain why hardwoods can tolerate more stress. Since the next lesson focuses on arch bridges you can explain that arch bridges, which experience mostly compression forces, are built from materials such as concrete, stone, and brick because these materials are very good in compression.

In conclusion to the post-lab discussion, you could discuss the other tests scientists conduct on materials such as the hardness and tensile tests. It is also important to note that the test results are published in material reference books available to engineers who use this data to select the desired materials for a structure.

Lessons Four and Five

These lessons will focus on the design of the arch and trussed bridges and how they handle tension or compression. The primary concept students should understand is that an arch bridge relies primarily on compression while a truss bridge relies primarily on axially loaded members acting in tension and compression. An activity will follow the lecture to help students understand the strength of a triangle (the basic shape utilized in a truss). Lecture

An arch bridge is a bridge that utilizes the arch as its main design as this bridge carries

its weight outward along the curve of the arch to the supports at each end. The supports, known as the abutments, carry the load. The abutments also keep the ends of the bridge from spreading out by creating two equal and opposite horizontal forces that push inward on the arch. (See NOVA's website http://www.pbs.org/wgbh/nova/bridge/meetarch.html for an activity that allows students to examine the importance of abutments.)

Arch bridges rely primarily on compression because as forces are carried outwards along the curve of the arch, the molecules of the material are compressed. When selecting a building material for an arch bridge, engineers must consider only materials that are strong under compression. These materials include stone, concrete, or steel.

Trusses are like a beam bridge because forces are transverse to the axis of the whole truss. A truss is identified by its series of triangles that are connected by a lower and upper chord or flange. Forces are carried along the axis of the assembled members that form the shape of a triangle. The members of the truss carry forces of tension or compression but not both.

As stated in Lesson Two, bending occurs when both tension and compression are acting on a member. Members which hold the deck for the cars, trains, people, bikes and other objects crossing the bridge are subjected to both tension and compression. Bending in theses members may combine with axial loads in truss members which adds some complexity to the analysis of this type of bridge.

The following Activity will help students understand why a triangle can sustain more force than a quadrilateral. It can also help them understand how members are axially loaded.

Activity

Students will compare two basic shapes: the triangle and the square. They should discover that the triangle can sustain more force than a square. In addition to this activity, you may want the students to find resultants of vectors.

Materials: Popsicle Sticks, rubber bands, and pins

Procedure:

1. Create a rectangle using the popsicle sticks and pins.
2. Apply a force to the pivot points and record what you observe about this structure.
3. Now take a rubber band and attach it to two pins to create a diagonal in the rectangle. (This will now form 2 triangles.)
4. Apply a load to the pivot points and record what you observe.

Analysis:

1. Did your change help to make the structure stronger. Explain.
2. How might this particular structure explain how a truss bridge carries the load of moving vehicles?
3. Can you identify which members are in tension and which members are in compression?

Post Activity Lecture

As stated earlier, a truss is a series of triangles that consist of members and joints to form a stable configuration. A truss bridge must have two support nodes to sustain both vertical and horizontal forces. A fixed joint supports the horizontal and vertical direction while a rolling joint only supports the vertical direction. Loads on a truss bridge cause the members to be in either tension or compression. A stable structure or a structure in equilibrium has the weight of a static or dynamic load equal but opposite in direction to the support forces.

(figure available in print form)

A truss can be more efficient than a beam bridge. A truss uses only axial forces which means that a member is either in tension or compression, but not both. Each member will sustain forces along its axis. The compression members are short and thick while the tension members are typically longer and thinner. To further explore which members of a truss are in tension or compression you may want to go to the following website: John Hopkins University: What is Engineering? - Virtual Laboratory: "Bridge Designer", http://www.jhu.edu/~virtlab/bridge/truss.htm. On this website students are able to build a truss, apply loads, have the computer software calculate how much force each support applies, and visually see what members are in tension or compression. This is an excellent "hands on" interdisciplinary (science and math) activity for students in eleventh and twelfth grades.

When a trussed bridge is designed, strength and stiffness must be considered. The strength of a material determines the size of the member required to support the anticipated loads calculated by engineers. Since members of a truss can be in either tension or compression, steel is a material that is often selected for the construction of a truss because steel can sustain both tension and compression. In addition to the stress a material can sustain, engineers want every part of the bridge to behave elastically (the ability of a material to deform minimally during loading and return to its original length after the load is removed). As discussed in earlier lessons, the engineers rely on the Modulus of Elasticity to determine which alloy of steel (as each one will have its own stress-strain curve) is adequate for the function of the member. Engineers use their professional judgement to stay within allowable stress limits. It is important that the material of each member is not sustaining too much or too little stress.

