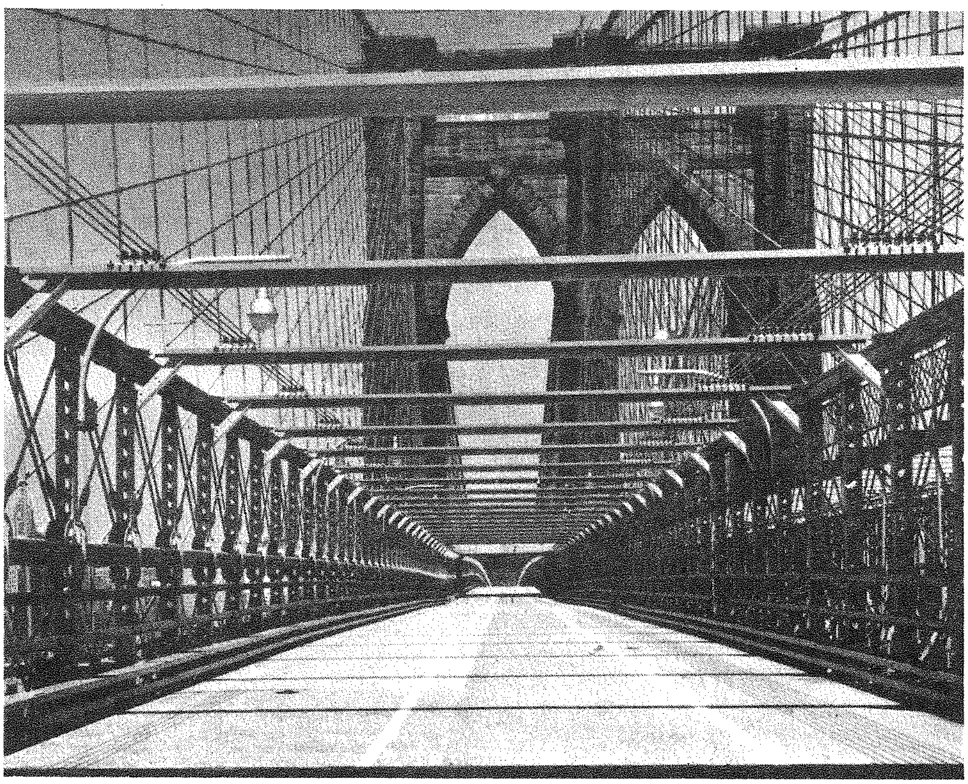
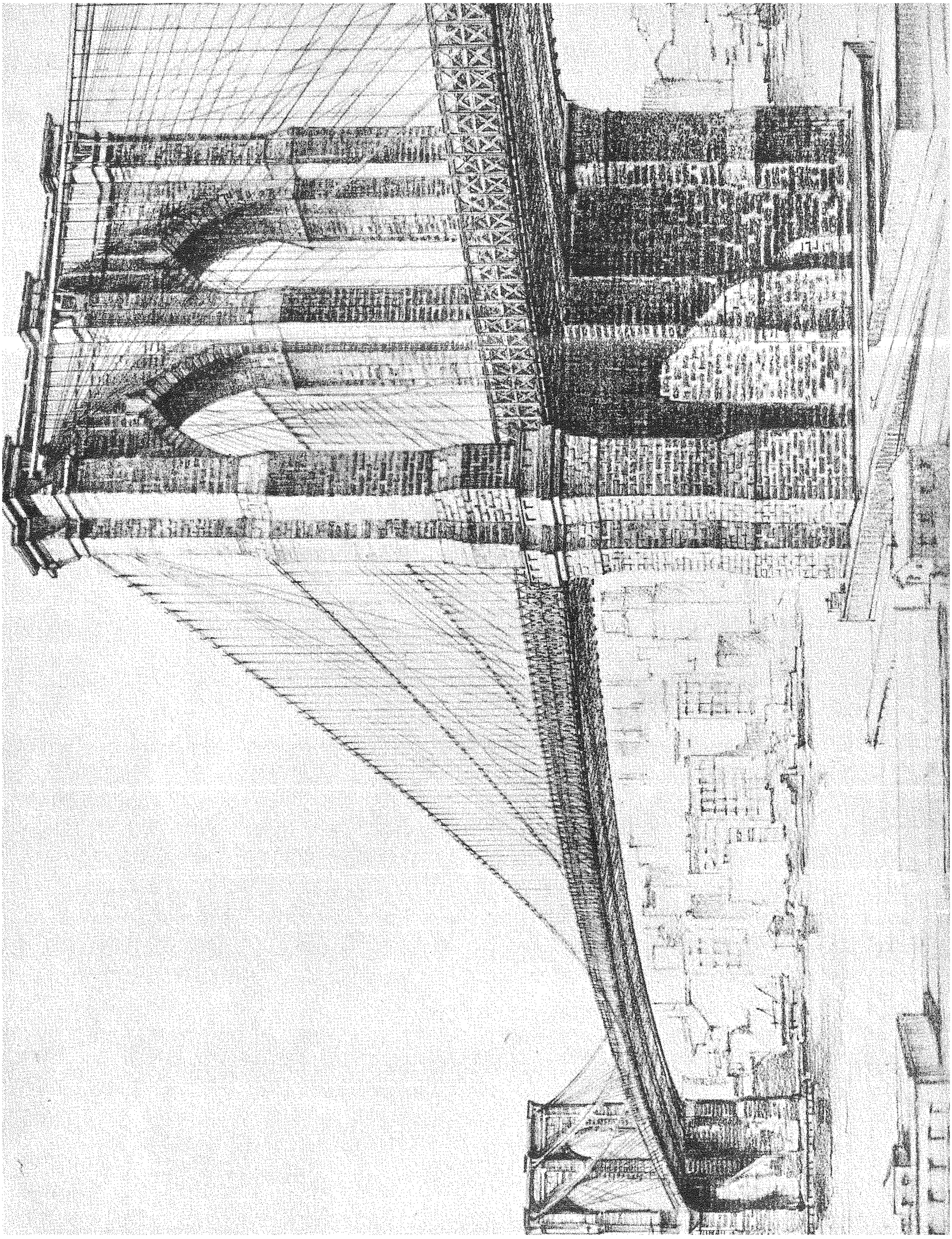
THE RECONSTRUCTION OF THE



