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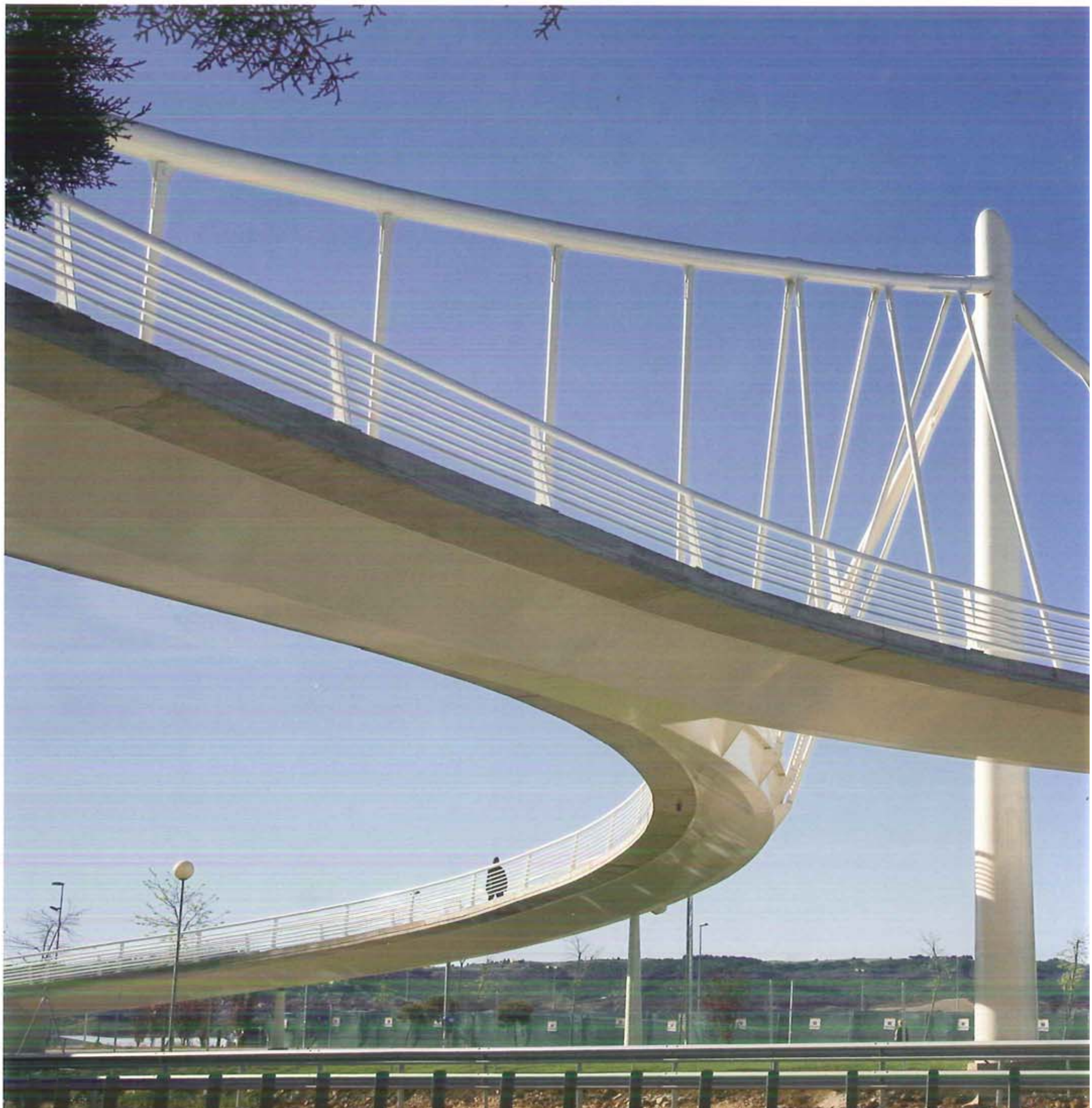

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# Footbridge over Highway A-2, Guadalajara, Spain

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## Summary

Public opinion in many communities is contributing to the growing demand for structures that are more than just utilitarian. Bridges, however, are a product of engineering in no need whatsoever of adornments or inefficient members to enhance their elegance. By means of an example, the paper illustrates that good form follows function design yields economic solutions that meet even the most exacting aesthetic standards, provided that the designer observes a few basic rules about structural form, bridge integration in the landscape, transparency, slenderness and harmony.

