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The Designing of the Eads Bridge

JOHN A. KOUWENHOVEN

When the Eads Bridge across the Mississippi River at St. Louis was completed in 1874 it was the largest and most important metal-arch structure ever built, and it still ranks as one of the world's great bridges.¹ Even before its completion it was internationally recognized as "the most highly developed type of bridge-building of the present day," in the design of which "the alliance between the theorist and the practical man is complete."² The history of its construction, written by Calvin M. Woodward, dean of the Polytechnic School of Washington University, is one of the classics of engineering literature.³

On opening day, July 4, 1874, the bridge was christened the Illinois and St. Louis Bridge; then, after the bankruptcy of the company that had completed it, it was for a time known formally as the St. Louis Bridge—the name Woodward used. But even while it was still under

JOHN A. KOUWENHOVEN has served as an advisory editor for *Technology and Culture* since the journal was founded. He dedicates this article in honor of Melvin Kranzberg.

¹When the eminent bridge engineer David B. Steinman collaborated with Sara Ruth Watson on *Bridges and Their Builders* (New York, 1941), a historical narrative of bridge building from prehistoric times to the present, they devoted whole chapters only to the Eads Bridge, the Brooklyn Bridge, and the Firth of Forth Bridge. In Joseph Gies's *Bridges and Men* (Garden City, N. Y., 1963) only Eads and his bridge and the Roeblings and the Brooklyn Bridge get two chapters each.

²Editorial in *Engineering* (London) (October 10, 1873).

³C. M. Woodward, *A History of the St. Louis Bridge: Containing a Full Account of Every Step in Its Construction and Erection, and Including the Theory of the Ribbed Arch and the Tests of Materials* (St. Louis, 1881). All who have since written about Eads and his bridge, including Steinman, Watson, Gies, and a number of others, have depended almost entirely on Woodward for facts and conclusions relating to the technology, except Howard S. Miller, whose recent "Historical Appraisal" (in *The Eads Bridge*, Quinta Scott and Howard S. Miller [Columbia, Mo., and London, 1979]) provides fresh insights based on some fresh material. The manuscript records of the companies involved in building Eads Bridge were "lost" after Woodward used them. I found them in the 1950s (after fruitless searching elsewhere for several years) in a vault at the Terminal Railroad Association's headquarters in St. Louis and was allowed to make transcriptions and photostats (documents hereafter cited as TRRA files). Many of the records have since been turned over to the Missouri Historical Society for safekeeping and the original engineering drawings are now in the Washington University archives.

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construction it was frequently called, as it is now officially named, the Eads Bridge, in recognition of the unique role of its chief engineer, James Buchanan Eads (1820–87). As his colleague W. Milnor Roberts said in the spring of 1869, Eads was “different in position from Chief Engineers in general, not merely from being the *projector* as well as the designer of the work, but because he [was] one of the largest owners, and one who [had] induced the subscriptions.” After ten months’ service as Eads’s associate engineer, in full charge of operations while Eads was on sick leave, Roberts was well aware that, as he told Eads, “the Bridge, in its inception, in its plan, and in its noble battle against very fierce and extreme opposition, is eminently yours.”⁴

Eads’s position as chief engineer was different also in that he had no prior experience in bridge engineering, having spent his life hitherto chiefly in association with people who thought of bridges over navigable rivers as obstructions to commerce, not as desirable objects to build.⁵ It is of interest, therefore, to try to determine in what sense he really was the “designer” of his bridge and how he became qualified to be its chief engineer.

So far as I have been able to discover, Eads first became interested in the problems of bridging the Mississippi in the spring of 1866, and his interest at that time was solely in making sure that if a bridge were built it would not be a serious obstacle to river traffic. He was then forty-six years old, and most of his adult life had been spent in enterprises concerned with river transportation. In 1839, as a young man of nineteen who had already demonstrated considerable mechanical and commercial aptitude, he had become what was known as a “mud clerk” (second clerk, under the clerk, or purser) on the fine steamboat *Knickerbocker*, whose Captain was E. W. Gould.⁶ The *Knickerbocker* was in the Cincinnati-St. Louis-Galena trade. Less than a year after Eads

⁴Roberts to Eads, May 5, 1869, J. B. Eads Collection, Missouri Historical Society, St. Louis, Missouri. Roberts (1810–81) was one of the greatest and most admirable civil engineers of the 19th century and should be made the subject of a full biography. He was appointed Eads’s associate engineer on July 9, 1868, and served until the end of April 1870. He made no contribution to the design, so far as I know.

⁵There is no adequate biography of Eads. Aside from a few biographical articles (those published in his lifetime are the most useful) and some obituaries, the only publications of consequence are a brief book by his grandson Louis How (*James B. Eads*, Riverside Biographical Series, no. 2 [Cambridge, Mass., 1900]) and Florence Dorsey’s *Road to the Sea: The Story of James B. Eads and the Mississippi River* (New York, 1947), which is rather offhandedly documented and much given to romanticized imaginings. The most important of Eads’s own writings are included in *Addresses and Papers of James B. Eads* (St. Louis, Mo., 1884), which were edited by his son-in-law Estill McHenry.

⁶Fifty years later Gould published his garrulous but invaluable chronicle *Fifty Years on the Mississippi; or Gould’s History of River Navigation* (1889; reprint ed., Columbus, Ohio, 1951). For Eads’s service on the *Knickerbocker* see pp. 483–85, 592–94.

joined her crew, the *Knickerbocker* was sunk by a snag near Cairo while laden with a large cargo of lead from the mines at Galena. The loss of this valuable cargo impressed Eads with the necessity for devising machinery that would facilitate salvage operations, and by 1841 he had designed the first of the diving-bell boats, or “submarines” as he called them, with which he built up the salvage and wrecking business that made him a wealthy man.⁷

Basically these submarines were adaptations of the double-hulled snag boats which Henry Miller Shreve had perfected in the 1820s and 1830s.⁸ But Eads personally planned them, supervised construction, and designed much of the machinery with which they were equipped. Correspondence between Eads and his wife in the late 1840s and early 1850s is full of references to his work on the new submarines he was building,⁹ and from these letters it is clear that Eads did more than suggest general ideas to be carried out by skilled professionals. In November 1850, for example, when Eads was in St. Louis designing a powerful centrifugal pump for use on *Submarine No. 4*, his wife, then at his parents’ home near Le Claire, Iowa, wrote that she hoped he would not have to stay in town to superintend its construction and thus miss another Christmas with the family. Surely, she thought, his “minute drawings and directions” would be sufficient for the workmen who would make the pump.¹⁰

As Captain Gould said in his 1889 history of navigation on the Mississippi,¹¹ the crude and unwieldy diving-bell boats at first used in the salvaging business presented an open field for Eads’s mechanical genius, “which soon resulted in improved boats, and machinery.”

⁷James D. McCabe, Jr., “James B. Eads,” in *Great Fortunes, and How They Were Made* (Philadelphia, New York, and Boston, 1871), pp. 211–12; How, pp. 9–20.

⁸Louis C. Hunter, *Steamboats on the Western Rivers* (Cambridge, Mass., 1949), pp. 193–94.

⁹Through the courtesy of James Eads Switzer, a grandson of Eads, I was permitted to make transcripts of the 213 letters in the correspondence between Eads and his first wife, Martha Dillon Eads, 1844–52.

¹⁰Martha Eads to Eads, November 22, 1850. The pump, like those Eads later used in constructing the foundation of the west abutment pier of his bridge (see James B. Eads, *Report of the Chief Engineer, October 1870* [St. Louis, 1870], p. 4) was a steam-powered centrifugal pump of the kind recently invented by James Stuart Gwynne and patented by him in 1851. Eads had acquired the sole right to use pumps of Gwynne’s type “on the Mississippi and its tributaries,” and his use of them on *Submarine No. 4* “inaugurated a new era in the business of wrecking on Western rivers” (Taylor and Crooks, *Sketch Book of St. Louis* [St. Louis, 1858], pp. 115–16). An illustrated paper about Gwynne’s centrifugal pumps was published in the *Transactions of the American Institute . . . for the Year 1852* (Albany, N.Y., 1853), pp. 104–7. Gwynne exhibited them at the first world’s fair, London, 1851 (see *Official Descriptive and Illustrated Catalogue of the Great Exhibition . . .* [London, 1851], 3:1441).

¹¹See n. 3 above.

Within a few years Eads and his partner, William S. Nelson, had “an immense collection of working stock, of every improved construction, and every piece of it bore evidence of Capt. Eads’ genius and master mind.” The whole culminated in the construction of *Submarine No. 7*, which, Gould says, “for ingenuity of device, and concentration of mechanical power” excelled all predecessors and anything that had been constructed since.¹² Equipped with derricks, diving bells, and two Gwynne centrifugal pumps, she was capable of raising the largest steamboats.¹³ A comparison of the accompanying 1858 lithograph of the *No. 7* (fig. 1) with the 1870 lithograph of the “Construction Works and Machinery” for sinking the caisson and laying the masonry of the east pier of Eads Bridge (fig. 2) suggests that Eads drew heavily on his earlier experience as a designer when he undertook the bridge job.

There had, of course, been new problems to face, among them the design of the travellers (the system of movable pulleys) by means of which the stones for the pier’s masonry were lifted off barges tied alongside the construction boats and carried to the spot above the caisson where they were lowered for the masons to place in position. Eads had first experimented with the design of such travellers when his men were laying the foundations of his first pier, the west abutment, on the St. Louis levee early in 1868. As he said in his 1868 report, “the large framework and machinery” for laying stone, “designed to expedite the construction of the channel piers,” was erected over the west abutment in order “to have the machinery fairly tested and its manipulation fully understood before using it on the piers, where so much depends on the celerity of operations.”¹⁴

By the time he wrote those words (in May 1868) the machinery, driven by one engine, was capable of placing 500 tons of stone in position in a ten-hour day, and its performance gave “entire satisfaction.” But there had been difficulties. In the diary of Benjamin Singleton, the engineer in charge of work on the levee, there is the following entry under date of February 28, 1868: “Have trouble with hoisting apparatus. Eads designed a traveller to be used in laying stone and made a mistake in putting a friction clutch on the hoist instead of on the traveller rope, and the friction clutch slips just where

¹²Gould, p. 486.

¹³Taylor and Crooks, pp. 116–17. In 1861–62 Eads converted this vessel into the ironclad gunboat *Benton*, which Admiral Mahan called “the most powerful fighting-machine” in Flag-Officer Foote’s river squadron, of which she became the flagship. See A. T. Mahan, *The Gulf and Inland Waters* (New York, 1883), pp. 11–12; and *Official Records of the Union and Confederate Navies*, ser. 1, vol. 22 (Washington, 1908), pp. 773–77.

¹⁴Eads, *Addresses and Papers*, p. 510.

