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Cable Anchorage Repairs on New York City Suspension Bridges

Réparation de l'ancrage des câbles des ponts suspendus à New York

Reparaturen an Kabelverankerungen New Yorker Hängebrücken

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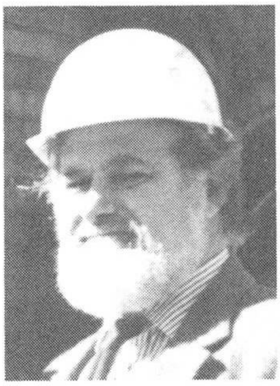

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SUMMARY

Severe corrosion in the eyebars anchoring the main cables of the Manhattan and Bronx-Whitestone bridges led to concern about the reduced level of safety. Innovative steps to strengthen these members by cutting and re-anchoring cable strands or by prestressing are presented. Less extensive repairs to cable strands on the Triborough Bridge and a method of holding strands on the George Washington bridge during repairs are also described.

RÉSUMÉ

La corrosion sévère des ancrages des câbles principaux des ponts de Manhattan et de Bronx-Whitestone suscitait l'inquiétude à cause de la réduction de la sécurité. Des méthodes nouvelles pour renforcer ces éléments, en coupant et ancrant de nouveau les torons des câbles, ou en utilisant la précontrainte, sont présentés. Des réparations moins laborieuses des torons des câbles du pont de Triborough et une méthode pour immobiliser les torons du pont de George Washington durant les réparations sont aussi décrites.

ZUSAMMENFASSUNG

Starke Korrosionserscheinungen an den Oesenstäben, die die Hauptkabel der Manhattan- und Bronx-Whitestone-Brücke verankern, liessen eine Reduktion der Tragsicherheit befürchten. Es werden neuartige Methoden vorgestellt, wie durch Abschneiden und Neuverankerung der Kabel oder durch Vorspannung diese Bauteile verstärkt werden könnten. Ferner werden preiswerte Kabelreparaturen an der Triborough-Brücke und eine Methode zur provisorischen Kabelhalterung während Reparaturen an der George-Washington-Brücke erwähnt.

1. INTRODUCTION

In 1850, the collapse of the suspension bridge at Angers brought to an end suspension bridge construction in France for 20 years. The cause was corrosion of the iron wires inside the concrete encasement below the ground level. [1] Wires had been embedded in this manner for 20 years, based on observations that iron bars embedded in concrete do not corrode. The bundled wires unfortunately are not bars. The mishap led to regulations requiring solid bars embedded in concrete to which to anchor cables. In 1845, Roebling anchored his cables by looping his wires around a strand shoe, much like passing a rope around a thimble, and fastened this to eyebars embedded in the masonry anchorages, a system which has been used in nearly all American suspension bridges since that time.

The steel eyebars anchoring the cables on two important suspension bridges in New York City, the Manhattan Bridge across the East River between Manhattan and Brooklyn, and the Bronx-Whitestone Bridge, between Queens and the Bronx, are the subjects of major rehabilitation projects. During routine inspections, it was noted that the paint on the eyebars just above the face of the concrete in which they are embedded was subject to exfoliation caused by expansion of the rust below. The bars had been painted only a few years before.

When chipping off the layers of loose rust, it was seen that a hard dark gray layer of corrosion product was firmly attached to the steel. Wire brushing only polished this material, and chipping with chisels and hammers was necessary to remove it. In both bridges, it quickly became obvious that the dark corrosion product concealed considerable section loss, and removal by grit blasting was required to clean the bars to white metal. During this process, it was found that the steel bars are indeed protected from corrosion inside their concrete embedment. In both cases, corrosion loss stopped abruptly at the concrete surface. Above the concrete surface, varying degrees of corrosion were found, with losses exceeding 40 percent in some eyebars (Figure 1, in inches).

