B & O Railroad, Tray Run Viaduct
Spanning Tray Run
Rowelsburg Vicinity
Preston County
West Virginia

HAER No. WV-18

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WRITTEN HISTORICAL AND DESCRIPTIVE DATA

PHOTOGRAPHS

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, D.C. 20240

HISTORIC AMERICAN ENGINEERING RECORD

B & O Railroad, Tray Run Viaduct

HAER WV-18

Location:	Spanning Tray Run, Rowlesburg Vicinity, Preston County, West Virginia
Date(s) of Construction:	Present bridge dates to c. 1905 Original bridge dated to 1851-1852
Present Owner:	The Chessie System
Significance:	The original bridge on this site was designed by Albert Fink and utilized his patented truss type. It was replaced by a wrought iron trestle in 1887. This structure was replaced by a masonry arch bridge in circa 1905. The history of the Tray Run Viaduct is most notable because of its association with Albert Fink.
Historian:	Dennis M. Zembala, 1974

TRAY RUN VIADUCT

INTRODUCTION

Fink's cast-iron viaducts for the Baltimore and Ohio at Tray Run and Buckeye Run (1851-1852) were important steps in the evolution of iron construction. Derived from traditional timber forms, they were an important first step in translating those techniques into metal structures. The size and shape of their members and the details of their connections provided later engineers with a grammar of construction on which more advanced forms were based. Between 1851 and 1875, American engineers built upon Fink's precedents to produce a number of similar structures with even more impressive proportions. The influence of these works illustrates an important aspect of the development of structural engineering, namely, that the overall forms of structural designs are based on numerous small innovations in construction details. In this respect, the impact of these viaducts was direct as well as indirect. A number of engineers who were associated with Fink on the B&O, and later on the Louisville and Nashville Railroad, went on to build similar structures. On the other hand, the two viaducts received considerable attention in the professional literature, and Fink's drawings were publicized in Europe and America. [1] It is impossible to tell just what impact this literary dissemination may have had, but it is possible that it influenced the design of at least one famous British viaduct.*

Perhaps the most important influence of these pioneering works was felt beyond the scope of the railroads. By the late 1860's, Fink's linear continuous iron trestles had evolved into a series of free-standing, independently braced towers connected by short truss spans. [2] In effect, towers such as these were metal cages whose construction anticipated the use of similar technology in the high-rise buildings of the 1880's.

The following account attempts to show the seminal role of Tray Run and Buckeye Run Viaducts in the development of iron structures. It is a highly technical account for two reasons: (1) because their construction attracted enough attention that the designs were preserved in the journals, and (2) because their importance lay in the details of construction more than in overall form. Fink's viaducts were replaced in the 1880's by modern structures, but their influence may be seen in modern metal-framing techniques.

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* Crumlin Viaduct in South Wales (1853-1857).

HISTORY

The scenario for the Tray Run and Buckeye Run Viaducts was set by the conjunction of geography and financial difficulty. The B&O was in a squeeze to complete the line to Wheeling by January 1, 1853, or risk losing its Virginia charter. Chief Engineer Benjamin H. Latrobe was straining his resources against the Alleghenies while President Swann held creditors at bay with elegant speeches. While work proceeded from both ends of the line, the structures of the greatest engineering difficulty progressed simultaneously at various points. The Cheat River Grade was one of the more awe-inspiring of these areas of special difficulty. After crossing one of Fink's bridges at Rowlesburg, the line began its ascent of the ridge which rises steeply from the west bank of the Cheat. This ridge has the form of a scallop in which each indentation carries a small brook into the river. Between these ravines, the projecting hills slope at a high angle. In order to make the track as straight as possible, the B&O's engineers decided to cross these ravines at their mouths instead of snaking the line into the canyons and back out again. Since the amount of water in Tray Run and Buckeye Run was small, the original plan called for construction of a solid masonry embankment with a culvert to carry the water under the road. According to one source, the intention to build the masonry wall to the level of the roadbed was abandoned after the partially-built structure showed signs of weakness. [3] Time was another factor that weighed against the all-masonry plan. The deadline for completion of the road was rapidly approaching, and the engineers decided to terminate the masonry at Tray Run, 90 feet above the level of the stream, and to complete the viaduct with a cast-iron trestle.

