A PEDESTRIAN BRIDGE ON A WORLD HERITAGE SITE

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1 - AN HISTORIC SITE

By the IX Century, a small village and sea port developed along the North bank of the river Douro, soon becoming one of the most important cities in the North-West of the Iberian Peninsula. In the following centuries, the LOCAL (CALE, in Latin language) of the sea PORT (PORTUS, in Latin language) was more and more the centre of an active and prosperous region named PORTUS CALE, which turned into independent PORTUGAL on the first half of the XII Century.

Porto is now a city of half a million inhabitants facing its twin city, called Gaia, on the left bank of river Douro. Porto is the cultural and economic centre of Northern Portugal, whilst Gaia has always played second role to Porto. But Gaia nurses the cellars of Port, the supreme wine, and profits from vintage views over the river and the steep slopes of the medieval quarters of Porto. Recently, UNESCO has declared the entire area a World Heritage site.

2 - AN INSPIRATION FOR OUTSTANDING BRIDGES

For many centuries, the steep granite slopes of the riverbanks have witnessed life on both sides of the river with few commercial contacts. Crossing a deep river at least 160 m wide, every winter with water speeding at 10 m/s, could be quite an impossible task.

But on the XIV Century, calm waters allowed for a temporary bridge of boats to be installed, and the crossing of the river by the Portuguese Army was achieved in just a couple of hours. Other temporary boat bridges were then set up in the following centuries, but it was only in 1806 that a semi-permanent bridge boat was open for the general public to use. Unfortunately, three years later, hundreds of Porto inhabitants were drawn in the river when the boat bridge collapsed under the weight of the population fleeing away from the Napoleon Army.

Two more boat bridges were installed before a permanent suspension bridge was built in 1843 across the 160 m narrowest section of the river and above the maximum flood water level of the river. The design and construction procedure devised by Stanislas Bigot was in line with similar ones around the world, but its sway movement, even under moderate winds, and corrosion of its metallic components meant this bridge was short lived, and it was demolished in 1888.

In the meantime, the railway from Lisbon had arrived in Gaia and crossing the river Douro was a priority. An international competition was organised and the solution presented by Gustave Eiffel, together with his partner Théophile Seyrig, was chosen and built in less than two years, and open to traffic in 1877 (Fig. 1).

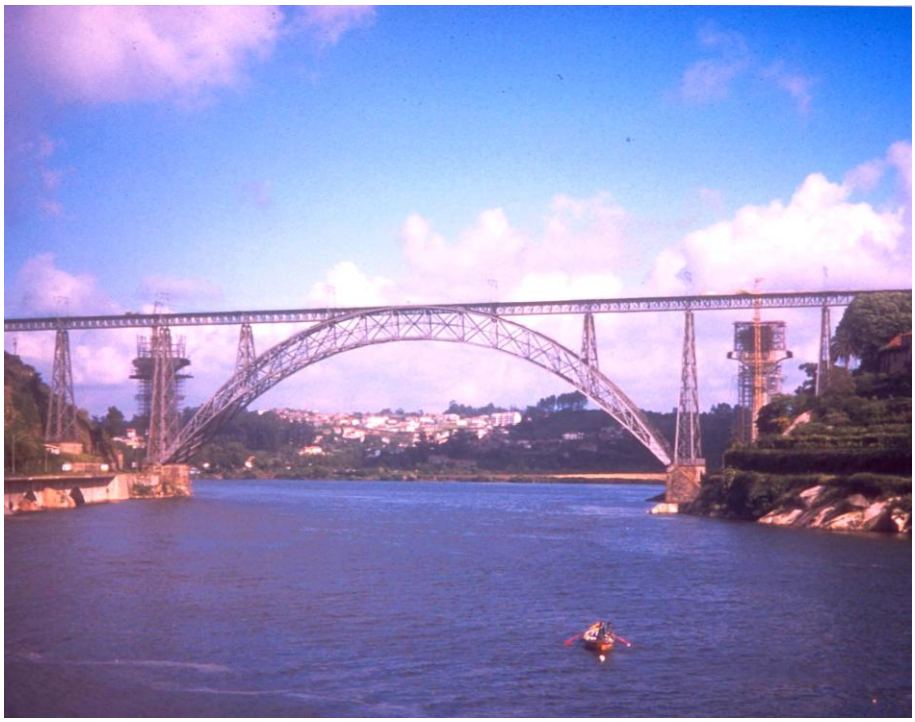

Figure 1 – Maria Pia bridge

Porto was now entering a period of prosperity, and the pedestrian suspension bridge was displaying corrosion and was not able to fulfil the requirements of an approaching motorised society. Therefore, another international competition was organised and the double deck arch bridge designed by Théophile Seyrig was open to traffic in 1987 (Fig. 2).

Figure 2 – Luiz I bridge

This 114 years old beautiful bridge is presently one of the *ex-libris* of Porto.

