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Recent Approaches to Corrosion Protection in Stay Cable Design

Nouvelles solutions pour la protection des haubans contre la corrosion

Neue Lösungen für den Korrosionsschutz von Schrägkabeln

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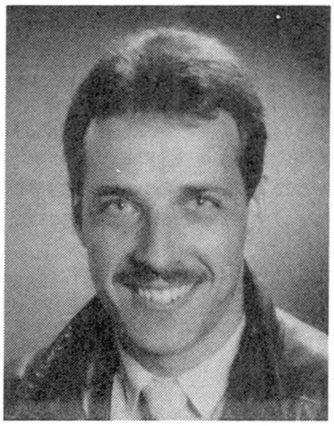

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SUMMARY

One way to approach corrosion protection of stay cables is to use multiple robust protective barriers. Another way is to focus on inspectability, sacrificing some advantages of the first approach. The paper describes an alternative solution, using monostrands, which retains the basic advantages of both major approaches.

RESUME

Une approche consiste à donner la priorité à la protection des haubans contre la corrosion en combinant plusieurs systèmes protecteurs. L'autre approche consiste à privilégier la possibilité d'inspecter les câbles, ce qui nécessite l'abandon de certains avantages du premier système. L'article décrit une solution basée sur l'utilisation de monotorons qui permet de satisfaire aux deux exigences.

ZUSAMMENFASSUNG

Eine Möglichkeit, das Korrosionsschutzproblem bei Schrägkabeln anzugehen, ist die Verwendung von mehreren, kombinierten Schutzmaterialien. Eine andere Variante legt das Schwergewicht auf die Inspizierbarkeit. Dabei werden teilweise die Vorzüge des ersten Systems vernachlässigt. Der Aufsatz beschreibt eine Lösung mit Monolitzen, was zu einem System mit Vorteilen aus beiden Philosophien führt.

1. INTRODUCTION

Corrosion protection and durability are among the main concerns for stay cables. Other import factors, such as fatigue and static tensile efficiency; installation methods; inspectability; adjustability; and replaceability are also considered. But they are not subjected to the same extensive and sometimes emotional discussions as corrosion protection. This paper will add some more fuel to the debate.

2. CURRENT SYSTEMS

The types of cables commonly used can be divided into four main categories [1,2]. Those are parallel bars; parallel wires; parallel 7-wire strands; or helical/locked-coil structural strands.

Helical and locked coil structural steel strands are the original types of cables for stays. They are often made of galvanized wires. In addition, resins, polyurethane based compounds, certain types of greases or waxes or other compounds are used to fill the spaces between the wires. Often the external surface is painted.

Parallel bars and parallel wire bundles are usually encased in a plastic or steel tube. The void is subsequently grouted. Most common grouting compounds are cement grout, polyurethane based compounds, or grease and wax-type materials. The wires may be galvanized, but not if cement grout is used. To ensure a minimum cover of the grouting compound around the bar or wire bundle, helical spacers or similar means are installed.

The same approach has also been used in many cases for parallel 7-wire strand bundles, i.e. polyethylene tube plus cement grout. This is particularly true in the USA, where several bridges have been built successfully with this system. One of the advantages of a strand system is , that it can be adapted to a variety of new corrosion protection methods. Experience from other fields, such as ground anchors, or tendons for prestressed concrete, can be applied.

3. TWO BASIC APPROACHES TO CORROSION PROTECTION

3.1 General

The high tensile strength steel used as the load carrying member in cable stays is relatively sensitive to corrosion. Reliable corrosion protection systems are therefore essential. In recent years, two basic ways to approach the corrosion problem have evolved:

a) Use of multiple robust protection barriers, leading to a system where one or several materials can take over the protective function for a material which has failed. This improves reliability and life expectancy, but makes direct inspection more difficult.

b) Concentration on inspectability, allowing easier detection of a failure, however at the expense of robustness, reliability, and life expectancy.

Both ideas have certain advantages and disadvantages, and both have been used on several projects.

