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Covered bridges speak to a careful observer: insight into the geometry and manufacture of Smith trusses

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Abstract

Wooden covered bridges using patented Smith trusses were widely built in the American Midwest during the 25 years following the US Civil War (1865-1890). The geometry and construction of these bridges has proven puzzling to modern observers. The author, engaged in designing repairs to a Smith truss bridge at Cataract, Indiana, examined scribe marks, remnants of painted numbers and similar evidence left by the builders. This showed that some geometric complexities were a result of simple patterns used during layout and construction of the bridge. This was confirmed by inspection of seven other Smith trusses in Indiana and Ohio. The evidence left by the builders also sheds light on the design and manufacture of these bridges, illustrating how their inventor attempted to bring wooden bridge construction, with its roots in medieval timber framing, into the industrial age. The author feels that conservators studying style and structure - the realms of the architect and the engineer - may lose sight of the more prosaic world of the craftsman and builder. The insight gained regarding Smith trusses demonstrates how consideration of original construction methods and constraints can improve our understanding of historic structures.

1 Introduction

American covered wooden bridges have their roots in medieval timber framing. The use of covered bridges was widespread in the United States during the 19th Century, but they were largely supplanted by metal spans beginning in the 1880s.

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Covered bridges used numerous types of supporting trusses. The Town Lattice, the Burr Arch, and the Howe were the most common. Between the late 1860s and the late 1880s another type often built in the American Midwest was the Smith Truss. Two variants are shown in Figure 1.

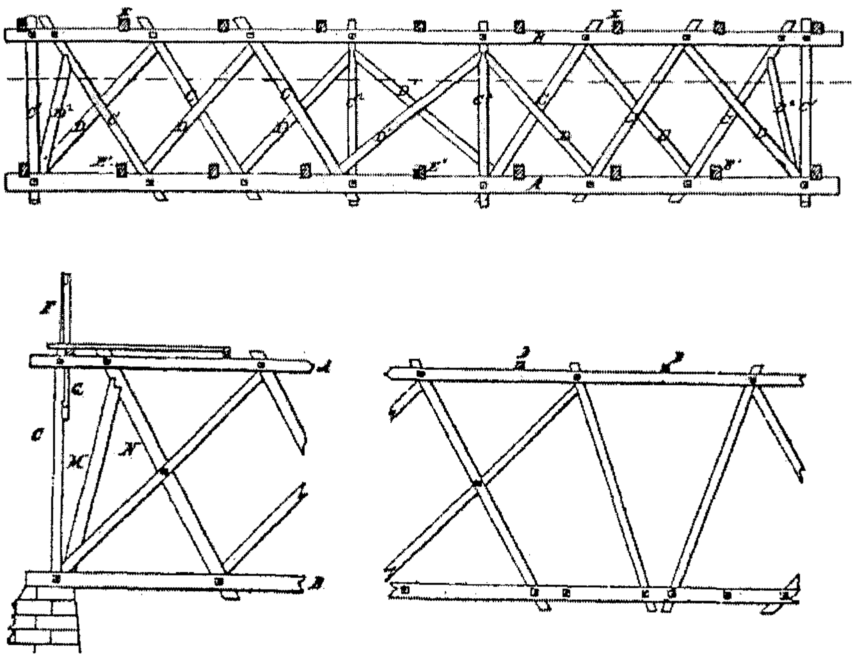

Figure 1. Two variants of the Smith Truss. Type 1, from patent drawings of 1867 (above), and Type 2, from patent drawings of 1869 (below).

The inventor of the Smith truss, Robert Smith (1834-1898), was an Ohio cabinetmaker's son. He received the first of his bridge design patents in 1867. In 1870 he opened what became the Smith Bridge Company in Toledo, Ohio, a major port city on Lake Erie. While various builders constructed Smith truss bridges throughout the USA, most were built by Smith's company and were erected in Ohio and Indiana. The company also built other types of truss bridges.

Cataract Bridge was only one of several hundred bridges the Smith Bridge Company built in 1876; already many of them were metal rather than timber. By 1890, when Smith sold the company, they had stopped building wooden bridges altogether.[1] Renamed the Toledo Bridge Company, the company was purchased in 1901 by J.P. Morgan who combined it with 24 other bridge companies to create the monopolistic American Bridge Company. [2]

There is a great deal of public enthusiasm for covered bridges in the USA, but their numbers dwindled during the last century. In recent years more public funds have been made available for their preservation; arson rather than neglect

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probably takes the largest toll on covered bridges today. The author's company, J.A. Barker Engineering, is currently designing repairs for several covered bridges, including a 42 meter span at Cataract, Indiana, whose Smith trusses are shown in a measured drawing in Figure 2.

