Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 57/1/57/2 (1989)

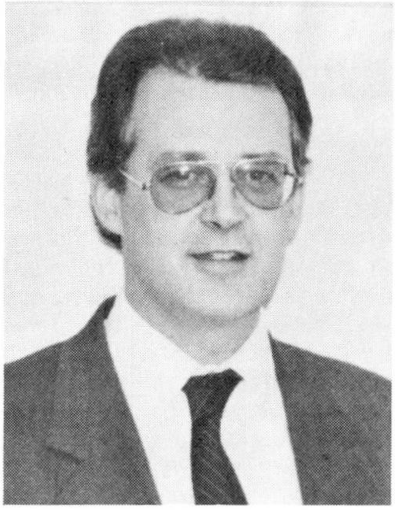
Rubrik: Workshop 3: Durability of suspended structures

Inspection Evaluation, and Rehabilitation of Suspension Bridge Cables

Inspection évaluation et remise en état des câbles de ponts suspendus

Inspektion Beurteilung und Instandsetzung der Kabel von Hängebrücken

Peter SLUSZKA
Vice President
Steinman
New York, NY, USA



Peter Sluszka, born 1948, received his degree in structural engineering at Hofstra University, Uniondale, NY. He has supervised numerous bridge inspection, bridge rehabilitation, and new bridge design projects, including New York City's four East River Bridges. He is currently Principal-in-Charge of Steinman's New York and Chicago operations.

J. Joseph HAYDEN
Vice President
Steinman
New York, NY, USA

J. Joseph Hayden, born 1930, received his BSCE at Norwich University, Northfield, VT. He has completed various assignments on many of the world largest structures including, the straits of Mackinac, George Washington and Verrazano Narrows Bridges in the USA and the Tagus River Bridge in Lisbon, Portugal. At Steinman, he is Division Manager of International Operations.

SUMMARY

Recent inspections of the main suspension cables of the Williamsburg, Brooklyn (New York, NY), and I-74 (Bettendorf, Iowa) Bridges provide a sampling of the longevity and durability of three differing types of cable construction. The cables of each bridge will be rehabilitated in a manner dictated by the details of the original design.

RÉSUMÉ

Les récentes inspections des câbles principaux des ponts de Williamsburg et Brooklyn (New York, NY) et de la I-74 (Bettendorf, Iowa) fournissent un échantillon de longévité et durabilité de trois types de ponts suspendus différents. Les câbles de chaque pont vont être remis en état en respectant les détails des conceptions originales.

ZUSAMMENFASSUNG

Kürzliche Inspektionen der Hauptkabel der Brücken von Williamsburg und Brooklyn (New York, NY) und der I-74 (Bettendorf, Iowa) stellen eine Stichprobe für die Dauerhaftigkeit und das Langzeitverhalten dreier verschiedener Typen von Hängebrücken dar. Die Kabel jeder Brücke werden in einer durch die Einzelheiten des ursprünglichen Entwurfs bestimmten Art und Weise instandgesetzt.

1. THE THREE BRIDGES AND THEIR CABLES

1.1 Brooklyn Bridge

Brooklyn Bridge spans New York's East River, connecting Manhattan with Brooklyn Heights. It is the most famous of John A. Roebling's suspension bridges, completed in 1883 and now a national monument. The main suspended span is 486 m long and is flanked by two suspended side spans, of 283 m each. Each of its four main cables is comprised of 5358 galvanized steel wires, 4.67 mm in diameter. After spinning, the cables were compacted, coated with a thick paste of white or red lead, and then tightly wrapped with 3.8 mm diameter galvanized steel wire. This was then sealed with several coats of paint. The wrapped cables are 400 mm in diameter.

1.2 The I-74 Bridges

The I-74 Bridges are twin, nearly identical suspension bridges crossing the Mississippi River between Bettendorf, Iowa, and Moline, Illinois. The original bridge, now serving Iowa-bound traffic, was completed in 1935, and the newer structure now serving Illinois-bound traffic, was completed in 1959. Both have main suspended spans of 226 m, and suspended side spans of 113 m. Each bridge is supported on two cables, 241 mm in diameter, including wrapping wire. These cables are of a construction that markedly differs from the Brooklyn Bridge. Rather than building up the cross section with thousands of individual wires, these cables consist of 37 shop-fabricated galvanized structural strands, 31 of 38.1 mm diameter, and 6 of 25.4 mm diameter. Each strand contains 19 or 37 wires, twisted in layers. The strands are laid parallel to each other, roughly forming a circular cross section. Extruded aluminum fillers are added around the circumference to round out the surface, and the whole is tightly wrapped with 3.8 mm diameter galvanized wire, and covered with three coats of paint.

2. INSPECTION SAMPLING, AND TESTING

2.1 Brooklyn Bridge

Inspection of the Brooklyn Bridge cables was performed in two distinct parts: Wrapped areas between the anchorages; and the unwrapped individual strands within the anchorage chambers. The four cables were visually inspected end to end and based on conditions observed, an in-depth investigation was programmed.

2.1.1 Wrapped Portions

Two sections of the cable in the main span and one section in the Manhattan side span were unwrapped and split open with oak wedges. Because cable bands are located every 2.3 meters, it was first necessary to remove the suspender and cable band (or cable post) to provide enough free cable (about 7 meters) to penetrate with the wedges. It was found that the wrapping wire beneath the cable bands had begun to corrode significantly due to the tendency for moisture to lay between the ribbed surface of the wrapping and the smooth inner surface of the cable bands. The outer layer of main cable wire immediately below the wrapping and cable bands had corroded sufficiently to consume most of the zinc galvanizing and rusting of the wires had occurred. One wire had lost over 75 percent of its cross section and had broken. The remainder exhibited localized loss of material that is commonly referred to as "pitting" although in the strict technical definition no real pits were present (the technical definition of a pit is a defect that is at least as deep as its width at the surface). At the areas between cable bands, the surface wires were still in excellent condition. Dried red lead paste covered most of the surface, but in occasional spots powdery zinc oxide from the galvanizing coated the exposed wires.

Oak wedges were driven between the wires at four radial points (one point at a time) and the cable was penetrated approximately 15 cm, or almost to its center. It was found, even under the cable bands, that all corrosion had been limited to the outside layer of wires. From the second layer in, the original galvanizing was still in near-perfect condition.

Fifty seven wire samples were cut from the cables at various locations and sent to Columbia University's Carleton laboratory for testing. The cut wires were replaced with lengths of new wire spliced in using a combination of pressed-on and threaded ferrules.

The results from the laboratory indicated that the typical corroded wires had not lost measurable strength as compared to uncorroded wires, but it was apparent that the original material was not uniform and was of considerably lesser quality than modern bridge wire. Carbon content varied from 0.55 percent to 0.91 percent, whereas modern wire is generally in the range of 0.78 to 0.82 percent. Average tensile strength was 1,100 MPa, and the proportional limit was approximately 690 MPa. The most significant finding was that the original wire was of low ductility: reduction of area varied from practically zero to 26.5 percent; reduction of area for modern galvanized bridge wire will typically be on the order of 35%.

Fatigue testing results and microscopic examination of longitudinally sectioned wires provided the assurance that there was no evidence of stress corrosion cracking in the wires.

2.1.2 Cable at Anchorages

The initial inspection on the anchorages revealed serious corrosion and numerous broken wires were found both between the splay band and strand shoes, as well as at the back of the shoes, where concrete had been placed in contact with the wires. The confined space of the anchor chambers provided barely enough room for a man to pass between the strands and the chamber walls. It was impossible to determine the full extent of corrosion damage at the shoes or within close proximity to the splay band. It was apparent that extraordinary measures would be necessary in order to fully examine and evaluate the conditions at the anchorages. The possibility existed that entire strands were damaged beyond repair, and it was therefore decided to develop procedures and equipment to splice entire strands concurrently with developing a detailed program to continue the investigation.

First, the anchor chambers would need to be enlarged to provide working space; second, the existing splay bands would need to be removed to allow spreading of the strands for inspection at the splay points, and third; repair details for various possible conditions needed to be developed. With the assistance of the faculty and staff at Columbia University's Carleton Laboratory, a mock-up of a typical anchor chamber and splayed cable was constructed. Clamps, sockets, and jacking equipment were designed for the worst case scenario, in which entire strands would need to be cut, socketed, and reanchored in the field, something that had never been done before. New splay bands and strand spreader frames were designed.

Working in the mock-up, methods were tested for zinc-socketing of the strands in the horizontal, rather than the usual vertical position.

A contractor was awarded the contract to assist Steinman in enlarging the chambers, relocating the cable splay points, and if need be, cutting and replacing the deteriorated strands. It was decided to start at Cable B in the Brooklyn Anchorage. After the chamber had been modified, two temporary splay bands were installed spanward of the existing band, and the old band was removed. In a series of "leap frog" moves, the two temporary bands were moved up along the cable until they reached the location of a new permanent splay band about 4 meters from the original splay. Horizontal and vertical spreader frames were placed between the strands and the strands were gradually spread apart using specially designed hydraulic equipment. The placement of the new splay was such that the total length of each strand would be unchanged after the splay relocation was completed. Electronic strain gauges were used to monitor stresses in the anchor eyebars as the strands were spread.

