GRAND LARGE FOOTBRIDGE : IN BETWEEN A TRUSS GIRDER AND A STAY-CABLE BRIDGE

Julie GAUBERT – Jean-Bernard DATRY

setec tpi

The Grand Large footbridge, located in the district of the same name in the city of Dunkirk, France, links the old industrial wasteland in the process of restructuring to Malo-les-Bains, a seaside resort and touristic area of the town. Its silhouette with multiple tension rods blends with the maritime character of the site and its reasonable height does not over-shadow surrounding constructions.

Introduction

In 1969, the small town of Malo-les-Bains is attached to the city of Dunkirk, north of France, and becomes one of its neighborhoods. It adjoins the then thriving shipyards. In the 80's the shipbuilding declines, the firms close one after the other and around 150 hectares of land is deserted.

Conducted notably by S3D (Société de Développement du Dunkerquois), a urbanism plan intended target is to reconquer this lost space. In the 90's, new neighborhoods were constructed on a territory that used to belong to the harbor. New infrastructures, such as moving bridges, were built to reconcile the new urbanization and the part of the port still in activity.

The last area not yet rebuilt, renamed "quartier du Grand Large" (meaning "Open Sea Neighborhood "), is nowadays in complete transformation. Numerous low-energy habitation lots has been erected, the wasteland has been turned into tidy public spaces. The AP2 warehouse, nicknamed "the cathedral" by the locals and last relic of the industrial past of the area, was transformed into an exhibition room. A twin construction, the façade of which is an inflatable envelope in ETFE, was joined to it. This new building was designed by the architects Lacaton & Vassal, and now houses the Regional Founding for Contemporary Art (FRAC). However, this new neighborhood is separated from the city center by the marina, and from the beach and commercial area of Malo-les-Bains by the canal that regulates the water level of the "wateringues", canal network of the hinterland.

The Grand Large footbridge is the last project led by the Urban Community of Dunkirk. It is both a symbolic and physical link between these cultural and leisure poles, which will contribute to the opening up of the neighborhood. It enables its inhabitants to limit the use of the car and to reach the sea front by foot or by bicycle. Its construction is included in a new landscaping project: the existing soil of the mound was depolluted and planted and large parts of the FRAC forecourt's pavement are to be turned into planted areas.

Design of the solution in context

Route and surroundings

The footbridge links the inner street of the FRAC, located above the ground level, to the Alliés dyke, continuing the promenade of the sea front of Malo-Les-Bains. A simple structure of 103 m long first passes the square located in front of the FRAC, and lands on a mound of soil. The main footbridge, with a total length of 180 m, curves before it crosses the outlet canal with a slanted span.

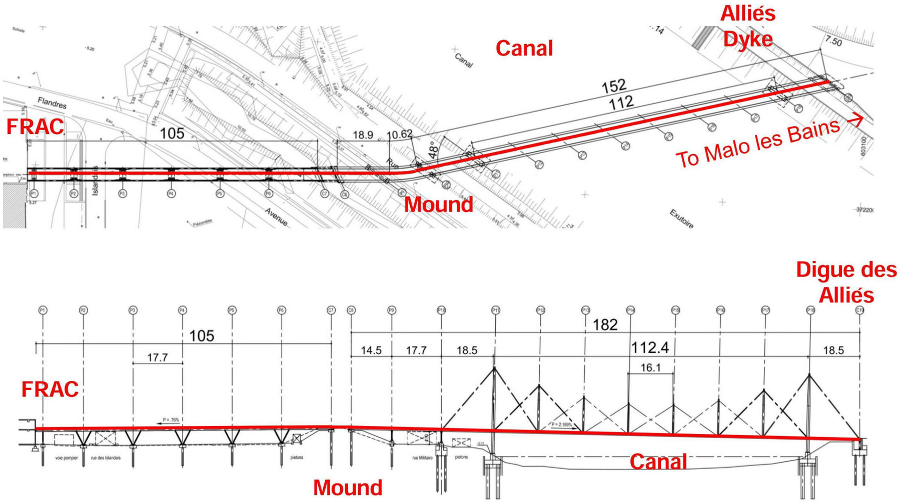


Fig1: Horizontal and vertical alignment

The mound at the junction of the two footbridges has been rearranged in order to allow people to go back down to the square or other paths located 5 m below the footbridges.

