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# Cable-Corrosion-Protection Systems for Cable-Supported Bridges in Japan

## Protection contre la corrosion des câbles de ponts suspendus et haubanés au Japon

## Kabelkorrosionsschutzsysteme für Kabelbrücken in Japan

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**SUMMARY**

The paper discusses the changes in cable-corrosion-protection systems for Japanese cable-supported bridges. For cable-stayed bridges, non-grout-type cable is becoming the most dominant system due to its good workability on site. For suspension bridges, the wire-wrapping method has been widely used. The validity of this system in Japan is discussed.

**RÉSUMÉ**

L'article traite de l'évolution du système de protection contre la corrosion des câbles de ponts suspendus et à haubans au Japon. Pour les ponts haubanés, le câble sans injection est devenu le plus courant en raison de sa mise en place facile. Pour les ponts suspendus, la méthode par enroulement a été la plus couramment adoptée. La validité de ce système au Japon fait l'objet d'une discussion.

**ZUSAMMENFASSUNG**

In der vorliegenden Abhandlung wird die Entwicklung von Kabelkorrosionsschutzsystemen für japanische Kabelbrücken diskutiert. Im Falle von Schrägseilbrücken wird heute wegen der guten Verarbeitbarkeit vor Ort hauptsächlich mit nichtinduzierten Kabeln gearbeitet. Für Hängebrücken findet hauptsächlich das Drahtwicklungsverfahren Anwendung. Die Brauchbarkeit dieses Systems wird in Japan diskutiert.

## 1 INTRODUCTION

It is said that the first modern cable-stayed bridge in the world was built in Sweden in 1955, the Strömsund Bridge. So, only 40 years has passed since then. In Japan, it was only in 1968, when the Onomichi-Bridge, the first long-span cable-stayed bridge was built. For the cable-corrosion-protection systems of the cable-stayed bridges, several methods have been tried in this short period. But, even at present, we still do not find any final solution. In the former part of the paper, we overview how the cable-corrosion protection systems for the Japanese long-span cable-stayed bridges have changed and discuss merits and problems of each protection system.

On the other hand, the history of modern suspension bridge started in the U.S.A. about a century ago. For the cable-corrosion-protection system, wire-wrapping method has been adopted on many bridges. In the latter part of the paper, we briefly refer to the investigation for the validity of wire-wrapping method in the high-humid atmosphere like Japan, which is now being proceeded by the Honshu- Shikoku Bridges Authority.

## 2 CABLE-CORROSION-PROTECTION SYSTEMS FOR CABLE-STAYED BRIDGES

Table-1 is the chronological list of Japanese cable-stayed bridges, whose span length is larger than 200m. From this table, we can see how the cable-corrosion-protection systems have changed in Japan. The details will be discussed in the following chapters.

