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HISTORIC AMERICAN ENGINEERING RECORD

READING-HALLS STATION BRIDGE
HAER No. PA-55

Location: Part of a private drive on the south side of U.S. Route 220, 1.2 mile west of junction of U.S. Route 220 and State Route 147, Muncy vicinity, Lycoming County, Pennsylvania

USGS 7.5 Minute Series, Muncy Quadrangle, Pennsylvania, 1965 (revised 1973)
UTM Coordinates: 18.346400.4566340

Date of Construction: ca. 1846

Designer/Builder: Richard B. Osborne (1815-1899), Chief Engineer, Philadelphia & Reading Railroad

Present Use: Bridge carrying private drive over railroad

Significance: The Reading-Halls Bridge is almost certainly the oldest all-metal truss bridge in active service in the United States, a lone survivor from the first series of all-metal trusses of any kind designed and constructed in the United States. This Howe pony through-truss bridge followed shortly after the construction in 1845 of the very first all-metal truss bridge, the West Manayunk Bridge, also designed by Osborne and built by the Reading Railroad.

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Transmitted by: Richard K. Anderson, Jr., HAER,

PROJECT DATA AND ACKNOWLEDGEMENTS

The effort to record the Reading-Halls Station Bridge for the Historic American Engineering Record began in 1980 when slides of the bridge, taken by HAER Staff Engineer Donald C. Jackson, were shown to HAER staff members. The structure's Egyptian revival decorative motifs generated great interest in its age and design, so much so that HAER Staff Architect Richard K. Anderson, Jr. organized a volunteer recording party in April, 1980 to make field measurements of the bridge. Anderson was accompanied by his wife, Elizabeth H. Anderson, Donald C. Jackson, and Gregory G. Fitzsimons. Anderson later prepared HAER measured drawings of the bridge, and the HAER office dispatched Jet Lowe, HAER staff photographer, to photograph it in January, 1984.

The bridge was listed in the National Register of Historic Places in January, 1980 after a nomination was prepared in 1979 by Mr. Tom Richey of the Muncy Historic Survey Project. Donald Jackson attempted further research into the bridge's history, but many trails led to dead ends. (There was, for example, evidence that records on this structure perished in a fire in Pottstown, Pennsylvania shortly after 1900.) Mr. Jackson published a short, illustrated article on the bridge in the newsletter of the Society for Industrial Archeology in March, 1980, hoping that this might reach readers who could shed more light on the structure. A response was received from Mr. Edward M. Kutsch of Douglassville, Pennsylvania by the SIA's newsletter and published in its July 1980 edition. Richard Anderson of the HAER staff corresponded with Mr. Kutsch, who in time not only sent copies of photographs he had made of a sister bridge to the Reading-Halls but measured drawings as

well. Mr. Kutsch's drawings and photos also supplied data on the endposts, castings now missing from the Reading-Halls Bridge. Photos of this same sister bridge were also received from Richard Sanders Allen of Albany, New York. Both gentlemen kindly agreed to the reproduction of their materials for the HAER record.

In 1984, Anderson contacted Dr. Emory L. Kemp of West Virginia University to see if he would perform a structural analysis of the bridge to determine its ultimate capacity and see if such an exercise would yield any historical clues. Dr. Kemp, who was spending a year as a Regents' Fellow at the Smithsonian Institution's National Museum of American History, kindly agreed to the proposal and became very interested in the bridge's history. His interest later led him to write the bulk of the HAER historical report for this project. In the meantime, Mr. John H. White (Senior Historian, Division of Transportation, Museum of American History) recommended to Anderson that the Interstate Commerce Commission's valuation records of American railroads from the World War I period be consulted for possible further information on the Bridge. This was done with the considerable and patient help of Mr. E. Hoffstetler of the ICC, who ordered boxes of records on numerous occasions from the ICC warehouse for Anderson's research. Robert M. Vogel (Curator, Division of Mechanical and Civil Engineering, Museum of American History), as always, gave generous access to his voluminous files and permitted Anderson to make measurements of the Manayunk Bridge truss for comparative drawings.

Finally, HAER thanks the Barlow family and Mr. and Mrs. James L. Poust, in addition to CONRAIL, for their hospitality and permission to record this structure.

THE READING-HALLS STATION BRIDGE

The history of bridge development in mid- and late-19th century America is written in iron. As one of the very first all-iron truss bridges to be built in America, the Reading-Halls Station Bridge occupies some of the first pages in iron truss bridge chronicles. Using iron primarily for its fire resistance, the bridge combined a newly patented truss configuration with many decades' advances in the use of iron, thus helping to mark the turning point from wooden bridges built on craftsmens' rules of thumb to iron bridges designed on proven engineering principles. Because of this bridge's place in the history of iron bridge engineering, it would be well to briefly survey the growing place of iron in the world when the bridge was built.

In the late 18th and early 19th centuries, iron was being employed in a bewildering array of new machines, structures, and products required by a rapidly growing urban-industrial society in Britain and later in America. Iron was, however, more than just a utilitarian material and became the symbol of an Age of Progress and of engineering works on a heroic scale. Iron was the medium used by engineers to produce such wonders of the age as the Menai Suspension Bridge by Thomas Telford, Brunel's Great Western Railway which featured monumental bridges at Windsor, Chepstow, and Saltash, together with a trio of steam ships, the Great Western (1838), the Great Britain (1842), and the Great Eastern (1858). The latter two were the first modern iron-hulled steam-driven ships in the world. The Crystal Palace, arguably the most significant building of Victorian Britain, became the symbol of British industrial might at mid century. It was constructed entirely of iron and glass, except for wood floors and trim. With some justification the Victorians came to believe that "anything" could be built of iron and powered by steam. With Darby's successful smelting of iron with coke in 1709, cast iron could be produced in much larger quantities and much more economically than ever before. It soon became possible to cast large structural components, as demonstrated by the world's first large iron bridge cast at the Darby works and erected in 1779. It survives at a place appropriately called Ironbridge in Shropshire, England. By the end of the 18th century, iron had been employed in the construction of numerous arch bridges, imitating earlier masonry forms. Such bridges employed cast iron in its most efficient manner--direct compression--since it is immensely strong in compression but comparatively weak in tension (and hence also in bending). Britain led in the use of cast iron for railway as well as highway bridges. The iron industries in France and America were not nearly as advanced at this time and could not produce large castings suitable for bridges; such components were also costly to transport over long distances on the poor roads of the day.

In 1783-84 Cort introduced iron puddling and a new system of rolling wrought iron rods, bars, angles and other simple shapes. Puddling reduced the carbon content in pig iron, yielding an iron which could then be worked into useful shapes by a rolling mill rather than a blacksmith's forge hammer. Following the introduction of Cort's inventions there was a marked increase in iron production as engineers and inventors found numerous new applications for what was then considered a "new" engineering material.

Thus, Britain dominated the production of iron not only in sheer quantity but also in the range of products available. This position of leadership was to last until the middle of the 19th century. For example, British rails were used for the double-tracking of the Reading under the direction of Richard B. Osborne during 1844.[1] The use of iron structures was not, however, the sole dominion of British engineers in the late 18th and 19th centuries. Continental, especially French, engineers and their American counterparts made major contributions to the applications of iron to both bridges and buildings.[2]

In America, Thomas Paine and Robert Fulton were active in promoting the use of iron structures. Paine's iron bridge investigations, or as he called them, his pontifical matters, occupied a central role in his life for more than two decades. It has been shown that his ideas were the source of the preliminary design for the famous Sunderland Bridge (1796) over the River Wear in England.[3] In fact, wrought iron bars from Paine's 100-foot long demonstration model were incorporated in the Sunderland Bridge, which was the most notable bridge since the erection of the first iron bridge in 1779. Fulton was involved with canal projects, amongst his many other activities, as reflected in his book on the subject published in 1794.[4] During his sojourn in Britain he was involved with both Telford and William Jessop in the use of iron for aqueducts, which later lead to Telford's masterpiece, the 1,000-foot long Pont Cyssylte aqueduct (1805) over the River Dee in Wales.

