The Eads Bridge
Spanning the Mississippi River
St. Louis
St. Louis Co.
Missouri

HAER No. MO-12

HAER
MO,
96-SALU,
77-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

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

HAER
MO
96-SALU,
77-

HISTORIC AMERICAN ENGINEERING RECORD

The Eads Bridge

MO-12

Location: Spanning the Mississippi River at St. Louis, St. Louis County, Missouri

Date of Erection: 1869 - 1874

Designer: James Buchanan Eads

Present Use: Vehicular bridge (railbeds no longer in use)

Significance: The Eads Bridge was constructed as the first link to Illinois over the Mississippi River at St. Louis. The domination of the river trade was no longer as important as before the War between the States, and Chicago was fast gaining as the center of commerce in the West. The Bridge was conceived as a solution to the futile quest to reverse this new found eminence.

The Bridge, generated in controversy, was also considered a radical design solution, though the ribbed arch had been a common construction technique for centuries. The triple span, tubular metallic, arch construction was supported by two shore abutments and two mid-river piers. Four pairs of arches per span (upper and lower) were set eight feet apart, supporting an upper deck for vehicular traffic and a lower deck for rail traffic.

Construction involved varied and confusing design elements and pressures. State and Federal charters precluded suspension or draw bridges, or wood construction. There were also constraints on span size and regarding the height above the water line. The location dictated a change from the low Illinois floodplain of the east bank to the high Missouri cliff on the west bank of the river. The bedrock was exceedingly deep.

These pressures resulted in a bridge noted as innovative for precision and accuracy of construction and quality control. Utilization of cast chromium steel components is arguably the first use of structural alloy steel in a major building construction. (Though the bridge as actually completed contained large - and unknown - amounts of wrought iron.) Eads argued that the great compressive strength of steel was ideal for use in the upright arch design. This decision resulted from a curious combination of chance and necessity, due to the insufficient strength of alternative material choices.

The particular physical difficulties of the site stimulated interesting solutions to construction problems. The deep caissons used for pier and abutment construction signaled a new chapter in civil engineering. Unable to construct falseworks to erect the arches because they would obstruct river traffic, Eads' engineers devised a cantilevered rigging system to close the arches.

Although recognized as an innovative and exciting achievement, the Eads Bridge was over capitalized during construction and burdened with debt. With its focus on the River, St. Louis had a lack of adequate rail terminal facilities, and the bridge was poorly planned to coordinate rail access. An engineering and aesthetic success, the bridge was bankrupt within a year of opening.

Transmitted by: Kevin Murphy, Historian HAER, April 1984

Note: Additional information under HABS No. MO-1190

Bibliographical reference:

Miller, Howard S. and Quinta Scott; The Eads Bridge; University of Missouri Press; Columbia & London: 1979

ADDENDUM TO
EADS BRIDGE
Washington Street Spanning Mississippi River
Saint Louis City
Missouri

HAER No. MO-12
HAER
MO,
96-SALU,
77-

XEROGRAPHIC COPIES OF COLOR TRANSPARENCIES

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
Washington, D.C. 20013

EADS BRIDGE
(St. Louis Bridge)
(Illinois & St. Louis Bridge)
Spanning the Mississippi River at
Washington St.
St. Louis City
Missouri

HAER No. MO-12

HAER
MO
96-SALU,
77-

ADDENDUM TO:
EADS BRIDGE
Spanning the Mississippi River at
Washington St.
St. Louis City
Missouri

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
Department of the Interior
Washington, D.C. 20240

HAER
MO
96-SALL
77-

HISTORIC AMERICAN ENGINEERING RECORD
EADS BRIDGE
(ST. LOUIS BRIDGE)
(ILLINOIS & ST. LOUIS BRIDGE)

ADDENDUM TO A 2-PAGE REPORT PREVIOUSLY TRANSMITTED TO THE LIBRARY OF CONGRESS IN 1984.

I. INTRODUCTORY SUMMARY

Location: Spanning the Mississippi River from Washington Avenue, City of St. Louis, Missouri, to Broadway, East St. Louis, St. Clair County, Illinois

Quad: Granite City, IL-MO

UTM: A 13/746240/4279110
B 13/745000/4279140

Date of Construction: 1867-1874 (with multiple subsequent modifications)

Engineer: James B. Eads

Present Owner: City of St. Louis, Missouri: roadway deck and approaches
The Bi-State Development Agency: rail deck and approaches

Present Use: The roadway deck is restricted to pedestrian use and one lane of automobile traffic (no trucks or busses) which is reversed from westbound in the a.m. [peak to eastbound in the p.m. peak, because of severe structural deterioration in the east approach structure. The rail deck, which last accommodated rail traffic in 1974, is currently without track and is programmed for light rail transit use commencing operations in 1993.

Significance: This National Historic Landmark is significant as the first bridge and one of the first structures of any kind to make extensive use of steel. The Eads Bridge was one of the first bridges in the United States employing pneumatic caissons, among the deepest submarine construction work ever, employing the largest caissons then accomplished anywhere. It was the first bridge to be built entirely using cantilever construction methods, avoiding the need for falsework; and it was the first bridge to use hollow tubular chord memebers. Eads Bridge was also the first bridge designed so that any part could be easily removed for repair or replacement. With three spans over 500 fee long, some 200 feet longer than any built previously, its construction was a significant engineering feat. The National Historic Landmark boundary extends between the two roadway touchdown points.

Historian: John H. McCarthy, Sverdrup Gorporation-Metro Link Project Management Group -- January 1991.

II. HISTORY OF THE BRIDGE

A. Need for the Bridge and Historic Context

Stagecoaches and wagon trains initially settled much of the American hinterland from the major outposts of civilization. These outposts were located along the river network, because the rivers offered the easiest travel for long distances. Keelboats, operated by legendary characters such as Mike Fink, plied the inland waterways until the significantly faster and larger steamboats made their appearance.[1] The Zebulon M. Pike, the sixth steamboat to enter the Mississippi River, coming from the Ohio River, was the first to arrive in St. Louis, on August 9, 1817.[2] By 1853, a total of 600 steamers and 45,500 tons of goods were handled annually at the St. Louis levee. By 1860, 3,454 steamboats and 844,000 tons of freight came to the St. Louis levee.[3] Passenger movements were also very significant; 1,045,269 passengers, for example, moved in and out of St. Louis by steamboat in 1855, a number far exceeding the total population of the city.[4] Many settlers were heading west in the 1840s and 1850s, when St. Louis earned its title "Gateway to the West."[5]

During the Civil War, the Union's Chief Quartermaster spent $180 million in St. Louis, sparking a 296 percent increase in the city's manufacturing in the 1860s; but the Union's Civil War policies crippled river commerce.[6] A blockade of the river from the end of 1861 until 1863 (when there was little money left in the South and almost all river traffic was government work), martial law throughout the war, and a five percent tax on all goods shipped, coupled with a permit requirement for every steamboat shipment, clearly favored rail shipments out of Chicago, which were unfettered by any such limitations.[7] After the Civil War, it became apparent that the railroad simply offered a faster, better-service connection to the East than the old route using the New Orleans to St. Louis corridor available to the steamboats.

