AMERICAN TRUSS BRIDGE CONNECTIONS IN THE 19TH CENTURY.
I: 1829–1850

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ABSTRACT: In 1829 Stephen Harriman Long built a wood truss with details well suited to the mechanical behavior of wood. The truss was statically determinate, prestressed by wedges and required no tensile connections for the diagonals. In 1840 William Howe and Amasa Stone improved Long’s design by using threaded vertical iron rods for prestressing. In 1839 Long patented a truss with diagonals that were pretensioned by using wedges on the vertical members. Long’s method of prestressing the diagonals in tension was improved by Thomas and Caleb Pratt, who prestressed by tightening threaded iron diagonals. However, their design was not immediately successful for bridges with wood chords because prestressing often caused local crushing of the wood. Therefore, the dominant American truss at mid-century was the Howe truss, wonderfully adapted to the properties of wood, statically determinate, prestressed, easily adjusted and maintained, and with precompressed diagonals bearing on joint castings without positive connections to the chords and verticals. All these features were destined to be abandoned by American engineers over the next 20 years.

INTRODUCTION

In 1895 John E. Greiner wrote a paper entitled “What is the Life of an Iron Railroad Bridge?” Along with Greiner’s technical article were published discussions and correspondence that exceed the length of the original paper. Together they highlight design issues and indicate a wide spectrum of opinions and solutions to problems. In short, they provide insights into the state of the art of bridge building at the turn of the century.

By the last decade of the 19th century, Greiner had experience with the engineering corps of three bridge companies and the Baltimore & Ohio Railroad Co. He suggested that the “details of connections have heretofore been the weakest parts of bridges, are the first to cause trouble and, as a rule, must be strengthened long before the main sections are in any danger” and that “details should receive individual attention independent of the attention bestowed upon main members, and in considering them it should be remembered that the strength of the weakest member of the weakest bridge on the line of a railroad is a measure of the capacity of the traffic on the road.”

Other American civil engineers of the period placed equal importance on bridge details. George S. Morison, previously an engineer on the Erie Railroad and the builder, at that time, of several of the world’s longest metal trusses, felt “the difficulties, wear ... occur in the details.” Former engineer for several bridges (including the Eads Bridge) and railroad companies, Onward Bates insisted that even while main members may be “reasonably safe,” a bridge depends on “other features” that, in their own right, “may be treacherous,” and that “cause the engineer of maintenance to have uneasy dreams.” He defined these other features simply as “details and connections.” Charles D. Purdon, a one-time engineer for nine different railroads, claimed that “in old bridges when calculated for present loads, the trusses show up fairly well excepting the hip vertical, and the weakest parts are the floor and its connections.” Louisvile and Nashville Railroad en-

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gineer Richard Montfort concluded that the lives of “old bridges” are most often determined by the “details.”

These engineers were using strength and serviceability design criteria. From an entirely different viewpoint, architects have made similar statements on the importance of details. Details and connections affect the constructability, economy, performance, durability, safety, and beauty of a design. Good design requires simple, elegant connections that reflect thought, ingenuity, and the state of the art in material and erection technology and structural design concepts. Fine details evoke a valued sense of individuality and craftsmanship.

Our intent is to describe the evolution of 19th century American truss bridge connections. Pivotal forms are discussed for their insights into structural design and the behavior of various trusses. The study begins with the wooden trusses of Stephen Harriman Long, who started designing bridges for the B & O Railroad in 1829. Of course, Timothy Palmer, Theodore Burr, Lewis Wernwag, Ithiel Town, and others built many notable wooden bridges prior to Long. Lee Nelson’s study of the Colossus of 1812 (Nelson 1990) clearly points out Wernwag’s concern and pride in the details of his bridge. The builder’s description of the bridge that accompanied a promotional broadside states, in part

The dry rot is entirely prevented by the timber being sawed through the heart, for the discovery of any defect and kept apart by iron links and screw bolts, without mortice or tenon, except the king posts and truss ties. No part of the timber comes in contact with each other, and can be screwed tight at anytime when the timber shrinks. Any piece of the timber can be taken out and replaced if required without injury to the superstructure. (Nelson 1990)

Clearly his objectives were to simplify connections, prevent decay, provide for adjustment and replacement of parts, and avoid tension connections. Town’s lattice trusses were connected by wood dowels, or trenails, which did not allow for adjustments nor for easy replacements (Dreicer 1993). Wernwag’s Colossus and Burr’s bridges mixed truss and arch forms, thus precluding simple analyses for determining forces in various parts of the bridge. It was Stephen Harriman Long who first designed trusses to have a known flexural strength, using details perfectly suited to the mechanical behavior of wood.

