CE EN 495
Communication in Civil Engineering
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Section 1

Column Buckling Paper

Submitted to:
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by
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When you were growing up, you may have enjoyed playing with Legos. Remember back to when you got a new set of Lego bricks. You may have sat there, contemplating the set of lego bricks on the floor before you. Did you spontaneously start putting the bricks together, hoping something nice would turn out? Or did you carefully plan what you were going to build first, thinking carefully about your final product as you connected each brick? If you were like me, you had a design in mind--a picture in your head of the final product; and as you built your lego structure, you thought about your original plan.

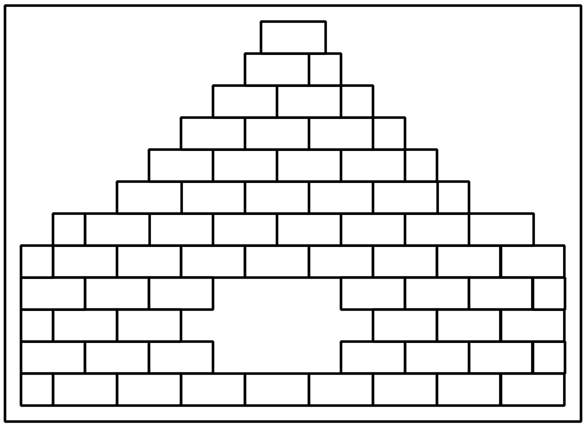

Figure 1: My First Lego Structure

You may have modified or even completely changed your plan as you went along. But when you were done with your Lego structure you were proud of your accomplishment.

When you build your bridge, it will be the same as when you created buildings with lego bricks as a boy. You will first start with a plan in your head; you may already have a plan. Then, you will put your plan on paper. You can have a specific design (with the lengths of the columns and drawings of the structure) figured out before you even begin building your bridge.

As you begin making your bridge, you will probably find problems with your design. You may have to make changes to your design or even start over at the beginning. Designing and building your bridge can be challenging; but it is also fun and exciting. When you are done, you will have a feeling of satisfaction and accomplishment.

You may be wondering how to design your bridge. In this paper, I will show you how to design a bridge that will stand up to a pretty good load--and possibly even win the balsa wood bridge contest! Some of the questions you may be asking yourself are:

- How does a bridge work?

- What is the secret of designing my bridge so I can win this contest?

I will first talk about how a bridge works. Then, I will explain the secret of good balsa wood bridge design--designing your bridge to withstand buckling.

How does a Bridge Work?

A bridge works like a spider web. If you think about it, the thin, sticky web from a spider can hold an amazing amount of weight. The tiny web must hold the spider itself, as well as the spider's eggs and food. How does the web hold up? The secret is that a spider web strand is strong in tension. In other words, when a weight such as the spider hangs on its web, the web can resist that weight; and the web is connected to the wall so that each of the little web strands is in tension.

A spider web is a lot like a rope. If two people pull on a rope, that rope can withstand almost anything. But if two people push on a rope, the rope will just bend. In figure 1, you can see an picture of two people pushing and pulling on a rope. When the people pull on the rope, the rope holds them up; the rope is in *tension*. When the same two people try to push on the rope, the rope does not hold them up; therefore, the rope has very little (if any) *compressive* strength.

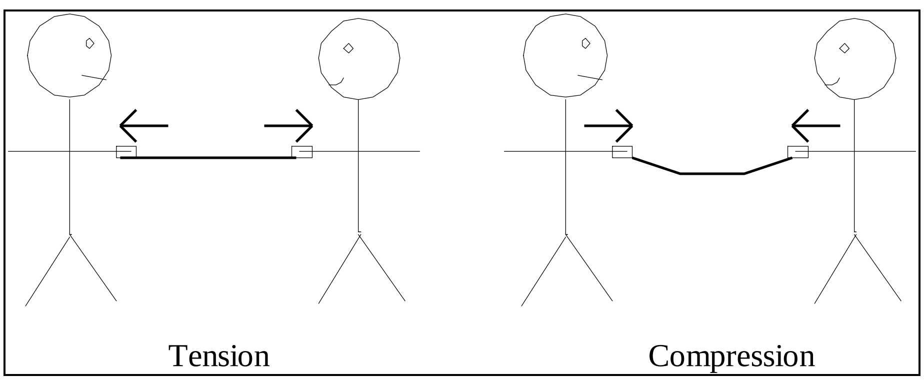

Figure 2: A rope is strong when two people pull on it (in tension), but when two people try to push the rope together (or to compress it), the rope has no strength.

