Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 68 (1993)

Artikel: Expert system for integrated cabel inspection

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DOI: https://doi.org/10.5169/seals-51872

Expert System for Integrated Cable Inspection

Système expert pour le contrôle intégral des câbles

Integrale Kabelprüfung mittels eines Eypertensystems

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SUMMARY

The premature replacement of cables of different bridges made it clear, that inspections must include bridge cables. A kowledge-based expert system for the inspection and the evaluation of different cable structures is based on a thorough theoretical knowledge of all members of the structure, a feed-back of field tests, an application of different technologies and of numerous results of inspections. For final evaluations the geometric form of the cable , the cable alignment, the construction of end sections and end-terminations as well as the conditions of clamp-seatings must be discussed. Based on this information the structural safety and further use can be evaluated. Recommendations for suitable maintenance and rehabilitation measures can be given.

RÉSUMÉ

Un système expert a été développé afin de permettre des inspections périodiques pour la maintenance et la sécurité des câbles de ponts haubanés. Défini comme système d'inspection intégrale, il comporte la connaissance théorique approfondie de tous les éléments porteurs, les résultats d'essais sur le site, l'utilisation de diverses méthodes d'essais non destructifs et d'innombrables résultats d'inspections. L'appréciation finale tient compte de la forme géométrique du câble considéré, de son allure, de la conception de ses ancrages et de l'état de ses sabots de serrage. A partir de cet ensemble d'informations, il est possible de déterminer la sécurité structurale et la durée de vie restante, ainsi que de fournir des recommandations relatives à des mesures appropriées d'entretien et de réhabilitation.

ZUSAMMENFASSUNG

Für den Unterhalt und die Sicherheit von Ingenieurbauwerken sind periodische Inspektionen nötig, insbesondere bei Brückenkabeln. Zu diesem Zweck wurde für unterschiedliche abgespannte Tragwerke ein Expertensystem entwickelt. Als integrales Inspektionssystem umfasst es gründliche theoretische Kenntnisse aller Tragelemente, Ergebnisse von Feldversuchen, die Anwendung verschiedener zerstörungsfreier Testverfahren und zahlreiche Inspektionsergebnisse. In die endgültige Beurteilung sind die geometrische Form des betreffenden Kabels, sein Verlauf, die Gestaltung der Verankerungen und der Zustand der Klemmenschuhe einzubeziehen. Aufgrund dieser Informationen können die Tragsicherheit und weitere Lebensdauer ermittelt sowie Empfehlungen für geeignete Unterhalts- und Sanierungsmassnahmen agegeben werden.

INTRODUCTION

To evaluate the maintenance and safety of engineered structures periodic inspections are mandated. The premature corrosion of cables of different bridges - which forced their early replacement - made it clear that these inspections must include bridge cables. The inspection of bridge cables today is based on a mature technology, which has been widely used over the past twenty years. In Germany the ICI (Integral Cable Inspection) is practised, developed by DMT-Rope-Testing-Institute. This Integral Cable Inspection is built on a thorough theoretical knowledge of the condition and properties of the materials in question (wire, cable, socket), of the structural design as well as of the behaviour of the component parts when subjected to static and dynamic stress. Further on this Integral Cable Inspection consists of a feed-back of sixty years of field tests, practical application and results of cable inspections by

- extended visual inspections
- adapted NDT technologies such as
  - electromagnetic methods
  - ultrasonic testings
  - electrooptic inspections

The primary task of ICI is to prepare a report which includes a reliable assessment of the external and internal condition of the cables. Based on this information, their structural safety and further use can be evaluated. In addition, the owner can be furnished with recommendations for suitable maintenance and rehabilitation measures. The following are significant damage-related ICI findings:

- Damage to the corrosion protection,
- Evidence of external and internal corrosion,
- Mechanical distortions and damage,
- Broken or cracked wires,
- Adverse installation and environmental conditions, and
- Material damage caused by fatigue or external events.

Frequently these findings are caused by structural or constructional details. Also, environmental conditions can be significant. The following describes parts of Integral Cable Inspection methods which have been used for these examinations, including some noteworthy findings and conclusions.

TYPES AND CONSTRUCTIONS OF BRIDGE CABLES

Cables of suspension or cable-stayed bridges and guys of broadcast towers, chimneys, hall roofs or similar structures are high-strength tension members of the load-carrying system. Tension forces are applied via suitable end fittings, such als poured spelter sockets, resin sockets or clamps.