When time came to assign responsibility for the viaduct's design, Latrobe faced a dilemma. He had at his disposal both Albert Fink and Wendel Bollman, two men of exceptional talent. Each had considerable experience in cast-iron structures by this time, and both had patented designs for trusses. Bollman's model had been the basis for bridges between Harper's Ferry and Cumberland. Fink, although he had been with the B&O less than three years, had built the two-bridge span over the Cheat at nearby Rowlesburg and was at work on the Great Iron Bridge, then under construction over the Monongahela at Fairmont. The designs of both men had won Latrobe's confidence--Bollman's through practice and Fink's mainly through its basis in sound theory. Latrobe's problem was exacerbated by the rivalry (friendly?) which had sprung up between the older Bollman and the young German engineer. The precocious Fink (then 24 years old) had excellent scientific training behind him and was out to prove his worth on a practical level. Bollman, on the other hand, had been with the company for 20 years. The degree of competition between the two has never been documented. [4] Yet it would be hard to imagine such a situation in which some competitive spirit on both sides would not make the decision a difficult one for the chief engineer. Latrobe's problem was solved in part by sheer geography. Construction of the Kingwood Tunnel was proceeding with difficulty, making major demands on Bollman's time. Fink, on the other hand, was working more closely with the Mt. Clare foundry in the process of casting the members for his bridge at Fairmount. It was logical that under these circumstances, Fink be placed in charge of the two viaducts as well. As in the case of the Fairmont Bridge, he responded admirably.

The work of Albert Fink is an outstanding example of the transfer of European technology to America. The immigrant son of a German architect, Fink studied engineering and architecture at the Polytechnic School of Darmstadt. After graduating in 1848, he worked for one year for the Offenbach firm before his enthusiasm for the German revolutionary movement forced him to leave the country. Like many of the so-called "'48-ers," Fink and his brother Henry found their way to the United States, arriving at the port of New York in the spring of 1849. There they sought professional employment in various architectural and engineering firms with no success. After a similarly discouraging stay in Philadelphia, they moved on to Baltimore, where the B&O was beginning construction on its line from Cumberland to Wheeling. After some initial disappointment, Latrobe hired Albert Fink in December as a draftsman in the Baltimore office. Fink impressed the chief engineer and rose rapidly in the department, becoming one of Latrobe's principal assistants. [5] In 1854, he patented his famous design for iron truss bridges. Between 1851 and 1857, many examples of Fink's truss were built by the railroad on the line between Cumberland and Wheeling, and later on the Parkersburg Branch (Northwestern Virginia Railroad). After the Civil War, it was used exclusively on lines in the western U.S. and abroad. From 1851 to 1857, Fink was actively engaged in experimental work for the B&O on prefabricated metal structures. His bridge over the Monongahela River at Fairmont (1852-1853) was the second largest iron railroad bridge in the world (the longest was Steven's tubular bridge over the Menai Straits in Britain) and brought him international recognition. In 1857, Fink joined the Louisville and Nashville Railroad and built the famous bridge over the Green River, south of Louisville. From 1859 to 1865, he was Chief Engineer and Superintendent of Construction for the L&N, responsible for rebuilding the road after it had been destroyed by Confederate forces. He was also responsible for the mile-long bridge over the Ohio River for the Pennsylvania Railroad (1868-1870) at Louisville. The main span of this bridge was 400 feet, at that time the world's longest truss. According to Carl Condit, the truss which Fink designed for the channel spans of this bridge became the basis of long-span railroad bridge construction. [6] From 1870 until his retirement from professional activity in 1888, he was mainly concerned with the financial aspects of railroads. After serving as a vice-president of the L&N from 1870 to 1875, he became Commissioner of the Southern Railway and Steamship Association, a combination of about 25 southern railroads. The same methodical attention to detail that characterized his designs also distinguished his administrative career and brought him recognition as the "father of railway economics." He was the first to work out the intricacies of cost analysis for railway enterprises. [7] His achievements as head of the Southern Railway and Steamship Association earned him the admiration of Garret, Harriman, and the Vanderbilts, and as a result he was called to New York, where he served as Commissioner of the Joint Executive Committee of the Trunk Line Commission, a high-powered joint-rate group composed of the most prestigious northern railroads (the B&O, Pennsylvania Railroad, Erie Railway, New York Central, and Hudson River Railroad). Both in engineering and in administration, Fink's career had a large impact on modern railroad practices.

