

VIADUCT OVER RIVER ALMONTE – SITE CONTROL SUPERVISION

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SUMMARY

With a 384 m long main span, this arch bridge sets a new world record as the longest span on a single concrete arch bridge used for high speed trains. Almonte's span is considerable even when compared with non-railway concrete arch bridges.

The arch has been erected by cantilever method construction with the aid of temporary cable-stays from two temporary steel towers (using form travellers specially designed for this bridge). The deck is constructed using an overhead movable scaffolding system. This article summarizes the site control activities and special operations undertaken during the structure erection, as the monitoring system, the geometrical control and some aspects of calculation related to its construction.

Keywords: *Arch bridge, high speed railway, world record, cantilever construction method, site control.*

1. INTRODUCTION

The Viaduct over River Almonte at the Reservoir of Alcántara is an arch bridge with a main span of 384 m and a total length of 996 m. It will become, once completed the last stages of the deck, the longest span in a high-speed railway and the third longest concrete arch in the world.

The construction includes many special features and demands unusual operations for the erection of its elements. According to this complex erection, extensive control activities have been undertaken in order to reach some specific and demanding criteria.

This paper gives an overview of the main points of the construction of this outstanding structure.

2. CONSTRUCTION PROCEDURE

2.1. General features

The erection procedure has been developed with the aim of respecting as much as possible the Reservoir of Alcántara, which has a depth of almost 60 m at this point. The fulfilment of this objective is completed with two viaducts at both ends of the main bridge with moderate spans of 36 to 45 m. These access viaducts have the same geometry deck that the arch span in order to use the same overslung movable scaffolding system (Fig. 1). The deck is jointless along its North, South and over-arch sections, of almost one kilometre, and has a standard construction method for a railway box-girder post-tensioned concrete deck.

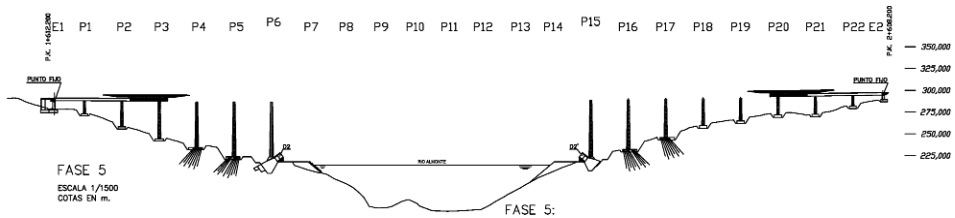


Fig. 1. Construction stages of viaduct's access spans, out of the main arch.

The arch is erected with a cable-stayed cantilever method (Fig. 2 and 3). The total length of the arch is divided into 67 in-situ cast segments, 33 on each half plus one key segment. In order to ensure to stay within the allowable stresses and maintain the optimal geometry, the segments are supported by stayed cables during the construction.

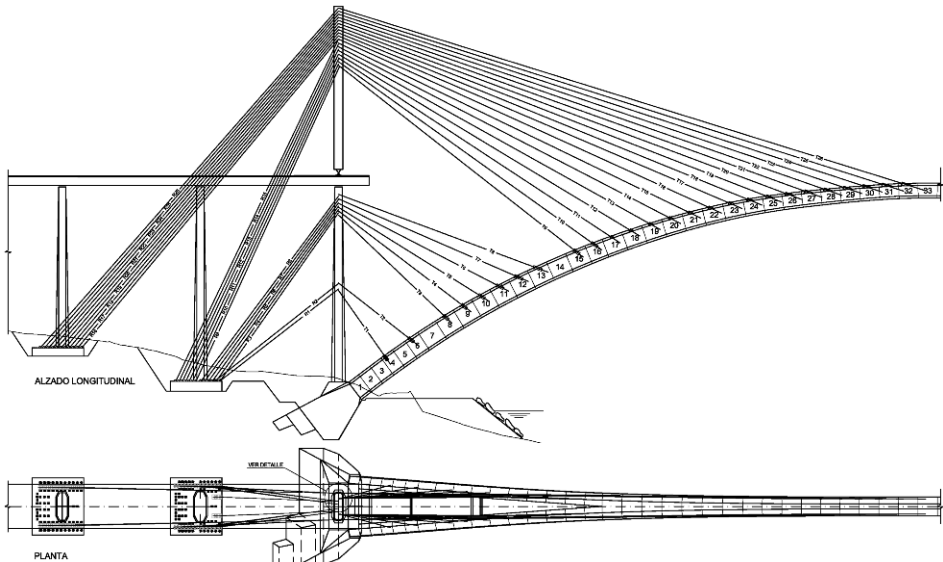


Fig. 2. Numbered scheme of the arch segments and temporary stay cables.