WOODEN TRUSSES OF STEPHEN HARRIMAN LONG

R. G. Wood’s biography of S. H. Long (1784–1864) (Wood 1965) reveals the extraordinary breadth of Long’s work and
the length of his public service. For close to 50 years, Long served in the U.S. Army’s Corps of Topographical Engineers and was centrally involved in building the nascent infrastructure in roads, canals, railroads, and river navigation. He built bridges and buildings, locomotives and steamships. He worked from Maine to Georgia, from the mouth of the Mississippi to Alton, Ill., and north. Long’s focus on truss bridges likely began in 1827, when he was appointed to the board of engineers of the B & O Railroad and continued until the 1840s, after which his principal work was the improvement of river navigation throughout the South and Midwest.

Long benefited from a rigorous formal education. He graduated from Dartmouth in 1809 and then taught school in Philadelphia, coincidentally at the same time that Wernwag was building his “colossus.” In 1814–1815 he was an assistant professor of mathematics at the U.S. Military Academy at West Point, and from 1817–1824 he commanded exploratory expeditions to the American West. He evidently read French works on theoretical mechanics, since he cited Claude Navier in an 1825 article on lifting mechanisms for canal boats (Long 1825). As a member of the board of engineers for the B & O, Long strongly favored wooden trusses. Wood was more economical than stone for rail bridges but less durable and largely unproven for railroads. Although the B & O chose to construct traditional stone-arch viaducts, Long was allowed to build one wooden bridge over the railroad right-of-way. The bridge was completed in August 1829, named by Long the “Jackson Bridge” and patented by him on March 6, 1830. The patent drawing is shown in Fig. 1. What is significant is not the form of the bridge, which was depicted and discussed by Navier (1826), nor the awkward “superior arch braces,” which were probably never used. Instead it is Long’s details. All of his patent claims rested on the details and included:

1) Two modes for splicing the string pieces (i.e., the chords);
2) a system of bracing .... the stresses or thrusts communicated by the braces are resisted by shoulders or stops as nearly as may be at right angles with the grain, or fibers of the timber;
3) a system of counterbracing;
4) a mode of furnishing the main braces and posts with metallic bearings;
5) a mode of keying, or wedging, by means of which the central parts of the truss frames, and consequently of the bridge, may be elevated, and sustained, in case of a subsidence or sinking of those parts, which is liable to happen from a shrinkage or, extraordinary compression of the timber. (Long 1836)

The position of the wedges at the ends of the main braces is shown in details 8 and 9 of Fig. 1. Long noted that the wedges were “essential to the trussing and stiffening of the bridge” and that care should be taken to “drive them as hard as they may be driven, with an ax or sledge weighing 4 or 5
pounds.” Long’s detail for splicing wood tension chords was essentially that suggested by Navier. In brief articles in the *Journal of the Franklin Institute*, (Long 1830a,b,c), Long explained the differences between his truss and the work of Wernwag, Burr, and Town. He noted that his “braces act uniformly in the direction of their axes, and exclusively by thrust. Their connection with the truss frames is such as to preclude any action by tension.” A “testimonial” written in January 1833 by George Winchester (Long 1836), president of the Baltimore and Susquehanna Railroad, nicely summarized the importance of Long’s details. Winchester indicated his familiarity with wooden bridges, especially Town’s and Burr’s, and insisted that Long’s was “superior to any of them, in point of strength, solidity, permanency, and above all, in the facility with which it can be repaired, by replacing any piece of timber without disturbing the structure, so that by constant slight repairs the bridge will be perpetually reinforced, at a very slight expense. These bridges have been passed more than five months with a steam engine and tender weighing at least ten tons, with heavy trains of carriages attached, without causing the slightest perceptible motion.” Long’s trusses were certainly among the first to carry loads of trains powered by steam engines.