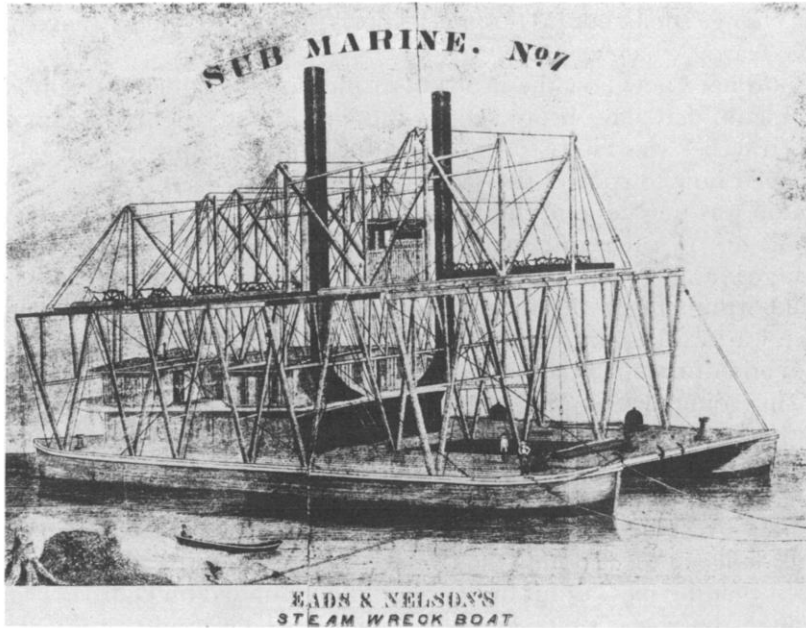


FIG. 1.—Steam-powered “Submarine” designed by Eads in 1856 to facilitate salvage operations (lithograph from Taylor and Crooks, *Sketch Book of St. Louis* [St. Louis, 1858]).

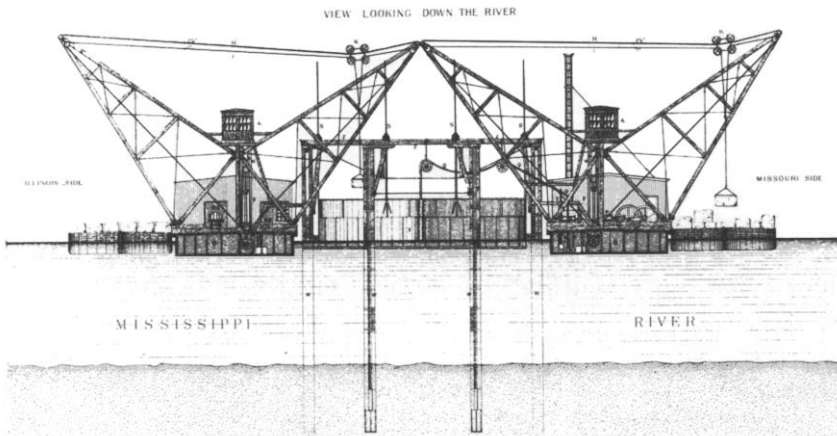


FIG. 2.—Eads’s apparatus for sinking the caisson and laying masonry for the east pier (from C. M. Woodward, *A History of the St. Louis Bridge* [St. Louis, 1881]).

it is needed most to hold stone in proper place. I have urged him to let me change them, but his obstinacy knows no bounds. He will have his own way at whatever cost."¹⁵

I do not know how the problem of the slipping clutch was solved. Singleton may have been right in thinking Eads's original design of the traveller was faulty, or he and his men may simply not yet have learned how to control the mechanism properly. In any event, Singleton was not alone in thinking Eads was obstinate in his insistence upon his own designs; many who thought they knew more about bridge building than he did learned, as did Singleton, that he could be stubborn about having his own way. And usually, if not always, his own way was based upon firsthand knowledge of the conditions to be met and of the materials and methods required to meet them. If this meant going against precedent or against the opinion of recognized authorities, he stubbornly persisted.

But to return to Eads's career on the river before he became interested in bridge building: it was during his years of active participation in the wrecking business that he acquired the intimate firsthand knowledge of the action of the river's currents that caused him later to insist that the piers of his bridge should be founded on bedrock even though the nation's most eminent engineers had decided it was unnecessary. When, in the summer of 1867, Eads's bridge company was still being challenged by a rival group that claimed the exclusive right to build a bridge at St. Louis, the head of the rival group—a Chicago bridge contractor named Lucius B. Boomer—convened a board of civil engineers to consider Eads's plans. This Committee on Foundations and Piers included E. S. Chesbrough, constructor of the lake tunnel of the Chicago waterworks; William J. McAlpine and his brother Charles L. McAlpine, who had been associated in building a bridge over the Harlem River in New York, where they did pioneering work in employing the pneumatic process in sinking foundations; and William Sooy Smith, who had sunk the pneumatic foundations for the bridge across the Missouri at Omaha. The committee concluded that, since bedrock was so far below the river's bed, it was

¹⁵This diary, the original manuscript of which I have been unable to trace, is known to me only in the form of a mutilated clipping I found by chance, and transcribed, in the morgue of the *St. Louis Post-Dispatch* in October, 1956. (I was given access by courtesy of Donald Grant, then one of the paper's distinguished correspondents.) The clipping was undated and its source was not indicated. The heading, partly flaked away, was: DIARY [approximately thirteen letter spaces missing] GE, which I assume to have been DIARY OF THE BRIDGE. From its contents it is clear that the diary was that of Benjamin Singleton, whose supervision of the early work on the west abutment pier is mentioned in Eads's 1868 report, reprinted (without the important appendices) in Eads, *Addresses and Papers*, p. 510, and in Woodward, pp. 17 and 33.

altogether safe to build foundations which were "entirely independent of any support to be gained from it." Piers carried down through the sand to a point below the limit of the current's scouring power, which they fixed at a maximum of 45 feet below low water, could, they officially concluded, be safely supported by wooden or iron piles driven firmly into the sand.¹⁶

To Eads such a conclusion was absurd. He knew from personal experience that in time of flood the sand over bedrock was scoured to a depth much greater than 45 feet. As he later said in his first report as chief engineer, "I had occasion to examine the bottom of the Mississippi, below Cairo, during the flood of 1851, and at sixty-five feet below the surface I found the bed of the river, for at least three feet in depth, a moving mass, and so unstable that, in endeavoring to find footing on it beneath the bell, my feet penetrated through it until I could feel, though standing erect, the sand rushing past my hands, driven by a current apparently as rapid as that at the surface."¹⁷

But experience had also taught Eads that the deepest scour—perhaps even to bedrock itself—occurred not in flood time but during low water, in the winter when the river at St. Louis froze over with a crust of ice 10–15 inches thick. On two occasions in his years on the river he had undertaken to cut a channel in the ice through which he could remove from the gorged ice one of his diving-bell boats to a place of safety: "The surface ice being removed from the canal and hauled off on its sides, I found the quantity of submerged ice which continually arose, when that in sight was removed, was so great that the supply seemed inexhaustible."

Eads understood, then, that when the narrowed river at St. Louis was solidly frozen, "backing up," or raising, the water in the wide unclosed stretches above the city 10 or even 20 feet above its former level, the currents sweeping below the ice were greatly increased in force. Floating ice from the open stretches above the city was constantly being carried under the solid crust, forcing the accelerated current to cut deeper into the sandy bed. "As rapidly as the latter is cut away," he wrote, "fresh supplies of ice are driven under, and thus the mass continues to grow in depth and the current to be directed nearer to the rock."¹⁸

Piers erected in the channel of the river would, he knew, facilitate

¹⁶See *Proceedings and Report of the Board of Civil Engineers Convened at St. Louis, in August, 1867* (St. Louis, 1867). These proceedings were summarized and discussed in Major G. K. Warren's *Report on Bridging the Mississippi River (Annual Report of the Chief of Engineers for 1878, app. x3 [Washington, 1878])*, pp. 1058–60.

¹⁷Eads, *Addresses and Papers*, pp. 490–97.

¹⁸*Ibid.*, p. 498.

the formation of an ice gorge at the bridge in winter, and they would certainly tend to hold that gorge in place until the sand was scoured out around and between them “to an unknown depth.” “For these reasons [he reported to the directors of the bridge company] I have maintained and urged that there is no safety short of resting the piers for your Bridge firmly upon the rock itself. On no other question involved in its construction does my judgment more fully assure me that I am correct. . . .”¹⁹

* * *

As I indicated earlier, I know of no evidence that Eads concerned himself with the problems of bridging the river at St. Louis before the spring of 1866. In 1865 a group of St. Louis men (Eads not among them) had acquired a charter from the state of Missouri and a supplementary charter from Illinois to build such a bridge, and in December of that year Senator Benjamin Gratz Brown of Missouri introduced a bill in the U.S. Senate authorizing its construction. Brown’s bill was referred to the Committee on Post Offices and Post Roads, whose chairman reported it back to the full Senate in March 1866 with a substitute bill as an amendment. This bill provided that the bridge might be a pivot or other form of drawbridge or else one of continuous spans. If the latter, its bottom chord was to have an elevation not less than forty feet above the city directrix²⁰ and spans not less than 250 feet long or, if a drawbridge, not less than 100 feet on each side of the pivot.

Eads and his rivermen associates knew that a bridge with such low and narrow spans would materially interfere with navigation. His salvage firm, Eads and Nelson, had been involved in salvaging the cargo and hull of the *Effie Afton* after she collided with the piers of the first railroad bridge across the Mississippi—the ill-fated and badly designed drawbridge built at Rock Island by Lucius B. Boomer in

¹⁹Ibid., p. 499. From the very beginning, Eads had intended to go to the rock with his channel piers. That was part of his plan as reported in the St. Louis papers some weeks before Boomer’s board of engineers convened (see, e.g., *St. Louis Democrat* [July 21, 1867]). However, he did not at first intend to carry his east abutment pier, on the East St. Louis shore, to bedrock. The cost of doing so would have been very great, and he believed a pile foundation could be adequately protected from the action of the current with rip-rap stone. But his complete success in founding the deepest of the two channel piers (the east pier) on rock determined him to do the same with the east abutment, “thus terminating forever all doubts as to the absolute stability of each one of the four great piers” (see his third report, October 1870 [*Addresses and Papers*, pp. 564–65]).

²⁰A curbstone at the foot of Market Street indicating the “high water” of 1828, which was the datum plane for all city engineering in St. Louis.

1855–56.²¹ And many steamboats and barges had been damaged on the piers of this and other bridges since that first memorable episode.

Thus it was that in April 1866, when the Senate was considering the substitute bill opposed by the rivermen, Eads became chairman of a committee appointed by the St. Louis Chamber of Commerce to consider what restrictions on bridge building “were really demanded by the marine interests” and what those interests could concede to “the requirements of land transportation in crossing the river [while preserving] a comparatively uninterrupted navigation.” Eads, reporting for the committee at a meeting in the Merchants Exchange on April 18, proposed a resolution (adopted unanimously) that Congress should be asked to pass a general law requiring that all bridges crossing the river “shall have a clear height of fifty feet over the main channel, between the lowest part of the bridge and high water mark, measured in the center of the span.” Further, that all bridges below the mouth of the Missouri (which of course included any bridge at St. Louis) “shall have one span of 600 feet or two spans of 450 feet each,” and that no suspension bridge or drawbridge of any type should be permitted.²²

The committee recommended those unusually long spans because Eads had assured them arches that long were entirely practicable, even though straight-chord trusses increased in weight so rapidly in proportion to length that their great cost made them virtually impracticable. “It was for this reason,” Eads later said, “that in defining the height the words ‘*measured in the center of the span*’ were inserted by this committee.”²³

Few if any experienced bridge engineers in 1866 would have so confidently assured the members of the committee that a 600-foot

²¹The suit brought against the bridge by the *Effie Afton*'s owners was a landmark case, in which Abraham Lincoln, one of the lawyers for the railroad, argued so impressively that the trial ended in a hung jury—in effect a victory for Chicago and the railroads over St. Louis and the rivermen. Eads's connection with the case came to light only in 1963 when the Davenport Public Museum acquired some letters revealing that Eads and Nelson's agent recovered the *Effie Afton*'s freight. See the *Davenport-Bettendorf Times-Democrat* (January 20, 1963); also G. K. Warren, pp. 1033–40; Albert J. Beveridge, *Abraham Lincoln* (Boston, 1928), pp. 598–605; and Lincoln's concluding address to the jury as reported in the *Chicago Daily Press* (September 24, 1857) and reprinted in *Collected Works of Abraham Lincoln*, ed. Roy P. Basler (New Brunswick, 1953), 2:415–22.

