



# MODEL BRIDGE DESIGN

## 5 Steps to Building a Model Bridge

Illustrated, step by step guide on how to design and build model bridges

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# Table of Contents

## Introduction

1. Know the Rules
  - a. Be able to define in your own words what the bridge must accomplish
  - b. Do not get disqualified
  
2. Design the Bridge
  - a. Design the bridge around the loading points
    - i. Plan for extra bracing around load point
  - b. Choose a truss to use
    - i. Warren
    - ii. Pratt
    - iii. Howe
    - iv. K truss
    - v. Design your own
  - c. Draw the bridge to scale
    - i. Use graph paper
    - ii. Draw forces
    - iii. Label everything
    - iv. Title and date
  
3. Gather Materials
  - a. Wood
    - i. Hobby stores
    - ii. Specialized Balsa.com
    - iii. Wood selection
  - b. Tools
    - i. Glue
    - ii. Saw/Exacto knife
    - iii. Gram scale
    - iv. Clamps/clothespins
  - c. Workspace
    - i. Good lighting
    - ii. Good ventilation
  
4. Build the Bridge
  - a. Step One
    - i. Tape down top and bottom chords
    - ii. Glue on truss
    - iii. Repeat for other side
  - b. Step Two
    - i. Make two piles of books
    - ii. Tape trusses to piles

- iii. Glue on top lateral bracing
    - iv. Glue on bottom lateral bracing
  - c. Double check for leaning
    - i. Glue on lateral bracing
    - ii. Weigh the bridge
    - iii. Record weight and all specs in notebook
- 5. Testing and Evaluation
  - a. Testing Procedures
    - i. Always test before competition
    - ii. Bathroom scale method
    - iii. Bucket and sand method
    - iv. Practice testing under time limit
    - v. Videotape
  - b. Evaluation Procedures
    - i. Efficiency = Mass supported / Mass of bridge
    - ii. Determine what failed first
    - iii. Improving design and construction

Bonus: 25 Quick Tips

## Introduction

I have good memories of building model bridges. I would have Balsa wood scattered everywhere, glue bottles half empty lying around, designs constantly floating through my head, etc. I grew up building bridges for a competition called Science Olympiad. When I entered high school, the Bridge Building event was replaced with Towers, and later Boomilever. This guide is the product of the years I spent trying out different ideas until I eventually became the top builder in middle school, and one of the best high school builders in the state of Georgia.

Because building model bridges was such a big part of my life, I wrote a song several years ago commemorating my experience in Science Olympiad. I have included it here for kicks and giggles.

Working late on the last Friday night  
Before competition, I'm running out of time  
I think I've got a chance to be the best in state  
I just hope this last minute bridge can hold the weight

I can hardly move my fingers because of all the glue  
I've got the bridge builder blues

I've got basswood and balsa scattered all around  
I grab some of the sticks and I start going to town  
Pretty soon I will emerge from this mess  
With a fine looking bridge that's sure to impress

And from head to toe I'm covered up in glue  
I've got the bridge builder blues

At the competition people gather around  
Amazed these little bridges can hold thirty-three pounds  
Though I made a sturdy bridge, without a single flaw  
What can a person do against old Murphy's Law

I had to shave off all my hair to get out all the glue  
I've got the bridge builder blues

And now it's my turn, and my hands are shaking  
I only get more nervous the more time that this is taking  
Cup after cup after cup of sand I pour  
I don't know if my nerves can stand this anymore

Am I the only one, or have you got them too?  
I've got the bridge builder blues  
(What about you?)

My brother and I made a music video of this song, which you can watch at youtube:

<http://www.youtube.com/watch?v=JjAY8y64SWQ>

## 1. Know the Rules!

I volunteered at the Georgia Science Olympiad State tournament in March of 2007. While I was there, I had the opportunity to measure the structures for compliance with the current rules and specs. Not only was I nervous about accidentally breaking something, but I was also nervous for the students. Over the years, I have seen plenty of bridges and towers disqualified because they were 2mm too narrow or just barely too long. I did not want to have to be the bearer of bad news to anyone.

It is easy to avoid being disqualified. All you have to do is know and understand the rules and guidelines given to you for the bridge. It does not matter what type of competition you are in, whether it is a class project, or the International Bridge Building Competition, the single best advice I can give anyone is to **know the rules**. When I was a competitor in Science Olympiad, I literally memorized the two pages of rules for Bridge Building from the official handbook.

You do not need to go quite that far. A good rule of thumb is simply to be able to say in your own words what your bridge must accomplish. It is really handy to have this understanding before you even start designing the bridge. One year I had built a tower, and the night before competition I was going over the specs one last time. I found that my tower was 2 inches too short. Ouch.

