Robert Smith's Trusses

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Abstract

Robert Smith's all-timber bridge truss, patented in 1867, had two principal innovative features. One was the all-diagonal arrangement of the truss web members. The other was Smith's idea of using trusses with not just one set of web members, but two, three or more as needed to build longer spans and support heavier loads. Previous scholarship regarding Smith's trusses has not clearly distinguished the two innovations. This paper does so, and explores improvements Smith made to his truss in the first years after obtaining his patent for it.

Smith's all-diagonal web may have evolved from the multiple kingpost truss' web, which has vertical tension members. Indeed the earliest form of the Smith truss, known only from the inventor's 1867 patent drawings, retained a kingpost at midspan. By 1868 Smith had eliminated this kingpost, substituting two inclined posts forming a 'V'at midspan.

Smith's 1867 patent describes his concept of using multiple sets of web members for greater strength, but the patent drawings show only a truss with a double web. This has caused confusion among historians in the past. Smith trusses with a single set of web members have not been recognized as Smith trusses at all, while Smith trusses with a triple web were thought to be a later development.

Figure 1. Cataract Covered Bridge, an 1876 Smith truss structure. 2006 (post-rehabilitation) photo by the author.

1. Introduction

Robert Smith (1833-1898) was remarkable for several reasons. This paper discusses only the design of his all-timber bridge trusses, the subject of his first U.S. patent (#66,900), issued in July, 1867. The author discussed some other aspects of Smith's career and accomplishments in a previous paper.[1]

The author has visited about two thirds of all extant Smith truss bridges, made measurement and inspection notes on most of these, and, while working for J.A. Barker Engineering of Bloomington Indiana, performed detailed structural analysis and prepared rehabilitation plans for one, the Cataract Covered Bridge in Owen County, Indiana (Figure 1).

An article by Raymond Wilson, published in 1967, rescued Smith and his trusses from obscurity.[2] Wilson brought more attention to Smith trusses than anyone had for years, but he got several things only half right. Consequently the typology he introduced for Smith trusses – which has been used ever since – is confusing and fails to fully or accurately characterize Smith's innovations. This paper hopes to remedy this.

2. Smith's 1867 Patent Trusses

Smith may have gotten the idea for his truss from the multiple kingpost truss (Figure 2a). Perhaps he was also influenced by Louis Wernwag, who splayed the posts in his trusses to a degree. In a multiple kingpost truss web tension members (the posts) are vertical and notched between paired upper and lower chord timbers. The web compression members (called 'braces' in the 19th Century) tilt towards midspan and bear on notches in the posts near the chords. The panel width (distance between posts) is limited, to a large degree, by the magnitude of the floor loads the lower chord supports.[3]

The Smith truss patent included two basic innovations. First, Smith's posts, other than the endposts and a remnant notched kingpost at midspan, tilt away from midspan (Figure 2b). The patent still refers to all web tension members 'posts', even though here most aren't vertical. This paper uses Smith's nomenclature, 'posts' for web tension members and 'braces' for web compression members, in deference to the inventor and for brevity.

[1] Reckard, Matthew, *Smith Trusses: Bringing Covered Bridges into the Industrial Age*, presented to the Covered Bridge Preservation: First National Best Practices Conference, Burlington, Vermont, 2003. Available http://www.uvm.edu/coveredbridges/papers/reckard.html, last accessed May, 2013.

[2] Wilson, Raymond E. "The Story of the Smith Truss", in *Covered Bridge Topics*, April 1967, published by the National Society for the Preservation of Covered Bridges.

[3] Lower chord timbers are truss tension members. But since in covered bridges they directly support the floor beams, and thus the weight of the deck and traffic, they are also beams. Bending forces (moments) in a uniformly loaded beam vary with the *square* of the unsupported span length, so a span twice as long can only support a quarter as much. Upper chords act as beams too, supporting roof and snow loads.

