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History and Physics:
The Covered Bridge at Old Sturbridge Village

An Interactive Qualifying Project Report
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By

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Authorship Page

The work was evenly divided throughout this report. In the earlier sections about the history of bridges in America, each group member covered two or three sections. Mike took the first three discussing the origins of trusses in Europe through the first pile driven bridges in early America. Dan followed up with king post and queen post designs and truss/arch designs. Finally, Joe wrote the sections pertaining to Ithiel Town and Howe / Pratt designs.

The technical section of the report was divided up in the same manner. Mike worked on the bullet points and potential model ideas. Joe wrote about mortise-tenon joints and explained why bridges were covered. Joe also addressed the conversion of loads to tension and compression. Dan covered seasoned lumber versus green lumber as well as the basics of tension and compression with respect to a large solid bridge with less material. Dan also spent some time reviewing the current OSV website and writing the section on suggestions for modification. He also wrote the section on the history of the 'Vermont Bridge' and a section about the basics of bridges.

After this initial drafting, all three group members worked on the report as a whole. Though various parts were divided up, the group made extensive use of peer editing techniques. The entire report was complied and revised by the whole group on several occasions. This IQP represents a group effort that was managed efficiently and effectively through the hard work and cooperation of the group.

Abstract

The purpose of this project was both to research the history of covered bridges in New England, and to explore ways that the engineering principles in these covered bridges could be explained to visitors of Old Sturbridge Village. The project focused particularly on the "Vermont Bridge" at Old Sturbridge Village.

Table of Contents

Table of Figures

1.0 Purpose

The purpose of this project was to relate technology to society. This was accomplished in two ways. First, we sought to explain how covered bridges work to the visitors of Old Sturbridge Village. Second, we researched the environment that made covered bridges a useful and important part of early America.

2.0 Literature Review

While there is a good deal of published material on covered bridges, much of it does not really pertain to this project. Several books in the literature romanticize covered bridges and serve more as tourist guides than historical or technical accounts of covered bridges. Some of these works provided useful information about a bridge's history; particularly what repairs were performed on it or the existence of earlier bridges on the same site. The most useful books for our purposes provided detailed information about how the bridges were erected and their major technical strengths and weaknesses.

The libraries that supplied our source material were the Gordon Library at WPI, the research library at Old Sturbridge Village, and the American Antiquarian Society here in Worcester. Many of the texts in the Gordon Library were of a technical nature, although some were either folklore pertaining to covered bridges or were general overviews of bridges throughout history. The Library at Old Sturbridge Village holds mostly tourist guides and books of poetry, but also holds a critical document, a copy of a brochure by Ithiel Town touting his Town Lattice. Town was a key player in early bridge design whose full history is discussed at length in the pages that follow. We also made use of previous research materials assembled at the library concerning the history of the bridge at Old Sturbridge Village.

The American Antiquarian Society yielded one of the most useful books that we found, *Theory of The Construction of Bridges and Roofs*, a textbook from 1873. This was approximately around the same time when the Vermont Bridge was constructed. It provided actual systems to model a Town lattice with, and while it might not have taken all of the forces and reactions in the Town lattice into account it certainly noted a large number (if not all) the engineering principles. Ultimately, a circulation copy of *Theory of The Construction of Bridges and Roofs* was found at the Gordon Library at WPI.

Overall, we found a large volume of literature covering the non-technical aspects of covered bridges and an equally large volume of literature on construction techniques. What all three libraries lack are books that explain the engineering concepts behind covered bridges to a general audience, one not necessarily having a strong technical background.

3.0 Computer Programs Used

During the course of this project, we made use of several computer programs. We made use of both Pro/ENGINEER Wildfire and AutoCAD. However, we found one program particularly helpful, West Point Bridge Designer 2004 (WPBD)[1]. WPI Professor of Mechanical Engineering Holly Ault, whom we consulted early in the process, introduced us to the program. The software enabled us to create model bridges and then test their strength when a moving load was applied. The United States Military Academy offers a contest each year utilizing this software as a realistic and engaging introduction to engineering. The software is free to download and use.

The program is rather simple to use when compared to the magnitude of its powerful calculations. Creating a new design in West Point Bridge Designer begins with a screen called "Select the Deck Elevation and the Support Configuration" (Figure 1); this screen allows the user to modify several options.

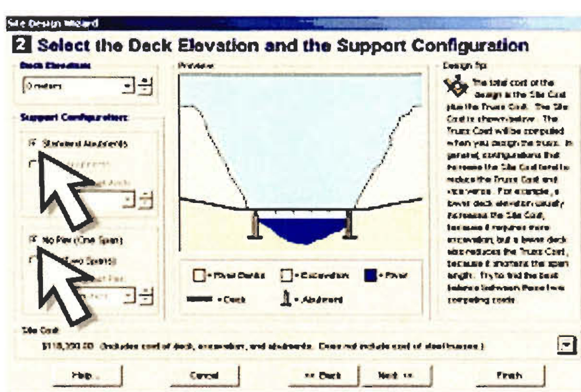

Figure 1: First Screen of WPBD

The next screen allows one to select a Standard Truss Template or elect to create a new template. For the most part, we chose to create our own. After choosing the

[1] http://bridgecontest.usma.edu/

template, the Drawing Board Screen appears (Figure 2). It is on this screen where the bulk of the design is completed.

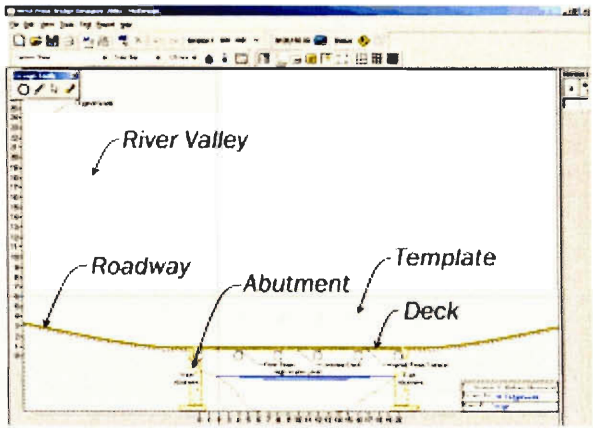

Figure 2: Drawing Board of WPBD

Major functions of the drawing board include placing joints and members. Joints, being places where members intersect, are placed first using the onscreen rulers as a guide. Members, being large supportive beams, are laid down second, drawn from joint to joint. (Figure 3)

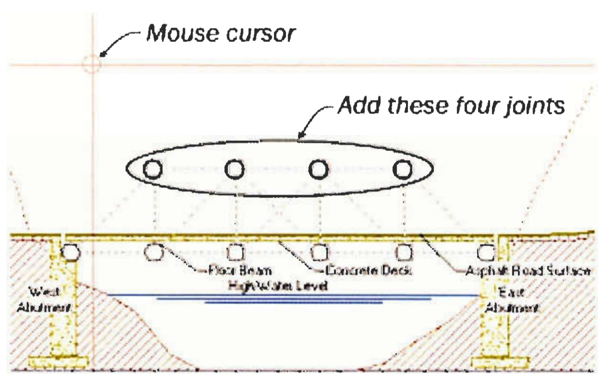

Figure 3: Joints

Finally, WPBD allows one to select member properties for each individual member. Things such as material, cross section and size of the structural members are available for modification. (Figure 4)

Figure 4: Material Properties Bar

Finally, after the design is complete and the materials selected, a load test is possible. Here the computer crunches numbers to determine if the bridge is stable and if so it allows a truck to drive over it. While the truck is driving over the bridge, the members glow blue and red designating both tension and compression respectively. This ability to watch such forces in action is invaluable. (Figure 5)

Figure 5: Load Test in Action

4.0 Technical Aspects of Covered Bridges

The following section will address technical issues related to bridge design. This section attempts to explain how the physics of such bridges work. It also attempts to use language in such a way that any park visitor would be able to understand the fundamental concepts behind these structures. Also included in this section is a brief history on the 'Vermont Bridge' of OSV.

4.1 Bridges: The Basics

Bridges are an important part of everyday life. Bridges provide passage over some sort of obstacle. While some bridges are well known, like the Golden Gate Bridge (Figure 6), most are nearly invisible to the modern day traveler. In fact, most people take bridges for granted. The following paragraphs will explain just how these seemingly natural structures work and function today.

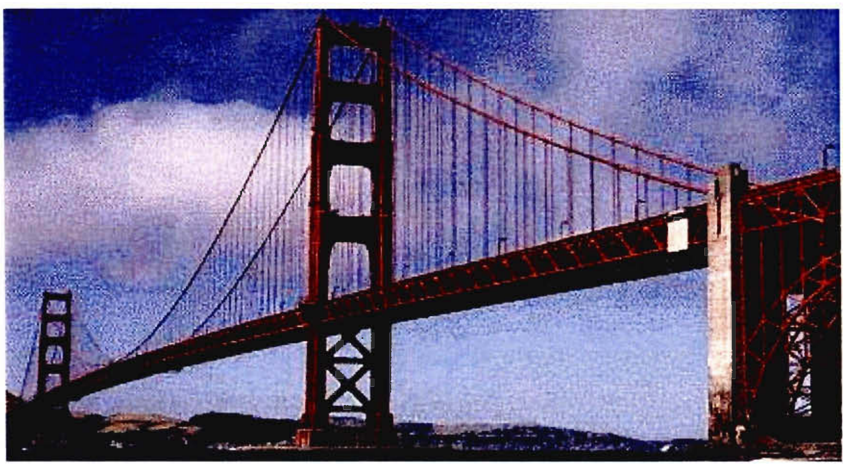

Figure 6: The Golden Gate Bridge

There are really just three types of bridges: the beam bridge, the arch bridge, and the suspension bridge. The major difference between the types is the distance they are able to cross. In the world today, beam bridges are used to span shorter distances. Arch bridges span medium distances. Suspension bridges span giant distances. Behind all the technology associated with bridge design lays some very simple concepts dealing with the forces of **tension** and **compression**.

The beam bridge is the simplest type of bridge. It consists of a rigid horizontal structure (a flat surface) resting on two ends. All of the weight placed on top of this bridge is traveling directly downward. For example, the elephant in Figure 7 has bent the bridge under its weight. However, the beam is not just moving one way. There are two forces at work, what engineers call tension and compression. One of these, tension, means pushing out, just as if you pulled the two ends of a spring apart. The bottom of the beam in the bridge is experiencing tension. Nevertheless, the top of the beam is getting smaller, the force engineers call compression. Compression can be seen when you push the two ends a spring together. In Figure 7, the red arrows show the beam in compression; the blue arrows the tension.