Needless to say, I stayed up late that night trying to fix the problem as best I could. If only I had double-checked the height *on my drawing*, I could have saved myself a lot of last minute headache and had a better performance. I could have stopped this problem well before I started to build.

I can tell you lots of stories of people in Science Olympiad who did not know the rules very well—and it showed on competition day. Not only is a disqualification embarrassing, you can easily prevent one by spending a little more time reading and reviewing the rules.

This first section can be a little dry and may seem as if I push it too hard, but trust me on this one. It is normal to just want to jump right into building a bridge, but it is worthwhile to step back and get a good look at the big picture. Do not worry, we are now moving on to the more fun part of bridge building. That is, if I have not bored you to death yet. Hang in there grasshopper!

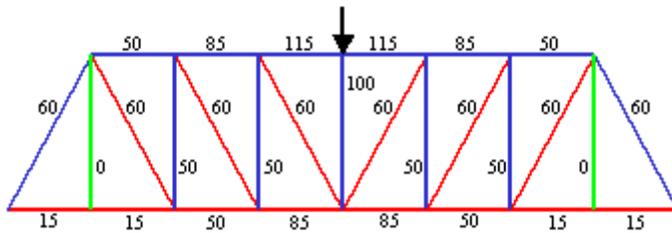
## 2. Design the Bridge

What is the most important part of a model bridge? I suggest that the most important part is the two inches or so where the bridge is loaded, aka. the load point. In fact, this area of the bridge is so important that the design of your

bridge needs to "center" around this point. The load point and the surrounding area have to sustain the most stress anywhere on the bridge.



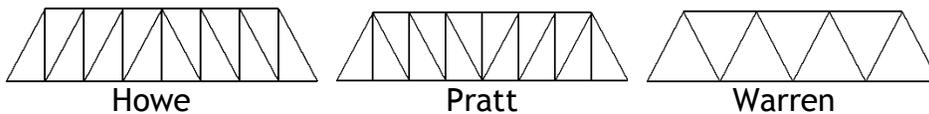
The red circle on the above illustration shows where the load is concentrated. You can check this out by using JHU's Bridge Designer (link below). Here is an example from my [truss design](#) page:



You can see the larger numbers in the middle of the bridge along the top and bottom chords. The numbers continue to get smaller toward the ends of the bridge. Obviously the section that holds 115% of the load is going to have to be larger than the section that only holds 50% if you want to build an efficient bridge.

This is something that a lot of bridge builders overlook. A lot of times people think the top and bottom chords need to be a consistent size for their entire lengths. It certainly is easier to build that way. But if you are going for pure efficiency, your chords should taper out at the ends. You can see one implantation of this in the example bridge I build for this guide later on.

The major choice you have to make in the design of your bridge is what truss you will use. A "truss" is simply what you see looking at the side of a bridge. I have already shown you two trusses in the illustrations above on this page. Here are more examples:



You can choose to use a common truss, such as the Warren, Pratt, or Howe shown above. Another less common, but still interesting truss is the K truss. Engineers have used these trusses in real bridges for many, many years. You can still see examples from old railway bridges. You can get more information about each of these trusses on my [truss design page](#). I would recommend using one of these three trusses as the design for your bridge if you are a beginner to model bridge building.

However, if you feel adventurous, you can also make up your own truss. One way to do this is mix two of the trusses I mentioned above for a hybrid design. I did this on my [Fernbank Bridge](#). One note of caution: if you do decide to design your own truss, make sure you plug it into the [Bridge Designer](#). This fun little program will show you how the load is spread throughout your truss. This is extremely valuable information for you as the designer. If you do not know how to use the Bridge Designer, see my [Bridge Designer Help page](#).

Once you have picked out the truss design, you need to draw it on paper. I would recommend getting some 11" by 17" graph paper. Or you could tape two or more sheets of regular graph paper together for the same effect. Using graph paper makes it easy to keep the bridge symmetrical and even. If you have access to a CAD program, that will work also.

It is a good exercise to draw at least one bridge design to 100% scale. That means every piece of your bridge that you draw on paper will be the same size as it is in real life. I do not draw many designs to 100% scale anymore. I just draw an outline. However, it is good for beginning builders to see the full design on paper. It is easier to build with a 100% scale drawing.

Part of drawing out the design means you have to decide how big every piece on the bridge should be. This can be a daunting task, so I hope to give you an idea how to start. A general rule is simply to be safe rather than sorry. If you do not know how big a piece of wood has to be in order to hold the amount of force on it, you will just have to guess. Once you get used to working with wood you will develop a working knowledge of relative strengths of different sizes of wood.

