ALMONTE VIADUCT – CONSTRUCTION PROCESS

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SUMMARY

The Almonte Viaduct is a huge challenge for those who have been involved in the construction of this singular structure. Never a viaduct like this was built for a railway line. New construction processes and techniques have been implemented during the construction of the different elements of this gorgeous viaduct. This article describes the most notable aspects during the construction of the bridge.

Keywords: *Concrete arch bridge, railways arch bridge world record, construction with a temporary cable stays system, self-compacting concrete, singular viaduct, specific form traveller, high speed railways viaduct.*

1. INTRODUCTION

The Almonte viaduct is located in the west of Spain close to the Portuguese border, in Caceres province. The viaduct is situated within the Embalse de Alcántara- Garrovillas section in the Spanish Madrid-Extremadura high speed line that ADIF AV (Administrador the Infraestructuras Ferroviarias. Alta Velocidad), the Spanish high speed railways authority belonging to the Development Ministry is building since 2.009. The section will be part of the European Madrid-Lisbon High Speed Line that will join both neighbour countries. The HS line passes through a very important environmental value area within the corridor indicated by the Environmental Impact Statement and in parallel to the Alcantara reservoir where two important rivers, Almonte and Tagus, flow into.

The terrain close to the Almonte mouth is a hilly area with lots of deep valleys with gradual slopes. The construction of the Alcantara dam, around 1960, caused that both river banks were highly flooded and expanding the river width up to 400 metres in several areas. The corridor indicated by the Environmental Impact Statement crosses the Almonte River in an area where the river width goes up to 340 m. The Environmental Impact Statement indicates that the riverbed cannot be affected by any HS line element. To tackle this issue several viaduct typologies are studied, all of them with a main span of 380 metres. This span length is fixed to avoid the river affection and to get the main span supports away from the reservoir maximum water level. Steel typologies, such as lattice-arcade, double plane cable-stayed viaduct and concrete arch with concrete deck viaduct, among others are studied. Finally the lower concrete arch viaduct with concrete deck solution was selected by ADIF AV due to the minor cost in the bridge maintenance and the good behavior obtained with this kind of typologies after the construction of the Contreras viaduct within the Madrid-Valencia HS line, that it is in that period one of the larger railways arch viaducts in the world with a 261 meters main span.

ADIF AV entrust to the Joint Venture formed by the Spanish designers IDOM and Arenas & Asociados the design of the section where is located the Almonte Viaduct. The specific viaduct design is carry out by Arenas & Asociados and is finished in December 2.009. A concrete deck viaduct with a 384 meters lower concrete arch is designed. Once built it will become the longest arch viaduct for railways and the third longer in the world considering concrete arch viaducts for highways and railways only surpassed by the Wanxian Viaduct (420m) in China and KrK I (390 m) in Croatia.

In April 2.010 the Embalse de Alcantara-Garrovillas section project is bid and it is awarded to a Joint Venture formed by the Spanish FCC CONSTRUCCIÓN (85%) and the Portuguese Conduril Engenharia (15%). ADIF AV entrusts the Detailed Design Project to the main contractor who develops it in house through FCC Technical Services. The viaduct construction starts in August 2.011 beginning the arch construction in April 2.012. The arch is closed in August 2.015 and the viaduct is expected to be completed next May 2.016.

2. VIADUCT DESCRIPTION

The structure consists in a 996 meters length continuous deck. The foot alignment is straight with a light vertical curve in elevation (Kv=45000) being the sag in one of the access viaducts. This vertical curve causes longitudinal slopes smaller than 1.4%. The deck is a post tensioned box girder with a constant depth of 3.10 meters and a permanent width of 14 meters.
The viaduct is split in three different stretches. North approach viaduct or North spans, South approach viaduct or South spans and Main Span or Main Part (Fig. 1).

