So I'm going to look at truss behavior now, putting all these pieces together and figure out how a truss behaves. I think it's more fun to apply it to an actual bridge. So I chose a bridge, a local bridge, the Taftsville Bridge. It's a covered bridge, a wooden truss with a covering. It was built in 1836 by Solomon Emmons the third. So it's close to here. It's well documented. Lots of studies by the government and others been done on the bridge. And it was also recently reconstructed.

So it's got two spans. So it's a two span bridge, meaning there's abutments on both sides plus a column or abutment in the center of the bridge, so forming two separate spans. I've created a model here in a CAD program. I'm using SolidWorks, just a computer aided design tool that allows us to visualize and draw the actual truss. So this is one span of the truss drawn here. And it is just the truss, the arch.

So you can see the truss is very symmetrical. It's got two trusses on each side. It's got a roadway. I'll highlight the roadway down the center. So that's where the cars and the traffic go. That's where most of the load is going to get generated. And we approximated the load to be 20 kilonewtons per meter. So I've already done it as a line load down the center. And I'm going to take half that load to each side. It's a symmetric truss. So here I'll highlight this truss on the side. So each truss will take half of that load.

And then further for trusses, we said-- earlier I mentioned I like to apply the load at the joints. So that's the proper way to load a truss, is to apply the load at the joint. So if I'm taking half that load, that 20 kilonewtons per meter, over to this truss and then I want to apply separate loads at each of these panel points. And I've calculated that based on the width that each panel point is taking. And that's about 3.5 meters. So it will be a downward force each of these points. It turns out that's 35 kilonewtons. So that's the force that I'll be applying.

One thing about trusses, so this bottom number that I'm highlighting right here, so this bottom number on the truss, I typically call that a bottom chord. Just a fancy word for the bottom of the member. And then the top is the top chord. And then you have diagonals. So these members that I'm showing here are the diagonals and the vertical members. So that's kind of how we distinguish the different pieces of a truss bridge.

I'm actually-- so this is a great program to show the three dimensional characteristics of a truss. You can do analysis on this program, too. But I'm going to move to a different structural analysis program. I think it'll be easier for us to see what's going on. So I'm going to look at lines. So the truss members are represented by lines. Again, these bottom ones would form the bottom chord that I'm highlighting. And the upper ones up here form the upper chord.

I have it supported at both the edges. And I'll show you that I've already put the load on there. So let's go ahead and look at the loads on the joints. So there we see the 35 kilonewtons acting at each of those panel points. The units are shown down here in the corner as kilonewtons and meters. So all the numbers you see will be either in kilonewtons or meters.

So I've got the applied load. And really, let's just go in an analyze it. So when I use these programs, I'm using them to figure out deflected shapes, forces, stresses, what's happening in the truss. So let's go ahead and analyze the Taftsville Bridge.

And the first thing we see is a deflected shape. That's somewhat intuitive. So loads are just pulling down. So we see a nice bending form. The bottom, if we look carefully at this bottom chord where I'm highlighting it, looks like it got longer. Here was the original shape. And it got longer to do that bending. And then the top chord-- here was its original line. And it got shorter. So that indicates to me that the upper chord is going to be in compression. It's shortening, so it should be in compression. And this bottom number is getting longer. And it should be in tension.

So I can go ahead and actually look at the forces. So let's look at the axial forces in this case. In this diagram, the blue is indicating tension and the red is indicating compression. So we have the bottom chord in tension, which we expected. And the upper corner is red, so it's in compression. I can hover over these and see the values. So we see then the bottom chord, we have the largest force. And that's 280 kilonewtons in tension. Upper chord has pretty comparable but slightly lower at 262 kilonewtons.

And diagonals, all our diagonals in this model, are in compression. And that's somewhat important, and a much lower force. So the diagonals, especially the ones in the middle, do not carry all that much of the compressive force. The outer diagonals do carry a decent amount of compressive force. And that'll be important when we figure out the sizes.