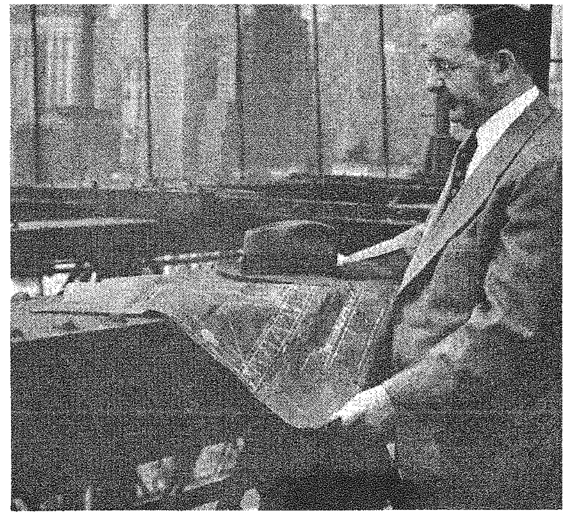
BROOKLYN BRIDGE

D. B. STEINMAN, B.S., A.M., C.E., Ph.D., Sc.D.

Reprinted for the
SOCIETY FOR INDUSTRIAL ARCHEOLOGY
Through the kindness of Mrs. D. B. Steinman
April 1972



The Reconstruction of the Brooklyn Bridge



D. B. Steinman, B.S., A.M., C.E., PhD., Sc.D.

Reprinted from the Columbia Engineering Quartely, *November 1952*

Introduction

It is no accident that the grand, old Brooklyn Bridge remains the most satisfying esthetically of all great bridges—because its two builders, father and son, were artists at heart. In 1883, after thirteen years of heart-breaking toil, the great work was finished. The two master-builders had paid their price—one with his life, the other with a crippled body. The father had dreamed the Bridge. The son, with gallant fighting spirit, had carried that dream to fulfillment. No inspired builder of a medieval cathedral brought to his work a greater singleness of purpose, a more selfless devotion, than the two Roeblings lavished on their crowning work. The best in their characters went into its building. Of granite and steel and dreams, the Bridge was built.

When the colossal structure was completed, it was the engineering achievement of the century—the longest single span ever built, the tallest and strongest, the first to use steel cables. Today there are bigger bridges—but they never could have been built had not Brooklyn Bridge shown the way. And its story is still the greatest bridgebuilding story of all.

In recent years, the Brooklyn Bridge structure had been little more than a majestic monument—not because of any inadequacy of strength but for the simple reason that the traffic needs of the Automobile Age, with more than 50,000,000 motor vehicles on our highways, could not possibly have been foreseen in 1869 when the bridge roadways were planned.

The need for reconstructing the Brooklyn Bridge has long been recognized. As far back as 1903, Gustav Lindenthal, then commissioner of bridges of New York City, presented a plan saying, "The present structure was never intended and dimensioned for the traffic it has to bear now. The suspended structure, from anchorage to anchorage about 3600 feet long, is in a worn-out and weakened condition, requiring constant and expensive repairs to keep it safe. The rebuilding of the bridge has become imperative." Since then four more bridges (Williamsburg, Manhattan, Queensboro, and Triborough) have been added over the East River to carry the constantly increasing highway and rapid transit traffic, and the adjacent bridges have been carrying much of the traffic that should and would logically use the Brooklyn Bridge if its capacity permitted. In spite of high maintenance costs and the recognized need for major reconstruction, money was never available, and the Brooklyn Bridge remained in service, without substantial improvement, since 1883. It has been carrying as much as three times the load for which it was originally designed. Its builders knew it would.

In 1934 I prepared and submitted a comprehensive and detailed plan for the major reconstruction of the Brooklyn Bridge and its approaches. It represented a radical innovation, but boldness in making use of new possibilities has ever characterized major bridge achievement. Under the 1934 plan, the imposing towers that give the bridge its distinctive character would be retained, as well as the cables and the anchorages, but the entire suspended structure, including the stiffening trusses, floor system and roadway, would be replaced by a completely new structure built wholly of structural aluminum alloy to modern type and of large traffic capacity. The new design, using a double deck, would have increased the traffic capacity from two vehicular lanes to *twelve*. By using aluminum, the total dead load on the bridge would not be increased, despite the six-fold increase in highway capacity. The estimated cost of the complete modernization was $6,250,000, with $2,000,000 additional for the approaches. At the time, this plan seemed too ambitious and was laid aside. At present prices, the cost would be much more than twice as great.

In 1948, the municipal authorities finally decided to have the bridge reconstructed to meet modern traffic needs, and the engineering of this task was entrusted to me. I was engaged to make the engineering studies and to draw the plans for rebuilding the structure—the suspended roadways, the stiffening trusses, and the approaches—so as to increase the capacity of the bridge from two lanes to six lanes of modern highway traffic.

When people expressed concern about the proposed reconstruction and modernization of the beautiful old span, I was glad to reassure them that the appearance of the bridge would not be changed.

Preservation of the Beauty of the Bridge

In the reconstruction of the Brooklyn Bridge, great pains have been taken to preserve all of the features that have given the bridge its distinctive character—its monumental beauty, its noble quality, and its enduring simplicity, grace, and charm.

The Brooklyn Bridge was conceived, planned and designed as his crowning lifework by the pioneer master-builder, John A. Roebling, who suffered the tragedy of dying from an accident on the final surveys in 1869, before the first stone was laid. The great work was nobly completed by his son, Col. Washington A. Roebling. Later generations clearly see what the Roeblings wrought. In an age of superficial embellishment and pretentious atrocities the two bridgebuilders gave no thought to the prevailing fashion in design. They were not architects, but workmen seeking to do an honest and sturdy job. How the thing was going to work and how to make it last were their chief concern. So they built honestly and soundly. And sound building is beautiful building.

