VIADUCT OVER RIVER ULLA IN THE ATLANTIC HIGH SPEED RAILWAY LINE, SPAIN

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INTRODUCTION

Viaduct over river Ulla constitutes the boldest and high-profile undertaking in the High Speed Atlantic Railway Line in Galicia, in north-western Spain. It is currently under construction and it will be finished before the end of 2014. Its location, close to the firth of Ulla, a landscape of outstanding natural beauty and strong environmental constraints, was the object of a project tender among the most reputable Spanish specialists. The project constraints focused especially on the following aspects:

- The outstanding nature of the project, which required serious consideration of the aesthetic qualities and viaduct integration into the landscape.
- The reduction of the number of piers in the water course, within the deflection limits of HSR bridges, minimizing the impact on the marshes and riversides.
- The erection procedures, being suitable to the works scale, had to be kept as independent as possible from the inlet's course, to avoid environmental damage as much as possible.
- Visual transparency and minimal bridge interference with the surrounding landscape.

All these determining factors guided the solution to a haunched steel-concrete composite lattice, with double composite work at the hogging zone, three main spans 225+ 240+225 meters long, and several 120 m long approach spans. This means a main span about 20% longer than the current world record, the Nantenbach Bridge in Germany, with a single 208 m long span.

1 DESCRIPTION OF THE VIADUCT

The resulting viaduct is 1620 m long with a span distribution of 50+80+3×120+225+240+225+3x120+80 metres (*Fig. 1*).

The structural solution of a steel lattice with double steel-and-concrete composite action adequately solves the previously stated conditions.

The deck was designed as a haunched lattice in the five main spans, their depth ranging from 9.15 m to 17.90 m, and as a 9.15 m constant-depth lattice in the approach spans.

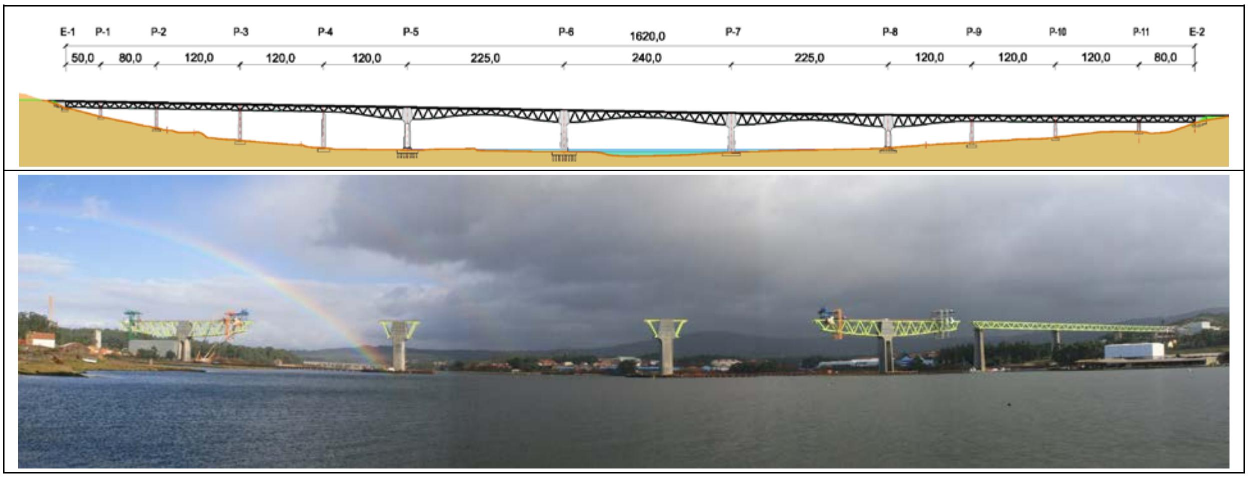

Fig. 1. a) Elevation view of the viaduct over river Ulla; b) Current state of the works (January 2014)

The four central piers are rigidly connected to the lattice deck (*Fig 1*) creating composite frames which bestow the required stiffness upon the three central spans in order to withstand the stresses arising from loads acting on alternate spans within the stringent deformation limitations in HSRL bridges.

