

The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling

Kirti Gandhi, Ph.D., P.E.

President, Gandhi Engineering, Inc., New York, NY

ABSTRACT: The St. Louis Bridge, built by Captain James Eads in 1874, and the Brooklyn Bridge, completed by Colonel Washington Roebling in 1883, shared innovative techniques and established precedents for designing long-span bridges in the years ahead. Despite the St. Louis Bridge being a steel arch bridge which differed from the wire suspension construction of the Brooklyn Bridge, both of these structures were considered the largest bridge of the time, and continue to hold historic significance. Despite the achievements of both Eads and Roebling, their individual successes were overshadowed by a dispute between the two men. The root of this disagreement was the design of caissons used for the foundation, as each engineer claimed to be the first to design the caisson for his bridge foundation. This paper looks at the St. Louis Bridge, the Brooklyn Bridge, and the dispute which came to define these two giants of Civil Engineering.

1 INTRODUCTION

The St. Louis Bridge, built by Captain James Eads in 1874, and the Brooklyn Bridge, completed by Colonel Washington Roebling in 1883, shared innovative techniques and established precedents for designing long-span bridges in the years ahead. Both used methods and designs that challenged engineering preconceptions; pneumatic caissons were used to reach the riverbed to secure the bridge foundation and daring long-span designs defied previous building standards.

2 THE ST. LOUIS BRIDGE

The idea of a suspension bridge across the Mississippi River in St. Louis was first proposed by Charles Ellet in 1839 to the Mayor of St. Louis. Ellet's bridge had a main span of 1200 feet, side spans of 900 feet, and a deck 27 feet wide with a 19 foot roadway and two 4 foot wide sidewalks for a sum less than \$600,000. His proposal was accepted, but the Mayor and City Council refused to proceed with the extravagantly wild and unsafe scheme (Steinman 1957). A second attempt to build a bridge in St. Louis failed in 1855 when the supporters of the bridge did not raise the estimated \$1.5 million needed to build the bridge to carry railways and pedestrians.

John A. Roebling, after completing his railway suspension bridge with a clear 800 foot span over the Niagara Gorge in 1855, proposed a suspension bridge in 1866. His scheme (Figure 1) was made public by his son, Washington, in 1869 in a book "Long Span Railway Bridges" written by his father and published posthumously (Roebling 1869). Roebling's proposal was not accepted possibly due to concerns about the safety of suspension bridges.

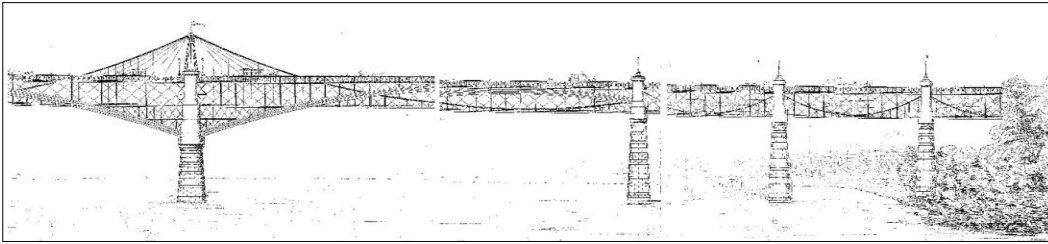


Figure 1: Roebling's proposal for building a suspension bridge in St. Louis (Roebling 1869)

The history of the St. Louis Bridge, as given by Colonel W. Milnor Roberts, involved two rival companies that were each formed to build the St. Louis Bridge (Roberts 1872-3). One company was created in 1864 in St. Louis and the other in Illinois in 1867. In March 1868 an act was passed to consolidate the two companies, and in July 1868, the act of consolidation was recognized and sanctioned by the United States Congress. All the powers of the two companies were vested in a new company, the Illinois and St. Louis Bridge Company.

The act of the U.S. Congress recognizing the first company in 1866, before the consolidation of the two companies, stipulated that the bridge could not be a suspension bridge or a draw bridge, but must be constructed with continuous or unbroken spans, and subject to three additional conditions. One of these conditions was that the bridge must have at least one span 500 feet in clear or two spans of 350 feet with a minimum vertical clearance of 50 feet above the highest tide elevation recorded on the Mississippi River at St. Louis over the navigable channels.

There were two competing groups interested in building the St. Louis Bridge. One group, backed by 27 engineers, recommended two equal spans of 368 feet, preferring it over the three spans of 500 feet designed and proposed by Eads. The group of engineers had serious doubts about the feasibility of building a 500 foot arch because no one had built an arch using wrought iron, and no one had considered using steel which was very expensive in comparison to iron at this time. In May of 1868, Eads answered satisfactorily and conclusively to all of the objections raised by the first group and prevailed. In the final design, Eads selected 520 feet in length for the center span and 502 feet for the side spans. The bridge built by Eads is shown below in Figure 2.



Figure 2: The St. Louis Bridge built by James Eads (Williams 1877)

3 THE BROOKLYN BRIDGE

The first notion of a bridge across the East River in New York City was published by Thomas Pope, an architect and landscape gardener, in 1811. He called his patented bridge the "Flying Pendent Lever Bridge." He built a model approximately 50 feet long on a scale of 3/8th of an inch to one foot to "illustrate a bridge suitable to span the East River at New York" (Pope 1811).

The length of the single span was 1800 feet and the height of the abutment was 223 feet. No one attempted to build the bridge proposed by Pope.

After John Roebling successfully completed the Niagara railway suspension bridge with a clear span of 800 feet, he began contemplating a bigger assignment. He wrote a final report to the owners of the bridge – without mentioning the East River or Brooklyn Bridge – and stated that the future may hold “railway bridges suspended of a 2000 foot span, which will admit of the passage of trains at the highest speed” (Roebling 1855).

John Roebling was appointed Chief Engineer of the New York Bridge Company on May 23, 1867 and submitted his first report on the proposed East River Bridge to the Bridge Company on September 1, 1867 (Roebling 1867).

In 1869 a board of consulting engineers was appointed to review the plans to build the Brooklyn Bridge proposed by John Roebling. Its members were all well-known engineers of the period including Horatio Allen, W.J. McAlpine, J. Dutton Steel, Benjamin H. Latrobe, John Serrel, J.P. Kirkwood, and J.W. Adams. They unanimously agreed that “there is no insurmountable obstacle to building a suspension bridge of a 1,600 span and even much greater” (Engineering 1869a).

