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East River Bridge Rehabilitation in New York

Rénovation de ponts sur la East River à New York

Erneuerung der East-River-Brücken in New York

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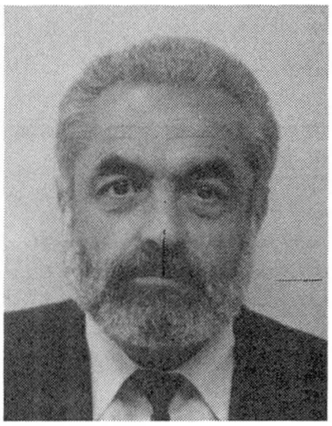
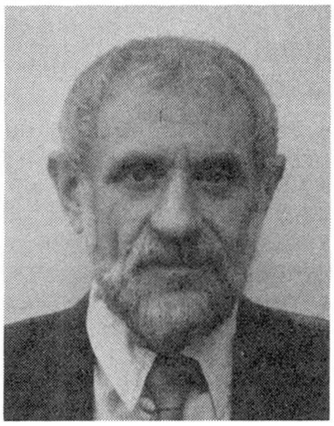


Edward Kotlyarsky, born 1937, obtained his civil engineering degree in bridges at the Dniepropetrovsk Railroad Transp. Inst. USSR. Edward Kotlyarsky, employed by Steinman Consulting firm since 1979 is responsible for the rehabilitation design of long span bridges in New York City and the State of New York.



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SUMMARY

The rehabilitation of the Brooklyn and Queensboro Bridges, two of New York's most famous and historic structures, is presently under way. All construction operations including replacement of main carrying members were performed with minimal disruption of existing traffic, and the historic architectural details of the structures were fully preserved. In order to reach the final objective, the designs had to incorporate specific, detailed construction procedures and sequences.

RESUME

La rénovation des ponts de Brooklyn et de Queensboro, deux des ouvrages historiques les plus renommés, est actuellement en voie d'exécution. Toutes les opérations de construction, y compris le remplacement des éléments porteurs principaux, se font avec une interruption minimale du trafic routier existant; par ailleurs tous les détails architecturaux historiques des structures sont entièrement conservés. En vue d'atteindre l'objectif final, le projet doit tenir compte des procédés et des opérations successives de construction d'un caractère spécifique et détaillé.

ZUSAMMENFASSUNG

Gegenwärtig werden die Brooklyn- und Queensboro-Brücke, zwei von New Yorks berühmtesten historischen Bauwerken erneuert. Alle Baumassnahmen einschliesslich des Austausches der Haupttragelemente erfolgen unter minimalen Verkehrsbeschränkungen. Die architektonischen Einzelheiten der Bauwerke wurden voll gewahrt, was nur dank besonderer, detailliert geplanter Bauvorgänge möglich war.

1. INTRODUCTION

The unique design and construction aspects of the rehabilitation of two major East River Bridges in New York City is the subject of this paper.

In the late 1970's the Steinman firm was contracted to design the rehabilitation of the Brooklyn Bridge which was originally designed by John A. Roebling and opened to traffic in 1883, and Queensboro Bridge, opened to traffic in 1909. Both bridges required major repairs and replacement of details to correct their longstanding environmental deterioration.

The bridges are vital connections between Manhattan, the cultural and economic heart of the New York Metropolitan Area, and other parts of the city. Each Bridge services more than 100,000 vehicles a day and any severe disruption of the traffic would result in significant social and economic consequences. Both structures are designated as National Historic Landmarks.

2. BROOKLYN BRIDGE

2.1 Original Conditions

The Brooklyn Bridge is a combination suspension and cable-stayed bridge with the main span 486.4 m (1595 ft - 6 in) long and two side spans of 284.4 m (933 ft) each.

With its record span (for twenty five years) and elegant appearance, the bridge was undoubtedly a breakthrough in suspension bridge construction. Furthermore, the Brooklyn Bridge represented the first use of steel wire for suspension bridge cables.

During its existence, the bridge had sustained extensive deterioration (including many broken stays), major reconstruction, some buckling of the lower chords and unsymmetrical saddle movements caused by severe overloading.

Unlike most of the modern suspension bridges having two main cables and stiffening trusses, the four trusses of the Brooklyn Bridge are suspended on four cables. The highly redundant floor system features floorbeams spanning between the trusses and spaced at 2.3 m (7.5 ft) along the bridge. The stresses in these members depend on load distribution between the cables. Existing dead load tensions in the Main Cables were determined using surveyed polygons and field measured suspender forces. The required measurement of forces during construction influenced the design and was specifically provided for in the contract documents.

