MARINEDA FOOTBRIDGE IN A CORUÑA (SPAIN)

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Summary

Designed with smooth and slender forms, Marineda footbridge in A Coruña (Spain) is a composite structure for pedestrians and cyclists that solves the access to one of the largest shopping centers in Spain, flying above a high-traffic highway.

The maximum deck height and the geometry in plan were established by the necessary vertical clearance over the highway and the situation of the starting and end points. In this way, and with the idea of avoiding structural elements over the deck to minimize visual impact, a three-span curved slender beam was designed. The main span is 85.8 meters long and comprises a composite airtight box-girder deck with variable depth from 1.75 meters near piers to 1.00 meter in midspan section. The two lateral spans, one on each side, are formed by a post-tensioned voided slab rigidly connected to pier and abutment, and with a strut element underground forming a rigid frame. In these spans the maximum deck height is 1.90 meters and the minimum is 1.00 meter. The deck width is 4.00 meters to accommodate both cyclists and pedestrians and has a transverse slope of 1.5% from the centerline to each side.

The curved geometry in plan, with a radius of 55 meters, and the stiffness of the lateral spans allow for an integral structure design without joints, that, along with the slenderness of the main span, give an unique appearance to the footbridge..

Keywords: composite; slenderness; integral; dynamics; curved geometry; load tests, damping.

1. Introduction

A Coruña is a city situated in a peninsula in the northwest of Spain surrounded by a beach on one side and a port on the other. Marineda footbridge is located in the area known as A Grela. Originally created as an industrial park in the outskirts of the city, today A Grela is fully incorporated into the street network due to the expansion of the surrounding residential areas. As part of the urban development, a large commercial and leisure center, Marineda City, was built during the last years. However, the lack of crosses over the highway next to which the shopping center is located generated a barrier effect to the movement of pedestrians.

Marineda footbridge is part of a walkway plan designed to increase permeability by facilitating access to pedestrians and cyclists, taking special care of the formal aspects. As a result, the change of use which is being generated in the area, from industrial to residential and leisure will develop with a simultaneous improvement of the urban landscape.

2. Design

The smooth and curved shapes of the bay as well as the city´s Marina dock have been one of the starting points on which the design of the new structure has been based on. From these concepts, the determining factors of the location and its particularities were studied in detail.

The maximum deck height and the geometry in plan were established by the necessary vertical clearance over the highway and the situation of the starting and end points. In this way and with the idea of avoiding structural elements over the deck to minimize visual impact, a three-span curved slender beam was designed.

Fig. 1. Aerial view of the city with the beach on one side anf the port on the other