Fig. 3. Arch's cantilevered stage construction.

There are 26 pairs of stay cables on each side with their corresponding back stays. Cables 1 to 8 are anchored to the piers rising on both riverbanks. The anchorages for cables 9 to 26 are set on the temporary steel pylons built over piers P6 and P15. Cable forces are adjusted during the construction whilst releasing some cables on intermediate construction stages for avoiding excessive stresses.

After the arch closure is reached, spandrel columns are erected (Fig. 4) and cranes and temporary towers dismantled. Finally, the last deck spans over the arch are concreted with a standard movable scaffolding system (Fig. 5).

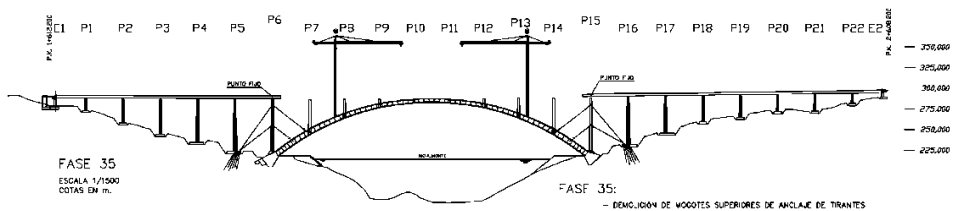


Fig. 4. Construction stages of spandrel columns over the arch.

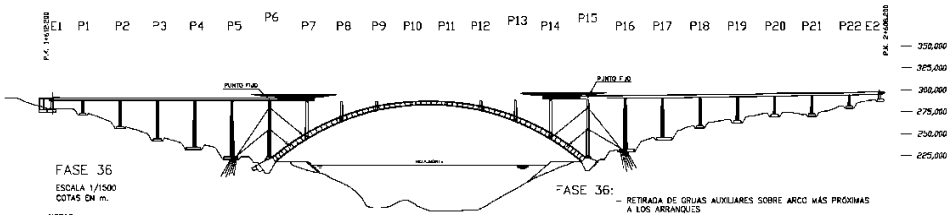


Fig. 5. Construction stages of deck over the arch.

2.2. Special features

2.2.1. Arch's foundations

The arch abutments are two reinforced concrete blocks of 7400 and 6300 m³ that spread the compression loads to the rock-bed. The rock around the blocks is heavily injected (Fig. 6) with 255 tons of cement in order to fill all cracks and discontinuities.

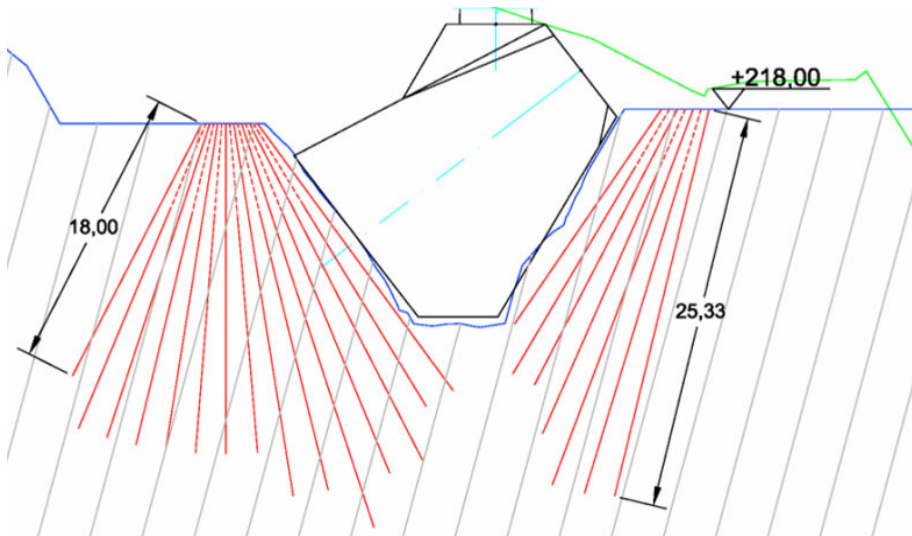


Fig. 6. Scheme of drills for injections in the South abutment area.

2.2.2. Retaining foundations

The global equilibrium of the 192 m half-arch cantilevered structure, is achieved with multiple anchors placed at the retaining foundations adjacent to the riverbank piers. These anchors have a depth length of between 22 and 26 m, with a pretension load of 2000 kN.