**Keywords**: footbridge; site constraints; conceptual design; detailing; safety; serviceability; economy; elegance; creativity.

## Introduction

The fundamental objectives of bridge design are structural safety, service performance, economy and elegance. All four goals must be attained, although their relative importance varies from case to case depending on the consequences of failing to do so.[1] Structural safety is clearly the most important of the four, because unsafe bridges may lead to loss of life or property. By definition, structural safety and serviceability are achieved through the correct application of codes and standards. Consequently, the achievement of these objectives depends chiefly on the engineer's analytical skills. Economy and elegance, in contrast, are not subject to hard-and-fast rules. Although some guidelines for improving the cost-effectiveness and aesthetics of bridges exist, fortunately such criteria cannot be standardized. Economy and elegance in bridge design therefore depend mainly on the designer's creative talent.

Many key aspects of a bridge project are governed by construction site-related and geometric, functional, constructional and economic constraints. But demanding boundary conditions often spur careful and indeed even innovative structural design. Given the relationship between elegance and the efficient use of materials in bridges, a satisfactory and aesthetically pleasing conceptual design is usually also a cost-effective solution, although not necessarily the least expensive, as may be illustrated by the footbridge over motorway A-2 at Guadalajara.

## Boundary Conditions

As it skirts the city of Guadalajara, the Madrid–Barcelona A-2 motorway separates a consolidated residential area within the municipal district of the city from a recently developed retail facility. The local authorities therefore made the building permit for the new mall contingent upon the construction of a pedestrian bridge between the two areas, to be financed by the developer.

The footbridge was to span the entire width of the 32 m motorway, plus what was regarded to be a safe distance on each side, with no intermediate columns and at a sufficient height to ensure a 6 m clearance, starting from a site within the residential area, more specifically in Amistad Park. Eduardo Guitán Avenue, the access road to the shopping mall, runs parallel to and at a distance of 16 m from the motorway. The footbridge landing was to be sited on that 16 m strip. In light of the substantial number of expected users, the deck was to be generously dimensioned, with a width of over 4 m. Both a stairway and a ramp were to be provided as approaches from the Eduardo Guitán Avenue side. Given the stipulated clear height over the motorway, the length of these two approach structures would depend on the admissible slope.

The motorway was to remain open to vehicle traffic during construction. Detours onto Eduardo Guitán Avenue were to be allowed on only a few nights.

In most structures, economic constraints play a decisive role in the adoption of the final solution. This case, which involved a private investor, was no exception. Nonetheless, in


(a)


(b)

*Fig. 1: Layout of footbridge over motorway A-2. (a) Aerial view. (b) View from Amistad Park (Photo: Paco Gómez)*

view of the location of the bridge and its intended use for pedestrian access to a popular new retail facility, for reasons of publicity the owners also wanted a landmark structure with a sound, modern, elegant and, at the same time, cost-effective design. For all the foregoing, it was particularly important in this case to strike an optimal balance between economy and aesthetics.

## Conceptual Design

The shape adopted for the footbridge structure ensues from the above functional requirements and site constraints. The total width of the main span bridge deck over the motorway is 4,75 m. As it nears the strip of land between the motorway and the adjacent access road, the deck splits into two 2,55 m wide branches, one forming the aforementioned stairway and the other the ramp (*Fig. 1*). These branches curve off the main span – the smallest radius measuring 27 m – and subsequently run parallel to Eduardo Guitán Avenue at the admissible grade as they slant downward to the landing. Further to this overall scheme, the total length of the footbridge between abutments is 89 m.

