Structural Engineering: Building a Bridge

Introduction

Since earliest recorded time, mankind has attempted to reshape the environment. One of man's first attempts to alter the environment involved the use of natural materials, such as trees and vines, to cross natural barriers. Trees were cut down and laid across narrow rivers, streams, or canyons, thus allowing access to a much larger area. Primitive rope bridges, the forerunner of modern ***suspension bridges***, were strung across rivers. These early bridges allowed people to cross, but were impractical for moving heavy loads or for vehicle traffic.

Bridges are designed by mechanical designers or civil engineers. ***Civil engineering*** is a branch of engineering related to the building of municipal systems, such as roads, bridges, dams, and other systems, to help society manage the environment.

Engineers are often required to work within limited ***specifications*** and confined requirements for structures. A number of design factors must be considered by the engineer when a bridge is designed. (See Figure 1.)

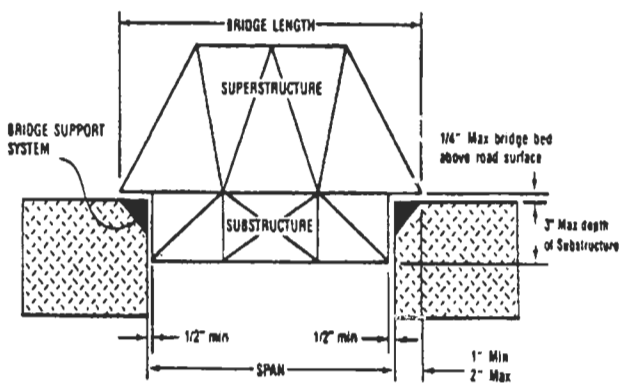

Figure 1 - Bridge Diagram with Specifications

When considering these design factors, certain questions must be answered, such as:

- What is the ***span*** of the bridge?
- What will be the ***load*** on the bridge?
- How large must the structural members be to withstand the compressive, tensile, and shear forces placed on them?

This activity is one of the Technology Student Association (TSA) competitive events. If your school offers a TSA program, you may choose to enter your bridge design in competition at the local, state, and national level.

Activity Description

In this activity, you will design and construct a bridge to a given set of specifications. You must include a drawing showing the structure in the ***top view*** and ***front elevation***. The bridge must span, or cross, a distance between two supporting ***abutments***. Since this is a team event, it would be best for you to work cooperatively with another student on this project.

Materials and Supplies

drafting or 1/8" graph paper, 11" x 17", (2 sheets)
ruler or scale
pencils
balsa wood strips, 1/8" x 1/8" x 36" (7 lengths)
single-edge razor blade or X-Acto knife
waxed paper
white glue
T-head pins
cardboard or foam core board, 18" x 24"

Researching Bridge Designs

1. Before you begin designing your bridge, you must conduct some research of the forces that will be applied to your bridge; the shape and size of structural members to carry the load; and construction techniques to insure a strong and durable bridge.

Some of the terms you must be familiar with are:

Load - the weight that will be on the bridge (live) and the weight of the bridge itself (dead).

Compression - to press or squeeze together; when a load is placed in the middle of the bridge, the top of the bridge is compressed. (See Figure 2.)

Tension - a force tending to cause extension, elongation, or pulling apart.

Shear - a force acting on a solid body as to cause adjacent parts to slide past one another parallel to the place of contact.

Torsion - the act of twisting or being twisted.

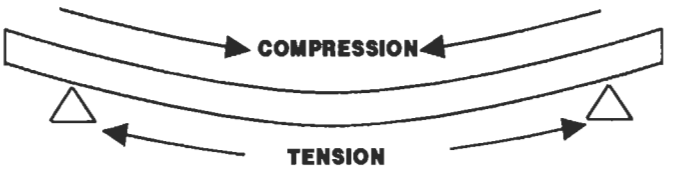

Figure 2 - Compression

2. After you have collected your data, you are ready to make several ***thumbnail sketches*** of possible design solutions.

3. From your thumbnail sketches, choose the design that you think will be the best. You will make a full-size ***multiview*** drawing of this design.

PART NAME	MAXIMUM	MINIMUM
Span		
Bridge Length		
Bridge Width		
Substructure Length		

Figure 3 - Design Specifications

Producing the MultiviewDrawing

1. Obtain the design specifications from your teacher. Record the information on the chart in Figure 3. Make sure you include the maximum and minimum allowable sizes, as you will be required to stay within these ***tolerances***.

2. Select a sheet of 1/8" 11" x 17" graph paper. Tape it to a drawing board, so that you may begin drawing a top view and front elevation of your design. (See Figure 4.)

