The Pitsco Bridge Book

PITSCO

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On the cover: The bridge in the background is the Eads Bridge that crosses the Mississippi River between St. Louis, Missouri, and East St. Louis, Illinois. Completed in 1874, this bridge is still in use today.

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Chapter 1 – Bridge Overview

History of Bridges

When driving or riding from home to school, how many bridges do you cross? Don't know the answer? You probably haven't noticed all the bridges over railroads, rivers, creeks, and highways on the route. That's the job of bridges – to make travel smooth.

Human travel has greatly improved due to bridges. There was a time when to cross a river, people had to walk along its bank until they found a place where the water was low enough to cross without being swept away by the current. A steep embankment or small gorge had to be traveled around – unless you wanted to climb down it and back out on the other side.

Similar to this bridge, primitive log bridges were often logs that fell across a stream. Photo courtesy of MorgueFile.com.

The earliest bridges were primitive. Logs falling across a stream are considered the earliest type of bridge. Following that was the practice of stringing large vines across the two areas needing to be bridged. People climbed across on this primitive cable bridge.

Engineered arches originated in the Middle East approximately 4,000 B.C. They were also found a thousand years later in Egypt. But the Romans applied the arch for bridges and aqueducts around 800 B.C.

Though they constructed many kinds of bridges such as wooden and beam bridges, the Roman stone arch bridges withstood heavy use, the elements, and time to become the notable bridge of that era. Many of the stone arch bridges and aqueducts built by the Romans can still be seen in Europe.

With the fall of the Roman Empire, Europe experienced an economic and social breakdown. Governments were small, local bodies that could not support new development or even maintain existing structures very well. During the following five centuries – called the Dark Ages by historians – bridge engineering came to a halt.

However, other areas of the world continued to create new bridge forms during this time. There is written record – but no archeological findings of – a suspension bridge built in India in the seventh century. Not long after that, suspension bridges made of iron chain were built in China.

The simple clapper bridge led to the reemergence of bridge building in Europe, if not true bridge engineering. Though clapper bridges are considered by many to be a prehistoric style of bridge – the Tarr Steps in Somerset, England, for example, date back to 1,000 B.C. – most of the clapper bridges in Europe were built during the Middle Ages. These bridges feature large, flat slabs of stone placed across the top of stone piers. Clapper-style bridges were also built in China during the Middle Ages.

European bridges built with engineering principles in mind, however, did not really return until the construction of the Pont d'Avignon in France.

Tarr Steps, the clapper bridge over the River Barle, is said to be the oldest bridge in Europe. Photo courtesy of MorgueFile.com.

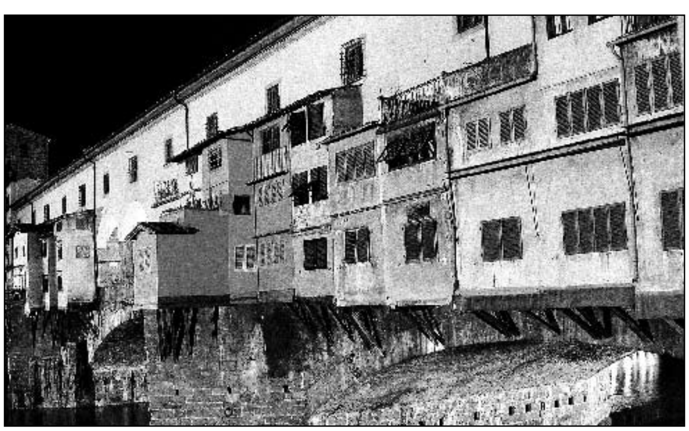
According to legend, the monk Benezet built the bridge, which featured more than 20 stone arches that together spanned nearly 3,000 feet. It was a remarkable bridge for 1187 A.D., the year it was completed, and four of the arches remain today.

The next notable bridge of the medieval period was the old London Bridge, which was a massive stone bridge that replaced an older wooden bridge. Built by yet another religious man, Peter Colechurch, London Bridge was completed in 1209 A.D. It featured 19 arches.

Though this bridge lasted more than 600 years (it was replaced in 1823), it needed frequent repair that makes clear the logic behind the nursery rhyme "London Bridge is Falling Down."

London Bridge was also an example of a popular development of the late Middle Ages: inhabited bridges. Not only did these large bridges serve as crossings over water, but also as building foundations. Homes and shops were built right on the bridges. The Ponte Vecchio in Florence, Italy, is another famous inhabited bridge. Built in 1333 A.D., it is still in use today.

During the next several centuries, stone arch bridges continued to be massive objects with heavy stone piers with a variety of arch shapes. However, these hefty bridges blocked 50 to 65 percent of the water flow.



Ponte Vecchio in Florence, Italy, was one of the many inhabited bridges built in the Middle Ages. Photo courtesy of MorgueFile.com.

Brothers of the Bridge

Even though Europe in the late Middle Ages had more organization and funding than during the Dark Ages, governments still had difficulty creating and maintaining bridges – or they simply didn't want to bother.

In response to this, some individuals or religious orders would take it upon themselves to build and maintain bridges (though it is more accurate to say they raised the funds to hire craftsmen to build and maintain the bridges) as well as to assist travelers.

One of these religious orders was called the Brothers of the Bridge. Some believe the monk Benezet, credited with building the Pont d'Avignon in France, founded this order. But even without the Brothers of the Bridge, Benezet inspired quite a lot of folklore. In some stories, he was divinely inspired to build the bridge and received divine assistance. Legend has it that Benezet was able to move a stone that 30 men could not and also thwarted the Devil, who was trying to kill him. Benezet eventually became a patron saint – of bridges, of course.

In the late 18th century, Frenchman Jean Perronet – sometimes called the father of modern bridge building – changed that.

Perronet, the director of the first college of engineering, was the first bridge builder to understand the structural importance of the arch. During the late 18th century, he designed bridges with flattened arches and slender piers that could still support considerable weight.

His last bridge, the Pont de la Concorde in Paris, France, was not only graceful but also blocked just 35 percent of the water flow with its piers.

The next big innovation in bridge engineering was the iron bridge.

The first built was a cast iron arch bridge at Coalbrookdale, England. Completed in 1779, it still stands today. As the Industrial Revolution progressed, many of these iron bridges were built.

Wooden bridges were also popular at this time. But the wooden truss bridge really took shape in the United States during the early 19th century, namely because the young country had the large timber needed as materials for these bridges. Truss designs use the structural strength inherent in triangles and later were made with iron.

But with the spread of railroads carrying heavy trains, the wooden and iron bridges did not always have the strength to support the weight. Additionally, many builders untrained in engineering were building bridges during the mid-to-late 1800s. The resulting large-scale bridge failure caused many deaths both in Europe and America.

From these failures came both the use of a stronger material – steel – and the acceptance of bridge building as a professional engineering endeavor. The remainder of the 19th century and early 20th ushered in an era when many impressive and landmark bridges were constructed.

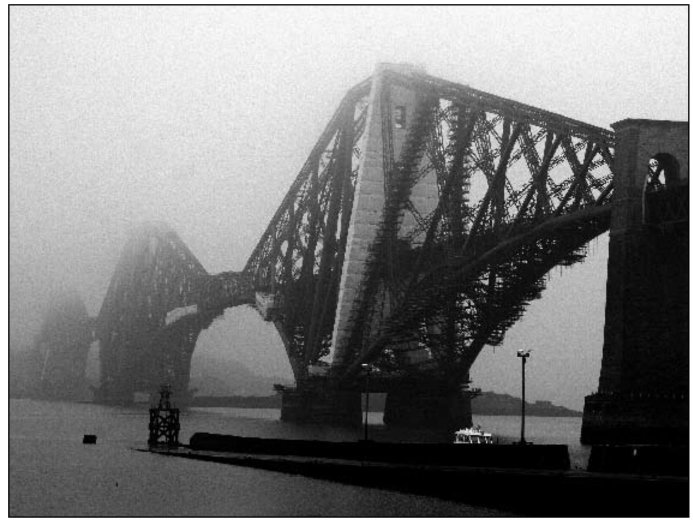
One of the first of these was the Eads Bridge in St. Louis. Designed and built by James B. Eads, the bridge was an innovative construction that was key to bridging the east and west sides of the country and to helping secure St. Louis' position of importance. Eads, who had built gunboats for the Union Army during the American Civil War, worked as a salvager of boats on the Mississippi River and knew the river better than most.

Based on his knowledge of the sandy riverbed and the river's extreme floods, Eads decided the bridge piers had to reach the bedrock – which required digging depths of up to 135 feet below water level. To achieve this, Eads was the first bridge builder to use pneumatic caissons. Working in the compressed air caused caisson disease, called "the bends," which killed 14 of his workers. The system Eads developed to make this work environment safe was a great influence on compressed-air safety laws created later.

Eads was also ground-breaking in his choice of bridge design and materials. He chose an arch bridge made of steel, which was manufactured to his strict specifications. At the time, the arches were longer and higher than any arches built before that time. Plus, the bridge was built using cantilever construction – built from the ends toward the middle to prevent blocking river traffic during construction.

Suspension bridges such as the Brooklyn Bridge and Golden Gate Bridge, cantilever bridges like the huge Firth of Forth in Scotland, and steel arch bridges such as the Sydney Harbor Bridge in Australia also exemplify the bridges built during this period.

The end of the 20th century witnessed the engineering envelope pushed even further with projects like the 17.5-mile Chesapeake Bay Bridge and Tunnel, which used several bridge types. Another example is the Akashi-Kaikyo Bridge in Japan, which currently holds the record as the world's longest suspension bridge.



The Firth of Forth bridge in Scotland was one of the early steel cantilever bridges. Photo courtesy of MorgueFile.com.

Some bridges are considered great even if they never really existed. The Ruck-a-Chucky Bridge – called the most famous bridge never built – was designed in the 1970s to cross over a proposed dam on the American River in California. The Ruck-a-Chucky's unique design called for a severely curved roadbed supported by cables anchored in nearby slopes. However, the vote to build the dam failed, so the bridge was never built.

With origins in accidental or hastily constructed bridges, the modern bridge is more than a practical construction. It inspires beauty, creativity, and ingenuity – and safely connects us to rest of our world.

