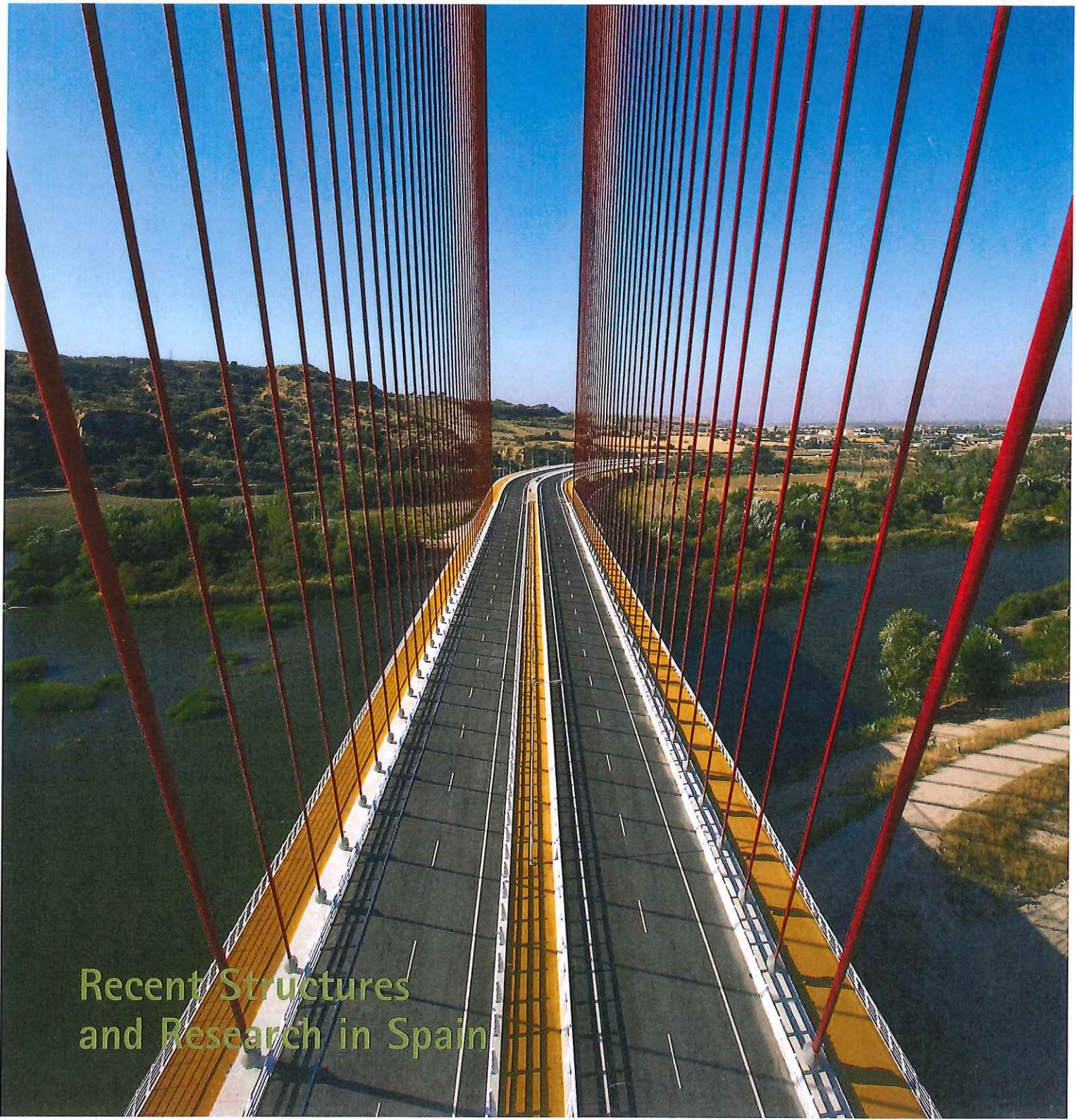


SEI Volume 24 | Number 1 | February 2014

STRUCTURAL ENGINEERING INTERNATIONAL



International Association for Bridge and Structural Engineering (IABSE)



Recent Structures
and Research in Spain

Structural Engineering International

International Association for Bridge and Structural Engineering

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Talavera de la Reina Cable-Stayed Bridge, Spain (Photocredits: Carlos Hormigos, Estudio AIA), See article on Pg. 127.

