COHESTRAND STAY CABLES AND SUSPENSION CABLES FOR AN EXTENDED DURABILITY

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SUMMARY

With the introduction of the individually protected parallel strand system (PSS), Freyssinet has lead the way for stay cables with a higher durability. However, the application of PSS system on cable stayed bridges with a slender pylon using a deviation saddle, or on the main cables of suspended bridges, implied singular points through the saddle or the hanger collars with reduced durability.

The Cohestrand® is new seven-wire strand released in year 2000, protected with a polyethylene sheath fully bonded to the steel wires. It enables to make cables with continuous anticorrosion barriers through the deviation saddle and / or the suspension collars. Details of two projects using the Cohestrand® are presented:

- the Sungai Muar bridge, a 132 m main span cable stayed bridge in Malaysia, using the multi-tube saddle;
- the Kanne bridge, a 96 m main span suspension bridge in Belgium, using the Cohestrand suspension cables;

1 INTRODUCTION

1.1 Durability of cable structures

Tremendous progress has been made during the 1980’s and 1990’s to improve the corrosion protection and durability of stay cables. The parallel strand system (PSS) introduced by Freyssinet is now recognised as the state of the art technology for stay cables. Each cable consists of individually protected strands, housed in an external stay pipe. Each strand, also called monostrand, is made seven galvanised wires, protected by a polyethylene sheath extruded onto the strand after filling the interwire spaces with petroleum wax.

On the contrary, the corrosion protection of the main cables of suspended bridge has hardly evolved over the last 50 years, and relies mostly on hot dip galvanisation.

The main obstacle of the adaptation of the parallel strand system to suspension bridges is the clamping of the hanger collars on the parabolic main cables. To prevent the collars from sliding, a high clamping force is necessary, requiring direct steel to steel contacts. Hence, any addition corrosion protection of the main cable, such as zinc paint, outer sheath or wrapping with wires, is always interrupted at the collar level.
1.2 The Cohestrand®

To enable a continuous corrosion protection throughout the hanger collars of suspension bridges, or through the deviation saddles of cable stayed bridges, this corrosion protection shall be capable of resisting both transversal clamping and longitudinal slipping forces, i.e. shall be fully bonded on the steel tensile element.

Freyssinet has developed during the late 1990’s the Cohestrand® with this purpose. The Cohestrand® is similar to a monostrand, except for the petroleum wax which is replaced by special resin:

- **Main tensile element**: 15.7 mm nominal diameter seven-wire strand, with 1860 MPa ultimate strength, and fatigue resistance of 300 MPa over 2 millions cycles;
- **Internal corrosion protection**: hot-dip galvanisation in conformity with the NF A 35-035 standard (see ref [1]);
- **External corrosion protection**: 1.5 mm thick high density polyethylene (black HDPE class PE 80 or PE 100), extruded on the strand and formulated for its excellent resistance to ageing;
- **Bond void filler**: compound of polybutadiene resin (PolyBd®) resin wrapping all the wires, including the central one, and adhesion element (Orevac) on polyethylene. This bond compound is a hydrophobic product, resistant to water vapour and oxygen and capable of transferring compression (clamping force) and shear forces (tangential force of the hanger collar) from polyethylene to steel wires.

The key aspect of the Cohestrand manufacturing is the co-extrusion of the PolyBd®, the Orevac and the polyethylene onto the strand, with a precise control of extrusion parameters to obtain a sufficient bond. This complex process has been industrialised in cooperation with one exclusive strand supplier (Trefileurope), and is submitted to a strict quality control. The minimum shear resistance of the compound shall be 4 MPa at 20°C, between the outer sheath and the seven wire strand. The triple barrier protection of the strand benefits of quality, homogeneity and reliability properties that can only be provided by industrial methods.

Thank to its mechanical properties (bond) the triple anticorrosion barrier of the Cohestrand can extend on the cable from end to end, without any discontinuity, neither in hanger collars, nor in deviation saddles. This is the key to avoid any weak point in the corrosion protection of the cables, and to obtain an outstanding durability.

2 COHESTRAND STAY CABLES USING DEVIATION SADDLES

2.1 Deviation saddles in the pylon

On most cable stayed bridges, the stays are straight cables anchored in the deck and in the pylon. However, to simplify the design and the construction of the pylon, the two anchorages of symetric stays are sometimes replaced by one deviation saddle, each
cable being continuous from the deck anchorage in the back span to the deck anchorage in the main span. This enables more slender solid pylon, or avoids the crossing of stays in the pylon, and is especially appropriate for the cables of extradossed bridges.