²²*Missouri Republican* (April 19, 1866). The act of Congress authorizing a bridge at St. Louis, as finally passed and approved July 25, 1866, included the requirements Eads's committee had suggested as to the height of the spans but reduced the length by 100 feet, calling for one span of 500 feet or two of 350 feet (U.S. Congress, House, *Executive Document No. 194*, 43d Cong., 1st sess. [1866], p. 9).

²³Eads, “Review of the U.S. Engineers' Report on the St. Louis Bridge,” *Addresses and Papers*, p. 83.

arch was “entirely practicable.” No bridge had ever been built anywhere of such long span, except a few suspension bridges, and Congress had forbidden suspension bridges at St. Louis.²⁴ To be sure, Thomas Telford, the great Scottish engineer, had proposed a cast-iron arch of 600-foot span back in 1801, but no arch actually constructed had spanned more than 400 feet, and no trusses even that long had yet been erected. Work had begun on a truss bridge over the Leck river at Kuilenburg (Culenburg) in Holland, whose main span was to be almost 500 feet, but that was 100 feet less than Eads wanted Congress to require for the main channel span at St. Louis, and many experienced American bridge engineers doubted that even the Kuilenburg bridge was practicable.²⁵

Eads’s confidence in the feasibility of 600-foot spans can be explained, I think, partly by his lack of practical acquaintance with bridge engineering and partly by his considerable firsthand knowledge of the properties of iron and steel. The same civil engineers who said in 1867 that it was unnecessary to go to bedrock to provide safe foundations at St. Louis also asserted that there was “no engineering precedent” for the 500-foot spans for which Congress finally settled and which Eads (as they knew) had by that time determined to build.²⁶ From the professional bridge engineer’s point of view this was a simple statement of fact, as we have seen. But to Eads, whose ideas about bridge building had not yet been trammelled by what practical bridge engineers and contractors called “the custom of the trade,” there were ample precedents, including Telford’s unrealized 600-foot arch. As he said in his rebuttal to the 1867 report, surely Telford’s assertion in 1801 that a cast iron arch of 600 feet was practicable furnished “some ‘engineering precedent’ to justify a span of 100 feet less in 1867.”

When we take into account [he continued] that the limit of the elastic strength of cast iron in compression is only about 8,000 pounds to the square inch, and that in cast steel it is at least seven or eight times greater, and consider the advance that has been made in the knowledge of bridge building since the days of Tel-

²⁴There was considerable distrust of suspension bridges at the time, despite the success of Roebling’s bridges at Niagara and Cincinnati. Many suspension bridges here and in Europe had collapsed, including Charles Ellet’s great bridge over the Ohio River at Wheeling, whose main span was more than 1,000 feet long (see David B. Steinman, *The Builders of the Bridge* [New York, 1945], pp. 170–73).

²⁵Even in 1869, after the Kuilenburg bridge was completed, E. S. Chesbrough told Major Warren that it had not been used long enough, in his opinion, to be pronounced a “safe precedent,” and William Sooy Smith still thought 500-foot spans were “barely practicable. They may or may not prove permanently safe and reliable” (Warren, pp. 1070, 1072).

²⁶*Ibid.*, p. 1067.

ford, it is safe to assert that the project of throwing a single arch of cast steel, *two thousand feet* in length, over the Mississippi, is less bold in design, and fully as practicable, as his cast iron arch of 600 feet span.²⁷

What mattered to Eads was not the precedent of some bridge already erected, whose plans need only be copied or modified. To him it was clear that where data on materials and workmanship in spans so great were not supplied by structures of equal magnitude, what was required was "such thorough acquaintance with the strength of materials as experience and experiment alone can furnish, together with a knowledge, obtained by careful study and observation, of the laws which guide us in the combination of these materials."²⁸ By 1866 he had acquired considerable acquaintance with the strength of materials and knowledge of the laws governing their combination. Throughout the Civil War and since, he had been in close contact with men in the Naval Ordnance Bureau and Bureau of Steam Engineering who knew as much about the qualities of iron and steel as anyone in America. He had built a fleet of ironclad gunboats and seven double-turreted iron river monitors which played an important part in the Union campaign to open the Mississippi from Cairo to New Orleans and in Admiral Farragut's victory at Mobile Bay.²⁹ Hitherto overlooked sources give us a clearer notion than we have had of his substantive role in the design of these vessels and their armament.

In all this work, as in the later work on the bridge, he had expert professional assistance. One of the young civil engineers in his drafting room was George P. Herthel, Jr., a graduate of Rensselaer Polytechnic Institute who had also studied in Berlin and Karlsruhe Polytechnic schools.³⁰ But it was the naval constructor Edward Hartt whose assistance was most important to him in the early stages of the work, as he handsomely acknowledged some years later in a letter to Gustavus Vasa Fox, who had been assistant secretary of the navy when

²⁷Eads, *Addresses and Papers*, p. 513.

²⁸*Ibid.*, p. 514.

²⁹See Fletcher Pratt, *Civil War on Western Waters* (New York, 1956), pp. 14–23, 37, 129–30; and How (n. 5 above), pp. 22–41. As Pratt says, the turrets Eads designed for his river monitors later became the standard type on American warships. For Eads's controversy with John Ericsson over turret design see Eads's letters on the subject dated June 4, 1867, December 4, 1869, and January 29, 1870, in *Addresses and Papers*, pp. 467–80.

³⁰See William H. Bryan, "The Engineers Club of St. Louis: Its History and Work," *Journal of the Association of Engineering Societies* (February 1900), pp. 161–62. Herthel later organized a patent agency which handled some of Eads's inventions, including the sand pump employed in the sinking of the piers for the bridge (see Letters Patent no. 105,056, July 5, 1870).

Eads was building his ironclads and monitors. "This gentleman [Hartt] you may remember was sent here as inspector of the hulls I built for the Gov't. They were iron and this was a novel matter with me. Hartt was so zealous in hurrying their construction that he frequently worked for days at a time in my drawing room making detail plans of various parts of the work and in this way greatly aided me and did labor I would have had to pay others, much less competent, for doing."³¹

As to Eads's role in developing the turrets for his monitors, we have a letter he wrote Assistant Secretary Fox on April 14, 1864, about the tests to which his turret on the monitor *Winnebago* had been submitted in the presence of Chief Engineer James W. King of the navy's Bureau of Steam Engineering. Eads was seriously ill at the time and confined to his house.

It gives me great pleasure [Eads wrote] to inform you that Mr. King called to say to me yesterday that my steam turret had been thoroughly tested and was a most complete and triumphant success. He said he should write to you today and in a few days after make an official report of the whole thing.³² He characterized the experiments he had made with it yesterday as being the most important made for many years in the Navy.

It has been a matter of great regret to me that so much delay has occurred in bringing this matter to its present state of perfection and demonstration. Much of it has been owing to my ill health, but more to those difficulties which attend most of our workers in iron at the present time. Besides this there were in the machine itself so many objects to be attained, surrounded with difficult conditions, all of which had to be reconciled and so simplified as to admit of practical operation [*sic*], that I found it required an amount of thought and time I had underestimated, and which will scarcely be credited in looking at the simplicity which it now presents. The vessel in which it was to be placed was so shallow as to necessitate the guns dropping on both sides of the vertical cylinder. This spread them wider apart than was desirable and left less room on the platform. The ports were to be strongly closed and quickly opened, and to be readily moved out of the way if their machinery were disabled. The guns to have great elevation and depression, and be moved out and in by machinery that should be operated by the engineer and yet be

³¹Eads to G. V. Fox, January 8, 1871, Fox Papers, New-York Historical Society, New York, N.Y. I am indebted to Ari Hoogenboom for calling my attention to these and other Eads letters in the Fox Papers.

³²King's official "Report to the Navy Department of the Eads Steam Turret" was dated at Washington, April 30, 1864.

automatic. The platform likewise moving automatically so that it could not jam the guns by careless raising when loading, nor by sinking when they were in their ports if the engineer was confused; and yet to be entirely under his will at all other times—these and many other desirable ends were to be attained and the whole to be done by machinery of the simplest kind and least liable to derangement.

This labor is now over and cannot present itself again in any others that may be built.³³

As to Eads's knowledge of the properties of steel, I do not know whether or not steel parts were employed in any of his turrets or gun carriages during the war, but the navy men with whom he worked may well have directed his attention to this relatively new material. Cannon were made and tested as early as July 1, 1861, of steel puddled in Troy, New York, and Trenton, New Jersey, and forged, bored, and rifled in New York City.³⁴ Henry Augustus Wise, a naval commander who joined the Naval Ordnance Bureau in 1862 and became its chief in 1864, had secretly investigated Krupp's manufacture of steel weapons.³⁵ And early in 1863 Assistant Secretary Fox was urging John Ericsson to get his associates in the *Monitor* project to build a Bessemer steel works.³⁶

In the years after the war Eads continued to work on the design of naval turrets and the steam mechanism for handling heavy guns. There are records of tests of his steam gun carriage on the Hudson River in the spring of 1867 which were so satisfactory that ordnance bureau chief Wise (now Captain) wrote to inform Eads that the Department of the Navy was releasing him from "all pecuniary obligations concerning it."³⁷ It is quite probable, then, that when in 1866

³³Eads to Fox, April 14, 1864, Fox Papers.

³⁴*The New American Cyclopaedia*, ed. George Ripley and Charles A. Dana (New York, 1863), 15:76.

³⁵Wise became acting chief in 1864 and was not officially chief until 1866 (see *Who Was Who in America: Historical Volume* [Chicago, 1963], p. 591).

³⁶See Victor S. Clark, *History of Manufactures in the United States* (New York, 1929), 2:19.

³⁷This letter, dated May 29, 1867, was found for me in 1958 by Mildred Mott Wedel in the National Archives, War Records Division, Old War Records Branch, Record Group 74, "Miscellaneous Letters, Navy Ordnance." Eads's achievements as a designer of naval armaments have been largely ignored. Further designs were described in a report he made to the secretary of the navy, February 22, 1868 (U.S. Congress, House, *Executive Document No. 327*, 40th Cong., 2d sess. [1868]), and in illustrated articles published in *Engineering* (London) (August 28 and September 4, 1868). A monitor turret was exhibited by the navy's ordnance bureau at the Centennial Exhibition, Philadelphia, 1876. It was equipped with two 15-inch guns, one mounted on Eads's carriage "by which it was run out and otherwise regulated by steam" and the other on

Eads told his fellow rivermen in the St. Louis Chamber of Commerce that 600-foot arches were entirely practicable, he based that statement on solid knowledge of the properties of iron and steel. But there is no evidence that he yet had any thought himself of designing a bridge at St. Louis or elsewhere. That idea did not, I think, occur to him until almost a year later.