Following multiple false starts beginning as early as 1836, the first railroad construction in Missouri began on the Pacific Railroad in St. Louis on July 4, 1851. While Chicago had a tributary rail network of over 4,000 miles by 1857, financial problems and scandals resulted in only 796 miles of track being laid in Missouri by 1860.[9] A national railroad convention held in St. Louis during October 1849 involved 1,000 delegates from 13 states who advocated building a transcontinental railroad.[10] This dream was realized 20 years later with the driving of the golden spike at Promontory Point, Utah on May 10, 1869.[11] By that year, the Mississippi River had been crossed at Quincy, Illinois and at Davenport, Iowa with rail bridges, and the Missouri River had a rail crossing at Kansas City, but St. Louis was still five years away from a Mississippi River crossing.[12]

Ferries crossed the Mississippi River at St. Louis from 1797 when Captain James Piggott began ferry service.[13] The first bridge proposal for crossing the Mississippi River at St. Louis was made by Charles Ellet in 1839.[14] Ellet's proposal for a suspension bridge on pile foundations with a 1,200-foot main span and 900-foot side spans held by five-inch-thick wrought-iron wire cables and accommodating a 19-foot roadway and two four-foot-wide sidewalks was rejected by St. Louis' elected officials as implausible and enormously expensive at an estimated cost of $757,566.[15] In 1855, St. Louisian Josiah Dent obtained Missouri and Illinois charters to build a railway suspension bridge across the Mississippi, but was unable to raise the $1.5 million in capital required.[16] A third proposal for a suspension bridge was made the following year by John A. Roebling, who successfully spanned the Niagara River in 1855 and would later, with his son, build the Brooklyn Bridge.[17] Roebling proposed several additional concepts in 1858 including combining suspension cable and parabolic arches with 500, 600, and 800 foot spans, but these concepts were not implemented.[18]

By 1865, the City was especially anxious to get a bridge and passed a resolution which stated that it had "become indispensably necessary to erect a bridge across the Mississippi River at St. Louis, for the accommodation of the citizens of Illinois and Missouri, and the great railroad traffic now centering there."[19] Subsequently, the City Engineer, Truman H. Homer, submitted an elaborate report calling for a tubular bridge with three spans of 500 feet each providing only 22 feet of clearance above high water at an estimated cost of $3,332,200.[20]

Homer's proposal did not advance, but it definitely focused attention on the need for a bridge and a possible solution. The St. Louis community was optimistic about the prospects for growth and recognized the competition presented by Chicago, which had a superior rail network and was more favorably received by Eastern capital sources. An interesting contemporaneous commentary on this situation is L. U. Reavis' book, St. Louis, the Future Great City of the World, which predicted that within 100 years St. Louis would be the center of the world's commerce and civilization, as well as the world's greatest railway center.[21] This 1871 book devoted to the City's future greatness was, significantly, dedicated to James B. Eads, who at that time was still three years away from completing his bridge.

B. The Builder -- James B. Eads

Eads Bridge is perhaps the only major bridge in the world named for its builder. He was recognized as its champion from before construction and through the long and difficult construction period. While formally called the Illinois and St. Louis Bridge and the St. Louis Bridge at times, the bridge is known today as Eads Bridge. As such, an appreciation of its builder is valuable.

James Buchanan Eads was born in the backwoods of Indiana at Lawrenceburg on May 23, 1820.[22] Eads exhibited ingenuity at an early age when he mystified his mother and sisters with a small model steamboat that raced across the floor, powered by a concealed rat.[23] Eads completed his formal schooling at the age of 13 when he moved to St. Louis with his parents.[24] The family's arrival by river on September 13, 1833 involved a predawn fire which destroyed the steamboat along with all their possessions.[25] Eads sold apples on the St. Louis riverfront and then secured a job as a dry goods clerk and worked in this position for five years.[26] His merchant employer noticed his mechanical ingenuity and gave him his first engineering book. The merchant's fine collection of technical books on mechanical engineering and boat design were made available to Eads. In early March, 1839, he took a job as "mud clerk" on the steamboat Knickerbocker so that he could visit his parents who had moved to Iowa shortly before that time.[27] Eads worked on the steamboat for three years and developed an absorbing interest in the Mississippi River. He came to know the River the way the steamboat pilots did, and he discerned the laws of nature controlling it.[28] The Knickerbocker sank after being ripped open by a snag in the River, causing Eads to recognize the extent of valuable goods waiting to be salvaged from the river bottom.[29]

When he was 22 years old, Eads exhibited sufficient self-confidence and practical experience to persuade two St. Louis boat builders, Calvin Case and William Nelson, to become his partners in a salvage business.[30] He prepared clearly drawn plans for the construction of a diving bell which he designed and patented, and which the partnership built along with a variety of necessary mechanical equipment and a twin-hulled salvage boat known as "submarine."[31] Eads himself worked as a diver much of the time and increased his understanding of the River's scouring and depositing activity.[32]

With success in the salvage business, Eads married Martha Dillon on October 21, 1845 and soon thereafter began investigating other business opportunities so that he could reduce his need to travel away from home.[33] He decided to open a glassmaking plant at St. Louis in 1846, which did well until an economic depression in 1848 forced Eads into bankruptcy.[34] Eads paid off his debts after borrowing money to buy back a share of the salvage business. By 1851, he was successfully operating four salvage boats.[35]

The death of his young son, followed by the death of his wife in a cholera epidemic on October 13, 1852, brought on overwork and illness.[36] The widow of Eads' cousin nursed him back to health, while looking after his two daughters. Eads subsequently married this woman, Eunice Hagerman, on May 2, 1854 and they honeymooned in Europe.[37] This first of many European trips for Eads afforded him an opportunity to study river and harbor public works projects.[38] He built and occupied a palatial house, called Compton Hill, located west of then fashionable Lafayette Square (the grounds of which are today a public park, called Terry Park).[39]

Eads and his partners purchased snag boats (outfitted for removing debris from the river system) from the federal government in 1855 when the government discontinued using these steamboats.[40] The next year, Eads proposed to contract with the government to maintain inland river channels using the boats, and gained a strong appreciation of the need for maintaining good political contacts after Congress defeated the bill authorizing his contract.[41]

Eads advocated the use of ironclad gunboats at the outbreak of the Civil War, when President Lincoln called him to Washington.[42] However, his initial efforts were rebuffed, and only later did the government prepare plans of its own for bidding, which Eads successfully won with a low price.[43] Eads signed a contract with the government on August 7, 1861 in Washington to build seven ironclad gunboats at Carondelet immediately south of St. Louis.[44] He did not have the timber cut or the iron rolled, but he organized a work force of 4,000 men and launched the gunboats within 100 days. Eads' first gunboat, the St. Louis, was the first ironclad boat in America and the first such boat to engage in a naval battle anywhere, on February 6, 1862 at Fort Henry.[45] Eads invented a steam-actuated rotating gun turret for his ironclad gunboats, which played a significant role in multiple Civil War battles.[46]

In 1837-39, Lieutenant Robert E. Lee devised a series of dikes to force the Mississippi River to scour the River's west bank at the St. Louis harbor in order to save the St. Louis levee from being buried in the river's shifting sandbars, which would have left the City inaccessible to the River's lifeblood steamboat commerce.[47] From 1867-74, Captain James B. Eads used his knowledge of the River's hydraulics to successfully bridge the Mississippi River at St. Louis to keep the all important transcontinental rail commerce from bypassing St. Louis. Without Eads' dominant role, the first bridge crossing at St. Louis would probably have been delayed and would not have been the innovative, precedent-setting structure that still stands today. Eads called the bridge his greatest work in life; but he did not simply retire after its completion.

Eads further enhanced his reputation as a hydraulics engineer by saving the port of New Orleans. Eads proposed to build two 2-1/2-mile-long jetties into the Gulf of Mexico to restrict the River's flow, causing it to scour a channel of sufficient depth to allow ocean-going ships to avoid getting stuck in the River's shifting sand.[48] He proposed to build the jetties at his own expense and to be paid $5 million only if the channel depth was increased from its normal 14 feet to 30 feet.[49] Amid considerable debate and doubt, Congress authorized the undertaking and Eads began work in June 1875. Construction difficulties and financial requirements caused problems, but Eads persevered until construction was completed the next year. It took a few seasons of high water flows, but the river scoured a 30-foot channel by 1879, the port of New Orleans was saved, and Eads collected his fee. The river pilot station was named Port Eads in his honor.[50]

In 1879, Eads attended the Interoceanic Canal Congress focused on building the Panama Canal and proposed instead to build a rail crossing at the Isthmus of Tehauntepec in Mexico which would save 2,000 miles compared with the Panama location.[51] Eads' concept provided for a single track of a dozen parallel rails supporting an enormous locomotive and rail cars (with 1,200 wheels each), which could transport ships of 10,000 tons.[52] Eads went to Mexico and secured the necessary charter to implement his ship-railway concept, but shortly afterwards he was afflicted by the recurring lung illness that had bothered him for 30 years.[53] Eads went to Nassau on his doctor's orders, where he died on March 8, 1887.[54] Without Eads, the Mexican ship-railway concept collapsed.