The number of anchors in retaining foundations (an example is shown in Fig. 7) rises up to 60 units plus 6 reserve units.



Fig. 7. View of one retaining foundation with anchorages for both bed-rock and stay cables.

2.2.3. Formwork of arch segments

The concreting of the arch is made segment to segment with a cantilever formwork traveller (Fig. 8) that fits to all geometries of arch: from segment 1 to 15 the arch is two legged and from 16 to 33 is only one piece varying in width and depth.



Fig. 8. View of cantilever formwork before joining in one piece.

2.2.4. Temporary towers

The articulated temporary steel towers are placed on the arch's edge piers. Afterwards, a rotation operation is undertaken in order to raise both towers from their horizontal position over the deck (as explains Fig. 9). This system allowed execution time savings.

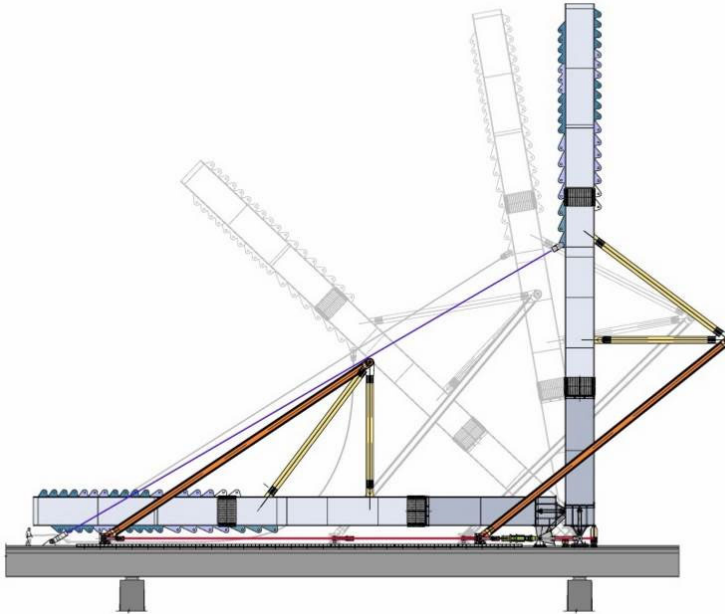


Fig. 9. Elevation of temporary tower at four different erection stages. It can be observed the auxiliary mechanism of rotation (yellow and orange).

2.2.5. Temporary stay cables

The stay cables are individually-protected multi-strand cables, identical to permanent stay cables (steel type Y 1860 S7; 150 mm^2 section). The number of strands varies from 15 to 53 $\Phi 15.2 \text{ mm}$. The strands are not galvanized as enough corrosion protection is achieved by a semi-bonded individual HDPE sheath is extruded into the strand after the interstices have been filled with wax.

Usually both ends of the stay cable are articulated in vertical direction in order to facilitate their installation.

3. MONITORING OF THE BRIDGE

The erection of a bridge with such particular construction features like Almonte Viaduct, requires permanent structural monitoring, starting in its execution and throughout its entire service life. For this reason a full scale measurement program was implemented, with almost 100 points of data record (Fig. 10 and 11) in each side of the bridge, although this number has changed considerably during construction.

After an initial stage to decide which factors should be analysed, under what conditions, which monitoring system to be installed and what frequency and accuracy of recording, Staff was organized at three levels that influence each other and interact continuously:

- 1) A surveyor company records, maintains and presents the data with the behaviour of the structure.
- 2) A primary analysis makes an immediate coherence evaluation with theoretical predictions providing it to bridge designer, and simultaneously assesses the perfection of records. At this level the total station survey is compiled with automatic data acquisition measurements. This primary analysis is developed by an independent engineer, different to the staff of levels one to three.
- 3) A secondary analysis evaluates in depth the correlation with theoretical predictions and makes corrections to model calculations in order to improve the accuracy of forecast and appraise the origin and consequences of divergences. This secondary analysis was executed by two independent engineers, one of them Arenas & Asociados, the design engineers.

The installed system initially included 93 points of recording, listed in Tab. 1. Data is automatically transformed to the engineering units in site, and presented via internet to the three levels previously mentioned.

Table 1. Recorded parameters of Almonte Bridge (only one semi-arch).