Although Fink's European background provided him with a framework for scientific design, it offered little in the way of actual precedents appicable to the engineering problems of American railroads. The structural form of the Tray Run Viaduct and its companion at Buckeye Run had no known antecedents in contemporary European iron construction. In Europe, a long tradition of masonry building was only slowly being replaced by iron. Stone masonry viaducts persisted well into the middle of the 19th century, partly because stonecutters and masons were not only available but plentiful along the settled routes of European railroads. The metal forms that did exist in Europe differed radically from American practice. In iron bridge construction, emphasis was placed on the use of iron in compression. Cast iron was the primary material, and it was used mainly in the form of columns and plates. British and Continental truss forms were mainly of the lattice type, with riveted rather than pinned connections. [8] In the absence of evidence to the contrary, we can assume that Fink's design was highly original when considered in the context of contemporary iron structures.

In the absence of precedents in contemporary iron construction, it appears that the design for these viaducts evolved directly from the medieval tradition of timber trestles. Techniques for wooden shoring were well developed in mine operations, ship and dock building, and military and civil engineering.* Much less costly than masonry, timber construction offered a quick and proven alternative until the reliability of iron structures could be demonstrated. Even after the development of metal trusses and trestles, the plentiful supply of wood in this country made it the choice of many of the most important railroads. Fink and the B&O clearly relied heavily on this timber tradition for the basic ideas of their metal viaducts on the Cheat.

The existence of wooden precedents for Fink's structures does not minimize their creative contributions to the evolution of all-metal construction. The task of translating wooden forms into metal was a difficult one in view of the general lack of precise techniques for calculating the strength of materials. Timber framing had evolved

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* In fact, many of the trestles and bridges on the B&O itself were built temporarily in wood until they could be replaced by iron or masonry.

through a long period of trial and error, and the knowledge of load limits for different sizes of members of various woods was part of the intuitive professional baggage of the skilled millwright or engineer. Virtually nothing was known of the strengths of wrought and cast iron, and a few early failures had made railroad engineers very cautious about their use. [9] The B&O's engineers and the Mt. Clare Foundry made large contributions in determining the strengths of these new materials and relating them to their most appropriate form. Elucidation of the appropriate size and shape for iron members was equally as important as the ability to manufacture raw materials of reliable quality. The system of joining the members, and the appropriate size of dowels, are just two of the details of construction which had to be carefully worked out before structures such as these could be put into service with some measure of confidence.

A simple description of the Tray Run Viaduct provides some insight into the complexity of the process whereby the basic ideas of timber construction were extrapolated into iron. Longitudinally, the Tray Run Viaduct was 445 feet long. Of this length, 234 feet was straight, the remainder being on a curve of 800 feet radius. It consisted of a series of vertical bents separated by inclined posts in the form of an inverted "V." (See photocopy of drawing, HAER WV-18-5.) At the bottom, the inclined and vertical bents were joined by bolted flanges (2 inches) at cast-iron shoes. These shoes each had an upper and a lower part. The lower shoe rested in a niche cut into the top of a single stone footing, while the upper shoe simply rested on the lower. Three longitudinal ridges on the upper part fit into corresponding slots of the lower part to prevent side-slipping. These shoes were 26 feet on centers and were joined by longitudinal cast-iron struts with bolted flanges. The vertical posts were bipartite, the bottom member measuring 26 feet 11-3/4 inches, and the top member 22 feet 5-3/8 inches. The lower segment was cast integral with the top of the shoe. [10] Upper and lower sections were joined slightly above the midpoint by bolted flanges. A second flange on each piece, 12 inches from the end, served to hold in place the perforated cast-iron panels (2 feet deep) which connected the posts both longitudinally and latitudinally. At the upper end, the vertical posts terminated in a flange surmounted by a dowel (4-1/2 inches) which fit into a cast-iron sleeve. This sleeve was cruciform on the outside with bolt fittings to connect it to the horizontal members. The horizontal members were perforated with cast-iron panels as well, but they differed from those at midway in that they were arched. The longitudinal ones had a span of 13 feet (radius 6 feet 7-1/2 inches), while those supporting the track were 17 feet (radius 10 feet 6 inches). Finally, an additional panel in the form of a quadrant projected 5 feet laterally from every other post to carry the walkway beside the track. The inclined posts which made up the inverted "V" were cast as one piece, terminating in a single capital. Together with the longitudinal strut which connected the shoes, they formed a series of triangles intended to add stability under moving loads. All posts were battered slightly toward the midline to form a structure which tapered from 28 feet at the base to 17 feet at the springing point. This served to offset lateral forces due to wind, but also to counteract the lateral thrust which would result from a load on the arch. In addition, each set of vertical posts was tied laterally by a pair (one above the other) of double-diagonal wrought-iron tie rods and a single latitudinal tie rod at the springing point.