Except for those little devices by which a good builder strengthens the main lines and hides the rough spots, they seem to have given no conscious thought to looks. There must be approaches to lift the span up in the air to clear the masts on the river below. The Roeblings lifted them, therefore, over a series of arches whose joints they finished off with cushions of smooth stone. At the point where the span rises and flies across the river, there must be towers with double arches to let the traffic through. Simply because Gothic arches suited their engineering plan, the Roeblings built Gothic arches. The tops of the towers they finished naturally and simply in plain heavy stone. That is all—not an inch of carving, not a single concession to ornamentation. No conscious art; merely the honest work of master craftsmen. But in this fine and sincere workmanship the builders, father and son, recaptured the simple and natural beauty that endures. The Brooklyn Bridge remains the finest monument of their age.

Centuries hence men will still marvel at the gigantic towers—more wonderful than the pyramids—standing like sentinels above the busy waterway, with the everlasting sea beating against their mighty bases, and with their granite masonry rooted deep below the rushing tides.

There is timeless strength in those towers, and poetry in the cable-borne span. The two are harmoniously joined. Between the two pierced granite towers the arching roadway slowly sweeps upward to meet the swift downward sweep of the cables.

In these curves and proportions, in the composition of the ensemble, we behold the spirit and the character of the builders—an aspiration visible, a conception of enduring beauty.

All of the dominant features of the composition, the massive anchorages, the monumental towers, the powerful cables, the vertical suspenders, the radiating stays, the arching of the span, the curves and proportions, all these have been preserved without change.

Perhaps the most distinctive feature of the Brooklyn Bridge is the system of inclined stays radiating downward from the tops of the towers to the floor of the span. The magic of the resulting weblike tracery of lines has been the delight of artists and poets, and of all who love beauty. But these radiating lines were not gratuitously added for artistic effect; the genius of Roebling introduced them primarily for the critical function of adding rigidity to the span, and then took advantage of the additional load-carrying capacity which they incidentally supplied.

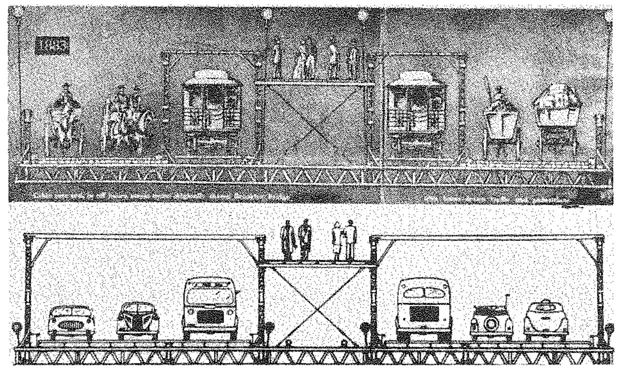
In the modernization of the structure, these wonderful radiating stays have been faithfully retained and fully utilized.

Perhaps the popularly best-known feature of the Brooklyn Bridge is its wide, elevated promenade. To millions who have enjoyed it through the years, it has been associated with nostalgic memories of pleasure, romance and thrill. In his 1869 report, his last testament, Roebling recorded his realization of the future usefulness and drawing power of this great walkway high above the river and the flanking streets.

This raised central promenade has been preserved. I have successfully resisted all official proposals that the time-hallowed elevated boardwalk be replaced by one of concrete, asphalt, or other composition. Instead I have retained the comfortable and resilient plank construction, but have redesigned it to reduce the cost of maintenance.

Another feature of historic and nostalgic charm was provided by the old-fashioned lighting fixtures along the sides of the promenade. These familiar old-time lighting fixtures have been preserved in the reconstruction.

The vision that John A. Roebling's genius had crystallized—the lines and the form, the power and the grace, the beauty and the magic of this masterwork—all of these have now been preserved for posterity.



PROPOSED FINAL STAGE

Rearrangement of the Stiffening Trusses

At the time the Brooklyn Bridge was planned and built, the science of suspension bridge design was still in its crude infancy. Roebling's intuitive genius produced a structure that has endured. Nevertheless a number of features of the design are seen to be unscientific in the light of modern theory and knowledge. The reconstruction of the bridge afforded an opportunity and provided the necessity of making some essential changes in the basic design, in order to secure the desired improved efficiency and enlarged capacity.

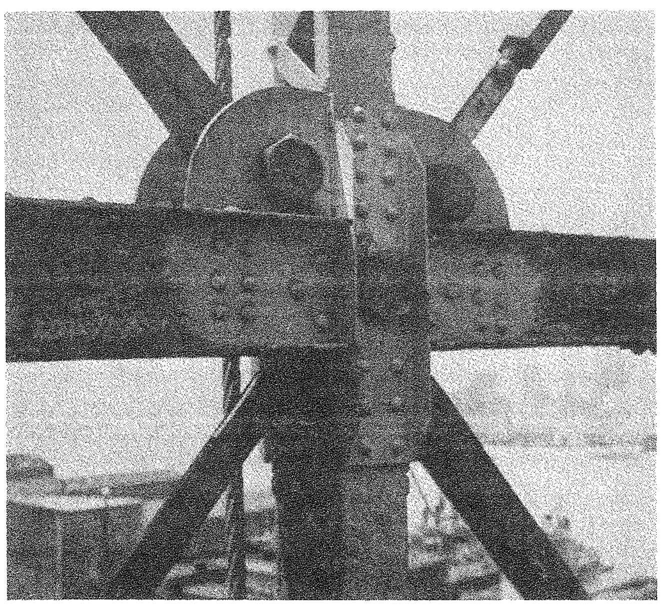
The primary and outstanding change that was necessary was the simplification and rearrangement of the stiffening trusses. The Brooklyn Bridge was built with *four* cables and *six* stiffening trusses—two inner trusses, 17 feet deep; two intermediate trusses, 17 feet deep; and two outer trusses, only 8 feet 9 inches deep. The inner and outer trusses were located under the four cables, but the two intermediate trusses had no cables above them to which they could transmit their share of the total load. This was an unscientific arrangement, materially impairing the efficient functioning of the structure as a whole. Moreover, the intermediate trusses interfered with the desired clear roadway width of 30 feet, leaving a roadway width of only 16 feet 7½ inches. This was too narrow for two lanes of modern highway traffic. Cars could barely squeeze two abreast through such restricted width, and in actual use it was virtually only a single-lane roadway. Both necessity and efficiency therefore required the removal of the two intermediate trusses, thereby simplifying the cross-section by reducing the number of stiffening trusses from six to four, one under each cable, and at the same time yielding two clear roadways, each 30 feet wide, or a total of six highway lanes for vehicular traffic.

