STADSBRUG NIJMEGEN CABLES INSTALLATION AND TENSIONING CHALLENGE

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SUMMARY

The Nijmegen Arch Bridge is a spectacular steel construction made of 7,000 tons steel with a 285 m span over the River "Waal" in the Netherlands. Redaelli's contribution to this remarkable structure is presented in this paper, which describes the entire process of installation and tensioning of crossed hanger cables and all related challenges. The crossed hanger's configuration made the task of installing and tensioning the cables more difficult due to significant interaction between the hangers. Estimation of final cables forces was performed using the vibration method.

Keywords: *Cables, Arch Bridges, crossing hangers, Full Locked Coil, Vibration Method*

1. INTRODUCTION

The new bridge across the river Waal was built to smoothen inbound and outbound city traffic. The total length of the bridge is 1400 m: a succession of concrete arches approaches on both sides the main span arch bridge, which consists of a 285-meter long single tied arch structure crossing the river Waal. The arch is 60-meter high and it is connected to the bridge deck by a cable system of crossed hangers.

Redaelli supplied the complete cable system, consisting of different size of Full Lock Coiled (FLC) Cables (diameters 72 mm, 82 mm, 93 mm and 95 mm) with a length ranging from 13 to 80 meters. FLC cables are connected to the arch with fixed TTF fork sockets, while the cables are anchored to the deck by means of adjustable cylindrical socket with spherical nut.

Table 1.1 *Redaelli's cables supply for the Nijmegen Bridge.*

TYPE	Q.ty Nr.	Rope Diam. [mm]	Socket TOP	Socket BOTTOM	Length range [m]
FLC72	24	72	TTF68	CYW72	51.1 ÷ 55.8
FLC82	16	82	TTF76	CYW80	36.5 ÷ 48.6
FLC93	8	93	TTF88	CYW92	29.7 ÷ 33.3
FLC95	12	95	TTF92	CYW92	21.7 ÷ 50.2

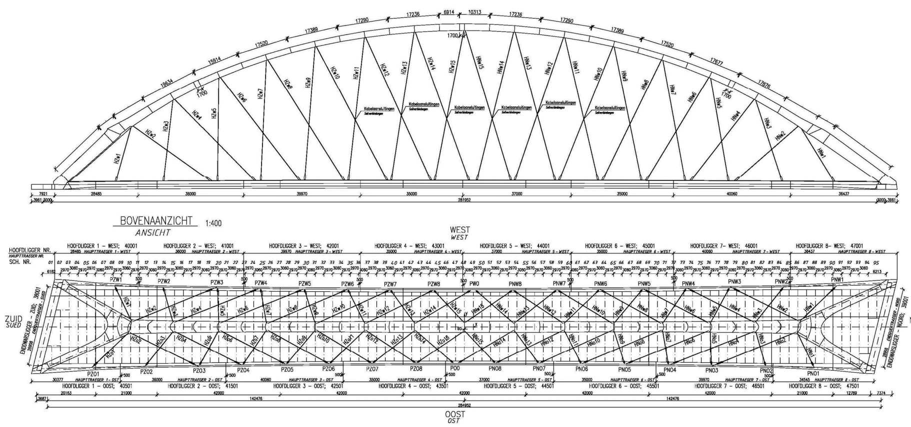

Fig. 1. *Nijmegen Arch Bridge side and plan view with cables scheme.*

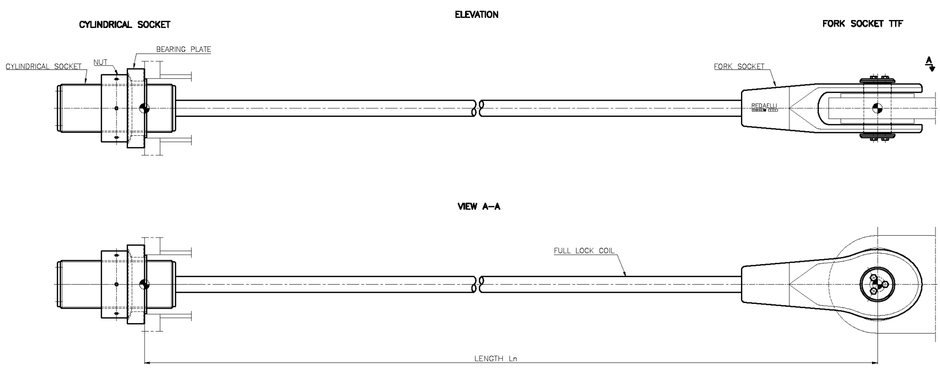

Fig. 2. *Redaelli's cables general arrangement.*

Fig. 3. *Redaelli's TTF fork socket (left) and adjustable cylindrical socket (right).*