* * *

Early in 1867 there were rumors in St. Louis that a group of men who had in 1865 procured a charter to build a bridge were about to sell out to people who did not want a bridge to be built. Eads presided at a meeting in the Merchants Exchange at which a committee was appointed "to obtain information with respect to legislation . . . upon the subject of bridging the Mississippi," and the man he appointed as chairman of that committee was Dr. William Taussig, a physician turned banker who had been an associate of his since gunboat days.³⁸

At a meeting at the Exchange about a month later, with Eads again in the chair, Taussig read his report. It concluded by quoting a long, evasive letter from Judge John M. Krum, chairman of the group who controlled the charter, which ended with the assertion that "anyone who has sense enough to go from one house to another ought to know that the *corporators* of a chartered company cannot sell out, for they have nothing to sell."³⁹

When Taussig sat down, Eads said he was sorry Judge Krum could not have attended the meeting, as there were some matters his letter did not fully explain. It was true, of course, that the corporators had no right to sell out a charter, but they might, Eads observed, "empower certain parties to open books and receive subscriptions, and create stockholders," and those stockholders *would* own the charter. "If the stock was subscribed by parties outside of St. Louis it might fall

an Ericsson carriage "worked by hand power, taking the united effort of four men to direct its movements" (see J. S. Ingram, *The Centennial Exhibition Described and Illustrated* [Philadelphia, 1876], p. 134; and Centennial Commission, *Official Catalogue, Department of Machinery* [Philadelphia, 1876], p. 69).

³⁸The reader will have to take this on faith. Documentation of Taussig's long association with Eads, dating back to 1849 or 1850, is in my possession but would occupy too much space here.

³⁹A detailed report of this February 16 meeting appeared in the *Republican* the next day. Incidentally, two years later Judge Krum demanded and got \$6,500 for his share of the ownership of the charter in question (manuscript minutes of the July 9, 1869, meeting of the directors of the Illinois and St. Louis Bridge Co., TRAA files [n. 3 above]).

into the hands of the enemies of St. Louis,” or of “parties who are opposed to the building of a bridge,” in which case there might be a delay of many years before any bridge was built.

I am not sure, but I suspect that it was at this meeting, or just prior to it while Eads and Taussig were looking into the matter of the charter, that Eads determined to take the bridge project in hand. At all events, ten days later Eads and a group of his intimate friends and close business associates had subscribed for \$300,000 worth of stock in the company holding the charter, and on March 23 Eads dominated a meeting of the stockholders at which his old and dear friend Charles K. Dickson was, on his motion, elected president and he himself designated engineer-in-chief. Soon afterward Taussig was appointed solicitor. By July 11, 1867, Eads had so far determined his plans that he was able to submit estimates of the cost of the bridge he proposed to build, its approaches, the tunnel that would be required under the streets of downtown St. Louis, and the property that would have to be condemned. His plans and estimates were approved, and he was authorized “to commence active operations” and “to open negotiations with some party, for the construction of the Bridge and approaches.”⁴⁰

There is no need to unravel here the long and complex corporate history of the company that built the bridge.⁴¹ The point I want to establish for present purposes is that between mid-February and mid-July 1867 Eads had worked out plans for his bridge detailed enough to serve as the basis for cost estimates.

In the later stages of this initial planning he was ably assisted by Henry Flad, a German-born and German-trained civil engineer whom Eads selected as his chief assistant soon after the stockholders’ meeting of March 23. Flad was forty-three in 1867 and had had considerable experience in railroad construction. Born near Heidel-

⁴⁰ See bound volume of manuscript records, “Charters and Proceedings, St. Louis and Illinois Bridge Co.,” pp. 25, 26, 30, 39, TRRA files. The probable reason for Eads’s unwonted desire that a bridge be built was that he had recently become interested in several railroad enterprises that were of interest also to the officers of the Pennsylvania Railroad. This aspect of Eads’s career has been completely ignored by his biographers. The reader will find references to it in my article, “Eads Bridge: The Celebration,” *Missouri Historical Society Bulletin* 30 (April 1974): 159–80 (republished in *The Eads Bridge*, catalog of an exhibition prepared by the Art Museum and the Department of Civil Engineering, Princeton University, 1974, pp. 48–73). Some particulars are given in my commentary on “Downtown St. Louis as James B. Eads Knew It . . .,” *Missouri Historical Society Bulletin* 30 (April 1977): 181–95 (esp. items 8, 13, 14, 23, 31, 46).

⁴¹It is told in Woodward, pp. 12–31, with the omission of important details too “hot” to publish while the participants were alive and without some material details that were unavailable to Woodward but have come to light since, as my notes, I trust, make clear.

berg, he was educated in civil engineering at the University of Munich, after which he worked for the Bavarian government on projects for the improvement of the river Rhine. During the revolution of 1848 he served in the Parliamentary army as captain of engineers; after the defeat of the Parliamentary forces he escaped to France and thence to the United States in the fall of 1849. He worked during the 1850s on construction of the western end of the Erie Railroad, then on the Ohio and Mississippi Railroad from Cincinnati to East St. Louis, and finally on the St. Louis and Iron Mountain Railroad from St. Louis south to the iron mines at Pilot Knob. During the Civil War he served with distinction as an engineer with the Union forces, building fortifications and rebuilding railroads, and was mustered out as a full colonel at the end of 1864. In the spring of 1865 he became chief assistant engineer of the St. Louis Board of Water Commissioners under James P. Kirkwood, the renowned builder of the Brooklyn waterworks who had been hired to design new waterworks for St. Louis.

Just when Eads first met Flad I am unable to say. In the memoir published after Flad's death in the *Transactions* of the American Society of Civil Engineers (of which Flad had been president in 1886–87) it is said that the two men met while Eads was engaged upon plans for gun carriages and turrets and Flad was assistant engineer under Kirkwood. The rooms then occupied by the water commissioners being larger than they needed, Eads had requested and been granted space in which to place a draftsman at work, and this was followed by frequent discussions between Eads and Flad on engineering matters "which led to mutual recognition of each other's abilities and laid the foundation of a life-long friendship."⁴²

This dates their meeting sometime before March 1867, when Kirkwood relinquished his appointment and Flad became a member of the Board of Commissioners which hired Thomas Jefferson Whitman (Walt Whitman's brother) as Kirkwood's successor.⁴³ It may have been through George P. Herthel, the young draftsman who had worked for Eads in the gunboat days, that the meeting came about, since Herthel and Flad worked together in 1866 designing and erecting the first hydraulic elevators in St. Louis.⁴⁴ Herthel may well

⁴²Robert Moore, Joseph P. Davis, and J. A. Ockerson, "Memoir of Henry Flad," *Transactions of the American Society of Civil Engineers* 42 (December 1899): 561–66. Davis (chief engineer of AT&T in the 1890s) had been Thomas Jefferson Whitman's assistant on the St. Louis waterworks in 1867–69 and was treasurer of the Engineers Club of St. Louis when it was founded in 1868 with Flad as president (see Bryan [n. 30 above]).

⁴³M. L. Holman, "Water Works, City," in William Hyde and Howard L. Conard, *Encyclopedia of the History of St. Louis* (New York, 1899), 4:2471–72.

⁴⁴Bryan (n. 30 above), pp. 161–62.

have been the draftsman for whom Eads found space in the water commissioners' office. At all events we know that as early as April 1867 Flad was engaged in surveys connected with the location of Eads's bridge.⁴⁵

It is certain, I think, that Eads had formed tentative plans and had made the decision to use steel before he hired Flad to assist him. By the end of March he had publicly proposed plans for a double-decked bridge with three arched spans of steel, each approximately 500 feet long, with the railroad on the lower deck running into a tunnel under the city.⁴⁶ But these plans were still rudimentary when, in May and June, Eads corresponded with Jacob Hayes Linville, bridge engineer of the Pennsylvania Railroad, whose empire-building vice-president, Tom Scott, was a director of Eads's company. Eads had shown a very rough "sketch" of his proposed bridge to Linville when he was in Philadelphia in late April or early May. On June 3 he sent Linville tracings of the drawings then on hand. These, he indicated in a letter dated three weeks later, "had no dimensions of parts on them, and exhibited no completed system of bracing, neither horizontal, vertical or transverse. Nothing in fact but a method of bracing between the four arched ribs, and the struts and tension rods shown between the arches and the top member, the position, number and size of which had not been determined nor the counter bracing shown." The depth and form of the braced arch ribs had not yet been determined, but the ribs themselves consisted "of four rectangular bars of steel of large section, apparently about four by six inches."⁴⁷

However, as Eads told Linville in his letter of June 24, he had been "for some time considering upon the propriety of substituting a ribbed arch in the place of the braced arch shown on the plan I sent you."

⁴⁵The manuscript ledger of the St. Louis and Illinois Bridge Co. records payment to Flad of \$41.60 "for surveying" on April 15, 1867, the same day that \$400 was paid to R. B. Lewis, whom Eads described in his 1868 report as "a gentleman of great experience and high reputation as a locating engineer, and for many years in the service of the Pennsylvania Railroad" (Eads, *Addresses and Papers*, p. 482).

⁴⁶These plans are mentioned in a letter written on April 4, 1867, by Isaac Sturgeon, president of the North Missouri Railroad, published in a pamphlet entitled *Alton & St. Charles County and the St. Louis & Madison County Bridge Companies Consolidated* (n.p., n.d.). A copy was bound into a volume of pamphlets relating to Eads Bridge that belonged to Henry Flad and was loaned to me by his granddaughter, Mrs. Towner Deane of St. Louis. Eads's 500-foot spans conformed to the requirements of the law Congress had finally passed July 25, 1866 (U.S. Congress [n. 22 above]). By using three such spans he was able to bridge the 1,500-foot river with only two piers standing in the stream to interfere with navigation.

⁴⁷The name of the Pennsylvania's vice-president, Thomas Alexander Scott, is not in Woodward's index and appears but once in the text (p. 15), without mention of his connection with the railroad. The first quotation is Eads to Linville, June 24, 1867; the other is Linville to Eads, June 13, 1867 (TRRA files [n. 3 above]).

In the longest span [515 feet] it would be about 8 feet wide, composed of an upper and lower rectangular steel rib retained in their relative positions by a system of diagonals between them, somewhat after the plan of the bridge at Coblenz on the Rhine. It would not be deep enough to prevent some tension on the lower member, nor so deep as to create much strain from excessive temperature in the upper one. It would be supported on a central pivot or joint at each pier, as in the Coblenz bridge, but on a better method.

The reference to the Coblenz (Koblenz) bridge in connection with the change of plans Eads was considering is especially interesting because a long illustrated article about that bridge had been published more than two weeks earlier in *Engineering* (London), a paper Eads knew well.⁴⁸ The bridge had been completed in 1864, but was currently in the news because the drawings for it were then on display at the Paris Universal Exhibition. *Engineering* called it “one of the finest and most interesting structures of its kind in Europe,” which “in beauty of appearance . . . is equal to any modern railway bridge in existence” (see fig. 3). Eads must surely have noted that comment, for he had persistently asserted in his correspondence with Linville that he chose the arch form because it would be “more commodious and attractive” than any truss bridge, and that “strength with durability, and beauty with economy” could best be achieved by that form.