From the backwoods of Pennsylvania James Finley erected a diminutive 70-foot span iron suspension bridge across Jacob's Creek in 1801 and launched the modern era of long-span suspension bridges in Europe and America. The arch and its inverse, the suspended chain, provided engineers, enterpreneurs, and inventors a context for developing a plethora of patented bridges including many hybrid designs such as the bow string arch, the trussed arch, and the trussed beam. Beams and girders were cast in iron or built up of wrought iron components. This was clearly the pioneering period of iron bridge engineering and it is a complex web in the history of technology transfer and the development of new structural forms.[5]

Another seemingly disparate development was the timber covered bridge, which had its origin in the Alpine region of Europe but became associated in fact and legend with America's bucolic 19th century past.[6] Bridges were a "key" element in the American internal improvements movement, which aroused much interest on the part of bridge builders. It was not, however, a cooperative movement based upon well-understood principles of mechanics, or directed on a national basis. Instead, it was an intensely competitive movement firmly in the hands of builders working in the craft tradition. Thus a myriad of timber bridge patents emerged during the first half of the 19th century, with the Burr, Long, Town, and Howe amongst the best known of this genre.[7]

A form of timber truss which is important to the development of the all-iron railway bridge was patented in 1840 by William Howe (1803-1852), who was from a family of inventors, one of whom is credited with the invention of the sewing machine. This truss eliminated the complicated joints of other all-timber trusses by substituting threaded iron rods for the tension verticals and by replacing complex wooden joints with simple timber (later cast iron) junction boxes. The iron components for this truss were all the same and could be produced in quantity and delivered on site. Since all the joints were the same and did not require the skill of a shipwright to notch and peg the members together, the erection of Howe trusses was quickly and easily accomplished by semiskilled workers. Equally important, the Achilles heel of all timber truss bridges was the problem of sustaining tensile forces at the joints. This was overcome in the Howe truss with the iron tension verticals and cast iron junction boxes. Tension splices were still required in the bottom tension chords. With the rapid spread of railways in the quarter of a century preceding the Civil War, numerous bridges were required to carry increasingly heavy locomotive loads. These bridges were reaching unprecendented lengths, because railways require much flatter grades than roads. With its simple framing and ease of construction, it is little wonder that the Howe truss became the most popular timber truss used on American railroads.

THE PHILADELPHIA & READING RAILROAD

The Philadelphia & Reading Railroad was one of the earliest railroads in America, having been chartered April 4, 1833. Unlike the Baltimore & Ohio's grand vision of connecting Baltimore with the Ohio River system, the Reading was conceived as a coal-hauling railroad of comparatively short length. It was constructed to connect with the Little Schuylkill Railroad at Reading and deliver anthracite coal to the Philadelphia market. The Schuylkill Navigation already served the route with its canal, but in the 1830s it was not viewed as a competitor to the canal since it was thought that with the expanding coal market there would be plenty of business for both companies.[8]

For nearly a decade beginning in 1833 there was a business depression in

America which coincided with the building of the Reading. Nevertheless, under the able leadership of Moncure Robinson (1802-1892), who was appointed chief engineer in 1834, the construction proceeded steadily, and the Reading-Pottstown section opened in May 1838. During this period it became clear that the Little Schuylkill Railroad would not be built. Since this would cut off a rail line to the coal fields, the Reading petitioned the legislature to extend its line from Reading to Port Clinton. The Act was approved in 1837, and in December 1839 the entire road was opened for traffic.

By any standards Moncure Robinson was one of America's leading Antebellum civil engineers. He was one of the few American engineers of the period to have had the benefit of a college education. He attended William and Mary College and later studied in Paris. His early career was directed towards canal work, like so many of his peers. However, beginning in 1825, he spent two and one half years in Europe. Charles Ellet, Jr. was to make a similar pilgrimmage at about the same time to study in France. Ellet returned to America as the enthusiastic proponent of the French wire suspension bridge, whereas, Robinson returned as an advocate of the British railway system and could see the immense possibilities for railways in America. In a paper on technology in America, Darwin Stapleton argues convincingly that all of the early railways used British and European technology by employing engineers trained in Europe or Britain.[9] This was certainly the case for the Reading.

Upon his return to America, Robinson was engaged in railway surveys in Pennsylvania and in railway construction in Virginia and elsewhere from 1830 to 1833. He was only 32 years of age when he was appointed chief engineer of the Philadelphia & Reading Railroad in 1834. In the case of bridges he became an advocate of Ithiel Town's lattice timber truss bridge (patented in 1820) and was responsible for numerous lattice trusses built on the Reading.[10] His training, European experience, and obvious ability propelled him into the select ranks of leading railway engineers. Thus, he served not only on the Reading but also acted as a consultant on a number of railway construction projects, including the Richmond & Petersburg Railroad, where he was responsible for the design of the mighty James River Bridge. This continuous 19-span bridge crossed the James River at Richmond with a total length of 2,844 feet. Completed in 1838, it was the most impressive Town lattice truss bridge ever built in wood.[11]

Until the mid 1850s only small, simple iron shapes were rolled in wrought iron. Since a Town lattice truss uses only bars and angles, it would have been a comparatively easy matter to transform the Town timber truss into the all-iron railway bridge. With Robinson being the leading proponent of the lattice truss and also the chief engineer of the Reading, one would have expected the first iron bridge on this line to be an iron lattice bridge, but that was not to be. In 1840, Robinson was elected to the presidency of the Richmond, Fredericksburg & Potomac Railroad and was at the same time asked to serve as a consultant to the Czar of Russia. These assignments effectively ended his engineering contribution to the Reading Railroad.

Ironically, iron lattice trusses became very popular in Britain and Europe during the next two or three decades and many notable wrought iron lattice bridges were built. A bridge composed of six 400-foot spans was built across the Vistula at Dirschau in 1857, and the Passau Bridge was completed in 1861 over the Inn River in Austria with a clear span of 420 feet. The Rhine

Bridge at Cologne was built with four 322-foot clear spans. This bridge featured Gothic Revival towers which gave it a monumental appearance. Numerous wrought iron lattice railway bridges were built during this time in the British Isles, but despite its champions, it was never popular in America.[12]

ENTER RICHARD B. OSBORNE and THE IRON RAILWAY BRIDGE

Richard Boyse Osborne (1815-1899) was born in London and educated in both England and Ireland.[13] By a circuitous route through Canada, Chicago, and St. Louis that began in 1834, he entered service on the Reading as a draughtsman in 1838. The position was probably secured for him through his friend, G.A. Nicholls, who had joined the company three years earlier. Osborne rose rapidly in the company as a civil engineer and was appointed chief engineer in 1842 upon the resignation of Wirt Robinson, a nephew of Moncure Robinson. In 1845, he left for Ireland to become chief engineer of the Waterford & Limerick Railway and resigned his position with the Reading. During his tenure as chief engineer the main line was double tracked, which necessitated the construction of numerous bridges. It was in connection with this work that Osborne introduced the first all-iron railway bridge in America. This bridge, known as the West Manayunk Bridge, was erected and put into service early in 1845 as the first of a group of iron Howe truss bridges.[14] Earlier, Osborne, who was aquainted with William Howe, had been responsible for the construction of a large timber Howe truss over the Schuylkill. He says:

In April 1845, I had carefully prepared a model of a Howe truss bridge 10 feet long, showing a span of 200 feet, to take with me, having arranged with Howe, the patentee, to take out the Patent for Great Britain and Ireland.[15]

The Manayunk Bridge, which was the harbinger of legions of iron truss bridges, had the following dimensions, as described by Osborne in his memoirs:

During the winter of 1844, as a guide to us in arranging plans for the superstructure in iron to replace several old timber bridges, we got up plans for an Iron Howe, which was the first ever constructed of that material, all the others being of timber. The site we chose for this experiment was about half a mile east of the Flat Rock Tunnell, a small bridge of 34.2 feet span. This was thought to afford a fair test, as the tracks were only four feet apart, and ties were on the bottom chord. This centre truss was only 31-1/2 inches in height, so as to be below the platform steps of the passenger cars, while the outer trusses are 41-3/4 inches in height.