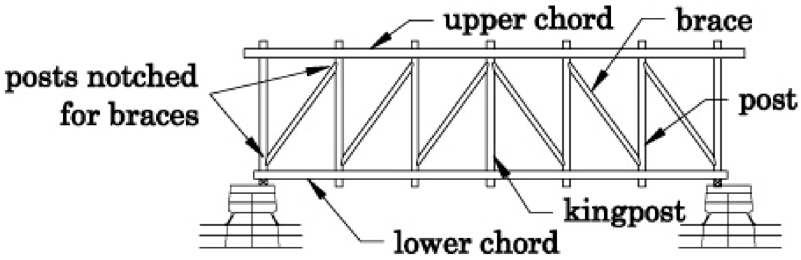

Figure 2a. Multiple Kingpost Truss.

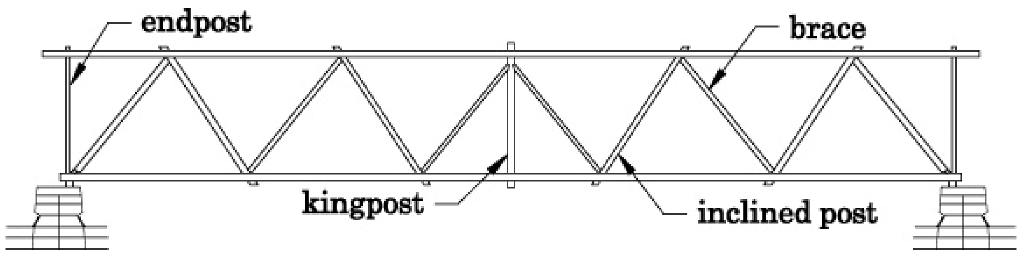

Figure 2b. Smith prototype Single Truss.

Smith's tilted posts stretched the truss panels out (compare Figures 2a and 2b). This had advantages. For a given span the total length of web timbers was reduced, as was the number of notches between posts and chords. Also, posts and braces now met at nearly right angles, eliminating the need to notch the posts at the joint. They could be simply butted and spiked together, simplifying construction (Figure 3).

Figure 3. Cataract Bridge. Owen Co, IN (detail). Typical Smith truss post/brace butted joint. Photo: J.A. Barker Engineering

But the new truss (called a “single truss” in the patent description) was not without drawbacks. The most significant is that the increased span of the lower chord between truss joints greatly reduced the floor loads (traffic weight) that it could support.

Smith addressed this with the second of his innovations. He added a third piece to the chords so they could sandwich a second set of web timbers offset from the first. One set notched into the chords between the first and second chord timbers, while the other fit between the second and third.

Simply offsetting two “Smith single” web sets leaves one sticking out at each end, with end posts in different places (Figure 4a). Clearly, the concept requires modification of the outermost panel at each end. Smith’s solution was to move the outer end post inwards to the position of the inner one, and the bottom of the brace in the outer panel with it. The brace in this drastically shortened panel thus became very steeply inclined, and its top no longer met the inclined post squarely. Consequently the timbers at this joint had to be notched, something like a kingpost (Figure 4b and Figure 5). In this arrangement, the posts in one web set cross the braces in the other; the resulting truss, in elevation view, appears as a series of ‘X’s between the horizontal chords. Smith’s patent calls this a “double truss”.

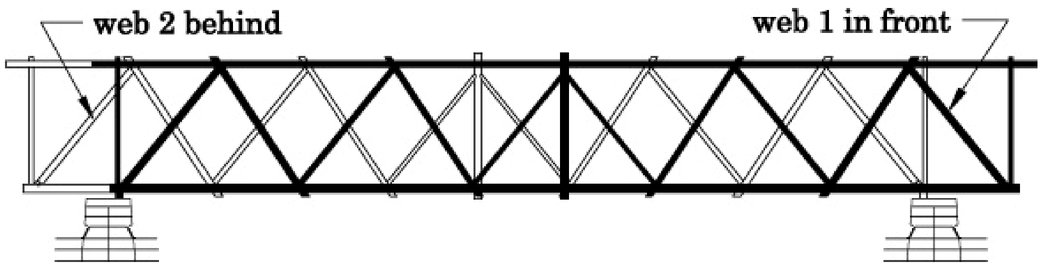

Figure 4a. Two prototype Single Trusses offset longitudinally.

