

La Vicaria Arch over La Fuensanta reservoir

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ABSTRACT: La Vicaria Arch is a through arch bridge placed over La Fuensanta Reservoir on the River Segura, Albacete (Spain). The total length of the viaduct is 260 m, with 2 arches that spans 168 m. Each arch is inclined 10° inwards at both sides of the deck. The arch sections are quasi-rectangular formed by folded steel plates filled with self-compacting concrete. The deck section comprises two longitudinal steel beams connected with a concrete slab. The construction system involves assembling a 120 m tied arch on the ground and after that, lifting it 40 m with hydraulic jacks to connect it to the rest of the structure, built as a cantilever erection. This article describes the most relevant facts of the bridge and peculiarities related to the construction process.

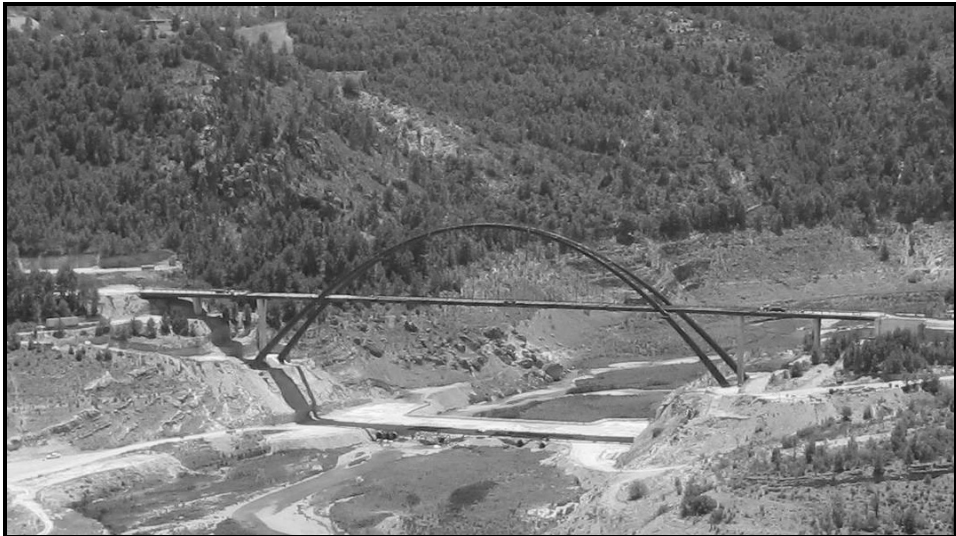


Figure 1 : The Vicaria Arch. (13-06-2007)

1 INTRODUCTION

La Fuensanta Reservoir and the River Segura, near its origin, divide the municipal district of Yeste into 2 parts. This village has 4000 inhabitants and it is the main town of an isolated and mountainous region in the southern part of the province of Albacete. The bridge will provide direct access to the village from the east (up until now it has only had communication from the north) and saves 50 minutes in journey time by avoiding going around the large reservoir. In fact, the bridge will re-establish an old track interrupted by the building of the dam (1932).

After a project study, the owner of the bridge, the *Confederación Hidrográfica del Segura* (Segura Water Authority), decided that a singular bridge was the appropriate solution for satisfying an old demand of the Yeste population. Ferrovial-Agromán, as the builder and final designer of the bridge, gathered together previous ideas and provided a complete solution, which includes an innovative construction process.



Figure 2 : Location (14-03-2007)

2 THE PROJECT. GENERAL APPROACH.

2.1 Location

The bridge over the River Segura is part of the future road that will join Yeste with its neighbouring area to the east. In this place, the river flows from south to north, leaving a mountainous area and reaching open terrain, where the reservoir is situated.

The topography has special characteristics at the crossing; the river flows slowly along a 120 m wide horizontal terrace; on both sides there are 25 m of steep limestone rock hillsides up to the reservoir's maximum level; and finally, there is 45 m of gentle slope until the road level on both sides. The road passes 24 m above the water level when the reservoir is full, and 44 m above the level of the river when the reservoir is almost empty.

2.2 Other factors

Apart from its singular characteristics, the ownership wanted maintenance requirements reduced to a minimum. The limited availability of local resources and the necessary evolutionary process of a bridge of these dimensions, made it advisable, from a construction point of view, to maximise prefabrication elsewhere and reduce on-site work.