Table-1 Cables for Japanese cable-stayed bridges

| | Bridge | Completion | Main Span (m) | Cable | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Type[1] | Wire[2] | Size(mm) | No. of Planes | Cable Pattern[3] | No. of Cables | Corrosion -Protection[4] | Grout |
| Steel | Onomichi Br. | 1968 | 215 | LCR | galv | Max ϕ70x4 | 2 | C | 2 | Paint | Nongrout |
| | Toyosato Br. | 1970 | 216 | PWS | galv | ϕ5x127, 154 | 1 | F | 2 | Plastic-Covering(H) | Nongrout |
| | Suehiro Br. | 1975 | 250 | PWS | galv | ϕ5x(169x7+127x6) | 1 | F | 2 | Plastic-Covering(H) | Nongrout |
| | Kamome Br. | 1975 | 240 | PWS | galv | ϕ5x114, 184, 271 | 1 | F | 10 | Plastic-Covering(P) | Nongrout |
| | Rokkou Br. | 1976 | 220 | PWS | galv | ϕ5x217 | 2 | F | 5 | Plastic-Covering(P) | Nongrout |
| | Yamatogawa Br. | 1982 | 355 | PWS | galv | ϕ5x217x19 | 1 | H | 4 | Plastic-Covering(P) | Nongrout |
| | Meiko Nishi Br.(1st) | 1985 | 405 | PWS | galv | ϕ5x163~379 | 2 | F | 12 | PE-envelope | Cement, wire coating |
| | Yasaka Br. | 1987 | 240 | PWS | nongalv | ϕ7x 73~301 | 2 | O | 6 | PE-envelope | Cement |
| | Katsushika Harp Br. | 1987 | 200 | PWS | nongalv | ϕ7x121~313 | 1 | F | 21 | PE-envelope(D) | Cement |
| | Torikainiwaji Br. | 1987 | 200 | PWS | nongalv | ϕ7x379~421 | 1 | F | 8 | PE-envelope(D) | Polymer Cement |
| | Iwagurojima Br. | 1988 | 420 | PWS | galv | ϕ7x139~277 | 2 × 2 | F | 11 | PE-envelope(D) | Polybutadiene resin |
| | Hitsuishijima Br. | 1988 | 420 | PWS | galv | ϕ7x139~277 | 2 × 2 | F | 11 | PE-envelope(D) | Polybutadiene resin |
| | Tokachi Chuou Br. | 1988 | 250 | PWS | nongalv | ϕ7x 85~301 | 2 | F | 7 | PE-envelope | Cement |
| | Yokohama Bay Br. | 1989 | 460 | PWS | galv | ϕ7x199~421 | 2 | F | 11 | PE-envelope | Nongrout |
| | Tenpozan Br. | 1989 | 350 | PWS | nongalv | ϕ7x211~349 | 2 | F | 9 | PE-envelope | Cement, wire coating |
| | Sugawarashirokita Br. | 1989 | 238 | PWS | galv | ϕ7x 91~163 | 1 | F | 11 | PE-envelope | Nongrout |
| | Ikuchi BR. | 1991 | 490 | PWS | galv | ϕ7x151~241 | 2 | F | 14 | PE-envelope | Nongrout |
| | Higashi Kobe Br. | 1993 | 485 | PWS | galv | ϕ7x265~367 | 2 | H | 12 | PE-envelope(D) | Nongrout |
| | Kemi 1st Br. | 1993 | 238.8 | PWS | galv | ϕ7x151~301 | 2 | F | 10 | PE-envelope | Nongrout |
| | Tsurumi Tubasa Br. | 1994 | 510 | PWS | galv | ϕ7x283~499 | 1 | F | 17 | PE-envelope | Nongrout |
| | Meiko Higashi Br. | 1997(U.C.) | 410 | PWS | galv | ϕ7x199~349 | 2 | F | 12 | PE-envelope | Nongrout |
| | Meiko Nishi Br.(2nd) | 1997(U.C.) | 405 | PWS | galv | ϕ7x109~199 | 2 | F | 12 | PE-envelope | Nongrout |
| | Meiko Chuou Br. | 1997(U.C.) | 590 | PWS | galv | ϕ7x199~397 | 2 | F | 17 | PE-envelope | Nongrout |
| | Tatara Br. | 1999(U.C.) | 890 | PWS | galv | ϕ7x163~379 | 2 | F | 21 | PE-envelope | Nongrout |
| PC | Yobuko Br. | 1990 | 250 | PS | nongalv | ϕ11.1~ϕ12.7x19 | 2 | H | 17 | PE-envelope | Nongrout |
| | Aomori Br. | 1992 | 240 | PS | nongalv | ϕ15.2x61~73 | 1 | F | 10 | FRP-envelope | Cement |
| | Tokachi Br. | 1995(U.C.) | 251 | PS | nongalv | ϕ15.2x55~61 | 1 | F | 16 | PE-envelope | Cement |
| | Ikarajima Br. | 1996(U.C.) | 260 | PS | nongalv | ϕ11.1~ϕ15.2x19 | 2 | F | 16 | PE-envelope | Nongrout |
| | Notojima Br. | 1999(U.C.) | 230 | PS | nongalv | ϕ15.2x27~48 | 2 | F | 14 | PE-envelope | Cement |
| | Ayunose Br. | 1999(U.C.) | 200 | PS | nongalv | ϕ15.2x19~27 | 2 | F | 12 | FRP-envelope | Cement |