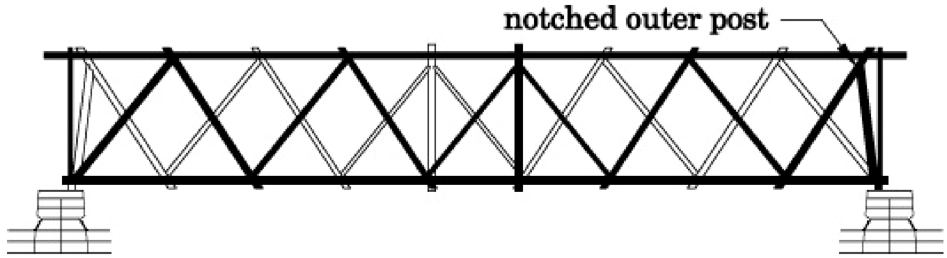

Figure 4b. Prototype double truss

Offsetting the two web sets lengthwise reduced the distance between supports for the chords by half, greatly increasing the lower chord’s ability to support floor loads. It also increased the upper chord’s ability to support roof (including snow) loads, and reduced its vulnerability to buckling.[4] Yet another result was that the timbers from the two web sets could be bolted together where they crossed. This halves the unsupported length of the braces, strengthening these compression members against buckling too. All this combines to make a Smith "double" truss far more robust than his "single".

Whether the foregoing accurately represents Smith's thought process in developing his truss is speculation. What is certain is that the result is the double truss shown in Smith's patent drawing (Figure 5).

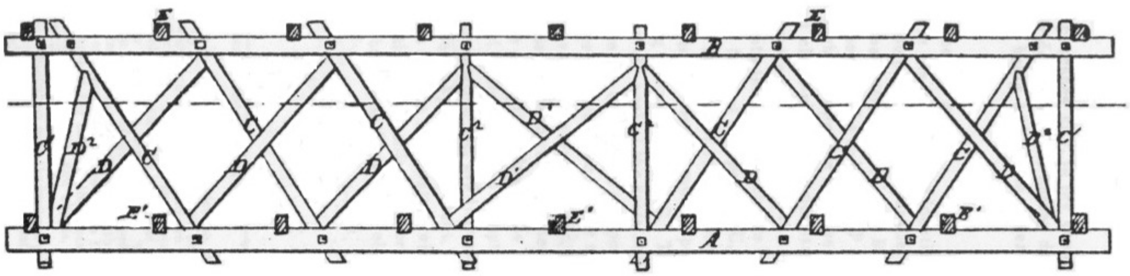

Figure 5. Smith truss elevation view. Detail from U.S. Patent # 66,900 (July, 1867)

It is important to note that Smith's patent says of this drawing:

> "The bridge represented is known as a double-truss bridge, as there are two sets of posts and braces. Bridges may be made with a single truss, or with three or more, depending upon the strength required."

Buonopone et al,[5] as part of their study for HAER, confirm with 20 Smith bridges what this author's previous work[6] showed with eight examples: Smith used "triple" trusses for longer bridges. Twelve of the 20 in the HAER study are "double truss" bridges. They span between 59' and 146'. Of the eight "triple" truss bridges, seven span 150' or more (the exception, Brown Bridge near New Hope, OH, is unusually wide for a Smith bridge).