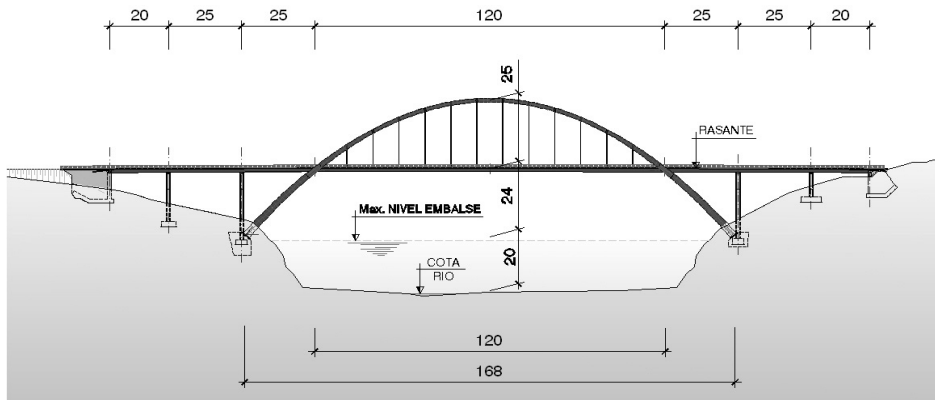


Figure 3 : General view

2.3 Description of solution adopted

The solution adopted is a 168 m through arch bridge with approaching spans: it is the optimum solution if permanent supports inside the reservoir is avoided, taking into account the valley's morphology and the width of the reservoir at this point. The suitable conditions of the hillsides for the foundations and their symmetry in relation to the valley's axis made it possible to lay the foundations of the arches next to the reservoir's highest level.

A composite arch and deck structure was chosen with "corten" steel because of its minimum maintenance requirements, and otherwise, it enables the manufacture of large metal pieces in the factory, its subsequent transport and assembling on the work site, to form an evolutionary structure and, finally, the structure become a composite one by concreting of the arch and deck (using the metal structure as formwork) to acquire suitable rigidity and resistance properties.

The aim has been to optimise the outer dimensions of the bridge sections (making the most of the qualities of the composite section) to obtain extremely slender and spectacular arches. Its characteristic cross section, rectangular folded shape, creates a shadow lines, formed by the folded steel plate over its own surface, that enhance the geometric purity of its rational shapes, as a counterpoint to the chaos of the natural forms in the beautiful country surrounding it.

Table 1 La Vicaria Arch. Main Parameters.

Total length (m)	260
Spans length (m)	(20+25+170+25+20)
Span / Rise (arch)	3.4
Span / Depth section (crown of arch)	140
Span / Depth section (base of arch)	70
Span / Depth section (deck)	134

The ratios span/depth sections show the great slenderness of the structure, that implies flexibility to the group arch-deck. This required special attention to deflections during the design of the construction stages and the life-time of the bridge. The asymmetric loads on the arches produce undesired strains which are reduced through: the sequential concreting of the arch and deck to maintain the antifunicular loading of the arches, in order to keep the loads well balanced at all times. Provisional shoring and anchorages are done in the abutments during construction; and in service, installation of dampers in the abutments so that the deck acts as a brace against the anti-symmetric deformation of the arch.

3 STRUCTURAL ELEMENTS

3.1 Deck

The deck comprises a continuous composite structure of concrete and steel supported simply on columns using neoprene and rigidly connected to the arches at their intersection. Its width is 11.5 m; there are 2 lanes for vehicles and 2 pavements with a width of 1.5 m.

Its section is made up of two longitudinal steel box beams with a 1 m depth, with a 9 m separation between axes. Every 3 m, the longitudinal beams are cross braced by flange steel beams.

The concrete slab is 0.25 m thick and is connected to both the box beams and the crossbeams. The deck is concreted in situ on pre-slabs which are supported on crossbeams, working with the slab in service.

