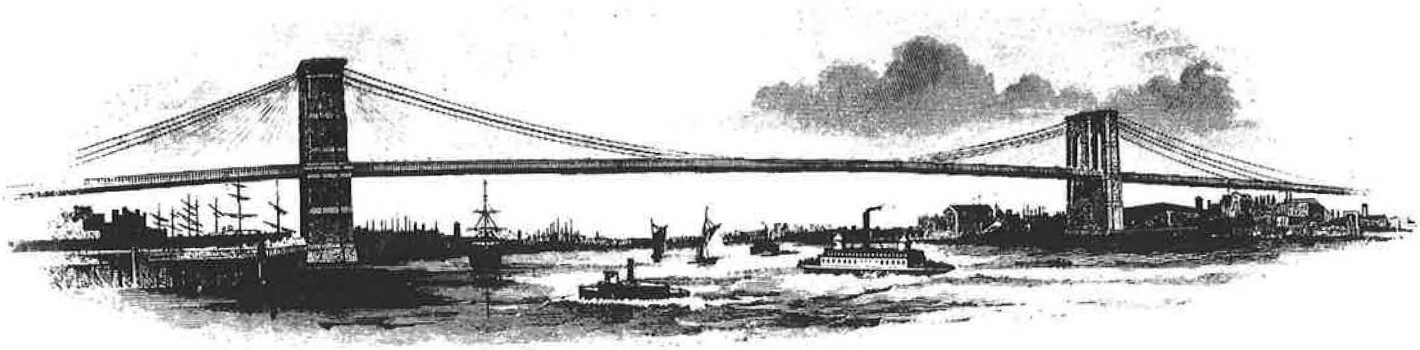

The Brooklyn Bridge– A Monument to an Age of Challenge and Creativity

BRENDA J. VUMBACO

In the last several months, local, national, and international newspapers, magazines, journals, and other media have been punctuated with stories about a very special bridge. The Brooklyn Bridge celebrated its 100th birthday on May 24, 1983, and an international community paid it homage. Why?

The most obvious answer rests in the fact that the Bridge is indeed witness to the engineering genius and skills of John A. Roebling, its designer; to the dedication and creativity of Washington Augustus Roebling, his son and the overseer of the Bridge's construction; to the loyalty and sacrifice of Emily Roebling, Washington's wife, who became a vital link between her invalid husband and the Bridge's workers during construction operations; and to the courage of thousands of laborers who transformed the dream of the Bridge into a reality.

The not so obvious answer can be found in some of the most unlikely places—among them the poetry of Walt Whitman, the canvases of Joseph Stella, the photography of Erich Hartmann, and the unbridled striving of man's imagination and creativity to subdue the forces of nature.

The Brooklyn Bridge, which began to take shape in John Roebling's mind and on his drawing board in the 1850s, owes its existence in part to the fact that Roebling once got ice-bound on a ferry headed across the East River to Brooklyn. This incident helped to reinforce his determination to find another way to make the journey across the river. Since then, the Brooklyn Bridge has done more than span a river and connect the two Boroughs of Manhattan and Brooklyn; it has spanned time.

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EAST-WEST LINK

There are longer bridges today and even longer ones planned for the future. There are other sleeker, feathery, threadlike suspensions, but none is as much a monument to time and place as the Brooklyn Bridge. Its construction was a 19th-century marvel. It was likened in significance to the Eiffel Tower in Paris. Its revolutionary and daring physical design, and even the defiance that helped to produce it in the face of a city government that had a Boss Tweed at its center, were viewed as symbolic of man's pioneering spirit, brashness, audaciousness, and will to win in the face of great odds.