Upon completion of the strand spreading and removal of concrete behind the strand shoes, a detailed inspection was made strand by strand. It was considered very fortunate by all involved that the serious corrosion and breaks were primarily confined to surface wires. Most of the wires were slightly corroded, or uncorroded, although much of the galvanizing zinc had been consumed by oxidation. The operations proceeded in the remaining seven anchorages and similar conditions were found. All in all, several hundred broken or seriously corroded wires were found, but these were repairable by splicing in new sections of wire, and no full strands needed to be replaced.

This work was completed in early 1987.

2.2 I-74 Bridges

Our assignment on the I-74 Bridges was to perform a close condition inspection of all cables and the superstructures of both bridges. The cables to be inspected included all handropes, main cables and all suspenders of both bridges.

2.2.1 Suspenders

All of the suspender ropes were inspected and as anticipated in bridges of this design with no center tie, one-way traffic, and increasingly heavy truck traffic, many of the shorter suspenders near mid span of both bridges contained cracked or broken wires. The mechanism which causes these breaks are fatigue related and caused by the differential longitudinal motion under live load of the main cable with respect to the top chord of the stiffening truss. The measured motion of 19 mm though relatively small, is sufficient to alternatively stress the suspender wires near the extremity of the suspender. The cyclical loading causes the wires to break over a period of time and the number of breaks occurring increases rapidly once the critical number of live load cycles has been reached. It has been recommended and accepted that center ties be installed on both bridges and that all suspenders with cracked wires be replaced.

2.2.2 Main Cables

The main cables of both bridges were inspected from anchorage to anchorage and included all associated cable bands, saddles and appurtenances.

The anchorages were inspected first and found to be in very good condition. No deterioration, rust blooms, moisture or staining were found on the splay saddles, splay strands, strand shoes or eyebar assemblies and no cracks or water were found in the chambers themselves.

The next step was to inspect the main cables between anchorages to determine if water had entered the cables and if so what damage had occurred as a result. Here we found that the paint on the cable wrapping was in poor condition with many cracks in the paint layers, some loss of galvanization and some rust on the wrapping wire. In addition, we found pop-outs of the bottom caulking and staining had occurred at many cable bands which is a sure sign that water under pressure or water under freezing conditions had been present in the cable. At random we removed some cable band bolts and found that no bolts from the top of any band was rusted, however, all bolts removed from the bottom of the bands were deteriorated with some section loss and the bolt chambers were filled with rust. Some of the rust and some of the bolts were wet. Next we removed some of the sealed covers from the tower saddles and the cable bent saddles to see if any leakage was occurring at these points. We observed that the sealed covers were watertight and that the cables across the saddles were in like new condition. The covers were replaced and resealed. Based upon our findings that water was entering the cable thru the many small openings in the paint protection at the wrapping wire it was decided to unwrap the main cables at various points between cable bands for closer inspection. The areas to be unwrapped were designated by us and were chosen to reveal varying types of cable exposure to water. Total length of unwrapping was 83 meters (horizontal projection) on the 4 main cables.

The unwrapping procedure began by first having the contractor install the work platform on both sides of the cable for the full length of the panel to be worked on.

To start the unwrapping, the wrapping wire was cut with a small electric grinder at a designated point where damage to the main bridge strands would not occur. Once the initial cut was made, the wrapping was unwound by hand, cut into pieces using a wire cutter and removed. Tie wire was placed around the cable to hold the aluminum fillers in place. With the wrapping wire removed, the strands and fillers were exposed.

Each of the 18 aluminum fillers was marked with an identification number as it was removed from the cable and placed in a special box made to hold the fillers. These fillers were then taken to the plaza area on the bridge where they were wire brushed clean and painted with neoprene paint.

With the aluminum fillers removed, the strands were inspected. Hard wood wedges driven between the strands along with a hydraulic wedge were used to spread the strands apart. A putty knife, steel awl, magnifying glass, flashlight, and a fiber optic device were used to inspect the strands. All of the strands, except where noted, were covered with a maroon colored paint. The paint had been applied before the strands were placed on the bridge.

In some locations, the strands were found to have white oxide formation along with, or sometimes without, deposits of ferrous rust. In cases where the ferrous rust was at a more advanced stage, "pitting" typical local corrosion was found. In order to determine if the individual wires had any defects such as cracks, the wires were carefully cleaned using a stiff bristle brush and a cleaner solvent to remove as much white oxide and ferrous rust deposit as possible. Once the wire was sufficiently clean, the wires were carefully examined by an engineer using a magnifying glass. No cases of visible wire cracking were found. Since the cables are composed of twisted wire strand, it was undesirable to remove wire samples for labratory testing, and the conditions found did not warrant further investigation.

Since the extent of damage was generally limited to localized areas, the condition was discovered in time to save the cables by applying a new protective wrapping of neoprene to preclude the entrance of water.

3. CABLE REHABILITATION PROGRAMS

3.1 Brooklyn Bridge

There were several factors that influenced the scope of rehabilitation required for the cables of the Brooklyn Bridge. In contrast to present practice, the cables had been wire wrapped continuously prior to installation of the cable bands and suspenders. While the original wrapping had admirably protected the cables throughout most of their length, the cable bands were trapping moisture and corrosion was taking place beneath them.

The bands were also prone to slipping down hill on the cable because their design precluded a secure clamping effect. The original red lead paste was dried out and did not afford the necessary sealing between the wrapping wires. It was also found during our general inspection that virtually all of the wire rope suspenders were seriously corroded near their lower sockets, and would need to be replaced, as would the diagonal wire rope stays.

The cable rehabilitation contract, designed and inspected by Steinman, includes the removal of all existing wire wrapping, cable bands, suspenders and stays. New bands of modern design and new suspenders will be installed, followed by the rewrapping and painting of the cables. The greater part of the cables will be rewrapped with galvanized wire bedded in a thick paste of red lead. At the sag points, where the cables pass below the roadway and are subject to splash by runoff water and deicing salts, the cables will be wrapped with 3mm thick neoprene wrapping material.

All eight anchorage chambers have been enlarged and now provide ample space for inspection and maintenance of the strands, which will remain in their newly spread configuration. All broken and badly corroded wires have been replaced with sections of new wire, using a technique developed by Steinman. Since past experience has shown that the cutting of threads on the existing wires is difficult and uncertain, a length of damaged wire is first cut out and to its two ends are spliced new wires using specially designed ferrules. These ferrules consist of a mild steel cylinder, approximately 10mm in outside diameter, bored to accept a hardened helical steel wire insert of slightly larger inside diameter than the original bridge wires. After inserting the end of one old and one new wire into the ferrule, a hydraulic press crimps the ferrule onto the wire, developing a splice that is 95 percent as strong as the original wire. The two mating ends of the new wires which have shop-cut threads, are then spliced using a ferrule with internal left and right hand threads. The threaded ferrules act like turnbuckles and permit the spliced wires to be stressed to a predetermined tension. After repair of the damaged wires, the cables are now more than adequate to carry the dead and live load of the bridge.

It is fully expected that the rehabilitated Brooklyn Bridge will serve New York City for at least another one hundred years.

3.2 I-74 Bridges

Our recommendations for protection of the cables was as follows:

Clean the loose paint from the cable exterior by wire brushing and wrap neoprene flashing completely around the cable along its entire length over the existing wrapping wire. The exposed neoprene wrapping surface should be painted for protection. The lead wool packing between the wrapping wire and the cable band will need to be removed and replaced with caulking in order to ensure a watertight seal.

It is not considered necessary to recommend complete removal of the wrapping wire because both the main cable and the wrapping wires are in relatively good condition. The major problem is that the lead-based paint on the exterior of the wrapping wire has failed, permitting water to enter the cables between the wrapping wires, and similar to other cables of this design, no red lead paste had been applied under the wrapping wire. Neoprene wrapping has been used on suspension bridges for the past 16 years with very good results. Neoprene wrapping placed over the original protection represents the best means of positively waterproofing the cables.

The cable bands should be reconditioned by removing the caulking from the bottom slot separating the cable band halves in order to permit any water which may leak into the cable to drain rather than being retained. It is also recommended that the lower cable band bolts be replaced with new ones and that the loose rust inside the cable band bolt housings be removed. This loose rust tends to retain moisture which is detrimental to the cable strands. A program of cable band bolt retensioning should also be performed at the same time.

4. CONCLUSION

These bridges can give the Engineering profession valuable insight into the longevity of different suspension bridge cable designs. Most notably, it can be seen that the Brooklyn Bridge, with its galvanized wires, red lead paste coating, and galvanized wrapping wire, performed almost perfectly for 100 years. The I-74 bridges, with galvanized strands, galvanized wrapping wire, but no paste sealer under the wrapping wire, will need relatively minor cable rehabilitation work after 50 years in service.

