Long Railway Viaducts with Special Spans: Part-1. Arch Construction by Balanced Cantilever with Auxiliary Cables

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RAILWAY ARCH BRIDGE OVER THE CONTRERAS RESERVOIR ON THE MADRID-LEVANTE HIGH-SPEED RAILWAY LINE

ABSTRACT: Part of the Madrid-Valencia high-speed railway line, the Contreras Reservoir – Villargordo del Cabriel stretch represents an example of the use of the state-of-the-art construction systems, instigated by the limitations resulting from a layout that allows the running speed of up to 350 km/h, with large radii bends and gradients of less than 30‰ in area with rugged terrain conditions. It is against this background that the arch bridge over the reservoir stands. This is a reinforced concrete arch bridge with a 261 m span and an upper prestressed concrete deck that on the construction completion date was world record holder for a concrete railway arch bridge (Fig. 1).

Figure 1. View of the arch bridge built over the Contreras Reservoir

1 GENERAL DESCRIPTION

The bridge amounts to a total length of 587,25 m. The arch span measures 261 m and the mid-span sag is 36,944 m, which determines a span-to-rise ratio of 1/6,77 (Fig. 2).

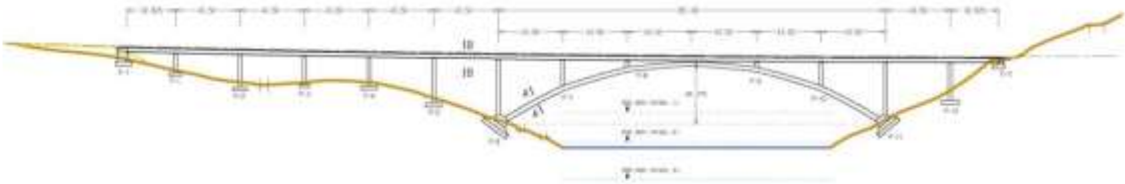

Figure 2. Elevation, plan view and cross sections

The arch is embedded in two large plinths that allow the diffusion of the load over the affected ground by means of direct foundations. It is divided in six parts with a polygonal directrix. That way the non-funicular arch is maintained while reducing the bending moments that would exist in the area between the vertical columns if the arch were perfectly curved.

The cross section is a box girder with a variable depth ranging from 2,80 m at mid-span to 3,40 m at the ends. The box girder width is also variable ranging from 6,00 m in the centre of the arch to 12,00 m at the foundations, which is the width required to resist the great bending moments of the vertical axis produced by the plan curvature of the arch and the crosswind. The box girder walls range from 0,60 to 1,35 m.

The upper deck span distribution is 32,625+12x43,50+32,625 m. The piers P-6 to P-11 are supported on the lower arch structure. The deck is made of a 3,00 m deep box girder (which determines a 1/14,50 span-to-rise ratio), a 5,00 m wide lower slab, a 6,50 m wide upper one, and series of segments that complete the total section width of 14,20 m. The web thickness is 0,50 m. The webs are thickened over the piers until reaching a total thickness of 1,27 m, to allow the anchoring of the service prestressing cables. The lower slab is 0,30 m thick.

The arch has a polygonal curved directrix in the vertical plane, which corresponds to the non-funicular of the permanent loads. In plan the arch is drawn within the circular alignment of 3 875 m radius in order to avoid eccentric forces at the points where the piers are built-in in the arch. It is made of reinforced concrete C-70, due to the great compressive forces it must bear.

The variable height of the piers ranges from 3,53 to 35,38 m. All the piers are generated by one basic pier which has a rectangular box-girder cross section of a 2,60 m constant width and a variable depth ranging from 5,20 m on the upper edge, 3,20 m at the "waist" situated 5,00 m away from the upper edge, and a widening towards the base.

2 ERECTION PROCESS

The construction method eventually chosen for this bridge and given its situation with respect to the water of the reservoir and the land was the cable-stayed free cantilever launching of the two semi-arches embedded in their foundations (Fig. 3).

A slight modification was taken into account. The proposal was to build the arch by cable-stayed incremental launching as well, only it was to be launched from the first pier of the arch, which was to be extended until reaching the ground where it was then appropriately. At the beginning of the construction, after a particularly favorable hydrological year for this purpose, the reservoir water level was such that the foundations of the temporary pier were above water level for months on end.

