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Improved Corrosion Protection for Parallel Cables of Cable-Stayed Bridges

Amélioration de la protection contre la corrosion des câbles porteurs de ponts haubanés

Verbesserter Korrosionsschutz für Parallelkabel von Schrägseilbrücken

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SUMMARY

The paper gives an overview of cable failures, corrosion protection developments and current practice, outlining the need for high-performance protective measures when parallel wire stay cables are exposed to high stress. It then describes the development of corrosion inhibitive, flexible grouts with superior performance, permitting cable duct injection before installation or even in the workshop in order to arrive at higher long-term protection levels and ease of installation.

RÉSUMÉ

L'article fait état des désordres dus à des câbles défectueux, mentionne l'historique et les pratiques courantes de protection contre la corrosion en soulignant la nécessité de réaliser une protection à haute performance dans le cas des câbles porteurs (à fils parallèles) soumis à de fortes contraintes. Il décrit ensuite le développement et les performances des coulis flexibles permettant une injection dans la gaine des câbles avant leur mise en place ou même en atelier, afin de parvenir à de hauts niveaux de protection à long terme et conserver une mise en oeuvre facile.

ZUSAMMENFASSUNG

Der Artikel gibt eine Übersicht von Schäden an Brückenseilen und deren Ursachen. Die historische Entwicklung des Korrosionsschutzes und heutige Praxis werden zudem gezeigt. Die Notwendigkeit besonders hochwertiger Schutzmassnahmen im Falle von Paralleldrahtbündeln für hochbeanspruchte Schrägkabel wird besonders herausgestellt. Anschliessend wird die Entwicklung und Anwendung flexibler Füllmassen mit aktiver Korrosionsschutzwirkung und überragendem technischen Leistungsvermögen beschrieben, die bereits unter kontrollierten Bedingungen im Werk injiziert werden können und somit die Sicherheit erhöhen und den Einbau erleichtern.

1. INTRODUCTION

A number of spectacular shortcomings and failures of cables on stayed bridges over the last couples of years have sincerely alarmed the engineering community. The article "Cables in Trouble" [1] and subsequent publications in numerous countries resulted in a world-wide wave of most alarming damage reports becoming public knowledge. A typical example is Germany's "Koehlbrand" bridge in Hamburg, where 25 broken wires were detected in 1976 on a routine inspection, i. e. only 2 years after opening of the bridge. As a consequence, all cables had to be exchanged in 1978, costing more than US$ 10 mio at the time.

1.1 Causes

A very thorough survey on causes of damage and a comprehensive list of current methods (by design and selection of materials) for corrosion prevention is contained in the Saul/Svensson publication "On the corrosion protection of stay cables" [2].

There is a multitude of causes and a variety of corrosive effects involved, the main ones being:

- "conventional" atmospheric corrosion caused by presence of electrolyte and oxygen, accelerated by corrosion stimulators as present in industrial or marine atmosphere, namely chlorides and sulphates. Higher concentrations of chlorides, e.g. deriving from de-icing salts, are known to cause severe pitting.
- stress corrosion cracking/fatigue corrosion caused by the much higher dynamic stresses compared to conventional suspension bridges. There are still disputes amongst metallurgists whether certain high tensile steels may be more susceptible to this type of corrosion than mild steel.
- corrosion caused by contact of different metals/alloys in moist, salty conditions (bimetallic corrosion).

2. CLOSED COIL CABLES

2.1 Previously employed Protective Methods

There is a long reference record of reliable long-term protective systems for Locked Coil Cables of conventional suspension bridges. However, the majority of them cannot be employed anymore these days for environmental reasons as they were often based on red lead combinations (practically non-degradable and known to cause blood diseases) or contained zinc chromate (considered carcinogenous). Furthermore, many of them - as one learned the hard way - cannot cope with the stresses occuring on large stay bridges as these materials tend to embrittle in the long run.

2.2 Current Practice

Important improvements have been made in the design an manufacture of the cables themselves, e.g. by reducing the alloy content of copper, sulphur and phosphor, thus also increasing fatigue strength or by employing more sophisticated hot dip galvanizing methods with better controlled pre-treatment and thickness.
Modern protective systems are usually based on polyurethane combinations, using flake pigments in the outer coatings to arrive at maximum UV, water vapour and oxygen diffusion resistence ("barrier principle") [3]. The German Federal Department of Transport recently published a very complex draft standard on supply and testing requirements for coatings, sealants and injection resins for cables [4]. Typical (and clearly defined) requirements of the cured materials include flexibility (bending test), permanent elongation ability, vapour diffusion resistance, adhesion on new and old galvanized surfaces after artificial ageing, resistance to salt spray, simultaneous action of condensed water and sulphur dioxide, oil resistence, intercoat adhesion and compatibility with other substances found on/in cables. Weathering tests, pinhole detection and dynamic exposure (pulsating load) form also part of the approval procedure. This Standard should inevitably lead to much longer life and maintenance cycles.