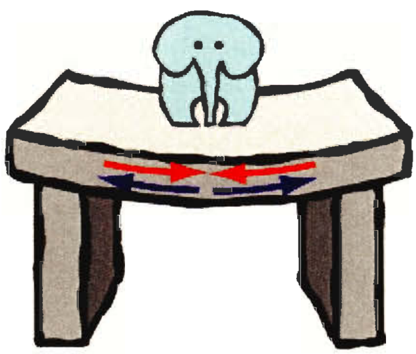

Figure 7: The Beam Bridge

The arch bridge uses these same two principles in a different way to reach even greater distances. As an elephant passes over an arch bridge, it pushes the ends toward the center, compressing the top. The arch bridge is squeezed together and the forces are carried outward along the arch to each end. The ends in turn push back and this results in the arch remaining intact (Figure 8). The arch bridge naturally moves the weight from the bridge deck to its ends, the abutments. The arch bridge is always under compression.

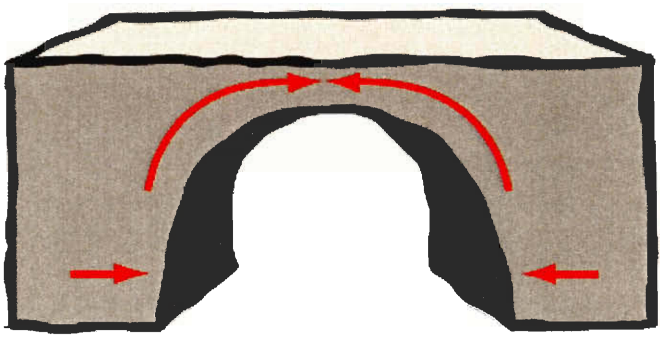

Figure 8: The Arch Bridge

Finally, we come to the suspension bridge, which is able to span the greatest distances. This type of bridge uses large cables to hold up the roadway. These cables, metal ropes, are draped over towers and then tied into blocks at either end. As cars travel over the bridge, the cables undergo tension, which in turn causes the towers to undergo compression as seen in Figure 9. Through this ingenious system, suspension bridges can span gigantic distances.

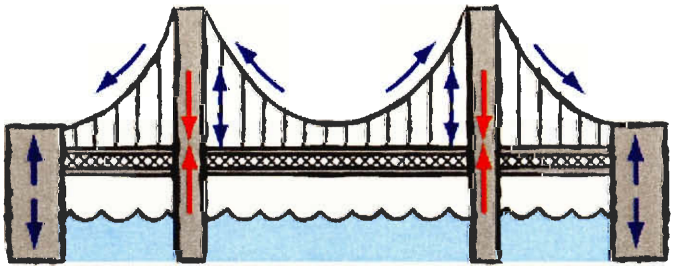

Figure 9: The Suspension Bridge

Finally, it is worth mentioning a little more about beam bridges. The bridge at Old Sturbridge Village, like most covered bridges, is a special sort of beam bridge. Beam bridges are made stronger by a truss system. A truss system uses triangles between an upper and lower member to dissipate a load throughout the truss work. Each member is alternatively placed in tension and compression (Figure 10). The next section will cover the technical details behind the truss system; more specifically, how it applies to the Town lattice.

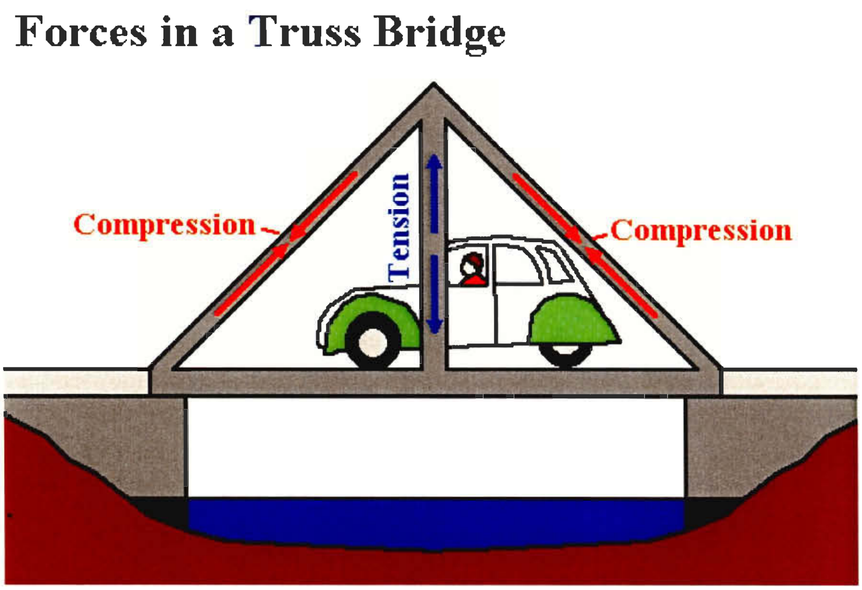

Figure 10: Forces in a Truss Bridge

4.2 Bending, Tension & Compression

The purpose of any given bridge is the same, to allow passage across a depression or obstacle. While the purpose of a bridge is very simple and straightforward, the physics behind a bridge are more complex. This report explores the Town style lattice in some detail using simple explanations and diagrams that may be helpful for Old Sturbridge Village staff seeking to educate their visitors.

To begin this section, a simple bridge will be analyzed to introduce basic topics such as bending, tension, and compression. To start, let us picture the simplest of all bridges: a Simple Beam Bridge. This would simply be a continuous wooden beam spanning a gap of some sort (Figure 11). If we apply a downward force at the center of the

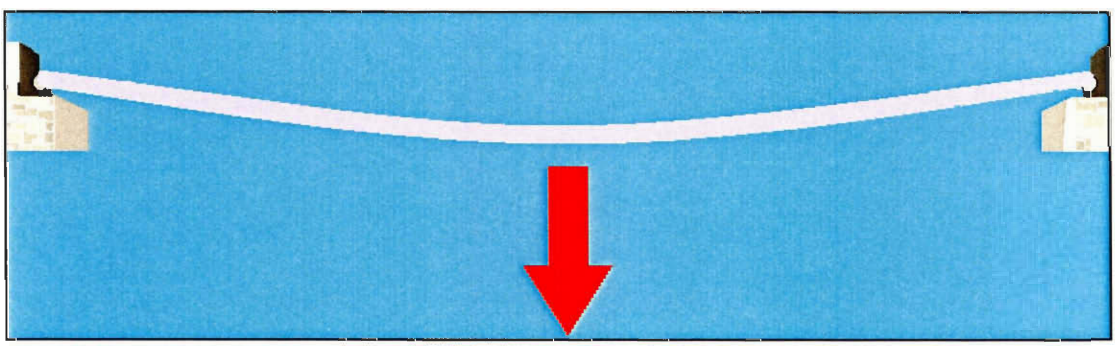

Figure 11: Bending in a Simple Beam Bridge

bridge similar to someone standing in the center, we will see that the beam bends. The bending of this beam is caused by the torque that the force exerts on either abutment, the abutment being otherwise known as the point at which the bridge is secured at either end. One only needs to be familiar with Newton's laws, namely for every action there is an equal and opposite reaction. For any weight pushing down on the center of the bridge, the abutments must push up an equal amount. Now you have forces acting in opposition that are offset from each other. This is a very important factor, because you have **bending moments** acting on the object instead of purely **normal forces** like **compression** and **tension**. A good way to explain this difference would be to use an analogy:

1) Take a pencil and place it on a flat table surface. Now press down on the pencil. This pencil is in **compression:** your finger is applying a force in one direction on the pencil and the table is reacting against that force. The important note is that the reaction is **directly against the force of your finger**.

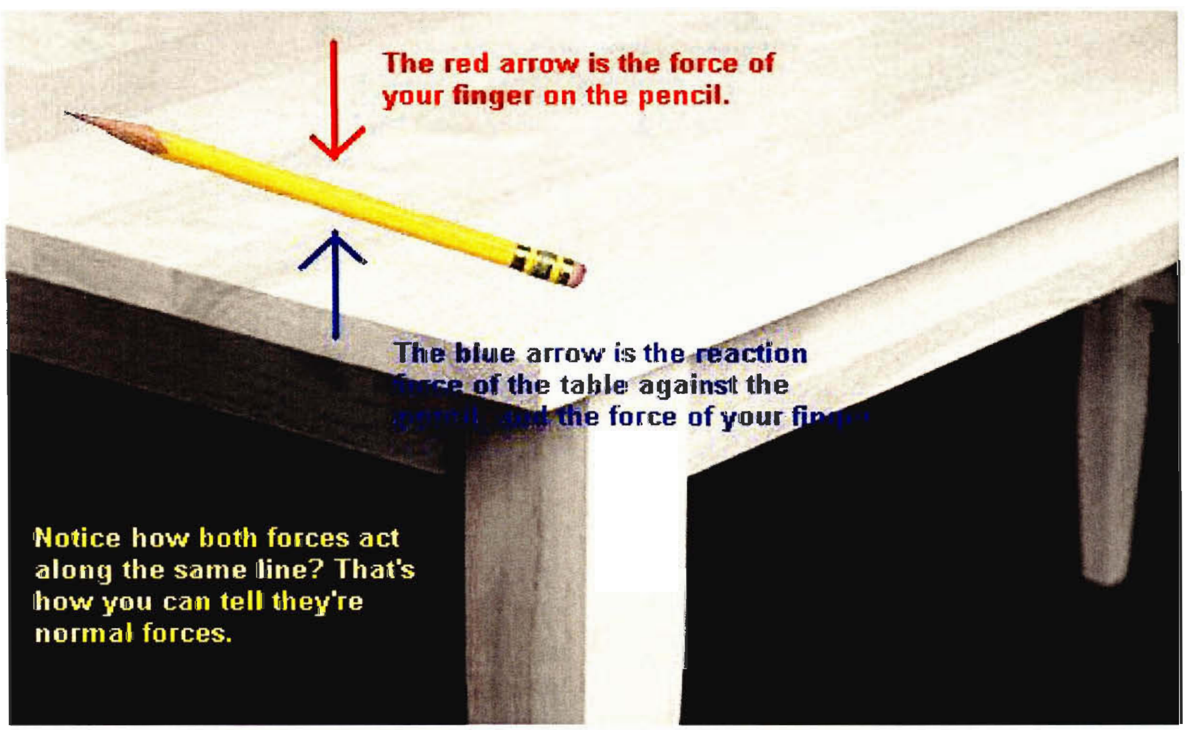

Figure 12: Normal Force Pencil Example

2) Now take the same pencil and place half of its length on the table and half over the edge of the table. Now press down at both ends. You now have something more closely approximating the forces applied to a bridge. One finger is pressing down over

the edge, the edge of the table is pressing up against the pencil, and your other finger is pressing down against the pencil. There is one important thing to note here **none of these forces are acting directly against each other**. Each is offset by a distance, making the pencil act like a lever and the edge of the table like the fulcrum. Now instead of simply dealing with force we are dealing with **bending moments**. A **moment** is a force that has leverage. For example, it is difficult to turn a nut without a wrench, this is because using a wrench gives you leverage. In principle if you double the length of a wrench, it will take half as much force to turn the nut. This is because the action and its equal and opposite reaction are further apart. When dealing with a moment the force being applied is **multiplied** by the distance of how far it is from the thing it is being applied to. To extend the analogy, if you are trying to lift something heavy with a lever you are using **a small force with a long lever applied by you to defeat a large force with a small lever applied by the thing you want to lift.** The equations are now dealing with **length** and **weight** instead of just weight; this is why the pencil is more likely to break when pressed on the edge of the table, and it is one of the **most important principles in bridge design.**

