The History of the Wire Rope's Invention

and the Decisive, but Unfortunately Transitory, Role of French Engineers

by Jean Marc Teissier and Don Sayenga

Part Two: The Legacy of Ferdinand Arnodin: His Rope, His Closing Machine

Ferdinand Joseph Arnodin (1845 – 1924).

The cable with parallel wires for suspension bridges invented by Marc Seguin and Guillaume Henri Dufour had a very simple architecture. The multi-strand rope for hoisting applications was invented by Julius Albert, and was then developed, among others, by Robert S. Newall, Andrew Smith and John August Roebling. This rope has a sophisticated architecture. These two types of cable didn't have the same purpose, and were not designed to fulfill the same needs. On suspension bridges, static ropes bear tensile forces (the problem exists only when winding onto a reel, so without any loading). However, in a hoisting system the rope is wound and unwound under load on sheaves or on drums, bearing simultaneously bending stresses and tensile stresses, which generate fatigue loading.

The cable with parallel wires had its Golden Age before the Basse-Chaine accident, between 1825 and 1850. The hoisting ropes were used for inclined or vertical transportation systems, especially for mining applications.

In the 1860s, during the gold rush in the American West, ropes were also used for the aerial cable car. From the beginning of the 1870s the street cable car offered new opportunities, and enlarged the market for wire ropes. The cable car applications were very demanding on ropes, and thus motivated a significant number of innovations and technical improvements, which were mainly focused on the strands' design. The "Seale" strand was developed by Thomas Seale when he was technical director of a line of street cable cars. The "filler" strand was invented by James Stone (1889) in order to reduce wear of the wires in a rope. All these improvements were implemented in order to increase the service life of the wire ropes under bending fatigue loading.

Hoisting ropes were replaced often because of the fatigue generated by bending over sheaves (and/or drums), and also by the clamping devices of the cars. Thus, they usually didn't have time to corrode. For a suspension bridge it is exactly the opposite: the ropes are bearing static loading and they remain in place for a very long time, compared to the hoisting ropes. The corrosion becomes a critical factor.

Ferdinand Arnodin, who was the successor of Marc Seguin, was very aware of the imperfections of cables with parallel wires: they must be fabricated on the site, it is very difficult to get a proper distribution of the load among the wires, and there was a geometrical problem (wires are too short on the external radius and too long on the internal radius – problem however almost solved with Vicat technique). And lastly, the cables were hugely sensitive to corrosion because the position of each wire is very different, and thus some channels were created in between the wires, enabling water to propagate along the rope. Ferdinand Arnodin discovered the multi-strand ropes when their use became required, after the publication of the Malézieux report. Arnodin called them the "American ropes," and in France they were also named "ropes with twisted wires."

Arnodin acknowledged that these ropes were advantageous for certain points compared to the cables with parallel wires, but the first experiments have shown that a lot of problems were not solved.

Ferdinand Arnodin imagined his rope in that context. The rope with alternate directions of lay was born. This moment is not dated accurately, but it is positioned between 1879, which is the date of the completion of the Saint Ilpize Bridge, and 1883, which is the date of the beginning of the construction of the Lamothe Bridge on which one of Arnodin's ropes was used for the first time, but only for the inclined guy ropes. The

continued on page 18

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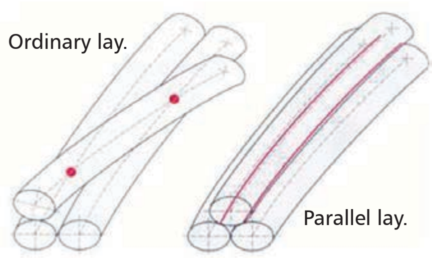
continued from page 16

Tonnay-Charente Bridge after the 1886 renovation was the first bridge to be fully fitted with Arnodin's ropes.

Ferdinand Arnodin compared his rope to Seguin's rope and the American rope. (See illustration next page)

The principle of removability which was a golden rule for Ferdinand Arnodin, required the use of several small ropes. These ropes were fabricated in a workshop, shipped to the site and then installed on the bridge.

