The Association of
PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
of the Province of British Columbia
PEACE RIVER BRANCH

Bridge Engineering Principles

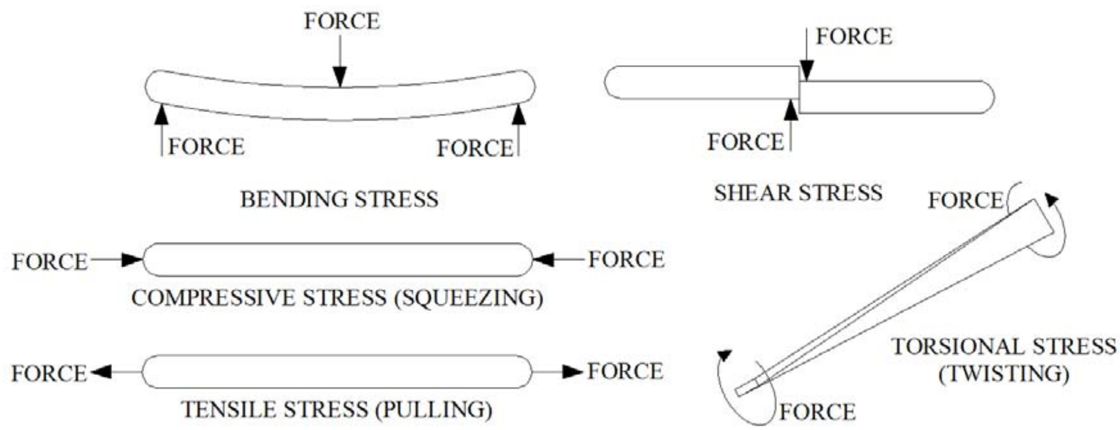
The following is a basic overview of the principles involved in building, and testing, a Popsicle bridge. Because this document is aimed at a variety of age levels the content may be too basic or advanced for your group. If you have any questions about the content, or you would like some more advance content, please feel free to contact the Peace River Branch of the Association of Professional Engineers and Geoscientists and we will do our best to accommodate your needs.

Force

Force can be defined as that which causes a mass to accelerate. Force has common units of pounds force (lbs) or Newtons $\left(\frac{kg \times m}{\sec^2}\right)$. The equation used to mathematically define force is Force = Mass x Acceleration (F=M·A). In other words 1 Newton is the force required to accelerate 1 kilogram by 1 m/sec^2, or 1 pound force is the force required to accelerate 1 slug by 1 foot/ sec^2. You will notice that the imperial unit for force is pounds force and not just pounds. There is a common inaccuracy in our language that is only really important when talking about physics. The word weight truly refers to a force – this is why your weight on the moon is not the same as your weight on earth. To fully understand this we need to dissect the mathematical meaning behind the force term. Two components go into calculating a force; the first is mass, the second is acceleration. What is mass? Mass is the amount of stuff present in a given sample, lets say a person. A person's mass will be the same whether on earth or the moon – in both places that person is made up of the same amount of stuff. Mass has two common units; kilograms (kg) and slugs. So a person might have a mass of 70 kg or 4.78 slugs. For the example of weight, or the downward static force exerted by an object, the acceleration of interest is the acceleration due to gravity. The acceleration due to gravity can be defined as the pull one object exerts on another. For this pull to be felt, one of the objects has to be extremely massive. For most people the most massive object they will encounter is the earth. The acceleration due to gravity on the earth is 9.8 meters/sec^2 or 32.2 feet/sec^2. So a person on earth might weigh (70kg x 9.8m/sec^2) = 686 Newtons or (4.78 slugs x 32.2 feet/sec^2) = 154 lbs. On the moon the same person will weigh (70kg x 1.62 m/sec^2) = 113 Newtons or (4.78 slugs x 5.32 ft/ sec2) = 25 lbs. So when a person says they weigh 154 lbs they are being true to physics, but when they say they weigh 154 kg, they're actually referring to their mass. As a further twist, it's also interesting to note that the acceleration due to gravity changes with altitude. So your weight at sea level will be slightly different that your weight at the top of a mountain (Newton's law of gravitation $F_g = G \cdot \frac{m_1 \cdot m_2}{r^2}$, where G is the gravitational constant).