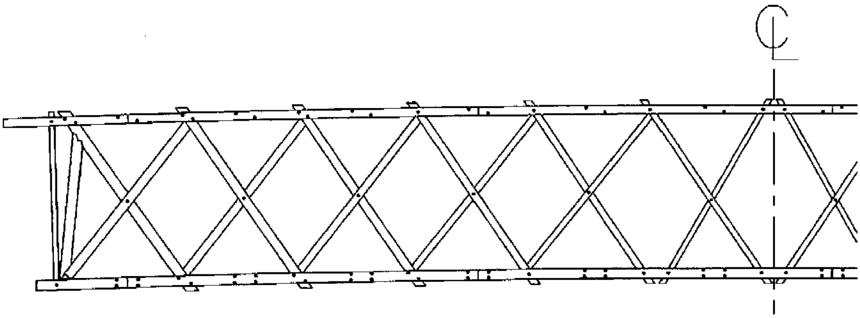

Figure 2. "Type 3" Smith truss in the 1876 bridge at Cataract, Indiana. Drawn showing original camber (slight arch). Today the trusses sag slightly due to failure of some lower chord timber tension splices.

2 Smith truss characteristics

As can be seen in Figures 1 and 2, all Smith trusses have vertical end posts flanked by unique bracing posts that slant sharply upwards from the end posts at the lower chord to meet the first regular diagonal web member. Most or all other Smith truss web members are diagonals arranged in two or more overlapping sets. Each set forms a string of 'W's, like a Warren truss. The two sets are offset, however, so that diagonals cross in the middle to form a pattern of 'X's. For this reason Smith trusses have sometimes been called "double intersection Warren" trusses. Most Smith trusses have two sets of diagonals, whose ends are sandwiched between the three timbers that form the top and bottom chords. This is the arrangement at Cataract. On longer spans heavier construction is used: there are three sets of diagonals between four chord timbers. In these cases the outer two sets of diagonals parallel each other with the middle one running counter to them.

Raymond Wilson, in a paper published in 1967, classified Smith trusses into four types.[3] This taxonomy is generally in use today. Type 1 is based on the 1867 patent, distinguished by a pair of vertical posts at mid-span. Type 2 Wilson says is "the 1869 Patent Truss", distinguished by a pair of diagonals forming a 'V' at mid-span (both types can be seen in Figure 1). Type 3 has diagonals crossed to form 'X's throughout its length, as in Figure 2. Wilson's Type 4 Smith trusses are like Type 3, except with a third set of diagonals.

Wilson's taxonomy is problematic. He describes his four types as a chronological development. Yet Smith's first patent (for the Type 1) describes using extra sets of diagonals (like a Type 4) for longer spans and heavier loads. [4] Size, not age, correlates with the number of sets of diagonals in the eight Smith bridges the author has inspected (the five largest bridges have three sets

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of diagonals; the three smaller bridges have two sets of diagonals). The author feels only the first three of Wilson's types should be used, noting the number of sets of diagonals if appropriate.

Wilson's classifications have other difficulties. He lists two 1867 bridges in Michigan (White's and Bradfield) as "variant Type 4" Smith trusses; other sources list them as Brown truss bridges (a rare type patented by Josiah Brown in 1857).[5] It would be instructive to examine the bridges themselves but both have now been lost. Wilson classifies the Engle Mill Road Bridge (Greene County, Ohio) as a "variant" of a Type 3; the author found it to be not a variant but a classic Type 3 with later alterations. Wilson lists many other bridges as "variants"; many may instead be simply altered. Indeed, the author has seen only one Smith truss bridge that has no major alterations. This is the Type 3 bridge at Cataract, Indiana. A photograph of it is shown below as Figure 3.