Here is one way to get a general idea of the strength of a piece of wood. Take a stick of wood, about three inches long, and push down on it with a bathroom scale underneath. You have to keep watching the scale to note the force when the piece breaks. Typically, the results from this simple test give you the minimum amount of force that piece can hold. If that same three-inch piece had been glued in a bridge, it would have held more force without breaking. However, you can get a rough idea of where to start and work from there.

After you have drawn the bridge design to scale, I like to pencil in some more information. Besides drawing the basic design, also add some of the information you get from the Bridge Designer. I would label which pieces will be in compression and tension, and the amount of force on each piece. Since you probably do not know when the bridge will break, when using the Bridge Designer make the total force equal to 100. That will give you the percentage of force that is on any given piece.

I have drawn dozens of bridge designs throughout the years. After a while it was hard to keep track of them all. Therefore I began to add some additional

details such as a title and date to each design. You will see examples of all these extra details in the pictures of my drawings in the Building section.

### 3. Gather the Materials

#### How to Choose Good Wood

Now that you have drawn a sweet bridge design, you are almost ready to start building. I know, you feel like you have waited long enough, but just be patient. There are few things you need to get before you can start building. The first thing to get, naturally, is the wood. Your particular rules may specify what type of wood you can use, or it may be completely up to you. Most likely, if it is specified, you will use either Balsa or Basswood. Both of these can be easily found at local hobby stores and places online (such as [Specialized Balsa](#)). Other common wood choices are popsicle sticks or toothpicks. These are also readily available.

Not all wood is equal. You may be thinking, "It's a toothpick, they're all the same." Unfortunately, that is not the case. Some toothpicks will be stronger than others. It is the same with popsicle sticks, Balsa and Basswood, or anything else you may be using. Here are some tips on choosing good wood:

Balsa will give you the most problems in your attempt at getting good wood. This is because Balsa wood is sold in a wide range of densities and stiffnesses (did I just invent a word?). You may find two sticks of wood at a hobby store that are the same size, but one may be twice as strong as the other. If this surprises you, please check it out for yourself.

So how do you find good wood? When you work with Balsa wood a lot, you can begin to recognize signs about the strength of the wood. Stronger wood is more dense. You can do a "squeeze" test, where you lightly squeeze a stick of Balsa between your fingers. If the Balsa begins to crush easily, then you have a low-density piece. If the piece is hard to squeeze then it is more dense. Obviously, lower density wood of the same size will be weaker. However, there is a time and place for both low and high-density wood.

Please do not start squeezing every stick of Balsa wood in your local hobby store. Unfortunately you ruin the end of the stick by performing this test. The bad thing about this test is that it is not very exact and will not give you a clear picture of the density of the wood until you have been doing it for a while.

Another clue to the density of wood is its color. Typically, wood that is lighter in color is also lower in density than darker wood. Remember that the higher the density, the stronger the piece of wood is. Basswood is naturally much more dense than Balsa, and you cannot use the squeeze test for it.

For more information about Balsa and Basswood, [click here](#). Also check out my webpage about [choosing good popsicle sticks](#).

### **Glue: Holding Everything Together**

Glue is second only to wood in its importance on your bridge. Because of its importance, people have long sought out the “perfect” glue. I joined this search, and I believe found it. Weldbond cooks your dinner, makes your bed, cleans the house, and did I mention it bonds wood well? Okay, so Weldbond does not quite meet all the expectations for the perfect glue, but it does come close. It is lightweight, dries quickly, is very strong, and is cheap. Those are the four categories you want to consider when looking for a potential glue.

- Weight
- Drying Time
- Strength
- Cost

Your rules may limit what type of glue you can use, so do the best with what you have.

For Balsa wood, yellow wood glue thinned with water (about 70% glue 30% water) is a good choice. Polyurethane based glues (such as Gorilla glue) are very strong, but they are heavy and slow to dry. Cyanoacrylate (CA glue) is a good choice if you want a very fast drying glue. For more information about glue, see my [Glue Tips](#) page.

### **Tools**

You can build a model bridge using only things found around the house. However, a couple specialized tools that will make things easier for you.