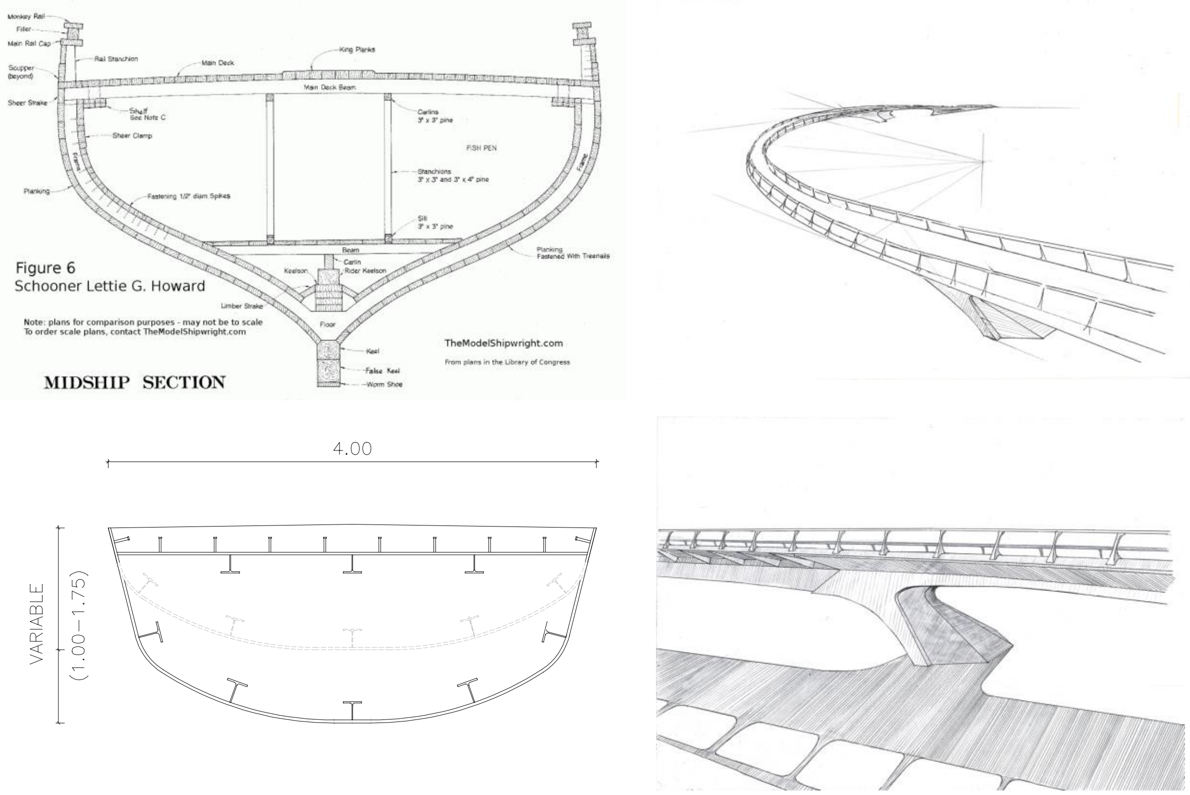

Fig. 2 Footbridge cross section compared to a boat hull section and first sketches of the structure

The main span is 85.8 meters long and comprises a composite airtight box-girder deck with variable depth from 1.75 meters near piers to 1.00 meter in midspan section. The cross section is composed of a concrete slab with a depth of 0.20 meters over a steel girder formed by two plates; a straight one at the top and a curved plate with variable radius at the bottom. The two lateral spans, one on each side, are formed by a post-tensioned voided slab rigidly connected to pier and abutment, and with a strut element underground forming a rigid frame. In these spans the maximum deck height is 1.90 meters and the minimum is 1.00 meter. The deck width is 4.00 meters to accommodate both cyclists and pedestrians and has a transverse slope of 1.5% from the centerline to each side.

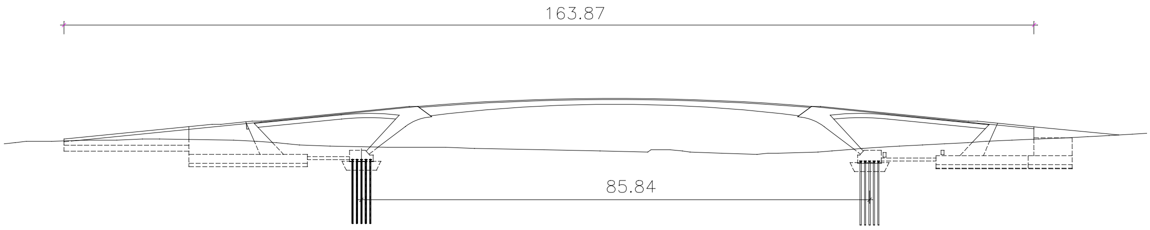

Fig. 3 Footbridge layout

Deck formal appearance is continued by piers, designed with curved geometry in section and elevation, and leaned to reach the limited free space left by suburban services (telephone, gas, sewage and medium and high voltage electricity lines). Pier foundations were solved with 24 11-meter-long micropiles per pier.

With reference to the structural configuration, the curved geometry in plan, with a radius of 55 meters, allows for an integral structure design, without joints and providing the necessary stiffness. Nevertheless, some degree of flexibility is needed to ensure the appropriate behaviour of the deck post-tensioning forces. For that purpose, a first excavation and subsequent filling with granular material of the first 1.50 meters of the micropiles was carried out.