We made the bottom chords of 2-1/4 inch square rolled iron, which we afterwards changed for other bridges into plates of 1 to 1-1/4 inches of greater depth according to the required area. The top chords were 2 inch square. The bottom chords were 2-1/4 inches square. The braces of cast iron 3-1/4" x 2-1/2" hollowed, and 3'4" long: height of the main trusses - 41-3/4 inches. Projections were welded on the chords between which the Skewback blocks rested on the chords. Height of the centre truss - 31-1/2 inches.

40.83 ft. length at 38.50/100 dollars equals 157.95/100 dollars, total cost.[16]

For reasons which have not been determined, the clearance between the double tracks was only four feet. The bridge consisted of three parallel trusses; since the center truss carries twice the live load of the outside trusses when two trains are on the bridge, one would have expected the center truss to be deeper to increase both its strength and stiffness. However, because of the very restricted clearance the center truss was fabricated with a depth lower than the floor level of the rolling stock. Consequently, it had to be made much heavier than a comparable truss of greater depth. At its opening, Osborne reported:

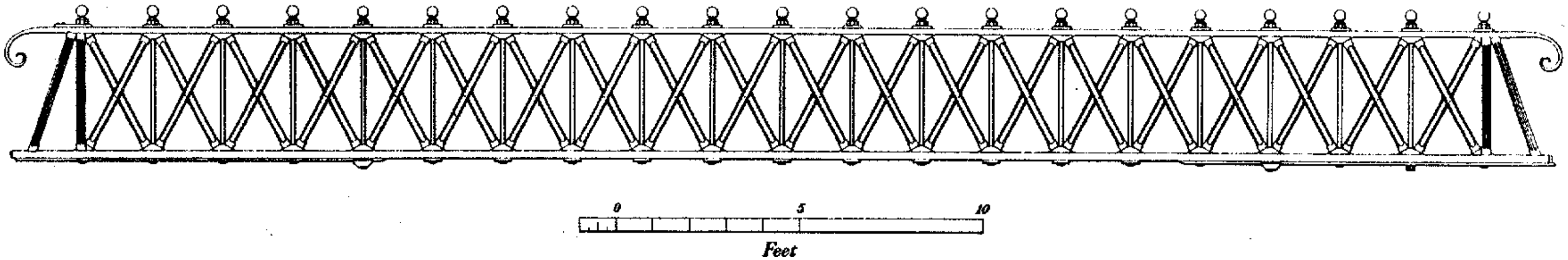
> It was erected in 1845, and President Tucker came up to see the first trains cross it, and was pleased with it, but said it looked very light in comparison to the timber structures and suggested that we leave the false work up within 1/2 an inch of the bottom chords to give it a longer test. This we did, and they remained until they fell down. This iron bridge carried many millions of tons before alterations became necessary for widening the space between the tracks from 4 to 6 feet. It was erected in February of 1845. During the 4 months of 1845 up to the time of my leaving for England in May, we were kept busy in perfecting the work on the main second track, which we had pushed through under many hindrances; also building stone arches [Osborne's emphasis] to replace wooden structures, and at the constant work of trying to stiffen our weak Lattice

bridges, over which Superintendent Nicholls was running his very long trains of coal at 20 miles an hour!

During this time we also erected circular Howe truss roofs for protection of the large stock of timber always kept on hand at the Pottstown yards, with pumps, jacks, and derricks, where we also had prepared a portable steam saw mill: and had, too, erected some additional water tanks for the supply of our fast increasing number of engines.[17]

Advantage could have been taken of the narrow clearance between the tracks to have designed a bridge with just two outside trusses and a deck to carry both tracks. This would have resulted in larger trusses but ones of more economical structure and better proportions. Despite its rather fragile appearance this bridge continued to carry rail traffic until 1902, when it was retired from service. With the increase in locomotive weights it must have been supported by bents for most, if not all, of its life, in a manner similar to the Reading-Halls sister bridge once located near Steelton (see HAER photo PA-55-24).[18] One of the Manayunk trusses has miraculously survived and is now on display at the Museum of American History of the Smithsonian Institution in Washington, D.C. (see Figure 1, page 15).

With Moncure Robinson no longer associated with the railroad company and evidence that many of the timber lattice trusses had insufficient lateral bracing it is not surprising that Osborne, who had experience with Howe trusses, should turn to this particular truss type and replicate it in iron.[19] One of the compelling reasons for using iron in buildings was that it provided much greater fire protection compared to heavy timber framing.



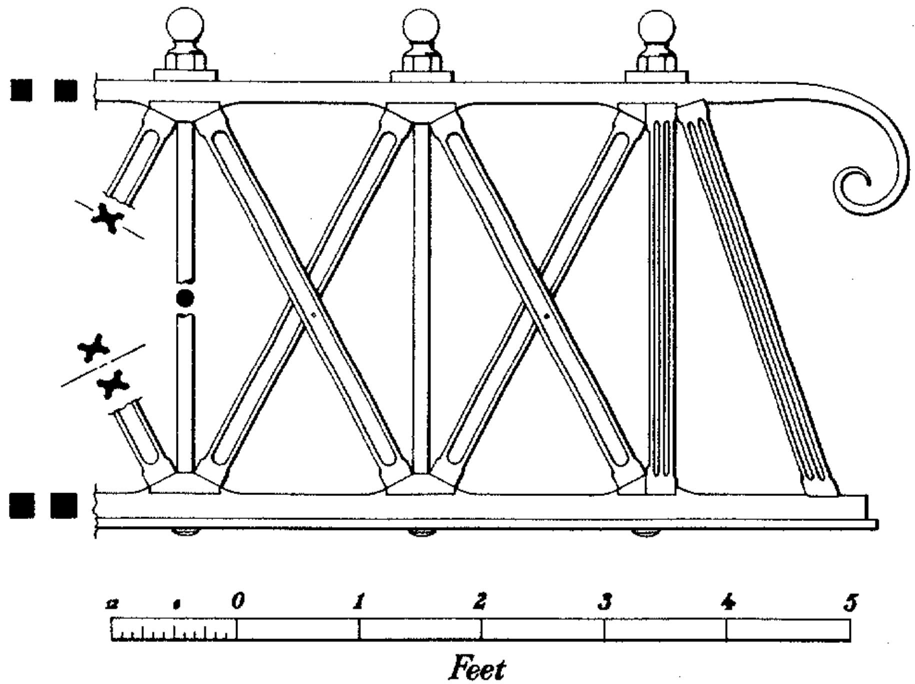


Fig. 1

MANAYUNK BRIDGE TRUSS

As preserved in the
Museum of American History
Smithsonian Institution
Washington, DC

Measured and delineated by:
Richard K. Anderson, Jr., HAER

This was also the case for the early Reading iron bridges. Competition with the Schuylkill Navigation had become so intense that canal men resorted to violence in an effort to stop the railroad from taking revenues from the canal. There was a long history of mayhem on the canal which caused concern in Phildelphia for years.[20] The case for the use of iron under these circumstances was well stated by Osborne:

> The boatmen of the Schuylkill Canal had been threatening to burn our bridges, and with armed watchmen and bulldogs, the important structures were guarded, they having in 11 weeks after the Richmond division was opened, burned down the big lattice bridge over the River at the Falls of Schuylkill. This bridge, 694 feet long, and 70 feet over the water, with Kensington ship carpenters I replaced with trestles, and it occupied till the 7th of September, 1842, to complete it, at a cost of 14,403 dollars. The very night of the day of completion, a low bridge of 50 feet span on the main line, opposite Manayunk, they sent up in smoke, but in 5 days and nights it was replaced.
>
> At Pottstown the superstructure of different kinds of bridges were kept ready for immediate use, and bills of timber for the longer spans were stored in sheds for any emergency. Brother John and self were kept busy and on the constant move, and without special means of conveyance, till one of the little English engines was fitted up for our special use, and called "Engineer".
>
> The expense of keeping up a large force of watchmen to protect our bridges from the incendiaries of the Canal, has been for the fiscal year

of 1843, as much as 11,778 dollars. The cost of this same, in 1844, amounts to 8532 dollars, a heavy tax on the Roadway Department for the privilege of using a perishable material like timber, enough to have paid the difference in cost of building in iron or stone originally, and we are now doing much to remedy this error, and will continue till there is not a single bridge superstructure of timber on the road.[21]

THE READING-HALLS STATION IRON TRUSS BRIDGE

Although the Manayunk Bridge is heralded as the first of its kind in America, it should be viewed as the first of a set of iron Howe truss bridges erected on the Reading ca. 1845-47. As previously cited, Osborne had been "arranging plans for the superstructure in iron to replace several [emphasis added] old timber bridges," and in the official Reading annual report for the year ending November 30, 1846, the following was written by G.A. Nicholls under "Iron Bridges":

> Including construction of 6 bridges, built with the "Howe" iron truss, in all 220 lineal feet; and 3 bridges now making of 187 lineal feet. Amount $15,439.47.[22]

This reference for its importance is frustratingly vague, since it confirms the construction of at least six iron Howes, but stops short of giving enough information to directly confirm whether the Reading-Halls Bridge was among the nine bridges cited. The annual report published in 1848 notes that "6 iron bridges, 25 to 40' span, begun before December 1, 1846 have been erected..."[23] If one assumes then that the spans of the three bridges "now making" in 1846 were of equal length, each span would be about 62 feet. Allowing an extra 7 or 8 feet (the difference between the Manayunk's truss length and its span) for these last three bridges would give a truss length of 69 to 70 feet--the same as for Reading-Halls, for all practical purposes.

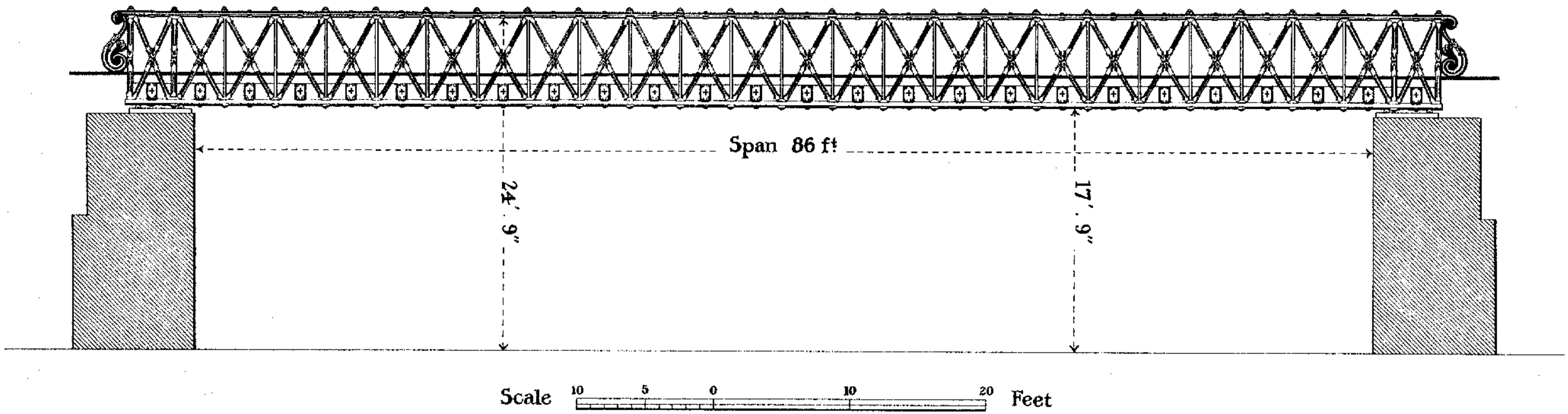
At this point, the bridge's Egyptian Revival detailing becomes an important reason for counting the bridge among these latter spans. The cast iron diagonals and counter diagonals have prominent Egyptian decorations, and judging from its sister bridge at Reading, the end posts were also graced with this kind of decoration. (Since the wrought iron members were produced by rolling, it was not feasible to embellish them, and they were left plain in contrast to the cast iron components.)

As early as 1823, the French engineer Navier illustrated the use of Egyptian revival columns in his book on suspension bridges and used this style on his ill-fated Pont des Invalides.[24] Navier's influence is reflected on the Egyptian style columns used by Ellet on his Fairmount Bridge (1841-42), and such columns form a prominent feature of Roebling's Niagara Suspension Bridge (1851-55). I.K. Brunel proposed an Egyptian motif for his original Clifton suspension bridge design (1830), which included not only Egyptian towers but sarcophagi for the anchorages. The Egyptian Revival enjoyed popularity in the first half of the 19th century and was thought to be particularly appropriate to large engineering works because it symbolized strength, durability, and monumentality. However, it never became the accepted style for engineering or industrial structures in quite the same way that Classical and Gothic Revivial styles were used by architects.

Osborne evidently was comfortable with the Egyptian Revivial style and continued to use it even after his return to Ireland. An engraving of his Ballysimon Bridge, designed for the Waterford & Limerick Railway ca. 1850, shows a liberal use of lotus-like decorative forms (see Figure 2, page 20). Significantly, the dimensions scaled off the engraving from panel to panel and between the chord centerlines are the same as for the Reading-Halls Bridge.

Remarkably, it appears that not only the Reading-Halls Bridge but its two sisters--the three bridges "now making" in 1846--survived well into the 20th century. One, located south of Reading, Pennsylvania, was razed around 1965 to make way for a highway interchange (see HAER photo PA-55-17). A second was apparently located on the Reading's Steelton Branch as late as 1928; its fate has not been elucidated (see HAER photo PA-55-24). These bridges can clearly be considered sisters of the Reading-Halls bridge by comparing photographs of them (HAER photos PA-55-17 to 24) with HAER photos of the extant Reading-Halls span.