These four calyx-shaped central piers are formed by a trapezium head 17.5 m high and 11.00 m to 16.80 m wide, and a shaft 8,00 m wide, growing with a 1H:25V slope in piers P6 and P7 and a 1H:50V slope in piers P5 and P8. The average height of the piers, measured up to the lattices' lower member, is about 42 m (60 m up to the crowning point).

The stiffness of these piers was optimized in order to restrain deck rotations at the pier section but preventing that bending moments taken by the pier itself (and then transmitted to the foundations) from becoming a decisive design constraint.

In this way, piers P5 and P8 (*Fig. 1*), at the sides of the 225 m spans, were designed with two detached shafts from base to head, in order to avoid the excessive bending moments arising from two main sources: the disproportion of a 225 m span next to a 120 m span, and those produced by the temperature and shrinkage displacements, larger than in central piers due to their greater distance to the neutral displacement point.

The structure's design, preserving the structural orthodoxy, placed special care on the integration of shapes and geometry between the concrete piers and the deck's steel lattice. The smooth depth variation along the deck, with an upward concavity, confers a serene appearance over the Ulla river's course.

Lateral side span piers P1 to P4 and P9 to P11 are of a more conventional design. Their hollow-box cross section, with a 0.30 m thick wall and a 3.50 m x 8.50 m cross-section at the top, varies in depth both transversely and longwise. The pier height ranges from 52 m to less than 20 m.

The main spans are designed with a double haunched lattice deck, with a total depth ranging from 9.15 m at the midspan section to 17.90 m at the pier section (*Fig. 2*). The lattices, modulated in 15 m long segments, are 6 m apart, measured between the upper flange midpoints, featuring a 1H/17.5V outward slope. The adjacent spans giving access to the haunched main ones were designed with constant depth.

