Footbrigde near School C+S in Guarda, Portugal

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ABSTRACT: The present paper describes the design of a new footbridge located in the city of Guarda, in northern Portugal. Due to its privileged settings and visual exposition, the new structure's aesthetics were carefully incorporated in its design, resulting in a structurally efficient and rational bridge with a strong architectural form, thus creating a landmark for the city of Guarda. This paper includes the relevant description of the conceptual design and the structural analysis and behaviour, specially the dynamic response due to the pedestrian excitation.
Keywords: footbridge, aesthetic, lateral vibration.

1 INTRODUCTION

In November of 2001, the governmental road authorities IEP – Instituto de Estradas de Portugal put out the tender for the conceptual design of a footbridge in the city of Guarda, in northern Portugal.

The footbridge is included in the new River Diz Urban Park, crossing the new VICEG Guarda's outer boulevard. The structure will be located in one of the main entries of the city, in a privileged site, becoming a landmark of Guarda. Due to that reason, aesthetics aspects played a decisive role in conceiving the structural solution.

The main purpose of the new footbridge is to establish a pedestrian crossing over the VICEG road, connecting an urban area which includes a school, to the Guarda railway station. Several reasons limited the location of this crossing, with the final choice leading to a straight line connecting two points placed at the entrance of an existing roundabout.

Preliminary studies included solutions with a support planted in the inside of the roundabout. However, these were abandoned because of the visual barrier that a pier in such position should create.

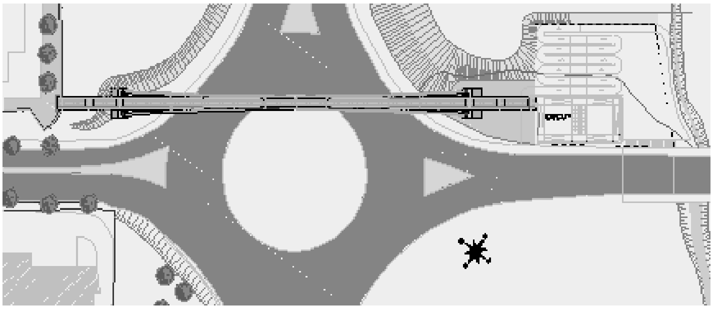


Figure 1 : Footbridge location – top view.

After several minor changes, the final solution consists of a single span double arch with a suspended deck that crosses over the roundabout, as it is described next.

2 CONCEPTUAL DESIGN

The bridge is composed by two main substructures: the footbridge itself with a total length of 120.20m and the northern access, which is an independent structure rising from the ground, containing the stairs and slopes.

The northern access was conceived combining steel elements with region's characteristic natural stone to meet with Guarda's traditional constructions.

Figure 2 : Footbridge general view (computer simulation).

The footbridge itself has to be a very transparent and light structure but at the same time capable to gather 90.0m without any supports.

To achieve this major span, a steel double arch was designed to suspend a very slim cable stayed composite deck. The deck is extended beyond either end of the arch abutments, where it is supported by concrete piers defining two more spans of 8.125m wide, which is approximately the same distance between deck's cable suspension points.

3 STRUCTURE DESCRIPTION

3.1 General characteristics

The footbridge has a 3.00m deck width and a total length of 120.20m. The spans have the following partial lengths: 2x8.125+90.00+8.125+5.85m

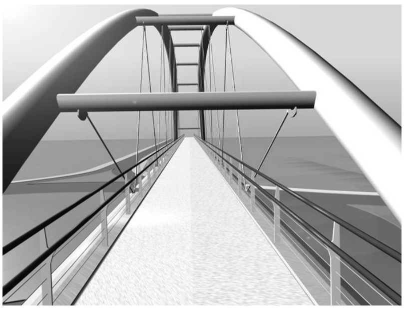


Figure 3 : Computer simulation of pedestrian's point of view.

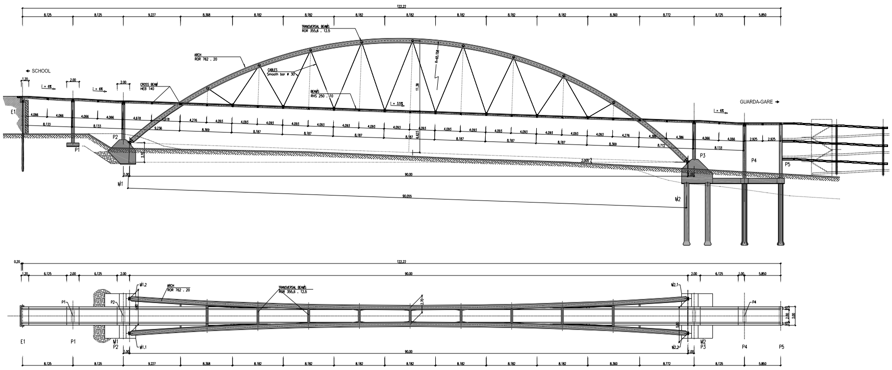


Figure 4 : Footbridge elevation and top view (design drawings).