Rope Bridges – From the Inca Empire to Ireland

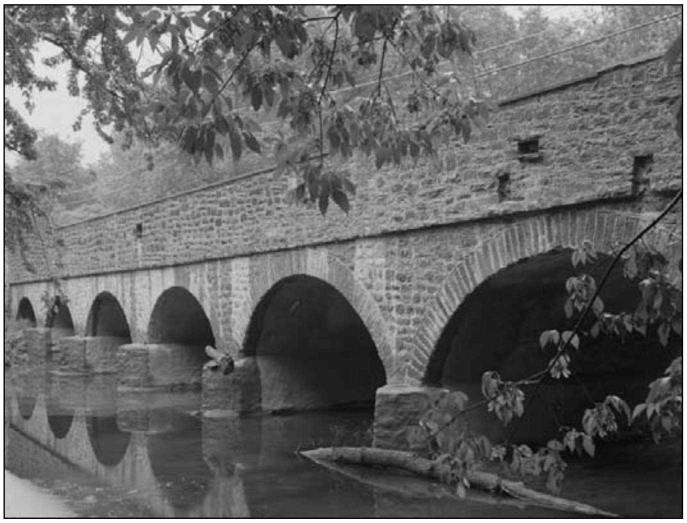
While medieval Europe was building big, heavy stone bridges, the Inca Empire was busy constructing relatively light and slender rope bridges over gorges and canyons. These bridges, the ancestor of the suspension bridge, connected the Inca road system. Because the Inca Empire made a 2,500-mile swath down the western edge of South America, this transportation system was vital in running the vast empire.

These rope bridges – some up to 150 feet long – were made of native grasses or other fibers woven into long cables. Because the cables eroded over time, villagers replaced the cables each year.

Villagers in Huinchiri, Peru, still rebuild the rope bridge near their community every year. Despite having a modern bridge nearby, they continue this custom to honor their ancestors. This yearly event was featured in NOVA's production, Secrets of Lost Empires: Inca.

The Carrick-a-Rede bridge in Ireland is a descendant of the Inca rope bridges. Photo courtesy of The Library of Congress.

Rope bridges were later built in Europe and Asia, including the famous Carrick-a-Rede bridge in Ireland originally used by fishermen. Now, the bridge is a tourist attraction.



A stone arch bridge spanning the Skippack Creek at Germantown Pike, Skippack, Pennsylvania. Photo courtesy of The Library of Congress.

Modern Bridge Designs

The stone arch bridge design is among the strongest and most durable. Stone is a naturally strong and enduring material for a bridge. In stone arch bridges, the stones are in compression (pressing against each other). The cost for labor and transporting stones for these types of bridges is great.

Steel arch bridges are also capable of covering great spans and bearing heavy loads. The Bayonne Bridge in New Jersey, which is 5,780 feet long, is one such bridge. Its cables are suspended from the arch to the roadbed. This bridge is a combination of the arch, truss, and suspension bridge designs. In this case, the steel arch is under compression and the cables holding up the roadbed are in tension.

The suspension bridge design is beautiful and very functional. It is capable of covering longer spans than any other type of bridge and is extremely efficient in terms of materials. The Golden Gate Bridge in San Francisco, California, is a suspension bridge that spans 4,200 feet.

The Bayonne Bridge in New Jersey is a steel arch bridge, though it also incorporates elements of truss and suspension bridges. Photo courtesy of The Library of Congress.

Suspension bridges are supported by steel cables under tension, which hold up the roadbed. These steel cables are made of individual strands capable of supporting thousands of pounds.

The Golden Gate Bridge in San Francisco. Photo courtesy of The Library of Congress.

The George Washington Bridge in New York City – spanning 3,500 feet – uses four such cables. Each is three feet in diameter, one mile long, and includes more than 26,000 strands. Each cable can support nearly 80,000 tons. The individual strands amount to a total of 107,000 miles – enough to circle Earth four times. Each

A wooden truss bridge over a frozen river in Wyoming. Photo courtesy of the Library of Congress.

A steel truss bridge. Photo courtesy of MorgueFile.com.

This photo of the MacArthur Bridge , built over the Mississippi River between Iowa and Illinois, demonstrates how the ends of a cantilever bridge are built first. Then, the middle is placed between. Photo courtesy of the Library of Congress.

tower supporting the cables consists of 20,000 tons of steel and more than one million rivets!

Where the abundance of wood exists, a simple truss bridge serves well. Wooden bridges are easy to build yet are capable of carrying heavy loads. The truss design is much more rigid and stronger than simple designs where boards are laid across the river.

The model bridge built by following the instructions in this book is a simple truss bridge.

Steel truss bridges are not as capable of great spans as other bridge designs. However, they are quickly assembled, or even prefabricated, and support great loads. This type of bridge is used extensively for railroad bridges. Trusses distribute the load to a large number of steel beams.

They may not look like it at first appearance, but cantilever bridges are a type of truss bridge. However, they are built toward the center of the river from each bank. The bridge is then joined with a section in the middle.

The Quebec Bridge, which crosses the St. Lawrence River in Canada, is one of the world's longest cantilever bridges, spanning 1,800 feet. It was completed in 1917 and still is in use today.

One of the most challenging steps in building a cantilever bridge is setting the center section in place. The center section of the Carquinez Strait Bridge in California – a 700-ton, 150-foot-span bridge – was floated out under the bridge. Then, it was lifted into place with counterweights. Counterweights are weights applied to offset the weight of the object being lifted.

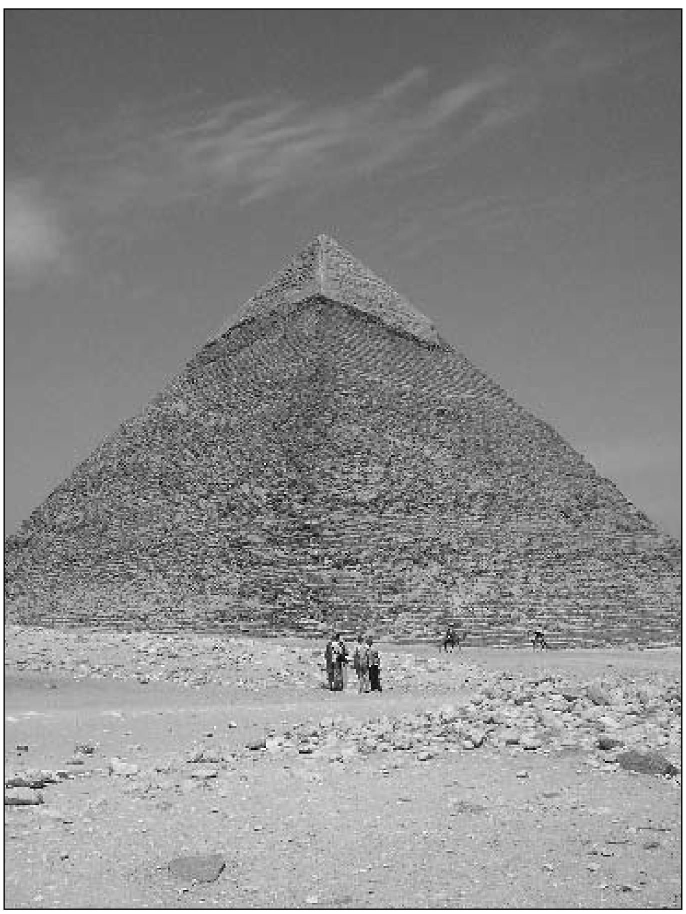
Bridge and mechanical engineers have studied and tested various truss designs for many years. Engineers use combinations and variations of truss types in their work. The most frequently used truss types are shown on this page (Figure 1).

Engineering is an exciting and dynamic profession, and there are many types of engineers in the field. Normally, bridges are engineered by mechanical design engineers or civil engineers.

Engineering as a profession goes back to roughly 3,000 B.C. Today, the profession uses sophisticated computer systems and materials.

Early engineers built irrigation systems covering thousands of miles. Today's civil engineers design multilevel automobile interchanges, complex airport runway structures across highways, and many other technologically sophisticated systems.

Civil engineering is a branch of engineering relating to the building of municipal systems, such as roads, bridges, dams, communication towers, and other systems to help society accomplish a safe and manageable environment.



Professional engineering dates back to the pyramids of ancient Egypt. Photo courtesy of MorgueFile.com.

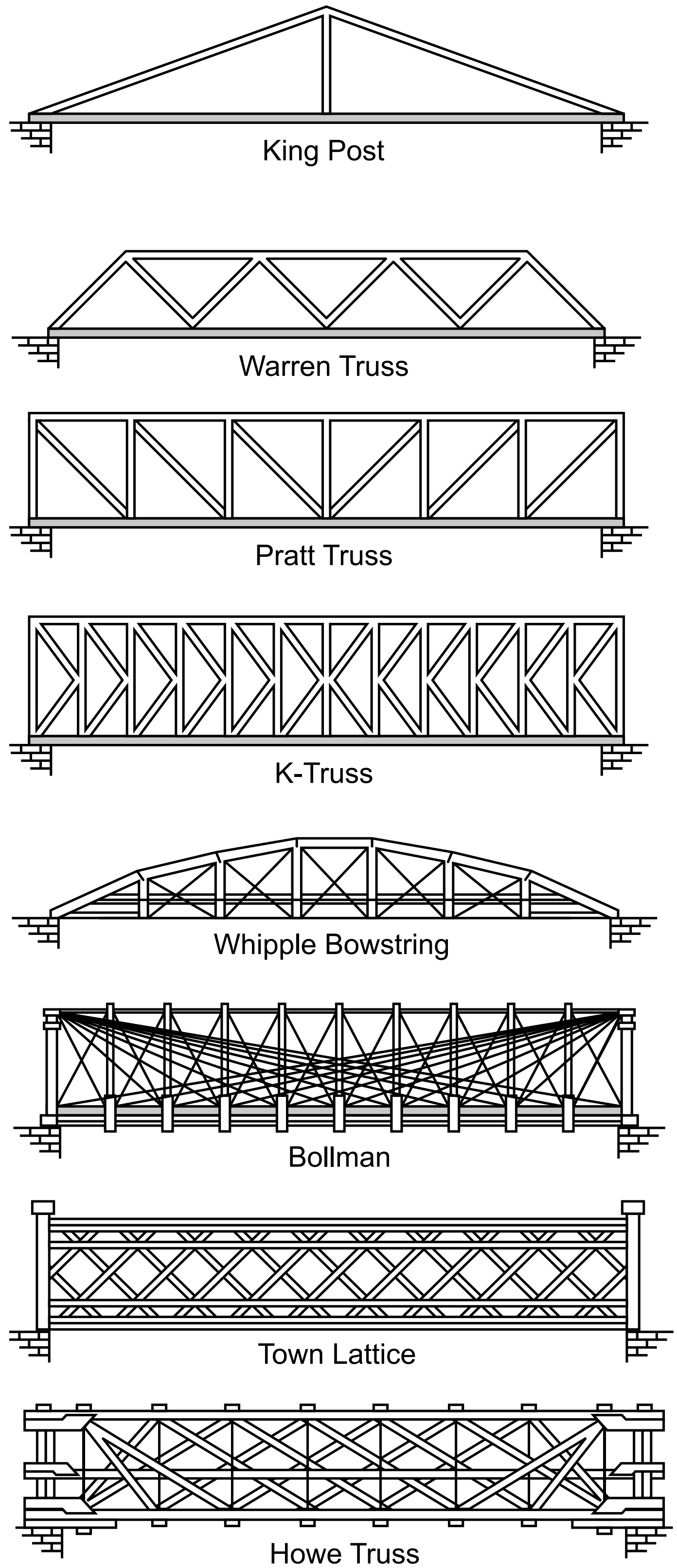


Figure 1

Civil engineering is a rewarding profession with opportunities for many exciting experiences.

