Constructed against great adversity over a 14-year period, this 128-year-old landmark continues to serve the people of New York and America.

The Brooklyn Bridge: First Steel-Wire Suspension Bridge

BY JIM TALBOT

STEEL CENTURIONS
SPANNING 100 YEARS

Our nation's rich past was built on immovable determination and innovation that found a highly visible expression in the construction of steel bridges. The Steel Centurions series offers a testament to notable accomplishments of prior generations and celebrates the durability and strength of steel by showcasing bridges more than 100 years old that are still in service today.

NEW YORK'S FAMOUS suspension bridge over the East River linking Manhattan with Brooklyn—the Brooklyn Bridge—was a mammoth civil engineering project for the late 1800s. Its two massive granite piers, standing 276.5 ft above mean high water, were designed to provide clearance below its suspended deck for the masts of sailing ships. The piers towered over the existing skylines on either side of the river and extended down 44 and 76 ft below the water on the Brooklyn and Manhattan sides. The main span reaches 1,595.5 ft across the river and the bridge's total length, including approaches is more than 6,000 ft.

A contemporary with the steel-arch Eads Bridge over the Mississippi at St. Louis, the Brooklyn Bridge was the world's first major steel suspension bridge: the main cables, the suspenders, and the truss deck were all steel. The four 15.75-in.-diameter main cables, 3,578.5 ft in length, run from the anchorages on either side, over saddles on the pier tops, and swoop in a catenary to the level of the deck below. The deck is an 85-ft wide stiff steel truss suspended from the four cables by vertical and diagonal steel wire ropes.

A Roebling Bridge

The designer, John Augustus Roebling, was a German immigrant who, with his brother, came to America in the early 1830s. They founded a farming settlement called Saxonburg in Western Pennsylvania. Having been trained as an engineer in Berlin, Roebling soon grew impatient with farming. He returned to engineering with a series of jobs that included surveying rail lines and improving canals. At the time, canal boats were loaded onto railcars and pulled up and over mountains using long, expensive hemp ropes. Roebling started producing wire ropes for this purpose on his Saxonburg farm. He also designed several

The Brooklyn Bridge, which today carries an estimated 145,000 vehicles per day, was built at a time when the tallest building in New York was only 5 ft taller than the bridge's 276.5-ft towers.

The 85-ft-wide main deck of the Brooklyn Bridge had a pair of rail tracks for passenger trains down the center flanked by lanes for coaches and a pedestrian promenade. Pedestrians paid a 1 cent toll on opening day and 3 cents thereafter. The vehicle toll was 5 cents. By 1884, a year after the bridge opened, 37,000 people a day were using the Brooklyn Bridge to cross the East River.

suspension bridges and aqueducts using wire rope. In the late 1840s he moved his successful bridge construction and iron wire rope business to Trenton, N.J.

By the time Roebling designed the Brooklyn Bridge in 1867, he was a highly respected engineer and prosperous businessman. His plans called for suspension cables made from steel, which he considered "...the metal of the future." City and federal approval of the bridge design took two years until June of 1869. Later that month, while on a ferry pier sighting a position for the bridge, Roebling's toes were caught and crushed between pier piles and beams by an incoming boat as it bumped against the dock. Directing his own medical treatment after amputation of his toes, he died 24 days later of a tetanus infection and seizures.

Roebling's son, Washington, took over as chief engineer when construction began in early 1870. He had assisted his father on other suspension projects, and was familiar with European experiences with caissons, which would be needed to complete the piers. He served as chief engineer for the next 13 years, taking the bridge to completion. During much of that time he was suffering from a severe physical disability resulting from his supervisory work inside the pneumatic caissons. Little was understood at the time about caisson disease or "the bends."

