Third Bosphorus Bridge

Conceptual design and structural behaviour of the cable systems

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Abstract The choice of having a thin streamlined deck with all the eight roadways and two railways on the same level imposed to conceive an innovative cable system for the suspension of the Third Bosporus Bridge. This has been achieved by combining parabolic main cables with vertical hangers, together with stiffening cables connecting directly the deck to the towers. The main cables and the hangers are placed in vertical planes located between the railways and roadways, while the stiffening cables are also anchored between the railways and roadways in back span and on the edges of the deck in the main span. Because of the high ratio live load / permanent load, the stiffening cables remain under a low tension under permanent loads, increasing their sag and reducing their efficiency. This cable layout has also given the possibility to reduce the construction schedule by allowing the contractor to start the erection of the deck by the cantilever method in parallel of the procurement and erection process of the main cables. The paper will detail the cables layout and give information on each type of cables used.

1 Introduction

In order to comply with the KGM requirements of the competition for the Third Bosphorus Bridge that asked for "…an elegant suspension bridge, in the same line as the two other Bosphorus bridges", the choice has been made to conceive a thin streamlined deck with all the roadways (2 x 4) and railways (2) on one single level.

Suspension bridges are very efficient to carry uniform distributed loads, but when it comes to shorter loads placed unsymmetrically on the deck – like railway loads – a significant displacement of the main cables is required to find their proper equilibrium geometry (fig. 1). This displacement is generally incompatible with the deformation and rotation requirements of the railway systems.

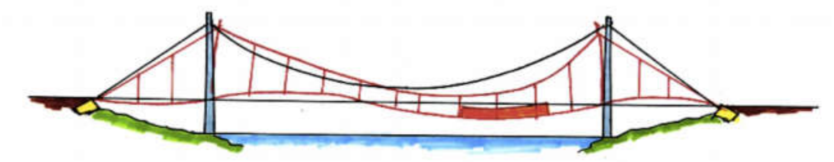


Fig. 1: Deformation of a suspension bridge under unsymmetrical loading

The usual way to limit the deck deformation for long span suspension bridges carrying railways has so far always been to increase the rigidity of the deck by conceiving them as two level decks, with the railways passing under the roadways. These decks are thus made of huge trusses with heights in the order of magnitude of 13-15 m (fig. 2), which are not comparable to the streamlined decks of the two first Bosphorus bridges.

Fig. 2: Seto Great bridge with a two level deck

2 Cables layout

The 5.5 m high deck of the Third Bosphorus Bridge imposed to find the required rigidity in an innovative cable system. This has been achieved by combining the cable system of a suspension bridge – parabolic main cables with vertical hangers – together with stiffening cables connecting directly the deck to the towers.

The main span is thus divided in three zones: the central part of the deck is suspended by the main cables, the areas close to the towers are supported by the stiffening cables, and in the transition zones, the deck is both suspended by the main cables and the stiffening cables (fig. 3).

The role of the transition zone is to provide a transition as smooth as possible between the two other systems. For this reason the two transition zones have been extended on a length of 240 m each and are composed of 11 stiffening cables and hangers.

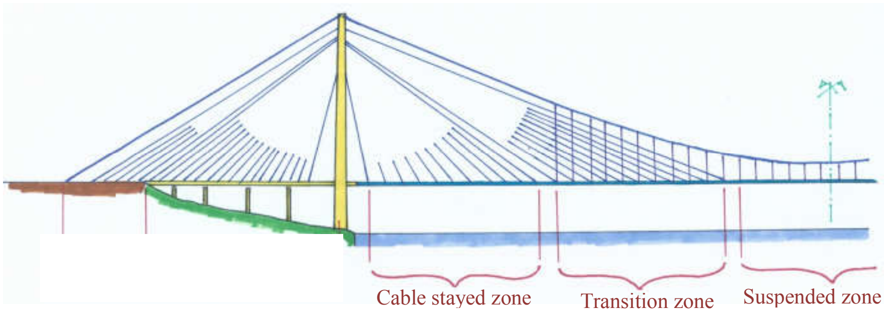


Fig. 3: Main span zones

In the back spans, five pairs of stiffening cables are directly anchored in the ground, behind the expansion joint. This creates a disequilibrium of the horizontal components of the stiffening cable forces in the deck. The equilibrium is obtained by a corresponding tension force of approx. 80 MN under permanent loads in the central part of the main span (fig. 4). This tension force has a favourable effect by increasing the stability of the deck, especially in the transversal direction.