This scientific rearrangement of the cross-section also called for the deepening of the two outer trusses from their half-depth of 8 feet 9 inches to the same full depth, 17 feet, of the other trusses, so that the outer trusses could take their proper share of the total load and transmit that share effectively to the cables above them. With their half-depth, the outer trusses were not doing their share of the work. They were contributing only 10 per cent to the total vertical stiffening of the bridge. With their reconstruction to full depth, they are now contributing 50 per cent of the total vertical stiffening of the bridge.

The combined effect of the change was equivalent to removing the full-depth intermediate trusses from their ineffective and objectionable intermediate location and transferring them to replace the inadequate half-depth trusses under the outer cables. Actually, in the interests of economy of labor and material, the half-depth outer trusses were left in place but were built up to the full-depth uniform truss-height by utilizing salvaged top chords from the scrapped intermediate trusses.

The new eyebars that were placed in the outer trusses were all carefully adjusted with the aid of precision strain-gauge measurements.

As indicated in the cross-sections, both in the original design and after reconstruction, each stiffening truss has an intermediate chord, consisting of one or two longitudinal 6-inch channels, sitting on top of the floorbeams and riveted to the vertical posts of the stiffening trusses. In removing the intermediate trusses, the bottom chords were left in place for participation in resisting the horizontal thrust from the diagonal stays; and the intermediate chords were also left in place to form the top chord of a new distributing truss to aid the floorbeams. The intermediate trusses were removed by flame-cutting the diagonals and counters close to the pins and flame-cutting the vertical posts at the tops of the intermediate chords.



(Engineering News Letter)

The intermediate trusses, although they were not directly suspended from any cables, performed the valuable function of distributing the effect of concentrated floor loads. With the intermediate trusses completely removed, each floorbeam would have to carry its wheel loads without help from adjacent floorbeams. This would have overstressed the floorbeams. To improve this condition, we added light diagonal members between the retained bottom chords and intermediate trusses. In this manner, stiff *distributing trusses* were formed that reduce the stresses in the floorbeams due to concentrated wheel loads by fifty per cent.

For the appearance of the bridge, the effect of the revision of the stiffening trusses was to produce simpler and cleaner lines, with only four stiffening trusses instead of six, and with only one truss depth instead of two different truss depths. The total truss height remained unchanged. Prior confusion of lines, as seen in perspective, was reduced or eliminated.

New Roadway Slab

The Brooklyn Bridge roadways were originally of light construction, consisting of timber planks. These were later replaced with wooden paving blocks. This paving could not stand up under the stream of automobile traffic. Moving in single file or barely squeezing two abreast, the cars elbowed their way over the narrow roadways, rattling the old wooden paving blocks out of their beds and jamming the bridge from end to end. Modern automobile traffic created a condition the old bridge could not accommodate and remedial measures were clearly necessary.

The original light-weight construction limited the permissible dead load of any new construction. The use of a conventional modern reinforced concrete slab for the new roadways was precluded.

The official authorities recommended an open steel grid for the new roadways, so as not to increase the dead load of the bridge. This was favored by the Maintenance Department as the open grating would eliminate snow removal and sanding. There was one difficulty, however. While asking for an open grating for the roadways in the main span over the river, the officials insisted upon a solid floor construction in the flanking land spans. More than half the area under the two land spans comprises streets, sidewalks, open docks and uncovered industrialized space. The authorities feared that this area would be menaced by objects falling through the open grating.

The proposed combination of open grating in the river span with solid slab in the land spans was found, however, to be impracticable, for a very interesting reason. The unbalanced dead load in main span and side spans would produce a serious unbalanced cable-pull on the towers.

The small steel rollers under the saddles on top of the towers of the Brooklyn Bridge have never functioned as intended. The rollers simply have not rolled. They have become skewed, imbedded, and rusted, virtually "frozen" from the start. As a result, unbalanced cable-pull on the tower-tops, from elastic elongation or thermal expansion of the cables, has produced serious bending strains in the towers, tending to loosen joints in the masonry. (That is why the later suspension bridges have been built with flexible steel towers, to reduce and resist the bending stresses). In the Brooklyn Bridge, the cumulative unbalanced pull on the tower-tops has repeatedly caused the cables to overcome their friction and to "jump" in their saddles, thereby alarming the public but actually producing a readjustment of strain and relief of stresses. In 1922, two of the main cables on the Manhattan tower slipped in the saddles and moved toward the river by ½ and 1¾ inches, respectively, thereby giving evidence of excessive unbalanced cable pull.

The unbalanced horizontal force on the tower tops of the Brooklyn Bridge combined with the vertical load produces a resultant that comes to the edge of the critical "core-area" of the horizontal masonry joints of the tower (corresponding to the "middle-third" in simpler sections). Any aggravation of this condition, as by adding unbalanced dead load to main span and side spans, might be critical.