A civil engineers must have a number of skills, most of which are gained through a college education. They must also have a considerable knowledge of math, science, and technology. The following are classes civil engineers would take in college.

• **Drafting** – Teaches skills and knowledge needed to visually communicate ideas on paper or computer using accepted engineering standards and terms.

• **Surveying** – Instructs how to accurately gather information about Earth's surface and graphically display the various levels of the land on a drawing.

• **Soil Science** – Provides experiences in testing various types of soils to determine their characteristics. For example, bridges, dams, roads, and buildings must have firm foundations to withstand the weight placed on them. Sandy or muddy soils require deep foundations while other soil types require a lesser foundation. Bridge designers must take these factors into account during the overall design of a bridge.

• **Mathematics** – Teaches essential skills for engineers such as calculating stresses on a structure or analyzing the material requirements of each member.

• **Materials and Processes** – Provides an understanding of the strength and other characteristics of metals, woods, plastics, and various materials used in construction.

• **Transportation** – Creates an awareness of all laws relating to standard specifications of transportation and the construction of roadways, bridges, and other highway systems.

• **Environmental Issues** – Examines how the environment affects construction and provides the information necessary to protect people and the environment.

• **Physics** – Explores physical principles and mathematical equations that are key to designing sound structures.

Civil engineers work with many challenging projects such as this highway interchange in Greenwich, Connecticut. Photo courtesy of The Library of Congress.

Bridges must be built to withstand the environment as well as traffic. This bridge over Tacoma Bay in Washington State (shown completed above) was destroyed by a 42 mph wind (below). Examples like this illustrate the importance of good engineering. Photos courtesy of The Library of Congress.

Chapter 3 – Bridge Design

Factors in Bridge Design

A number of factors must be taken into account when an engineer is designing a bridge. Earlier, several bridge designs were described. In addition to these, an engineer must consider the following when designing a bridge:

• What is the span of the bridge? Span means the length of the bridge from one side (bank) of the river to the other.

• What will be the load on the bridge? Load means how much weight will be on the bridge.

• What type of load will the bridge have? Engineers consider two types of load: live load, which is the weight of the vehicles and people expected on the bridge, and dead load, which is weight of the bridge itself.

• What environmental factors will affect the bridge? For example, will the bridge need to withstand strong winds, ice, snow, extreme cold, or heat?

• What is the budget allowance for the bridge?

• What are the soil characteristics of the banks?

• What are the soil characteristics of the bottom of the river if support columns are required in the bridge design?

• What is the time frame in which the bridge must be built?

After considering these and other factors, including the aesthetics (attractiveness) of the bridge, the engineer is ready to begin the design.

Considerations in Bridge Design

The number of design possibilities for a bridge is almost limitless. However, certain facts about the design of a bridge are necessary for the engineer to design a strong, durable bridge. Terms for bridges are shown below (Figure 2). Some of these basic facts and terms are described and discussed as follows.

The terms load, compression, and tension are the words commonly used in the design of a bridge. When the load is placed in the middle of a beam, it presses on top of the bridge, creating compression. The bottom of the bridge tries to pull apart, creating what engineers refer to as tension (Figure 3).

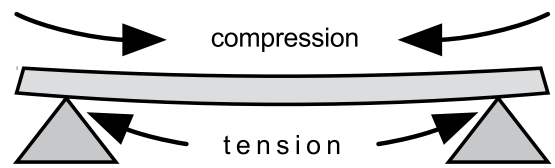


Figure 3

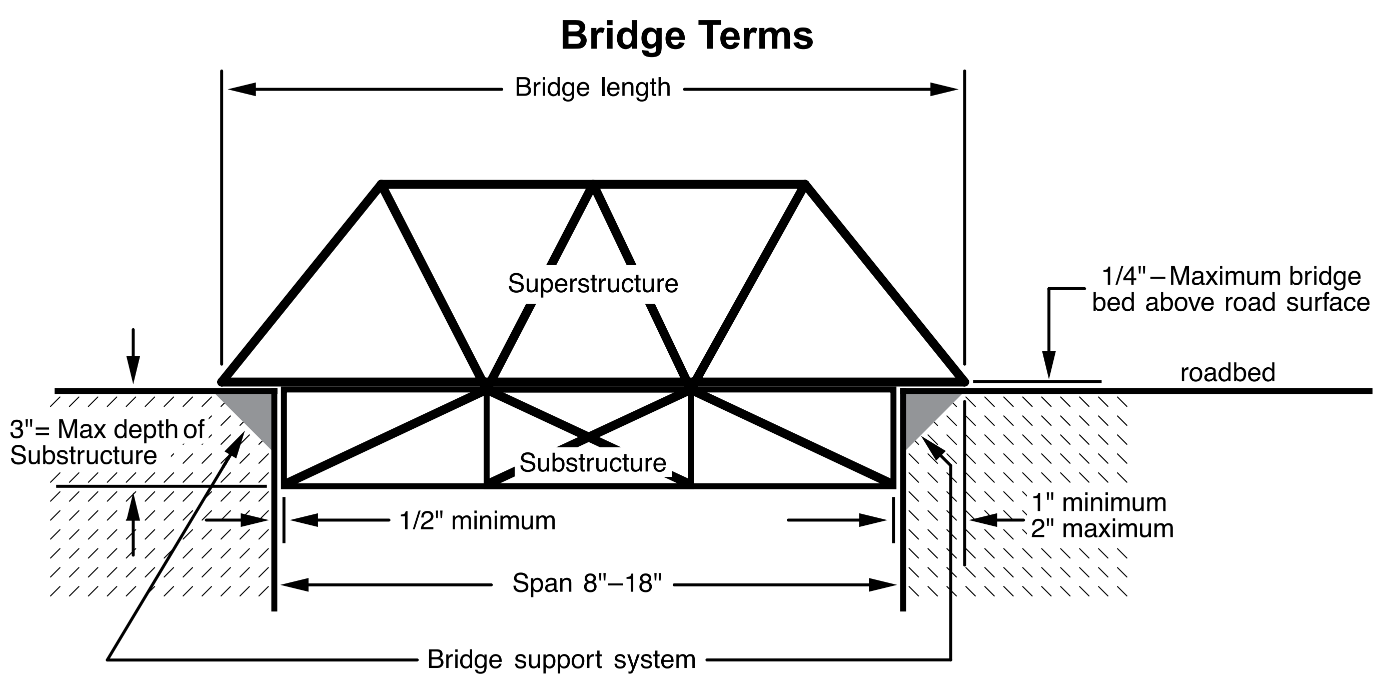


Figure 2 – The truss structure above the roadway of a bridge is called the superstructure. The substructure is the portion of the bridge below the roadway of the truss bridge. To further strengthen the design of a bridge, an engineer might choose to add a substructure. This and other terms shown above are used in bridge design competitions such as the one sponsored by the Technology Student Association, Science Olympiad, and others.

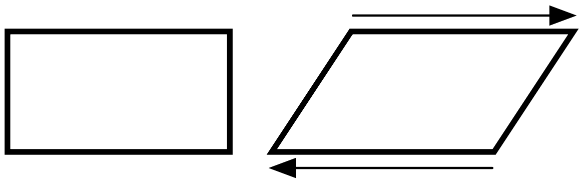


Figure 4 – The effect of racking

Racking is a kind of stress that distorts a square or rectangle, which causes it to become a parallelogram (Figure 4).

To strengthen a square or rectangle, a diagonal brace converts the rectangle into two triangles, making the figure much stronger (Figure 5). The brace serves to keep the length of the diagonal constant. This action minimizes the racking effect. When designing bridges, engineers often convert figures into triangles since triangles are the strongest possible figure.

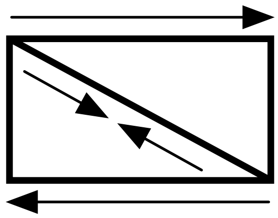


Figure 5 – A diagonal brace stiffens a rectangle.

The bridge shown in Figure 6 is a variation of a simple beam with triangular bracing used in the truss design. A truss distributes the load across several parts, or members, of the bridge. If each member helps support the load, then the load is not concentrated on one member, which could fail under that much stress.

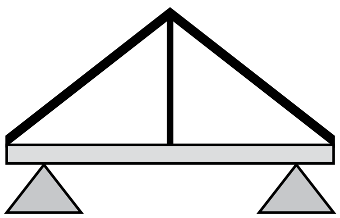


Figure 6 – A simple truss bridge (King Post type)

The King Post type of truss in Figure 7 transmits the load to all of the members so the roadway (beam) does not take all of the compression and tension. Additional vertical members further distribute the load.

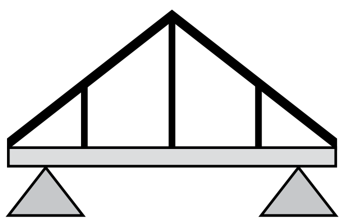


Figure 7 – Adding members to a King Post truss strengthens it even more.

Since a triangle is much stronger than a four-sided figure, designing the truss as shown in Figure 8 would further strengthen the bridge.

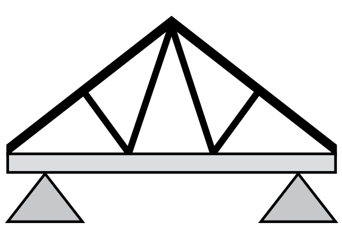


Figure 8 – The triangular position of the trusses increases both strength and stiffness. This type of truss is frequently used for building roofs.

The truss structure above the roadway of a bridge is called the superstructure. The substructure is that portion of the bridge below the roadway of the truss bridge. To further strengthen the design of a bridge, an engineer can add a substructure.

