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Robustness of Stranded Cables in Suspended Bridges

Robustesse des câbles à torons dans les ponts suspendus

Die Robustheit von Seilen im Brückenbau

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SUMMARY

Locked coil spiral ropes have proven themselves in bridge construction in Europe. Of course, special attention has to be paid to the characteristics of these tendons in the zones of anchorage, deviation and transversial compression. If the special features described in this paper are adhered to during construction, assembly and later on during maintenance, robustness and a long lifespan can be expected from these elements.

RÉSUMÉ

En Europe, les câbles à torons gainés ont fait leurs preuves dans la construction de ponts. Il faut naturellement porter une attention particulière aux caractéristiques de ces éléments de traction dans les zones d'ancrage, de déviation et de compression transversale. Tenant compte des remarques faites dans cet article sur la construction, l'assemblage et la maintenance ultérieure des torons, on peut s'attendre à une grande robustesse et une durée de vie importante de ces éléments.

ZUSAMMENFASSUNG

In Europa sind sehr gute Erfahrungen mit vollverschlossenen Spiralseilen im Brückenbau gemacht worden. Dabei muss auf die Eigenart dieser Zugelemente im Verankerungs-, Umlenk- und Querpressbereich natürlich besonders eingegangen werden. Werden bei der Konstruktion, der Montage und der späteren Wartung die in diesem Bericht angespro-chenen Besonderheiten der vollverschlossenen Spiralseile beachtet, dann kann von ihnen eine grosse Robustheit und lange Lebensdauer erwartet werden.

Locked coil spiral ropes measuring up to 180 mm in diameter and consisting of high-strength steel wires are complex structural ties, but if used correctly they are very robust and durable and have proven themselves very well in bridge- and building-construction [1], [2].

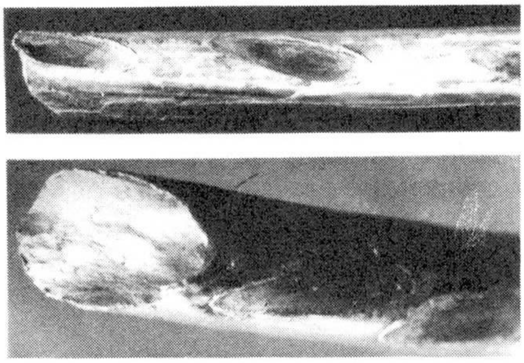
CHARACTERISTICS AND MECHANICAL BEHAVIOUR OF LOCKED COIL SPIRAL ROPES

The individual wires are arranged in helixes with alternating lay direction. This results in low bending- and constraint stress when bending the whole cable (Fig. 2). With increasing cable tension the radial pressure between the wires, resulting from the helix, increases and the relative movements of the wires decrease more and more. Frictional resistances in the cable and local deformation at the crossings of wires of neighboring layers (Fig. 1) result in a non-linear stress-strain relationship of the cables as a whole; this is especially evident during the first loading.

Even if shortly before failure the radial pressure of the wire-helixes compresses the spiral rope radially to such a degree that the entire cable reacts almost like a solid bar, integrating also single prematurely broken wires within less than one lay-length. The ultimate load is approx. 5 % less due to the helical or spiral geometry than the total of all single wires' strenghts and the tension stiffness is about 15 % less than that of an individual wire [3].

The wires are integrated by static friction occurring between neighboring wires. To overcome this, energy dissipates resulting negatively in fretting corrosion and positively in increased damping. The tension stiffness of the cable drops considerably after the wires start moving against each other thus overcoming the static friction [4].

For over 100 years now Z-shaped wires are used for the outer layers of spiral ropes, with their "heads" pressing more and more on the "foot" of the neighboring wire under increasing longitudinal tension thus locking the cable mechanically. Z-wires fill the cable cross-section better than round wires and their "heads" form a smooth cable surface (Fig. 4). A disadvantage of this type of wire with line pressing on the neighboring wires are their intensive friction movements along these lines due to stretching or compressing of the wire spirals. In the case of round wires this contact lines are only accidental. They occur methodically as soon as the gap between the wires closes due to transversal contraction.



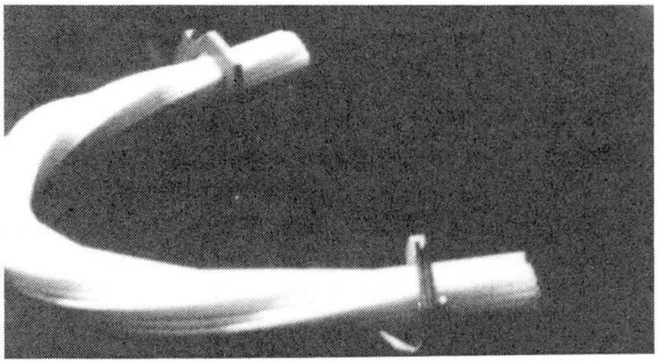


Fig. 1: A deformed round wire taken from a rope's core.