The only two known Smith "single" truss bridges are also the shortest known Smiths: the 42' Feedwire Road Bridge, built in 1870, and the 50' Jasper Road (aka Mud Lick) Bridge, built in 1877. Both are in Montgomery County, OH; both were built by the Smith Bridge Company, have been moved and had timber arches added. Neither was included in Buonopone et al's study because in recent times they have not been recognized as Smith trusses except by this author.[7]

Smith's idea of adding web layers to increase the strength of his trusses may have been influenced by Ithiel Town's lattice trusses. Town's second bridge patent, of 1835, did

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[4] Upper chords are truss compression members, and thus vulnerable to buckling. Such vulnerability is proportional to the square of the unsupported length (other things being equal).
[5] Buonopone, Stephen, Sarah Ebright, and Alex Smith: *Structural Study of Smith Trusses*, Historical American Engineer Record publication PA-645, 2012.
[6] Reckard, Matthew, op cit.
[7] The misidentification is a consequence of Wilson's typology, as discussed later in this paper.

much the same thing to his truss, doubling the layers of diagonal planks in the lattice truss web. Perhaps because of this precedent, Smith did not explicitly claim the idea of multiple webs as one of the innovations of his patent, even though he described it there.

3. Modifications 1867-1870

The truss shown in Smith's first (1867) patent might be called a prototype. He may have built trusses like this, but if so neither they nor photographs of them survive. Smith refined his trusses over the next three years to make them stronger, easier to build, and/or more efficient in use of materials, as described below. None of the changes were fundamental enough that he patented them.

3.1 Midspan web member arrangement

By 1868 Smith eliminated the remnant vertical kingpost in the middle of his trusses, substituting a pair of inclined posts. The result in a 'single truss' is shown in Figure 6. The new pair of posts approximated a 'V' at midspan. Both extant Smith 'single truss' bridges have this form. This 'single truss' approximates a continuous series of inverted 'V's between horizontal chords, much like a Warren truss but with a couple of important differences. First, posts and braces in a Warren truss meet at a single point on the chord axis; on a Smith truss they never do. Second, transfer of forces between members of a Warren truss is made through metal fasteners – bolts or pins – but in Smith trusses is always through direct contact between timbers. [8]

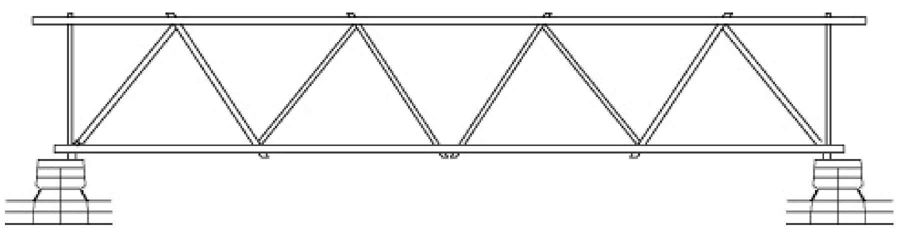

Figure 6. Smith Single Truss, 1868 and later

An advertising lithograph for Smith bridges printed between late 1867 and late 1869 shows single, double, and triple truss versions with 'V's at midspan (Figure 7).[9] The single truss is shown carrying a light load (a horse and rider), the double a heavier load

[8] The Warren truss was invented in Britain and patented there in 1848, intended principally for use in iron railroad bridges. Several iron members in the same plane can be joined at a single point using a heavy bolt or pin, as is typical on early metal trusses, both Warrens and other types. In an all-timber truss like a Smith such a joint isn't practical, for the timbers would have to be notched so deeply at the joint they would be badly weakened. The writer is satisfied that Robert Smith didn't develop his truss as a timber adaptation of the Warren truss. If he had his 1867 patent wouldn't have shown the truss with vertical posts at midspan.

[9] The lithograph advertises "Smith's Patent Truss Bridge", and so must postdate the July, 1867 patent. It lists Tippecanoe, Ohio as the address, and thus must predate Smith's 1869 move to Toledo, Ohio (which is where Smith's second patent of December 1869 says he resides).

(two horses pulling a wagon), and the triple an even heavier load (a train). As in the single truss, web members in the double and triple trusses form ‘V’s at midspan (rather than ‘X’s as elsewhere) because there are no braces (compression diagonals) in the central panels to cross the posts (tension diagonals).