Bridge Cables - Corrosion Protection in Germany

System	Function	Parallel cables	Locked coil
2K-Epoxy	Primer for steel and galvanized surfaces		+
2K-PUR solventfree	Low viscosity injection material	+	
2K-PUR solventfree	Sealant (flexible grout)	+	+
2K-PUR high-solid	High-build flexible protective coating		+
2K-PUR	Topcoat, UV-resistant, flexible	+	+

According to Technical terms of delivery "TL-KOR-Seile", Bundesministerium für Verkehr.(Department of Transport)

3. PARALLEL WIRE CABLES

These cables consist of a bundle of straight or slightly twisted wires (diameter 7mm or 1/4 in.), connected to steel anchor heads. This type of stay cable was originally developed from post-tensioning systems and was introduced in the early sixties. General requirements for these cables were published in the USA in 1986 [5].

3.1. Previously employed Protective Systems

The outer protective shell consists normally of UV-resistant Polyethylene or stainless steel ducts which are filled with a cementitious grout injection after erection. The grout is destined to provide active corrosion protection by its high alkalinity. Whereas the PE ducts (sometimes wrapped with PVC-tape) present a reasonable reference record (see [2]), the grout - although perfectly ok on smaller bridges - presented problems on some large bridges due to its weight (density) during application and its relative brittleness in the dynamic exposure, leading to cracking and water ingress.

3.2 Current Practice

The most widespread practice for protection are shop-fabricated cables incorporated in PE ducts. This permits optimum quality control during fabrication and exactly predetermined length. They are transported to site on coils, i.e. relatively well protected from the environment, and then injected with grout after installation. Whilst the performance of the cementitious grout can be considerably improved by incorporating appropriate admixtures reducing shrinkage, easing injection and increasing flexibility, injection on site is a lengthy, tricky process which may require extensive scaffolding in case of a larger bridge. Although the right admixtures (e.g. plasticizers and retarders) would permit large injection shots, this is in practice limited by the pressure resistance of the ducts as one does not only have to overcome friction but also the hydrostatic pressure in the inclined duct.
In addition to the standard protection, i.e. PE duct and grout, other protective layers were sometimes used, e.g. epoxi-coated wires (Quincy bridge, Illinois/USA) [6], directly PE extruded wires (Kemijoki River bridge, Finnland and Annacis Bridge, Vancouver/Canada). Galvanized wires were also used but should not be used in direct contact with alkaline grout to avoid reaction and possible hydrogene embrittlement, so that an additional polyester coating was employed at the Meiko-Nishi Bridge in Japan.

4. CONCLUSIONS

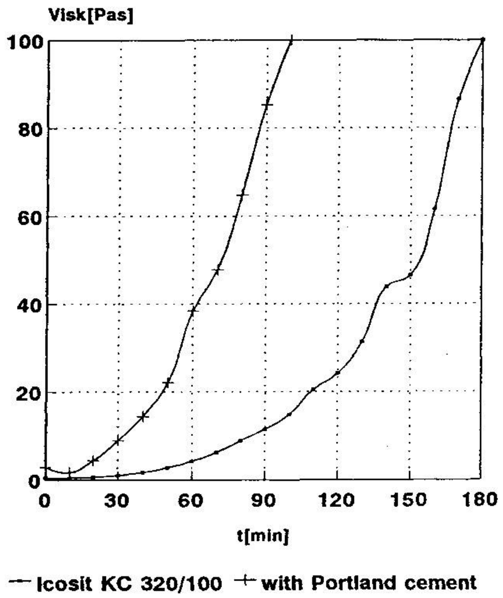
It is obvious that completely shop-fabricated cables offer considerable advantages with regards to optimum fabrication and injection conditions and in particular with regards to installation time and procedure on site. This was successfully achieved with a number of bridges already, using injection materials of permanently plastic consistency like grease (Tähtiniemi Bridge, Finnland) or petroleum jelly (Annacis Bridge, Vancouver). However, considering that sun radiation on a black PE duct may easily raise temperature above +70°C (158°F), such materials tend to become liquid and may leak out, presenting - apart from the loss of corrosion protection at the top - a considerable risk of environmental pollution. Field tests using nitrogene gaz filling to cut out moisture (as recently demonstrated on a Rhine bridge in Germany) were technically successful but proved to be excessively expensive, requiring permanent monitoring.
It is obvious from the above, that non-thermoplastic, permanently flexible injection materials offers evident advantages over the other solutions presented. In 5 years research work, the Japanese Yokohama Rubber Company developed a Polybutadiene Polyurethane Compound which was used for cable injection of the Iwakuro-jima and Hisuishi-jima cable stay bridges of the Honshu-Shikoku link in 1986/87, however injected on site [7]. This solution is said to work perfectly well but proved to be very expensive, required the use of stainless steel ducts due to the flammable nature of the injection material and relied exclusively on its imperviousness to water, i.e. offered no active corrosion protection.