Work started on the Brooklyn Bridge in 1869 and it was opened by President Chester A. Arthur on May 24, 1883. The bridge completed by Roebling is shown in Figure 3.



Figure 3. The Brooklyn Bridge (Scientific American 1877)

4 CAPTAIN JAMES EADS

James Eads, the builder of the St. Louis Bridge, was born in Lawrenceburg, Indiana on May 23, 1820. At age 13, his family moved to St. Louis, and from then on he supported himself by first selling apples on the street, working in a store, and then, beginning in 1839, as a clerk on a Mississippi steamboat. He had very little formal education, but had a keen interest in all things mechanical. His knowledge was entirely gained by self-study and practice (Engineering News 1887). On this steamboat, he learned that after five years the submerged cargo of a sunken ship belongs to the retriever; and with this information, Eads discovered the lucrative profession of raising sunken riverboats (Jackson 2001).

In 1842 he formed a company to raise sunken riverboats. As the business expanded, Eads acquired a fleet of boats and was given the title “captain” which followed him for the rest of his life. He used to say that there was not a stretch of 50 miles from St. Louis to New Orleans, in

which he had not stood on the bottom of the river under his diving bell (Railroad Gazette 1887).

During the Civil War, Eads was called upon by President Lincoln to share his knowledge of the Union Army against Confederate attacks on the Mississippi river. This made him a friend of General Ulysses S. Grant who later became President of the United States.

In 1867, Eads was engaged in the planning of the St. Louis Bridge. His design of a three-span arch bridge was chosen over a truss bridge proposed by a rival group. Despite a lack of experience in bridge building, his creative genius, background in raising capital for businesses, and his elegant bridge design won the favor of influential supporters.

To calm the fears of skeptics, Eads (Figure 4) appointed a staff of experienced assistants with impressive experience in building bridges. Three of these engineers included, Col. Henry Flad, Mr. Charles Pfeifer, and Col. W. Milnor Roberts (Eads 1871). Colonel Roberts was selected to take charge of the project in the absence of Eads, as well as provide technical and administrative support. Pfeifer analyzed the various bridge components and calculated stresses. Colonel Flad, besides being on the front line of construction, was responsible for the cantilever erection scheme for the arches. There were two other engineers, Walter Katte and Theodore Cooper, who also became prominent in the bridge engineering field. Katte was the construction engineer for the bridge erector, Keystone Bridge Co., and Cooper was the inspector who made sure that all materials and workmanship were of the highest quality and complied with the construction specifications.

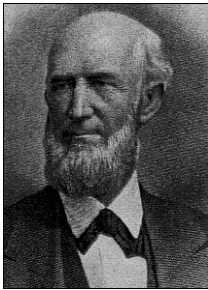


Figure 4: Captain James Eads (Woodward 1881)

In the summer of 1868, Eads was ordered by his physician to take a trip to Europe to recover from his failing health. During his trip he took every opportunity to visit important bridge construction sites with deep foundations. He returned from Europe fully recovered on May 1, 1869. In his report to the Board of Directors, in September 1869, Eads discussed witnessing the sinking of masonry piers by the “plenum pneumatic process,” and claimed that he could improve this process and sink the piers of the St. Louis Bridge safely, expeditiously, and more economically than the method he had originally proposed (Eads 1868).

5 COLONEL WASHINGTON A. ROEBLING

Washington Roebling’s upbringing and education contrasted significantly from that of James Eads. Unlike Eads, Roebling had a formal education including prep school at the Trenton Academy and a degree in civil engineering from Rensselaer Polytechnic Institute (RPI) in Troy, NY. His thesis at RPI was “Design for a Suspension Aqueduct” to carry the Poestenkill Creek in Troy, NY (Roebling 1857). The weight and quantity estimates of the bridge components were so detailed that they leave no doubt to the reader’s mind about Roebling’s familiarity with the construction of a suspension bridge. After finishing college in 1857, Roebling worked for his father, John Roebling, at his mill making wire ropes (Schuyler 1931). This experience at his father’s company allowed Washington Roebling to become familiar with steel ropes which – one day – would be responsible for suspending the Brooklyn Bridge above the East River.

Roebling's next major career move was in 1861 when he enlisted in the Union Army. He intended to design suspension bridges for the army, but largely spent his time writing a publication on military suspension bridges (Mulholland 2006). When he retired from the army as a Colonel in 1865, Washington Roebling married Emily, his commander's sister, whom he had met while she was visiting her brother at the army camp (Sayenga 2009). Shortly after his marriage, Roebling began to work with his father in Cincinnati to construct a suspension bridge over the Ohio River to connect Cincinnati and Covington, Kentucky (Schuyler 1931).

After finishing the Cincinnati and Covington Bridge, Washington Roebling, accompanied by his wife, went to Europe to study pneumatic caissons being used to set bridge foundations (Sayenga 2009). In 1868 he returned brimming with new ideas after seeing a French engineer successfully use pneumatic caissons to sink the piers of a bridge over the Allier River at Vichy. After the time spent studying caissons in Europe, Washington Roebling began to work with his father, John Roebling, who had recently begun the Brooklyn Bridge project and participated in the alignment surveys. In 1869, shortly after Washington Roebling joined his father, John Roebling sustained a painful injury to his foot. The injury became infected and, less than a month after his injury, John Roebling died in June 1869 from tetanus (Mulholland 2006). With his father gone, Washington Roebling, at 32 years old, was appointed by the Board of Directors to be Chief Engineer in charge of building the Brooklyn Bridge in August 1869 (McCullough 1983). *Engineering* (1869c) observed that although the inhabitants of Brooklyn and New York City "sustained a great loss in the untimely death of Mr. John A. Roebling, they are fortunate in that he has left behind him a son possessing the genius of his father, as well as the benefits of his great experience". Similar to the talented engineers working with Eads, Roebling (Figure 5) also had well-respected assistant engineers on his team. Notable engineers included Charles C. Martin, Francis Collingwood, Samuel Probasco, Col. William H. Paine, and George W. McNulty.



Figure 5: Washington A. Roebling (Schuyler 1931)

Given the stark differences between the upbringing and career paths of Eads and Roebling, it is easy to imagine that a disagreement between the two men could be partially professional, as well as tinged with a sense of superiority on the part of each man. Eads was likely to consider himself more experienced in understanding the nature of working with rivers, whereas Roebling likely felt superior in understanding the science behind bridge building.

