RECONSTRUCTION OF NEW YORK CITY'S WILLIAMSBURG BRIDGE

BIOGRAPHIES

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SUMMARY

The Williamsburg Bridge in New York City opened to traffic in 1903. It has been undergoing extensive rehabilitation by the New York City Department of Transportation since the early 1990s and is nearing the completion of its major reconstruction work. Previous contract work included rehabilitation of the main cables and both the South and North Roadways. The central section of the bridge, which contains two subway lines, underwent a track/signal and structural support steel rehabilitation as well. The last phase of on-going work includes replacing rocker arms at the main towers with 2,500 kip rotational sliding bearings. The replacement requires temporary towers that will support the main truss under subway and traffic loads. The existing rocker arms will then be cut and the support system removed in order to install a new box column-box girder frame to support the new bearings. The rotational sliding bearings at the anchorages will be replaced as well. This required designing an ingenious jacking system to relieve load on these bearings. The main towers were strengthened using 815,000 pounds of steel plating, added on top of reinforcing plating installed soon after the bridge was built. A blocking system was used to tension the new reinforcing plates during installation. The dead load on the main suspended span has increased since the bridge was first built, and the profile has flattened, causing a slight kink in the subway track profile at each main tower. This is a bottleneck, because it decreases throughput capacity for New York City Transit. Suspenders were jacked and adjusted in a complex, staged pattern to adjust the bridge to its original profile and allow the two lines of subway trains to travel at their design speed across the bridge. Overall, over 7,000,000 pounds of steel was replaced or added, in order to replaced corroded steel, strengthen existing members, and add additional access platforms.

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By
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INTRODUCTION AND HISTORY

The Williamsburg suspension bridge spanning over the East River in New York City, shown today in Figure 1, opened to traffic in 1903. It is one of many suspended, fixed, and movable spans over the East River that form New York City Department of Transportation's (NYCDOT's) infrastructure connecting Manhattan with the boroughs of Brooklyn, Queens, and the Bronx. It was designed by Leffert Lefferts Buck as one of the last major suspension bridges for the horse and carriage. Following the Brooklyn Bridge, which captured the imagination of engineers, poets, and artists after it opened in 1883, the Williamsburg Bridge was considered an "ugly duckling" by comparison. L.L. Buck countered the aesthetic criticism of the bridge with the words "but it is strong". This first major suspension bridge to use steel towers to support the main cable, over 100 years later, is still strong. With a wooden carriageway replaced previously by concrete deck and currently by orthotropic steel deck, and its pedestrian footwalk replaced with a new footwalk/bikeway system that is barrier-free, the bridge has, through the vicissitudes of over 100 service years, worked its way into the hearts of New Yorkers. Like the subway system that travels over it, the bridge seems complex until you get to know it; the huge stiffening truss is full of connection angles, lacing bars, and thousands of details. Yet like New Yorkers themselves, the bridge is get-the-job-done functional, and the overall structure on the skyline is raw and simple.

Figure 1. The Williamsburg Bridge in New York City.

The main suspended span is 1,600 feet long, with side spans each 596.5 feet. The main span is suspended, while the side spans are each supported by three intermediate towers as well as at the anchorages and main towers. The anchorages are each 114.25 feet long. The Manhattan Approach viaduct is the longer of the two approach viaducts at 2,090.25 feet; the Brooklyn Approach viaduct is approximately 1,557 feet long. Four cables suspend the stiffening truss approximately 135 feet above mean high water level in the East River. The stiffening truss is 67 feet wide and approximately 40 feet deep and is pinned at each main tower.

PREVIOUS WORK

NYCDOT's rehabilitation of the Williamsburg Bridge began in the early 1990s, and the major construction work will be completed early in 2006. The work has extended over several contracts and the final construction cost will total approximately $900 million. Figures 2 and 3 show section views of the Main Span and Manhattan Approach, respectively, with the major previous work highlighted. The previous work largely entailed reconstructing the South Roadways (blue), reconstructing the subway lines (red), and reconstructing the North Roadways (tan). The South Roadway reconstruction is shown in Contract 5, the subway reconstruction is shown in Contract 6, and the North Roadway reconstruction in Contract 7, currently already completed, is shown in the "before-reconstruction" configuration for comparison. The rehabilitation work is described below.