The 51 m main span is delimited by the columns that support the approaches. It comprises both the single deck that arches over the motorway and part of the access branches that rise from the shopping mall. The span is suspended from a single, freestanding pylon 17 m tall that rises from the strip of land separating the motorway from the access road, situated between the two branches. The parabolic upper chord of the suspension system follows the layout of the centreline of the deck in the main span, to which it is connected with hangers spaced 3,2 m. The suspension system for the access branches consists of two parabolic upper chords, one for each branch, and slanted hangers. With the configuration adopted, formally speaking the main span is a self-anchored, spatial suspension bridge (*Fig. 2*). The stiffening girder designed into the main span extends into the approach spans, where it becomes the girders for the stairway and ramp. Two approach spans, measuring 10 and 16 m, are needed for the Eduardo Guitán Avenue side access, whereas only one, 12 m long, is required on the Amistad Park side.

*Fig. 2: Spatial system, view from the ramp (Photo: Paco Gómez)*

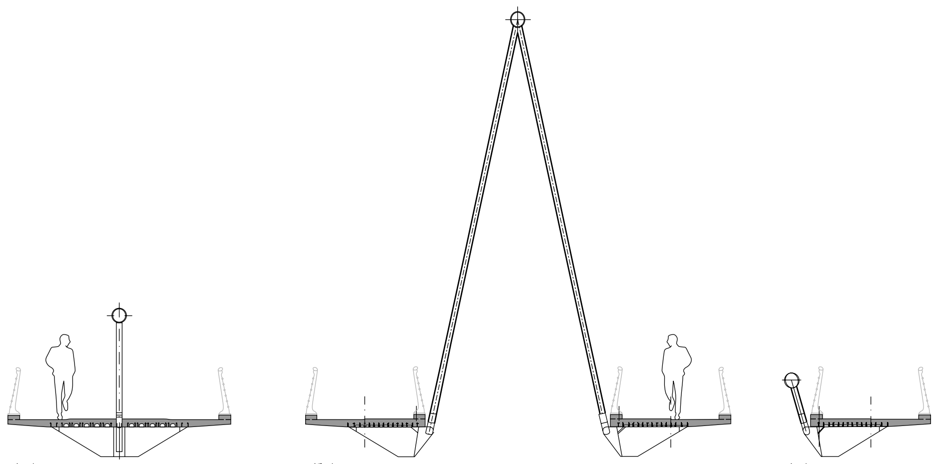
For reasons of economy, circular hollow section shapes rather than cables or tension rods were chosen for both the upper chords (diameter 323 mm) and the hangers (diameter 127 mm). Consequently, as the structural system is actually more a truss, this is a suspension bridge in formal terms only.

The stiffening girder is a composite member comprising an open trapezoid steel box and a composite slab (*Fig. 3*). With a section height of 650 mm, the main span has a slenderness ratio of nearly 80. To reduce deformation in this very flexible system, the 0,15 m deep composite slab is made of lightweight concrete with a density of 1900 kg/m$^3$ and a characteristic compressive strength of 40 N/mm$^2$. Stiffness is further enhanced and system deformation mitigated, particularly on the main span, by the composite makeup of the pylon, a circular shaft with a concrete fill and a variable diameter, tapering to 780 mm at the top.