6 SIMILARITIES BETWEEN THE BRIDGES AND THEIR BUILDERS

With the invention of the Bessemer Process in Europe, the cost of steel had decreased considerably and it was possible to build bridges on a grander scale with structural capabilities previously unimagined. In the past steel was unaffordable as a construction material notwithstanding its superior strength compared to wrought iron. Both Eads and Roebling used steel for their bridges. Eads used steel for the tubular arch members which constituted a small

percent of the total weight of the bridge. Roebling constructed a large part of the Brooklyn Bridge from steel and the cables are exclusively made of steel.

Both Eads and Roebling spent a great deal of time and effort proportioning the key elements of their bridges to make them aesthetically pleasing; Eads in using tubular members and determining the relationship between the length of the center spans (520 feet) and the end spans (502 feet); and Roebling in his towers.

They both also devoted considerable thought and energy to protecting the most vital bridge components: Eads by using six enclosed staves to protect the tubular arch against the atmospheric influence and Roebling by covering the galvanized wires of the compacted cables inside a continuous wire wrapping (Gayler 1909).

Both Eads and Roebling instituted stringent quality control programs. Colonel Henry Flad, Chief Assistant Engineer to Eads, developed a testing machine which was capable of detecting a change in the length of a specimen equal to two hundred thousandth of an inch (Eads 1870). The same machine was calibrated to apply a weight up to 100 tons. Specimens of steel, iron, woods of various kinds, granite, brick limestone, concrete, cement, models of tubes, trusses, etcetera were tested in trial runs. Eads had defined stress limits for compression, tension, and yield in pounds per square inch, and modulus of elasticity between 26,000 ksi and 30,000 ksi. The specifications clearly stated that "failure to stand any one of such tests will be sufficient cause for the rejection of the piece" (Eads 1871).

Roebling developed similar specifications for his steel cable wire (Roebling 1876). When bids (or tenders) were invited for the supply of 3,400 tons of steel wire to form the main cables of the Brooklyn Bridge, the bidders were required to submit samples of their wires, and these wires were tested by Roebling's two assistant engineers, Charles C. Martin and Colonel William H. Paine (Engineering 1877).

Despite the St. Louis Bridge being a steel arch bridge which differed from the wire suspension construction of the Brooklyn Bridge, both of these structures were considered to be a crowning achievement. In addition, the two bridges shared the objective of supporting train traffic, as well as pedestrians. The Brooklyn Bridge continued to transport elevated trains and streetcars until 1948 when the rail lines were removed in favor of additional road space for cars. This reconstruction work was completed in 1953. The St. Louis Bridge was modernized in 2003 in order to support light rail cars and increased vehicular traffic on the bridge.

Although the St. Louis Bridge and the Brooklyn Bridge were engineering successes of historic measures, financially they followed different paths. The St. Louis Bridge had problems meeting its obligations to note and bond holders as early as January 1876; it was sold on December 20, 1878 under decrees of foreclosure on the first and second mortgage (Railroad Gazette 1876, 1878). The Brooklyn Bridge, on the contrary, was a great success due to income generated by daily commuters traveling between Brooklyn and New York.

In 1872 Eads and Roebling, two well-known and highly respected civil engineers, became associated with a well-publicized quarrel. The root of this disagreement was the design of the caissons used in the construction process, as each engineer claimed to be the first person to have designed the caisson structure used to lay the bridge foundation. The argument between Eads and Roebling, a back-and-forth series of articles written by the engineers and published in journals, survives today given the highly public forum in which this dispute occurred.

7 EADS' DESIGN OF PNEUMATIC CAISSONS

Until 1859, only two bridges were built in the United States on pneumatic pile foundations, and the airlocks used in sinking the piles of these bridges was the invention of Alexander Holstrom (Smith 1874). Europe was ahead of the U.S. in developing techniques for deep underwater foundations until the construction of the St. Louis Bridge in 1868. The two piers of the St. Louis Bridge were required to be founded on rock at a depth of more than 80 feet to avoid their failures from scouring during high floods in the Mississippi. Colonel Roberts (Roberts 1872-3)

noted that during the sinking of the piers it was recorded that “a rise of only about 16 feet on top of the ordinary ten feet flow above extreme low water, has scoured out more than 40 feet of sand; the rock bed upon which the caissons finally rested exhibited a smooth, water-worn surface.”

The caissons created by Eads were made of wrought iron (Figure 6). The east pier was 82 feet long by 60 feet wide and the west pier was 82 feet by 48 feet. The air chambers which were located at the bottom were 9 feet high. The caissons designed were very similar except the east piers had seven air locks while the west piers had five air locks.

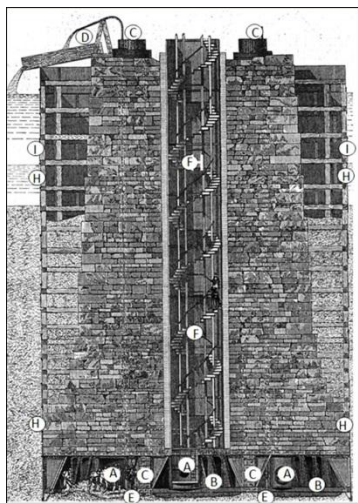


Figure 6: The caisson designed by James Eads (Engineering 1871)

- | | | | |
|--------------|-----------------------|------------------|--------------------------|
| A Air lock | B Air Chambers | C Timber girders | D Discharge of sand pump |
| E Sand pumps | F Main entrance shaft | G Side shaft | H Iron casing |
| | | | I Caisson bracing |

The air locks were circular vertical chambers with diameters varying between 5 and 5½ feet and the height between 6 and 12 feet. The air locks had two doors; the first opening into the open air-shaft and the second leading into the air chamber. This system was designed in such a way that only one door would open at any time.

The air pressure in the air chamber was much higher than the atmospheric pressure in the open air shaft because it contained compressed air. Workers enter the air lock by entering through the first door between the air shaft and the air lock. After closing this door, the air pressure in the air lock is gradually increased by pumping compressed air into the chamber until the air pressure is equal to that in the air chamber. At this point the person opens the second door of the air lock and enters the air chamber where the construction activities are taking place, closing the second behind himself. Again, the pressure in the air lock is reduced to that of the atmospheric pressure. For those leaving the air chamber, the process is reversed and the air lock is pressurized first.