Usually, the deviation saddle is a singular point along the cable, where the high quality corrosion protection of the free length of the cable is often replaced by some weaker protection. Indeed the deviation saddle must provide a fixed point in the pylon to resist horizontal forces in the pylon arising from unsymmetrical live loading on either span; A solution is often to unsheath the monostrands in the saddle area, and grout them to ensure a sufficient bond to the saddle tube. Such a saddle creates a weak point with regards to corrosion protection, fatigue resistance and replaceability of the cable.

2.2 The multi-tube saddle

Using the Cohestrand, Freyssinet has developed a high performance deviation saddle, called the multi-tube saddle, to solve all the above disadvantages.

This saddle is made of a bundle of individual deviation tubes placed inside a large steel saddle tube. The space between the individual tubes is filled in factory with a special high strength cement grout (compression strength at 28 days > 130 MPa). The saddle is delivered on site fully assembled and grouted. Once the saddle is installed in the pylon, the strands are threaded one by one through the individual tubes.

This saddle provides an individual deviation of each strand by a small tube, and the fix point of the cable is obtained from friction of each strand on its individual deviation tube. Using Cohestrand, the friction can transfer through the sheath, hence the HDPE sheath of the strands is continuous through the saddle and the corrosion protection of the free length is not interrupted in the saddle. A special surface treatment of the tubes ensures that the friction forces between the strand and the saddle is greater than 0.5, which is enough to block unsymmetrical forces on most bridges.

At both saddle terminations, specially designed guide blocks filter the angular deviations of the cable (construction tolerances, catenary effects, wind effects). As radial forces are not transmitted between the strands, the fatigue performance of the multi-tube saddle is excellent: this saddle was successfully tested with 2 million cycles of 200 MPa axial fatigue loading. Finally, this saddle enables individual replacement of each strand.

![Fig.3 longitudinal and cross sections of multitube saddle](image-url)
2.3 Sungai Muar bridge (Malaysia)

The Sungai Muar bridge is located in Malaysia, about 150 km South-East of Kuala Lumpur in the state of Johor. It was designed by Jean-Muller International and built by Ranhill Corporation Sdn. Bhd. and was opened to traffic in 2003. It is a 632 m long bridge, with a concrete box girder deck, 21.4 m wide, and a central fan of stays. The total length of the bridge is, with a main span of 132 m. In the two pylons, 7 nos. stay cables are deviated by multi-tube saddles.

For this first application, the saddles were manufactured and grouted in France, then delivered to Malaysia. The stay sizes range from 37 to 73 T15.7 strands. The stays were installed strand by strand, each strand being stressed from both its ends with the Isotension system.

3 PARABOLIC SUSPENSION CABLES

3.1 Immobilisation of hanger collar on the suspension cable

Conventional hanger collars achieve their immobilisation by the bolting of a heavy twin shell metal collar around the main cable. This requires direct steel to steel contact, with elevated and uneven contact pressures on the main cable, leading to fatigue vulnerability. Moreover, as the external anticorrosion barrier is interrupted through the collar, where water can be retained in the voids between the wires, and corrosion results.
Freyssinet developed the Cohestrand to extend the advantages of the parallel strand system to the parabolic suspension cables. The main cable is made up of a compact group of Cohestrand. The strands have a circular section and so fall into a natural hexagonal pattern. The anchorage of the cable are similar to stay cable anchorages, using special wedges. The deviation saddles in the pylon, if any, are the multi-tube deviation saddle presented above.

In addition, a special collar clamping system has been developed, to provide uniform clamping stresses to all the strands of the main cable, and safely transfer the sliding component of the hanger force to the cable.

The clamping force of the Cohestrand collar is obtained from radial compression: a set of six conical wedges are placed around the hexagonal cable, and blocked into the conical hole machined in the collar tube, as shown on the drawings below. These wedges are power seated, using a reaction frame and hydraulic jacks. The collar is oriented along the slope of the suspension cable such that the system is self-compensating, for delayed cable compaction from creep.

The protective sheath of the Cohestrand is continuous through the hanger collars and pylon saddle, thus avoiding any singular point in the corrosion protection between the cable anchorages. This collar concept also avoids steel to steel contacts to prevent any fretting corrosion.

3.2 Kanne suspension bridge (Belgium)

The Kanne bridge crosses the Albert Canal near Kanne, in the Flemish province of Limburg in Belgium. To enable the widening of the canal, the old arch bridge was to be replaced by a longer bridge, and a suspension bridge was selected for architectural reasons. Being the first suspension bridge built in Belgium since 1960’s, the owner paid a lot of attention to durability, and wanted the same durability as for stay cables. In
particular, the continuity of the anticorrosion barriers through the collars was specified in the tender documents.