Fig. 2: Arrangement of wires in a curved and twisted hexagonal wire bundle.

In case of a clamp, to suspend a hangar or secondary rope from a main cable or rope, the radial prestressing forces have to be as intensive as possible and the transition zones should not be too long, because with varying cable load they allow for fretting inside the rope and between the cable surface and the clamps. (This is a result of recent research and contradicts the general opinion recommending soft transition zones.) Since the cable under increasing longitudinal load withdraws from transversal compression of the clamp due to its transversal contraction, even high clamp pressures are only effective under dead load and service loads but will not affect the ultimate load [3], [5].

DURABLE PROTECTION OF WIRES AND LOCKED COIL ROPES

Nowadays all wires are hot dip galvanized and emphasis has to be put on the galvanization not becoming too thick because then it cannot be applied evenly especially to Z-wires. The layer of a zinc-iron-alloy should not become so thick that it reacts brittle, showing early cracks or extensive flaking.

Now a metal layer consisting of a zinc-aluminum-alloy can be applied to wires. The zinc-iron-alloy layer is reduced to a minimal thickness compared to the generally used galvanization and the Zn-Al-alloy is 2 to 3 times as hard as pure zinc applied as an outer layer during the hot dip galvanizing process [9].

Even though extensive flaking occurs at a reduced pace compared to high-grade zinc and when using the Zn-Al-alloy only a thin zinc-iron-layer has to be applied, it has to be observed that, when using this type of layering (Galfan), all advantages of the hot dip galvanization are preserved. In Germany such metall layers are tested [10].

Still, red lead based on linseed oil is preferably used to fill the cavities of spiral ropes because for example poly-oil with zinc powder (zinc powder paint), hydrocarbon-synthetic-resin with aluminum particles (metal coat) or poly-waxes (APP or Cordalen) are sophisticated means of protection. A deliberate pigmentation with zinc powder or zinc chromate does not only bring advantages by absorbing moisture. Under certain temperature conditions and with a faulty mixture of a PV-resin used as binder, strong blistering may occur in the presence of residual moisture.

Amount and type of pigmentation decisively determine the friction resistance. Zinc powder increases it, aluminum particles decrease it.

A two-component resin or dehydrogenating oil used as binder is determining the remaining viscosity of the filling during the aging process. On the one side filling material may escape through gaps (bleeding) and harmful substances may enter through cracks. Here red lead, also generally applied between galvanized wires, act most favourably. All other materials have to be tested individually and used according to the respective requirements and only with extreme discretion [11].

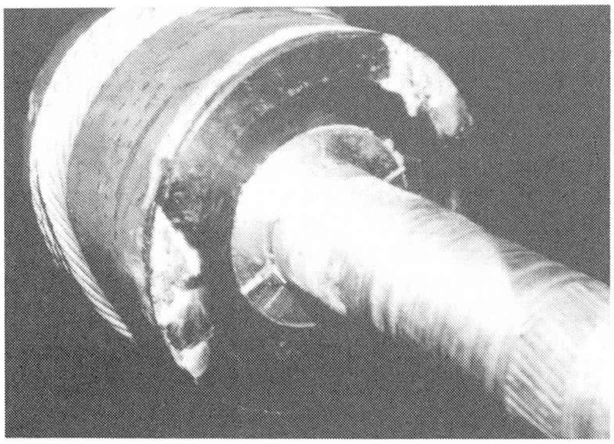
The outer layer of locked coil ropes with its complete, smooth surface is applied with a brush in several layers up to a thickness of 500 µm. In Germany a polyutherane-based resin is used with a coloured finish. Its pigmentation has to guarantee sufficient UV-protection as well as shock-resistance. This layering has proven itself up to now as long as the filling material does not produce any gas. The more gas is produced, the more permeable and thin the layering has to be.

The movements of a spiral rope at the points of transition to anchor sockets or to the clamping resp. deviation zones must be distributed evenly using bond transition lines. The bond joints to be used have to be made of permanently elastic material and be carefully detailled. A bond joint moving distinctively must be equipped with sufficiently adhesive contact areas between the bond and the mobile edges, and be the thinnest at its center. The joint may not withdraw from its flanks and must distribute a relative movement as acceptable elongation along a finite length (Fig. 6).