In the case of the Brooklyn Bridge towers, there is a very fortunate saving feature. The towers rest on compressible timber cushions formed by the roofs of the caissons on which they are founded. These massive timber cushions are fifteen feet thick under the Brooklyn tower and twenty-two feet thick under the New York tower. The elastic compressibility of the timber cushion permits the masonry tower to rock on its base, thereby relieving the strains in the masonry from unbalanced cable-pull. Precision surveys with transit show that the deflection graph for each tower is a straight line, as in a hinged column, and not a curve as in a cantilever beam. This action has undoubtedly saved the tower masonry from serious racking strains in the past.

Accepting this saving feature as a welcome margin of safety, it did not seem prudent to do anything that would augment the unbalanced forces on the towers. I therefore recommended the adoption of a uniform roadway construction for the three spans.

The use of an open grating in all three spans with a net under the land spans was considered and discarded. Another idea considered a closed floor in the land spans and an open grating in the river span, counterweighted with heavy concrete curbs to equalize the weights, but this would have been uneconomical.

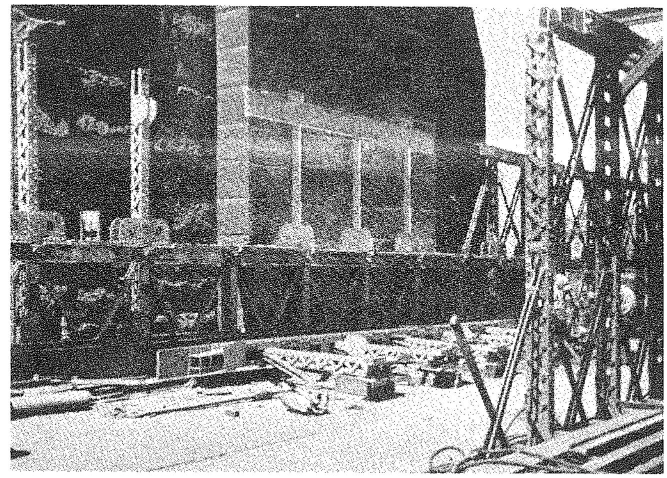
It was finally decided to use a closed floor of the lightest possible type. The new roadway slab is of 3-inch "I-Beam-Lok," with a special arched pan under each square of the mesh to reduce the volume of concrete. The widest spacing of stringers is only 3′–6″, which makes the I-Beam-Lok strong enough even without the concrete filling. This construction, with the concrete filling, increased the dead load of the bridge by an amount equivalent to 15 pounds per square foot of roadway. A live load of 40 pounds per square foot had been proposed. The increase in dead load reduced the live load capacity of the bridge from the proposed value of 40 pounds to 25 pounds per square foot of roadway. This figure, however, is ample when it is considered that normal bridge traffic will be restricted to passenger cars.

Locally, the roadway slab, stringers and floorbeams are capable of sustaining three 17-ton trucks abreast. The 25 pounds per square foot loading applies to the overall loading of the bridge and does not prohibit the passage of properly spaced repair trucks, fire engines or other emergency vehicles.

The contractor elected to place a construction joint in the floor slab along the center stringer of each roadway. He was thus able to work from the old roadway and complete all demolition and construction adjacent to the inner trusses. Then working from the new half-roadways he completed demolition and construction adjacent to the outer trusses.

Reinforcement of the Stiffening Trusses

The Brooklyn Bridge has many unique features that should be noted to appreciate the problems of reconstruction. The bridge is of the suspension type with four main cables which are cradled (hanging in slightly inclined planes). The stiffening trusses pass through the towers where they are rigidly fixed against all motion. They are pin-connected to the anchorages which are located at the ends of the land spans. The bridge is "five-hinged," counting the pin-connection at each anchorage and a slip joint at each mid-span. The expansion or slip joints are located in the stiffening trusses at the centers of the land and river spans. This arrangement with slip joints at mid-span was necessitated by the incorporation of the system of diagonal stays radiating from each tower top to points of attachment in the bottom chord. The slip joints cannot transmit bending moment, but do transmit shear by means of tongues projecting across each slip joint from the top and bottom chords on one side of the slip joint to the chords on the other side.



(Engineering News Letter)

The stiffening trusses hang from the cables by wire rope suspenders at 7′–6″ spacing, which is the general spacing of the floorbeams. In addition to these suspenders, the portions of the stiffening trusses adjacent to the towers are carried by the diagonal rope stays that originate at the tower tops and fan out to connect to the bottom chords of the stiffening trusses at 15′–0″ spaces. In the region of the diagonal stays, since the stays partially relieve the vertical suspenders in carrying the dead and live load of the bridge, the curves of the main cables are flatter than where the loads are carried solely by vertical suspenders.

There are 125 panels in each 930-foot land span. The slip joint is at Panel Point 60. Panel Point 122 is at the anchorage. The diagonal stays are attached to the bottom chords of the stiffening trusses at alternate panel points, between Panel Points 7 and 55.

The main or river span is 1595½ feet. There are 107 panels between each tower and the center of the river span where the slip joint is located. Symmetrical about each tower, the diagonal stays are attached to the bottom chords of the stiffening trusses at alternate panel points between Panel Points 7 and 55.

The stiffening trusses are "quadruple intersection Warren trusses." A vertical section anywhere between the verticals at the panel points will cut *four* eyebar web members. The members that slope downward toward the river are termed "diagonals" and are fixed in length. The members that slope upward toward the river are termed "counters" and are adjustable by means of sleeve nuts.

The entire system of cables, diagonal stays, and stiffening trusses is highly "redundant" or "indeterminate," rendering accurate stress analysis highly difficult and involved. A change in adjustment of any member produces a readjustment of stresses in other members and affects the vertical curvature and alinement.

A careful analysis of the stresses in the stiffening trusses revealed high compressive unit stresses in the bottom chords in the regions of the diagonal stays. These high stresses were produced by the superposition of thrust reaction from the diagonal stays added to the stresses from normal truss action. It was decided to reinforce the bottom chords in the overstressed regions where the calculated unit stresses exceeded 30,000 pounds per square inch. The regions in which the bottom chords required reinforcement extended between Panel Points 17 and 45 in the land spans and between Panel Points 17 and 42 in the river span.