Eads was elected vice president of the American Society of Civil Engineers in 1882, twice elected president of the St. Louis Academy of Sciences, and received many honorary degrees, including LL.D. from the University of Missouri.[55] He was the first native-born American to be awarded the Albert Medal by the Royal Society of Arts of Great Britain in 1884.[56] In 1920, he became the first engineer to be elected to the American Hall of Fame at New York University.[57]

C. Construction Chronology

The first step in building the Eads Bridge occurred when State Senator Norman Cutter secured a Missouri charter in 1864 for the St. Louis and Illinois Bridge Company and a year later secured a similar charter in Illinois.[58] The Illinois charter was strongly opposed by the Wiggins Ferry Company which had a monopoly. The charter was granted with a provision intended to preclude bridge construction, namely, a prescribed location in the heart of the City, which was overcome by building a connecting tunnel.[59] Congress authorized a federal franchise in 1866 over the vigorous opposition of the steamboat interests and the railroad companies that used northern bridges. The federal charter precluded using a suspension bridge for the crossing and required one span of a minimum of 500 feet in length and two spans with minimum 300-foot openings, conditions that were thought to preclude building the bridge.[60]

James B. Eads was selected as engineer-in-chief in early 1867 by the St. Louis and Illinois Bridge Company after it had sold $300,000 in subscriptions.[61] Eads presented his conceptual plans to the company's directors in July 1867 and actual construction began on August 20, 1867.[62] Eads' widely distributed plans for the crossing called for three steel arches, each of over 500 feet in length, connected to stone piers founded on bedrock. The plans provided for a two-track rail deck beneath a roadway accommodating 34 feet for four wagons abreast, including streetcars and trams, and two 8-foot sidewalks.[63]

A rival company, the Illinois and St. Louis Bridge Company, headed by Chicago contractor Lucius Boomer attempted to sabotage the original company's efforts.[64] The rival company, without acknowledging its involvement, called together a group of prominent engineers in St. Louis to issue a formal resolution discrediting Eads' plans for the 500 foot spans, then took out newspaper advertisements to undermine public support and confidence, and finally brought suit on the validity of the original group's charter once construction began in Illinois.[65] With the last move, the St. Louis group reluctantly agreed to a compromise consolidating the two companies on March 5, 1868 after which Eads was reelected as engineer-in-chief, his plans were reapproved, and new state and federal charters were secured based on his plans and using the rival company's name, which, in effect, was bought out.[66]

The first construction difficulties occurred in building the west abutment cofferdam.[67] Achieving a watertight cofferdam at this location proved exceptionally difficult because of the extensive residue of iron and oak steamboat parts lying below the water, including three whole steamers, two of which had burned and sunk at the foot of Washington Avenue during the Great Fire of 1849.[68] Bedrock was reached at this location in February 1868, and Eads presided at the laying of a limestone cornerstone on the bedrock on February 25, 1868.[69]

Eads published a report in May 1868 to restore confidence in his plans and stimulate subscription sales, the lack of which had brought work to a halt.[70] The report convincingly presented his case to both lay and technical audiences for using arches rather than trusses (including an explanation of each and the greater economy of the arches), for extending the piers to bedrock rather than relying on pilings within the readily scoured river bottom, for using floating caissons to get the two river piers to bedrock (which he subsequently changed to pneumatic caissons), for using tubular chords of steel, and for affirming the feasibility of 500-foot spans based on "engineering precedent".

The City of St. Louis offered to issue $4 million in bonds on the strength of Eads' report, but the company feared losing the bridge to the City if the bonds went into default and instead secured sufficient funds privately to resume work in May 1868.[71] Eads developed severe bronchitis in July 1868 and left for Europe under his doctor's orders to take the prescribed convalescent cure of the day for those who needed rest and could afford it.[72] He resigned his position, but the company refused the resignation.[73] Work continued in Eads' absence but not at the same pace, which eventually brought an end to the money coming in and all employees were discharged on September 1. After the sum of $25,000 was secured by subscription, the west abutment was raised above high water between October 28, 1868 and January 10, 1869. Eads returned to the U.S. in December 1868 and met with New York bankers and railroad representatives, but left for Europe in January 1869 for his health.[74] The bankers in New York and in London refused to advance any more money on bonds until the bridge piers topped high water, and so the company sold $1.8 million in stock in New York and $1.2 million in stock in St. Louis. On his second European trip, Eads met with French and English engineers and came away convinced of the need to use compressed air for the remaining bridge caissons, because such airtight pneumatic caissons would permit workmen to lay firm foundations without interference from the river's current and shifting bottom.[75]

Eads returned to St. Louis in April 1869 in good health to revise his plans to accommodate the pneumatic caissons, and by July 1 had 1,000 men at work and 1,500 by September 1.[76] He secured equipment in duplicate, including 24 boats, 37 engines, 31 pumps, 29 derricks, 40 travellers, and 24 hydraulic hoists.[77] As part of the work effort, Eads helped perfect the pneumatic caisson and invented the sand pump, which uses high pressure water flow to remove silt, sand, and gravel from the caisson chamber.[78]

The caissons were built by Eads' former salvage company partner and included plates cut up from the salvaged U.S. ironclad Milwaukee, which had been designed and built by Eads and sank in Mobile Bay during the Civil War.[79] The masonry contract was given to James Andrews of Pittsburgh, with limestone quarried at Grafton, Illinois and granite to face the limestone dressed in Richmond, Virginia and Portland, Maine and shipped by water to the construction site.[80] Two shiploads of the granite from Maine were sunk off the coast of Florida, seriously delaying the work, when ironically, suitable granite was subsequently discovered 100 miles away in Missouri.[81]

Work on the east pier began first. The east pier caisson was towed upriver eight miles from the Carondelet yards in October 1869.[82] Pier construction reached the river bottom in November and reached bedrock, 95 feet below the water's surface, on February 28, 1870, an event heralded by cannon blast and steam whistles. At the 67-foot level, Eads had brought visitors and press down in the caisson and telegraphed greetings to the New York City bridge company directors and others.[83] Filling the air chamber, which was begun on March 1, was completed on May 27.[84] With careful plans, constant engineering supervision, duplicate equipment, and a large work force, work had continued uninterrupted around the clock for five months, even during 15 days in the winter when ice cut the pier off from land and the workmen lived at the pier.[85]

Work on the west pier commenced on January 3, 1870, reached the riverbed one month later, and reached bedrock on April 1.[86] This pier, which went down 86 feet below the water's surface, was filled on May 8, 1870. During the summer of 1870, both the east and west river piers and the west abutment were raised several feet above high water.

