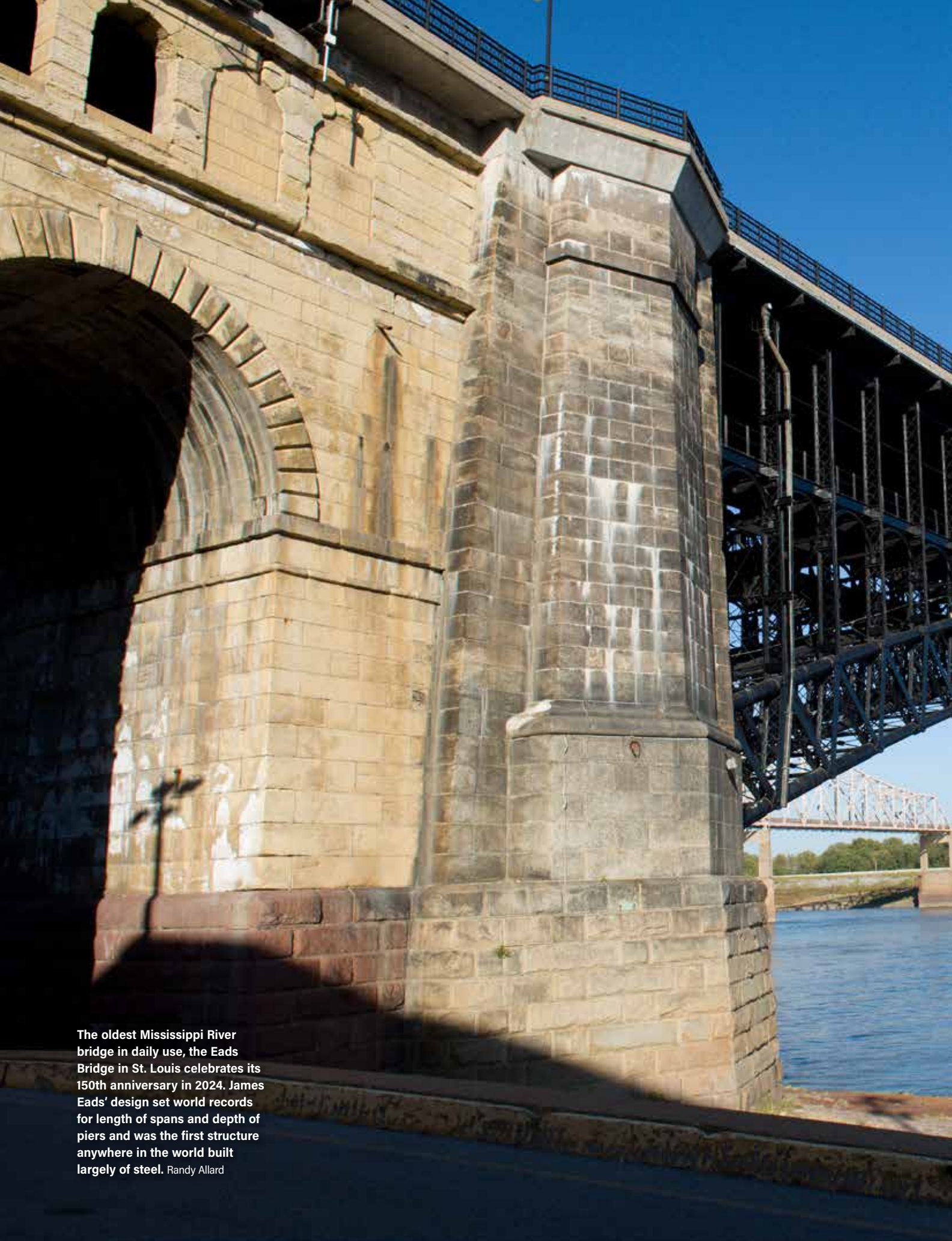
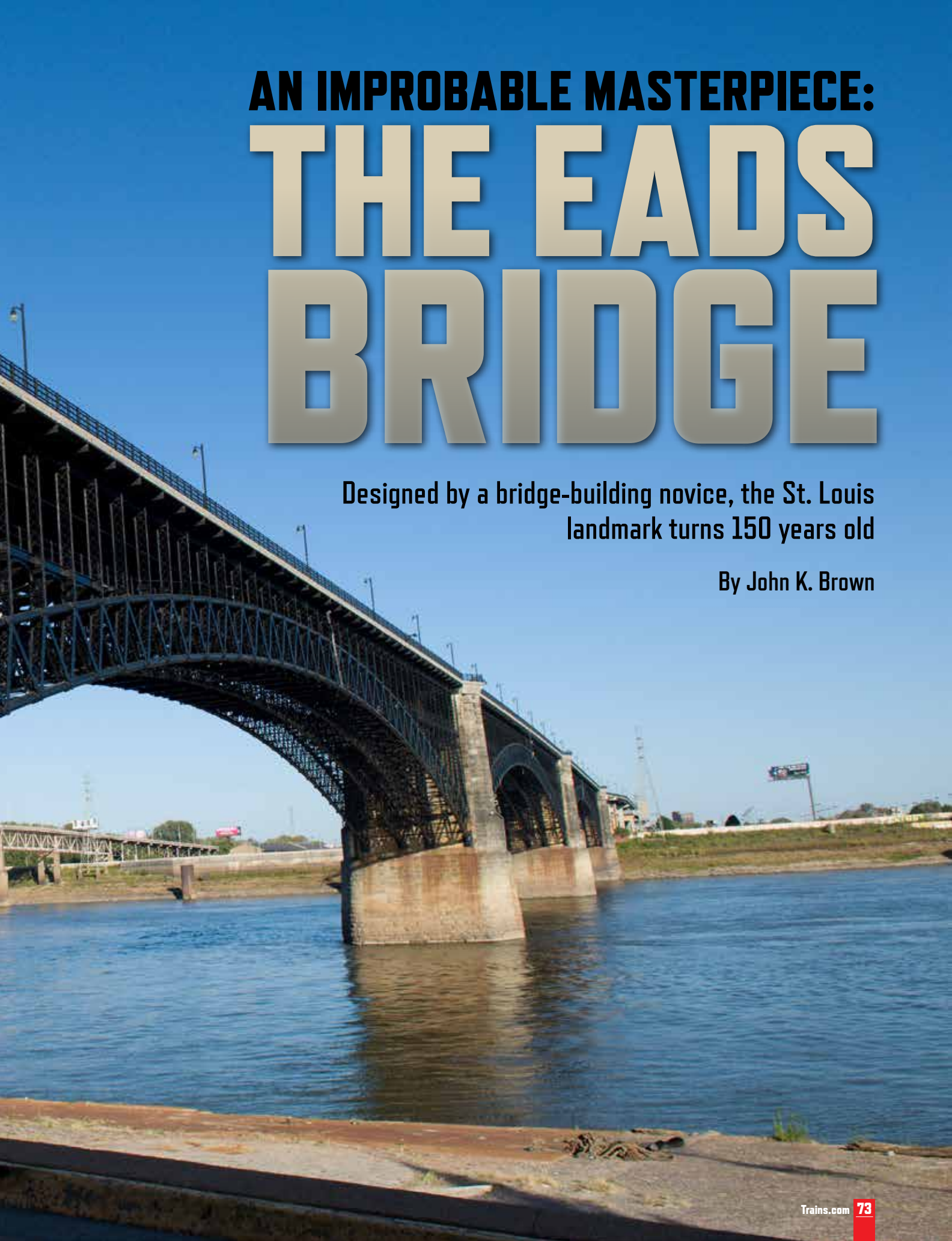


