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A TRINITY OF BRIDGES: The Smithfield Street Bridge Over the Monongahela River at Pittsburgh

JAMES D. VAN TRUMP

PITTSBURGH's first river bridge — that over the Monongahela River at what is now Smithfield Street — is, historically speaking, three bridges built successively at the same site by a trinity of famous American bridge engineers, Lewis Wernwag, John A. Roebling, and Gustav Lindenthal, all of whom had been born in Germany and thus had learned their technology from that early and famous fountain of engineering. It was America, however, a new and developing country, that gave them the widest scope for their abilities, and Pittsburgh with its great need for bridges was a special beneficiary of their knowledge, as it was a showcase for their talents.

This essay is a study, therefore, of the three versions of the bridge erected at Smithfield Street as well as a consideration of the development of the technology of bridge construction during the nineteenth century.

From the first settlement at Pittsburgh until 1818, the only means of transportation between the town and the farther banks of the rivers was by canoe or skiff. As the community developed, some kind of ferry service became mandatory, and in 1818 Jones's Ferry operated between the foot of Liberty Street in Pittsburgh to the south bank of the Monongahela. Passengers were carried in skiffs while stock was taken over on flatboats. About 1840 a horse ferry was introduced in which blind horses, as a rule, were used as motive power — they

Mr. Van Trump, architect, historian, and vice-president of the Pittsburgh History and Landmarks Foundation, has written numerous articles on the architecture of Western Pennsylvania.—Editor

were made to tramp upon a horizontal wheel, the revolution of which propelled the boat across the stream.

A few years later Captain Erwin established a steam ferry from a site on the south bank of the Ohio slightly below the confluence of the rivers at the Point, but this was never a success.¹ Subsequently the Jones Ferry was abandoned and a steam ferry operated from Saw Mill Run on the south bank of the Ohio to Penn Street in Pittsburgh, and this line was in use until the increasing number of river bridges made it redundant.²

Prior to the building of the Monongahela Bridge, all traffic passing from one side of the river to the other at Smithfield Street was carried on a little ferry owned by Enoch Wright of Westmoreland County and Andrew Herd of Allegheny County, who leased the buildings, ferry, and improvements to one Robert Shanhan. Where the ferry landed on the South Side stood Enoch Wright's stone house. After the bridge was constructed, the ferry interests were bought out by the Stock Company.³ Before the introduction of dams toward the end of the nineteenth century, the streams at slack water were relatively shallow, and numerous islands and sand bars were in evidence. There was, for instance, a long sand bar in the Monongahela at the site of the Smithfield Street Bridge;⁴ this river flatland that is shown on the very early maps of Pittsburgh was of sufficient extent that grain could be grown on it at low water. It must be remembered also that there was extensive traffic on all three rivers and the spans of bridges had to be sufficiently high to allow boats to pass beneath them.

The first of Pittsburgh's highway river bridges was the Monongahela (later Smithfield Street) Bridge. Erasmus Wilson, a late nineteenth-century historian of Pittsburgh, has left the best account of its construction and we quote it here:⁵

"In the year 1810 a bill was introduced in the [Pennsylvania]

1 J. N. Boucher, *A Century and a Half of Pittsburgh* (New York, 1908), 2, 387. See also C. W. Dahlinger, *Pittsburgh: A Sketch of its Early Social Life* (New York, 1916), 29-30.

2 The route of Jones's Ferry appears on the McGowan map of Pittsburgh of 1852, together with other ferry routes plying the local rivers.

3 Herbert Du Puy, "A Brief History of the Monongahela Bridge, Pittsburgh, Pa.," *Pennsylvania Magazine of History and Biography* 30, No. 2 (1906): 187-88 (hereafter cited as Du Puy, "Monongahela Bridge").

4 A 1795 map of Pittsburgh shows the sand bar, but on the Molineux map of the city of 1830, it has disappeared.

5 Erasmus Wilson, ed., *Standard History of Pittsburg Pennsylvania* (Chicago, 1898), 112-14.

State Legislature providing for the construction of two bridges at Pittsburg — one over the Monongahela and one over the Allegheny, and an estimate of the probable cost of such a structure was made by Judge Findley. It was calculated by him that the 1,200 feet of river would require chains of 1,590 feet and four such chains of inch and a half square iron bar weighing sixty-four pounds to the foot, with some excess, would amount to \$8,800; smith work would cost \$3,080; a bridge thirty feet wide would require \$900 worth of plank; three piers would cost \$15,000; other expense, \$1,050; right to use certain patents, \$1,200; putting together, \$1,296; incidentals, \$1,000; total \$32,326. James O'Hara, William McCandless, David Evans, Ephraim Pentland, Jacob Beltzhoover, Adamson Tannehill, Thomas Cromwell, Thomas Enochs, and Dr. George Stevenson were the commissioners appointed to open books for the subscription of stock in the Monongahela bridge. John Wilkins, James Robinson, Nathaniel Irish, George Shiras, George Robinson, Isaac Craig, James Irvin, John Johnston, and James Riddle, were authorized to open books for the subscription of stock in the Allegheny bridge. Probably owing to the war of 1812, the bridges were not built at that time and in 1816 the law was reenacted, and the Governor, on behalf of the State, was authorized to take 1,600 shares of stock in each bridge. The law specified that one was to be built over the Monongahela at Smithfield Street and one over the Allegheny at St. Clair [now Sixth] Street . . .

"The last installment of stock for the Monongahela bridge was called for by the treasurer, John Shaw, to be paid May 15, 1818. The first arch was laid on the piers on Saturday, June 20, 1818. [The bridge] was rapidly built, when once begun, and rested on two abutments and seven intermediate piers of stone. It was constructed of wood and iron, with the catenarian curve of arches, the contract price being \$110,000. As if to favor the contractor the weather during the fall was excellent.

"The beautiful bridge over the Monongahela has nearly reached the northern shore; it will probably be crossed before Christmas. The one over the Allegheny is not so far advanced, but yet enough is done to insure its completion. Pittsburg will then exhibit what no American city or town has ever yet done — two splendid bridges over two mighty streams, within 400 yards of each other.⁶

"On Saturday (November 21, 1818) the last arch of the Monongahela [Bridge] being completed, and the whole floored, the

6 *Pittsburgh Gazette*, Nov. 24, 1818, quoted in *ibid.*, 113.

undertakers and builders announced the pleasing event by the discharge of cannon from the middle pier and the display of the United States flag waving over the central arch, having attached to its staff a beautiful banner with appropriate representations. The City Guards and the new company of Washington Guards from Birmingham, heralded on their respective sides of the river, marched across and fired salutes. In the afternoon the workmen sat down to a substantial dinner, at which Mr. Johnston, the meritorious undertaker and superintendent, presided

"November 26, 1818, John Shaw, treasurer of the Monongahela Bridge Company called a meeting of the managers to appoint a gatekeeper to receive the toll, as follows: Foot passengers, 2 cents; vehicles of four wheels and six horses, 62½ cents; vehicles of two horses, 25 cents; vehicles of one horse, 20 cents; horse and rider, 6 cents; horse alone, 6 cents; each head of cattle, 3 cents; each head of sheep, 2 cents

"The State held \$40,000 worth of stock in the Monongahela bridge, and was required to assist in repairing the damage caused by the falling [of part] of the span in 1831-2."

Llewellyn Edwards describes the Monongahela Bridge as follows: "The substructure consisted of two abutments and seven piers of stone masonry. The superstructure had eight covered wood truss spans and an overall length of 1500 feet."⁷

Richard Allen also comments on both the Monongahela and Allegheny bridges (the latter not finished until 1819). The Monongahela Bridge was a Burr truss structure, and Allen states that "its outstanding feature was the toll collector's living quarters. He was housed in a small apartment built above the barn-like portal on the Pittsburgh side."⁸

The Burr truss which appears so frequently in the chronicles of early American bridge construction was named for Theodore Burr (1771-1822), a well-known bridge designer of his day. Like his contemporaries, he, for all but very short spans, combined the arch and truss (witness the "catenarian arches" of the Wilson account quoted earlier), but instead of combining them by strengthening the arch by

7 Llewellyn Edwards, *A Record of the History and Evolution of Early American Bridges* (Orono, Maine, 1959), 198.

8 Richard S. Allen, *Covered Bridges of the Middle Atlantic States* (Brattleboro, Vermont, 1959), 75. There is also a description of the bridge in "A View of Pittsburgh" in *The Franklin Magazine Almanac for 1820*, 51-52, and in Rebecca Eaton, *Geography of Pennsylvania* (Philadelphia, 1837), 235.

the truss, as did the rest, he strengthened the truss by the arch. His design was in reality merely a series of king posts, and it is safe to say that the majority of wooden covered bridges built in the United States were of the Burr truss design.⁹

The designer of both the Monongahela and the Allegheny bridges was Lewis Wernwag (1769-1843), perhaps the most famous of all early American bridge engineers. Born in Germany, he came to the United States at the age of seventeen and settled in Philadelphia. He specialized in wooden truss spans, his first famous work being a single-span bridge constructed in 1812 over the Schuylkill River at Philadelphia. He later constructed many highway and railroad bridges. A letter from his son John to Samuel Smedley, published in the *Engineering News*, August 13, 1885, includes a list of twenty-nine bridges built by his father during his active career of twenty-seven years.¹⁰ Of all these bridges the Monongahela was among the most famous.

Joseph H. Thompson was selected to build the Monongahela Bridge and a contract was made with him on July 9, 1816, to construct Wernwag's "double-passage wooden-bridge covered from end to end, . . ." The contract price was \$110,000.¹¹

The Monongahela span gave many years of good service to the developing Pittsburgh region, but it disappeared in ten minutes in a long trailing line of smoke and flame at two o'clock in the afternoon during the Great Fire of April 10, 1845,¹² one of those huge conflagrations that devastated American cities in the nineteenth century.¹³ At the time of its destruction it was still the only bridge over the Monongahela at Pittsburgh.