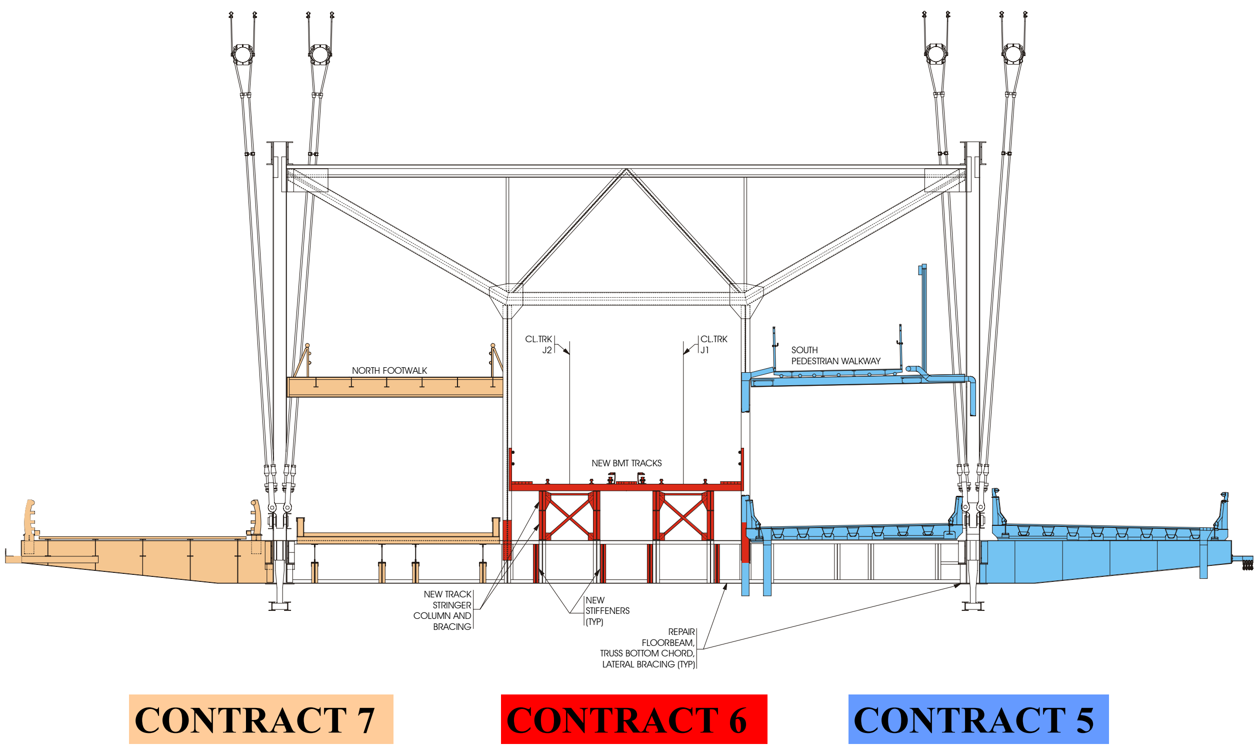

Figure 2. Main Span showing Contracts 5 and 6 completed, Contract 7 shown before reconstruction for comparison.

Cable Rehabilitation

The first major reconstruction contract involved rehabilitating the main suspension cables and suspender system. The four main cables, each consisting of 7,696 bright steel wires, were unwrapped, wedged open, inspected, oiled, and rewrapped with a cold-seal neoprene wrapping system. Failed wires were spliced with ferrules, where possible. The suspenders were replaced, and a special adjustment link and equalizer system was designed in anticipation of future suspender adjustments.