The east abutment, which originally was to be built on pilings 50 feet below low water surrounded by riprap, was extended to bedrock 136 feet below high water at an added cost of $175,000.[87] The east abutment caisson was launched on November 3, 1870, reached bedrock at a depth of 109 feet 8 inches below the water's surface on March 28, 1871, and was filled and sealed by April 30, 1870. This work was interrupted by a tornado on March 8, 1871 which caused $50,000 in damage, one death, and eight injuries.[88] Significantly, Eads revised his design following the tornado to add a wind truss between the piers.[89]

Working in the caissons at such depths as required for the pier construction resulted in workmen experiencing pressures in excess of the previously experienced two and three atmospheres, which had not caused any problems.[90] The greater air pressure resulted in what is commonly called the bends. Of the 352 men who worked on the east pier in the air chamber, 80 were afflicted, of that number, 12 died and two were paralyzed for life.[91] Eads' physician, Dr. Jaminet, worked on the problem and required increasingly restrictive precautions based on his specific findings until the problem was solved.[92] One death occurred from the 86-foot-deep west pier caisson work, and one death occurred on the 100-foot-plus depth work on the east abutment, which was attributed to a flagrant violation of the rules.[93]

After 3-1/2 years, the foundations were complete and ready for the steel arches. Keystone Bridge Company of Pittsburgh, the leading steel company of the day, was contracted in February 1870 to provide the steel for the bridge and assume all risk associated with its erection.[94] The company's president was James H. Linville, who had written to the bridge company in 1867, when he was hired as a consulting engineer, that Eads' bridge was "entirely unsafe and impractical, as well as in fault of the qualities of durability."[95] However, Andrew Carnegie, a 35-year-old vice president with Keystone, wanted the project.[96] Keystone subcontracted the work to the Butcher Steel Company of Philadelphia; and Carnegie & Kloman, Carnegie's own company, took the wrought iron part of the work.

Eads held firmly to the technical specifications established for each metal part, requiring 100 percent testing and use of a grade of metal quite unusual at that time. Such adherence to requirements was not the practice of the day and caused considerable difficulty for the metal fabricators who had little or no experience in making the necessary bridge parts and had not properly priced their work under the circumstances. Eads' practice in this matter raised the standard in bridge building at a time when one in every four bridges built was falling, a fact recognized by London Engineering on October 10, 1873.[97]

A total of 48 skewbacks of forged iron were required.[98] Fourteen were made in New Jersey and 34 in Massachusetts, and all were accepted. However, after six months' effort, including the development of a new annealing furnace, $33,600 worth of 34-foot-long steel anchor bolts for the skewbacks were rejected after causing considerable damage to the testing machine. Instead, Eads ordered wrought iron bolts, the first of which tested out on August 18, 1871, followed quickly by the rest.[99] This action was taken even though it delayed masonry work during the summer of 1871.

Chrome steel was tested for the envelope or shell plates for the arch tubes, but was found to be too brittle.[100] A trade metal, called "homogeneous steel," was finally secured with adequate strength and ductility. Crucible steel was specified for the 6,216 staves to be placed within the hollow steel arch tubes, but crucible steel had never been fabricated in such large pieces and the Butcher steel works could not produce it satisfactorily. After six months of testing some 6,000 staves using the testing machine designed by Eads' assistant engineers, which Eads had installed at the Butcher facility in Pittsburgh, none met the test of 60,000 pounds per square inch.[101] Chrome steel was then experimented with in place of the crucible steel for the staves, which consumed another six months.[102] Finally, a British metallurgist was brought in to supervise mixing and melting the chrome steel, and work progressed slowly but satisfactorily. The first stave was rolled on May 1, 1871 and the first batch of staves was accepted on March 1, 1872.[103]

Getting the specified strength on the eyebars proved difficult and a compromise was reached to settle for a lesser strength steel at a reduced price, but of a greater thickness to compensate for the reduced strength.[104] Difficulties also surfaced in making the 1,012 tube couplings of rolled steel which were ordered on October 24, 1870. The first ingots cast on November 25, 1871 cracked in rolling, and it was not until after extensive experimenting that acceptable couplings were turned out on January 2, 1872, when steel was used for the lower castings and wrought iron was used for the upper castings.[105]

The delays and changes resulting from the manufacturing difficulties required extending the construction contract deadlines. Bonuses and penalties were negotiated to try to expedite construction and compensate for the delays, and the bridge company agreed to make extra payments, for example, to ensure that construction would proceed simultaneously on six points, at each end of the arches, because delays meant losses in anticipated rail revenues.[106] When the structure was completed, Carnegie received a $30,000 bonus for early completion, calculated at $1,000 per day.[107]

Andrew Carnegie had volunteered to go to London to sell additional bonds for the bridge's continued construction, which he did in March 1869.[108] His success brought him a position on the bridge company's board of directors and blocks of shares in the company.[109] At the December 1871 stockholder's meeting, Carnegie proposed hiring an independent engineer of outstanding reputation to review the bridge plans to recommend any appropriate changes or cost savings, and Eads readily agreed.[110] James Laurie was engaged on January 3, 1872. Laurie could only find minor cost savings, which would have sacrificed the beauty of the bridge, and his request for a test of the bridge's tubular form was met with fully satisfactory results.[111]

The arches were constructed by cantilever rather than with falsework, because of the need to accommodate steamboat traffic. Timber towers were erected on the piers and abutments from which balancing cantilever supports were projected outward to hold the advancing bridge superstructure.[112] Elaborate series of jacks were used to counteract temperature changes in the erection cables and the arches. The first two half arches on the west span approached closure on September 14, 1873 with Eads in London for his health negotiating a new half million dollar loan contingent on closure within five days, and assistant engineer Colonel Henry Flad in charge of construction in St. Louis.[113] Hot weather caused substantial differential distortion in the arch members, which did not respond to the first 15,000 pounds of ice nor to a total of 60,000 pounds of ice.[114] It was 98 degrees by 5:00 p.m. on September 16 and the problem had grown worse before Flad gave up on his method of forcefully moving the arch members into place and implemented Eads' recommendation to cut the ends of the last two arch members and bolt a wrought iron plug into place to link the arch, which was completed by 10:00 p.m. on September 17.[115] Eads was cabled on the morning of the 18th and the loan secured. The inner ribs of the central and eastern arches were linked by December 1873 and everything seemed under control.[116]

Then Eads' chief inspector, Theodore Cooper, found two tubes ruptured on January 19, 1874.[117] With assistant engineer Flad sick in bed, Cooper telegraphed Eads, who was in New York preparing for a January 20 stockholders meeting in which he was scheduled to report on the bridge's construction progress for the purpose of raising the final funds needed to complete the project.[118] After getting over what must have been shocking news arriving at midnight before his presentation, Eads determined the problem and wired explicit instructions on how to resolve the situation by reducing the strain caused by the still-in-place construction cables.[119] Replacement tubes were ordered and subsequently installed; and no further such construction problems occurred after the temporary cables were removed.

As the arches neared closure, the powerful steamboat lobby launched an attack on the bridge, which because of its long graceful arches, optically appeared to be much lower than its 55 feet above high water at the crown of the arch and 88 feet at low water. Enlisting Secretary of War William Belknap, influential St. Louis steamboatmen were granted a hearing on September 4 and 5, 1873 in St. Louis by a board of military engineers, which hastily determined that the bridge was a hazard to navigation that needed to be modified by a drawbridge over a canal through the east approach at great cost.[120] Eads prepared a detailed written response to each of the board's findings, and then Eads, in the company of the bridge company's executive committee chairman, Dr. William Taussig, paid a call on the Secretary of War and President Grant.[121] Grant told his cabinet appointee to drop the matter.[122] In the years following completion of the bridge, steamboat chimneys were lowered and reduced in diameter, reducing their weight and wind resistance thus improving the boats' draft, speed, and, in the opinion of some, appearance.