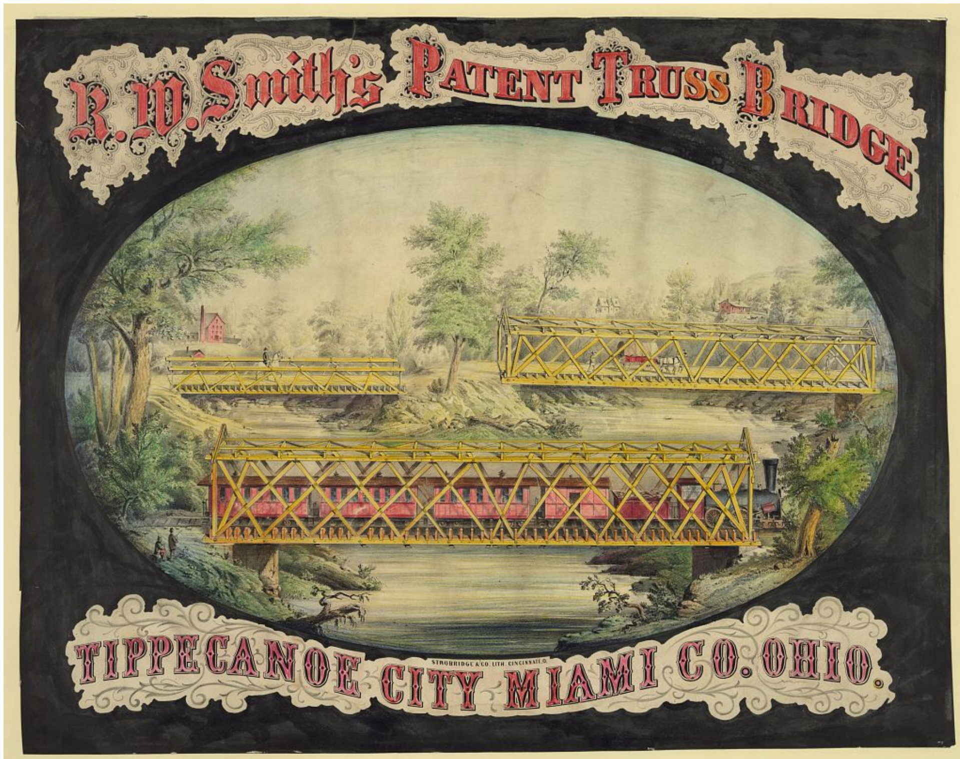

Figure 7. Smith Bridge advertising lithograph, circa 1868. Source: Library of Congress[10]

The triple truss shown in the lithograph shows each web set offset from both of the others. Diagonal web members thus cross *two* diagonals going the other direction. If Smith ever built trusses like this, none remain. In all extant Smith “triple” trusses (there are at least eight) the third set of web members is directly behind the first. Consequently they look exactly like a double truss in an elevation drawing.

Just such a “triple” truss is drawn in Smith’s second patent (#97,714), of December, 1869 (Figure 8). Like the trusses in the lithograph, the one drawn in the 1869 patent has a ‘V’ configuration at midspan.[11]

[10] U.S. Library of Congress: Accession number LC-USZC4-5593.
[11] Note that the 1869 patent is*n’t* for the truss, but for bridge lateral bracing attachments and portal bracing. The Smith “triple” truss (and his “single truss”) were described in, and covered by, the 1867 patent, even if Smith hadn’t drawn them there. And evidently Smith (or perhaps the Patent Office) did not consider the ‘V’-shaped rearrangement of midspan web timbers a significant enough improvement in his truss to warrant patenting