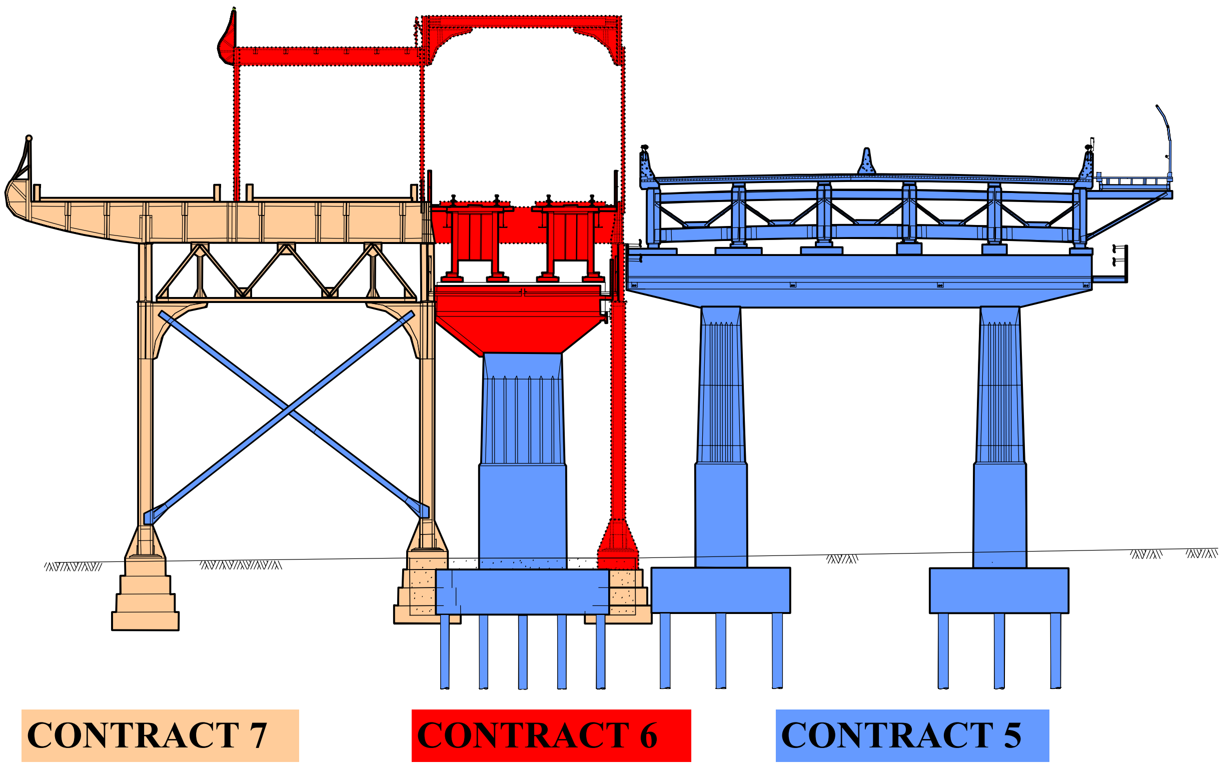

Figure 3. Manhattan Approach showing Contracts 5 and 6 completed, Contract 7 shown before reconstruction for comparison.

Roadway Reconstruction

The North and South Roadways each consist of four lanes, each roadway consisting of two inner lanes and two outer lanes. The existing roadways were constructed of open steel grid deck and concrete-filled grid deck at various locations. The North Roadways and South Roadways were replaced in two separate contracts. After traffic was rerouted, the existing decking was removed, two lanes at a time, and replaced with a closed rib orthotropic deck system. Special tilting jigs and gantries were used to bring the new panels to location for placement and field welding of the orthotropic deck plate. New steel roadway barriers were also added. The approaches to the bridge were widened. The existing short-span deck system supported on steel columns was opened up and replaced with longer 125-foot spans on concrete hammerhead piers. A new pedestrian footwalk-bikeway system was designed for barrier-free access across the bridge.

Subway Reconstruction

Two subway tracks cross the Williamsburg Bridge from the first subterranean station in Manhattan to the first elevated station in Brooklyn. New York City Transit (NYCT) had planned a signal upgrade capital program for this line, and it was incorporated into a complete rehabilitation of the track stringers and support system, signal system, and rails. New relay rooms were added for a state-of-the art signal and communication system. The track profile was revised to increase underpass clearance at several cross streets on the Manhattan Approach.

CURRENT WORK

Main Tower Strengthening

Major reconstruction work was planned for the main towers. In the 1930's additional steel plating was added to the steel towers, presumably because it was realized that the dead and live load on the bridge had increased significantly since it first opened. The wooden carriageways had been replaced with concrete/steel deck, traffic volume had increased, and subways were now operating on the bridge instead of trolleys.