So if I were designing this bridge, I would design the upper and lower chord to have the biggest cross section, and then the diagonals and verticals could have smaller cross sections, which is exactly what the designers did. So I have historic drawings that gave me all the actual shapes. And they're all rectangular wood cross sections. But they have different sizes.

I see I use one member for the upper chord, a different member for this lower chord. I have the diagonals in there as a smaller cross section. And the verticals have the smallest cross section. One difference is these diagonals and the end diagonals. The end diagonals again had that higher compressive force. So they are actually doubled up and have a larger cross section. So that's why they have their own separate name on their cross section. So the name just goes back to the material properties in the cross section that are stored elsewhere. And I've already put that in.

But let's go ahead now and look at the stress. So I'll rerun this, rerun it. And I can see the forces. Let's actually zoom in if we want to, so we can see those forces. And then I'll hover and see how the stress has changed. So on the bottom chord, we have 280 kilonewtons That the axial force and 262. Then if I switch to look at the axial stress, so let's look at the stress.

Again, if I want to calculate stress, when we calculate stress when we did for columns, just force over area. So I could do those by hand. The Computer is doing it for me. I can see in the bottom chord I get a stress of 2,325. I think the upper chord will have the higher stress. The stress in the chord is 3,750. And that's going to be in kilonewtons per meter squared. So again, my units are down here, so 3,750 kilonewtons per meter squared. That's the stress in the upper chord.

And that's what I would look at to figure out if the bridge is OK. So is that value high? Is it low? Is the bridge OK? We don't know the exact material properties. Somebody probably does. Somebody took probably a chunk of the original bridge and tested it. But a modern timber bridge would have an allowable stress of about 10,000 kilonewtons per meter squared, or kilopascals, so 10,000 versus 3,750 units.

So the bridge is OK. But we do like a high factor of safety on our bridges. Four or five is not unreasonable. So it's a little-- it's getting close. So at some point, somebody put an arch in this bridge as well. And I think that was to provide redundancy and to provide a slightly higher factor of safety, OK.

All right, so what else can we do with this computer model? I like to use computer models to kind of experiment to do little parametric studies. So we can change different things. And as a designer, I would change things to figure out how that changes my model, how that changes-- how design parameters might change how it's behaving.

And one thing I want to look at is the height. So if I change the height of the bridge, if I'd made the bridge taller, and we'll do that in a second, if I make the bridge taller, will the forces in the bridge increase, decrease, or remain the same? So I can go in here. And I'll change the whole height. I'm just going to change the grid. It's currently at a height of 3.5. I'm going to change that to seven meters tall.

And we should see the bridge get taller. And here we see it. It's a much taller bridge now. So it's twice as high. Everything else stayed the same. So I should be able to rerun it and get our analysis results. And let's make sure. I don't want to be in stress. So I'm going to change it to force so we can make some better comparisons. So here's the force, the forces in this taller bridge.

And let's look at the bottom and top chords. So the bottom chord was originally at 280 kilonewtons. And now we see it's only at 140. So increase in the height by two, decrease the force in the chords by about a half. Same thing for the upper chord. We still get fairly high forces in the diagonals. And it's not always completely linear. It'll be based on soffit weight, too. But it's pretty close. So increase in the height decreases the forces.

And that was analogous to what we found with funicular forms. So as those funicular forms were close to vertical, the forces were lower. As they got closer to horizontal, they were higher. So we're getting a similar behavior. So change in the height will change the forces. But where tension and compression are is all the same.

So what happens if I change the diagonals? So let me go back. And I'm going to go back to the original size. So I'll change this back to 3.5 meters high. OK. And let's run that and see the forces.

And again, remind ourselves that in this configuration, all of the diagonals were in compression. Verticals were in tension. We had tension along the bottom chord and compression along the top chord. But the diagonals-- the key is the diagonals were in compression. So that was for this configuration with standard kingpost truss. So what happens if I take all those diagonals and switch them? So instead at the middle they're making a V.