5. CONSEQUENCES

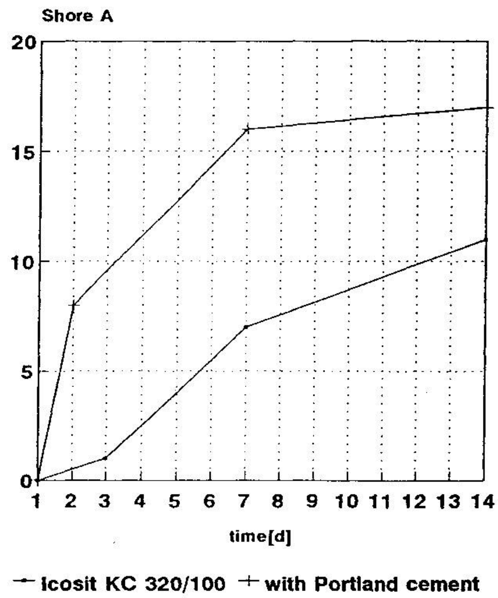
In 1982, the German Sika subsidiary began research work in the same direction, resulting in a 2-pack, flexible, solvent-free polyurethane combination incorporating corrosion inhibitors. In 1985, 50 tons were successfully employed for the corrosion protection of 15 m long, prestressed parallel wire rock anchors on a large hydroelectric site in Bulgaria. 4 more similar projects followed during the next 2 years, including a nuclear power station.

Until 1987, following a performance specification by the legendary bridge designers Leonhardt, Andrae & Partner, Stuttgart, the injection material, now named Icosit KC 320, was further optimized and subsequently used for the first time on a cable stay bridge in Pforzheim/Germany. After some more applications in the field and extensive full scale tests in the workshops of one of the most renown cable manufacturers in Switzerland, injecting cables, rolling them on a coil and leaving them in this condition for some weeks before unrolling and testing, the product was fully released. In 1989, stay cables were manufactured and injected with the flexible Polyurethane at the workshops of Messrs. Spanstaal in Utrecht/Netherlands. The cables were subsequently rolled on coils, shipped to England and installed at the Connaught Swing Bridge, London Docklands. Already in 1986, the material had undergone extensive corrosion tests, including salt spray, and proved its outstanding performance [8]. As corrosion protection does not only rely on the displacement of humidity but also on the active effect of the hydrophobic corrosion inhibitors embedded into the polyurethane matrix, the protection effect is also achieved in case of larger movements and even in case of cracks in the PE ducts (which are quite often reported in literature [2]). The pot-life limit of 30 - 60 minutes permits large injection shots.

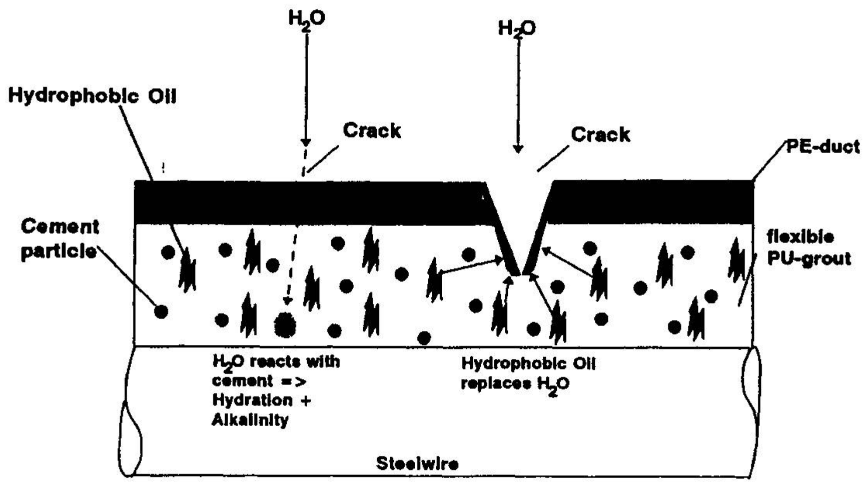
Viscosity Development at 20°C



Curing progression at 20 C



Optimum economy can be achieved by mixing the injection material up to a proportion of 1:1 by weight with Portland cement. Laboratory comparison tests (1000 hours salt spray) proved that the alkalinity and the affinity of the cement to steel provided an even better adhesion and maximum corrosion protection, in fact considerably superior to all other systems tested.



Corrosion Protection Mechanism of flexible PU grout

In case of long, thick parallel cables, workshop injection and transport on coils might sometimes not be possible. However, a competitive advantage will still be gained by injecting the cables on site before installation, as long as they are laid out on the bridge ramps. This avoids the erection of extensive scaffolding as normally necessary for injection of the cable ducts after installation.
The use of the corrosion-inhibitive, flexible polyurethane grout does undoubtedly increase the safety factor of parallel stay cable corrosion protection considerably, particularly where high dynamic stresses and corrosive environments are concerned. From the ecological point of view, the cured polyurethane grout can be regarded as inert.

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