After the fire the old piers and abutments were repaired and on them the now-famous John A. Roebling constructed a new wire cable suspension bridge for a contract price of \$55,000. Work began on the

9 D. B. Steinman and S. R. Watson, *Bridges and Their Builders* (New York, 1941), 121-22.

10 *Dictionary of American Biography* 10, Pt. 2: 2-3 (cited hereafter as *D.A.B.*). See also Robert Fletcher and J. P. Snow, "A History of the Development of Wooden Bridges," *Proceedings of the American Society of Civil Engineers* 57 (1932).

11 Du Puy, "Monongahela Bridge," 194.

12 *Ibid.*, 198.

13 There is a contemporary oil painting by the Pittsburgh artist, William C. Wall, "The Great Fire of 1845," on display at the Old Post Office Museum, Pittsburgh (on loan from John H. Follansbee), which shows the Monongahela Bridge in flames. Another canvas, attributed to the same painter, and in the possession of the museum, shows the ruins of the city and the bridge just after the fire.

new structure in June 1845, a short time after the fire. D. B. Steinman has given a full and colorful account in his biography of Roebling of the construction of this first of the famous engineer's highway bridges.¹⁴ What began in Pittsburgh culminated in the 1860s in his final master work, the Brooklyn Bridge.

John A. Roebling as a bridge engineer is so well known that any biographical data would seem almost redundant, but some account of his life is necessary here because of his importance in Pittsburgh pontine history.¹⁵ He was born in Mühlhausen, Germany, in 1806, received his engineering education at the Royal Polytechnic Institute in Berlin, and emigrated to America in 1831, settling at Saxonburg in Butler County, some twenty-five miles north of Pittsburgh. This town, which he established, became the chief focus of his early engineering career and here he established his wire rope manufactory which was later moved to Trenton, New Jersey. His wire cables were used first on the inclined planes of the Pennsylvania Canal's Portage Railroad in the mountains of western Pennsylvania; his first important bridge was a suspension aqueduct which he constructed in 1844-45 to carry the Pennsylvania Canal over the Allegheny River at Pittsburgh.¹⁶ As the aqueduct neared completion, the Monongahela Bridge burned, and Roebling almost immediately received the commission to construct the new one. As a result of the fame of these two structures, Roebling now was established as America's foremost bridge engineer. He went on to design such famous structures as (another Pittsburgh work) the second Sixth Street Bridge over the Allegheny River (1858-1860), the Niagara Railway Suspension Bridge (1851-1855), the Cincinnati Bridge over the Ohio (1856-1867), and finally the Brooklyn Bridge which he was never to see finished, since he died as a result of an accident in 1869 when work on the bridge piers had just begun.

John Roebling was more than a competent bridge engineer. He was also a prolific writer and he published his achievements as they appeared. Consequently, the best description of the second Monongahela Bridge is that from his own pen:¹⁷

14 *The Builders of the Bridge: The Story of John Roebling and His Son* (New York, 1945), 89-100 (hereafter cited as Steinman, *John Roebling*).

15 *D.A.B.* 16: 86-87; Steinman, *John Roebling*; Hamilton Schuyler, *The Roeblings—A Century of Engineers, Bridge Builders, and Industrialists* (Princeton, N. J., 1931); "John A. Roebling," *Engineering News* 10 (May 26, 1883): 246.

16 John A. Roebling, "The Wire Suspension Aqueduct Over the Allegheny River at Pittsburgh," *Journal of the Franklin Institute*, 3rd ser., 10, (1845): 306-309. The bridge is illustrated on 307.

17 "The Wire Suspension Bridge Over the Monongahela River at Pittsburgh,"

"The new Suspension Bridge over the Monongahela . . . was commenced in June, 1845, and opened for travel in February, 1846. The piers and abutments of the old wooden structure, which was destroyed by the great fire, required extensive repairs to be fitted for the reception of the new superstructure. The whole length of the work between the abutments, is exactly 1,500 feet, and is divided into eight spans of 188 feet, average distance from centre to centre. The piers are 50 feet long at bottom, 36 feet high, and 11 feet wide on top, battering 1 inch to the foot.

"Two bodies of substantial cut stone masonry, measuring 9 feet square and 3 feet high, are erected on each pier, at a distance of 18 feet apart. On these the bed plates are laid down for the support of the *cast iron towers*, to which the *wire cables* are suspended by means of *pendulums*. Each span being supported by two separate cables, there are therefore, 18 cables suspended to 18 towers.

"The towers are composed of four columns moulded in the form of a two sided or cornered pilaster; they are connected by four lattice panels, secured by screw bolts. The panels up and down stream close the whole side of a tower, but those in the direction of the bridge form an open doorway, which serves for the continuation of sidewalks from one span to the other.

"On top of the pilasters or columns, a massive casting rests, which supports the *pendulum* to which the cables are attached. The upper pin of the pendulum lies in a seat which is formed by the sides and ribs of a square box occupying the centre of the casting. For the purpose of throwing the whole pressure upon the four columns underneath, 12 segments of arches butt against the centre box, and rest with the other end upon the four corners.

"The pendulums are composed of four solid bars of 2 feet 6

The American Railroad Journal 19 (Apr. 4, 1846): 216; also (June 13, 1846): 376. The version quoted here is from a reprint in a periodical published at Pittsburgh and edited by Neville B. Craig, *The Olden Time* (June 1846) 1: 286-88 (reprinted 1876 under a Cincinnati imprint). See also Gustav Lindenthal, "The Monongahela Bridge—Rebuilding of the Monongahela Bridge at Pittsburgh," *Engineering News* 10 (July 7, 1883): 314-15; 11 (Mar. 14, 1884): 239, 241, 371; "The Suspension Bridge," *American Railroad Journal* 19 (Feb. 21, 1846): 126; Col. S. M. Wickersham, "The Monongahela Suspension Bridge," *The Scientific American Supplement* 15 (1883): 6201; "The Monongahela Suspension Bridge at Pittsburgh, Pa.," *Engineering News* 10 (May 26, 1883): 243-44; *The Iron Age* 31 (June 21, 1883): 3, 5, 1. Roebling's *American Railroad Journal* article is also illustrated with a lithographed plate of his own drawings for the structure. Steinman, in his biography, also reproduced two Roebling drawings for the bridge—opposite 134.

inches long, from centre to centre of pin, 4 inches by one inch — the pins are three inches in diameter. To the lower pin, the cable of one span is attached directly and the connection formed with the next cable by means of four links of 3 feet 6 inches long and 4 inches by $1\frac{1}{4}$ inches.

“The opposite cables, as well as the pendulums, are inclined towards each other — the distance between being 27 feet at the top of the towers, and 22 feet at the centre of a span. The pendulums on the abutments, however, occupy a vertical position.

“The two sidewalks are outside of the cables, and 5 feet wide. The roadway is contracted to 20 feet, and separated from the sidewalks by fender rails, which are raised from the floor by means of blocks of 6 inches high, 8 feet apart. The total width of the bridge between the railings is 32 feet.

“The anchor chains which hold the cables of the first and last span, are secured below the ground in the same method which was applied to the [Pennsylvania Canal] aqueduct — their oxidation is guarded against in the same manner.

“The cables are $4\frac{1}{2}$ inches in diameter, and protected by a solid wrapper; they are assisted by stays, made of $1\frac{1}{4}$ inch round charcoal iron; the suspenders are of the same material, $1\frac{1}{2}$ inch diameter, and placed 4 feet apart.

“The peculiar construction of the Monongahela bridge was planned with the view of obtaining a high degree of stiffness, which is a great desideratum in all suspension bridges; this object has been fully attained. The wind has no effect on this structure, and the vibrations produced by two heavy coal teams, weighing seven tons each, and closely following each other, are no greater than is generally observed on wooden arch and truss bridges of the same span. This bridge is principally used for heavy hauling; a large portion of the coal consumed in the city of Pittsburgh passes over it in four and six horse teams.

“As a heavy load passes over a span, the adjoining pendulums, when closely observed, can be noticed to move correspondingly — the extent of this motion not exceeding one half inch. By this accommodation of the pendulums, all jarring of the cast iron towers is effectually avoided. Another object of the pendulums is to direct the *resultant* of any forces to which the work may be subjected, through the centre of the towers, as well as of the masonry below.

“Two of the piers of the old structure had once given way in

consequence of the shaking and pressure of the arch timbers, when subjected to heavy loads. Such an accident can never take place on the new structure, as the piers are only subjected to the quiet and vertical pressure of the towers.

"I do not recommend the application of pendulums in all cases; but in this, it appeared to me the best plan which could be adopted.

"The two towers on each pier are connected by a wooden beam, properly encased and lined by the same mouldings which ornament the top of the castings.

"The lightness and graceful appearance of this structure is somewhat impaired by the heavy proportions of these connections, but I had to resort to it for motives of economy.

"The whole expense of this structure does not exceed \$55,000 — a very small sum indeed for such an extensive work.

"A great portion of this work had to be done during the winter, and in cold weather; it was accomplished without any accident, with the exception of one of the workmen who was seized by fits and killed by falling off a pier."