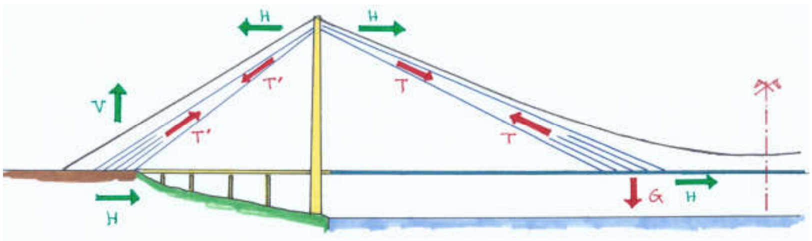


Fig. 4: Balance of longitudinal forces

In the main span, the longitudinal spacing of the stiffening cables, as well as of the hangers, is 24 m while it is 15 m in the back spans.

For an obvious ease of their installation, the main cables and the hangers are placed in vertical planes located between the railways and roadways, taking advantage of the pylons A-shaped geometry. In the main span, the stiffening cables are anchored on the edges of the deck, between the roadway and the walkways, in order to avoid any conflicts with the hangers in the transition zone (fig. 5).

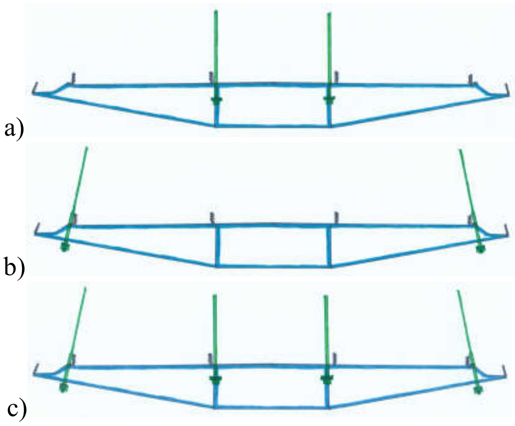


Fig. 5: Stiffening cables and hangers organisation in main span:
a) suspended zone / b) cable stayed zone / c) transition zone

In back span, the stiffening cables are anchored between the railways and roadways (fig. 6). As they are placed almost in the same vertical planes than the main cables, the two longest stiffening cables in back span could only be installed when the main cables were sufficiently loaded, and their sag sufficiently reduced, to avoid any contact.

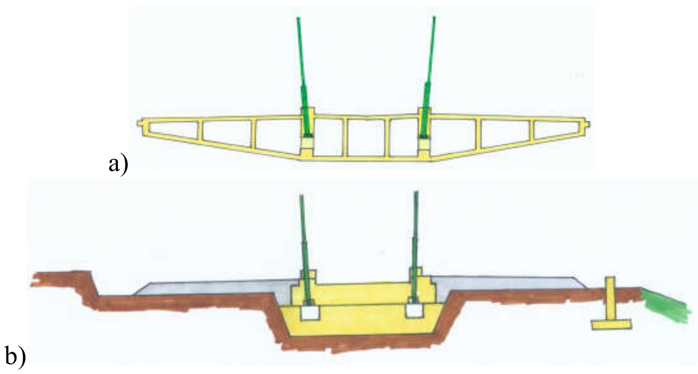


Fig. 6: Stiffening organisation in back span: a) concrete deck / b) ground approach

3 Main cables

The main cables are made of Prefabricated Parallel Wire Strands (PPWS) with a wire diameter of 5.4 mm each. The wires are pre-assembled in hexagonal-shaped strands of 127 wires that come with their total length from one anchor block to the other, with sockets at both ends. The length of the each strand is determined individually, considering its actual position in the whole cable, and is approx. 2’420 m. The main cables are composed of 113 strands in the main span and 122 strands in the back spans, because of the steeper slope of the cables in the back spans. The 9 additional strands are directly anchored on the tower saddles (fig. 7).

Fig. 7: Anchoring of the additional strands on a tower saddle

The main cables are protected against corrosion by a dehumidification system (fig. 8).

Dry air is injected in the main cables :

- at mid-span, 1/6th and 5/6th of the main span;
- at mid-span of the back spans.

Wet air is extracted from the main cables:

- at anchor blocks;
- at tower saddles;
- at 1/3rd and 2/3rd of the main span.