On the east pier, the maximum depth at which the caisson was founded was 110 feet, 6 inches below the surface of the water. With a pressure of 48 pounds per square inch, men were allowed to work one hour at a time, up to three times per day. Almost all of the excavation was removal of sand from the river bottom while the caissons were lowered by adding masonry on the top. One of the most simple and yet most novel, effective, and ingenious devices used for the removal of sand was the sand pump invented by Eads (Figure 7). There were no moving parts and, therefore, no danger of clogging the pump. The operation of the pump is described by Roberts as follows:

A stream of water is forced down through one pipe and caused to discharge near the sand into another annular jet in an upward direction. The jet creates a vacuum below it by

which the sand is drawn into the second pipe or pump, the lower end of which is in the sand and water, and the force of the jet drives the sand on upward to the horizontal discharging pipe above the surface of the river as soon as it passes through the annular opening in the jet.

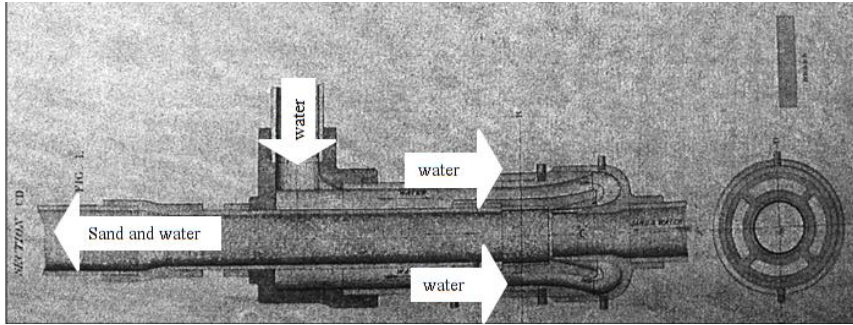


Figure 7. Details of the pump created by James Eads (Woodward 1881)

For the east pier the sand pumps work perfectly when the discharge pipe was 120 feet in vertical height above the jet. It required a gang of six or seven men to shovel the sand and manage one sand pump; two sand pumps were powered with steam and a pump.

With the construction of the deep caissons and the first bridge over the Mississippi, Eads established his supremacy in solving the most difficult engineering problems of his time. He was the first one to place the air locks within the air chamber at the bottom of open air shafts and he invented a sand pump which considerably reduced the construction time necessary within the caissons. Other firsts in building the deep foundations for the St. Louis Bridge are listed by Woodward (1881).

8 ROEBLING'S DESIGN OF PNEUMATIC CAISSONS

Brooklyn had an air of festivities the day the first caisson (Figures 8a and 8b) was released from Greenpoint, Brooklyn in May 1870 (Roebbling 1870a). The caisson was pulled five miles down the East River by six tugboats in two stages – to account for tides – over two days. Eventually it came to rest next to the Fulton Ferry docking slip (Roebbling 1870b). Due to the fact that the work was being done out of sight, the caisson and the workers became a topic of intense interest for many New Yorkers with reporters and artists regularly visiting the work area and publishing reports. Construction of the caissons of the Brooklyn Bridge is covered in greater detail by Collingwood (1872-3, 1874, 1875).

Similar to Eads, Roebbling intended for the base of the Brooklyn Bridge foundation to lie directly on the bedrock underwater. Washington Roebbling, who had spent a great deal of time in Europe studying the structure of caissons, was to step in and become the engineer in charge of building the bridge. The dimensions of the caissons varied between the Brooklyn and Manhattan locations, but were approximately 170 feet long by 102 feet wide, or about half the length of a city block (Roebbling 1872a). This would be the first attempt to sink a structure this large into the ground. The structure of the caissons built by Roebbling were similar to those designed by Eads; Roebbling's caissons were built of yellow pine, caulked to prevent air leakage, and contained immense air-locks to monitor the air pressure in the work chamber (Roebbling 1873a). Unlike the system devised by Eads, the caissons in New York used a sand siphon created by Roebbling's team to remove the excavated materials (Collingwood 1872-3).

The objective of clearing away earth submerged below water was straightforward, but the workers began to face severe health problems as the caissons sank deeper into the ground. The workers were unaccustomed to working under such air pressure and suffered from

decompression sickness due to a build-up of nitrogen in their bodies. It was eventually discovered that workers should not quickly emerge after working; instead, the safest method was to slowly climb the stairs when finished working. As the caissons continued to sink deeper and be succumbed to greater pressure the workers began to tire quickly and work shifts were decreased to keep the workers in good health (Roebing 1872b, 1872c).

Washington Roebing also suffered from multiple attacks of the bends throughout the construction of the Brooklyn Bridge; his health problems eventually exacerbated to the point in which he supervised the bridge construction via a telescope from his home (Salvadori 1980). Yet, despite the setbacks, the work progressed with bedrock reached in New York in May of 1872 (Roebing 1872b). The depth of the bedrock was significantly shallower in New York than in St. Louis. On the Brooklyn side of the East River, workers hit bedrock at 44.5 feet and in New York bedrock was reached at 78.5 feet (Collingwood 1872-3).

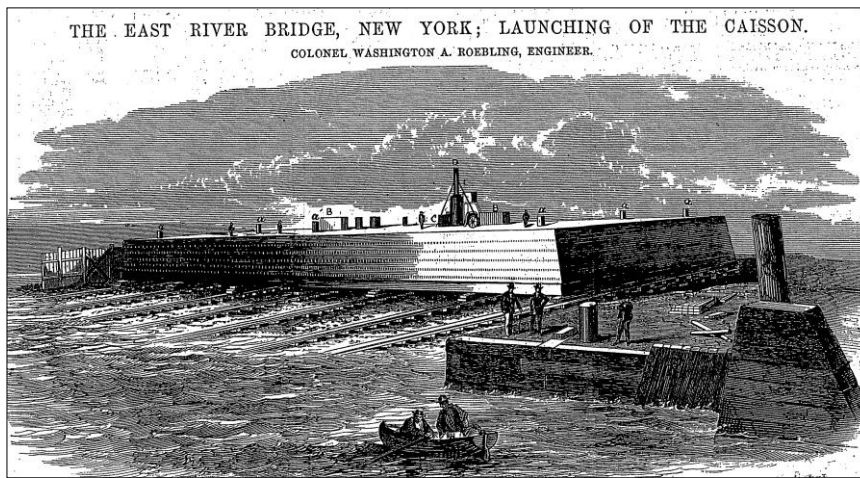


Figure 8a: The Brooklyn caisson before being launched (Engineering 1870)