Almost 80 years have passed for another bridge to be built in Porto. This bridge carries a motorway at the height of 68 m over a reinforced concrete arch spanning 270 m across the river. A world record at the time of its construction, the design by Edgar Cardoso of this beautiful bridge near the mouth of the river has received wide acclamation (Fig. 3).

Figure 3 – Arrábida bridge

The bridge designed by Gustave Eiffel was 114 years old when the railway lines were moved, in 1991, to a new portal frame bridge (Fig. 4) designed also by Edgar Cardoso. This outstanding bridge has a central span of 250 m and runs almost parallel to the Eiffel's bridge.

Figure 4 – St. João bridge

More recently, a new motorway East of Porto crosses the river Douro at a section with shallow banks, over a multi-span bridge with two spans of 150 m (Fig. 5), designed by Antonio Reis.

Figure 5 – Freixo bridge

3 - THE NEW BRIDGES

The XX Century may have been a dormant period for Porto, but new life and new ambitions rose as the last Century was coming to a close. The metropolitan area of Porto has now almost two million inhabitants, it is fast becoming a city of services with a daily incoming population of several hundred thousands, and a brand new light Metro system is under construction.

3.1 – The Infante D. Henrique bridge

This bridge is to be named after the Portuguese *Infante D. Henrique,* no doubt one of the most remarkable sons of Porto and Portugal, who has lead the European adventure of meeting other civilisations around the Globe.

I have had the pleasure of creating and designing this bridge together with Professor Fernández Ordóñez and Professor Francisco Millanes, of IDEAM SA (from Madrid). A bridge inspired in Maillart's works-of-art, with an extremely shallow and thin arch “flying” 280 m over the river with a rise of 25 m (Fig. 6).

Figure 6 – Upstream view from Luiz I bridge (photomontage)

The structure is made up of plans only, with no curved elements. No ornament is added to the bridge. Every element fulfils a functional and structural role. As a result, this bridge exhibits the virtue of simplicity in its structural pureness.

This elegant arch is 1.5 m thick and it is stabilised by a prestressed concrete box beam deck 4.5 m high. The arch width decreases from 20 m at the abutments to 10 m along the central 70 m, where it is united with the deck into a 6 m high box beam with an outline that maintains the view of the arch (Fig. 7).

Figure 7 – Downstream view from Gaia bank (photomontage)

3.2 – The Pedestrian bridge

Navigation by tall ships is possible up to the Luiz I bridge and the riverbanks are becoming major leisure and tourist areas. But the lower deck of that bridge cannot be closed for road traffic and its narrow sidewalks are uncomfortable and even dangerous. Consequently, the Porto and Gaia Municipalities got together just before summer 2000 and asked for a “XXI Century” pedestrian bridge to be studied for the exact location of the XIX Century suspension bridge. Obviously, this location would not affect the navigation of tall ships.

The challenge was to conceive a truly state-of-art bridge that would enhance the beauty and character of the World Heritage site. At first, the very powerful presence of the beautiful bridge designed by Theóphile Seyrig seemed to raise an impossible task. But power is best dealt with by not facing it head on. So, lightness would have to be a main feature of the new bridge, no “flying” cables could be considered, and a true state-of-art structural material had to be chosen (Fig. 8).

Figure 8 – Upstream view of the Pedestrian bridge, in front of Luiz I bridge (photomontage)

A splendid solution of a slender single arch spanning 156 m with a shallowness ratio of 1:13 that raises the arch slightly above the Luiz I bridge lower deck, in order to secure the “reading” of the latter, was conceived with stainless steel as the structural material. Several photomontages of the bridge were displayed for public scrutiny and it has attracted and immense appraisal (Figs 9, 10, 11 and 12).

Figure 9 – Downstream view of the Pedestrian bridge, at the back of Luiz I bridge (photomontage)

Figure 10 – Upstream view from Porto of the Pedestrian bridge (photomontage)

Figure 11 – Upstream view at twilight of the Pedestrian bridge (photomontage)

Figure 12 – Pedestrian bridge next to Luiz I bridge (photomontage)

The arch is a mono-box cross-section clamped to the granite foundations. The stiffness provided by that structural system guarantees proper response of the structure to human induced vibrations and increases the safety factor with respect to buckling instability phenomena. On the other hand, it generates higher stresses due to imposed deformations induced by thermal actions.

The box cross section is 6.6 m wide, 3 m high at the foundations and 2 m high at the centre span, and it has a hydrodynamic shape to account for the high water level of the river in case of major floods (the "design flood" is 1.8 km^3 per day, with a water velocity over 10 m/s).

The pedestrian walk is 5.6 m wide and is made of non-slippery timber planks. On approaching the river banks, the walkway is detached from the arch in order to guarantee a maximum slope of 10% and to reach the existing platforms (Fig. 13).