Cables for these structures are mainly of the fully-locked type. Spiral strands or stranded cables, as well as parallel wire strands or cable bundles, are also used. Fully-locked cables and spiral strands usually have diameters up to 110 mm. The largest fully-locked cables, manufactured for a bridge in Bangkok, have a diameter of about 180 mm. Larger cables are possible, but construction, handling and transportation problems have precluded their use. The need for larger cross-sectional areas is met by cable bundles. Although they are easy to manufacture, this alternative is problematic. It is very difficult or even impossible to inspect, maintain, repair or replace parts of a cable bundle. The distinct features of parallel wire bundles and cables must be recognized for their inspection and evaluation. The strength of cables is always less than the aggregate strength of their individual wires. Bundles of parallel wires are not subject to such a strength reduction. On the other hand, a broken wire in a wire bundle reduces the strength over its entire length, while a broken wire in a cable regains its full strength after a few lay lengths because of friction. The following discussion does not require a distinction between cables, cable bundles and parallel wire bundles. The generic term cable will be used.

INTEGRAL INSPECTION METHODS FOR CABLE SUPPORTED STRUCTURES (ICI)

The inspection of long-span suspension cables or high-rising guys poses numerous problems. But it is inevitable to inspect these cables from end-connection to end-connection. The dimensions and arrangement of these cables alone cause difficulties for the inspector. Any cross-section along the load-carrying length of these cables can be the weakest. Therefore, a reliable inspection requires unrestricted access to the cable under test over its entire length. These cables, between terminations, may be several hundred meters long. Occasionally, existing technology will not allow an inspection of certain cable sections. Then, cables can only be evaluated by logical inference with all its imponderabilities.

Theoretic Knowledge About Material and Cable Specifications

As a basis for later examinations and evaluations, all significant material specifications and cable properties must be ascertained by quality control procedures and acceptance tests. These evaluations include tensile tests and, possibly, fatigue loading tests of sections of the original cable.

Extended Visual Inspections

Based on a thorough theoretical knowledge an extended visual examination is the most important component of all inspections, Figure 1. The primary objective of a visual examination is to determine the external condition of the cable and to find exterior damage of the corrosion protection. Furthermore, visible changes of this surface frequently indicate internal damage. For the visual inspection of guyed structures of moderate height, a climbing or telescope crane is often adequate. The bridge cable inspection device developed for and owned by the government of Germany allows a safe visual inspection of most large bridges in Germany. All NDT-technologies are good helps to ensure

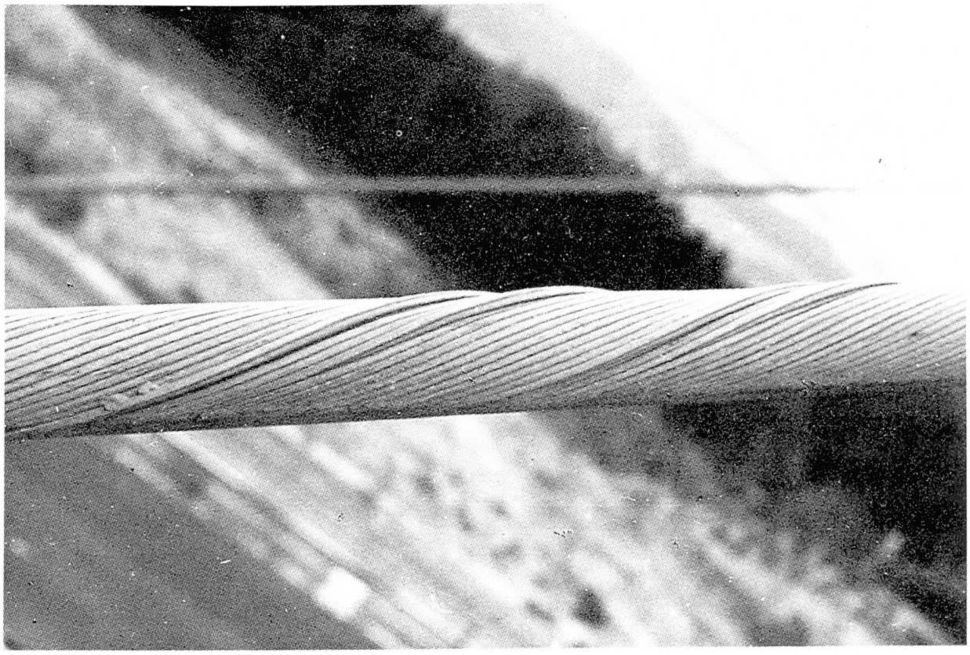

Fig.1: Mechanical distortion

the result of a visual examination but it must be pronounced that all the following NDT-technologies remain restrictive helps without a visual inspection.