Refer to Figure 9 on the following page for these and other terms used in the bridge design competition sponsored by the Technology Student Association.

Designing Your Model Truss Bridge

To effectively and successfully design your own truss bridge, several of the basic methods used by engineers will be followed. Upon completion of the design, you will build a model of the truss bridge. The actual model will allow for testing of the design to determine its soundness or efficiency.

Determine the efficiency of your model by the load (in grams) that your bridge holds. This will give you a failure mass. This failure mass can be divided by the mass of your bridge in grams. The formula looks like this:

Efficiency = Failure Mass (g)/Mass of Structure (g)

Note: If your load is measured in pounds, multiply the number of pounds by 454 grams to find the failure mass in grams.

Design Steps

The steps to be followed in designing, building, and testing your model truss bridge are:

Step 1: Complete truss design and sketch ideas.
Step 2: Complete a three-view sketch (top, side, and end) of the bridge you plan to build.
Step 2b: Drafting (optional)
Step 3: Build the model truss bridge you designed.
Step 4: Test the model truss bridge you designed.

Note About the Steps: Now that the four steps have been outlined, each will be explained in detail throughout the rest of the book.

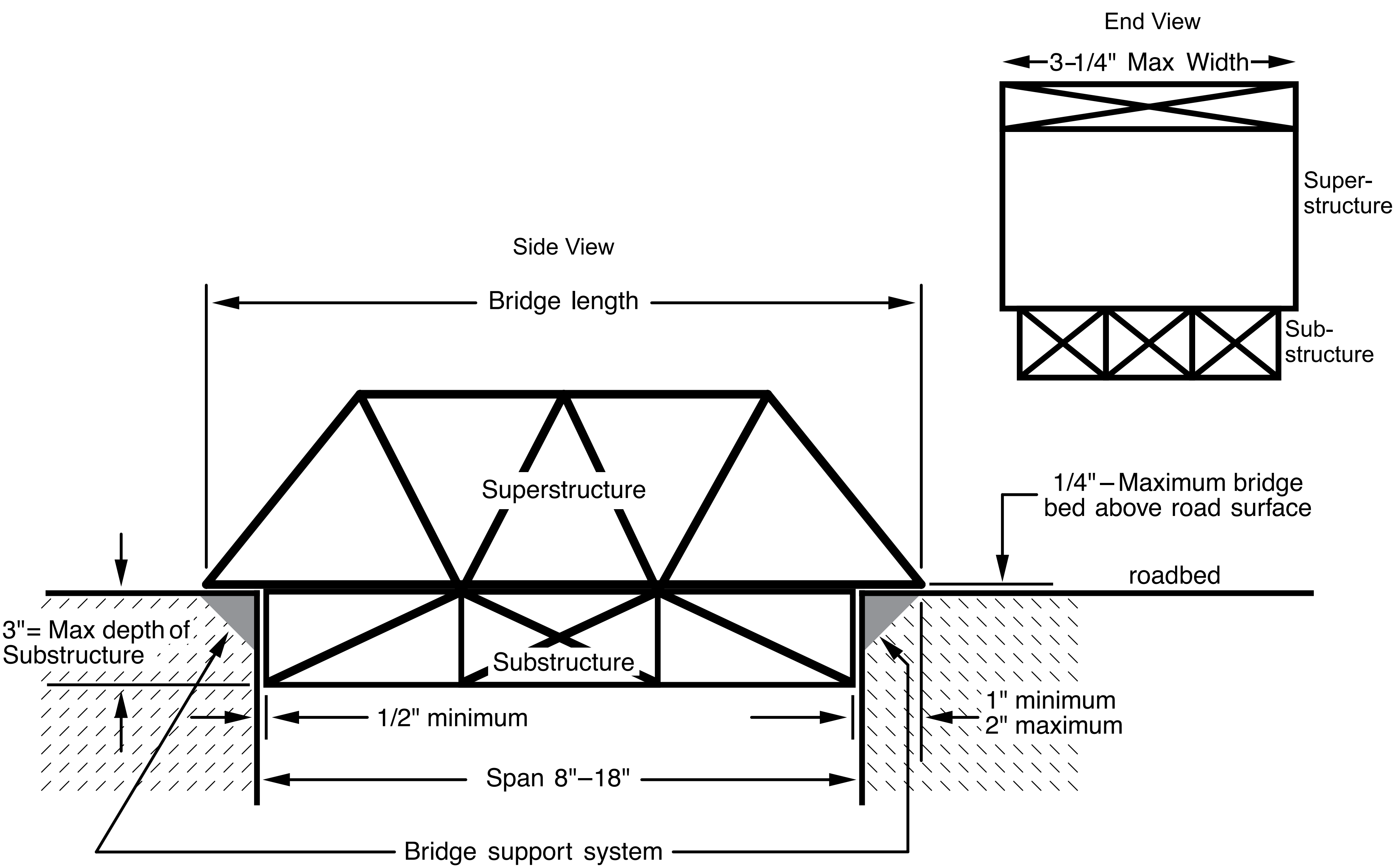


Figure 9 – Typical Model Bridge Terms and General Specifications

Note: This sheet may be reproduced and used as a transparency master.

Step 1: Making Design Sketches

Design sketches help the engineer to develop different ideas. Review the two truss design ideas provided in Figure 10. In the remaining spaces, sketch trusses with superstructures and some with both superstructures and substructures.

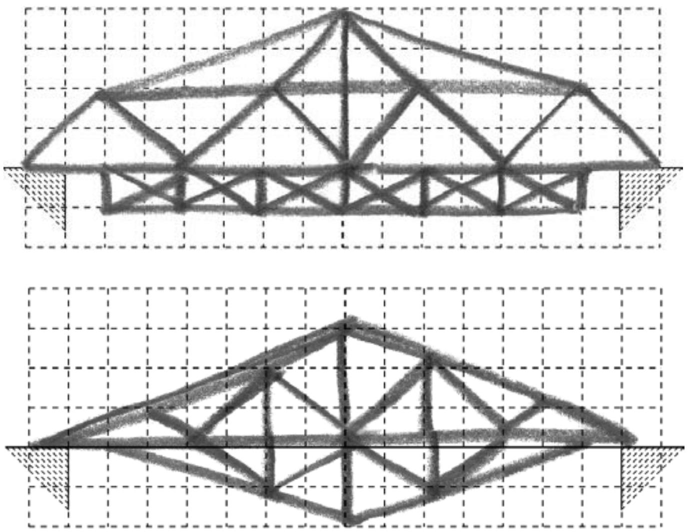
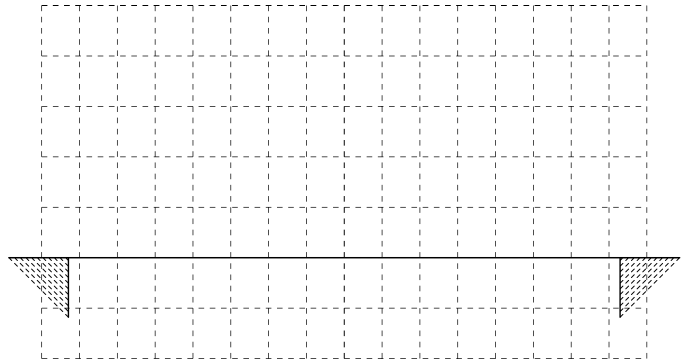
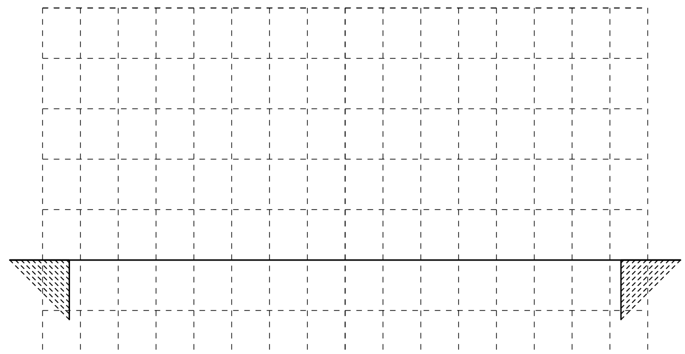
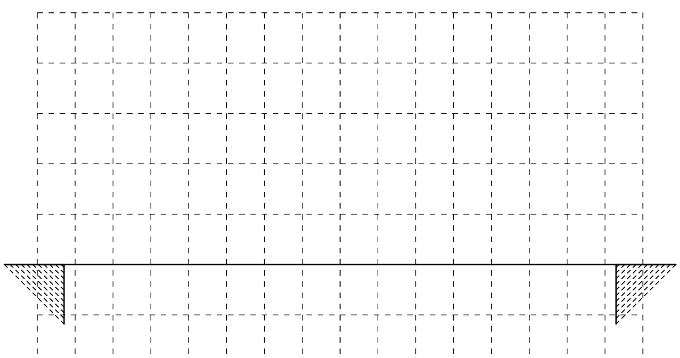
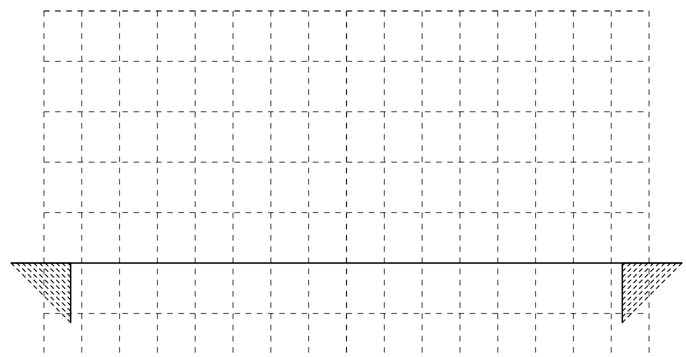


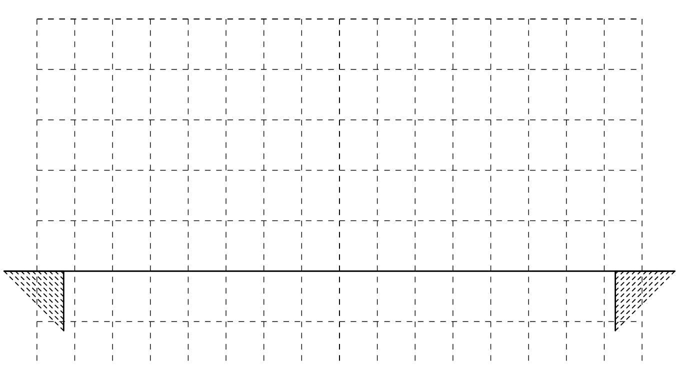
Figure 10 – Hand-drawn sketches of bridge designs on grid paper

