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Bridging the Mississippi: A History of the Rivalry between Suspension and Arch Modes of Engineering

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Introduction

The iron and steel arch bridge[1] spanning the Mississippi River in downtown Saint Louis just north of the Gateway Arch is commonly known as the Eads Bridge. This is not the official name. The official name at the time of its opening on July 4, 1874, was the "Illinois and St. Louis Bridge."[2] The fact that this bridge is not only still standing but also providing daily passage over the Mississippi River for light rail and automobile traffic is a testament to the ruggedness of its construction. The bridge's existence and permanence seem assured today. However, the inception and eventual construction of the first bridge to cross the Mississippi River at Saint Louis was in doubt from the first discussion of any bridge at Saint Louis. It was not until James B. Eads took control of all aspects of the Saint Louis Bridge project in early 1867 that a bridge at Saint Louis became a reality. Although the completed bridge is an iron and steel arch bridge, the technology to build a suspension bridge spanning most, if not all, of the Mississippi River existed at the time of the construction of the Eads arch bridge. Several proposals for suspension bridges at Saint Louis were submitted from 1839 to 1865 but all were rejected. Analysis by Eads of the components, and construction methods, of both types of bridges led him to the conclusion that an arch bridge was the superior type bridge and the type to build at Saint Louis.[3]

My thesis will examine the evolution of bridge-building technology, specifically suspension bridge-building technology, research the decision making process Eads employed in selecting an arch bridge design, and present conclusions that Eads reached

[1] Appendix G.
[2] Henry Petroski, *Engineers of Dreams* (New York: Alfred A. Knopf, 1995), 59.
[3] C.M. Woodward, *A History of the St. Louis Bridge* (St. Louis, MO: G.I. Jones and Company, 1881), 15.

that resulted in his belief that an arch bridge, built with the new technology of steel, was superior to a suspension bridge.

The Civil War had brought the economic growth of Saint Louis to a near standstill. Trade with the South was virtually eliminated. After hostilities ended the southern economy slowly improved. Saint Louis, a longtime trader of the South, saw their own economy expand as well. Cotton was a major component of the Saint Louis economy in the 1850's and after the war played an even greater role in the Saint Louis economy. By 1874, the year the Eads Bridge opened; over 100,000 bales of cotton were flowing through the Saint Louis economy. Due to new technology that was implemented at Saint Louis to compress bales of cotton, rail transport from Saint Louis to eastern destinations became cheaper than river transportation. The Wiggins Ferry monopoly on freight crossing the Mississippi River at Saint Louis, coupled with increased economic growth at Saint Louis, highlighted the need for a bridge at Saint Louis. In his book, *Lion of the Valley*, James Neal Primm believed the economic gain from the cotton trade demanded a bridge at Saint Louis when he stated; "The demands of the cotton trade emphasized the need for a railroad bridge across the Mississippi."[4] The absence of a bridge across the Mississippi River at Saint Louis might seem to have prevented any business across the river, but early in the city's history a system of ferries provided adequate, if not ideal, river crossing.

Canals, steamboats, ferries, and railroads were all forms of transportation in use in the decades leading up to the construction of the Eads Bridge. As the mode of transportation progressed from canals to steamboats to railroads the need for new infrastructure progressed as well. Stone and wood bridges spanning minor streams and

[4] James Neal Primm, *Lion of the Valley* (Boulder, CO: Pruett Publishing Company, 1981), 292-293.

rivers provided satisfactory crossing for pedestrians and horse drawn wagons. As the need to cross wide and deep rivers, such as the Mississippi River at Saint Louis, developed during the mid-nineteenth century, pedestrians, horse riders, and wagons required the services of a ferry system. Difficult, time consuming, and often an expensive monopoly in many cities, ferries did provide an important service. As railroads began expanding and encountering rivers they also relied on the ferry systems.[5] Before the arrival of railroads, the principal demand for a bridge came from pedestrians, horse riders, and wagons. In 1852 this changed in Saint Louis when the Pacific Railroad of Missouri began operating out of the city. In 1854 the Ohio and Mississippi Railroad reached Illinoistown, present day East Saint Louis. The Mississippi River created an obstacle for railroads. It was an obstacle they could overcome, but not without great difficulty. In the early history of the railroads arriving at the Mississippi River, goods transported by the railroads were unloaded from the train, loaded onto a ferry, transported across the river, unloaded from the ferry and eventually loaded back onto a train and transported to their destination. This was an expensive, time consuming process. This process was improved upon when railcars were ferried across the river and then attached to a train for further transport. This was faster and cheaper than unloading and reloading railcars but still not ideal because occasionally weather conditions kept the ferries from operating and scheduling freight processing often resulted in delays. The expense, time, and labor required to ferry train goods and train cars across the river pushed the need for a bridge to a higher priority. Because of this a bridge to support rail traffic over the

[5] George Rogers Taylor, *The Transportation Revolution 1815-1860* (Armonk, NY: M. E. Sharpe, Inc., 1951), 29.

Mississippi River at Saint Louis was needed.[6] Continuous rail traffic, via a bridge, was needed to solve these issues and increase rail efficiency. These and other developments caused Saint Louis leaders to reaffirm the need that Saint Louis build its first railroad bridge.

Difficulty in crossing the Mississippi River at Saint Louis was not the only reason a bridge was needed at Saint Louis. The city of Chicago was expanding its trade westward in the early 1850's and railroads were a major component in this expansion. Rail traffic to and from Chicago was increasing much faster than at Saint Louis during this time. Rail traffic for the western United States from Chicago was built via a northern route, excluding Saint Louis. The east bound rail traffic to Chicago terminated at Davenport, Iowa and the west bound traffic from Chicago terminated at Rock Island, Illinois. The completion, in 1854, of terminals at these locations sparked the construction of the first Rock Island Bridge.

Referencing a survey performed in 1837 by Robert E. Lee, chief engineer Henry Farnam and consulting engineer John B. Jervis of The Railroad Bridge Company, tasked with building the Rock Island Bridge, selected the site to place the Rock Island Bridge. This site was the narrowest part of the river between Davenport and Rock Island. Even so, it was a considerable distance at approximately 1,500 feet. The Mississippi River at this location was shallow, rarely more than six feet deep during low water. The banks of the river were high above the normal river level, greatly reducing damage from flooding. The river bed at this location was all solid bedrock. These characteristics made

[6] John H. White, Jr, *Wet Britches and Muddy Boots: A History of Travel in Victorian America* (Bloomington and Indianapolis, IN: Indiana University Press, 2013), 427.

construction much easier than other possible locations south of this point, as the Mississippi River deepened, and increased in flow speed, complicating pier construction.[7]

The Rock Island Bridge was a wooden truss bridge with masonry piers. These piers lacked sufficient mass or anchoring even as they sat on bedrock. Twice in the bridge's history these piers would be moved by a force of nature. In 1856, while preliminary planning work was being performed for a bridge at Saint Louis, a freight train crossed the Rock Island Bridge for the first time, approximately 250 miles north of Saint Louis. This was a bad omen for Saint Louis because with each passing day goods that may have previously crossed the Mississippi River at Saint Louis on a ferry were now bypassing Saint Louis. As a result, businesses using this new route no longer played a role in the economy of Saint Louis. Even with its less than substantial construction the Rock Island Bridge proved its worth the day it opened as freight trains transporting goods flowed across it regularly. With each crossing the Rock Island Bridge diverted business away from Saint Louis.

Even though the completion and use of the Rock Island Bridge reinforced the need for a bridge at Saint Louis this was not the first time Saint Louis had considered a bridge across the Mississippi River. The first proposal, in 1839, was submitted by Charles Ellet, Jr. for the construction of a pedestrian and wagon suspension bridge with a main span of 1,200 feet and 900 feet side spans. Ellet was an engineer who, through lectures on bridge building and hands-on experience, became a bridge designer and builder. Ellet's suspension bridge proposal scared Saint Louis city officials to the point of rejecting his design. Saint Louis city officials allowed Ellet to prepare and distribute documentation

[7] Frank F. Fowle, "The Original Rock Island Bridge across the Mississippi River," *The Railway and Locomotive Historical Society Bulletin*, no. 56 (1941): 9.

with specifications for his bridge before they decided that a bridge of the size Ellet was proposing was unrealistic. Although the mayor of Saint Louis stated they could not justify spending the amount of money Ellet estimated the bridge would cost, this may have been an excuse as many city officials thought Ellet's plan was outrageous, unsafe, and they sent him on his way as fast as they could. Ellet's experience and overseas bridge building education were of no value to his proposal being accepted.[8]

Although Ellet's design was revolutionary, a suspension bridge was a viable option for the first bridge to span the Mississippi River at Saint Louis. In 1839, this 1,200 foot main span would have been far ahead of its time. It would have been nearly 330 feet longer than the longest suspension span in use. It would have exceeded the length of the main span of the Wheeling Suspension Bridge, built in 1849, by almost 200 feet and the main span of the Roebling Suspension Bridge, built in 1866, by almost 150 feet. Even though the rejection of Ellet and his plan was the correct action taken, a suspension bridge at Saint Louis remained as a possible solution for bridging the Mississippi River.[9]

[8] David B. Steinman and Sara Ruth Watson, *Bridges and their Builders* (New York: Dover Publications Inc., 1941), 175.

[9] Gene D. Lewis, *Charles Ellet Jr. The Engineer as Individualist 1810-1862* (Urbana, IL: University of Illinois Press, 1968), 119.

Chapter 1

The Evolution of the Suspension Bridge

The origin of the suspension bridge cannot be definitively determined. However, evidence shows they were used as a necessity to routinely traverse a deep cut in the earth, or a body of water too deep or dangerous to cross by fording. From these basic but important needs, magnificent structures such as the Brooklyn Bridge owe their existence. Progressing from the initial suspension bridge, probably made of some type of vegetation, to a modern suspension bridge like the Brooklyn Bridge, required many years of development, immense manpower, large financial input, loss of life, and much trial and error. The three countries that provided the majority of these resources, and reaped the most benefits were the United States, Great Britain, and France. Other countries contributed resources to furthering the science of the modern suspension bridge; however the aforementioned countries were the key developers.[10]

Judge James Finley, of the United States, is widely recognized, by academics and engineers, as the originator of the modern suspension bridge. Although the British and French were well versed in engineering, Finley developed the first modern suspension bridge in Pennsylvania. To be considered a modern suspension bridge two parameters had to be met. The decking of the bridge needed to be a flat surface and not follow the curve of the suspension cables, and the bridge needed to be built sturdily enough so that no discernable movement of the bridge decking or bridge took place while being crossed. Finley was able to accomplish these two requirements in Pennsylvania in 1801 and the first modern suspension bridge was born. A diagram of the chain bridge built in 1808

[10] G. F. Fordham, "On the Theory of Suspension Bridges with some account of their early history," *The Irish Penny Journal*, Vol. 1, No. 34 (Feb. 20, 1841): 267-268.

over the Schuylkill River, was very similar to the first modern suspension bridge, Finley's Jacob Creek Bridge. The diagram portrayed an unmistakable likeness to suspension bridges that were built over the next one hundred years.[11] Although the Jacob Creek Bridge was a small bridge with a span of seventy feet, according to historians Kemp and Fluty in their book, *The Wheeling Suspension Bridge,* it contained all the "…elements of the modern suspension bridge."[12]

The elements of a modern suspension bridge consisted of a main supporting iron chain, bar chain or cable, towers to support these components and anchorages to which the main support element was anchored, a level deck, and some type of stiffening assembly for the deck. The anchorages were usually very large man-made masonry structures but could also be naturally occurring rock that was used as an anchorage. The portion of the supporting element that extended from the towers to the anchorages was known as the backstay. A stiffening truss under the deck helped keep the deck from twisting and undulating. Suspenders from the main supporting element supported the level deck.[13]

Many ideas for improvements were proposed in the early years of suspension bridge development. One of those ideas came from John Templeman, an associate of Finley's, who suggested, among other materials "…wire built up in parallel strands"[14] as the main supports in an 1810 patent. This might be the earliest reference to using wire

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[11] Emory L. Kemp and Beverly B. Fluty, *The Wheeling Suspension Bridge: A Pictorial Heritage* (Charleston, WV: Pictorial Histories Publishing Co., 1999), 5; H.J. Hopkins, *A Span of Bridges: An Illustrated History* (New York: Praeger Publishers, 1970), 177; Tadaki Kawada, *History of the Modern Suspension Bridge Solving the Dilemna between Economy and Stiffness.* Translated by Harukazu Ohashi. Edited by Richard Scott. (Reston, VA: American Society of Civil Engineers, 2010), 18; James Finley, "A Description of the Patent Chain Bridge,' *The Port Folio,* 3no6 (1810), 441-453.
[12] Kemp and Fluty, *The Wheeling Suspension Bridge*, 5; Appendix B.
[13] Kemp and Fluty, *The Wheeling Suspension Bridge*, 5; Appendix A.
[14] Kemp and Fluty, *The Wheeling Suspension Bridge*, 5.

instead of heavy iron chain, and the other components of an early chain suspension bridge. One improvement that Finley was aware of was the need for building stiffness into his bridges, a concept that became more important as wind stress came into play. Due to Finley's suspension bridge design and construction, western society began to accept suspension bridges as permanent structures. The view of the suspension bridge as an unsafe device used by uneducated people began to fade. With the erection of each new suspension bridge, an improved reputation as a safe mode of crossing an obstacle was being garnered by these bridges.[15]

From his initial suspension bridge in 1801, until 1810, Finley enjoyed a very successful career as a bridge builder. There were many suspension bridges built using Finley's patents and although they were of varying lengths the trend was towards longer spans. When Finley's success in the development of suspension bridges reached Britain, in the very early nineteenth century, engineers combined this information with their engineering knowledge and began building advanced suspension bridges. The British expanded on Finley's work with suspension bridges by adding improvements such as the use of eye bar, instead of chain, to the bridges they built.[16]

In 1821, the French visited Britain to study their suspension bridges and shortly thereafter embarked on their own suspension bridge building era. As the French adopted the suspension bridge in their country they replaced the eye bar of the British design with wire cable and built their first wire suspension bridge in 1823. This bridge, the Pont Saint-Antoine, was built in Geneva, Switzerland in 1823 by Guillaume-Henri Dufour, a

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[15] David McCullough, *The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge* (New York, NY: Simon and Schuster, 1972), 74.