Electromagnetic Inspection

Electromagnetic (EM) inspections allow examinations of a cable's interior. These inspections show external as well as internal cracked or broken wires, abrasion and corrosion. Practical instruments for in-service wire rope inspection, were first developed by DMT-Rope-Testing-Institute and University of Stuttgart in 1930. Since then, these procedures have been improved and adapted for novel applications by using advanced technologies as they became available. Instruments - which can simultaneously detect localized faults and measure loss of metallic cross-sectional area were used for the inspection of bridge cables and guys in Germany since about 1970. All present EM instruments are usually hinged.

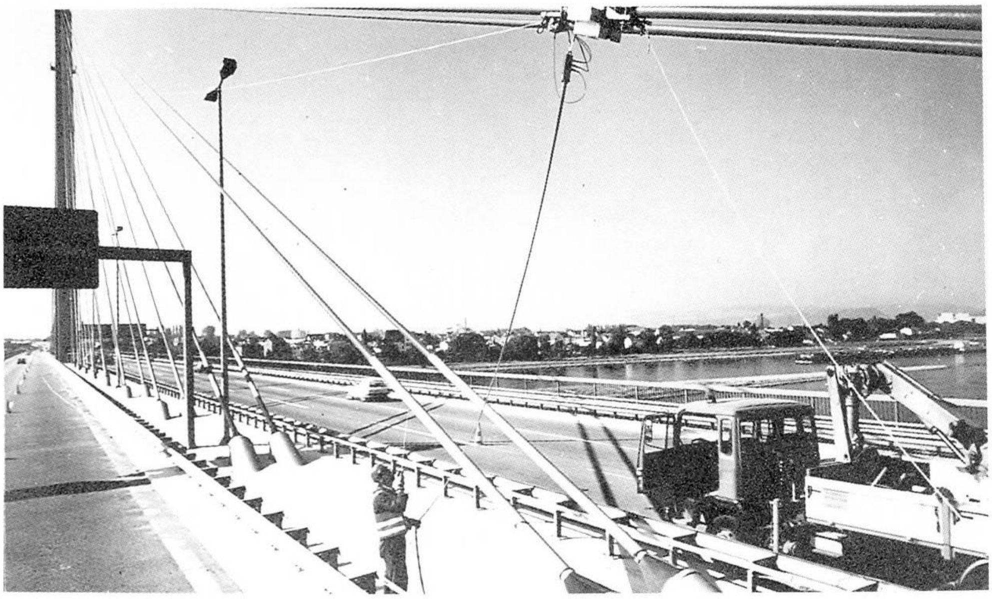

Fig. 2: Working situation

To perform an inspection, the instruments are pulled along the cable with a winch, Figure. 2. While the instruments travel along the cable test signals are recorded. These signals can be recorded or stored and processed by a portable data acquisition computer. The EM-inspection is easy to be performed. But the interpretation of the graphs is hard. Inspectors who dont regulary interpret EM graphs will fail.

Inspection of End Sections of Cables by Electro-optic Methods

The end sections of cables are frequently situated in narrow spaces where only an endoscope or borescope allows sufficient vision for a photographic or video documentation. The reason of nearly 60 % of all problems with cables lies in the structural design of this region.

Ultrasonic Testing

Terminations and end sections of cables constitute stress concentration points and are therefore particularly susceptible to damage. In addition, access to these segments is often more than difficult. Therefore, the inspection of these areas requires additional efforts and, under certain conditions, specialized inspection techniques and equipment. For example, specially adapted ultrasonic inspection methods, developed by DMT-Rope-Testing-Institute, can detect flaws and corrosion, even inside the end sockets. Wire breaks and cracks up to 600 mm inside the spelter or resin socketing can be reliably detected, Figure 3.