N°	Parameter	Points of recording
1	Wind direction	1
2	Wind speed	1
3	External air temperature	1
4	Internal arch air temperature	1
5	Stay cable temperature	6
6	Concrete arch temperature	12
7	Concrete pylon temperature	4
8	Steel tower temperature	4
9	Foundation clinometer	4
10	Concrete pylon clinometer	1
11	Steel tower clinometer	2
12	Arch clinometer	2
13	Concrete pylon clinometer	1
14	Arch rebar strain gauge	12
15	Steel tower strain gauge	4
16	Stay cable strain gauge	40

The system was further improved with the addition of 5 accelerometers on the arch to analyse the dynamic behaviour with following purposes.

- 1) Continuous measurement and recording of the vertical and horizontal accelerations.
- 2) Empirical evaluation of vibration modes of arch in construction stages.
- 3) Evolution of vibration modes of the bridge along time.

Other accelerometers were subsequently used for specific analysis of the stay cables. The aim of these measurements was assess the need for damping of the longer stay cables of viaduct.

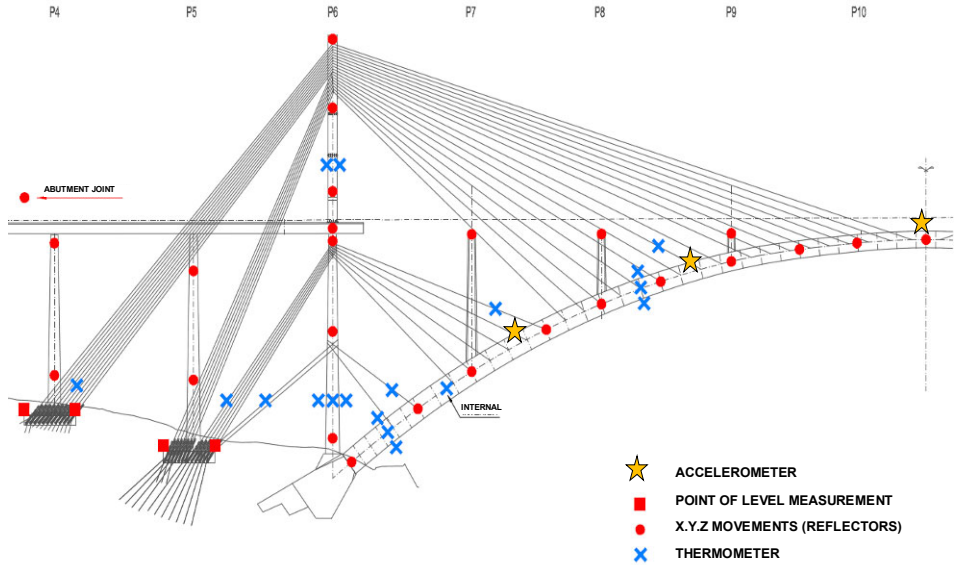


Fig. 10. Accelerometric, movement (vertical, transversal, longitudinal) and temperature devices.

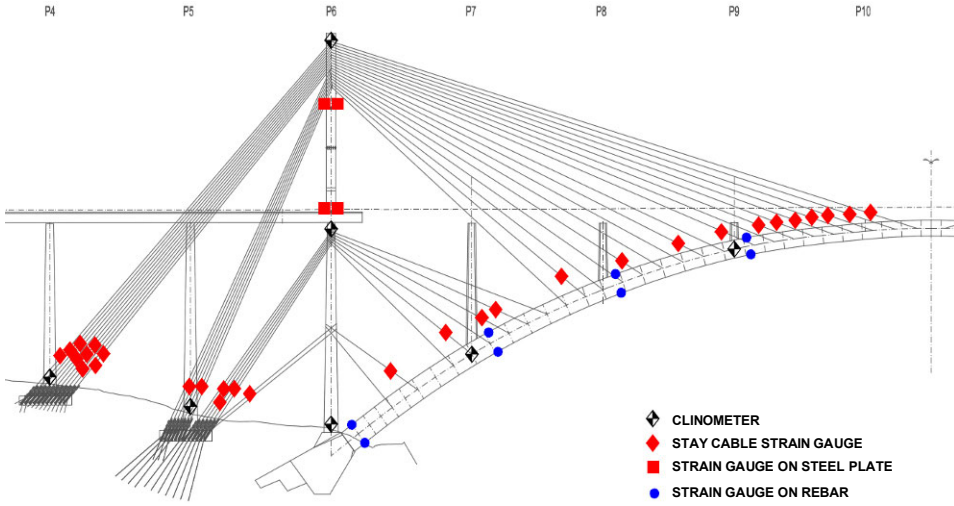


Fig. 11. Clinometer devices and strain gauges.

