VIADUCT FOR THE HIGH SPEED RAILWAY OVER THE RIVER ULLA (SPAIN)

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Abstract

The North-NorthWest new High Speed Railway crosses the deep (115 m) and windy valley of the river Ulla using a bridge that is 630 long. The bridge is an arch bridge that is 168 m long and 105 m high. The access spans are 52,0 m span.
The cross section of the arch is a reinforced concrete rectangular hollow section (7.7mx3.5 m). The shape of the arch is a "gothic" arch. The construction of the arch was a segmental construction using 26 segments for each half of the arch. Some temporary cables were used for the construction of the arch.
The deck is a continuous deck made of prestressed concrete. The total length of the spans located above the arch is 179 m and is made of six spans. The approaches are 1987 and 251 m long. The spans are 52 m long and the deck is 3.89 m high and 14 m wide. The construction of the deck was a span by span segmental construction using movable scaffoldings.
The piers are made of reinforced concrete. The width of the piers of the accesses spans is 3,5 m. The piers of the main spans are 2,5 m width. The width of the piers P5 and P11 located on both feet of the arch are 3,5 m width.

Keywords: High speed railway, stilted arch, stays, deck's segment, monitoring bridge, self-launching formwork girders.

1. LOCATION

The Viaduct over the River Ulla was built for the High Speed Railway line to the North-West of Spain to cross over the deep valley of the River Ulla. The location is a environmentally protected by a L.I.C. ((European Union General Interest Location) declaration, so there was no possibility of placing any piers on the 150 m width of the central part of the valley.

The valley is placed on a SW – NE direction, and so strong winds from the nearby Atlantic Ocean were to be considered.

Finally, it is to be said that the magnificient Viaduct of Gundián (figure 1), built in 1958, is located upstream the new Viaduct of the High Speed Railway.

Fig 1. Viaduct of Gundián (1958) located upstream the new viaduct

2. ANALYSIS OF STRUCTURAL SOLUTIONS

In order fulfilling the requirements of the location of the bridge, the total length of the bridge has to be some 630 m, having a central span 160 m and a maximum high over the terrain close to 115 m.

And so, three main solutions were analysed:

- <u>Solution I: Segmental prestressed concrete girder</u>
  Total length equal to 630 m having a central span of 159.4 m. The depth of the deck varies from 8.4 m when connecting to the central piers to 4.0 on mid central span (figure 2)

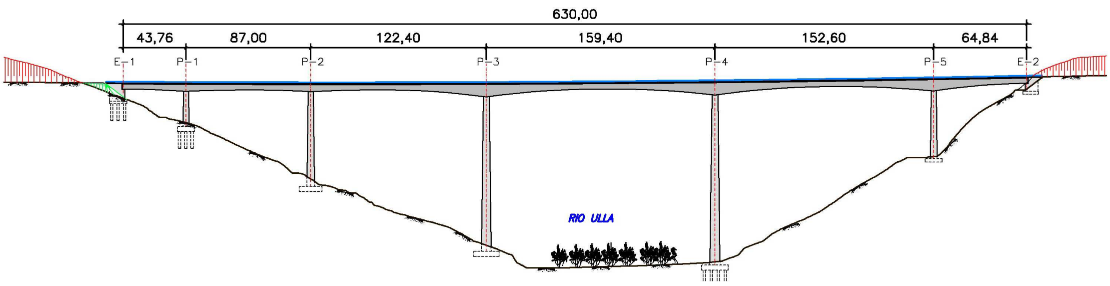

Fig 2. Solution 1. Segmental prestressed concrete bridge

- <u>Solution II: "Ojival" concrete arch</u>, central span = 168 m.
  "Ojival" (Tilted) arch made of reinforced concrete having a central span of 168 m and a vertical distance from the foundations to the central segment of 105 m. (Figure 3). The deck is a prestressed concrete box girder. The spans of the deck are 26.5 to 36.5 m long when supported by the arch and 52.0 m on both approaches to main arch.

