CONCEPTUAL DESIGN OF THE NEW COIMBRA FOOTBRIDGE

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Summary

This paper presents the conception and general design of an innovative and slender pedestrian and cycling bridge currently under construction over the river Mondego, in the city of Coimbra, Portugal. This unique bridge is a remarkable structure that will open new challenges into the conception and design of footbridges without resource to expensive and decorative structural solutions. The bridge displays innovative characteristics and a complex dynamic behaviour.

Keywords: Pedestrian bridge; cycling bridge; steel structure

1. Location and soul of the bridge

River Mondego is the largest river springing in Portugal and on its way to the Atlantic Ocean goes through Coimbra. Just downstream of the city, a small dam creates a reservoir of irrigation water for the rich agricultural lands that spread from Coimbra to the mouth of the river and provides Coimbra with a refreshing lake more than 200 m wide where water sports take place. Coimbra sits one of the oldest European universities and it depends very much on the lively presence of many thousands of students, who have always taken the riverbanks as their favourite relaxing places.

Those banks are very low and flat near the river and thus are flooded easily in wet winters. Therefore, building construction was never considered near the river and the correct decision was taken a few years ago to build parks on its banks. The northern park was open recently and attracts thousands of people on a summer day. The southern park will be ready soon and construction of a pedestrian and cycling bridge connecting the two parks started in June 2005 for a construction time of 9 months. Therefore, it will be open in spring 2006.

That is the splendid setting for the design of a bridge that it was requested to be a landmark for the city of Coimbra in the 21st Century. A landmark in its innovative structural solution, as an attribute to the University up in the hill on the northern river side, and in its simplicity of form, as an attribute to the Carmelites Convent up in the hill on the southern river side.

The bridge was designed by the authors of this paper, the first leading the engineering team from AFAssociados (www.afaconsultores.pt) and the second leading the architectural team from Ove Arup (www.arup.com).

2. Bridge conception

Rowing, sailing and windsurf competitions should pass under the bridge. Rowing requires that deck and supports in the river guarantee a total free section 81 m long and 2 m high across and above the maximum summer water level. Sailing and windsurf require a free section 7 m high along 30 m.

Slopes of the ramps should guarantee comfort for all and use of the bridge by wheelchairs. Along the bridge, a strong feel of stay and relaxation above the calm waters of the river should be achieved.

But the most important constraint in the conceptual design of the bridge was the local landscape and topography. The river banks are just 20 cm above the water level. Evidently, to cross the river, people will have to go up to the bridge deck. Then, the high of the bridge must be as low as possible. That is, a long free span of more than 81 m had to be achieved with the deck rising to no more than 10 m above water level. Obviously, a beam for that span and so low in height would look enormous and heavy. Light and transparent solutions could be provided by either suspended or cable stayed decks. But very close upstream, a road cable stayed bridge was built recently and the two would conflict visually. Furthermore, suspended or cable stayed bridges are expensive and their cost would go over the maximum allocated. The alternative was to design a very shallow arch bridge (Figure 1).

Fig. 1 – Aerial view (photomontage)

The design has evolved from an initial concept based on a three span steel box girder bridge from its inception to a more articulate architectural statement, which will also enhance the user's experience as they traverse the space between the banks of the Mondego. The fundamental architectural "move" proposed is a "cut" with a transverse shift of the bridge deck at its midpoint, generating a space at the centre of the bridge where pedestrians and cyclists are encouraged to stop and experience different views of the bridge, water and landscape. As a result of this "move", the bridge is transformed from a connection element between two points into a destination in itself.

The architectural "move" of cut-and-shift is visually reinforced by an offset of the now two discontinuous supporting planes to the outside edge of the bridge deck. As opposed to the original scheme, composed of two equal parallel sections, the supporting plane is "folded" orthogonal to the plane of the deck and the deck itself is varied in width with a widening at mid-span reflecting the horizontal moment distribution induced by the cut-and-shift.

Therefore, this bridge is more than the walkway across the river. Its anti-symmetric structural form, both in plane and in cross-section, provides a "true" meeting space for the intellectual wisdom of the University with the spiritual wisdom of the Monastery. Indeed, this bridge will be a place to rest and meditate.

3. Bridge design

The bridge has a total length of 274.5 m along two 4% inclined ramps 4 m wide and coming up from each bank. In elevation, these ramps are connected by a parabolic transition arc at the centre of the river. In structural terms, the bridge is composed by one central parabolic arch and two lateral parabolic half arches defining, together with the deck of those ramps, two continuous triangular frames (Figure 2).