The original locations of these three bridges have not been determined, other than that they were probably along the Reading main line. There is no question but that their carrying capacity became insufficient with the rapid weight increase of locomotives and cars, so that they were soon removed to branch line service or retired to carry only road vehicles. From 1871-72 the Catawissa Railroad, which Osborne served as a consultant in 1851-52, constructed a line along the Susquehanna River north to Williamsport, Pennsylvania, with stations at Muncy and Halls. A decade later the company was in financial difficulties, and the Reading took over this portion of their



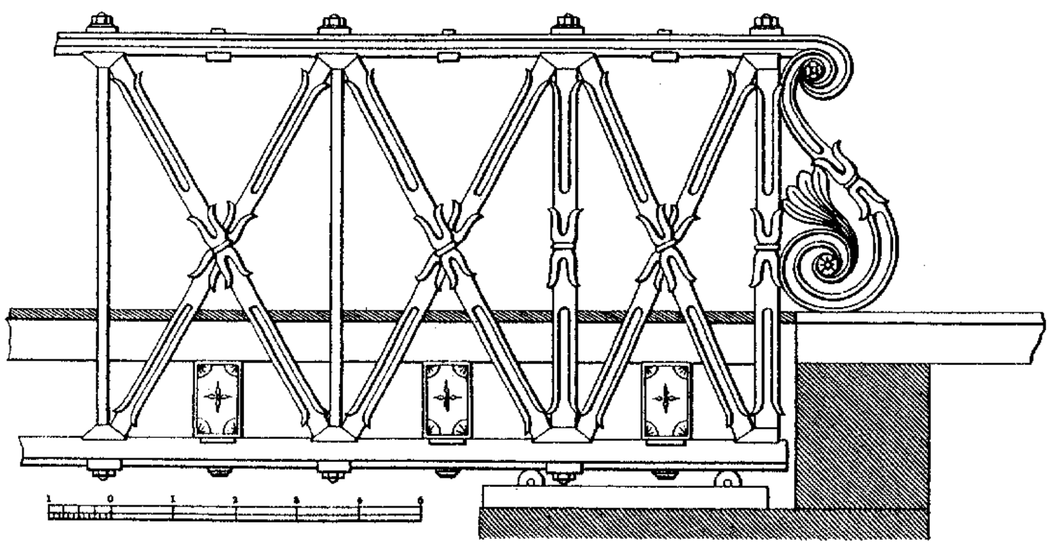


Fig. 2

WATERFORD & LIMERICK RAILWAY

BALLYSIMON BRIDGE

Adapted from: John Weale, Theory, Practise and Architecture of Bridges (London, 1852) line in 1883-84.[25] Consequently, the Reading-Halls span must have been moved to its present location as a highway overpass after this date (no date was found inscribed in the present stone abutments). Little is otherwise known about its migrations. The sister bridge which carried Route 83 (now Ninth Street) over the Reading Main line south of Reading appears in the ICC valuation records of 1919 as Bridge No. 56/49; it remained at this location until its destruction ca. 1965.[26]

In the case of these three bridges, the top and bottom chords consisted of four parallel wrought iron bars, 1-1/4" x 4" in section (the width being just as Osborne's memoirs, quoted previously, stated "for other bridges"). The verticals are sets of three round threaded rods 1-3/4" in diameter. Both the paired diagonals and single counter diagonals were cast in iron, as were the joint ("skewback") blocks and endposts. In its present form, the Reading-Halls bridge is missing three panels in each truss at the south end, and it has been adapted to carry a wooden deck on transverse floor beams made of old steel railroad rails (see HAER drawings). The rails are simply laid on top of the bottom chords between the panel points, with nothing more securing them than occasional lugs welded to the rail bottoms or loose bolts hung through the bottom rail flanges between the chord bars to keep the rails from moving laterally. In railroad service, the track structure was undoubtedly carried on timber or iron floor beams that rested on the bottom chords between the panel points, thus inducing bending into the bottom chord. (The preferred method, used universally in truss bridges since the late 19th century, is to connect floor beams only at panel points to avoid bending chords.) Early sketches of the Manayunk Bridge and the engraving of the Ballysimon Bridge show the same detail; undoubtedly it was originally used on all of Osborne's other bridges built in the same period. Longitudinal stringers were laid on the floor beams of these bridges, and the ties and rails laid on the stringers. American railway bridges rarely used ballasted track, and Osborne's bridges on the Reading were no exception. His later Irish bridges, which had iron floor beams but no ballast, can be considered an American innovation in the British Isles.

As yet no maker has been identified for these three iron bridges. No builder's plates are known to survive, and there are no markings cast or embossed on the Reading-Halls Bridge members. The Manayunk Bridge was made by the Reading in its repair shops at Pottstown, Pennsylvania,[27] and others may have been made there as well. However, the railroad's annual report for 1845 notes that a "survey was made to connect the Phoenix Iron Works and factories at French Creek with the main line."[28] It is quite possible some Reading bridges were made here. The Phoenix Iron Works eventually became part of the Phoenix Bridge Company, one of the nation's premier bridge builders.[29]

The wrought iron chord bars of the Reading-Halls Bridge are held in position by the cast iron joint blocks, which lie in small recesses cut into the chord bars (a detail similar to the Manayunk and Ballysimon bridges). These blocks also serve to hold the verticals, and bosses cast integrally with the blocks engage the hollow cores of the cast iron diagonals to hold the members in place.[30] Since the diagonals cannot transmit tension forces through such a connection, they can be considered to be pin-connected but capable of taking only compression for purposes of analysis. The paired diagonals, inclined from each end of the truss toward the truss center, carry stresses while the bridge is in use, whereas the single counter diagonals are intended to distribute moving loads.

The trusses of the Manayunk and Ballysimon bridges were all supported at the ends by two widely spaced single rollers. The bottom chords in the above bridges rested on these rollers through an intermediate plate inserted to distribute the loads concentrated under each bar. These plates may have existed at the Reading-Halls original installation (they are now absent), where one of these rollers would have been under the shortened end panel of each truss. These end rollers would have carried no load at all when the bridge was in use, since the downward deflection of the trusses at their centers would have shifted the loads entirely to the innermost rollers. (The trusses at the current installation bear on 12" x 24" pieces of 1/2" steel plate.)

It has not been determined why the end panels of the Reading-Halls Bridge and its sisters were designed to be shorter than the other panels, though aesthetics were probably the major consideration. The Manayunk and Ballysimon bridges have nearly full-length end panels. In addition, a curious condition occurs in the end panels of both the Reading-Halls and Route 83 bridges: the inclinations of the paired diagonals and single counter diagonals reverse. Examination of the joint blocks in the end panels at Reading-Halls showed that the blocks were cast with bosses to hold the diagonals in the "normal" positions, although it was not possible to confirm whether or not these blocks were cast with <u>three</u> bosses per pad, thus permitting the diagonals to be installed either way. Most likely these end panels were damaged by vehicles, especially when only one end post survived at the Route 83 bridge. (An accident may also account for the lost end panels on the south ends of both the Reading-Halls trusses.) New members were simply substituted in reverse because it was easier to slip them in where there were no bosses and hold them in place by tightening the nuts on the vertical rods. Proper re-installation would have required partial disassembly of the truss in order to spread the chords and get the diagonal ends in over the bosses--considerably more work.[31] Some diagonals in other panels at the Route 83 bridge were replaced by pipes (see HAER photographs), presumably after vehicular damage, or possibly by water freezing inside their cores. (One diagonal facing away from the roadway at Reading-Halls has a large chunk spalled off at the bottom, strongly suggesting ice damage.)

In addition to these conditions, the surviving bridge is missing at least one and sometimes two of its verticals at many panel points. Some of these rods were turned into the sway bracing outboard of the trusses, since the flattened ends of the braces show threads. The bridge does not appear to be suffering neglect. Its capacity has been posted at 12 tons, which is creating insurance problems for the owners of nearby farm buildings, the bridge being the only access to them from Route 220 for fire trucks in the event of fire. The present owner of the structure, the U.S. Government's Consolidated Rail Corporation (CONRAIL), is presently exempt from historic preservation regulations binding on government agencies or federally funded enterprises. These regulations would probably result in the bridge's removal to a museum or a protected area should its owner decide to replace it. However, at present CONRAIL could demolish the bridge at any time without notice.

STRUCTURAL EVALUATION

The field measurements made of the Reading-Halls Bridge not only provided raw material for the measured drawings but necessary dimensions for a structural evaluation of the bridge. In addition to the geometric data, such an analysis requires information on the strength of materials used and the selection of an appropriate live loading. The strength of the iron can be obtained by testing samples of the material in the structure under consideration or by using typical stress and strain data of the period.