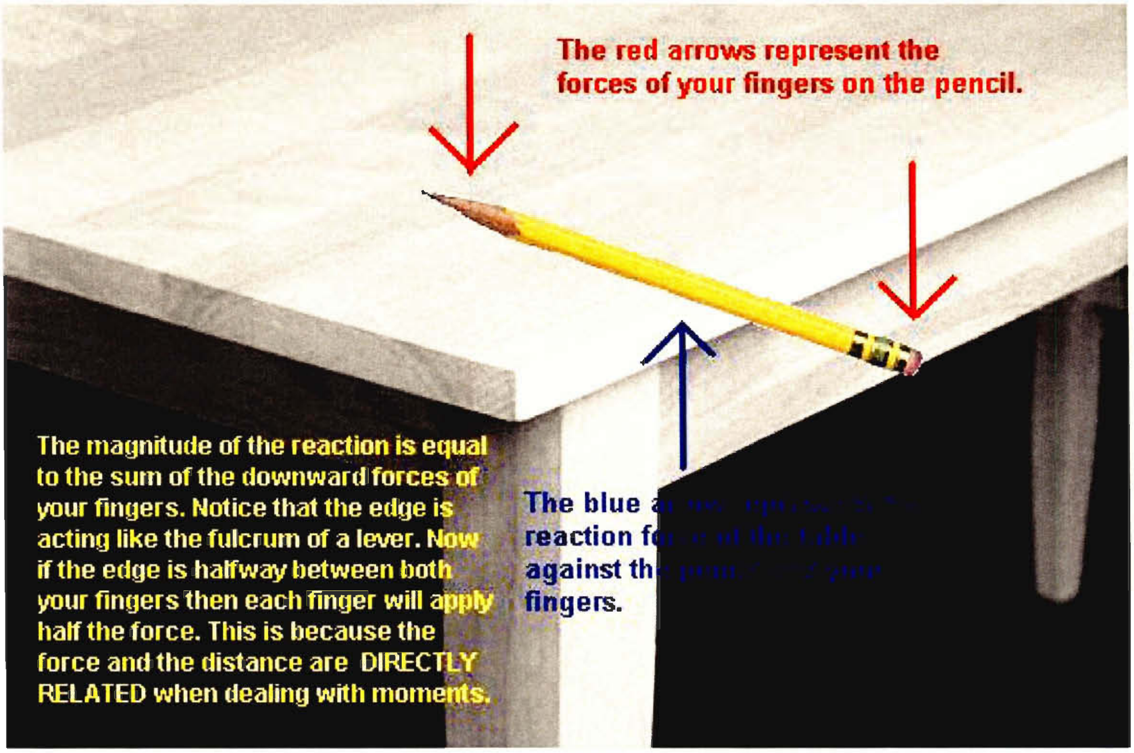

Figure 13: Applied Moment Pencil Example

Now compare the two pictures of pencils. Look at the forces and where they are. In the normal force pencil, the force and its reaction occur at the **same point along the pencil meaning no moment.** In the applied moment, pencil there is **distance between the forces causing a bending moment.** Notice in the diagram below there are two boards laid across a ravine, like a bridge. A weight sits on each board, now since a moment is equal to the force applied times the distance between the force and its reaction, it makes sense that doubling the length of a board will double the bending moment just like doubling the weight would double the bending moment. Therefore, a bridge twice as long is subject to as much bending as a bridge with twice the weight, at least with regards to moments.

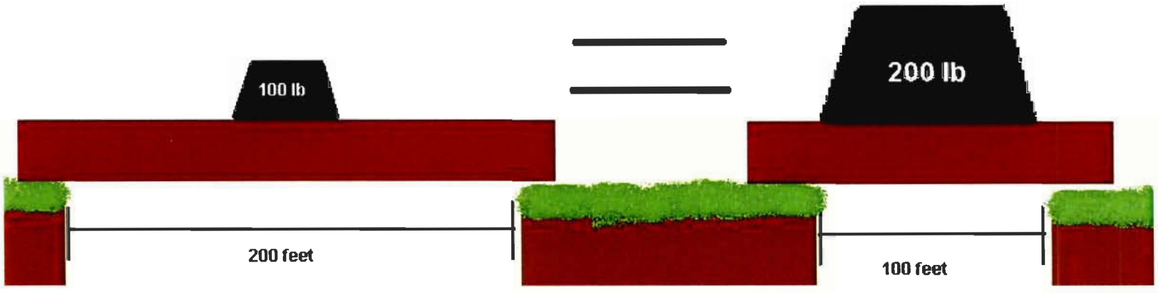

Figure 14: Long Bridge Small Weight = Short Bridge Large Weight

It is important to understand the difference between moments and normal forces. Moments occur when a force and the force in reaction to it are not aligned along the same axis, but instead they are offset. There are two kinds of normal forces: compression and tension. Any object in tension has forces being applied to it that are directed away form each other. These forces would tend to elongate the object in tension. Any object in compression has forces being applied to it that are directed towards each other. These forces would tend to squish an object being compressed.

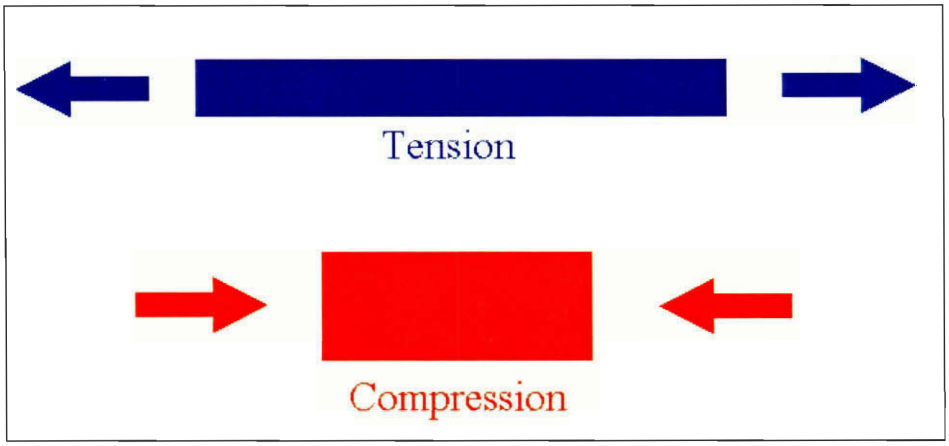

Figure 15: Tension and Compression

Both compression and tension are called **normal forces** because while they act in opposition they both act **along the same axis**. There is a second kind of force/reaction couple called a shear force. Shear forces are similar to moments because they do not act along the same line of action. With shear forces, the force and reaction are right next to each other, but not along the same axis; this makes them like the blades of a pair of shears. A major reason it is important to differentiate **normal** and **shear** forces is something called **stress**. **Stress is force applied over a cross sectional area**, and different materials have different **maximum allowable stresses**, the most force that can be applied over an area before the material begins to break. The major point here is that a material's **maximum allowable normal stress** will not be equal to the material's **maximum allowable shear stress**. The best real world analogy for this would be opening a bag of chips. If one were to pull directly on the top and bottom of the bag it would take far more force to tear the bag than if one were to apply a shear force to the top of the bag. Often times people will use shear force to tear things instead of normal force without even knowing that is what they are doing. Try tearing a thick pile of papers sometime, and you will likely find you use shear force as opposed to normal force. This leads us to the differences between the shear and normal maximum allowable stresses of wood.

4.3 Tensile Strength

The major function of any truss system is to transmit the weight of the vehicles that use the bridge to the abutments. The efficiency at which they do this is what makes for a successful, durable, and cost effective bridge. Since we are dealing with wooden bridges, it would be helpful to know something about the wood itself. Wood is composed of grains running parallel to the length of the tree. These grains produce vastly different properties depending on the direction in which they are oriented. For instance, Red Oak has an ultimate **tensile strength (maximum allowable normal stress)** of 16,300 PSI parallel to the grain, but perpendicular to the grain **(maximum allowable shear stress)**, it drops to 7,200 PSI[2]. Douglas Fir also exhibits a similar condition when its ultimate tensile strength drops from 15,600 PSI to 350 PSI.[3] So as you can see Red Oak is more than twice as strong if the wood is in either tension or compression versus the load being applied perpendicular to the grain in a shear situation, while Douglas Fir was more than 40 times stronger. Wooden bridges used this fact to their advantage by building truss systems that can ideally be looked at as two force members, meaning that they are only in tension or compression. Therefore, when a load is applied to the deck of the bridge, the weight tries to push the bridge down. Instead, the nearest truss is put in a state of tension and holds the bridge up. (Figure 17)

As the span of a bridge increases, it becomes progressively more difficult to design and build the bridge. This is because the increased length of the bridge also brings along a large increase in the weight of the bridge. Another factor to consider is the bending moment exerted by a given weight on the bridge. Therefore, if the span of a

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[2] Callister, William D, Material Science and Engineering an Introduction (New York: John Wiley and Sons Incorporated, 2003) 749.
[3] Callister, 749.

bridge were doubled, its weight would also increase two-fold or more. Moreover, of course, if the length of the bridge doubles, the bending moment will increase. The bending moment that affects the bridge as mentioned above is equal to weight times distance, so for this situation the bending moment will increase by a factor of 4.

4.4 The Truss System

To nullify the negative effects of the long span bridge, it is necessary to use a truss. The job of the truss is simple; it has to transfer the weight of the bridge itself and the weight of anything on it to the abutments. If it does this efficiently, there will be very little weight left to bend the timbers of the bridge. If it does not transfer the load to the abutments in an efficient manner, then there will be a lot of unsupported weight in the center of the bridge, and hence, a high bending moment. The efficiency of the truss is what separates the successful truss designs like the Town, Howe, and Long trusses from the other trusses that floated downstream and ended up as someone's firewood.