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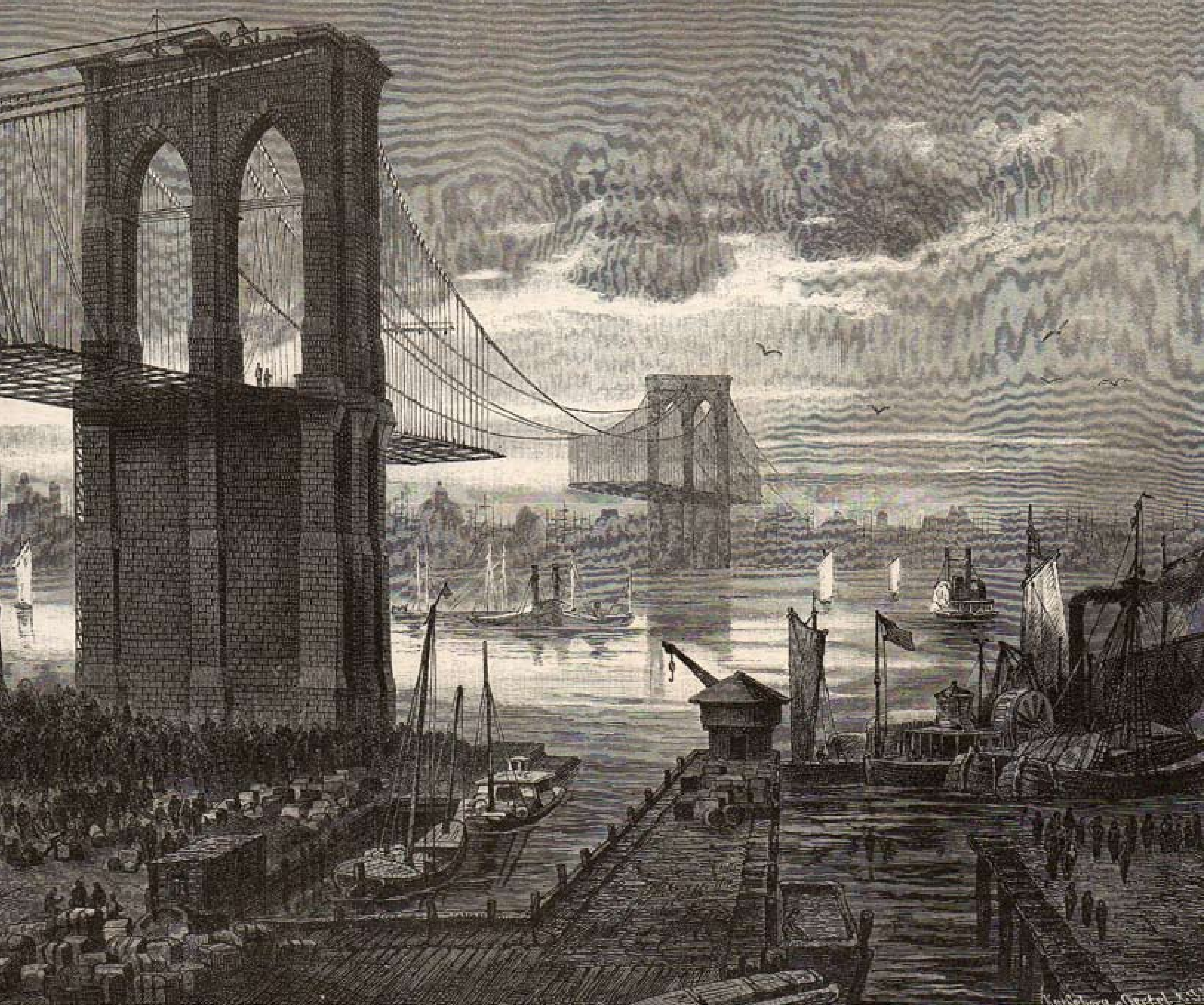

▲ This 1881 drawing shows how, with the main suspension cables in place, crews worked from both sides of the river to advance the deck over the water. As steel cross beams were added, planks were placed for the workers to stand on.

Building the Piers

Completion of the bridge piers took three years. Work began on the Brooklyn side pier where the caisson sank slowly toward bedrock because workers often had to cut or blast through huge boulders. Conditions were miserable and turnover was high. The final depth was about 45 ft and the maximum air pressure reached 21 psig. Only a few workers suffered leg paralysis.