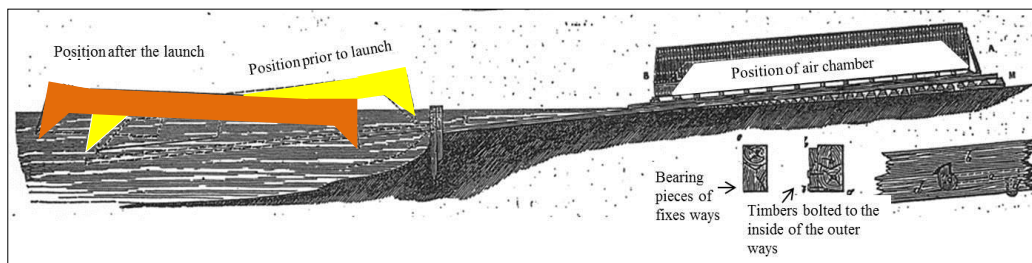


Figure 8b. Launching of the Brooklyn caisson (Engineering 1870)

9 EADS' LETTER IN *ENGINEERING*

The disagreement between James Eads and Washington Roebing was linked to ownership in the design of caissons; the problem began with Roebing's publication in 1872 of a 92-page booklet titled "Pneumatic Tower Foundations of the East River Suspension Bridge" (Roebing 1872a). This booklet explained the construction and purpose of the caissons used for the foundation of the East River Bridge. In the second paragraph of the preface of his booklet Roebing acknowledged that despite his two pneumatic caissons (located in Brooklyn and New York) being the largest in size, the St. Louis Bridge caissons went deeper than those used in

building the Brooklyn Bridge. Roebling's account of the construction of the two caissons was largely impersonal and did not blatantly claim ownership of the idea of placing the air-lock at the bottom of the air shaft rather than above water level. A paragraph on page 71 of his booklet became the reason for the feud between Eads and Roebling, as well as a \$100,000 lawsuit filed by Eads against Roebling for the infringement of his patent. The paragraph reads as follows:

The idea of placing the air-lock at the bottom of the air-shaft, below the water level, in place of above it, in masonry caissons, is not new, having been proposed in England as long ago as 1831 by Lord Cochran, and again by Wm. Bush in 1841, and still later in 1850 by G. Pfaunmuller, of Mayence. It, nevertheless, remained for Captain Eads, in his St. Louis caissons, to make the first practical application of the same on a really large scale in this country.

To a casual reader, this paragraph credited Eads for converting the European idea into a reality for the first time in the United States. Yet, as Eads read these words, he believed the statement implied that he had copied the caisson design – specifically placing the air-lock at the base of the air shaft – from predecessors and was not attributed credit for his innovations. Eads found this statement to be tremendously insulting.

After Washington Roebling published his booklet, James Eads responded with a letter to the editor of *Engineering* on April 16, 1873 which was published on May 16, 1873 (Eads 1873a). In this letter, he asserted that the previous engineers referenced by Roebling did not use the same air-lock system as Eads' design with the air-lock placed below water level. Eads also claimed his open-air staircase shaft system was an original design for which he deserved credit.

Eads taunted and tormented Roebling about his lack of understanding about patents held by previous inventors, Lord Cochran and William Bush, whose names Roebling had mentioned in his paragraph to which Eads objected. When Eads was – seemingly – giving credit to Roebling, his tone was dripping with sarcasm. An example follows:

Colonel Roebling's generosity to me in one point has made him unjust to himself, and has probably delayed his acknowledgment to Herr Pfaunmuller. The credit he gives me for making the first practical application of Pfaunmuller's idea "on a really large scale in this country" belongs exclusively to himself.

The implication, according to Eads, was that Roebling had not only copied Pfaunmuller's ideas, but Eads' ideas, as well. Eads ends his letter by saying that Roebling's failure for the last three years to credit him with the design of the pneumatic caissons which Roebling appropriated, and his silence to give Eads the credit for his patent, had compelled him to correct the record. Nowhere in his letter did Eads mention that he had filed a \$100,000 lawsuit against Roebling for infringement of his patent.

10 WASHINGTON ROEBLING'S REPLY

When Eads' letter was published in *Engineering*, Roebling was traveling in Europe. His letter dated at Wiesbaden, Germany was June 12, 1873 and was published in *Engineering* on June 27, 1873 (Roebling 1873c). After reading Eads' letter in *Engineering*, Roebling observed that Eads' "skill in blowing his own trumpet is only surpassed by his art in writing abusive and unjust articles about other people." Roebling also claimed that the description of the pneumatic caissons from his booklet gave credit to Eads' originality with a nod to the influence of predecessors in Europe. He explained the nature of the dispute between himself and Eads as follows:

The principal point of dispute, however, between us is as follows: Captain Eads virtually makes the broad claim that any device which has been used in a pneumatic cylinder can be

made the subject of a new patent when applied to a “masonry caisson” and in that spirit has had several patents granted. I choose to differ with him on that point, and before paying the round sum with which he proposes to tax the engineering world for the next fifteen years, I have preferred to leave the matter to the decision of the court of law, where it is now being tried.

Roebing’s main argument against Eads’ patents was that neither did Eads invent the airlock, nor did he invent any device related to the airlock. Eads’ main innovation was positioning the air lock at the base of the air shaft rather than at the top; Roebing did not believe this warranted a patent.

Roebing’s skepticism about granting patents by different countries without thorough research and investigation was justified. In 1869 he learned that patents were granted in England for wire rope fastenings designed by Charles Lundborg in Sweden (Figure 9). He responded by showing wire rope fastenings developed and used by his father’s business more than 30 years ago (Figure 10).

If Roebing had concluded his letter in *Engineering* at this point, the statement would have been less offensive. However, he went on to accuse Eads of stealing his ideas and insulted him by calling him names. Roebing sarcastically commented that “. . . where would you go to find an easier material to sink [a caisson] through [a river] than at St. Louis, or a more difficult one than in the East River” (Roebing 1873b). This response did not help Roebing to establish a good relationship with the public and continued to escalate his dispute with Eads.