TABLE OF QUANTITIES OF MONONGAHELA BRIDGE

Length of bridge between abutments	1500 feet.
Number of spans	8
Average width of spans from centre to centre	188 "
Diameter of cables	4½ inch.
Number of wires in each	750
Weight of superstructure of one span, as far as supported by the cables	70 tons
Tension of cables resulting from it	122 "
Weight of four six horse teams, loaded with 104 bushels of coal each	28 "
Tension resulting from it when at rest	49 "
Weight of 100 head of cattle at 800 lbs.	40 "
Tension resulting from it when at rest	70 "
Aggregate weight of one span as far as supported by the cables, plus 100 cattle at rest	110 "
Tension resulting from it	192 "
Ultimate strength of two cables	860 "
Section of anchor chains	26 inch.
Section of pendulums	63 "

In 1859 an agreement was made with the Pittsburgh and Birmingham Railway Company, a horse car line then being constructed from Pittsburgh to the South Side across the river, to permit the line to cross the bridge at the price of fifteen dollars per car each month. In 1865 the structure acquired gas lights, and the foot toll was reduced to one cent per person.¹⁸ In 1861, a wooden truss bridge was built a little farther upstream at South Tenth Street;¹⁹ Roebling's span was no longer the only bridge crossing the river, and in later years was increasingly referred to as the Smithfield Street Bridge.

The structure during its years of service often was tried sorely — sometimes when it was crowded with people viewing a steamboat race, sudden rushes would be made from one side of the bridge to the other.²⁰ Such conditions afforded a real test of the designer's foresight in providing various features that assured enduring stability. The bridge continued in service for thirty-five years, carrying the heaviest kind of street traffic, horse cars, steam rollers, and eight-horse teams pulling heavy trucks loaded with iron and machinery. The multiple span arrangement, though quite satisfactory for an aqueduct with its loading constant or uniform in all spans, was under a disadvantage in a suspension bridge carrying variable loading. Despite the system of inclined stays which Roebling had installed, a loaded span sometimes deflected as much as two feet with a corresponding smaller rise of the adjoining spans. Not only the designer but the profession profited by this experience.²¹

Due to the enormous volume of traffic on Roebling's bridge, it began to show signs of strain, and the Board of Managers of the bridge company decided to look into the possibility of providing a new structure. On February 1, 1871, bids were presented to the board, but soon afterward the city of Pittsburgh tried to secure the franchise. This brought out a stockholders' meeting on May 27, 1872, contesting the city's right to such action.²² This difficulty retarded the new improvement and the Panic of 1873 with its resultant economic woes prevented anything being done, but in the summer of 1880 the board

18 Du Puy, "Monongahela Bridge," 202.

19 Henry Joseph White, and M. W. von Bernewitz, *The Bridges of Pittsburgh* (Pittsburgh, 1928), 32.

20 See description of a scull race in *Harper's Weekly* 19 (June 8, 1867): 363-64, with a wood engraving after a sketch by C. S. Reinhart, showing the bridge.

21 Steinman, *John Roebling*, 100.

22 Du Puy, "Monongahela Bridge," 202.

finally decided to demolish the Roebling bridge and construct a new one.²³

The Board of Managers of the bridge company called to their aid a local engineer, Charles Davis (1837-1907), who submitted a design for another suspension bridge. Davis was one of those American engineers who seemed to have learned their profession "in the field," so to speak, particularly in railway surveying. He had been consulting engineer for Pittsburgh's Point (suspension) Bridge (1875-1877) and in 1881 was elected Engineer of Allegheny County, a position he held until his death.²⁴

Work on Davis's bridge began in the summer of 1880. It was to be a suspension bridge having two channel spans of 360 feet each and two shore spans of 180 feet each. Foundations for the channel piers were put in first, and the piers built up to an average height of ten feet each. Because the winter of 1880 was unusually severe further work on the bridge was stopped.²⁵ None of the drawings for this abortive design seems to have survived.

In February 1881, the bridge company was reorganized, and as a consequence, all work on Davis's bridge stopped and all prior contracts cancelled. The man who now held the controlling interest in the company's stock, David Hostetter, was also largely interested in the Pittsburgh and Lake Erie Railroad and he wished a different type of structure, because he thought it might be possible to run cars from his own line on the south bank to the lines of the Baltimore and Ohio on the north. Consequently, a young German engineer, Gustav Lindenthal, was called in to make a design for a through-truss bridge.²⁶

The new bridge engineer was also an immigrant. He was born in 1850 in Brünn, Moravia, Austria-Hungary, and had been educated at the Provincial College of Brünn and at the polytechnical schools of Brünn and Vienna. He worked on railways in Austria and Switzerland before coming to America in 1874; in 1876 he assisted in the construction of buildings for the Centennial Exposition in Philadelphia. In 1881 he established himself in a private engineering practice in Pittsburgh. He was engaged in many railway and bridge projects,

23 Gustav Lindenthal, "Rebuilding of the Monongahela Bridge at Pittsburgh, Pa.," *Transactions of the American Society of Civil Engineers* 11 (Sept. 1883): 355 (hereafter cited as Lindenthal, "Monongahela Bridge").

24 *Biographical Review, Pittsburg and the Vicinity* (Boston, 1897), 24: 475-77; *Memoirs of Allegheny County, Pennsylvania* (Madison, Wisc., 1904), 1: 37-38; *Pittsburgh Gazette Times*, Feb. 22, 1907.

25 Lindenthal, "Monongahela Bridge," 355.

26 Du Puy, "Monongahela Bridge," 203.

including the reconstruction of bridges on parts of what is now the Erie Railroad, various bridges in and near Pittsburgh, and railway surveys and estimates in Pennsylvania and neighboring states. By the age of forty, he had established a reputation as one of America's great bridge engineers, and certainly the new Smithfield Street project was no small factor in his rise to fame.

In 1890 he set up a consulting office in New York City, devoting most of his time to bridge work. His best-known works are the Queensboro Bridge (1901-1908) over the East River in New York, the Hell Gate Bridge (completed 1917) for the New York Connecting Railroad, and the Sciotoville Bridge (1914-1917) over the Ohio River. In 1902-1903 he served as commissioner of bridges for the city of New York. In this capacity he advocated and established the practice of the association of engineers, in the design of large bridges, with architects whose special interest lay in the esthetics of bridge construction.

As an engineer, his greatest vision never materialized — a bridge over the Hudson River at New York. From 1880 until his death in 1935, he worked on the problem of transportation from New York to the New Jersey side of the river and he constantly urged the adoption of his North River Bridge scheme. However, complications arising from decisions of the United States Army Engineers with reference to clearance defeated final approval of the plan. The long span — 3,100 feet — heavy loading, and the huge costs of this project may be taken as a measure of Lindenthal's vision.

Originality and boldness characterized Lindenthal's designs. He differed from many of his American contemporaries in his frequent choice of more complex structural forms and in some of his views as to working stresses. Like Roebling, he wrote many technical papers and contributed to learned journals, chiefly on bridge design, but his chief monuments were his works. Pittsburgh is fortunate still to possess the first of his great designs which yet functions today, still serving its contiguous land areas and supporting weights that the engineer could not have foreseen when it was designed.²⁷

As in the case of Roebling, Lindenthal's is the best account of the construction of the Smithfield Street Bridge.²⁸ In 1881 "the writer

²⁷ *D.A.B.* 21, Supplement 1, 498-99; *Transactions of the American Society of Civil Engineers* 32 (1904); *Who's Who in America* (1934-35); *Who's Who in Engineering* (1931); *Civil Engineering* (Sept. 1935); *Engineering News Record* (Aug. 8, 1935); *Electrical Engineering* (Sept. 1935); *New York Times*, Aug. 1, 1935.

²⁸ Lindenthal, "Monongahela Bridge," 355, ff.

was invited for consultation and to suggest suitable changes in the plans, which should provide for a widening of the bridge by adding another roadway or track, should this ever become necessary in the future. After having submitted such plans, they were accepted and the writer was engaged to carry them out. This plan proposed to utilize the foundations and piers which had been commenced. They were to be built upon, without any offsets, to a width on top of 56 feet.

"As the width of the superstructure may ultimately reach 64 feet, or eight feet wider than the piers, it became necessary to let the sidewalks project over the masonry. The present width is 48 feet on the channel spans; the room on the piers for widening the bridge was left on the up-stream side. For the channel spans Pauli trusses²⁹ were proposed, 25 feet 8 inches apart, centre to centre, and the centre line of the new floor (of 48 feet width) was shifted down-stream 8 feet 2 inches from the centre line of the old bridge. The sidewalk on the up-stream side was proposed to be detachable, so that the floor may be widened and the sidewalks again connected to it.

"For the approaches to the channel spans, plate girder deck spans, on lighter masonry piers, were proposed. This arrangement allows of increasing the width of the bridge by simply adding more plate girders to each span on the piers which are long enough for that purpose. Being a deck bridge, it afforded an unobscured entrance view to the channel spans, the trusses of which were to rest on ornamental towers, giving to the superstructure an architectural appearance of strength and stability.

"The shifting of centre line of new floor 8 feet 2 inches down-stream from the centre line of old bridge allowed of erection of the new superstructure without stopping travel on the old bridge, in a manner described more in detail below.

"The Pauli truss type commended itself for the channel spans in this instance, for several reasons:

- "1. The pleasing appearance (for a city bridge) in comparison with the ordinary parallel chord truss.
- "2. The fact that the trusses could be made high in the middle (without detriment to their stability in case of high winds),

²⁹ These are lenticular, "bow-string," or "fish-belly" through-trusses, named for the famous German engineer Friedrich August von Pauli (1802-1883). For Pauli, see *Zeitschrift für Baukunde* 7 (1884): 379-96; *Allgemeine Deutsch Biographi* 25 (Leipzig, 1887): 251-58; and *Zeitschrift des Vereins Deutscher Ingenieuren* (1865), "den Artikel von Gerber über die Berechnung des Bruckentragers nach Paulischen Systems."

thereby reducing the chord strains and chord sections. In connection with the light and slender web-members, it permitted of an economy in the trusses of over 9 per cent, as compared with parallel chord trusses (with inclined end posts) of same height (50 feet). The deflection and vibration of high trusses is small and their rigidity great.