[16] Kawada, *History of the Modern Suspension Bridge*, 19; E. L. Kemp. "Links in a chain The development of suspension bridges 1801-70," The Structural Engineer, Volume 57A, no.8 (1979): 257-258; Appendix H.

Swiss Army technical officer, and Marc Seguin, a French engineer. Seguin took the lead on building suspension bridges in France from Claude L.M. Navier. Navier, a French scholar, had researched British suspension bridges, produced a report on them for the French government, and promoted their development in France. Navier's work helped produce a large increase in suspension bridge building in France, which resulted in the construction of more than 200 suspension bridges between 1830 and 1850.[17]

Even as the British and French continued their research and improvements on suspension bridges, Finley continued to build. Although Finley designed and built many bridges before his death in 1828, it was Charles Ellet, Jr. who improved on Finley's design and secured his own legacy with the construction of the Wheeling Suspension Bridge.

Ellet was born in 1810, years after Finley developed the components of the modern suspension bridge. Ellet left home in his late teens to find the technical work that suited him more than the work involved in running a family farm. Ellet found a position with the Chesapeake and Ohio Canal in 1828 and quickly advanced to assistant engineer in 1829. Desiring more than this job could give him, he quit and traveled to France to expand his engineering expertise. He attended several lectures given by leading French engineers, including Navier. Ellet also toured various areas of Europe before returning to the United States in 1832. His expertise in bridge design and building was mostly due to experience, with little formal bridge engineering education. He gained most of his

[17] Kawada, *History of the Modern Suspension Bridge*, 48-53; Appendix I.

education from self-study: time spent touring overseas attending lectures in France, and meeting prominent French engineers involved in bridge construction.[18]

Once back in the United States, Ellet categorized the suspension bridge work of Finley and others as primitive. The main reason for this was because they were building bridges with chain or bar chain and not using the new technology of drawn wire to build suspension cables of great strength. Ellet advocated wire suspension bridges as the French had developed them rather than bars or rods for chains that the British had used for their suspension bridges. It is interesting to note that Ellet derided the work of Finley and others as primitive when Finley initially advocated a stiffening truss, and the first patent for wire use in a suspension bridge occurred in the United States in 1810. Ellet, to his detriment, may have downplayed the use of a stiffening truss. He tendered a design for a suspension bridge over the Potomac River shortly after his return from Europe but did not receive the contract for this bridge. Ellet did not let this rejection deter him. He was determined to build long-span suspension bridges using the newer technology of wire cables.[19]

Eventually Ellet was successful in building a wire suspension bridge. The Schuylkill River Bridge, built by Ellet in 1842 as the first wire suspension bridge in America, cemented his reputation as a master bridge builder. Partially due to his success with the Schuylkill River Bridge, he was selected, in 1847 by the board of directors of the company formed to bridge the Ohio River at Wheeling, Virginia, to build a bridge across the Ohio River at Wheeling. This suspension bridge was the longest span in the world at

[18] Lewis, *Charles Ellet Jr. The Engineer as Individualist 1810-1862*, 7-26; Kemp and Fluty, *The Wheeling Suspension Bridge*, 7.
[19] Emory Kemp, "Iron, Engineers, and the Wheeling Suspension Bridge," *Upper Ohio Valley Historical Review* 11 (Spring-Summer 1982): 2-11; Kemp and Fluty, *The Wheeling Suspension Bridge*, 7.

the time of its construction. Ellet's reputation as a master bridge builder was questioned after this bridge, the Wheeling Suspension Bridge, collapsed in 1854. The collapse occurred during high winds which caused the bridge to fail because it was not built with sufficient stiffness. It is very likely this collapse could have been avoided if Ellet had been more receptive to unsolicited offers of help. When John A. Roebling, a young civil engineer with an interest in bridge building, attempted to establish himself in the suspension bridge building business, he wrote to Ellet in early 1840 offering his talents to work on the Schuylkill River Bridge. Roebling later contacted Ellet concerning this bridge contract but did not receive a positive response from Ellet. This was undoubtedly an eventful twist of fate for both Ellet and Roebling, although more so for Ellet. Had he encouraged Roebling and hired him to work on the Schuylkill River Bridge, it is possible that Ellet's reputation as a suspension bridge builder would have no blemishes on it. As often happens when new workers are added to a company, they bring different ideas and experiences with them. Occasionally these workers are instrumental in moving companies in different and better directions. Roebling would most likely have steered Ellet to the need for stiffened suspension bridges and avoided the failure of the Wheeling Suspension Bridge.[20]

In 1837, which was very early in his bridge building career, Ellet described the function of a suspension bridge:

> The suspension bridge enables a light and weak structure to yield repeatedly to a heavy body passing over it, to acquire a new state of

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[20] David B. Steinman, *The Builders of the Bridge* (New York: Arno Press, 1972), 170-171; Emory L. Kemp, *Charles Ellet, Jr. and the Wheeling Suspension Bridge, in Proceedings of an International Conference on Historic Bridges to Celebrate the 150th Anniversary of the Wheeling Suspension Bridge October 21-23, 1999 Wheeling West Virginia*, ed. Emory L. Kemp (Morgantown, WV: West Virginia University Press, 1999), 18.

> equilibrium, and return to its former situation as soon as the disturbing force is withdrawn.[21]

This description gives the impression that Ellet did not completely understand the requirements of a suspension bridge. Although it is true that a suspension bridge will yield somewhat to a heavy body passing over it, a light and weak suspension bridge was not the correct design for a long lasting suspension bridge. The Wheeling Suspension Bridge collapsed in 1854, seventeen years after Ellet first described how a suspension bridge handled moving loads. Although it was wind that caused the collapse of the Wheeling Suspension Bridge, not a moving load, his disregard for stiffening components played a major role in its collapse. After the collapse of the Wheeling Suspension Bridge Ellet attempted to continue his bridge building activities but was not successful in acquiring any contracts. Apparently Ellet, even though a gifted engineer, never completely understood the need for incorporating stiffness into his suspension bridges.[22]

John A. Roebling graduated from the Royal Polytechnic Institute in Berlin in 1826 with the degree of Civil Engineer. He was now ready to conquer the world; at least the bridge building world. In Germany his options were very limited. Because of the government hierarchy the avenue most open to him was as an employee of the Prussian Government building roads and small bridges. At the end of his three year apprenticeship he felt he needed to break away from this position or possibly remain locked into a stable, but depressing, government job.[23]

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[21] *House Report* No. 135, 24th Cong., 2d Sess. (1837), 21-25 quoted in Gene D. Lewis, *Charles Ellet Jr. The Engineer as Individualist 1810-1862* (Urbana, IL: University of Illinois Press, 1968), 27.
[22] John A. Roebling, *Final Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies* (Rochester, N.Y.: Steam Press of Lee, Mann, and CO., Daily American, 1855), 8.
[23] Steinman, *The Builders of the Bridge* , 10-17.

Roebling knew he must go to America where he would have more opportunities for a fulfilling career and life. He planned and developed an agricultural community in rural Pennsylvania for immigrants from Germany. From 1831 to 1837, Roebling toiled to make this venture a success. In 1837, Roebling decided that farming was not for him and struck out on a new path; a path of engineering and invention. His inventions produced many patents. In addition to his inventing, Roebling found work on the Sandy and Beaver Canal as an engineering aide. At the end of this canal work Roebling found a new position as a surveyor for the railroads. Roebling's intelligence and engineering capabilities kept him employed from the time he left his agricultural settlement. Realizing he needed bridge building experience to attract attention from governments or private enterprises seeking bridge building skills, he searched for a position as an assistant or apprentice on a bridge building project. He needed a connection to advance his career. This was how Ellet entered Roebling's life.[24]

As a young man Roebling followed Ellet's accomplishments. Roebling wrote to him to obtain his review, and approval, of his plan to use wire cables to replace the hemp rope used by the Allegheny Portage Railroad for hauling railroad cars up and down mountains. Roebling felt a positive opinion of his plan, from Ellet, to use wire cables would help sway the Pennsylvania Board of Public Works to approve his plan. One important piece of advice that Ellet gave, and Roebling used, was not to have a splice in his cable but to make it of one long continuous piece. Roebling constructed the first wire cable in America after obtaining approval of his plan from the Pennsylvania Board of Public Works. The development of the wire cable by Roebling was a major component in the successful construction of permanent suspension bridges. Roebling and Ellet

[24] Steinman, *The Builders of the Bridge*, 42-55.

conversed many times concerning bridge building ideas before they became alienated over the building of the suspension bridge over the Schuylkill River. Roebling looked to Ellet as an undeclared mentor before their rift began.[25]

On the journey to the safe development of permanent suspension bridges many suspension bridges had failures and collapses, often just a few years after construction was completed, and often with loss of life. A major component of these failures was the lack of understanding of the effect of wind on suspension bridges. Wind often caused much oscillation and undulating motion of suspension bridges that were not heavy enough or braced correctly for controlling the wind. Many engineers did not understand this issue, and therefore did not realize the need to compensate for wind. The suspension bridges that were not affected by wind were probably engineered more by chance than by deliberate engineering to withstand wind oscillation. The eventual understanding of wind dynamics in the mid-twentieth century on suspension bridges was a technological breakthrough that eventually made suspension bridges much safer.[26]

Suspension bridge collapses were taking place before, and up to the time, a bridge across the Mississippi River at Saint Louis was being discussed. These collapses did not completely stop suspension bridge construction. A railway and road bridge was proposed over the Niagara River in 1845 by Charles B. Stuart and William Hamilton Merritt, an engineer and entrepreneur respectively. Because of the volatility of the Niagara River, and frequency of ice buildup in winter, no piers or falseworks could be used to build a bridge over the river. This led Stuart and Merritt to believe only a suspension bridge would work in this location. The only precedent for a railway suspension bridge was a

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[25] Lewis, *Charles Ellet Jr. The Engineer as Individualist 1810-1862*, 74-75.
[26] Kawada, *History of the Modern Suspension Bridge*, 36-41.

suspension bridge built for the Stockton and Darlington Railway in England in 1830. Opened over the River Tees on January 1, 1831, for railway traffic, this bridge near Stockton proved that deflection in a suspension bridge was a danger during the first trial of the bridge. This bridge was looked upon to provide great service to the community via railway traffic but failed in its first test. The bridge was not able to support a load less than the original weight design specification without considerable deformation. An initial test with a less than maximum number of rail cars caused a peak to form in the track ahead of the rail cars. Once half of the rail cars surmounted this peak a coupling failure occurred, due to the great flexibility of the bridge, sending half the cars one way and half the other way. Once the problem was determined, the bridge was strengthened but remained a suspension bridge. After this correction, "The bridge then received an indefinite number of wagons."[27] This was in 1831, eighteen years before the opening of the Wheeling Suspension Bridge. Ellet had arrived in France on June 7, 1830, approximately six months before the railway suspension bridge over the River Tees was tested, and stayed in Europe until returning to the United States in 1832. How Ellet could have missed the results of this test of the first railway suspension bridge in the world is not known. One of the engineers that Ellet held in high regard, Claude L.M. Navier, spent time in Britain studying the state of suspension bridge building and must have had contacts in Britain familiar with this test. Is it possible he was also unaware of this testing of the world's first railway suspension bridge? This does not seem likely. The results of this test should have alerted Navier, and Ellet, to the need for stiffness in suspension bridges, even if they were not intended to carry rail traffic. At the very least Ellet should

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[27] William Hylton Dyer Longstaffe, *The History and Antiquities of the Parish of Darlington in the Bishoprick* (Darlington, UK; The Proprietors of the Darlington and Stockton Times, 1854), 364.

have considered this before embarking on his suspension bridge building career. It would appear he knew nothing of this test or chose to ignore the test results. It is understandable that wind-induced loads causing problems were little understood in the early days of suspension bridge building, however, the advantage of having a flexible suspension bridge that Ellet felt: ". . .would deflect under live loads to assume a more efficient configuration as loads moved across the bridge" was put to rest with the first railway suspension bridge. Although the suspension bridge for the Stockton and Darlington railway was strengthened and made suitable for rail traffic, increased traffic caused the bridge to become a choking point on the railway. In 1844 it was replaced by a much sturdier iron girder bridge. The weight and action of a locomotive and train cars was not always required to cause a suspension bridge to experience movement or collapse. It was often poor construction, wind, and occasionally a mass of people.[28]

Early in the history of suspension bridges the Samuel Brown Broughton Chain Pier failed, twice, once in 1833 and again in 1836 after being rebuilt. Both failures were caused by violent storms. The Menai Straits Bridge also suffered damage from high winds during stormy conditions. Initially damaged in 1826, it was rebuilt, suffered damage again in 1836 and then again in 1839. During load testing by marching troops on April 16, 1850, the bridge at Angers, France, collapsed. This collapse shook the confidence of the French considerably and they suspended the construction of suspension bridges for the rest of the nineteenth century.[29]

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[28] Kemp, *Charles Ellet, Jr. and the Wheeling Suspension Bridge*, 24; Maurice W. Kirby, *The Origins of Railway Enterprise: The Stockton and Darlington Railway, 1821-1863* (Cambridge, Great Britain: Cambridge University Press, 1993), 74.
[29] Kemp, *Charles Ellet, Jr. and the Wheeling Suspension Bridge*, 23-24.