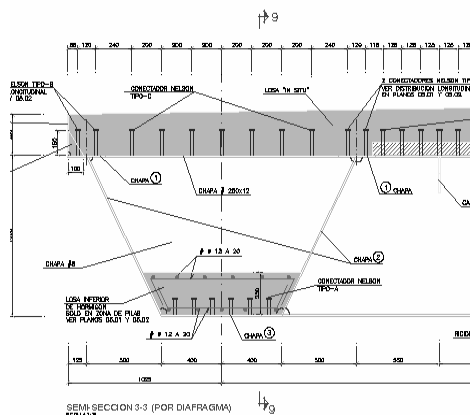


Figure 4: Section of the deck

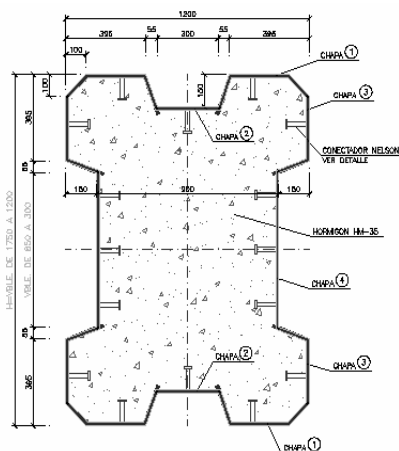


Figure 5 : Section of the arch

3.2 Arches

The span of the arches is 168 m, of which 120 m is over the deck. They incline 10° inwards to the deck, so that the axes of the arches are separated 3.8 m at the crown and 21.7 m at the base. The rise is 48.9 m, of which 25 m is over the deck. Over the deck, both arches are cross braced to each other by 6 crossbeams with a similar outer section to that of the arch.

The arch sections are quasi-rectangular steel tubes (see figure), filled with self-compacting concrete. This peculiar rectangular shape is formed by 4 metal plates which are folded and welded at their ends. Their width is constant along the arch and their depth varies from 2.4 m to 1.2 m.

The deck is connected to the arch by means of 12 pairs of vertical hangers, separated 9 m longitudinally. The hangers are carbon steel bars with a diameter of 85 mm, protected with polyethylene sheathing.

At the arches and deck intersection point, 60 m from the centre of the bridge, both elements are joined rigidly by a cross brace.

Each arch is embedded at its ends in a reinforced concrete block with variable dimensions on each bank (the smallest is 6 m long, 7 m high and 5 m wide), until reaching the suitable foundation surface in the rock, determined by geotechnical conditions. The steel arches are rigidly connected to the foundation block through a joint of 28 bars of 40 mm diameter.

The sloping of the plane of the arches towards the deck's axis means that the compression applied by the arch to the foundations has a perpendicular component to the longitudinal plane of the bridge and parallel to the contour lines of the hillside. In order to avoid transmitting this force to the rocky mass, the blocks on each bank have been cross braced to each other using a reinforced concrete brace, which balances the reactions of the 2 arches.

3.3 Piers

Piers are Y-shaped and concreted in situ. The 2 support points of the deck in each pier are in a crossbeam that connects the 2 longitudinal beams. This arrangement strengthens the visual continuity of the depth section of the deck along the bridge, as well as its slenderness.

The highest piers, next to where the arch begins, are 24.3 m high. The foundations were laid in the brace which cross braces the anchor blocks of the arches on each bank. The other 2 piers also lay on spread footings.

3.4 Abutments

The abutment on the left bank is a closed type abutment to limit the volume of the embankment at its front. It is an open type abutment on the right bank and almost buried. At both cases, shallow foundations were used.

The side walls of the abutments house retaining prestressed tendons their interior which fix the deck to the abutment during lifting (see construction process). Part of the abutment foundation is in a inclined plane in order to provide a perpendicular contact surface to the forces of the anchoring to the ground.

4 STRUCTURAL ANALYSIS

The development of the project of the bridge mainly consisted in the following works:

- Definition of basic parameters of finished bridge.
- Definition of construction process.
- Measuring the elements that define the bridge's general sections.
- Design of special elements which are very common due to the bridge's geometry.
- Verification and checking of each development phase of bridge in construction.
- Verification and checking of bridge in service.

The structural analysis was carried out using a 3-D bar linear calculation model of the completed bridge and each of the partial structures of the evolutionary assembly. The special elements were checked with 3-D plate linear calculation models for detailed verification.

The Serviceability Limit States, as well as the Ultimate Limit States, were checked according to existing Spanish regulations and recommendations (IAP, RPX, RPM, EHE).

Different non-linear and dynamic calculations were carried out, with results that did not noticeably differ to those produced in the linear calculation.

5 CONSTRUCTION PROCESS

5.1 Description of method

The structural efficiency of the finished arches contrasts with the difficulty experienced in their construction. The reason behind this is that in the traditional method (centering), the arch does not work supporting its own weight until it is totally completed with the keystone. The high cost of producing this arched falsework resulted in it falling into disuse.