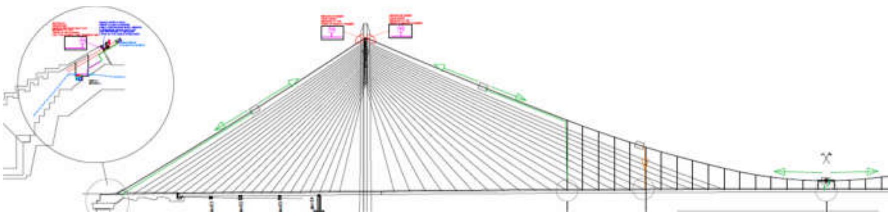


Fig. 8: Main cable dehumidification system layout

4 Hangers

The hangers are made of Parallel Wire Strands (PWS) with a wire diameter of 7 mm each and the number of wires for each hanger varies from 109 to 367. Hangers are single cable, their upper anchorage are made of fork ad pin while their lower anchorage are made of threaded sockets and nuts which allow adjustment lengths of +500/-700 mm (fig. 9).

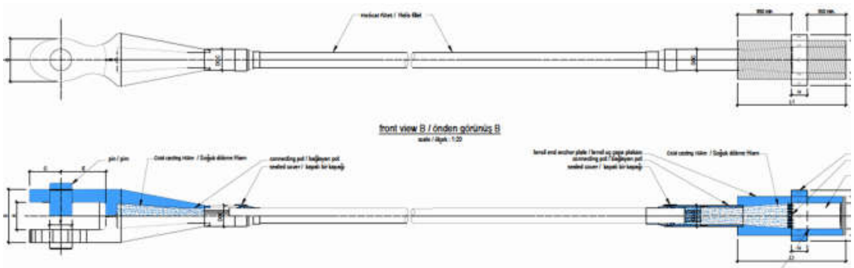


Fig. 9: Hanger layout

The lower anchorages are protected against rotations of the deck and the resulting bending stresses in the hangers by deviators (fig. 10). The hangers rotations and bending stresses will thus be concentrated at the deviators and not at the anchorage. The large radius of the deviator also controls the bending stresses.

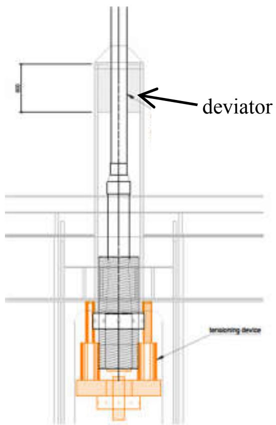
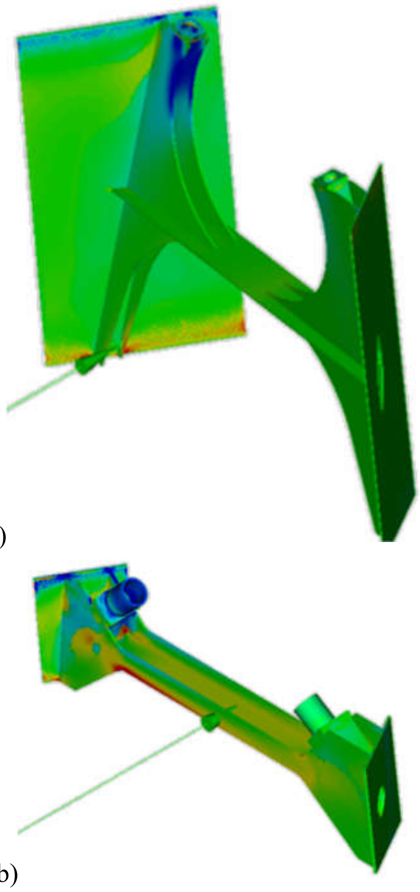


Fig. 10: Hanger lower anchorage

5 Stiffening cables

The stiffening cables are made of T15S strands – 150 mm^2 each – and the number of strands for each cable varies from 65 to 151. The longest stiffening cables have a length of approx. 600 m, which makes them some of the longest in the world.