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International Association for Bridge and Structural Engineering

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Viaduct over River Ulla: An Outstanding Composite (Steel and Concrete) High-Speed Railway Viaduct

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Abstract

The viaduct over River Ulla is located in the Atlantic High Speed Railway Line between A Coruña and Pontevedra, in the northwest of Spain. Its location, close to the firth of Ulla, in a landscape of outstanding natural beauty and strong environmental constraints, was the object of a tender among the most renowned Spanish structural specialists.

The solution chosen was a 1620 m long viaduct, with three main spans of 225 + 240 + 225 m and several approaching spans of 120 m length each, which meant a main span being about 20% longer than the Nantenbach bridge in Germany, the current world record in High Speed Railway composite steel and concrete truss girder beam bridges.

The main spans have been designed with a double composite steel and concrete truss deck, with double composite action in hogging zones, and a total depth ranging from 9,15 m at the mid-span section to 17,90 m at the section over the piers. The adjacent spans that give access to the depth-varying main ones have been designed with constant depth.

This article describes the structural conception of the bridge and the three different constructive processes that had to be used due to the access and the environmental restrictions.

Keywords: high-speed railway bridge; double composite action (steel-concrete); truss; launching; lifting; self-equilibrated cantilevers.

Introduction

"Arroyo las Piedras" viaduct,¹ finished in 2005, was the first composite steel and concrete bridge of the Spanish High Speed Railway Lines (HSRL). Its typical span (63,50 m) was slightly longer than that of the Oregon Viaduct (63 m), located at the French Mediterranean High Speed Railway Line, which was the longest composite steel and concrete span for this typology until that moment.

Several composite steel and concrete solutions have been constructed in the Spanish HSRL ever since. The details in Ref. [2] discuss some of the most remarkable projects designed by the authors with composite steel and concrete solutions.

This article focuses on viaduct over River Ulla, an outstanding composite steel and concrete solution for a bridge located in an unique landscape.

A Unique Solution for a Unique Undertaking

Viaduct over River Ulla constitutes the most important intervention in the High Speed Atlantic Railway Line

between A Coruña and Pontevedra, in Galicia, in the northwest of Spain.

Its location, close to the firth of Ulla, near the Atlantic Ocean shore and in a landscape of outstanding natural beauty and strong environmental limitations, was the object of a tender among the most renowned Spanish structural specialists. The chosen alternative solution is described in this paper, and it will be finished in the first semester of 2014.

The project restrictions focused on the following aspects:

- The outstanding nature of the project required serious consideration of the aesthetic qualities and the integration of the viaduct with the landscape.
- The reduction in the number of piers within the water course, considering the natural limits of HSR bridges, minimising the impact on the marshes and riversides.
- The erection procedures, being suitable to the work scales, shall be kept as independent as possible of the river watercourse, to avoid environmental damage as much as possible.
- Visual transparency and minimal bridge interference with the surrounding landscape.

All these determining factors led the solution to a composite steel-concrete haunch truss, with double composite