Currently, the development of new processes for building arches has made this typology popular once again. The now common method for building upper deck arches involves advancing the arch and deck as a cantilever construction from both banks, forming a closed frame where the upper deck acts as a tie balancing the horizontal component of the arch section under the deck.

The Vicaria Arch proposes a new construction method for through arches by dividing the arch into 3, with 2 upper deck arches on each side as a cantilever construction with the aforementioned procedure, and a central lower deck arch with smaller dimensions, built using falsework on the ground until a bowstring is formed. Once the three self-supporting partial structures have been built, using the 2 side lattices, the bowstring is raised to its position and the arch closed.

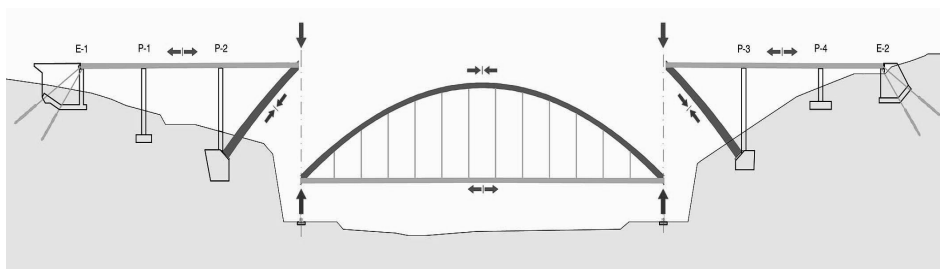


Figure 6 : Structural transmission of forces during the lifting.

5.2 Construction stages

5.2.1 Substructure. Piers and abutments

The foundations of the piers and abutments are shallow. Due to the existence of karstic cavities in the rocky mass on the left bank, it was necessary to apply consolidation works to the ground behind the foundations of the arches.

5.2.2 Tied arch

A work platform was prepared at the bottom of the reservoir, where the central 120 m of the steel deck, divided into 13 segments, was assembled. 6 falsework towers were erected coincident with situation of hangers 2, 4, 6, 7, 9 and 11. Each semi-arch was divided into 3 steel segments supported on the towers and joined to each other as well as to the ends of the deck. 2 keystone segments were placed and the semi-arches joined, closing the 2 central arches.

The arched falsework was removed and the hangers placed. The shoring was removed from the bowstring lifting with hydraulic jacks from the ends of the deck, and loading the tied arch bridge.

5.2.3 Approaching spans and cantilever

The steel structure of approaching spans was assembled on the ground and placed with a crane. The steel bases of the arches (from arch's basement to deck's intersection) were placed in one single operation with a crane (33 m in cantilever), and embedded in the foundation block. Having positioned the two pieces of arches on one bank, they were joined at the top by means of a steel brace placed with a crane. Consequently, the crane placed the steel structure of the deck from pier to the arch-deck intersection.

5.2.4 Lifting

Once the retaining tendons that fix the deck to the abutment were tensioned and the lifting machinery placed on the edge of the deck's longitudinal beams, the bowstring was raised until it faced the deck and arch erected in cantilever construction. The arches were joined, the lifted load let go, the tendons in the abutments released, and the decks joined.

5.2.5 Concreting of arch

Due to the flexibility of the steel arch, the arch was filled with concrete in 2 phases to maintain the balance of the antifunicular loads applied to the arches, when the hardening process began in each phase. The arch was divided into 5 m long watertight modules, which were filled alternately in each phase with self-compacting concrete.

5.2.6 Concreting of deck

Once the arch was rigid, the deck was concreted from the centre towards the exterior in order to reduce strains and forces acting during construction.

5.2.7 Finishes

Road surface, pavement, handrails, parapet walls...

5.2.8 Installation of dampers in abutments

Once the bridge was loaded with its entire dead load, dampers and shock absorber devices were installed to reduce the vertical deflections produced by asymmetric live loads in the arch, and let slow deflections in the deck due to thermal and rheological actions.



Figure 7 : Lifting (26-04-2007)



Figure 8 : Construction site (07-05-2007)

6 CONCLUSION

La Vicaria Arch shows how composite sections can optimize construction process, and minimize auxiliary facilities, in order to create slenderer and challenger bridges.

REFERENCES

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RPX-95: “Recomendaciones para el proyecto de puentes mixtos para carreteras”. Ministerio de Fomento.
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EHE: “Instrucción de Hormigón Estructural”. Ministerio de Fomento.