## Detailing

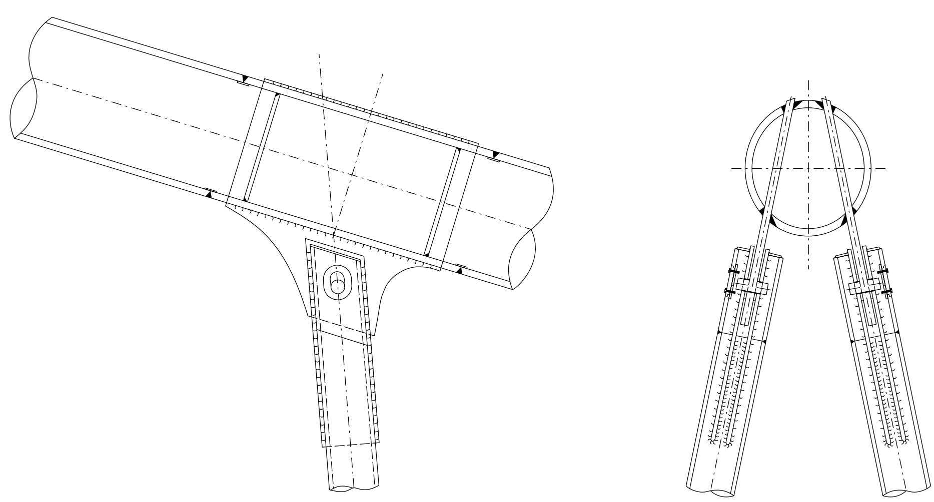
Special attention was likewise paid to the good detailing that is essential to ensure correct load transfer mechanisms, sufficient fracture toughness and durability. Good detailing may also facilitate the fabrication of a structure and significantly affect the final visual impact of a footbridge.

To ensure suitable truss member performance, the connections between the hangers and the two box girders



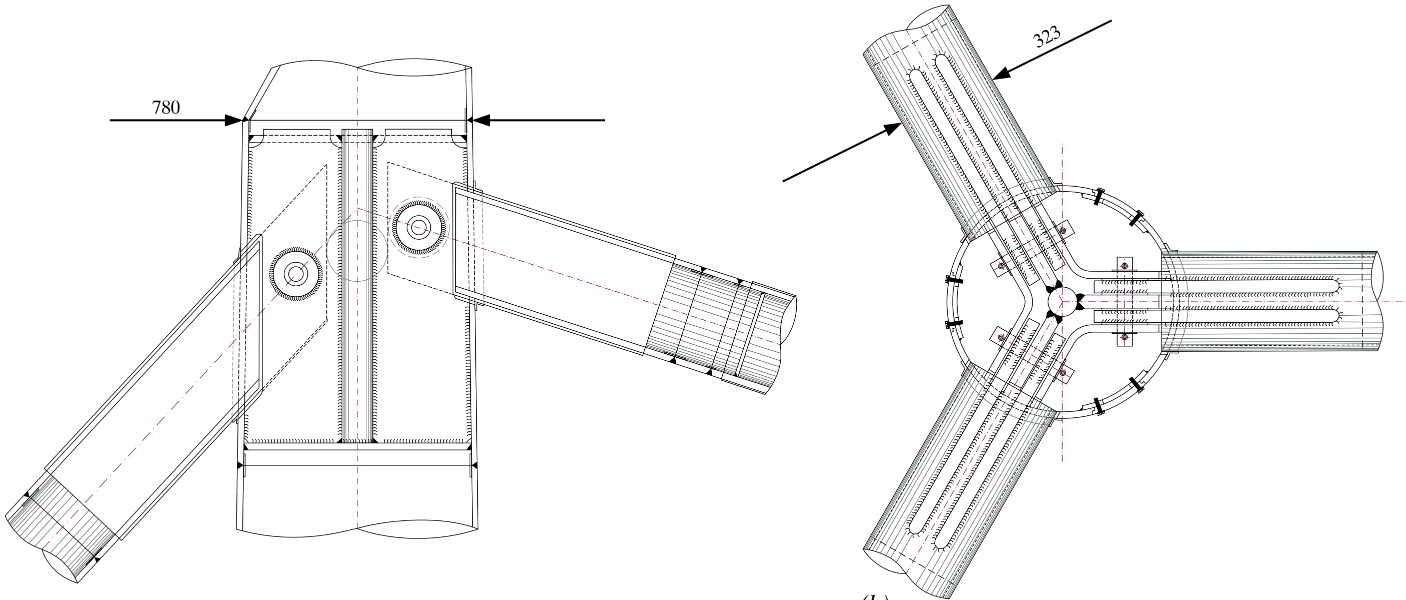
*(a)* *(b)* *(c)*

*Fig. 3: Cross sections. (a) Main span. (b) Division into two branches. (c) Ramp*