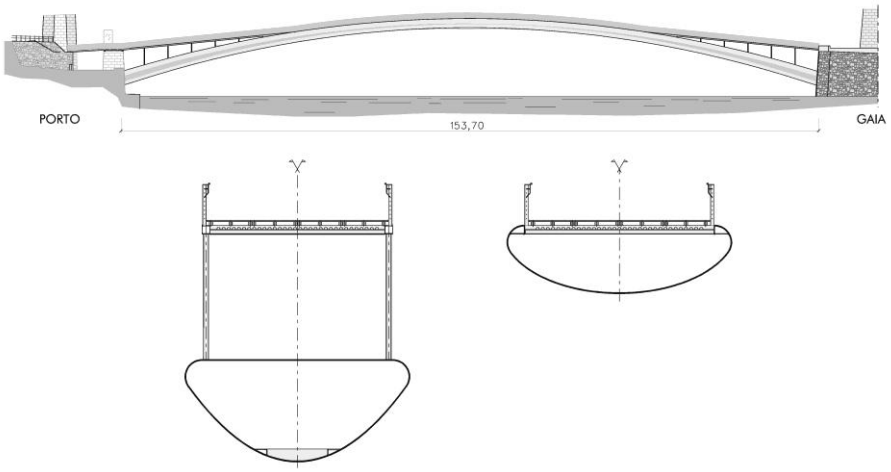

Figure 13 – Elevation and cross-sections of the bridge

The envisaged construction method is to mount the entire arch along the river bank, where a proper finishing can be provided to the stainless steel, before transporting the bridge to its final location with the help of floating cranes (Fig. 14).

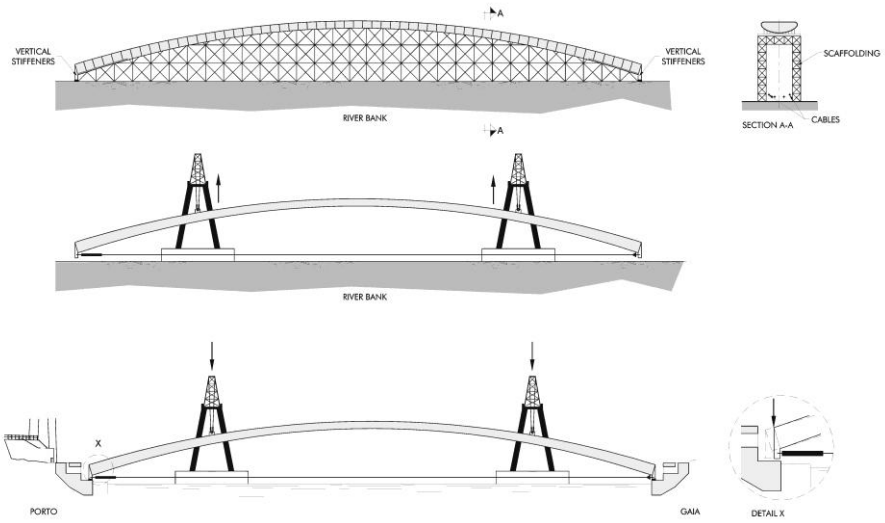

Figure 14 – Construction method of the bridge, elevation and cross-sections of the bridge

The total weight of the bridge is around 700 tons, more than half of which is austenitic-ferritic stainless steel of the class EN 14462 (ASTM S31803) in the 20 mm thick outer plate, and the remaining is S-355J2G3 steel in internal cross frames and stiffeners.

For an estimate cost of 7.0 million Euros, decision on the start of its construction is yet to be taken.

The major innovation of this bridge is clearly the use of stainless steel as structural material. For the bridge detailing, the previous experience of IDEAM SA (in Madrid), lead by Professor Francisco Millanes, in the design of the stainless steel *Pasarela de Abandoibarra*, in Bilbao, was sought in order to ensure the success of the design (Fig. 15).

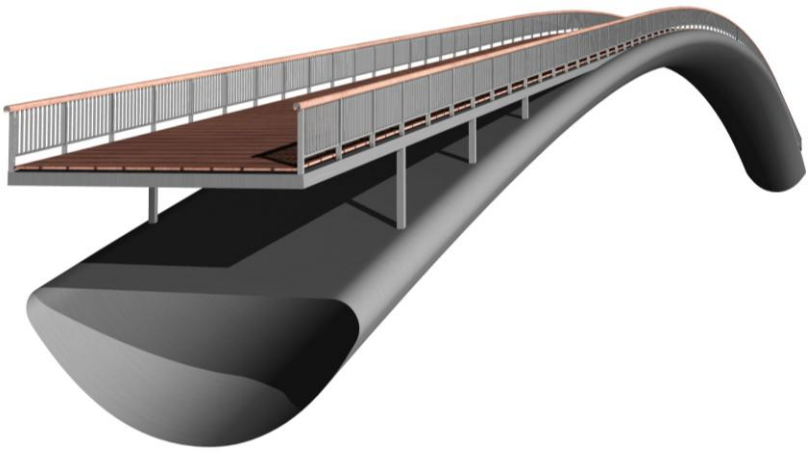

Figure 15 – Pedestrian bridge