The oldest Mississippi River bridge in daily use, the Eads Bridge in St. Louis celebrates its 150th anniversary in 2024. James Eads' design set world records for length of spans and depth of piers and was the first structure anywhere in the world built largely of steel. Randy Allard

AN IMPROBABLE MASTERPIECE:
THE EADS BRIDGE



Designed by a bridge-building novice, the St. Louis landmark turns 150 years old

By John K. Brown

The Eads Bridge, a double-deck road and rail bridge across the Mississippi River at St. Louis, celebrates its 150th anniversary in 2024. It is the oldest bridge in daily use on the river, but the structure has been amazing and improbable from its origins. A riverman, James Eads, proposed it in 1867 with all its major design concepts. He had never designed or built a bridge, yet this one, his first offering, would break world records for the length of its spans and the depth of its stone foundations. To place those two piers on bedrock beneath the flowing Mississippi and its sandy riverbed, Eads became the North American pioneer in using pneumatic caissons. He was so influential that Washington Roebling went to St. Louis to learn all he could before undertaking his own bridge in Brooklyn.

On July 4, 1874, upwards of 200,000 people attended the grand opening celebration for this engineering triumph. The crowds marveled at the superstructure, for it too was unprecedented. Like no other bridge on the continent, its three shallow arches seemed to skip across the river. The broad roadway on the upper deck gave travelers unobstructed views of the mighty Mississippi and the city it had created. The lower deck carried two standard gauge tracks, finally connecting St. Louis to the national railway map. Most of those 60,000 miles of lines lay east of the river, so the new bridge promised to transform the city and the country. To carry the loads of its twin decks, Eads had specified steel for the arches. His was the first structure — of any kind, anywhere in the world — largely built of steel.

The St. Louis Bridge on Jan. 10, 1875. In years past, such ice jams blocked the ferries connecting St. Louis to the eastern railroad network, isolating the city. This view shows the grace and utility of Eads' shallow arches. Robert Benecke; Missouri Historical Society

LIFE ON THE MISSISSIPPI

Until he turned to the project of bridging the river, James Eads had spent most of his working life on, in, and under the Mississippi (see "Who was James Eads?" page 77). Captain Eads' career in salvage had taught him valuable lessons about the river: its currents, the shifting sandy bottom, and its threats — sudden freshets, crushing winter ice jams, and an endless burden of driftwood that included whole trees. By 1866, Eads was devoting his considerable energies and capital to western

In 2024, the Eads Bridge marks 150 years of service. The amazing and improbable story of its construction combines inspiration, determination, and the use of then-new materials and building techniques. Randy Allard

railroads. Investments in two lines, the North Missouri and the Atlantic & Pacific, tied him to Thomas Alexander Scott, then vice president of the Pennsylvania Railroad. Like Scott, Eads believed that a bridge at St. Louis would boost his hometown, tie his western investments to the PRR, and shower wealth on all involved.