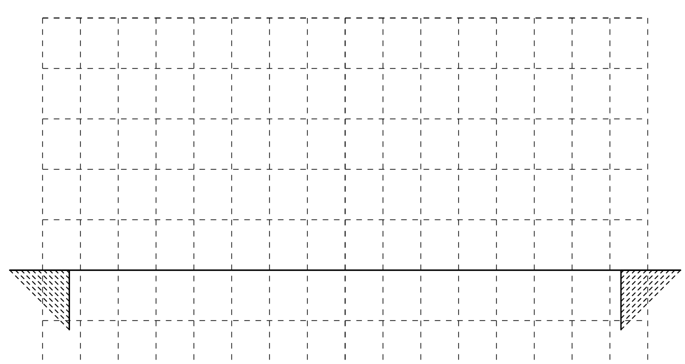












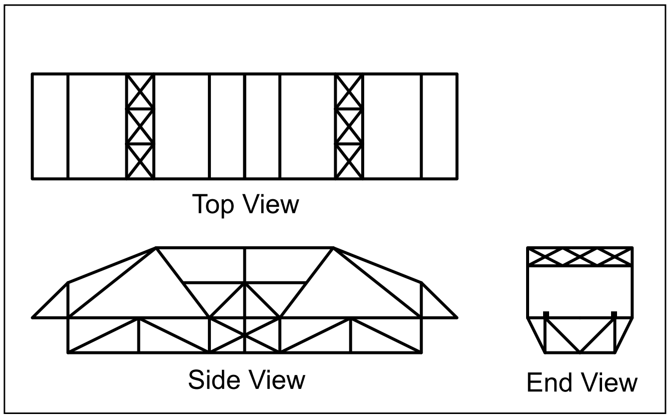


Figure 11 – An example of a completed three-view sketch

Step 2: Completing a Three-View Sketch

Complete the top, side, and end view sketches of a model bridge you plan to build. The placement of the views is noted in the grid paper provided (Figure 15). Draw the views to full scale. If the bridge is to be made of balsa wood, each member will be 1/8 inch wide. If it is to be constructed of basswood, each strip will be 3/32 inch wide.

If building this bridge for a competition other than a classroom contest, be sure to follow the rules for the bridge competition in which you are competing. Links to the various competitions and organizations can be found in the resources section of this book.

Ask the instructor to provide the exact span for the bridge before beginning your three-view drawing. The span should be the same for all model bridges built in the class if the models will be competing against each other.

The roadway surface inside the bridge must be open to allow a block of wood that is one inch thick and two inches wide to pass through the entire length of the roadway surface (roadway size may vary among different competitions) (Figure 12). The block will be used during the testing of the bridge.

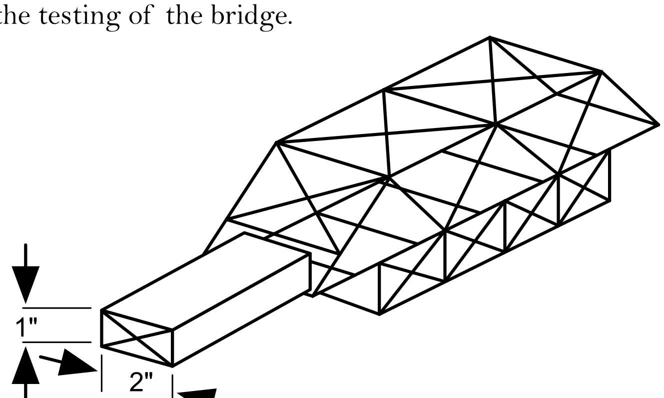


Figure 12 – Diagram showing placement of the test block into the bridge roadway

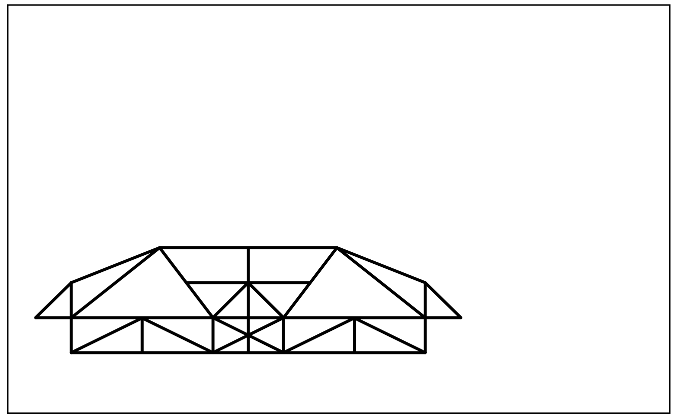


Figure 13 – Side view of the bridge drawn in bottom-left corner of grid sheet

1. On the large grid sheet provided, sketch the side view of the bridge to full scale. The side view is the one you would see if you were in a boat in the river and the bridge was in front of you (Figure 13).

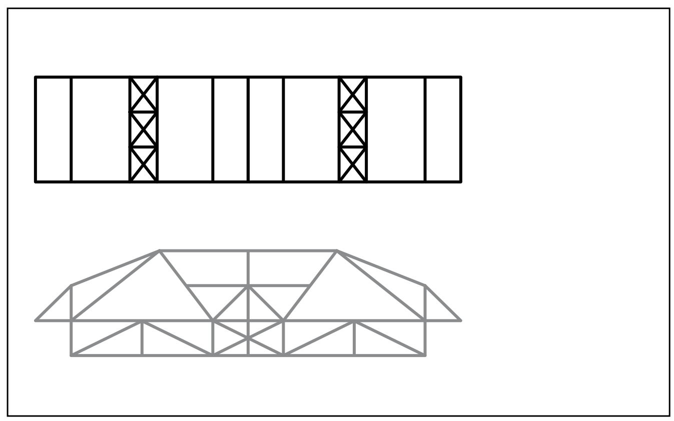


Figure 14 – Same view as Figure 13 but with the top view added directly above the side view.

2. Next, draw the top view to full scale (Figure 14). Align it directly above the side view. The top view is the view you would see if you were in an airplane looking down at the top of the bridge.

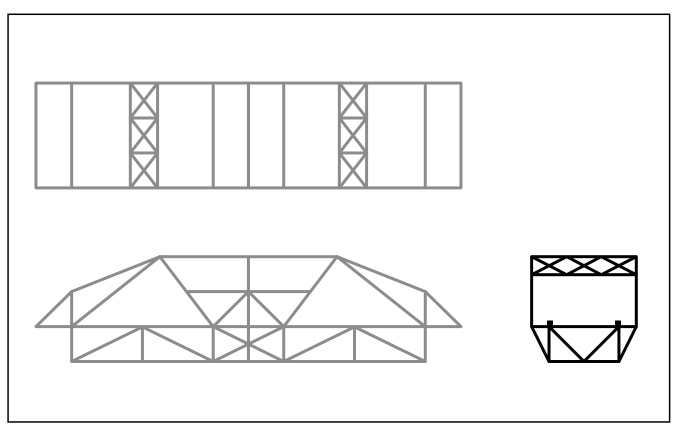


Figure 15 – Same as Figure 14 but with the end view added to the right of the side view

3. Now, draw the end view (Figure 15 on the previous page). This is the view you would see if you were in a car approaching the bridge.

4. Use a ruler or scale to measure the length of the 1/8-inch material the model will require. Remember to include two sides, one top, one bottom, and the substructure (if used) when computing the total amount of material necessary.

Step 2B: Drafting (optional)

Upon completing the three-view sketch, your teacher might ask you to complete a drawing of your bridge. When drawing the bridge, use the following tools and symbols.

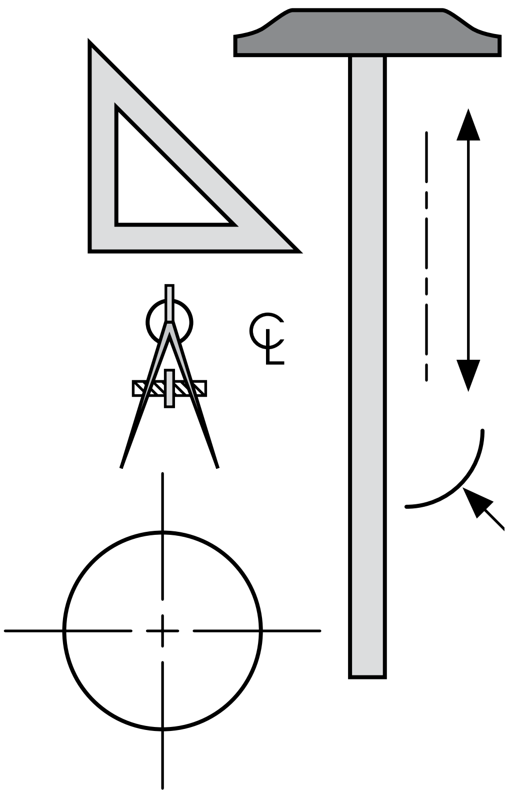


Figure 16 – Drafting tools and symbols. Clockwise from top left: a triangle, T square, centerline, dimension arrows, angle center mark, compass, and centerline symbol (center).

Drawing technical information using international standards and symbols is called drafting. A drawing of the bridge you designed and sketched is called a civil engineering drawing or it may be referred to as a mechanical drawing.

Figure 17 (on the next page) shows a bridge in three views and includes typical engineering standards of description and dimensioning.

Computer-Aided Drafting

Drafting today includes the use of computers and advanced programs. Computer-aided drafting, called CAD, is commonplace in engineering offices and schools around the globe. These software programs provide design assistance, accuracy, immediate scalability, and the opportunity to make design changes rapidly. They also automate this dimensioning processes.

Drawings are instantly displayed on the computer screen (Figure 18). They can also be output to high-speed plotters – providing a hard copy of the drawing.