The efficiency of the truss depended on its geometry, materials, and possible construction techniques. The geometry is the most difficult part, especially for some early bridge designers who used very little mathematics, if any, to analyze their structures. Instead they used common sense, which can be almost as effective, to design their trusses. When common sense failed, which it often did, they would surely fall back on determination, and build another.

The red arrow in the simple illustration below (Figure 17) is pulling straight down on the center of the multiple king post truss system. This will act similar to the way it would act if a large object were parked in the center of the road surface. To start analyzing the truss system we will start with the upper and lower chords, which will act in unison, because they are tied together by the lattice system.

Picture a giant solid beam, one that if hollowed out you could drive you car through. When looking at this giant log from the side and watching it bend under force, one can envision the top is under compression and the bottom is under tension. (Figure

16) Upon further analysis, one can see that somewhere towards the center of the timber the forces of tension and compress negate each other. If the material in the center of the bridge is under no load, it therefore is not helping hold up the bridge. The greatest stresses are acting upon the top and bottom chords, the long pieces of wood running along the top and bottom of the bridge. However, the top and bottom chords need to be held together so that when a load is applied to the bottom chord it is transferred to the top chord also. That is one of the jobs of the truss system, which transfers the forces much more efficiently than a solid piece of lumber. It does this more effectively because of the fact that wood is stronger parallel to the grain than perpendicular to the grain, which was discussed previously. This creates a sturdy yet lightweight structure allowing passage over rivers and valleys.

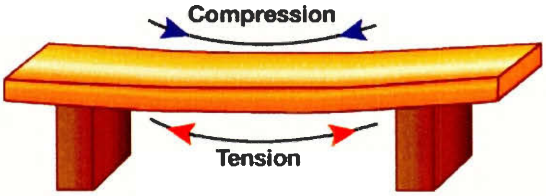

Figure 16: Tension and Compression

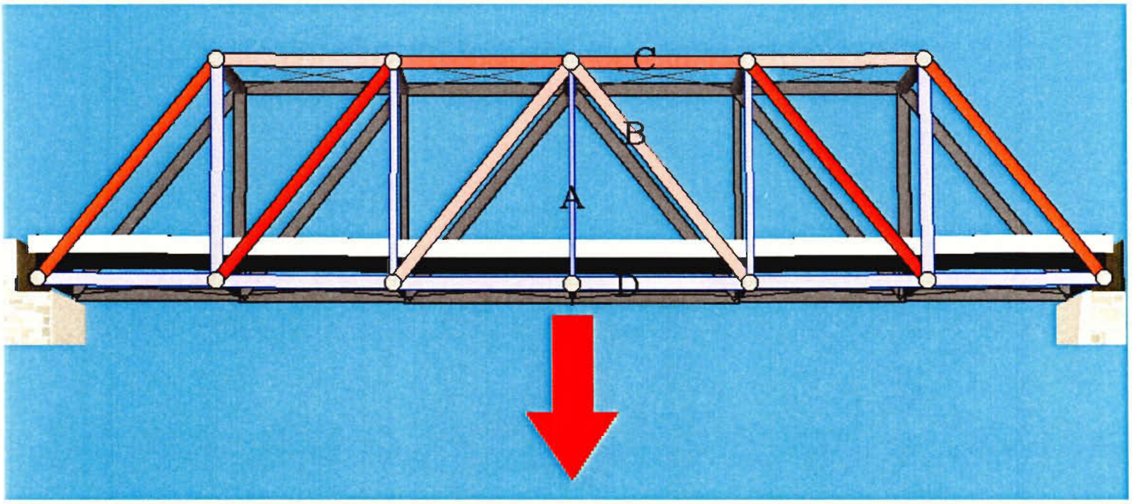

Figure 17: Red Members are in Compression; Blue Members are in Tension

Knowing that the lower chord is in tension and the upper chord is in compression, we can move on to the individual members. The plummeting lower chord would pull member A in the above figure downward. Therefore, member A would have to be in tension if the force is pulling it apart. Member A is going to pull downward on both members C and B. Member B is going to be in compression because of the force being directed inwards. Member C is going to be pulled downward, and be in compression as stated above. Member B is going to push downwards on the next member and this pattern will continue until the lattice ends and the force is transmitted into the abutment.

The importance of the materials selected for the construction of the bridges cannot be overstressed. The properties of wood vary considerably depending on the species. The strength, density, hardness, and durability of the wood are especially important for bridge construction. Through trial and error, it was found that Spruce was the preferred wood for the upper chords and the truss system.[4] The lower chords were found to work best when constructed out of Southern Long-Leaf Pine, and the treenails were always made from oak.[5]

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[4] American Society of Civil Engineers. American Wooden Bridges. (New York: ASCE Historical Publications, 1976) 50.
[5] American Socie120ty of Civil Engineers, 50.

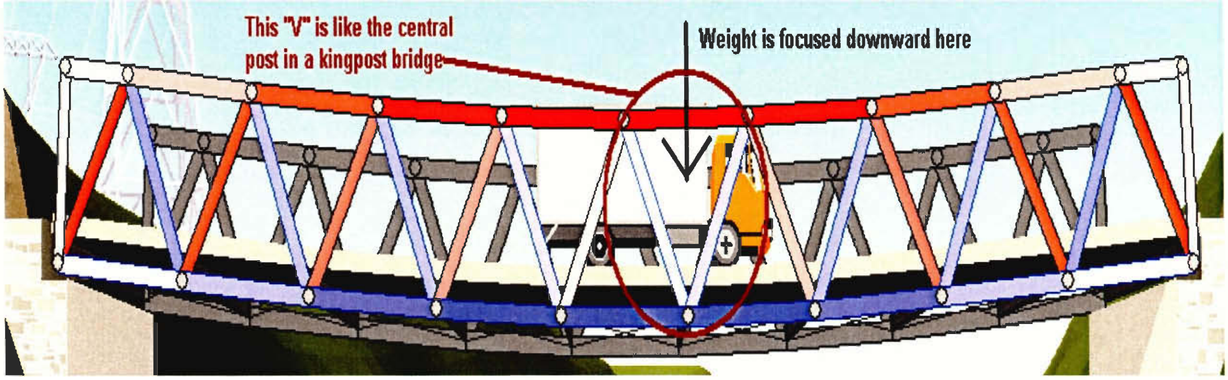
4.5 Truss Construction Techniques

Construction techniques are the final major factor in designing a functional truss system. No matter how perfect a given truss design is, if it is not constructed properly, it is destined for failure. Therefore, the skill and patience of the bridge builders plays an important role in the success or failure of a bridge. An experienced bridge builder would be capable of constructing the bridge, but also of predicting the future. For instance, most early bridges were constructed from green hewn timbers. These timbers will shrink considerably when they season, which can be potentially devastating for a bridge. Nevertheless, experienced bridge builders, who have probably already lost a few bridges, have figured out ways to reduce the effects. They could cut the boards too long, having calculated what the boards will shrink to. They could also use iron hardware and bolts, so as the bridge changes shape, they could adjust it using the screws.

4.6 The Town Lattice: How It Works

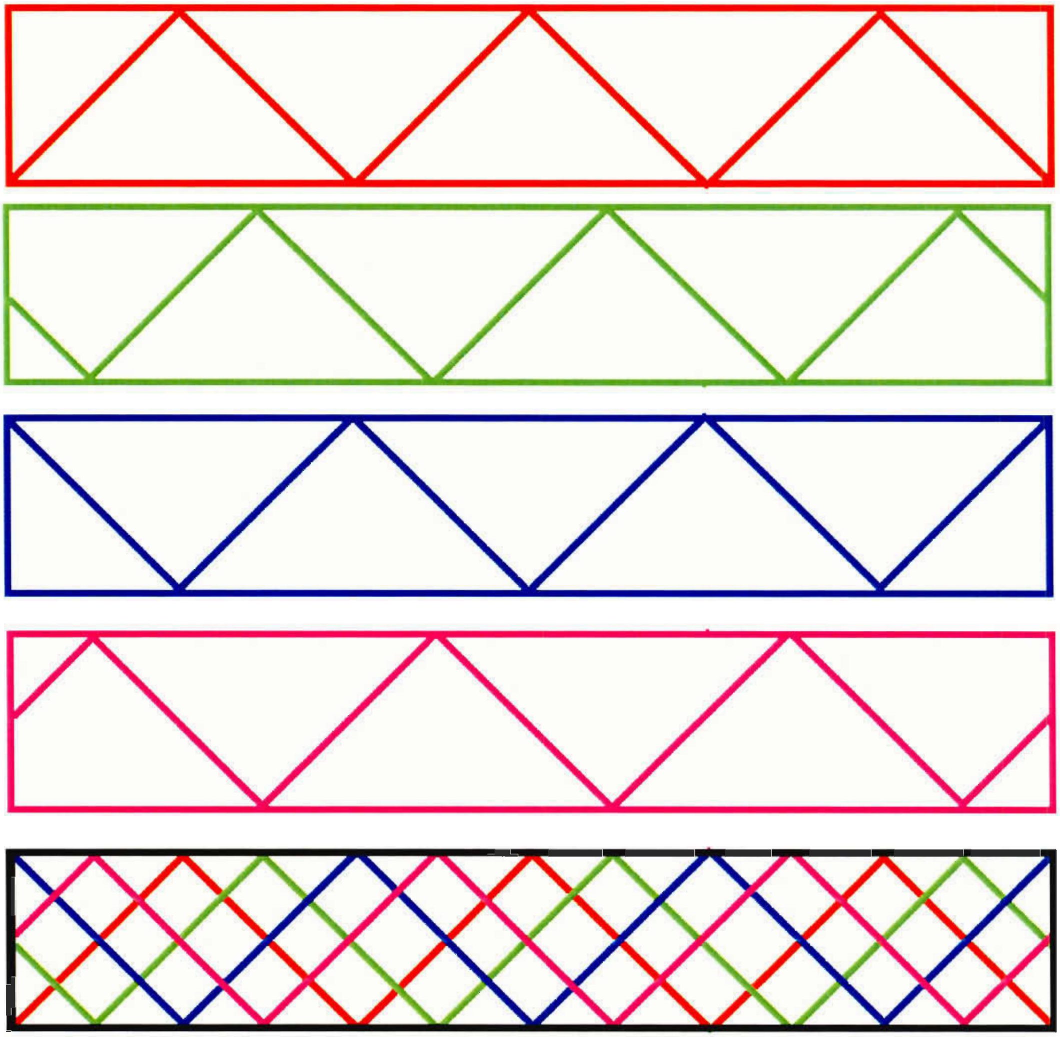
The Town lattice is named for Ithiel Town who patented the lattice design in 1820. There is some dispute over whether he invented the design or whether there were pre-existing designs in Vermont, but Ithiel Town was competent in both engineering and business. This set him apart from several of his predecessors who were often rural craftsmen with little formal engineering education and rarely worked to ensure they got credit for their work.