The existing bottom chords between Panel Point 17 in the land span and Panel Point 17 in the river span are of double depth, each half-section consisting of a 9-inch channel set on top of another 9-inch channel with webs vertical. The regions requiring reinforcement were beyond the double-depth chords, calling for lengthening the extent of the double-depth chords. Instead of using 9-inch channels to be set on top of the existing 9-inch channels, it was decided to use 8x4 angles for the new material. With suspenders and diagonal stays in the way, the angles were easier to erect than channels.

To make the bottom chord reinforcement effective in sharing stress, it was applied when the stresses in the bottom chord were reduced to as low a value as controlled removal of the dead load of the original floor permitted.

Within the main towers, the bottom chords are in contact with the tower masonry on one side and close to masonry ledges on the underside. Pockets thus formed were holding dirt and moisture and causing considerable corrosion of the lower flanges of the bottom chords. Cramped quarters made general reinforcement by riveting impracticable and the compression stress in the bottom chord precluded use of welding.

At the faces of the towers, where cutbacks in the tower masonry provided room for riveting, the lower flanges of the bottom chords were reinforced locally to rest on new bearings. Between the bearings, the lower chords were cleaned thoroughly and encased in concrete. The concrete was carried up high enough to serve as curbs for the roadways. In this way, the chords are stiffened to increase their load-carrying capacity and also protected from dirt and moisture.

New Roadway Stringers

The reconstruction of the roadways required a complete new set of longitudinal stringers.

The new roadway stringers are 8-inch 23-pound standard I-beams. Their span is short, the floorbeams being spaced 7′–6″

The depth of the new stringers is the same as that of the old stringers under the train tracks and it was hoped that the track stringers could be used under the new roadway. It was found, however, that the corrosion of the top flanges under the track ties was far advanced and the idea of re-using the old track stringers had to be abandoned.

The new stringers were furnished in 30-foot lengths and were erected with staggered joints. In the regions of the diagonal stays, the stringers and floor slabs have no expansion joints. This permits the floor to participate in resistance to thrust from the diagonal stays and also provides lateral stiffening for the unbraced bottom chords. Outside the regions of the diagonal stays, the stringers and floor slab are provided with expansion joints at 90-foot intervals.

Reinforcement of Floorbeams

Reinforcement of all of the floorbeams would have been very difficult and, fortunately, was made unnecessary by the conversion of the remnants of the old intermediate trusses into effective distributing trusses. The distributing trusses, however, are not adequately effective in reducing stresses in the end floorbeams at the slip joints. To give further support to these end floorbeams, auxiliary distributing trusses, three panels long, were built 6′–9″ away from and parallel to the main distributing trusses. In this way, the end floorbeams at the slip joints are braced and stiffened by two intermediate distributing trusses instead of one.

New Top Struts

With the removal of the intermediate stiffening trusses and the raising of the outer trusses to full height, new top struts were required as braces between the top chords of the inner and outer trusses.

In order to facilitate any future removal of pins from the top chords, the section chosen for the top struts consists of two channels arranged to form a T. This section provides other advantages such as increased vertical stiffness and a flat top that does not hold debris.

Around the towers, where the promenade is supported by the top struts, special sections were adopted to act as beams as well as struts.

Reconstruction of the Promenade

The timber promenade is the most hallowed feature of the Brooklyn Bridge. It has served and given pleasure to countless thousands through the years, including those walking to work across the span as well as those strolling for pleasure. At the same time, the promenade has been the greatest nuisance for maintenance, especially whenever the timber stringers under the floor planks started to decay. The timber promenade and its supporting stringers required complete replacement, and due consideration was given to the use of permanent and fireproof materials. All substitutes for timber, however, increased the dead load, and the dead load problem had already been made acute by the adoption of a closed roadway slab. For this reason, as well as to preserve the tradition and comfort of the elevated boardwalk, it was decided to retain the timber flooring for the promenade.

The new promenade was laid to the boardwalk specifications of the Park Department. The stringers are creosoted for preservation, and the planks are salt-treated for fire prevention. The opportunity was taken, after removal of the old promenade, to replace with steel all timber supports under the stringers.

Installation of an Inspection Walkway

The space under the promenade had been used to carry the electric cables for trolleys, trains, telephones and lighting. These cables, with the exception of a 1,000,000 CM drainage cable for the protection of telephone cables against electrolysis, have all been removed, leaving the space clear. In order to provide convenient access, along the length of the bridge, for inspection and maintenance, an inspection walkway was installed in this space. This was laid on the floorbeams, with cross-walks connecting to the roadways every 120 feet.

The inspection walk serves several purposes. It partially closes a dangerous open space, it provides a storage space for materials when repairs are to be made, it provides cross-overs between the roadways and it makes it unnecessary for maintenance men to walk long distances along the busy roadways.

The inspection walk is a light open steel grating protected by wire rope-strand handrails.

Riveting vs. Welding

At the request of the Department of Public Works, wishing to avoid the use of welding, the details in the contract drawings for the reconstruction of the bridge were made up entirely with riveted connections. This limitation was especially restricting because of the inconvenient dimensions of the old steel channels of the bridge members, fabricated when the application of steel was in its infancy. Compared with modern channel sections, the old steel channels on the Brooklyn Bridge have thicker webs and narrower flanges. Rivets through the old channel flanges were necessarily small and difficult to drive.

Fastening of the new longitudinal stringers to the top chords of the old latticed floorbeams posed a problem. The top chords of the old floorbeams consist of two 6-inch channels, back to back, with flanges horizontal. It was impossible to drive rivets through the channel flanges because of their narrowness and, in addition, the presence of web reinforcing plates between the channel flanges. Connection between the new stringers and the old floorbeams was accomplished by means of clip angles, riveted to the vertical webs of the channels that form the top chords of the old floorbeams.