"3. The bottom chord or cable is exposed to the sun's rays as much as any other truss member; therefore unequal temperature effects in the trusses are avoided. The covered floor construction is independent of the trusses as to temperature effects.

"4. The floor had to be cambered 18 inches in each 360 foot span to agree with the general grade of the new bridge. A straight bottom chord with a rise of 18 inches in 360 feet was undesirable.

"At first it was proposed to build the new structure 15 feet higher at highest point than the old bridge. But the river men, in the interests of navigation, demanded the structure to be at least 20 feet higher, or 57 feet above low water mark, to which the Bridge Company objected, on the ground that the additional 5 feet height would injure travel over the bridge much more, by reason of a steep grade at the Pittsburgh end, than it would benefit navigation.

"There is no statute prescribing the height of bridges over the Monongahela River. The case was taken to a court of equity, and argued there by lawyers pro and contra, resulting in a preliminary injunction against the Bridge Company building the bridge lower than 20 feet. To continue the litigation would have required much time. After a suspension of work at the bridge for 10 months the Bridge Company decided to accede to the demands of the river men.

"The following is a description of the material and methods used in the construction of the bridge:

MASONRY

consists of a gray, hard and durable sandstone, free from admixtures of clay or iron oxide particles. It was quarried near Homewood, Pa. on the Pittsburgh and Lake Erie Railroad where it is found in large blocks of 100 to 500 cubic yards, without any stripping. The masonry is rock-faced, with drafts 1 inch wide all around the face of the stones, which are in courses of alternate headers and stretchers.

"The dimensions of the stones are 24 inches to 16 inches in thickness, 7 feet to 4 feet in length, 3 feet to 11 feet in width, with

beds and joints dressed regular and true. The backing for the abutments and wing walls consisted of regular shaped stones, with dressed beds; for the heart of the piers concrete filling was used. It was applied in layers of 12 inches thick. It proved superior in every way to ordinary stone backing. Iron clamps bind the stones in the pier heads in every course.

"The use of spalls was not permitted in any part of the masonry. All spaces between stones were filled with concrete, rammed with iron rammers, making every course absolutely water-tight. Great attention was given to the bond. The stone blocks were laid in alternate header and stretcher courses, which made the coincidence of stone joints in the heart of the pier impossible. In this way each stone is bonded in every direction. The concrete backing, after setting, was very hard and tough; it adhered to the stones with great tenacity, and made the piers monolithic in fact.

"In the execution of the work care was taken to set every stone immediately before setting. When laid in position the stone was settled by repeated blows of a heavy wooden ram. Any stone breaking under this operation was removed.

"The face joints of the finished masonry were cleaned out to a depth of 1 inch, and thoroughly moistened, and caulked with Portland cement and sand mortar, mixed one to one.

"For all face masonry exposed to the weather American Portland cement was used for the mortar; for concrete backing and foundations, Rosendale cement was ordinarily used.

"All cements were required to be so finely ground that 90 per cent of the whole would pass through a sieve of 50 meshes to the lineal inch. Tests as to its tensile strength were conducted on a Fairbanks testing machine with moulded briquettes of pure cement.

"Rosendale cement made of a stiff paste, having been one day in water and one day in the air, at an even average temperature of 70 degrees Fahrenheit (in a room), was tested to show the tensile strength of at least 40 pounds per square inch.

"American Portland cement briquettes, under same conditions, were tested to show a tensile strength of at least 80 pounds per square inch.

"Similar briquettes, after having been four days in water and one day in the air, at the above average temperature, were tested for a tensile strength of 60 pounds per square inch for Rosendale cement, and 150 pounds for American Portland cement.

"The concrete used throughout the work was composed of 2 parts of sound broken stone, passing through a 3 inch ring; 2 parts of clean gravel from the size of a pea to 2 inches diameter; 2 parts of washed river sand; 1 part of Rosendale cement of accepted quality.

"For concrete under water 2 parts of cement were used to allow for waste by washing in depositing it under water. With a little care in the operation the loss, however, was insignificant. The stone, gravel and sand were first mixed on a board platform, then the cement added, and the whole mass thoroughly rehandled in a dry state. Water was then added in barely sufficient quantity to reduce the whole mass, by lively and severe shoveling, to a stiff mortar. This was put immediately in place in layers of not over 12 inches thick, and thoroughly rammed with iron rammers about 5 inches square and weighing 36 pounds, until the mass flushed uniformly over the whole surface.

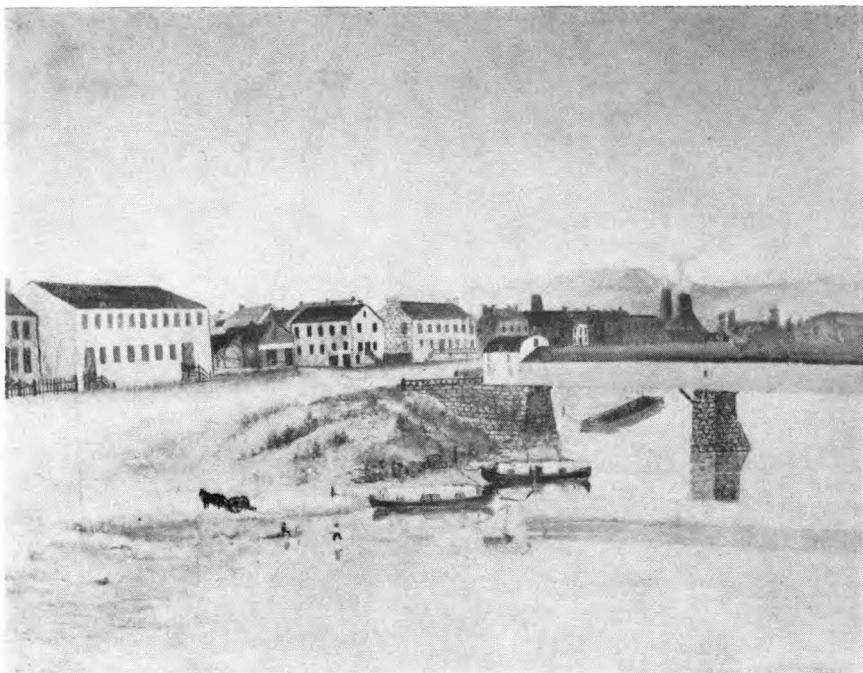
"For depositing the concrete under water for the pier foundations square wooden troughs were used, reaching down to almost the bottom, and the concrete dumped in and raked even with iron rakes having long handles. The running out of the concrete was prevented by sheet piling. When a change in the masonry of Pier No. 4 required the removal of a few stones they were found to form with the concrete backing one solid mass, which had to be rent asunder with steel wedges and sledge-hammer, and would sometimes break through the stone rather than through the concrete.

"Openings or slots for one car track were left in the new abutments and piers to accommodate travel on the old bridge.

"The pier posts of the channel spans on the down-stream side have their bearing near to the pier ends, and to prevent cracking of the channel piers or uneven settlement after the superstructure should be in place, riveted iron anchors were walled into the top of piers Nos. 2, 3 and 4.

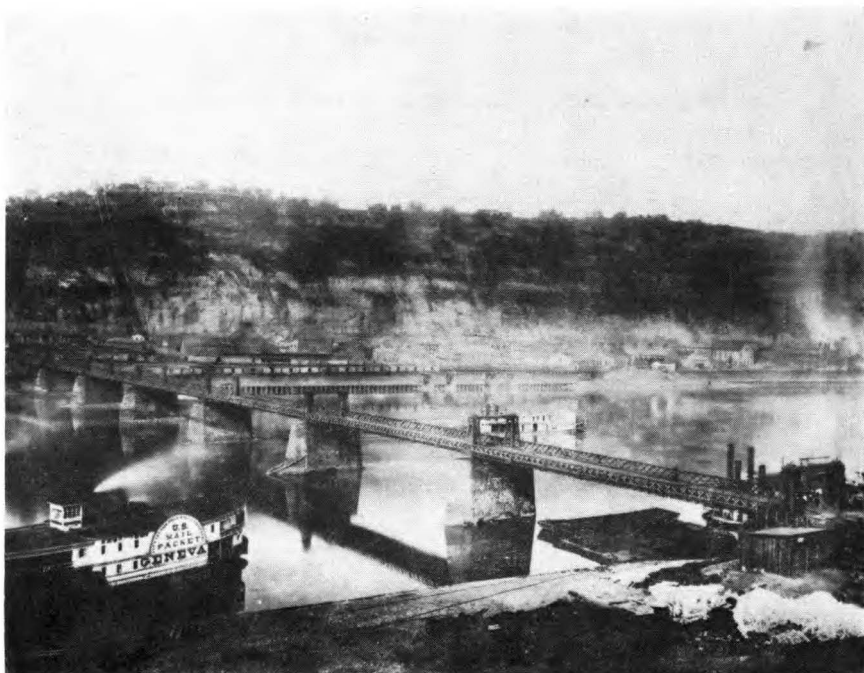
"The coping on the piers, consisting of two projecting courses of cut stone, was nearly all in place for a grade 15 feet higher than the old bridge, at the time of the dispute with the river men. When the height of the piers was increased to suit a grade 20 feet higher than the old bridge, the additional masonry was built on top of the coping in the form of pedestals of cut stone.