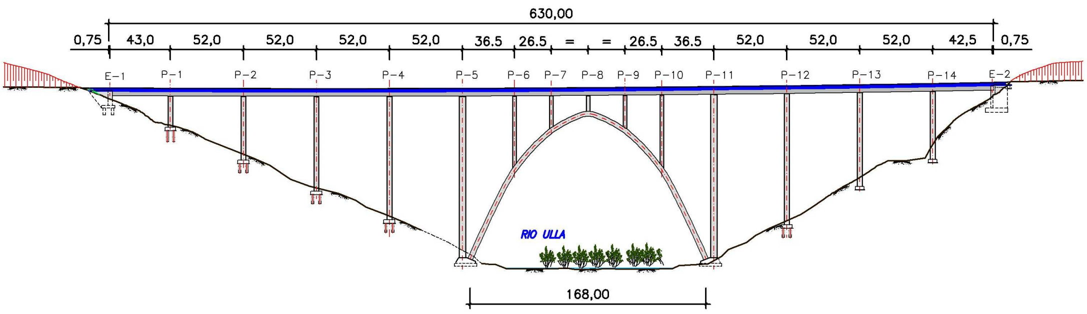

Fig 3. Solution II. "Ojival" arch (central span = 168 m)

- <u>Solution III: Concrete arch</u>, central span = 280 m
  Concrete arch made of reinforced concrete having a central span of 280 m and a vertical distance from the foundations to the central segment of 90 m. (Figure 4). The deck is a prestressed concrete box girder. The spans of the deck are 30 to 35 m long when supported by the arch and 53.4 m on both approaches to main arch.

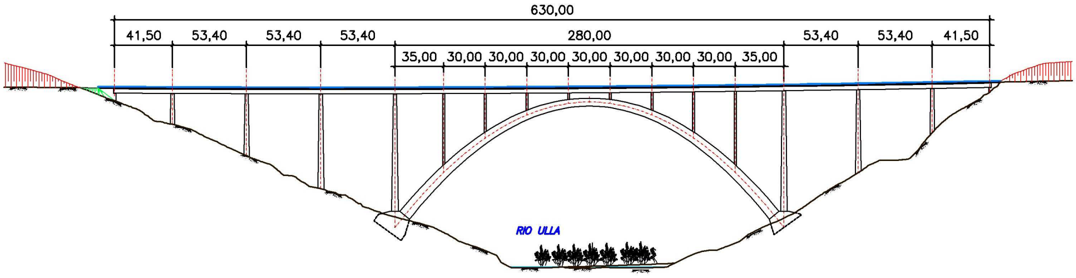

Fig 4. Solution III. Concrete arch (central span = 280 m)

3. DEFINITION OF THE PROPOSED SOLUTION

In the end Solution II. “Ojival” concrete arch – central span = 168 m was selected for the detailed design and finally constructed. Following a brief presentation of each structural element of the bridge is presented.

Fig 5. General view of the bridge

3.1. The Arch

The main arch is a rectangular cross box section (7.7 m x 3.5 m) made of reinforced concrete. The axis of the arch is not a continuous line but it is made of straight segments that are 2.5 m long each one. The span of the arch is 168 m and the height is 105 m. The total length of the arch is 277.56 m. The central segment of the arch is 11 m under the level of the deck.

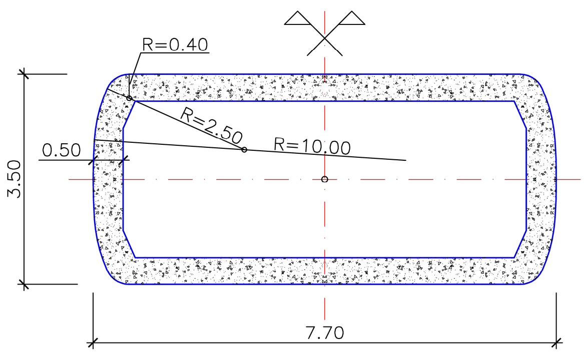

Fig 6. Cross section of the arch

The thickness of the deck 0.45 m, typically, (figure 6) but increasing it when getting the central segment of the arch. The cross section is not a perfect rectangular section, but the edges are curved in order to improve the resistant conditions of the arch when the dynamic effect of the wind load is to be considered.

Fig 7. Construction of the arch

There are 5 vertical piers connecting the arch to the deck. The central pier is on the central segment of the arch and the other piers are distanced 26.5 m one from each other.

3.2. The Deck

The deck is a continuous prestressed concrete deck that is 630 m long. The main segment of the deck is supported by the arch; it is made of six spans that are 26.5 + 4x36.5 + 26.5 m. The approach deck from the left abutment is 251 m long, divided in 5 spans that are 43 + 4x52. The approach deck from the right abutment is 198 m long, divided in 4 spans that are 3x52 + 42.5 m.