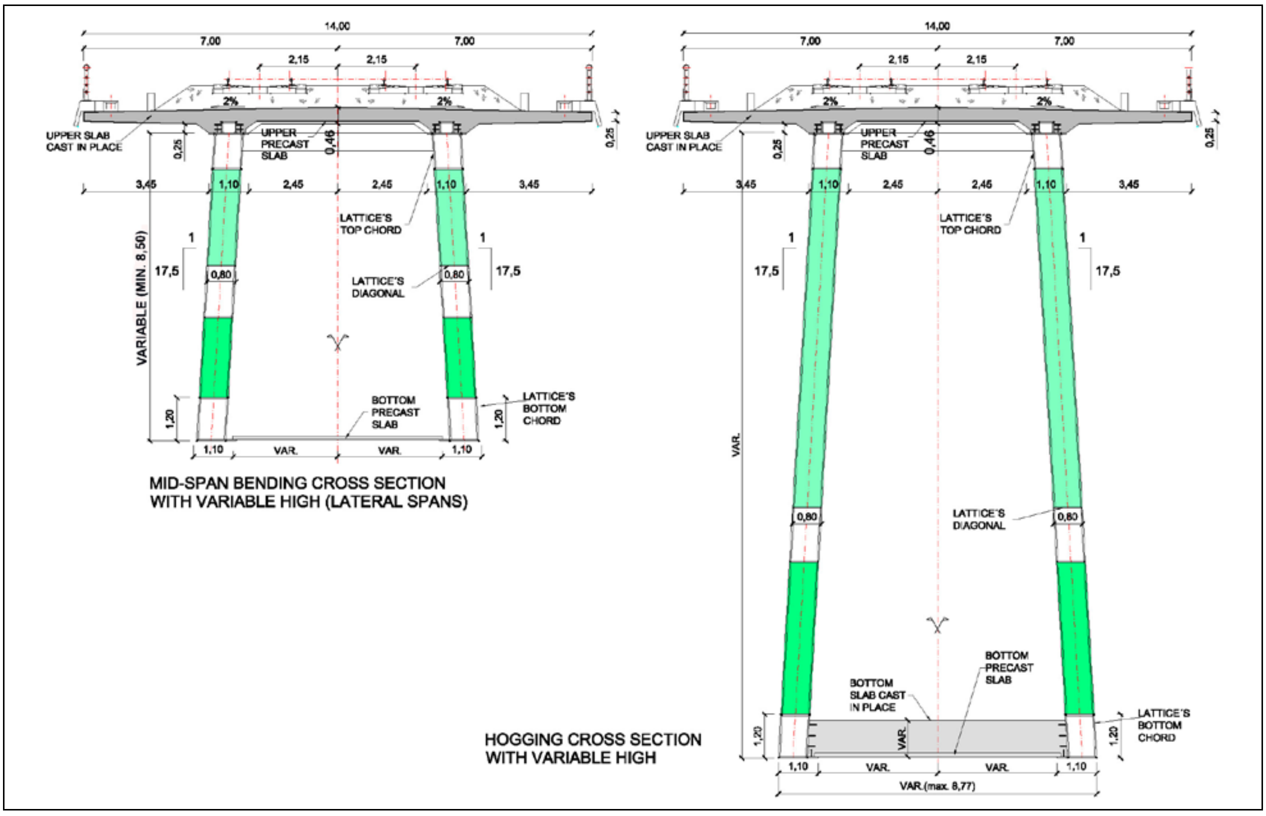

Fig. 2. Sagging cross sections and hogging cross section in the variable depth central zone

Both the upper and lower members' cross-sections are parallelogram-shaped girders, 0.80 m wide, 1.00 m deep the upper chord and 1,20 m deep the lower one. Diagonal members are also parallelograms (0.8 m wide and 1.00 m deep).
The upper member features a box-like head embedded in the concrete slab lodging the connection, allowing a shear transference closer to the center of gravity of the composite upper chord and minimizing the appearance of local forces and moments in the connections.
The steel grade is S-355-J2+N and K2+N for the approach spans and S-460-M and ML for the three main spans.
The upper slab thickness is 0.46 m at the center line and 0.25 m over the steel upper chords. The slab, made of cast-in-place C35/45 concrete, is poured on precast concrete slabs spanning the space between the upper chords of both lattices. The lateral cantilevers of the slab are cast using a movable formwork.
Along the hogging zone, a C50/60 bottom concrete slab is arranged between members, thus allowing for double composite action. The thickness of this lower slab ranges from 0.30 m to 1.10 m. Along the sagging zone, the deck's lower face is visually closed using thin precast concrete slabs, with no structural role but to create a path to allow for extremely easy inspection and maintenance operations.

2 DESCRIPTION OF THE CONSTRUCTIVE PROCESS

The chosen procedure to construct the viaduct shall conjugate minimal river affection (always reversible) and erection means suitable to the bridge magnitude.
The foundation of the piers P-5, P-6 and P-7 are located on the river, and they have being built with a huge double enclosing sheet pilling 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 the pier P-7.
So as to access to the foundation of the 3 piers located on the river, a provisional steel access bridge has been built, supported in temporary driven piles placed each 6 m. The construction of this provisional access was carried out respecting the natural course of the river avoiding any possible contamination or affection to the protected local fauna. That simplifies the works with road access from both sides of the river, avoiding the need of boat special resources.
Once the foundations have been completed the piers are erected by means of a climbing formwork. When the shaft of the piers P5 to P8 is finished, the zero steel segment (with "W" shape) was assembled in horizontal position at the bottom of the piers, and once both side lattice segments are finished, they were lifted and fixed in their position on site over the piers. Each of these segments weights around 375 t each, and their dimensions are 35 m length per 17.5 m depth (*Fig. 3*).

Fig. 3. View of the erection of the zero "W" steel segment over one of the central piers

Completed the concrete part of the head of the piers, the steel lattice of the central spans with variable depth is simultaneously erected by a successive cantilever method, from the pier section to the closing segment at midspan (*Fig. 4*). This method ensures independent work at the bridge from the marshes, river and surrounding vegetation.