Town's lattice can be best explained as a series of triangular trusses that are combined to form a single truss. This of course raises the question, "How does a triangular truss work?" the answer is: pretty much the same way as a kingpost truss. The only difference is that instead of having vertical posts the triangular truss uses other angled posts to support the tension of a moving load.



Here blue denotes tension while red indicates compression. Notice that this triangular truss is really quite similar to a multiple kingpost design. The only difference being that instead of a central post. Here there is a central "V" to be in tension. Apart from that it transmits force the very same way.

Figure 18: Triangular Truss System



A Town Lattice is effectively four triangular trusses, overlaid one on another. As a load moves along the bridge it transfers from one triangular truss to the next. In this way there is almost always a support underneath the moving load.

Figure 19: Town Lattice

The big bonus of the Town Lattice (Figure 19) is that the weight is spread over several smaller trusses. This has a number of benefits besides the obvious one of spreading a load over a larger system. With multiple trusses, each truss could be smaller and thus bridge builders could use milled timbers instead of large logs that they would have to hew themselves. Apart from the fact that it was faster and easier to mill lumber than it was to hew it there was also the benefit that milled lumber was seasoned while hewn lumber was green.

Wood expands and contracts with direct relation to temperature and moisture. Even though this was a known fact, green timber, the wood of freshly cut trees, was often used in bridge construction. Generally, a 12-inch wide board would shrink to around 11 ¼ after it had fully seasoned.[6] This shrinkage could lead to huge stresses at the connections years after the bridge was constructed–and to the bridge's premature failure. Therefore, there was a huge advantage to using milled lumber, which could easily have had time to season prior to construction. This worked out well for Town's particular design as his method relied on smaller pieces of wood that could more easily be transported from sawmills to the construction site.

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[6] Yeomans, David T, The Development of Timber as a Structural Material (Brookfield: Ashgate Publishing Limited, 1999) 252.

Yet another advantage to using smaller members in the bridge was the fact that a Town Lattice did not use mortise and tenon joints. Oddly enough, a lack of mortise and tenon joints is actually a good thing when referring to the structure of a wooden bridge. After the beam is cut to be the tenon, its cross sectional area has been reduced by 66% on average.[7] Therefore, the weakest part of the beam no matter how big it may be is going to be in the tenon where it has the smallest cross sectional area.[8] The mortising process also weakens the bottom chord where the beam attaches. You effectively reduce its cross sectional area by 20% and effectively reduce its depth by 50%.[9] This is a major concern, because wherever the lattice members are mortised into the horizontal members, the horizontal members are weakened

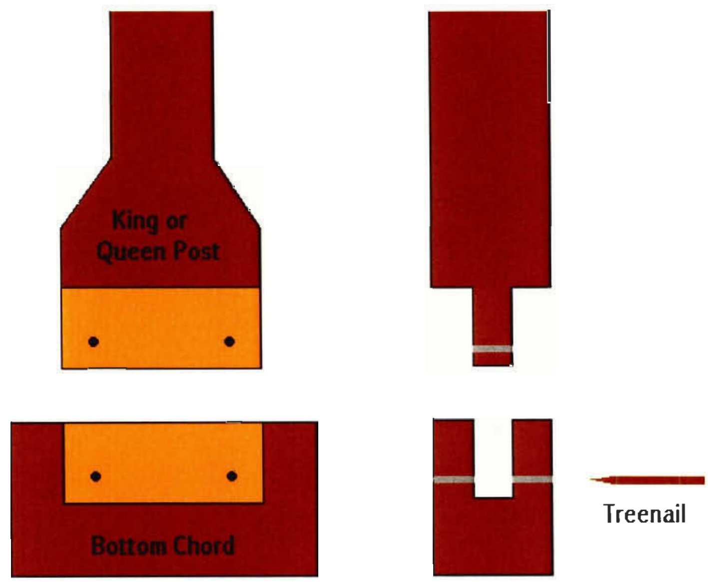

Figure 20: Mortise and Tenon Joints

[7] Yeomans, 262.
[8] Yeomans, 258.
[9] Yeomans, 258.

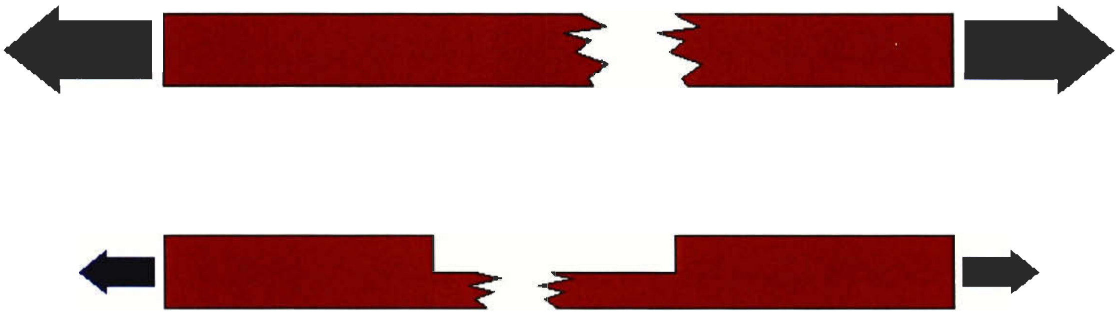

Figure 21: Failure of Full-Sized Beam vs. Reduced Beam

tremendously after they are mortised for every member (Figure 20). Since most of the members of any truss system can ideally be considered two-force members (they are either in a state of tension or compression) it is possible to use the following explanation. Let us say that a given beam is broken in tension with a force of 10 tons. Now lets say that the beam is notched, so that its cross sectional area is reduced by 50%. This beam with the reduced cross section will fail with a force of roughly 5 tons in the reduced section (Figure 21) These principals will still hold in a similar fashion for beams in tension, compression, or shear forces (bending the beam). The members of a Town Lattice are not mortise and tenon joints, and therefore the Town Lattice was not subject to the weaknesses of mortises and tenons. Instead, a solid member was used so there was no "weak point" on the member. Furthermore not putting in a mortise and tenon setup made building a Town lattice faster and easier since you did not have to chisel anything out, you just had to drill the holes.

This brings us back to ease of construction. Since the Town lattice was composed almost entirely of small common sized pieces of lumber, it was possible to purchase them at local sawmills or lumber yards. This saved a lot of time during the construction process, because it meant that they did not have to hew their own beams from felled trees. These small pieces of lumber could be maneuvered by hand much easier then larger hewed beams necessary in some other lattice types. Some of these larger beams would often require the building of a crane to help position them, whereas the lumber in this lattice could more often than not be done completely by hand.

4.7 Why Cover The Bridge?

Whenever discussing covered bridges the first question that always comes to a child's mind is always, why is the bridge covered? To answer this question, here is a list of all the possible reasons, starting with the most important and working towards the more whimsical. The most important reason for covering a bridge is to keep water out of the bridge's joints.[10] Here water could either freeze or cause rot, depending on the season. The roof could in many cases actually double the life of a covered bridge. The second reason is to keep the roadway clean and dry, to reduce slippery conditions.[11] The addition of the roof also stiffens up the bridge considerably, similar to the way a roof on a car is a vital structural component.[12] The roof also helped to keep the bridge's timber from drying out on hot summer days.[13] It is said that many farm animals would not cross a bridge if they could see or hear the river, so the covered bridge must have made the crossing much easier.[14] Finally, the roof kept snow off the bridge in the winter, even though in practice snow had to be thrown back onto the bridge so that horse drawn sleds and sledges could be slid through with greater ease.[15] The planks that people traveled over might do better when exposed to snow, however the main supporting structure had no need to be exposed to the elements, actually moisture and heat applied to any wood will cause it to crack and decay over time. Therefore, it still made sense to cover a bridge to protect the truss from snow.

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[10] Sloane, Eric, American Barns and Bridges (New York: Wilfred Fund Incorporated, 1954) 85.
[11] Sloane, 85.
[12] Sloane, 85.
[13] Sloane, 85.
[14] Sloane, 85.
[15] Sloane, 85.

5.0 History of Early American Bridges

The following section considers various design issues in the history of early American bridges. It considers different sorts of bridges roughly in the order they developed. It ends with Ithiel Town and his truss system, as these issues are most pertinent to the Vermont Bridge at Sturbridge.

5.1 The Origins of Truss Reinforced Bridges

Truss bridges are a recent development in the history of bridge architecture being introduced sometime during to the sixteenth century.[16] Surviving bridges before that date were predominantly constructed of stone using an arch design. Nearly all wooden designs, including pile supported, arch supported, or pontoon designs, have decayed and disappeared over the years. The only other accounts of early wooden bridge building (aside from the decayed pile, arch and pontoon bridges) are suspension bridges built by the early South American and Central American nations like the Mayans and Peruvians.

Palladio and Leonardo DaVinci developed early truss system and covered bridges in Europe[17]; a few early truss bridges were built in their time. However, the wooden truss technique did not come into widespread use in Europe. Later in 1742, Giacomo Leoni translated the works of Palladio into English. Shortly thereafter Palladian architecture came into common style in England when "Lord Burlington… had an 87-foot bridge of the Palladian arch-truss design erected in the garden of Wilton Park".[18] Still, while they may have been fashionable, wooden bridges were not the norm in Europe. Reliable stone arches were already in wide use throughout Europe, so there was no need to replace them with wooden truss systems. Furthermore, "Sizable, workable wood had become scarce."[19]

While it would seem that the Colonies provided an ideal environment for applications of Palladio's work (as timber was available almost everywhere) this did not mean that his designs were initially used in the American colonies. On the frontier, there

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[16] Tyrrel, Henry Grattan, History of Bridge Engineering (Chicago: Published by Author, 1911) 121.
[17] Tyrrel, 121.
[18] Allen, Richard Sanders, Covered Bridges of the Northeast (Brattleboro: The Stephen Greene Press, 1974) 11.
[19] Allen 11.

was a greater potential for skilled craftsmen to hand down their trade from generation to generation. So while covered bridges and truss systems embodied engineering principles that may have been practiced and available in large population centers it can be assumed that even in the post-revolutionary period there were pioneers breaking into new territories by using the familiar technology and materials that they had available to them at the time.

This section will perhaps explain the seemingly disjointed progression of this paper. More heavily settled areas would often pursue advanced engineering techniques, while areas that were being explored might only use engineering techniques for transit as advanced as walking across a felled tree. I hope that this will explain the jump from bridge building and truss systems in Europe to the progression of bridges in the new world.