The designer found through finite element modeling that during maximum current live load and extreme temperature conditions that the main towers were overstressed. NYCDOT determined that this overstress condition was undesirable for rehabilitation work intended to last for the next 100 years. Therefore, the main towers required strengthening. The method chosen to strengthen the towers was similar in principle to method used in the late 1930s. Additional reinforcing plates were added to various faces of the towers above and below the roadway deck. Since the towers are not overstressed in the dead load condition, the exact amount of pre-stressing introduced in the new reinforcing plates was not of ultimate importance. Their purpose is to help distribute live load.

Plate packs of various lengths were added to reinforce the entire length of the affected tower faces. An inner and outer reinforcing plate comprises each plate pack, with the inner plate being of suitable thickness with perforations to match the tower's existing rivet pattern. Each tower consists of eight main columns. In each tower, the four columns on the main span side of the tower were reinforced. Below the roadway and stiffening truss, these four columns are vertical and reinforcing was required on the North and South fascias of each column. Above the roadway, these four columns are inclined in both the longitudinal and transverse directions as they extend to the tower top and saddle rooms. The two exterior columns in this line of four columns were reinforced on the faces in the direction of bending (East and West faces). The two interior columns were reinforced on the North and South faces.

Figure 4. Steel erector's shop test of reinforcing plate tightening procedure, before performing the operation on the bridge.

The reinforcing procedure consisted of first building a temporary scaffold with decking over the operating roadways and subway track areas. A temporary roller and guide angle system with a motorized winch at the tower top was used to pull plates up the tower faces and into position. This system was used successively on each tower face and was designed by the steel erector to be used on all dihedral faces. The reinforcing system consisted of two plates, a fill plate and an exterior reinforcing plate. The first two top plate packs in succession were placed in position at the tower top and bolted at their top ends. A block of suitable thickness was placed against the tower column at the midpoint of the upper plate pack, and the plate pack was then drawn down at its lower end and the reinforcing splice plate was then installed, locking the upper plate pack in position. The block was then removed, and the rest of the upper plate pack was drawn down using temporary undersized extra-long bolts. The plate pack was then secured by field-drilling and installing the final high-strength bolts. The procedure was then repeated down the face of each tower column. Approximately 815,000 pounds of steel reinforcement was added to the main towers. The procedure was first tested in the steel erector's shop, as shown in Figure 4.

Bearings

The bearings at the anchorages (Panel Point 0 East and West) and at the main towers (Panel Point 30 East and West) were replaced.

The existing bearing mechanism at the main towers consisted of a rocker arm with an upper pin in the stiffening truss bottom chord. The rocker arm's lower pin was connected to a complex load path system, portions of which were added after the bridge first opened, consisting of a built-up girder-column frame that partially supported some of the bearing load. Over the years some of the pins exhibited excessive wear, such that the stiffening truss at the Southeast bearing location (Brooklyn Tower South) was approximately 2 inches lower than at the Northeast bearing location. These rocker arms were sometimes "frozen" in position, and did not allow the bridge to move smoothly with changes in dead and live loads and temperature effects.

The rocker arm at each of the four locations was replaced with a special combination of sliding and pot bearing, designed for 2,500 kips. Since the existing girder-column frame support system was inadequate for accepting 100% of the dead and live loads in the new configuration, this bearing support system needed to be replaced as well. There was no purchase area to jack the stiffening truss off of the existing bearing support system. Furthermore, rail and vehicular traffic could not be shut down except for short periods while the actual jacking operation of lifting or lowering the stiffening truss was occurring. Each location required a temporary steel tower and strongback system for jacking the stiffening truss to relieve the load in the rocker arm. The temporary bearing system needed to sustain longitudinal bridge movements of +/- 16 inches, and a maximum bearing coefficient of friction of 6%. Supplemental heating was required for winter work. After the temporary tower was constructed and the stiffening truss jacked to relieve the load in the rocker arm, the arm was cut. The rocker arm system was removed along with its supporting truss. The girder-column frame system, now encased by the temporary steel jacking tower, was removed in sections, and the new box girder-box column bearing support frame was then assembled in its place. The new bearing was then installed and the stiffening truss was lowered onto its new combination pot/sliding bearing.

At the anchorages, a similar challenge was encountered. The existing bearing consisted of upper and lower castings with a central pin to provide rotation. The lower casting rested on a keyed roller nest that provided longitudinal movement. A two-jack system with strongback was used to jack the stiffening truss off the bearing, using the anchorage ledge for purchase. Since access was severely limited by the stiffening truss and anchorage back wall, the strongback system required additional reinforcement of the stiffening truss at the localized area of lifting. The existing bearing was removed, and new pot/sliding bearings with 1,200 kip capacity were installed.