3.2 *Arches*

On the bridge's major span, the deck is suspended from two superior arches, pinned at the supports, spanning 90.00m and with a height of 18.00 m.

Each arch is a steel piece formed by welded ROR 762.20 profiles. The two arches are connected by 9 transversal steel elements (ROR 355.6.12.5 profiles) and the suspension cables are connected to them.

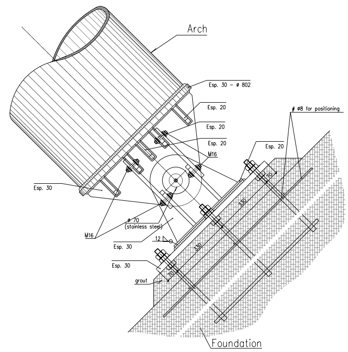


Figure 5 : Arch base connection detail.

3.3 *Suspension Cables*

The suspension cables are smooth stainless steel ∅30mm bars with pinned connections at both ends. They were positioned in a way to look like a truss.

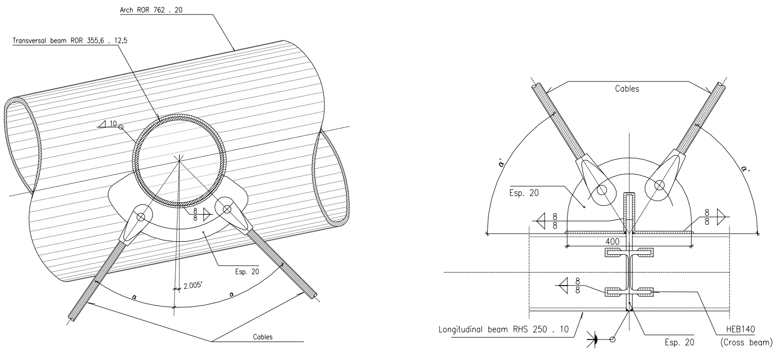


Figure 6 : Suspension cables connections details (top and bottom).

3.4 Deck

The deck is a "composite" structure formed by a steel grid with two longitudinal beams (RHS 250.10) 2.70m apart and by transverse beams (HEB140) every 4m.

The concrete slab is assembled by precast panels with 3.00m width per approximately 2.0m in order to avoid any type of formwork.

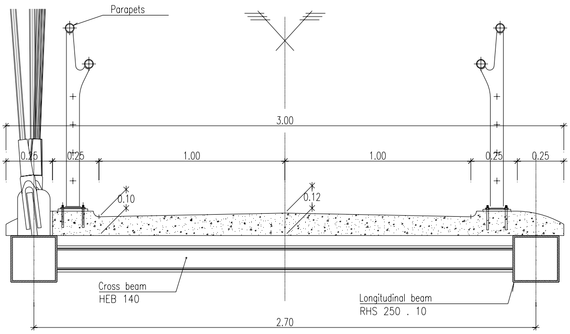


Figure 7 : Deck's Cross section.

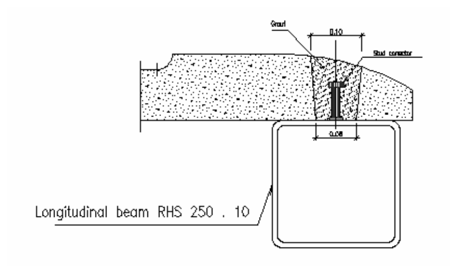


Figure 8 : Connection detail.

For each panel, the connection between the reinforced concrete slab and the steel longitudinal beams is established by 4∅16mm stud connectors. Except for its contribution to the transversal rigidity of the structure, no composite interaction between the slab and the steel beams was considered.

3.5 Piers and foundations

The piers and foundations are made of reinforced concrete cast in situ. The piers have a rectangular cross section of 2.00x0.50m.

The foundations of the southern supports are superficial. On the contrary, the foundations of the northern supports are ∅0.80m reinforced concrete piles.

4 STRUCTURE ANALYSIS

The following actions were considered in the structural analysis:

- Dead loads;
- Pedestrian live loads (4.00kN/m^2);
- Temperature gradients;
- Wind (performed by an equivalent static analysis);
- Earthquake (Zone D as defined in Portuguese Code , $\zeta = 2\%$, $\eta = 1.2$);
- Accidental action due to the breakdown of two suspension cables;
- Vibrations induced by pedestrians.

Except for the vibration study, the structural analysis was performed with a three-dimensional computer model using SAP2000 software.

The physically non-linear behaviour of the suspended cables was performed using the following constitutive law:

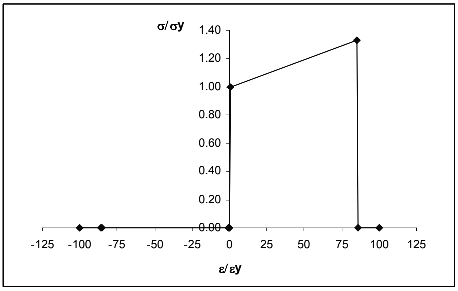


Figure 9 : Cables material constitutive law.