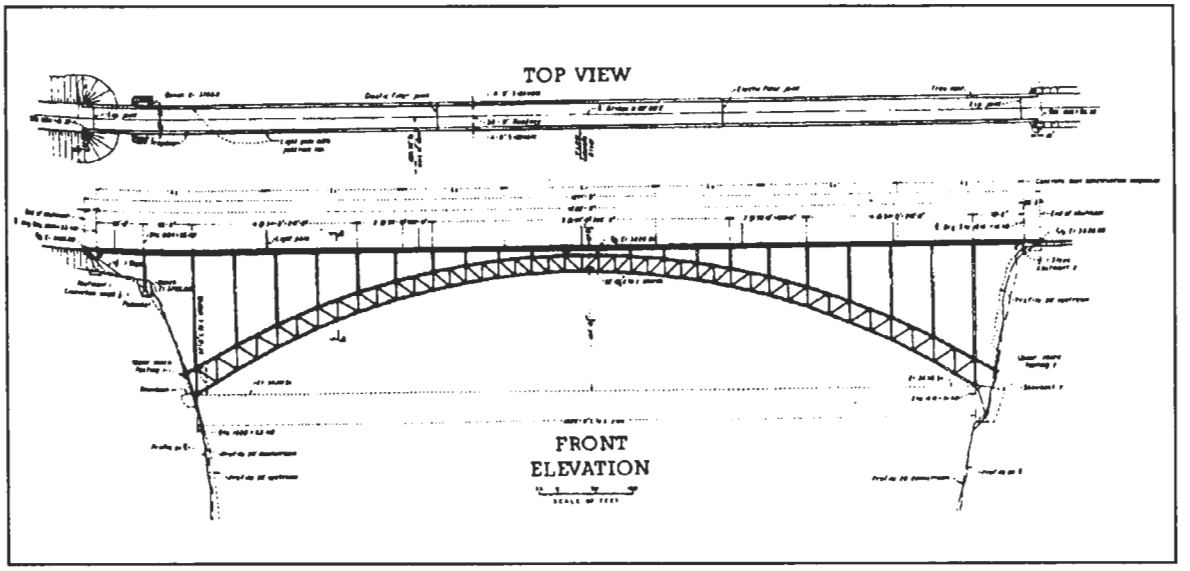

Figure 4 - Top View and Front Elevation

3. Draw a horizontal ***center line*** approximately 3" down from the top of the paper.

4. Draw a vertical center line approximately 8-1/2" from the left side of the paper.

5. Using these center lines, begin to lay out the top view of the bridge design. At the intersection of the two center lines, draw a 1/4" diameter circle. This circle represents the bolt of the test block that will be used to test your design.

6. To lay out the length of the bridge, you must measure to the right and left of the intersection along the horizontal center line. Measure 1/2 of the length of the bridge to the left of the intersection and place a dot; then do the same to the right of the intersection. The distance between the two dots should be equal to the length of the bridge. After you have verified the length, draw a vertical construction line at each dot.

7. To lay out the width of the bridge, you will measure above and below the vertical center line. Measure 1/2 of the width of the bridge above the intersection of the two center lines and place a dot; then measure the same amount below the intersection and place a dot. The distance between the two dots should be equal to the width of the bridge. After you have verified the width, draw a horizontal construction line through the dot above the extension connecting the two vertical guidelines. Do the same below the center line. You now have the rough layout of your bridge design in the top view. After you complete the rough layout of the front elevation, you will come back and complete the top view.

8. Draw a horizontal line approximately 3-1/2" up from the bottom of the paper. This horizontal line will represent the bottom of the ***roadbed*** of the bridge. The point where the horizontal line intersects the vertical center line is the center of the bridge in the front view.

9. Extend the vertical lines in the top which represent the length of the bridge down to the roadbed line in the front elevation.

10. Now lay out the ***substructure*** of the bridge. Notice in your TSA rules that there must be a 1/2" clearance between each end of the substructure and the span. Remember to measure from the center of the bridge.

11. Determine the distance for the substructure from the bottom of the roadbed. Draw a horizontal line to represent the bottom of the substructure.

12. Measure the maximum height of the roadbed and draw a guideline to represent this distance.

13. Now lay out the ***superstructure*** of your bridge design. Notice that there is no height limit above the roadbed for the superstructure.

Completing Your Drawing

1. After considering your research and reading the instructions, complete the drawing of your design. Notice that all structural members are 1/8" x 1/8", and that the squares on your graph paper are the same size. Draw all structural members full size.

2. The top view shows the completed bridge in a "birds eye view" from above the structure.

3. The front elevation shows the completed bridge looking from the front. Notice that it shows the superstructure and the substructure, as well as the roadbed.

Building Your Bridge

1. Place your drawing on the cardboard or foam core board, taping it down so they will not shift.

2. Place the wax paper over the drawing. This will protect your drawing during the construction process.

3. Begin construction by laying out the balsa strips over the drawing and cutting them to length. Pins may be placed in or around the members to hold them in place.