In 1836 Long received a patent for a lateral bracing system for compressive chords and published a booklet with tables giving the depth of trusses and the cross-sectional area of all members for a set of spans ranging from 16.8 m to 91.5 m (55 ft to 300 ft) (Long 1836). The significance of Long’s booklet was recognized by the 19th century German engineer and technical writer Karl Culmann (1851), who reproduced and discussed some of Long’s tables as a part of a work on American and English bridges. The tables show that Long proportioned the areas of chords using Navier’s analogy of a parallel-chord truss as a beam (Gasparini and Provost 1989); that is, stresses in the chords were determined by treating a truss as a beam consisting of two areas (the chords), separated by the web members. In 1839, Long patented another truss (U.S. Patent No. 1397) with details as shown in Fig. 2. Long called it a “suspension” truss because the diagonals were made to act in tension by prestressing with wedges at the top of the vertical posts, as shown in detail 2 of Fig. 2. The design was less practical for wood because it required detailing tension connections for the diagonals, which were not orthogonal to the chords, but it showed Long’s understanding of prestressing. Moreover, Long may have realized that the system was better suited to iron, because he carefully stated that his patent was “new and original . . . not only with respect to the construction of wooden bridges, but also with respect to bridges composed of iron, or partly of iron and partly of wood.”

Long’s Jackson Bridge design of 1829 set the course for U.S. truss designs well into the 1850s in the sense that most trusses of that period were

- Statically indeterminate because of the counter braces
- Prestressed by means of adjustable elements (or wedges)
- Without "positive" connections for the diagonals
- With continuous chords, spliced between panel points

These features are evident in an existing Long truss in Miami County, Ohio, called the Eldean Bridge and shown in Fig. 3. Built in 1860 by James and William Hamilton of Piqua, Ohio, the bridge consists of two spans, each about 34 m (112 ft) long. The proportions of the bridge approximate those suggested by Long in his 1836 book. Fig. 4 shows that the diagonals are not "positively" connected to the chords or vertices and are prestressed by wedges, which are only at the bottom for this bridge. Fig. 5 shows a typical lower chord splice, placed between the panel points. The bridge is a fine example of early U.S. bridge-building technology.

**HOWE-STONE TRUSS**

The dominant truss in the period of transition from wood to iron was patented by William Howe in 1840 as a double-
intersection truss (Fig. 6) and later modified, very likely by his brother-in-law, Amasa Stone (Condit 1960), into its classic single-intersection form (see Fig. 7). Stone purchased the patent rights and formed a company with Azariah Boody in 1841–1842 to market, design, fabricate, and erect Howe trusses as an integrated enterprise.

The essential features of the Howe truss are that it is statically indeterminate and prestressed by tightening the threaded vertical iron rods. The diagonals are prestressed in compression and so do not require positive connections at the joints. Thus, the structural behavior of the Howe truss is exactly the same as Long's 1829 Jackson Bridge. But prestressing by tightening nuts is racially easier and more efficient than driving wedges. The Howe truss, therefore, made Long's all-wood design, which had been built throughout New England, obsolete. Since iron verticals are used, the Howe truss required

![Image of Howe Truss Bridge]

**FIG. 7.** Classic Single-Intersection Howe Truss and Joint Details [from Cooper (1889)]

![Image of Joint Details and Joint Blocks]

**FIG. 8.** Details of Reading-Halls Station Howe Truss Bridge [from Kemp and Anderson (1987)]
"joint blocks," either of wood or iron, to provide bearing surfaces for the diagonals. Howe used Long's details for splicing the chords and Long's method for bracing the compressive chord laterally (Long's 1836 patent). The procedure used by Howe and Stone to size the chords is unknown; they may have used Navier's analogy, since it was explained in D. H. Mahan's 1837 book.