I've already drawn that bridge with reverse diagonals. So I'm going to switch to that one. And you see I've taken the original bridge and just switched all the diagonals. And I would like to see what happens. Everything about this bridge is the same. I used the same cross sections. I used the same load. Here I'll go ahead and show you the load. So it also carries 35 kilonewtons.

Everything's the same except for those diagonals switched. And let's go ahead and run it and see what values we get. So here's the picture of the axial forces. And we can see the bottom is still in tension and the top is in compression. That's not going to change. The load is still causing a deflected shape, where the bottom is getting longer and the top is getting shorter. So I expected those to stay the same.

We did get a slight shift. So 280 was the highest force in the standard kingpost Taftsville bridge. And it was in the bottom chord. It's now shifted to the top. So the highest force is in that upper chord. And it's in compression at 280 kilonewtons with a slightly lower force in the bottom chord. But the big shift to me is where we have tension and compression in the diagonals. So we now have tension in these diagonals, where we had compression before. And that can sometimes be desirable.

So as a designer, these diagonals are the longest spanning, open spanning portion of the bridge. And when they're in compression, we have a possibility of buckling, so pushing on it and it moving laterally, which is not desirable. So sometime shifting those and putting them in tension is desirable. I'm sure the designers looked at that. And the forces aren't all that high. But if you're designing a truss and you want to think about where you have tension and where you have compression. And you could do that by just changing orientations.

We will look at analyzing these by hand as well. And hopefully you'll see why those are switching. So if you're interested in understanding and calculating those forces, check out the next video. You can also try to build your own truss or a different type of truss structure.

All right, so this is my model of the Taftsville Bridge, a bridge not too far from Dartmouth. So I've modeled it all with pin joints. We're assuming it's pin joints. I have for external supports a pinned support on one side and a roller support on the other. Because that's the minimum number of supports we need. These yellow lines I'm using to represent the load. This would just be one load case. But it would be a pretty standard load case.

So I'll assume that's an evenly distributed load on the joints. That's the load from the deck acting downward. So my first step would probably be to solve for these reactions. And I can do that using the overall bridge. And I could sum moments about a point and solve for reactions. I can also notice that if it's evenly distributed, it's just going to have half of the load on both sides acting upward. But those would be solvable.

You would have potentially a horizontal force. But for this loading case, there is no horizontally applied loads. So this horizontal reaction would be zero. We'd just get these two upward forces. And that would be my starting point.

And then I would want to look at the forces and the numbers of the bars. Because that's how I'm going to be able design or analyze those bars to see if they have too much stress in them, or design this section to make sure it's the right size.

So how do we go about doing that? We would typically look joint by joint at the truss. The key is when I look at a joint, so I'm going to start with this joint, this support. So let's draw that joint. Those are the two bar forces. We have a reaction force. And I'll use this to show my force in the bar. So I've cut through the bar.

We know that a truss member has only tension or compression in the bar. So when I cut through those bars to draw this free body diagram, I'm exposing either a tension or compression force. My habit with trusses is to make those all tension. And if I get a positive value when I do my math, I'll leave it in tension. If I get a negative, I know it's supposed to be in compression. It just helps me keep everything somewhat more organized.

So I could use this free body diagram. I could sum forces in the X direction, sum forces in the Y direction and solve for these two bar forces. Let's call them bar one and bar two, or F1 and F2, the force in those bars. So using that equilibrium, I should be able to solve for those two. Then I could move to a new joint. So if I move here, I actually have too many unknowns.

So the better joint is to go up here. Because then when I draw the free body diagram for that one, I have that direction there and straight down, now I expose those bar forces. This is F1. So I know its value from my previous free body diagram. I'm left with two unknowns. I can again use two equations. And Y equals 0 equals 0 and solve for these two additional forces and just keep moving my way through the truss.

This happens to be a statically determinate truss. I've checked the number of bars plus three equals the number of joints times two. So it is solvable. And we can just move our way through.