Designing bridges – A quest for beauty

Armando RITO
Civil Engineer
Lisboa
Portugal

Summary

Bridge design is essentially based on technical, functional, safety, durability and cost considerations. Aesthetics, having been for many years a secondary issue for designers, is nowadays of primary concern.

Some personal thoughts, illustrated with a few examples from some of the author's designs will next be presented as a tentative contribution to this subject.

Keywords: *bridge; aesthetics; function; technical; structure; beauty; architecture.*

1. Introduction

The primary concern of a bridge designer is technical. Aesthetics usually comes later if it comes to be considered at all.

We begin a design looking at issues like functionality, safety, economy, durability and, this being with frequency regrettably overlooked, feasibility.

The function of a bridge is simple and it is, primarily, to connect two points over an obstacle, be it a river, a gorge, a plain that must be preserved, a route or whatever.

That means that a bridge is, essentially, a utilitarian object. But as a built object inserted in the landscape and involving modifications on its surroundings, be them natural or built, its aspect is a mater of the utmost importance.

The bridge structure being totally apparent, its structural options will be clearly reflected in its final and long-lasting aspect. Therefore an unfortunate structural design decision can dramatically disfigure the bridge and its environment.

That's why, as bridge structures are themselves architectural objects, their design must be concurrently an engineering and architectural task.

A structurally sound design is always a good foundation for an aesthetically pleasing structure. A poorly designed one can never be aesthetically rescued by any architectural "embellishment" to conceal its inadequacy.

Function must govern design, thus defining form, and form must clearly represent the function for which the structure was conceived, this meaning that the structural logic must be clearly exposed on the final result.

Functional designs are simple and simplicity is beautiful. Simplicity of design leads to simplicity of construction and simplicity of form. Aesthetics must reinforce the predominantly technical design not to be superimposed on it.

As an engineer, our strong feeling is that the structural designer must be able to handle himself the aesthetics of his own structures. As bridge designers we must always keep in mind that our art and skills will remain, for the rest of the bridge's life, openly and permanently exposed affecting, for better or worse, other people lives.

2. Some examples

The following bridge examples intend to show how the author tried to blend form and function, integration on the surrounding environment and economy in a quest to achieve beauty in his designs.

The author had the privilege of working at the beginning of his career, and later on of teaching although briefly, with late Professor Edgar Cardoso the grand master of bridge design of the last century in Portugal.

This kind of opportunity marks indelibly one's career. Although our approach to design was distinct, the concerns with structurally sound, aesthetical and economical design are similar. Good lessons always leave a mark that, even with average students, comes forth, sometimes unexpectedly, in the solution of difficult situations.

The designs of Professor Cardoso, despoiled of any unnecessary ornamental element, perfectly integrated in their environments, come out as the natural solution for the crossings conveying an image of great lightness and simplicity to the interconnection of the two banks of the rivers crossed.

We will show three of his bridges, Arrábida, Mosteirô and S. João, all built over the Douro river.

Let us look at Arrábida Bridge, built in 1962 and span record for some years, located at the mouth of the Douro at Porto. *(Fig. 1, 2).*

The structure, bold for the time of its construction, is functional, simple and beautiful and is a landmark and a pride for the Porto city.

The arch is slender, the structural member's dimensions are well balanced and their proportionate distribution confers to the bridge great harmony granting its perfect integration on the river mouth. Its evident load carrying shape conveys a sense of grace and stability. The bridge aged well, passing effortlessly the test of time.

Fig. 1 Arrábida bridge

Fig. 2 Arrábida bridge

Another example is Mosteirô bridge. This bridge, with a central span of 110 m, designed by Edgar Cardoso in 1970 and completed 2 years later, was built to substitute the old steel trussed one, which was to stay submerged after the construction of the Carrapatelo dam. Prof. Cardoso decided to use two of the old bridge piers as foundations for the new one. So the new bridge had to be light. He masterly combined the use of his recently developed concept of "reinforced-prestressed concrete" with the aesthetical and structural ones of the steel trussed bridge that was to be submerged.