When the roadway deck was completed and agreement was reached with Keystone, the bridge company announced in the April 17, 1874 editions of local newspapers that the bridge would be open to the public the next day.[123] However, the Keystone Company sent a midnight telegram to Dr. Taussig that Keystone was holding the bridge as security for payment due on the advice of its lawyers.[124] By the next morning, Keystone had removed four lengths of stringers and planking, and posted a contingent of men to forcibly prevent anyone from taking the bridge. Eads was in Washington at the time, but eventually a compromise was worked out which permitted the upper roadway deck to be open to pedestrians on May 24, 1874, when over 15,000 persons paid to walk upon the bridge. On June 3, 1874, four bays hitched to the heaviest of coal wagons crossed over the roadway deck.[125] On June 9, 1874, the first train crossed over the rail deck after General William Tecumseh Sherman, who had effectively brought an end to the Civil War with the march to Atlanta, ceremoniously drove the last spike joining the rails from the East to Eads Bridge.[126] The train proceeded into the tunnel to Eighth Street, which was as far as the rail had been laid; the two oversized rail coaches (which were broad-gauge vehicles whose carriages had been modified to standard gauge) scraped the sides of the tunnel, and the lack of a ventilation tower caused the locomotive's thick black smoke to temporarily engulf the passengers before the train returned safely to the open air again.[127]

On July 2, 1874, a public test was held with a 700-ton load consisting of 14 locomotives with tenders full of coal and water, which were brought across the rail deck as a unit and as two 7-locomotive trains moving across both tracks and stopping in the middle of the bridge.[128] The upper roadway was full of spectators, as was the levee, and a great shout of success was exclaimed upon the successful completion of the test. The test was accomplished with one apparently reluctant engineer, whose wheels were going in reverse when he was dragged across the bridge by the other six locomotives in his unit.

The formal dedication took place on July 4, 1874 with a 15-mile-long parade and multiple speeches.[129] The dedication also included an inaugural train ride on a three-engine, 15-palace-car consist for 500-plus dignitaries, who experienced smoke problems in the still unventilated tunnel.[130] An expected dignitary, President Grant, was not in attendance.[131] An elaborate, but overbilled fireworks display in the evening using the bridge as a backdrop concluded the festivities for an estimated half million visitors who thronged to the rooftops, the levee, and the 50 steamboats and other water craft fanned out in a double arc in the river.[132]

D. <u>Modifications</u>

Eads Bridge was modified many times over the years. A few of the main arch ribs have been replaced because of corrosion over the years and because of damage caused by a barge accident, for example, in the early 1970s. The vertical supports of the two floors were reinforced and the original rod cross bracing between the arch ribs was removed and replaced by riveted stiff bracing to increase the loading capacity of the bridge.[133] The railroad floor beams and stringers were replaced and through plate girder spans were substituted at cross streets and the alley on the west approach to accommodate heavier locomotives. The rail high line arched opening through the west approach was rebuilt with an insensitive steel beam to afford a wider clearance envelope; and a metal staircase was added to the south face of the west arcade between the roadway and rail decks. The timber deck with iron beams on the west approach was replaced in the early 1920s with a reinforced concrete deck.[134] The west approach brick arcade was bricked up by 1920. Similarly, the timber roadway deck over the main spans was also replaced, resulting in the loss of cast iron cornice detailing on the piers, and the typical section was modified to increase the traffic area and reduce the sidewalk area. All of the original handrailing and light standards have been removed from the roadway deck as have the first replacements; an old handrail remaining on the rebuilt east approach roadway does not match the original main span handrail shown in multiple pictures. Electric streetcar lines were built and then removed from the roadway deck. Also, the original Third Street entrance was removed entirely. A large section of the east arcade, still visible today, was rebuilt following damage in the 1896 tornado.[135] The east approach, originally of wrought-iron Phoenix columns, was entirely replaced with a different structure before the 50th anniversary of the bridge's dedication.[136]

The Eads Bridge was lighted in the 1980s (with a special system of clamps so as not to mar the bridge). Towboat operators can dim this decorative lighting to permit their safe passage between the bridge's piers.

The eight colossal statutes, a pair atop each pier, and the four square towers, a pair at the east end of the east stone arcade and at the west end of the west stone arcade, which were shown in several early renderings, were never built.[137] Smaller towers were later built and removed; only an insensitive toll booth and toll booth house remain on the west arcade.

E. <u>Ownership and Future</u>

The Illinois and St. Louis Bridge Company went into receivership on April 14, 1875, less than a year after opening the bridge, because the first revenue-paying regular passenger train service took almost that long to secure.[138] Within less than five years of the opening, a railroad boycott had forced the bridge company into bankruptcy, and the $10-million facility was auctioned off on December 20, 1878 for $2 million.[139] Jay Gould became the owner in 1881, sold $13.75 million in bonds, and his Missouri Pacific Railroad Company leased the bridge and tunnel for 500 years.[140] The lease was subsequently assigned to the Terminal Railroad Association of St. Louis (TRRA), the association of the railroads operating within the St. Louis area. The last train to cross the bridge was an Amtrak passenger train in 1974, 100 years after the opening. The roadway deck is currently used only by pedestrians and by one lane of automobiles operating eastbound in the evening peak traffic period and westbound in the morning peak traffic period and at other times, as a result of load limits and the closure of the westbound roadway portion of the east approach structure, because of substantial deterioration.

The pattern of railroad operations, dissatisfaction with tolls, and erection of competing bridges led a St. Louis consulting engineer, Charles E. Smith, writing in Railway Review in 1924 on the 50th anniversary of the completion of the Eads Bridge, to forecast that the railroads would agree to use the Municipal (later MacArthur) Bridge rail tracks owned by the city in exchange for which the city would take over the Eads Bridge and remove the electric streetcars from the roadway deck so that they could be "operated on the railroad tracks in connection with a rapid transit system in St. Louis."[141] This was accomplished 65 years later on August 31, 1989 when the City of St. Louis exchanged its MacArthur Bridge with the TRRA for the TRRA's Eads Bridge. The City has retained title to the roadway deck of the Eads Bridge and has turned over the rail deck to the Bi-State Development Agency as part of the St. Louis community's local in-kind match for a light rail transit system, called Metro Link, now under construction with a projected June 1993 scheduled opening. A funding source for improving the roadway deck and approaches has not been identified at this time.

III. ENGINEERING AND AESTHETIC SIGNIFICANCE OF THE BRIDGE

Eads Bridge was considered a fantastic engineering feat at the time it was built. The unprecedented length of its spans, 200-feet longer than any built previously, was awe inspiring. Eads' engineering accomplishment was recognized when the American Society of Civil Engineers, founded in 1852, designated Eads Bridge "A National Historic Civil Engineering Landmark" on October 21, 1974 in the bridge's centennial year for its first time use of hollow tubular chord members, use of steel, use of cantilever construction methods, use of pneumatic caissons, and use of replaceable components.[142]

Eads Bridge has long been recognized as an aesthetic tour de force for its graceful arched spans which are both airy and muscular at the same time, for its clean, flowing silhouette, for its solid dressed piers, and for its classic Roman aqueduct feel arcades. The slightly longer center span is a subtle, but effective design detail enhancing the look of the bridge.[143] Eads had consulted noted St. Louis architect G. I. Barnett, who suggested the style of ornamentation for the piers and the arcade sections.[144] Many artists have painted and photographed the bridge over the years. A notable example is the levee view of Eads Bridge with a steam locomotive and steamboats painted by the St. Louis and western painter, Oscar E. Berninghaus.

The combination of Eads Bridge's engineering and aesthetic strengths is in itself a notable feature by today's standards. The following sections describe the special engineering features of the bridge and ties of notable Americans to the bridge.

A. Steel Ribbed Arch Design

Eads described the arched trusses used in his bridge as "a form which often combines the highest economy with the most elegant and graceful proportions in architecture and engineering."[145] The ribbed arch design provides for pairs of arches cross-braced to hold their shape and relative position, of which four pairs are used for each Eads Bridge span. This design concept yields an economy of materials and cost for the great strength achieved.[146] Tubes were used to yield the highest value in compression and the greatest economy in construction, the first ever application of hollow tubular chord members on a bridge.[147] Each of the 24 arch tubes consists of 40 sections connected by couplings. Each section consists of a quarter-inch-thick shell rolled from flat steel into an 18-inch diameter circle and butt riveted, containing six grooved chrome steel staves, which project beyond the end of the shell to interlock with the adjacent tube staves.[148] The center arch spans 520 feet and the two side arches each span 502 feet. The extensive use of steel was unprecedented. The Eads Bridge was the first significant steel structure of any kind in the world.[149]

B. <u>Pneumatic Caissons</u>

Pneumatic pier construction was first accomplished by John Wright in 1851 for a bridge at Rochester, England.[150] A few years later, British Engineer I. K. Brunel built the Royal Albert Bridge at Saltash, England using pneumatic caissons; and in 1859, the caissons were employed on the Rhine Bridge at Kehl, after which they were generally used throughout Europe.[151] William Sooy Smith was the first American to propose using pneumatic caissons in 1859 for a bridge which was not built, and Smith was using one on a railroad bridge over the Missouri River at Omaha in 1869 as Eads was at work on his caissons.[152] Eads' pneumatic caissons, however, were clearly the largest ever built to that time and remain among the deepest ever sunk.[153] Eads invented a sand pump for use in building the pier foundations with pneumatic caissons, and along with Washington Roebling, builder of the Brooklyn Bridge, perfected pneumatic construction techniques.[154] The great depth of the caissons sunk at St. Louis exposed the workers to caissons disease, commonly called the bends, which was unknown in America at the time.