Since the start of preliminary construction activities in July 1867 with trial borings at the tower and anchorage sites,

Milestones in Construction of Brooklyn Bridge

16 April 1867	New York legislature authorized the New York Bridge Co., with a capital stock of $5,000,000, to build and operate a bridge over the East River.
23 May 1867	John A. Roebling appointed the chief engineer of the East River Bridge.
July-August 1867	Trial borings made at the tower and anchorage sites—first actual work on the bridge.
July 1869	Center-line surveys begun.
3 January 1870	Clearing and dredging of Brooklyn caisson site begun.
19 March 1870	Brooklyn caisson launched.
3-4 May 1870	Brooklyn caisson towed to site and placed in position.
15 June 1870	First block of stone placed on Brooklyn caisson
22 Dec. 1870	Brooklyn caisson descent stopped, at 44.5 feet below mean high water.
April 1871	Dredging and preparing of New York caisson site begun.
11 Sept. 1871	New York caisson towed to site and positioned.
31 October 1871	Last timber course placed in roof of New York caisson and first stone course started.
18 May 1872	Washington Roebling stopped descent of New York caisson, on hardpan rather than bedrock, at 78.5 feet below m.h.w.
July 1872	New York caisson completed (filled in with concrete), after 221 days of work.
15 February 1873	Excavation at Brooklyn anchorage begun.
26 June 1873	First stone laid in Brooklyn anchorage.
Early spring 1875	Brooklyn tower saddles hoisted into position.
Early May 1875	New York anchorage begun.
June 1875	Brooklyn tower completed.
5 August 1875	First stone laid in New York anchorage.
1 October 1875	Brooklyn anchorage completed, ready for cable making.
July 1876	New York tower completed.
July 1876	Saddles mounted in New York tower.
July 1876	New York anchorage completed. Anchorage chains of both anchorages ready to receive cables.
14 August 1876	First wire rope raised to position over towers, anchorage-to-anchorage. First physical connection between the two cities.
1877-1882	Approaches built.
9 February 1877	Temporary footbridge completed and first crossed; first pedestrian passage between the cities.
11 June 1877	Cable making begun.
5 October 1878	Last cable wire laid up; cable making completed except for wrapping. (Greatest length of wire run out in one day: 88 miles).
25 October 1878	Cable wrapping begun.
17 February 1879	Cable wrapping completed.
January 1881	Placement of steel floorbeams begun.
10 Dec. 1881	Last floorbeam placed.
Spring 1883	Diagonal stays installed.
Spring 1883	Electric arc lights installed—first electrically illuminated bridge.
24 MAY 1883	BROOKLYN BRIDGE OFFICIALLY OPENED
18 August 1883	First trial crossing of passenger car over cable railway.
24 Sept. 1883	Bridge cable railway opened for service.
1 January 1898	Brooklyn became a borough of New York City; bridge placed under jurisdiction of NYC Department of Bridges.
26 January 1915	Bridge name officially changed from NEW YORK & BROOKLYN BRIDGE to BROOKLYN BRIDGE, by ordinance of the Board of Aldermen.

Source: Robert M. Vogel. *Building Brooklyn Bridge.* © Smithsonian Institution, Washington, D.C., 1983.

the Bridge has remained a part of the consciousness of America. The Bridge became what John Roebling himself had predicted—a national treasure and an inspiration to Americans and others around the world.

The Bridge reflects a time in the development of America and in the history of technology that was marked by an almost spiritual desire to conquer the forces of nature. Nineteenth-century advances in industrialization and technology became suggestive of a sense of historical mission that was personified in the doctrine of Manifest Destiny. The union of a continent was alluded to by Walt Whitman in 1871. His "Passage to India" sang the praises of civilization's movement to the Pacific coast and beyond: "Nature and Man shall be disjoin'd and diffused no more." The East and West coasts of the United States (as in many other countries) were united by bridge, canal, and railroad. This union was more than just a metaphor; it became a principle—and one in which John Roebling strongly believed.