Design of the main crossing

The designers, ***setec*** *tpi and the architect Brigit de Kosmi, proposed two diverse but architecturally consistent structures for the two footbridges. For the crossing of the canal, considering the span length, the variation of the water level and the soil resistance, the only suitable solutions were the above-supported and self-anchored ones. The truss girder was immediately eliminated, as it would have too strongly marked the environment.*

Two more classical designs, a symmetrical suspended bridge or an asymmetrical stay-cable bridge were considered, but were not studied further: The pylon of the stay-cable bridge, too high, would have been competing with the FRAC, and the suspended structure was regarded as too bland. A more unique structure was eventually proposed: A stay-cable bridge with numerous masts and stay crossing like the diagonal of a truss girder. The general behavior of the structure also resembles the one of a truss the upper chord of which would have been removed, but the height of the masts varies along a curve that reminds us of the catenary of the suspended bridges.

The multiple masts and stays blends with the port and maritime environment and reminds us the close presence of the sailing ships in the neighboring harbor, as if a gigantic vessel dropped its anchor in the waters of the outlet canal.

Fig. 2: View of the footbridge from the mound

This structure reminds us the Fink trusses, used until the end of the 19th century, mainly for railway bridges. That is why this type of structure is sometimes called “inverted Fink Truss”.

Fig.3: Bolivar Bridge in Arequipa, Peru– 1882- designed by Gustave Eiffel

The inverted Fink truss differs from its ancestor by its statically indeterminate behavior. In order to adapt the lever arm between the crossing of the cable and deck, the height of the masts should follow a parabolic curve.
The height of the pylons is 23 m above deck level, respecting the usual height to span length ratio of cable-stayed bridges. The distance in-between masts is 16 m, allowing an optimal inclination of stays. The masts are located on each side of the deck, liberating space for the pedestrian to move along the bridge and limiting the transverse forces in the masts. The masts work in pair, forming a succession of U-Shaped stiffeners with the crossbeams of the deck. Because of the slanted span, the crossbeams form an angle of 45° with the axis of the footbridge.

Structural behaviour

Under a distributed load, the structure undertakes a global bending moment that compresses the deck and tensions the stays (that work both as diagonals and superior chord) around the pylon, and tensions the deck and compresses the stays in the middle of the spans.

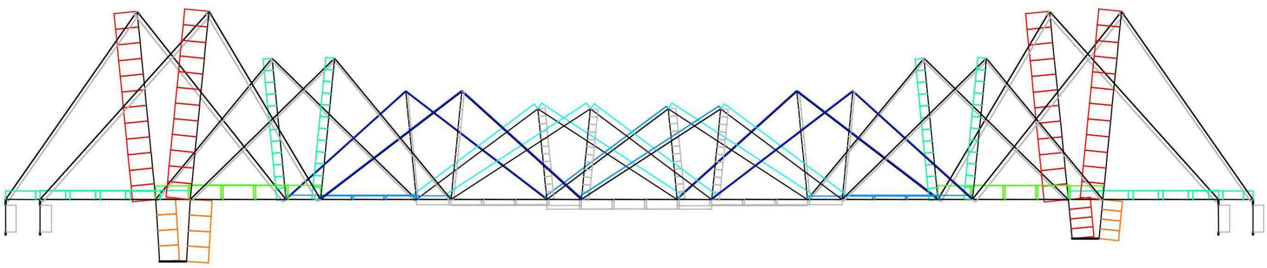


Fig.4: Normal forces in compressed elements

The tensioning of the stay system is necessary to assure that the stays are never compressed and that the system remains stable, by inverting the sign of the mid-span bending moment:

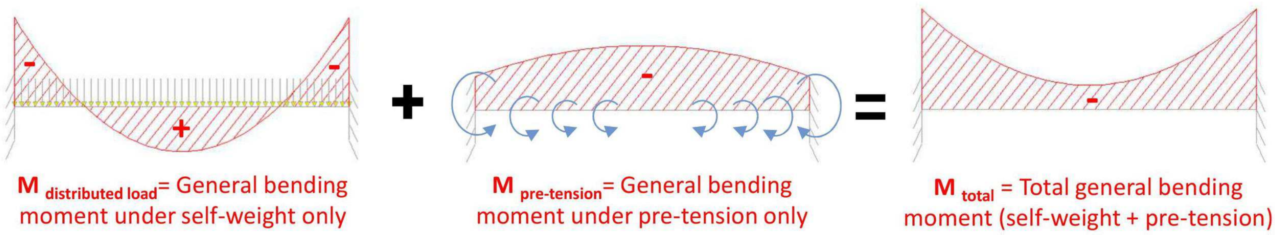


Fig.5: Global bending moment in the structure

The principles of the tuning of the stays are the following:

- *The tensioning of the holding back rods (in blue) allows the head of the masts to be straightened up.*
- *The tensioning of the other rods (in red) allows the deck to be brought back to its theoretical position.*

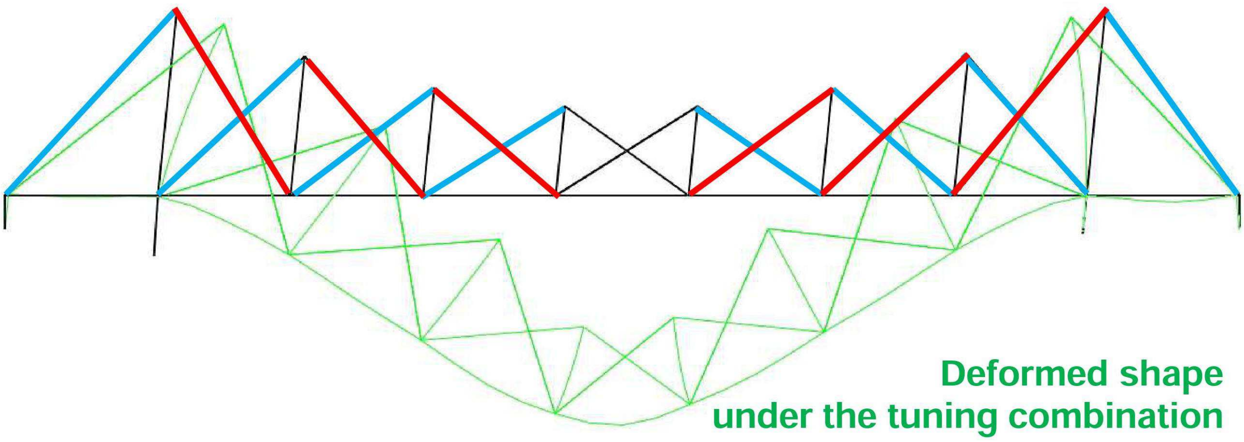


Fig.6: Tuning of the stay-cables

Numerically, the method is exactly the same as the one used to determine the tuning of the classical stay-cable bridges:

- *The influence matrix linking the tension in each stay to the displacement of the control points is constructed by tensioning one stay each time with a unit tension force.*
- *The target displacement vector that cancels the displacement of the control points is multiplied with the inverse of the influence matrix, in order to obtain the tension that has to be applied at each stay.*

The tuning combination is 1.15 (G+G') +1.15 Q, in order to ensure that no stay is compressed under service loads combinations.

However so as not to over tension the tension rods, for the Ultimate Limit State combinations, the central rods are allowed to relax for certain load cases, and an incremented calculation has been performed.

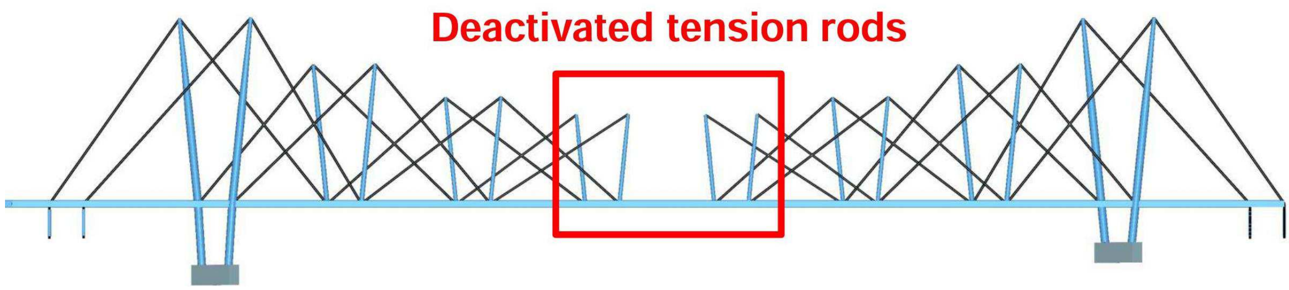


Fig.7: Behavior of the structure at the Ultimate Limit State

Beyond a certain level of loading, the central stays are no more tensioned. They are deactivated for the following increment of load. The structure therefore functions as two facing cantilevers.