We can appreciate the result thus obtained by the master engineer: a bridge of striking lightness encompassing the calm waters of the reservoir. (*Fig. 3, 4*)

Fig. 3 Mosteirô bridge

Fig. 4 Mosteirô bridge

The S. João bridge at Porto, located around 2 km upstream from the Arrábida bridge, is a multi-span prestressed concrete railway bridge, with a main span of 250 metres. (*Fig. 5*)

The new bridge, a replacement to the Dª Maria arch bridge designed by Eiffel and Seyrig, had to be located very near to the old one and also to another steel arch bridge built in 1886, the D. Luís bridge designed by Seyrig. Thus, the aesthetical issues related to the integration of the S. João bridge on the surrounding environment were very demanding.

The minimalist and restrained configuration adopted, with its strong compact line, created a counterpoint to the latticed and open lines of the Eiffel steel bridge.

Fig. 5 S. João bridge

Fig. 6 S. João bridge

Note the elaborate design of the pier's shapes, how well they blend with the powerful and neat deck, and how the bridge springs forward across the deep valley of the river. (*Fig. 5, 6*)

As function must dictate the design of the bridge, taking advantage of the construction methods is a good chance for obtaining good looking shapes.

When designing a bridge and during the search for the best structural solution, a fundamental concern must be: how is it going to be built, with what kind of equipments?

This imposes on the designer the use of specific geometrical forms namely on the piers. We can, without loosing functionality and economy and, even so, avoiding unnecessary complications, give to the piers a harmonious shape that will blend well form and function.

Fig. 7 Piers - construction stage

Fig. 8 Piers – final view

The Labriosque viaduct is located on the A3 Northern Highway.

It is 1 km long and 45 m high.

The construction method, envisaged at the design stage, was the span-by-span one.

To ease construction and avoid modifications at construction stage this method was from the beginning incorporated in the shape of the upper part of the piers giving them the configuration of a fork.

So, it was very easy to accommodate the self-launching form carriers and the complementary equipment needed for the construction of the decks without the need of any change on the original design and, therefore, of the original concept of the viaduct. (*Fig. 7, 8*)

Fig. 9 Labriosque viaduct piers – final view

Fig. 10 Labriosque viaduct piers – final view

We attempted to take advantage of that constraint to give the piers a careful treatment of form and detail in order to obtain added esthetical value for the viaduct. (*Fig. 9 to12*)

Fig. 11 Labriosque viaduct

Fig. 12 Labriosque viaduct

The IP3 Highway is being constructed trough the impressive scenery of the northern vineyards of the Douro region, from where the Port wine comes, a spectacular site of rare beauty. In this location four bridges were built within around 10 kilometres of road.

Two of them (Fig. 13, 14) were completed in 1998 and the last one in 2003, (Fig.15, 16). Miguel Torga bridge was completed by the end of 1997.

The Varosa and Balsemão valley bridges have two parallel six span box girder decks with a total length of 460 m each. The current span is 100 metres long. They cross the valleys at a maximum height of 120 m. (*Fig. 13, 14*)

The parallel piers, one for each deck, have maximum heights of 80 m.

Their shafts have a hollow rectangular variable cross-section decreasing from base to top in the first 30 m. This cross-section widens laterally along the last 6 metres at the top in order to accommodate the box girder.

Fig. 13 Varosa bridge

Fig. 14 Balsemão bridge

The Corgo valley bridge has two parallel decks, a total length of 625 m and crosses the valley at a maximum height of 80 m. Each one of the two parallel bridge decks is a five span box girder with current spans of 145 metres. (*Fig. 15, 16*)

The piers have a maximum height of 70 m. Here, their shafts have a hollow rectangular constant cross-section from base to top.

Fig. 15 Corgo bridge

Fig. 16 Corgo bridge

The Miguel Torga bridge at Régua, named after one of our most prominent writers and poets of the last century and born in that region, crosses the Douro river valley.