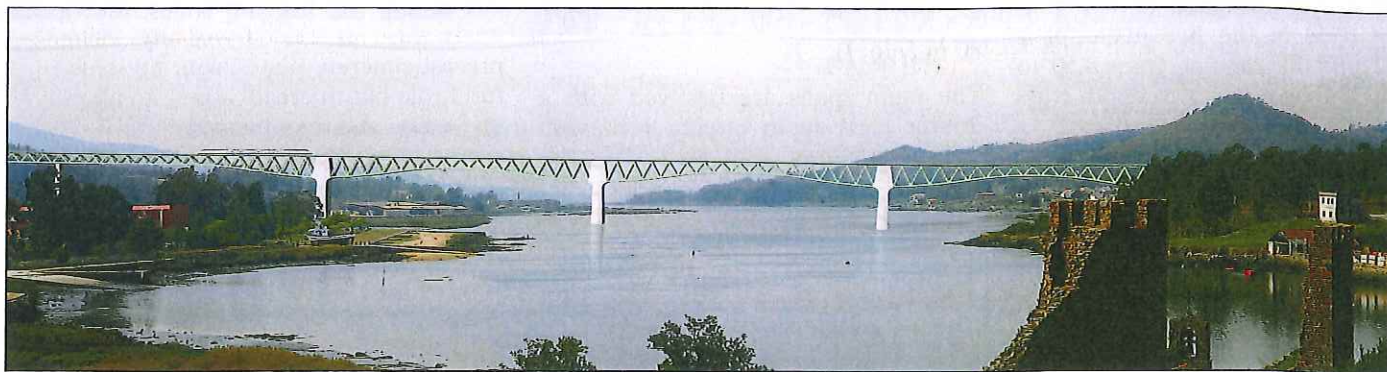


Fig. 1: View of viaduct over River Ulla



Fig. 2: Lateral view of viaduct over River Ulla

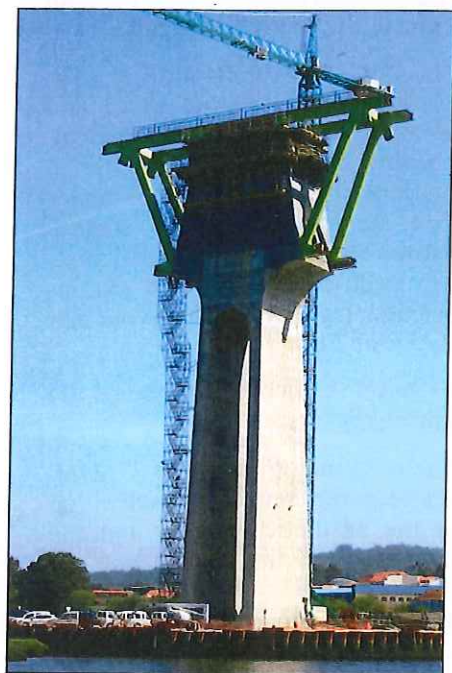


Fig. 3: View of the outer piers P-5 and P-8

action at hogging zones next to the piers, three main spans measuring 225 + 240 + 225 m long (Fig. 1) and several approaching spans measuring 120 m long, which means that the main span is about 20% longer than the current world record, the Nantenbach bridge over River Main in Germany,³ with a single 208 m long span.

Structural Concept

The deck was designed as a depth-varying truss in the five main spans (Figs. 1 and 2), ranging from 8,50 to 17,25 m and as a constant depth truss (8,50 m) in the approaching spans.

The four central piers, with elegant architectural shapes, are longitudinally connected to the truss deck creating longitudinal frames that lend the required stiffness to the three central spans (Fig. 2) to withstand the strains that arise from loads acting on alternate spans within the stringent deformation limitations in High Speed Railway (HSR) bridges.

The two lateral piers of the four central piers (Fig. 3) were designed with a lighter cross section consisting of two separate concrete shafts monolithically connected to the deck and to the foundation. This lightening allowed preserving some degree of stiffness against alternate loads, while achieving the necessary flexibility to permit the temperature and shrinkage-imposed displacements.

The design of the viaduct, preserving the structural orthodoxy, has placed special care on the integration of shapes and geometry between the concrete piers and the steel truss of the deck. The smooth depth variation along the deck, with an upward concavity (Figs. 1 and 2), confers a serene visual integration over the course of River Ulla. The colour choice, pearly grey for concrete and green for the truss, enhances this effect.

Structure Overview

The resulting viaduct is 1620 m long with a span distribution of 50 + 80 + 3 × 120 + 225 + 240 + 225 + 3 × 120 + 80 m (Fig. 4).

The main spans are resolved with a double truss depth-varying deck, with

a steel depth under the upper concrete slab ranging from 8,5 m at the midspan (left cross section of Fig. 5) to 17,25 m at the section over the piers (right cross section of Fig. 5). The trusses, which are modulated in 15 m long segments, are transversally separated by 6 m, measured between the upper flange midpoints of the upper chords, and show a 1H/17,5V outward slope. The lateral adjacent spans have been designed with 8,5 m constant depth (left cross section of Fig. 5).

The cross section of both the upper and the lower chords of the steel truss is 0,80 m wide parallelogram-shaped girders. The upper chord is 1,00 m deep while the lower chord is 1,20 m deep. Diagonal members are also parallelogram shaped, with main dimensions 0,80 m wide and 1,00 m deep.

The upper chords have a boxed beam welded to their upper flanges that is embedded in the concrete slab and lodges the connection, allowing a shear transference closer to the centre of gravity of the composite steel and concrete upper member and avoiding the appearance of local forces and moments in the upper joints.

The steel quality is S-355-J2+N and K2+N for the approaching spans and S-460-M and ML (according to the terminology in Ref. [4]) for the three main central spans.