1)LCR : Locked Coil Rope, PWS : Parallel Wire Strand, PS : Prestressing-wire Strand
2)galv : galvanized wire, nongalv : nongalvanized wire
3)Cable Pattern (F : Fan, H : Harp, C : Convergent, O : Others)
4)Plastic-Covering(H) : hand-lay-up, Plastic-Covering(P) : prefabricated-segment, PE-envelope(D) : Double Envelope

2.1 Corrosion-protection for locked coil ropes (bridges in 1960s)

In most of the cable-stayed bridges in the 1960s, locked-coil-ropes (LCR) have been selected as cable materials, especially in Germany. In the German bridges, in these days, LCR were manufactured of ungalvanized wires in fear of hydrogen brittlement. And the voids were filled with red lead during rope closing. After application of all permanent loads, the surface of the cable was thoroughly cleaned and two basic coats of red lead and two finishing coats like iron glimmer were applied.

In Japan, however, LCR were manufactured using galvanized wires, applying a minimum amount of lubricating oil during closing to avoid any concern about the future stains of the surface. The outer surfaces were usually painted after the dead load has been fully applied. In the Onomichi Bridge, whose cable is LCR, for example, the cable repainting has been done almost every 5 years, and the cables are now judged to be healthy by the observation from the outer surface, after 26 years of bridge life. The recent German corrosion-protection practice for LCR has been modified, taking into account of cable corrosions in some cable-stayed bridges. In the new practice, wires are to be galvanized with a zinc weight of 280g/mm$^2$. The inner voids are to be filled with polyurethane with zinc dust, or linseed oil with red lead. Outer surface is to be coated with polyurethane.

2.2 Corrosion-protection for PWS-cables (bridges in 1970s)

Entering into the 1970s, LCR was still the most popular cable material for cable-stayed bridges in foreign countries, especially in European countries. In Japan, however, manufacturing technology of the parallel-wire-strand (PWS) had been developed for the suspension bridges of the Honshu-Shikoku Bridge Project. Then, the PWS, comprising of galvanized wire of 5mm in diameter, was introduced into the cables for cable- stayed bridges. A ‘PWS’ is a bundle of galvanized wires arranged in parallel to construct a hexagonal cross section without any tendency to twist. A large ‘PWS’ is sometimes used as an individual cable, but in many cases a multiple number of ‘PWSs’ are bundled into one large cable.

PWS-cables were applied, for example, in Toyosato Bridge, Kamome Bridge, Rokko Bridge, Suehiro Bridge and Yamatogawa Bridge, all of which were built in 1970s. The corrosion-protection for the PWS-cable was usually performed by a plastic-covering. The plastic-covering, in early 1970s, was done by a hand-lay-up method. This is to coat a fiber-reinforced-plastic (FRP) layer, on the cable on site. In the latter 1970s, a prefabricated-segment method was newly developed to improve the workability of a hand-lay-up method. This is to fabricate the FRP segments in the shop, and only to connect them on site to form the covering. But, for these works, an installation of temporary footway along each stay cable, a catwalk, is indispensable. At the same time, some expansion joints have to be installed on the covering with some intervals, because the difference of the expansion-and-contraction between the cable and covering has to be absorbed. In some cable-stayed bridges, lasting about 20 years, some damages are found like small cracks on the covering and some deterioration on expansion joints. Then, some repairing works are required for these plastic-coverings, at present.