Between 1864 and 1879, upwards of 25 major railroad bridges were built over the Ohio, Mississippi, and Missouri rivers, with hundreds more over their tributaries. These crossings played essential roles in creating regional rail systems, developing key junction points, promoting car interchange, growing the farm economy, and generating national wealth.

Notable examples included the Steubenville (Ohio) crossing over the Ohio River (1864), with its iron-truss superstructure fabricated by the new Keystone Bridge Co., and the Union Pacific's bridge over the Missouri River (1872), with 11 iron truss spans that finally connected the transcontinental line to the Eastern railroad network.

Although they served railroads, most of the biggest bridges were created by profit-seeking entrepreneurs. This private-sector approach suited many carriers, as the western lines were chronically short on investment capital. Furthermore, their own officers could profit by investing in the new crossings. The bridge promoters also drew investors from local elites, eastern bankers, and far-off Europeans. All envisioned building a no-frills iron bridge of adequate capacities to meet immediate needs, that would charge a toll for each freight car and a fee for every passenger that crossed. For their backers, this looked like a guaranteed route to wealth. Except for the Eads Bridge, all the long-span bridges were of patented designs of iron trusses. These first-generation improvements over composite wood/iron bridges had superstructures fabricated in specialized factories at the Keystone Bridge Co., Phoenix Bridge, Chicago's American Bridge, and others.

A studio portrait of James Eads circa 1874.
Photographer unknown; Missouri Historical Society

MAN OF STEEL

Ignoring this new approach, in the summer of 1867 James Eads offered his own design for an arch bridge made of steel. The proposal fell between bold and foolhardy. The first American Bessemer steel works had just fired its initial and imperfect batches that May. Iron was the new, new thing, not steel. Even as Eads launched his steel bridge project, two other promoters presented plans for iron rail bridges for St. Louis. Lucius Boomer's American Bridge Co. had a record of success in the industry. The Baltimore Bridge Co. combined the talented resumes of Shaler Smith and Benjamin Latrobe. But Eads held a key advantage, his friendship with Tom Scott. Scott, in turn, was passionate to harvest wealth out of projects across the continent.

In that long-ago summer, the long-desired dream of St. Louisans to have a bridge became a two-man contest: the neophyte Eads against the long-established Boomer. Tom Scott and his Philadelphia friends chose to back Eads. On Oct. 29, 1867, Scott instructed his young right hand, Andrew Carnegie, to convey that message. Scott and his boss, PRR president J. Edgar Thomson, were convinced that "you and your associates are the men of St. Louis to whom the Penna *(sic.)* RR should adhere."

Thomson and Scott chose Eads, despite his inexperience, because Boomer and his bridge project were aligned with promoters tied to the Lake Shore line and the New

This view shows the two pontoon boats, *Alpha* and *Omega*, building the west pier. Stone laying is well advanced, forcing the iron caisson down into the riverbed. Robert Benecke; Missouri Historical Society

York Central. They picked Eads only to block those rivals to the PRR. In fact, Thomson and Scott saw little to like in Eads' drawings. In June, the PRR's chief bridge designer, Jacob Linville, had dismissed those plans as "entirely unsafe and impractical."

Eads simply pressed ahead. As he had written to his wife years earlier, "Drive on is my motto." Because the PRR backed Eads, Boomer's project stalled, and the two bridge ventures consolidated in January 1868. For the next year, Eads focused on raising capital, issuing a new prospectus in February 1869. It envisioned total capitalization at $10 million (equal to $231.4 million in 2023), and it enticed investors with the prospect of doubling their money. With the proceeds from stock sales, work began on the two river piers in October 1869.

Thomas Alexander Scott. This portrait accompanied a flattering profile in *Harper's Weekly* (July 12, 1873) that cast Scott as the selfless servant of national progress. Wood engraving from a photograph by F. Gutekunst; author's collection

DOWN TO BEDROCK

During the previous winter, Eads had studied pneumatic caissons while touring Britain and France. Imagine a large iron box, much like a shoe box, but inverted, with no bottom. Once pinned into place with wooden pilings, that caisson floated at the spot where Eads would build a pier. The top face of the east pier caisson measured 82 by 60 feet, the largest yet attempted in the world. Crews would then bring limestone and granite blocks out to "pontoon boats," designed by Eads and tied to the caisson. Each boat had six double-beaked cranes, controlled by operators perched 50 feet above the deck. From that lofty spot, a crane man could pluck a 7-ton block off a barge, transport it over his own pontoon boat, and place it on the caisson.

Each new block of stone would add weight to the caisson, forcing it down into the river. Air compressors on the pontoon boats would adjust the buoyancy of the descending caisson until it landed on the sandy riverbed. It all amounted to a kind of brute-force ballet. European engineers

had developed the method, which Eads saw in use on the Allier River in France. He then pioneered its use for deep foundations in North America. Compared to the rivers of Europe, the Mississippi was treacherously wild.