3.2 The "multiple barrier" approach

Strands can be protected at the steel works by several means. Systems available today include:

- Grease and plastic sheath (so-called monostrands);
- Galvanizing;
- Epoxy coating;

- Epoxy-tar and plastic coating;
- a combination of galvanizing with some of the above.

In connection with an outer sheathing and a grouting compound, systems providing three, four or even five protective barriers may be created. The result is an extremely reliable and durable system. This is particularly true, because the two outermost layers, namely the exterior tube and the grouting compound, have a substantial thickness. Provided the grouting compound is a cement grout, they have both a relatively high physical resistance. Hence, there is excellent mechanical protection against vehicle impact, vandalism and abrasion. Dampening and fire resistance (when cement grouted) are also favourable properties of this system.

Since these cables are usually preassembled on site [3] or at works, heavier installation equipment than for the method described under 3.3. is needed. Furthermore, the injection procedure requires a certain amount of time. Usually, the injection is only conducted after final cable force adjustment and the full dead load (pavement etc) is present.

3.3 The "inspectability" approach

The other way is to put emphasis on the inspectability of the cable system. In this case, a bundle of single strands without external tubing or grouting is used. The strands may be galvanized and coated with a layer of epoxy-tar and a plastic sheathing [4].

The idea is to provide easy access for a visual inspection of the cable. In case of a defect, the suspect strands would be replaced. The single strand installation method makes it possible to use relatively small and lightweight equipment. Nevertheless, the following should be considered:

- The coating of the strand is rather thin, typically 1.5 mm. Mechanical protection, fire resistance, and durability are reduced.
- Only the outermost strands can be visually inspected. In fact, only the coating of them and not the relevant steel surface can be seen.
- The critical areas in the anchorages are normally difficult to reach for an adequate inspection.

4. THE MONOSTRAND STAY CABLE

4.1. Concept

A stay cable type providing all the advantages of the "multiple barrier" approach, and still allowing an inspection and/or single strand replacement, has been developed by VSL. The cable consists of a bundle of parallel, greased and sheathed monostrands; a grouting compound; an outer sheathing; and anchorages. The cross-section of the cable, and the principal design of the anchorage is shown in Fig. 1 and Fig. 2, respectively.

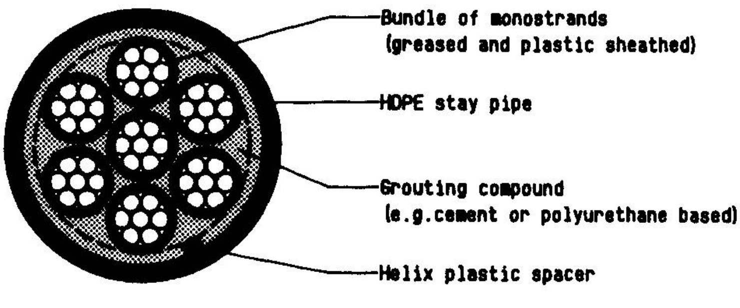

Fig. 1 Cable cross-section

A special strand sleeve connects the end of the monostrand plastic sheathing with the anchorhead, and seals it against the grout injection of the stay (Fig.2). The details of the anchorage require the injection of an appropriate corrosion preventive compound in the anchorage. Search for this compound is described in Section 5.