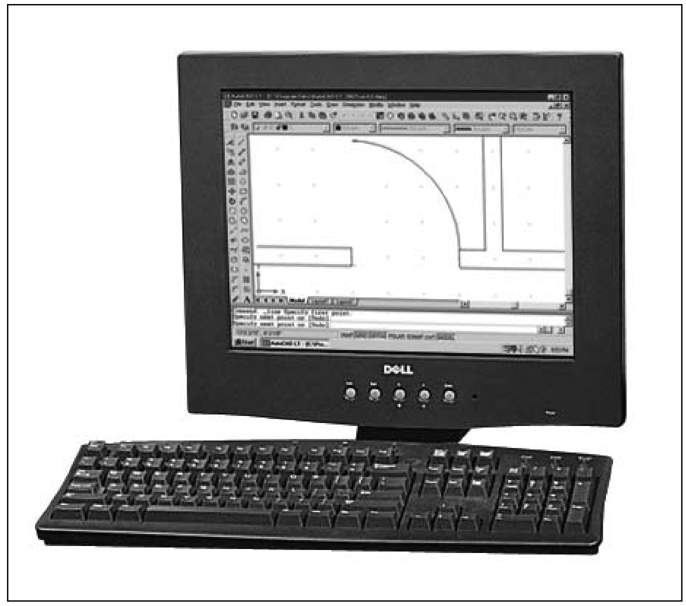
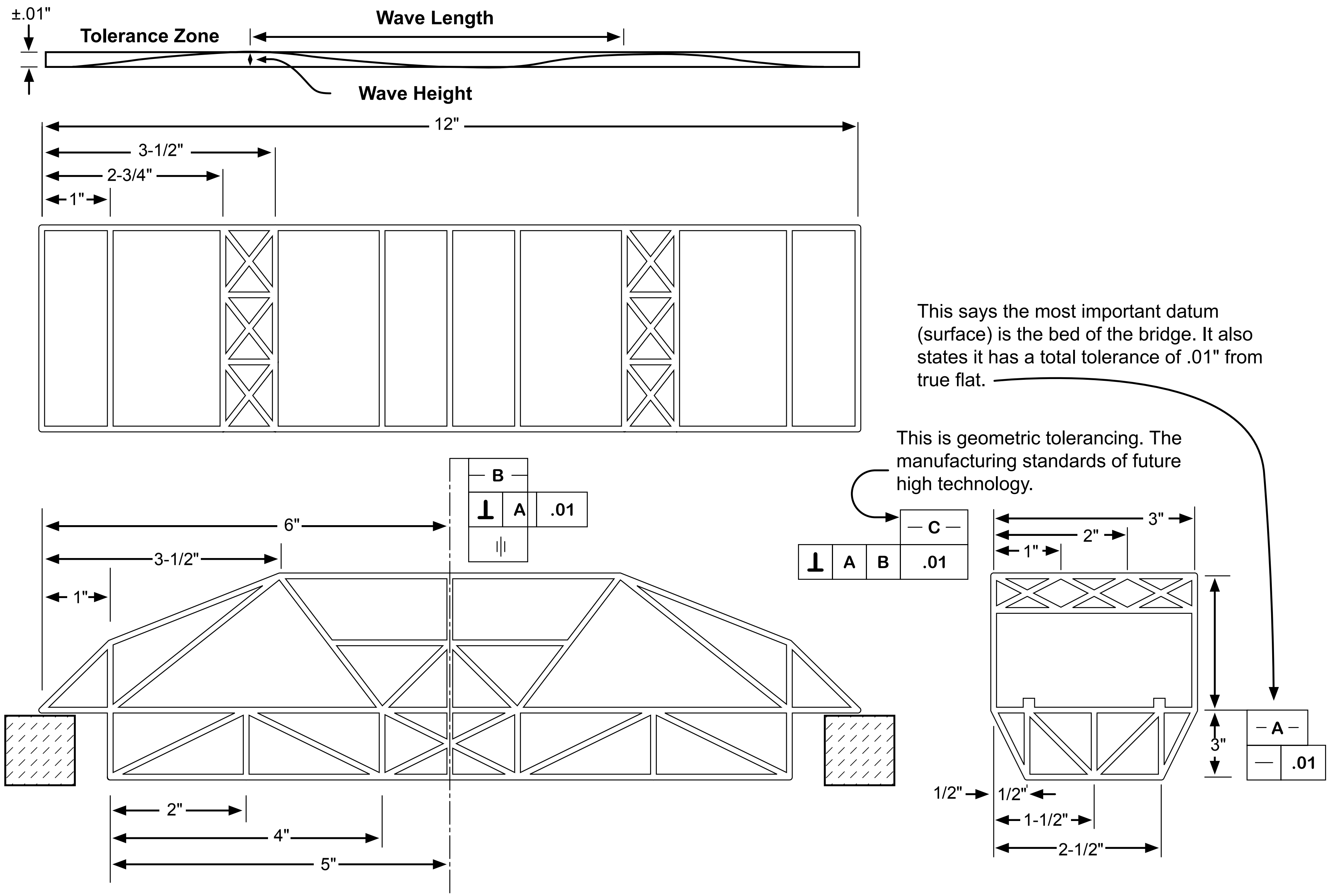


Figure 18 – Computer-aided drafting (CAD)



Designed by:	Scale:	Date:
Class:	Wood used:	Inspected by:

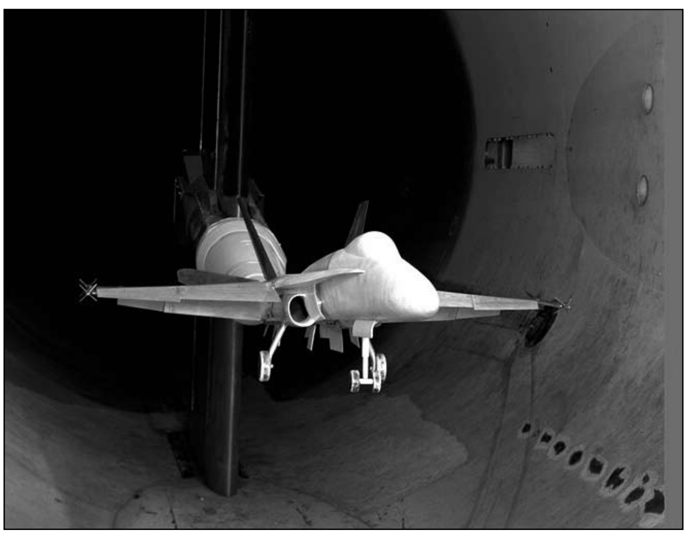
Figure 17

Chapter 4 – Building Your Model Truss Bridge

The Purpose of Models

Models are used by all kind of engineers to provide a three-dimensional example of how a final building, bridge, or structure will look. Models also allow the engineer to try different solutions for problems prior to building the structure. A scale model of a bridge may cost an engineer several thousand dollars. However, the cost of the model will be far less than the cost of that project. The engineer must take every precaution to ensure the design meets all requirements of the client and building codes.

The Wright brothers used model wing sections in a wind tunnel to gain a better understanding of flight. Models used for designing modern aircraft and automobiles are placed in wind tunnels with wind speeds ranging from a small breeze to hundreds of miles per hour. Models of spacecraft are made and carefully tested prior to actual construction.



This F-18 model is being tested in a 12-foot wind tunnel. Photo courtesy of NASA Ames Research Center.

Today's computer programs are also capable of generating a model on-screen to test various aspects of plane and bridge design, not to mention other products.

Architects use models to experiment with wind forces on structures. Models also help architects see how the appearance of the building will blend with the area in which it will be built.

Models have played an important part in the history of movies as well. From the original 1933 version of *King Kong* to movies made in recent years, models make the impossible possible in movies. In the early years of cinema, the models looked more like small toys. Over time, those small physical models were used along with robotic models and computer models to create more updated effects (the *Star Wars* and *Jurassic Park* movies are good examples).

Now, computer modeling has largely taken over in creating fantasy rides such as the *Pirates of the Caribbean* movies and even updated version of *King Kong*.

Models – whether six inches tall and made by hand or completely computer generated – enable simulations of spacecraft, creatures, or entire planets that exist only in the mind of the creator.

Model Construction Methods

When making a wooden model of a bridge, joints are often the most critical aspects of making the model as strong as possible. Once a joint fails, the structural integrity of the entire bridge is weakened. This weakening starts a chain reaction that can cause the total failure of the structure.

Using the appropriate glue is another vital element in building a strong bridge. A good aliphatic-type wood glue is recommended, such as Pitsco Colored Structures Glue. Its color enables quick identification of joints and the amount of glue used, which can be important in various competitions. Pitsco HD Bond Adhesive also works well.

While building, consider that glue does not work well on the end grain of wood. You will make a stronger bridge if the joints are made with the side grain of the wood.

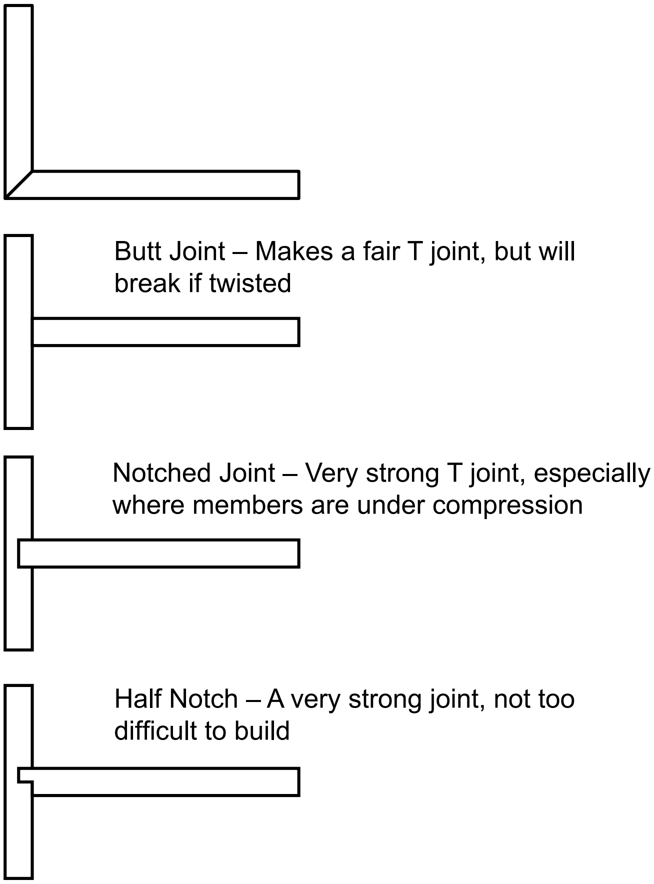


Figure 19 – Joint types

You can increase wood joint strength by utilizing various joint types (Figure 19). A butt joint is easily broken, but a joint like the notched joint can endure more stress. In addition to using better types of joints, making tight-fitting joints also enhances the joint strength. Contrary to what you might think, adding extra glue around a loose joint will do little to strengthen it.

Braced joints, although difficult to make, provide the combined effect of the notched and half-notched joints (Figure 20). This provides an extremely strong joint.