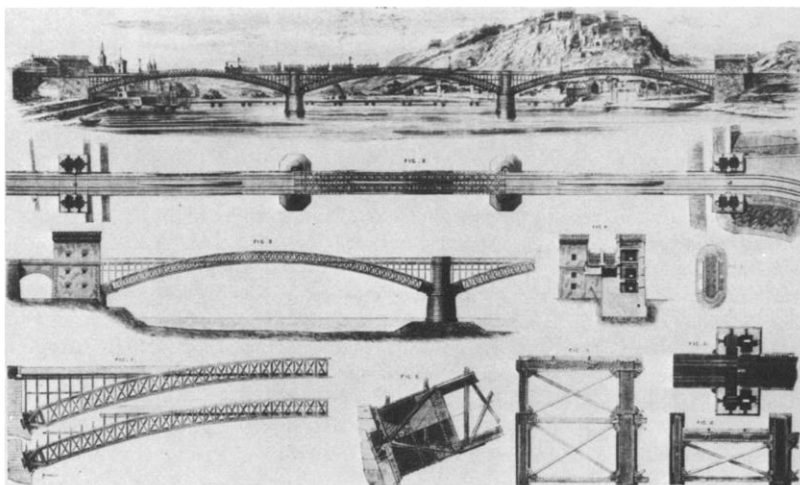


FIG. 3.—The Coblenz (Koblenz) railway bridge, with structural details (wood engraving from *Engineering* [London] [June 7, 1867], facing p. 586).

⁴⁸*Engineering* (London) (June 7, 1867), p. 586.

By the end of July, when large drawings of his bridge were on display at the Merchants Exchange, it was widely publicized that Eads had chosen a style “somewhat similar to” or “resembling” the Koblenz bridge, but with an upper highway deck and a lower deck for a double-track railroad instead of the single railway deck at Koblenz, and with much longer spans.⁴⁹ Essentially this was the design Eads would present ten months later in his first published report as chief engineer. Of the three spans the center one would be 515 feet long and the other two 497 feet. Each span would be formed of four ribbed arches of cast steel, having a rise of about one-tenth of the span, and each ribbed arch would consist of “two ribs placed seven feet apart, one above the other, and strongly braced between with diagonal steel braces.” Though the upper and lower steel ribs were now only 7 feet apart, instead of 8 as when Eads wrote to Linville on June 24, they were still, I assume, rectangular in section; as late as November 1867 Eads was still looking for manufacturers capable of making steel bars 28 feet long of 3- by 6-inch section.⁵⁰

By that time Eads had added to his engineering staff a young German-trained assistant named Charles (Karl) Pfeifer. Pfeifer had come to America early in 1867, at the age of twenty-four, with excellent training in engineering and mathematics and had settled among the Germans in St. Louis. It was presumably through Henry Flad that

⁴⁹See the articles about Eads’s plans published in the St. Louis and out-of-town papers at this time. The *Democrat’s* article of July 21, 1867, was quoted at length in the *Chicago Tribune* of July 23, and the *Republican’s* of August 5 was reprinted entire in the *East St. Louis Gazette* of August 8. It is not, I think, just to say as Miller (n. 3 above) does that Eads downplayed the influence of the Koblenz bridge on his design “until his own bridge was almost completed” (p. 90).

⁵⁰In early November 1867, the general manager of Park Bros. & Co.’s Black Diamond Steel Works in Pittsburgh told J. Edgar Thomson, president of the Pennsylvania Railroad, that he had no facilities for making bars of the size Eads had named (3 by 6 inches, 28 feet long) and that “an entire new mill, foundations, Engines, Steam Cranes & c would be necessary before they could touch the order” (Andrew Carnegie to Eads, November 9, 1867). Carnegie, who had resigned as superintendent of the Pennsylvania’s Pittsburgh division in March 1865, had since been headquartered in Pittsburgh to oversee some of Thomson’s and Thomas A. Scott’s investments in various enterprises, including the Keystone Bridge Co., and was soon to take charge of their investment in the bonds of Eads’s bridge company. His press copy of his letter to Eads is among the Carnegie Papers in the archives of the United States Steel Corporation, Pittsburgh. After many years of unsuccessful attempts to get access to these papers I had the good fortune to enlist the aid of the late George Ketchum, a highly respected citizen of Pittsburgh, well known to the officers of U.S. Steel. Through his intervention I received permission in 1973 from the secretary of the corporation to go through all Carnegie’s letter books and other papers of the years involved in the building of Eads Bridge and to transcribe, and in some instances make photocopies of, those relating to the building and financing of the bridge. There are hundreds of them, a few of which were used (and occasionally misapprehended) by Joseph Frazier Wall in *Andrew Carnegie* (New York, 1970).

he came to Eads's attention. He was appointed assistant engineer on August 19, 1867, and thereafter worked closely with Flad on the mathematical investigations and calculations for the bridge.⁵¹ As Eads said in his 1868 report, several months of patient labor were spent by Flad and Pfeifer "in investigation of the arch with spandrel bracings, the ribbed arch with pivoted ends (as in the Coblenz bridge), and with fixed ends, and of various depths." But so far as I have been able to discover Pfeifer played no part in the designing of the bridge aside from his extremely sophisticated mathematical computations of the necessary dimensions of its constituent parts—dimensions which Eads sometimes disregarded, as we shall see.⁵²

I have not ascertained when or how Eads decided to abandon the rectangular ribs and adopt instead the tubular form described in his first report. It must have been after early November 1867 and before the end of April 1868 when he sent "plans in detail and data for computation" to Julius W. Adams, vice-president (and later president) of the American Society of Civil Engineers, who was soon to serve on the board of consulting engineers convened by John A. Roebling to pass upon his plans for the Brooklyn Bridge.⁵³ The plans sent to Adams were substantially those Eads published in his first report, which was dated June 1, 1868 (though much of it had appeared in the newspapers in May), and which specified that the upper and lower ribs of the arches (now again spaced 8 feet apart) would consist of "two parallel steel tubes, nine inches in diameter, placed side by side."⁵⁴

⁵¹The date of Pfeifer's first employment on the bridge comes from Singleton's diary (n. 15 above).

⁵²For a full discussion of Pfeifer's and Flad's computations and how they led to Eads's decision to use the ribbed arch with fixed ends rather than the arch pivoted at the ends as at Koblenz, see Woodward, chap. 26. See also Charles Pfeifer, "The Theory of Ribbed Arches," *VanNorstrands Eclectic Engineering Magazine* (June 1876). Most of what I know about Pfeifer comes from his granddaughter Katherine Pfeifer Chambers of Overland, Missouri, with whom I corresponded in 1957. The rest comes from Woodward (who frequently mentions his work as a supervisory engineer during the construction of the bridge piers); the manuscript records of the bridge company; and an obituary in the *St. Louis Globe-Democrat* (February 18, 1883).

⁵³Steinman (n. 24 above), pp. 316–17, and David McCullough, *The Great Bridge* (New York, 1972), pp. 21–23. Eads sent the plans and data to Adams on April 29, 1868, with the request that Adams carefully examine them in detail and judge if they were "entirely safe, practicable and judicious," as we learn from Adams's twelve-page reply, dated June 4, 1858, which is among the bridge company records in the TRRA files (n. 3 above). Adams had been listed as a member of the board of engineers assembled by Lucius Boomer, whose *Report* (n. 16 above) was artfully modulated to produce the impression that Eads's plan to build 500-foot arches was impracticable. But Adams "took no part [in the deliberation of the convention], not having been present," as he later told Major G. K. Warren (Warren, pp. 1067–68).

⁵⁴Eads, *Addresses and Papers*, p. 505.

The only testimony we have as to who should be credited with these tubular arched ribs comes from Carl Gayler, another German-trained civil engineer, who worked in Eads's drafting room under the chief draftsman, William Rehberg. Gayler did not enter the employ of the bridge company until 1869 or 1870, at least a year after the decision to use tubes had been made, and his comments on the subject were not made until many years later, when he was the sole survivor of Eads's engineering staff.⁵⁵ But he would have been unlikely to underestimate the contributions of his fellow Germans on the staff.

Writing in 1909 Gayler said that "an unprecedented amount of labor and time" had been spent in merely proportioning the bridge, and that "this proportioning, this designing of our bridge, was the exclusive work of Jas. B. Eads."⁵⁶ And twenty years later, at a banquet given in his honor by the Engineers Club of St. Louis, he gave specific instances of the ways in which Eads dominated the design process. He recollected well, for instance, how Carl Pfeifer (Gayler's brother-in-law) "had made a sketch of what he considered a proper cross-section for the chords of the arches, all in the European style: plates and angles riveted together" and how Eads promptly vetoed it. "Tubes, safely enveloped, had been one of his earliest conceptions," Gayler said. "Eads just loved this part of the work and all the minutest details of the tubes with their couplings and pin connections, the skewbacks and anchor bolts, all of it to the last 1/8 of an inch are the work of Eads, of course always subject to Pfeifer's established effective areas."⁵⁷

John A. Roebling, whose suspension spans at Niagara and Cincinnati had won him international recognition and whose plans for the Brooklyn Bridge had recently been accepted, had expressed the belief that the best form in which to employ iron for upright arch bridges was the cylindrical. "I venture to predict," he had said, "that the two great rival systems of future bridge engineering will be the inverted and upright arch—the former made of wire, and the latter of pipe, both systems rendered stable by the assistance of lattice work, or by stays, trusses and girders." But Roebling thought it worthy of notice

⁵⁵Gayler's obituary in the *St. Louis Globe-Democrat* (September 3, 1933) says he was born in Stuttgart in 1850 and came to the United States in 1870, but an article about him in the *Post-Dispatch* (February 27, 1927) says he was employed by the bridge company "from the summer of 1869 . . . until the completion of the bridge, five years later." Company records for 1874 indicate that Gayler was a draftsman in the engineering office on a salary of \$125 per month. For an example of his work see pl. 2, "Section of East Pier and Caisson," in Eads, *Report of the Chief Engineer, October, 1870* (St. Louis, 1870).

⁵⁶Carl Gayler, "Bridge Designing," *Journal of the Association of Engineering Societies* 40, no. 3 (March 1909): 114.

⁵⁷Carl Gayler, speech prepared for an Engineers Club banquet, typescript dated January 28, 1929, Gayler Papers, Missouri Historical Society.

“as a curious professional circumstance” that iron cylinders had “never been used in arching, although proposed on several occasions.”⁵⁸

Actually they had been used, by a man well known to Eads, in a bridge that may have suggested to him not only the tubular form for his ribs but also the novel method by which he built up the tubes. It has been pointed out before that Eads may have been influenced by the “water-pipe bridge” constructed in 1858 as part of the Washington, D.C., aqueduct by Captain Montgomery C. Meigs of the army engineers.⁵⁹ It was Meigs, then quartermaster general, who in 1861 had given Eads the contract to build the first of his ironclad gunboats, and it is entirely possible that Eads saw Meigs’s pipe bridge on one of his many visits to Washington. But whether or not he had ever seen the bridge, he must surely have seen the article about it, and the drawings of it, published in *Engineering* (London) May 3, 1867, while he and Flad were working on their earliest designs. As shown in figure 4, Meigs’s 200-foot span was supported by two arched tubes, each composed of seventeen straight lengths of cast-iron pipe. This pipe, 4 feet in diameter, was made in 12-foot pieces with flanged, slanted ends which when bolted together intersected on a plane parallel to a radius of the ideal circle of which the arch was a segment. Through these arched tubes, supporting the roadway, the water of the aqueduct flowed.