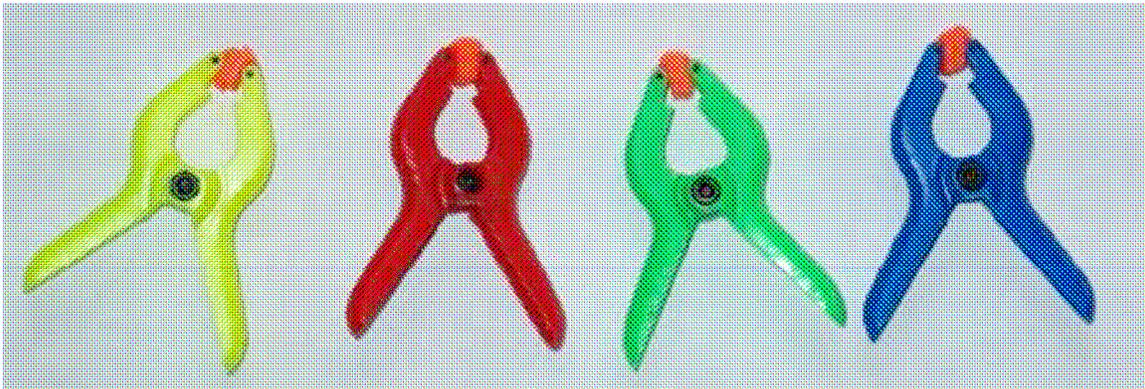


I love my miniature saw. They are not very expensive, and if you are going to be doing a lot of cutting you will not regret getting one. I would definitely get a saw if you are going to be cutting harder wood such as Basswood or popsicle sticks.

Another option for a cutting tool is an Exacto knife. An Exacto knife is extremely sharp, and you must be very careful using it. I do not let my middle school students even handle an Exacto knife unless they can show me they are mature enough, or already have experience with one. If you buy one, make sure you get one with a cap to keep it and you safe. An Exacto knife can also make cuts that are impossible for a saw to do, so it is handy to have both.

In addition to a cutting tool, clamps are also very helpful. Clothespins work very well, and you probably have some lying around the house. You want some that are fairly strong, but not strong enough to crush the wood. This is especially important if you are working with low density Balsa wood. Balsa wood is easily crushed.

I also have some clamps that I got from the dollar store that I really like. They open much wider than clothespins, and are slightly stronger. They are a little trickier to use, but they have become my best friends.



If you are serious about building an efficient model bridge, you have to have a gram scale. I bought a [miniature gram scale](#) off Ebay for only \$15. It was definitely one of the best purchases I ever made. A gram scale that measures to 0.01 grams like this might be too expensive to buy if you are building only one bridge. However, you may know someone who would let you borrow one. Most schools have a digital gram scale of some sort.

I like to have a digital scale when I am measuring very small pieces of wood. I weigh each and every stick of wood that I get and then calculate the density and stiffness coefficient. I am highly selective on the wood I use in my bridges.

You do not need a whole lot for this amazing hobby of bridge building. Here I have listed the less common tools, but you also may want some other common items such as masking tape, paperweights, ruler, etc.

### **Workspace**

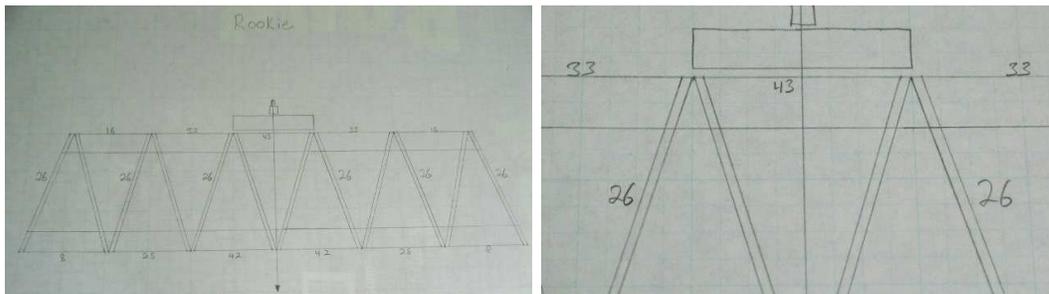
It is worthwhile to put a little thought into where you are going to be constructing your bridge. Places like a garage or workshop work great, but not

everyone has that option. You can build the bridge almost anywhere, but be cautious of using the new kitchen table. You want to work in a place with good lighting, good ventilation, and have a trashcan nearby.

#### 4. Build the Bridge

Hurray! Now we come to the actual construction of the bridge. In this guide I am going to be outlining one method of building a model bridge. You may find another way that works better for you. This method is the simplest I know of, something you come to appreciate after building hundreds of bridges. But feel free to modify this method as you see fit. This is a very generic sample, and you will have to adapt it to your specific situation.