Early suspension bridges were designed and built to be strong. Their engineers knew they had to support the weight of people, wagons, horses, trains and any other object that needed to cross their bridge. These bridges were not built with adequate stiffness to resist movement caused when the bridge was crossed, or when wind caused them to move uncontrollably. One of the major concerns of the general public concerning suspension bridges was that they appeared to collapse for no apparent reason. There were other types of bridges that collapsed but suspension bridges were acquiring the reputation of being the bridge type that the public, and some engineers, believed was unsafe. Initially feared as unsafe, suspension bridges had gained public acceptance as safe with the bridges built by Finley in the early nineteenth century. As more suspension bridges were built and collapsed, their reputation as a safe structure declined among all, not just the public. There were indeed valid reasons for the collapses that occurred but the public and many engineers often did not know the reasons. Once it was determined that many of the collapsing bridges were not designed and built with the appropriate amount of stiffness even the layperson could understand the reason for collapse. They might not be able to comprehend the physics behind the bridge oscillations from moving loads or wind dynamics, but they could understand that great movement in a suspension bridge was not safe. The layperson had probably experienced some unstable structure in his or her lifetime, whether from a stairway, footbridge, or other everyday item and realized that left uncorrected this structure would eventually fail. It took only a simple thought, even in an uneducated mind, that movement in a structure as substantial as a suspension bridge was not a desirable event.[30]

[30] Steinman, *The Builders of the Bridge*, 177-183.

Even as the requirements for suspension bridges to be built with a certain amount of stiffness began to be understood, many engineers still did not completely comprehend this concept. One engineer that did understand the need for stiffness in suspension bridges was John A. Roebling. Roebling understood the dangers of uncontrolled and unrestricted movement in suspension bridges. Because of this Roebling was able to design the Niagara Falls Suspension Bridge, and later the Brooklyn Bridge, with sufficient stiffness to dampen and control any oscillation or movement in his bridges. This was not an experiment; Roebling had experience with stiffening suspension bridges for quite some time before construction began on the Niagara Falls Suspension Bridge.

Many believed that Roebling added stays and other improvements to the Wheeling Suspension Bridge when it suffered extensive damage in a violent storm in 1854. Among the repairs made were improvements to control the movements of the Wheeling Suspension Bridge from sources such as wind and moving loads. These improvements included adding a stiffening truss, stay cables, and a single suspension cable on each side of the bridge composed of numerous smaller wires compressed into one single round cable, and wrapped with a single wire to retard corrosion. These cables replaced Ellet's original six horizontally aligned French style cables. To be a successful and permanent suspension bridge two features were required; stiffness and economy. Wire cable contributed to both of these features. By combining wire into cables, Roebling was able to construct cables that were stronger and lighter than comparable chain and bar components. Although there is some confusion and disagreement as to whether Ellet or Roebling actually performed the repairs to the Wheeling Suspension Bridge, there is no disagreement that the repairs and improvements had been performed in typical Roebling design and style. At the very least, it appeared Roebling had major input into the repairs.[31]

Around the time Saint Louis city leaders were deciding they needed a railroad bridge, not just a bridge, across the Mississippi River for the first time, Roebling was opening his Niagara Falls Suspension Bridge to the public. The year was 1855, thirteen years before construction began on the Eads Bridge. Among the many engineers who said a suspension bridge was a dangerous structure in and of itself, but even more so when designed as a railroad suspension bridge, stood one man who knew better; John A Roebling. Roebling was the foremost supporter of suspension bridges being built to carry railroads. There were other engineers in the United States, as well as foreign countries, who believed suspension bridges could be safely used by railroads. These engineers did not have the understanding of the construction required to make a suspension bridge sturdy enough to safely carry railroad traffic. The one engineer with this knowledge was Roebling.

To build the Niagara Falls Suspension Bridge, Roebling first had to become the chief engineer of the bridge. This was not easy to do since Ellet was already the chief engineer. Due to some questionable activities concerning Ellet's use of money received from events surrounding the bridge, he was relieved of his duties. Therefore a new chief engineer was needed for the construction. It took the bridge companies over three years to select a new chief engineer. They picked Roebling, an engineer who had developed wire cable in the United States, built four suspension aqueducts, and had a much better

[31] Kawada, *History of the Modern Suspension Bridge*, 76; Alan Trachtenberg, *Brooklyn Bridge: Fact and Symbol* (New York: Oxford University Press, 1965), 56.

understanding of the need for suspension bridges built with the correct amount of stiffness than any engineer on earth. Roebling made the most of this opportunity.

The completion of his first suspension aqueduct in Pennsylvania in 1845 put Roebling on track to gain the knowledge he needed to build the Niagara Falls Suspension Bridge. Although the aqueduct consisted of seven spans that were each only approximately 162 feet long, they were incredibly strong. This length was much less than future suspension bridges Roebling created, but the experience of creating a suspension aqueduct that carried 2,000 tons of water gave Roebling the knowledge to build stiff suspension bridges. This 2,000 tons of water statement does not carry much weight initially. When analyzed it is determined 2,000 tons of water equates to 4,000,000 pounds. The largest steam locomotive ever built in the United States, in 1941, with tender attached, weighed just over 1,200,000 pounds. This was just thirty percent of what Roebling's aqueduct could carry. These numbers alone proved that Roebling's aqueduct construction method more than qualified him to build the Niagara Falls Suspension Bridge. The vast weight of water carried by the aqueduct proved that Roebling's design using stiffening components and wire cable was sound. He used skills and techniques learned at the aqueduct in the construction of the Niagara Falls Suspension Bridge.[32]

In addition to using wire cable in the construction of his suspension aqueduct, Roebling also incorporated a unique technique to anchor the cables. In his book *The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge*, David McCullough stated that Roebling attached cables ". . . to great chains of iron eyebars embedded in

[32] American Locomotive Company, *Growing with Schenectady: American Locomotive Company* (Schenectady, NY: American Locomotive Company, 1948), 31; Kawada, *History of the Modern Suspension Bridge*, 77.

masonry, a plan not used in any prior suspension bridge and the one he would use on every bridge he built thereafter."[33]

Because of his knowledge Roebling was the ideal engineer to design and build the Niagara Falls Suspension Bridge. When Roebling was selected to lead the construction of this bridge engineers all over the world were skeptical of its possibility of success. According to Takada Kawada in his book *History of the Modern Suspension Bridge*, one of these engineers was "Robert Stephenson the leading engineer of British railroads at that time . . . ." Stephenson believed that suspension bridges did not possess adequate stiffness for running trains over them and he was probably correct until Roebling came along. Upon hearing of Roebling's appointment as chief engineer, Stephenson sent Roebling a letter suggesting he rethink his plan to build the Niagara Falls Suspension Bridge. In his letter Stephenson stated "If your bridge succeeds then mine have been magnificent blunders."[34]

Based upon his experience and abilities, it is doubtful Roebling seriously considered Stephenson's suggestion and statement. Roebling forged ahead and completed the bridge four years after construction began. On March 16, 1855, Roebling proved that a railway suspension bridge was feasible when a full size train crossed the Niagara Falls Suspension Bridge.[35] This train was specifically designed to be as heavy as possible. Twenty double-loaded cars were pushed across the bridge by a locomotive weighing twenty-eight tons. Roebling reported that no vibrations were felt from the bridge during this test. After this successful test trains began using the bridge within a few days, and

[33] David McCullough, *The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge*, 50.
[34] Kawada, *History of the Modern Suspension Bridge*, 77.
[35] Greenhill, *Spanning Niagara: The International Bridges 1848-1962*, 29; Appendix C; Appendix D; Appendix E; Appendix F.

shortly afterwards trains were crossing about one every hour. Roebling wrote to his family that "No one is afraid to cross. . . ."[36] In his May 1, 1855 report to the bridge owners he stated that:

> The trains of the New York Central, and of the Great Western Rail Road in Canada, have been crossing regularly since the 18th of March, averaging over 30 trips per day.[37]

It was not only Roebling singing the praises of his bridge. Alfred Pairpoint, an Englishman documenting his travels in the United States and Canada, was very interested in the bridge. Pairpoint observed heavily loaded trains crossing the bridge and was impressed at the strength of the bridge. From his perspective, Pairpoint believed that a suspension bridge at this location was the only bridge type that would have been successful.[38]

Five years after the bridge opening Roebling presented a report, on August 1, 1860, to the presidents and directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies. This report, on the condition of the Niagara Falls Suspension Bridge, detailed the results of Roebling's inspection of this bridge. Roebling spent three days in July inspecting his bridge and then reported his findings. The main issue Roebling found that needed to be addressed appeared to be ". . . rapid wear of the rails, many of which require renewal." Roebling attributed this rapid wear to the great amount of rail traffic crossing the bridge in a twenty-four hour time frame. He stated the

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[36] John A. Roebling to Charles Swan, Special Collections of the Library of Rutgers University, quoted in David McCullough, *The Greatest Bridge: The Epic Story of the Building of the Brooklyn Bridge* (New York, NY: Simon and Schuster, 1972), 82.
[37] Roebling, *Final Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies*, 3.
[38] Alfred Pairpont, *Uncle Sam and His Country* (London: Simpkin, Marshall & CO., 1857), 112.

average number of trains crossing the bridge each day to be approximately forty-five. Using instruments to test the deflection of the bridge, Roebling recorded measurements for five trains crossing the bridge in 1860 to compare with his measurements when the bridge was new in 1855. Among these five trains crossing the bridge was "A train, composed of the engine 'Essex,' and tender, of 35 tons weight, drawing 10 empty cars. . . ." After gathering his measurements, Roebling found that the amount of deflection for a train crossing the bridge in 1860 was the same as in 1855. Another area that Roebling addressed was the slow speed that trains must adhere to when crossing the bridge. Opponents of suspension bridges as railway bridges pointed to this low speed as an inherent weakness of railway suspension bridges. Roebling addressed this by stating that the reason for the slow speed over the bridge was for safety. He also made it clear that, in this case at least, a higher speed does nothing for passengers on a train crossing this bridge. By keeping passenger trains to less than five miles per hour three distinct steps were achieved: The bridge is a connection between two termini of relatively short distance, passengers will be able to enjoy the scenery when the bridge is crossed at a slower speed, and the bridge was designed with safety features that will be most effective when traversed at a slow speed. Should freight trains need to cross the bridge at a high rate of speed in the future, Roebling confidently assured the presidents and directors that modifications could be made that would allow for faster trains crossing. For an additional $20,000 he could make the bridge safe for high speed freight trains. This reinforcement of the bridge would eliminate any possible damage to the bridge from high speed freight trains.[39]

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[39] John A. Roebling, *Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies on the condition of the*

Roebling also reported that although he inspected other areas of his bridge, the cables supporting the bridge were the most important feature. He produced a lengthy explanation of how iron exposed to vibration under tension, or to bending and twisting, will eventually undergo an internal change in its makeup. Bridges built with no regard for stiffness are exposed to vibration at all times from traffic as well as wind loading. This vibration, left unchecked, shortens the life of bridge components. This internal change can be catastrophic in a suspension bridge as it could cause enough cables to fail to no longer support the bridge. To eliminate this possibility Roebling built his bridges with enough stiffness to eliminate, or reduce to a negligible value, any vibration or torsion that could be transferred to the iron cables. Roebling ended his report with an assurance that the cables of the Niagara Falls Suspension Bridge ". . . may safely be trusted for a long series of years."[40]

Roebling felt that the many rivers and gorges in the United States could only be practically bridged by suspension bridges. He felt the tubular, arch, and truss type bridges were not feasible for these wide and deep spans. Of course, the suspension bridge was the specialty of Roebling, so it was only natural that he leaned toward suspension bridges and away from any other types. At about the same time he was building the Niagara Falls Suspension Bridge, Roebling had started construction of a more advanced railway suspension bridge to span the Kentucky River for the Lexington and Danville Railroad. This suspension bridge was to have a single span of 1,224 feet at a height of over 300 feet

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Niagara Railway Suspension Bridge. August 1 1860 (Trenton, N.J.: Murphy & Bechtel, Printers, opposite the City Hall, 1860), 3; Roebling, *Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies on the condition of the Niagara Railway Suspension Bridge*, 4-6.