Stress

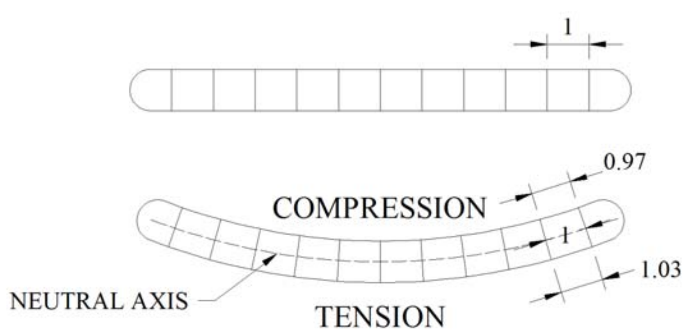
Stress is defined as force per unit area and has the common units of Pounds force per Square Inch (psi) or Pascals (Pa) (a Pascal is a Newton per square meter or kg/m sec^2). In construction there are five basic types of stress which concern engineers. These are bending, tensile, compressive, shear, and torsional stress (see picture below). For the purpose of building Popsicle stick bridges we are really only interested in bending, compression, and tensile stresses. When we take a close look at bending we'll see that it is just a combination of tensile and compressive stresses. Of these three types of stress tensile is perhaps the easiest to measure. As a result engineers will take samples of material and, using special machines, subject them to higher and higher tensile loads until they break. By dividing the force at which the sample breaks by the cross sectional area of the sample the materials Ultimate Tensile Stress (UTS) can be determined. The ultimate tensile stress is given the symbol σ (Greek letter sigma), and essentially represents the strength of a



material. For comparisons sake a sample of plain carbon steel might have a UTS of 50,000 psi, while pine (which is what Popsicle sticks are made of) might have a UTS of 1,000 psi. It is important to recognize that UTS is not the only important consideration when selecting a material, but material selection is a bit outside the scope of this summary.

Let's take a closer look at tension and compression. Tension is the stress an element experiences when exposed to a pulling force. To get a feeling for tension think about a piece of string. String can only experience tension; it is not able to resist pushing or bending. Compression is the opposite of tension; it's the stress an element experiences when exposed to a pushing force. Sand is an example of a substance which can only experience compression. A column of sand can support a large load, but is unable to resist any pulling force. As most materials have different tensile and compressive loading potentials, it is important to know what sort of forces will be exerted on every member in a building or bridge.

Bending combines both tensile and compressive forces in a single element. To demonstrate this, take a look at the picture below.



It's pretty obvious from this picture that bending puts one face into tension while the other is in compression. It also logically follows from this conclusion that at some point between the two faces there must be a point where there is no tension or compression. This point is called the neutral axis. The mass of material above and below the neutral axis will always be equal. So in a symmetrical member the neutral axis will be along the midline, but will not necessarily be along the midline in an irregularly shaped member. This simple concept of leverage can be used to explain several more complex concepts in structural engineering. The first is why it's easier to break a Popsicle stick when it's bent on its flat side as opposed to its edge. To explain this we have to explain the concept of leverage. This one is pretty simple and can easily be demonstrated by the classroom door. Leverage (also called moment or torque) occurs when a force is applied to an object which can rotate about a pivot point. In the case of the classroom door the pivot is the hinge and the force applied comes from the person wanting to open the door. In the case of bending a Popsicle stick the pivot is the neutral axis and the force we're concerned with is the tension or compression on the outside faces. Moment is calculated by multiplying the force applied by the distance from the point of force application to the pivot. If you increase the applied force, or the distance from the pivot point, the moment increases. That's why door handles are put as far from the hinge as possible – we make the distance from the point of force application to the pivot point as large as possible, that way a small applied force will create a large moment. So the Popsicle stick is harder to break when bent on edge because we've increased the distance from the neutral axis to the point of maximum force.

- Explain the difference between tensile, bending, and compressive forces with examples of the equations used to calculate each.
- Explain truss elements and why they are a superior way of building a bridge.
- Sample FEM output for simple bridge design
    - Calculate the amount of popsicle sticks required to make a simple beam with the same strength as a truss element.
- Hints on building a strong bridge
    - Truss
    - Strength comes from the Popsicle sticks, not the glue – but well glued joints are a must.

Additional information:
http://andrew.triumf.ca/andrew/popsicle-bridge/
http://www.eir.ca/resources/presentations/**Bridge**s%20-%20By%20Doug%20Knight.doc