Work on the Manhattan side pier began in September of 1871. This caisson met mostly sand, which could be sent up through a pipe propelled by the air pressure. The caisson sank relatively quickly but went to greater depths. At about 75 ft the required air pressure neared 35 psig. Three workers died from caisson disease shortly after leaving the air locks. Roebling, himself a victim of the disease, stopped the work before completely reaching bedrock. Helped greatly by his wife, Emily, he continued working as chief engineer, but was rarely on site.

Main Cable Preparations

By mid-1876 the towers were up, and it was time to add the four main steel cables. To begin, a boat towed a single wire across the river from Brooklyn. Crews hoisted the wire over the two towers, then used it to pull a heavier ¾-in. steel working rope over the piers between the two anchorages. The process was repeated to create a second working rope. Crews spliced the two working ropes together to form a continuous loop or "traveler." The first traveler served to haul steel rope across to create a second traveler. The length of one traveler loop was 6,800 ft or more than a mile.

The steel ropes for the two traveler loops stood about 27 ft apart at locations that approximated the position of the four main bridge cables. Their initial function was to haul more wire ropes to build a temporary footbridge and a series of platforms across the river for work crews. Later the travelers began their main function: to carry the steel wires for the main cables from anchorage to anchorage, two at a time. Because each main cable consisted of 5,434 parallel steel wires arranged in 19 strands, the travelers cycled back and forth many times to create a main cable. As one side of a traveler returned to Brooklyn, the other would be carrying a pair of wires to Manhattan.

Wire Fraud

The elder Roebling's specification for the main cable wire called for No. 8 Birmingham gauge galvanized steel wire (0.165 in. diameter) that could withstand 3,400 lb of tension before breaking. The wire had to lie straight when uncoiled from a reel. The project would need 6.8 million lb of the steel wire. Several firms in the U.S. and Europe, including the Roebling factory in Trenton, bid on the wire contract and submitted samples for testing. Some controversy developed over the quality of the newer, less expensive Bessemer steel versus the more traditional crucible steel. The contract went to J. Lloyd Haigh of South Brooklyn, N.Y., that submitted crucible steel.

Later, Washington Roebling discovered that the Haigh firm was sometimes delivering rejected wire rather than the good wire passed by inspectors. A good percentage of the steel wire deliveries were made by the Bessemer process as well. To compensate for the rejected steel wire already in the cables, Roebling required 150 more good steel wires per cable than originally planned. Additionally, the elder Roebling had calculated a safety factor of six for the main cables. His son figured the safety factor may have been reduced, but was far more than sufficient. Lastly, he learned that the original sample of wire submitted by Haigh was made by another firm.

Stringing the Steel Wire

As chief engineer, Roebling struggled in supervising the building of the superstructure because caisson disease had reduced him to an invalid. He and his wife, Emily, supervised the project with a telescope from their residence in a nearby building. With help from her husband, Emily Roebling learned math and engineering and served as a communication liaison with the engineers on site.

Work started on placing the main cable wires between the two anchorages in February 1877. Crews on the anchorages and platforms positioned or "regulated" the wires as they were hauled over by the travelers, lashing 286 wires into strands. One strand was at the center, surrounded by six strands, and surrounded again by 12 strands. The crews built the cables from the bottom up to form this arrangement. Sixteen machines wrapped the finished cables with iron wire to finish the job. Clamps moved ahead of the machines to bind the wires tightly to form a cylinder. Lastly the wires were oiled and painted. Crews completed the work on the main cables by October 1878.

Constructing the Deck

The deck consists of a steel truss suspended from the four main cables by 1,520 galvanized steel wire ropes and 400 diagonal stays. In designing the bridge, the elder Roebling believed that a heavy, stiff deck was the key to stabilizing suspension bridges under conditions of high winds. The Brooklyn Bridge deck arches slightly upward, enhancing its aesthetic qualities. Once the suspending cables were in place, crews added steel cross beams, working out from the anchorages. They stood on planks placed over the beams as the deck advanced over the water. After the suspending ropes and deck beams were in place, crews installed the diagonal stays.