The track itself was on crossties supported by timber stringers (6 inches by 15 inches). There were four of these stringers (13 feet long) layed in pairs. Their ends were set in a pair of cast-iron chair which rested on each arched panel.

The minute attention to detail which emerges from the above description provides a graphic illustration of the importance of these viaducts in the evolution of structural theory and design. By 1850, the superiority of cast iron in compression and wrought iron in tension was an established fact. Tests had been devised to determine the strength of materials under simple, static loads. The problem which remained was that of accurate determination of the nature of stress and its distribution on a complex structure composed of many members. Fink's concern for detail was aimed directly at this problem. The sizes of members, for example, were calculated so that the various elements would relate to each other as whole numbers. The length of the sloped sides of the "triangles" was 50 feet, their base was 25 feet. The bents were battered toward the midline enough to make the springing point of the arch--and hence the tied rod--50 feet above the base line of these triangles. Similarly, the recurrence of some dimensions and their multiples strongly indicates that Fink's approach was mathematically oriented. (The transverse section, if extended until the bents meet, would form a triangle whose height would be five times its base.) While it is not exactly clear what he had in mind, it is certain that he was thinking of these viaducts as geometry problems, attempting to isolate the individual forces at work as much as possible. Such a desire for symmetry probably stemmed partly from the need to minimize the effects of thermal expansion, since unequal expansion was one of the major stumbling blocks to the acceptance of early metal construction. Since the coefficient of expansion is a constant, members expand in direct proportion to their length. If in a structure of this type the members are of radically different lengths, a variation due to expansion would result in a distortion of the shape of the whole, making it subject to secondary stresses under a load. (This was exactly the advantage of Fink's truss design over that of Bollman.) [11] Whatever the reason, it is clear that Fink was concerned with the theoretical basis of iron construction as well as its practical application. He was trying to lay the foundation for a more scientific approach to iron construction, based on mathematics and a rational understanding of structures. Consequently, he took great pains in the design of the details of construction to make his structures models of design simplicity.

So little research has been done to date on the original evolution of these structural details that they have been taken for granted and their importance has not been realized. Yet the most superficial study of the Tray Run and Buckeye Run viaducts reveals Fink's concern for detail and his methodical approach to design. Fink had a rigorous training in the scientific approach to structures and always sought to explain each member in terms of its function. As a consequence, his designs are characterized by their simplicity and the absence of extraneous members. Taken as a whole, his work was a major step toward the adoption of the analytical approach to structural design.

During the 1850's, Fink and the B&O laid the groundwork for the great era of iron bridge building which followed the Civil War. In that period, speed of construction often made the difference between success and failure in the fierce competition between railroads for western trade. Once the details of such construction had been worked out, railroad engineering departments and bridge companies turned their attention toward development of large and efficient fabricating shops which could turn out more or less standardized structures on demand. These structures could then be transported to the site and assembled rapidly with a minimum of skilled labor.

THE IMPACT OF FINK'S DESIGN

The Cheat River viaducts were particularly important in the development of metal bridge piers for the high-level bridges of western railroads. Rivers in the west were wider and faster than those in the east and demanded larger, higher bridges. According to Condit, the first engineer to really make use of such metal piers was George Morison. Morison was chief assistant to Fink's good friend Octave Chanute, engineer of the Erie Railroad. His bridge over the Genesee River at Portage, New York, (1875) included two iron trestle piers over 200 feet high. [12] Yet Morison's work was actually preceded by a number of structures more closely connected to Fink's Cheat River viaducts. It was the Baltimore Bridge Company, founded by Latrobe himself in partnership with C. Shaler Smith, that was most indebted to Fink's pioneering work.