4. Glue pieces as required. Remember, if you plan to glue pieces together (laminate), you must follow the rules of ***lamination***. (See Figure 5.)

5. When the glue sets, remove the pins and lift the bridge off the wax paper.

6. Assemble the roadbed, superstructure, and substructure as required by your design.

7. Allow the completed bridge to dry on the wax paper for at least 12 hours.

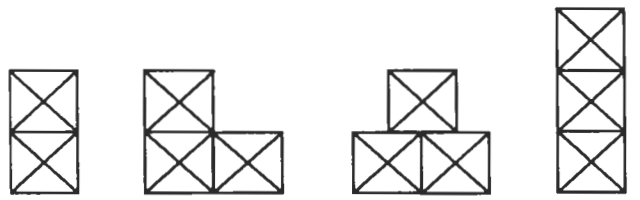

Figure 5 - Rules of Lamination

Testing the Bridge

In order to determine the ***efficiency*** of your bridge design, the model must undergo a destructive test in which weight will be applied until the bridge falls apart.

1. Weigh the bridge and record the mass in grams.

2. Place the bridge on the tester, centered between the two supports.

3. Slide the test block to the center of the span and attach the test hook.

4. Begin adding weight to the test hook. Continue adding weight until failure.

5. Calculate the load at the time of failure.

Efficiency of Design

To compute the efficiency of your bridge, use the following formula.

$$\text{Efficiency} = \frac{\text{load (lbs.) x 4.54 (grams/lbs.)}}{\text{mass of structure}}$$

The higher the answer (efficiency) you record means your design is more efficient than someone who recorded a lower number.

Safety

Be very careful when using an X-Acto knife or single edge razor blade; these blades are very sharp. Always cut on a cutting mat or surface, not on the table or desk. Be sure to cut away from hands and fingers.

Ecology

While trees are a renewable resource, we must not be wasteful. Conserve materials; don't start cutting your balsa strips until you have drawn your design and double checked your measurements.

Vocabulary

suspension bridge
specifications
tolerances
deflection
compression
tension
torsion
shear
efficiency
lamination
substructure
superstructure
roadbed
clearance
abutments
span
load

On Your Own

1. Visit the library, and research bridge design. What types of bridges are there? Obtain or draw a diagram of each of these types.

2. Make a list of all the bridges that you see this weekend and their locations. What type of bridges are they, and what do they carry?

Office of Vocational, Adult, Career, and Community Education
Technology Education
Dade County Public Schools
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TEACHER GUIDE
STRUCTURAL ENGINEERING

Objectives: Upon completion of this assignment, students will be able to:

- Describe the terms deflection, torsion, compression, tensile, and shear.
- Demonstrate an ability to follow closely specific rules and specifications.
- Explain the process of "engineering".
- Complete a multiview drawing of a design.
- Complete a structure to specific specifications.
- Determine efficiency of the design through a destructive test.

Helpful Hints:

1. Obtain a copy of the *TSA Curricular Resources Guide* that is currently in use. Make copies of the structural engineering section for each of your students.

2. Review the requirements for this event carefully before you begin this assignment. You will need to determine the span of the bridge before you begin to give directions, or before students begin drawings.

3. Obtain all necessary materials for this activity before you begin. Pitsco has available a Bridgepak for this activity that contains all the necessary materials and a copy of the *Bridge Building Book* as well. (Item # 23116)

4. You will need a Bridge Tester for this activity. You may wish to construct a tester of your own out of a few pieces of 2" x 8" wood. You will also need a test block. The test block can be made out of a piece of 1"x 2" wood. Cut the test block to the following dimensions: 3/4" x 2" x (span - 2"). A test hook can be made from a piece of threaded rod, a few washers, and nuts.

5. Many vendors have commercial bridge testers available that test the bridges with an hydraulic jack and require no buckets of sand, lead shot, or gravel. The Bridge Tester is expensive, approximately $650.00. (Pitsco item # 23115)

6. You will also need the following items: a gram scale to measure the weight of the bridges in grams, a plastic bucket (5 gallon size) to hold the weight attached to the test hook, and sand, gravel, or lead shot.

7. Many vendors offer a package of computer software called Bridge Builder for the Apple®, Macintosh®, and MS-DOS® compatible computers that is great for kids to experiment with structural designs.

STRUCTURAL ENGINEERING (Cont'd.)

8. Building surfaces will be needed, one for each team. You may use corrugated cardboard or a piece of foam core.

9. In order to make checking lamination easier, place a small amount of food coloring in your Elmer's white glue. Red works best.

10. This activity is great for some interdisciplinary work. Try to get the math and science teachers to co-sponsor a school-wide bridge building contest.