Radial stays running from the top of the towers to the truss bottom chords is another unusual feature of the bridge. The stays extend out to the quarter points in the main span and to almost the mid point of each side span. These portions of the bridge are referred to as the "stay regions". Because of the presence of slip joints in the stiffening truss upper chords in the stay regions during erection, the horizontal component of stay forces was transmitted mainly to the bottom chords.

Presently, the bridge carries six lanes of passenger cars. The rehabilitation criteria was to increase the load capacity almost three times for accommodation of two lanes of light trucks and one lane of buses in each direction. After combining existing dead load stresses with computed live load stresses it was found that the truss bottom chords in the stay regions and floorbeam members were substantially overstressed.

Inspection of the bridge revealed that the cable and truss chords were in generally good condition, but there was severe corrosion in the suspenders, stays, truss pins, truss verticals, diagonals, and floorbeams. Since replacement of this historic and much admired structure was not an option, the suspenders and stays had to be replaced along with truss pins, diagonals, some truss verticals and portions of floorbeams.

2.2 Design and Construction

Existing suspenders were replaced with new 35 mm (1 3/8 in) diameter galvanized wire ropes attached to the cable with new cable bands. Suspender attachment to the truss bottom chord consists of two stirrup rods, galvanized stirrup casting and bridge bowl (Fig. 1), provided for required adjustment of suspender length. The socket baskets were filled with zinc. Solid rods were used in areas requiring very short suspenders.

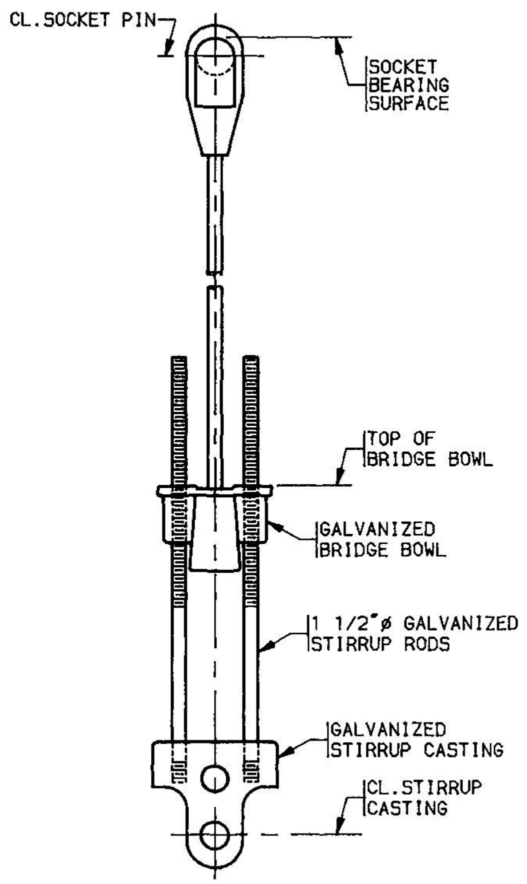

Fig. 1 New wire rope suspender

Upon completion of the suspender replacement, existing stays were replaced with 41.4 mm (1 5/8 in) galvanized structural wire ropes. The stay assembly and its attachment to the truss is similar to that of the suspender.

Replacement procedures were done at one truss at a time. The minimum allowed distance between suspenders simultaneously removed was four panels.

Removal of stays proceeded symmetrically on both sides of each tower starting with the longest ones. In order to reduce stay tensioning forces the reverse sequence was used for new stay installation. No more than one traffic lane was closed during replacement of suspenders and stays.

The best way to achieve desirable stress conditions was by regulation of the forces rather than by costly and time consuming reinforcement of the existing members.

Existing forces in suspenders and stays were adjusted to achieve the following goals:

a. Redistribution of the dead load in the proportion of 24% to each outer and 26% to each inner cable in order to reduce the floorbeam stresses and to smooth out suspender loads along each cable.

b. Reduction of the existing dead load compression stresses in the bottom chords of the stiffening trusses in stay regions.

New suspender and stay forces were predetermined in order to achieve these objectives. These forces produced changes in the cable and truss profiles. A practical way to obtain new desirable stress-strain conditions in the stiffening trusses was to change the length of the suspenders and stays.

The new suspenders were installed initially at a length to maintain the existing geometry of the structure and then gradually adjusted to their final design length. Since truss displacements due to force changes were small and neglected, the values of suspender adjustments were equal to corresponding changes in cable elevations. For the same reason the new stays were installed at their final design length.