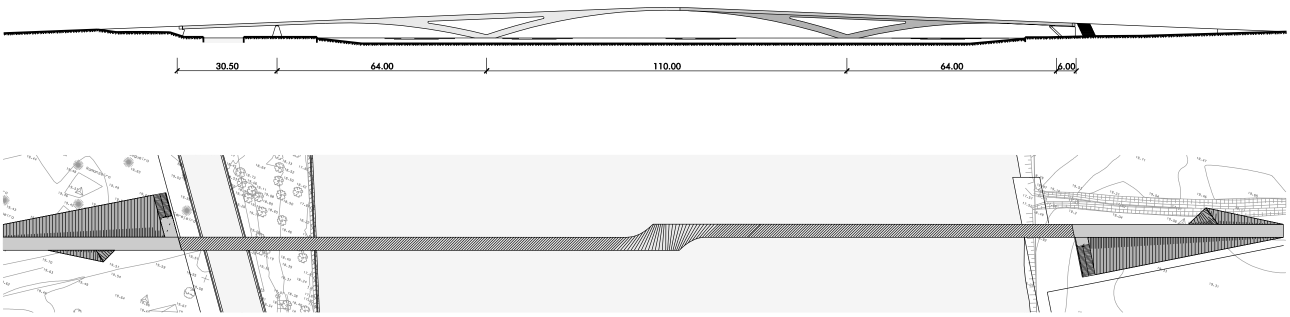


Fig. 2 – Elevation and plan view of the bridge

A very special feature of the bridge is the anti-symmetrical development of both arch and deck cross-sections along the longitudinal axis of the bridge (Figure 3), which results in a complex torsion behaviour under vertical loads but leads to an increased lateral stiffness when compared to the traditional structure with symmetrical cross-sections positioned symmetrically along the entire length [1].

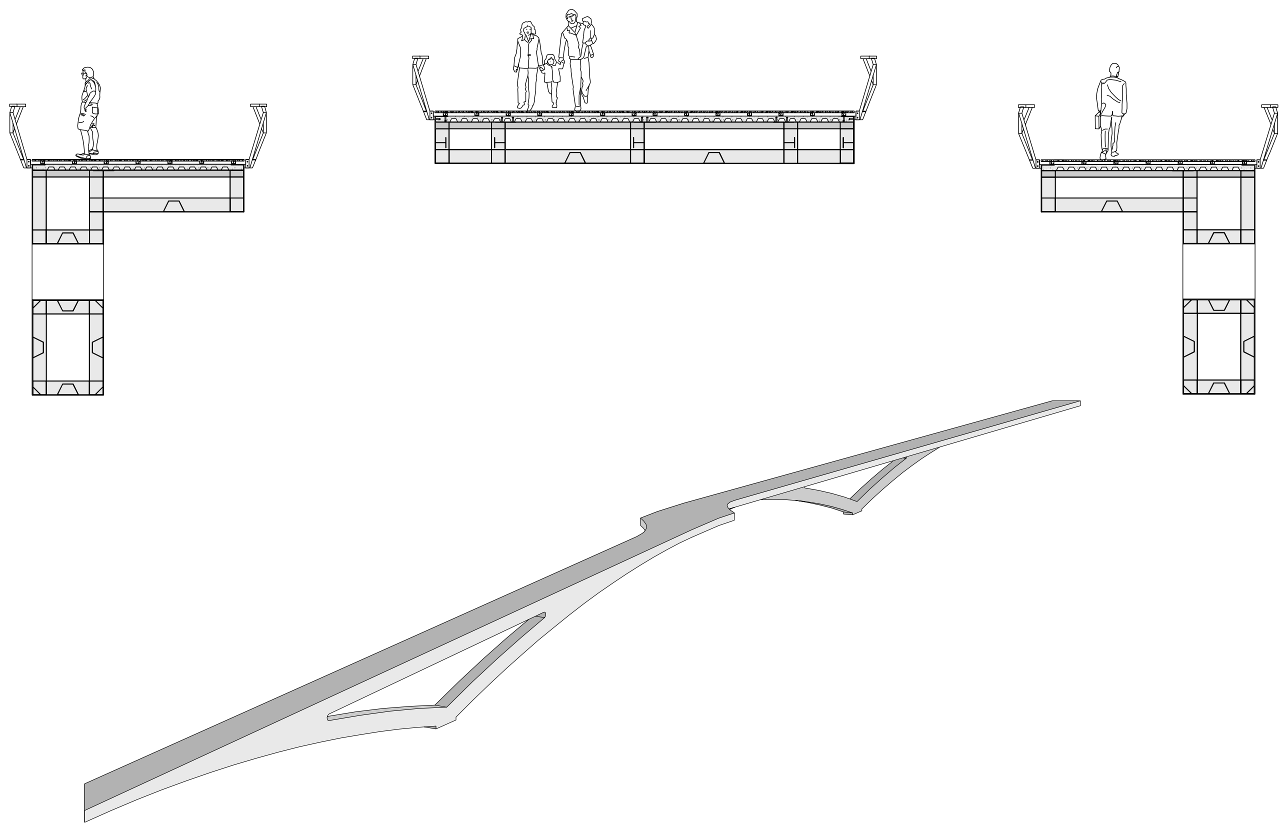
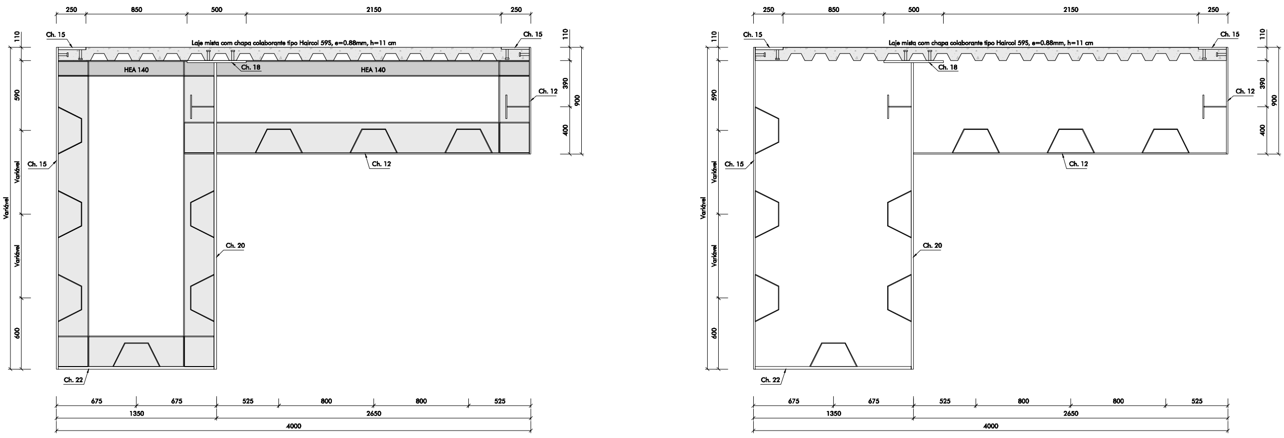