The caisson reached the riverbed, 34 feet below the surface, on Nov. 25, 1869, one month after the first stone came aboard. Now the work entered a challenging new phase. Knowing the river's forceful currents and its winter ice gorges, Eads had decided to limit his bridge to just two piers, and to take them all the way down on bedrock. To that end, the stone pier would need to descend 60 more feet through sand and gravel. After the air compressors expelled all the water from the caisson, sandhogs or "submarines" descended an iron staircase built inside the pier. An air lock gave access to its interior. Gangs worked shifts around the clock, shoveling sand to patented "sand pumps," another Eads innovation that ejected the spoil into the river (they worked much like the steam injectors of contemporary locomotives).

The submarines were paid $4 a day (equivalent to $97 in 2023), a good wage for unskilled labor in that era. But they earned it. At a depth of 60 feet, many began to feel aches and pains in their joints and muscles. The caisson landed on bedrock on Feb. 28, 1870, 93 feet down. To keep the water out, air pressure inside reached 44 psi, or three times the norm at sea level. By then many submarines had severe pains, even bouts of paralysis. They still needed to work every day, filling the caisson with concrete to seal it forever. Before completing that essential task, 13 men died from caisson disease. Today we know that "the bends" is caused by dissolved gases forming bubbles inside the body tissues during too-rapid decompression.

The remaining stonework for the two piers and two abutments required another 18 months. Thanks to improved safety measures, only one more man died of the bends. By then, Eads was focused on the next looming issue — securing adequate steel to build the superstructure.

FINANCIAL COMPLICATIONS

As the stone piers grew above the river, Eads and his associates in the Illinois and St. Louis Bridge Co. turned to three new and intertwined challenges. They searched for a steel works capable of making the load-bearing arches (known as chords to engineers) of the superstructure. They needed a specialist bridge builder to fabricate other parts in wrought iron, then erect the three arches and two decks over the river. And they had to find a banker willing to finance all this.

For three years, Edgar Thomson and Tom Scott knew they possessed solutions to some of these challenges. If their PRR agreed to funnel its business to the new bridge, those guaranteed revenues could entice an investment banker to float a new bond issue for Eads' company. Income from bond sales would then pay the steel works and the bridge builder for their contributions. Since Thomson and Scott controlled the Keystone Bridge Co. of Pittsburgh, this solution appeared to offer more benefits to all the parties.

WHO WAS JAMES EADS?

BORN IN 1820 on the Indiana frontier, James Eads moved with his family to St. Louis during boyhood. His formal education ended at age 13 when he became a clerk in a dry-goods store. From those obscure and unpromising origins, Eads became a classic American success story. His professional life unfolded in six distinctive chapters, each novel but growing from past achievements. Three years before he died, his accomplishments earned a singular honor. He became the first American to receive the Albert Medal, joining such luminaries as Faraday, Bessemer, and Pasteur. Bestowed at a London ceremony by the Prince of Wales, the award recognized "distinguished merit in promoting the arts, manufactures, and commerce."

From 1842, young Jim Eads undertook dangerous work in river salvage, searching for sunken cargos and wrecks of the steamboats mortally wounded by collisions, fires, or explosions. Using boats, gear, and a diving bell of his own design, he amassed a fortune by the 1850s. His lifetime honorific, Captain Eads, reflected those years on the western rivers.

When the Civil War broke out, he hurried to Washington City, called there by his friend Edward Bates, Lincoln's attorney general. Eads advised the president and his cabinet to build a fleet of steam-powered gunboats to take control of the Mississippi, the chief highway into the rebellion. By August 1861, Captain Eads had taken a contract to build seven ironclad gunboats, each weighing 500 tons. He had never built a warship, and did not own a shipyard, foundry, or machine shop. Yet his fleet was ready for battle six months later. In February 1862, a month before John Ericsson's *USS Monitor* fought to a draw in Virginia, Eads' innovative ships gave the Union its first significant victories of the war, leading the river bombardment that helped capture Forts Henry and Donelson. The combined army/navy assaults made a national hero of Ulysses Grant, and proved fundamental to the Union's eventual victory in the war.

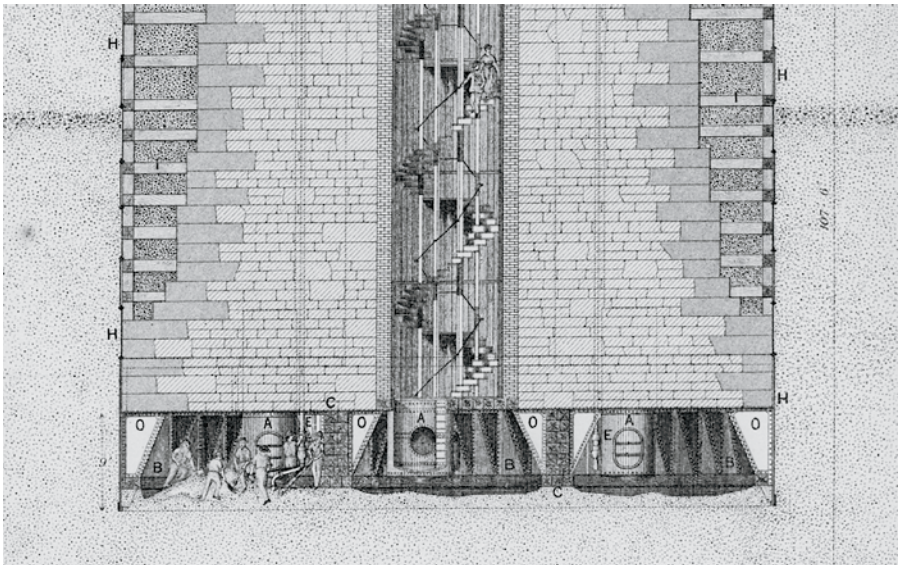
The St. Louis Bridge followed the war. His years in salvage had given Eads unique understanding of the river, while his wartime work on the ironclads had provided lessons in managing complex engineering and large organizations. Collaborations with naval officers working on ordnance also grew his familiarity with steel.