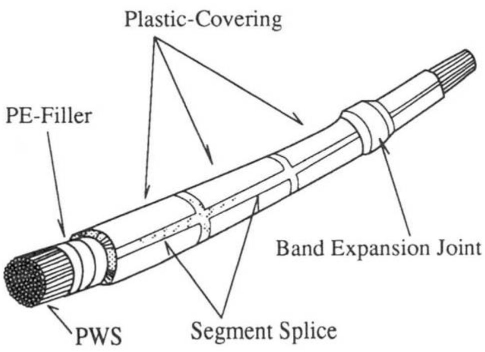


Fig. 1 Plastic coverings on PWS (prefabricated-segment method)

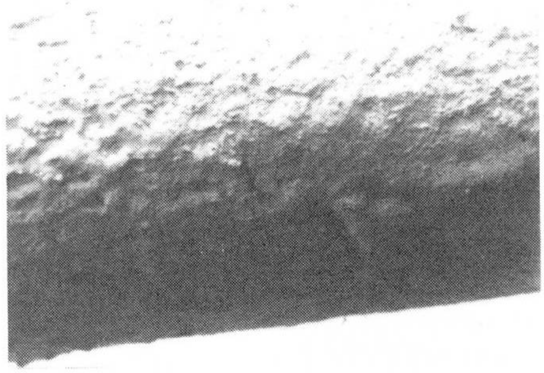

Photo 1 Cracks on plastic-covering (20 years after completion)

### 2.3 Corrosion-protection for grouted-parallel-wire-cables (bridges in 1980s)

A Parallel-Wire-Cable (PWC) is a parallel wire bundle of prestressing wires (not galvanized), incorporated as a tension member in a polyethylene (PE) tube filled with cement grout for corrosion protection. In the 1980s, PWC became popular in the Japanese cable-stayed bridges, using high-strength wires of 7mm in diameter and fatigue-resistant anchor sockets as the end fittings. In this system, PE is enveloped in the shop, and grout is done on site, and a catwalk installation is not required at the site. For the PE material, high- density PE was selected, to resist weathering, high-pressure, high-heat and external injury. At the same time, 2-3% of carbon is mixed to protect the tube from ultra-violet rays.

When heavier corrosion-protection is required for the important bridge or for the bridge at severe site conditions, additional protection methods have to be applied as follows.

(1) Use of two-layer-PE-tube:
This is to use two layers of PE tubes, so that the cracks on the surface do not reach to the cables. This was applied, for example, to Hitsuishijima Bridge, Iwakurojma Bridge, Katsushika-Harp Bridge and Torikainiwaji Bridge.

(2) Use of galvanized wires:
This is to use galvanized wires instead of nongalvanized prestressing wires. As hydrogen is produced with zinc and cement milk, there is a fear of hydrogen brittlement. Then, for galvanized wires, following countermeasures are required.

1) By coating a polyester coating on galvanized wires, zinc is isolated from cement milk. This was applied in the 1st-Meikounishi Bridge.

2) Instead of cement milk, synthetic resin like poly-butadiene was selected for the grout material. This method is not only good to solve the problem of hydrogen brittlement, but also good to protect the grout material from cracks, caused by the expansion-and-contraction of the cable, which is sometimes seen in the cement grout. But, this method is very expensive because of its large scaffoldings, and it also requires very severe quality-control, which makes the work on site complicated. This was applied to the Hitsuishijima Bridge and Iwakurojima Bridge.

As described above, the problem of a grout-type cable is its troublesome work on site and cable-quality's dependence on site work. In the prestressed concrete bridges, however, prestressing-wire-strands with PE-tube and cement grout are still the dominant cable materials, because their procurement is easy and cost-saving for contractors.