In the pylons, the stiffening cables are anchored on steel anchor boxes, which transfer the vertical loads to the concrete of the pylons shaft by means of studs. The anchor boxes are not connected to each other, but transfer their vertical forces integrally to the pylon. The horizontal components of the stiffening cables forces are mainly self-equilibrated within each anchor box. Due to the shape of the pylons, the layout of the stiffening cables and the constraints of accessibility to the anchorages (tensioning with mono-strand and annular jacks), the geometry of the anchor boxes is complex and varies all along the pylons height (fig. 11).



a)

b)

Fig. 11: a) Anchor boxes 1-3 / b) Anchor boxes 9-22

Because of the presence of heavy trains, combined with the very pessimistic roadway loads defined by the standards, the ratio live load / permanent load reaches the high value of 0.54. As a comparison, the Normandy bridge, which is a purely roadway bridge with 2 x 2 lanes, has a ratio of 0.28. This high ratio means that the stiffening cables will remain under a low tension under permanent loads, increasing their sag, which reduces their efficiency and increases the risk of cable vibrations. To minimize these effects, high strength steel with a Guaranteed Ultimate Tensile Strength (GUTS) of 1960 MPa has been chosen for the strands, allowing to be used at a higher stress level under permanent loads than the standard GUTS of 1860 MPa.

A cable system with anchorages containing a strand guide deviator device to allow for a higher stress limitation under SLS combinations according to Eurocode 3 (part 1-11) was of course mandatory. Even with these specially designed anchorages, the anchoring areas remain the weak point of all stay cables. Thus it has been decided to protect all the anchorages subject to high rotations from any bending stresses, due to cable sag and sag variation, by installing deviators close to the anchorages. The cable rotations and bending stresses will thus be concentrated at the deviators where the strands are continuous and straight, and therefore less sensitive to fatigue issues.

Even more important was to avoid any over-dimensioning of the stiffening cables that could result from considering unnecessary high traffic loads (railway, roadway and the combination of them) and would automatically lead to a reduction of the stress level under permanent loads.

To even further reduce the risk of cables vibrations under wind excitation, all the stiffening cables are provided with damping devices installed close to their lower end. The selected damping system is called External Hydraulic Damper (EHD) and is made of rigid V-shaped steel masts fixed on the deck. The masts support two pairs of damping pistons, positioned with a relative angle of 60°, allowing for a damping in both the vertical direction (direction of the cable sag) and the transversal direction (fig. 12). The specified logarithmic decrement of the damping devices is 4% for the 8 shortest stiffening cables and 6% for the longest ones.

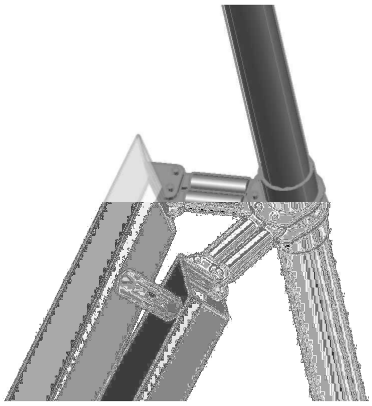


Fig. 12: Damping device

6 Construction sequences

This cable layout has also given the possibility to reduce the construction schedule by allowing to start the erection of the deck by the cantilever method, like any stay cable bridge, in parallel of the long procurement and erection process of the main cables. 21 segments of deck on each side have thus been erected by the cantilever method, bringing the maximum cantilever to 532 m (fig. 13).

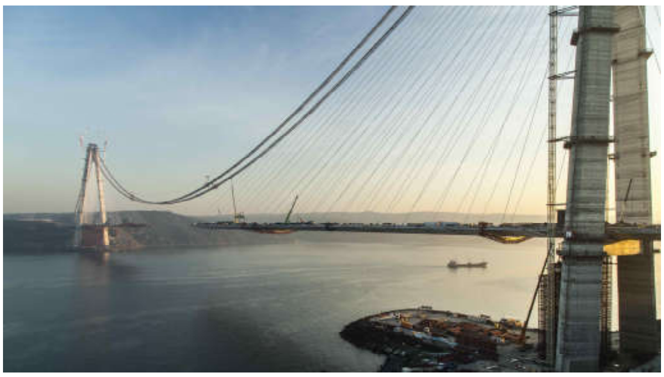


Fig. 13: Maximum cantilever erection phase

As there are no hangers on back spans, tension increases in main span during erection due to incremental addition of deck segments need to be equilibrated at the tower saddles by setting them forward, i.e. in the direction of the main span. The total set forward at the tower has been approx. 2.7 m and it has been applied in 12 steps in order to avoid any slipping of the saddles due to temporary disequilibrium of the horizontal forces.

7 Conclusion

If this combination of hangers and stay cables has been applied on some old bridges, the most famous of them being certainly the Brooklyn Bridge, it is the first time it is applied on a modern bridge, and it is probably not the last time considering the determining advantages it brought to this project in terms of aesthetic, rigidity and construction schedule.