Even before the bridge opened, Eads had embarked on another novel project, advocating a navigable channel through the Mississippi River delta so that ocean freighters could reach the docks at New Orleans. The delta had grown choked with silt during the war. The Army Corps of Engineers proposed to a new canal to access New Orleans, a proposal that Eads denounced in strong language that made the Corps his enemy. By constructing jetties to concentrate the river's natural currents, Eads avoided the high cost of a canal while flushing the silt and deepening the South Pass channel from 14 feet (1874) to 31 feet in 1879. Success earned him another fortune, $5,950,000, paid by the U.S. Treasury ($185.1 million in 2023).

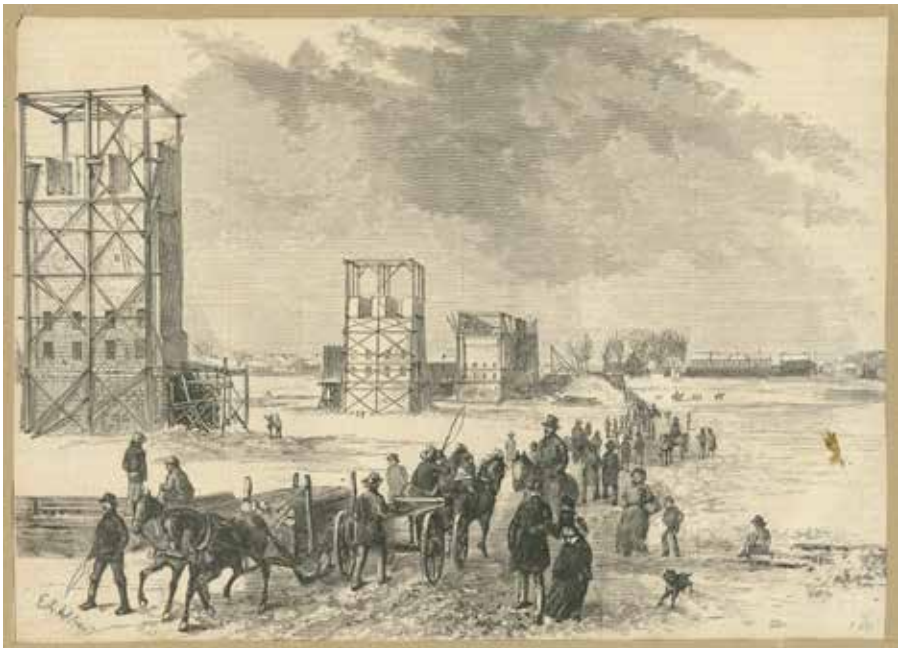
During the last decade of his life, Eads earned international regard for his expertise in the hydraulics of rivers and harbors. During this chapter, he gave expert testimony to the British Parliament, and advised the Grand Vizier about a bridge over the Bosporus. He even prepared drawings for that 3,500-foot railroad bridge to unite Europe and Asia.

The sixth chapter of his remarkable career focused on promoting and designing his Tehuantepec Ship Railway. The venture had all the Eads hallmarks. Rejecting a traditional canal, then under consideration across the Isthmus of Panama, he proposed a massive railroad over the Isthmus of Tehuantepec in Mexico. A ship-hauling railroad, capable of carrying iron freighters weighing 8,000 tons with their cargos, at speeds up to 10 mph over the 60-mile route. Fanciful or feasible, the ship railway died with Eads in March 1887.

His death by pneumonia, just shy of age 67, harkened back to a lifetime of bouts with respiratory illness and his years of breathing in and under the Mississippi. The editors of the *Railroad Gazette* marked his life with a handsome tribute, noting that "his personality inspired affection and enthusiasm in men of all ages and conditions." In their assessment, "he combined courage, enthusiasm, persistence, insight, and judgement in such measure as to amount to genius." — *John K. Brown*



This detail from an engraving illustrates the caisson's construction and the work of the "submarines." It shows the main airlock (labeled 'A') and the digging galleries. The men dig away, carting sand in barrows to the sand pump ('E') whose operator suctions the spoil. A fashionable lady and gentlemen descend the circular staircase to observe these strange sights.
Detail of an engraving from Woodward, *History*, plate XIII



In December 1872, the Mississippi River at St. Louis froze hard, allowing people, teams, and wagons to cross on the ice. By this point, Eads and his men had been laboring for 5 years.
Engraving by E.A. Abbey, "Ice Bridge," *Harper's Weekly* (Jan. 18, 1873): 52. Missouri Historical Society

Steel was another matter entirely. Thomson did not believe any American steel works could fulfill Eads' requirements. Furthermore, Keystone's Linville had dismissed Eads' arch design as unsafe and impractical — and there was no better bridge man in the country. Linville had prepared his own plans for a conventional iron truss bridge for St. Louis. Back in October 1867, Andrew Carnegie had gently tried to steer Eads away from his exotic ideas, writing that "Mr. Thomson believes you will find it necessary to modify the present plans as you proceed." Eads, however, clung to his unique design, so Thomson and Scott hung back from fully committing to Eads.