Geometry

Pylons and masts

The pylons are steel hollow tubes with a diameter of 1 016 mm, topped by a conical part. The geometry of the secondary masts is similar, but their diameter varies from 510 to 610 mm. The masts are embedded into the deck, and leaning toward the outside. The stays are anchored into it at the top and the bottom by thick plates that transmit the forces of the stays to the mast by shear force. Theses plates go through the masts and the horizontal forces are directly transmitted.

Fig.8 : View of the masts from the decks

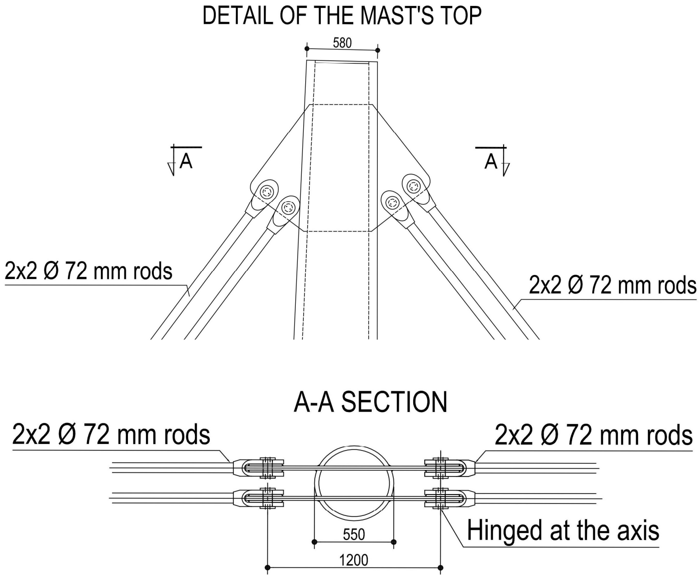


Fig.9 & 10 : Stays anchorage - details

Stay system

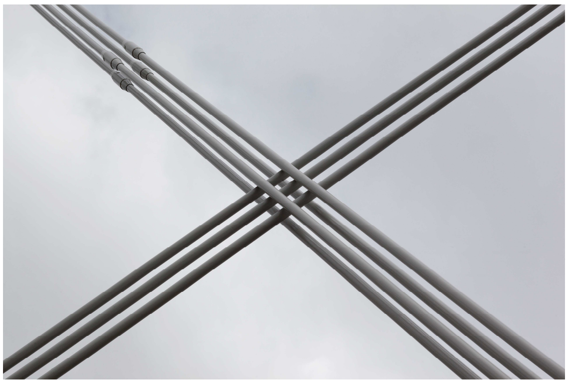


Fig.11: Crossing of the tension rods

The cable stay system is located on either side of the deck, and consists of solid tensioning rods for which the number vary according their position on the span. Four rods are needed for the anchor stays,and one or two rods for the central stays. The rods diameter is 72 mm and their steel grade S540. The rods are hinged at both ends and anchored at the top and bottom of the masts. Adjustable connecting sleeves allow the lengths to be modified.The use of a variable number of rods allows the crossing of the groups of stays without an offset.

Deck

The deck is composed of two 80 cm high and 70 cm wide steel box-girder, linked between them by slanted crossbeams (IPE profile for standard section and a welded section linking the masts) spaced at about 4 m. These crossbeams supports the joists - IPE or UPN 180 profiles, spaced 0.5 m - that carry the wooden deck in maçaranduba .The bracing of the bridge is carried out by hollow tubes arranged in “K” shapes.