The construction process was carried out by first executing the approach viaduct and the deck piers using a climbing formwork for the piers and scaffolding truss for the deck.

The first section of each semi-arch, between the foundation and temporary piers, is built upon a centering supported on the ground. Once the centered arch section is built, piers P-7 and P-10 are executed over the arch, to allow the advance of the scaffolding truss towards these piers.

The centering is then dismantled and the advance of the semi-arches is initiated using cable stayed free cantilevers. To this end metal pylons were placed on the deck, following the vertical line of the temporary piers. From this moment on, the semi-arches advanced in free cantilevers while casted in situ using form traveler. To enable such procedure, we placed nine successive bundles of stay cables on each semi-arch.

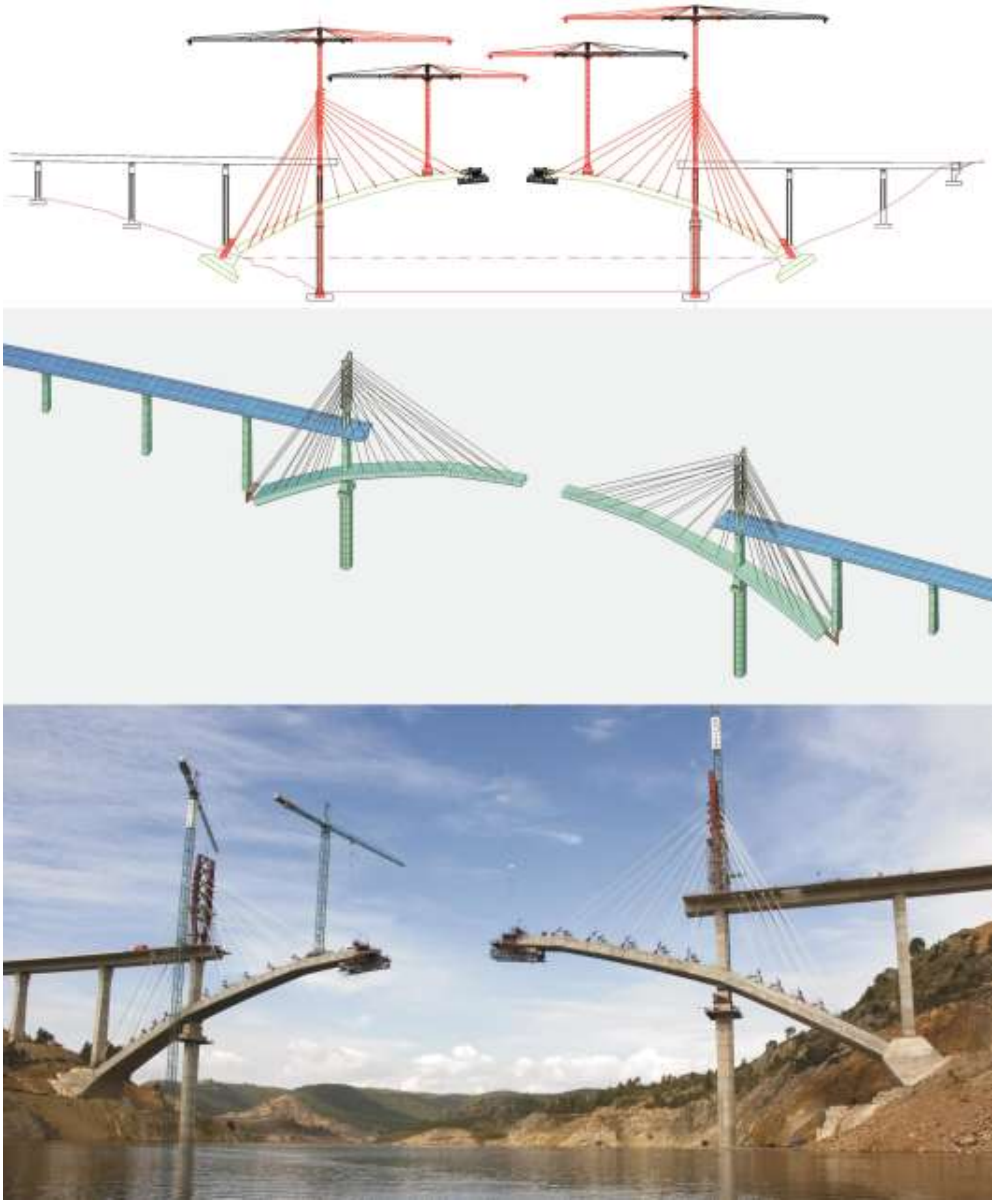

Figure 3. Cable-stayed free cantilever launching. Drawing, model and reality.