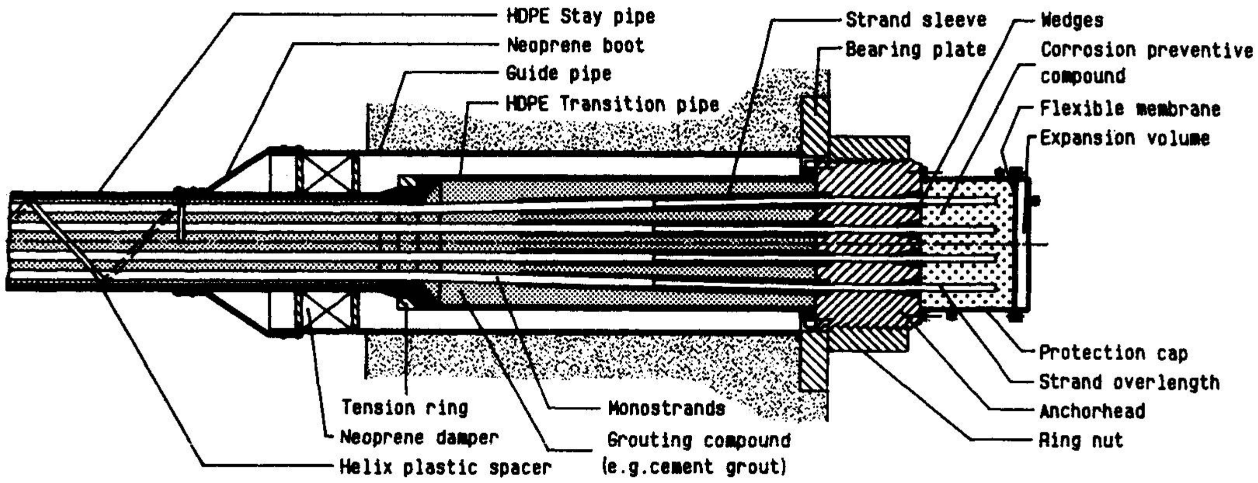

Fig. 2: Cable anchorage

4.2. Inspection or replacement of an individual strand

The nature of the monostrand in principal allows one to detension and pull out a strand at any time. With the details of this anchorage concept, pull-in of a new strand is easily feasible. This can either be done by:

- attaching the new strand directly to the one to be replaced, and pulling them through together; or
- removing the old strand first, pushing in a thinner strand and using that one to pull in the new strand.

While the new strand is pulled in, it runs through a greasing device. This concept not does not only permit one to replace a damaged strand, it also permits one to establish a surveillance program to check the actual condition of the steel surface.

Trials have shown that such a replacement procedure of a strand is simple, fast and reliable [5, 6].

5. EVALUATION OF THE CORROSION PREVENTIVE COMPOUND

5.1 General remarks

Monostrand type stay cables were first used at the Kemijoki River Bridge at the arctic circle in Rovaniemi, Finland. Due to the extreme climatic conditions, extensive testing was performed. The search for a suitable corrosion preventive compound for use in the anchorage is now specifically described because it yielded some suprizing results.

5.2 Summary of tests conducted

In total, the following tests were carried out:

- Various tests with small samples of grease and other corrosion protective materials at low temperatures and elevated temperatures (-50°C to + 70°C). Fifteen different products were examined in total.
- Low and high temperature tests with complete stay cable anchorage specimens. The temperature range was from -50°C to +50°C. Three products were tested.
- Several injection tests with complete stay cable anchorages.
- Examinations of the compatibility of the corrosion preventive compound with polyethylene; cement grout; and with the permanent corrosion protective grease of the monostrand.

5.3 Test results

The low temperature tests revealed certain problems with wax-like materials. Due to the need to apply the compounds hot, cracks and gaps up to several millimetres width appeared at low temperature. These were particularly evident along surrounding components, such as tube, anchor head, protection cap and partially, strands. The cracks do not close again on reheating to ambient temperature.

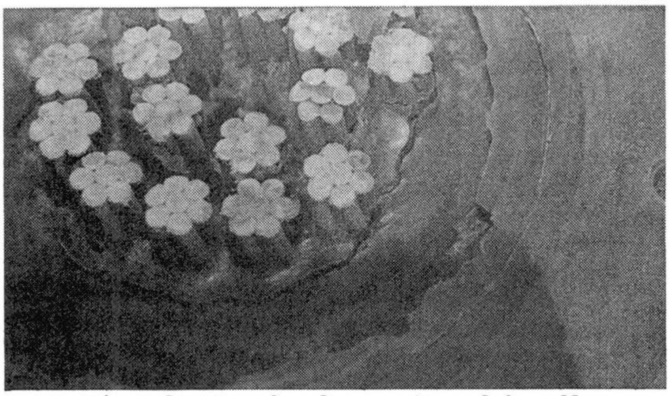

Fig. 3: Crack along strand bundle

The testing led to a cold-applied, soft material. The substance is thixotropic and has approximately constant viscosity over a wide temperature range. According to information from the manufacturer, the compound remains pumpable down to -18°C. The dropping point is 260°C. Although also this material shrinks at low temperatures, its behaviour is completely different from that of hot-applied materials. It forms internal cavities within the volume of the compound only. These cavities close again upon reheating to ambient temperature.