Inspection Program for the Lisbon Suspension Bridge

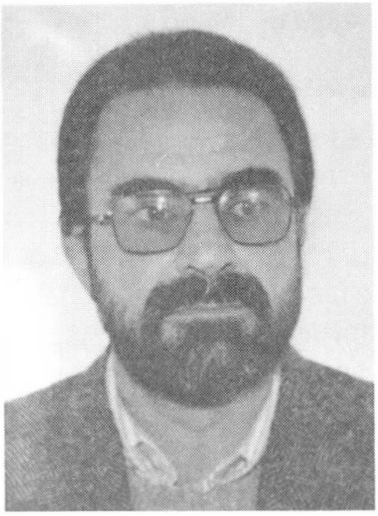
Programme d'inspection pour le pont suspendu de Lisbonne

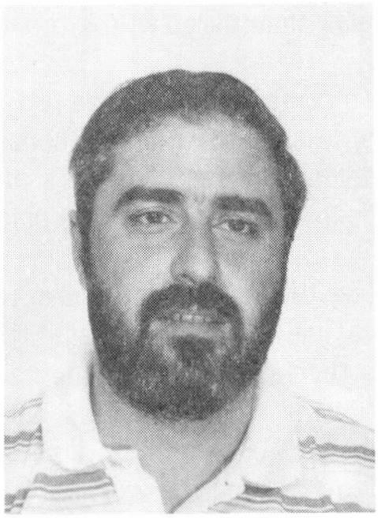
Untersuchungsprogramm für die Hängebrücke in Lissabon

Fernando BRANCO
Assoc. Prof.
Techn. Univ. of Lisbon
Lisbon, Portugal

António C. COSTA
Mec. Engineer
Instit. Soldadura e Qualidade
Lisbon, Portugal

João AZEVEDO
Assoc. Prof.
Techn. Univ. of Lisbon
Lisbon, Portugal





SUMMARY

The guidelines of the inspection program for the suspension bridge in Lisbon are presented. The program considered an overall inspection for corrosion and the analysis of the structural behaviour of several elements. The principal findings and the inspection techniques are presented.

RÉSUMÉ

On présente les lignes directrices d'un programme d'inspection pour le pont suspendu à Lisbonne. Ce programme consiste en une inspection générale de la corrosion et de l'étude du comportement de quelques éléments structuraux. Les résultats principaux et les techniques d'inspection sont présentés.

ZUSAMMENFASSUNG

Die Richtlinien eines Untersuchungsprogrammes für die Hängebrücke in Lissabon werden dargestellt. Dieses Programm besteht aus einer generellen Korrosionsuntersuchung und aus der Analyse des Verhaltens einiger Tragelemente. Die wichtigsten Ergebnisse und Untersuchungsverfahren werden beschrieben.

1. INTRODUCTION

The " 25th of April" bridge in Lisbon is one of the longest suspension bridges in the world with a total length of 2276m and a central span of 1013m. An observation program to study its structural behaviour was developed and implemented during its construction and carried on for several years after the bridge opening, in 1966.

Recently the Portuguese Highway Authority (J.A.E.) decided to widen the deck to carry six traffic lanes (presently it has 4 lanes). Simultaneously, studies are also being developed to introduce the railway traffic in the lower part of the deck, solution that was considered in the initial design of the bridge.

To come up with these projects, the implementation of a detailed inspection program of the structure was considered a priority task by the J.A.E. As a matter of fact during the last 23 years miner routine inspections have been undertaken, but now a deep assessment of the bridge was felt necessary.

Due to the unusual characteristics of this type of job a research was developed to define the guidelines of the inspection program. This is presented in this paper referring the main aspects to be considered in the inspection of the anchor blocks, towers, main cables, hangers, truss beam, joints and bearings. Based on the inspection, the main findings are also referred as well as some particular problems faced during the works.

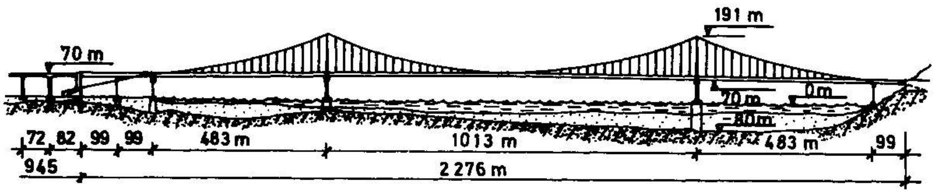


Fig. 1 - LISBON SUSPENSION BRIDGE.

2. THE SUSPENSION BRIDGE

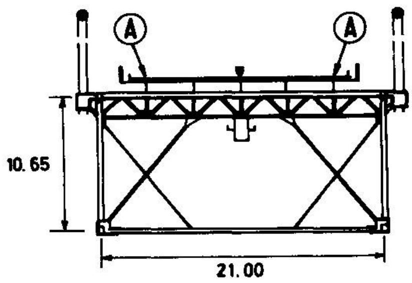
The "25th of April" bridge is a steel structure with a total length of 2276m connected with a concrete approach viaduct (north side) with 945m. The steel structure includes the suspended structure with a 1013m central span and two 483m lateral spans, and a supported continuous stiffened truss with a south end span (99m) and two north end spans (2x99m) (Fig. 1).

There are seven supports along the bridge: the two abutments (P_1, P_7), the two main towers (P_3 , P_4), an intermediate column in the south side (P_2) and two other in the north side (P_5, P_6). The suspension structure is defined by supports P2 and P5 at which the main cable passes below the deck level. These columns are fixed at the base and slip free for the deck, at the top. The main towers are 191m high and are fixed at the base in concrete caissons which found 80m below water level.

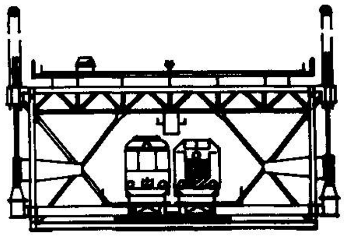
The truss beam is, 10,6m high and 21m wide, suspended from the hangers (23m apart) about 70m above water level. Fig. 2 shows the actual cross section and the future situation with the train. The actual widening design considers the space between the border of the upper deck and the hangers.

The main cables have a diameter of Ø = 0,586 m and are made of 11 248 steel wire (Ø = 5mm - f_{yu}= 1560 N/mm^2). During construction the wires were tied in groups of 304 units, then compacted and tied with helicoidal wire and finally painted with anticorrosive paint. The hangers are connected to the main cables with two shell clamps tied with high strength bolts.

The structure was built with several types of steel. The connections between steel members were mainly done with high strength bolts.



a) Actual



b) Future

Fig. 2 - DECK CROSS SECTION.

3. THE INSPECTION PROGRAM GUIDELINES

The two main objectives of this program are:

- To perform an overall inspection for corrosion problems;
- To check the structural behaviour of the bridge elements.

The study began with a preliminary research about suspension bridge inspection techniques [1,2]. Next the program was developed considering the guidelines for the inspection of each main structural element. These are briefly referred.

3.1 Anchor Blocks

Inside the concrete cameras, where the cable anchors are placed, usually high humidity may occur. This may be associated to corrosion problems what leads to a careful inspection of cables and anchorage. The main structural problem associated with these elements is its movement along the time, what may lead to the collapse of the bridge. Topographic periodical inspections are highly recommended.

3.2 Columns

The steel bridge columns and the towers need a general inspection for corrosion. Special attention should be paid to:

- The base of the columns where the highest forces usually occur;
- The transverse cross beam in the top of the towers where unusual forces may occur due to asymmetrical loading;
- The connections of the cables to the top of the columns, to check for eventual slips.

3.3 Main Cables

The problems that may occur in the cables are the corrosion and cracking of the wires. A visual external inspection should be done along the cable with particular attention to the anchor zones and the lower part of the parabola where the water from rain converges and accumulates.

For the internal inspection of the cables there are presently two electromagnetic techniques, available [4]: The Foucault Current Method and the Induced Current Method. The first one measures the oscillations in the magnetic field of a solenoid placed around the cable, which is proportional to the oxidation of the wires. In the second method one measures the induced current that arises in an alternative magnetic field placed around the cable, due to its imperfection. This technique was developed to find cracked wires which are shown by tension peaks in the induced tensions.

3.4 Hangers and Cable Bands

The hangers corrosion is also an important problem, especially in the lower connection, but a visual inspection is usually sufficient. The structural problems associated with the hangers are the following:

- Inclination - inclined cables are associated with slips in the clamps;
- Hangers Tension - when connection problems occur, the tension may decrease. This can be checked measuring its vibrations frequency which is proportional to the tension [3];
- Longitudinal Profile of the Deck - irregular profiles of the deck are usually associated with suspension problems;
- Cable Bands - should be visually checked to detect slips. To check the clamping forces two methods are now under research: the ultrasonic measurement and the use of a hydraulic "bell" system that tensions the bolt from the nut side [1].

3.5 Deck Truss Beam

In this element the inspection should consider the corrosion and the local problems. Regarding corrosion, attention should be paid to water retaining details, zones near water gutters and closed sections where the internal inspection is also necessary. The local problems are associated with car damages in the structure, fatigue problems in welded connections (especially at midspan and support sections), and cracked or loose bolts in the connections.