C. <u>Cantilever Construction/Reconstruction Capability</u>

Robert Stephenson and Brunel had both proposed using the cantilever method for bridge construction.[155] A German engineer by the name of Karl Culman published an outline on the concept of cantilever bridge construction in 1866, and a year later the first known cantilever bridge, designed by Heinrich Gerber, was built across the Main at Hassfurt, Germany.[156] C. Shaler Smith, who experimented with cantilever construction on a small scale for an 1869 rail crossing over the Salt River in Kentucky, was living in Missouri from 1868 onward, working on the St. Charles Bridge over the Missouri River.[157] Eads spoke at the dedication of Smith's St. Charles Bridge and had engaged Smith as a consultant on his bridge.[158] Smith may have suggested the use of the cantilever construction method to Eads.[159] Assistant Engineer Flad worked out the detailed erection plan for the Eads Bridge in July 1870; and the Eads Bridge, whose entire superstructure was constructed by the cantilever method, became the first major bridge to be built without falsework for its main spans.[160]

Additionally, the Eads Bridge was the first bridge designed so that any part could be easily removed for repair and replacement, a feature which has been used multiple times as deteriorated or damaged tubes have been reconstructed.[161]

D. Association With and Influence On Notable Americans

Andrew Carnegie credits his involvement on the Eads Bridge project as the seminal event in his successful financial career, according to his autobiography written at the end of his life.[162] Carnegie volunteered to go to London to sell bonds in 1869, his first large-scale experience in financing, when the Illinois and St. Louis Bridge Company expressed an interest to sell $4 million in bonds.[163] He called on Junius Morgan, father of J. Pierpont Morgan, who turned the bond documents over to lawyers for review and subsequently requested revisions. Morgan noted that Carnegie had mentioned going to Scotland and suggested that Carnegie stop off on his way back to America in about three weeks after the changes had been made by letter agreement. Instead, Carnegie returned the next day with the requested changes made, and so Morgan bought all $4 million of the bonds. Carnegie had relied on the trans-Atlantic cable to have the board of directors in St. Louis meet and adopt the changes line-by-line enumerated in his lengthy cable. Further, Carnegie met with the financial editor of the "The Times" to differentiate his bonds from other less secure American bonds, which raised the value of his bonds five percent on the London Exchange. Carnegie's resourcefulness and style so impressed Morgan that he spread the good word about Carnegie in all the right circles, with the result that Carnegie's financial reputation was firmly established.

Jay Gould acquired control of the Eads Bridge in an elaborate scheme to solidify his railroad empire.[164] When the Eads Bridge went into receivership, New York banker J.

Pierpont Morgan became a receiver, as did Solon Humphreys.[165] J. Pierpont Morgan was powerful, but not widely known at that time, and Solon Humphreys, an original Eads Bridge company director and stockholder was an unknown associate of Morgan's. Humphreys had some experience with railroad financing and was tapped by Gould to become one of his right-hand men in organizing Gould's western railroad empire.[166] Gould got a Congressional charter and began construction of a rival bridge 45 miles north of St. Louis, which forced the Eads Bridge owners to capitulate and turn the bridge over to him.[167] The Eads Bridge and tunnel at St. Louis became the linchpin of Gould's transcontinental operation, connecting the East with the Wabash to the West with the Missouri Pacific.

Prominent Chicago architect, Louis Sullivan, whose 1890-91 Wainwright Building in St. Louis is credited as the first skyscraper for its use of structural steel with a skin expressing that structural form, as opposed to load-bearing walls, wrote about the influence of the Eads Bridge on his thinking when he was a young man in his Autobiography of an Idea.[168] Sullivan compared the Eads Bridge to the Kentucky River Bridge, completed three years after the Eads Bridge, but using iron rather than steel:

> Here was romance, here again was man, the great adventurer, daring to think, daring to have faith, daring to do. Here again was to be set forth to view man in his power to create beneficently. Here were two ideas widely differing in kind. Each was emerging from a brain, each was to find realization. One bridge was to cross a great river, to form the portals of a great city, to be sensational and architectonic. The other was to take form in the wilderness, and abide there, a work of science without concession.[169]

Sullivan appreciated in the Eads Bridge that combination of purposeful function with elegant form. After expressing his admiration for Eads in his autobiography, he sets out his idea, or concept of architectural form fitted appropriately to the human function to be served.

Poet Walt Whitman, whose brother was associated with the bridge's construction, wrote five years after its completion in 1879 that "I have haunted the river every night lately, where I could get a look at the bridge by moonlight. It is indeed a structure of perfection and beauty unsurpassable, and I never tire of it."[170]

Theodore Cooper and others of the engineers who worked on the bridge went on to work on many additional bridges and become eminent structural engineers, whereas this bridge was the only one Eads ever built.[171]

IV. IDENTIFICATION OF SIGNIFICANT BRIDGE SOURCES

A. C. M. Woodward

Calvin M. Woodward wrote the definitive history of the building of Eads Bridge based on eye witness participation, the records of the bridge company, and the review and comments of those responsible for building it.[172] The latter include Eads, Dr. Taussig, assistant engineers Colonel Henry Flad and Charles Pfeifer, as well as Theodore Cooper, who kept extensive notebooks as a part of his job supervising the bridge's construction. Woodward's quarto album was published by G. I. Jones and Company of St. Louis in 1881. The book is formally titled: "A History of the St. Louis Bridge; containing a Full Account of Every Step in its Construction and Erection, and including the Theory of the Ribbed Arch and the Tests of Materials (Illustrated by numerous Wood-cuts and Fifty Full-page Lithographs and Artotypes). The 412-page volume includes the following inscription signed Jas. B. Eads:

> "The History of the Saint Louis Bridge" by Professor Woodward, has been carefully examined by me, and I believe it to be a correct record of the most important facts connected with the inception and execution of that work. The detail drawings and illustrations are remarkably correct, and the explanatory descriptions are clear and accurate. I have no hesitation in commending the book, and the professional views expressed by the author in it, to the careful consideration of civil and mechanical engineers, and the public generally.[173]

At the time of the book's publication, Woodward was the Thayer Professor of Mathematics and Applied Mechanics, and Dean of the Polytechnic School of Washington University in St. Louis. He wrote the book to "help secure for the structure and the men who built it their true place in history," and he noted that, even though he closely watched the building of the bridge and rode one of the test engines, until he completed his research, he "did not properly appreciate the magnitude, strength and beauty of the structure itself, nor the skill, courage, and energy displayed in its construction."[174] His book was placed in the Library of Congress in 1881 and is found in multiple rare book collections, notably in St. Louis (e.g., The Engineers' Club of St. Louis and Washington University's Rare Books Collection) and elsewhere (e.g., Princeton University's Firestone Library). Most subsequent written descriptions of the bridge rely on Woodward to some extent.