One very important matter to consider is whether the use of jacks at the key in a bridge built using temporary cable staying should or should not be applied. Jacks at the arch key are aimed at eliminating the forces and strains produced in the arch as a result of the deformation provoked by shortening of the directrix due to axial compression.

In this case, it was decided against placing jacks at the key, since nothing is gained from the structural point of view while it complicates the execution. This by no means implies that such a decision is to be generally applied in all cases.

RAILWAY ARCH BRIDGE OVER THE TAJO RIVER IN THE ALCANTARA RESERVOIR

ABSTRACT: Placed in the High-Speed Railway Line Madrid-Extremadura, the bridge has a total length of 1488m. The span distribution is influenced by the crossing of the Tajo River, which takes place with an arch, 324m long, and dividing the deck over it in six spans of 54m each one. The approach spans are 60m long, inserting two transition spans of 57m. The emblematic element of the bridge is aforementioned arch. With curve directrix, it is formed by a hollow variable section between (4.00m – 3.50m wide; 12.00m – 6.00m high). With its man span length of 324m, it will surpass the bridge over the Contreras Reservoir, currently the largest railway arch bridge executed in Spain.

1 GENERAL DESCRIPTION

The bridge has a total length of 1488m, with a span distribution of 45 + 9x60 + 57 + 324 + 57 + 7x60 + 45m.

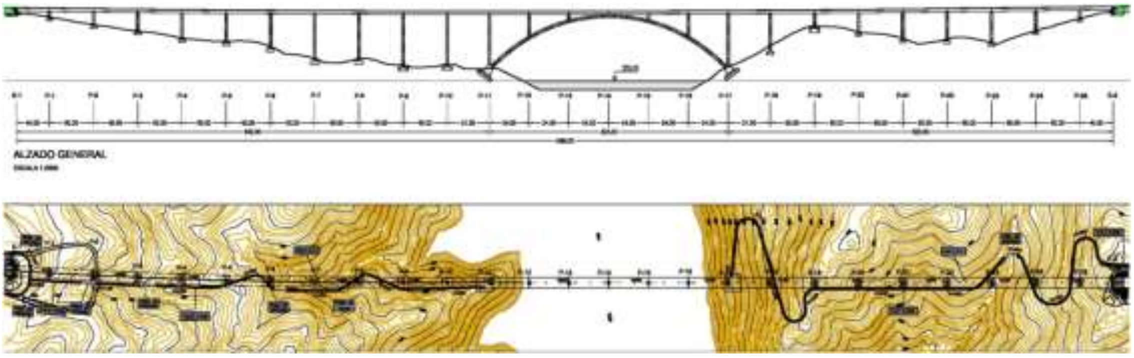

Figure. 1. General definition

The deck consists on a hollow prestressed concrete section with a height of 4.00m. This slenderness allows the structure to save appropriately the 60m approach spans, and so the 54m spans over the arch which, due to its flexibility, causes complementary bendings. The lower slab is 5.00m wide, and 6.50m the upper one, completed with cantilevers to reach a total width of 14.00m. The web thickness is 0.50m. Concrete HP-50 is used in the approach spans. Concrete HP-70 is necessary in the track over the arch.