Homework Activity

Students must identify at least three different truss bridges in Connecticut and bring in a picture of each type of truss bridge. They must explain to the class how each bridge carries the load and try to identify the members in compression and tension.

Lessons Six, Seven, & Eight

The purpose of these lessons are to define what a suspension bridges, recognize that these types of bridges rely primarily on tension, and understand the process involved in building a cable-stayed bridge.

Lecture

The last type of bridge to define is the suspension bridge. This type of bridge can be easily be recognized by the large pylons (tall towers rising above the water) and the cables that gracefully hold up the road deck. Some examples of this type of bridge include the Brooklyn and George Washington Bridges in New York City. The cables are attached on top of the pylon and then pulled down in a parabolic or catenary shape down to two anchor points (one as you approach the bridge and the other as you leave the bridge) on land.

A disadvantage to a suspension bridge is its reaction to the wind. This was discovered during the collapse of the Tacoma Narrows Bridge in Washington State. This bridge began resonating with the wind and began to move like a wave in the ocean This bridge was not stiff enough. Although the Tacoma Narrows Bridge was designed to withstand 120 mph winds, it eventually collapsed due to the excessive movements of the bridge during a 40 mph wind which magnified through resonant frequencies.

The collapse of the Tacoma Narrows Bridge was a result of the differences in air pressure above and below the road deck. Similar to the wing of an airplane, the greater wind pressure below the deck and lower wind pressure above caused a lifting of the road. The varying wind speeds along different parts of the deck caused the road to lift and twist. You can experience this type of behavior when you walk across a suspended

foot-bridge. As you shift your weight back and forth or up and down you will notice the swaying motion. This is an excellent way to understand how cables of a suspension bridge remain in tension. The Tacoma Narrows Bridge collapse forced engineers to redesign the road decks of this type of suspension bridge. Engineers realized that the roadway itself does not have to be rigid, but should flex when loads go across it. The flexes of the road are designed within tolerable and limits in large structures. The solution to keep the road stable and stiff was to add a larger truss below the deck so that wind approaching the bridge would be resisted more easily. The Verrazano Narrows Bridge that links Staten Island to Brooklyn is an another example of a suspension bridge.

Activity

Students will watch the video *NOVA* - "*Super Bridge*" . This movie tracks the work of engineers, construction crews, contractors, and surveyors. Students will be able to observe the construction of a bridge from the concept including engineering surveys to opening day of the newly constructed bridge.

During the movie students should be taking notes. They should be instructed to pay close attention to the following topics:

- Constraints of the bridge design
- The process of building a tower
- Explain the dangers construction workers face including the definition of "the bends"
- Explain problems encountered throughout the construction of the bridge and explain how they were resolved
- Discuss the economics of building the bridge

Post Activity Discussion

The following are a list of questions that you can discuss with the class.

- What are the steps taken in building a bridge from conception to final construction?
- Describe the design criteria for this specific bridge.
- What problems occurred before and during construction?
- How can engineers avoid problems of this kind in the future?
- What types of materials were used for the various parts of the bridge and why might this be?
- Are there advantages to the cable-stayed bridge versus the suspension bridges of the past? Explain.

Lessons Nine, Ten, & Eleven

Objective

The objective of this lesson is to demonstrate their knowledge of bridges by

designing and constructing either an arched or trussed bridge.

Lab Activity

In this lesson students will design their bridge on paper and then select the materials

needed to build their bridge. They can choose from the following materials when constructing their bridge: concrete (they will create the mixture), wood, or metal. Glue can be used to represent a weld and pins or small nails may be used for joints to represent bolts or rivets.

Post Lab Activity

Each group of students will be expected to present their bridge to the class and discuss the following topics:

- Why they choose that specific bridge type
- How did they decide what material to use when constructing their bridge
- How their bridge sustains loads
- How the bridge remains in equilibrium
- What members are in tension, compression, or both
- How did their method of constructing a bridge compare with the process an engineer follows

In conclusion of this unit, you may want to summarize as a class. You can form five groups of students to discuss the three types of bridges and their characteristics, the science involved in selecting materials, and finally the economics involved in the construction of a new bridge. You may also want to take the students on a field trip to view different types of bridges New York City and Connecticut. While on the tour, you may have students report on each bridge visited.