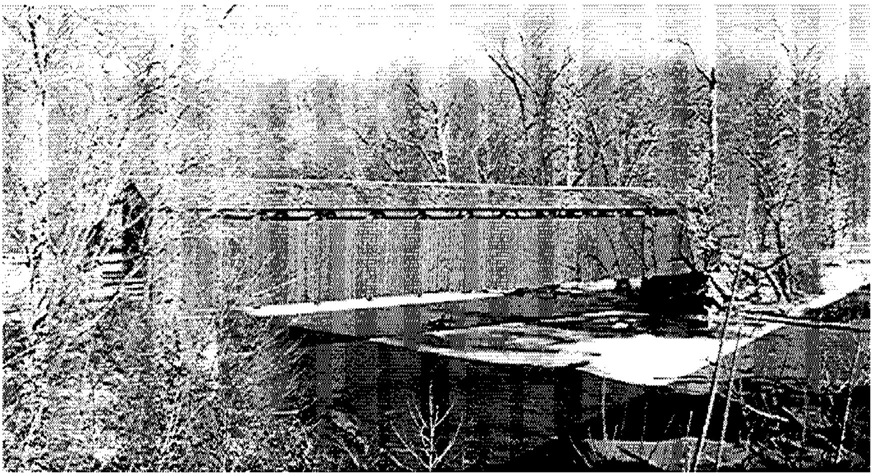

Figure 3. Cataract Covered Bridge, a 42 m span Smith truss.

3 Smith trusses' seemingly curious features

Probably fewer than two dozen Smith truss bridges remain. One recent count listed 22 (14 in Ohio, 6 in Indiana, one in Pennsylvania, and one in California). [6] No original plans for Smith truss bridges survive, as far as the author knows. The American Bridge Company no longer has any of the Smith Bridge Company's records. [7] Thus one has only the bridges themselves to learn from.

Modern observers of Smith trusses have been puzzled by several of their features. Among these are:

- Some diagonals pass between and extend beyond the chord timbers while others don't.
- Pairs of diagonals generally meet at a point on the chords, but near mid-span they sometimes intercept the chords a short distance apart.

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- The bridges were built using traditional English units of measurement (feet and inches). Yet some basic dimensions of the trusses don't seem to be sized in whole numbers of these units. At Cataract, for example, measurement between bolts where diagonals cross (the centers of the 'X's) yields a standard panel length of 10' 11 5/8" (10 feet plus 11 5/8 inches).
- Dimensions one would expect to be repeated sometimes aren't. For example most bolts mentioned above are almost (but not exactly) 7' 4" above the lower chord (about 2250 mm), but the two nearest mid-span are almost (but not exactly) a foot lower than this (about 2 m).
- Splices in the chords are located nearly midway between panel points, but never exactly midway. The difference varies from almost nothing to about 250 mm.

4 Deciphering Smith trusses at Cataract

While there is much popular interest in covered bridges, few enthusiasts are technically trained. Antiquarians, if they note oddities like those mentioned above, are likely to regard them as romantic mysteries. Engineers tasked with fixing the bridges may have little time for or curiosity about the details of their origins. The author's opportunity to carefully examine the Cataract Bridge, however, has revealed details that may assist both groups.

4.1 Structural aspects

Diagonals in a Smith truss that extend beyond the chords are designed to be in tension at least some of the time. In Smith trusses the tension diagonals and the chords are both notched and bolted together to form a joint. The diagonal must extend past the chord so that there is a shear surface beyond the notch to resist the pull on the timber. At Cataract (and other Type 3 trusses) this includes all of the diagonals that extend outwards (away from mid-span) as they rise from the lower chord. These are marked 'C' in the upper drawing of Figure 1.

Cutting notches takes time and weakens the timbers. Since notches are not needed to transfer compressive forces, Smith truss diagonals that are always in compression are simply butt-jointed in the angle between a chord and a tension diagonal and spiked in place. On a Type 3 truss this includes most (not all) of the diagonals that extend inwards (towards mid-span) as they rise from the lower chord. These are marked 'D' in the upper drawing of Figure 1. At the ends of these timbers three members - a chord, a tension diagonal, and a compression diagonal - meet at a single point.

The pair of inward-leaning diagonals nearest to mid-span may be under tension under some loading conditions. For this reason their ends, like the outward-leaning diagonals, are notched and pass through the chord.

If two tension members met a chord at the same point using notched joints, the timbers would have to be notched so deeply that they would all be badly weakened. Instead on Smith trusses the geometry is adjusted so that adjacent tension diagonals intercept the chords a short distance apart. In this way they can use the same notch type as all the other tension diagonals. On Type 2 trusses this adjustment in the geometry occurs once on the lower chord at mid-span (see the lower drawing in Fig. 1). On Type 3 trusses like Cataract it occurs three times on the lower chord and once on the upper (see Fig. 2).