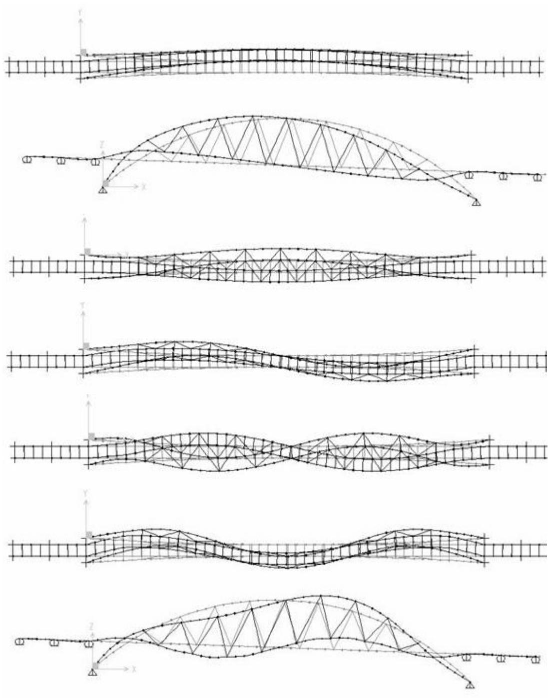
The geometric global non-linear behaviour was considered performing a P-Δ analysis.

The arches stability was verified accordingly with the DIN4114 code, assuming its behaviour to a compressed column.

This model confirmed all the dimensions of the structural elements.

The numerical model analysis showed high sensitivity of the structure to pedestrian induced vibrations due to the natural frequencies in close vicinity of 1 Hz - for the 1st (f1≈0.70Hz) and 3rd (f3≈1.22Hz) transversal modes – representing a risk related to dynamic amplification by transversal excitation. Concerning vertical excitations, higher modes (7th to 11th) with natural frequencies ranging from 3.3Hz to 4.30Hz had a moderate to low risk level.

In the next figure the principal mode shapes of the structure and the corresponding natural frequencies are resumed.



Mode 1 – lateral
f1 = 0,70 Hz:

Mode 2 – vertical / longitudinal
f2 = 0,89 Hz:

Mode 3 – lateral
f3 = 1,22 Hz:

Mode 4 – lateral
f4 = 1,61 Hz:

Mode 5 – lateral
f_5 = 2,49 Hz:

Mode 6 – lateral
f_6 = 2,85 Hz:

Mode 7 – vertical / longitudinal
f7 = 3,29 Hz:

Figure 10 : Mode shapes and natural frequencies.

Simplified calculations were made to estimate the vertical and horizontal acceleration induced by pedestrian traffic, showing that something should be done to control the dynamic behaviour of the bridge.

For this purpose a more complete numerical study was carried out by the Vibest- Laboratory of Vibrations and Monitoring of Structures of the University of Porto (FEUP), in order to predict possible situations of excessive vibrations and study the most effective way to avoid them.

This study included the analysis of the following situations:

- Single pedestrian walking in fixed position assuming a sinusoidal excitation
- Small group of people walking synchronized on the bridge
- Big group of people walking on the bridge

The conclusions of this special study confirmed that the best way to limit acceleration induced by pedestrian traffic was to adopt Tune Mass Dampers (TMD), increasing the structure's damping properties.

Assuming a global damping of ζ=1% the analysis including the contribution of several possible locations and characteristics of TMD devices revealed a satisfactory dynamic behaviour adopting 4 devices with a total mass of 6616kg.

As a remark, it is important to say that the final characteristics of the TMDs can only be achieved after the construction of the bridge, and the on site measuring of the structure's real damping properties.

The numerical simulation gave the following results:

- In respect to the lateral modes (1st e 3rd) the TMD is very effective reducing the acceleration due to the continuous flow of pedestrian of 1person/m^2 to values inferior to those specified in the BS5400 code;
- For the vertical modes (7th to 11th), with natural frequencies ranging from 3.3Hz to 4.30Hz, the use of the TMD reduces the acceleration due to the continuous flow of pedestrians of 1person/m^2 to values inferior to those specified in the BS5400 and ONT83 codes. Only in

the case of a running pedestrian or a non-synchronised running group of 14 people, the acceleration can go up to $2m/s^2$, but this has a low probability of happening, because this means very high footstep frequencies.

5 CONCLUSIONS

As a conclusion, one can say that the new footbridge will certainly become a landmark of Guarda, showing that it is possible to conceive light and elegant structures without compromising safety or pedestrian comfort.
On this situation, that can be achieved using special devices like tuned mass dampers or any other damping devices.

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