B. Centennial Exhibition

An exhibition prepared by Princeton University's Art Museum and its Department of Civil Engineering was mounted at both the Princeton and St. Louis Art Museums in 1974 on the centennial of the opening of Eads Bridge.[175] The 84-page catalogue prepared for the exhibition includes: an article (pp. 12-33) by Princeton Professor David P. Billington relating the art and the engineering of Eads Bridge; an article (pp. 34-47) by J. Wayman Williams, Jr. on Eads and his bridge; and a reprint (pp. 48-73) of the Missouri Historical Society "Bulletin" (30, No. 3, April 1974, pp. 159-80) article prepared by Barnard College, Columbia University professor John A. Kouwenhoven on the formal dedication ceremony opening Eads Bridge. The catalogue also contains a complete listing of the exhibition materials, including: four oil paintings loaned from St. Louis collectors; five drawings including a bound volume of original drawings from the St. Louis Public Library; 12 prints, including two Currier & Ives, predominantly from the Missouri Historical Society and the St. Louis Public Library; 17 photographs, including multiple stereoscopic views, predominantly from the Missouri Historical Society and the St. Louis Public Library, plus a photograph showing a plane flying under the bridge in 1910 from a University of Missouri, St. Louis negative; and 8 memorabilia and miscellaneous items, including a copy of Woodward's quarto album, photocopies of newspaper clippings of the dedication, postcards, a dedication invitation, a model of the bridge, and a section of the original steel arch. In addition to the St. Louis sources, the Smithsonian Institution, the National Park Service, the

Engineering Societies Library, and private collectors, such as John A. Kouwenhoven of Dorset, Vermont, were represented.

C. Other Repositories

Washington University's Olin Library Special Collections in St. Louis contains a set of original Eads Bridge drawings and drawings for many subsequent modifications, which were donated to the National Museum of Transport in St. Louis County on June 27, 1974 by the Terminal Railroad Association of St. Louis and placed on permanent loan at the University. A total of 213 drawings, or about half of the TRRA collection is available on microfilm at this time. Washington University also has a listing of 100 items in the collection of Professor Kouwenhoven, the majority of which are duplicates of the University's holdings.

The Mercantile Library, a private subscription library in St. Louis, founded in 1846, is another source of Eads Bridge material, including the Herman T. Pott National Inland Waterways Collection, which includes "Bridges-Eads Bridge, St. Louis 1950-1983" (Box P1-33, Folder No. P1-1-Br-21).

V. FOOTNOTES

1. Edward Ruhlman, East-West Gateway Coordinating Council, Historical St. Louis Metropolitan Area (Washington, D.C.: Clearinghouse for Federal, Scientific, and Technical Information, December 1968), 54.

2. Workers of the Writers' Program of the Work Projects Administration (WPA) in the State of Missouri, Missouri, A Guide to the "Show Me" State (New York: Hastings House Publications, Revised Edition July 1954), 97.

3. Ruhlman, 60.

4. Ibid., 56.

5. Ibid., 66.

6. WPA, 304.

7. Ruhlman, 69-70.

8. WPA, 100.

9. Ibid.; Ruhlman, 69; and March, 1037.

10. WPA, 100.

11. Ruhlman, 71.

12. David D. March, The History of Missouri, Vol. II (New York and West Palm Beach: Lewis Historical Publishing Company, Inc., 1967), 1034 and 1041.

13. WPA, 99.

14. David B. Steinman and Sara Ruth Watson, Bridges and Their Builders (New York: G. P. Putnam's Sons, 1941), 177.

15. Ibid. The largest suspension span of that day was only 870 feet.

16. Ibid., 178.

17. Ibid., 177; and David Plowden, Bridges: The Spans of North America (New York: The Viking Press, 1974), 130.

18. Steinman and Watson, 178.

19. Ibid.

20. Ibid.

21. L. U. Reavis, St. Louis, the Future Great City of the World (St. Louis, 1871). The entire book details the potential growth St. Louis could achieve.

22. March, 1041.

23. Dr. Irwin Ross, "Practical Dreamer: James B. Eads - The Engineer Who Tamed the Mississippi," Consulting Engineer, May 1970, 81.

24. Ibid.

25. Princeton University, The Art Museum and the Department of Civil Engineering, The Eads Bridge (exhibition catalogue) (Princeton: Princeton University/The Art Museum, 1974), 40.

26. Joseph E. Vollmar, Jr., "The Eads Bridge and The Incomparable Mr. Eads," Congressional Record, 2 July 1974, 22120.

27. Princeton University, 40; and Ross, 81.

28. Ibid.

29. Vollmar, 22120.

30. Princeton University, 34. None of the sources given in the footnotes identifies the incorporated name(s) of Eads' salvage business.

31. March, 1042; and Vollmar, 22120.

32. Princeton University, 34-37.

33. Ibid., 37.

34. Vollmar, 22121.

35. Princeton University, 40.

36. Ibid.

37. Ibid.

38. Ibid., 37.

39. Vollmar, 22121; and John Albury Bryan, Lafayette Square, The Most Historic Old Neighborhood in St. Louis, (St. Louis: Landmarks Association of St. Louis, Inc., 1969), 16.

40. Princeton University, 37.

41. Ibid.

42. Ibid.; and Ross, 81.

43. Princeton University, 37.

44. Ross, 81.

45. Ibid.

46. Ibid.; and Princeton University, 37.

47. WPA, 302.

48. Ross, 83.

49. Ibid., 84.

50. Ibid.; and Princeton University, 41.

51. Ross, 84.

52. Ibid., 85.

53. Ibid.

54. Ibid.

55. Princeton University, 41; and March, 1042.

56. Princeton University, 41.

57. March, 1042.

58. Steinman and Watson, 178.

59. Ibid., 179.

60. Ibid.

61. C. M. Woodward, A History of the St. Louis Bridge (St. Louis: G. I. Jones and Company, 1881), 15.

62. Ibid., 16.

63. Ibid., 39.

64. Ibid., 18-31.

65. Ibid., 19-29.

66. Ibid., 29-30.

67. Ibid., 32.

68. Ibid.

69. Ibid., 17.

70. Ibid., 33.

71. Ibid., 2-3.

72. Vollmar, 22121.

73. Woodward, 55.

74. Ibid., 56.

75. Ibid., 58-59.

76. Ibid., 60.

77. Ibid., 60-61.

78. Plowden, 128; and Steinman and Watson, 186.

79. Princeton University, 53.

80. Woodward, 60.

81. Ibid., 62; and Charles E. Smith, "Fiftieth Anniversary of the Eads Bridge," Railway Review, 1 November 1924, 650.

82. Woodward, 61.

83. Steinman and Watson, 189.

84. Woodward, 63.

85. Steinman and Watson, 187; and Woodward, 61.

86. Ibid., 62.

87. Ibid., 63.

88. Ibid., 64.

89. Ibid., 65.

90. Steinman and Watson, 190.

91. Steinman and Watson, 191.

92. Woodward, 249.

93. Ibid., 251.

94. Ibid., 66.

95. Ibid., 16.

96. Steinman and Watson, 194.

97. Woodward, 70.

98. Smith, 651.

99. Ibid.

100. Ibid.

101. Vollmar, 22121.

102. Smith, 652.

103. Ibid. Neither Smith, nor Woodward (see p. 88), nor any of the other sources given in these footnotes identifies, by name, the British metallurgist who successfully mixed the chrome steel from which the staves were fabricated.

104. Ibid.

105. Ibid.

106. Woodward, 169.

107. Woodward, 194-196.

108. Andrew Carnegie, Autobiography of Andrew Carnegie with a new foreword by Cecelia Tichi (Boston: Northeastern University Press, 1986 edition), 149-150.

109. Woodward, 106.

110. Ibid., 106-107.

111. Ibid., 114 and 116-120.

112. Ibid., 160.

113. Ibid., 174-177.

114. Ibid., 176.

115. Ibid., 177.

116. Ibid., 189.

117. Ibid., 184-185 and 190. Cooper had fallen from a wooden plank on December 2, 1873 90 feet into the water and survived by rolling himself into a ball. He went home to change his clothes and returned to work the same day.