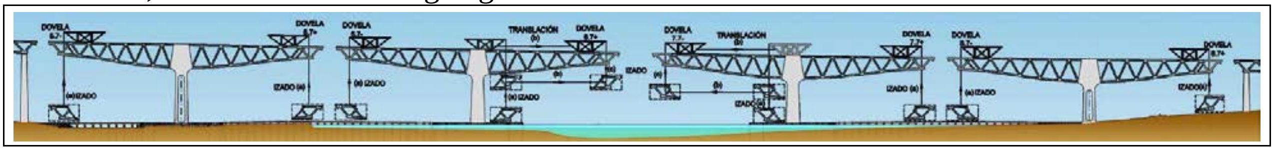

Fig. 4. Scheme of the constructive procedure by incremental equilibrated cantilevers

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

The segments that constitute the spans between piers P-4/P-6, and P7/P-9, are vertically lifted on site (*Fig. 5*), but the segments between piers P-6 and P-7, were there is only access by boat, have to be transported by the movable gantry cranes. These two movable gantry cranes have been designed to pick the segments at the base of piers P-6 and P-7 (*Fig. 4*) and they are able to translate the segment hanged to its final position for the vertical lifting to be welded in place. This procedure currently under construction will finish before autumn 2014.

Fig. 5. View of the lifting of one segment of the main central spans, constructed by incremental equilibrated cantilevers

The constant depth spans of both sides of the river are built by different procedures due to the different inferior crossing conditions. The side near the abutment A1 has several local road crossing and a local railway crossing, so the constructive process is by launching in three different phases (*Fig. 6a*). As there is not 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 m), over temporary props.

Each 120 m span are assembled on site over the launching yard by welding the segments over temporary supports, and once finished are launched.

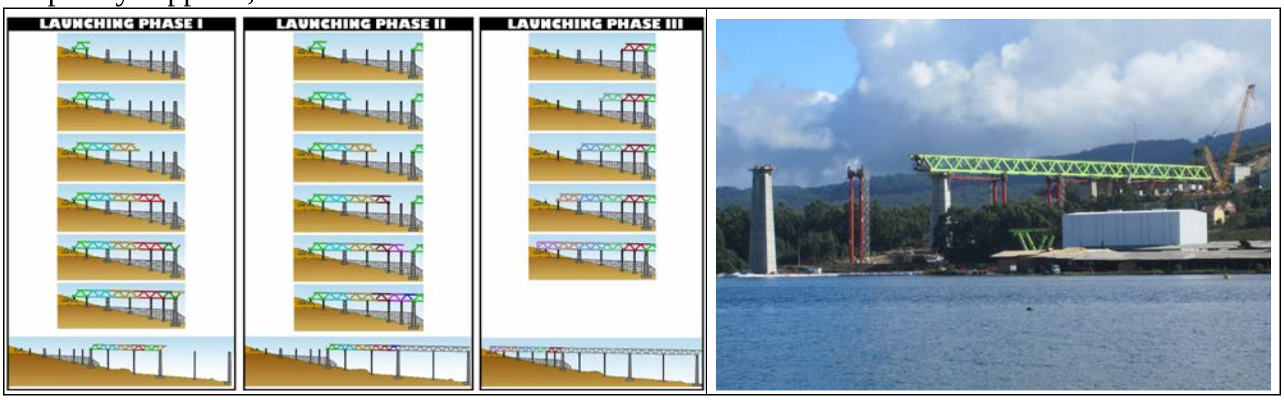

Fig. 6. a) Scheme of the constructive procedure by launching in three phases; b) View of the launching phase II.

The second launch operation moved two complete spans of 120+120 m length (*Fig. 6b*), and finally the lateral side spans 1 and 2 (50+80 m) are welded on site over the temporary props by erecting each segment with the use of cranes.
The approaching spans on the side of the abutment A2, do not have the same restrictions as the ones on the side of the abutment A1. As there are no inferior interferences, a complete span lifting procedure has been designed.
The complete span are welded on site by assembling each segment propped on the ground (*Fig. 7a*), and finally each span are vertically lifted and welded to the previous one giving continuity to them. The approximate weight of span 10 and 11 (120 m) is 900 t, and span 12 is (80 m) is 465 t weight. *Fig. 7b* shows the lifting of the span 12.