5.2 Felled Trees and Pontoon Bridges: The First and Simplest Bridges

When early Americans needed to cross rivers they might not have had very much training as craftsmen and they might not have had sawmills available; in fact they might not even have bothered to hew the logs they used in construction. The very first bridges were built using techniques like these: one or more trees were felled and the logs were laid side by side across the space that was to be crossed. In many cases, the only place that the logs would have any support would be at either bank or where there might be some sort of post support.[20] Bridges of this type might have additional structural components. For example, in some cases the surface of the bridge would be packed with dirt so that travelers would have a smooth surface to travel over. In other cases, a handrail made from a small sapling might be placed on one side of the bridge.[21]

These early bridges had some rather obvious technical weaknesses. Many of them probably offered very poor footholds since they were made out of simple logs and the rounded edge would be treacherous, particularly if the bridge was only one log wide. With no central post supports, the length of the bridge would be limited, after a certain distance the logs would begin to bow in the center and ultimately crack from bending too much. There is also the question of how the logs might be secured together. If they were bound by cord or rope that might be subject to quick decay, the bridge could fall apart after only a few short years.

A more advanced bridge type that ultimately proved to be something of a dead end in development was the floating bridge, or pontoon bridge. George Washington approved construction of such a bridge across the Schuylkill in 1776. The bridge was

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[20]Allen, 6.
[21] Edwards, Llewellyn Nathaniel, A Record of History of Early American Bridges (Orono: University Press, 1959) 20-21.

later dismantled when the British took Philadelphia but parts of it may have been used in the British pontoon bridge across the Schuylkill built in 1777.[22] In this type of structure, several logs were laid in the water side by side. Often they would be slightly staggered[23] this would make transportation over them easier because the entire width of the bridge would not have a joint at a single point. A joint like that would sink when subjected to a weight, and cause the sections before and after it to rise out of the water. A bridge with staggered joints would spread that bend out over a larger area.

One of the major strengths of these bridges was the fact that they could be moved or disassembled easily. This was good for two reasons: firstly, the bridge could be moved aside to allow boats to pass through; and secondly, the bridge could be removed in the winter to protect it from ice damage, in colder regions like New England.[24]

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[22] Edwards, 28-29.
[23] Edwards, 28-29.
[24] Edwards, 28.

5.3 Bridges Using Pile Driven Support Posts

Nearly all bridge designs use mid span supports to prevent the bridge from breaking. This is true in both stone arch designs and wooden designs. Therefore, when early Americans first needed something to span greater distances they chose to cut down trees, which was the first step in a system for building piles in the middle of rivers.

This was no easy task as the early Americans were lacking several things that would normally be needed for construction in the water. Therefore, they relied on their own ingenuity in these cases, which provided some interesting results. In several cases, early Americans built a large wooden grid and then built a large support structure atop that grill. Once they had accomplished this, they placed enough rocks in the grill to cause it to sink. Essentially, they built the support above water and then sank it into place.[25] One example of this type of bridge is the "Great Bridge" over the Charles River at Cambridge, Mass., built in 1662.[26]

A simpler strategy was to instead drive a pile (in this case a stripped tree trunk) down into the river's bed. It worked like driving a nail into a board, just on a much larger scale. The tree trunk was placed vertically over the riverbed and then a large weight was repeatedly dropped onto its top. The first "authentic construction record" for one of these bridges was in 1761 for Sewall's Bridge in York, Maine.[27]

These bridges each had a new and different weakness. While it was not a systemic weakness, the early Americans may have lacked the ability needed to determine the quality of the riverbeds they planted these posts in. Therefore, these supports might sink down into the mud of the river's bed, breaking portions of the bridge or providing

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[25] Edwards, 25.
[26] Edwards, 24.
[27] Edwards, 26.

inadequate support. Sometimes stone was dumped into the river to provide a sturdier bed for supports to be placed upon to counteract this problem.[28] Support posts could be damaged by cold weather conditions. Ice flowing down the river could easily run into these supports and compact. With a strong enough current, the ice could knock a support loose and breaking the bridge. Joseph Willard of Lancaster, Massachusetts, watched this event in 1826, writing this about it in his journal:

> It has till lately been usual to build them [bridges] with piers resting upon mud sills, inviting ruin in their very construction; for the ice freezing closely around the piers, the water, upon breaking up of the river in the spring, works its way underneath the ice, which forms a compact body under the bridge raised by the whole fabric, which thus loosened from its foundations, is swept away by the accumulative force of the large cakes of ice that become irresistible by the power of a very rapid current.[29]

So while supports were necessary to span certain distances they were also often difficult to assemble and subject to failure if they were not built firmly into the riverbed and made to withstand objects running into them. This meant that a system to make longer bridges with fewer supports would be an important step in the right direction. This led to truss and arch design.

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[28] Edwards, 25.
[29] Edwards, 33.

5.4 King Post & Queen Post Truss Designs

A truss is a structure made of many smaller parts. Early on, bridges made of wooden timbers employed the use of the king post truss. The king post truss (Figure 22) is the simplest type of truss system.

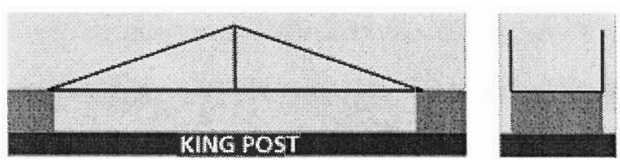

Figure 22: The King Post Truss System

The queen post truss (Figure 23) adds a horizontal top chord to achieve a longer span. This works well except the center panel is somewhat less rigid due to a lack of diagonal bracing.

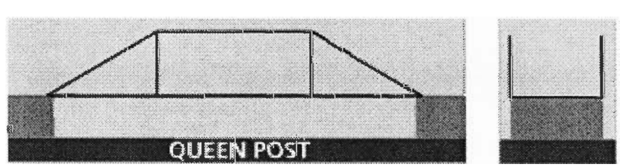

Figure 23: The Queen Post Truss System

5.5 Burr Arch Style

The Burr Arch style added a large wooden arch to a multiple king post system (Figure 24). The Burr Arch is named after Theodore Burr who patented this system 1804. This major improvement increased the strength and stiffness of the bridge as a whole. Bridges were now able to span over 250 feet without additional supports save the abutments on each bank. Figure 25 shows a nice photo of a Burr Arch design.

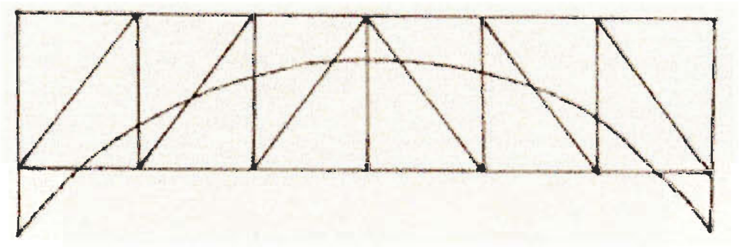

Figure 24: Sketch of a Burr Arch

Figure 25: The Burr Arch in Action

5.6 Ithiel Town Style

Ithiel Town was born in Thompson, Ct, in 1784, the son of a gentleman farmer.[30] He attended an architectural school in Boston run by Asher Benjamin.[31] Sometime around 1811 he started an entrepreneurial construction business, which eventually evolved into a successful New York architectural practice sometime after 1829, in partnership with A.J. Davis.[32]

In January of 1820, Town patented his first truss design, which consisted of a closely spaced array of intersecting diagonals that formed a web.[33] This first design, however, was found to lack transverse rigidity and stiffness in practice.[34] These findings led to a second patent in 1835 that included the original design with the addition of secondary chords and a double web.[35] These modifications helped to make his design the most popular truss design of its time.

Ithiel Town may not have been the creator of the lattice bridge. After Town was credited with its invention new evidence surfaced showing that "in 1813 an unknown carpenter built several bridges of this type over Otter Creek in Vermont… thus it was an anonymous builder who first developed the truss type used in 1819 by Ithiel Town."[36] This is a story that has been repeated in more than one text, the evidence to support this claim however remains absent from the story. Whether or not Town invented or simply improved lattice bridges, he did succeed at two important things. Firstly he evaluated the lattice as an improvement to be used as a standard, while that may seem small it was a

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[30] Yeomans, 351.
[31] Condit, Carl W. American Building Art 19th Century (New York: Oxford University Press, 1960) 89.
[32] Yeomans, 351.
[33] American Society of Civil Engineers, 47.
[34] Edwards, 59.
[35] American Society of Civil Engineers, 47.
[36] Edwards 56

marked improvement to find something that worked best and use it rather than building a bridge through trial and error, that was part of what made him an engineer. Secondly he successfully made what should be a standard into a standard bridge design through good marketing. In summation Town both identified what should be a standard and established it as a standard, while related these are two different accomplishments.

Town represented something new in bridge design. Unlike his predecessors, Town was a promoter and salesman who sold the rights to his truss design to earn a living.[37] Most bridge builders previously were involved in a bridge's design and construction, which drastically limited the popularity of their prospective designs, because it took multiple years to construct even one bridge. Town instead spent most of his time convincing the directors of bridge projects to use his truss system.[38] If they decided to use his truss system, they would pay a fee. The fee was generally a dollar for every foot of length, so a 200 ft long bridge would cost 200 dollars.[39] In order to promote his truss system Town published brochures, and even went on business trips all over America and England. Town was so successful he amassed a small fortune.

Town developed his role as a salesman of bridge design at a particularly significant time. In the early nineteenth century, a new system of roads was developing. Previously road had often been built and maintained by the farmers and residents of an area. Now a new form developed, the commercially financed toll roads which were supported by private corporations that sold stock to people beyond the locality. . "Even before the war of 1812 considerable progress had been made in the Middle Atlantic and New England states toward linking together the chief commercial centers by means of

[37] American Society of Engineers 50.
[38] Allen, 15.
[39] Sloane, 100.

turnpikes… these roads were typically built by private stock companies, which were chartered by the state governments."[40] Merchants needed to transport their goods to make money, and so they were willing to pay people to devise means by which to transport those goods. This meant profit for civil engineers in America.

As road building expanded in the early republic, civil engineering became a lucrative field. Ithiel Town was a part of that field at its outset. While Congress had "created the present Corps of Engineers… at West Point" in 1802 their primary purpose was to "function as a military academy in addition to building forts and batteries."[41] However as time progressed military engineers began to use their technical knowledge for civic works. "By 1830 the military academy was indeed functioning as a technological college." Town was distinctive. As Stilgoe notes, "in the United States in the early nineteenth century most civil engineers had military training."[42] While he may not have been a pioneer technologically, Town , as one of this nation's first civil engineers, was perhaps the first to profit from the spread of that technology. To draw a modern analogy: Ithiel Town was like a Bill Gates of Covered Bridges.