(figures available in print form)

Bibliography

Allen, Edward and Zalewski, Waclaw, *Shaping Structures: Statics* , John Wiley & Sons, Incorporated, New York, N.Y., 1998 (This is a good source for teachers to use for technical information about behavior of materials and how engineers design a safe structure.)

Avakian, Paul W.; Blaustein, Daniel; McLaughlin, Charles W.; Reel, Kevin; *Science Interactions* , Glencoe/McGraw-Hill, 1996 (This teacher's edition gives excellent short exercises in which students can test the basic principles of physics.)

Cutnell, John D. and Johnson, Kenneth W., *Physics 3rd edition* , John Wiley & Sons, Inc., 1995 (This college level book is an excellent resource for the accelerated physics' student. It gives many examples of how physics relates to the engineering of structures.)

Dupre, Judith, *Bridges* , Black Dog & Leventhal Publishers, New York, 1997 (This is an excellent introductory book for students because it displays photographs of the three types of bridges from all over the world and some history about each bridge.)

Friedman, Thomas and Goodwin, Neil, screenwriter. *Super Bridge* . Director Neil Goodwin. Peace River Films, 1997 (This video is an excellent way for students to experience first hand the process of building a suspension bridge. Students are also able to watch problems encountered during the construction of cable-stayed bridge.)

Gordon, J.E., *Structures: Why Things Don't Fall Down* , Plenum Press, London, England, 1978 (This book is an excellent resource for teachers and students because it is humorous, easy to read, and explains scientific terminology in a way that is easy for students to understand.)

Jupp, Edmund W., "*Bridge Watching for Beginners*" , http://www.media.uwe.ac.uk/masoud/projects/bridges/text/contents.htm (This website is a good resource for the basic terminology of engineering a bridge. Students will find this website easy to read and interesting to explore the world of bridge building.)

Nova On-Line, "*Super Bridge*" , http://www.pbs.org/wgbh/nova/teachersguide/bridge (November, 1997) (This website offers the teacher and student many lab activities in which students can explore the physics of building a bridge.)

Salvadori, Mario, *Why Buildings Stand Up: The Strength of Architecture* , W.W. Norton & Company, New York, N.Y., 1980 (This book is a good resource for teachers because it discusses the engineering of structures and how they stand when subjected to natural forces. This book also gives good mathematical examples and explanations of how different shapes provide strength for structures.)

RESOURCES AND REFERENCES

Allen, Edward and Zalewski, Waclaw, *Shaping Structures: Statics* , John Wiley & Sons, Incorporated, New York, N.Y., 1998 (This is a good source for teachers to use for technical information about behavior of materials and how engineers design a safe structure.)

Dupre, Judith, *Bridges* , Black Dog & Leventhal Publishers, New York, 1997 (This is an excellent introductory book for students because it displays photographs of the three types of bridges from all over the world and some history about each bridge.)

Friedman, Thomas and Goodwin, Neil, screenwriter. *Super Bridge* . Director Neil Goodwin. Peace River Films, 1997 (This video is an excellent way for students to experience first hand the process of building a suspension bridge. Students are also able to watch

problems encountered during the construction of cable-stayed bridge.)

Gordon, J.E., *Structures: Why Things Don't Fall Down* , Plenum Press, London, England, 1978 (This book is an excellent resource for teachers and students because it is humorous, easy to read, and explains scientific terminology in a way that is easy for students to understand.)

Jupp, Edmund W., "*Bridge Watching for Beginners*" , http://www.media.uwe.ac.uk/masoud/projects/bridges/text/contents.htm (This website is an excellent resource for a basic descriptions and visual aides for the study of beam, arch, and suspension bridges.)

Karweit, Michael, "*John Hopkins University: What is Engineering? - Virtual Laboratory: Bridge Designer*" , http://www.jhu.edu/~virtlab/bridge/truss.htm (August, 2000) (This website is an excellent resource for Physics teachers and students. You are able to create a truss, apply loads, perform calculations and determine which members of a truss are in tension or compression.)

Locke, Derek, "*Brantacan Home Page - Bridges*" , http://www.brantacan.co.uk/index.htm, (2001) (This website is a good resource for pictorial representations of arch, truss, and suspension bridges.)

Salvadori, Mario, *Why Buildings Stand Up: The Strength of Architecture* , W.W. Norton & Company, New York, N.Y., 1980 (This book is a good resource for teachers because it discusses the engineering of structures and how they stand when subjected to natural forces. This book also gives good mathematical examples and explanations of how different shapes provide strength for structures.)