The upper cast in place slab is made of C35/45 concrete (0,46 m depth at the midpoint and 0,25 m at the edges) and placed directly over the steel upper chord, configuring a composite steel and concrete cross section structure.

Along the hogging zones near piers, a C50/60 concrete slab is connected to the bottom steel chords (see right cross section of Fig. 5), allowing a double composite action (steel and concrete) strength mechanism. The thickness of this lower slab ranges from 0,30 to 1,10 m.

Along the sagging zones, the deck's lower face is closed visually using precast concrete plates, with no structural role but to create a path to allow inspection and maintenance.

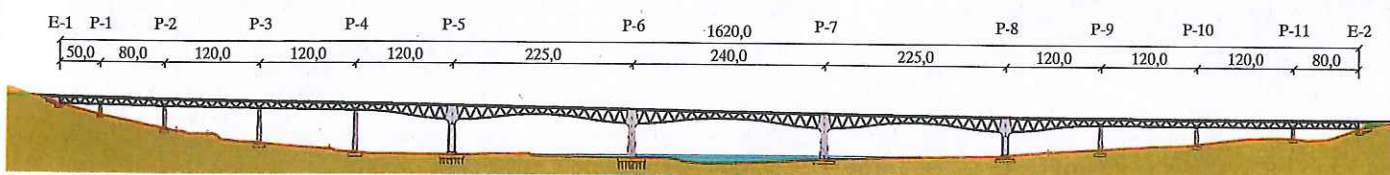


Fig. 4: Elevation view of viaduct over River Ulla (Units: m)

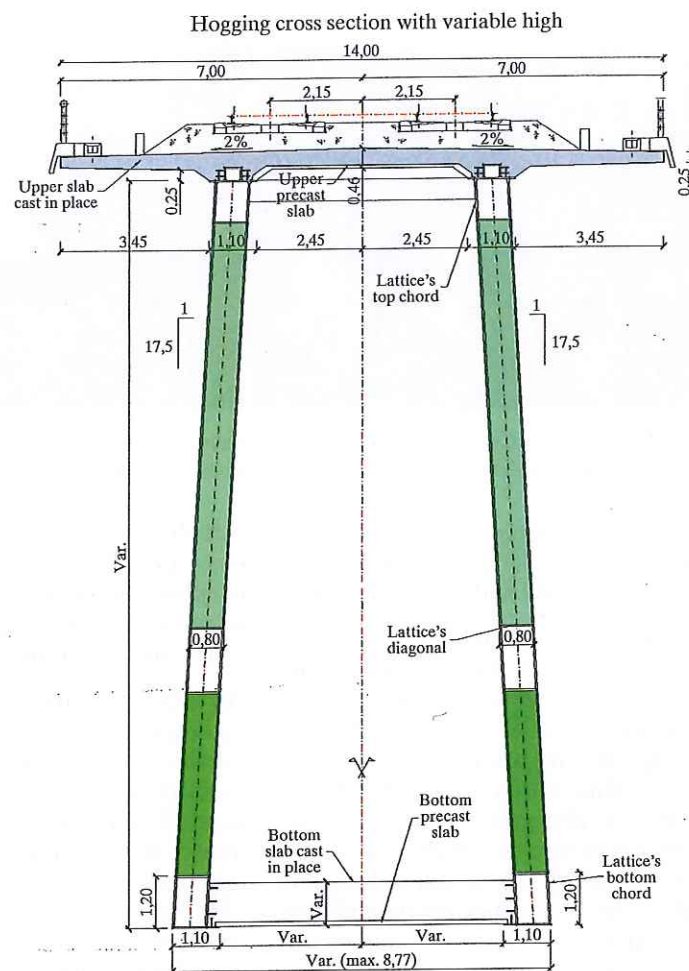
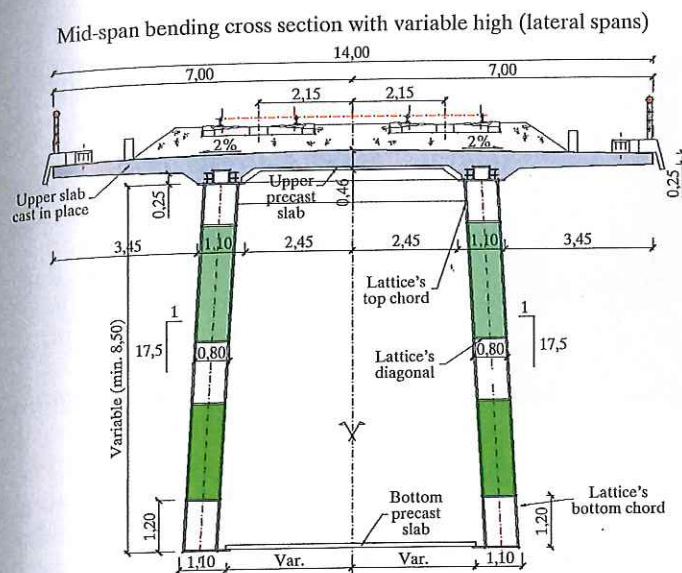