An example of something that has lots of compressive strength is concrete. If you put a piece of concrete on the ground and push down on it, it is almost impossible to break the concrete. When you push down on the concrete, the concrete is in compression.

Now, lets apply materials that are strong in tension and compression to building a bridge. Think about the Golden Gate Bridge in San Francisco. First, this bridge has cables on the top. These cables can hold lots of weight when they are being pulled (in tension). Therefore, the engineers designed the Golden Gate Bridge so the cables would only hold pulling, or tension, forces.

But the large concrete and steel columns under the bridge are very strong in compression. Therefore, the engineers designed the Golden Gate Bridge so the concrete and steel would only hold pushing, or compressive, forces.

In figure 3 on the next page, I have drawn a simplified picture of the Golden Gate Bridge, showing where the compressive and tensile forces are on the bridge. With the cables, concrete, and steel working together, the Golden Gate Bridge is able to hold up a massive amount of weight. Your bridge should work much the same way, except your balsa wood columns will only be in compression.

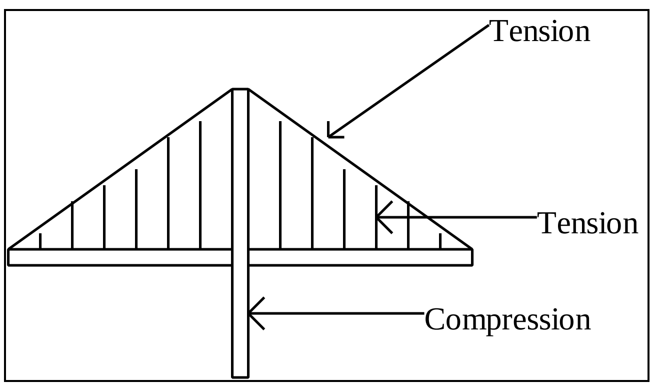

Figure 3: The Golden Gate Bridge has cables in tension as well as steel and concrete in compression to hold it up.

What is the Secret of Designing my Bridge so I can Win the Contest?

Think about the following bridge:

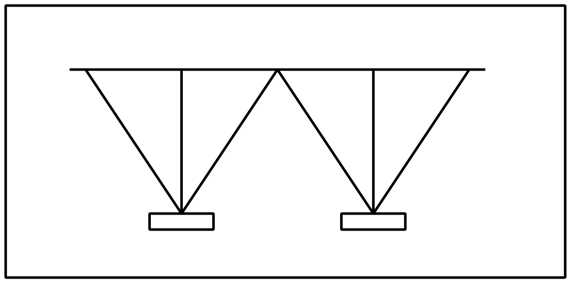

Figure 4

Without any weight on it, the bridge will hold up just fine. But when you put a weight on the top of the bridge, this is what happens:

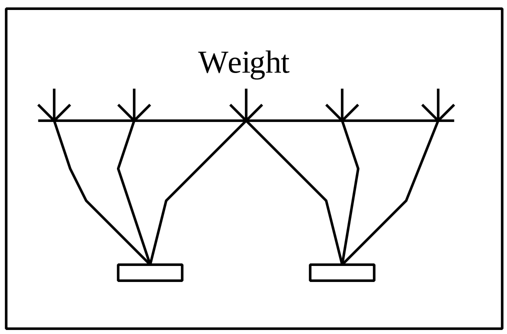

Figure 5

The bridge falls apart! The weight which causes the columns of the bridge to break, crack, and buckle is called the *critical force*. Over 200 years ago, a Swiss mathmetician named Leohnard Euler (his last name is pronounced "Oiler") derived an equation to calculate this critical force. Civil engineers still use this equation today, and it is known as Euler’s equation. His equation goes like this:

$$P_{cr} = \frac{p^2 \times E \times I}{L^2}$$

This equation may seem pretty complicated. But when you break it down and look at both sides of it, you will find out that it is easy to understand; and Euler’s equation shows you how to design your balsa wood bridge! Let's look at the different parts of Euler's equation and figure out the mystery of how to build a successful balsa wood bridge.