The bridge has a sharp in-plan curvature of 600 m and is also curved in elevation. It has eleven spans, and the main one is 180 m long. (*Fig. 17*)

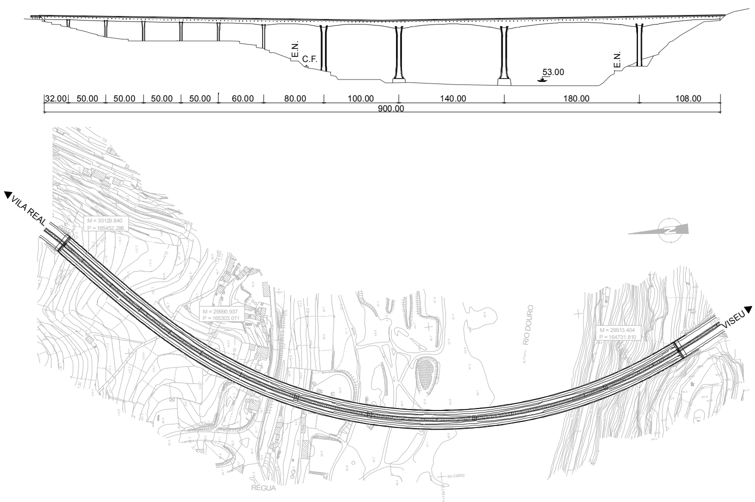

Fig. 17 Elevation and plan

Observing carefully at how the valley evolves, we can see that if we had divided the bridge platform in two decks to span this valley it would have become cluttered with piers and the bridge structure would have lost unity strongly impairing its aspect and the beauty of the site. (*Fig. 17, 19*)

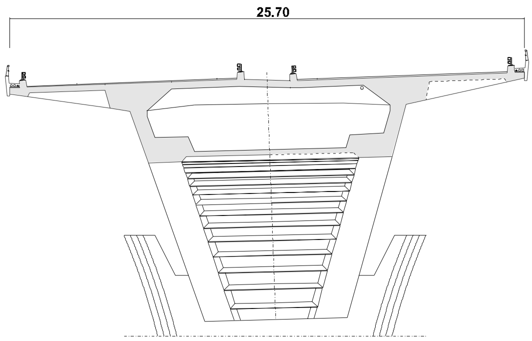

Fig. 18 Deck cross-section

As a final result we would have not one bridge crossing the valley but with distinctly parallel ones. The logical choice was to design a single-cell box-girder of variable height cross-section, 900 m long and 25.70 m wide, crossing the valley at 94 m high was adopted for the deck. (*Fig. 18*)

Fig. 19 Régua bridge - general view from downstream

We had to support the heavy deck, either during construction or during service life. However, the actions during construction were much more severe than the ones due to service. We don't like to have imposing piers designed to comply with the needs of stability during construction. What is necessary at that particular stage latter on becomes superfluous and, usually, unaesthetic. It is a waste of money and shows a lack of concern for beauty and for the surrounding environment.

In this case, to combine in one pier the contradictory demands of increased resistance and stability during construction and enough slenderness and unity with the deck during service, was a difficult task.