In February of 1870, money finally brought Scott, Thomson, and Carnegie to close a deal with the Illinois and St. Louis Bridge Co. Eads' company committed to pay that trio a bonus of $250,000 if those men would bring an investment banker, the PRR, a steel maker, and a bridge builder to the deal. The bonus amounted to approximately $6 million in 2023 dollars.

Atop that personal reward, the three men grasped other benefits and profits: chiefly new business for the PRR and for their own Keystone company. If steel simply proved impossible, Keystone could enhance its margins by erecting Linville's iron truss bridge.

Troubles in procuring suitable steel did nearly overwhelm Eads' company. As Thomson had predicted, Bessemer steel lacked the requisite strength and uniformity. Besides, no Bessemer plant in the world would even quote for the job. Eads settled on a small Philadelphia producer of crucible steel, the William Butcher Steel Works, but its products typically failed his strength tests. Two years of troubles with steel finally drove Butcher bankrupt, ignited acrimonious revolts by Carnegie and Keystone, and caused Eads to scale back his demands.

But Eads did largely prevail in the end. The Butcher works was reorganized as Midvale Steel, and its output improved under the management of William Sellers, one of America's top mechanical engineers.

As built, the superstructure had 4.8 million pounds of steel, 6.3 million pounds of wrought iron (mostly in the bracing that connected the steel chords), and 1.6 million pounds of wood in the decks and sidewalks. A steel bridge, more or less.

The troubles with steel embittered the men at Keystone Bridge. But they remained tied to Eads' company, contractually bound to erect the arches and build the decks. That work finally began in March 1873. Here too, the unique design called for novel methods. Eads' first assistant engineer, Henry Flad, devised an unprecedented cantilevering system to support the developing chords from above as they reached out from the abutments and piers.

Flad's approach required laborious calculations and much expense, but kept the river clear for the ceaseless traffic of steamboats and barge tows that still made St. Louis the leading inland port of the continent.

As arch construction advanced, a succession of new difficulties assailed Eads and his bridge. In August, Keystone gave notice it would ignore its contractual commitment to bear all responsibility for closing the arches. Eads' men would have to meet the challenges of placing the final steel tubes that would make them self-sustaining. As they brought the first arch to near completion, the Army Corps of Engineers declared that the bridge illegally obstructed navigation on the river. And at just that moment, the Panic of 1873 overwhelmed Wall Street and the national economy.

In their combined effect, the Corps and the Panic threatened Eads' access to additional capital, funds essential to

The arches are nearing completion in this December 1873 photograph. A river ferry awaits passengers on the Illinois shore. Robert Benecke; Woodward, *History*, plate 44

completing the bridge.

Eads still drove on. In an October meeting at the White House, his old acquaintance from the war listened intently as Eads described the army's campaign against the bridge. President Ulysses Grant summoned the Secretary of War and overruled the Corps on the spot. On Dec. 18, 1873, a team of engineers and laborers placed the final tubes in the two middle chords of the east arch, making it self-supporting. Finally, the city had its bridge, seven years in the making. At noon, "a party of ladies and gentlemen walked out to the middle arch and hoisted the Stars and Stripes." Across the waterfront, whistling and cheering marked the moment.

Despite the milestone, much work remained: completing the arches and decks, building the sidewalks, painting the structure, and finishing the approaches. Eads' team also finished a 4,400-foot tunnel under downtown, connecting the bridge to a site for a new station. At the grand opening celebration on July 4, 1874, Captain Eads thanked many contributors to the project by name, including the banker Junius Morgan in London who had sustained the project with capital. He had nothing to say — not a word of thanks or acknowledgement — for Edgar Thomson, Tom Scott, or Andrew Carnegie. In a private letter to banker Morgan, Eads explained that opposition from the Pennsylvania Railroad "has, I believe, cost our company not less than a million and a half of dollars."

Eads had prevailed in building his improbable masterpiece, but Tom Scott had extracted a heavy price. The cause of his antipathy is unknown and unknowable. With Scott pushing a boycott of many carriers, the Illinois & St. Louis Bridge Co. fell into foreclosure just nine months after it opened. (Scott may have sought exactly that result, hoping to acquire the bridge at a court-appointed sale of assets.)

This final act clouds most accounts of Eads and his bridge, but casting the venture as a financial failure is woefully incorrect. Half of all American railroads passed through bankruptcies and reorganizations during the depression of the 1870s, including the Santa Fe, Burlington, and Kansas Pacific. History does not record these companies as failures.