Delays in steel deliveries plagued work on the deck and approaches and almost caused the removal of Roebling as chief engineer. Finishing touches included terminal buildings at each end and electric arc lamps along its length. The 85-ft wide deck accommodated a pair of rail tracks for passenger trains down the center flanked by lanes for coaches and a pedestrian promenade.

Opening ceremonies for the bridge finally took place on May 24, 1883, with president Chester Arthur and Governor Grover Cleveland attending. Washington Roebling was unable to attend the ceremonies, but his wife Emily held a reception at

Poised for Innovative Rehabilitation

A structure as prestigious as the Brooklyn Bridge would not measure up to the public's expectations without its approach spans which, like the bridge itself, also require maintenance and repairs. One of these, the Franklin Square Bridge, is scheduled for rehabilitation in the near future. This medium-span structure forms part of the Manhattan approach to the Brooklyn Bridge at Pearl Street. The rehabilitation includes the replacement of the current bridge deck with an orthotropic steel deck, an innovative solution that reduces both overall weight as well as installation time.

The replacement of the bridge deck is a crucial element during rehabilitation activities, as it has a direct impact on road users on a daily basis. It is therefore essential to minimize this impact by selecting a rapid replacement solution. Orthotropic steel deck, which consists of long, shop-fabricated modular deck panels, fast-tracks the installation process by reducing field assembly time. The possibility of a shop-applied wearing surface has been analyzed and could minimize field work, thereby limiting traffic disruptions.

Increased traffic on the Brooklyn Bridge, which now handles 145,000 vehicles daily, has forced engineers to rethink the way certain operations are conducted and to propose solutions that will minimize the repercussions on traffic. At the same time, they must also consider costs, including the social costs of undertaking major road repairs in an urban setting. New York City-based Weidlinger Associates, Inc., designed the 12,000 sq. ft of orthotropic deck needed for the north and south Manhattan approaches with these considerations in mind. The firm's expertise pointed to the use of orthotropic deck, an ultralight concept that offers the distinct advantage of reducing the loads exerted on the structural elements of the existing bridge as well as the benefit of accelerated bridge construction. Structal-Bridges, a member of both AISC and NSBA, will fabricate a total of 24 orthotropic deck panels weighing some 450 tons for the project at its Claremont, N.H., plant.

The use of orthotropic deck on the Brooklyn Bridge, which will undoubtedly satisfy as well as greatly appease its users, marks a coming together of history and innovation. The rehabilitation also includes the modernization of drainage systems, deck joints and guardrails and will continue through 2012.

Information provided by Structal-Bridges.

their nearby residence. Previously she had the honor of taking the first ride across the bridge. The trains started running in September, moved by an endless cable. A year after the bridge opened, 37,000 people a day were using it to cross the East River.

Washington Roebling, while partially crippled and hurting, lived on until 1926, dying at the age of 89. He actually ran his father's company, John A. Roebling's Sons, during his last years after the death of his son Karl. During that time he changed the mills over from steam to electric power, set up a department for electrolytic galvanizing of wire, and oversaw the cables for New York's Bear Mountain Bridge over the Hudson River. Himself a key part of the Roebling family legacy, he sometimes complained of being confused with his father. "Many people think I died in 1869."

During the years from 1944 to 1954, the trolley and elevated train tracks were removed and roadways were widened to three lanes in each direction. Work crews also strengthened the trusses and installed new horizontal stays between the four main cables. In 1964 the bridge became a National Historic landmark. In 1999 it received new decking to replace crumbling concrete. Currently the Brooklyn Bridge carries an estimated 145,000 vehicles a day, but is off limits to commercial traffic. Pedestrians and cyclists continue to share the raised promenade down the center of this celebrated, iconic American bridge. **MSC**

Much of the information for this article is from The Great Bridge, *by David G. McCullough, Simon & Schuster, New York, 1972.*