Fig. 5: Cross sections (Units: m)



Fig. 6: Execution of the excavation of the pile cap for the foundation of P-5 on the river



Fig. 7: Aerial view of the construction of the piers inside the river

The central and lateral piers of the viaduct show a well-differentiated geometry and structural response. The four central main piers (from P-5 to P-8) are monolithically connected to the deck, configuring a longitudinal frame that increases the stiffness of the structure and enhances its behaviour regarding horizontal forces (Figs. 1 and 3). The stiffness of these piers has been

optimised to restrain deck rotations, to control the deflection of the three main central spans and to reduce the bending moments transmitted to the foundations.

This way, piers P-5 and P-8 at the sides of the 225 m spans (Fig. 3) have been designed with two detached shafts from base to head, to avoid the excessive

bending moments arising from the decompensation of a 225 m span next to a 120 m span, and those produced by the temperature and shrinkage displacements, both of them greater than in central piers due to their further distance to the neutral displacement point.

Besides, the piers of the side spans P-1 to P-4 and P-9 to P-11 have a more

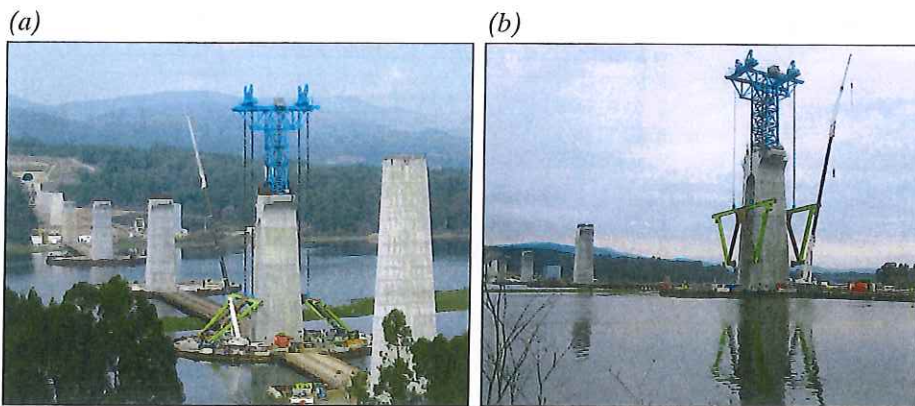


Fig. 8: Views of the simultaneous upright position operation of the two segments (a) and lifting process of the zero "W" steel segment over the central piers (b)

conventional design with a hollowed box girder cross section varying in depth both transversally and longitudinally.

The lateral piers and both abutments are crowned with two spherical bearings, one of them totally free and the other transversally restrained. All the bearings are disposed with the horizontal sliding surface, except the one of the A1 abutment, which are disposed following the longitudinal deck slope ($-1,8\%$), to avoid undesired vertical displacements on the railway track. At the A2 abutment, due to the weak slope, the sliding surface is kept horizontal.

The foundation of the piers is supported by the existing granite substratum by direct foundation, except piers P-5 and P-6 where the alluvial deposit thickness prevents the use of footings and forces of profound foundations (Fig. 6). The biggest one is the P-6 foundation with 56 piles of 1,5 m diameter and a reinforced concrete pile cap of $34,5 \times 30 \times 5,5 \text{ m}^3$.

Constructive Procedure

The procedure chosen to construct the viaduct shall conjugate minimal river affliction (always reversible) and erection procedure suitable to the bridge magnitude.

The foundations of piers P-5, P-6 and P-7 are located on the river (Fig. 7), and they are being built with a huge double enclosing sheet piling circular

wall (the exterior one has a diameter of 68 m and the interior one of 48 m) to allow the drain construction of the piles and the pile cap in P-5 and P-6, or the shallow foundation of pier P-7.