"After the erection of the superstructure had so far progressed that travel could be turned on to one track on the new bridge, the old bridge was abandoned, and the taps and openings in the masonry of the new abutments and piers successively walled in and closed. In this



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The Wernwag bridge over the Monongahela, built in 1818, and destroyed by fire in 1845. Picture painted by Leander McCandless.



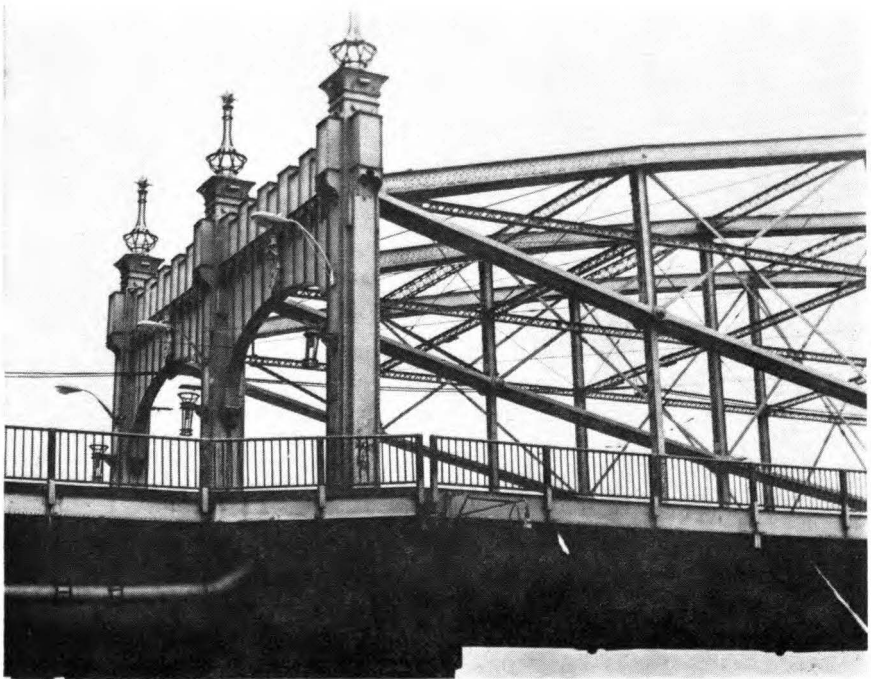
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This is John A. Roebling's Monongahela suspension bridge, built in 1846. View is looking from downtown towards Mt. Washington.

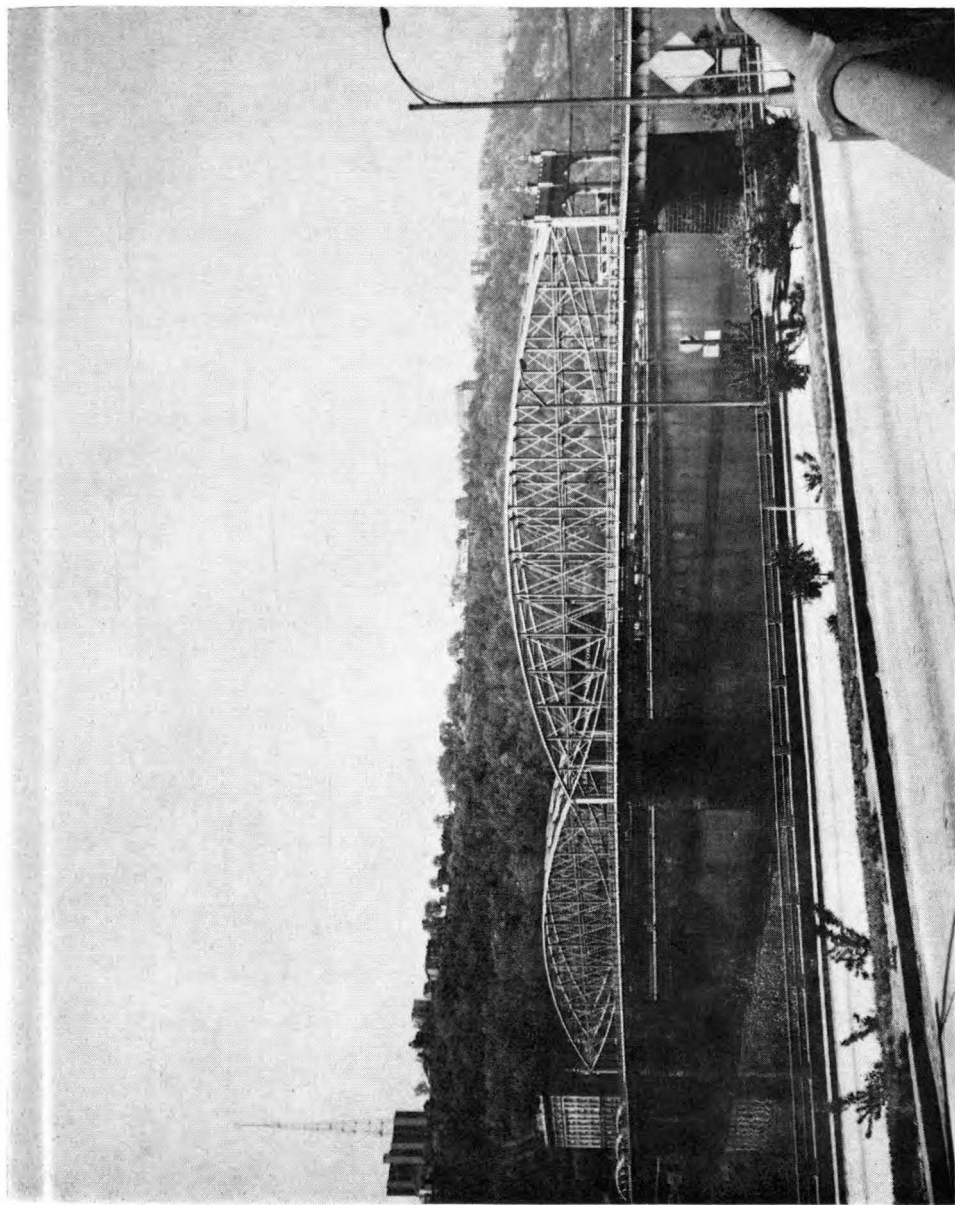


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North portal of Lindenthal's Smithfield Street Bridge. Photograph shows the original wrought-iron portal.



One of the present portals of the Smithfield Street Bridge.



The Smithfield Street Bridge as it appears today.



View of the through-trusses of the Smithfield Street Bridge.

wise it was possible to complete the masonry work without stopping travel on the old or new bridge.

SUPERSTRUCTURE

"The roadway is at present 22 feet 10 inches wide in the clear, and two sidewalks each 10 feet in the clear. The full width of the bridge on the deck spans of approaches is 43 feet 6 inches, and on the channel spans, which are through spans, 48 feet.

"The bridge can be widened out, if ever required, to 64 feet. This made it necessary to erect the present superstructure nearer to the down-stream end of the piers. It detracts much from the appearance of the bridge, which is unsymmetrical at present.

"It was important not to stop travel during the rebuilding of the bridge. Passengers and freights from and to the Pittsburgh and Lake Erie Railroad must pass over it. Besides, there is a heavy traffic in coke, iron and other mill material, which would have been compelled to take a long, roundabout way. The construction of the superstructure had to be arranged to allow of the erection first of one track and then of the other.

"If the new bridge had really been built 15 feet instead of 20 feet higher than the old one there would not have been left height enough near the ends of the channel spans for teams to pass under on the old bridge. It was therefore intended to erect the channel spans about 5 feet higher than their proper grade, and to complete the floor and tracks of the same.

"The pier posts would have temporarily rested on sand jacks, by means of which both spans, weighing about 1600 tons when completed, could have been simultaneously lowered in a few hours to their proper grade. One track and sidewalk on the plate girder approaches on the down-stream side would have been meanwhile prepared for use. In this way travel would have been interrupted only for one day. But this operation became unnecessary when the new grade was raised 20 feet above the old bridge.

CHANNEL SPANS

"It was found that *the use of steel, in the trusses at least*, would prove economical as compared with wrought iron. The saving based on the prices at that time was over \$21,600.

"The Pauli trusses were designed with an uneven number of panels, namely 13, in order to get two tangential points of attachment for each truss to the floor-construction, thereby securing greater

longitudinal and transverse rigidity of the entire bridge frame. Roller bearings for pier posts were avoided; the middle posts, supporting two truss ends each, have a fixed and square bearing on heavy pedestal castings on the pier. Each end post has a bearing on a 6 inch steel pin in a cast-iron pedestal on which it can rock. It is probable that very little movement takes place on account of friction on the pin, and that the posts would bend or spring. The resulting bending moments on the end posts have been considered in proportioning them.

"The projected length, 27 feet $7\frac{5}{8}$ inches, of all panels being alike, it follows that the lengths of chords in a curved line are unlike, and if the curve were a circle or a parabola, then the angles formed by the straight chord sections would also all be unlike.

"For practical reasons it is desirable to have these angles all alike, so as to have only one template for the beveled joints. This condition would prescribe the character of the curve, in this instance a sine-curve. The difference in curvature between a sine-curve and arc of a circle was found to be small ($2\frac{1}{2}$ inches). The difference in the bevel points was inappreciable ($\frac{3}{64}$ inch). Therefore a true arc line was then assumed for the chords to facilitate other calculations.

"The vertical web-members are in tension from the dead load or from a uniformly distributed live load. They will sustain compression strains only from an uneven distributed load. Near the centre of truss they are long and slender, requiring intermediate bracing, which was placed at half the truss height for the entire length of trusses.