The Town Truss was not only a well-advertised design; it also had some major advantages over most of the previously designed truss systems. For instance, ideally a Town Truss exerts only a vertical force on the abutments, whereas most other designs exerted both horizontal and vertical forces.[43] This made construction of the abutments much easier if you did not need to compensate for horizontal forces that would tend to push the abutments apart. It also made the construction of multiple span bridges much

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[40] Taylor, George Rogers, The Transportation Revolution (Armonk: M.E. Sharpe Inc, 1951) 17.
[41] Stilgoe, John R., A Common Landscape of America, 1580 to 1845 (New Haven: Yale University Press, 1982) 122.
[42] Stilgoe, 124.
[43] Condit, 89.

simpler, because the towers could be much simpler and smaller if they did not have to deal with the same horizontal forces that would tend to push them over. Another advantage was the fact that they were constructed entirely of common sizes of lumber.[44] These common pieces of lumber were readily available at any sawmill, which eliminated any hewing processes. The hewing process that was common previously took a good percentage of the total construction time for the bridge, and made it necessary to get entire trees of substantial size and straightness dragged to the work site. Using smaller pieces of wood also increased the ease of construction for the bridge, because the individual beams could be lifted into position by hand, without using a hoist. Town style bridges did, however, tend to warp over time, due to insufficient rigidity of nailed connections and a lack of posts.[45]

Even with its tendency to warp over time, the Town lattice had enough of an advantage over other designs of its time that it is probable that more of them were built than any other single type of lattice.[46]

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[44] Condit, 89.
[45] Condit, 89.
[46] American Society of Civil Engineers, 156.

5.7 Howe/Pratt Design

William Howe (1803-1852) has been described as a farmer, millwright, architect, and as an entrepreneur.[47] In 1840, he was granted two separate patents concerning his own truss system that would be put to use for more than half a century.[48] It was not until August of 1846 that he was granted a patent for the truss system that is still in use today.[49] At this time, he was a millwright working out of the small town of Spencer, Massachusetts.[50] His design was innovative, considering the fact that it was both easy to build, and it provided an effective truss system. In its simplest form, it used a continuous array of X-shaped braces. Multiple offset layers could also be used, which made it look similar to a Town style truss system. The major improvement over earlier truss systems was the addition of adjustable wrought-iron tensioning rods that were positioned vertically between the X-braces.[51] These rods were especially useful as the bridges aged, because they could be tensioned to help relieve the inherent sagging of the lumber.[52] Another advantage of these iron-tensioning rods was the ease of which they could be replaced or reinforced. However, iron rods were found to fail as the weight of both trains and their cargo continued to rise.[53] Nevertheless, if the rods failed, it was a simple task to unscrew it, and bolt another in its place. Like many other patented designs, however, the wrought-iron tensioning rods did not originate with Howe; they were already in widespread use throughout Europe.[54] His patent also included the use of arches to further strengthen his truss system, but in practice, they were seldom used. In fact, the arch

[47] Yeomans, 357.
[48] American Society of Civil Engineers, 56.
[49] Yeomans, 359.
[50] Yeomans, 357.
[51] Yeomans, 357.
[52] American Society of Civil Engineers, 57.
[53] American Society of Civil Engineers, 63.
[54] Yeomans, 359.

rarely ever appears on any truss with spans smaller than 140 feet.[55] During the beginning of 1845, Howe built his first all-iron truss, but did not proceed with any further patent litigation. [56] He was confident that his existing patent would be sufficient, which he would later regret.

Thomas W. Pratt and his father Caleb Pratt received a patent in April 1844 for yet another wrought-iron reinforced truss system.[57] His design was the opposite of the Howe Truss, because it used wrought iron for the X-braces and wood for the vertical members. Pratt thought that wood should only be used for the simplest of loading techniques, so he used them for the vertical supports, which should only be subjected to tension. Unfortunately, he failed to realize that his bridge was too heavy, with the introduction of so much additional wrought iron. It also required the construction of intricate angle-blocks to help attach the iron rods to the chords.[58] However, the Pratt truss, unlike the Howe version, could be designed to incorporate a curved upper chord.[59] The curved upper chord was considered vital for bridges with long spans, because it helped to counter the sagging effect of the center of the bridge. As wooden bridges continued to become more expansive and iron cheaper the Pratt Truss worked ideally as a solid iron truss.[60]

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[55] Yeomans, 359.
[56] Yeomans, 360.
[57] American Society of Civil Engineers, 62.
[58] American Society of Civil Engineers, 63.
[59] American Society of Civil Engineers, 63.
[60] American Society of Civil Engineers, 63.

5.8 History of Vermont Bridge

Within the confines of Old Sturbridge Village, there are currently two covered bridges. One of these structures is not really a covered bridge but rather a concrete bridge with a fake arch-frame construction added later. However, the other bridge is an actual covered bridge that has been relocated to Sturbridge. This bridge is an authentic all wooden Town lattice style bridge with an interesting history.

In Sturbridge Village today the authentic covered bridge is called the 'Vermont' Covered Bridge. The Vermont Bridge was originally built around 1870 in Dummerston, Vermont in order to span Stickney Brook. In 1869, Stickney Brook cut itself a new channel during a deluge[61] and warranted the construction of this particular bridge. At first, the bridge was referred to as the 'Taft' Bridge. 'Taft' happened to be Josiah Taft III who owned and operated the well-known Taft Tavern just west of the West River. The tavern was situated on a route used by local travelers and stagecoaches traveling from southern New England to New York State.[62] Simply allowing Vermont Route 30 to cross over Stickney brook was no easy task and the Taft Bridge "took a terrific pounding for a good many years without flinching."[63] Unfortunately, there were no local legends of unusual circumstances surrounding the Taft Bridge at the time. However, the bridge did make history in 1951 when the Vermont Highway Department presented the structure to Old Sturbridge Village. Taft Bridge was dismantled piece by piece and moved over seventy-eight miles southward to Sturbridge. As dramatic (and expensive) as this move was the bridge probably made headlines again in August of 1955 when hurricane Diane

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[61]Brattleboro Daily Reformer, The Story of Covered Bridges in Windham Co., VT (1937)
[62] Loomis, Alice, Dummerston; an "Equivalent Lands" Town 1753-1986 (Dummerston, Vermont: Dummerston Historical Society, 1990)
[63] Morse, Victor, Windham County's Famous Covered Bridges

pushed the Taft Bridge off its abutments at Sturbridge. The bridge began to float downstream but was quickly lassoed and roped to shore by a heroic effort by the staff at Old Sturbridge Village. The bridge has since been slightly relocated (1955) and now spans the channel connecting the Village Mill Pond and the Quinnebaug River. When first built in 1870 the bridge cost somewhere in the low hundreds; the combined bill after moving it in 1951 and relocating it in 1955 totaled to exactly $25,540.08![64] Today the bridge is a common sight to many visitors and is still crossed by the village carryall.

[64] Allen, Richard, Covered Bridges of the Northeast (pg 70)

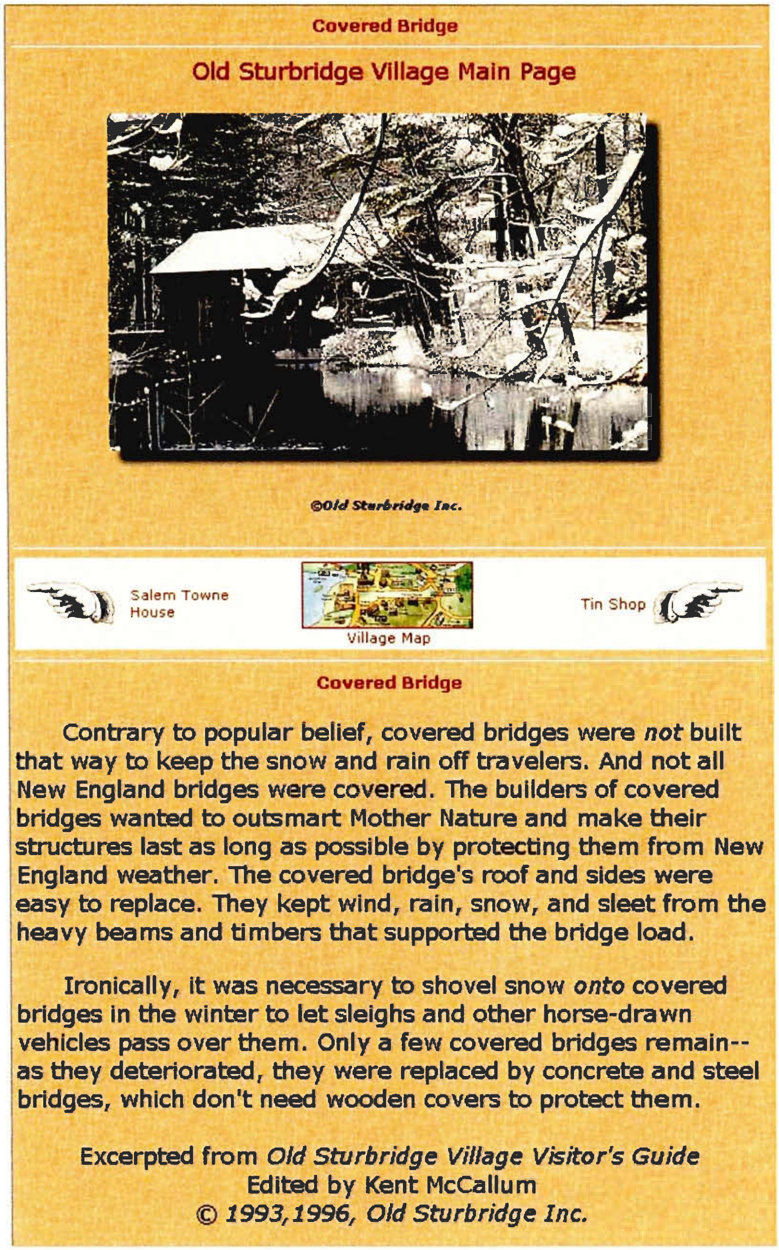
6.0 Website Suggestions for Modifications

Old Sturbridge Village has a very informative website that contains an extensive amount of information from maps to games, and databases to recipes. It does not, however, discuss the Vermont Bridge.

The website provides a virtual tour of the village. Selecting the appropriate link brings up a colorful map of the village. From here, each building on the map can be clicked upon to get information that is more detailed. When investigating the Vermont Bridge a rather simple page appears with a limited amount of information and a picture of the bridge in winter. After browsing through several other pages, it is apparent that the material on the Bridge lacks several main components.

First, each individual webpage is devoted to a single building has its original location clearly presented in the center of the webpage. This information is a vital part of each building's unique history, as each building in The Village has different origins. While most pages contain this information, the page devoted to the 'Covered Bridge' does not.