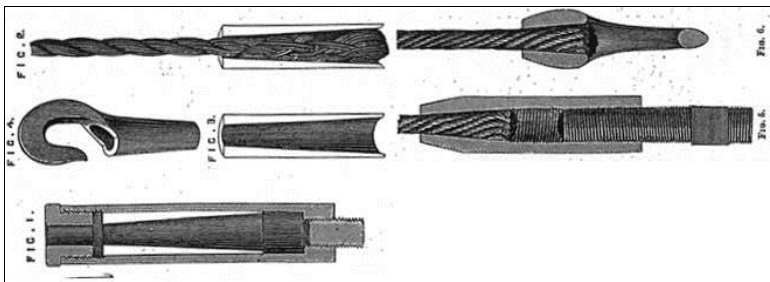


Figure 9. Wire rope fastenings designed in Sweden by Charles Lundborg and patented in England by J.E. Holmes in 1869 (*Engineering* 1869b).

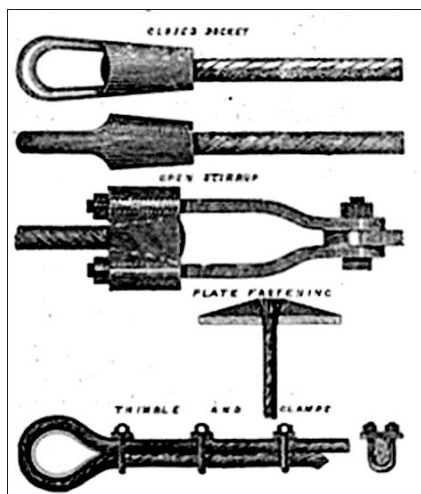


Figure 10. Wire rope fastenings used by John A. Roebing since 1839 without a patent (*Engineering* 1869c).

11 REJOINER FROM EADS

The published response from Washington Roebling encouraged James Eads to – again – respond to the claims in *Engineering*. In September 1873 his response was published showing three cross-sections of caissons (Eads 1873b). The first was Roebling’s original design, the second was Eads’ design, and the third showed Roebling’s modified design (Figure 11). If the drawings are correct, the structure designed by Roebling was clearly influenced by the ideas of Eads. Although the exact construction dates are somewhat unclear, it is agreed that James Eads began constructing his caisson prior to Washington Roebling. These letters revealed that Roebling had visited Eads in St. Louis in 1870 to view the caissons and later Eads had visited the work site of Roebling to see the progress of the Brooklyn caisson. Eads’ response to Roebling also mentioned a series of five features in the St. Louis caisson that he believed were unique by being used in combination together. The remainder of Eads’ letter devolves into a series of cantankerous criticisms over trivial matters.

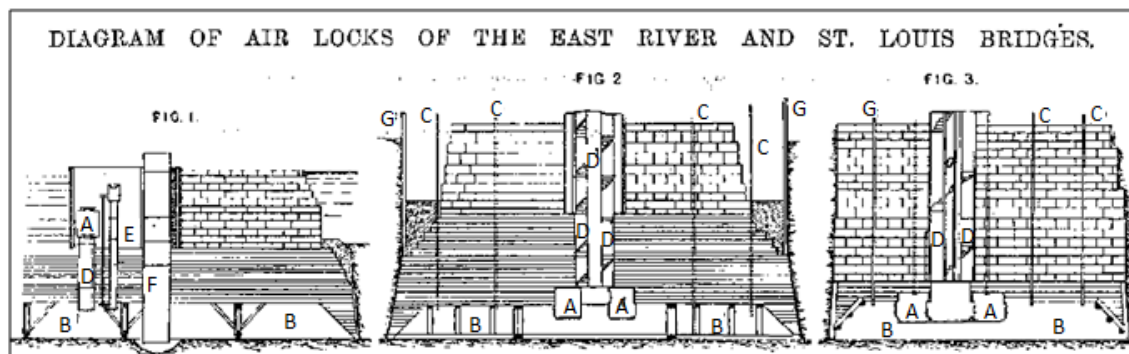


Figure 11: A – Air locks, B – Air chamber, C – Sand pipes, D – Air shaft, E – Supply shaft, F – Water shaft, G – Cofferdam (Eads 1873b)

12 THE U.S. ARMY ENGINEERS’ INVESTIGATIONS AND FINDINGS

In 1873, while the St. Louis Bridge was under construction, several business men linked to the steamboat companies filed a formal protest against the bridge to the Secretary of War. He convened a “Board of Engineer Officers” (the Board) to examine the construction of the bridge and report if the bridge would prove a serious obstruction to navigation, and if so, to determine the means of modifying the construction.

The Board consisted of Colonel J.H. Simpson who had his headquarters in the city of St. Louis, Major Gouverneur K. Warren (brother-in-law of Washington Roebling), Major G. Weitzel, Major William M. Merrill, and Major Charles R. Suter.

After two days of hearings, the Board issued a report on September 11, 1873 addressed to General A.A. Humphreys, Chief Engineer of the U.S. Army, concluding that the “bridge, as at present designed, will prove a very serious obstruction to the navigation of the Mississippi River.” To remedy this problem, the Board recommended building a 120 foot wide canal behind the east abutment with a draw bridge over the canal to allow the easy passage of large boats (Simpson, et al 1873).

General Humphreys concurred with the findings of the Board, and submitted the report to William Belknap, the Secretary of War, with a recommendation dated October 6, 1873 suggesting that it be submitted to Congress during the next session for further action. The Secretary of War approved the recommendation of General Humphreys on October 10, 1873 and authorized him to forward the report to the bridge company. General Humphreys complied and submitted the report on October 15, 1873.

13 EADS' RESPONSE TO THE U.S. ARMY ENGINEERS' FINDINGS

Eads and the officers of the Bridge Company were concerned that the U.S. Army Engineers' report would affect their credit rating and their ability to raise capital to complete the bridge (Woodward 1881). Eads vigorously defended the bridge by responding to each and every objection raised in the report, concluding that the bridge was built according to the dimensions listed in the charter of the Bridge Company and approved by the U.S. Congress (Woodward 1881).