Originally formed to build bridge trusses on Fink's and Bollman's patents, the Baltimore Bridge Company played an important role in the development of later high-level iron and steel viaducts. Following Fink's precedent, the company built a number of structures whose designs provide a graphic illustration of the evolution of viaduct structures. In 1868, under the direction of C. S. Smith, Frederick H. Smith, and Charles H. Latrobe, the company was at work on six viaducts for the Cincinnati and Louisville Short Line, a feeder line to Fink's L&N. The most famous of these was the Bullock Pen Viaduct, 470 feet long and 60 feet over the level of the stream. This structure formed the basis of F. H. Smith's patent of 1869 covering the system of combined iron trusses with iron substructure. [13] While the design for these trestles differed from Fink's, it owed much to the earlier structures in terms of detailing. Smith's use of timber instead of cast iron for longitudinal struts indicates that Fink's earlier design may have been troubled by the effects of thermal expansion on these members. The following year, the Baltimore Bridge Company built two similar structures, the Running Water Viaduct for the Nashville and Chattanooga Railroad and the Lyon Brook Viaduct for the New York and Oswego Midland Railroad. In these structures, the basic form of modern high-level viaducts is more discernible. Instead of being continuous longitudinally, these structures were separated by Fink trusses over the rivers. The longitudinal struts were of wood except for the sections supporting the channel span, where iron was used instead. [14] The decision to use iron for these members indicates a change in the engineers' approach to design. For the first time, these end sections were condeived of as separate towers or piers. Fink's use of continuous stringers had been abandoned. In later structures, Smith and Latrobe achieved stability by reliance on a series of independently braced piers. The next step toward the development of the modern system of independently braced iron piers was taken in 1871. In that year, C. Shaler Smith and C. H. Latrobe designed the famous Verrugas Viaduct (erected 1873) for the Oroya Railroad near Lima, Peru. In that structure, three piers supported four Fink trusses (three of 100 feet and one of 125 feet). It was this technique that soon attracted the attention of engineers in the United States and abroad and became the established practice for high-level bridges.*

Fink's viaducts appear to have had considerable influence on the development of shelter structures as well. While there is no direct link between these works and the appearance of the metal-framed office building, there is no doubt that they were part of the gradual accumulation of techniques which led to that development. Those whose lineage can be most directly traced to this precedent include a number of circular roundhouses built on the B&O in the 1860's and 1870's. These structures differed radically from the circular roundhouses built by the company in the 1840's. The earlier examples owed much to contemporary British and Continental railway practice. The one at Mt. Clare (1847), for example, followed the British method of supporting the lantern and central roof section with cast-iron pillars (11 at Mt. Clare). The roundhouse at Martinsburg (1849), although its interior construction is unknown, bore a striking resemblance to the front of one of the Paris-Orleans Railway at Etampes. [15] The European examples were principally of heavy timber construction, and it is likely that, except for the cast-iron columns, this was probably true of the B&O structures as well. The structure at Martinsburg was destroyed by the Confederate Army in

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* The Crumlin Viaduct in South Wales (1853-1857) seems to have anticipated these efforts. It was an exception to the British preference for masonry construction during this period, yet, in the long run, served as an important prototype.

1862 and not rebuilt until 1866. When reconstruction did begin, the new roundhouse and an identical one nearby were built on an entirely different system. It is in the detailing of this 1866 version that the influence of Fink's viaducts can be seen most clearly (see drawing of West Roundhouse, HAER, sheet 3 of 5). The frame of the central portion of this structure is essentially a cast-iron tower formed by 16 octagonal struts battered toward the center in the shape of an Indian tepee. These struts rise at an angle of 48.2° to a compression ring composed of 16 cast-iron bracket beams. Each strut consists of four sections connected by shorter cast-iron sections designed to receive latitudinal bracing struts of similar design. Longitudinal connections are of the dowel-and-sleeve type, and consequently all members except the bottommost have male and female ends, a prominent feature of Fink's viaducts. The design of the connecting sections is essentially the same concept as the cruciform member at the top of the Tray Run and Buckeye Run viaducts. The cast-iron brackets rest on a flange cast integrally with the longitudinal member in a similar fashion to that at the middle joint of the viaduct struts. The two brackets adjoining each strut are bolted to each other, the bolt passing through a hole cast in the sleeve itself. The bracket beams of the compression ring are cast-iron perforated arched panels almost identical to those of the viaducts. A second roundhouse at Martinsburg, identical to the first, was begun in 1870 and completed in 1872. [16] During the 1870's, the B&O built others at Piedmont, Grafton, and possibly Wheeling. Fink's own Louisville and Nashville built an identical example for its shops at Louisville, and it is entirely likely that others once existed at various points on that line. [17]