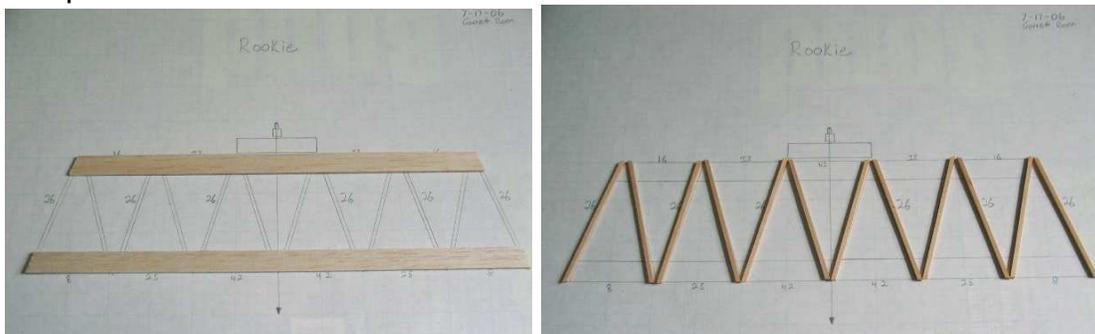
The first thing you want to do is lay out the full scale drawing on a hard surface. You might want to tape the drawing down so it does not move around as you are trying to build. Here is a sample design:



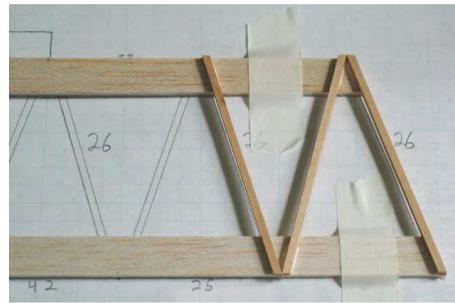
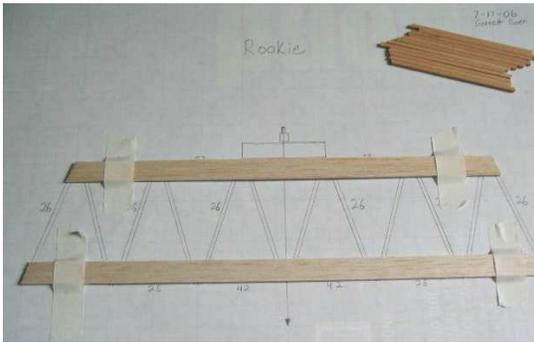
You can see the numbers on the drawing. Those numbers represent the percent of total load on each member. I have also drawn a “loading block” for visual purposes.

#### Step 1

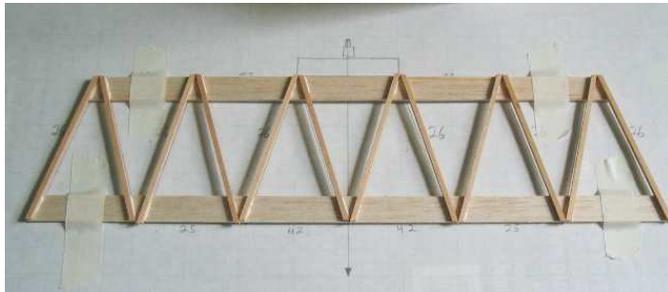
Cut out every piece you will be using for this side of the bridge. This example bridge only has two different sizes of pieces, but your bridge may be more complicated.



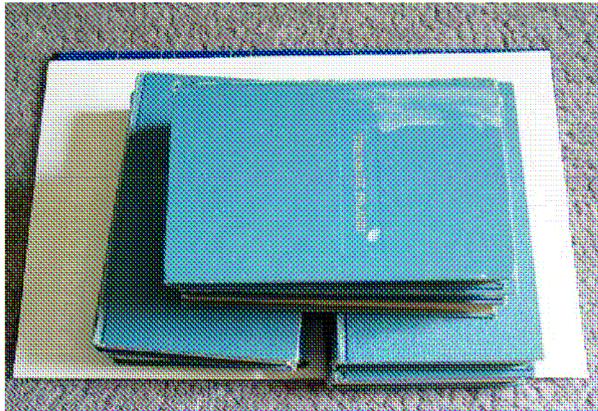
Now take all the pieces off the drawing. Tape down the top and bottom chords. Make sure to tape in-between where the side members are supposed to go! Then you can glue on the rest of the sticks.



Here is a finished side:



While the glue is drying, lay something heavy over the entire truss, to help hold down all the pieces. I normally use books or any heavy object around.



Note: If you are using different sizes of pieces for the compression and tension members, you need to glue on the smaller pieces first, then lay something over the bridge until it dries. Then glue on the bigger pieces and once again lay something over the bridge.

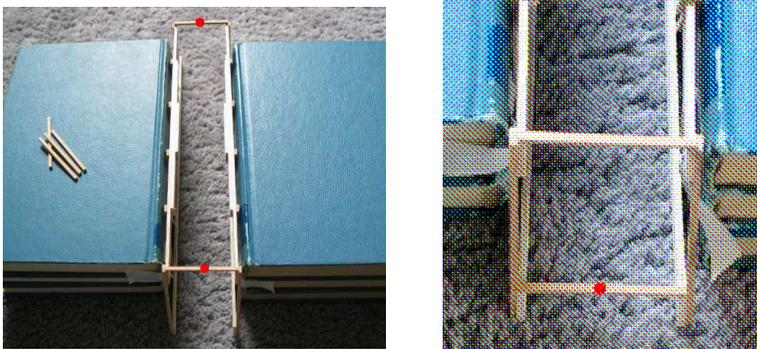
Repeat this process to make the other side of the bridge.