"The suspenders from trusses to floor, which were all stiffened to prevent vibration, were not made adjustable; their exact lengths were calculated to give the required camber of 18 inches to the floor construction. The truss camber was obtained by shortening the lower and lengthening the upper chord members $\frac{3}{16}$ inch, so that after erection it amounted to 2 inches.

"All diagonal bars were made adjustable and single; they are strained from partial loads only. The trusses were adjusted to their proper shape by means of these ties, which received a slight initial strain.

"The top and bottom *chords, pier-posts, diagonal-ties, and pins* are of steel; *all other parts are of wrought-iron with steel rivets.* The calculated sections of the vertical web-members for steel were so light that for practical reasons they were all made of *wrought-iron* and of the same section.

QUALITY OF STEEL USED

"Every heat of steel was tested and its quality determined before any more work was done to it.

"For the compression members and pins, the steel was required to stand the following tests on specimen bars $\frac{3}{8}$ inch diameter :

Elastic limit : 50 to 55,000 pounds per square inch.

Ultimate strength : 80 to 90,000 pounds per square inch.

Elongation in 8 inches : Minimum 12 per cent.

Reduction of area at fracture : Minimum 20 per cent.

Cold bending : 180 degrees around its own diameter without crack.

Cold punching of holes in flat $3 \times \frac{1}{4}$ inch bars ; $\frac{3}{16}$ inch from the edge without crack or distention of metal.

"All specimens and shapes were required to be finished at nearly the same heat, as it was observed that rods finished at a lower heat would give higher tension results than samples of same steel finished at a higher heat.

"The Andrew Kloman firm in Pittsburgh had contracted to procure the steel and to furnish the steel shapes.

"The intention was to use Bessemer steel for the compression members ; a large lot of Bessemer steel was tested, but few samples were found to stand the required tests. The difficulty seemed to consist in controlling the uniformity of the steel within close limits for quality and strength. After a while the attempt was given up and *open hearth steel* was substituted. No trouble was then experienced in getting a uniform grade of steel of prescribed quality.

"The top chord sections consist of four leaves, which were originally designed to be each a 20 inch steel plate with 4x4 inch angles for flanges. In ordering the steel it was discovered that enough plates of that width could not be procured in the required time. Therefore, the chord sections were changed to 10 inches and 12 inches steel plates, with 4x4 inch angles, composed as shown in the drawings [not reproduced here].

"Notwithstanding the great care used, the finished plates and angles were by no means a uniform product. According as they in rolling were finished at a higher or lower heat, they would have different degrees of hardness. Steel plates and angles finished at a lower heat had a smooth surface, and the noise of punching them resembled pistol-shots, while plates finished at a higher heat had a rougher surface, and there was hardly more resistance to punching than in wrought-iron.

"The specifications for riveted steel work provided that the punched rivet-holes, $\frac{3}{4}$ inch diameter, should in the assembled parts be enlarged to 1 inch diameter by reaming. The time for the delivery of the steel work growing short, the question was considered whether the reaming of the holes could be avoided, to hasten the completion of the work at the shops. Messrs. Kellogg and Maurice, in Athens, Pa., had the contract for this part of the work.

"To that end the following experiments were made:

"Ten specimens were cut from the same steel plate $\frac{1}{4}$ inch thick; one specimen was tested to ascertain the tensile strength of the steel in the specimen. The nine other specimens, all alike in form, were prepared as shown in sketch [not reproduced], for the purpose of ascertaining the effects of punching holes, of punching and reaming, and of drilling. The tests were expected to show the amount of reaming required, and whether any annealing effects from the hot rivet on the injured steel around the punched hole could be observed.

			<i>Strain per Square Inch Pounds</i>
1. Plain specimen $3 \times \frac{1}{4}$ "	Without holes	Broke with	89 730
2. 2 holes punched 1" dia.	No rivets in holes	Broke in punched	
3 holes punched $\frac{1}{4}$ " dia.		hole with	72 000
reamed to 1"			
3. Prepared as No. 2	No rivets in holes	Broke in punched	
		hole with	63 870
4. Prepared as Nos. 2 & 3	Rivets in all holes	Broke through punched	
5. 2 holes punched 1" dia.		hole with	85 000
3 holes punched $\frac{1}{4}$ " dia.	No rivets	Broke in punched	
reamed to 1"		hole with	71 000
6. Prepared as No. 5	No rivets	Broke in punched	
		hole with	55 200
7. Prepared as Nos. 5 and 6	Rivets in all holes	Broke in punched	
		hole with	83 320
8. All holes drilled 1" dia.	No rivets	Broke in hole with	79 330
9. 2 holes punched $\frac{1}{4}$ "			
reamed to 1"			
3 holes punched $\frac{1}{4}$ "	No rivets	Broke in hole with	64 400
10. Prepared as No. 9	Rivets in all holes	Broke in hole with	83 32 -

"The conclusion from these tests was that the injured steel (of the quality used in this instance) around the punched hole was in part restored by annealing in contact with the hot rivets, the size of which was large in proportion with thickness of steel plates and angles as used in the chords.

"The reaming of the punched holes to a greater extent than to

make the rivet holes smooth and straight was therefore dispensed with, and a reduction in the price for the finished work agreed upon.

"The same quality of steel as for the compression members was used for them; they were forged from solid steel billets, and turned to size. No appreciable difference in the hardness of the metal in the pins was observed.

"For *tension members* and rivets, the steel was required to stand the following tests on specimen bars $\frac{5}{8}$ inch diameter :

Elastic limit : 45 to 40,000 pounds per square inch. — Yield.

Ultimate strength : 70 to 80,000 pounds per square inch.

Elongation in 3 inches : Minimum 18 per cent.

Reduction of area at fracture : Minimum 30 per cent.

Cold bending : to a loop 360° around its own diameter, without crack.

Cold punching in $3 \times \frac{3}{4}$ inch bars of 1 inch rivet holes : $\frac{1}{4}$ inch from the edge without crack or distention of metal.

Open hearth steel of the above and uniform quality was obtained without trouble.

"The eye-bars were made by the Kroman process, i.e., the bars were rolled from billets between reversible and adjustable rolls, in such manner as to leave the ends thicker than the bar. The ends were then spread and forged to the proper shape of the eye, under a steam hammer. The heaviest steel bars for this bridge were 28 feet $6\frac{1}{2}$ inches long, centre to centre of eyes, and $1\text{-}13/16$ inches thick. All steel billets and all steel bars required very close inspection for flaws, the detection of which was sometimes difficult.

"It has been stated that for the detection of flaws in steel or iron, a magnetic needle had been used with success, though the manner of its use the writer has not heard stated. A device for the certain discovery of flaws in steel bars is certainly needed. Where the solid metal sections are proportioned very economically to the work they have to do, flaws are a source of great danger, especially in attenuated steel structures; flaws in wrought-iron are more likely to happen in the direction of the fibre, but in steel they can as well happen crosswise to the direction of the tension strain as any other way.

"Three steel bars 9 feet long between centres of eyes, and 4 inches \times $1\text{-}1/16$ inches in section were tested to ascertain the effect, if any, of annealing the finished bars. The results were as follows :

	Bar A		Bar B		Bar C	
	Annealed		Not annealed		Not annealed	
	Eye	Eye	Eye	Eye	Eye	Eye
Diameter of eye.....	9"	9"	9 $\frac{1}{4}$ "	9 $\frac{1}{4}$ "	10"	9"
Least cross-section of eye.....	5.72"	5.82"	5.83"	5.72"	6.80"	5.77"
Excess of metal in eye over bar.....	7.9%	3.6%	3%	3.2%	3%	3%
Elongation of pin-hole.....	0.4"	0.72"	0.45"	0.44"	0.38"	0.4"
Average section of bar.....	4.42"		4.22"		4.33"	
Average reduced area after test.....	3.90"		3.97"		3.80"	
Reduction in percents.....	10%		5%		10%	
Reduction at fracture.....	43.87%		37.5%		37.55%	
Elongation of whole bar.....	10.5%		10.3%		11.1%	
Elongation for 12 inches near fracture.....	24.6%		23.2%		22.1%	
Elastic limit per square inch.....	43,140 pounds		45,360 pounds		40,940 pounds	
Ultimate strength.....	74,310 "		78,186 "		73,760 "	

Pin-hole in one eye of bar C was bored $\frac{1}{4}$ inch out of centre line of bar, and accounts for its lower ultimate and elastic limit.

A specimen from the same heat of steel, of which the above bars were made, showed on a $\frac{3}{4}$ inch round—

Elastic limit	46,389 pounds per square inch
Ultimate limit	78,898 " " " "
Elongation in 8 inches	18.0%
Reduction	30.2%

"The net section of the heads through the pin-holes for all eye-bars being at least 50 percent more than the bars, and the good effects from annealing being doubtful in the above tests, it was thought not necessary to anneal the steel bars.

"For steel rivets the above quality of tension steel proved very suitable. The rivets were tough and tenacious.

"It was, however, observed that the manufactured rivet-heads would easily break off with few blows, the fracture in each instance showing a fine granulated appearance.

"Rivet-heads, however, made by hand or riveting machine were very tough, and could not be broken off; they had to be cut off.

"The cause for the brittle rivet-heads was supposed to be the upsetting by blows, in forming the head at a high heat in dies, producing sharp corners under the rivet-head and around the rivet-stem.

PLATE GIRDER SPANS

"There are six plate girders in each span beneath the flooring, namely, one girder under each rail and one girder under each sidewalk, which is detachable on the up-stream side.

"This arrangement was chosen to admit of the erection first of the new down-stream street track, which came to lie sideways of, but

on a higher grade than, the down-stream track of the old bridge. To this track travel was confined during erection. Plate girders were chosen for this reason that for the limited depth of floor (for a grade 15 feet higher than old bridge, as at first contemplated), it gave a more rigid construction than open girders of low depth. It was also more convenient to work into them, and *get rid of a lot of wrought-iron which was on hand*, and was left over from orders for the suspension bridge originally intended to be built.