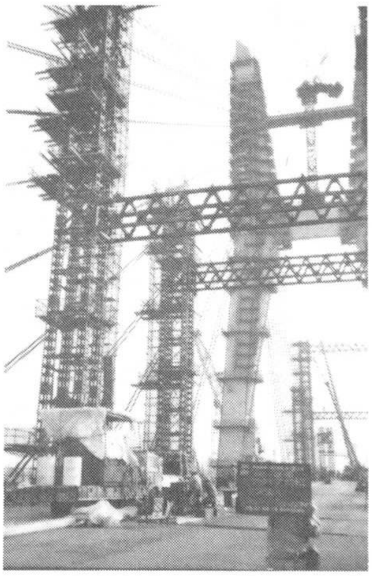

Photo. 2 Grouting of polybutadiene resin (Iwakurojima Bridge)

### 2.4 Corrosion-protection for nongrout-type cables (bridges in 1990s)

Based on the above background, nongrout-type cables, which does not need complicated grouting, have come into wide use in the Japanese steel cable-stayed bridges from late 1980s. In these cables, parallely-bundled galvanized steel wires are tightly enveloped by PE-covering to isolate the cable from outside, in the completely quality-controlled shop. Both ends of the cable is anchored by fatigue-resistant end- fittings, for which several structures are manufactured by some companies. These cables are featured as follows.

(1) To enable the reeling of the cable, each wire is bundled with a lay-angle of not more than 4 degrees. The experiments show that this lay-angle will not deteriorate cable's properties like the Young's modulus, tensile strength, and fatigue strength, comparing with values of each wire.

(2) PE-envelope is completely shop-fabricated by a directly extruded PE jacket, after wrapping the bundled wires with a corrosion-protection tape or after coating wires with corrosion-protection

compound. This cable-work does not require further works on site, like scaffoldings-installation and groutings, after cables are erected. Due to the good workability of the nongrout-cables, the selection of multi-cable-bridges became easier.

(3) Even when the PE-envelope is injured, the durability of the cable can be kept for some time, as wires are galvanized. Of course, the replacement of injured PE-envelope can be done easily. Then, the inspection of the cable can be done, by tearing off part of the PE-envelope, and by watching the cable from the torn-PE-window.

(4) The color of the PE-covering is black, as carbon is mixed in it. To manufacture colored cables other than black, cable-coloring technologies have been developed. One is to extrude a colored thin fluoro polymer on the black PE layer to change the black cable to colored one. Another is a paint coating system. It consists of an application of a primer, made from adhesive components for PE-envelope and for the finish coat, and a baking of the primer with the far infrared ray. The finish coat is usually done by fluoro-olefin paint. The light color is not only good for the good sceneries but also good for the temperature control of the cables.

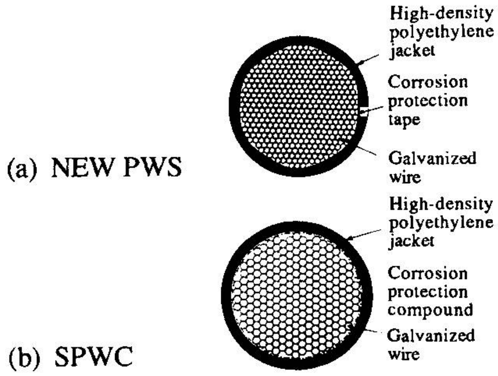


Fig. 2 Nongrout-Type-Cables

## 3 CABLE-CORROSION-PROTECTION SYSTEMS FOR SUSPENSION BRIDGES

In most of the Japanese suspension bridges, parallelly-bundled galvanized steel wires of 5mm in diameter are used. For the corrosion-protection, its outer surface is usually coated by corrosion-inhibiting paste, on which galvanized steel wires are wrapped tightly circumferentially. This system has been widely used in many bridges. In this system, however, intrusion of rain during the cable-erection cannot be protected. According to the inspection of U.S. suspension bridges, which was executed by watching inside of the cable with the aid of wedges, although some corrosions of galvanized wires were seen in a few layers of outer cables, the inside were judged to be healthy.