Suspender Adjustment

Over the years, dead and live load on the original bridge had increased. This caused the stiffing truss to flatten out on the main span and increased the stresses in the stiffening truss chords. Since the stiffening truss is hinged at the main towers, this joint also caused a visible kink in the subway rail profile at these locations, especially on very hot summer days. Subway trains were required to reduce speed when riding over these profile kinks. NYCT's strategy to boost system capacity by increasing existing line throughput was hindered by this speed reduction over the Williamsburg Bridge.

The profile of the main span was raised to match its profile at the time of original construction. This would alleviate two problems: stiffening truss chord stresses and track profile discontinuities. All suspenders from the main towers to midspan were adjusted to raise the bridge profile. The maximum suspender adjustment was 21 inches at midspan, tapering to a 1-13/16 inch adjustment at the first suspender. Each suspender socket was foreseen with a threaded tension rod attached to a suspender adjustment link and equalizer when it was replaced as part of an earlier contract in the rehabilitation. Temporary rods were threaded into the suspender adjustment links, and a jacking yoke was attached to the temporary rods and to the suspender above the socket. In this way, the suspender sockets were jacked against the adjustment link, and the tension rod loosened so that its adjustment nuts were retightened, shortening the length of the tension rod. The tension rods were saw-cut as they grew too long for working access.

The sequence of adjustment was optimized using a finite element model of the suspension bridge that had been prepared for the overall reconstruction design effort. Adjusting suspender lengths starting at the main towers and working toward midspan resulted in the fewest number of adjustments. The increments of the adjustments were maximized at 2 inches. This maximum increment of adjustment allowed subway trains to continue operating on the bridge without interruption, because NYCT specifies that the maximum curvature in a 31-foot chord (the centerline-to-centerline distance of the wheel trucks) is +/-1/4 inch. Each adjustment during the sequence was checked for this tolerance on the computer. With each suspender adjustment link and equalizer engaging two cables, an adjustment at one location raised two of the four cables at a time. The steel erector was required to adjust all four cables simultaneously (North and South) at the analogous East and West panel points to ensure symmetry and adherence to the tolerance. Ten passes, for a total of 1,116 adjustments, were required to raise the profile 21 inches at midspan. A typical suspender adjustment jacking system is shown in Figure 5.

Figure 5. Suspender adjustment showing the two cable suspenders with tension rods being jacked.

Miscellaneous Improvements and Conclusion

Various other improvements were carried out to prepare the bridge for its next 100 years of service. Two traveling maintenance platforms were installed for inspection and maintenance of the main span. The traveling maintenance platforms are approximately 119 feet wide and 17 feet long, in order to inspect one complete panel point without needing to move the platform. The platforms were tested in the fabrication shop on a dummy rail system and then barged to the bridge, lifted with their rails in place, and attached to the new rail system installed as part of the project's scope. A new hoist system for each anchorage chamber is intended to haul barrels of oil and other equipment for oiling the cable strands. New access platforms in the anchorage will aid in inspecting and maintaining the cable strands. A ventilation system will also be installed in each anchorage chamber. New security features are also included.

Extensive corrosion on the main and intermediate tower bracing necessitated replacing these members. Old sections composed of angles and lacing bars were replaced with built-up I-sections with web perforations to reduce weight, drain water, and reduce build-up of debris that would aggravate corrosion. Over 7,000,000 pounds of new steel replaced existing corroded structural steel or provided enhanced access through new maintenance platforms and walkways.

The Williamsburg Bridge celebrated its 100th birthday on December 19, 2003. The hard work of intensive inspection, maintenance, and reconstruction have prepared the bridge to embark on another 100 years of service, and NYCDOT can proudly say that it has saved another familiar New York City treasure on the East River skyline. The authors wish to thank the thousands of design engineers, project engineers, project managers, construction managers, ironworkers, crane operators, environmental engineers, historical researchers, expediters, administrative assistants, and other workers of every imaginable skill whose individual expertise over the past nearly two decades helped save for future generations a marvel of engineering: the Williamsburg suspension bridge.