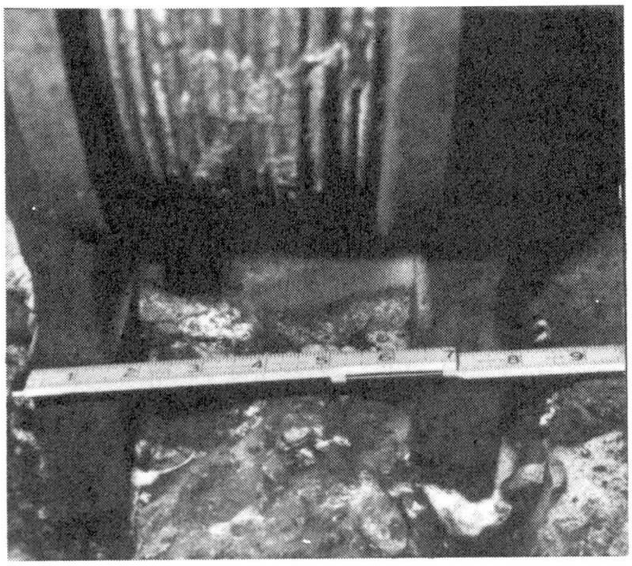

Figure 1. Corroded Eyebars on Manhattan Bridge

In both cases, drainage from the roadway is the major culprit in causing the corrosion. In the Manhattan Bridge, this chloride laden water entered through cracks and porosity in the unreinforced concrete vaults, exacerbated by the presence of an abandoned, but not sealed, system of clay tile drains in the concrete.

On the Bronx-Whitestone. the water entered through a joint between the roadway and -the anchorage and fell onto the concrete just next to the eyebars.

On both these bridges the eyebars emerge only a few feet from the concrete surface inside the very confined cable chambers - 3.3 m wide on the Manhattan Bridge and 4.6 m wide on the Bronx-Whitestone. The eyebars are arrayed in very tight groups, with only 50 to 125 mm between eyebars across the width of the chamber and about 350 mm vertically. It is virtually impossible to reach inside to the center of the array, and special calipers had to be made to measure the remaining thickness of the eyebar shanks.

2. MANHATTAN BRIDGE

On the Manhattan Bridge, the average loss in section in one of the cable anchorages was over 27 percent, with losses in some eyebars up to 44 percent. An analysis of the remaining eyebar strength, showed that the cable could not safely carry the transit or highway loads on this side of the bridge supported by this cable (there are four subway tracks on the bridge). Fortunately, this side of the bridge was closed for rehabilitation work, and the closure was extended for 18 months so the cable anchorage could be reinforced.

Because of the lack of access to the eyebars, a new anchorage system for half the cable was designed (Figure 2). The anchorage has longitudinal vaults 2.5 to 6 m wide, separated by 1.5 m thick concrete walls. The 2.4 m deep steel transfer girders were installed above and below the eyebar array, extending into adjacent chambers through openings cut through the concrete walls. These girders are anchored into the massive gravity anchor block by means of seven high strength steel rods at each end, installed in 860 mm diameter inclined shafts drilled 20 m into the concrete. The lower end of the shafts was accessed by means of tunnels driven into the back face of the anchorage, through which steel anchor girders were installed to receive the bottom end of these anchor rods.

The cable had many corroded wires; 10 percent of the wires had ferrous rust and 34 wires were already broken because of section loss. Five hundred wires had badly rusted sections removed and new wires spliced in. It was necessary to cut and reconnect 18 of the 37 strands of the cable to the new transfer girders, just to provide enough space to access inner strands. Half of these were then cut and reanchored to the vacated eyebars.

The procedure of reanchoring the strands to the new girders consisted of cutting one strand, using clamps and jacks to gradually relieve the force in the strand. The wires in each half strand were cleaned, fluxed and fastened to sockets using molten zinc. These sockets were connected to the transfer girders by high strength rods and had a force equal to the calculated load on the bridge jacked into them by means of Biach jacks. The force in each strand due to dead load is 1,550 kN with live load the total strand force to 2,100 kN. During jacking, a force of 2,760 kN was applied to set and test the sockets, and to be certain that the strand was pulled back out of the cable, into which it had slipped by about 15 mm. The force was then lowered to 1,600 kN and the nuts turned into bearing.

In order to prevent stretching of the anchor rods or flexure of the girders as load was transferred to them, the anchor rods were prestressed to hold the transfer girders firmly against the concrete of the anchorage. Because of the great force involved, this prestress was applied in steps as the cable strands were attached to the girders. During all operations, forces in the strands were monitored by means of strain gages attached to wires, as well as to the rods between the sockets and the transfer girders.