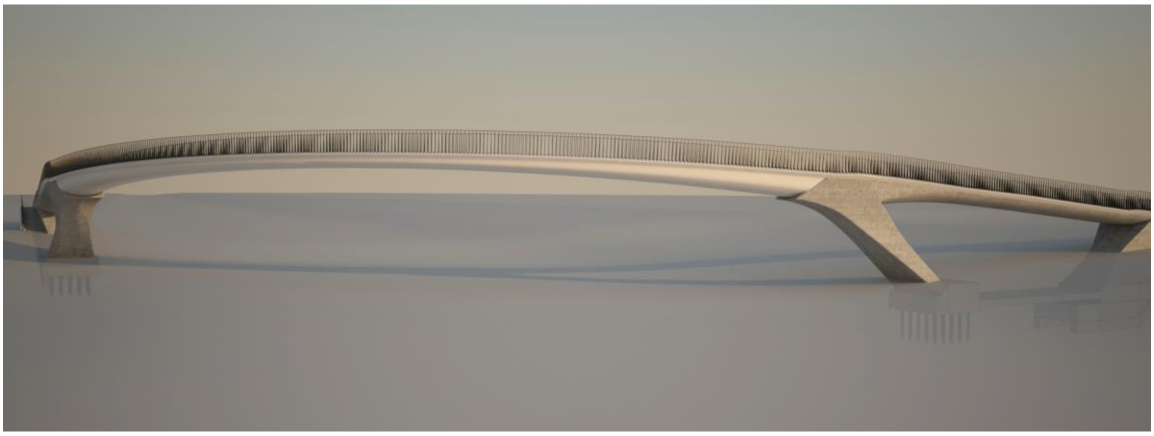

Fig. 4. Footbridge visualization (1)

Both its configuration as an integral structure, without bearings, and the airtight box-girder increase the durability of the structure and limit maintenance actions.

Fig. 5. Footbridge visualization (2)

3. Structural analysis

3.1 Static analysis

Static analysis has been done with Bentley RM Bridge, taking into account both longitudinal construction sequence and cross section evolution, from steel box-girder to composite box-girder. Geometric and material non linearities due to creep and shrinkage have also been considered in the analysis.

Final dimensions of each element of the structure, deck, piers, abutment, foundation and strut, were reached out after a successive approximation process due to the configuration as integral structure. During the process, the goals were to optimize the structural behaviour while maintaining an adequate aesthetic approach.

Composite box girder was designed according to Eurocode 4-Part 2: Bridges, and Eurocode 3-Part2: Bridges, verifying all ULS and SLS checks while the rest of the concrete elements of the structure were designed according to Eurocode 2. All these concrete elements were designed to keep the tensile stresses under the maximum values allowed by the codes in order to avoid cracking, improving the durability and without losing stiffness. As it can be seen in the sketch showed in figure 6 it was necessary to design the deck of the lateral spans as a post-tensioning element.

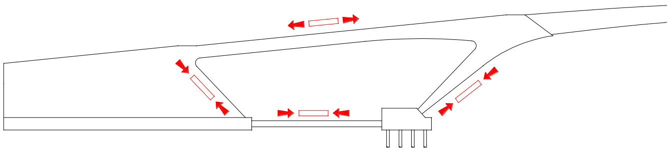

Fig. 6. Simplified flow of forces in the lateral spans

3.2 Dynamic analysis

Dynamic checks have been done according to codes [1] and [2] using Autodesk Robot software and considering a damping coefficient of 0.4%

Fig. 7. First vibration mode (1.4 Hz)

According to [1] footbridge was classified as class C and the maximum allowed vertical acceleration was established as 0.68 m/s^2. Calculation results are shown in table 1.

Dynamic action	Maximum vertical acceleration (m/s^2)
Walking (N=2)	0.12
Jogging (N=2)	0.05
Walking (0.8 persons/m^2)	0.56

Table 1. Results of dynamic calculations according to [1]

With these results it can be concluded that the dynamic behaviour of the footbridge is correct.

According to [2] footbridge was classified as class II based on the traffic level and with medium risk of resonance due to the main frequency range (1.4 Hz). Dynamic behaviour was analyzed for load case 1 with a load density of 0.8 pedestrians/m^2. The results are presented in table 2

Load direction	**Maximum vertical acceleration (m/s^2)**
Vertical	0.55
Longitudinal	0.08
Transversal	0.51

Table 2. Results of dynamic calculations according to [2]

With these results the footbridge shall be in a mean range of comfort for vertical vibrations (0.50<acel<1.00 m/s^2), but nearly in the maximum range of comfort (0<acel<0.50 m/s^2). For horizontal vibrations the structure is expected to be within the range of maximum comfort (0<acel<0.10 m/s^2).

4. Construction sequence

In the first stages of the construction sequence, the geometry of the foundations had to be adapted to fit job-site requirements, adjusting dimensions to the available space. Concreting of the lateral spans was made using a scaffolding system and, before installing the central steel box-girder, the first deck post-tensioning stage was applied.

Fig. 8. Foundations

Fig. 9. Scaffolding system for lateral spans

The steel box-girder was divided into two segments for erections purposes. A temporary support was installed at midspan and each segment was erected by crane at night. After finishing the steel work placement, the last post-tensioning stage of the deck was carried out. Finally, the top deck slab over the box-girder was poured, completing the construction sequence.