As I have said, Meigs’s bridge may have reminded Eads of the advantages of the hollow cylinder as a structural form; in any event we know that he investigated the possibility of using steel pipe for his arches. In his first report he referred to the fact that cast-steel tubes had been “recently drawn cold by hydrostatic pressure in France, from steel expressly prepared for the purpose,” but he had found that the process had not been carried “to any extent beyond the production of gun barrels.” To avail himself of the advantages of the tubular form of construction he had therefore proposed “to have the steel rolled for the arches in bars of nine feet length, and of such form that ten of them shall fill the circumference of a nine-inch lap-welded tube 1 inch thick, in the manner that the staves of a barrel fill the hoops.”⁶⁰

⁵⁸Quoted in L. U. Reavis, *Saint Louis: The Future Great City of the World* (St. Louis, 1870), p. 104.

⁵⁹See, e.g., David P. Billington, *Structures and the Urban Environment* (Princeton, 1978), p. 31, n. 8. An earlier iron-tube bridge had been erected at Brownsville, Pa., in 1836, but I have no reason to think Eads (or Meigs, for that matter) knew of it (see Carl Condit, *American Building Art* [New York, 1960], pp. 184, 320).

⁶⁰Eads, first report, *Addresses and Papers*, pp. 527–28.

In the course of design changes during the next two years the dimensions and details of Eads's tubes were altered considerably, but the idea of using staves enveloped in an encircling steel hoop remained constant. And that idea may, it seems to me, have been suggested by the fact that, as originally built, Meigs's cast iron pipes had been "lined with staves of resinous pine, 3 in. thick, to prevent the freezing of the water." This pine-stave lining had later been removed—because it was unnecessary and because the bridge was much less affected by temperature changes when the water was allowed to flow in contact with the metal of the pipes—yet the mention of it in *Engineering* may well have been what suggested to Eads the possibility of forming his steel tubes as he did.⁶¹

As indicated earlier, the design of the bridge in May 1868 specified that the upper and lower ribs of the arches would each consist of two such tubes, 9 inches in diameter. By February 1870 (when a contract for the construction and erection of the superstructure was made with the Keystone Bridge Co. of Pittsburgh) Eads had substituted a single tube 13 inches in diameter for the two smaller tubes.⁶² A few months

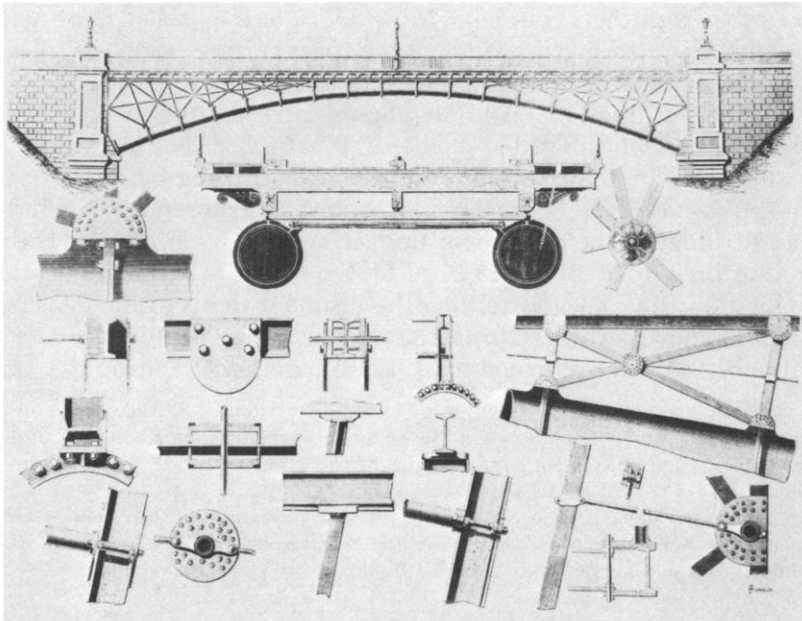


FIG. 4.—Montgomery C. Meigs's "water-pipe bridge," Washington Aqueduct (from *Engineering* [London] [May 3, 1867], p. 447).

⁶¹"Water-Pipe Bridge, Washington Aqueduct," *Engineering* (London) (May 3, 1867), p. 448.

⁶²Woodward, p. 67.

later the diameter of the tubes was increased to 16 inches, and finally, toward the end of 1870 or early in 1871, the 18-inch tubes actually used in the bridge had been adopted.⁶³ And by this time the number of staves composing the tubes had been decreased from ten to six, while their length had been increased from 9 feet to approximately 12.⁶⁴

Such changes obviously required, and were interdependent with, changes in all the subsidiary elements of the great spans. In renegotiating his contract with Keystone in February 1871, Eads had to discuss changes in forty-six separate categories, one of which (the ninth in the numbered sequence) was concerned with the extra compensation Keystone was entitled to “by reason of increased diameter of the tubes from 16” to 18”, the introduction of stay bolts, the substituting of steel for iron in the enveloping tubes and laps, the wrot [*sic*] iron bands at the ends of the tubes, and the change of ‘grooves’ instead of ‘screws’ for the coupling joint and increased cost of turning off the corrugation of channel bars.”⁶⁵

Though there is no reason to question Carl Gayler’s assertion that Eads was personally responsible for designing “the minutest details of the tubes with their couplings,” this does not mean that Eads made detailed engineering drawings of any parts of the bridge or of the machines and devices used in building it. Like many great engineers he could not draw very skillfully, though he communicated his ideas to his draftsmen in crude sketches.⁶⁶ What those sketches were like is suggested by figure 5, showing the only drawing by Eads that is known to exist. It is scrawled on the back of a memorandum, in Eads’s handwriting, of the agreement he had arrived at with James Harrison, a director of Boomer’s rival bridge company, containing their suggestions for amicably settling the disputed rights of the two companies. They had worked out the agreement in Washington late in January 1868 and returned to St. Louis together.⁶⁷ During the jour-

⁶³See the “memoranda” of a conference between Eads and G. B. Allen of the bridge company and two representatives of the Keystone Bridge Co., St. Louis, February 6, 1871, in the minutes of a special meeting of the directors of the bridge company February 13, 1871, TRRA files (n. 3 above).

⁶⁴The length depended on whether the tube was to be used in the upper or lower member of one of the ribbed arches of the center span or in the upper or lower member of a side span (Woodward, pl. 29).

⁶⁵See n. 63 above.

⁶⁶George Stephenson, who designed every detail of the Liverpool and Manchester Railway in 1825–30—locomotives, bridges, tunnels, roadbed, and track—made none of the working drawings for these things. They were made by his principal draftsman, Thomas Gooch, who got his instructions from Stephenson either by word of mouth or what he called “little, rough hand sketches on letter paper” (see Samuel Smiles, *The Life of George Stephenson* . . . [New York, 1868], p. 295).

⁶⁷See the *Democrat*’s report, January 30, 1868, that they were returning together after

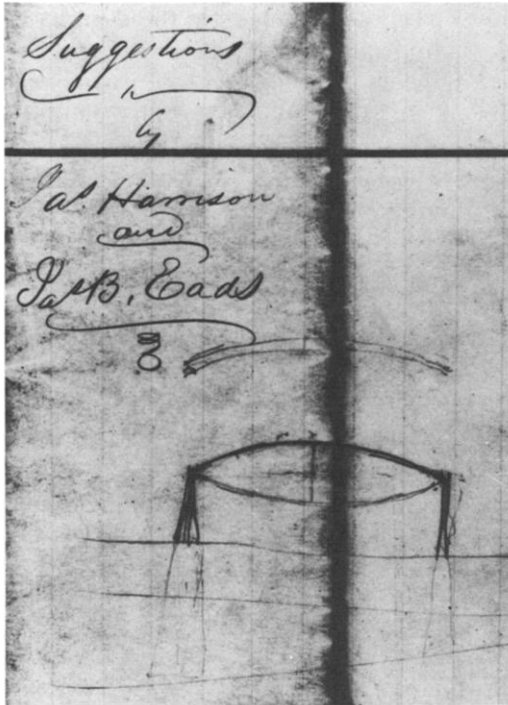


FIG. 5.—The only known example of a drawing by Eads. The sketch is of an upright arch and a suspended arch between piers extending down to sloping bedrock. The curved lines just below Eads's signature probably represent the upper and lower ribs of the ribbed arch.

ney, as I suppose, Eads was explaining to Harrison why he was convinced that an upright arch bridge could be constructed out of the almost untried metal, steel, even more economically than a suspension bridge, then regarded as the most economical form for long spans—giving the same reasons he presented a few months later in a long section of his first report, “Suspension and Upright Arch Bridges.”⁶⁸ At any rate this crude sketch or one much like it was probably the basis of the figure numbered 11 in that section of the report.⁶⁹

arranging a settlement. Harrison was the iron expert in the St. Louis firm of Chouteau, Harrison, & Valle, which in 1865 had become partners in the Kelly Process Co., at whose experimental works in Wyandotte, Mich., the first “Bessemer” steel in America was made in the fall of 1864 (see “Iron Making in Pennsylvania,” in *Pennsylvania and the Centennial Exposition* [Philadelphia, 1878], 1, pt. 2: 56–58). Here is another possible source of Eads's knowledge of steel.

⁶⁸Eads, *Addresses and Papers*, pp. 519–27. It is worth noting that at this time the British Board of Trade forbade the use of steel in bridges. Not until three years after Eads Bridge was completed was the ban removed (see H. Shirley Smith, *The World's Great Bridges* [New York, 1953], pp. 76, 85).

⁶⁹Eads, *Addresses and Papers*, p. 522.

A number of the changes Eads made in the design of the tubes, as in the design of less important structural members, were suggested by the mechanics or engineers associated with companies that fabricated the various parts of the superstructure. The change from screw threads to grooves in the coupling joints of the tubular ribs was, as I recently discovered, the suggestion of William Sellers, the distinguished mechanical engineer who was president of the Franklin Institute from 1864 to 1867 and who, it now appears, was one of the principal owners of the Wm. Butcher Steel Works in Philadelphia, the recently established firm to which Keystone awarded the subcontract for most of the steel used in the bridge. In a letter written the day before the Eads company signed the contract with Keystone, Andrew Carnegie told Eads that "Mr. Sellers [on behalf of Butcher] made us a bid for the steel tubes complete, provided you accepted some changes in mode of constructing—He has a plan which avoids screws altogether & cast iron also which he says will save considerably in material (as you of course lose in cutting threads) & make a better job—But it increases Cost per lb."⁷⁰

Sellers's connection with the Butcher Works, and with the great Philadelphia banking house of E. W. Clark and Company—which gave an urgently needed loan of \$250,000 to Eads's bridge company only on condition that President Thomson and Vice-President Scott of the Pennsylvania Railroad (and their agent Carnegie) see to it that Butcher got the steel contract—has not hitherto been made known. Nor did the officers of Eads's company know of the connection. When Carnegie was in New York on March 7, 1870, about to embark for England to negotiate the sale of \$2.5 million of the Eads company's first mortgage bonds, which he and Thomson and Scott had "taken" at 90 percent of face value, he telegraphed E. W. Clark and Company, begging them not to inform the treasurer of Eads's company "about our confidential efforts to throw the steel contract your way. . . . no one knows about it in St. Louis and no one should know."⁷¹

⁷⁰Carnegie to Eads, February 25, 1870, Carnegie Papers. The awesome difficulties the Butcher Works encountered in fabricating the grooved steel couplings Eads designed in response to Sellers's suggestion are recounted at length in Woodward, pp. 122–56.