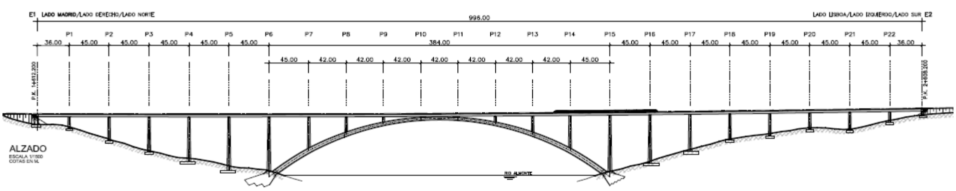

Fig. 1. *Viaduct longitudinal profile.*

2.1. Approach viaduct

Both approach viaducts join the Main Span (arch) with the abutments. North approach viaduct is 261 meters long with a spans distribution as follows 36+5x45 m, whilst the South approach viaduct is 351 meters long with a 7x45+36m spans distribution. Both are a continuous post tensioned deck and are built "in situ" using two Overhead Movable Scaffolding Systems (MSS).

2.2. Main viaduct

In this part is where is placed the 384 meters length arch. Over the arch are raised eight piers that support the deck that runs continuously in the whole viaduct. The spans distribution over the arch is 45+7x42+45 m, being the central span very singular because deck and arch merges in the seventeen central meters.

The arch has a rise of 67.5 m. Therefore the rise/span ratio is 1/5.7. Due to this ratio the viaduct looks quite slender.

The arch geometry is very singular because the arch has two legs in the starting point that merge in a unique leg 87 meters away from the starting point, keeping this configuration until the keystone is reached. Therefore the cross section is variable in the whole length. The arch geometric shapes are as follows:

- Two legs part: From the foundations rise a single 4.17 solid segment with an octagonal cross section 19 meters width and 6.90 meters depth. From that point the two hollow legs grow up with a hexagonal cross section 6.90 meters depth and 3.70 meters width. The geometry is variable and changes centimetre to centimetre making the cross section wider and taper gradually until the two legs meet and form a single octagonal leg 87 meters away from the foundations. The wall thickness is between 0.64 m and 1.07 m.
- Single leg part: In this part the cross octagonal section is hollow and variates from a 6.09 depth and an 8.37 m wide to a 4.80 m depth and a 6.0 width in the arch keystone. Wall thickness variates between 0.97 and 1.16 meters.

The arch construction process considers the successive cantilever method. The cantilever is supported temporarily by stay cables which are anchored to the main piers (P6 & P15) or to both temporary steel towers located on the top of the deck as an extension of those main piers. The segments are built using a couple of form travellers in each side of the viaduct. Once both form travellers reach the single section part of the arch then change their configuration and turn into a single form traveller.

The different resources, the innovative materials and the most significant tools used during the construction of this viaduct are what are described in the next chapter where the technical features and the construction processes of the different parts of the viaduct are to be found.

3. VIADUCTS ELEMENT IMPLEMENTATION

The complexity in the different parts of the viaduct implementation makes that innovative materials, new tools and highly sophisticated elements, some of them really new in the bridges and civil works construction are being used in this project:

3.1. Retaining foundations execution

Retaining foundations are one of the most important elements in the structural behaviour during the construction phase of the cantilever deck as all the weight is transmitted to the ground through those foundations that at the same time, through the temporary stay cables, hold the cantilever providing stability to the whole scheme. These foundations, 4 and 5 on the N bank and 16 and 17 on the S bank, have a footprint of 17.40 x 18.00 and a depth of 3.00 m and house in their interior the necessary ground anchors to hold the foundation to the rock massif. 60+6 2000 KN anchors formed by 12 Y1860S7 steel strands are designed with lengths between 22 and 26m and with a root length of 16m. for each foundation. At the same time, inside each of these retention foundations are housed the anchors for the temporary cable stay system formed by 832 no macalloy bars with 40 and 50 mm diameter and lengths between 3 and 7 m. The need to keep a perfect alignment of theses anchors makes necessary to geometrically control the positioning in a very precise manner with maximum allowed errors of 0.5 deg.

