2nd Edition!

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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1. Know the Rules
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    b. Don't get disqualified

2. Design the Bridge
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Bonus 25 Tips

Building a model bridge—balsa wood scattered everywhere—glue bottles half empty lying around—good memories. I grew up building bridges for a competition called Science Olympiad. The Bridge Building event was replaced with Towers, and then Boomilever. This guide is the product of the years I spent trying out different ideas until I eventually became the top middle school, and one of the best high school builders in the state of Georgia.

If you haven't seen my music video, Bridge Builder Blues, you should. The second verse goes like this:

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

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 didn't 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 doesn't matter what type of competition you are in, whether it be 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 out of the handbook.

You don't 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 two short because I misread the instructions. 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 didn't 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.

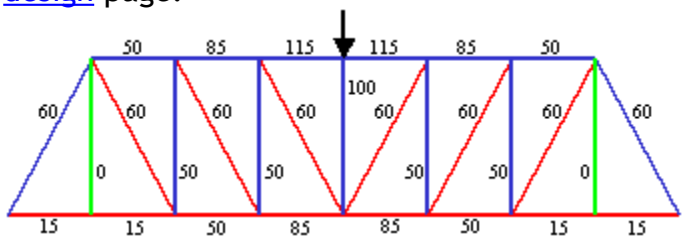
This first section can be a little dry and may seem as if I push it too hard, but trust me on this one. It is normal to just want to jump right into building a bridge, but it is worthwhile to step back and get a good look at the big picture. Don't worry, we are now moving on to the more fun part of bridge building. That is, if I haven't 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, 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.

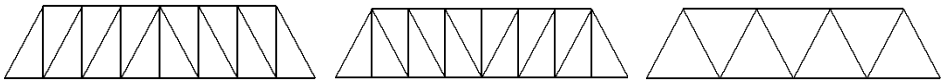
The red circle shows where the load is concentrated. You can check this out by using JHU's Bridge Designer (link below). Here is an example from my truss design page:



You can see the larger numbers in the middle of the bridge along the top and bottom chords. The numbers continue to get smaller towards 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%. At least this is true if you are going for 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 implementation 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 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 certainly 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 don't 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 together two or more sheets of regular graph paper. 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 don't 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.

Part of drawing out the design means you have to decide how big every piece on the bridge is. 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 don't know how big a piece of wood has to be in order to hold the load on it, you will just have to guess.

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 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. If you don't know when the bridge will break, then simply make the total force in the Bridge Designer equal to 100. That will give you the percentage of force that is one any given piece.

I ended up drawing dozens of bridge designs throughout the years. I added some things such as a title and date to each design to help me keep track of them all. You will see examples of all these extra details in the pictures of my drawings in the Building section.

3. Gather the Materials

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 is, naturally, 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 Balsa or Basswood. Both of these can be easily found at local hobby stores and places online (such as Specialized Balsa). You may have to use popsicle sticks or toothpicks, which are also readily available.

Not all wood is equal. You may be thinking, "It's a toothpick, they're all the same." Unfortunately, that isn't 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.

How do you get 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. There is a time and place for both low and high-density wood.

Please don't 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 isn't very exact and won't 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 can't 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 doesn't 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 look for in 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, there are a couple tools that will make things easier for you.

I love my miniature saw. They aren't very expensive, and if you are going to be doing a lot of cutting you won't regret getting one. I would definitely get one 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 don't 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. An Exacto knife can 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. 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 only 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. I have listed the less common tools, but you also may want some other common items such as masking tape, paperweights, ruler, etc.

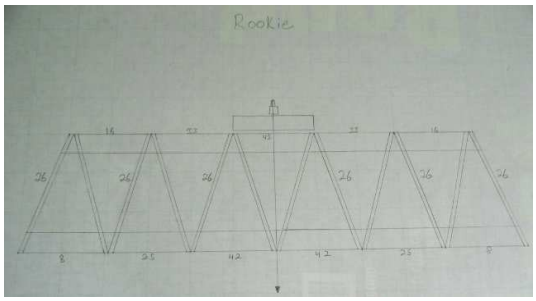
Workspace
It is worthwhile to put a little thought into where you are going to be constructing your bridge. Places like a garage or workshop work great, but not everyone has that option. You can build the bridge almost anywhere, but be careful of the new kitchen table. You want to work in a place with good lighting, good ventilation, and have a trashcan nearby.