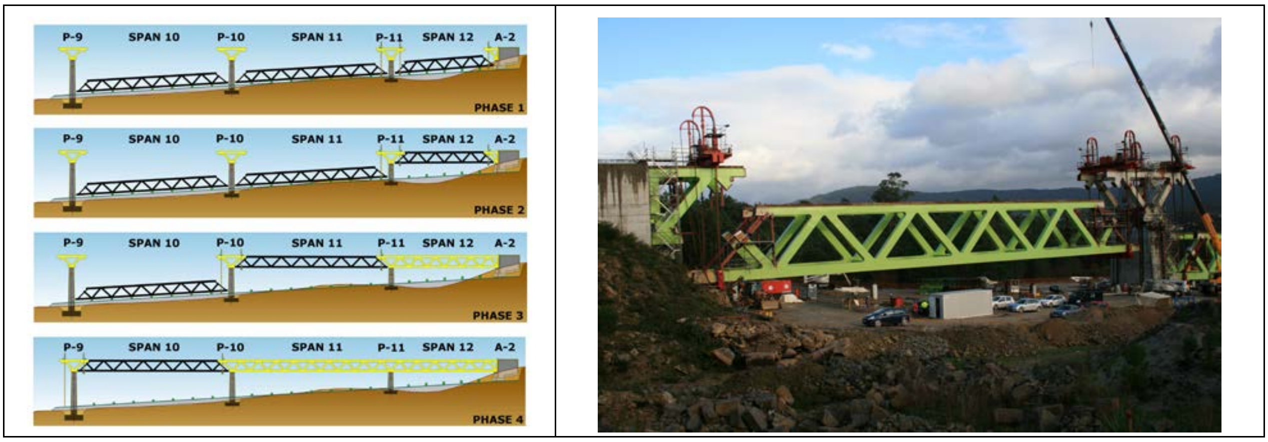

Fig. 7. Scheme of the constructive process of spans 10, 11 and 12; b) View of the lifting of span 12.

Once the assembly of the steelwork is completed, the lower precast concrete plates are placed and the subsequent lower slab concrete casting done. The upper concrete slab is poured over precast concrete slab.

3 MANUFACTURE OF THE DECK´S METALLIC STRUCTURE.

The singularity and complexity of the bridge´s metallic structure, as well as the huge amount of structural steel, nearly 20,000 tons, made it necessary to divide the manufacture in 4 groups of workshops, 3 of which located in the north of Spain and 1 in Portugal.
In order to handle, manufacture and ship the steel elements to the worksite, the deck's lattices are divided into the following simple elements (*Fig. 5*): upper nodes, upper chords, lower nodes, lower chords, horizontal struts and cross bracings.

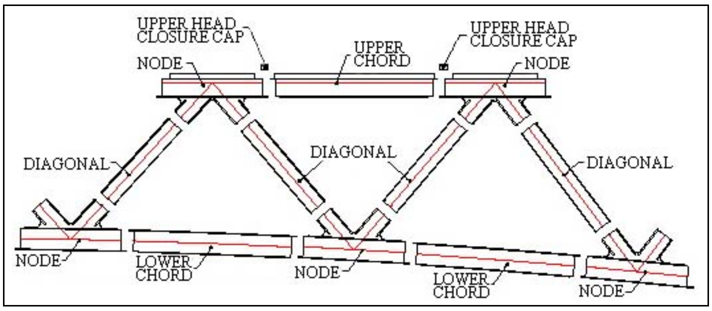

Fig. 8. Break-down into simple elements for shop manufacture

Once each module's individual elements are ready, and prior to being shipped to the worksite, they are welded in larger subsets, depending on the case: node+chord or node+chord+node. The subsets and the rest of simple elements (diagonals, horizontal struts and bracings) are shipped and, later on, assembled in the on-site shops, thus making up the modules of the lattice.
The assembly of individual pieces and pre-welded subsets required setting up remarkable permanent facilities on both banks of the river. It was also necessary to arrange large storage and