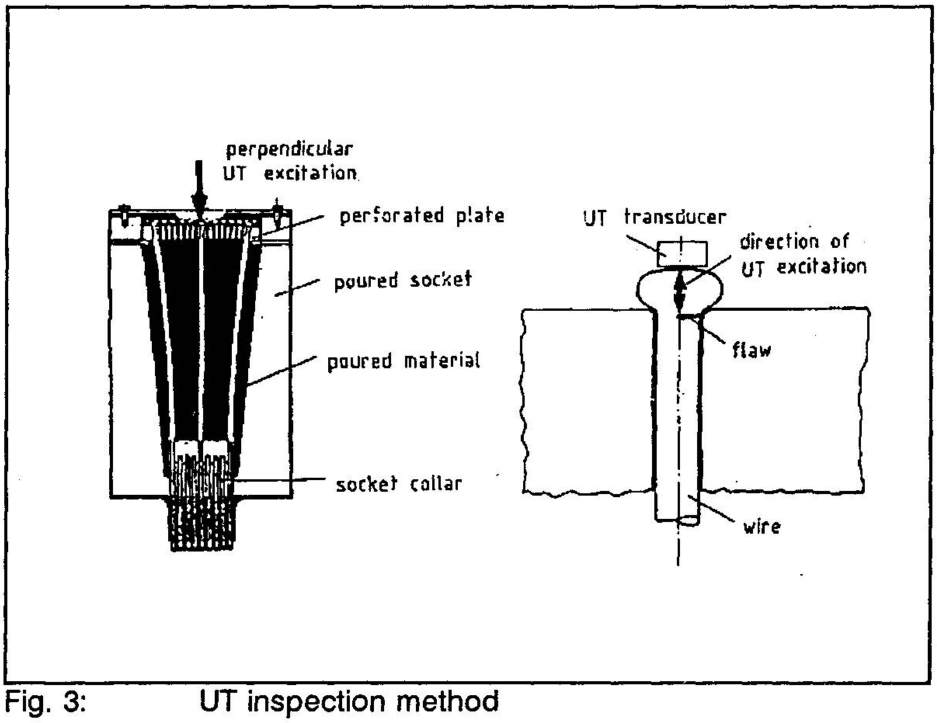

Fig. 3: UT inspection method

RESULTS OF ICI'S PRACTICAL APPLICATION

The following sections describe some findings of previous examinations.

Cable alignment

An alignment which allows unobstructed access between cable terminations is important. An unsuitable cable arrangement can make the complete inspection of the cable, rehabilitation of the corrosion protection, or other work difficult or impossible. Under adverse conditions, maintenance can only be performed to a limited extent and with difficulty. Often, inspections are possible only by using an endoscope. In some installations, cables contact adjacent cables or other structural members. In other cases, cables are led through openings of steel or concrete members which are too small. In these cases, wind can make cables rub against structural members. Under relatively favorable circumstances, this rubbing action will cause damage only to the corrosion protection. However, rubbing can also cause fretting corrosion or other damage, like cracking, of the wire surfaces. Under ideal conditions, the design of a structure should not require the cable to be deflected over its entire load carrying length.