The Bridge was viewed as an essential part of a continuous highway from East to West, and surveying for the Bridge was begun in 1869—the same year that the transcontinental railroad was completed. Deborah Nevins wrote that "Roebling's sense of mission led him to view the forms of suspension-bridge design and the goals of engineering in metaphysical terms: the curve of a bridge's cables was based on an elemental curve of nature, the catenary, and in the combination of tension and compression in his bridges Roebling saw the forces of nature in a state of idealized harmony." (From the Brooklyn Museum's ***The Great East River Bridge,*** 1883-1983).

Roebling's Bridge symbolized the critical role of transportation and communication in the westward movement of civilization. It was also to become, in the words of President Chester A. Arthur, who presided at its opening on May 24, 1883, "a monument to democracy itself".

> **"It is in large spans, where the principle of suspension asserts its full claims, and where it will forever stand without a rival, no matter what novelties may turn up in the future. Within the whole range of engineering, no system of construction presents such favorable conditions as is offered by the suspension system. Fully aware that opposite opinions are taught in textbooks on engineering, I know that I am exposing myself to criticism, but I also know that the future history of engineering will do me full justice."**
>
> **— John A. Roebling**

BUILDING THE BRIDGE

John Roebling, the engineer and designer of the then East

River Bridge, first proposed its construction in 1857. New York and Brooklyn were at that time independent cities, and both maintained that such a feat was impossible and "downright crazy". However, Roebling persisted. And, in the years following the Civil War, he was able to obtain sufficient financial backing from a group of Brooklyn businessmen. Roebling was named chief engineer of the project on May 23, 1867. Construction began in January 1870 with the clearing and dredging of the site for the Brooklyn caisson.

However, tragedy soon struck. Roebling's foot was crushed by a ferryboat as he stood at the edge of a Brooklyn wharf. He died shortly after the start of bridge construction of lockjaw.

His son, Washington Roebling, took over. But tragedy struck again. In 1872, he was taken from an underground caisson suffering from paralysis because of the intense below water pressure (a form of the "bends"). For the next 11 years, the younger Roebling sat in a Brooklyn waterfront house, barely able to move but watching through a telescope as his beloved bridge went up, stone by stone, rivet by rivet, wire by wire. Roebling's communications link to his workers was his wife Emily.

At the heart of the Bridge's design were the caissons, and Washington Roebling was the authority on this subject. A caisson is a wooden box filled with compressed air, and the largest one for the Brooklyn Bridge was almost 0.5 acre in size. The theory behind the caisson was simple, but apply-

"Iron and steel are the materials which pre-eminently stand foremost as elements of civilization. That nation which attains to the highest perfection in its skillful production and application to the various arts of life, will rank also highest in the scale of social advancement and political power. This proposition wants to be more fully comprehended in our country. If the government of a nation refuses to protect these branches of industry, which more than any others are calculated to give it power and wealth, and to make it independent, such nation will find itself rapidly outstripped by other people who have better comprehended this fact. The material forms the basis of the mental and the spiritual; without it the mind may conceive, but cannot execute."

— John A. Roebling

South Street seaport and view of lower Manhattan taken from Brooklyn Bridge while under construction in 1876.

Bridge Facts and Figures

General	
Length of main span	1595.5 ft
Length of each side span	930.0 ft
Length of bridge proper	3455.5 ft
Total length, including approaches	5989.0 ft
Clear height at mid-span, above high water (at 90°F)	135.0 ft
Clear width of bridge	85.0 ft
Grade of roadway	3.25%
Caissons	
Size at base	
Brooklyn	168 x 102 ft
New York	172 x 102 ft
Depth of base below high water	
Brooklyn	44.5 ft
New York	78.5 ft
Volume of timber	
Brooklyn	111,000 ft^3
New York	118,000 ft^3
Towers	
Height above high water	276.6 ft
Height of roadway above h.w. at towers	119.0 ft
Height of arches above roadway	117.0 ft
Width of arch openings	33.8 ft
Weight of masonry	
Brooklyn	79,000 tons
New York	97,000 tons
Anchorages	
Size at base	129 x 119 ft
Size at top	117 x 104 ft
Height at front (river face)	89.0 ft
Weight--total of both	115,000 tons
Number of anchorage-chain eyebars	1,520
Average size of eyebars	12 ft x 3 in x 8 in