[40] Roebling, *Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies on the condition of the Niagara Railway Suspension Bridge,* 20.

above the Kentucky River. After construction of the stone towers needed to carry the suspension cables was completed the Financial Panic of 1857 caused the project to come to a halt, as one of the worst economic crises in United States history began. After the Financial Panic of 1857 and the Civil War passed, work began again on a bridge to span the Kentucky River. The original plans for a suspension bridge were scrapped and a cantilever bridge was built in its place. Although Roebling was not able to finish the construction of this suspension bridge, he was sure that with increased demand for transportation much longer railroad suspension bridges would be built: "We may then see Railway Bridges suspended of 2000 feet span, which will admit of the passage of trains at the highest speed."[41]

With a span of 825 feet, the Niagara Falls Suspension Bridge was nearly twice as long as any railroad suspension bridge built previously. Roebling knew that this bridge required a very stiff and stable construction. To acquire this stiffness he built the non-railway deck eighteen feet below the railway deck. He connected the two decks by means of stiffening trusses. To provide the required stiffness these trusses were built of wooden posts and connected with diagonal iron rods. The stiffness provided by this construction allowed trains to use the bridge with complete safety. Based on his experiences with other structures he used a unique arrangement of these components to negate the destructive powers of storms, trains, and all other forces acting upon his bridge in a manner that could cause it to fail. It was because of the large number of bridge failures, and the larger number of flimsy bridges currently in use that could fail, that Roebling advocated for engineers to embrace his techniques. Roebling felt that by incorporating his

[41] Roebling, *Final Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies*, 5.

designs and construction methods, other engineers, and the public, would benefit from the advancements in safety these features provided. Roebling stated "The Niagara Bridge possesses all the stiffness that is wanted, and much more than is actually needed for the *safe* passage of trains." With this statement Roebling was telling the entire world that suspension bridges, and especially railway suspension bridges, could be made safe if engineers built the correct amount of stiffness into them. Many engineers did not heed his advice. As late as the 1940's, suspension bridges such as the Tacoma Narrows Bridge, which collapsed in high wind, were being built without regard for what Roebling knew in the mid-nineteenth century.[42]

By building stiffness into his bridges Roebling had solved a dilemma that had confounded suspension bridge builders for decades. With the successful completion, and use, of the Niagara Falls Suspension Bridge Roebling established the suspension bridge as the primary safe means of spanning long distances. The bridge was safe for rail traffic when it opened, and remained safe for rail traffic throughout its forty-one year life. Over the course of these forty-one years improvements were made to the bridge to keep it safe. Components made of steel or iron replaced original components made of wood and stone. In 1896, locomotives and the cars they pulled had increased in weight so much that continued use of the Niagara Falls Suspension Bridge was unsafe and it was replaced. Roebling proved, in 1855, that safe railroad suspension bridges could be built and, if maintained properly, serve safely for many years. Based on the success of the Niagara Falls Suspension bridge, there does not appear to have been a valid reason to have

[42] Roebling, *Final Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies* quoted in Kawada, 78-79; Roebling, *Final Report of John A. Roebling, Civil Engineer, to the Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies*, 5.

eliminated a suspension bridge as a choice for the bridge to span the Mississippi River at Saint Louis.[43]

Washington Roebling, son of John A. Roebling, was well on his way to becoming accomplished in the construction of suspension bridges when he completed his thesis at Rensselaer Polytechnic Institute. His thesis, *Design for a Suspension Aqueduct,* was developed to transport water from the Poestenkill Creek into Troy, NY. The detail of Roebling's thesis proved that as early as 1857 Washington Roebling understood the physics required to build a suspension bridge capable of carrying heavy and dynamic loads. This thesis for a suspension aqueduct could easily have been used as a point of reference in the construction of a railway suspension bridge.[44]

The bulk of the young Roebling's knowledge must have come via his formal education, but then again undoubtedly his father conveyed a great base of suspension bridge knowledge to his son. An article in an 1869 issue of *Engineering* supported this assertion when referring to the death of John Roebling it stated: ". . . 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."[45]

As a bridge building team, John and Washington Roebling were careful to use technologies and materials that had been proven to be safe and effective. It was not that they were not innovative, because they were. However, they wanted to be sure that proven concepts went into the bridges they built. Just as the aqueducts provided proven

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[43] Kawada, *History of the Modern Suspension Bridge*, 83; Ralph Greenhill, *Spanning Niagara: The International Bridges 1848-1962*, 27.
[44] Kirti Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling," *Gandhi Consulting Engineers and Architects*, 4.
[45] "Wire Rope Fastening," Engineering V. 8 (1869): 319 quoted in Kirti Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling," *Gandhi Consulting Engineers and Architects,* 5.

techniques and experiences that were used in the Niagara Falls Suspension Bridge, this same process of using proven concepts from the Niagara Falls Suspension Bridge, and the Roebling Suspension Bridge, was carried forward in the design and construction of the Brooklyn Bridge. If a suspension bridge design by John Roebling had been selected for bridging the Mississippi River at Saint Louis, his death would not have caused much, if any, disruption as his son Washington was capable of building any suspension bridge John Roebling had designed.[46]

Many years passed after the rejection of Ellet's plan in 1839 before another proposal to span the Mississippi River at Saint Louis was submitted. Saint Louis city resident Josiah Dent submitted plans for a suspension bridge in 1855. Dent obtained charters from Missouri and Illinois that enabled him to form a company to build a bridge at Saint Louis. The railroads had made much progress in laying track in the previous fifteen years and Dent planned to build a railroad suspension bridge over the Mississippi River to accommodate them. The fact that only one railroad entered the city of Saint Louis did not deter Dent, as railroads being built from the east would need to cross the Mississippi River. Dent's plans called for a single span suspension bridge of 1,500 feet, ninety feet above high water to eliminate any steamboat interests claiming obstruction with their chimneys. This was definitely a plan ahead of its time. The estimate for this bridge was $1,500,000, roughly twice as much as Ellet's proposal. Financial, and railroad, support could not be secured and this proposal failed when only a very small amount of the $1,500,000 was raised.[47]

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[46] Donald C. Jackson, *Great American Bridge and Dams* (Washington, DC: The Preservation Press, 1988), 131.
[47] C. M. Woodward, *A History of the St. Louis Bridge*, 10; Steinman and Watson, *Bridges and their Builders*, 176.

The same year Dent submitted his plan, men associated with the Pacific Railroad of Missouri, as well as several men from southern Illinois who felt that their business loyalties and prospects would fare better with Saint Louis than Chicago, formed the Saint Louis and Illinois Bridge Company. Bridging the Mississippi River, so that railroad traffic, and goods, could arrive and depart Saint Louis without the use of the ferry system, was a major concern to these men. Organized with good intentions, the Saint Louis and Illinois Bridge Company did not make an immediate impact on bridging the Mississippi River and languished for close to a decade. The next proposal, in 1856, came from John Roebling, not a household name yet but quickly on his way to becoming a respected bridge designer and engineer. Roebling submitted a proposal for a suspension bridge which was not accepted by the city. Two years later Roebling revised his design and submitted several variations to the city in hopes of building the first bridge across the Mississippi River at Saint Louis. None of his designs were accepted. If a Roebling design had been accepted, we might have a suspension bridge in Saint Louis built by one of the premier builders of suspension bridges of the nineteenth century. Instead we have a unique iron and steel arch bridge, built by one of the premier self-taught engineers of all time. Possible safety concerns of both Roebling's and Ellet's proposals, the most promising engineers of the day, were reasons they may not have been accepted.[48]

As the years passed, Saint Louis city officials and civic leaders realized that a bridge needed to be built. Railroads were building more roads towards Saint Louis and unless a bridge was constructed railroads could decide to route their roads away from Saint Louis, and adversely affect the economy of Saint Louis for years to come.

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[48] Robert W. Jackson, *Rails across the Mississippi A History of the St. Louis Bridge* (Urbana and Chicago, IL: University of Illinois Press, 2001), 3; Steinman and Watson, *Bridges and their Builders*, 176; Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling", 1.

Individuals also wanted a bridge that allowed them easy access across the river at all times of the year, and in any kind of weather. As talking and planning for a bridge at Saint Louis dragged on, the Civil War began and intruded on the plans for a bridge at Saint Louis. The Civil War pushed bridge development back partly because of major destruction of railroads in Missouri during the war. No action was taken between the time Roebling submitted plans for a bridge at Saint Louis in 1856 and 1864. In early 1864, Missouri state senator Norman Cutter sponsored legislation to authorize a new organization with the original Saint Louis and Illinois Bridge Company name. This was passed by the Missouri legislature. Although the original company appeared to be dormant, and the legislation seemed to nullify any previous bridge charter, many people in Saint Louis believed the original company created in 1855 might still be legitimate. After gaining approval from Missouri in early 1864, Cutter waited until January 1865 to attempt to gain approval to perform business in Illinois: specifically bridge building business. With no action from Cutter between February 1864 and January 1865, it was thought Cutter was positioning himself to sell the rights to build a bridge at Saint Louis to the highest bidder.[49]

On February 7, 1865, Saint Louis city officials selected Truman Homer, the city engineer, to evaluate possible bridge scenarios and develop a plan for a bridge that served the residents, the railroads, and the needs of the city. Four days after receiving the request from the city council for plans for a bridge, Homer provided a report to the city council. This report was more feasible than some of the previous proposals. The plan Homer submitted referenced a memo he received from the Common Council of the City of Saint Louis on February 7, 1865. This memo stated a bridge was needed at Saint Louis for

[49] Jackson, *Rails across the Mississippi*, 6-7.

citizens and ". . . the great railroad traffic now centering in this city. . . ." In his report Homer recommended a tubular type bridge with three spans of 500 feet each. His bridge would only be approximately twenty-two feet above high water. He justified this height because he knew steamboats could have their chimneys built in a fashion that allowed them to be raised and lowered at will. Homer estimated the cost of his bridge to be $3,332,200. With every proposal the cost of the bridge increased.[50]

Homer's plan was prepared well but was not accepted by the city, just as the others were not. The major difference between the Homer plan, and all previous plans, was that Homer did not want a suspension bridge to be built. He was strongly opposed to suspension bridges. One reason for Truman Homer stipulating the bridge at Saint Louis should not be a suspension bridge may have been partially due to the need for this bridge to carry rail traffic. The statistical information on bridge failures, and collapses, would be difficult and time consuming for Homer to acquire, but as an engineer, although not a bridge engineer, he would be more likely to obtain and keep track of this type of information than the average citizen. Living in a large city like Saint Louis, Homer had the luxury of the telegraph, couriers, the postal service, fellow engineers, and newspapers to keep him informed of news concerning bridge issues. These statistics would have supported Truman Homer's dislike of suspension bridges. Armed with this information Homer would have been justified in opposing a suspension bridge at Saint Louis. This could have been the turning point for why there is no suspension bridge at Saint Louis. Roebling submitted another proposal for a bridge at Saint Louis after Homer's report,

[50] Truman Homer, *Reports of the City Engineer and Special Committee to the Board of Common Council of the City of St. Louis in relation to a Bridge Across The Mississippi River At St. Louis* (St. Louis MO: M'kee Fishback and Company, Printers and Binders, 1865), 3; Woodward, *A History of the St. Louis Bridge*, 10-11.

although it, like the first, was not selected. Why were Roebling's designs rejected when he had years of practical experience building bridges, specifically suspension bridges? Many people in the early nineteenth century believed suspension bridges were unsafe. Many more believed a railroad suspension bridge was not only unsafe, but a recipe for disaster. These two reasons alone would have justified Roebling's designs not being selected. It is possible that minds in Saint Louis were made up and marching toward an act of congress that forbid a suspension bridge at Saint Louis.[51]

Even as Truman Homer was creating his plans for a bridge, work was being performed in the background by Cutter to secure the appropriate approvals to construct a bridge. Since Cutter had already created a new bridge company and secured a charter from the state of Missouri to build a bridge Cutter began the process of obtaining a charter from the state of Illinois. Cutter had more difficulty receiving a charter from the state of Illinois. By the time approval was being sought from the state of Illinois, several groups, with reasons not to have a bridge built, had realized that a bridge was going to be a major threat to their business interests. The Wiggins Ferry Company, various steamboat and railroad companies, and quite possibly a group of business executives from Chicago began putting up obstacles to a bridge being built at Saint Louis. It was not physical obstacles but political obstacles that the eventual builder of the first bridge at Saint Louis had to overcome.[52]

James B. Eads, the engineer who would eventually build the first railway bridge to span the Mississippi River at Saint Louis, believed the ferry and transfer companies were involved in attempts to block a bridge. In his June 1, 1868 report to the president

[51] Howard S. Miller and Quinta Scott, *The Eads Bridge* (St. Louis, MO: Missouri Historical Society Press, 1979), 73; Jackson, *Rails across the Mississippi*, 88; Petroski, *Engineers of Dreams*, 31.
[52] Steinman and Watson, *Bridges and their Builders*, 176-177.

and directors of the Illinois and St. Louis Bridge Company, Eads made it clear that he believed the ferry and transfer companies had conspired figuratively to place roadblocks in the path of the bridge. It is quite believable that the Wiggins Ferry Company attempted to stop any bridge being erected at Saint Louis. An annual statement from the Wiggins Ferry Company dated April 30, 1875, contains a note stating their concern for competing with, as they called it ". . . the Bridge." Even though it is clear, by the date, that any battles to stop construction of the Eads Bridge had failed, the Wiggins Ferry Company's fear of competition with the bridge remained. The note attempted to assure that the Wiggins Ferry Company, and two other transfer companies, are ". . . all three competitive against the Bridge." First and foremost in another note are concerns about how ". . . the Bridge . . ." will affect business: "What effect the Bridge will have on the Ferry Co. as far as Ferrying receipts are concerned no man can tell at present." Clearly there was concern that the Eads Bridge could, and probably would, severely damage the Wiggins Ferry business. These two notes give weight to Eads' argument that the Wiggins Ferry company had tried to block construction of his bridge.[53]

The rejection of the Homer plan did not slow the Cutter group. After receiving approval from Missouri and Illinois, Cutter sought approval from Congress via legislation. During the planning phase for the bridge at Saint Louis, members of the Cutter faction convinced Missouri Senator B. Gratz Brown to introduce, on February 15, 1866, Senate Bill 38. This bill stated, among other things, that the bridge at Saint Louis

[53] James B. Eads, "Saint Louis Bridge. Report to the President and Directors of the Illinois and St. Louis Bridge Company," in *Addresses and Papers of James B. Eads together with a Biographical Sketch*, ed. Estill McHenry (St. Louis, MO: Slawson & Co., Printers, 1884), 511; Wiggins Annual Statement, *Annual Statement of Wiggins Ferry Company ending April 30th 1875* (St. Louis, MO: Peugnet Collection 73-0068 Missouri Historical Society, 1875), 1; Blue Note (St. Louis, MO: Peugnet Collection 73-0068 Missouri Historical Society, ND), 1.

could be built as a drawbridge or with unbroken or continuous spans. When B. Gratz Brown introduced his bill for the bridge to be built at Saint Louis he wanted a bridge that would be strong, permanent, and considered a work of art.[54] As progress towards bridge construction continued to move forward steamboat interests in Saint Louis became increasingly concerned. They knew they had eventually to coexist with bridges and began making plans to retain as much power as they could. Because of this, the Saint Louis Merchants Exchange created a committee to study steamboat concerns and produce a document to be submitted to Congress that addressed issues concerning bridge construction. The steamboat interests did not know that the man appointed as chairman, James B. Eads, would be putting up river obstacles of his own in the near future. As chairman of this committee Eads retained his lifelong interest in clear river navigation. He also had several business interests he attended to. One of these was involvement in railroads. Any legislation to be passed could greatly affect Eads business interests. The immediate outcome of this Eads-led committee were several restrictions "to be placed in any congressional legislation by the Missouri delegation." Two of these restrictions dealt specifically with types of bridges that could not be built. Drawbridges were to be banned as well as suspension bridges. The integrity of suspension bridges was questionable and their banning was an understandable reaction when suspension bridges had often failed.[55]