An anonymous letter published in the *Railroad Gazette* criticized the Army Engineers' report and provided the cost estimate prepared by Colonel Henry Flad (the assistant engineer to Eads) to build the canal and the draw bridge (1873). This cost estimate was \$3,065,497, however the letter commented that the cost would increase to \$10 million if the work was done by the government.

The Board of Engineer Officers reconvened in January 1874 to review the response from Eads, the survey, and the cost estimates for the canal and drawbridge. The Board issued a Supplementary Report dated January 31, 1874. It estimated the total cost to implement the recommendations to be \$1,172,436.12. The Supplementary Report reaffirmed its original decision that "if no acceptable modifications can be made (to the bridge) then it (the bridge) should be entirely reconstructed" (Woodward 1881).

General Warren wrote a separate opinion expressing his frustrations against Eads and his supporters for framing a charter to build a new bridge which explicitly excluded the construction of a suspension bridge. As stated before, John Roebling had submitted his proposal in 1865 to build a suspension bridge across the Mississippi River at St. Louis which was rejected. In part, his report stated:

I am not indifferent to the interest of those who have lavished their money in this undertaking [of building the St. Louis Bridge]; but a greater public interest should not be destroyed unnecessarily for their sake. I am convinced that a bridge suited to this great want, at an expense much less than has already been made, almost if not entirely unobstructing [sic] navigation, could years ago have been completed, upon design well known and tried in this country, had not the authors of the present monsters stood in the way (Woodward 1881).

Although Washington Roebling had nothing to do with the opinion expressed by his brother-in-law, the public in general and engineers in particular, considered this as retaliation against Eads and related to the feud between Eads and Roebling.

Eads was able to defy the recommendations of the U.S. Army Engineers due to his relationship with President Ulysses S. Grant. After consulting with Eads, Grant issued an opinion stating that "Congress had authorized the building of the bridge. . . so only Congress could decide to pull it down" (McCullough 1983). Once the bridge was built, it looked magnificent and people appreciated it. Congress did not vote to pull down the bridge; and the whole matter of it being an obstruction to navigation was soon forgotten.

Since 1873, Roebling had been crippled with the "bends", and was not in any position to direct his work force on the construction site. Instead, he needed to conserve his energy and concentration to focus not only on the construction, but also the financial, administrative, and political problems facing the project.

The years 1875 and 1876 were very hectic, as far as activities for the Brooklyn Bridge were concerned. The removal of the existing buildings on the site of the anchorage had started on May 7, 1875 and excavation had reached a depth of twenty feet. As of February 1876, the New York tower had reached the height of 208 feet and left 30 feet yet to be completed. The anchorage on the Brooklyn side was practically complete and the New York anchorage was in an advanced condition. Since August 1875, 27,000 CY of the masonry of the anchorage was completed. The last of the masonry of the anchorages was completed in the beginning of

September 1876. The towers and anchorages were completed and the construction of the bridge proper was about to begin, including the spinning of the cables between the two anchorages passing over the two towers. Each cable was going to have 19 strands and each strand was going to contain 330 wires.

The idea of defending himself against the lawsuit by Eads was mentally taxing. Had Roebling been as physically healthy and active as Eads, he would have likely defended Eads' claim in a court of law. Rather than defend himself, he decided to make an out-of-court settlement for \$5000 (Engineering News 1876). At the time, Roebling was in poor health, had a crushing workload, and the dispute had been unresolved for five years. It was prudent for Roebling to make a settlement of \$5000, or five cents on the dollar for the amount which he was originally sued, to Eads. For Eads this was a moral victory, and an acknowledgment from Roebling that he had copied Eads' design of pneumatic caissons by placing the airlocks at the bottom of the air shafts. The five year old feud between the two giants of civil engineering was finally settled for \$5000, after both Eads and Roebling had spent five years and a great deal of money attempting to defend their reputations.

14 CONCLUSION

Given the harsh upbringing of Eads – who had to fend for himself since he was thirteen – and the comparatively comfortable childhood of Washington Roebling, it became evident that Roebling was not well-equipped to handle the ugly politics of a public dispute. Eads, on the other hand, had a history of working in the business world. This experience provided him with a real-world savvy in handling the dispute with skill. Eads understood how to make his point while winning over public opinion; he emerged from the fight as the winner. Roebling, on the other hand, lost his temper in a public forum and shortly after gave up the argument against Eads' claims. Years later, as evident in the quote below (last sentence), Roebling reflected on the harsh repercussions of the dispute due to his poor handling of the situation.

More than the financial loss of \$5000, Roebling's hurt was psychological and one of isolation as a result of the feud with Eads. He discussed this incident later in life as follows:

I adopted this suggestion of [air-locks from]Mr. Sickels [which were used] in the N.Y. Caisson – This led to a fierce attack and lawsuit for \$100,000 damages on part of Cpt. Eads of St. Louis to whom a patent for this idea had been granted in the meantime. . . The whole Engineering world in the U.S. sided with Cpt. Eads, most unjustly so, because the facts are exactly as here stated. These feelings were actuated entirely by jealousy – the Brooklyn Bridge was by far the largest and most prominent Engineering work of its day – Throughout its construction the attitude of the Engineering fraternity towards me was one of hostility, envy and hatred (Mulholland 2006).

Unfortunately, Roebling never recovered from this isolation for the remainder of his life.

15 ACKNOWLEDGEMENTS

The author thanks Robert Mayo, Christopher Bassett, and Ms. Ling Zhang of Rensselaer Polytechnic Institute's Folsom Library for their assistance in locating the references; and Brenda Hill of Gandhi Engineering, Inc., for her help preparing and editing this paper.

REFERENCES

Collingwood, F., 1872-3, "A few facts about the caissons of the East River Bridge," Trans., ASCE V.1, Paper XXX, pp. 353 – 366.

