A Demonstration of the Effect of Arches and Pre-Tensioning in Bridges

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Introduction

There are many ways to prevent or lessen the deflection (and ultimately failure) within a bridge under both its self-weight and applied loading. This shows a demonstration of how two of those ways, creating arches and the use of pre-tensioned concrete or cables, can do this.

Concepts

The use of an arch in a bridge resolves the applied loads into compressive forces and reduces the level of tensile stresses within the structure. The forces are also taken down a load path towards the base or supports of the bridge.

The idea of pre-tensioning uses a similar concept of reducing the tensile stresses within a structure cause by an applied load.

Model 1: Fixed Bridge

This is the simplest requirement for a bridge, to be able to span from one location to another over a gap (right). The bridge is just a regular 12 inch flexible plastic ruler.

Below shows a mass of approximately 250g balanced on mid-point of the spanning ruler. Added weights have been placed at the support locations to prevent the entire bridge from slipping.

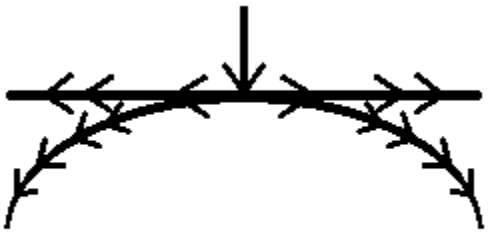
The deflection is quite a clear one here. This is what is aimed to be improved upon in the next two models.

Model 2: Simple compression arch bridge

The model (right) consists of a different, but identical, ruler for experimental control purposes spanning the same gap with another ruler (same type) arched underneath it. Because the gap distance is smaller than the ruler's length, the ruler is required to arch in such a way to fit in the gap.

Theoretically this bridge should hold a larger load with less deflection.

This is clearly proven; there is significantly more weight (a mass of approximately 650g) on the bridge and there is very little deflection involved.



The arch transfers forces applied partially into horizontal thrusts transmitting them to the base of the structure.

In other words the arch is providing a load path to the base, increasing the overall structural stiffness and effectively decreasing the overall deflection of the bridge.

Model 3: Pre-tensioned cables within a bridge

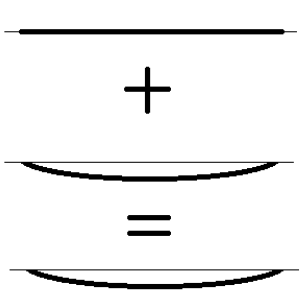
The next model is not a replica of what would be pre-tensioned cables within a bridge, but it does demonstrate the same effect of pre-tensioned cables. Again the same type of ruler is used over a gap of the same distance. Holes are made near the four corners of the rectangle, and these are for the string to go through, acting as cables within the structure. Equal weights are attached to both sides of the strings; this introduces the tension in the strings and pulls down on both ends of the ruler. This creates the slightest camber across the span of the bridge.

The images below show this arrangement holding the same loading applied as in model 1 its respective deflection:

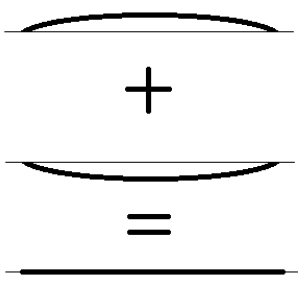

And the same again, but with a larger mass:


As expected the larger mass causes a larger deflection. Comparing this result with the one obtained from the first model of a simple bridge, there is not much difference in deflection even though model 3 is holding a much larger mass; proving the tensioned string is providing something useful to structure.

Simple bridge



Pre-tensioned bridge



The two diagrams on the left show the concept of the deflection obtained from a simple bridge and a bridge with pre-tensioning aids.

The same change in deflection is "added" on when a load is applied, but because the pre-tensioned bridge has an upwards camber, the result is a straighter bridge.

The similar concept can be applied when speaking about the tensile and compressive stresses with the material of the bridge. When pre-tensioning is introduced, the underside of the bridge

will go under compression; so when a load is applied it will cancel out or decrease the amount of tensile stressed in the bridge. This is a particularly useful concept for materials such as concrete, which is strong under compression, but weak in tension.

Conclusion

The models successfully show the positive effect of arches and pre-tensioning on bridges in deflection. The arches provide a load path to the base of structure and increase overall stiffness. The pre-tensioning is not as effective but also contributes to the stiffness of the structure, as well as introducing some stresses and a negative (upwards) deflection before loading is applied so they will ultimately cancel out, or reduce the overall effect.

These models just show a demonstration of one of each of the concepts. There are many more ways that arches and cables can be used in bridges.