The arch bridge installation presented several challenges. The main span was firstly assembled on site on the river bank and then moved onto its 12-m high pillars using two barges placed under the bridge and slowly de-ballasted to take over the load in the strand jacks. This installation procedure required that all hanger cables (except few hangers interfering with temporary arch towers) were installed and tensioned while the bridge was still on the river bank. Then, remaining cables were installed and tensioned as the bridge was in its final location. Thus, a complete check of cables axial forces was necessary to provide possible adjustments needed to reach the final configuration (both in terms of geometry and forces) required by the Designers. Redaelli's approach to site activities is addressed in details below.

2. CABLE INSTALLATION AND TENSIONING

The first step of Redaelli site activities was to install cables on the bridge assembled on temporary supports, the arch being sustained by two temporary towers. Cable installation was performed connecting fork sockets to anchoring plate in the arch and bottom cylindrical sockets through anchoring pipes. All cables were installed in one sequence except eight cables (nominally Hxx4 and Hxx5) which had to be installed after bridge launching due to the presence of temporary towers. Further to this, in order to avoid cable damage due to significant movements of the deck expected during launching, eight cables (nominally Hxx12 and Hxx14) were installed only at the top at the arch, while the bottom socket was placed and secured out of the anchoring pipe by means of textile slings. Installation of these cables was completed after the bridge was in the final position.

Fig. 4. *Lifting on a FLC cable.*

Cable tensioning was performed in the following load condition: self-weight of the bridge plus wooden track for Manitou movement on the deck. This activity was executed strictly following the specific tensioning sequence and the procedure issued by the Designer with small force increments (approx. 5 % load increments) up to the target load indicated in the procedure. At each tensioning step two cables were tensioned together, one at East and one at West side of the deck. Throughout tensioning activities, topographic survey of the deck and the arch was done to verify relevant displacements of the reference points. Furthermore, theoretical displacements of deck and arch were checked verifying socket thread length related to nut position. Theoretical thread length was calculated using theoretical deck and arch displacement values combined with cable elastic elongation due to force applied.

The tensioning system used for this project is composed of the following items:

- one spreader beam designed with a special “nose” to fit the grooves of the lower sockets ring anchor plate;
- one contrast clamp to press down the cylindrical socket;
- one tensioning beam;
- two threaded steel bars;
- two hollow jacks.

The tensioning system was connected to an electric pump complete with hosepipes and digital gauge. The system was installed by positioning the spreader beam inside the grooves around the bottom pipe and fixing it by means of four pre-stressed threaded bars which connected together the two halves. Afterwards, the contrast clamp was placed around the rope and the tensioning beam was located on the clamp, passing the threaded bars through the tensioning beam and into holes properly placed in the bottom anchoring beam. The hollow jacks are inserted on the bars and fixed at top with bolts. During cable tensioning (or tension check), the jacks pull the bars and move the tensioning beam, contrast clamp and bottom socket downwards. Thus the cable is stressed till the desired force and the nut of the bottom socket can be tightened to fix the position. The cable force is measured recording the jack’s oil pressure with a digital gauge.

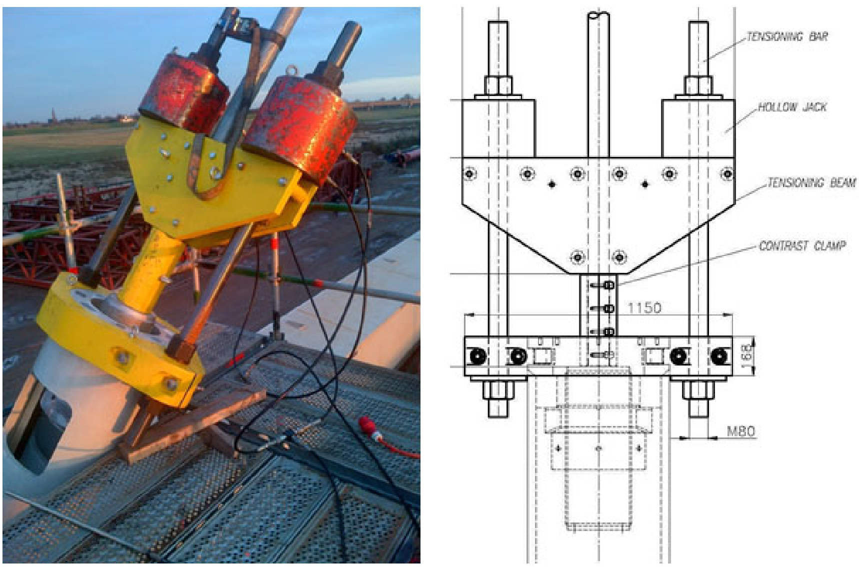

Fig. 5. Picture and sketch of tensioning system.