In a similar manner the bridge can be studied under the actual loads used by the engineer in his design, by typical loads or design standard live loads used at the time of its construction, or actual locomotive and rolling stock weights. In addition, much can be learned about the behavior of historic structures by measuring the strains and deflections of critical members when the structure is subjected to controlled loadings. In the case of the Reading-Halls Bridge neither the design stresses nor loads are known, no test loads were applied to the structure, and no coupons were removed for analysis. Thus, the structural evaluation is based upon the application of design loads, together with allowable stresses and moduli of elasticity used by engineers in the 1840s. The typical values for cast and wrought iron were:

Cast Iron:	Ultimate Compressive Strength	= 80,000 p.s.i.
	Allowable Compressive Strength	= 16,000 p.s.i.
	Ultimate Tensile Strength	= 18,000 p.s.i.
	Allowable Tensile Strength	= 4,000 p.s.i.
	Modulus of Elasticity	= 17.5×10^6 p.s.i.

Wrought Iron:	Yield Point Compressive Strength	= 31,000 p.s.i.
	Allowable Compressive Strength	= 13,000 p.s.i.
	Ultimate Tensile Strength	= 51,000 p.s.i.
	Allowable Tensile Strength	= 14,000 p.s.i.
	Modulus of Elasticity	= 29×10^6 p.s.i.[32]

Squire Whipple (1804-1888) was one of the leading pioneer iron bridge builders in America, having built combined cast and wrought iron bow string arch overpass highway bridges for the Erie Canal beginning in 1841. Later, in 1846, he developed a parallel chord truss and the next year issued his well-known book on the design of bridges entitled Bridge Building. This was the first American publication available on bridge design and analysis. It, therefore, marked not only the transition from wood to iron for structures, but also the transition from bridge building by the craft tradition to bridge design firmly in the hands of engineers. A little later in 1851 Herman Haupt published the second American book on bridge design with special reference to truss bridges.

Since Osborne's work was done before either Whipple or Haupt published their works, we do not know what, if any, analytical method he used. Judging, however, from an examination of the surviving Osborne trusses the proportioning of the members and the joints leads one to the conclusion that the design was largely the result of empirical rules being applied to a proven bridge type, but using iron which was then a new structural material.

In the early period of railway bridge building in America a uniformly distributed live load was accepted as standard for design. Waddell reports:

> In the early days of railway bridge designing the live load adopted was a simple uniform advancing load, amounting to about two thousand (2,000) pounds per lineal foot. This was soon increased to a long ton or two thousand two hundred and forty (2,240) pounds per lineal foot. The next step was to place a locomotive at the head of the train, giving the spacing of the various axles and the loads upon them; and as it became customary to use double headers to haul long trains, the bridge loadings were soon increased by providing for two engines in advance of the cars.[30]

For the Reading-Halls analysis a live load of one long ton (i.e. 2,240 lb.) per running foot of track was used, with the trusses in their original 18-panel configuration. Thus the two trusses each bear half the live load, or 1,120 lbs. per lineal foot. For single span pin-connected trusses the maximum force in the top and bottom chords occurs at mid-span under full live load, in this case, a uniformly distributed load of one long ton per foot of bridge span applied over the entire bridge. Since the chords are of virtually constant cross section and are parallel to each other (unlike a bow string truss) the maximum stress will also occur at mid-span. A minimum total effective cross sectional area of 18.00 sq. in. was used for the Reading-Halls chords in this analysis. By assuming that both the dead loads, i.e. the self-weight of the entire structure (track included), and the live loads are concentrated at the joints, it can be assumed that the members carry applied forces without bending. This simplifies analysis considerably and was the standard assumption made in the design of such structures.

The maximum force in the diagonals occurs at the end of the truss where these members carry the shear loads to the support. Again, since all of the diagonals are the same throughout the truss the maximum stress also occurs at the end. The maximum loads and stresses for the bridge are shown in Figure 3, page 29.

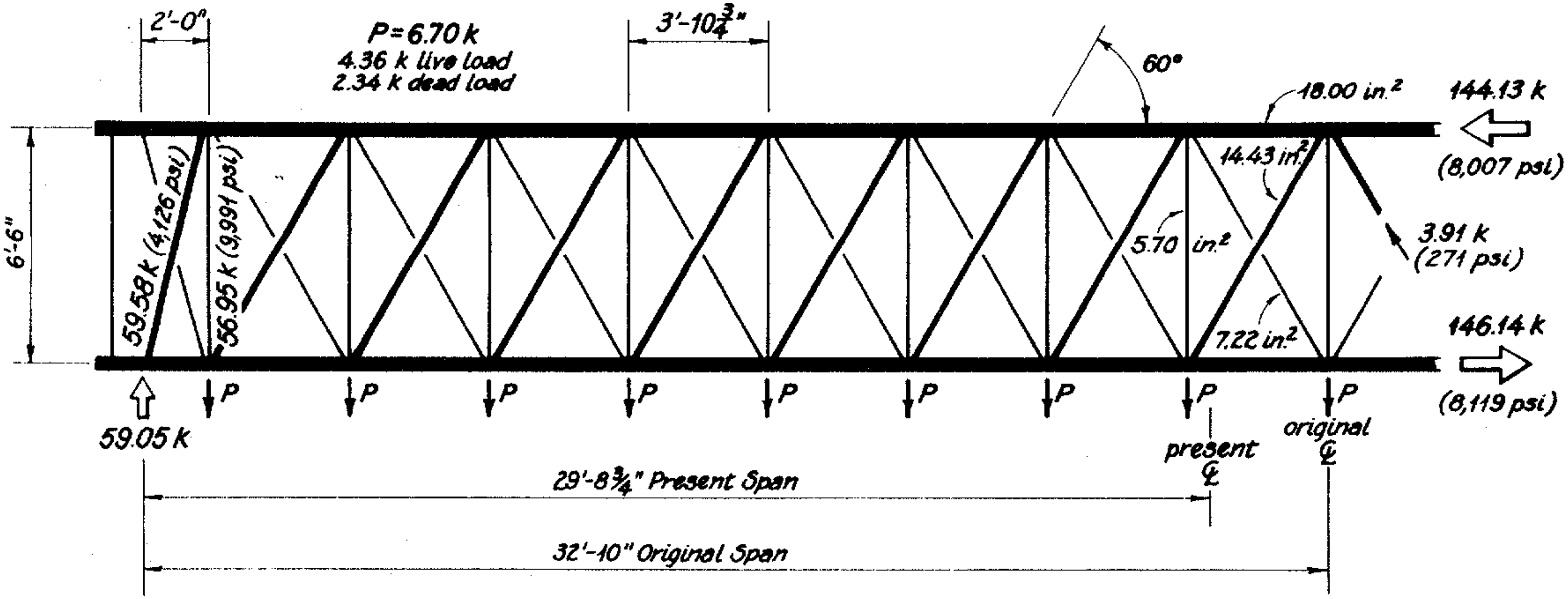
A calculated dead load of 2,340 pounds per panel was used, including the dead load of the truss itself (1,480 lbs.) and one-half that of a single-track railroad superstructure consisting of 10" iron floor beams (520 lbs. for a box beam made up of two 8"x3/8" plates and two 10" channels @ 23.8 lbs. per foot, or their equivalent in plates and angles), floor beam endplates (10 lbs.), wooden stringers and ties (220 lbs.), iron rails (80 lbs.), and miscellaneous hardware (30 lbs. for spikes, etc.). A live load of 1,120 lbs. per lineal foot, or about 4,360 lbs. per panel was used. The end diagonals were found to be lightly stressed under maximum load, the greatest stress being only 4,126 pounds per square inch compared to an allowable stress for cast iron of 16,000 p.s.i. The average ultimate compressive strength for cast iron can be safely assumed to be 80,000 p.s.i., so that the 16,000 p.s.i. allowable stress represents a safety factor of five, compared to less than two for modern steel structures (allowing for inaccuracies in the castings and the presence of blow holes, shrinkage cracks, and other common flaws). The mid-span diagonals are hardly stressed at all under full loads as shown in Figure 3. It is apparent from the analysis that the truss could have been designed with smaller

Calculated Dead Load = 1,200 lbs./lin. ft. of bridge or 600 lbs./lin. ft. each truss (2,340 lbs. per panel)

Assumed Uniform Live Load = 2,240 lbs./lin. ft. of bridge or 1,120 lbs./lin. ft. each truss (4,360 lbs. per panel)

Cross sectional areas shown are minimum effective cross sectional areas for members indicated

k = 1,000 lbs.