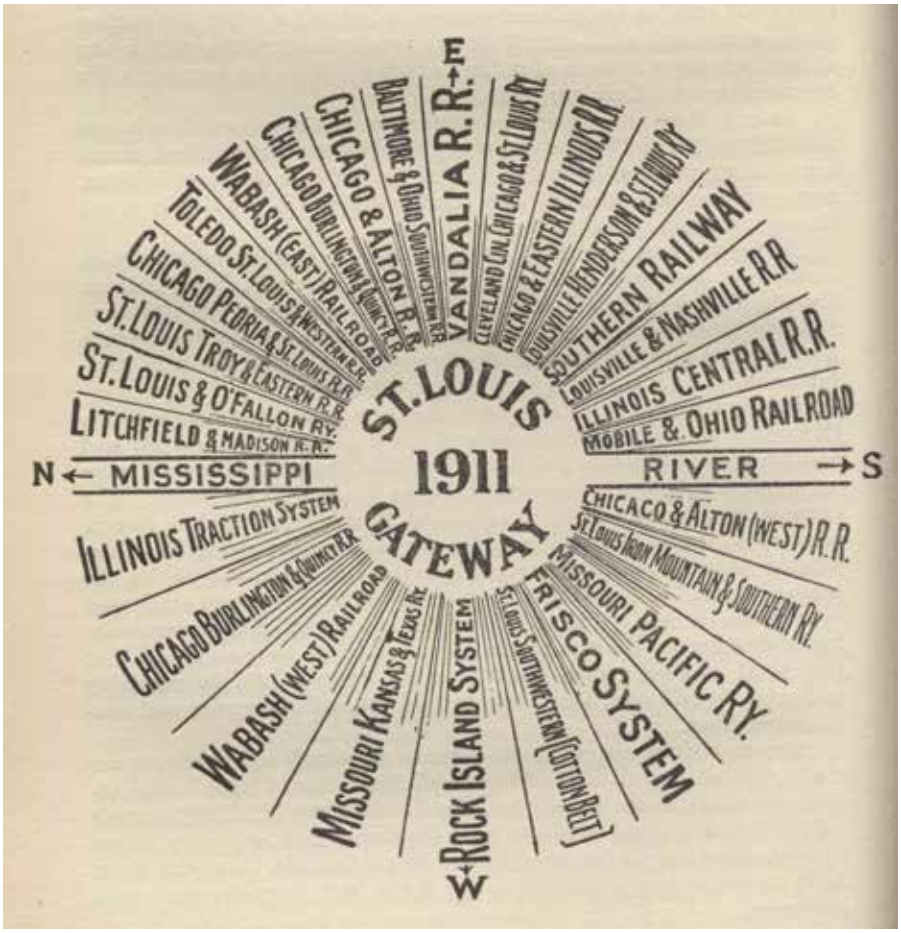
SUCCESS WRIT LARGE

After reorganization in 1879 by its London bankers, the bridge proved a great financial success and an engine of growth for the region and the nation. Between 1880 and 1900, St. Louis grew from sixth to fourth place among American cities (ranked by population). The rail connections created by the bridge powered much of that progress. From 1889, it became the chief asset of the Terminal Railroad Association of St. Louis, formed that year by six St. Louis carriers. By 1902, 14 railroads shared ownership of the TRRA, which in turn provided terminal and interchange services to all area lines.

In 1902, the Terminal Association had revenues of $1.83 million. After debt servicing, this left a cash surplus of $367,000, a 20% return on its gross (a year earlier, profits had reached 24%). Here was success writ large.

The operational history of the bridge also reflected the genius of its designer, promoter, and chief engineer. Eads planned that his bridge would gather up all the traffic of eastern lines and deliver it to a new union station serving all St. Louis carriers. It did just that, although thanks to Scott's antipathy, the Union Depot opened a year after the bridge. It was successful from the start, serving 60 passenger trains on its first day (an oft-repeated error claimed it failed too, serving just 14 trains a day). By 1891, the station served a daily average of 230 arrivals and departures by 19 carriers.

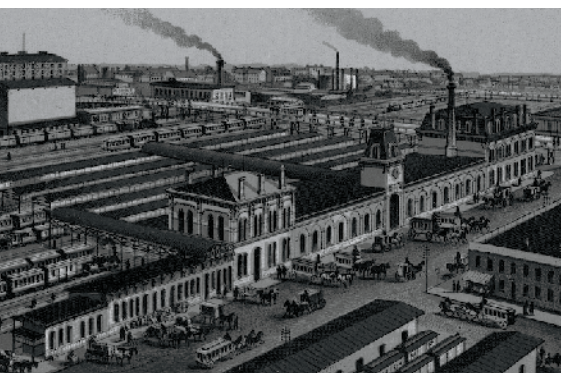
With its double tracks, the bridge had ample capacity — and strength — to bear this growth in freight and passenger traffic.



The St. Louis Merchants Exchange illustrated the city's gateway position this way. The Terminal Railroad Association connected each line. Image from Merchants, *Statement* (1910) p. 88

According to the *Railroad Gazette*, "on several occasions" freight trains started over the river with one or more cars already derailed. Once a 35-ton locomotive derailed on the span, running some distance before the engineer could stop his train. As with so many elements, Eads and his engineers had designed an unusual floor system which bore up well under these accidents, containing the damage.