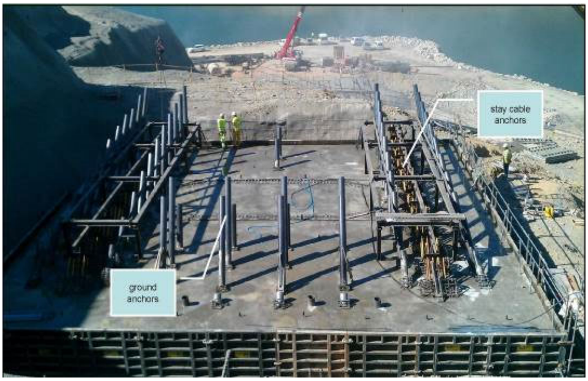

Fig. 2. *Retaining foundations.*

3.2. Arch abutments execution

The dimensions, geometry and steel and concrete volumes of the arch abutments have made it necessary to produce a detailed method statement where all the needs have been included. The abutments design has been developed in accordance with the necessary geometry to guarantee their stability on the slopes of the valley where the viaduct is located penetrating on the mentioned slopes until rock bed, able to hold and distribute the efforts from the viaduct in service phase, was reached.

Before placing the steel and pouring the concrete a systematic ground treatment is made through consolidation injections that, after the washing of the joints and subsequent filling with cement slurry, allow for a sufficiently stable support of the foundations that eliminates possible abutment settlements due to failure of the joints in the rock. More than 7.000m injections are made, injecting the order of 300 tons of cement.

Once the foot and the rear of the foundations have been treated, more than 600.000 kg of rebar steel are placed in each foundation. The volume of sulphur-resistant HA-30 concrete for each of the abutments is 7.423 m^3 for pier 6 (North bank) and 6.330 m^3 for pier 15 (South bank). The approximate dimensions for the abutments are 40 m long on the back, 19m in the front and 18m total depth. Due to the foundations being of such a big size, it is decided to divide the concrete pouring works in 9 different phases guaranteeing the pouring of each one in a single working day, adjusting approximately to 1.000m3 each phase.

Pouring the whole foundation in a single phase is not considered as viable due to the high temperatures produced during the concrete setting caused by the hydration heat. Furthermore, pouring more than 6.000 m^3 of concrete continuously is considered a risk because, even the project has two 80m3/h batching plants on site, there are no other batching plants nearby that could supply the project's needs of concrete in case of breakdown, being the closest one more than 50 Kilometres away thus creating important logistic problems.

3.3. Main piers elevation execution

Piers 6 and 15 are the most important during the arch execution because they are the elements that, through the cable stays, transmit all the efforts and actions from the arch to the retaining foundations. The piers, with heights in excess of 65m, have an octagonal footprint that varies as the height increases to end with a rectangular head of 6m x 2.4m (fig 3). Differently to all the other piers that are hollow up to the last 2.5m, these two piers are solid along most of its height to enable them to support the huge efforts they hold during the execution of the cantilever. Built in 50 MPa characteristic resistance concrete, they are executed in 5 m sections using a climbing formwork. The steel reinforcement is assembled on the ground and lifted with cranes. The passage pipe for each of the stays -8 families of them for each pier, 32 stays- is solved by means of two auxiliary steel structures per pier, lower and higher, which are placed in the correspondent section and must be geometrically checked both on the ground and again when placed at height prior to placing the rebar steel. Tolerance levels in the stay pipe alignment are very reduced 0.5 deg. Once the tubular structure is placed, the correspondent rebar steel is placed. For this, a 3D model has been previously produced where all the possible interferences between rebar and structure have been analysed to optimize the position of the steel bars (Fig.4 and 5). Concrete is poured by means concrete pumps.

Fig. 3. *Pier 15.*

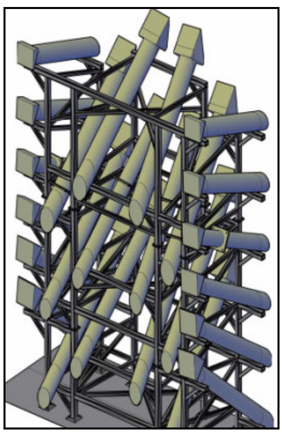

Fig. 4. *3D structure model.*

Fig. 5. *Lower tubular structure.*

3.4. Cantilever execution

The success in the execution of the bridge is based mainly on how to solve both 192m long cantilevered arches with a most peculiar geometry with two hexagonal arms that start from a common base with octagonal geometry and that, halfway through the cantilever, blend themselves in a single leg with octagonal geometry. The depth and width of the section are variable along the cantilever what complicates enormously the formwork installation, rebar placing and concrete pouring. That is the reason why the travelling formwork selection, rebar positioning and concrete type selection have been key in the project success.