Wrought Iron Verticals, Top and Bottom Chords:
E = 29 x 10⁶ psi; Allow. Stress = 14,000 psi (c), 13,000 (t)

Cast Iron Diagonals:
E = 17.5 x 10⁶ psi; Allow. Stress = 16,000 psi (c)

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Fig. 3

STRESS DIAGRAM

Reading-Halls Station Bridge

diagonal members without the risk of a compression or buckling failure. An alternative would have been to increase the panel spacing to the same dimension as the depth, which would have resulted in square panels and 45-degree diagonals. Such a configuration would represent a considerable saving in materials and to a certain extent in erection costs.

The wrought iron chords are also lightly stressed with 8,007 p.s.i. compression in the top chord and 8,119 p.s.i. tension in the bottom chord. In addition to the direct tension in the bottom chord a secondary bending stress of 2,602 p.s.i. would result from placing the floor beams at the middle of the panels rather than connecting them directly to the joint. Thus, the maximum tensile stress in the bottom chord would have been 10,721 p.s.i. With an allowable stress of 14,000 p.s.i. in tension and 13,000 p.s.i. in compression the chords were not stressed to the allowable design limits under full live load. This undoubtedly served them in good stead, since additional strength was required with increased locomotive weights to which these early bridges were subjected as time passed.

In 1876 the 157-foot span iron Howe truss at Ashtabula, Ohio collapsed as a passenger train rolled slowly across the bridge in a blinding snow storm. Nearly one hundred people were killed in the worst railway accident of all time in America. Like so many other early railway bridges in which cast iron was used inappropriately or was defective, the Ashtabula collapse was just one of an alarming series of bridge failures which could be blamed on cast iron. The Ashtabula failure effectively ended the use of cast iron for bridges, but its use for columns in buildings persisted much longer. Thus, it is noteworthy that the behavior of the Reading-Halls Bridge under load was controlled by the stress levels in the wrought iron chords, which are ductile and would deform when overstressed, giving ample warning of failure. The use of four separate bars for the chords provided further safety since defects in one member would not necessarily result in the overstress of the entire chord. The bars are supported at each panel point by spacers cast to the joint blocks so that buckling is not a mode of failure one would expect since the buckling load is nearly twice the ultimate load for these wrought iron chord members. Thus, increasing the panel spacing, as suggested above, would not have caused a buckling failure of the chord if the truss had been loaded to collapse, though perhaps the diameter of the verticals might have had to have been increased.

The use of four chord bars is also a safety improvement over the two-bar chords used at the Manayunk Bridge. In fact, a number of comparisons between the Manayunk Bridge and the Reading-Halls Bridge suggest refinement of Osborne's concepts and details. Instead of one vertical bar per panel point, in the Reading-Halls there are three. The heavy acorn or ball nuts used on the verticals of the Manayunk Bridge have been abandoned for lighter, cheaper hex-nuts on the Reading-Halls. The cruciform section used on the Manayunk diagonals has been superceded by a hollow elliptical section, which is stronger and more efficient in resisting buckling per weight of iron used. As mentioned before, the bosses cast into the joint blocks are much larger on the Reading-Halls, leading to less likelihood of a diagonal member working out of place in the truss. Both these bridges were erected with sway bracing to the inside of the trusses, since clearances permitted trains to pass without interference with the braces. The exterior sway bracing system presently applied to the Reading-Halls detracts from the bridge's aesthetics, but gives ample clearance for automobiles on the roadway.

In 1844 the Pratt truss was patented and became the most popular truss type in America. Compared to the earlier multiple kingpost or Howe trusses, the Pratt reversed the direction of the principal diagonals. Hence, the verticals carry only compression loads while the diagonals are required to sustain only direct tensile forces. As a result, the diagonals, which were the longest members, could be fabricated from light bar or rod stock since members in direct tension neither buckle nor bend. The shorter verticals were better able to carry compression loads without buckling. The Pratt truss in its iron form featured simple pin-connected joints, which were superior to the junction boxes, spacers, and threaded rods of the Howe truss; it was also easily assembled without skilled iron workers and was better able to withstand repeated train loads. Thus, when transformed into the all-iron truss, the traditional composite timber and iron Howe truss was really no match for the Pratt truss, and its use faded from the scene by the time of the Civil War.

The Reading-Halls Station Bridge is a very important example of the all-iron railway bridge. It was a considerable improvement over the all-timber truss so prominent in its day, and is one of the earliest all-iron truss bridges anywhere. It is an extraordinary relic of a pivotal period in bridge engineering and an important symbol of the Age of Progress.

N O T E S

[1]Wrought iron rails were imported from Britain by numerous American railways in the Antebellum period, for example, see American Railroad Journal 16 (New York, 1843) pp. 381-383. Jay V. Hare, "History of the Reading," The Pilot and Philadelphia and Reading Railway Men 10 (August 1909) refers to the addition of a second track laid during 1843-1844, using British rails.

[2]For a background on European and American developments in the use of iron for structures see:

Hans Straub, A History of Civil Engineering (Cambridge, Massachusetts: The M.I.T. Press, 1964)

Llewellyn Nathaniel Edwards, A Record of History and Evolution of Early American Bridges (Orono, Maine: University of Maine Press, 1959)

Carl W. Condit, American Building Art, The Nineteenth Century (New York: Oxford University Press, 1960)

[3]Emory L. Kemp, "Thomas Paine and his Pontifical Matters," Transactions of the Newcomen Society 49 (1977-78)

[4]Robert Fulton, A Treatise on the Improvement of Canal Navigation, 1796

[5]There are a number of publications dealing with the early development of iron bridges, amongst this group are:

H.J. Hopkins, A Span of Bridges (Newton Abbott, Devon, England: David and Charles, 1970)

Llewellyn Nathaniel Edwards, A Record of History and Evolution of Early American Bridges (Orono, Maine: University of Maine Press, 1959)

P.S.A. Berridge, The Girder Bridge (London: Robert Maxwell, 1969)

George Duggan, Stone, Iron and Wood Bridges (New York: D. Appleton and Co., 1850)

F.B. Brock, "Truss Bridge Patents, 1797-1865," Engineering News and American Contract Journal, a series beginning 28 October 1882 and ending 14 July 1883

John G. James, "The Evolution of Iron Truss Bridges to 1850," Transactions of the Newcomwen Society 52 (1980-81) London

Henry Grattan Tyrell, History of Bridge Engineering (Chicago: pub. by author, 1911)

Theodore Cooper, "American Railroad Bridges," Transactions of the American Society of Civil Engineers 21 (1889) New York

[6]Covered timber bridges hold a special place in the American public's affection. Thus, there is a rich literature on the subject, including legendary as well as sound historical and technical information on covered bridges. Amongst the most informative are:

Richard Sanders Allen, Covered Bridges of the Middle Atlantic States (Brattleboro, Vermont: The Stephen Greene Press, 1959)

Richard Sanders Allen, Covered Bridges of the Northeast (Brattleboro, Vermont: The Stephen Greene Press, 1957)

Committee on History and Heritage of American Civil Engineering, American Wooden Bridges (New York: American Society of Civil Engineers, 1976)

[7]Committee on History and Heritage of American Civil Engineering, American Wooden Bridges, pp. 130-141.