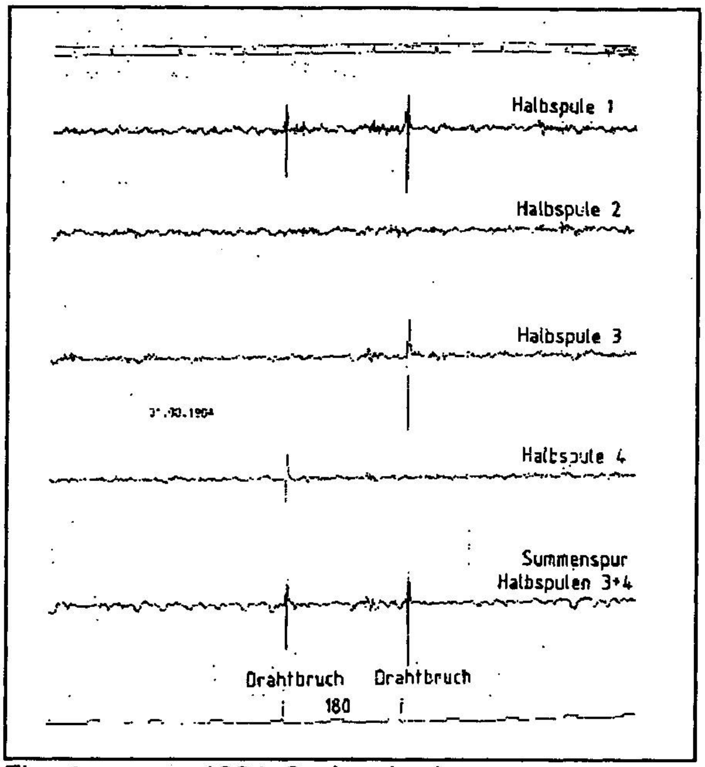

Fig. 4: 1984, 2 wires broken

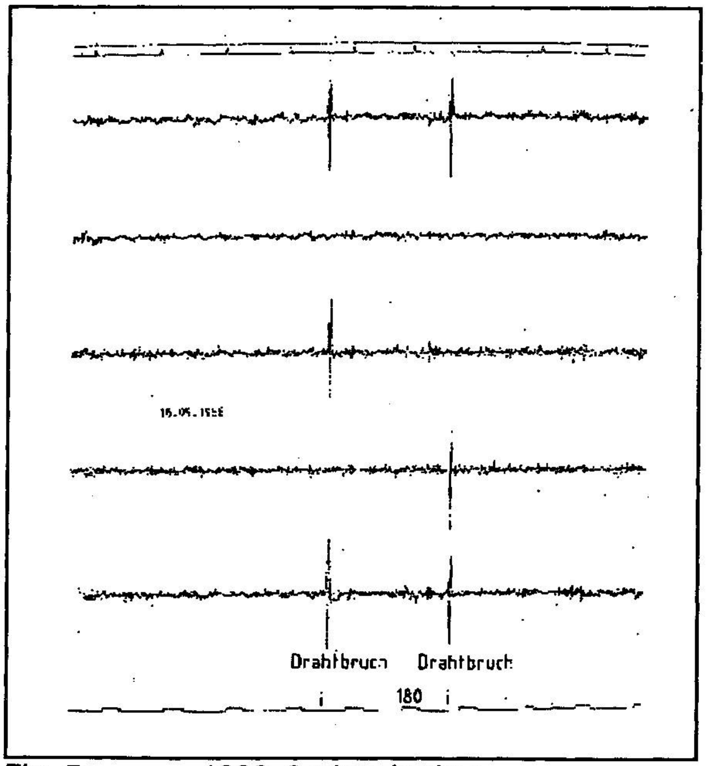

Fig. 5: 1986, 2 wires broken

EM-Inspection

Some bridge cables have been inspected repeatedly because of suspicious graphs. Figure 4 shows the graph gained in August 84 with two wires broken. Two years later, in Sept. 86, the graph for the same cable section is shown in Figure 5. By reason of the dynamic stress the spaces between the ends of wire breaks have increased and consequently the magnetic field measured has also changed. A third test on the same cable section was carried out on May 90. In addition to the two already ascertained wire breaks, a third incipient wire break in the same section of the cable is indicated in the graph (Figure 6). To detect corrosion under an undamaged corrosions protection coating is as important as to detect wire breaks! Figure 7 and Figure 8.

End terminations

Poured cable connections are more complex than cable attachments which use clamps. For poured connections, attention must be given f.e. to left-over serving bands at the base of the socket, to cracks, to cavities in the poured material, and to material which, because by thermal setting, has crumbled away. For clamped connections, firm seating of clamps and wedges must be verified. Furthermore, changes in the cable surface near and in contact with the clamps frequently indicate problems. For older structures, anchorage arrangements are often susceptible to damage. Moreover, these end connections are often anchored in the ground or embedded in concrete foundations and are accessible only under unusual conditions and with difficulty. In other cases, constructional details at the base anchorage allow the accumulation of water and debris, Figure 9.