## Step 2

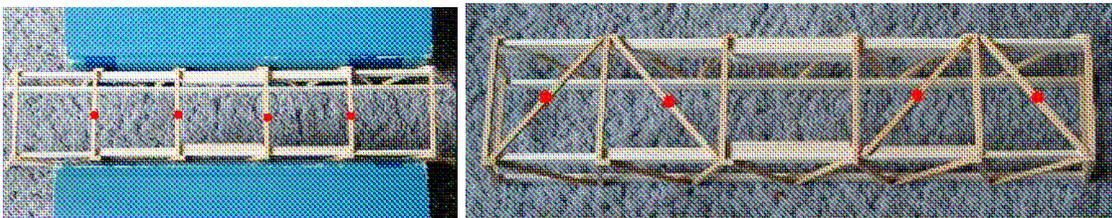
Once the two sides are completely dry, you can proceed with the next step. Make two piles of books, spaced apart the exact width you want the bridge to be. Be sure to use a ruler to make the spacing precise. The two piles do not need to be the exact same size, but both piles should not be any taller than your bridge. Encyclopedias work great for this.

Tape both sides of the bridge to the inside of the piles (see below). You want to make sure that each side is perfectly vertical, and is not leaning at all. This is extremely important. You can easily adjust the two piles of books to take out any lean.

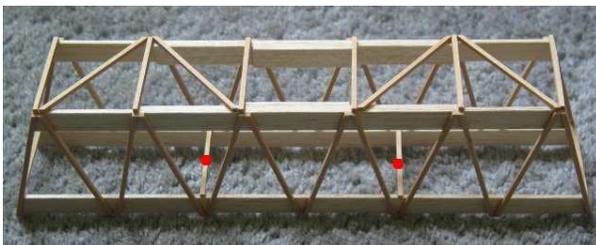
Now you will glue the two sides together by gluing on lateral bracing. First glue two pieces to connect the ends of each side on both top and bottom.



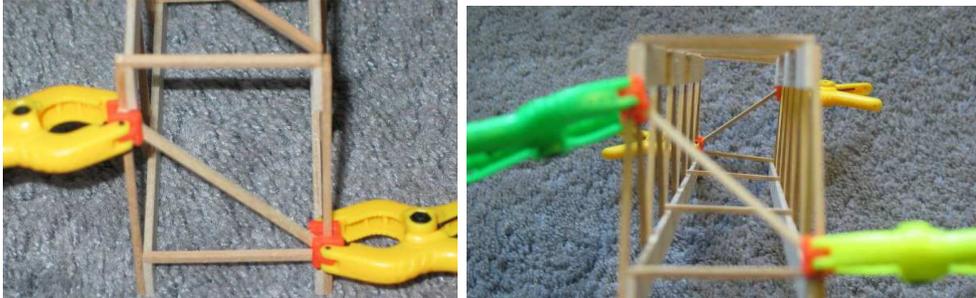
Now glue on more lateral bracing:



After these have dried, carefully un-tape the bridge and move the piles of books out of the way. You will now glue on connectors for the bottom of the bridge. The bottom does not need as many connectors as the top, but it does need some. In this example bridge I have glued on a total of four.



After you let the bracing dry, you want to double check that your bridge is not leaning. Even the slightest bit of lean will greatly reduce the strength of your bridge. I cannot stress that point enough. If your bridge is leaning, you will need to use lateral bracing to pull the bridge back into shape. For this, you will need some sort of clamps such as clothespins.



This is the last step to the construction of the bridge. You will want to let all the glue dry completely as specified on the glue bottle. Usually this will take 24 hours. Make sure the bridge stays dry and out of direct sunlight. Congratulations on finishing a fine work of art.

Now is a good time to enter all the specs of the bridge into a log. Make sure to write down the weight, as it will be very important in determining the efficiency of the bridge. The bridge in the pictures weighs 15.95 grams.

\*This method of joining the two sides of the bridge is a less common approach, but one I found simple and easy. The more common technique is to make a jig for the inside of the bridge and tape the sides to the outside of the jig.

## 5. Testing and Evaluation

Now comes the fun part. You finally get to destroy the bridge you have spent hours making. There are a couple of different methods of testing a bridge. You can choose which one will bring you the most enjoyment.