Fig. 10. Erection of the first steel segment of the deck

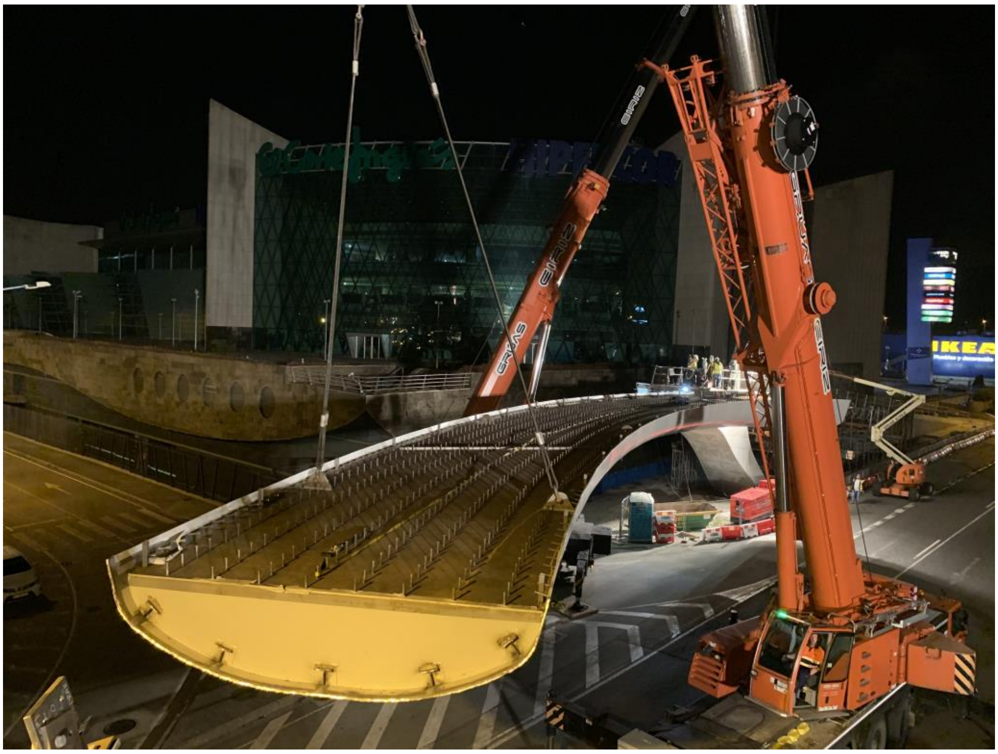

Fig. 11. Erection of the second steel segment of the deck

Fig. 12. Steel deck finished with temporary support at midspan

Fig. 13. Temporary support at midspan removed

Fig. 14. Final appearance of the footbridge

5. Load tests

Two load tests were made once the footbridge was completely built. A static one, using 1-ton sandbags, and a dynamic load test with the help of an athletics club. Some groups of athletes ran over the footbridge at different preset velocities and frequencies that were compared with theoretical calculations. In table 3 it can be seen that differences between theoretical values and measurements are around 10%.

Dynamic parameter	**Theoretical**	**Measurements**
Frequency	1.40 Hz	1.54 Hz
Damping	0.40%	0.36%

Table 3. Differences between theoretical dynamic parameters and measurements

In table 4 maximum acceleration measurements are shown for different simulated hypotheses carried out during the dynamic load tests.

Dynamic load test	**Maximum vertical acceleration (m/s^2)**
Vandalic jump (2 persons, 1.4Hz)	0.87
Vandalic jump (4 persons, 1.4Hz)	0.91
Walking (8 persons, 1.4 Hz)	0.29
Jogging (2 persons, 3 Hz)	0.04
Jogging (8 persons, 3 Hz)	0.10
Sprint (2 persons, 3 Hz)	0.05

Table 4. Maximum vertical acceleration during dynamic load tests

Structural behaviour was considered satisfactory, acceleration measurements during vandalic jumps could be considered in a medium range of comfort, whereas in normal situations acceleration measurements were in a maximum range of comfort.

6. Acknowledgements

We would like to thank the special effort and dedication shown by the Engineer of Commissioning Authority (Xunta de Galicia) Mr. Felipe de la Vega Gándaras, and the Principal Contractor (J.V. FGómez-Emesa) to overcome all the difficulties that have arisen due to both geometric complications of the structure as well as the various affected suburban services, which are always present on a Construction Site in an urban environment.

7. References

[1] BSI, National Annex to BS EN 1991-2:2003, Eurocode 1: Actions os structures-Part 2, 2008.

[2] SÉTRA, Assessment of vibrational behaviour of footbridges under pedestrian loading, Ministry of Transport and Infraestructure, Paris, 2006.