As of March 20, 1866, major amendments for Senate Bill 38, including the restrictions from the Eads-led committee, had been submitted to Congress by B. Gratz Brown. In little more than a month these amendments stipulated that a suspension bridge

[54] David P. Billington, *The Innovators: The Engineering Pioneers who made America Modern* (New York: John Wiley & Sons, Inc., 1996), 145.
[55] U.S. Congress, Senate Bill, S. 38 39th Congress 1st Session, 9-10; Jackson, *Rails Across the Mississippi*, 11-23; Norma L. Peterson, *Freedom and Franchise: The Political Career of B. Gratz Brown* (Columbia, MO: University of Missouri Press, 1965), 157.

was an invalid option, the minimum lengths of the spans had increased dramatically, and the span over the main steamboat channel ". . . shall be fifty-feet above the city directrix, measured to the lowest part of the bridge at the centre of the span." The amended bill required the spans to be no less than 500 feet, but did not allow a suspension bridge to be built. It is interesting that suspension bridges were banned as they were beginning to be constructed in a much safer manner, especially by Roebling. Suspension bridges had already been built with greater spans and therefore a minimum span of 500 feet could easily have been constructed. This reworked bill contained wording that made it appear impossible to build any type of bridge at Saint Louis. The specifications in the amended bill were met with suspicion and resistance. However, these issues were eventually reconciled and President Andrew Johnson signed the Senate bill into law on July 25, 1866. This bill authorized bridge construction across the Mississippi River at various points, including Saint Louis. The wording referencing the height of the bridge at the center seemed to tie back to Eads design of the bridge being an arch bridge. Brown was not only instrumental in getting Senate Bill 38 signed into law, after leaving office he also supplied a great deal of granite used to build the bridge.[56]

It has been stated that many did not believe there was anyone with the knowledge, and ability, to build a 500 foot non-suspension span at the time the bill was passed.[57] If so, then why put these stipulations in the bill? Who was so afraid of having a bridge built across the Mississippi River at Saint Louis that they possibly got Congress to approve a clause in the bill authorizing a bridge, but that the bridge could not be a suspension

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[56] U.S. Congress, Senate Bill, S. 38 Amendment 39th Congress 1st Session, 1; Jackson, *Rails across the Mississippi*, 17-18; Peterson, *Freedom and Franchise: The Political Career of B. Gratz Brown*, 168.
[57] Petroski, *Engineers of Dreams*, 38; Steinman and Watson, *Bridges and their Builders*, 177-179; Woodward, *A History of the St. Louis Bridge*, 13-21.

bridge, and that its spans could not be less than 500 feet? Was it the Wiggins Ferry Company? The Wiggins, and other ferry and transfer companies, would have supported these, and any other, stipulations they felt could prevent a bridge from being built. This made them prime suspects for twisting the arms of legislators to have the bill written a certain way. They had a substantial investment in their ferry company and would not want to lose it. Since the Wheeling Suspension Bridge was complete, and the Roebling Suspension Bridge almost complete, the Wiggins Ferry company would have had the foresight to realize a suspension bridge could be built across the Mississippi River. Therefore it was only a matter of time before a bridge at Saint Louis began cutting into their business. If the Wiggins Ferry company did get this “no suspension bridge” clause into the bill, were they assuming the bridge to be built would be a truss or arch bridge? Either of these bridge types would require more river piers than a suspension bridge. These piers would be considered obstructions, making a truss or arch bridge design approval less likely.[58]

It could also have been supporters of the Saint Louis-backed bridge building company who had these stipulations inserted in the bill. They could have believed, or been told, that a non-suspension bridge with 500 foot spans was possible, especially since one had already been built in Holland. The Kuilenburg Bridge was built on the river Leek in Holland in 1866 and had a single 515 foot span. This bridge was built one and a half to two years before the Eads Bridge was started. It is possible that Eads knew of the construction of this bridge and supported the stipulation that the spans of the bridge at Saint Louis could be no less than 500 feet, knowing that he was able to build spans this

[58] Jackson, *Rails across the Mississippi*, 57; Miller and Scott, *The Eads Bridge*, 80; Woodward, *A History of the St. Louis Bridge*, 12-13.

long when others might not believe it was possible. This could have been a ploy to get the ferry and transfer companies to agree to this legislation and remove them as obstacles.[59]

The Eads Bridge was built to serve a practical purpose. It was built with the expectation that it would bring prosperity and relief to the city of Saint Louis and its citizens. Saint Louis had realized the need for a bridge for many years but it was not until the construction of the Rock Island Bridge that the leaders of Saint Louis determined that the economic well-being of the city depended on constructing a bridge across the Mississippi River at Saint Louis. With the increasing number of railroads being built in the United States the bridge needed to be a railroad bridge at a minimum, but the necessity for pedestrian and wagon traffic was also a priority.

How did Saint Louis end up with an arch bridge spanning the Mississippi River and not a different type of bridge? There were several bridge builders with the experience and ability to span the Mississippi River that Saint Louis city leaders could have chosen. Considering that James Eads had no experience building bridges it seemed to be a great risk to select Eads as the individual to design and build the bridge across the Mississippi River at Saint Louis. At the time of the planning and construction of the Eads Bridge technology existed to build a safe, sustainable, railway and roadway suspension bridge across the Mississippi River at Saint Louis. This technology had been proven for many years prior to the planning of the Eads Bridge.

Leading up to the construction of the Eads Bridge three of the most capable United States engineers of the early to late-nineteenth century; Charles Ellet, Jr., John A. Roebling, and James B. Eads, each had attempted to become the builder of the first

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[59] Charles Kendall Adams, LL.D., ed., Johnson's Universal Cyclopedia (New York: A.J. Johnson Company, 1893), 771.

bridge across the Mississippi River at Saint Louis. Ellet and Roebling were two of the greatest United States bridge engineers. Eads, although not a bridge engineer, was one of the greatest United States engineers. It is quite conceivable that people standing on the Saint Louis riverfront today looking at the first bridge to span the Mississippi River at Saint Louis could be looking at a suspension bridge. If that were the case, it would be the third oldest working suspension bridge in the United States, behind the Wheeling Suspension Bridge at Wheeling, West Virginia, and the Roebling Suspension Bridge at Cincinnati, Ohio.

Chapter 2

A Saint Louis Solution

It was the self-taught engineer, James B. Eads, who was successful in building the first bridge across the Mississippi River at Saint Louis. Eads, who had no formal engineering education or experience building bridges, was counted on to bridge the Mississippi River at Saint Louis in order to bring the railroad, and hopefully prosperity, into Saint Louis from the east. A good argument for selecting Eads to build the bridge across the Mississippi River was because of his many talents over a wide range of areas. His accomplishments as a river salvager and Civil War gunboat builder were widely known in Saint Louis. His background as a self-starter, who often needed to devise technical solutions on short notice as well as obtain financing for his projects, gave his supporters confidence he would complete his projects. The ability to acquire the money needed to get the bridge built was an important reason that the leading men in Saint Louis supported Eads. This support was orchestrated by Eads himself when he decided to take control of the Saint Louis and Illinois Bridge Company to keep the construction of the bridge out of the hands of individuals wishing to deny Saint Louis a bridge and subsequent economic growth. Eads handpicked the men he wanted on his team to get his bridge built. He shared his designs with these men to garner their support. This was a relationship that benefited both Eads and his backers. His backers knew Eads had the technical ability to build his bridge but more importantly they knew their financial investment was safe with him. Eads was a shrewd and experienced businessman who knew how to convince investors that his projects were worth their investments. Even with Eads' expertise in acquiring funding, financial resources in America and Europe were not interested in funding the construction of the bridge until certain amendments were made to the Illinois charter.[60]

Once the amended Senate Bill 38 had been signed into law, Missouri Senator Norman Cutter, who had created the second charter for the Saint Louis and Illinois Bridge Company in 1864, began acquiring financial backing and engaging bridge building companies interested in financing and constructing the bridge. At about this time, Lucius B. Boomer, a bridge builder from Chicago, attempted to secure the rights from Cutter, to build the bridge at Saint Louis. There were many in Saint Louis who believed Boomer was trying to gain control of the building of the bridge to delay or stop construction of the bridge at Saint Louis to benefit Chicago. Before Boomer was able to secure the contract to build the bridge, financing had to be in place. This required that changes be made to the Illinois charter to appease investors. Boomer wanted the contract so he promised his support in getting changes made to the charter.

Once word was received in Saint Louis that Cutter and Boomer were working together to get amendments made to the Illinois charter, the concern in Saint Louis ballooned. A meeting was held on February 17, 1867, in the Southern Hotel, and Eads was appointed chief engineer. In an effort to build confidence in his abilities and design, and to thwart any possible attempt to replace him, Eads assembled a group of accomplished engineers with bridge building experience. As chief engineer, Eads was ultimately responsible for the bridge but relied heavily on these engineers for all aspects of successful completion of his bridge. One of the most important areas these engineers were involved in was the testing of the components and materials to be used in the bridge. Henry Flad, Eads' chief assistant engineer, developed a machine to be used to test

[60] Jackson, *Rails across the Mississippi*, 23-24; Woodward, *A History of the St. Louis Bridge*, 15.

materials to an extremely precise tolerance. Eads established guidelines for all materials to be tested. Those that did not pass all tests required were rejected. These engineers did not disappoint Eads and were an integral part of his success. The collection of selected engineers, along with Eads engineering intelligence, political, and financial influence, insured the completion of his bridge over the Mississippi River.[61]

Eads was convinced that the people of Saint Louis realized the importance of a bridge at Saint Louis and began working on a plan to keep the construction of the bridge from falling into the hands of what were perceived as Chicago interests. While Eads worked on his plan, Boomer felt that now that he had an exclusive charter from Illinois to build a bridge the Saint Louis group would no longer pursue a bridge. This did not happen as Boomer found that support for the Saint Louis group grew because people believed Boomer had nefarious intentions. Boomer attempted several strategies to discredit the Saint Louis group's construction plan, but was not able to gather enough support to stop them. Every time Boomer presented a flaw with the Saint Louis and Illinois Bridge Company plan, Eads addressed and rebutted any accusation put forth by the Boomer group. As both groups realized continued agitation between them resulted in no bridge, discussions were held between the groups to attempt to resolve differences, but to no avail. Eventually the two companies were able to agree to a consolidation with the remaining company being named the Illinois and St. Louis Bridge Company, adopting the plans developed by the Saint Louis and Illinois Bridge Company, naming Eads the chief engineer, and paying off Boomer. Once this consolidation was finalized construction proceeded with no fear of another bridge company interfering.

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[61] Woodward, *A History of the St. Louis Bridge*, 15; Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling", 4-6.

Although there were several factions who did not want a suspension bridge built at Saint Louis it is entirely possible that the Eads Bridge is not a suspension bridge because of Eads himself. In his book, *James B Eads*, Louis How, Eads' grandson, made it clear that Eads was very exacting, knowledgeable, and driven. He was also tactically forceful and demanding when the situation required such action. How demonstrated this trait when he stated, "His wide and thin-lipped mouth shut so emphatically that it made it plain his intention to do, in spite of all, what he believed could and should be done." Describing Eads forcefulness, How gives us the following: "Some one said that it was a hundred horse-power mouth. It admitted no trifling. When it spoke seriously, it spoke finally." Reading the letters written by Eads to the editor of an engineering magazine, confronting and rebutting Washington Roebling's comments of Eads Bridge and some of the components of his bridge, give a good example of the determination Eads possessed. At the formal opening of his Bridge on July 4, 1874, Eads continued to display confidence in his abilities when, in his address to those gathered that day, he stated that he had experienced no respite from worry when the piers reached bedrock, or when the first heavy locomotives were driven over the finished bridge, for he: ". . . had felt no anxiety on the subject."[62]

Another example of Eads self-assurance is recorded in the diary of the engineer in charge of the work on the west abutment. When referring to some machinery that he believed needed correction, but that Eads believed was just fine, Benjamin Singleton

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[62] Louis How, *James B. Eads* (Freeport, New York: Books for Libraries Press, 1900), 61; James B. Eads, *Address at the Grand Celebration of the Opening of the St. Louis Bridge, July 4, 1874* in *Addresses and Papers of James B. Eads together with a Biographical Sketch*, ed. Estill McHenry (St. Louis, MO: Slawson & Co., Printers, 1884), 43.

wrote that: ". . . his obstinacy knows no bounds. He will have his own way at whatever cost."[63]

As demonstrated in the following quote from his report to the president and directors of the Illinois and St. Louis Bridge Company, Eads was very confident in his abilities: "Must we admit that because a thing has never been done, it never can be, when our knowledge and judgment assure us that it is entirely practicable?" Clearly Eads had the personality and confidence, if not the formal technical training, to get his bridge built. As part of the amendments to Senate Bill 38 Eads' committee also specified lengths of spans to be built. Is it possible Eads was planning to build his own bridge and wanted to make sure it was of a type only he could construct and therefore have no competition? Eads later disclosed that he persuaded the Saint Louis Merchants Exchange Committee to advocate very long spans. Because of these long spans a truss bridge was impracticable, but Eads was confident he could build arch spans of these lengths. Although these opinions by a self-taught engineer who had never built a bridge before seemed questionable, it must be remembered that Eads accomplishments to this point in his life were vast and bold. His self-assurance and driven attitude had allowed him to accomplish much. Because of the unprecedented demands required by Senate Bill 38, of any bridge to be built at Saint Louis, it was believed there was no engineer in the United States with the ability and experience to build this bridge.[64]

This was clearly incorrect but exactly what Eads would have wanted all to believe. Several bridges, though not arch bridges, had been built in the United States that easily surpassed the 500 foot span length requirement. The Niagara Falls Suspension

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[63] John Kouwenhoven, "The Designing of the Eads Bridge," *Technology and Culture* 23 (Oct. 1982): 540.
[64] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 516; Jackson, *Rails across the Mississippi*, 18; How, *James B. Eads*, 58.