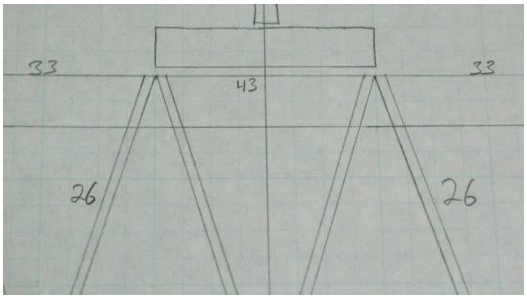
4. Build the Bridge

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 doesn't move around as you are trying to build. Here is a sample design:

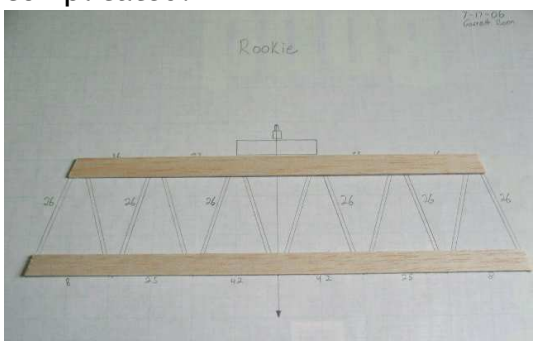


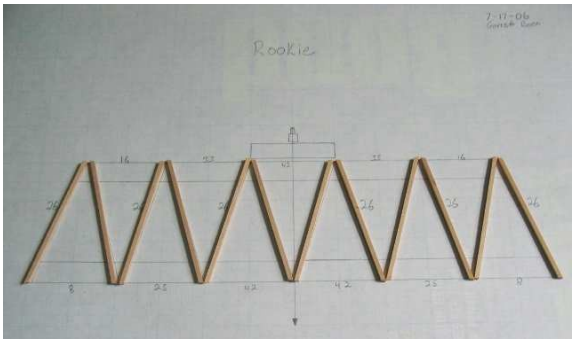


You can see the numbers on the drawing. Those numbers are from the % of total load. I have also drawn a "loading block" for visual purposes.

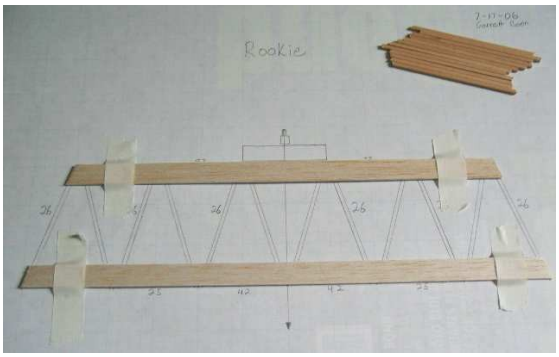
Step 1

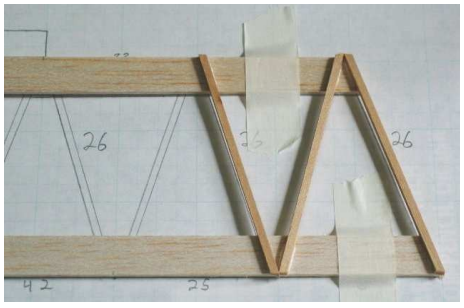
Cut out every piece you will be using for this side of the bridge. This bridge only has two different types of pieces, but your bridge may be more complicated.



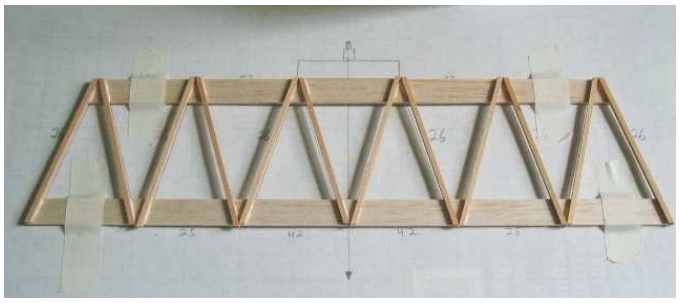


Now take all the pieces off the drawing. Tape down the top and bottom chords. Make sure to tape in-between where the other pieces are supposed to go! Then you can glue on the rest of the sticks.





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 tensions 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.

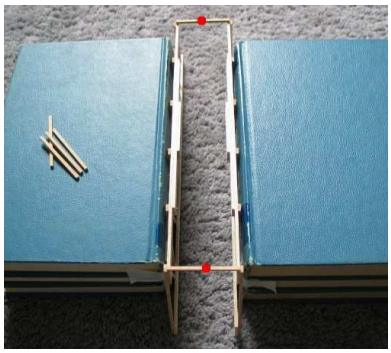
Repeat this process to make the other side of the bridge.