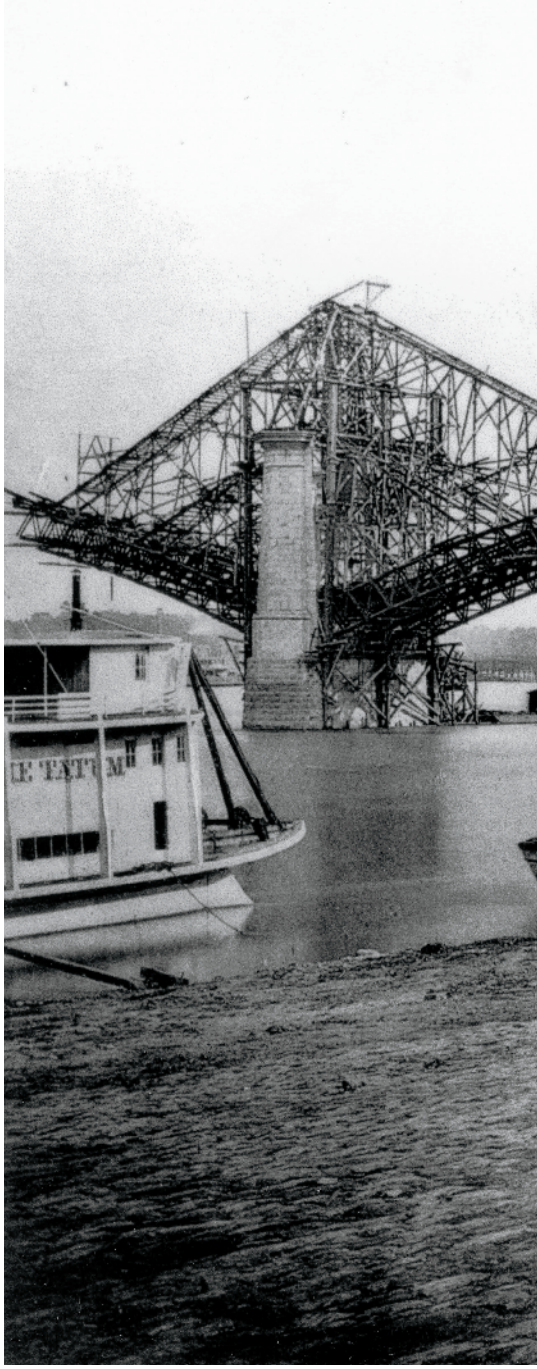
One mystifying problem on the bridge could only be managed, never corrected. Civil engineers described it as "rail creep." Quite literally, the rails moved. The northern track (for westbound traffic) crept toward St. Louis at the rate of a foot a day. The eastbound track did just that, moving at roughly the same rate. Rarely encountered at other bridges, the problem elicited detailed investigation, many theories, and no authoritative answers. Heroic efforts to fasten the rails in place failed. An engineering report from 1884 noted that "steel spikes, bolts, straps and splice bars have been sheared off and torn asunder ... and connecting tracks in East St. Louis pulled out of line ... the rails themselves so buckled and twisted that when one was removed it could not have been replaced again by eight inches." Engineers could only adapt to this problem. At three locations, short sections of rail were added or removed many times each day. This rudimentary solution required nearly full-time attention from eight men working around the clock.



Opening in 1875, St. Louis Union Depot proved a fine facility. Trains from the East continued to stop in East St. Louis, where those carriers maintained servicing facilities. *Souvenir of St. Louis* (1882), author's collection

CHANGING TIMES

During the 20th century, the Terminal Railroad Association made extensive improvements and repairs to the Eads Bridge.



Supported by temporary towers and cables, the steel tubes cantilever outward from the abutment and the west river pier. Robert Benecke, Woodward, *History*, plate XLIII

Its strength increased from a Cooper E-36 rating in 1921 to Cooper's E-45 in 1970. The shift from steam to diesel locomotives eased the stresses on the arches. And its extraordinary strength has proven essential on those occasions when strong river currents overpowered towboats or their barges, causing them to strike the bridge piers, even the superstructure.

In line with national trends, St. Louis and its rail network fell into decline after 1950, with dwindling rail traffic abandoning the bridge in 1974, its centennial year. In 1989, the City of St. Louis swapped its MacArthur Bridge (originally known as the Municipal or Free Bridge) for the Terminal

Railroad Association's Eads crossing. City planners wanted the bridge and tunnel to create a new route for electric-powered light-rail trains to serve downtown.

With its rededication in 2003, this oldest bridge on the Mississippi was back in business. The restored roadway deck carries auto traffic in four lanes without tolls. On the rail deck beneath, trains of the MetroLink light-rail system connect St. Louis's eastern and western suburbs to the urban core and the airport.

Each weekday, those trains cross the Mississippi 300 times. Passengers from Illinois enjoy fleeting views of the river and the bridge's iron and steel sinews before plunging into the darkness of the 1874 tunnel with its two new downtown stations. In 2016, the bridge and its approaches returned to like-new condition thanks to a $48 million restoration. With its original strengths intact, the restored bridge should have a service life reaching to 2091 or beyond, according to engineering projections.

By any conventional understanding, that remarkable longevity would also seem improbable. James Eads would greet that news with his characteristic self-assurance. In his remarks on opening day, he predicted that "this bridge will endure as long as it is useful to man." 1

JOHN K. (JACK) BROWN taught history, ethics, and writing in the Engineering School of the University of Virginia for 25 years. His book, Spanning the Gilded Age: James Eads and the Great Steel Bridge, *will be published by the Johns Hopkins University Press in May 2024.*