Bridge had a span of 825 feet; the Wheeling Suspension Bridge had a span of 1010 feet, and the Roebling Suspension Bridge had a span of 1057 feet. The construction of these three bridges had begun before 1857; eight to nine years before the bill in Congress stipulated the span length of the bridge at Saint Louis. Any of the builders of these three bridges could easily have built a bridge across the Mississippi River at Saint Louis with a center span of 500 feet. Considering the suspension bridges these builders had already built it seems likely that the center span would be much longer than the bill required, possibly reaching 1,000 feet or more. This would leave steamboats plenty of room for maneuvering around other steamboats and any piers in the river. The physical restrictions imposed for the building of the bridge at Saint Louis were not the only obstacles to be overcome for successful construction of the bridge. In addition, political and financial hurdles had to be surmounted to move forward with the bridge at Saint Louis.

The opposition by steamboat interests to railroads and bridges spanning rivers was not unique to Saint Louis as it began its process to acquire a bridge across the Mississippi River. Steamboat interests in the east realized, years earlier, that bridging the Ohio River for the railroads terminating at the river created problems for themselves. The construction of a bridge over the Ohio River brought several problems home to the steamboat operators. Although these operators felt assured that Congress would require the bridge builders leave the river navigable, there was no protection from Congress for passengers and freight lured to the railroad and bridge for faster and cheaper transit over the river.[65]

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[65] Elizabeth Brand Monroe, *The Wheeling Bridge Case* (Boston, MA: Northeastern University Press, 1992), 22.

One of the major obstacles cited by steamboat operators was that the bridges did not provide enough clearance for their smokestacks to pass under them. Even though the steamboats were, or could have been, equipped with the machinery necessary to lower the smokestacks to pass under a bridge, the steamboat operators claimed this was a difficult and dangerous task. They wanted to see the bridges raised or removed to accommodate their smokestacks. Taller smokestacks were part of an attempt by steamboat builders to make their engines more efficient, by increasing the furnace draft, and therefore less costly. This method was known as the natural draft method. There was another method, the artificial draft method, which used fan blowers and steam jets to increase draft and therefore improved the engine efficiency. This method did not require the tall heavy smokestacks and consequently removed the need to have excessive clearance from water level to bridge. This artificial method was in use by 1850 and if it had been incorporated by all, or most, steamboats it would have eliminated the argument that there was not enough clearance for the steamboat smokestack. This would have weakened the steamboat interests' position against any bridge planned or already under construction.[66]

There was a suggestion that a truss bridge be built at Saint Louis. This was dismissed when Eads determined that; "Steel trusses 500 feet long would have to be made extremely heavy…." Eads believed that he could build a steel arch 500 feet long that was just as strong, but lighter and therefore much cheaper. Eads believed that arches were the most cost effective construction method for the bridge at Saint Louis, ". . . the plan adopted for the construction of this Bridge, instead of being needlessly expensive, is

[66] Monroe, *The Wheeling Bridge Case*, 27.

really the most economical of all known methods."[67] Eads was adamant his arch bridge design was the only design capable of providing the strength and stability needed to span the Mississippi River for rail traffic. In addition to providing the solidity needed Eads selected his arch design over all others for its timeless beauty acquired at a cost-effective price.[68]

On this point Eads was possibly wrong, as suspension bridges had proven to be very economical, then again Eads gave a very persuasive argument that his arch bridge could be cheaper than a suspension bridge. In his *Report to The President and Directors of the Illinois and St. Louis Bridge Company* in 1868, Eads went into great detail to explain and justify why he picked an arch over a suspension bridge for the bridge at Saint Louis. He explained that cast iron had an elastic strength of about 7,000 pounds per square inch before a permanent set occurred, and wrought iron had an elastic strength of 18,000 to 25,000 pounds per inch before permanent set. If a permanent set did not occur the metal would resume its normal shape and elasticity. The elasticity and permanent set properties were the keys to his selection of an arch bridge. The forces exerted on the arch bridge are compressive in nature whereas on a suspension bridge they are tensile. When cast iron wires are exposed to tension, as in a suspension bridge, they are stretched and narrowed. If the tension is within the elastic limits the wires will resume their normal shape and strength. If the tension exceeds the elastic limits the wires will receive a permanent set and remain stretched, narrowed, and weakened with internal defects. Once this occurs subsequent tension of these wires can cause catastrophic failure. When cast

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[67] How, *James B. Eads*, 61; Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 487.

[68] Billington, *The Innovators: The Engineering Pioneers who made America Modern*, 149; David P. Billington, *The Tower and the Bridge: The New Art of Structural Engineering* (Princeton NJ: Princeton University Press, 1983), 113-116.

iron is exposed to compression, as in an arch bridge, it is compressed and expands in diameter. If the compression is great enough to cause a permanent set to occur the cast iron will undergo a physical change, but it will be in the form of expansion in diameter, the opposite of a permanent set from tension. Because of this the structural integrity of the arch bridge, although weakened, is maintained at a higher level of safety than is the suspension bridge that undergoes an event of tension that effects a permanent set on its suspension wires. Eads pointed out that he had no evidence ". . . that iron or steel, when under compression, are anymore liable to fracture by sudden jarring than when at rest; or that their strength is at all impaired by vibration when under compression." The same could not be said for iron or steel when under tension, as in a suspension bridge. When under tension, iron or steel are more likely to incur damage such as fracturing, and loss of strength when they are subject to conditions such as sudden jarring, concussion, and vibration. Because of this Eads presented a guideline for engineers to follow when using cast iron and or cast steel. When using these metals for tension the engineers should: ". . . leave a large margin within the elastic limit for safety but for compressive strains he may base his calculations on using them to the full limit of elasticity with entire safety."[69]

This was a key point in Eads argument that the total cost of his upright arch could be much less than a suspended arch. To obtain the maximum strength of an upright arch, such as Eads designed, steel in compression needed to be used. Eads was able to present to the president and directors of the Illinois and St. Louis Bridge Company the results of testing performed on various forms of steel. All tests showed the strength of steel improved, in both compression and tension environments, when worked by different

[69] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 520.

methods. These tests showed the elastic limit of cast steel was greater in compression than in tension.

After Eads presented these findings concerning testing using cast iron and cast steel, he proceeded to inform his audience of the results of his investigation into the viability of an upright arch. To determine the viability of the upright arch Eads sought the answers to two key questions: ". . . will the structure require more material by using the upright arch than the suspended one: and if so, how much more?" and ". . . will its construction and erection be more costly?"[70]

Eads presented an example, based on testing of cast steel in a compression and tension environment, as they related to an upright and suspended arch bridge. Even though his testing showed cast steel in an upright arch possessed nearly twice the strength as in the suspended arch, Eads example is presented with steel in an upright arch only being fifty-percent stronger than the suspended arch. In his example, Eads presented, based on testing, that ". . . an upright arch having 1,000 tons of cast steel properly disposed throughout its length, would sustain as great a load as 1,500 tons in the suspended form." Eads conceded that more bracing was needed in the upright arch than in the suspended arch to make the arch stable. Using his test results he felt he had an excess of 500 tons between the abutments for his upright arch, which he could use some, but not all, for bracing, compared to the steel in the suspended arch between the towers. Eads did not count the additional steel required in the suspended arch from the towers to the anchorages in this example. Eads believed the construction of the upright arch was more expensive than the construction of the suspended arch but countered this with the statement: "The greater cost of the erection of the upright arch could not possibly equal

[70] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 521.

the cost of the greater quantity of material required in the suspended one between the towers."[71] Eads also expanded on the excess of steel required beyond the towers by stating that he believed the material running from anchorage to anchorage is: ". . . usually double the length of the suspended arch . . . ." Because of this additional material required from tower to anchorage, Eads calculated that since steel in tension is half the strength of steel in compression, four times as much material is required in the suspended arch as in the upright arch. Eads goes one step further in proving his point that the upright arch was still cheaper to use than the suspended arch, even if steel did not have any strength advantage in compression as opposed to tension. He stated that the excess material required from the tower to the anchorage allowed him to build an upright arch, correctly braced, for less than a suspended arch.

Eads also argued that there was a cost savings in the masonry required for an upright arch as opposed to a suspended arch bridge. Eads stated that an upright arch had a downward thrust on the abutments that was roughly equal to the pulling strain on the anchorages. If the masonry required for the abutments was equal to the mass required for the anchorages, based on Eads suppositions, then the masonry in the towers to support the cables will be: ". . . that much more than the upright arch requires." Eads was quite confident in stating: ". . . all these facts clearly prove the economy of the upright ribbed arch over every other system of bridging with long spans."

After his presentation to validate his conviction for proclaiming his upright arch as being cheaper than a suspended arch, Eads disclosed the main reason why this was true:

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[71] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 522-524.

> The chief secret of the greater economy of iron suspension bridges rests in the fact that the limit of elasticity of iron wire is far greater in *tension* than the limit of elasticity for any form of iron known (except steel) when used in *compression*.[72]

Until steel was readily available for bridge construction iron wire suspension bridges were the most economical bridges. The use of cast steel flipped this advantage completely around and allowed upright arch bridges to be constructed cheaper, in comparable or greater lengths, and with equal safety as suspension bridges. Eads was able, through the use of illustrations and a layman type presentation, to describe how his upright arch could compete with the suspended arch when cast steel was used.[73]

With his great knowledge of the Mississippi River currents, ice flows, scouring, and depth to bedrock it is logical to question Eads decision to ignore the benefits of a long-span railway suspension bridge for Saint Louis. A span of 800 feet or more in 1868 was easily obtainable as an 825 foot span over the Niagara River had been successfully constructed thirteen years earlier. A long-span suspension bridge would have at most two piers in the Mississippi River, as does the Eads Bridge, but with more river clearance between them and possibly eliminating the shore abutments, completely negating additional water work for the abutments. With a long-span suspension bridge it was possible Eads could have placed his river piers in shallower water, or on land, thereby reducing death and injury from caissons disease. A long-span suspension bridge would have allowed more room side to side for boats to pass each other and would have reduced, or eliminated, any ice dams caused by piers being placed close to each other. In

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[72] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 525-527.
[73] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 521-527.

addition, less masonry in the river would have reduced the cost of the bridge. Eads knew this and also knew that because of its power, the Mississippi River could perform disastrous work on man-made structures. This required him to build his piers on a scale large enough to resist the force of the Mississippi River. To do this his piers required massive amounts of masonry at great expense. One way to lower the cost of his bridge would have been to have longer spans and thus require fewer piers or abutments and their accompanying high costs.[74]

Eads was aware the success of the Niagara Falls Suspension Bridge proved the feasibility of such a structure at Saint Louis. In his report to the principals of the St. Louis Bridge Eads showed no bias against suspension bridges, only presenting facts and results from his testing that supported his upright arch choice, when making his case for railway traffic and common traffic sharing the same bridge at the same time, albeit on separate levels. The ability to accommodate both means of traffic was entirely possible and had already been proven. Several examples of these bridges in operation existed in Europe and the United States, including the Niagara Falls Suspension Bridge. Included in Eads report, while referring to both the upright and suspended arch bridges changing shape due to a moving load, was an interesting quote from Eads. He acknowledged the suspension bridge could be used for railway traffic when he stated: “For railroad purposes, however, this could not be permitted in the suspended arch to any considerable extent.” Coming from a man with Eads’ reputation and personality this statement is as close as you can get to an endorsement by Eads for a railway suspension bridge, without being a direct endorsement.[75]

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[74] How, *James B. Eads*, 61.
[75] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 494-523.

In addition to Eads, Ellet had made comments and statements that implied railway suspension bridges were a valid and growing bridge type. Although not specifically designed as a railway bridge, Ellet appeared to suggest that one day in the near future his Wheeling Suspension Bridge would need to be refitted to handle rail traffic. Several railroads considered Wheeling the ideal location to connect east-west rail traffic. Because of this Ellet believed rail traffic would increase so much in the vicinity of the Wheeling Suspension Bridge as to require access to his bridge. This would require upgrades to the bridge to allow passage of rail traffic.[76]

Ellet's apparent lack of concern with the fact that the bridge might need to handle rail traffic in the near future implied he felt his suspension bridge could safely handle rail traffic with minimal modifications. When the original Wheeling Suspension Bridge was ravaged by high winds in 1854, this gave Ellet the opportunity to express his thoughts, to his wife in a letter, on rebuilding the bridge as a railroad bridge: ". . . the probability is that we shall soon enlarge the plan and convert the structure into a railroad bridge." It is obvious that Ellet's plan to rebuild his bridge with an emphasis on rail traffic gave him no pause for concern. Ellet also contacted railroads that were developing plans for terminating at Wheeling, and presented them with proposals for acquiring access to his bridge.[77]

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[76] Charles Ellet Jr., "Report on the Wheeling and Belmont Suspension Bridge, to the City Council of Wheeling," Philadelphia: John C. Clark 1847, 37, quoted in Elizabeth Monroe, *The Wheeling Bridge Case* (Boston, MA: Northeastern University Press, 1992), 49.

[77] Charles Ellet Jr., to Elvira Ellet, May 20, 1854, Charles Ellet Jr. Papers, Engineering Library, University of Michigan quoted in Elizabeth Monroe, *The Wheeling Bridge Case* (Boston, MA: Northeastern University Press, 1992), 152; Charles Ellet Jr., to C. Prentice, president; Charles Ellet Jr., to William P. Cutler, president; Charles Ellet Jr., to Benjamin Latrobe, engineer; June 17, 1854, Charles Ellet Jr. Papers, quoted in Elizabeth Monroe, *The Wheeling Bridge Case* (Boston, MA: Northeastern University Press, 1992), 152.