During cable tensioning activity the bridge deck was lifted from its initial position and temporary intermediate deck supports were removed. At the end of tensioning activity, the bridge was supported only at the start/end of the deck and in correspondence of the two temporary towers.

Fig. 6. *Site Activities.*

3. CABLE TENSION MEASUREMENT

As bridge erection was completed, Redaelli performed an assessment of the hanger's tensions final status. In order to minimize the time required to perform the overall cables forces survey and to provide the most efficient and adaptable support to the Designer for achieving the desired final configuration of the structure, it was decided to measure cables forces using accelerometers.

The estimation of cable forces is described in detail in the following section. It is worth noting that this method allows for an estimation of cable force based on the signal recorded by an accelerometer placed on the cable, which is subsequently excited. This method is rapid and does not require any removal of unwieldy equipment, thus minimizing the time required to evaluate changes of surrounding cable forces after any adjustment in axial force at single hangers.

The dynamic measurement of the vibrations of all cables has been carried out under the following conditions:

- bridge closed, all traffic forbidden;
- absence of any other site activity on the bridge deck;
- concerning the dead load: it lacks the final asphalt layer, the traffic divider and the handrails.

The above prescriptions avoided any influence on the cable load, as per designer request. Cable vibrations were measured using a single direction piezoelectric accelerometer conveniently located on the cable external surface, about 2 meters above the bottom anchorages. The accelerometer was attached to a plastic plate which was temporary fastened with plastic strips to the cable to be monitored. In order to set the key parameters to determine cable tension from its natural frequency, the cable loads were previously measured and calibrated by a hydrodynamic cylinder system which recorded readings during previous site checks. The results were used as a comparison. This process was crucial for shorter hangers, where the influence of boundary conditions (sockets) is extremely relevant for the accuracy of the entire process.

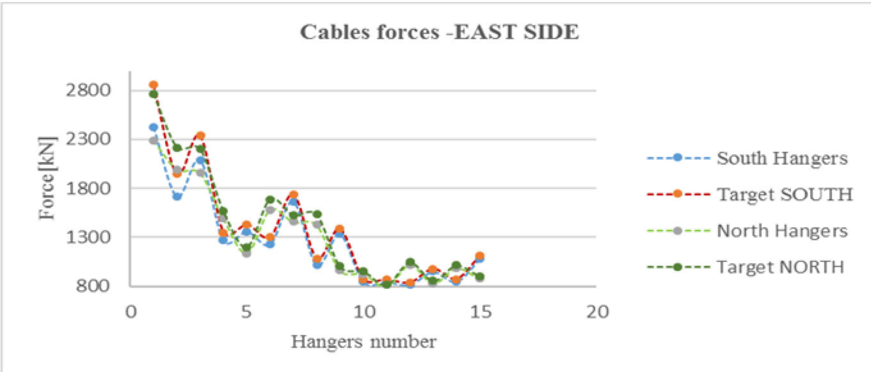

Fig. 7. *Cables forces, East side.*

The following graphs show a comparison between design cable loads and final actual forces, as measured on site on September 2013. It is plain to see that actual values are very close to the required ones, proving the efficiency of the structure design and of the erection procedure. Minor differences between target and measured values on the shortest hangers do not influence the overall stability of the structure.