Fig.12: Below view of the deck

Bearings

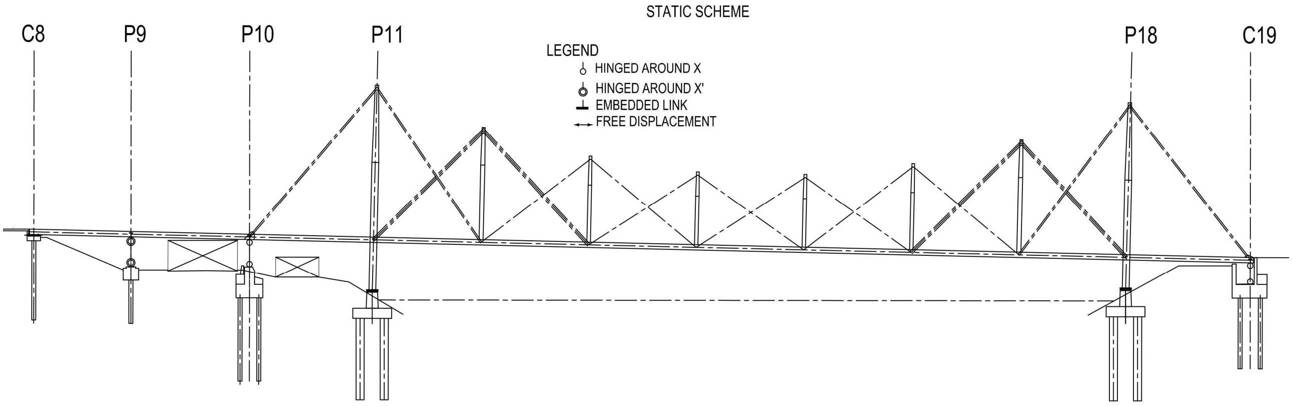


Fig.13: Static scheme of the bridge

The pylons (P11&P18), are embedded in reinforced concrete blocks. To diminish the effect of thermal dilatation that greatly increases the bending moment in the foundations, the blocks have been made the smallest possible to add flexibility to the structure.

The forces brought by the holding back tension rods is transmitted to the deck and two double-hinged stands (C19 and P10). At the abutment C19, the uplifting forces are counterbalanced by the weight of the abutment. At pier P10, the side span's weight and a concrete ballast at the foundation level equilibrate the tension.

The deck is simply supported on the abutment C8.

The foundations

Each pylon is founded on three barrette foundations with a 0,6 mx2,8 m section and a depth of 9 m.

Piers P9 and P10 and abutment C19 are founded on piles, each 0,6 m wide and 11 m deep in average. These piles have been dug with the hollow auger technique.

The abutment C8 is founded on micropiles.

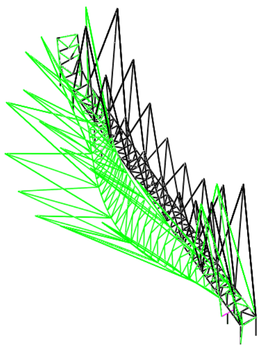
Dampers

During the design phase, calculations acceleration was done, following the recommendations of the SETRA guide « Passerelles piétonnes – Evaluation du comportement vibratoire sous l'action des piétons »:

- *The maximum vertical acceleration reaches 2,08 m/s², which is higher than the limit of 1 m/s² set for this type of footbridge by the SETRA guide. The installation of vertical dampers is compulsory*
- *The maximum horizontal acceleration reaches 0,106 m/s², which is close to the limit of 0,1 m/s². For security and comfort reason, dampers will be installed.*

Some dynamical tests have been performed after the construction. A first range of tests enabled to determine the frequency of the Eigen modes of the footbridge. The frequencies in the range of the frequencies that can be excited by walking or running are the following:

1) *Horizontal mode, frequency 0,71 Hz (0,69 Hz calculated). It is the main horizontal Eigen mode.*
2) *Horizontal and torsion mode, frequency 1,22 Hz (1,17 Hz calculated).*
3) *Horizontal mode, frequency 1,22 Hz (1,42 Hz calculated)*
4) *Vertical mode, frequency 1.70 Hz (1,71 Hz calculated). It is the main vertical Eigen mode.*



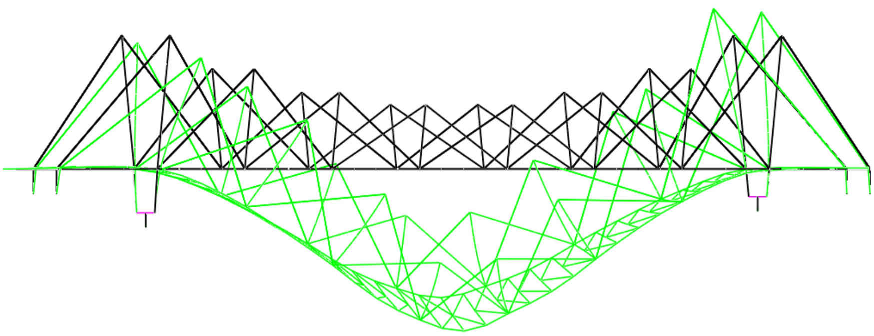


Fig.14 & 15: Main horizontal Eigen mode (left) - Main vertical Eigen mode (right)

The data measured during these tests are used to adapt finely the characteristics of the tuned mass dampers. These are positioned under the deck in the middle of the main span. The horizontal dampers are located in the middle of the deck, whereas the vertical dampers are located near the lateral beams in order to work for torsion modes as well.