Step 2

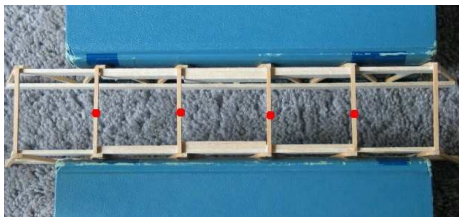
Once the two sides are completely dry, you can proceed with the next step. Make two piles of books, spaced apart the exact width you want the bridge to be. Be sure to use a ruler to make the spacing precise. The two piles don't need to be the exact same size, but both piles shouldn't be any taller than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

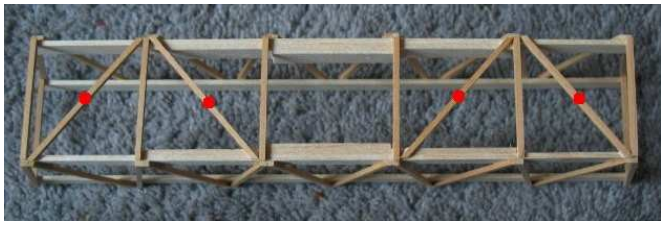
Tape both sides of the bridge to the inside of the piles (see below). You want to make sure that each side is perfectly vertical, and isn't leaning at all. This is extremely important. You can easily adjust the two piles of books to take out any lean.

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.

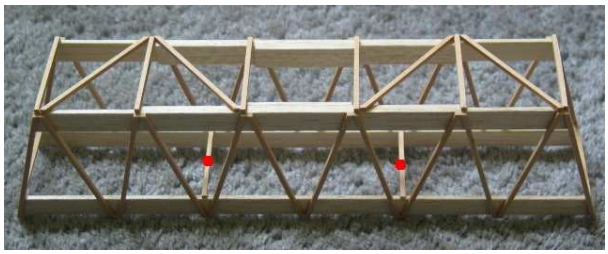


Now glue on more lateral bracing:

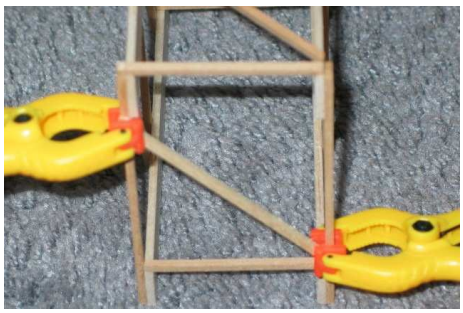


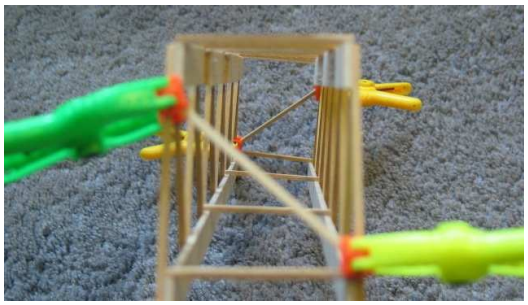


After these have dried, carefully un-tape the bridge and move the piles of books out of the way. Carefully flip the bridge over. The bottom of the bridge doesn't need as many connectors as the top, but it does need some.



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





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.

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.

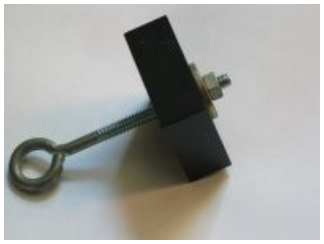
If you are building for a competition, you probably want to pretest your bridge. However, there are a few cases where you don't want to do this. If your competition happens to be only a couple days away, you don't want to test the bridge. Only test your bridge if you have enough time to build a new one. I learned this the hard way, and believe me, it isn't fun. I guarantee you won't 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, don't 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 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 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 weight the bridge fails at. You have to pay close attention, because you don't 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 lower 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 don't 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 follows 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 it held.

This second way is slightly more difficult to setup 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 (15kg) 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.

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 to 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 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 a competition. But now what? If you haven't 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.

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 isn't 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 from toothpicks probably won't be able to have as high efficiency as a bridge from popsicle sticks. This is due to several reasons, but I won't 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 can't 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 haven't changed since then, you can get a good idea of what your bridge needs to hold.

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 didn't 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 didn't break, the program will show you where the load isn't as concentrated, so you can reduce weight of those pieces.

Overall, bridge evaluation is a difficult subject with a lot of variables. I can't tell you exactly how to make your bridge better without seeing your bridge. One thing you may want to consider is 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 won't be of any help.

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 isn't 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 wasn’t good enough, which caused that piece to break loose. You probably noticed the bridge started bending a lot more after that piece came loose.

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.php