[8]Jay V. Hare, "History of the Reading," The Pilot and Philadelphia and Reading Railway Men 10 (June 1909), p. 2.

[9]Biographical information on Moncure Robinson can be found in:

Darwin H. Stapleton, "Moncure Robinson, Railroad Engineer 1828-1840," Benjamin Henry Latrobe and Moncure Robinson (Delaware: Eleutherian Mill Historical Library, 1974)

Charles E. Fisher, "Moncure Robinson," Railroad and Locomotive Historical Society, Bulletin 53, 1940.

[10]Darwin H. Stapleton, "Moncure Robinson, Railroad Engineer 1828-1840," pp. 33-34.

[11]Darwin H. Stapleton, "Moncure Robinson, Railroad Engineer 1828-1840," pp. 46-49.

Richard Sanders Allen, Covered Bridges of the Middle Atlantic States, p. 23

[12]Henry Grattan Tyrell, History of Bridge Engineering, pp. 171-172

[13]Biographical information on Osborne appears in two obituary notices and in an unpublished diary with a foreword by his son.

--- "Obituary of Richard Boyse Osborne," Proceedings of the Engineers Club of Philadelphia 17 (1900): 201-203.

--- "Richard Boyse Osborne, C.E.," Engineering News 52 n. 25 (1899): 394. A set of eight volumes of a diary prepared by Richard Boyse Osborne, together with a "Commentary of Richard Boyse Osborne," by his son John C. Osborne are in manuscript form and located at the National Library of Ireland.

[14]Sources disagree on the precise erection date of the Manayunk Bridge. Osborne recalls it being erected in February 1845 in his diary, p. 146. His brother and collaborator, John H. Osborne, reports it erected in June in the Report of the President and Managers of the Philadelphia and Reading Rail Road Co. to the Stockholders, January 12, 1846 (Philadelphia: Isaac M. Moss, 1846), p. 41. Finally, John G. James states that it was erected May 3-4 after Osborne's departure for Ireland in "The Evolution of Iron Truss Bridges to 1850," Transactions of the Newcomen Society 52 (1980-81), p. 86.

In the United States, the first use of iron for the structural components of a bridge was in 1801 for a chain link suspension bridge built on the Finlay patented system. The first cast iron arch bridge in America was erected in 1836-39 on the National Road in Brownsville, Pennsylvania. Built under the supervision of Capt. Richard Delafield, this bridge replaced an earlier Finlay suspension bridge and is still in service. Its five parallel arches have an

80-foot span and an 8-foot rise. (See L.N. Edwards, A Record of History and Evolution of Early American Bridges.)

[15]Osborne's diary, p. 148.

[16]Osborne's diary, p. 146

[17]Osborne's diary. p. 147

[18]Osborne reports under "Bridges" on p. 38 of the Report of the President and Managers of the Philadelphia & Reading Rail Road Co. to the Stockholders, January 12, 1846: "It will be remembered that the bridges were constructed for twelve ton engines." Maximum locomotive weights had risen to 27 tons by 1850, according to that year's annual report.

[19]Osborne's diary, p. 148

[20]--- History of Schuylkill County Pennsylvania (New York: W.W. Munsell and Co., 1881), p. 65.

[21]Osborne's diary, p. 134

[22]--- Report of the President and Managers of the Philadelphia & Reading Rail Road Co. to the Stockholders, January 12, 1847 (Phildelphia: Isaac M. Moss, 1847), p. 21.

[23]--- Report of the President and Managers of the Philadelphia & Reading Rail Road Co. to the Stockholders, January 12, 1848 (Phladelphia: Isaac M. Moss, 1848), p. 25.

[24]Claude Louis Marie Henri Navier, Memoire sur les Ponts Suspendus (Paris: de L'Imprimerie Royale, 1832), plate 12.

[25]Thomas T. Tabor, A Chronological History of Muncy (Muncy, Pennsylvania: Muncy Luminary Press, 1975)

[26]Interstate Commerce Commission, Bureau of Valuation, Philadelphia and Reading Railway System - Pre-inventory Schedule of Bridges, I.C.C. Account No. 15, Valuation Section 1-P, pp. 39-40. Dated October 17, 1919, this form records the length of the Route 83 Bridge as 68 feet and notes that the bridge has a wooden deck supported with "Old Rails as Fl. Beams." The following notes appear on p. 40:

Iron Trusses   Cast Iron
Web members - cast tubes
Similar to Br. on Steelton Branch '/c6 [unclear] Bridge
Also one other overhead bridge on
P & R Ry in Val Section ----? (look up notes
coal region)

These seem to be clear references to the Steelton and Reading-Halls bridges in the light of other evidence. The I.C.C. valuation records have not yet been located for these other two bridges. The authors have heard rumors that remains of the Route 83 bridge may still survive in a salvage yard in the Reading, PA vicinity. They have not tried to verify this, however.

[27] Victor C. Darnell, A Directory of American Bridge-Building Companies 1840-1900 Occasional Publication No. 4 (Washington, D.C.: Society for Industrial Archeology, 1984), p. 64.

[28] ---Report of the President and Managers of the Phildelphia & Reading Rail Road Co. to the Stockholders, January 12, 1845 (Philadelphia: Isaac M. Moss, 1845), p. 10.

[29] Victor C. Darnell, A Directory of American Bridge-Building Companies 1840-1900, p. 65.

[30] One of the authors (Anderson) had the opportunity to examine the remaining Manayunk truss in storage before it was placed on exhibit in 1986. Three of the diagonals were loose, and examination of the joints disclosed that the diagonals were secured in place only by very small pins--5/16 inch in diameter--corroded somewhat by the structure's years in the weather. The Reading-Halls design represents a considerable improvement in this particular joint detail so far as sturdiness is concerned. While no instance is known to the authors of any of the diagonals falling out of the Manayunk Bridge while it was in service, keeping the trusses tightened enough to prevent such an incident must have been a continual maintenance problem.

[31]While this account of repairs is plausible, some other evidence in the Reading-Halls trusses and questions of circumstance contradict it. For example, referring to Sheet 4 of the HAER drawings, joint block L_1 appeared in the field to have been clumsily modified on both trusses. It appears to be a "normal" block having two pads inclined at 30-degree angles. However, wedges seem to have been fitted under the ends of the end-panel paired diagonals to make up for the difference in the diagonals' inclination. Scraping at the apparent joint between the wedges and the blocks didn't clarify whether the wedges were cast to the block or not. An unused boss appears between the paired diagonals of the second panel, so perhaps these wedges are separate and are being held in place by a pair of bosses, thus keeping them from slipping out under compression. Joint blocks for L_1 could not have been cannibalized from U_1 in the now-missing southern end panels of the Reading-Halls trusses, because the pads facing the end panels at U_1 are continuous, whereas those for L_1 are not. In any case, some disassembly of the trusses would have had to have been done to place these odd blocks in their current location. If so, why weren't the end panel diagonals installed in their proper orientation on this occasion? Also, it seems peculiar that all the truss ends on both bridges would have received similar damage and repairs. The source of new diagonal castings for ones broken out of the end panels is also a question. Is it reasonable to think a stash of these was kept on hand or specially made for such a small group of outdated structures?

[32]Thaddeas Merriman and Thomas H. Wiggin, American Civil Engineer's Handbook (New York: John Wiley and Sons, 1930), pp. 620-628.

[33]J.A.L. Waddell, Bridge Engineering (New York: John Wiley and Sons, 1916), p. 98.