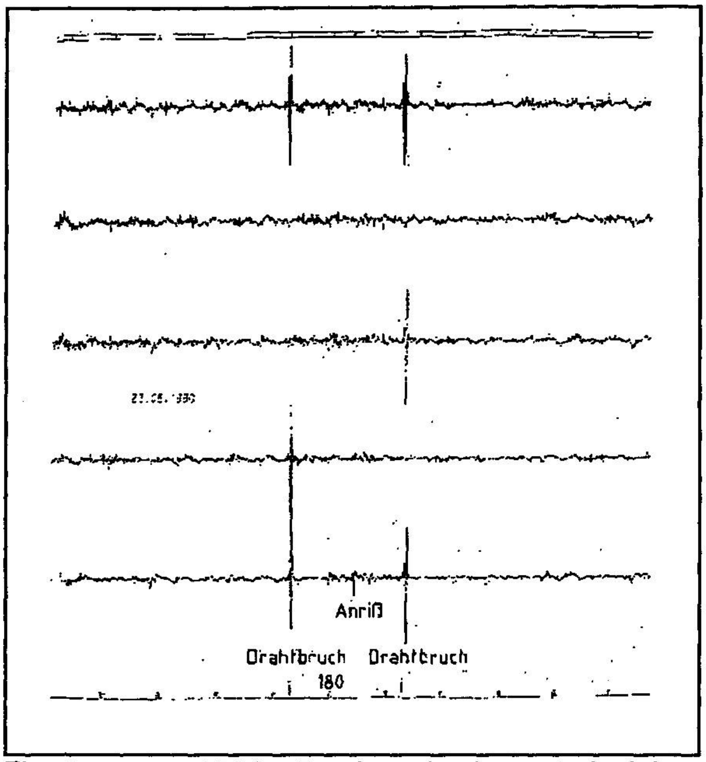

Fig. 6: 1990, 2 wires broken, 1 incipient crack

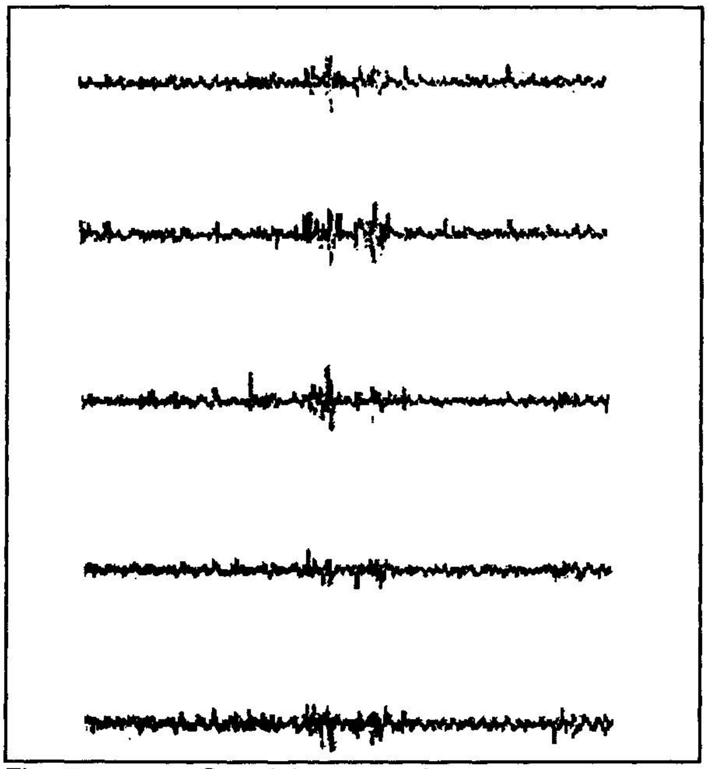

Fig. 7: Suspicious graph

<u>Band and clamp seatings, saddle bearings, splayed anchorages</u>

At points of directional change and in locations where forces are applied, the cable is subject to additional stresses. In particular, potential stress points are located along the restraining edges of end fittings. This can cause damage to the outside wires. For example, at clamping locations in suspensions bridges, the cable is forced into the shape of a polygon. Realistically, after opening and removing a clamp, the preexisting condition cannot be restored. Higher stresses on the cable and its wires are to be expected. This fact requires a careful evaluation whether or not a more accurate examination with opened clamp and band seatings is justified. Similarly, the individual wires of a cable which is deflected at saddles or splay anchorages are subject to additional stresses. At these locations, water accumulation - for example at gaps in clamps - combined with a possible reduction of the coating can cause accelerated corrosion. Furthermore, rubbing at loose clamps - possibly aggravated by corrosion - can cause broken wires. Early detection of these wire breaks is hard because a visual inspection at these locations is usually difficult or impossible. Therefore, the inspector must rely on secondary indicators, such as color changes on the surface, shifts and cracks in the corrosion protection coating, acoustic indication of movement, etc. Knowledge of structural details of a saddle or a splay anchorage is vital for an in-depth assessment. The base anchorages in older but also in some new - cable structures are especially susceptible to adverse environmental conditions. Penetration of water laden with deicing salts can cause severe corrosion of the end terminals. Salt water is particularly destructive when nonferrous metals are used as soft inserts at sockets or as padding for saddle supports and clamps.