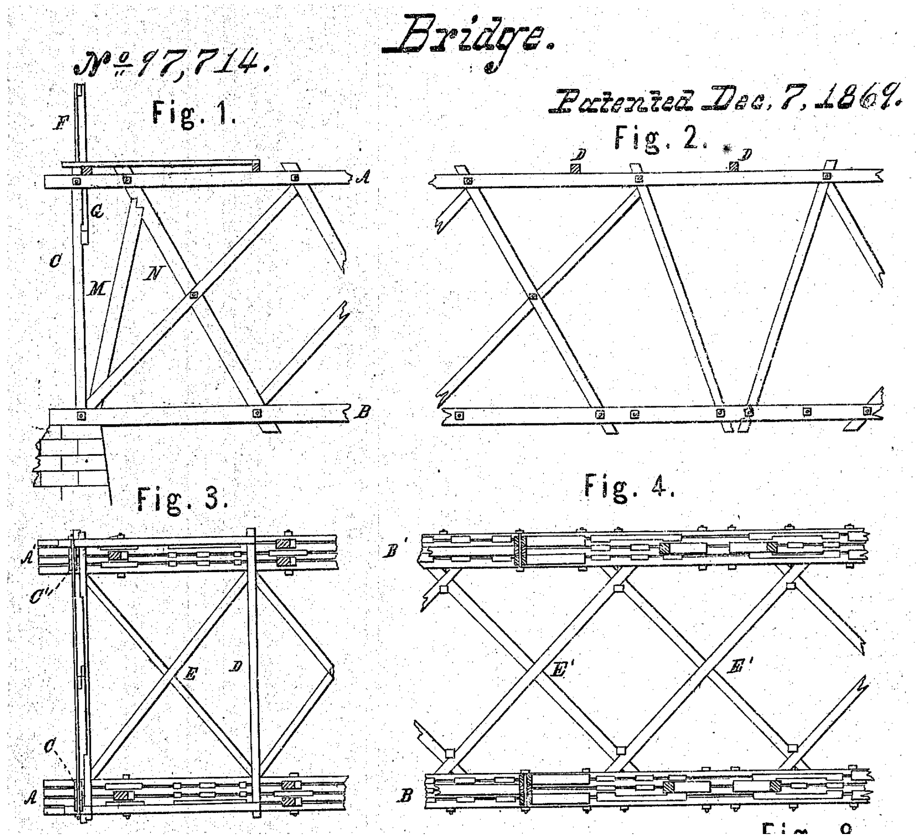

Figure 8. Detail of Smith's 1869 patent showing truss elevation and plan drawings. His Figures 3 and 4 are plan views of the upper chord and lower chords, respectively. The drawings are of a 'triple' truss; hence the four-piece chords.

Trusses are, almost by definition, arrangements of triangles, yet the 'V' arrangement results in quadrilaterals near midspan in Smith double and triple trusses, as seen in both Figures 7 and 8. The consequence would be substantial bending moments in the chord members and more deflection (sagging) under traffic loads.

Only the oldest two extant Smith 'double truss' bridges (and none of the triples) use the "V-center" form. They are the Kidd's Mill Bridge, in Mercer County PA, built in 1868, and the Johnson Road (aka Crabtree or Petersburg or Brushy Fork) Bridge, Jackson Co, OH, built in 1870.[12]

Smith began adding braces to midspan panels in his double and triple trusses not later than 1871, when the Buckeye Furnace Bridge in Jackson County Ohio was built. The change may have occurred as early as 1869 or 1870 (the "V-center" Johnson Road Bridge of 1870 was not built by the Smith Bridge Company and so may have already been an obsolete form).

[12] Buonopone et al, op cit, p.22

Although usually in compression, the midspan braces can go into tension under unsymmetrical traffic loads. Smith therefore notched them into the chords, giving them tension capability, rather than just butting them against the posts like the other braces.[13] The result is a truss that looks like the one shown in Figure 9: an uninterrupted series of 'X's between chords. Nearly all remaining Smith truss bridges – and probably the vast majority of all ever built – are of this form.