After all strands were reanchored, the bridge was shut down to subway traffic for one night, and the strand forces were tuned. All strain gages were read at each step; a program was developed to provide the force in each strand at each step. Two rounds of tuning were required to bring the strand forces to within 3 percent of the average strand force. The anchor rod shafts were then filled with concrete, and masonry walls were built to seal off the cable chambers. To prevent further section losses in the eyebars and cable, the chamber will be dehumidified.

The cable socketing procedure, which required specially cast steel sockets capable of holding 128 bridge wires was thoroughly tested in advance by requiring that the Contractor attach one socket of each size to a test section of strand, test the socket in tension, and saw cut the socket into quarters to inspect the interior. A final procedure was developed, requiring preheating to 427°C. Because of the high temperatures required, testing of wire specimens removed from the cable as well as new wires were tested by immersing in molten zinc at 427°C and 538°C. These tests show that the tensile strength decreases by up to 28 percent at 538°C. The socket tests, however, show that the loss of strength is only 8 percent for the entire assembly, an acceptable loss because the anchorage is not the location at which the cable is subjected to its maximum tension.

3. BRONX-WHITESTONE BRIDGE

On this bridge, the losses in area of the eyebars ranged up to 15 percent. Because of the short length subjected to corrosion, and because yield had not been reached in the corroded section, the ultimate strength of the ASTM A7 steel in the eyebars was depended upon for reserve strength until the repair could be made. Several of the severely corroded eyebars have been strain gaged and monitored to be certain that they are not subjected to yield.

In this anchorage, the eyebars are arranged in horizontal alignment, as opposed to the Manhattan Bridge, where the center row of eyebars is offset one half space from the others. Thus, it is possible on the Bronx-Whitestone bridge to needle girders through the loops formed by the strands. The wider cable chamber also makes it possible to provide direct anchoring of girders into the concrete inside the chamber. Girders have been designed which will bear directly on the front face of the strand shoes. By jacking forces into the girders by means of high strength anchor rods (ASTM A354 Grade BC with a tensile strength of 965 MPa), the girders will prestress the eyebars, thus reducing the tensile stress to an acceptable level. The forces in the eyebars and anchor rods will be measured by means of load cells permanently installed in the structure. This arrangement avoids the need for cutting cable strands. (Figure 3).

4. TRIBOROUGH BRIDGE

The forerunner of these major rehabilitation projects was the reanchoring of one strand one cable on the Triborough Bridge in New York City. More than half of the wires in the strand had been broken, again because of drainage from the deck above, and when the Contractor started to work on the rehabilitation, the remainder of the wires rapidly failed as well. The resulting tangle of wires had to be realigned by means of steel combs which aided in holding the wires while clamps were installed to hold the strand in shape.

Because it was the first field socketing of a suspension bridge cable in place, it was decided to use four sockets on the strand, smaller than those later used on the Manhattan Bridge. The procedure developed for preheating, providing filler tubes for zinc in the side of the socket, aligning and insulating was valuable in later designing the Manhattan Bridge procedure.

The strand shoe to which the strand was affixed was saw cut away from the eyebar pin, a new bearing block installed behind the pin and high strength rods and jacks used to re-stress the strand. There was concern that the strand would slip into the cable, and plans had been made to temporarily reanchor each quarter strand. The full release of the strand made this unnecessary, and pairs of quarter strands were reanchored directly to the original eyebars as they were completed. There was no difficulty in prestressing the strand, and it was pulled smoothly back out of the cable.

6. GEORGE WASHINGTON BRIDGE

Again, leakage from the roadway above has caused substantial wire loss and breakage in three of the 61 strands in one of the cables. The Owner has decided to provide tiebacks to prevent further loss in strand force while socketing these strands. Working with the contractor, a system of clamps, bars, tension rods and a strut have been designed which can be adjusted to fit any of the three. Gusset plates of ASTM A514 steel will be used to connect the clamp to a strut which provides the resultant force to turn the line of action of the strand tension downwards towards an anchorage prestressed against the concrete.

Because of limited space between strands and limited clearance to the steel framing supporting the roadway, flat eyebars are connected to the gusset plates to provide the needed tension. These eyebars anchor to a jacking beam which is, in turn, anchored by two high strength rods to the temporary anchorage.