Fig 16: Tuned mass dampers

Other tests were performed before and after the assembly of the dampers, allowing the measurement of the acceleration under vertical or horizontal excitation by a group of pedestrians. These tests consist in walking or jumping in a coordinate manner at the same frequency as the Eigen mode of the bridge.

The accelerations measured before and after the assembly of the dampers are compared, to check the efficiency of the damping system. For the vertical mode, more sensitive, the acceleration is divided by 6. For horizontal modes, the acceleration is divided by 2 or 4, depending on the mode.

Construction

The chosen contractors were Bouygues Travaux Publics Régions France for civil works and foundations, and Victor Buyck Steel Construction for the steelworks.

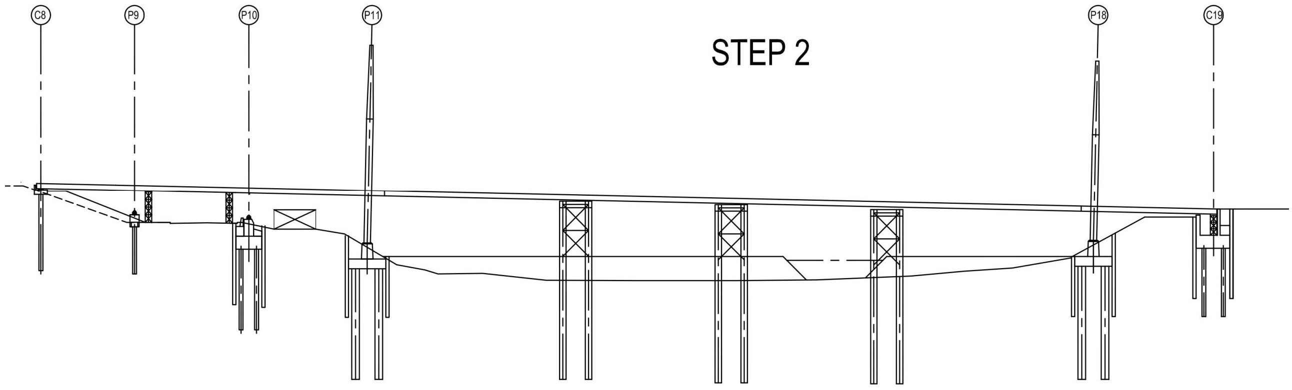
The bridge was constructed on temporary bearings. The elements were put in place with cranes. A temporary embankment was constructed to access to the middle of the canal. To ensure that the water would still flow during the construction, a temporary pier was set in the middle of the embankment.

After the foundations and reinforced concrete pile caps and blocks were constructed, the assembly of the steel structure lasted six months. The main steps of the assembly were the following:

<u>Step 1</u>: the main beams of the side span are put in place on temporary bearings

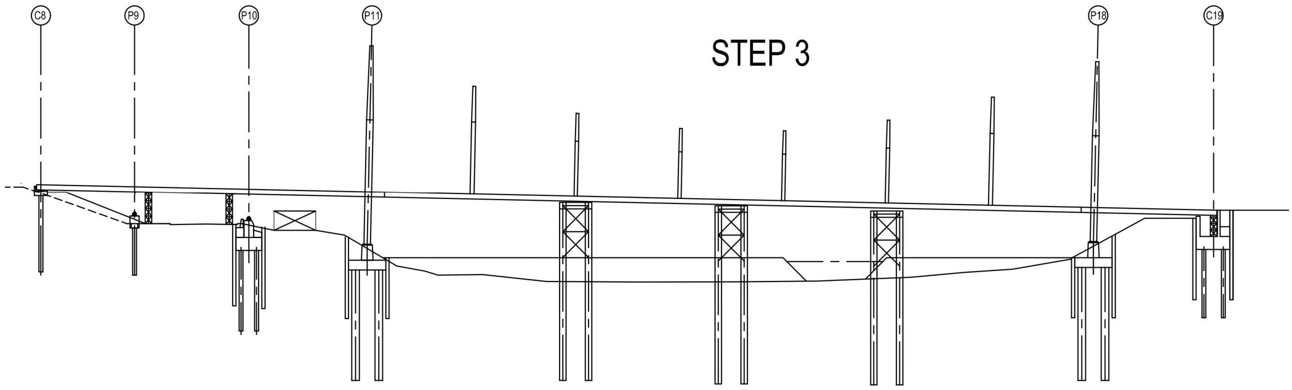
Fig 17: Assembly of the box-girders

Step 2: The main span is put in place on temporary bearings. The crossbeams, stringers and bracings are assembled.