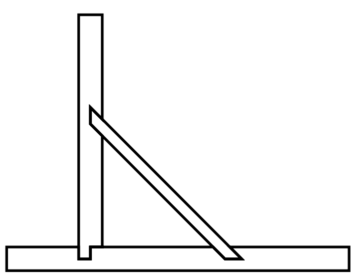


Figure 20 – Braced joint

A final suggestion before gluing joints is to scrape the the wood where the joints will be glued, using a hobby knife. The natural oils from your hands touching the wood prevents the best possible bond to the glue. Scraping the joint surfaces helps remove dust and oil.

The following drawings describe construction tips that should assist you in building your model bridge. Review each tip carefully.

Set a diagonal brace between two parallel pieces. This technique helps prevent racking.

1. Lay the diagonal piece across and mark with a knife (Figure 21).
2. Mark on both ends where the piece lies across the parallel pieces (Figure 22). Cut the marks.
3. Cut off the tips of the pieces so they fit into the corners (Figure 23).
4. Glue the piece in place (Figure 24).

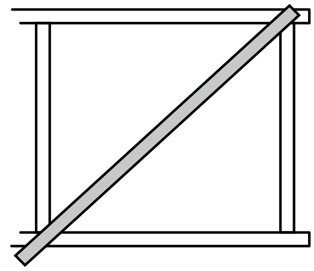


Figure 21

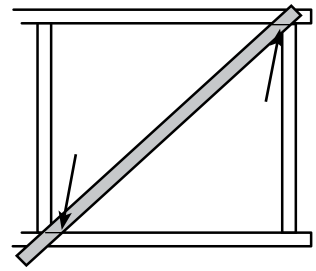


Figure 22

If you have trouble fitting a piece in a tight spot, try picking it up with a pair of tweezers instead of your fingers.

Use as many pins as needed to hold the wooden pieces in place.

Cross two pins over a strip of wood to hold it in place (Figure 26 on the next page).

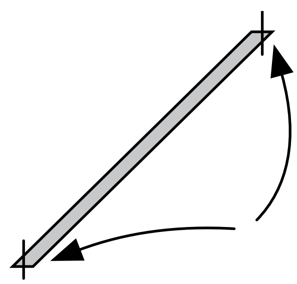


Figure 23

Use foam board as a working base. It is stiff and holds the pins better than cardboard.

A sharp knife gives cleaner, faster cuts than a saw. Cut on a protected surface and away from yourself. Alternatively, use the Pitsco Timber Cutter to cut the wood pieces.

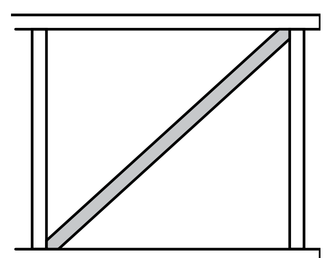


Figure 24

The Pitsco Lil' Termite Sander can also be used to accurately sand the wood members to a tight fit (Figure 25).

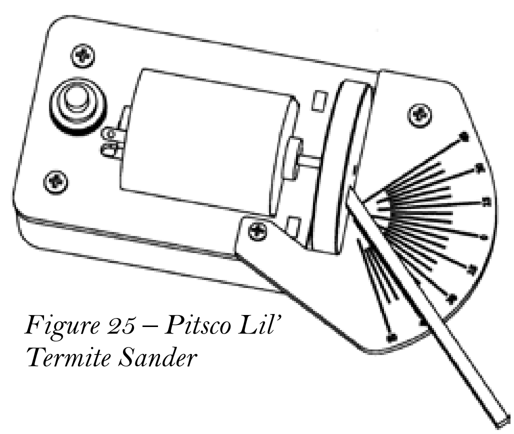


Figure 25 – Pitsco Lil' Termite Sander

Step 3: Constructing the Bridge

Check that the following materials and supplies are available:

- Balsa wood or basswood strips
- Hobby knife or Pitsco Timber Cutter
- Structure-Building Pins or T-pins
- Three-view sketch or drawing (full scale)
- Waxed paper (12" x 18")
- Masking tape
- Pitsco Colored Structures Glue or HD Bond Adhesive
- Ruler or scale
- Foam board (minimum 12" x 18")
- Square
- Tweezer set (optional)
- Pitsco Construction Caddy II (optional)
- Pitsco Accu-Fixtures Set (optional)
- Pitsco Timber Tester (optional)
- Pitsco Lil' Termite Sander (optional)
- Small clamping devices such as Bridge Construction Clips or clothespins (optional)

1. Using masking tape, attach your full-scale, three-view sketch or drawing to a piece of foam board.

2. Cover the three-view drawing with the waxed paper, and tape it in place. If a Pitsco Construction Caddy II is available, slide the foam board into the slotted ends of the caddy.

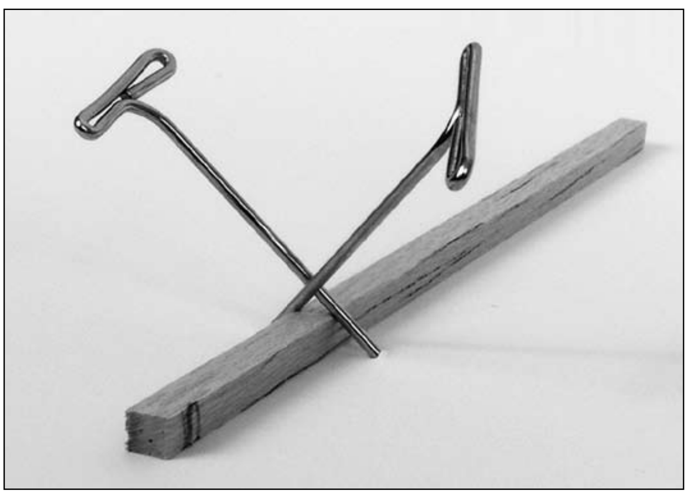


Figure 26 – Cross two pins over the piece of wood to hold it in place.

3. Cut strips of wood to fit the outline of the bridge, which the three-view sketch provides. Use the hobby knife or the Pitsco Timber Cutter to cut the wood. To ensure a nice fit, cut the pieces a little long on the first cut and trim the end to fit. If a Pitsco Lil' Termite Sander is available, use it to sand the ends to fit. Pin each piece into place (Figure 26).

4. Glue the pieces in place. Surfaces where strips connect should be coated with a thin film of glue. Use pins to hold the pieces flat (Figure 27).

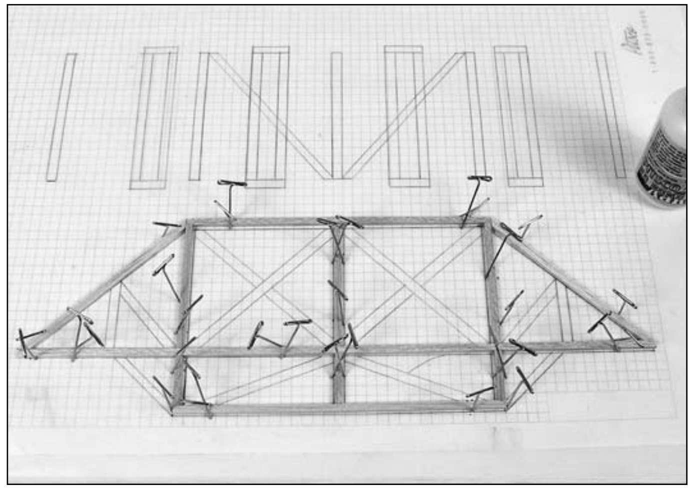


Figure 27 – Building the outline of the bridge side

5. After the outline has been glued into place, fill in the wood strips that make up the other members of the first side of the bridge. Make sure the joints are completely dry before moving the pins.

6. After the first side has dried, remove the pins and carefully lift the side off the waxed paper. Place the finished side on a flat surface.

7. Repeat Steps 1-6 to build the second side.

8. Cut and construct the cross braces that support the roadway of the bridge (Figure 28). Build each of

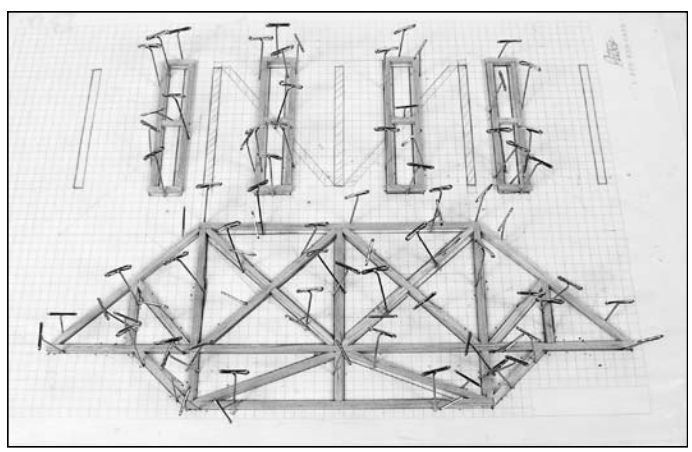


Figure 28 – Side of the bridge and roadway braces completed

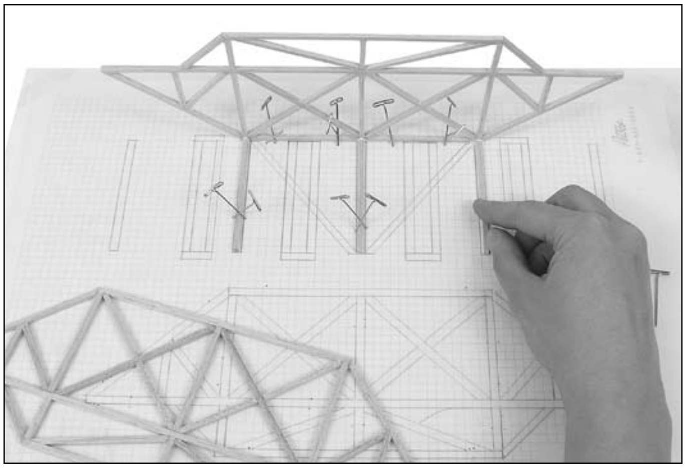


Figure 29 – Cross sections to go between the bridge halves

them exactly the same length.

9. Cut the cross braces that support the top of the bridge. Make each of them exactly the same length.

Important Note: These instructions show the top braces attached first. Depending on your design, it might be best to attach the roadway cross braces first. Before starting Step 10, review your design and start with whichever set of braces will best stabilize the structure.

10. Pin one side of the bridge so it is perpendicular to the foam board – note the top is facedown. Glue the top braces to the side (Figure 29). Use a square to ensure the side is perpendicular to the cross brace members.