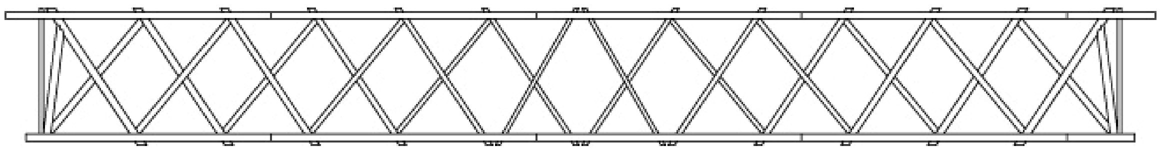

Figure 9. Example of a post-1870 Smith double truss (Cataract Bridge, Owen Co., IN., built 1876). Drawing by the author.

3.2 Variable post and brace size

A further improvement Smith made to his trusses was to vary the size of posts and braces. Forces acting on these members vary depending on their position in the truss. Despite this, in multiple kingpost trusses (from which Smith's truss may have been derived, as previously discussed) posts and braces are usually all the same size. They all appear the same size in Smith's 1867 patent drawings (Figure 4) too. In the 1869 patent drawings, however, (Figure 7) the width of posts and braces appears to vary; they are larger at the ends of the bridge and smaller at midspan, just like the forces they must resist.[14]

Perhaps Smith always built his trusses with varying post and brace sizes. He didn't claim this as part of his inventions in either patent, and so perhaps didn't think the feature worthy of depiction in the first patent's drawings. The feature is present in the oldest remaining Smith truss, the 1868 Kidd's Mill Bridge.[15] It is present in all Smith Company bridges the author has measured, including the 1870 single-truss Feedwire Road Bridge.

3.3 Notching of steeply inclined outer brace

In both the advertising lithograph and the 1869 patent drawing the notches at the tops of the steeply inclined braces at the ends of the truss are shown with a zigzag shape, in contrast to the simple kingpost-type notch shown in the 1867 patent (Figure 5). Such lightning-bolt notches at the tops of these braces (Figure 10) became a signature feature of Smith Bridge Company trusses (and sometimes help distinguish them from Smith trusses built by others).

[13] It isn't known if Smith knew from the start that these braces could go into tension. He may have built them at first like the other braces, only to have them work loose and fall out in the completed bridge!
[14] Smith's posts and braces are all the same *thickness* so notches at the chords can all be the same depth.
[15] Buonopone et al, op cit, p.44

Figure 10. Cataract Bridge, Owen Co, IN (detail). The zigzag notching of post and brace in the outermost panels is characteristic of the Smith Bridge Company. Photo: J.A. Barker Engineering

4. Modifications after 1870

After 1870 the Smith Bridge Company developed a composite truss, much like a Smith truss but with iron rods for the tension diagonals, for use on railroad bridges. Furthermore, the company began building all metal bridges as early as 1870, and by 1890, when Smith sold the company, they had stopped making wooden bridges altogether.[16] These developments are beyond the scope of this paper.

5. Wilson's Typology

In his 1967 article[17] Raymond Wilson divided Smith trusses into four types, which he asserted were a chronological development. He calls the truss shown in the 1867 patent

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[16] See Clark Waggoner, ed., entries on Robert W. Smith and Smith Bridge Company, *History of Toledo and Lucas County*, Munsell & Co., New York, 1888, pp. 786-787; also Eldon M. Neff, "Highlights in the Life of Robert W. Smith," *Connecticut River Valley Covered Bridge Society* XI, No. 4 (Spring 1963).

[17] Wilson, Raymond, op cit.

drawings "Type 1", and the one in the 1869 patent drawings, with a V at midspan, "Type 2". Later Smith double trusses, with Xs at midspan rather than a V, he calls "Type 3". Lastly, he calls Smith triple trusses (with Xs at midspan) "Type 4", claiming they are a late development.