Cables	
Number	
Diameter over wrapping	15.75 in
Length of each cable	3578.5 ft
Number of wires in each cable	5434
Total length of wire in each cable	3515 miles
Ultimate strength of each cable	12,314 tons
Weight of each cable	870 tons
Length of wrapping wire in each cable	243 miles
Suspenders and diagonal stays	
Total number of vertical suspenders	1520
Ultimate strength of each	70 tons
Total number of diagonal stays	400
Trusses and floorbeams	
Number of longitudinal stiffening trusses	6
Height of inner and intermediate trusses[a]	17.0 ft
Height of outer trusses[a]	8.7 ft
Length of floorbeams	86.0 ft
Depth of floorbeams	32 in
Costs	
Purchase of land	$3,800,000
Construction	$11,700,000
Total cost of bridge	$15,500,000

[a] In the 1953 reconstruction of the suspended superstructure, the intermediate trusses were removed and the outer trusses raised to the height of the inner trusses.

Source: Robert M. Vogel. *Building Brooklyn Bridge.* ©Smithsonian Institution, Washington, D.C., 1983.

Plan of the Brooklyn caisson (courtesy of the Municipal Archives of the City of New York).

ing it was another matter. As construction workers dug deeper and deeper, the wooden box sank under the weight of the limestone and granite tower erected directly on the caisson. All this rested on the caisson roof made of yellow pine. The roof of the caisson on the New York bank was made of 22 ft of solid timber logs, and it supported 28,000 tons of stone. No one before had attempted to build caissons of such magnitude.

In the 1870s very little was known, though, about the effects of air pressure on those working in compressed-air chambers. Workers, including Roebling, began getting the bends—marked by the presence of nitrogen bubbles in the booodstream. In 1872, Roebling was faced with a difficult choice. If the New York foundation was pressed downward to bedrock, maybe 100 or more men would die. If work were stopped, the foundation would then be resting on compacted soil. He gambled by halting the excavation more than 30 feet above bed rock and, 100 years later, the caissons under the enormous weight of the granite towers and their cables are holding firm and strong.

BRIDGE FEATURES

The Roeblings had made significant advances in the production of wire cables. John Roebling recognized that wire cable was far superior to hemp. Washington Roebling also held this view, and his determination to follow through on this theory resulted in some of the finest cable work and configurations known to engineering.

Almost invariably, suspension bridge towers are built of iron or steel, but the Brooklyn Bridge is granite. Its four Gothic, windowed arches are the sentinels of the roadways that pass through them. And the cables, developed by