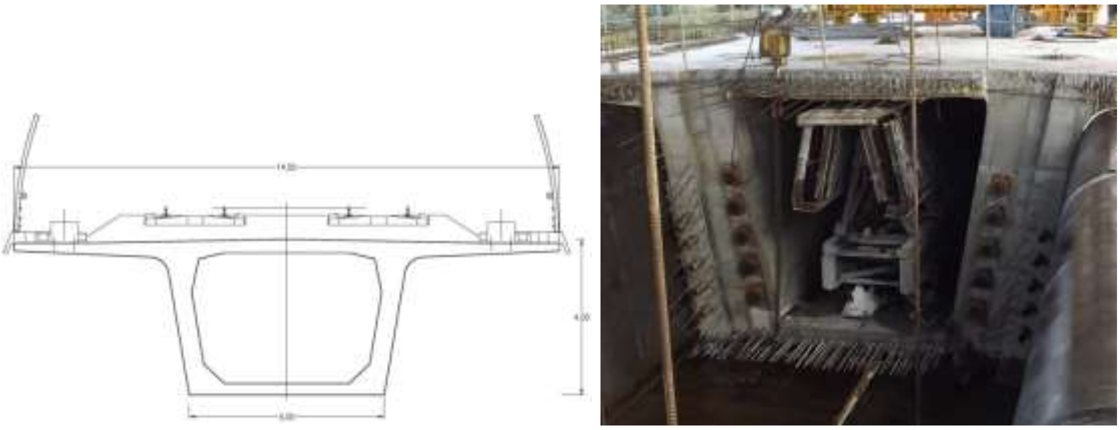

Figure. 2. Deck Definition

The approach spans have 5 prestressing tendons, between 25 y 37 ∅ 0.6” units in each web. In the spans over the arch they are complemented with upper and lower straight tendons.

Due to the deck length, larger than 1200m, the possibility of placing the fixed point of the horizontal actions in the key of the arch was studied and finally chosen as the best option. The increases of the stresses in the arch were acceptable. Using this configuration, typical expansion joints can be placed at both sides of the bridge.

The arch has a curve directrix in the vertical plan. This directrix has been obtained after a detailed process of optimization of the dead load bending stresses, looking for an approximation to the antifunicular curve of these actions. It consists on a quasi-rectangular hollow section with variable height between the start section, 4.00m, and the key section, 3.50m. The width varies linearly between 12.00m in the start section and 6.00m in the key section. The web and slabs thickness vary to achieve an almost homogenous distribution of the compression stresses. Concrete HA-70 is used.

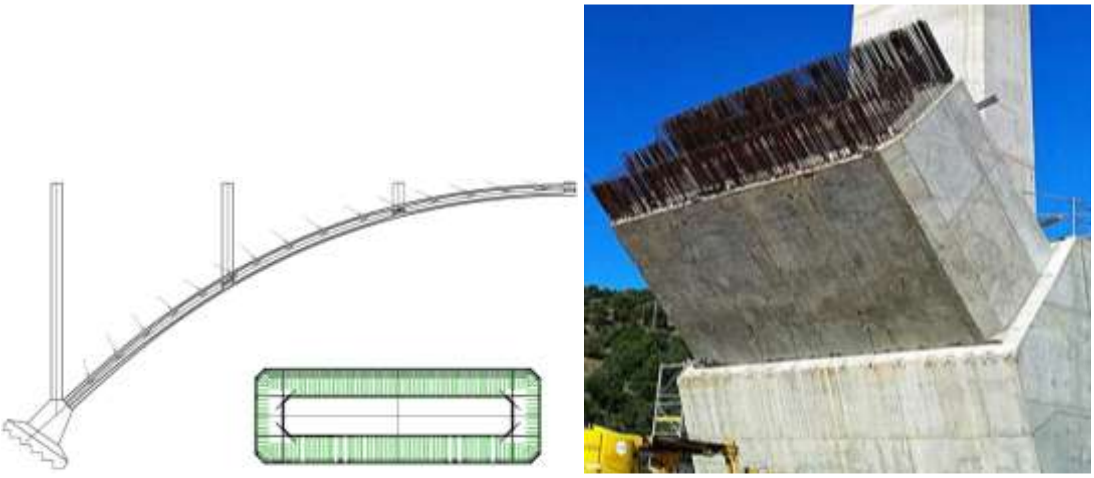

Figure. 3. Arch Definition

Due to the environmental conditions of the place, and also to the singularity of the structure, a complete study about the aeroelastic behavior of the arch, during the erection and also in service state, was developed with a reduced model in wind tunnel. The conclusion of this study was that the structure was not sensitive to any accountable phenomenon of instability due to wind in the different structural configurations.