⁷¹I should mention that at the end of William Sellers's term as president of the Franklin Institute, the institute's *Journal* published a "puff" about the steel works and its general superintendent, William Butcher (*Journal of the Franklin Institute* 54 [November 1867]: 293–94). The active partners, apparently, were Samuel Huston, president, and Sellers, who had "no more regard for [Butcher's] opinion, or his promises than if he were totally unknown to them" (Carnegie to Eads, October 18, 1870). But E. C. Clark of E. W. Clark & Co. was also a partner (Carnegie to William Butcher, September 15, 1870). On October 1, 1871, Butcher was replaced by William F. Durfee, who had been superintendent of the Kelly Process Co.'s experimental works (see "Iron Making in Pennsylvania") where he established "the first analytical laboratory built as

At any rate, Eads's readiness "to receive suggestions and advice upon the details, methods of construction &c" had been well known to Carnegie and the officers of the Keystone Company from the beginning. More than six months before Keystone took the contract to erect the superstructure, Carnegie had told Jacob Linville that Eads wanted "the suggestions of practical men like [John L.] Piper [Keystone's general manager] . . . and is disposed to do anything reasonable upon questions of detail."⁷² And when Keystone complained, after almost a year of work under the contract, that Eads had not yet provided all the working drawings, Dr. Taussig, chairman of the bridge company's executive committee, reminded them that Eads had made many changes "in accordance with the suggestions and views of your Engineers" and that "the calculations, drawings, tests etc. required for these changes necessarily consume time."⁷³

Changes resulting from the awarding of the steel contract to the Butcher Works, under pressure from Thomson and Scott (and Scott's "little white-haired Scotch devil," as Carnegie had been proud to be called a few years earlier),⁷⁴ were the cause of enormously costly delays. As Howard S. Miller has recently pointed out in the only study of Eads Bridge to add significantly to what was embodied in Woodward's classic study, the Butcher Works failed repeatedly to make the anchor bolts and staves which were the principal steel members of the bridge, and it was only after Eads arranged to have Butcher licensed to make chrome steel under Julius Bauer's 1865 patent that suitable bolts and staves were produced. As Miller also points out, the story of Eads's decision to use chrome steel was confusing at the time and has grown even more confusing since. From the data available to him Miller concluded that, far from being a bold innovator in employing structural alloy steel, Eads was at most "a metallurgical pioneer by default." Chrome steel was, Miller thinks, Eads's "second choice, an unknown material that looked promising only after carbon steel had made such a poor showing" (i.e., in early August 1871) and about which he knew little except what came from "the company's advertising circulars."⁷⁵

The data I have assembled do not support those conclusions. They

an adjunct to steel works" in this country, and who in 1869, at the American Silver Steel Co. in Bridgeport, made the first successful application in the United States of the newly invented Siemens reverberatory-regenerative furnace to the puddling of iron (see *Appleton's Cyclopaedia of American Biography* [New York, 1892], 2:271). In June 1873, after the bankruptcy and reorganization of the Butcher Works, Sellers became the president.

⁷²Carnegie to Piper, June 14, 1869, and Carnegie to Linville, June 19, 1869, Carnegie Papers.

⁷³William Taussig to Carnegie, January 7, 1871, Carnegie Papers.

⁷⁴Carnegie, *Autobiography* (Boston and New York, 1920), p. 72.

⁷⁵Scott and Miller (n. 3 above), pp. 110–13, 115.

indicate that Eads knew a good deal about chrome steel. He had furnished thirty-two samples of it to David Kirkaldy, the pioneer of steel testing in Great Britain, in 1868.⁷⁶ He had tried to interest Tom Scott of the Pennsylvania Railroad in investing in the chrome steel process early in 1869 and had himself, I am reasonably sure, been an investor in the Chrome Steel Works in Brooklyn (which had been set up by the American Tool Steel Company, of which Bauer was the chemist).⁷⁷ He had provided Kirkaldy with more samples to test on April 7, 1869, at about the same time that he arranged to have Henry Flad and his old friend James W. King (now a commodore) of the navy's Bureau of Steam Engineering spend forty-eight hours in the closest inspection of the works, on Eads's personal pledge "that Mr. Haughian's [the superintendent] trade secrets should not be revealed."⁷⁸ And he had, at a meeting of the directors of his bridge company on May 12, 1869, presented a "memorandum of agreement" he had worked out with the American Tool Steel Company (of which the Brooklyn Chrome Steel Works was an offshoot), which induced the board of directors to pass a resolution that it preferred "to contract with the American Tool Steel Co. for Twelve hundred tons of steel with the privilege of all the steel they may require in the construction of their bridge; provided the material furnished be of first class quality, and the price not greater than that charged by any other manufacturer for a similar article."⁷⁹

It seems likely that Eads's attention had first been directed to

⁷⁶Eads to William M. McPherson, president of the bridge company, February 12, 1872, quoted in Woodward, p. 116.

⁷⁷Scott, when considering this investment, had asked Carnegie to find out, in Pittsburgh, what the pioneer steel maker William Coleman thought about the process. Later he had his private secretary, R. D. Barclay, instruct Carnegie to visit the Chrome Steel Works and report on the plant, equipment, and personnel. Carnegie wrote to Scott about Coleman's opinion (he was skeptical) on March 8, 1869, and sent his report to Barclay on March 29, 1869. Though "not pretending to know about the Steel Manfr.," Carnegie reported that "the Steel I saw every where, looked well, I examined bars at every part of the shops & believe they are making a good steel. . . ."

⁷⁸Flad and King "weighed out the proper mixtures, placed them in the crucibles, melted them, cast the ingots, and had the steel finished by the hammer," after which they made "an elaborate and confidential report" to Eads (see Eads's October 1, 1871, report in *Addresses and Papers*, p. 593).

⁷⁹Manuscript minutes of the directors' meeting (see n. 3 above). The Chrome Steel Works were described in an article, "Chrome Steel," *Iron Age* (January 19, 1871), pp. 1-2. See also L. P. Brockett, "The Manufacturing Interests of Brooklyn and Kings County," in *The Civil, Political, Professional and Ecclesiastical History and Commercial and Industrial Record of the County of Kings and the City of Brooklyn*, ed. Henry R. Stiles (New York, 1884), 2:697-98; and *Half Century's Progress of the City of Brooklyn* (New York, 1886), p. 127. Much work remains to be done on the history of chrome steel and the people and companies involved in it.

chrome steel by the naval engineers with whom he worked so closely during the war and after—perhaps by Captain Wise, chief of the ordnance bureau.⁸⁰ Edward Fithian, chief engineer of the navy throughout the war and for some years thereafter, was convinced that chrome steel had “uniform texture in large or small masses,” and performed “three or four times more work than the best tools of carbon steel.”⁸¹ It was, as we have seen, Commodore King, who had supervised the testing of Eads’s turret and had been with Eads in Europe inspecting naval dockyards and ironclads in the fall of 1864,⁸² who went with Flad to investigate the chrome steel process in the spring of 1869. Furthermore, just before Eads arranged for C. P. Haughian of the Chrome Steel Works to teach Butcher how to make steel of Bauer’s patented mixture, Eads had appointed as his chief inspector of iron and steel (at Butcher’s Philadelphia works) Henry W. Fitch, who as a first assistant engineer in the navy had been assigned to special duty in charge of Eads’s gun-carriage at Fort Hamilton, New York, from June 1869 to June 1871 and had now been granted one year’s leave of absence from the navy at Eads’s special request.⁸³ Finally, it is worth noting that the president of the Chrome Steel Company (organized to run the Brooklyn works) was William W. Wood, chief engineer of the Brooklyn Navy Yard, which lay southward across the street from the steel works located at the corner of Kent Avenue and Keap Street—an interesting juxtaposition.⁸⁴

Clearly Eads had good reason to say, as he did, that before the contract with Keystone or the subcontract with the Wm. Butcher Works were made, he was satisfied that chrome steel “possessed qualities eminently suited for the bridge superstructure,” and that even though Krupp, and Petin Gaudet and Company, and “some of the most eminent steel makers in America” had assured him that crucible carbon steel could readily be made to meet his specifications, he did not

⁸⁰See nn. 35 and 37 above. Wise retired as chief in 1868 because of ill health and went to Naples, Italy, where he died April 2, 1869. We know that Eads went briefly to Naples in October or November 1868, where he may have seen Wise (Henry T. Blow to Eads, December 22, 1868, J. B. Eads Collection, Missouri Historical Society).

⁸¹Quoted in a generally skeptical article, “Chrome Steel?” in *Mines, Metals and Arts* (December 2, 1875), p. 135.

⁸²See Eads to Assistant Secretary G. V. Fox, October 4, 1864, Fox Papers, New-York Historical Society.

⁸³Woodward, pp. 83–84. Fitch’s prior service is documented in the National Archives (n. 34 above).

⁸⁴There is a brief biographical sketch of Wood in *Appleton’s Cyclopaedia of American Biography* (New York, 1889), 6:598–99, which does not mention his connection with the Chrome Steel Works.

at any time hesitate “to express [his] belief that the chrome-steel was most likely to meet the requirements of the Bridge.”⁸⁵

The changes in materials used, like the changes in the detailing of the tubes discussed earlier, important as they were in a structural sense, had little effect on the overall appearance of the bridge. But there were other changes of greater visual consequence.

As presented in Eads’s first report (1868) the bridge was to have a center span of 515 feet and side spans of 497 feet, supported by masonry piers whose upstream and downstream faces were to be rounded, as were those of the Koblenz bridge. At some point the piers were redesigned as shown in the undated drawing reproduced as figure 6, perhaps at the suggestion of George I. Barnett, a St. Louis architect of considerable distinction who had rebuilt and enlarged Eads’s own house in 1866, making it into a fashionable Italianate villa, and who in 1870 drew up the designs for a Grand Union Passenger Depot in the “Franco-Italian” style, which Eads and Taussig hoped to erect a couple of blocks west of the St. Louis end of the bridge.⁸⁶ By the summer of 1870, however, when the piers had been built above low water level, the final design (fig. 7) had been worked out.

By this time the length of the spans had also been changed. The center span was now to be 520 feet and the side spans 502, a 5-foot increase in the length of each arched rib or a total increase of 15 feet in the length of the superstructure between piers. Such an increase would one might suppose, require that the piers be spaced farther

⁸⁵J. B. Eads, *Report of the Chief Engineer, October 1, 1871* (St. Louis, 1871), pp. 11–12 (also in *Addresses and Papers*, p. 593). After Haughian returned to Brooklyn, Butcher and his successor, William F. Durfee, had considerable difficulty with production of suitable chrome steel for the anchor bolts and couplings, and in the end it was chiefly in the tube staves (the principal supporting members of the structure) that chrome steel was used. It is of course true, as Miller (n. 3 above) says, that short of analyzing samples from each of the 6,216 staves, there is “no way to know just how much of the ‘world’s first chrome steel structure’ was actually chrome steel” (p. 116). But the available data are reassuring. Early in 1928 J. N. Ostrum, a consulting engineer, drilled 1-inch inspection holes in the bottom of each of the tubes in the arches, and “analysis of the drillings revealed the steel to be a high carbon chromium steel extremely low in sulphur” (see “Eads Bridge Pronounced Safe,” *Railway Age* 84 [1928]: 1442–43; and E. E. Thum, “Alloy Bridge Steel Sixty Years Old,” *Iron Age* [September 20, 1928], pp. 683–86, 733–34). The carbon content of the drilling averaged .79 percent, the sulfur .009 percent, and the chromium .61 percent. Miller (p. 117n) gives the results of analyses made fifty years later of samples from a tube damaged by the collision of a towboat in 1973 which averaged carbon .641 percent, sulfur .022 percent, and chromium .453 percent. No sample ever taken from any one of the 1,036 tubes in the arches has revealed an absence of chromium. We need not hesitate to credit Eads with the first major application of any kind of structural alloy steel anywhere in the world.