4.2 Cataract bridge timbers

Examination of the timbers at Cataract reveals that the bridge, unlike most covered bridges, was an industrial product dependant on railroads, industrial machinery, and factory-floor production methods. Many early covered bridges are made of mixed species of local timber, commonly oak and poplar in Indiana. Not so at Cataract, where the timbers are all white pine, a lightweight, easily worked wood not native to the region. They could not have been brought to Cataract before railroads reached the area (waterborne transport does not extend here). Early covered bridge timbers are sometimes hand-hewn, sometimes the product of a nearby rural sawmill. Not so at Cataract. All surfaces of the Cataract timbers, both in the trusses and in the upper and lower lateral cross-bracing between them, are smooth. The dimensions of the timbers are precise. Every truss diagonal, for example, is exactly 6 ¾ inches thick, planed down from rough lumber 7 inches thick. In short, all the Cataract timbers were finished by an industrial planing mill. These existed only in cities, far from Cataract.

Painted marks, often faint and obscured by dirt and animal droppings, were found on top of the truss chords at Cataract. Carefully examined, they turned out to be numbers match-marking all adjacent pieces, not only at the splices in the three principal chord beams but the dozens of spacer and shear transfer blocks between them on each chord. These are evidence that the bridge was prefabricated elsewhere, dismantled, moved, and reassembled on site.

4.3 Cataract bridge's dimensions

Given that Cataract Bridge's timbers had been industrially processed, it seemed likely that it had an underlying geometry that would lend itself to industrial-type assembly. Careful examination of the timbers and their measured dimensions revealed such a simple plan.

There are two scored marks, one foot apart, on the top of the upper chord timbers at mid-span. Outwards from these marks, in both directions, are six more marks at exact 11' intervals, with a seventh mark 2' 4" beyond the sixth, at the outside of the truss' vertical end-post. On the bottom of the lower chord there are also two scored marks one foot apart at mid-span. Outwards from these, like on the upper chord, there are more marks at regular intervals in both directions, but these are 10' 11" apart, one inch less than on the upper chord. Like on the top chord, the outside of the end-post is at a distance of six intervals plus 2' 4". Finally, one foot inwards from the first of the 10' 11" interval marks, on both sides of mid-span, is another mark. The arrangement is shown in Figure 4.

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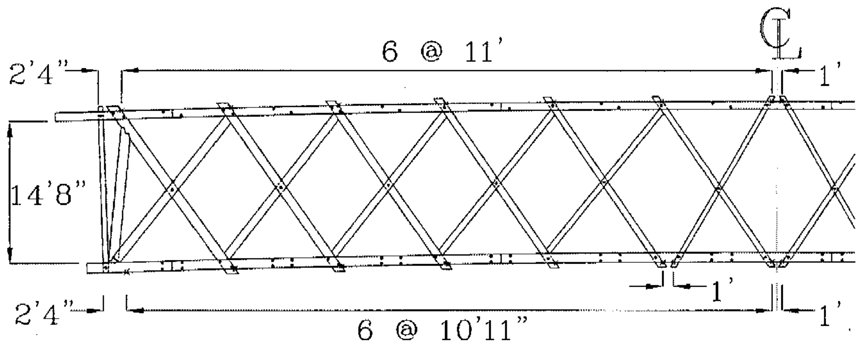

Figure 4. Basic dimensions of Smith trusses at Cataract Bridge.

These, and the 14' 8" height on the end posts, are all the measurements needed to lay out all of the timbers for the trusses, including the notches. The resulting structure will be slightly cambered (arched) due to the slightly smaller intervals on the lower chord.

The following manufacturing sequence, or a similar one, seems likely:

1. Assemble the chords (more about this below). Measure and mark them and the end posts as shown in Figure 4.
2. Place end posts with their outer edges on the outermost marks on the chords, square them, then score them and the chords along their lines of intersection. Cut notches to those lines (or parallel ones transferred to other faces of the timbers with the framing square).
3. Assemble end posts and chords. Square the joints, which requires bending the chords to the desired arc. A stringline or a straight line on the factory floor could be used to ensure the arc curvature is even.
4. Place tension diagonals on the chords, aligned with the marks. Score them and the chords along their line of intersection, and cut notches to these lines as was done for the posts. The ends of the diagonals, deliberately too long to begin with, could be trimmed off 6 inches beyond (and parallel to) the notches now or later.
5. Reassemble chords, end posts, and tension diagonals. Put compression diagonal timbers in position on the assembly, score at lines of intersection, cut to length, and place in the now-complete truss.
6. Drill bolt holes, paint match markings, and disassemble for shipment.

Note that the only measurements required in this sequence are in the first step. From then on pieces are marked in place, assuring precise notches and member lengths. This simple layout system would allow relatively unskilled carpenters to produce well-fitted timber trusses rapidly and with little chance for errors.