In this author's view, Wilson's typology is so problematic it should be abandoned. The principal problem is Wilson's focus on the arrangement of midspan web members. The inventor's fiddling with these arrangements in the two or three years after filing for his patent in 1867 is not central to the importance of Smith or his trusses. By the time the Smith Bridge Company opened its factory in Toledo (or, possibly, shortly thereafter) he had settled on the arrangement used in all but two extant Smith truss bridges, and probably nearly all that were ever built. Wilson calls these either Type 3 or Type 4, but the distinction he makes between them, that one is a chronological improvement on the other, is wrong.

Among other problems with Wilson's article and typology:

- Wilson seems not to have read the 1867 patent text, which says it covers not only the double truss in the drawings but single and triple (and more) trusses. Consequently he fails to recognize one Smith's principal innovations: adding web sets to his truss as needed to match strength requirements.
- Related to the above, Smith single trusses simply don't exist in Wilson's typology.
- Wilson says his "Type 2", shown in the 1869 patent drawings, looks like a 'V' at midspan but elsewhere has "single timber 'X's", i.e. two overlapping web sets - what Smith's 1867 patent called a 'double truss'. However the 1869 drawings are of a *triple* truss (see Figure 8), which according to Wilson's typology is the distinguishing feature of his "Type 4".
- Wilson claims that posts on Smith trusses are 60 degrees from horizontal and braces 45 degrees. In Smith trusses these angles are a consequence of the choice of truss height and panel width, not a design choice in itself, and so are (in the author's experience) never a round number. At Cataract Bridge, for example, they are approximately 56.4 and 50.8 degrees for posts and braces, respectively.[18]

6. Suggested Typology

The author suggests that the most important distinction to make between Smith trusses is the number of web member sets they have, and that the inventor's terminology is as good as any: one set of diagonals makes it a "single truss", two sets makes it a "double truss", three sets makes it a "triple truss". One might add that, with a single exception, all known Smith single trusses span 50' or less, doubles span between 50' and 150', and triples span more than 150'.

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[18] See J.A. Barker Engineering's 2003 rehabilitation plans for the bridge (author the designer of record), on file with the Indiana DOT, Project Designation 0101231; Construction Contract B-26992.

If one needs to distinguish the few early Smith double or triple trusses that look like a 'V' at midspan from the 90% which look like 'X's in the middle, one could call them 'early' versus 'mature' (or 'late'), or call them 'pre 1870' versus 'post 1870', or simply 'V-centered' versus 'X–centered'. The author favors 'early' versus 'mature'.

This leaves those Smith trusses known only from drawings – those with a kingpost at midspan, as shown in the 1867 patent (Figure 5), and triple trusses where each diagonal crosses others in two places, as shown in the advertising lithograph (Figure 7). If one needs to distinguish these it seems simplest just to call them 'prototypes known only from drawings'.

7. Observations on Smith Truss Performance

Inadequate maintenance is by far the greatest cause of problems with Smith truss covered bridges the author has observed. The worst culprits are failure to keep the abutment tops clear of debris and failure to maintain the roof. The former leads to the lower corners of the bridges getting buried in dirt, leaves, flood flotsam, and animal droppings and consequently rotting. The latter leads to decay throughout the structure, especially in upper chords and joints in the lower chord. Both of these issues are common to all timber covered bridges.

Aside from decay, the most commonly seen structural failure in Smith trusses is in the tension joints in the lower chords. Such failure is common not just in Smiths, but in all timber truss types that rely solely on C-shaped wooden "fish plates" fitted on one side of the joined timbers. One prominent 19th Century Hoosier bridge builder, J.J. Daniels, recognized this weakness and fitted iron bar reinforcement across the tension joints on the side opposite the fish plates (which he called 'hooks'). This was very effective, as evidenced by more than a century's performance of his bridges. Smith truss lower chord joints can be strengthened with retrofit Daniels-type or similar metal reinforcement.

8. Ackowledgements

Thanks to Jim Barker, to Dario Gasparini, and to David Simmons for their assistance and indulgence.