Almost all suspender adjustments were accomplished in increments, or "bites", to avoid overstressing members of the bridge. The maximum permitted "bite" at a particular location was determined using a 3D computer model. The values of the computed "bite" varied from 13 mm (1/2 in) for short solid rods to 75 mm (3 in) for long wire rope suspenders near the towers.

The adjustments were done by passes based on computed "bite" values. All passes progressed in each span from the shortest solid rod suspenders toward the towers.

The values of adjustments and the number of passes for outer cable "A" and inner cable "B" for half main span are shown on Fig. 2.

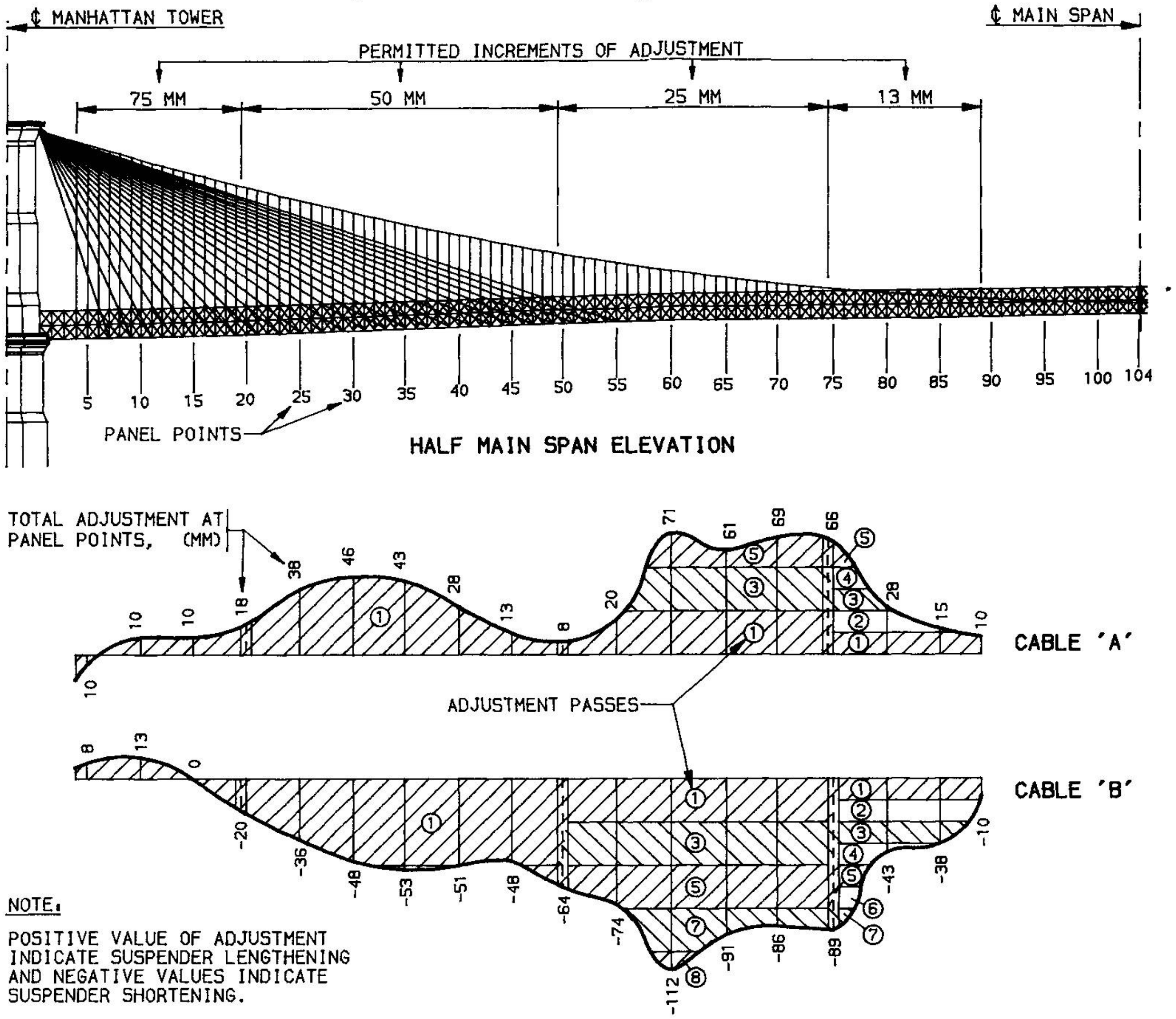

Fig. 2 Adjustment passes. Brooklyn half of Main Span

The adjustments are mainly positive for cables A and D and negative for cables B and C. When done, these adjustments increase tension in the inner and reduce it in the outer cables thus achieving the desirable dead load distribution.