11. The following is a partial list of vendors who carry bridge building supplies:
    Hearlihy & Co. 1-800-622-1000
    Midwest 1-800-831-5904
    Modern School Supplies 1-800-243-2329
    Pitsco 1-800-835-0686

    Local hobby shops:
    Orange Blossom 633-2521
    Pan American International 635-3134

LANGUAGE ARTS APPLICATION
STRUCTURAL ENGINEERING: BUILDING A BRIDGE

_____
Student Name

In all types of jobs you will find that you need the ability to communicate your ideas effectively. Writing skills are necessary in all occupations. Here are a few examples of how communication and writing skills are related to this activity.

Before a superstructure can be constructed on a site, it must be carefully designed and analyzed. There are many environmental concerns that must be considered before any construction begins. A prime example of this is Alligator Alley which connects the southeast coast to the southwest coast of Florida. This road crosses the environmentally sensitive wetlands known as the Everglades.

In this assignment you will be asked to write your opinion concerning some issues that deal with bridge and roadway construction.

1. What are some of the negative and positive impacts that various types of bridges and highways have on the environment?

_____

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2. Construction of a bridge involves earth moving and may reroute the natural path of canals and animals. What effects do you think this has on wildlife in the area?

_____

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LANGUAGE ARTS APPLICATION
STRUCTURAL ENGINEERING: BUILDING A BRIDGE (Cont'd.)

3. Wetlands are often a protected environment. List some reasons why construction is often prohibited in wetland areas.

4. What factors need to be considered when deciding what type of bridge to build across a waterway?

5. What effects can a bridge have on business and industry and the local economy?

6. What importance do computers play in the designing of bridges?

MATH APPLICATION
STRUCTURAL ENGINEERING: BUILDING A BRIDGE

_____
Student Name

In all types of occupations you will need the ability to apply mathematics effectively. Here are a few examples of how math skills are used in relation to this activity.

After the construction of your bridge has been completed, it should be tested to determine the efficiency of your bridge design. To calculate the efficiency of your model, two variables must be recorded - mass and load. First you need to weigh and record the mass(weight in grams) of the structure. Second, after a test block is placed in the center of the span, a test hook is attached and an increasing load is applied to the bridge until the structure fails. The load is measured and recorded in pounds (lbs.). After determining these two variables, use the formula to determine the efficiency of the structure. The greater the number is, the more efficient the design is.

$$\text{Efficiency} = \frac{\text{load (lbs.)} \times 4.54 \text{ (grams/lbs.)}}{\text{mass of structure (grams)}}$$

Example: The weight of your bridge measured 11 grams, and the load was 43 pounds. Calculate the efficiency of your design

Solution:

$$\text{Efficiency} = \frac{43 \text{ (lbs.)} \times 4.54 \text{ (grams/lbs.)}}{11 \text{ (grams)}}$$

$$\text{Efficiency} = \frac{195.39}{11}$$

$$\text{Efficiency} = 17.76$$

Try these:

1. load = 58 lbs., mass = 14 grams

   Efficiency = _____

2. load = 24 lbs., mass = 10 grams

   Efficiency = _____

MATH APPLICATION
STRUCTURAL ENGINEERING: BUILDING A BRIDGE (Cont'd)

3. load = 39 lbs., mass = 9 grams

   Efficiency = _____

4. load = 73 lbs., mass = 11 grams

   Efficiency = _____

5. load = 67.5 lbs., mass = 13 grams

   Efficiency = _____

6. load = 47 lbs., mass = 10.5 grams

   Efficiency = _____

7. load = 83 lbs., mass = 14 grams

   Efficiency = _____

8. load = 37 lbs., mass = 12.5 grams

   Efficiency = _____

9. Which bridge measured the highest efficiency rating? _____

10. Which bridge measured the lowest efficiency rating? _____

11. List your eight answers from most efficient to least efficient.

    1._____ , 2._____ , 3._____ ,

    4._____ , 5._____ , 6._____ ,

    7._____ , 8._____ .

QUIZ
STRUCTURAL ENGINEERING:
BUILDING A BRIDGE

_____
Student Name

True or False

_____ 1. The span of the bridge is the same as the length of the bridge.

_____ 2. A superstructure is the part of the bridge above the roadbed.

_____ 3. Lamination means cutting the structural members in half.

_____ 4. Compression is when a load is placed on a structural member Causing it to bend.

_____ 5. Torsion is a load that causes a structural member to twist.

_____ 6. The length of the bridge must be greater than the span.

_____ 7. Deflection is the result of a load placed on a structural member.

_____ 8. A substructure is the part of the bridge below the roadbed.

_____ 9. Clearance is a space between structural members.

_____ 10. Shear is a force that holds structural members together.