If you are building for a competition, you probably want to pretest your bridge. However, there are a few cases where you do not want to do this. If you procrastinated and your competition happens to be only a couple days away, you do not want to test the bridge. Only test your bridge if you have enough time to build a new one. I learned this the hard way, and believe me, it is not fun. I guarantee you will not want to stay up into the wee hours of morning the night before competition. It is really hard to do a good job when rushed.

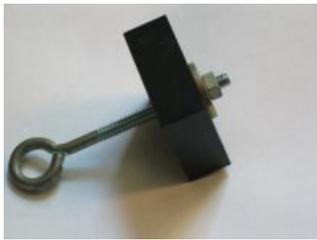
Also, you may not want to test your bridge if the goal of your competition is to break the bridge. You can, however, test the bridge a little bit, so that you know it can hold at least some weight. Once again, do not test it if you are very close to a competition.

### Testing Method #1

I use two main testing procedures. Both are fairly simple to set up, and most anyone can do either of them. The first way I use to test all my popsicle stick bridges. I simply set the ends of the bridge on two blocks, and put a non-digital bathroom scale on top of the bridge. I then push down on the scale with my hands until the bridge breaks.

The key here is to carefully watch the scale to catch the exact amount of force when the bridge fails. You have to pay close attention, because you do not really know when the bridge will fail. If I think the bridge will hold a lot of weight, I will use my body weight by carefully lowering myself onto the scale feet first. This method only works for top-loaded bridges.

### Testing Method #2



The second method I use for all my Science Olympiad bridges and towers. This method works for both top and bottom loaded bridges. First, I take the leaf out of our old table, and simply lay the bridge over the gap. You can pull two tables close together if you do not have a table with a removable leaf. I then put a loading block on the bridge. The loading block I use comes from Pitsco, and fits the Science Olympiad

rules. You can make your own loading block from a piece of plywood.

I then attach an eyebolt to the loading block, and hang a chain from the bolt. With a S-hook, I attach an empty 5-gallon bucket to the chain. I then proceed to fill that bucket up with sand. I stop when the bridge fails or I am satisfied with the amount held. This way can be used with either top-loaded or bottom-loaded bridges. When the bridge fails, I use a scale to weigh how much sand was in the bucket.

This second way is slightly more difficult to set up and do, but it provides more suspense. The first method can be done in less than a minute, where the second way might take 5-15 minutes.

If you are building a bridge for Science Olympiad or similar competition, I recommend the second method. I would also recommend that you practice loading the entire amount of sand within the specified time limit. I have seen many teams run out of time to pour sand when their bridge could have held the entire weight. This gave them a lower score than what their bridge was capable of.

I have made a study of the art to pouring sand. I know, I am a geek. But when you have a super light bridge it takes practice to get the maximum efficiency by sand pouring techniques. The main thing is to not waste your time pouring

the sand. The longer you take, the longer the bridge has to hold the load. Pour quickly but steadily.

There are also some competitions that will have a machine loading the bridge. Of course the machine will be able to load the bridge to a much greater extent than either of these two methods. In that case I would recommend not testing your bridge beforehand.

### **Prototypes**

Many people ask whether or not testing a prototype of their bridge will help. The problem with this is that it is very difficult to build two identical bridges. In a model bridge, even very minor differences in construction, the amount of glue used, type of wood, etc. significantly change the strength of the bridge. Testing a prototype will not give you worthwhile information about the efficiency of your real bridge. However, building a second bridge will help you improve your construction skills.

### **Safety First**

Always wear proper eye protection when you are testing a bridge. Always. You never know when the bridge will explode and send wood fragments into your eyes.

### **Evaluation**

So you have tested the bridge, either at home or at a competition. But now what? If you have not already, I would recommend plugging in your design to the [Bridge Designer](#), and adding a load in the program equal to the one your bridge held. By doing this, you can see exactly how much load was on each of the bridge members when they broke.

To measure the efficiency of the bridge, simply take the amount of weight the bridge held and divide that by the mass of the bridge. Of course you need to make sure to use the same units for each. I usually measure the mass of the bridge in grams, but load the bridge in pounds. So I convert pounds to kilograms by dividing the number of pounds by 2.2. Then, since that is kilograms, I multiply that number by 1000 to get the number of grams the bridge supported. Now I can divide that number by the mass of my bridge in grams.

Here is the equation for measuring the efficiency of a bridge:

$$\text{Efficiency} = \text{mass held} / \text{bridge mass}$$

The bridge in the pictures weighed 15.95 grams, and held 39 pounds. 39 pounds converts to 17.73 kilograms, which is 17730 grams. Dividing 17730 by 15.95 gives me 1111. So the bridge's efficiency score was 1111. That basically means the bridge held 1111 times its own weight. Please note I am not paying

attention to the number of significant digits here. This might sound complicated, but it really is not once you get used to doing it.