While several observers have acknowledged the importance of the B&O engineers in the origins of iron railroad structures, none have been very specific about the nature of the contribution. Most have focused on the fact that both Fink and Bollman patented all-iron truss designs and that the B&O built many examples of these bridges during the 1850's. These, in fact, were important achievements and should not be minimized. Yet, as we have seen, there were a myriad of details to be worked out before such major design breakthroughs were possible. The history of engineering generally focuses on the macroscopic design or form rather than the details which allow the structure to actually be built. While it is possible to trace direct links between Fink's Cheat River viaducts and the later work of the B&O, L&N, and the Baltimore Bridge Company, the evolution of structural forms is no more important than the development of these details. These viaducts were important contributions to the accumulation of a grammar of construction on which later engineers could draw with confidence. Once these details had been worked out, engineers were free to pay more attention to architectural form. Had the form of these viaducts been reproduced by the hundreds across the country, there would be few to contest their importance. Since it was only the details which were repeated, their importance was only evident to engineers. During the 1860's, wrought iron rapidly replaced cast in such structures. In spite of this, many of the techniques of construction developed by Fink and the B&O persisted. The pin system of construction and the use of cast-iron shoes and couplings was particularly suited to American railway practice where prefabrication minimized the need for skilled labor at the site. More important still was the method of design that Fink and his colleagues pioneered. By considering these viaducts as mathematical, geometrical problems, Fink advanced a more scientific approach to structures and laid some of the groundwork for modern structural analysis. The attempt to isolate the various functional elements of a structure made it easier for later engineers to determine the proper requirements of each (this facilitated, for example, the use of a spring balance, substituted for a tension rod, to measure the force acting on that rod under typical loads). It was this concern with functional simplicity that took railroad engineering out of the shadow of mysticism and allowed engineers to accurately calculate the needs and capabilities of their structures.*

Fink's original Tray Run viaduct was taken down and replaced by a wrought-iron trestle in 1887. This trestle was, in turn, replaced by the present three-span masonry arched viaduct sometime later. Buckeye Run Viaduct was replaced by a masonry wall in 1884. [18] Increases in the weight and speed of trains had made the old structures insufficient for the traffic. The techniques used by the engineer to discover such a deficiency in the cast-iron trestles owed much to the methods which Fink had originally devised to build them.

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* It was this same approach applied to the problem of cost analysis which made Fink one of the most respected managers in the field after 1875.

Footnotes

1. Eli Bowen, Rambles in the Path of the Steam Horse (Philadelphia, 1855), pp. 316-319; A. Bendel, Aufsätze Betreffend das Eisenbahnwesen in Nord-Amerika (Berlin, 1862), plate 30.

2. J. E. Greiner, "The American Railroad Viaduct - Its Origin and Evolution," A.S.C.E. Transactions, Vol. XXIV (October 1891), pp. 349-373.

3. Llewellyn Edwards, "Tray Run Viaduct," unpublished manuscript, Smithsonian Institution, Museum of History and Technology, Division of Mechanical and Civil Engineering, Washington, D.C.

4. Some clues to the nature of this rivalry may be offered by Fink's diaries in the Library of Congress Manuscript Division, which have yet to be translated from the German.

5. American Society of Civil Engineers, A Biographical Dictionary of American Civil Engineers (New York, 1972), p. 43.

6. Carl Condit, American Building Art: The 19th Century (New York, 1960), p. 124.

7. American-German Review, February 1949, p. 13; Bureau of Railway Economics, "Albert Fink (1827-1897) A Bibliographical Memoir of the Father of Railway Economics and Statistics in the United States," Washington, D.C.: Library of Congress, 1927; A. Fink, "Cost of R.R. Transportation, R.R. Accounts and Government Regulations of R.R. Tariffs. Extract of Annual Report of Louisville & Nashville R.R." Louisville: J. P. Morton & Co., 1875.

8. Brees, Railroad Practice (London, 1847).

9. Theodore Cooper, "American Railroad Bridges," A.S.C.E. Transactions, Vol. XXI (July 1889), pp. 14, 21; an Album of the Keystone Bridge Company from the early 1870's lists a large number of wooden railroad bridges.

10. A. Bendel, Aufsätze Betreffend das Eisenbahnwesen in Nord-Amerika (Berlin, 1862), pp. 60-61.

11. Robert M. Vogel, "The Engineering Contributions of Wendel Bollman," United States Museum Bulletin 240 (Washington, 1964), p. 91.

12. Condit, p. 112.

13. J. E. Greiner, "The American Railroad Viaduct - Its Origin and Evolution," A.S.C.E. Transactions, Vol. XXIV (October 1891), no. 503, pp. 352-353.

14. Ibid., Plate LXXIX.

15. Descriptions of Mt. Clare and Martinsburg structures in files of Historic American Engineering Record, Washington, D.C. A. Perdonnet and C. Poloncean, Portefarille de L'Ingenieus des Chemins de Fer (Paris, 1861), K16, 17, 29, 30, S. C. Brees, Railway Practice, London: J. Williams 1847.

16. See West Roundhouse Report, WV-1, HAER.

17. See 1882 drawing, HAER.

18. Edwards, p. 2.