3.4.1. Formwork travellers

One of the biggest challenges found by the Team in charge of the detailed design and the delivery of the Project has been the selection of the formwork travellers for each of the cantilevers. Such a singular geometry of the arch as well as the fact that it starts as two legs and then melts in one single leg has been a major challenge.

The most important firms specializing on the fabrication of these kind of equipment were contacted for them to produce a draft blueprint including the specific needs of both cantilevers with two initial requirements: on one side the formwork had to be built completely in steel and capable of supporting hydrostatic pressures up to 90 KN/m^2 – except for the frontal closings that would be done in wood- and on the other hand they had to be automotive along the whole length of the structure and capable of building segments up to 7 m long.

Amongst all the 10 firms contacted, only one local company was capable of presenting a draft blueprint detailed enough to, with the support from the Contractor's Technical Services, develop a formwork traveller useful to build the project with full guarantees.

Fig. 6. *Cantilever execution.*

Each half-traveller (Fig. 8) is formed by a large underslung beam over which rests the complex frame of beams and panels that form the carriage and a “C” or half-portal over which rests and stabilizes the carriage in the advancement phase. Each half-traveller is anchored to the finalised work by means of the principal anchor which is formed by 4 or 5 Ø75mm macalloy bars stressed to more than 300 tons and placed in the gravity centre of the traveller plus 2 Ø36mm macalloy bars placed in the rear end or rear anchor. In the advancement phase the carriage supports itself on the rear anchor and on the “C” in such manner that when the traveller is released from the principal anchor, by two hydraulic cylinders placed on the upper lid with two sliding tracks and two cylinders placed in the rear anchor, the traveller moves imitating the movement of a worm along the cantilever. All the carriage operation is done from a hydraulic control module. The carriage has secure access to each and every single element needed for its operation and for the installation of the formwork and pouring of the concrete for the segments.

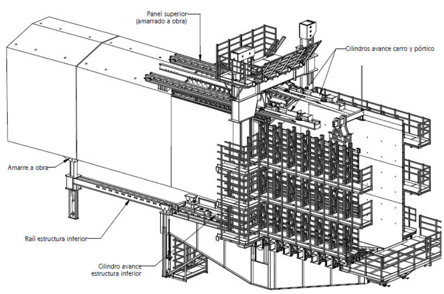

Fig. 7. *Traveller model.*

One of the most singular processes is the disassembly of the travellers after completion of the segment 32S and key segment or segment 33. This activity is done by lowering the weight of the carriages from the original 240 tons in its final configuration to as low as 100 tons with the help of the tower cranes system placed on segments 25 and 15 and then use a HEAVY LIFTING system to descend the remaining carriage composed of the lower beam and part of the formwork frame to a pontoon previously set in the river. The lowering process is done with a coordinate system of 4 HEAVY LIFTING hydraulic cylinders type HL 706 with 85 ton nominal capacity each with 5no Ø15,2 mm 1860 MPa steel strands each jack starting at a very reduced speed until the formwork carriage become free.

Fig. 8. *Form travellers before union.*

3.4.2. Concrete Typology

Due to the geometry of the segments as well as the complex and dense positioning of the rebar in them, the use of a self-compacting concrete is needed to guarantee that all the segment are correctly filled without leaving any kind of hole or cavities. The high characteristic resistance required (80 MPa) is also a new factor as it is not usual to work with such a high level of characteristic resistance for self-compacting concrete. In fact, up to this Project, in Spain there were practically no previous experiences combining characteristics, high resistance and self-compaction. Besides these requirements and in search of optimizing the work cycle so each segment can be executed in less than 12 working days with 24 hours shifts, 7 days a week, concrete must reach 40 MPa in a few hours so the carriage can be released and advanced with total security. A pipes and pumps system capable of lifting the concrete 80 m –vertical distance from the pumps to the key of the arch- and transporting it more than 200m –distance from the pumps to the farthest poring point- is used. The selected material and its main characteristics are the following:

ULTRAVAL SR SPECIAL CEMENT: Contains low quantities of AlC3. This fact avoid the possible delayed ettringite formation due to high temperatures reached during the concrete setting time and permit not to reach 75° C (167º F) during the concrete set and cured. It contains also higher grinding fineness than standard cements getting high beginning resistance (>40 Mpa – 5.800 psi) in 12 hours and more than 90 Mpa (13.050 psi) in 28 days with maximum quantities according to Spanish normative EHE 08 (460 kg/m³ - 28,7 lb/ft3) It is produced by Cementos Portland Valderrivas (FCC group) in Navarra (North of Spain)