*(a)* *(b)*

*Fig. 4: Hanger to upper chord connection. (a) Longitudinal section. (b) Cross section*




(a) (b)

*Fig. 5: Upper chords to pylon connection. (a) Longitudinal section. (b) Cross section (Units: mm)*


(a) (b)

*Fig. 6: Upper chord to girder connection. (a) General view during erection. (b) Diaphragm inside the box girder*

and the hangers and the upper chords (*Fig. 4*), as well as between the chords and the pylon (*Fig. 5*), consist of pins precision-fitted into holes in the respective members. For reasons of durability and aesthetics, the heads of these pins are positioned inside one of the members to be connected. Finally, the connection between the upper chord of each access branch and the corresponding stiffening girder consists of a hinge that allows for limited rotation (*Fig. 6*).

The connection schemes devised meet the following requirements for the design of structural details:

- Despite the complexity of the multipiece connections, the load transfer mechanisms are kept as simple as possible.
- Connection devices are set in the position in which they act most effectively (e.g. to resist shear rather than tensile stress).
- Details are designed to be compatible with simple manufacturing methods to contribute to improving the quality of workmanship and lower the risk of imperfections. This is an important issue because numerous potential failure mechanisms are closely related to the extent of manufacturing flaws.

## Construction

Once the abutments, columns and pylon were erected, the steel box girder comprising the main span was hoisted into place with two cranes (*Fig. 7*). Temporary supports were set as close as possible to the motorway during this stage of construction to reduce span lengths. Because no such arrangement was allowed on

*Fig. 7: Erection of main span box girder*

*Fig. 8: Stairway constituting the approach span (Photo: Paco Gómez)*

the median, however, a provisional stay cable was strung from the girder at mid-span to the top of the pylon and stabilized with two backstays. The upper chords and hangers were then assembled, along with the box girders forming the approach spans (*Fig. 8*). The lightweight concrete for the composite slab was poured after the provisional stay cables had been removed.

An elastic–plastic design procedure was deployed to ensure bridge structural safety both during and after construction. Given, however, that because of its extreme flexibility, system deformation would depend on how the construction stages were defined, action effects were also calculated in accordance with elastic theory, taking account of system evolution throughout. On the basis of the results, precamber was applied to the stiffening girder, upper chords and pylon to offset the deformation due to self-weight and permanent loads.

## Conclusion

The footbridge over motorway A-2 at Guadalajara illustrates how demanding conditioning factors can serve as inspiration for a satisfactory solution. The form follows function design adopted, characterized by the simplicity of its lines, was enhanced by the careful shaping of structural members and good detailing. This example shows that a modern, technologically advanced bridge design may also be elegant, with no need for inefficient members or adornments, at an affordable additional cost over the least expensive solution.

## Reference


[1] Menn C. *Prestressed Concrete Bridges*. Birkhäuser: Basel, Boston, Berlin, 1990; ISBN 3-7643-2414-7 (Basel); 535.


**SEI Data Block**

*Owner:*
RYG 55 Promociones Alcarreñas

*Structural engineers:*
P. Tanner, J. L. Bellod and D. Sanz;
Cesma Ingenieros, Madrid, Spain

| | |
|---|---|
| *Main contractor:* | Sarclo |
| *Steel structure subcontractor:* | Iturmo |
| Total length (m): | 89 |
| Width of the deck (m): | |
| – Main span: | 4,75 |
| – Approach spans: | 2,55 |
| Structural steel (t): | |
| – Pylon and columns: | 16 |
| – Deck: | 66 |
| Lightweight concrete in bridge deck ($m^3/m^2$): | 0,17 |
| Total cost of structure (EUR millions): | 0,51 |
| Service date: | April, 2008 |