Upon completion of the sockets, the strands will be reanchored to the eyebars in a manner similar to the Manhattan Bridge, and the tension in the temporary anchorage relieved gradually as the force is transferred to the eyebars.

7. CONCLUSION

These four projects demonstrate the feasibility of repairing deteriorated suspension bridge cable wires or eyebar anchorages. Thus far, no two cases have been alike, but with the application of innovative design, the repair of these important elements is possible and the life of these major structures extended.

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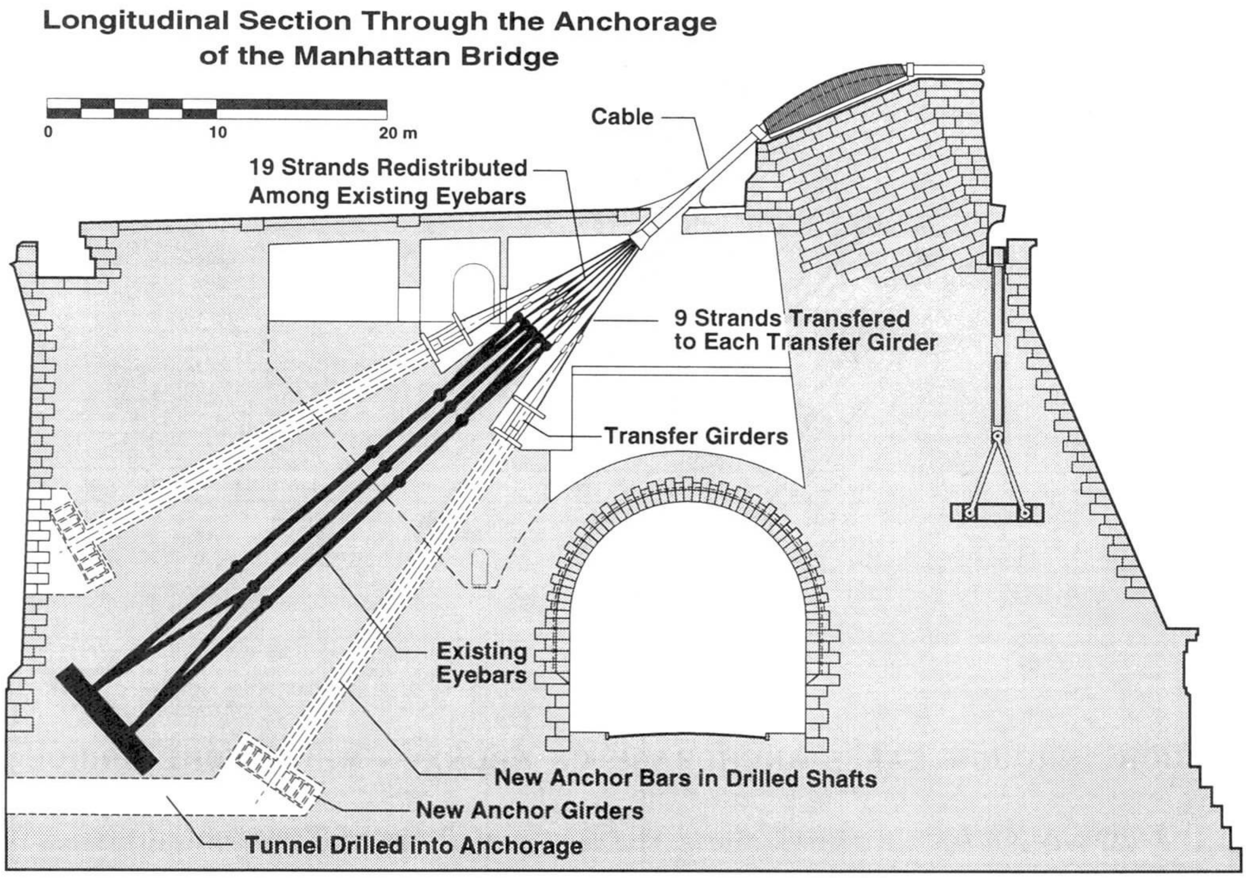
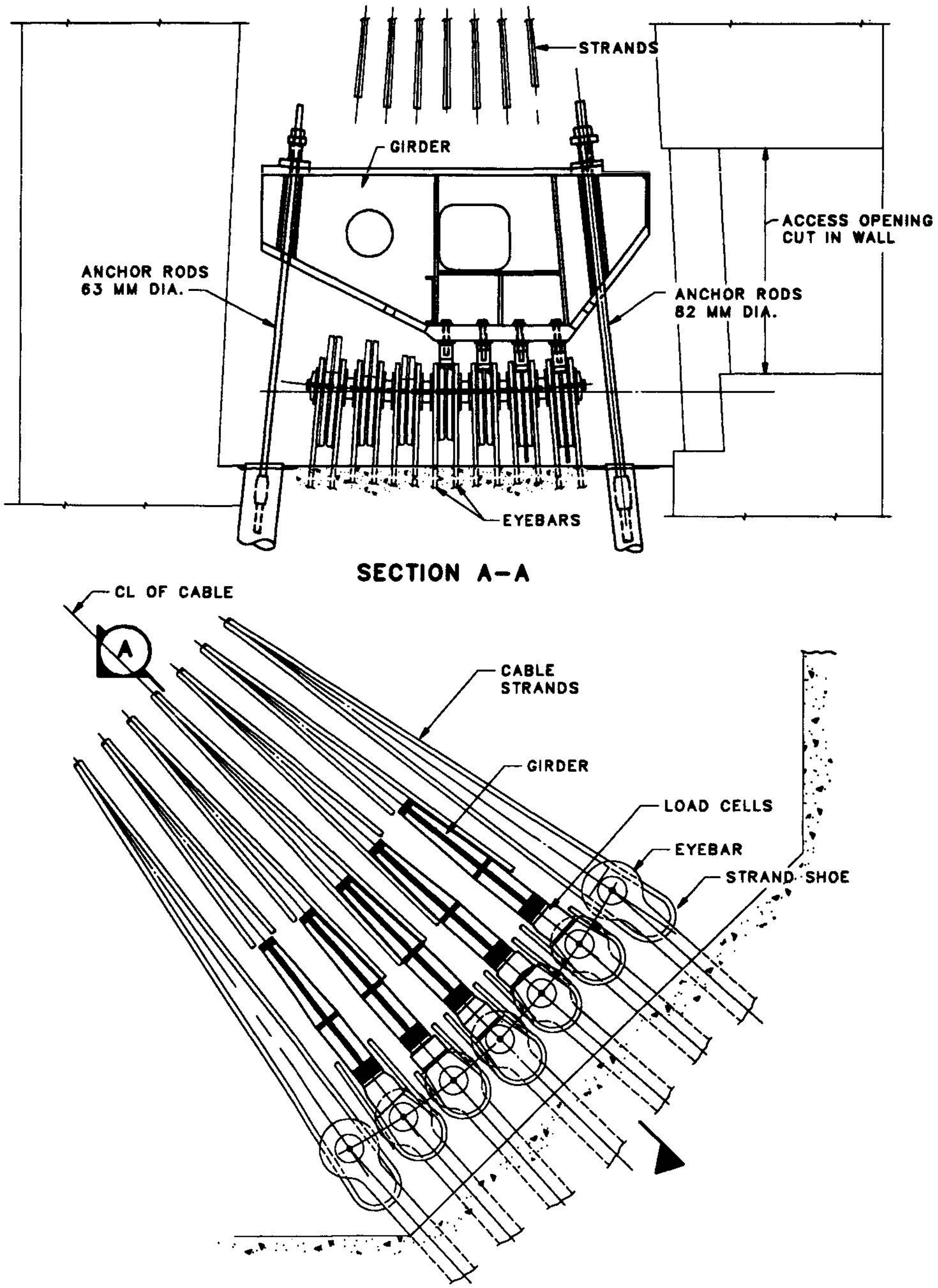


Figure 2. Reanchoring Scheme for Main Cable on Manhattan Bridge



SECTION THROUGH CABLE ANCHORAGE OF BRONX – WHITESTONE BRIDGE

Figure 3. Girders to relieve stress in eyebars of Bronx – Whitestone Bridge