- Collingwood, F., 1874, "Further notes on the caissons of the East River Bridge," Trans., ASCE, V. 2, Paper XLVI, pp. 119 – 134.
- Collingwood, F., 1875, "The foundations for the Brooklyn anchorage of the East River Bridge," Trans., ASCE, V. 3, Paper XCIII, pp. 142 – 146.
- Eads, James B., 1868, "The St. Louis Bridge method of sinking the piers," Engineering, V. 6, August 21, 1868, p. 175.
- Eads, James B., 1870, "Report of the chief engineer, testing machine," Engineering, V. 10, December 30, 1870, pp. 487 – 488.
- Eads, James B., 1871, "Report of the chief engineer, appendix, specifications for cast steel work," Engineering, V. 11, January 27, 1871, pp. 77 – 78.
- Eads, James B., 1873a, "Pneumatic foundations," Engineering, V. 15, May 16, 1873, p. 337.
- Eads, James B., 1873b, "Pneumatic foundations," Engineering, V. 16, September 5, 1873, pp. 195 - 196.
- Engineering, 1869a, "The East River Bridge," V. 7, April 2, 1869, p. 223.
- Engineering, 1869b, "Wire rope fastening," V. 8, September 17, 1869, p. 202.
- Engineering, 1869c, "Wire rope fastening," V. 8, November 12, 1869, p. 319.
- Engineering, 1870, "East River Bridge: New York," V. 10, June 10, 1870, p. 408.
- Engineering, 1871, "Method of sinking foundations for the piers of the St. Louis Bridge," V. 11, February 3, 1871, p. 80.
- Engineering, 1877, "Steel wire cables," V. 23, February 16, 1877, pp. 134 – 135.
- Engineering News, 1876, "The Eads method of sinking bridge piers," V. 3, July 15, 1876, p. 230.
- Engineering News, 1887, "James Buchanan Eads," V. 17, April 16, 1887, pp. 256 – 257.
- Gayler, Carl, 1909, "Bridge designing," Journal of the Association of Engineering Societies, V. 42, pp. 107 – 116.
- Jackson, Robert W., 2001, "Rails across the Mississippi: A history of the St. Louis Bridge," Published by University of Illinois Press, Chicago, IL, 2001, 265 pp.
- McCullough, David, 1983, "The great bridge: The epic story of the building of the Brooklyn Bridge," Published by Simon & Schuster, New York, NY, 1983, 636 pp.
- Mulholland, Brian, 2006, "Biography of John A. Roebling by his son Washington A. Roebling," Self published, 326 pp.
- Pope, Thomas, 1811, "A treatise on bridge architecture," Printed for the author by Alexander Niven, New York, 288 pp. and 13 plates.
- Railroad Gazette, 1873, "The report of the board of engineer officers on the St. Louis bridge," V. 5, November 8, 1873, p. 455.
- Railroad Gazette, 1876, "Illinois and St. Louis Bridge," V. 8, January 28, 1876, p. 45.
- Railroad Gazette, 1878, "Foreclosure sales," V. 10, December 27, 1878, p. 627.
- Railroad Gazette, 1887, "James B. Eads," V. 19, March 18, 1887, p. 176.
- Roberts, W. Milnor, 1872-3, "Description of the 'Plenum Pneumatic Process' as applied in founding the piers of the Illinois and St. Louis Bridge, at St. Louis, MO," Trans., ASCE, V. 1, Paper XXI, pp. 259 - 273.
- Roebling, John A., 1855, "Final report to the presidents and directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies," p.5, May 1, 1855, Steam Press of Lee, Mann, & Co., Rochester, NY, 47 pp.
- Roebling, John A. 1867, "Report to the president and directors of the New York bridge company on the proposed East River Bridge," Daily Eagle Print, Brooklyn, 1867, 48pp.
- Roebling, John A., 1869, "Long and short span railway bridges," Published by D. Van Nostrand, New York, NY, 1869, 46 pp. and 10 plates.
- Roebling, Washington A., 1857, "Design for a suspension aqueduct," Thesis for the degree of Civil Engineer, microfilm, Folsom Library, RPI, Troy, NY.
- Roebling, Washington A., 1870a, "East River Bridge," Engineering, V. 10, October 14, 1870, p. 275.
- Roebling, Washington A., 1870b, "East River Bridge," Engineering, V. 10, October 28, 1870, p. 322.
- Roebling, Washington A., 1872a, "Pneumatic tower foundations of the East River suspension bridge," Published by George W. Averell, New York, NY, 98 pp.
- Roebling, Washington A., 1872b, "The East River Bridge," Engineering, V. 14, September 6, 1872, p. 181 – 182.
- Roebling, Washington A., 1872c, "The East River Bridge," Engineering, V. 14, September 13, 1872, p. 198.
- Roebling, Washington A. 1873a, "East River Bridge New York," Engineering, V. 15, February 14, 1873, pp. 117 – 118.

- Roebing, Washington A., 1873b, "*East River Bridge New York*," *Engineering*, V. 15, February 21, 1873, p. 134.
- Roebing, Washington A., 1873c, "*Pneumatic foundations*," *Engineering*, V. 15, June 27, 1873, p. 458.
- Roebing, Washington A., 1876, "*Specifications for steel cable wire for the East River suspension bridge, 1876*," *Engineering News*, V. 3, October 28, 1876, pp. 350 – 351.
- Salvadori, Mario, 1980, "*Why buildings stand up: The strength of architecture*," Published by Norton, New York, NY, 311 pp.
- Sayenga, Donald (ed.), 2009, "*Washington Roebling's father: A memoir of John A. Roebling*," Published by American Society of Civil Engineers, Reston, VA, 277 pp.
- Schuyler, Hamilton, 1931, "*The Roebings: A century of engineers, bridge-builders, and industrialists*," Published by Princeton University Press, Princeton, NJ, 425 pp.
- Scientific American, 1877, "*Cable fasteners of the East River Bridge*," V. 37, p. 79, 82, August 11, 1877.
- Simpson, J.H., Warren, G.K., Weitzel, G., Merrill, W.E., and Suter, C.R., 1873, "*The St. Louis Bridge an obstruction to navigation*," *The Railroad Gazette*, V. 5, October 25, 1873, pp. 434 – 435.
- Smith, William Sooy, 1874, "*Pneumatic foundations*," *ASCE Transactions*, V. 2, Paper LXXXI, pp. 411 - 426.
- Steinman, David and Watson, Sara Ruth, 1957, "*Bridges and their builders*," Published by Dover Publications, Inc., New York, NY, 401 pp.
- Williams, J. David, 1877, "*America Illustrated*," Published by the Manhattan Printing and Publishing Company, New York, NY, 48 pp.
- Woodward, C.M., 1881, "*A history of the St. Louis bridge; Containing a full account of every step in its construction and erection, including the theory of the ribbed arch and the tests of materials*," Published by G.I. Jones and Company, St. Louis, MO, 391 pp. and 46 plates.