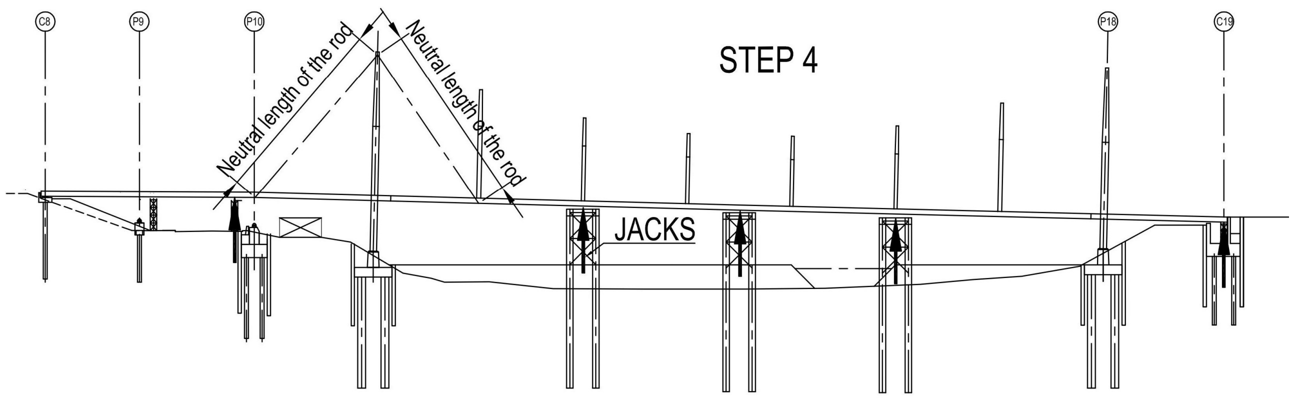
Step 3: The masts are put in place and welded. The wood floor is set in place.

The tuning of the tension rods relies entirely on the geometry and deformation of the structure during the construction, and the phasing of the assembly. A step by step calculation gives for each stage of the rods assembly the tension and the lengthening of the rod.