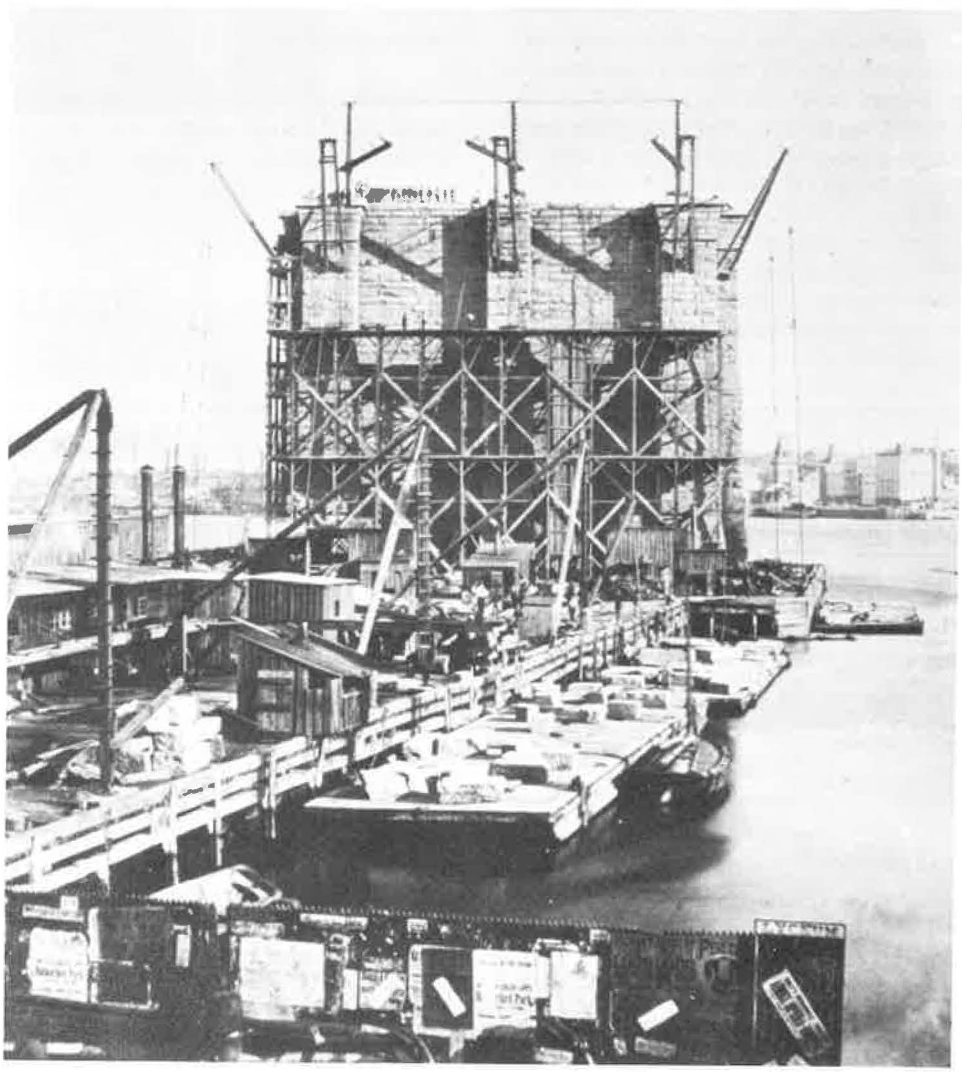
Roebling, mark the first major use of steel wire in America in such a large structure.

The Brooklyn Museum's history of the Bridge noted that the work on the Bridge was planned so that the anchorage structures and the towers would be completed at once. The anchorage system that John Roebling devised in his earlier bridges was used but on a much larger scale. Four 23-ton iron anchor plates, one for each of the four cables, were positioned at the bottom of each anchorage. Eighteen 12-ft-long eyebars radiated from the center of each plate, forming the first link in a double-tiered eyebar chain extending to the top of the anchorage. As successive links of the chain were attached to each other, they were encased in masonry. At the top, the number of eyebars in the link of the chain was increased to 38. Each of the 19 strands of wire that made up each cable was pinned between a pair of eyebars. After the 19 strands of a cable had been lashed together, the cable was wrapped with soft wire and coated with white lead—a technique also developed by John Roebling.

Composed entirely of steel, the bridge floor is itself an industrial and technological achievement of great magnitude. No such structure had been built up to that time, and the contractor had to design new machinery in order to manufacture the girders.

The floor system was formed from open-work girders and trusses, which are lighter than solid beams. The principal trusses were hung from the suspender cable, parallel to the towers (7 ft 6 in apart), with smaller trusses suspended half way between. Bolted to these trusses at right angles were six rows of other trusses that ran the length of the Bridge. The floor was constructed from the towers and the anchorages outward. As each girder was secured to the suspenders, planks were laid on top. This method created a working platform for the suspension of the next section of floor.