RIVER SAND USE: Produced 135 km (84 mi) away from the site are essential to avoid concrete blockage and segregation and to make possible pumping the concrete to long (>200 m – 656 ft) and height (>70 m – 230 ft) distances

FLY ASH AND CHEMICHAL ADMIXTURES USE: Fly ash use give higher long term resistance, improving self-compact quality. Besides last generation of super fluidisers are been used which are essential to keep the concrete in good conditions to be set in the first 90 minutes.

3.5. Temporary cable stays system

The temporary cable stays system used to hold the cantilevers and transmit the loads and efforts produced during the execution of the segments to the main pier or to the temporary tower and from there to the retaining foundations is a cable stay system designed as a permanent stay system but with durability and protection characteristics adapted to the temporary use that they are conceived for. The stay cables are produced on site and installed by the contractor's staff with full supervision from the BBR PTE staff, an FCC Construcción affiliated company. The selected system is HiAm CONA Stay Cable System. The cables are made of high resistance-low loosening post-stressing steel strands and with an individual encapsulation providing each strand with its own protection white tube and sealing details. White colour is chosen to lower the sunlight action on them and to minimize the influence of the sun radiation on the stay cables elongation. Two BBR HiAm CONA Nut Head + 0mm anchors are placed at each end where the strands are fixed by means of wedges. These anchors don't allow regulation but they do have a nut that allows the line-up of the strand through distribution plates and formwork pipes for its installation. To provide uniformity to along the stay cable, minimize the possibility of the strands separating during installation and minimizing the "rattling" effect, brackets are installed along them to hold the strands together. The anchor protection system is an A6L electrolytic galvanization according to EN ISO 4042. The stays are anchored to the arch or retaining foundations concrete by a hinged system of anchor frames adjustable by means of prestressing bars. The stays at the pier location are formed by a distribution plate and a guiding pipe cast inside the concrete. The anchors placed at the tower are installed on a frame with holding lugs which is fixed through bolts to the top of the tower. The different phases of a stay installation can be seen below.
For those situations when, due to geometry and attack angle, connecting the stays to the starting piers is not possible, the Project's authors designed a solution consisting of both twin staying towers 55m high placed over the executed deck above the main piers. This solution was improved during the detailed design development by the Contractor`s technical services.

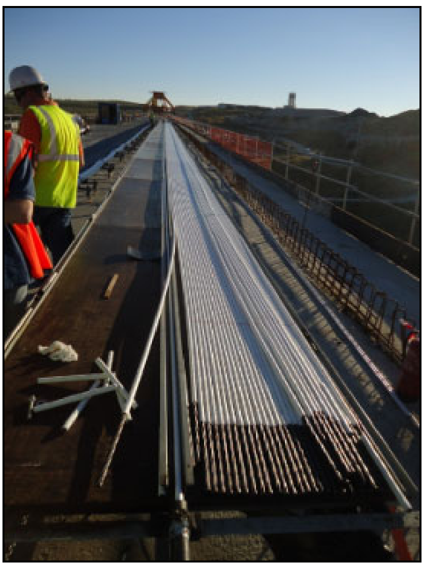

Fig. 9. *Strands cut to size.*

Fig. 10. *Nut Head anchor assembly.*

Fig. 11. *Cable stay mounting.*

Fig. 12. *Strands threaded.*

Fig. 13. *Anchor head assembly.*

Fig. 14. *Cable stay stressed.*

3.6. Temporary steel towers

The detailed design Project temporary towers are different in several aspects to those included in the original Design. First of all, the main frame is designed with open I section beams, different to the closed ones included in the original Project, so a more reliable execution in the factory can be guaranteed as all the welding points can be easily accessed in a critical element of the structure.