The steel part or the new bridge has a main span of 96.2 m with two side spans of 14.8 m. Concrete access bridges extend on both sides of the steel bridge. With a total width of 22.0 m, it carries two lanes of traffic between the suspension planes and two cycling / pedestrian lanes outside the suspension planes. The suspension is carried by two pylons, each consisting of two cylindrical masts distant of 12.0 m centre to centre.

Each main suspension cable consists of 75 strands, anchored in the top of the masts. In the back spans, a pair of 55 strands stay cables balances the horizontal force of the suspension cable. The stays are anchored in the deck, and pin connected steel members and ground anchors resist the deck uplift force.

On each side, the deck is supported by 24 hangers placed at 3.7 m intervals. Between the collars, the main suspension cable is contained within a white outer HDPE duct, which protects the individual strand sheaths from UV attack and mechanical damage. The duct sections are provided with expansion joints between hanger collars.

Each hanger is like a standard Freyssinet stay cable: it is made of 5 T15.7 monostrands placed within a white outer HDPE duct. The top hanger anchorage is pin connected to the collar, and the bottom hanger anchorage supports the deck through a tube.

3.3 Main cables of Kanne bridge

Freyssinet has proposed to use the Cohestrand system for the main cables of Kanne bridge. These 75 strand cables are the first industrial scale application of the on a suspended bridge. Indeed, only one prototype bridge had been built before, on a private property in the South of France: the Chartreuse bridge, with a span of 88 m and 7 strand main suspension cables.

The Cohestrand system had already been validated for creep by long duration test and by fatigue test (see ref [2]) on smaller units. To demonstrate that the concept was valid for large size cables, a full scale test was performed on a section of the main cable, to check the sliding resistance of the collar. This test was carried out in August 2004 in the testing laboratory of Freyssinet (fig.7), and demonstrated that the collar could resist a longitudinal force over 1200 kN before any slipping, i.e. nearly twice the design force $F_{d} = 640$ kN, or 6 times the maximum SLS sliding force on the actual bridge.

3.4 Construction sequence

As the steel deck of the Kanne bridge was erected on temporary supports, without the suspension, it was possible to prefabricate the main cables on the deck, with all the collars. Consequently, the strands could be threaded through the collars, and for cost effectiveness, it was decided to use closed collars without any bolts like the usual collars. Hence, each collar consisted of a tube machined on a lathe (fig.6). The eye plate used for the hanger connection was welded on the tube after machining.

Each collar and duct elements were laid on the deck, following the parabolic profile of the cable, to ensure that the strands had exactly their respective length in the final position of the cable (Fig.8).
After threading all the strand, sorting them into the desired compact hexagonal bundle, the collars were tightened, using a reaction frame, 3 nos. prestressing bars and hollow jacks. The wedges were located precisely at their final position along the cable, and blocked with a longitudinal force of 1000 kN (Fig. 9, 10).

Finally, the fully prefabricated cable has been lifted on the pylons, which had an open gorge to receive the cable with its anchorage and bearing plate. On the first end, the cable was lifted with a crane. On the other end, strand jacks were used, as they are more adapted to the oblique force arising in the cable during the erection (Fig.11, 12).

The hangers and the back stays are stressed according to the sequence defined by the design office. The suspension installation will be completed in March 2005. The bridge is due to open to traffic late 2005.
4 CONCLUSIONS

The Cohestrand is a new type of strand, developed by Freyssinet and exclusive partners during the late 1990’s. This material has been used on two innovative projects, where cables with an outstanding durability have been achieved:

- Stay cables with multi-tube deviation saddle;
- Suspension cables with continuous anticorrosion protection through the collars

In both cases, the principle of un-interrupted individual corrosion protection of each strand, from anchorage to anchorage, enable to achieve a 100 year design lifetime, alike on parallel strand stay cables.

Moreover, for suspension bridges, the compactness of the stay cable anchorage with wedges turns out to be very practical for self anchored suspension bridges or suspension bridges anchored in anchor chambers dug into the rock. Other application of the Cohestrand suspension system are the suspended nets used in architectural stadium roofs.

5 ACKNOWLEDGEMENTS

Kanne bridge :

- Owner : LIN Vlaanderen, Belgium
- Main contractor : Herbosch Kiere
- Sub-contractor for the steel part : Victor Buyck Steel Construction

6 REFERENCES