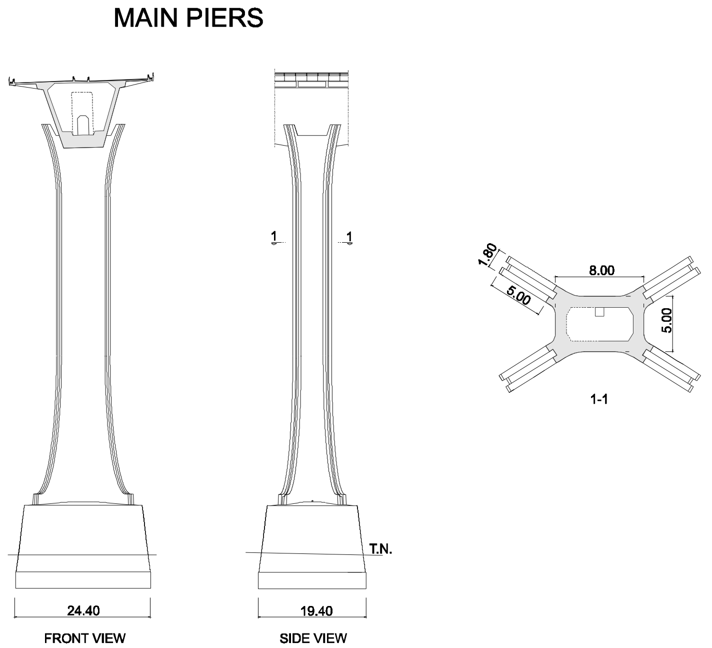

Fig. 20 Main piers - front and side views, cross-section

Fig. 21 View of main piers

A variable cross-section was evidently necessary. At the top, the pier had to be sufficiently wide to accommodate the large deck, reduce its size along the upper part of the shaft to be slender enough to fulfil its structural and aesthetical functions and then become wide again at its base to gather adequate resistance and equilibrium. Besides its structural functions, it should convey to the observer a full sense of power and capacity to support the enormous deck above. But there was one catch – it had to be simple to build! The solution found to fulfil all these requirements was to design a pier where the shaft had a constant tubular cross-section from base to top. Four ribs with constant thickness but of variable breadth provide the necessary widening and stiffening towards the base in the tallest ones. (*Fig. 20 to 25*)

Fig. 22 Detail view of main piers

Fig. 23 Main piers – base detail

Fig. 24 Pier's detail

Looking at the piers they seem to have a complex geometry but, in fact, they are very simple. The piers on the flood riverbed stand on rounded bases that hinder the effects due to the vortexes created by the ribs during the floods that in the Douro river are very violent. (*Fig. 23*)

Fig. 25 Pier's connection with deck

Fig. 26 Deck underside

Fig. 27 General view from upstream

Fig. 28 General view from left bank

The box section at the main piers is 12 m high. To reduce the apparent eight and give the impression of lightness to the deck in spite of its great dimensions, the box section is partially embedded in the pier heads. (*Fig. 18, 19, 20, 25*)

Due to the great width of the deck, the upper slab is stiffened and supported by transverse crossbeams at 5 m intervals (one per segment). In connection with these crossbeams, ribs were also placed in the lower slab. Although their structural contribution is small we decided to use them to give good visual unity to both lower faces of the upper and lower deck slabs and to "contain" visually its width within a good proportion with the remaining structural elements. (*Fig. 18, 26*)

From the very beginning of the project, aesthetics and environmental integration were of key significance. Careful attention to detailing and proportioning of all the elements was always present during the design process in the attempt that the bridge would deserve the splendour of the surrounding scenery. A good final product greatly depends also on careful detailing. As such, particular attention was paid to this matter because carelessly detailed shapes can ruin the overall aspect of even a well designed structure.

The site was fully rehabilitated to its initial condition, including the replanting of the original vegetation.

Cable stayed bridges, with almost immaterial decks and well designed pylons, can provide a magnificent visual equilibrium due to the grace and delicacy with which they can span any length. In fact, no such lightness and grace can be achieved with any other structural solution.

They are one of the most distinctive structures of our times and they grant the designers a great creative freedom. Unfortunately, they also have led to some of the major and imposing structural nonsense’s ever built!

In a structurally and visually successful cable-stayed bridge, floating decks suspended from the pylons via a fine web of unobtrusive cables, allows even the layman observer to grasp the structural unity between deck, suspension system and pylons.

In fact, it is a very accomplished structural solution due to the clear visibility and instinctive understanding of its structural system and the perception of balance between the forces involved.

The Arade river bridge, completed in 1991, is of the total suspension type and has a fully continuous prestressed concrete deck 850 metres long, 470 metres of which are stayed.