4. GEOMETRY CONTROL OF ARCH CONSTRUCTION

4.1. General criteria

For an optimal structural performance, the arch's geometry should match the best as possible with the geometric thrust line axis for all load combinations. This problem is solved with arch cross-sections that have the right thickness, in order to maintain the thrust line inside the central core of inertia, avoiding tensile stresses at service and construction load combinations.

However, the arch is not rigidly supported. It is a flexible cantilever rib with stay cables and all the structure is affected by temperature which is a main construction parameter, because each segment of the arch is poured at different temperatures. It is concluded that the best practice and construction philosophy, is to achieve overall geometric control of the structure by performing field survey work and erection operations (forces of stays and cantilever formwork placement) to a meticulous degree of accuracy, and then to rely on that geometric control produce a finished structure having the desired geometry.

This has been the general construction procedure:

- 1) Determine the geometric outline of the final structure under normal temperature (16 °C for this structure) based on accurately weights for all parts.
- 2) Determine the cambered (not-loaded) dimension of each component. This involves determining changes in the shape of each component from dead load geometry, and from normal to concreting temperature at each stage.
- 3) Placement, with due precision, of cantilever formwork at each specific construction stage. Simultaneously, adjustment of stay-cable forces if necessary.
- 4) Verification of resultant geometry at each stage, and determination of the corrections to be made on the next formwork placement or additional adjustment on stay forces.

It was necessary to carry out continuous and comprehensive studies of the structure under each erection stage, determining the corresponding stress and geometric data, preparing a step-by-step erection procedure plan and incorporating any checked measurement that was desirable. Under certain construction load conditions (wind, temperature, gravity loads), it was necessary to check the structural integrity of arch, stays, piers and foundations.

The placement of cantilever formwork traveller is controlled by four reflectors fixed at the end of the formwork (Fig. 12). It is then possible to determine the position of the end of the cantilever arch in any stage and compare it with theoretical calculations. There are many measurement points to determinate the position of the arch axis at each segment. This way the structure can be controlled along its whole length and at any time during erection.

As the arch grows, the influence of thermal loads, especially sunlight radiation, is decisive for the positioning of the dowel, so it is necessary to take all survey early in the morning when their influence is minimal. This requirement is mandatory in the case the measures are associated with checking the cantilever formwork position just before pouring.

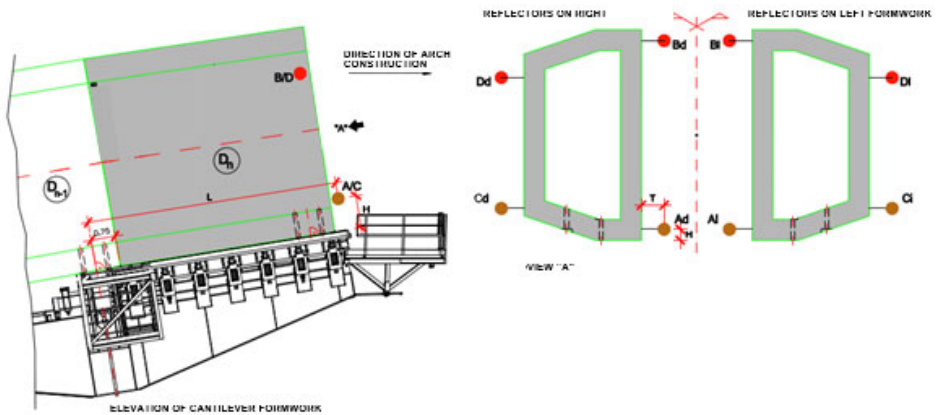


Fig. 12. Geometry control points of cantilever formwork traveller.

4.2. Construction tolerances

To act in good time, so that the maximum values of tolerance are not achieved in front of the final geometry of construction, pre-alarm values are set. These values are far away from construction's structural integrity or the future service capacity, and depend on the accuracy of measurement and expected movements in the arch during construction. Since the movements of the different stages are growing and the system becomes more flexible, and therefore more susceptible to other effects (e.g. temperature on the stay cables), alarms are defined in sections of segments. These were the allowed tolerances: segments 1 to 15 (± 50 mm), segments 16 to 13 (± 100 mm) and segments 24 to 32 (± 180 mm).

It should be noted that the final construction errors were never greater than 88 mm.

5. CONCLUSIONS

This paper introduces some of the construction features that have allowed overcoming the span of Viaduct over River Almonte: construction procedure, monitoring and geometry control.

Making use of technological tools that already exist, it is possible nowadays to erect outstanding and difficult structures. To achieve these features, it is necessary the help of a strict planning and a wide prevision of the different situations which can happen during construction, in accordance to the accumulated experience and knowledge of the present technological state.