Layout of the chords is also simple. Each has three parallel beams, each beam made from several timbers spliced end-to-end. The beams are notched frequently, with oblong blocks fitted between them to maintain the spacing and transfer and equalize stress between beams.

It might seem logical to place chord splices exactly midway between panel points on the truss. This might also give the best appearance. However this would require chord timbers to be many different lengths, since top and bottom panel lengths differ and there is an "extra" foot between panels at mid-span. This would require extra labor in construction and introduce chances for errors in cutting and fitting.

Instead at Cataract the staggered splices in the three beams are evenly spaced 11' 2" apart (about 3400 mm), 2" more than the interval of top chord marks described above. The result is that no splice is exactly midway between panel points, but all are close, and chord layout is very simple. Each of the 60 chord timbers in the bridge (except those lopped off at the ends) is 33' 6" long (about 10200 mm). All 24 "fish plates" used on the bridge's lower chord (tension) splices, all 100 lower chord spacer blocks, and all 124 upper chord spacer blocks, are identically sized and regularly spaced.

The upper chords are exactly 13 splice intervals long (145' 2", just over 44 m) and could have been made with exactly 13 timbers and no waste. The lower chord was probably built similarly, but trimmed to exactly 140' (a bit less than 43 m). Building upper chords longer than lower chords was normal practice for covered bridges; the overhanging roof built on the former helps protect the latter from weather.

Upper and lower lateral bracing is simpler yet. The bracing is made of crossed timbers, all the same size and with identical notches at their ends, that form two strings of overlapping "W"s like the truss diagonals. The crossed, lap-jointed ends attach to the chords using special cast iron brackets covered by Smith's 1869 patent.

5 Comparing Cataract with other Smith trusses

The author has inspected seven Smith truss bridges besides the one at Cataract. Like Cataract Bridge, all are single span structures and all were built between 1875 and 1878. They include the following:

Table 1. Smith truss bridges examined by the author.

Bridge Name	Location	Span (m)	No. of Panels	Yr. Built
Cataract	Owen County, IN	42	12	1876
Stevenson Road	Greene County, OH	29	10	1877
Brown	Brown County, OH	39	12	1878
W. Engel Mill Road	Greene County, OH	41	12	1877
George Miller	Brown County, OH	47	14	1878
North Pole	Brown County, OH	48	14	1875
Wheeling	Gibson County, IN	50	14	1877
Old Red	Gibson County, IN	52	14	1875

The bridges vary in width (from 4.3 to 5.6 m clear between trusses) and in height (from 4.3 to 4.7 m clear between upper and lower chords). Truss panel length shows little variation (3.24 to 3.48 m measured on the top chord) except at Stevenson Road, where it is only 2.72 m.

Many characteristics are the same in all the bridges, among them:

- All truss timbers are of planed white pine.
- Notched tension joints are similar in all the bridges.
- Chord splice intervals are always 2" greater than upper chord panel width, and lower chord panel widths are 1" or 1 ½" less.
- Adjacent tension diagonals are always spaced exactly one foot apart.
- Fish plates and chord spacer blocks are identical in all.
- All chords pieces are match-marked using the same numbering system in all the bridges.

In short, the examination of these bridges shows that the basic layout and construction system used at Cataract is common to all the Smith Company trusses.

6 Conclusions

Detailed examination of eight Smith truss bridges has revealed much about their geometry, the ways they were built, and the intent of their inventor. They illustrate that Smith trusses were produced in a manner very much at odds with the romantic conception of covered bridges as a remnant of an era of highly skilled timber framers creating hand-crafted structures from local materials.

Robert Smith designed bridges that could be produced rapidly in a central urban location using imported materials processed by industrial machinery and then shipped long distances by railroad for re-erection at their final destinations.

The similarity of the trusses from one Smith bridge to the next, their simple layout, the uniformity of the planed timbers, the repetitive use of identical components, and the minimizing of required measurements indicate Smith was attempting to speed production, reduce workers' skill requirements, and minimize the chances for fabrication errors.

All this is characteristic of the late 19th Century industrial age we are more likely to associate with the iron bridges that Smith also designed and built. Indeed, one may describe the Smith Truss as the inventor's attempt to bring modern industrial design and production techniques to an old technology - the covered bridge - so that it could remain economically competitive with the new bridge types, based on iron and steel, which were appearing on the market. In this he succeeded for more than two decades.

This work lends insight into Smith trusses specifically. In a larger sense it illustrates the importance of considering original construction methods and constraints when trying to understand and conserve historic structures. It is the author's opinion that this is often overlooked. In doing so we miss a great opportunity to gain knowledge about the historic structures in our care.

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