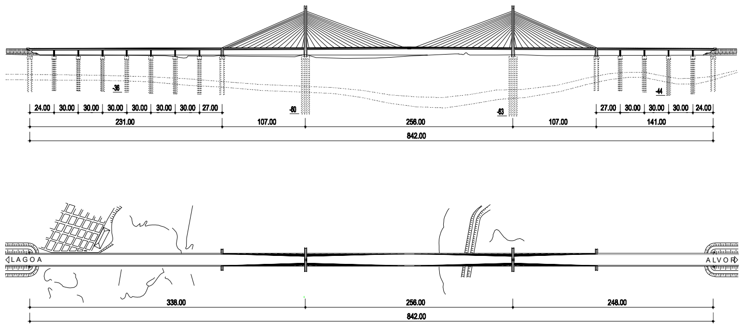

Fig. 29 Arade - Elevation and Plan

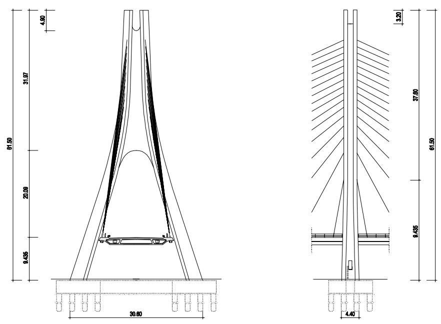

Fig. 30 Arade - Pylons

The very slender deck is only 1.40 metres thick, and is identical in the viaducts and bridge sections. At the early stages of the design we took the decision that it would evolve in a gentle upward vertical curve totally suspended by white stays from moderate rise pylons.

Fig. 31 Arade pylons

Use of high pylons, although requiring less steel for the stays, provide the bridge with a “stiff” attitude and we are not sure if the slighter additional expense on stays is thus warranted. The pylons will be higher and more expensive and the bridge will not be so beautiful.

In Arade bridge all shapes were subject to a detailed esthetical treatment with the intent of creating a harmonious combination between all the bridge elements.

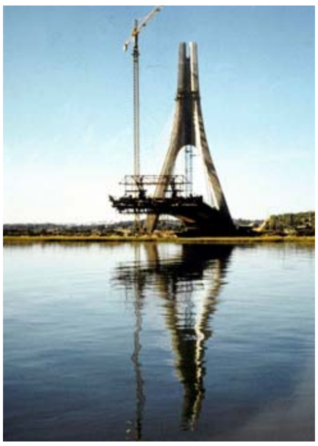

Fig. 32 Arade Pylons

Fig. 33 General view from downstream

The anchorage lines were combined with the white stays and the pylon's shape, allowing to create, for the suspension system, surfaces with the appearance of bellied sails that, in association with the slenderness and the slight rise of the deck, convey to the observer the idea that the bridge is planning above the water.

Fig. 34 Arade - View from the left bank

Great care was consecrated to the integration of the bridge in the vast estuary of the river with its salt-pans and marshes and, also, in the local white traditional Mediterranean constructions. Traditional chimneys and some Moorish construction's motifs were incorporated in the pylons design (e.g. curved lines, pylons rising clearly above the last upper stays)

We are often faced with the need to cross a somewhat flat valley with a deep gorge or a river with a large flood plain.

In this situation it is evident that different spans are needed and, generally, distinct types of structures will be used. For instance, large span boxes beam to surmount the gorge or the river and a continuous girder deck of moderate spans to cross the plain.

This usually creates an ill-solved visual discontinuity between the two structures.

It needs not to be so! Two examples are shown. In Fig 35 and in Fig. 27 access viaducts match exactly with the main structures. Box beams on the main spans blend precisely with the Π beam decks of the approach structures. Besides not having any visual discontinuity we can even have no structural discontinuity as, for example, in the cases of the bridge of fig 35 where structural continuity is also maintained.

Fig. 35 Sabor river bridge

The Sabor bridge (Fig. 35) deck is a 528 m continuous 9 span structure. The three spans that cross the river at a height of around 100 m are box girders, with a main span of 130 m. These three spans are continued monolithically by a 6 span concrete girder cast in place by the span-by-span method.