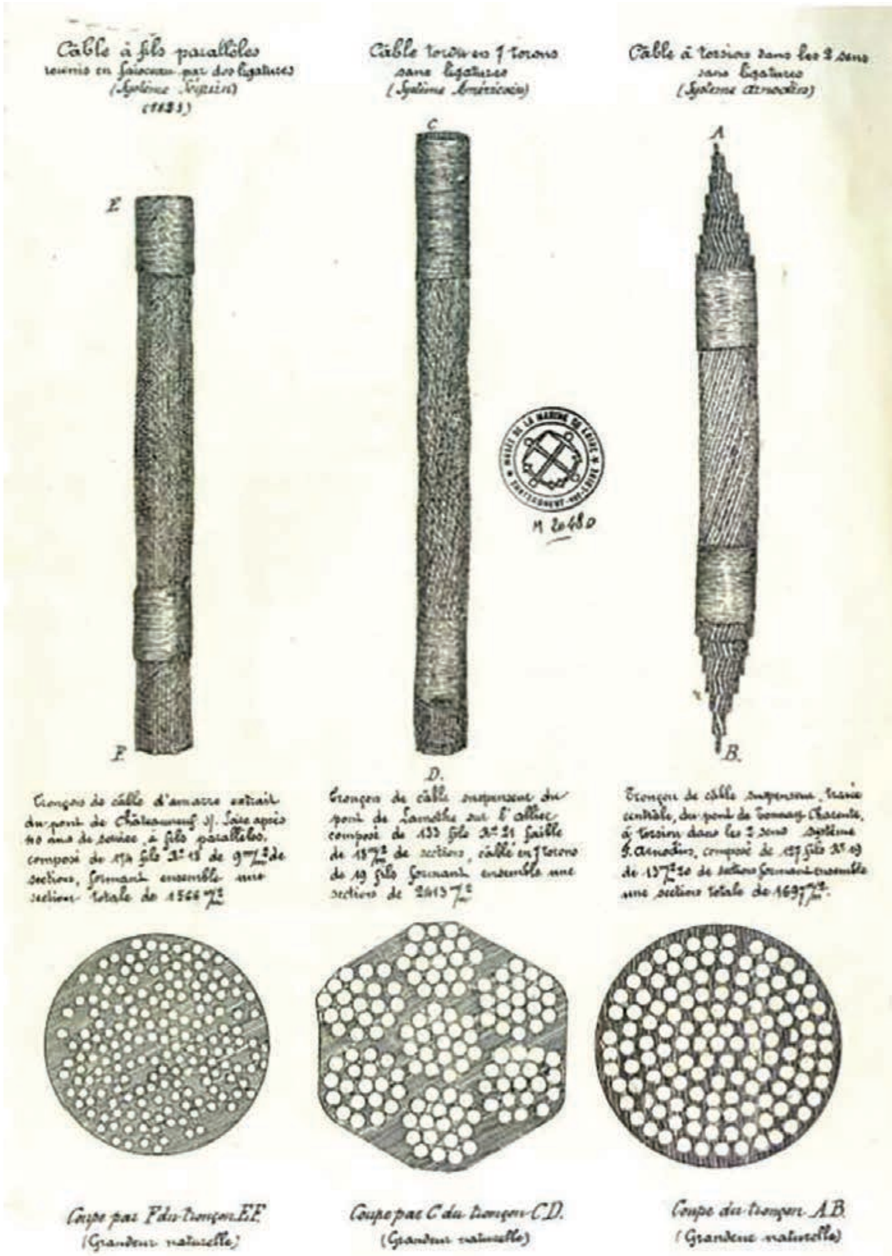
Ferdinand Arnodin re-used the idea of the American rope with twisted wires of strand, but implemented it for the rope. He created the spiral strand rope. With this geometry, the same wire is positioned alternatively on the inner and outer radius of the rope. During its installation the rope forms a parabolic shape. The internal motions of the wires make possible the transfer of the variation of length corresponding to the alternate position of the wires. The rope is flexible. The layers of wires can be twisted in the same direction (parallel lay), which makes it possible to arrange the wires with a minimum gap in between them.



With such an arrangement, the length of the wire on a layer depends on the geometry of the lower layer.

This arrangement was not appli-

continued on page 20



Comparison of the different types of ropes. (Arnodin's interview by the commission).