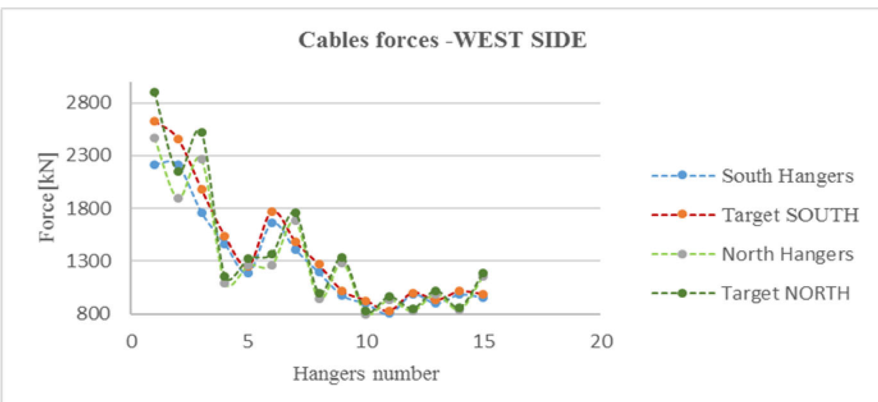

Fig. 8. *Cables forces, West side.*

4. ESTIMATION OF CABLE FORCES BY VIBRATION METHOD

Cable vibration method is the simplest and least expensive way to obtain actual cable forces by means of accelerometers applied on the cables. This technique has an easy set-up and does not interfere with anchorage plates or other parts of the structure. Cable vibrations are measured using a single direction piezoelectric accelerometer conveniently located on the cable external surface, near to the bottom anchorage. The position of the accelerometer is critical to obtain a correct identification of the cable frequencies. The accelerometer is attached to a plastic plate which is firmly fastened with plastic stripes to the cable to be monitored.

The measuring equipment includes the following items:

- Piezoelectric accelerometer
- Multisensor Input DEWE43
- PC with hard disc

The main characteristics of accelerometers employed by Redaelli are:

- Operating Temperature Range -20/+90 °C
- Maximum Acceleration +/- 55 m/s2
- Lower cut-off frequency: 0.1 Hz
- Higher cut-off frequency: 4000 Hz

Thanks to the high sensitivity of this device, it is possible to monitor a wide range of vibration modes. Once the accelerometer is fixed to the cable, the cable is manually excited and the acceleration time history is recorded. The measured signal data is instantly processed by a software which derives cable frequencies of the most significant modes. The quality of the time history and the vibration periods are immediately verified and the measurement is repeated if necessary.

Signal data is converted from the time domain into the frequency domain using the Fourier Transform. Peaks of the Fourier Transform identify the natural frequencies of the cable. The values corresponding to the most important vibration modes, typically the first two/three modes, are used to assess the cable tension as described hereafter.

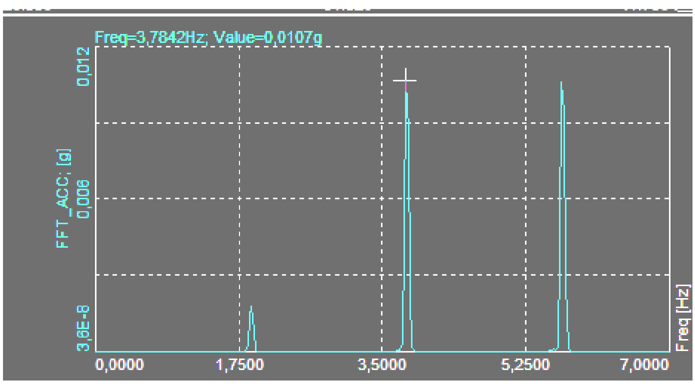

Fig. 9. *Example of FTT of Acceleration.*

Cable axial loads are estimated considering the simply supported beam model subjected to an axial tension. Using the corresponding analytical formulation, the key parameters to determine the tension from the natural frequency are the effective vibration length, the cable mass and the cable bending stiffness.

The effective vibration length takes into account the uncertainty of boundary conditions due to anchorage devices applied at the cable's edges. The selection of an appropriate effective vibration length is crucial to accurately reflect the actual vibration behaviour. For cables with a high mass to length ratio, the definition of the above parameters requires a deeper investigation which may involve a validation of the method using other devices. Once the effective cable vibration length is obtained, each modal frequency is simply a linear function of the cable force and flexural rigidity. Therefore, using a finite element model of the cable, it is possible to optimize the requested parameters and calculate the cable axial load.

CONCLUSION

Despite all challenges related to this project site activities, bridge erection and cables installation and tensioning was successfully completed. The entire process was fully satisfactory both in terms of site activities schedule and high quality standard required. The estimation of cables forces by vibration method proved to be extremely efficient in this project framework.

The completion of the Nijmegen Arch bridge was a remarkable achievement for all the parties involved in the project and another valuable experience in Redaelli record of projects.

Fig. 10. *Nijmegen Arch Bridge after completion.*