During each pass adjustments were made on all four suspenders at each panel point before proceeding to the next panel point. Subsequent passes were performed in predetermined sequence until all adjustments were completed.

Measurement of suspender and stay forces upon completion of adjustments as well as strain gauge readings of the stresses in truss chords have shown that the goals of adjustments were generally achieved.

3. QUEENSBORO BRIDGE

The Queensboro Bridge is a five span steel truss cantilever structure with truss approaches. The Queens approach consists of a series of fifteen truss spans in five groups of three continuous spans each (Fig 3). The span lengths vary from 29.57 m (97 ft.) to 50.56 m (165.87 ft.). Thermal movements and live load displacements of the trusses were originally provided for by steel roller expansion bearings and rocker pins at pp (panel point) Nos. 0, 20, 40, 58, 78, 82, and 86. Replacement of the Queens approach truss steel roller expansion bearings was one of the most challenging aspects of the entire bridge rehabilitation.

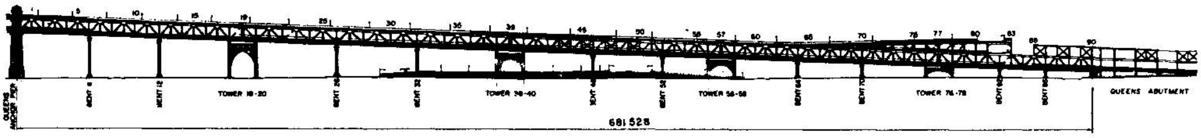

Fig. 3 Queens Approach Elevation.

During the in-depth inspection, it was found that none of these bearings were functioning, and, as a result, some of the supporting towers had cracked at the top. Restoration of the existing bearing components was impractical and to correct the problem it was necessary to replace all of the expansion bearings with an improved type. While jacking of the trusses was required, the entire operation needed to be performed with no disruption of traffic which averages 145,000 vehicles per day. These were the basic requirements that influenced the construction technology and, in turn, the design.

The design lifting force was 8541 kN (1920 kips), equal to the maximum dead and live load reaction at pp 82. Total longitudinal design movement at any expansion bearing was 135 mm (5.3 in). The height of the tower legs varied from about 21.4 m (70 ft) at pp 20 to only 4.6 m (15 ft) at pp 86. The Queens approach is located above an industrial area where there is an endless variety of underground utilities. Construction of footings to support temporary piers was therefore impractical, and the jacking equipment needed to be supported on the existing steel columns or their footings. Because there were no convenient lifting points on the trusses or floorbeams, the lifting force was applied to the upper bearing shoe of the existing bearing. The cast steel shoe was in good condition, and could be used as a part of the new expansion bearing.

The entire system for the lifting and lowering of the existing trusses (Fig. 4) consisted of a high strength steel space frame, two temporary expansion bearings each seated on a strongback, four 4448 kN (500 ton) capacity locknut jacks and the lower support system. The temporary expansion bearings allowed the truss and jacking frame to translate and rock during the entire jacking operation. There were two different types of lower support system used: jack support brackets bolted to the existing columns at pp Nos. 20, 40, and 58; and jack support columns seated on the existing footings at pp Nos. 78, 82 and 86. Another procedure was used to replace expansion bearings at pp 0.

Lifting frame geometry was complicated by the need to fit in a very congested area and to provide clearances required to dismantle and remove the existing bearing elements and to erect new bearing components. Structural analysis of the space frame revealed that after lifting the existing truss, the maximum combined unit stress in the frame legs due to axial force and biaxial bending was 371 MPa (53.8 KSI). Because of the high design stresses in the frame elements they were fabricated of high strength quenched and tempered low alloy steel ASTM A-514 plates with minimum tensile yield point 689.5 MPa (100 ksi). Because this material is not available in thickness greater than 63.5 mm (2 1/2 in) each frame was built up of five plates laminated to provide the total leg thickness of 254 mm (10 in), and bolted together with 25.4 mm (1 in) diameter ASTM A-490 high strength bolts, tightened to a minimum tension of 285 kN (64 kips). The two upper strongbacks were built up of seven 50.8 mm (2 in) plates and two 25.4 mm (1 in) plates. The 50.8 mm (2 in) plate thickness provided openings for four 44.45 mm (1 3/4 in) diameter tie rods at both ends of each upper strongback, where moment connections to the lateral frames were required. All tie rods were pretensioned to 44.5 kN (10 kips) each prior to the lifting operation. Each lower strongback was supported by two hydraulic jacks seated on two support brackets. Each bracket was connected to the existing column by seventy five 22.23 mm (7/8 in) diameter ASTM A-490 bolts through existing and new holes. The length of each of these connections was about 7.3 m (24 ft). Based on ASHTO requirements, the allowable shear stress on high-strength bolts in these connections was reduced by 20%.