As stated earlier in this article, John Roebling, like the artists and poets who followed him, saw a metaphysical connection in almost every part of the Bridge. The diagonal stays, which cross the vertical suspenders to create a web of



View of the New York tower in September 1873 (courtesy of the Museum of the City of New York).

wire have, like the towers of the Bridge, symbolized a harmony with nature as did the catenary curve of the main cables. At the same time the stays were essential to the Bridge's overall strength and stability.

Hundreds of stays span out from each tower to relieve the suspenders of some of the load. They are secured 15 ft apart to the Bridge floor and are clamped to the suspenders to further stiffen the structure. It has been calculated that the diagonal stays alone could support the roadway.

A unique feature of the Bridge is its pedestrian walkway. John Roebling states in his original plan "that in a crowded commercial city, such a promenade will be of incalcuable value." The walkway, built 18 ft above the roadway, has since been used as a place to exercise, socialize, relax on a bench, and enjoy the view of the city and the river.

"The rich gifts of nature must first be rendered subservient to man before he can hope to comprehend her true spirit. In this sense the advancement of the sciences and various arts of life may well be hailed as the harbingers of good; its laborers are our friends, not our enemies. The works of industry will be sown broadcast over the surface of the earth, and want will disappear.

Among the various branches of modern industry, perhaps none has produced riper and better fruits than the art of making and improving iron and steel. By the agency of steam, through the instrumentality of iron and steel, the physical powers of man have already been multiplied. And yet the great field has only been commenced to be broken; vast tracts remain yet untouched."

— John A. Roebling

BRIDGE AS MONUMENT AND MAGIC

This article was not intended, as the reader may have already guessed, to be a treatise on the engineering and construction detail of the Brooklyn Bridge. Rather its purpose was to touch upon, however briefly, the sensitivity, the appreciation for beauty, and the love of challenge inherent in the Roebling vision of a bridge that became a monument to an industrial and technological age. You can walk across the Brooklyn Bridge and finger its cables. You can touch the granite that came from Maine, and you can savor the great East River. And you can begin to understand why the world joined to celebrate the birthday of this Bridge. John Roebling's vision and Washington Roebling's engineering and construction skills made the Brooklyn Bridge, but the Brooklyn Bridge made the past tangible. Therein lay its magic and its majesty.

Acknowledgment

Information for this article was provided by the Brooklyn Museum, the Smithsonian Institution, and the New York Historical Society.

Eldon J. Yoder Dies; Active in TRB Programs and Committees Since 1948

Eldon J. Yoder, Purdue University professor and longtime TRB supporter, died on June 1, 1983. Yoder was head of the Soils and Pavement Design Laboratory for the Joint Highway Research Project, Purdue University, a major research facility for the Indiana Department of Highways.

During the TRB Annual Meeting last January, Yoder was presented with the Board's Roy W. Crum Distinguished Service Award. Yoder's citation called attention to his many accomplishments.

> "A native of Indiana, Yoder received his B.S. degree in 1945 and his M.S.C.E. in 1946 from Purdue University. He was awarded a Fulbright Fellowship on Pavement Design (1967-1968) at the University of Western Australia. Yoder has provided consulting assistance to governments in the United States, Central America, South America, Australia, Asia, Africa, and Europe. He taught for a short period at Ohio State University and worked for the Ohio Department of Highways before returning to Purdue University in 1949 to head the Soils Laboratory. In addition to his present position, Yoder is also in charge of Purdue University graduate and undergraduate courses on pavement, highway, and airport design.
>
> A member of several honor societies and professional societies, Yoder has published more than 100 technical papers and is the author or co-author of several definitive handbooks on pavement design—an area that is receiving increased attention because of its relationship to reducing the cost of maintaining the highway infrastructure."

Yoder's first affiliation with TRB came in 1948. In the years since, he served on 29 committees, task forces, councils, and NCHRP panels. He chaired 7 of these, including the Group 2 Council, and at the time of his death was leading the Planning Committee for TRB's Third International Conference on Low-Volume Roads.