⁸⁶Woodward, p. 144; *The City of St. Louis and Its Resources*, a pamphlet published by the *St. Louis Star-Sayings* (1893), p. 140; and *Description and Plans of the Proposed Grand Union Passenger Depot in St. Louis* (St. Louis, 1871), p. 13.

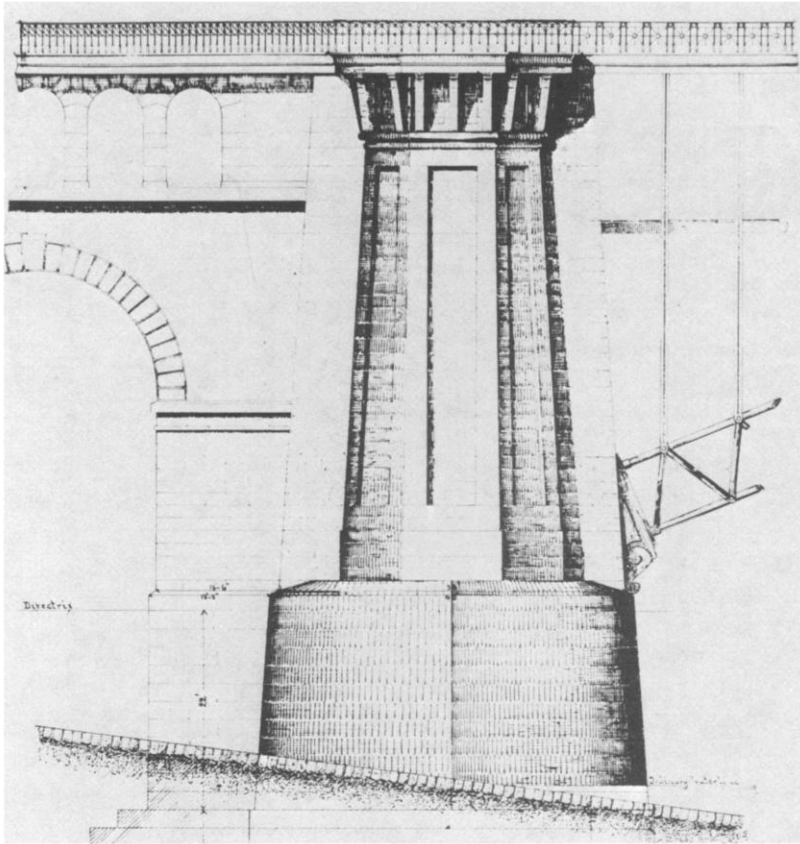


FIG. 6.—South elevation of the west abutment pier, as redesigned in late 1868 or early 1869 (original drawing, probably by William Rehberg, from the files of the Terminal Railroad Association of St. Louis, now in the Washington University archives).

apart than originally planned. Yet the increase in span lengths was not planned until after the location of the abutments and the two river piers had been determined and work had begun on their foundations.⁸⁷

Neither Woodward nor any subsequent writer who has discussed Eads Bridge seems to have noticed this puzzling aspect of the development of the design. But here again we can get a useful clue from Carl Gayler's reminiscences. Gayler was troubled by the fact that when the test loads were applied to the finished bridge in 1874 and the first

⁸⁷The driving of the piles for the east pier breakwater began about August 12, 1869; so by then the location of the river piers had been definitely established (see Eads's report, *Addresses and Papers*, p. 544).

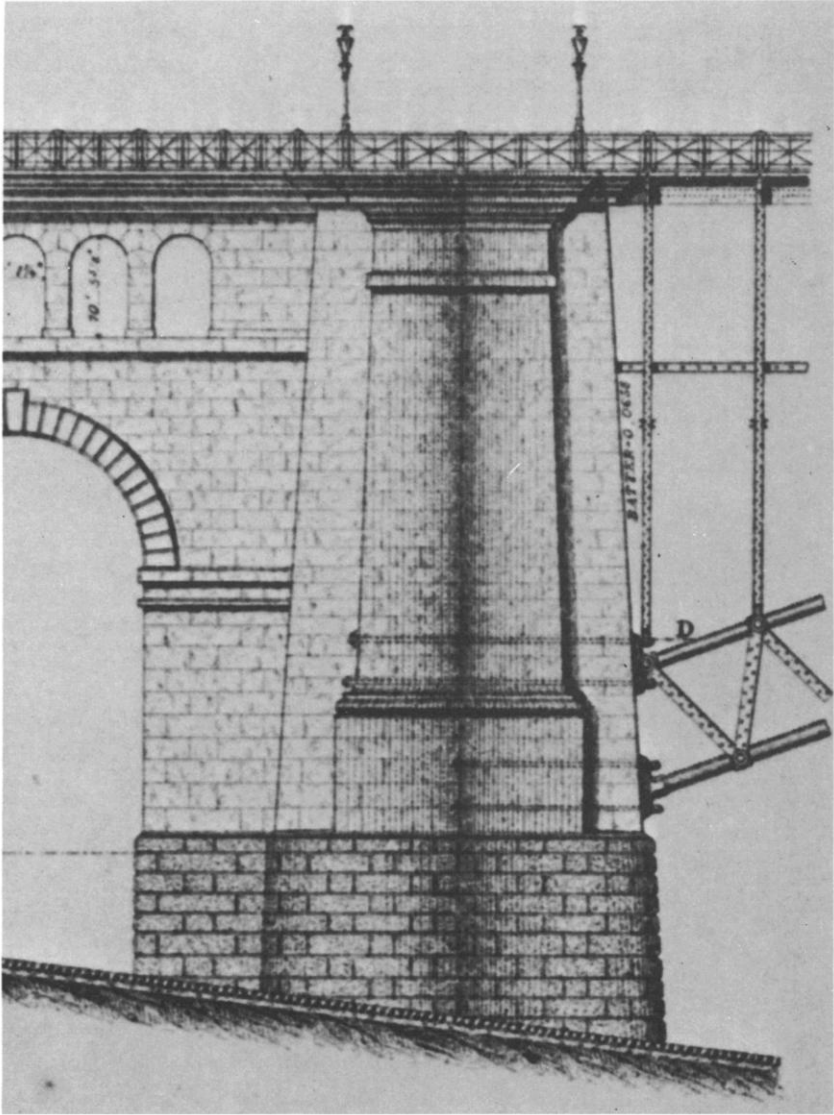


FIG. 7.—South elevation of west abutment pier, as finally designed and as constructed (detail of drawing by W. P. Gerhard, lithograph by Julius Bien, in C. M. Woodward, *A History of the St. Louis Bridge* [St. Louis, 1881], pl. 11).

train had covered the east span, “the east span arch sank and the center span rose: *the East river pier had bent.*”

I will give you the history of those River Piers [he continued]. Mr. Pfeifer, like the accomplished Engineer he is, has laid out one of those piers correctly with the pressure lines of the different as-

sumed loadings laid off, the lower end of the pressure lines striking the bottom within safe distance from the face of the Pier, as the law directs. When Eads comes to see the drawing (I was standing right there) he marks off with a pencil a slice of two or three feet thickness the whole height of the Pier. It was the artist in Eads who protested, and his artistic side led him into this blunder. Eads, true enough, didn't want the pier too slim, but he wanted above all a graceful looking pier. . . .

Poor Pfeifer argues and protests in vain. Eads is his Superior and that ends the controversy.⁸⁸

This was written almost sixty years after the event, and Gayler's memory played him false on a number of details.⁸⁹ But the specificity of the picture of Eads slicing "two or three feet" off the thickness of the pier as Pfeifer had drawn it is, to me at least, convincing. And if Eads did, indeed, slice say 2.5 feet off each side of the two river piers and off the river faces of the two abutment piers, that would have added 5 feet to the distances between them—exactly the amount by which the length of each of the three spans was in fact increased.

In any event, the center span of 520 feet with side spans of 502 feet had been adopted as part of what Eads referred to in his report of October 1870 as "modifications in the general arrangement of the arches and in the details of their construction, which will considerably improve the architectural appearance of the Bridge and simplify its fabrication." The principal changes, he said, were the use of the single cast-steel tube of 18-inch diameter, instead of two of 9 inches, in forming the upper and lower members of each of the four ribbed arches composing each span, and the spacing of the upper and lower tubes 12 feet apart instead of only 8 feet. But even more important, visually, was the raising of the railway so that in no place would it appear below the soffit of the arches as it did in the original design. In that design the railway was 8 feet lower than the center of the 515-foot middle span, a flat line slicing off the upper segment of the arch. In the revised design, with the lower tubes 12 feet instead of 8 feet below the upper tubes (thus deepening the ribbed arches by 4 feet), it was necessary to raise the level of the railway only 4 feet to keep it entirely above the soffit of the middle span's arches.

If the railway had been kept at this level over the side spans, it would have had to descend precipitously over the arcaded approaches at either end of the bridge proper. To lessen the approach grade it was necessary that the tracks should descend gradually each way from the center of the bridge, which would cause them to fall below the

⁸⁸See Gayler Papers (n. 57 above).

⁸⁹The test loads were not applied on July 4, as he says, but on July 1 and 2 (see Woodward, pp. 197–200).

soffit of the side spans even though their ribs had also been deepened 4 feet. To avoid this, Eads lowered the shore ends of the side spans by placing the skewbacks (which received the thrust of the tubular ribbed arches) 18 inches lower on the abutment piers. By so doing he lowered the centers of the side spans 9 inches, permitting the gradient of the railway to be correspondingly lower toward the ends of the bridge. Raising the tracks above the arch soffits would, Eads said, “unquestionably improve the appearance of the structure,” and the lowering of the shore ends of the side spans would also be an architectural improvement since “the effect upon the eye caused by it, will be somewhat similar to that produced by the camber of the bridge.”⁹⁰

These changes, like the trimming of the width of the piers, were primarily the work of what Carl Gayler called “the artist in Eads.” And, as Eads acknowledged, they involved “the necessity of revising the former investigations and results [so carefully worked out by Flad and Pfeifer], so as to ascertain the difference in the strains, and to determine the alterations required in the sectional areas of the various members of the structure.” And this, in turn, required that Rehberg, Gayler, and the others in the drafting room produce “an entirely new set of detail and general drawings.” No wonder there were delays that gave Keystone a plausible excuse for their own delays in erecting the bridge. It is nevertheless appropriate, I think, to close this discussion of Eads as a designer by quoting the climax of Taussig’s unpublished defense of his colleague during the controversies with Keystone in 1871:

I cannot be made to believe [Taussig wrote to Carnegie] that he has embodied anything in his plans for theory’s sake. Genius, as a general thing, never permits itself to be fettered by theories, and I take it that his genius is more of a creative than of a theoretical turn. Nor do I believe that he has added anything unnecessary to his plan for the sake of show or display. Our conversations on this point have been too frequent, and his endeavours to cheapen the cost too evident to me on many occasions. Apart from his own very heavy investment in the enterprise, every impulse of his would induce him to guard the interests of his Company in that respect, just the same as if he had not a Dollar invested in it. He is a noble character, as well as a noble Engineer.⁹¹

⁹⁰Eads’s October 1870 report, *Addresses and Papers*, pp. 577–78. Miller’s account of these changes is quite misleading (p. 136).

⁹¹Taussig to Carnegie, January 7, 1871, Carnegie Papers.