The Howe truss was readily adaptable to the rapid construction techniques desired by fledgling railroad companies anxious to complete their lines. Iron rods and the wooden sections used for compression members could be standardized and, to a large extent, prefabricated. Furthermore, the separate components of an existing bridge could be readily repaired, facilitating maintenance. Because of these factors, it became the dominant railroad truss of the time. As railroads began to experiment with all-iron bridges in the 1840s, the Howe truss, with cast iron for the compression members and wrought iron for those in tension, became the natural choice for some of

**Fig. 9.** Howe Truss Built by Frederick Harbach in 1846

**Fig. 10.** Howe Truss Built by Amasa Stone in 1849 [from Cooper (1889)]
the first designs. Three early iron bridges show the spectrum of design decisions on materials, sections, and connection details.

Richard Osborne’s West Manayunk Bridge of 1845 and the 1846 Reading-Halls Station Bridge studied by Emory Kemp and Richard Anderson (Kemp and Anderson 1987) were the first adaptations of the Howe truss to iron. Fig. 8, taken from their study, shows the principal details. There are no splices in the upper and lower chords, which consist of parallel quartets of 101.6 mm by 32 mm (4 by 1.25 in.) wrought-iron bars. The parallel bars are not efficient for precluding buckling in the upper chord and so relatively narrow panels, just under 1.22 m (4 ft), were used. The compressive diagonals are cast iron tubes, without positive connections to the joint blocks because of prestressing. In the tradition of 19th century iron castings, the diagonals have fine decorative detailing.

Massachusetts bridge builder Frederick Harbach built an all-iron Howe truss for a railroad in 1846–1847 (see Fig. 9) (Whipple 1889; Simmons 1993). Spanning 9.1 m (30 ft), it had a 1.8 m (6 ft) depth and eight 1.2 m (4 ft) panels. Apart from its cast iron upper chords and braces and wrought iron lower chords and vertical rods, the most distinctive feature was the tubular lower chord of “boiler iron 4.8 mm (3/16 in.) thick, riveted up with two longitudinal seams and 152 mm (6 in.) in diameter, two to each truss.” The upper chord was also a pair of cylinders, each over 102 mm (4 in.) in diameter. The braces and chords were “connected by cast-iron saddles shaped to fit the chords” (Whipple 1889).

In 1849 an iron Howe truss, shown in Fig. 10, was built by Amasa Stone and D. L. Harris (Cooper 1889). This deck bridge had a 15.2 m (50 ft) span. The bottom chord consisted of three plates with staggered splices between the panel points, probably similar to those shown in Fig. 11, which were used by Stone for a railroad bridge over the Ohio Canal in 1850 (Simmons 1989). The diagonals were orthogonal, cast as one piece and had a cruciform cross section. The top chord appears to have been two channel sections, nested to form a boxlike shape. Unlike the Reading-Halls Station Bridge, the Stone and Harris design is starkly functional, with no embellishment.

These three iron Howe bridges demonstrate the acceptance of cast iron for joint blocks and for compressive elements, and the use of nonpositive diagonal connections. Furthermore, they illustrate that prestressing, developed largely to counteract the shrinkage of wood, was also applied directly to iron bridges. The efficiency of tubular compression elements was recognized and used very early.

**TABLE 1. Prestressed Trusses with Tensile Diagonals and Compressive Verticalls**

<table>
<thead>
<tr>
<th>Patent</th>
<th>Truss type</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. H. Long, 1839 (U.S.–1397)</td>
<td>All wood, but patent included iron Single intersection Prestressed by wedges on verticals</td>
</tr>
<tr>
<td>T. and C. Pratt, 1844 (U.S.–3523)</td>
<td>Wood and iron Single intersection Prestressed by tightening nuts on diagonals</td>
</tr>
<tr>
<td>N. Rider, 1845 (U.S.–4287)</td>
<td>All iron Single intersection Prestressed by wedges on verticals All iron Multiple intersection Prestressed by wedges on verticals</td>
</tr>
</tbody>
</table>