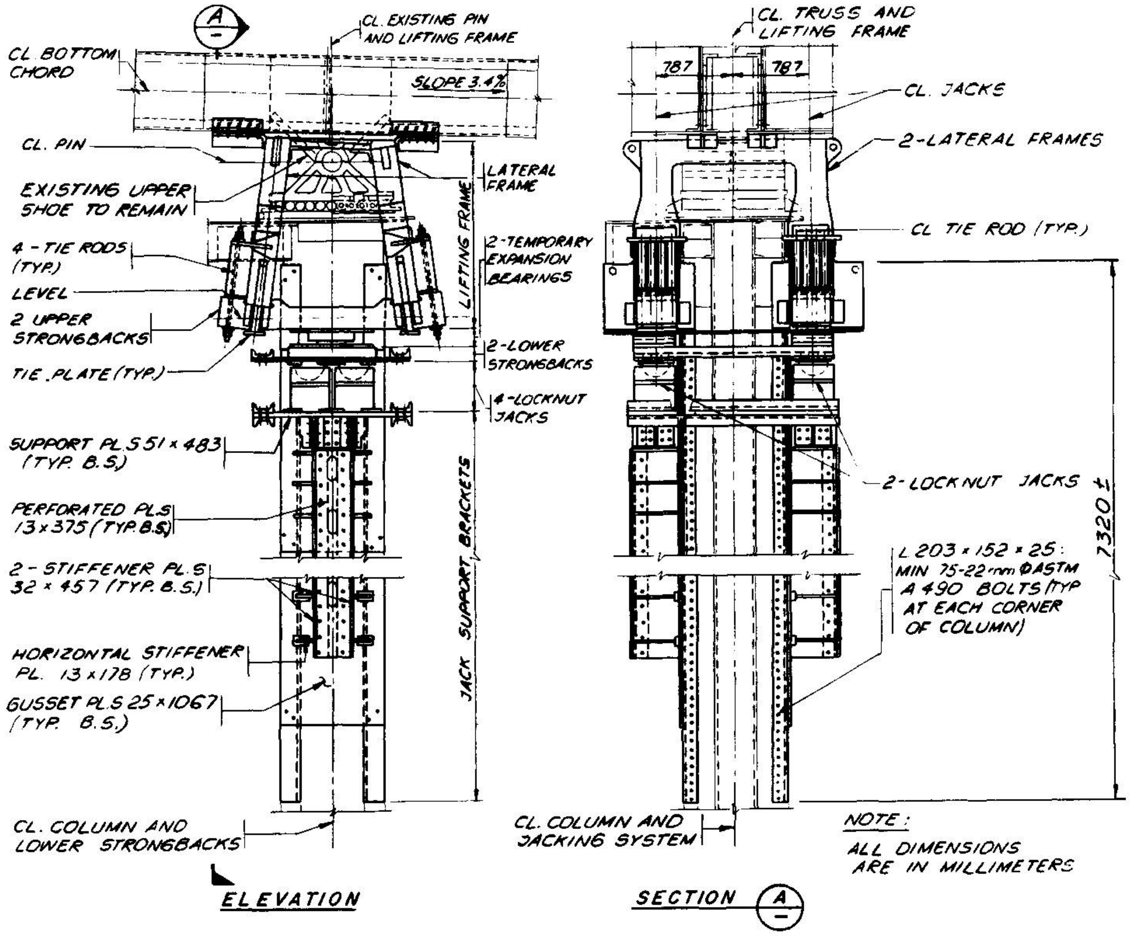

Fig. 4 Bearing replacement jacking system.

The height of columns at three panel point locations was not sufficient to provide such long connections. This circumstance required the design of temporary four column steel towers installed on the existing 203.2 mm (8 in) thick cast steel base and braced around and to the existing column. Two lower strongbacks were longer than that used at high existing columns to accommodate location of jacks directly above the temporary columns.

All four jacks were controlled by a synchronous lifting and lowering console that maintained simultaneous, equal vertical movement of jacks despite the different reactions on each pair of jacks along the bridge.

Only one space frame was fabricated to replace all twelve expansion bearings. The average duration of replacement of one expansion bearing, from the lifting to the final lowering of the truss, was five working days. There were no traffic restrictions on the bridge during each operation.