What is a good efficiency score for a bridge to have? That depends on the restrictions you had for building the bridge. A bridge made from toothpicks probably will not have as high of an efficiency as a bridge from popsicle sticks. This is due to several reasons, but I will not go into those here.

The best bridge I have built so far is my [Fernbank Bridge](#). It had an efficiency score of over 4200. However, I had virtually no restrictions as to how I could build the bridge, and what materials I could use. For Science Olympiad, the best bridge I built only had an efficiency score of 1584 (2004). Each year, as the rules change for Science Olympiad, the efficiencies will fluctuate. So I cannot exactly say what would be a good score for your bridge, unless it would be this: Better than anyone else in your competition ;).

There are simply too many variables in the various competitions to predict a good score without knowing the details of that competition. If your competition has been run for more than one year, you can ask what was the best bridge last year. If the bridge requirements have not changed since then, you can get a good idea of what your bridge needs to hold.

### **Getting Better**

But efficiency is only part of evaluating a bridge. If you want to improve, you need to know how and why your bridge broke. Or, if your bridge did not break, and held the maximum weight, you need to be able to know how to make the bridge lighter without losing strength.

This is where the [Bridge Designer](#) is extremely helpful. It shows you where the load is distributed throughout the bridge. If a certain area of your bridge broke, you know you have to make those pieces stronger. Or if the bridge did not break, the program will show you where the load is not as concentrated, so you can reduce the weight of those pieces.

Overall, bridge evaluation is a difficult subject with a lot of variables. I cannot tell you exactly how to make your bridge better without seeing your bridge. One thing you may want to consider is video taping the testing of your bridge. You can then watch it in slow mode, and perhaps get a clue where the bridge broke first. However, just watching from one angle sometimes will not be enough. If you can, get two or more angles. This will tell you a more complete story.

The ideal situation would be to have a camera on both sides of the bridge, as well as one camera looking through the bridge. But that is not a really practical solution. Sometimes you just have to guess at where the bridge broke, and go from there. Once you build and test several bridges, you should start seeing trends as to how the bridges break.

If you watched the video of me testing the bridge I built in this guide, you may have noticed the one piece that popped loose shortly before the bridge collapsed. What happened in this case is that one glue joint was not good enough, which caused that piece to break loose. You probably noticed the bridge started bending a lot more after that piece came loose.

When one piece comes loose like this, it puts a lot more stress on every other piece and will end up breaking them sooner.

I certainly hope this has been helpful to you. If you have any more questions, I would be more than happy to try to answer them. Just contact me through the form at <http://www.garrettsbridges.com/contact-me/>

## Bonus: 25 Quick Tips

1. Humidity affects the weight of your bridge. Keep your bridge in a closed container with a few grains of rice.
2. Go easy with the glue bottle. As a general rule of thumb, if you can see it than you are using too much.
3. Keep your hands clean! Oils and grease from your skin can ruin your glue joints.
4. Perfect practice makes perfect. The more bridges you build, the better your construction skills will be.
5. Keep your bridge from twisting by using [lateral bracing](#).
6. An L-beam is more efficient than a square, but harder to build.
7. [Balsa wood](#) comes in a wide range of densities and stiffness. Weigh each piece that you buy.
8. It is cheaper to buy Balsa in sheets and [cut your own wood strips](#).
9. It's still true, measure twice and cut once.
10. Keep a log of every bridge you build. Record notes and dimensions; you won't remember later on.
11. Try to videotape testing your bridge. You may get a clue on what failed first.
12. Always keep safety in mind when using sharp tools. Most mistakes are made when you aren't paying attention.
13. By cutting a piece in half, you more than double its strength in compression.
14. Good lighting when working will help you perfect those little details.
15. Always test your bridge before taking it to a competition, but leave enough time to build another.
16. Draw out your bridge on graph paper to make sure that it is symmetrical. I prefer the 11" x 17" graph paper.
17. Different [trusses](#) have different ways of spreading out the load.

18. Wood has about the same strength in tension, no matter how long it is.
19. CA glue is a fairly strong, light, fast-drying glue used by many builders.
20. Balsa wood sands very easily. Be careful not to sand off too much.
21. You can mix wood glue with water to cut down on weight. Doing this also helps the glue to seep into the wood, creating a stronger joint.
22. Remember to close your glue bottle when you are done using it.
23. Basswood will bend easier than Balsa wood. Try [steaming](#) or soaking your wood to help it bend.
24. Use [Lap joints](#) whenever possible to get the best strength.
25. What you want to look for in glue: drying time, price, weight, and strength