This action made it clear that Ellet felt his rebuilt bridge would be strong enough to handle rail traffic. This confidence in his bridge to handle rail traffic was presented by Ellet in 1854, twelve years before Eads began construction in Saint Louis. Although Ellet did rebuild his bridge he did not, for various reasons, rebuild it to handle rail traffic.

Because of the topography at the selected bridge site in Saint Louis, a suspension bridge would not appear to have any higher clearance than the highest point of the Eads Bridge, but it would have this same clearance for the complete main span since it would be unencumbered by the downward slope of an arch as it neared the piers. A unique aspect of the proximity of a bridge to downtown Saint Louis worked in the favor of a suspension bridge. A major complaint, by detractors, of the Niagara Falls Suspension Bridge was the slow speed the trains used when crossing it. Because the bridge at Saint Louis would have been located at the doorstep of downtown, a tunnel was required to allow the train to pass under downtown without disrupting the functions of the city. Eads stated that the tunnel, as of 1868: ". . . has been designed for the accommodation of a single railroad track only . . . ." This restricted the number of trains that could use the tunnel and was a limiting factor in the speed of trains using the tunnel. Because the tunnel was so close to the bridge trains traveling east and west slowed for the tunnel. This caused the train to be traveling slowly for the bridge crossing, making speed over the bridge a non-issue.[78]

In a report to the president and directors of the Illinois and St. Louis Bridge Company in 1868, Eads personally confirmed that any piers placed in the river for his bridge were a dangerous, but necessary, requirement. Eads knew from many years of experience on and below the river that anything in the river, including bridge piers, was

[78] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 509.

an obstruction. Placing piers in rivers, no matter their position, required river traffic to be alert and navigate around them. The thrust of his presentation: an obstacle in the river is a danger to navigation, has been true from the day man first navigated a log downstream and will remain true until the rivers run dry. What Eads did not present to his audience was that his bridge design placed these dangers closer to river navigators than necessary. A suspension bridge design with a main span of just 825 feet, the same span length of the Niagara Falls Suspension Bridge that was built in 1855 and still in operation thirteen years later, would have given almost 300 more feet of river navigation clearance for the all-important center span, with no lowering of the bridge as with an arch bridge. It may have been possible to eliminate bridge piers in the river by building a suspension bridge. In an apparent attempt to calm fears concerning these obstacles, Eads put forth, while defending his selection of Washington Avenue as placement for his bridge, an argument that since Washington Avenue approximately split the wharf roughly equally above and below the bridge, that this was an excellent location for segregating the Mississippi River traffic north and south of Saint Louis. Supposing that all river navigation adhered to Eads suggestion, Eads could have placed as many piers in the Mississippi River as he desired and they would not have been an obstacle and there would never have been any collisions with his bridge piers. Common sense and a little time spent discussing this plan with steamboat captains on the Saint Louis waterfront in 1868, would have eliminated this idea and elicited more than a few unkind words for Mr. Eads. Eads' Washington Avenue location for his bridge may have been the correct location, but his plan for dealing with bridge piers in the river, which would have been less of a problem with a suspension bridge, was little more than a calming suggestion for the president and directors of the Illinois and St. Louis Bridge Company.[79]

In 1873, steamboat interests met and petitioned the Secretary of War to review the Saint Louis bridge construction because they felt it presented serious obstruction, and dangerous conditions to river navigation. The Secretary of War organized a board of engineers to review the design and construction of the Saint Louis bridge. This board found, after several days of reviews and hearings, that the Saint Louis bridge design was flawed. 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." The Secretary of War approved the findings of the Board and the Boards report was forwarded to the bridge company on October 15, 1873.[80]

It is doubtful that Eads was able to control his emotions when he received this report with his bridge construction so far along, especially when he had complied with the construction stipulations approved by Congress. He was concerned with any possible changes being forced on him, but he was more concerned with this report and how it might affect the finances of the bridge company. Eads feared that this report could negatively "…affect their credit rating and their ability to raise capital to complete the bridge." To minimize the deleterious effects of this report Eads addressed each and every issue raised by the Board, and provided a defense of all issues in a report he presented to the Board. Despite providing a defensible report of his bridge, which Eads pointed out was: "…built according to the dimensions listed in the charter of the Bridge Company

[79] Eads, *Addresses and Papers of James B. Eads together with a Biographical Sketch*, 487-487.
[80] J.H. Simpson, G. K. Warren, G. Weitzel, W. E. Merrill, C.R. Suter, "The St. Louis Bridge an obstruction to navigation," *The Railroad Gazette*, V. 5 October 25, 1873; 434-435, quoted in Kirti Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling," *Gandhi Consulting Engineers and Architects*, 12.

and approved by the U.S. Congress" the Board, after reviewing Eads defense, stood firm.[81]

In addition to this official report by the Board, one member of this Board, General Kemble Warren, wrote his own opinion of the bridge situation. In his opinion Warren made it clear that he felt a suspension bridge, in place of the arch bridge, would have been a better choice for Saint Louis. While not using the term suspension, Warren lists cheaper cost, little to no river obstructions, and proven design as advantages of the bridge type he believed should have been selected. These are all characteristics of a suspension bridge.[82]

Warren was Washington Roeblings brother-in-law and most likely knew of the feud taking place between Eads and Roebling concerning the airlocks for the caissons of the Eads and Brooklyn Bridge. Eads believed Roebling had copied his airlock design for the Brooklyn Bridge without remuneration or crediting him for the design. It is not known if this feud colored Warren's opinion that Eads used various manipulations to get his bridge design specifications approved by Congress, but it is obvious that Warren felt Eads bypassed the cheaper, simpler and proven concept of a suspension bridge to build a bridge of his own design. While neither Eads nor Warren was formally trained in bridge building, Warren did possess a much greater degree of formal engineering education than Eads. Warren was an intelligent individual and competent engineer with many years of experience. He graduated from West Point second in his class with high marks. He spent many years exploring and documenting the Mississippi River as a Topographical Engineer. This was followed by many years exploring and documenting the western

[81] Gandhi, "The St. Louis Bridge, the Brooklyn Bridge, and the feud between Eads and Roebling", 12-13.
[82] Woodward, *A History of the St. Louis Bridge*, 282.

United States, often in perilous situations. At West Point he held the position of assistant professor of mathematics, where he spent approximately eighteen months before being ordered to take command of a New York regiment of Zouaves at the beginning of the Civil War. During the Civil War, Warren participated in many battles and engineering projects and always distinguished himself as a competent and successful, if cautious, leader of men. After the war, Warren continued his engineering work for the Corp of Engineers. This included supervising the construction of the first double deck drawbridges over the Mississippi River at Rock Island in 1867, and participating in other bridge building projects in the 1870's. It is obvious, from his experience and education, Warren was qualified to review and recommend in many aspects of engineering. Even though Warren had impressive credentials, it is possible he was unable to remain objective when considering Ead's Bridge and the complaints from the steamboat interests.[83]

Even with the report from a board of distinguished experienced engineers, and the Secretary of War approval, Eads was not to be denied. Drawing on past experiences Eads had access to President Ulysses S. Grant and wasted little time gaining an appointment with him. Grant sided with Eads and suggested the Secretary of War find other items to occupy his time. This ended any interference from the board of engineers organized by the Secretary of War to review the Saint Louis Bridge, and allowed Eads to finish his bridge.[84]

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[83] David M. Jordan, *Happiness is not my Companion: The Life of General G.K. Warren* (Bloomington, IN: Indiana University Press, 2001), 5-33; New York State Library, "Gouverneur Kemble Warren Papers, 1848-1882," http://www.nysl.nysed.gov/msscfa/sc10668.htm.

[84] Jackson, *Rails across the Mississippi*, 168.

Conclusion

The Wheeling Suspension Bridge was the longest suspension bridge in the United States when it was completed in 1849. The main span was 1,010 feet long from tower to tower. This bridge had no piers in the Ohio River because the length allowed them to be placed on land. This span length would not completely cross the Mississippi River at Saint Louis, but minimal side spans would complete the crossing of the Mississippi River. Another early suspension bridge was the first Lewiston & Queenston Suspension Bridge completed in 1851. This bridge, built by engineer W. Edward Serrell, had a deck span of approximately 849 feet. Similar to the span length of the Niagara Falls Suspension Bridge, this bridge proved the ability to span great distances was available. This bridge was wrecked by wind in 1864. As has already been discussed, the first successful railway suspension bridge in the world was the Niagara Falls Suspension Bridge. This bridge, completed in 1855, was 825 feet long; not long enough to span the Mississippi River, but at 825 feet provided more river clearance for steamboats than the Eads Bridge.[85]

The Roebling Suspension Bridge at Cincinnati, completed in 1866, provided proof that the technology existed to span most of the Mississippi River at Saint Louis with a suspension bridge. The bridge at Cincinnati had a main span of 1056 feet, side spans of 278 feet, and a total length of 2250 feet. The length of the bridge spanning the Ohio River at Cincinnati is 1612 feet. The Eads Bridge at Saint Louis has three spans of 502, 520, and 502 feet, for a river spanning length of 1524 feet, well within the 1612 foot length of the Roebling Suspension Bridge at Cincinnati. If the main span at Saint Louis

[85] Kemp, *Charles Ellet, Jr. and the Wheeling Suspension Bridge*, 22; Greenhill, *Spanning Niagara: The International Bridges 1848-1962*, 23; Hopkins, *A Span of Bridges: An Illustrated History*, 177.

was 1020 feet, quite feasible in 1868, this would leave side spans of 251 feet. This would give tremendous river clearance, allowing steamboats to have approximately 170 feet clearance as opposed to approximately 130 feet clearance between each boat with the Eads Bridge, and possibly more height clearance as well. A 1020 foot main span at Saint Louis would be conservative considering the Roebling Suspension Bridge at Cincinnati had a main span of 1056 feet when it was completed in 1866. This would only be approximately 200 feet longer than the Niagara Falls Suspension Bridge completed in 1855. Surely technology and techniques had advanced enough in the thirteen years between completion of the Niagara Falls Suspension Bridge in 1855, to the start of construction of the Eads Bridge in 1868, to support the additional 200 feet of suspension bridge.

The Niagara Clifton Bridge, a suspension bridge with a span of 1,268 feet, was designed by Samuel Keefer. Construction began in 1867 and was completed in 1869. This suspension bridge was initially built of wood with wire cables. In 1872, the wooden bottom chords, key components of many bridges, were replaced with steel. This bridge served for many years before failing in a major storm in 1889, and falling into the river below. This bridge would not span the Mississippi River, as others would not, but an accumulation of education and knowledge was building for future long-span suspension bridges.[86] Using just the preceding five examples of suspension bridges built from 1849 to 1867, with ever increasing main spans, it is obvious that the ability to span the Mississippi River at Saint Louis with a suspension bridge existed before Eads began

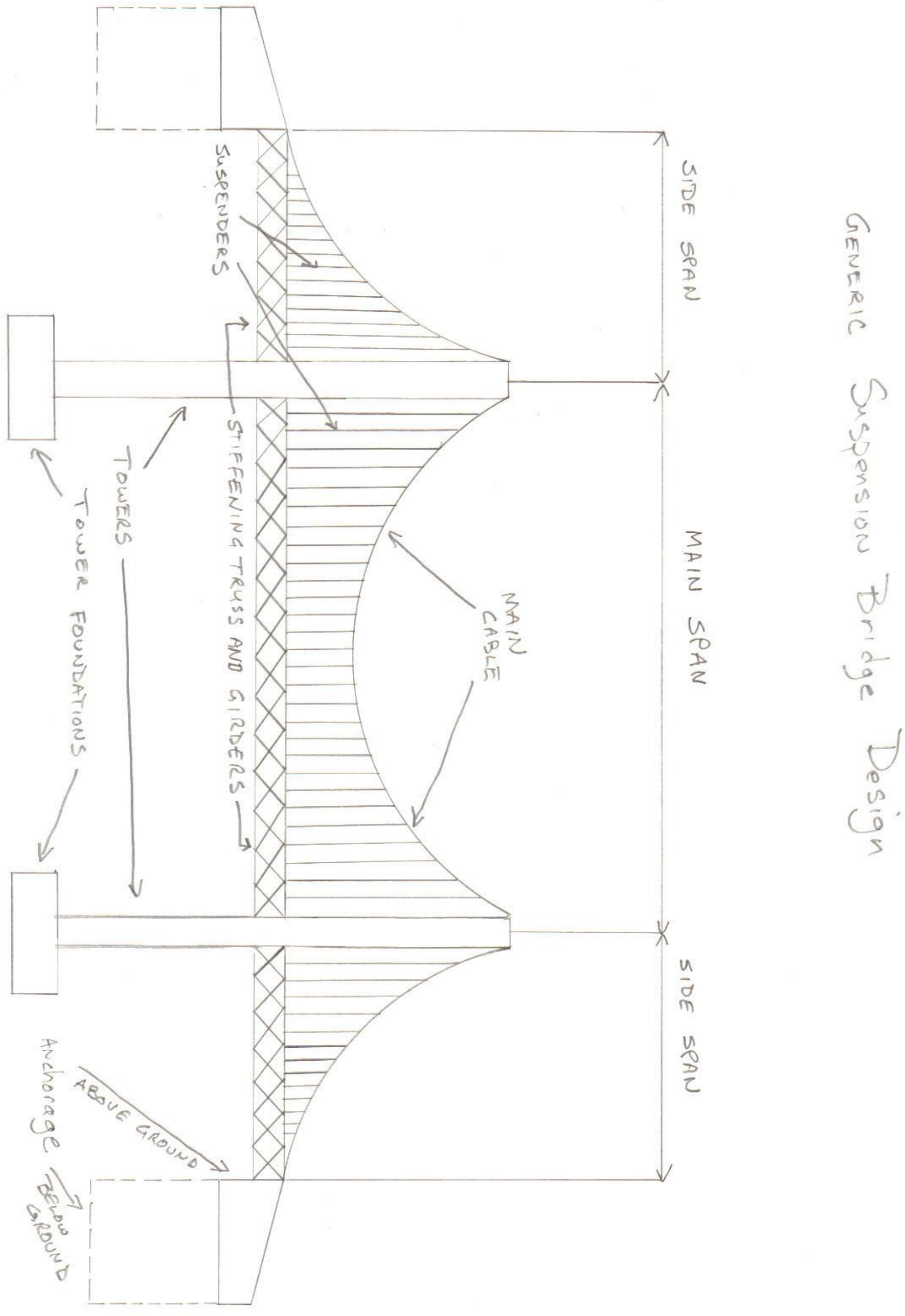
[86] Niagara Falls info, “The First Falls View Suspension Bridge,” http://www.niagarafallsinfo.com/history-item.php?entry_id=1393&current_category_id=208.

construction. Three of these bridges were completed years before Eads became involved in the considerations for a bridge at Saint Louis.