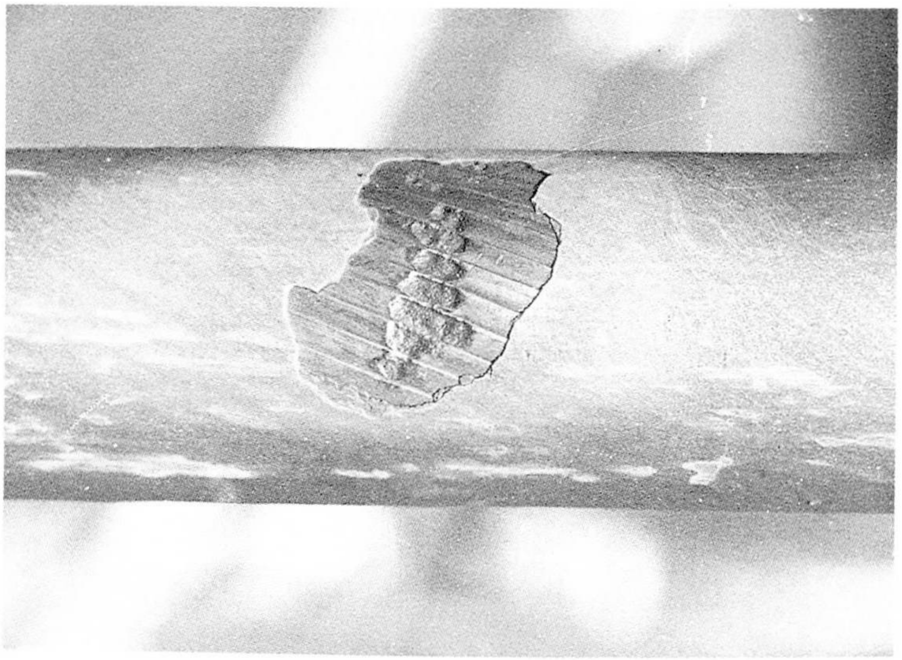

Fig. 8: Corrosion under coating

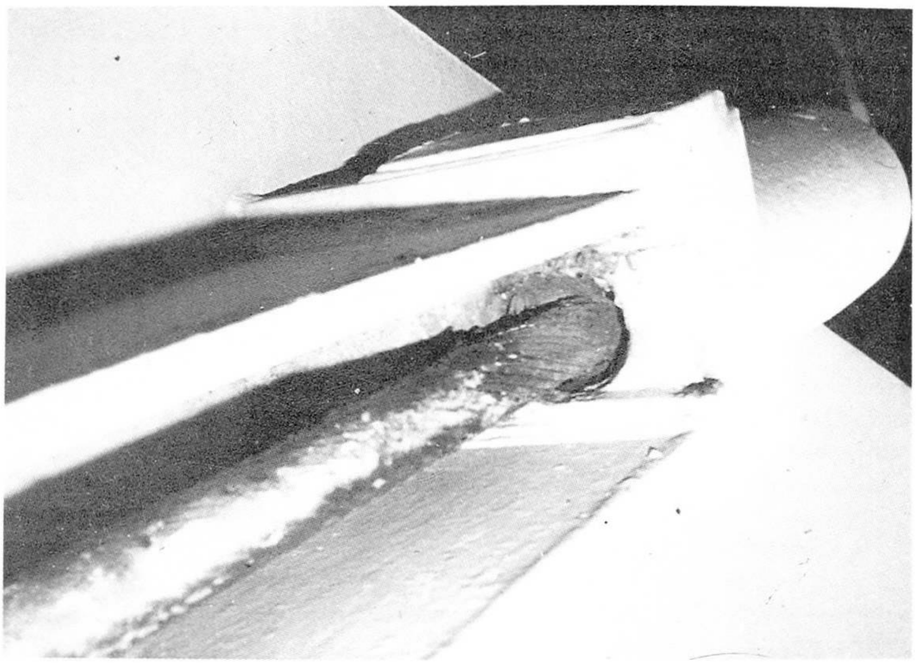

Fig. 9: Badly designed anchorage

Designs of corrosion protection

The design and consumption of corrosion protection of a cable plays an important role on the cable's life. Nearly about 50 % of a cable's troubles are caused by an unsufficiant corrosion protection. In the past, it was common practice to embed steel members of structures, including cables, in concrete or grout. This procedure makes an inspection difficult. However, this was not considered a serious problem. Load carrying cables were believed to be not susceptible to fatigue damage. Furthermore, grouting was considered a permanent corrosion protection. This practice has caused numerous problems. Therefore, it is hard to understand why load carrying members, such as cables and wire bundles, are still being constructed not inspectable. Although the use of protective plastics is promising and new, the previous basic problem remains: The load carrying elements cannot be visually inspected, which makes an assessment of their condition possible only by electromagnetic inspection. Even under normal conditions, varying external temperatures can cause water to penetrate a plastic coating through hair fissures and other crevices. Then, under an apparently undamaged surface, corrosion can develop undetected. Initial contamination of the cable by chemicals, sand, etc. can accelerate the corrosion process.

Fig. 10: Corrosion under a clamp seating

SUMMARY AND CONCLUSIONS