11. Add glue to the other end of the braces and pin up the other side parallel to the first side. Make sure all the pieces fit together squarely and are not loose (Figure

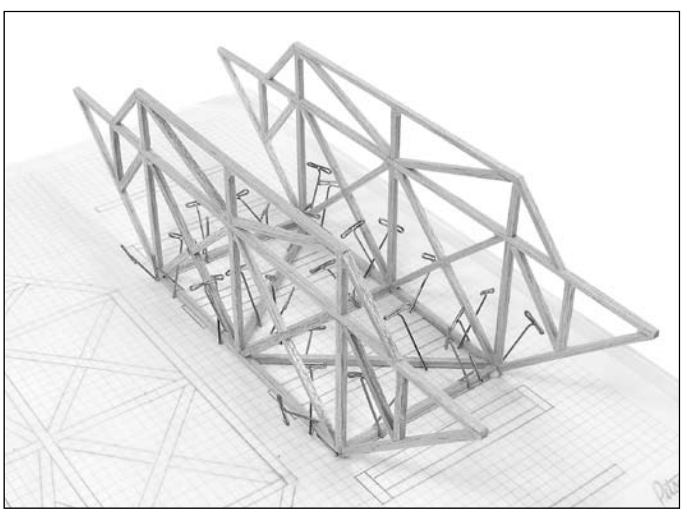


Figure 30 – Glue and pin up the second bridge side in place

30). Let this dry.

12. Pull out the pins and carefully remove the bridge from the work surface. Turn over the bridge. If needed, pin the bottom of the bridge to hold it in place.

13. Apply glue to the sides where the roadway cross braces will be attached. Put the cross braces in place. If needed, you can clamp the braces in place with clips

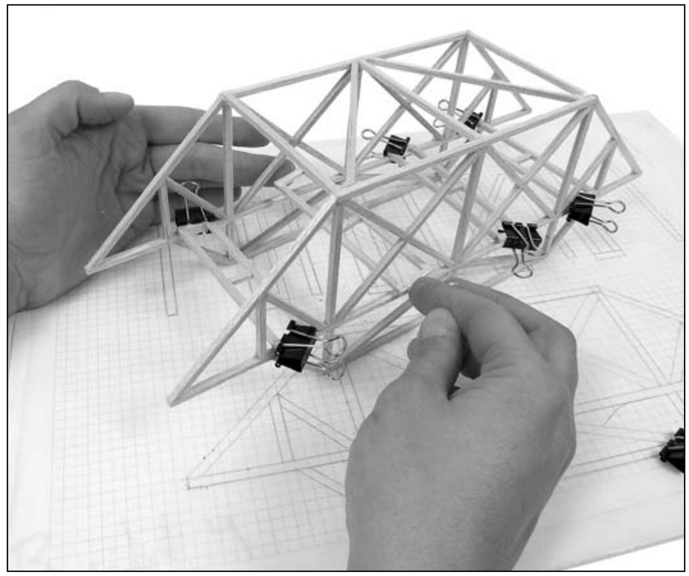


Figure 31 – Roadway cross braces glued in place

while they dry (Figure 31).

14. Remove the clamps, if used. Check all joints to ensure they are well-glued and that all members are securely in place. The bridge you designed and engineered

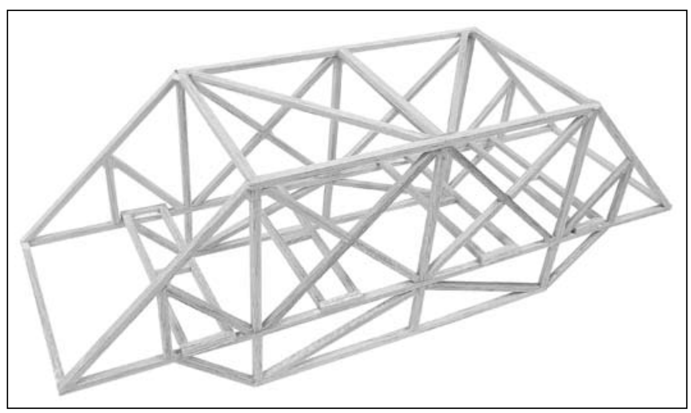


Figure 32 – A completed bridge

Chapter 5 – Testing the Built Model Bridge

Preparation for Testing

The teacher should first examine the completed bridge to make sure it meets all the specifications and to verify all its joints are glued correctly. The teacher might also compare the drawing with the completed model.

Step 4: The Destructive Test

Several different testers can be used for this step, including the Science Olympiad Tester, Pitsco Structure Tester, or Pitsco Pulley Bulley Bridge Tester. The following directions are based on using the Pitsco Structure Tester. If using another tester, follow the directions in that tester's user guide.

1. Place the Pitsco Structure Tester on a flat, level surface.

2. Set the toggle switch on the back of the tester to the desired unit of measurement (pounds or kilograms).

3. Remove the round spacer block from the well of the tester.

4. Screw one of the threaded shafts all the way into the hole in the well of the tester (Figure 33). Do not overtighten the shaft; it needs only to be hand tightened.

Figure 33

5. Slide the bridge-testing adapter over the threaded shaft until it rests in the well of the tester (Figure 34). Make sure the adapter does not cover the pump handle.

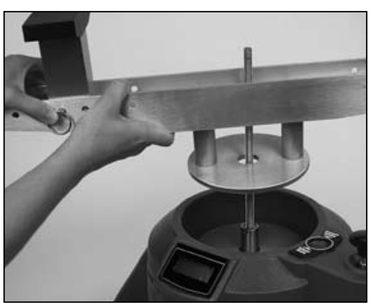


Figure 34

6. Set the span columns on the adapter, one on either side of the shaft. Using the bridge to be tested as a guide, adjust the position of the span columns so they support the bridge. Then, insert a span-locking pin through the adapter and into each of the columns to anchor them in place.

Figure 35

7. Locate the roadbed load blocks and choose the block that best fits the bridge. The block should be two inches shorter than the span of the bridge. Slide the block into the bridge (Figure 35) and center it.

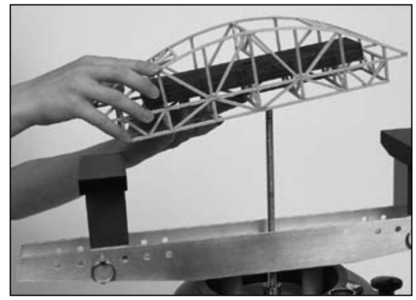


Figure 36

8. With the block in place, slide the bridge over the threaded shaft onto the span columns (Figure 36).

9. Place the load clip on the block and slide it onto the shaft (Figure 37).

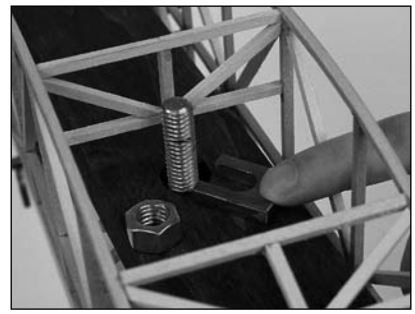


Figure 37

10. Thread the hex nut onto the shaft until it snugly contacts the load clip. **Note:** When using the longest roadbed blocks, slip the washer over the shaft first and then attach the load clip and hex nut. This will provide extra stability for the assembly.

11. Press the pressure release button, and then reset the digital display by pressing the reset button located just under the display.

12. Use the pump handle to begin to apply force to the bridge. Slow, steady strokes on the pump handle will yield the most accurate results.

The force should build gradually, as indicated by the digital display. Upon bridge failure, the digital display will hold the maximum force reading applied to the bridge. Record this value.

13. After the bridge has been destroyed, press the pressure release button on top of the unit to return the shaft to its extended position.

14. Remove the load clip and the roadbed load plate from the shaft. Pick up the broken pieces of the bridge. You are now ready to test more bridges.

15. Compute the efficiency of your tested bridge by using the following formula:

Efficiency = Failure Mass (g)/Mass of Structure (g)

Note: If the failure mass was measured in pounds, multiply the number of pounds by 454 grams.

For subsequent bridge tests, there is no need to repeat all the steps on the last page and a half. Follow this procedure:

1. Readjust the span columns to fit the next bridge.

2. Insert the appropriate roadbed load block in the bridge.

3. Place the bridge (with its block) over the shaft and replace the load clip.

4. Position the hex nut so it contacts the clip and tighten it.

5. Test!

Technology Student Association (TSA) Structural Challenge

Middle School

Participants (one team of two members per chapter) work to determine superior engineering as they conduct research and then model and test a structure that is designed to hold the greatest load. Teams submit their models for destructive testing.

High School

Participants (one team of two members per chapter) work as part of a team, on site with supplied materials, to build a model of a structure that is destructively tested to determine design efficiency.

For current information on TSA Bridge Competitions, refer to the Competitive Events Guide, available through the TSA Resources & Publications section of the TSA Web site: http://www.tsaweb.org/content.asp?contentid=436.

Other Competitions

To learn more about organizations that sponsor bridge-building competitions and activities, check out the following Web sites.

Technology Student Association
http://www.tsaweb.org/

Science Olympiad
http://www.soinc.org/

Science Decathlon
http://www.sciencedecathlon.com/

Winston Science
http://www.winstonscience.org/wsci/

International Bridge Building Contest
http://www.iit.edu/~hsbridge/database/search.cgi/:/public/index

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The National Trust, http://www.nationaltrust.org.uk/main/w-vh/w-visits/w-findaplace/w-carrickarede/

PBS, http://www.pbs.org/wgbh/nova/transcripts/2404inca.html

Wikipedia, Clapper Bridge, http://en.wikipedia.org/wiki/Clapper_bridge

Other Resources

To find these resources – and many others – please refer to Pitsco's Web site, www.shop-pitsco.com, or *Pitsco's Big Book of Ideas & Solutions* catalog. To order a free copy of the catalog, call 800-358-4983. This catalog and Web site also offer the bridge testers, cutting equipment, adhesives, and many other tools and materials mentioned in this book.

Balsa Bridges GS Teacher's Guide

Building Toothpick Bridges by Jeanne Pollard

Discovery School: Structures Software (WIN/Mac CD-ROM)

Dr. Zoon Bridge Building Video (DVD or VHS)

Dr. Zoon Straw Structures Video (DVD or VHS)

Dr. Zoon Structures Video Series (DVD)

Dr. Zoon Toothpick Bridges Video (DVD or VHS)

Masterpiece Toothpick Bridges by Nathan Fairchild

Model Bridges by Brian Rutherford

Straw Structures GS Teacher's Guide

Toothpick Bridges GS Teacher's Guide

Notes

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