Due to the nature of the material, high pressures can be produced at high temperatures if expansion is restricted. The solution to this problem is expansion volumes. While on the Kemijoki River Bridge, those expansion volumes were externally connected vessels, Fig. 2 shows the expansion volume integrated in the protection cap.

The suitability for injection of this material is excellent. The tests have shown that even the smallest cavities in the wedges are thoroughly filled with corrosion preventive compound. Air bubbles and gaps do not occur. A vacuum technique is used to ensure proper filling of the void within the strand sleeve.

5.4 Conclusions drawn from these tests

The tests indicated that "wax-like" injection materials are not generally suitable. This conclusion is applicable regardless of whether just the anchorage or the entire stay cable is filled with the "wax-like" material. The term "wax-like" implies here a material which must be heated and "melted" for injection and which always solidifies again on cooling. These wax-like materials as a rule have melting points and solidification points of approx. 60 to 85°C.

On cooling the material tends to shrink. In fact, however, this is only possible down to the solidification point. From this point down to the current outdoor temperature, the shrinkage process is impeded. Internal stresses, bond stresses with respect to the surrounding tubes and components, and possibly cavities then occur. In addition, this is made worse by the fact that the compound solidifies first at the edge. At ambient temperature these wax-like compounds are usually capable of accepting the stresses produced. If the temperature falls further, a point is reached at which these stresses become too high. Cracks and gaps then occur, typically along the actual surrounding surfaces that are to be protected (tube, anchor head, and partially along the strands as well). <u>This process is irreversible</u> because when the gaps and cavities develop, the stresses are very largely relieved. The corrosion protection action of the compound is then lost.

The cold-applied, soft material recommended exhibits a much more favourable behaviour. <u>It is injected at standard ambient temperature.</u> This material does, of course, also shrink on cooling, but this is an unavoidable, physical effect. The material is, however, capable of remaining adhering to the surrounding surfaces. Cavities occur in the interior of the material. <u>The process is reversible,</u> i.e. when the standard outdoor temperature is again reached, the cavities close again by self-healing.

6. STAY CABLE TESTING

In addition to the testing of corrosion protective materials, tests with cable anchorages and entire cable specimens have taken place. As the described cable system is of the "unbonded" type, the gripper wedge becomes a key part for the force transfer. High static tensile efficiency and good dynamic behaviour under fluctuating loads are required from this wedge.

A number of tests were performed to confirm the soundness of the system. A series of single strand tests with wedges and anchorheads were made. These consisted of fatigue tests with up to 260 MPa stress range at an upper load of 50 % of the strand capacity (GUTS) over 2 million load cycles.

For the Kemijoki River Bridge, a stay cable specimen with 32 strands was tested in a fatigue test, with a subsequent static ultimate tensile test. The stress range of the fatigue test was 185 MPa at 0.45 GUTS upper load. No wire failures occurred during the 2 million load cycles. An efficiency of 100.9 % and 96.5 % was reached in the ultimate tensile test, based on the nominal and the actual capacity of the tendon, respectively.

Future fatigue tests on larger stay cables with greater stress ranges are planned.

7. FINAL REMARK

The monostrand system highlighted here is an excellent combination of new ideas and materials with proven history. It combines the new ideas of focussing on durability on the one hand by using several corrosion barriers, and focussing on inspectability on the other hand by allowing easy removal of individual strands. It also imposes no limitations regarding the use of galvanized strands, polyurethane grout, or other features available on the market and sometimes specified by engineers today. This system has proven its viability and reliability in the first field application under extreme climatic conditions in northern Finland. It is now also approved in the United States.

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