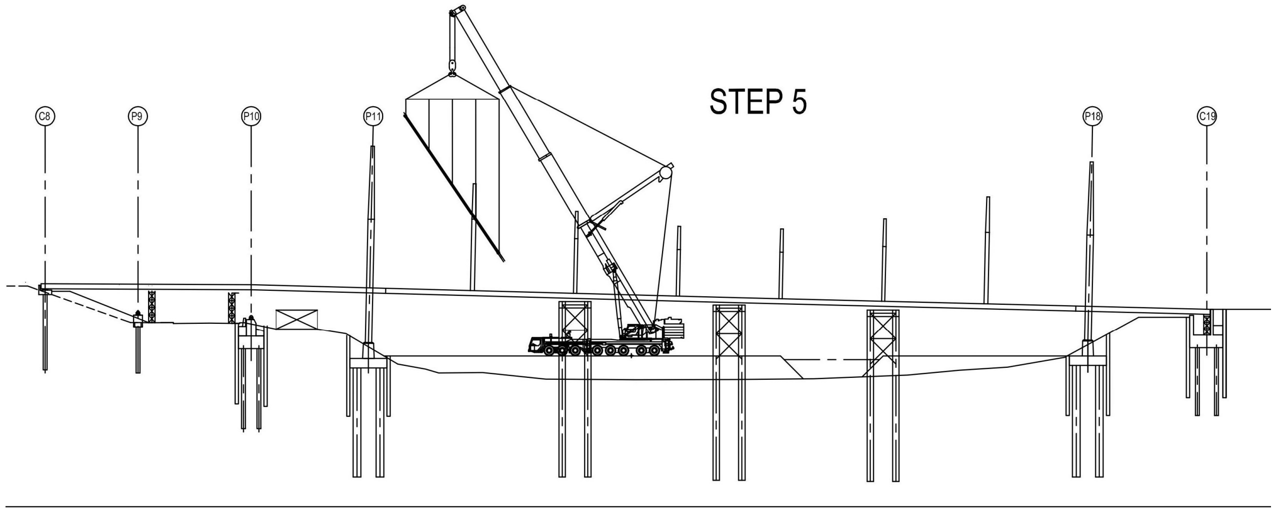


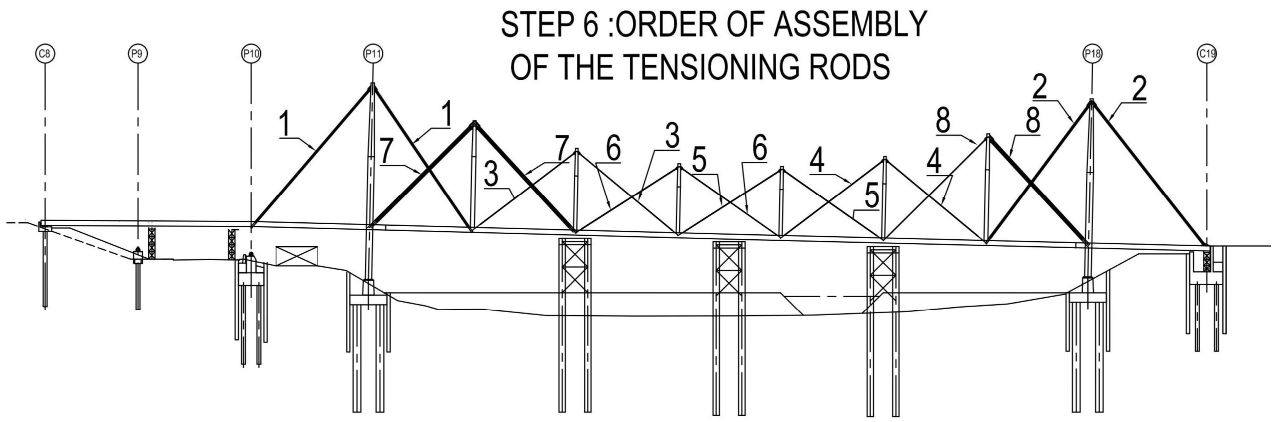
Step 4

- *The neutral length of the rods is calculated,*
- *The rods are cut and adjusted to the neutral length on site.*
- *The deck is jacked at each stage on the temporary bearings, so that the distance between the anchorage points at the top and bottom of the masts corresponds exactly to the neutral length of the rods.*

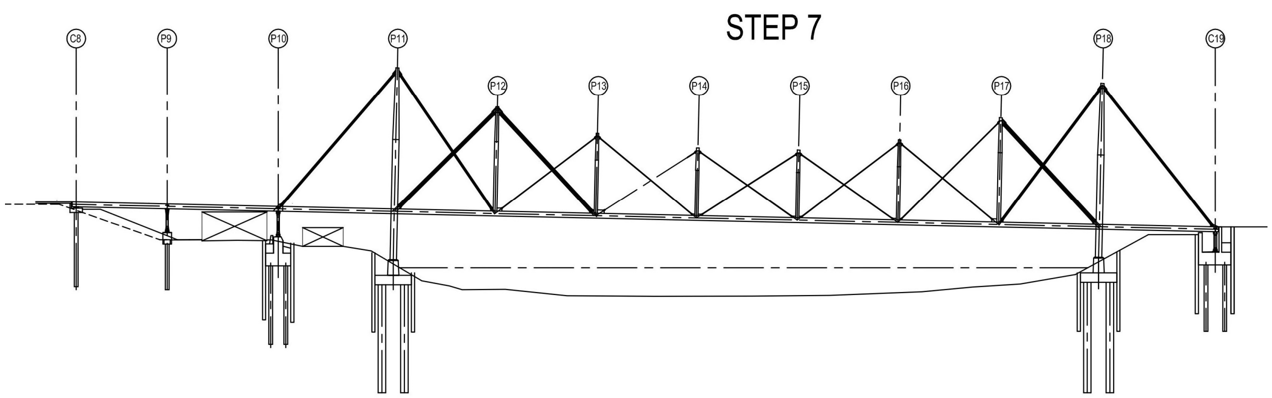


Step 5 & 6: The rods are assembled simultaneously on each side of the mast with the help of a swingle bar which allows the deformation due to the dead load of the bar to be neutralised.





Step 7: The double-hinged stands are set in place; the temporary bearings and the embankment are dismantled.



Conclusion

Thanks to the synergy between structure and architecture, we were able to design and create a footbridge with a unique and audacious architecture that yet blends perfectly to its surroundings, a former shipyard.

The footbridge was finished in May 2015, and the inhabitants of the Grand Large neighborhood have now made it their own. It has become a promenade area, joggers and cyclists enjoy its use and the many "love locks" that flourish before being cut by the municipal employees are the proof of its success.