Protection from vandalism, fire, shock or saline splash should be achieved without mantling the cable any further [13]. At points exposed to unfavourable attacks, the galvanization wore off sometimes within weeks. The fillers and paints applied incorrectly may become brittle when exposed to UV-radiation resp. rust may form after minimal damage (Fig. 6). The damage mechanisms may be disastrous, because if the cable's resistance is reduced only on a short stretch, the entire element becomes useless. By-passing these areas is rarely possible [14].

Therefore it makes sense to emphasize control and maintenance, rather than waiting until repair and renewal (replacement) become necessary. In any case replacement is more expensive and riskier than reasonable maintenance, including the renewal of the corrosion-protection every 10 to 20 years. These are also the periods in which traffic, coating systems and the climatic situation change and therefore longer-term predictions can rarely be ventured.

Locked coil spiral ropes are usually **anchored** in wedge-shaped metal cast steel sockets. Such socketing using hard zinc alloy is to fix the cable preferably at the exit of the socket by means of ahigh radial pressure. Thus a high friction resistance between the cable and its socket transfers the load over a short distance and fretting of the wires is reduced or eliminated. The usual casting length of 5 times the cable diameter is required only to cater for shrinking of the metal grout in the cone. The rear part of the cone containing the rope's broom does not render support under constant load and under service loads. In addition an attempt has to be made to leave the circular slot between the cable and socket as wide as possible to avoid fretting by allowing for an elastic shear deformation of the metal grout (Fig. 3). This prevents fretting corrosion under pulsating cable loads [6], [7].



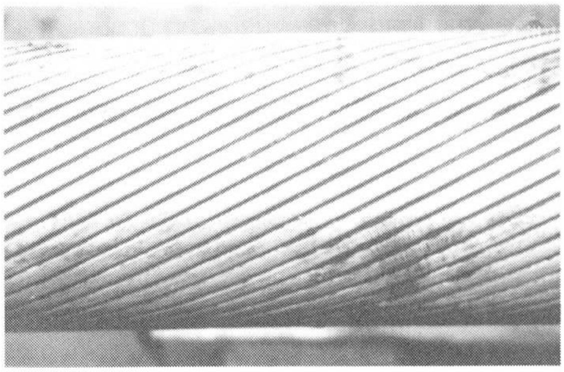


Fig. 3: Spiral rope with a wide circular slot between cable and socket to prevent fretting corrosion.

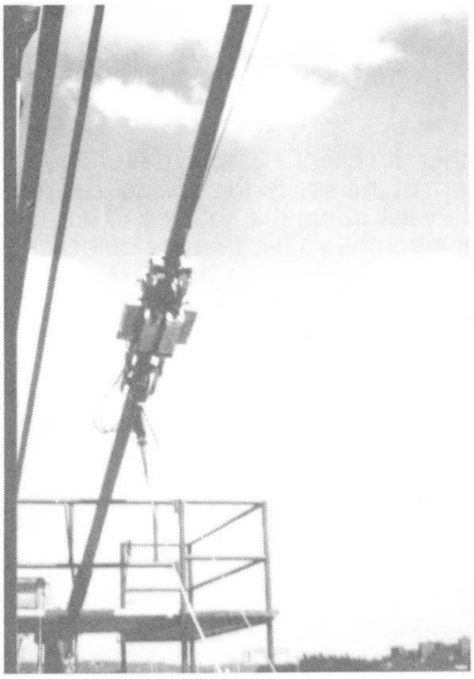
Fig. 4: the smooth surface of the Z-shaped outer layers of a locked coil rope.

In the case of a locked coil spiral rope being **deviated** over a saddle, the radius should not be smaller than 10 times the rope's diameter, because then only the wires in the cable remain consolidated. The deviation length should correspond to an integer multiple of the outer lay-length in order to allow for length adjustment of the individual wires (Fig. 2). If the wires are not too thick and thus their bending stresses remain minor, and if the cable is fixed firmly in a groove, neither a deviation nor a clamp or the anchoring should affect negatively the dynamic strength of a locked coil rope.

ROPES USED AS SUSPENSION CABLES OR STAY CABLES

Ropes are tendons which due to their small ratio of diameter and span assume a shape which is prescribed by the equlibrium between tensile force they transfer and their deadload. Their loadbearing behaviour is governed by their geometrical stiffness. Their joints, i. e. anchorages, clamps or curvatures are disturbance zones. The cable itself has to absorb the angular changes at fixed joints. In this case stranded tendons are considered to be very robust.