118. Ibid.

119. Ibid., 191.

120. Ibid., 263-271.

121. Ibid., 271-278; and Vollmar, 22121.

122. Ibid.

123. Woodward, 195-196.

124. Ibid.

125. Vollmar, 22122.

126. Woodward, 196.

127. Princeton University, 67-69.

128. Woodward, 197.

129. Ibid., 198; and Princeton University, 55.

130. Princeton University, 69.

131. Ibid., 59.

132. Ibid., 69-72.

133. Smith, 653.

134. Ibid.

135. St. Louis Globe Democrat 28 May 1896; p. 1; 29 May 1896, p. 5; and 1 June 1896, p. 3).

136. Smith, 653.

137. Princeton University, 52.

138. Ibid., 73.

139. Ibid., 45.

140. Smith, 653.

141. Ibid., 654.

142. American Society of Civil Engineers (ASCE), "Eads Bridge in St. Louis is Designated a National Historic Civil Engineering Landmark," press release: 21 October 1974.

143. Steinman and Watson, 174.

144. Woodward, 114.

145. Ibid., 276.

146. Ibid., 35-39.

147. ASCE.

148. Smith, 651.

149. Plowden, 126; Princeton University, 16; and ASCE in which American Institute of Steel Construction Executive Vice President John K. Edmonds is quoted as follows: "The Eads Bridge is of special interest to the steel industry because it was not only the first bridge to make extensive use of steel, but was one of the first significant steel structures of any type."

150. Steinman and Watson, 186.

151. Plowden, 66 and 128; and Steinman and Watson, 186.

152. Plowden, 128.

153. Ibid.; and Princeton University, 44.

154. Steinman and Watson, 186; and Plowden, 128. Eads brought suit against Roebling for patent infringement regarding pneumatic construction techniques.

155. Steinman and Watson, 200.

156. Plowden, 129.

157. Ibid., 128.

158. Princeton University, 63-64; and Steinman and Watson, 123.

159. Ibid.

160. Woodward, 160; and Steinman and Watson, 200.

161. ASCE.

162. Carnegie, 149-152.

163. Ibid.

164. Julius Grodinsky, Jay Gould: His Business Career, 1867-1892 (Philadelphia: University of Pennsylvania Press, 1957), 192-210.

165. Princeton University, 50.

166. Ibid.

167. Grodinsky, 338-341.

168. Louis H. Sullivan, The Autobiography of an Idea with a foreword by Claude Bragdon (New York: Press of the American Institute of Architects, Inc., 1924), 246-250 and 298.

169. Ibid., 247.

170. Princeton University, 6.

171. Plowden, 129; and Princeton University, 63.

172. Woodward, Preface, vii.

173. Ibid., Inscription following Table of Contents and List of Plates.

174. Ibid., Preface, vii.

175. Princeton University. The entire book catalogues the exhibit.

VI. BIBLIOGRAPHY

Given in chronological order of first publication for books and for other sources.

A. Books

Reavis, L. U. St. Louis, the Future Great City of the World. St. Louis, 1871.

Woodward, C. M. A History of the St. Louis Bridge. St. Louis: G. I. Jones and Company, 1881.

Von Hesse-Wartegg, Ernst. Edited and Translated by Frederick Trautmann. Travels on the Lower Mississippi, 1879-1880. Columbia: University of Missouri, 1990. First published in 1881 in Germany.

Scharf, J. Thomas. History of St. Louis City and County. Philadelphia: Louis H. Everts & Co., 1883.

Carnegie, Andrew. Autobiography of Andrew Carnegie with a new foreword by Cecelia Tichi. Boston: Northeastern University Press, 1986. First published in 1920.

Sullivan, Louis H. The Autobiography of an Idea with a foreword by Claude Bragdon. New York: Press of the American Institute of Architects, Inc., 1924.

Steinman, David B. and Sara Ruth Watson. Bridges and Their Builders. New York: G. P. Putnam's Sons, 1941.

Workers of the Writers' Program of the Work Projects Administration in the State of Missouri. Missouri, A Guide to the "Show Me" State. New York: Hastings House Publishers, July 1954. Originally published 1941.

Terminal Railroad Association of St. Louis. 50 Years of Transportation, 1894-1944, St. Louis Union Station and St. Louis. St. Louis: Simmons-Sisler, 1944.

Smith, H. Shirley. The World's Great Bridges. New York: Harper & Brothers Publishers, 1953.

Grodinsky, Julius. Jay Gould: His Business Career, 1867-1892. Philadelphia: University of Pennsylvania Press, 1957.

March, David D. The History of Missouri, Vol. II. New York and West Palm Beach: Lewis Historical Publishing Company, Inc., 1967.

Ruhlman, Edward -- East-West Gateway Coordinating Council. Historical St. Louis Metropolitan Area. Washington, D.C.: Clearinghouse for Federal, Scientific, and Technical Information, December 1968.

Bryan, John Albury. Lafayette Square, The Most Historic Old Neighborhood in St. Louis. St. Louis: Landmarks Association of St. Louis, Inc., 1969.

Plowden, David. Bridges: The Spans of North America. New York: The Viking Press, 1974.

Princeton University, The Art Museum and the Department of Civil Engineering. The Eads Bridge (exhibition catalogue). Princeton: Princeton University/The Art Museum, 1974.

Vollmar, Joseph E. James B. Eads and the Great St. Louis Bridge. St. Louis: Engineers' Club of St. Louis, 1974.

Scott, Quinta. The Eads Bridge (photographic essay by Scott and historical appraisal by Howard S. Miller). Columbia: University of Missouri Press, 1979.

Hebrank, Arthur W. The Geologic Story of the St. Louis Riverfront (A Walking Tour). Rolla, MO: Missouri Department of Natural Resources, 1989.

B. Other Sources

Illinois and St. Louis Bridge Company. "Collection of Proposals, Related Legal Documents, and Reports on the Building of Eads Bridge." St. Louis, 1867-1871. (St. Louis Public Library Rare Books Collection)

St. Louis Globe-Democrat, 28 May 1896, 29 May 1896, and 1 June 1896.

Smith, Charles E. "Fiftieth Anniversary of the Eads Bridge." Railway Review, 1 November 1924.

"Statement of the Trunkline Railroads of St. Louis upon the Proposed Exchange of the Eads and Municipal Bridges." St. Louis, c1927. (St. Louis Public Library)

"Missouri in the Hall of Fame for Great Americans." Missouri Historical Review XXXIII, July 1939.

"Missouri Miniatures - James Buchanan Eads." Missouri Historical Review XXXIV, April 1940.

Shoemaker, Floyd C. "The Missourian and Ten of His Outstanding Representatives." Missouri Historical Review XXXVIII, April 1944.

Ross, Dr. Irwin. "Practical Dreamer: James B. Eads - The Engineer Who Tamed the Mississippi." Consulting Engineer, May 1970.

Spinner, B. H. "Eads Bridge Repaired by Jacking." Civil Engineering, 6 June 1971.

American Society of Civil Engineers. "Eads Bridge in St. Louis is Designated a National Historic Civil Engineering Landmark." Press release 21 October 1974.

Vollmar, Joseph E. Jr. "The Eads Bridge and the Incomparable Mr. Eads." Congressional Record, 2 July 1974.

Davenport, Samuel R. "Delta Jam Eads; the Saga of the Man who Opened the Mississippi to Commercial Navigation." Louisiana Industry Review, April 1982.

Illuminating Engineering Society. "Lighting Eads Bridge." Lighting Design and Application, 8 August 1984. (Engineering Societies Library, New York)

East-West Gateway Coordinating Council. "Bridge Committee Report." St. Louis, 1985. (St. Louis Public Library)

News. "St. Louis Vies for Rail Link." Engineering News-Record, 2 October 1986.

Market Focus. "Laying Tracks for an Attractive Alternative." Engineering News-Record, 1 December 1988.