For accessing the foundation of the three piers located on the river, a provisional steel access bridge has been built, supported in temporary driven piles placed 6 m apart. The construction of this provisional access was carried out regarding the natural course of the river avoiding any possible contamination or effect on the protected local fauna. This simplifies the works with road access from both sides of the river, avoiding the need of boat or special resources.

Once the foundations have been completed, the piers are erected by means of a climbing formwork. When the shaft of piers P-5 to P-8 is finished, the zero steel segment (with "W" shape) was assembled in horizontal position at the bottom of the piers, and once truss segments on both sides are finished, they were lifted (Fig. 8a and b) and fixed in their position on site over the piers (Fig. 3). These huge segments weigh about 375 t each and their dimensions are 35 m length per 17,5 m depth.

With the concrete part of the head of the piers completed, the steel truss of the central spans with variable depth are simultaneously erected by a successive cantilever method, from the pier section to the closing segment at

midspan (Fig. 9). This method ensures independent work at the bridge from the marshes, river and surrounding vegetation.

The welding of the different elements—nodes, chords, diagonals and bracings—that constitute one segment is done at one of the three steel workshops located near the edges of the river. Once the segment is completely finished, it is transported to the pier base in modules that measure 15 m long by means of a special platform with multiple axes accessing.

Once the segment has arrived to the pier base, a gantry crane picks up the module close to the pier shaft, translating it to its final position and lifting it to be welded in place. This procedure began in July 2013 and presumably will be finished before spring 2014.

The constant depth spans of both sides are built by different procedures due to the different inferior crossing conditions. The side near abutment A1 has several local road crossings and a local railway crossing, hence the constructive process on this side is by launching in three different phases (Fig. 10a and b). For want of enough free space behind the bridge to prepare a launching yard as it would be conventional, due to a tunnel very near to the end of the abutment, the launching yard has been established between abutment A1 and pier 2 ($50 + 80 \text{ m}$), over temporary props.

Each 120 m span is assembled on site over the launching yard by welding the segments over temporary supports, and once finished, it is launched, as shown in Fig. 10.

The second launch operation moves two complete spans of $120 + 120 \text{ m}$ length, and finally, the lateral side spans 1 and 2 ($50 + 80 \text{ m}$) are welded on site over the temporary props by erecting each segment with the use of cranes.

The four lateral approaching spans near abutment A1 were finished in winter 2013–2014.

The approaching spans on the side of abutment A2 do not have the same

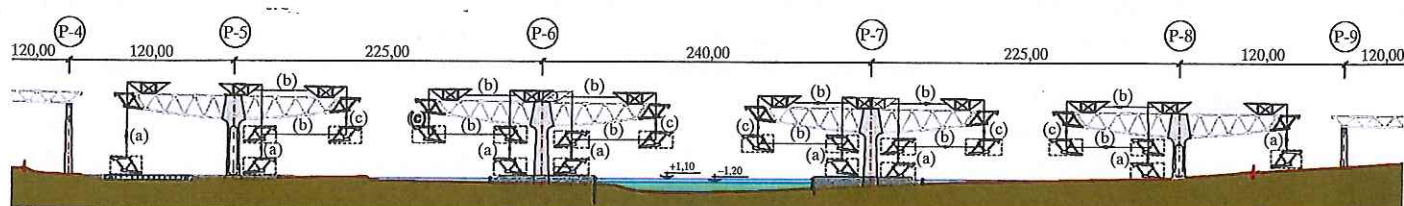


Fig. 9: Scheme of the constructive procedure by incremental equilibrated cantilevers (Units: m)



Fig. 10: (a) Scheme of the constructive procedure by launching in three phases and (b) picture of the current state of the works in December 2013 (launching phase III).