3.6 Supports and Joints

The inspection of these elements should consider essentially their cleaning to guarantee a good behaviour. This can be observed during a day, checking the temperature movements. Eventual cracks in the supports may be detected by unusual noises under traffic.

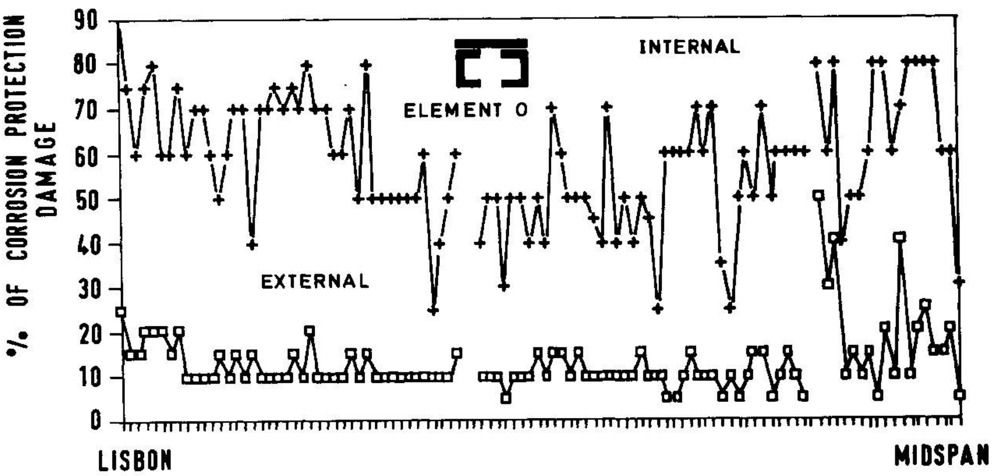


Fig. 3 - ANTICORROSION PROTECTION DAMAGE AT ELEMENT O, ALONG THE SPAN.

4. THE INSPECTION RESULTS

At the first stage of the program, the corrosion inspection was implemented. At the columns only superficial corrosion was found, mostly at the interior of the base section. The concrete caissons were also observed and filmed under water to check for concrete degradation, but no relevant findings were obtained. At the cables hangers and cable bands, and with an external observation, only small spots of superficial corrosion were found. Due to the good external condition, an internal observation with electromagnetic techniques was not considered necessary at this stage. All the bars of the deck truss were also inspected and plots of the superficial corrosion along the bridge were drawn for each element (Fig. 3). Structural damage by corrosion was found only in a few nuts of the bolted connections which presented section reductions of more then 20% . It is estimated that about 2% of the deck bolts will need to be replaced shortly. During deck inspection some transversal bars located over the longitudinal girders (shown in Fig. 2 by A). It is estimated that 13% of the total number present this problems.

The second phase of the program considering the inspection of structural behaviour of several elements is now under development. The first problem is the rechecking of the tension on the cable bands bolts. The results from the ultrasonic measurement and the hydraulic bell system are being checked with those from a prototype to come up with an easy and reliable technique. To obtain the hangers tension, a cable prototype is also under research to calibrate the vibration method, considering different lengths of cables. Also checked were the hand rails cables, over the main cables. Their forces were measured to analyse their capacity to carry the loads of the future inspection system.

4. ACKNOWLEDGEMENTS

The authors wish to thank Junta Autónoma das Estradas (J.A.E.) for their support to the realization of this paper. The inspection work was developed by Instituto de Soldadura e Qualidade (I.S.Q.) whose support is also acknowledged.

5. REFERENCES

1. BRANCO, F. A.; AZEVEDO, J. - Technical Aspects of an Inspection Program for the 25th of April Bridge (in Portuguese). Report CMEST. EP. 35, Lisbon,1988.

2. Instruction Technique pour la Surveillance et Entretien des Ouvrages d'Art - Pont Suspendus et Ponts à Haubans. LCPC- SETRA, Fasc. 34, Paris, 1984.

3. DRURY, J. C. - Measurement of Loads in Hanger Cables of Suspension Bridges. International Symposium on Suspension Bridges, Lisbon, 1966.

4. Controle Electromagnetique des Cables des Ponts Suspendus. Bulletin Technique, LCPC-SETRA, Paris, 1988.

Schäden und Sanierung von Brückentragseilen

Damage and Repair of Bridges Track Ropes

Défauts et réparations de câbles porteurs de ponts

Adolf SCHNEIDER
Dipl. -Ing. Dr.
Austria Draht Ges.m.H.
Bruck a. d. Mur, Österreich

Adolf Schneider, geboren 1925, studierte Metallurgie und promovierte am Institut für Fördertechnik an der Technischen Universität Graz. Er leitete ab 1959 das Technologische Laboratorium und von 1969 bis 1983 das Seilwerk der Felten & Guilleaume AG, Wien und bis 1985 das Seilwerk der Austria Draht Ges.m.b.H., in St. Aegyd. Er ist gerichtlich beeideter Sachverständiger und Konsulent.

ZUSAMMENFASSUNG

Im Bereich von Verankerungen, Aufliegestellen und Hängerklemmen treten, infolge von Seilschwingungen und Ermüdungskorrosion, manchmal schon nach kurzer Betriebszeit, Drahtbrüche in der Aussenlage von verschlossenen Tragseilen auf. Durch Einpressen von neuen Z—Drähten und durch Löten können Drahtbrüche in aufliegenden Tragseilen, auch unter voller Betriebsbelastung, saniert werden. Hohe Kosten, die für den Austausch der schadheften Tragseile notwendig wären, sind dadurch vermeidbar.

SUMMARY

In the regions of anchorages, saddles and cable-clamps wire breaks can occur even after short periods of operation due to rope oscillation and fatigue corrosion. It is, however possible to repair these damages under full load of operation by pressing in new Z — wires and soldering. Thus the high costs of replacing damaged track ropes will be avoided.

RÉSUMÉ

Au droit des ancrages, des supports et des serres-câbles apparaissent parfois, même après une court période d'exploitation, des ruptures de fils dans la couche extérieure des câbles porteurs clos. La cause de ces ruptures est liée aux oscillations du câble et à une fatigue due à la corrosion. En serrant de nouveaux fils, du type z, et en les soudant, on peut réparer des ruptures de câble, même sous pleine charge d'exploitation. De cette manière, on peut éviter de grands frais pour l'échange de câbles porteurs défectueux.

1. EINLEITUNG

Infolge von Seilschwingungen, manchmal auch im Zusammenhang mit Ermüdungskorrosion, treten des öfteren, insbesondere in der Außenlage von verschlossenen Tragseilen, nach verhältnismäßig kurzer Betriebszeit, Drahtbrüche auf. Diese befinden sich bevorzugt im Bereich von Verankerungen und Aufliegestellen oder im Bereich von Hängerklemmen. (Fig. 1)

Treten die Drahtbrüche vereinzelt auf, so genügt eine Sanierung der klaffenden Bruchenden durch Plombieren mittels Kunstharz. Dadurch wird das Eindringen von Feuchtigkeit verhindert. Tritt Drahtbruchhäufung auf oder befinden sich die Bruchstellen in benachbarten Z-Drähten, besteht die Gefahr, daß Z-Drähte aus dem Seil treten und sich auf weite Strecken aus dem Verband schälen. Um dies zu verhindern, sind im Bereich der Schadensstelle Schraubklemmen zu montieren. (Fig. 2)

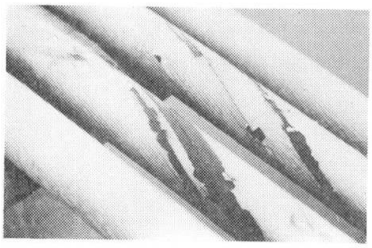


Fig.1 Drahtbruchhäufung in verschlossenen Tragseilen einer Hängebrücke im Bereich des Pylonsattels

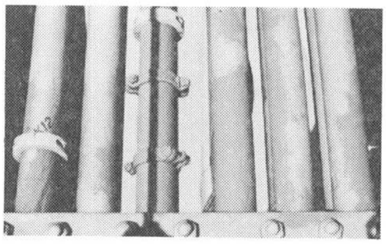


Fig.2 Drahtbruchhäufung in verschlossenen Tragseilen einer Hängebrücke im Bereich einer Hängerklemme

Tritt Drahtbruchhäufung im Bereich des Vergußkopfes auf, besteht vorerst keine Gefahr, daß die gebrochenen Z-Drähte aus dem Seilverband treten; die Krafteinleitung in den Vergußkopf wird jedoch so gestört, daß die weitere Zunahme der Drahtbrüche progressiv erfolgt.

Die Beurteilung von Drahtbrüchen in Brückenseilen bezüglich einer Sanierung erfolgt nach mehreren Gesichtspunkten. Es ist zu klären:

a) Ob der Seilschaden durch eine temporäre, örtliche Überbeanspruchung verursacht wurde, die durch konstruktive Maßnahmen oder durch eine entsprechende Wartung behoben werden kann.

b) Ob der Seilschaden durch Gewalteinwirkung entstanden ist und

c) Ob der Schaden bereits auf einen so hohen Dauerfestigkeitsverlust der Drähte zurückzuführen ist, daß die Tragseile innerhalb einer kurzen Zeitspanne den Zustand der Ablegereife erreichen.