A suspension bridge should have been an easier sell to the steamboat interests than the arch bridge Eads eventually completed in 1874. A suspension bridge should have had fewer obstacles to river traffic, since it should have needed fewer piers in the river. The height of the deck at the pier would be higher than the arch bridge as the arch would need to curve down to meet the pier.

Eads deftly explained why technically, based on the elasticity of cast iron and cast steel, an arch bridge was a better, and safer, option than a suspension bridge. In concert with this technical explanation Eads also explained why financially his arch bridge was a better choice. Although a suspension bridge would have been successful in place of the Eads arch bridge, the arch bridge constructed by Eads, based on his design, explanations and the all-important use of cast steel, was the correct and best choice of bridge type to have been constructed.

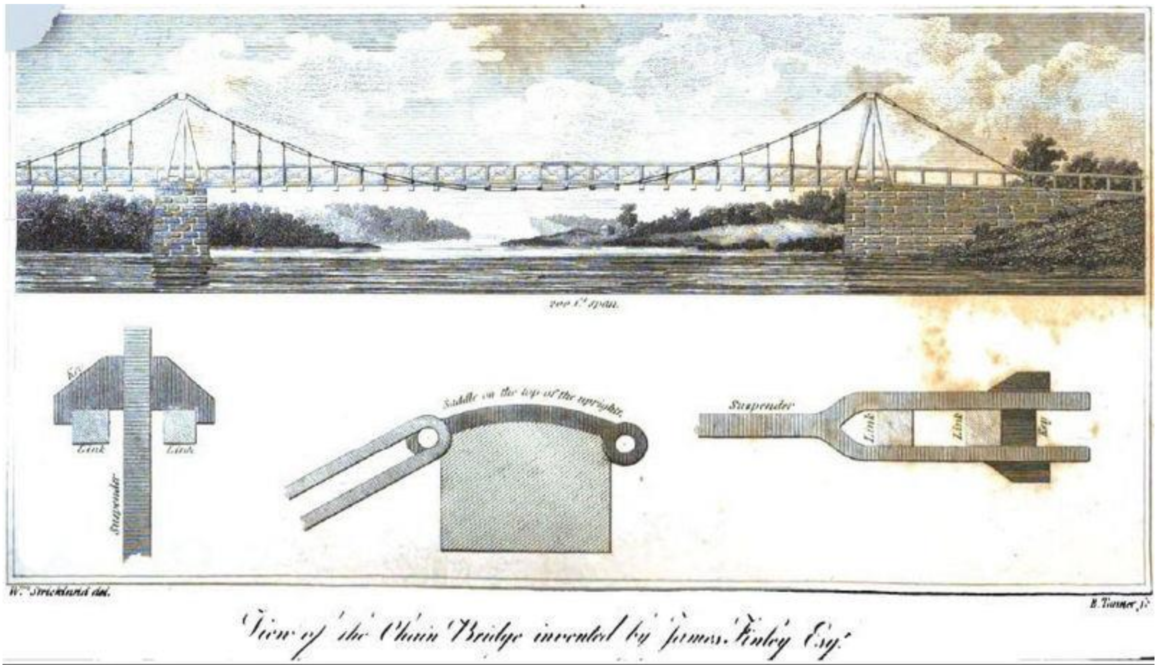
Appendix A



Generic illustration of a suspension bridge.

Kurt Timmerman, *General illustration of a suspension bridge*, 2014

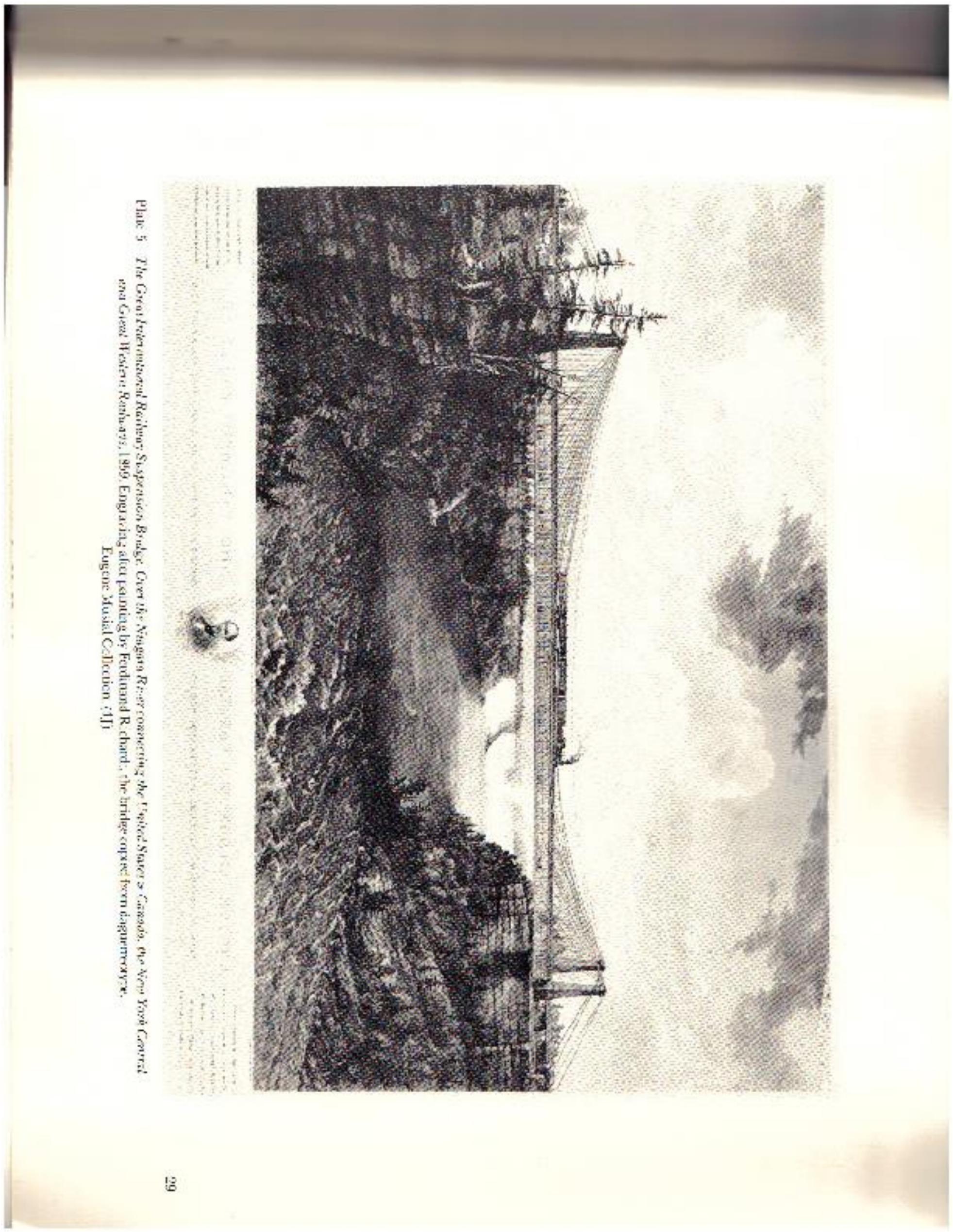
Appendix B



Example of Finley's Jacob Creek Chain Link Suspension Bridge that spanned Jacob Creek in 1801.

James Finley, "A Description of the Patent Chain Bridge,' *The Port Folio,* 3no6 (1810): 441-453.

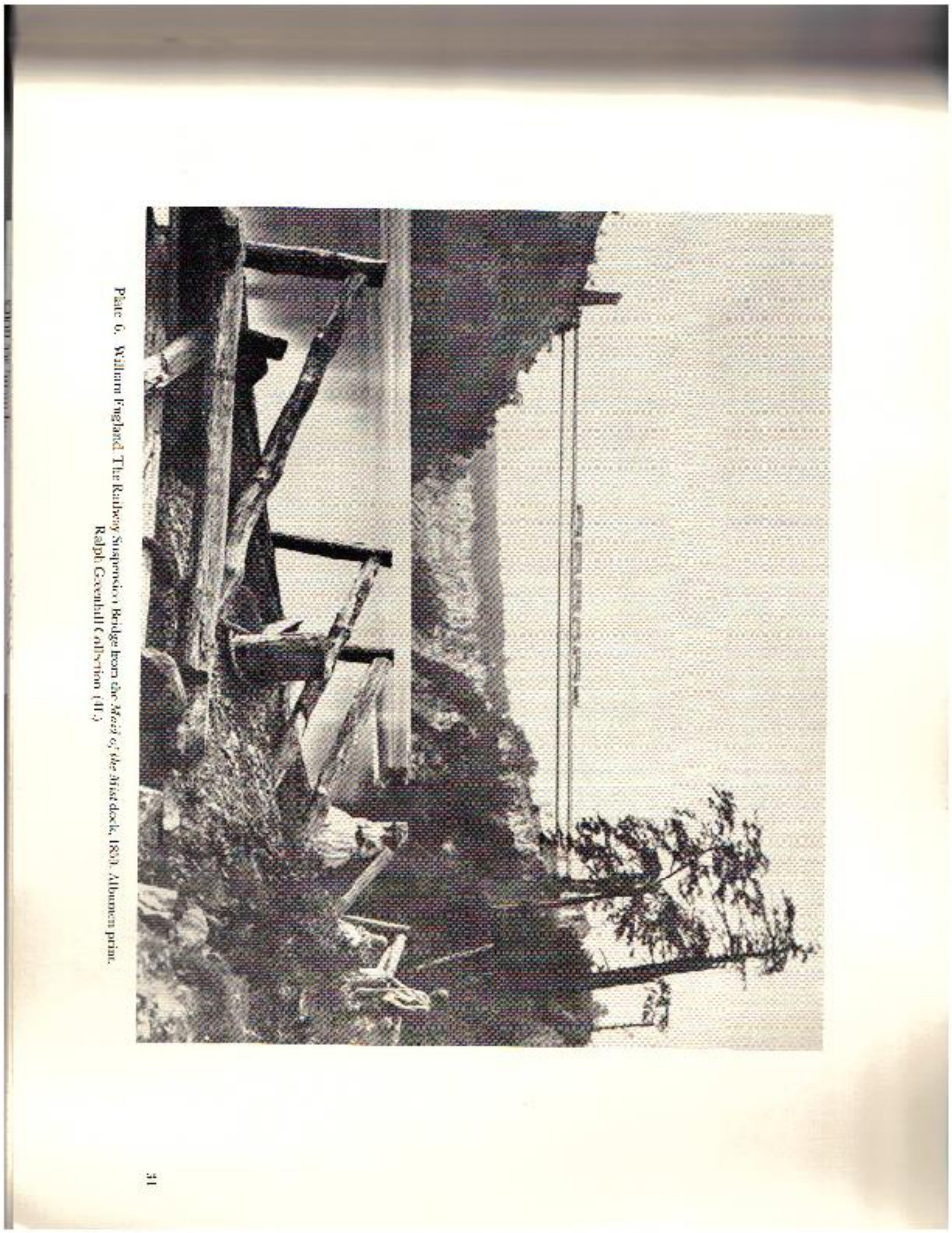
Appendix C



Niagara Falls Railway Suspension Bridge Illustration, 1859.

Ralph Greenhill, *Spanning Niagara: The International Bridges 1848-1962* (New York: Praeger Publishers, 1970), 29.

Appendix D



Niagara Falls Railway Suspension Bridge Photograph with full size train crossing bridge, 1859.

Ralph Greenhill, *Spanning Niagara: The International Bridges 1848-1962* (New York: Praeger Publishers, 1970), 31.

Appendix E

Niagara Falls Railway Suspension Bridge Photograph

William England, http://www.sanjeev.net/modernart/niagara-suspension-bridge-by-william-england-1691.html.

Appendix F

Niagara Falls Railway Suspension Bridge Photograph

William England,

http://www.vintageworks.net/exhibit/full_image.php/71/1/0/0/21347/11796_William_England.jpg.

Appendix G

Eads Bridge St. Louis Missouri, 2005.

Terry Turnbeaugh, *2005 Eads Bridge St. Louis Missouri*, 2005, http://www.nomadiksoul.com/nomadsplace/Gallery.html.

Appendix H

Example of bar chain suspension bridge/Clifton Bar Chain Suspension Bridge.

Example of bar chain suspension bridge/Clifton Bar Chain Suspension Bridge, http://img.readtiger.com/wkp/en/Uk_bristol_csbchains.jpg .

Appendix I

Example of cable suspension bridge/Wheeling Cable Suspension Bridge.

Example of cable suspension bridge/Wheeling Cable Suspension Bridge, http://media.photobucket.com/user/paulthreestang/media/Cross%20Country%209-11-11/Sept112011Trip447.jpg.html?filters[term]=wheeling%20suspension%20bridge&filters[primary]=images&filters[secondary]=videos&sort=1&o=6.

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