When work started, it was found that drilling holes for rivets in the old floorbeams was a very slow and difficult process. It seemed that the old steel had hard spots that resisted and dulled the drills. Finally, to expedite the work, the Contractor's proposal to weld the new stringers to the old floorbeams was accepted. The clip angles were eliminated. The beveled plates, filler plates and bearing plates required between the stringers and floorbeams were reduced in size.

The distributing truss, which was field riveted in the south roadway, was almost entirely field welded in the north roadway. With the exception of the work on the outer trusses and the reinforcement of the bottom chords of the four trusses, welding was substituted for riveting as the work progressed, with consequent saving in weight of material. More important, valuable time was saved in completing the work and opening the roadways to traffic.

Program of Demolition and Erection

With the main cable saddles frozen at the tower tops, the heavy masonry towers must act as anchorages to resist unbalanced cable-pull that is caused by live load and temperature.

Mindful of the objectionable effects of unbalanced cable-pull, a program of procedure for demolition and erection was included in the specifications to maintain a balance of cable-pulls in the land and river spans. The computations were based on influence lines for cable-pull in the respective spans.

The specified program was, of course, not the only one to give the desired results and, as is usually the case, the Contractor proposed an alternate procedure. It was examined for safety and approved after minor modifications.

The south roadway of the suspended spans was reconstructed, with its stiffening trusses, while one-way traffic was maintained on the north roadway, Manhattan-bound in the morning, Brooklyn-bound in the afternoon and evening. The reconstructed south roadway was opened to traffic in May 1951 and the north roadway was then closed for reconstruction. The latter was completed in May 1952 but cannot be opened to traffic until reconstruction of the north roadway approaches is completed.

Contracts for the reconstruction of the approaches, on plans prepared by me, have been let to the same Contractor who reconstructed the suspended spans. This work is expected to be completed late in 1953.

Electrical Work and Fire Protection

An entirely new lighting system has been designed for the bridge roadways. In the open approaches, where there is unlimited headroom, modern highway type lampposts are to be installed, with luminaires on arms projecting over the roadways.

Over the roadways on the suspended spans, luminaires are suspended from davit type brackets at the level of the top struts to avoid casting shadows.

The lighting fixtures for the roadways are of modern design but, for the promenade lighting, sentiment ruled. The original lampposts, with their distinctive hoods that are reminiscent of the gas-light or arc-light era, have been refurbished and installed on the top chords of the inner stiffening trusses to light the promenade.

For the convenience and safety of motorists, an emergency telephone system is provided to be installed on the roadways. This system will connect to a Police Department switchboard. At each emergency telephone, there will also be a fire alarm box connecting directly to the Fire Department.

For the use of the Fire Department, there will be a continuous 3-inch pipe line with frequent hose connections along each roadway, extending across the suspended spans and well into the approaches. Water may be pumped into the entire system by a fire engine in the street at either anchorage or by a fire boat at either main tower.

The reconstruction of the bridge forced the abandonment of a unique utility, the pneumatic mail tube system, that sent mail in carriers through 8-inch pipes between the post-offices of Manhattan and Brooklyn. These mail tubes were operated by a private company, and the expense of relocating the tubes was not warranted by the income from them. The mail tubes were removed from the suspended spans and the Brooklyn approach. They will be kept intact in the Manhattan approach, as they do not interfere with the reconstruction, and will be utilized to serve as a conduit for the cables of the emergency telephone system.

Increase in Dead Load

A comparison between the average dead loads of the bridge in pounds per linear foot, before and after reconstruction, is given in the following table.

	Before Reconstruction	After Reconstruction
For each outer cable	2,220	2,400
For each inner cable	2,500	2,520
Total for bridge	9,440	9,840

The total dead load of the bridge has been increased by 400 pounds per linear foot, or about four per cent. This increase is equivalent to 7 pounds per square foot of roadway. Unforeseen additions may raise this increase to 15 pounds per square foot. This is the figure used in arriving at an allowable live load of 25 pounds per square foot of roadway for the bridge fully loaded.

The division of dead load between the inner and outer cables has been more nearly equalized. The maximum dead load per cable, taken by the inner cables, has been increased less than one per cent.

Cost of Reconstruction

The cost of reconstructing the suspended spans was approximately $3,325,000. The complete replacement of the entire suspended structure, retaining the towers, anchorages, and cables, would have cost $8,000,000. In the state of the city's finances, this greater cost was prohibitive. Moreover, any further increase in loading capacity could not be realized without opening the bridge to heavy industrial traffic and flooding the City Hall district with trucks. It was decided, therefore, that the larger expenditure was not warranted.

To round out the work of reconstructing the bridge, I was also retained to prepare the contract plans and specifications for the reconstruction and widening of the approaches. The roadways of the approaches are being widened to match the new 30-foot roadways on the suspended spans. The Brooklyn end of the approach, east of Prospect Street, will be demolished and rebuilt to connect to Adams Street. An exit road to Fulton Street will be provided for eastbound traffic. Accesses from Sands Street and the Brooklyn-Queens Connecting Highway will be provided for westbound traffic. The accepted bid price for the reconstruction of the bridge approaches in Manhattan and Brooklyn is $3,576,474.

Personnel

My organization prepared the design studies and calculations and the contract plans and specifications, in close collaboration with the Department of Public Works headed by Commissioner Frederick H. Zurmuhlen. Among the members of the Department intimately connected with the development and execution of our work were J. Frank Johnson, Director of the Division of Bridges; I. M. Peyser, Chief of the Bureau of Bridge Design; and Theodore Mombelly, Resident Engineer.

The general contractor is the Klevens Corporation. The steel work was sublet to the Terry Steel Contractors, Inc., and the electrical work is being done by Fischbach and Moore.

In my office, the work was in charge of my principal associate, Mr. J. London, with the cooperation of the other principal associates on my staff, Messrs. W. E. Joyce, R. M. Boynton, and C. H. Gronquist.