The next few lines on each webpage, under the original location and date of completion, contain more locations and dates. These places and times tell the story of where and when the building might have been relocated, or even tell when an addition was added on or re-erected. Again, the Vermont Bridge's webpage fails to outline its somewhat dramatic history.


Covered Bridge

Old Sturbridge Village Main Page

©Old Sturbridge Inc.

Salem Towne House

Village Map

Tin Shop

Covered Bridge

Contrary to popular belief, covered bridges were *not* built that way to keep the snow and rain off travelers. And not all New England bridges were covered. The builders of covered bridges wanted to outsmart Mother Nature and make their structures last as long as possible by protecting them from New England weather. The covered bridge's roof and sides were easy to replace. They kept wind, rain, snow, and sleet from the heavy beams and timbers that supported the bridge load.

Ironically, it was necessary to shovel snow *onto* covered bridges in the winter to let sleighs and other horse-drawn vehicles pass over them. Only a few covered bridges remain--as they deteriorated, they were replaced by concrete and steel bridges, which don't need wooden covers to protect them.

Excerpted from *Old Sturbridge Village Visitor's Guide*
Edited by Kent McCallum
© *1993,1996, Old Sturbridge Inc.*

Figure 26: The Village's Current Bridge Webpage

Finally, the most clear and obvious feature to any webpage is the imagery. Each building in Old Sturbridge Village has at least one vibrant exciting picture. The Vermont Bridge simply shows the bridge in winter, devoid of any period action. We suggest that this picture be updated. While the romantic notion of a quaint New England covered bridge in winter might be attractive, a picture of a sleigh coasting through the bridge might be nice too. In addition, a better angle would do the picture justice as well; snow-covered trees and bushes obscure the current view of the bridge.

Beyond these observations, we suggest the use of informative diagrams. These pictures or small flash animations could easily explain how the physics of a covered bridge work. This would greatly enhance the educational value of the web space, and would make the bridge that much more interesting.

In addition, a short history of covered bridges might be appropriate. While many people have a notion or two about covered bridges, they almost certainly lack a full knowledge on the subject. This history might include a small diagram that shows where covered bridges appear throughout time with respect to other popular bridge types.

A short history of this specific bridge seems to be the next logical inclusion to this future webpage. The 'Vermont Bridge' has a rich history. From its original hometown of Dummerston, Vermont, this bridge was erected in a time long past. Its original name as the 'Taft Bridge' pays tribute to a local tavern owner and the overall style is attributed to famous executive Ithiel Town. Beyond names and dates the 'Vermont Bridge' even almost fell victim to hurricane Diane. There are now many stories to tell about a bridge that was once considered "unromantic.... (with) neither written records nor local legends..."; the fact that the 'Vermont Bridge' has been historically unremarkable before its time at Old Sturbridge Village made it an appropriate addition to Old Sturbridge Village, as now it will be appreciated far more greatly than it had been in the past. [65]

[65] Brattleboro Daily Reformer, The Story of Covered Bridges in Windham Co., VT (1937)

7.0 Model Description / Suggestions

The work done in attempting to write a few bullet points to summarize the technical aspects leaves a lot to be desired. Most technical aspects require a lot of explanation, illustrating these concepts by example is the most straightforward means to get these concepts across.

So here are some preliminary ideas on what could be done:

Firstly, a computerized means might be the simplest solution. The West Point Bridge Designer software is free for download on the Internet at http://bridgecontest.usma.edu/download.htm. It is an extremely easy to use simple program that animates how various bridges react to loadings. It illustrates tension with a blue color in the member of the bridge and compression with a red color. It can report the stresses in various members of the bridge as well. It has some weaknesses: only a one magnitude of weight may be moved across it, it only creates bridges composed of various kinds of steel as opposed to wood, and every point at which two members are linked it breaks any solid members in favor of a joint. Also for the purpose of showing people how certain covered bridges work it would probably be a better idea to simply have them run a load across a few pre-made bridges rather than have them design the bridges themselves.

Still the program automatically computes the forces acting in the bridge, and it already appears in a display so clear that it would almost make a good display system already. It might be possible to talk to the program's owners at West Point and see about either getting the rights to alter the program slightly to make a good display. The work needed to alter the program could be done by in-house people at OSV or perhaps by students at WPI or West Point.

The second idea is to actually build small models of a few bridge designs that could be subjected to loads to show how they react. Since part of what we want people to see is how certain truss designs are sturdier than other ones, or even a bridge with no truss at all we are looking materials with certain properties, specifically things that will bend a lot with out breaking. Materials of this kind would have a low modulus of elasticity and a high yield stress; the low modulus of elasticity means that the material will stretch and bend easily making it useful as a visual tool, the high yield stress means that the material will have to be or stretched very far before bending or stretching out of face. These properties can be summarized in saying the material needed would have to have a high resilience, it would bend a lot yet they would also snap back into shape rather than suffer permanent deformation or breaking.

One of the best materials to use for this would be high carbon spring steel that can be found at http://www.precisionsteel.com/products/default.asp?n_cat_id=3. However, steel might not be authentic enough to use at OSV; fortunately, there are some woods that might be able to serve a similar purpose. The wood with the highest resiliency can probably be found in what was used to make bows, as in bows and arrows. This wood should bend greatly and retain its original shape. One of the woods used today in bows is Brazilian Pernambuco; if that wood is unattainable then another wood might suffice. The dimensions of the model would need to be appropriate so that the model would visibly bend for demonstration purposes when subjected to weight, but it would also have to hold up to the rigors of being a display in front of several small children bending to great degrees while never being bent so far that it would be permanently bent out of shape.

There may be two ways to do this; first, the model could be built to actually support a significant weight before permanently deforming or breaking. This would depend on which material was used and again the dimensions of the model itself. For example a beam of spring steel 1/4 inch wide and thick would have a maximum bending moment of 365 lbs x inches meaning a 6 inch span could take 60 lbs. at one end bending before it would begin to deform.

The other way to protect a model such as this would be to place it inside of a Plexiglas box with a small hole in the bottom. Then run a wire from the midpoint of the bridge down through the hole so that people could pull on it or place weights on the wire to see how the bridge reacts. To protect the bridge from having too much weight put on it, a small bob could be welded into the wire so that the wire could only be pulled so far before the bob ran into the Plexiglas and blocked the bridge from being bent further (Figure 27).

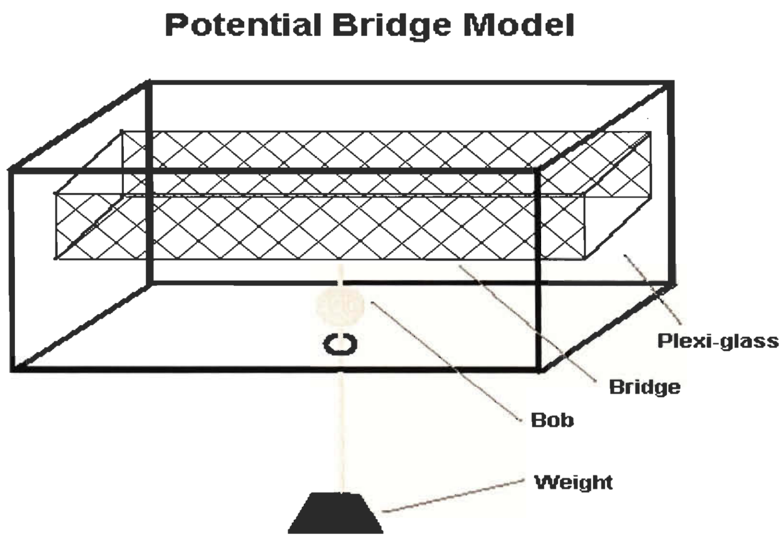


Figure 27: Model Suggestion

These are involved works that would likely take some time to construct and potentially outside workers to build. A steel model would likely require a welder, and really any of the models would require some design work since the extent of how far they could be bent before deforming would have to be calculated.

A simpler option might be to illustrate the major concepts in bridge design in the simple machines section of OSV. If holes were drilled through several wooden blocks and a rope run through them, then by pulling on the rope people could see how the spaces between the blocks grew on the side that the rope was being pulled toward and shrank on the opposite side. This could illustrate how the top of a bridge is in compression while the bottom is in tension. At the holes, the distance would remain almost unchanged showing that between the top and bottom the normal stress is at its lowest.

In summation, the best way to explain the technical aspects of the bridge to visitors would be through example. It would convey the concepts in a more concise, to the point fashion, and with greater clarity than a complicated explanation.

8.0 Where to Go Next

Before we discuss where this project might go in the future, we must establish in summary where it has been in the past. From our research, we found that not much actual engineering was taking place in 1870 when the Vermont Bridge was built. While the fundamental concepts of bridgework existed and thorough analysis techniques were available, people still went to work on a bridge guided only by a memory or perhaps a set of ideas. The Vermont Bridge, whether laid out ahead of time by a crafty engineer or erected on the spot by a homegrown carpenter, has stood the test of time. It even escaped certain doom by being moved to Old Sturbridge Village for historic preservation. After surviving a hurricane and being relocated once again, the Vermont Bridge has amassed quite a history. As the term has progressed, we have become intimately familiar with this history. We covered the history of bridges, covered bridges, reviews of statics and stress analysis, physics and more. However, this work is not complete. Old Sturbridge Village is constantly undergoing change in an effort to better educate its visitors. The Village will benefit from the information we have gathered and interpreted but there is definitely more work ahead.

We have made suggestions about models and websites; these ideas will hopefully illuminate paths unforeseen as of yet. The options for advancement are endless. Models come in all different shapes and sizes, and web technology improves each day. Signage might be placed around the bridge. Self-sufficient computer terminals might display various types of bridges and the forces acting upon them. Life-size models might be built of synthetic materials, allowing children to run over them and actually feel and see each member undergo tension and compression. Perhaps sometime in the future Sturbridge might run weeklong workshops on how to build a Town style lattice for interested hobbyists. Wherever this research is used, the opportunities for educational applications are limited only by imagination.

9.0 Conclusion

In conclusion, we poured countless hours into this project. We explored invaluable resources such as the library at Old Sturbridge Village and the American Antiquity Society in Worcester. Through meeting with workers at OSV on a regular basis (especially Jack Larkin), we gained a knowledge not found in books. Over the course of the term, we learned how to effectively work together and with others. When a problem would arise, we were there to solve it. While we did not get to the finish line with a specific product in hand, we did establish a foundation of research about the Vermont Bridge. Future project groups might now attempt to solidify a single goal. We are satisfied with our work here. While we believe that completing a specific project such as designing a website or building a model, might achieve a greater sense of accomplishment and self-satisfaction, our work here seemed to provide a critical foothold for future project work and for this reason, we are enlightened.

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