Secondly, an articulated solution is designed instead of a deck fixed tower. The hinge, located at the bottom of the tower, will allow from an structural point of view make the tower an independent element from the rest of the viaduct thus knowing all the time how it behaves. Besides the aforementioned, this solution allows for a tower lifting methodology that doesn´t need the assistance of big cranes placed on the deck but instead uses heavy lifting jacks, both in push and pull mode, which permit the assembly of all the different parts that compose the tower at low heights and reduces the working at height operations to one single movement with a duration of less than one day. Due to that horizontal assembling methodology the number of joints in the towers is minimized decreasing the number of bolted connections supporting huge efforts and reducing the possibility of failure.

3.6.1. Lifting Procedure

The lifting process (fig.15) of each of the towers is done using a 4no HL 1906 hydraulic HEAVY LIFTING cylinder pulling system capable of delivering 230 tons cylinders, positioned at a transversal truss fixed to the deck that pulls a transversal lower beam (where the 1906 pulling anchors are fixed) which push the tripod formed by a series of tubular frames that lift the tower until it reaches vertical position. The transversal lower beam slides along two parallel tracks. Two more HL jacks are used to retain the tower when it reaches 80º position. Two hinges are used: a temporary one until the tower reaches a 43º angle with the horizontal alignment and another definitive one, which is the proper tower, to which the loads from the temporary hinge are transferred through Macalloy bars at that point.

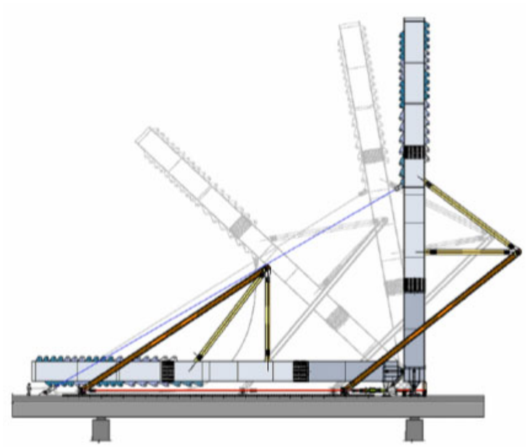

Fig. 15. *Lifting Procedure.*

Before commencing the lifting works the necessary auxiliary elements for the launching must be installed and the strands must be pre-stressed. During installation it must be checked that the pulling anchors fixed to the transversal lower beam axis are aligned with the pulling jacks placed on the transversal truss axis. These two axis must be, at the same time, placed in a parallel plan to the one defined by the two sliding tracks. The same parallelism condition must be checked for the axis of the pulling jacks and their anchoring to the structure.

Once the previous operations have been executed and the average wind speed verified to be lower than 10 m/s over a 10 minute period at deck level the lifting of the temporary tower commences. The transversal lower beam slides along the sliding track that has neoprene-Teflon pads in its lower side and those are left in contact with the Teflon part of the sliding track.

The load transference between provisional articulation and definitive articulation is done when the first sliding has finished and the transference position is reached. The definitive articulation is adjusted with wedges to the tower pin. After verifying the geometry, the base of the definitive articulation and blocking parts are filled with high resistance grout and the screwed joint adjusted and stressed to 1.000 KN. The pre-stressing of the lifting cables is increased in 120 KN until the provisional articulation is released from its loads and the screws are freed. After these operations the sliding continues.

Two breaking hydraulic jacks are installed to apply a constant load to the tower turning movement. They are placed in the opposite direction to the pulling jacks and will hold the structure in the final stage of the lifting process. These jacks are mounted over an independent auxiliary support fixed to the deck. The total load applied to each of the breaking jacks is 15 tons. Each jack holds two steel strands of the same kind as the ones used in the pulling jacks. The breaking force is activated when the structure reached 80º. After the breaking is activated the pulling load has to be increased to compensate the new breaking load.

4. CONCLUSIONS

Building a viaduct with these dimensions and scale is very complex and has been -and still is- a real challenge for all those involved in such gorgeous project. Geotechnical specialists, concrete and steel structural engineers, plant and formwork specialists, wind engineers, etc. have taken part in the design and delivery of this viaduct. The project scale is such that during the development of the detailed design and the delivery of the different viaduct elements ultimate generation materials are applied, newest and ingenious construction processes are developed, uncommon studies and calculations not usual in railways viaduct projects are carried out and an endless array of singularities that make this viaduct construction which its completion is very close an extraordinary challenge for everyone.

***Fig. 16**. Almonte Viaduct Current State.*