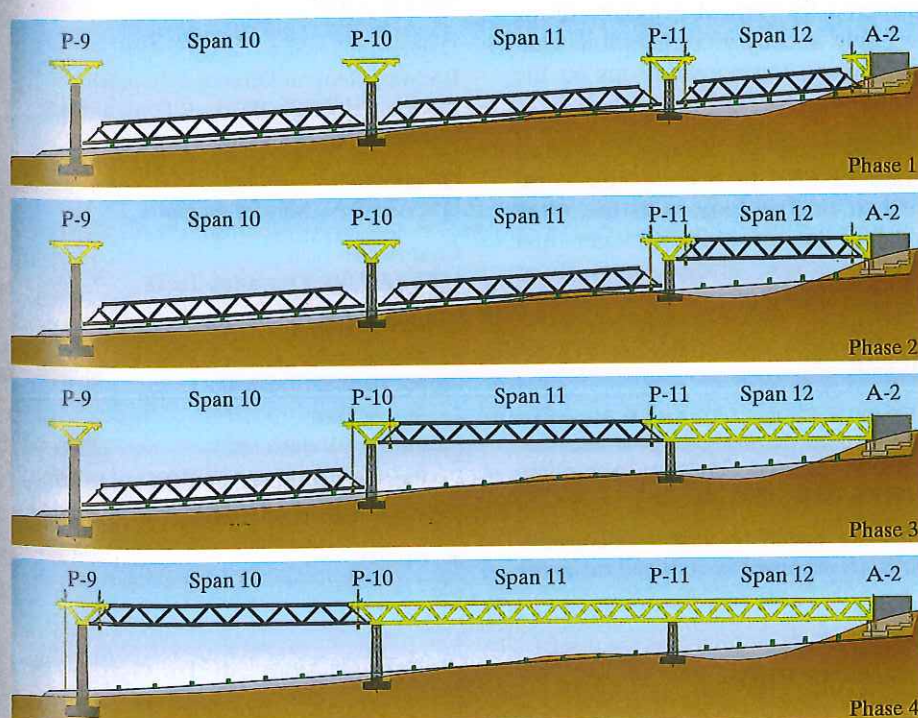


Fig. 11: Scheme of the lifting procedure of the approaching spans near abutment 2

restrictions as the ones on the side of abutment A1. As there are no inferior interferences, a complete span-lifting procedure has been designed (Fig. 11).

The complete span are welded on site by assembling each segment propped on the ground and finally each span will be vertically lifted, as shown in Fig. 11 and welded to the previous one giving continuity to them. The approximate weight of the 120 m spans is 1200 t and for the 80 m spans is 800 t.

Once the assembly of the steel work has been completed, the lower precast concrete plates are placed and the subsequent lower slab concrete casting is done. The next stage is the simultaneous and controlled downward displacement of 0,25 m of the deck at piers P-4 and P-9 sections, so as to reduce the bending moments of the rest of the dead loads and life loads on piers P-5 and P-8 produced by the decompensation of the span length at each side of



Fig. 12: (a) Approaching spans near abutment 2 (120 + 120 + 80 m) ready for vertical lifting and (b) current state of the works

these piers, 120 m on one side and 225 m on the other.

The upper concrete slab is placed over precast concrete plates bridging the space between steel upper chords of both trusses. The lateral cantilever part of the slab is cast using a movable formwork.

Finally, the precinct sheet piles of piers P-5, P-6 and P-7, as well as the provisional steel temporary access bridge, are removed and the corresponding corrective measures are taken. The current state of the works (December 2013) is shown in Figure 12a and b.

Conclusions

The location of viaduct over River Ulla in a very beautiful landscape and with strong environmental restrictions obliged the design of a composite steel-concrete truss solution, with 1620 m length and three outstanding main spans of 225 + 240 + 225 m length.

The large dimensions of the segments of the bridge and the difficulty of

construction associated with the various restrictions have necessitated the design of three different and complex constructive procedures, described in detail in the article.

The main central spans are built by incremental equilibrated steel cantilevers, while the lateral approaching spans, with 120 m of typical length, are constructed by vertical complete lifting in one side and by incremental launching and using temporary props on the other.

The bridge will be completed before summer of 2014 to become the world record in its typology, with the main span of 240 m, about 20% longer than the Nantenbach bridge over River Main in Germany.

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SEI Data Block

Owner:

Railway General Direction. Spanish Ministry of Public Works ("Fomento" Ministry)

Designers:

IDEAM S.A., Madrid, Spain

Contractor:

UTE río Ulla. Dragados-Tecsa

Structural steel (t): 19 300

In situ concrete (upper deck slab) (m³): 8620

In situ concrete (bottom deck slab) (m³): 2800

Passive steel (bridge deck) (t): 2900

Total cost (EUR millions): 95,6

Service date: Summer 2014

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Zurich, Jan. 30, 2014

Structural Engineering International (SEI), February 2014 issue

Recent Structures and Research in Spain

Dear Mr. Miguel Ortega Cornejo,

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