First, let's start with P_{cr}. $\mathbf{P_{cr}}$ stands for the critical force. If the critical force is high in each of your bridge columns, your bridge will be able to withstand lots of weight and win the contest. But if the critical force is low, your bridge columns will crack and buckle with a small amount of weight. How can you make sure the critical force is high in each of your bridge columns? The right side of the equation answers this question.

p is a constant which cannot be changed. But all the other stuff on the right side of Euler's equation can be changed.

E stands for the modulus of elasticity of your balsa wood bridge columns. The modulus of elasticity is a measure of the strength of your columns. The higher the modulus of elasticity in your balsa wood columns, the stronger your bridge will be.

One way to increase the modulus of elasticity in your balsa wood columns is to buy many bridge kits. From these kits, you can choose the strongest wood to use on your bridge. Another way to increase the modulus of elasticity, or strength, of your columns would be to coat them with glue.

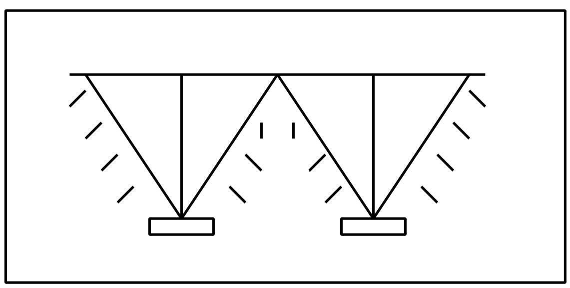

Figure 6: High-quality balsa wood increases the modulus of elasticity, making a stronger bridge.

I stands for the moment of inertia of your balsa wood columns. The moment of inertia has to do with the diameter of your balsa wood columns. If your balsa wood columns have a high moment of inertia, they will be strong; but if your balsa wood columns have a low moment of inertia, they will be weak.

One way to understand moment of inertia is to think about a popsicle stick. If you bend the popsicle stick one direction, the popsicle stick easily snaps in your hands. But if you bend it the other way, the stick is almost impossible to break. The stick has a low moment of inertia in one direction, but a high moment of inertia in the other.

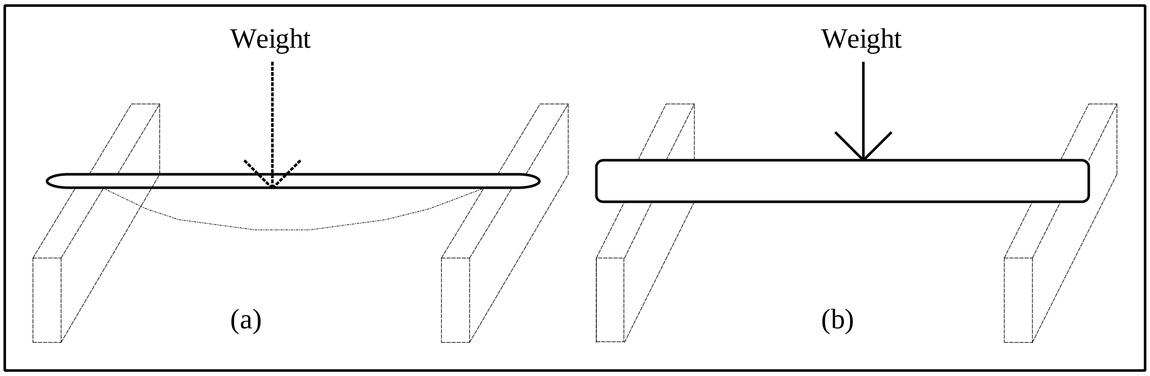

Figure 7: Popsicle sticks break easily in one direction (a), but they are almost impossible to break in the other direction (b). This is because of a low and high moment of inertia, respectively.