The piers have a maximum height of around 50 m. Their shafts have a hollow rectangular constant cross-section widening laterally at the top.

The Sado river bridge and its access viaduct, was a design/build tender and the available time for its construction was extremely short. The east structure, nearly 1800 m long, was built in 6 months and the entire works were completed in about one year.

Fig. 37 Sado river bridge and access viaduct

Fig. 38 Sado river bridge

Each of the two parallel bridge decks is a three span box girder with a total length of 302 m and each of the two parallel access viaducts, with a total length of 1452 m, is made of three continuous structures 484 m long each.

The pile-pier solution, which we have been using intensively in the last 10 years, is a very appealing solution. It avoids the use of massive pile caps and all the works and equipments needed to build them, as the pier becomes the logical upper extension of the pile.

On Sado bridge, the 135 m span 19.00 m wide decks rested, at each bearing, on four pile-piers with 2,50m diameter thus allowing us to dispense with the expensive and, due to the local geotechnical conditions, very difficult to build pile caps. (*Fig. 39*)

However, it would be aesthetically unacceptable to have the decks resting on for round columns at each bearing.

The problem was dealt with by designing two concrete curved plates enveloping the columns in a harmonious surface (*Fig. 39 to 42*)

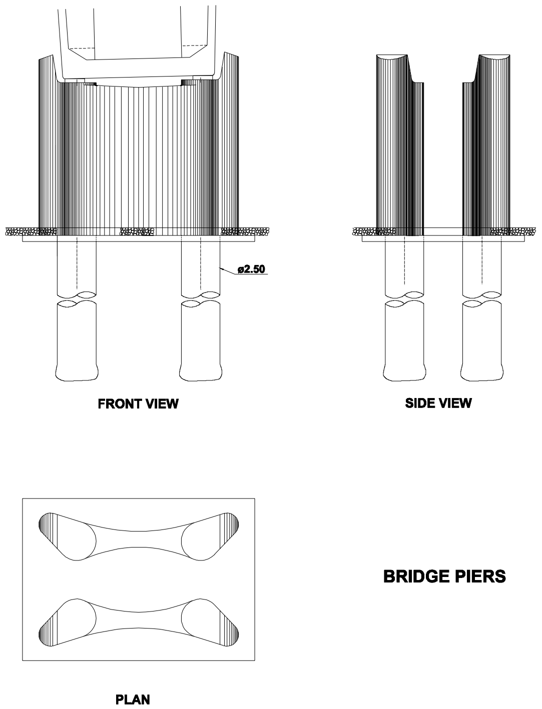

Fig. 39 Main piers – front, side and plan views

Fig. 40 View of the main piers

At this bridge and its south approach special care was taken with the aesthetical aspects. A serious effort was made to blend it with the vastness and platitude of the vast rice fields and the river that it crosses. The parapets are in textured coloured concrete giving a good combination with the fields it crosses. (*Fig. 44*)

Fig. 41 Front view of the main piers

Fig. 42 Main piers – inner view

Fig. 43 Sado Bridge viewed from the left bank

Fig. 44 Parapets

3. Conclusions

All these bridges were designed without any advice from architects. It's our belief that they prove that engineers themselves are fully capable of designing bridges with good aesthetic quality. Notwithstanding that, adequate training on architecture is essential to civil engineering students in order to develop their capability to appreciate and create grace, equilibrium, proportion and other essential aesthetic values.

To create successful and beautiful bridges, a complex and joint labour of skilful, discerning and demanding designers and Owners are needed. But if the Owner demands cheap designs no designer, no matter how talented he is, can deliver an aesthetically or, for that matter, structurally satisfying bridge.

Bridges, large and small, are constantly present on our day to day lives, and they contribute to ameliorate, or to ruin, the perception of beauty and, consequently, the quality of life. Thus, although aesthetic quality is an elusive and hardly quantifiable value, for bridge designers aesthetics should become a full concern of their everyday profession.

We can not keep ruining the environment and spreading around hideous and obtrusive bridges, no matter how technologically exceptional they are.