In all of this work, my staff and I were proud to be identified with this challenging opportunity to preserve John A. Roebling's crowning achievement and to continue his inspiring tradition.

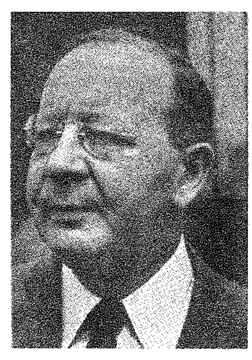
THE AUTHOR

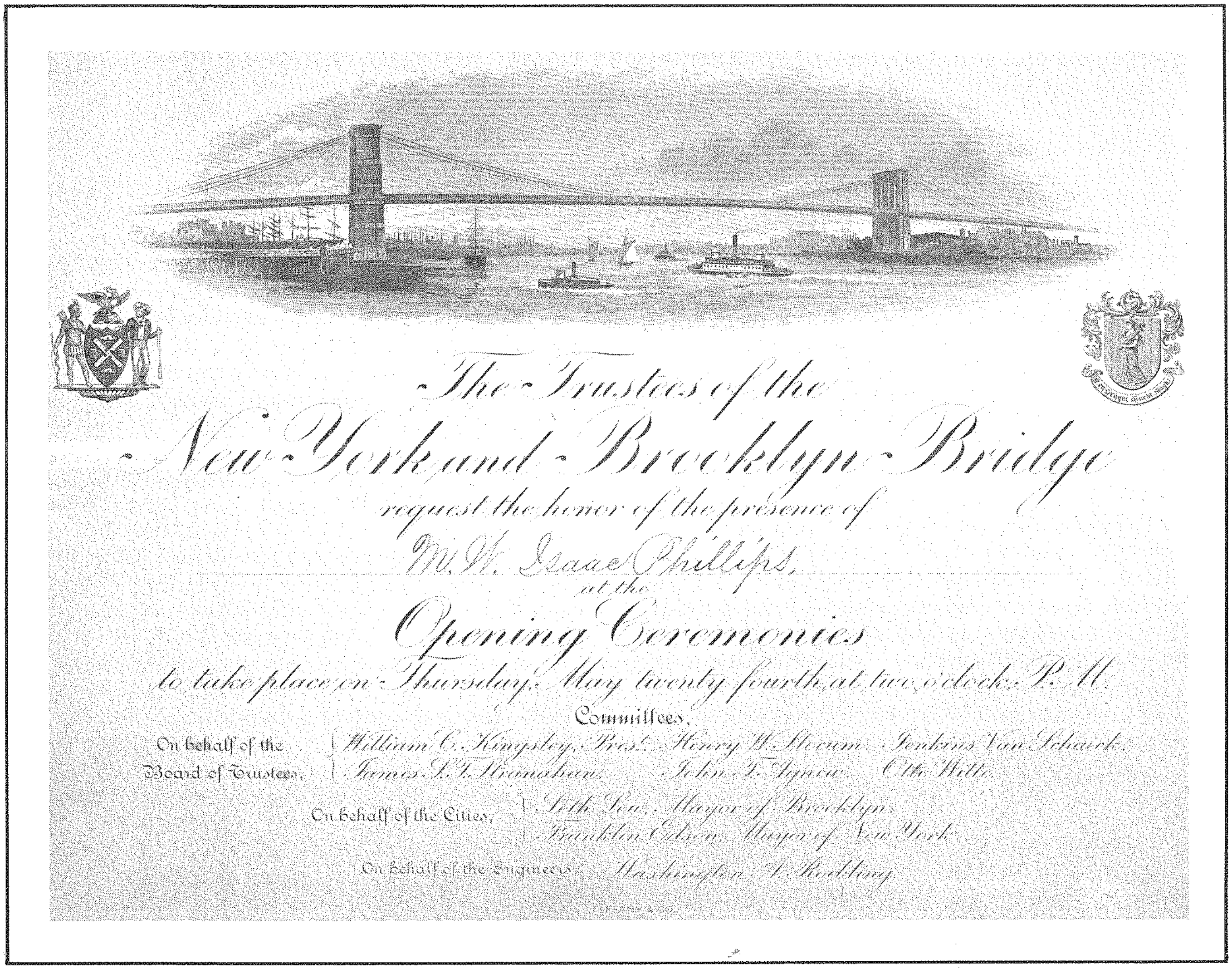
Dr. David Barnard Steinman received his B.S. (summa cum laude) from the City College of New York in 1906. At Columbia University he received the C.E. and M.A. in 1909, and the Ph.D. in 1911. He has held Professorships at the University of Idaho and at C.C.N.Y.

Dr. Steinman's many awards include a silver scroll presented jointly by eleven engineering societies for contributions to the advancement of engineering. He is also the five-time recipient of the Institute of Steel Construction's Artistic Bridge Award.

Dr. Steinman has been on the professional engineers' examination boards in New York State and is himself licensed in most of the United States. A recent addition to his many honors is the Ordre des Chevaliers de la Croix de Lorraine et des Compagnons de la Resistance. The order was awarded in recognition of Dr. Steinman's outstanding services to the Allied Armies in World War II.

This article is one of several that the author has contributed to QUARTERLY over the past few years.




The Trustees of the
New York and Brooklyn Bridge
request the honor of the presence of
M. W. Isaac Phillips
at the
Opening Ceremonies
to take place on Thursday, May twenty fourth at two o'clock P.M.

Committees,

On behalf of the Board of Trustees, William C. Kingsley, Pres't. Henry W. Slocum Jenkins Van Schaick
James S. T. Stranahan John T. Agnew Otto Witte.

On behalf of the Cities, Seth Low, Mayor of Brooklyn
Franklin Edson, Mayor of New York

On behalf of the Engineers, Washington A. Roebling

TIFFANY & CO.

Invitation to the Opening Ceremonies
of the

BROOKLYN BRIDGE

May 24, 1883

Original in the collections of the
Division of Mechanical and Civil Engineering
National Museum of History and Technology
SMITHSONIAN INSTITUTION