Fig. 3 - Cross-sections and perspective of the bridge

Cross-section of arches is a steel rectangular box girder 1.35 m wide and 1.80 m high and decks are composite steel-concrete box girders basically 4 m wide and 0.90 m thick. In between arches, the deck cross-section takes an L shape with the high of 1.50 m in the width of 1.35 m above arches underneath. Therefore, L shaped cross-sections of variable high result when deck and arch meet and intersect (Figure 4).



a) with transversal stiffener b) without transversal stiffener

Fig. 4 – Transversal cross-section when arch and deck intersect.

In the central "piazza" and in the lateral spans outside half arches, cross-section of the deck has then a constant thickness of 0.90 m, respectively 8 m and 4 m wide. The transition from 4 m to 8 m is made along parabolic curves to avoid highly concentrated stresses.

Central arch raises 9.362 m and spans 110 m, meaning a shallowness ratio of almost 1/12. Lateral half arches leap into the river banks, with a further southern span beyond an intermediate column in the left bank, in order to cross over a rowing canal. Resulting lateral southern spans are 64 m and 30.5 m long. In the northern side, the deck reaches the abutment in one single span 64 m long, but a compensation 6 m span still exists over this abutment in order to create a clamped effect that provides continuity to that 64 m previous span. In the middle of the river, the two half bridges 4 m wide meet tangentially to form a central "piazza" 8 m wide and 12 m long (Figure 5).

Fig. 5 – Views of the bridge towards West and North (photomontages)

Supports of the arches are inside the river and are clamped, but supports of the deck provided by the intermediate column on the left bank and by abutments are free to move longitudinally. Consequently, a key factor for the bridge global stiffness is the structural behaviour of its foundations, which are formed by vertical piles deep 35 m. Due to poor characteristics of the soil layers, piles are quite flexible under horizontal loads and the structural behaviour of the bridge is mixed arch and girder.

For a bridge more than 250 m long and 4 m wide, with large spans, it is no surprise that dynamic studies confirm that the bridge is prone to vibrations induced by pedestrians. A detailed numerical study of the bridge was performed [2] in order to identify the tuned mass dumpers (TMDs) required for several vibration modes.

The footbridge is currently under construction (Figures 6 and 7) and will be extensively tested, first to confirm the modal properties of the bridge and to calibrate the design of TMDs, second to tune those devices, and finally along the first year of service of the bridge in order to assess potential episodes of vibration and further tuning of the TMDs.

Fig. 6 – Bridge under construction (October 2005).

Fig. 6 – Details of propping of the bridge under construction (October 2005).

4. Conclusion

The parametric studies demonstrated how various geometrical changes in the bridge impact on the overall weight and hence the cost of structure, although fabrication costs for the more complex solution reduce somewhat the cost savings which were at first apparent.

It is also interesting to highlight how the individual geometric changes affect structural performance. From the results of the preliminary studies, certain architectural variations of the bridge geometry appeared to cause an imbalance of forces, which were detrimental to the bridge efficiency. However, the final arrangement is one where sculptural form and balance of forces form an optimum and totally “unpredictable” synergy.

This project offers an unprecedented opportunity to merge the architectural intent with engineering clarity and allow placing this extraordinary marker unambiguously on the Coimbra scene.

Within the restraints of budget and brief, this design could stretch the very definition of “BRIDGE”, exploring its artistic and social potential as well as challenging some of the traditional principals of bridge engineering.

Ultimately, the fusion between the different motivations, social, artistic or technical, are so intimate that the architectural "move" cannot be discerned by the physical form.

Acknowledgements

Acknowledgements are due to our colleagues at AFAssociados and at Ove Arup for their contributions to the discussions in which many of the final solutions were generated.

References

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