The piers have a variable height between 9.60 y 71.50m. All of them are generated from a basic pier with hollow section, 3.50m wide and variable dimension between in the upper part, 3.20m in the waist, and widening through the base.

Spherical bearings are designed for all supports. Only in the case of the key support, it is needed to create a fixed point for the horizontal actions.

Due to the need of supporting the expansion devices over the structure, box abutments with intermediate walls are projected, with maximum heights of 8.63m en E-1 y 9.64m en E-2.

To carry out the environmental prescriptions, it is necessary to design barriers, 3.00m high, for bird protection. The barrier is formed by steel curve tubes with 100mm of diameter, each 0.50m. In their lower part, horizontal tubes with variable diameters are placed. A specific study about the aeroelastic behavior of the different shapes of barriers has been developed, resulting this one the optimum solution.

2 ERECTION PROCESS

The erection of the deck is developed span by span using a scaffolding truss, placed over both abutments. The central spans placed over the arch are designed to be built using traditional formwork.

To avoid excessive stresses in the arch, it has been studied a very symmetric erection of the deck. Only one span of difference is allowed between both sides during the construction.

It must be taken explicitly into account in this case the deformability of the system composed by deck, arch and piers during the process of execution of the deck over the arch. The behavior as an elastic support is absolutely is essential for an appropriate design of the interaction between the different structural elements that form the bridge.

Figure. 4. Deck construction with scaffolding truss

The erection of the arch is done using cable-stayed cantilever launching with provisional steel pylons. These towers are stayed to the foundations of the close piers, needing ground anchors to support the actions.

The necessary auxiliary resources are: a tower placed over pier P-11 for the erection of one semi-arch and other identical one over pier P-17 for the other one; a form traveler for each semi-arch; a cable-stay system which supports the built truck of each semi-arch anchored in the tower and other one that supports the tower anchored in the foundations. Finally, ground anchors are necessary to hold the foundations.

Each tower is composed by two columns joined with a K bracing. The section of each column is a hollow steel box. These columns are separated 6.50m to make the retention system form a vertical plan. As this separation is larger than the dimension of the pier head, the tower width is reduced in the joint between both elements. The K bracing is composed of horizontal beams placed each 4.00m and diagonal elements. Both are steel double T rolled profiles.

The form traveler is a steel auxiliary structure designed to support the formwork of each arch segment and allowing the cast in situ of that segment. The form traveler is supported in the area of the arch that has been recently erected, to prepare the casting of the next segment. These segments are about 3.80m long, taking into account a form traveler with a total weight of 95Tons.

Figure 5 Arch erection with form traveler

The process has been conceived using 15 couples of stays supporting each semi-arch, and another 15 couples that hold each tower. There is a couple of stays anchored in the arch each three segments. The typical separation of the cables in the tower is 2.00m. Only the first couple needs more separation, because they are almost vertical

The erection process of each semi-arch begins with the casting of the first segment, which formwork is supported with a centering placed over the arc foundation. This segment needs a minimum length to allow, after the hardening of the concrete, the location of the form traveler to start with the sequence of cable-stayed cantilever launching. Once the form traveler is placed in its position, the following segment is casted in cantilever. After that, the form traveler moves to the end of the second segment, to begin with the execution of the following segment.

The disposal of the first family of cables requires special attention, because the pier is not braced yet by the stay system. The process begins with load steps of the 25% of the total load of the cable, following always a established sequence studied to avoid undesirable unbalances. It is necessary to control the displacements at the top of the pier. Once the first family of cables is placed, the sequence continues casting the following segment and moving the form traveler until the next cable is reached.

The process enters in an iterative phase. Nevertheless, sometimes is necessary to modify the load of the cables, in order to avoid excessive stresses in the arch.

The sequence finishes after the disposal of the last cables and an ultimate modification of the load of the cables, to reach the desired geometry of the arch. At that moment, one of the form travelers is removed, while the other is adapted to proceed to casting of the key segment of the arch. The process is completed dismantling the provisional stays, starting in reverse order, and removing the rest of elements of the provisional cable-stayed system.

Figure 6. Current status / Final view of the bridge