Longtime experience amply justifies regular periodic Integral Cable Inspections of bridge cables. However, there are no uniform and prescribed rules for these inspections, but one: a cable must be inspected from one end-connection to the other. Procedures for each structure must be individually designed and carrried out. For an extended visual inspection of accessible cable sections, suitable man carrying equipment is required. Nondestructive inspections for external and, especially, internal defects of accessible cables, cable sections or bundles are possible with electromagnetic inspection devices. The electromagnetic inspecction of cables is today a standard, based on a mature technology. Present instruments can be used for cables up to 175 mm diameter. But it is very important that the use of these instruments is controled by experts and interpretations of the recorded signals are done by the same experts. To assess the condition of sections near the anchorages and saddles, electro-optic systems can be useful. For certain types of cable connections, specialized ultrasonic inspections are possible. For a final evaluation of all findings, experience is important. Structural details must be known, especially for the first inspection of a structure. Only a thorough understanding of material aging, fatiguing, and other deterioration processes will allow a well-founded appraisal of the condition and safety of cable bridges.

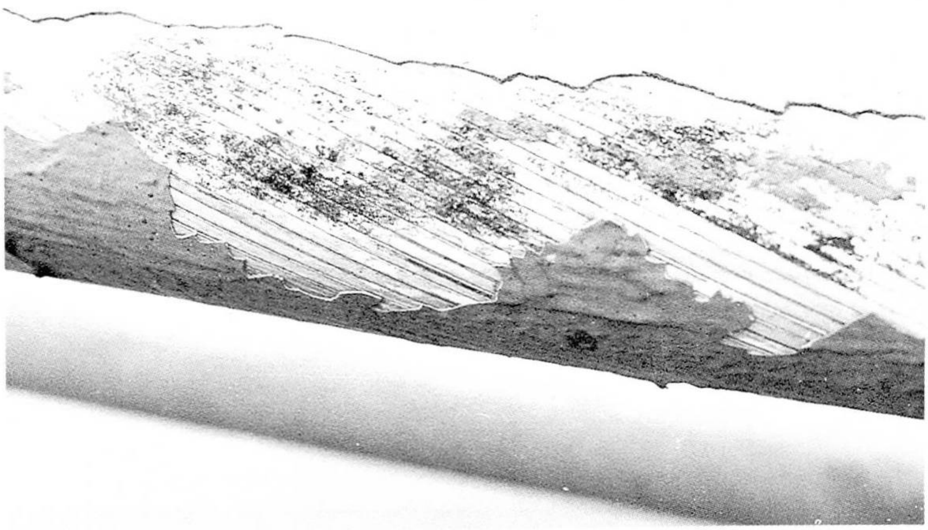

Fig. 11: Corrosion under an undestroyed corrosion protection, detected by EM-inspection