Im letzten Fall ist eine Sanierung des Seilschadens nicht statthaft. Handelt es sich hingegen um einen örtlichen Seilschaden mit bekannter Ursache und entspricht der Allgemeinzustand der Tragseile, in bezug auf Seil- und Betriebsicherheit, den einschlägigen Bestimmungen, so ist eine Sanierung zulässig. Die Sanierung der Tragseile ist, wenn dies möglich, einem Austausch vorzuziehen, da die Erneuerung der Tragseile nicht nur mit hohen Kosten verbunden ist, sondern auch den Verkehr auf längere Zeit beeinträchtigt.

2. SANIERUNG EINES VERSCHLOSSENEN TRAGSEILES IM BELASTETEN ZUSTAND IN DER SEILRECKANLAGE

Die Sanierung von Drahtbrüchen in verschlossenen Tragseilen wird schon seit Jahrzehnten praktiziert. Insbesondere müssen Tragseile von Personenseilbahnen nach Gewalteinwirkung, z.B. nach Blitzeinschlägen, saniert werden. Zu diesem Zwecke wurden früher die Tragseile entspannt und die Sanierung der gebrochenen Z-Drähte im unbelasteten Zustand vorgenommen. Im letzten Jahrzehnt wurden auch aufliegende Tragseile im belasteten Zustand mit nachhaltigem Erfolg saniert. Auf diese Weise konnten erhebliche Kosten, vor allem aber auch Zeit, eingespart werden. [1] [2] [3]

Tragseile von Hängebrücken, die gebündelt oder gefächert angeordnet sind, können nicht einzeln entspannt werden. Aus diesem Grunde ist die Sanierung einzelner, schadhafter Tragseile unter Betriebsbelastung oder unter jener Belastung vorzunehmen, die bei unbelasteter Brücke gegeben ist.

In der Seilreckanlage der AUSTRIA DRAHT Ges.m.b.H., kann die Sanierung bei jeder beliebigen Belastung, auch entsprechend den Bedingungen im Bauwerk, simuliert werden. Die dabei zu messenden Werte hinsichtlich des Drahtes, wie Wegstrecke zur Beseitigung der Drahtüberlänge nach dem Löten und hinsichtlich des Tragseiles, wie Belastungs-Dehnungs-Diagramm und Elastizitätsmodul, geben Aufschluß über die erforderliche Sanierungslänge und über das Verhalten des sanierten Tragseiles unter Betriebsbedingungen.

2.1 Vorbereitung des Versuches

Um das zehn Meter lange verschlossene Tragseil, 63 mm Durchmesser, belasten zu können, wurde es an beiden Enden mit Vergußköpfen versehen. Die äußere Z-Drahtlage weist in Seilmitte zwei nebeneinander liegende Drahtbrüche auf. (Fig. 3)

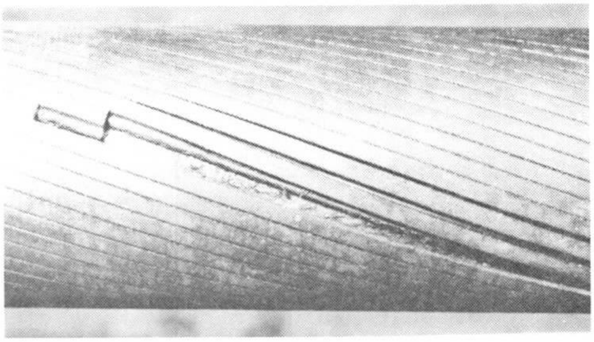


Fig.3 Verschlossenes Tragseil, 63 mm Durchmesser, mit zwei nebeneinander liegenden gebrochenen Z-Drähten, Belastung des Seiles in der Seilreckanlage: 1430 kN

Nach dem Einsetzen der Seilköpfe in den Kuppelwagen (Fig.4) und in den Klemmenwagen (Fig.5) wurde eine Last von 1430 kN, das sind 30 % der rechnerischen Seilbruchlast, aufgebracht. Mittels Einrichtung zur Konstanthaltung konnte die Belastung des Seiles während der Sanierung der beiden Drahtbrüche auf gleichem Niveau gehalten werden.

2.2 Versuchsdurchführung

Im ersten Arbeitsgang wurde das Bruchende des Drahtes Nr.1 aus dem Seilverband gehoben und der Z-Draht in Richtung Kuppelwagen aus dem Seilverband geschält. In einer Entfernung von 560 mm, das entspricht einer Seilschlaglänge, wurde der Z-Draht durchtrennt, geschäftet und mit einem neuen, 2800 mm langen Z-Draht, hart verlötet.

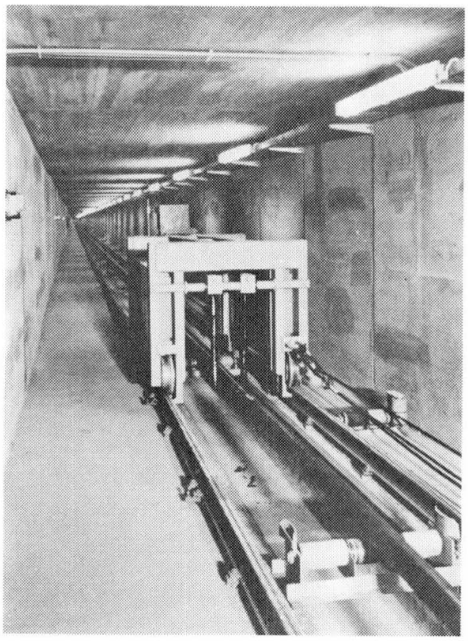


Fig.4 Seilreckanlage, 400 m lang, mit Einziehwagen, Kuppelwagen im rückwärtigen Teil des Tunnels

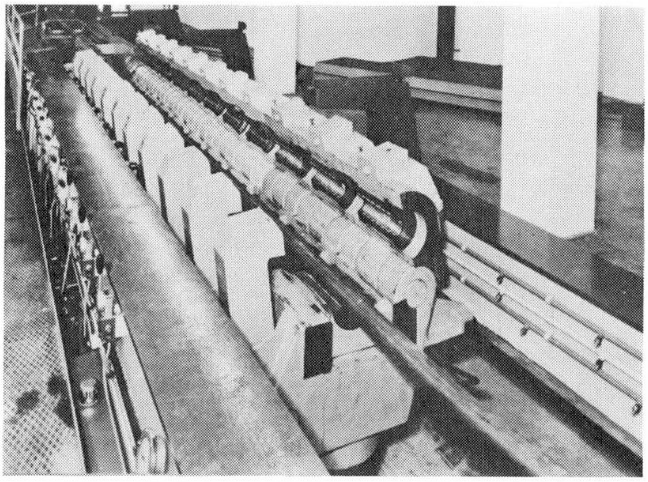


Fig.5 Klemmenwagen mit elf hydraulisch betätigbaren Klemmbacken

Im zweiten Arbeitsgang wurde der neue Z-Draht mittels einer gut passenden Schraubklemme in den Seilverband gepreßt und zwar vorerst bis zur ursprünglichen Schadensstelle. Im weiteren Verlauf der Sanierung wurde das zweite Bruchende des Z-Drahtes Nr.1 aus dem Seilverband gehoben und in Richtung Klemmenwagen, auf eine Länge von 2240 mm, aus dem Seilverband geschält. Anschließend wurde der neue Z-Draht von der ursprünglichen Schadensstelle mittels Schraubklemme in den Seilverband gepreßt. In einer Entfernung von 2800 mm von der ersten Lötung wurde die zweite Lötung mit kurzer Drahtüberlänge vorgenommen. (Fig.6) Nach Behandlung der Lötstelle mit Spezialwerkzeugen wurde im dritten Arbeitsgang die Drahtschlaufe mittels Schraubklemme bis zum Verschwinden in die Außenlage des verschlossenen Tragseiles gepreßt. (Fig.7) Hierzu war eine Wegstrecke von ein Meter Länge erforderlich. Die Gesamtlänge zur Sanierung eines gebrochenen Z-Drahtes beträgt in diesem Falle 3800 mm, das sind ca. sechs Seilschlaglängen. Mit der Sanierung des zweiten Drahtbruches wurde in gleicher Weise wie beim Drahtbruch Nr.1 verfahren.