Wire rope with alternate directions of lay.

continued from page 18

cable for a suspension bridge because in order to ensure a balanced distribution of the load among each wire, the length of the wire must be adjusted according to the level of the layer (the lay length increases when the level of the layer increases). This is all the more important when the number of layers is significant. A strand of a hoisting rope has usually 2, perhaps 3 layers, whereas Arnodin's rope has up to 10 layers. The lay length is different in each layer.

This rule can't apply to the central wire, which is finally the shorter wire, the wire which breaks first during a tensile test. In fact, this central wire is only a shimming element for the upper layers.

Such construction can be implemented with all the layers twisted in the same direction, but Ferdinand Arnodin selected another option, changing the direction of lay for each layer. This arrangement also provides a rotation resistant behavior to the rope.

For Arnodin's rope, all the wires have the same diameter, and each layer has 6 more wires than the lower layer (1+6+12+18+24+...)

Corrosion protection was taken into consideration, thanks to the geometry, and the fabrication process. Even if the suspension cable is made of several ropes (principle of removability), these ropes have a bigger diameter than the strands of a hoisting rope. They are thus made of wires with a bigger diameter, which are consequently less sensitive to corrosion. Wires are twisted according to a helix shape, thus the inclination of the "channel" created between two wires of the same layer is variable. Depending on the position on the helix, it prevents water from flowing toward the bottom anchor and then accumulating there.

Other preventive actions in relation to the closing machine developed by Ferdinand Arnodin, are implemented during the fabrication process. The central wire as well as the 6 wires of the first layer are soaked in an "anti-oxidizable composition." When the central part of the rope (1+6) is fabricated, it is again soaked into an "anti-oxidizable composition" as well as all the wires of the next layer. This process is repeated until the installation of the last layer of wires. Consequently, all the internal vacuums of the rope are filled with this "anti- oxidizable composition."

The Arnodin rope has inspired other engineers, including Arthur Latch and Telford Batchelor, who are the inventors of the locked coiled rope (a kind of

continued on page 22

Ferdinand Arnodin closing machine in the Saint Pantaléon de Larches factory.

continued from page 20

spiral strand rope where the external wires have the shape of "Z"). Initially all the layers were twisted in the same direction, but this made the installation difficult because of the torque generated by the rope. In 1887, Latch and Batchelor, employing the same idea as Ferdinand Arnodin, started twisting the layers in opposite directions.

When Ferdinand Arnodin (1880-1882) invented his rope, closing machines for the fabrication of the multi-strand ropes (7 strands of 19 wires) existed in England and the United States. It's very unlikely that Ferdinand Arnodin knew about these machines. He imagined and built a machine able to fulfill his specifics needs.

The fabrication process includes several manual steps, especially for the implementing corrosion resistance.

The machine is fitted with 8 wheels, 6 reels installed on each wheel. For the fabrication of the initial strand (1+6) only the first wheel is used, and it's rotating in one direction. For the installation of the second layer of wires two wheels are used. These wheels are rotating in the same direction, which is the opposite of the direction for the previous step. Repeating this process allows the machine to produce ropes made of 217 wires distributed on 8 layers, with a diameter of 68 mm if the wire diameter is 4 mm.

The Ferdinand Arnodin closing machine was initially built in Arnodin's factory in Chateauneuf sur Loire, in the beginning of the 1880s. When Georges Camille Imbault and Basile Baudin decided to begin constructing suspension bridges (1925), they built another closing machine, which was at

continued on page 24

continued from page 22
that time also installed in Chateauneuf sur Loire, which was the location of the Basile Baudin company as well.

When he designed this new machine, Georges Camille Imbault was living in England where the closing machines for the production of multi-strand ropes had been produced since 1840. He took advantage of this experience to design his machine. The new closing machine was able to produce ropes with 4 layers of wires in one operation, as compared to 4 operations with Arnodin's machine. The process for corrosion protection however could no longer be performed as planned by Arnodin.

This machine was more efficient, and the costs for production were lower than with Arnodin's machine. So, surprisingly but logically, the Arnodin company was the first client of the Baudin's wire rope workshop. The Arnodin closing machine was transferred by Gaston Leinekugel Le Cocq, in his new factory, in Saint Pantaléon de Larches. There, the machine was expanded to produce wire ropes with 10 layers of wires.

It is in this workshop, which had to be dismantled, that this machine was saved from scrapping in 2013. It is now awaiting funding in order to be installed next to the Martrou Transporter Bridge in Rochefort. WRN

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