assembly yards both below the viaduct’s vertical projection between pier P-9 and abutment E-2 and in a nearby expanse with access to the river through a wharf.
The outstanding size of the steel modules, 8.75 m high in the constant depth segments and up to 17.5 m high in the haunch spans, made it forceful to set up assembly workshops as large as actual steelwork plants, with over 20 m clearance, nothing to do with temporary facilities.
The complexity of the metallic structure has required an important amount of beforehand work in studies and development of a series of very repetitive details in order to do the assembly drawings. This way, the assembly drawings solve every encounter, welding, transition and specific detail, avoiding future executing problems.
In no case general details are used, nor without dimensions nor with tabulated dimensions that do not actually represent the thickness, geometry, intersection angles, gaps, welding toes and plate bevels in each and every specific welding crossings, thereby avoiding a big number of possible future executing issues.
The 131 drawings of the project, that define the metallic structure in detail, are developed in more than 6500 workshop drawings and nearly 22000 broken down drawings, defining with absolute accuracy each one of the plates, encounters and weldings of the bridge. This important engineering effort is essential to ensuring the correct design of all details, which have to accomplish very strict requirements related to fatigue resistance due to its being a composite bridge for high speed trains.
A clear example of the detail development in workshop drawings is the set of details shown in *Fig. 9*. *Fig. 9a* illustrates the details of the transition in the fillet welding between the flange and the web of a diagonal in its encounter with the node of the lattice: the flange of the diagonal transitions to be welded to the web of the node with partial penetration. A double cope hole (top and side) is necessary, solved by means of smooth transitions and flush grindings at the welding ends.
Fig. 9b shows a chord´s central web welding end detail in a node, where the partial penetration welding ends and smoothly transitions to a cope hole properly placed at the web´s end.

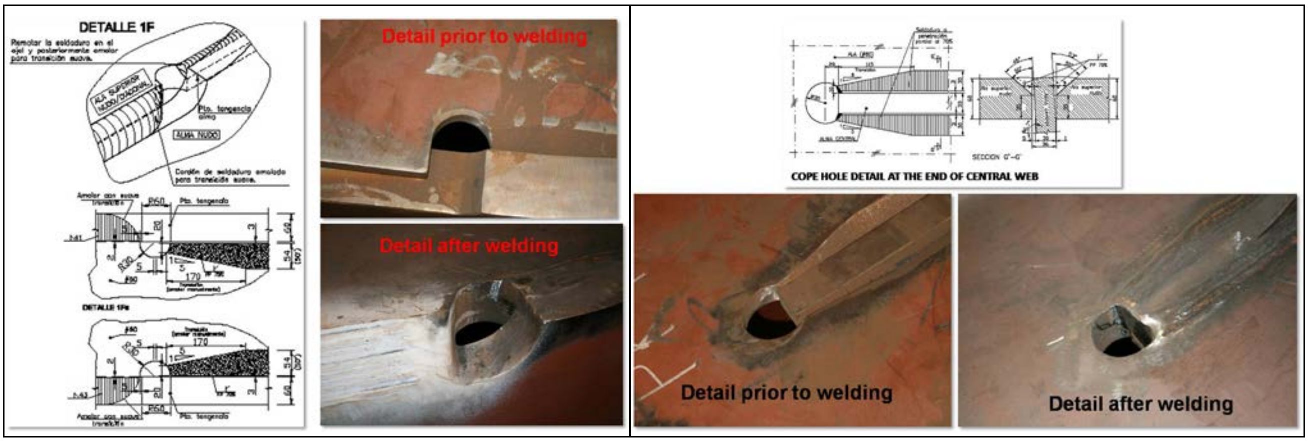

Fig. 9. a) Transition of diagonal flanges when entering nodes; b) End of central web in nodes, with a cope hole at the

The metallic structure development consists not only of workshop drawings and break down drawings, but also the assembly drawings of each typical element (nodes, chords, diagonals, and cross bracings).
An important achievement of this project has been avoiding the use of hoist gusset plates or auxiliary welded pieces during its workshop execution. Any auxiliary piece welded to a final element of the bridge is likely to worsen its fatigue category. Due to this, it has been a target to handle the elements without auxiliary welded elements, a feat accomplished by using self-designed lifting and turning tools that are re-used in the rest elements. Furthermore, this decision has turned out very successful and effective given the modularity of the structure, with quantity of elements with the same outer geometry. Anyway, in those cases where is necessary to use hoist gusset plates to assembly bigger modules in worksite, there are always workshop drawings with adequate fatigue details as well as specific procedures to remove those plates and repair the element. Provisions were made for thorough afterward control with ultrasounds or, where necessary, X-rays.