**PRATTS, RIDER, AND "SUSPENSION" TRUSSES**

Howe trusses were prestressed to place the diagonals in compression and the verticals in tension. Truss forms were
also designed so that prestressing would create tension diagonals and compression verticals. Four patents for such "suspension" trusses are given in Table 1. Two basic techniques were used to achieve the desired behavior. Long, Nathaniel Rider, and Stephen Moulton prestressed by using wedges on the verticals, while Thomas and Caleb Pratt prestressed by tightening nuts on the threaded iron diagonals. Long's all-wood design, although conceptually correct, was doomed to be a commercial failure because it required a complicated tension detail to connect the diagonals with the top and bottom chords. The Pratts' introduction of threaded iron diagonals, as shown in Fig. 12, was analogous to the simplification introduced by Howe to Long's 1830 patent. The Pratt truss required no positive connection between the chords and the verticals, which were prestressed in compression. Their patent description, which prescribes a method of erection, emphasizes that fact. The Pratt form is more efficient than the Howe form because the longer elements (the diagonals) are in tension. Nonetheless, the design was not immediately successful, becoming dominant only in the 1870s in its nonprestressed, single-diagonal form. Its slow acceptance was probably due to its less-than-satisfactory performance when wood was used for the chords and for the vertical elements. In comparison with the Howe truss, twice as many rods had to be tightened; moreover, the nuts were in an awkward inclined position and were difficult to tighten down. Additionally, the prestress forces seemed to cause some local crushing of the wooden chords. George L. Vose noted in his 1878 *Manual for Railroad Engineers* that "the prominent defects of the old fashioned Pratt Truss" were "the crushing of the top chord between the washer and the post." This would certainly have led to a loss of prestressing and decreased the vertical stiffness of the truss. Further, from a stress viewpoint, the prestressing increased the compressive forces in the top chord, which, in turn, increased the risk of buckling. For wood, the Howe truss remained the more suitable form.

An all-iron "suspension" truss was patented by Nathaniel Rider in 1845. It was a single-intersection truss, prestressed by wedges on the verticals (Fig. 13), precisely as Long had done six years earlier. By this time Long was over 60 years old, but he was apparently actively defending his patent, in which he had had the careful foresight to include iron trusses.

The New York Iron Bridge Co., which marketed the trusses after Rider's death, in 1848, acknowledged Long's priority in an 1850 bulletin ("Circular" 1850). It is likely that all single-intersection Long-Rider trusses had to give proper credit to Long. A Long-Rider bridge described in the April 25, 1912, issue of *Engineering News* ("An Old Truss" 1912) (see Fig. 14) bore a plate stating: "Patented 1939 by S. H. Long" and "built 1853 by M. M. White." It is of note that the diagonals are eyebars. Apparently Long's priority did not extend to mul-

![FIG. 12. Caleb and Thomas Pratt Truss Patented in 1844](image)

![FIG. 13. Details from Long-Rider "Suspension" Truss: A, Bottom Chord; B, Top Chord; C, Compensive Post; D, Eyebar Diagonal; E. Wedges Used to Prestress Truss [from Moulton (1848)]](image)
multiple-intersection forms, which were patented in England in 1847 by Rider’s colleague, Stephen Moulton. The multiple-intersection form was marketed as the “improved Rider truss.” Examples are described by Cullmann (1851), in Herman Haupt’s seminal 1851 volume on bridge design, and in Victor Darnell’s recent study (Darnell 1991). Because prestressing by wedges was awkward, the all-iron Long-Rider-Moulton trusses were built only for a relatively short time. Still they represent an alternate way of achieving tensile diagonals and an early use of eye bars and pins in America.

PRACTICES AND ISSUES AT MID-CENTURY

The dominant American truss at mid-century was the Howe truss, wonderfully adapted to the properties of wood, statically indeterminate, prestressed, easily adjusted and maintained, and with precompressed diagonals bearing on joint castings without positive connections to the chords and verticals. Essentially all these features were destined to be abandoned by American engineers over the next 20 years. By the 1870s, statically determinate, pinned trusses without adjustable elements and joint castings were considered the modern norm. These changes in American design practice reflect the properties of iron and steel, changes in fabrication technology, and advances in structural analysis.

Adjustable-length elements (or wedges) were used to pre-stress wood trusses because wood shrinks as it dries, because wood creeps at normal temperatures, and because it is difficult to design wood tension connections. These reasons for adjustable-length elements did not exist with iron. From a fabrication viewpoint, iron castings require considerable effort to form, cannot be easily modified to fit various spans, and their internal flaws are difficult to control and detect. From both cost and reliability viewpoints, it was logical that they would fall into disuse.