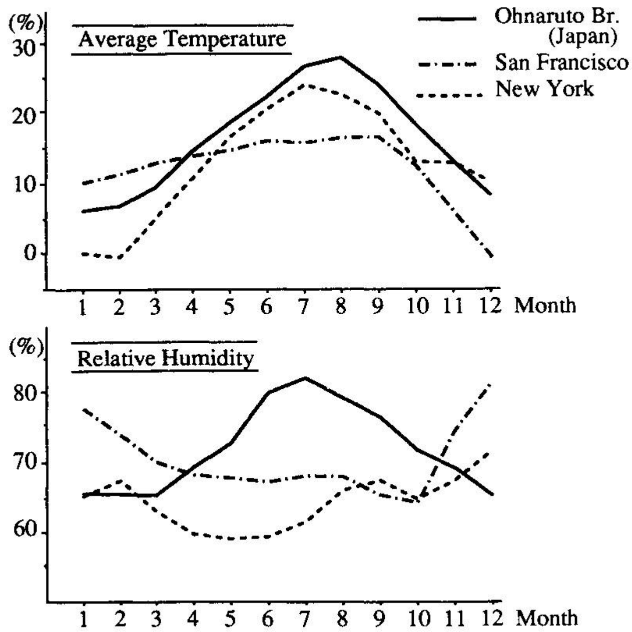


Fig. 3 Comparison of meteorological conditions between Japan and U.S.A.

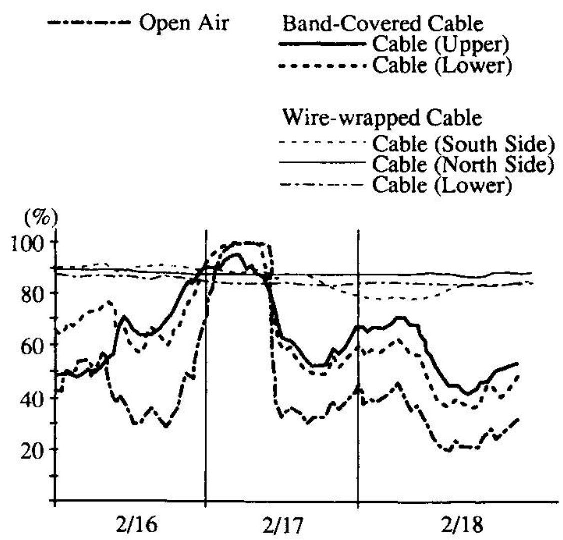


Fig. 4 Measurement of the humidity in the cable

As shown in Fig-3, Japanese meteorological condition is higher in the temperature and the humidity than in the U.S.A. Then, the validity of the wire-wrapping method in this atmosphere should be checked. The inspection of the cable of the Innoshima Bridge, lasting about 10 years, shows that some corrosions were seen in the wires of a few outer layers in the wire-wrapped cable, like American bridges. On the other hand, the band-covered cable, where any paste is not coated, were healthy. The difference of the cable's atmosphere between the wire-wrapped cable and band-covered cable was researched in the Ohnaruto Bridge. As shown in Fig-4, the wire-wrapped cables are always in high-humid environment, regardless of the humidity in the open air. On the other hand, the humidity under the cable-bands varies in accordance with the change of that in the open air. This means that there is a close relationship between cable's corrosion and high-humid environment.

Considering the severe meteorological environment of Japan, we judged that the humid atmosphere, which might cause the cable's corrosion, should be removed. From these standpoints, the Honshu-Shikoku Bridge Authority (HSBA) started the research for the dehumidification system of the cable. At present, air-blowing test by dehumidifier is proceeded at the Honshu-Shikoku Bridges, and came to the stage of almost practical use. We hope that the details will be presented in the near future.

## 4 CONCLUDING REMARKS

(1) In the Japanese cable-stayed bridges, cable-corrosion-protection systems have changed in the short history. In steel bridges, nongrout-type cables, which consist of parallely-bundled-galvanized-steel-wires and extruded PE-covering without grout, are becoming the most popular cable material. This is, firstly, due to the manufacturing-technology at the quality-controlled shop, and secondly due to the good workability on site.

(2) A research has been conducted for the validity of wire-wrapping method, which is mostly accepted for cable-corrosion-protection system in the Japanese suspension bridges. The research shows that the high-humid atmosphere might cause the corrosion of galvanized wires, and that it might be removed by dehumidification system.

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