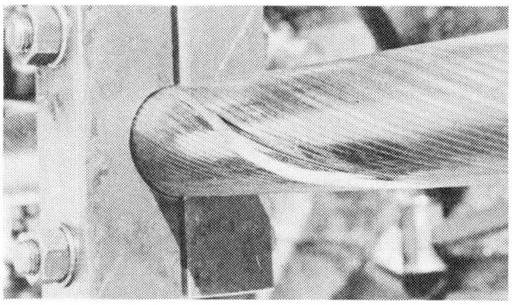


Fig.6 Einpressen der Drahtüberlänge (Schlaufe) in den Seilverband mittels einer Schraubklemme

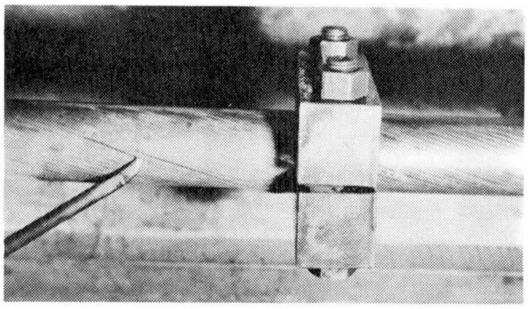


Fig.7: Seilzustand nach dem Einpressen der Drahtüberlänge in den Seilverband, Entfernung von der sanierten Bruchstelle: 2800 mm

Aus Fig.8 ist der Seilverband im sanierten Bereich ersichtlich. Alle Z-Drähte der Außenanlage liegen fest im Seilverband. Unmittelbar nach der Sanierung tragen die eingepreßten und gelöteten Z-Drähte nicht voll mit. Ein weitgehender Spannungsausgleich zwischen den Z-Drähten tritt jedoch nach mehrmaliger Be- und Entlastung auf.

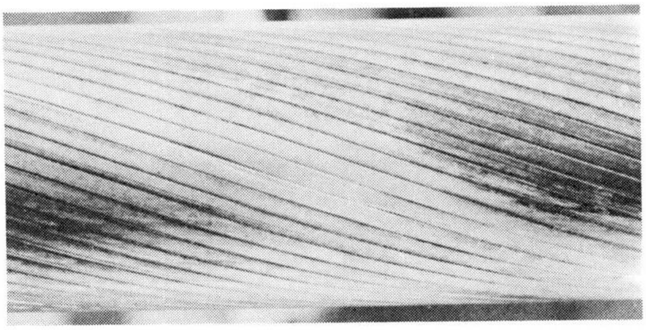


Fig.8 Verschlossenes Tragseil, 63 mm Durchmesser, Seilzustand im sanierten Bereich

2.3 Beschreibung der Seilreckanlage [4]

Die Seilreckanlage wurde 1970 im Werk Wien als Tunnelreckanlage, vier Meter unter Hüttenflur, errichtet. (Fig.4) Als Besonderheit der Anlage ist hervorzuheben, daß der Reckvorgang zu jeder Zeit bei konstanter Temperatur und unabhängig von den Außenbedingungen erfolgen kann.

Die wichtigsten Daten der Seilreckanlage:

Maximale Reckkraft:	5000 kN
Länge des Tunnels:	400 m
Hubweg des Reckkolbens:	3500 mm

Die Reckkraft wird mittels eines hydraulischen Reckzylinders aufgebracht. Je 12 mit Feinzinklegierung gefutterte Klemmbacken ermöglichen das Recken von Seilen bis zu 100 mm Durchmesser und 40 Tonnen Stückgewicht. Die Krafteinleitung erfolgt über hydraulisch betätigte Klemmbacken. (Fig.5) Dadurch ist es auch möglich, Seile mit einer Länge von mehr als 400 m vorzurecken.

3. SANIERUNG VON AUFLIEGENDEN VERSCHLOSSENEN TRAGSEILEN EINER HÄNGEBRÜCKE UNTER BETRIEBSBELASTUNG

In den verschlossenen Tragseilen, 72 mm Durchmesser, einer Hängebrücke mit 325 m Spannweite, wurden nach 18-jähriger Aufliegezeit eine große Anzahl von Drahtbrüchen festgestellt. Drahtbruchhäufung trat insbesondere im Bereich zweier Hängerklemmen auf, wo die Tragseile mittels Stahlplatten und Bügelklemmen eingespannt und gepreßt sind, wodurch es in Verbindung mit Schwingspannungen zu einer örtlichen Überbeanspruchung kam. Die Hängerklemmen befinden sich im Vorspannfeld der Brücke und sind nur 12 m vom Pylon entfernt. (Fig.2) Nach Überprüfung des Seilschadens konnte festgestellt werden, daß die Bruchenden der Z-Drähte die Form des Dauerbruches aufweisen. Ermüdungskorrosion trat nicht auf.

Da der Allgemeinzustand der Tragseile befriedigend war, wurde deren Sanierung durch Einpressen neuer Z-Drähte im Schadensbereich unter Betriebsbelastung beschlossen. Während der Sanierungsdauer, die drei Wochen in Anspruch nahm, mußte der Verkehr auf eine Fahrbahnhälfte eingeschränkt werden.

3.1 Lötstellenplan

Im Bereich einer Hängerklemme wurden in 6 von 12 Tragseilen insgesamt 24 Drahtbrüche festgestellt. Die Lage der Drahtbrüche in den einzelnen Seilen ist aus dem Lötstellenplan ersichtlich. (Fig.9) Die Verteilung der Lötstellen wurde so festgelegt, daß der Abstand zwischen zwei benachbarten Lötstellen 700 mm beträgt. Im Bereich der Hängerklemme wurde eine lötstellenfreie Zone von 4 m geschaffen. Aufgrund der Drahtbruchverteilung ergaben sich im zu sanierenden Bereich folgende maximale Einziehlängen bzw. Sanierungslänge: Seil Nr. 11: Einziehlänge 10,3 m und Länge des sanierten Bereiches 16,6 m.

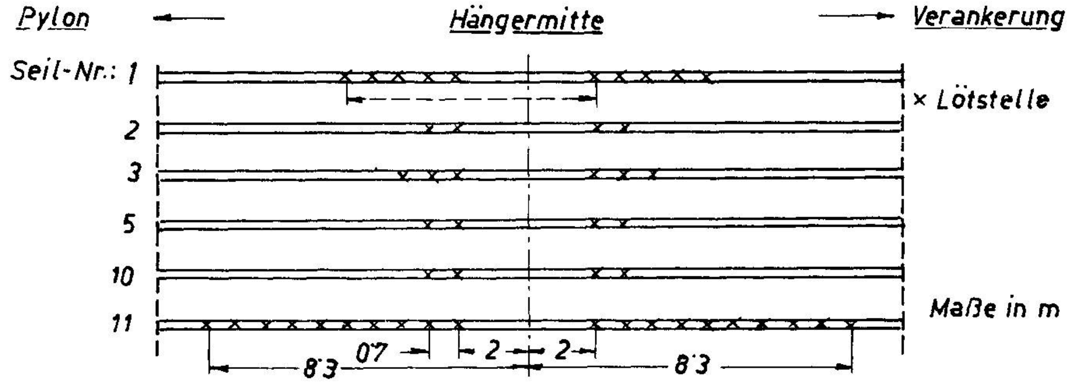


Fig.9 Lötstellenplan zur Sanierung der verschlossenen Tragseile im Bereich einer Hängerklemme

3.2 Sanierung der Drahtbrüche durch Löten und Versetzen der Stoßstelle

Diese Methode wird dann angewendet, wenn sich die Schadensstelle in unmittelbarer Nähe eines Pylons oder in Nähe der Verankerung befindet, so daß für das Vertreiben der Drahtüberlänge nicht genügend Wegstrecke zur Verfügung steht. Es wurde aus diesem Grunde jeweils ein Ende des einzupressenden neuen Z-Drahtes durch Hartlötung mit einem gebrochenen Z-Draht verbunden; das zweite Ende auf 200 mm Länge ausgeglüht und auf Stoß in den Seilverband gepreßt. Außerdem wurde das Drahtende mit Kunstharzkleber bestrichen und gegen Eindringen von Feuchtigkeit geschützt.

Vor dem Einpressen der neuen Z-Drähte wurde die Seiloberfläche durch Sandstrahlen gereinigt. Das Einpressen der Z-Drähte erfolgte wie im Kapitel 2.2 beschrieben. Die in die Tragseile gepreßten Z-Drähte liegen seit der Sanierung, die 1984 stattfand, noch immer fest im Seilverband. Eine zusätzliche Absicherung der sanierten Seillänge ist nicht erforderlich. Fünf Jahre nach der Sanierung zeigen die verschlossenen Tragseile keine nachteiligen Veränderungen. Der Erfolg der angewandten Sanierungsmethode ist nachhaltig.

Entsprechend der durchgeführten Methode können auch schadhafte Tragseile von Schrägseilbrücken saniert werden. Voraussetzung dafür ist, daß die Tragseile frei zugänglich sind und eine Arbeitsplattform errichtet werden kann.

LITERATURVERZEICHNIS

1. SCHNEIDER A., Restoration of a full-locked-coil track rope of high-strength steel wire under tension. Vail Aerial Tramway & Ski Safety Seminar, 8/1981 Vail, Colorado, U.S.A.
2. BRITISH ROPES GROUP, Repair of locked-coil ropes. Technical Information Bulletin No.12, Warmsworth Hall, Doncaster, Yorkshire, England.
3. OPLATKA G., Zur kritischen Länge von gebrochenen Formdrähten in der Decklage von verschlossenen Seilen. OITAF - 5. Internationaler Seilbahnkongreß München, 14.-20.9.1981.
4. SCHNEIDER A., Das Vorrecken der verschlossenen Tragseile für die Tragkabel der 2. Linzer Donaubrücke. Technisch wissenschaftliche Woche Österreichs in Polen, Warschau 1972.