Large angular changes usually occur under low tension and with long ropes and may result from vibrations caused by wind and traffic. From the wide spectrum of wind-gusts the ropes filter those a corresponding to their natural frequencies. The initiation caused by turbulences in the laminar wind (Karmann-Effect) is not affected even if the cable vibrations reach higher amplitudes. Accordingly vibrations induced fromn the bridge girder due to vehicles resp. sequences of vehicles may lead to high amplitudes. Except for angular changes at the ends, these vibrations do not result in substandtial stress amplitudes [8]. Ropes are better suited to resist angular changes than bundles. Compared to bundled strands, with strands consisting of 7 wires which are individually protected, but exposing a large surface, locked coil ropes are less sensitive. Ropes may be inspected individually and defects in the surface may be determined and repaired. This is not possible in the case of bundled single strands. Their development resulted in the tendons becoming one-way-products. Replacing ropes or bundles changes the state of stress of a structure calling for additional action.



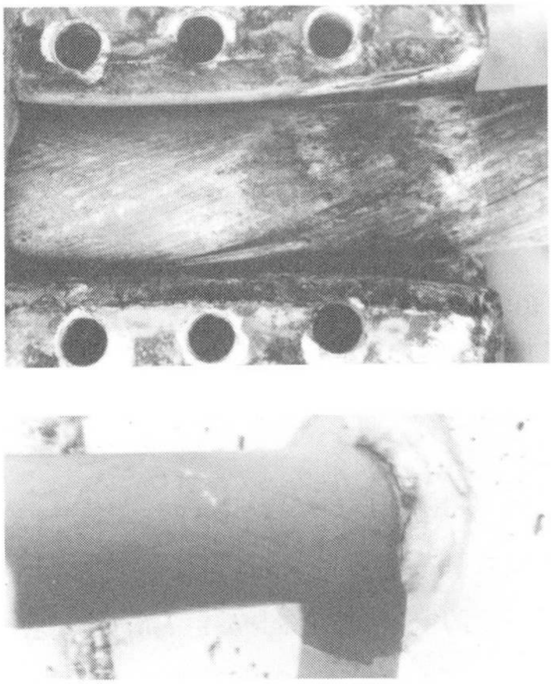


Fig. 5: Inspection of the individual cables by using magnet-inductive procedures. The apparatus moves along the rope and produces a graphical diagnosis.

Fig. 6: Damage to a cable at the entry to a deviation groove due to the use of the wrong sealing, which was also applied incorrectly (above) and cracks in a seal due to UV-radiation and cable movement (below), allowing water to penetrate.

What possibilities are there to maintain the structure? The spacing between the tendons should allow free access for inspection and maintenance. The tendon-units should be, neither too large nor too small to be checked (Fig. 7).

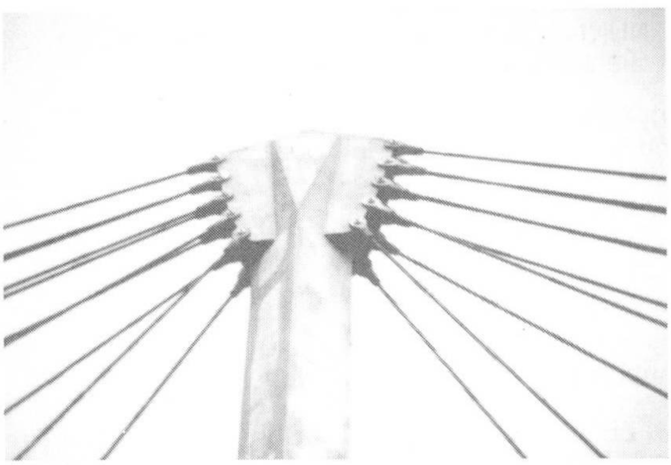


Fig. 7: Open rope bundles for large bridges. Gaps or slots must be avoided. Either care for close contact or provide ventilation and drainage.

Fig. 8: Mast head of a pedestrian bridge with easy access to the cable anchorings for inspection and maintenance.

It is possible to visually inspect the ropes using baskets running on the bridge cable, and to detect wire failures by means of magnet-inductive procedures (Fig. 5). In both cases the rope has to be freely laid up to the entries in the joints or anchorages (Fig. 8). Covered sections of tendons are dangerous [15], [16].

Laymen are unable to evaluate a cable after prolonged use. Either the client's employee (bridge inspector) familiar with the whole structure and constantly present at the site or the specialized rope inspector (expert) are of particular importance here. Together they will serve the safety and durability of a cable structure better than any sophisticated mechanical automatism for damage detection.

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