"Could the writer have foreseen that the new grade would be 20 feet higher than the old bridge, the deck spans of the approaches would have been made of two open girders of greater depth, in a manner that would have admitted of finishing both tracks on them at the same time. This would have been also more economical. As it was, the plate-girders were nearly finished when the change in grade was made.

"For all wrought-iron work in the bridge the quality of iron was required to be equal to that of standard bridge iron.

"Steel rivets were used for all wrought-iron bridge-members and girders.

REMOVAL OF OLD AND ERECTION OF NEW BRIDGE

"The new north abutment wall was located 40 feet back of the old one. In preparing the foundation for the same it was necessary to remove the anchorage of the old cables, and to construct temporarily two anchor chains attached to the second pair of old towers. Previous to this wrought-iron anchors had been imbedded into the foundation of new pier No. 1, which had been built up to obtain the requisite weight for the temporary anchorage.

"These anchor chains were composed of steel eye-bars, which were on hand from the intended suspension bridge. Each chain was made adjustable in length by means of a transverse screw rod, and four sets of eye-bars, forming a funicular machine. The chain could thereby be shortened with comparatively little power. To the cable the chain bars were attached by means of two wrought-iron plates. Between these plates were cast-iron friction clutches holding the cable, and pressed and held together with bolts passing through the plates. These were attached to the cable as near to the towers as possible. To prevent slipping of the clutches on the cable, the wire wrapping was removed, and spikes driven through the cable wires behind the clutches.

"The transfer of the anchorage was done without mishap while

travel as usual was going over the old bridge on both tracks. The pull per anchor chain was at times 160 tons.

"Under the first north span of the old bridge, false works had been built, which, after the transfer of the anchorage, supported the old roadway, and at the same time served for the erection of the iron girders for the new bridge. No other part of the old bridge was removed till after the erection of the new channel spans.

"In the false works for the latter an opening 100 feet wide near the Pittsburgh end was left for navigation, and temporarily bridged over with wooden Howe trusses. The false works were further so arranged as to clear one track on the old bridge, on which the team-travel moved in squads in alternate directions.

"To prevent accidents from anything falling from above on pedestrians or teams below, the false works were covered with a platform of planks, which were afterwards used for the new floor. The upper staging was built up on the outside of, and to half the height of, the trusses to be erected; at that height a traveling derrick, 30 feet high, moved on a track of iron rails. All material for the channel spans was lifted (by a hoisting engine near the south Pittsburgh end) to the platform, on which a temporary track was laid, and all material transferred on push-cars.

"With another hoisting engine, conveniently located on the upstream end of pier No. 3, the material for both spans could be handled and put in place without moving the engines.

"The Pittsburgh span was erected first. After the pier posts were put into position, the bottom chords and connecting web-members were put in place. The top chord sections, weighing from 7 to 9 tons, were picked up and placed on the verticals, one after the other, from each end in each truss. For closing the top chord, the two middle chord-sections were raised at one end till they met, and then sprung into line by pulling down these ends towards the bottom chord with block and tackle acting as a funicular machine.

"The false works of the Pittsburgh spans had settled more than was anticipated. Before it was possible to close the top chords the different panel points had to be jacked up 2 to 6 inches. No such trouble was experienced with the other span.

"During the erection of the channel spans no little anxiety existed at the possibility of an accident from some heavy weight dropping to the platform and breaking through to the constantly crowded old bridge below. Fortunately, the work was completed without such

accident, but there were two casualties, which both resulted luckily. One man fell from a height of 80 feet into the river, but was picked up and next morning was at work. Another man fell from a height of 50 feet into shallow water; he was able to report for work after two days.

"The *iron* floor construction was suspended to the trusses after these were swung.

"The detail of connections in the Pauli trusses being simple, the erection of the steel and *iron* work went off smoothly, and with no more expense than in parallel chord trusses. It commenced in the middle of September, 1882, and was completed December 31st, 1882.

"To the new *iron* floor construction the old bridge floor was temporarily suspended with *iron* plate-girders at the south end of the bridge. These down-stream towers were removed first, together with the cable they supported. The old bridge floor where it was not suspended from the new bridge was held up on wooden trestles.

"Three plate-girders in each span, supporting the down-stream track and sidewalk, equal to half the width of the new bridge, were put into position, and the paving for one car-track finished for the entire length of the bridge, without interrupting travel on the old bridge below.

"Temporary wooden trestle approaches, with plank floors for one track, were built at both abutments, because the filling in would have interfered with travel on the old bridge. All this work was much retarded by a stormy and severe winter. Travel was turned over the new bridge on the down-stream track on March 19th, 1883.³⁰

"During a high water, February 22nd, 1883, a heavy mass of ice came down the river on a swift current, and tore away a part of the false works supporting the old bridge in a place where it was not suspended from the new one. The old bridge was then in danger of falling into the river; but by promptly suspending the old floor to the new one, first with ropes and chains, and then with iron rods, the old bridge, after one and a half day's interruption, was again safe. This was the only interruption of travel throughout the whole work.

"After travel was turned on the new bridge, the gaps and open-

³⁰ The opening of the bridge was noticed in the following: *The Scientific American* 49 (Sept. 22, 1883): 175-80. There is a large full-page wood engraving of the north portal, with an insert showing a general view of the bridge; "Monongahela-Brücke, zu Pittsburgh in der Verlängerung von Smithfield Street," *Zeitschrift für Baukunde* 11 (1884): 258-60; "The Rebuilding of the Monongahela Bridge at Pittsburgh, Pa.," *Engineering News* 11 (May 24, 1884): 251-53, 265-66.

ings in the abutments and piers were walled in, as stated before. The remaining old towers, cables and bridge floor were removed, and the up-stream half of the plate-girder approaches completed.

"This was done by placing in position the remaining three plate-girders in each span, and the iron columns (supporting the girders near the abutments). At the same time the erection of the hand-railing and of the ornamental cast-iron tower progressed. The adjustment nuts of the diagonal ties in the channel spans were covered with ornamental castings, which prevent tampering with the sleeve-nuts.

"The filling in and regrading of the approaches at both ends, and the building of the toll-houses and bridge office, were completed simultaneously with the superstructure.

THE FLOORING OF ROADWAY AND SIDEWALK

"This consists of preserved wood, namely, gum-wood and white pine, preserved by the zinc-tannin process. On both the roadway and sidewalks the bottom planking distributes the weight on the *iron* and girders, so that the top sheeting or paving forms merely the wearing surface.

"To the top of *iron* floor girders are bolted wooden bolsters, to which is spiked the bottom cross-planking, 3 inches thick for the roadway, and 2 inches thick for the sidewalks.

"No provision is made to carry off the water sideways. The grade of the bridge is sufficient to carry off all surface water lengthwise. Besides, the durability of the preserved gum-wood is increased by keeping the floor moist (by sprinkling during the dry season).

"The space between the track rails and in the middle of bridge is paved with preserved gum-wood blocks, 3 inches thick and 3 inches high, laid with $\frac{1}{4}$ inch strips between.

"Every paving block is fastened down to the bottom planking with diagonal spikes. The paving blocks for the tracks rest on a 1 inch longitudinal sheeting of preserved white pine, which serves to distribute lengthwise any uneven pressure to the cross-planking beneath. The joints between paving blocks were filled with a hot mixture of tar, pitch, rosin, lard, lime and sand in such proportions as to run freely from the ladle.

"The space between the tracks and sidewalks is covered with a lengthwise top planking 3 inches thick.

"The sidewalks are 9 inches higher than the roadway. The wearing surface consists of white pine, 1 inch thick, on the bottom planking of gum-wood, 2 inches thick. In the curb are openings 30 inches long,

and on the average 3 feet apart for cleaning the roadway of mud and snow. Under the sidewalk, on the down-stream side, extends a box with a movable cover, the entire length of the bridge. This contains the water and gas pipes and telegraph cables. Every 150 feet are covered openings for hose attachment, provided for sprinkling the floor and for use during a fire.

"A small fire occurred in April, 1883. It originated on the old bridge, and scorched the floor of the new bridge near the southern end. It showed the necessity of guarding against fire on the new bridge. All wooden flooring is to be protected by a paint of quicklime and glue water, and all crevices and joints in the wooden floor to be filled with it.

"For the preservation of the lumber by the zinc-tannin process, the specifications stipulated that steaming in the curing cylinder should continue at 18 pounds pressure for four and a half hours; the vacuum should not be more than two pounds per square inch. Gum-wood should absorb 25 percent, and white pine $12\frac{1}{2}$ percent of the antiseptic solution under a pressure of 30 pounds per square inch. The solution is to be 5 parts (in bulk) of chloride of zinc to 95 parts of water. The lumber was to be left in it till each cubic foot of gum-wood had absorbed one and a half gallons, and each cubic foot of white pine 1.05 gallons of the antiseptic. After this a solution of tannin was forced into the cylinder, and the lumber kept immersed in it for 3 hours, under 80 pounds pressure.

"Borings from the end of a stick which were analyzed, contained 0.370 percent metallic-zinc in weight, equivalent to 0.789 percent of zinc chloride. This was rather a high showing, as 0.5 percent of zinc chloride was all that was expected.

"Borings taken from the middle of a stick 26 feet long, 12 inches by 6 inches, were found, on analysis, to contain 0.125 percent of zinc chloride, or only one-quarter of the amount intended to be injected; it is doubtful whether in long sticks the desired percentage can be attained, without very materially increasing the strength of the solution, which again would probably increase the percentage at the ends to such an extent as to render the lumber brittle after a while.