Long-term Anticorrosion Protection for Guys of Cable-Stayed Bridges

Protection à long terme des câbles de ponts haubanés

Dauerhafter Korrosionsschutz für seilverspannte Brücken

Roberto MAGLIE
Civil Eng.
National Highway Adm.
Buenos Aires, Argentina

Roberto Maglie was born in 1937. Graduated as Civil, Road and Building Engineer at the Buenos Aires Technology University. Was Chief Inspector at the Zárate-Brazo Largo Complex and Bridge Maintenance Chief at the N.H.A. where he is at present, Adviser on cable matters. Was awarded a 1st Prize by the Argentine Roads Association.

SUMMARY

A very durable multiple anticorrosion protection proposal is presented to be applied especially on parallel cable elements of stayed bridges or similar structures where, by a relatively higher initial cost, an evident increase in reliability and useful life of cables is achieved having an enormous safety reserve, reducing control and maintenance expenses that result in a lower final cost.

RÉSUMÉ

On propose d'appliquer une protection anticorrosive multiple de longue durée aux câbles parallèles des ponts haubanés, ou aux structures similaires, lorsque, pour un coût initial relativement plus élevé, on obtient une augmentation évidente de la fiabilité et de la durée d'utilisation des câbles, tout en disposant d'une énorme réserve de sécurité et en obtenant une réduction des frais de contrôle et d'entretien conduisant à un coût final plus bas.

ZUSAMMENFASSUNG

Ein sehr dauerhafter Korrosionsschutz für seilabgespannte Brücken oder ähnliche Bauwerke wird beschrieben. Durch höhere Baukosten wird eine wesentliche Erhöhung der Dauerhaftigkeit und der Lebensdauer der Kabel erreicht. Daraus resultiert eine grosse Sicherheit mit entsprechender Verminderung der Inspektions- und Unterhaltskosten, wodurch die Gesamtkosten geringer ausfallen.

1. INTRODUCTION

It is not easy task to conceive a structure from the viewpoint of its durability. Studies on the subject show a pronounced structure duration dispersion [1] and a certain contradiction between the frequency of the failure cases and the theories dealing with their reliability [2]. Though there exists already a definite trend towards tackling design from a probability viewpoint to solve questions concerning durability -and also safety and serviceability- it must be admitted that the material failure precise nature is not known.

Within a context so conceived, a multiple anticorrosion protection is proposed that seeks a durability as long as the stayed bridge useful life. This type of bridge, recognized as an economical, reasonable, aesthetical, lasting solution, especially efficacious for 200 to 500 m spans, has not offered a satisfactory "status quo" with respect to cable durability. During past years there have appeared cases of corrosion and deterioration in guys of important bridges in Europe, U.S.A., Latin America and Japan [3], [4], [5], [6], that lead to think that there is not an adequate coherence between the decisive structural importance these cables have and the protection safety and durability for which the most qualified stayed bridge pioneers, designers and constructors are crying out, clearly emphasizing the need for a robust and reliable corrosion protection system for the stay tendons.

2. ESSENTIAL IDEA OF THE SISTEM PROPOSED

The main objective is having a protection the duration of which approaches the bridge expected useful life (conventionally, 75 years). The design is based on the conviction that owing to the materials deterioration laws phenomenology, with respect to anticorrosion it is not possible to expect spectacular solution centered on a magic product or method, so to obtain a very long duration protection recourse must be had to a highly reinforced protection. High polymer materials have been chosen considering that high molecular weight enables them for lengthy duration, especially if suitable precautions are taken.

The central idea -the system fundamental key- is to protect a protective element considered essential; in this case a high density polymer inner pipe (HDPE) or similar to which should be guaranteed a sort of "hibernation" aided by other elements that besides acting also as anticorrosion protection, insulate the inner pipe from temperature and weather. Waterproofing should be paid as much attention to as temperature insulation.

3. DESCRIPTION OF THE PROTECTION

The system proposed (Fig. 1) is composed of a HDPE inner pipe (3) circling the tension elements bundle; another HDPE pipe (6), light or white coloured; an injection between pipes (4) and another injection (1) within the inner pipe (3) both of an elastomeric or plastic material or eventually portland cement with polymers and a two layered wrapping or otherwise only one tape complyind with the same purpose. The first helps as a fastener of the whole, and the external one, white or light coloured functions as a protection against UV rays, IR radiation, oxigen and ozone and as a temperature reducer. Also, if vibration produced in the cable by the wind are expected to be significant, it is advisable that external side of the wrapping be corrugated, scarified, ribbed or creased in such a direction that once in place it shows an aerodynamically oriented pattern for dissipating the vibratory energy.

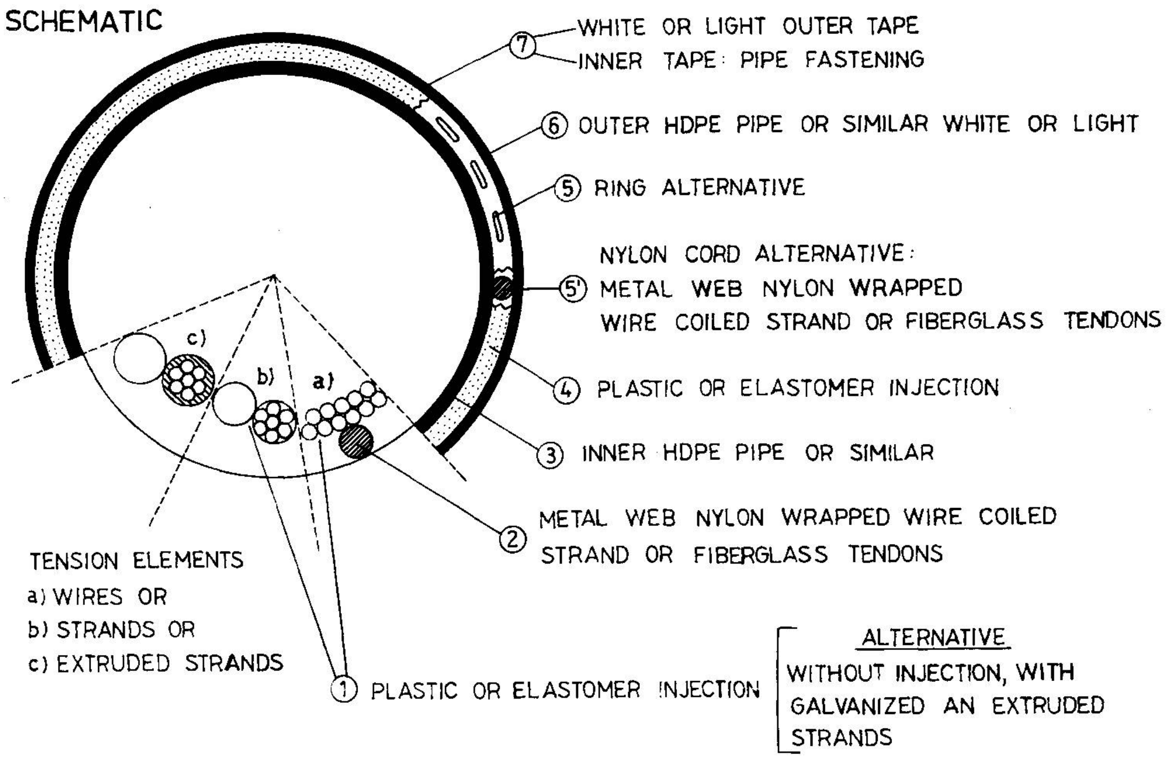


Fig. 1 - Cross section of the proposed cable and alternatives

The spacing between pipes may be obtained with rings (5) perforated for the injection to get through and welded to the inner piper only but in contact with the outer pipe, whitout adherence, with the object of allowing the longitudinal movement of the protection top part. The adhesion of the ring, that may be made of any suitable plastic material, can be achieved by the plastic welding update techniques developed nowadays. Though the polythylene thermal stability makes brief heating possible near the softening point without causing any trouble -provided that it does not occur simultaneously with mechanical loads- if it is desiderable to avoid a certain temperature range, a metal web nylon wrapped wire coiled strand (5') may be used over the pipe (or fiberglass tendons as those used for posttensioning concrete bridges), similar to the one used to fasten the wire bundle (2) acting also as spacer. This strand (2) helps -together with rings and the other strands (5')- in keeping the cable circularity the objective of which is to prevent additional interferences in future surveying performed by magnetic induction or similar method. If strands are chosen a tension elements (b) and (c) in Fig. 1, care should be taken that the fasteners and or spacers do not damage the HDPE pipe, the steel or the single tape wrappings.