The publications of Squire Whipple, Haupt, Cullmann, and others explained the analysis of statically determinate trusses by using joint-by-joint equilibrium. Navier’s analogy was no longer needed. It was understandable that designers should turn to statically determinate forms, for which element forces were easily computed. Unfortunately the statically indeterminate forms that had been designed in an approximate way and had performed so very well were abandoned. Prestressed Pratt trusses appeared in the wing structures of early biplanes; however, they were not used again for large-scale civil engineering structures until the 1960s, when computers for performing structural analyses became widely available. In addition to emphasizing statically determinate forms, early explanations of truss behavior emphasized that true truss behavior existed only if the joints were “pinned”; that is, if all the elements were precluded from carrying moments at their ends. Therefore eye bars became viewed as ideal tension elements.

In contrast with the American experience, British engineers did not have the strong wood/Howe traditions. They adopted riveted iron tubular bridges, riveted Town lattice trusses and the statically determinate Warren-Monzani truss. Fig. 15 shows the 1852 Newark Dyke Bridge (Cubitt 1853), a Warren-Monzani truss with pinned joints, eye bars, and fixed-length elements. By the late 19th century, these same characteristics would become the hallmarks of American design. After this early experimentation, British engineers abandoned eye bars in favor of riveted connections, presumably because they understood that the additional stresses from riveted connections were small and could generally be neglected and because riveted connections produced stiffer trusses.

In addition to the gradual abandonment of prestressed, statically indeterminate forms, American trusses were to evolve in other important ways:

- Lateral systems for bracing compressive chords of trusses and for resisting wind were designed and integrated into bridges; designers were adopting a three-dimensional view of bridge behavior.
- Floor systems to carry loads directly to the joints were designed to avoid bending chord elements.
- Efficient compressive elements, typically laced, boxlike sections, were designed.
- Designs considered the effects of concentrated wheel loads and of dynamic forces from trains.
- Designs met prescribed specifications.
At the same time, American engineers contested for control of the bridge design process and for independence from bridge companies, which had established integrated design, fabrication, and erection capabilities, and offered bridges from catalogs, on a turnkey basis.

**EPILOGUE**

High-strength steels in the form of seven-wire strand were developed in the early 1950s for prestressing concrete. Engineers can exploit the very high stress levels of which these materials are capable. Use of high-strength steel strands is facilitated by prestressing trusses and thus precluding stress reversals (from tension to compression) under service loads. Because of these high-strength materials and sophisticated structural analysis programs, the use of prestressed trusses is having a remarkable renewal. A recent design is the Roiz bridge near Grenoble, France, designed by Jean Muller and completed in 1990 (Muller 1993). It is a steel space truss, composite with a concrete top chord. It was built using 4 m (13 ft) long modules and was externally prestressed with tendons.

Prestressed trusses are being used for space structures such as the mast for the power array for Space Station Freedom, designed by Able Engineering for Lockheed ("Solar" 1993). Because the truss is to be deployed from a canister, it requires joints that can accommodate the kinematic motion. The truss is prestressed by axial forces in buckled struts, and is, therefore, a three-dimensional version of S. H. Long’s 1839 patent design. Prestressed trusses have also been used for domes such as the Thunder Dome (formerly the Florida Suncoast Dome) designed by David Geiger (Rosenbaum 1989). It is a remarkable application of Buckminster Fuller’s "tensegrity" ideas. Because of prestressing, the dome is constructed mostly of high-strength cable elements, with only a few compressive tubular posts. Geiger’s design is one of the most efficient structures ever built, and it has spawned others such as the Georgia Dome, designed by Matthys Levy (1991) of Weidlinger Associates.

Another notable truss design is the Paris station for the TGV, designed by Peter Rice of the Ove Arup Partnership, and completed in 1994 (Reina 1994). The trusses feature clean weldments, tubular sections, and prestressed cable elements. The design was a conscious effort to "be as daring and expressive as people in the 19th century" (Reina 1994). Although the word "engineers" should have been used, the design is a worthy tribute to the 19th century pioneers, a remarkable expression of structure and architecture.

**APPENDIX. REFERENCES**