"The borings were from freshly treated lumber. It is probable that the percentage is gradually increased to a limited extent in the heart of a long stick, owing to interchange of the solution by capillary attraction along the grain of the wood. The real antiseptic substance is the zinc chloride, while the tannin serves only to increase the adhesion of the precipitate to the wood fibres.

"Care was required in the inspection of the lumber before treatment. Sap, loose knots, cracks, windshakes, are of course as much a defect in treated as in untreated lumber. Any unsound, weak or soft wood will not be improved by the treatment, which aims merely to make the lumber more durable, by preventing rotting. It may be added that lumber, treated by the zinc-tannin process, will not lose anything in its value as a combustible, as the experience with the fire at Monongahela Bridge proved.

"The track rails on the bridge are 12 inches wide, and composed of flat bars $7 \times \frac{3}{4}$ inches, 2 feet long under the joints, and $\frac{3}{4}$ inch round spikes, with conical heads, countersunk to the full thickness of the rail ($\frac{3}{4}$ inch), so that the spikes may hold down the rail, no matter how thin it may have worn.

THE ORNAMENTAL TOWERS

are built of cast-iron, the roofs being of wrought-iron; they support merely their own weight; they incase the steel posts, which, to the eye, would seem very slender supports, and would appear out of proportion in comparison with the heavy piers and high trusses. The end posts can rock inside of the towers, which are not in any way connected with them. Where the trusses pass through the towers, room is left for expansion from temperature changes.

"The architecture of the towers is so planned, and the composing parts so arranged, that the portals may be widened out to suit the entrance to a wider bridge, should it be required.

PAINTING

"Besides painting the metal with raw linseed oil at the mills, and iron oxide paint at the bridge shops, two coats of white lead paint were applied to the erected steel and iron work. The white lead paint was used without any dryer, and mixed with boiled linseed oil only. All joints and crevices where water might collect, were puttied all around and raw linseed oil poured in, as much as they would hold.

"As the erection took place mostly in inclement weather, the shop paint came off in many places by dragging the pieces through slush and mud, which, especially in Pittsburgh, rusts iron rapidly.

"Rusty places were coated with a thin lime paste, which, after drying, was scrubbed off with wire brushes and freshly painted.

"All iron work under the flooring has been painted brown, all iron and steel work above the flooring is blue. The towers have a stone color.

LOADS AND UNIT STRAINS

Beginning from the north end, there are:

1. One 40 foot span, six equal plate-girders, proportioned for a live load of 10,800 pounds per lineal foot of bridge.
2. One 81 foot span, six equal plate-girders, proportioned for a live load of 9,000 pounds per lineal foot of bridge.
3. One 87 foot span, six equal plate-girders, proportioned for a live load of 9,000 pounds per lineal foot of bridge.
- 4 & 5. Two channel spans, 360 feet each, two equal Pauli trusses of steel and floor construction of iron, proportioned for a live load of 4,500 pounds per lineal foot of bridge and in addition a concentrated load of 40 tons on a 20 foot wheel base for each track; of these loads the sidewalks were assumed to carry 100 pounds per square foot.
6. One span, 88 feet 3 inches, six equal plate-girders.
7. One span, 84 feet 9 inches, six equal plate-girders.
- 8 & 9. Two spans, 60 feet each, six equal plate-girders in each.

All of these plate-girder spans proportioned for 9,000 pounds live load per lineal foot of bridge.

The wind truss and lateral bracing under the floor is proportioned for a wind force of 400 pounds per lineal foot of bridge.

The above live loads, in addition to the load of the superstructure in the different spans, produce no greater strains per square inch of useful metal areas than:

IRON

8,000 pounds in compression flanges of all plate-girders, floor beams, stringers, etc.

9,000 pounds in tension flanges of all plate-girders, floor beams, stringers, etc.

8,000 pounds tension in suspenders and hangers of channel spans.

4,000 pounds shear in iron web-plates.

12,500 pounds bearing strain on iron in rivet and pin-holes.

FOR STEEL

9,800 pounds to 13,200 pounds in compression members.

15,000 pounds in steel eye-bars.

10,000 pounds shear on steel rivets and steel pins.

20,000 fibre strain on steel rivets and pins from bending-moment.

18,000 pounds bearing strain on steel in rivet and pin-holes.

The following quantities of material were consumed in the construction of the Monongahela Bridge:

	Lumber, feet B.M.	594,000
Foundations	Piles, lineal feet	10,800
	Concrete, cubic yards	1,280
	Iron, tons	32
Stone masonry, cubic yards	10,500
	Iron, tons	1,070
	Steel, tons	740
	Cast-iron of towers, pedestals, etc., tons	196
	Preserved lumber for floor, feet B.M.	358,000
	Steel rails, tons	134
	Hand-railing, 2,980 lineal feet, pounds	120,200
	Filling, cubic yards	10,000
Approaches	Sidewalk pavements, square yards	1,400
	Street pavements, " "	2,200

The total cost of construction amounts to about \$460,000."

In 1890-1891 the bridge was widened by utilizing the provisions built into the original bridge.³¹ Lindenthal was both designer and contractor for this change. A third truss was added to each span on the upstream side of the bridge, which increased the width of the structure by twenty feet, eight inches and provided a second roadway. When this was done the street railway tracks ran on each side of the center line, but twenty-one years later the upstream trusses were moved four-and-a-half feet to the eastward, and the additional width made it possible to put both the electric car tracks on that half of the bridge and devote the opposite roadway to other vehicular traffic. Sidewalks eleven feet wide projected beyond the truss work. The floor system beneath the car tracks was also modified in 1911, but the other half remained essentially the same as in 1883.

Between 1911 and 1925 the elaborate wrought-iron bridge portals were removed and much simpler gateways of cast steel, designed by Stanley Roush, substituted. Here we can see the old idea of the monumental bridge portal in the process of disappearing, but even these later portals were highly ornamental.³²

In 1895 the city of Pittsburgh determined to secure title to the bridge and open it to the public, an action which was in accordance with the trend of the times. After the appointment of viewers and the taking of testimony on both sides, the commissioner's report

³¹ *Engineering News* 39 (Apr. 11, 1912) : 676-80.

³² "Decorating a City Bridge With Structural Steel Portals," *Engineering News* 42 (Dec. 3, 1915) : 1086.

was filed in court, and no exception being taken, the city assumed complete ownership of the corporation through purchase of the outstanding stock.³³ The purchase price of the bridge was \$1,000,000.³⁴

After 1911-1915 there were few changes in the bridge, but by the early 1930s it began to be in need of repair. In order to lighten the load on the structure, it was proposed to install an aluminum deck on the vehicular roadway, and this was carried out in 1934. According to *The Engineer* of London: "This is, as far as we have been able to ascertain, the largest bridge undertaking in aluminum that has yet been carried out. It has afforded engineers an opportunity to gain experience in the use of aluminum on a large scale. Regarded as an experiment in bridge building we suggest that its importance cannot be overrated."³⁵

In the early 1960s the bridge once again was exhibiting signs of wear and stress. The *Pittsburgh Post-Gazette* of April 10, 1964, announced that "approximately \$700,000 will be spent next year to rehabilitate the Smithfield Street Bridge . . . weight limits have been placed on the bridge."

The *Pittsburgh Press* for May 7, 1967, stated that the bridge would close in June to permit the installation of a new deck: "the contract for the repairs had been awarded to the Mosites Construction Company in July, 1966, and since that time substructure work has been completed as well as the fabrication of new aluminum deck panels. A polyester non-skid coating is to be applied to the panels." The *Post-Gazette* of November 16, 1967, announced that the bridge "closed since last June will reopen today at three o'clock. The total cost of repairing the structure was \$712,615."

In 1970 the Pittsburgh History and Landmarks Foundation placed one of its historic landmark plaques on the structure, and on May 28, 1974, the bridge was named an official city landmark by the City Planning Commission under the city's landmarks ordinance.³⁶

Perhaps the most famous double lenticular truss span in the world is the Saltash Railway Bridge spanning the River Tamar in Cornwall, England, which was designed by the great engineer Isam-

33 Du Puy, "Monongahela Bridge," 204.

34 *Pittsburgh Bulletin*, 32: 24 (Apr. 18, 1896).

35 "Aluminum Floor for an Old Bridge," *The Engineer* (London) 157 (July 27, 1934): 91.

36 *Pittsburgh Press*, May 29, 1974.

bard Kingdom Brunel and built in 1857-1859 just before his death.³⁷ Perhaps the Smithfield Street Bridge deserves no lesser fame. Impressive as is the Brunel bridge, the former is the more graceful and beautiful.

According to David Plowden: "The Smithfield Street Bridge was the first and largest bridge in the New World to employ the Pauli system of lenticular trusses, it remains the only example of this type in America."³⁸

The Monongahela Bridge at Smithfield Street is now within a few years of attaining its centenary, that magical state which should ensure its veneration by all who care about our technological monuments. Rumors of demolition still trouble the local air, but our great bridge, now the oldest on our three rivers at Pittsburgh, as well as the oldest steel through-truss span in America—if it cannot continue to bear increasing burdens—should be, like the great bridges at Wheeling and Cincinnati, eased into an honorable quasi retirement. Lindenthal's splendid spans have served long and well; they are now an almost indissoluble part of the cityscape. It is profoundly to be hoped that this tough, but graceful structure will, as it begins its second century, enter upon a new period of usefulness.

37 Eric de Mare, *The Bridges of Britain* (London, 1954), 180-81; see also David Plowden, *Bridges* (New York, 1974), 66.

38 Plowden, *Bridges*, 167.