One way to give your balsa wood columns a higher moment of inertia is to glue many pieces of balsa wood together to form one column. But just like the popsicle stick, your columns will break where the moment of inertia is lowest. So remember to make your balsa wood columns thick in every direction:

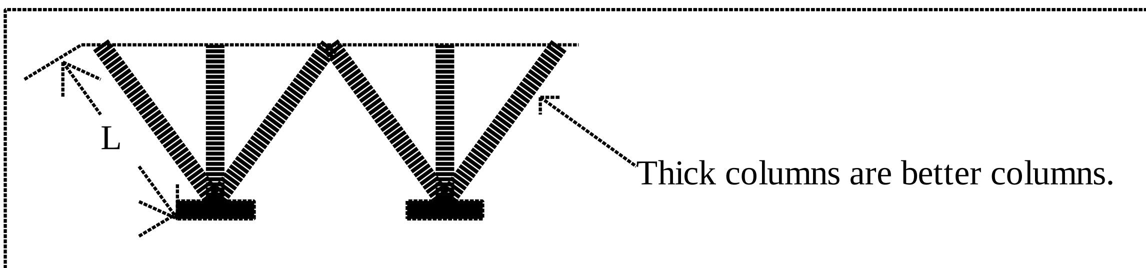

Figure 8: Thick balsa wood will make your bridge stronger by giving it a high moment of inertia.

L stands for the effective length of your balsa wood columns. This is the length of your balsa wood columns where nothing is holding them together. In figure 8, for example, the effective length would be L, as shown. But in figure 9, the effective length would be less, as shown. If the effective length of your balsa wood columns is low, then your columns will be less likely to crack and buckle.

One way to make the effective length of your balsa wood columns low is to put bracing between your columns. I recommend the following plan:

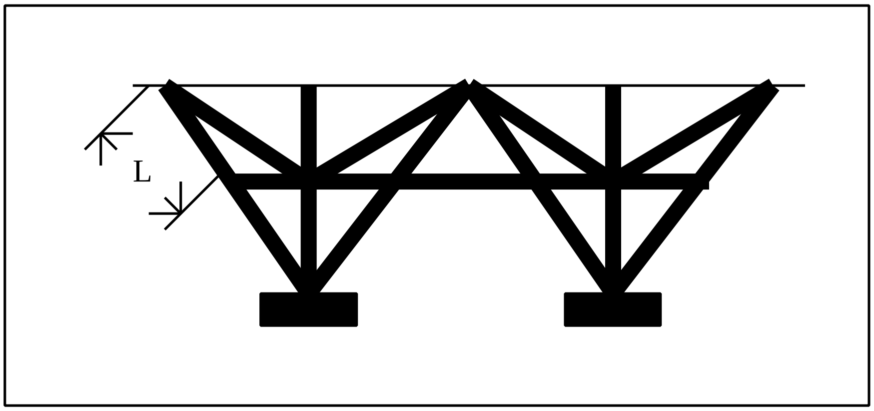

Figure 9: Bracing makes your bridge stronger by decreasing the effective length of your balsa wood columns.

Conclusion

Now, lets review how you can make a strong, winning bridge. It's as easy as 1-2-3:

1. Increase the modulus of elasticity, E, by getting the highest quality balsa wood available.
2. Increase the moment of inertia, I, by making sure your balsa wood columns are as thick as possible.
3. Decrease the effective length, L, of your balsa wood columns by adding bracing to your bridge.

That's how to do it. Mabye you have come up with your own ideas. If you have ideas, see if they work to make your bridge stronger. Some of the best and most interesting bridges are designed by young engineers like yourself. After you are done designing and building your bridge, you can stand back and look at your work of art. You will have a feeling of satisfaction that will stay with you. Who knows...you might even win the contest!