In the case of very lengthy cables and where -owing to the weight- the deflection requires lightening, the guy diameter can be reduced by eliminating strand (2) and making a direct extrusion on the bundle; or -in case strands are used,- injection (1), provided that the strands be extruded and galvanized individually. In any of these alternatives, the remaining protection (from 4 to 7) should be added to secure a long lasting useful life, according to the above mentioned concepts.

4. PROPOSED SYSTEM ADVANTAGES AND PECULARITIES

It is considered that the system described offers the following characteristic advantages: 1°) The plurality of the different component material, implies extreme safety, as a cause of corrosion is not apt to attack simultaneously different materials such as those of the proposed system with success; 2°) ageing or deterioration is notoriously retarded in the inner layers which greatly lengthens its useful life and consequently that of the cable; 3°) there is a large availability of time to change the outer protection without risk for the steel; 4°) spot accidental causes (notches, plastic components defects) dangerous in systems with less elements, lose importance in a multilayered system; 5°) independently from the tension steel anticorrosion properties, the protection emphasis should be placed on the steel "external" elements sum and synergy. This approach permits an absolute liberty in the choice of the tension elements proper. On this concern, it must be taken into account that steels suitable for tensioning have suffered a decrease in their response to strain and fatigue resistance owing to treatments applied directly on same (hot galvanizing or previous treatments such as sanding, phosphatizing and chromium plating) [7], [8]; 6°) without detriment to the bridge being correctly designed for vibration and fatigue, the proposed outer wrapping roughness makes more effective the cable antivibration response; 7°) the selection of a sum of differential thicknesses necessary for the impermeability an the decrease of the thermal gradient, as substitute for only one thickness, allows replacements by laters in case of deterioration, far off from the risk of the "all or nothing"; 8°) plastic injections capacity for deformation, expansibility or elastic resiliencie secures continuity and weather tightness, since they fill all voids and hollows and readjust in the presence of cable deformation; 9°) plastic flexibility, positioning of the cable with all its protection avoiding "in situ" injections, notoriously increasing quality levels and implying that during construction higher loads should not be incorporated, avoiding in this way stress checking tests under the urgencies and difficulties imposed al this stage; 10°) the multilayered system provides high shock absorption and the cuts and flattenings that may be caused by handling and mouting are circumbscribed to a periphery for away from the protection nucleus; 11°) high polymer injections or fillings permit obtaining mixes that under tensile stresses, for example, only shows very small depth fissures (0,03 to 0,05 mm) that are far from water penetration limits (0,1 to 0,2 mm) a behaviour highly superior to that of the rigid injections; 12°) the possibility of producing a cable entirely factory or "in situ" made, permits the control of the injections pressure in order to make it small enough so that it may not affect the pipes long duration desired, especially the inner one; decrease of the two thermodynamic coordinates (pressure and temperature) and absolute protection the inner pipe has against UV rays and other weather phenomena, are the main factors that permit forecasting a useful life similar to that of the bridge.

The importance -for the duration of the HDPE or similar pipe- of reducing pressure and temperature (they are variable and intermittent Δt) is verified inmediately when observing these materials characteristics curves based on plastic deformation and relaxation test and that relate temperature, duration, and triaxial stress originated by internal pressure [9]; 13°) the nylon strands do not leave any imprint on the HDPE pipes or any other high resistance plastic and do not imply restriction to the mobility of the elements they come into contact with; 14°) the proposal for the most external of the pipes is that it should be ligth coloured and treated against UV rays in spite of the outer wrapping having the same properties. This arrangement implies further safety in case that due to neglect in surveying there may come long period of time in which no wrapping deteriorations are detected; 15°) the proposed system can be easily rehabilitated. There is no problem with the wrapping and any pipe(s) section is replaced with half round pieces of the same material welded "in situ"; 16°) relaxation and creep may be reduced if certain precautions are taken and selection made. Recent investigations carried out in Japan [10] show that if the combination PWS (parallel wire strands) plus Hi-Am ("cold" mix for anchorage that melts only at 110°C) is adopted, creep and relaxation reach values of only 3,7 % respectively, while for LCR (locked coil rope) plus Z (Zamak type metal mix anchorage or similar) melting at 350 thorough 450°C, the values reach magnitudes of 13,8 and 10,3 % respectively.

As for steel pure relaxation in cables, it may be reduced if a considerable insulation against temperature is used, as the one provided for the protection. This relaxation depends on temperature and the initial stress and also on stress cyclic variation; a phenomenon that acquires some importance owing to the great stress oscillation amplitude. It must be considered that in some regions and seasons of the year, temperature on the surface of a great number of cables reaches up to 70 to 80°C. Other investigations made in relation with the steam curing influence on prestressing steels, over the mentioned temperature range (anisothermal Test) [11] , [12] , show that steel relaxation may be increased from 3,7 to 16 % above the one measured at the conventional 20°C temperature (isothermal Test). Notwithstanding the defferences that may be pointed out between the influence of the steam curing duration and the day-night cyclic Δt ; of the extrapolations used by researchers and that if certain steels such as the "stabilized" are used, a better response to relaxation is achieved (though these steels are more sensible to corrosion), it is important to remark that, anyway, the sum of the stresses during mounting and/or those originated by cyclic variation plus effect of the mentioned temperatures may induce relaxation that agree very little with the tensional demands supported by the stayed bridges, since to its temperature susceptibility are added higher demands imposed by the sustained increase of the main spans and the ever more sophisticated design of the deck transversal sections.

For this reason, a protection blockading the arrival of significant temperatures to the steel always implies an improvement -no matter its quantum- in relaxation decrease. There is another advantage to be added: high polymer injection imply no restriction to wire deffered deformation, which facilitates the possibility of the tension element total loss more accurate calculation, this characteristics being more important than the eventual restrictions -the evaluation of which is controvertible- that may present rigid injection system or other type of cables. All the factors that have been mentioned encourage the consideration that any improvement of the cables with references to deformation may be the reason that will make possible -as requirements increase- another step in the evolution of these bridges or of other stayed structures; 17°) offer great additional safety if sudden or undervaluated effects appear; 18°) have a satisfactory behaviour in the presence of wide range of climates; 19°) minimize the temporary protection problem; 20°) retightening, if considered possible, made whitout generating interference; 21°) offer an important reserve in the presence of fire, intentional damage and vandalism; 22°) minimize time between structural clousure and bridge opening to service; 23°) part of this arrangement -from (4) to (7), Fig. 1- may be thought of as a long lasting overprotection able to protect a wide range of existing tension members; 24°) the protection being highly reinforced, it is only logical to expect from it a high reliability and consequently be able to reduce the control usual periodicity. The resultant savings, only in this item, throughout the cable useful life, largely compensate the cost of more than one protection as proposed.

From the description of the system presented and the analysis of the advantages that have been pointed out, it is considered that the system complies with the objective of obtaining a long lasting protection ranking with the cable stayed bridge hierarchy and importance.

REFERENCES

1. MELCHERS R.E., Human Errors, Human Intervention and Structural Safety Predictions. IABSE Proceedings P-119/87.
2. SIEMES T., VROUWENVELDER T., Durability - a Probabilistic Approach - IABSE Proceedings P-85/85.
3. SAUL R., Experiencias en la reposición de cables de puentes, Carreteras (Argentina) N° 124, Julio-Setiembre, 1987.
4. STAFFORD D., WATSON S., A Discussion of some Critical Corrosion Problems in the Cable Elements of Stayed Girder Structures, International Conference on Cable-Stayed Bridges, Bangkok, 1987, p. 1048-1060.
5. MAGLIE R., Fissures in the Cables Polyethilene Ducts of Cable-Stayed Bridges. Submitted to the Bridges Maintenance and Rehabilitation Conference, Morgantown, West Virginia, U.S.A., August 13-16, 1980.
6. KAMEI M., MINATO T., SUGII K., IWASAKI M., Damage and Inspection of Bridge Cables, International Conference on Cable-Stayed Bridges, Bangkok, 1987, p. 1083-1091.
7. BUKOWIECKI A., Korrosionsuntersuchungen mit Vorspanndrähten, "Schweizer Archiv für angewandte Wissenschaft und Technik", EMPA, Dübendorf, Zürich, 1968.
8. RHEM G., RIECKE G., Kunststoffe zum Korrosionsschuts von Seilen und Spannstäben, Stuttgart, VDI, Beritche, Nr. 225, 1975.
9. HOECHST PLASTICS - Hostalen GM 5010 Pipes - Brochure - Chapter 2, pag. 17 and 18 - Edition Farbwerke Hoechst, August 1971.
10. WATANABE E., NAGASAKO M., YOSHIKAWA O., KURAUCHI M., Full-Size Creep and Relaxation Test on Steel Cables, International Conference on Cable-Stayed Bridges. Bangkok, 1987, p. 951-962.
11. VAN HERBERGHEN P., LAMBOTTE M., VAN ACKER A., VAN NIEUWENBURG, Etude dès pertes de précontrainte par relaxation de l' acier sous l' influence d' un cycle d' étuvage, International Congress FIP, New York, 1974.
12. NADER N., influence de l' étuvage sur la relaxation des armatures en précontrainte par pre-tension, Publications Tech. du CERIB N° 21, 1975.