Fig 8. Construction of the deck

The height of the deck is 3.89 m. The webs are inclined . The box section is 5.5 m width on the bottom face and 7.5 m on the top slab; there are one cantilever on each side of the top slab in order the total width of the upper platform equal to 14.0 m (Figure 9)

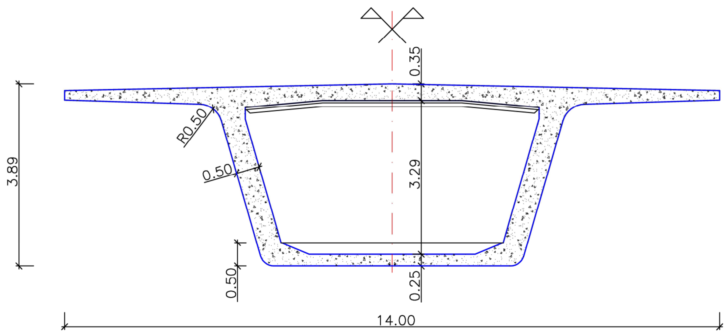

Fig 9. Cross section of the deck

The prestressing of the deck is made of 37 tendons made of 0.6" strands (1.40 cm^2). The tendons of the prestressing move up and down into the inclined webs of the concrete box of the deck. Additionally, there are 12 tendons placed into the bottom slab of the spans of the segment of the deck supported by the arch.

Because the bridge is supporting railway loads it is necessary having a fixed bearing somewhere, in order to support the big horizontal braking forces produced by the railway loads. The fixed bearing is located on the right abutment where the deck is anchoraged to the abutment using prestressing tendons.

3.3. The piers

The piers of the approaches are made reinforced concrete. The cross section is a box section: the depth is constant (3.5 m or 4.5 m) but the width varies from the top (5.5 m in width but increasing to 7.2 m at a distance of 3.35 m from the top of the pier) having a variation of 2/45 or 2/55 in width.

The piers that are connecting the central spans of the deck to the arch are also made of reinforced concrete. The cross section is also a box section (6.2 x 2.5 m)

Fig 10. Main pier of the approach deck

The cross section of the piers has an “hippodrome” shape, having two parallel faces and another two rounded sides (Figure 11). In doing so, the wind pressure coefficient is really reduced compared to the one of a rectangular cross section.

The thickness of the piers is always 0.35 m.

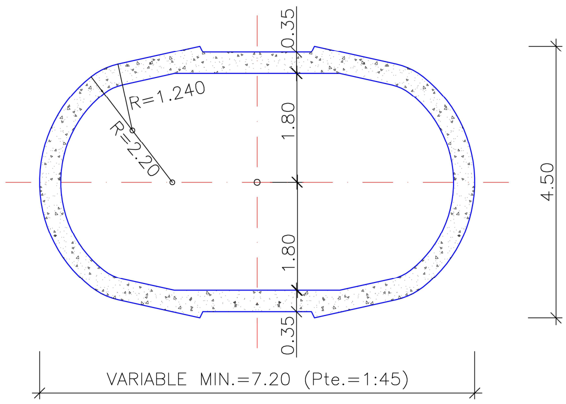

Fig 11. Cross section of the pier

Two type Pot bearings are placed on the top of each pier. On piers P1, P2, P7, P8 and P9 the bearings are free sliding and the remaining bearings are fixed bearings.

The foundation of the piers of the approaches (P1 to P4 and P12) are foundated using 8 cast in situ concrete piles that are 1.8 m in diameter. The foundation of pier P13 and P14 is a spread –shallow foundation. The pier P5 is supported by the foundation of the arch itself. This foundation is a spread foundation which dimensions are 25x16x6.20 m. The pier P11 is supported by the foundation of the arch. This foundation is made of a big pile cap which dimensions are 25x18x7.2 m. There are 32 1.8 m in diameter cast in situ concrete piles on the foundation of the said support of the arch.

3.4. The Abutments

The left abutment is made of reinforced concrete. The foundation abutment is made of 6 cast in situ concrete piles that are 1.8 m in diameter. There are also 24 inclined anchorages (1200 kN, nominal load) from the abutment to the terrain that are supporting the horizontal load of the deck due tensile effort produced on the deck while the construction of the arch as a cantilever. There are also 48 high strength steel bars connecting the anchorages to the deck itself.

The right abutment is an independent structure on its own constructed for supporting the horizontal loads produced by the railway actions. There is an upper reinforced concrete slab where the deck is connected using permanent prestressing tendons. The foundation of the abutment is a spread foundation which dimensions are 16x16x3 m,

The vertical load of the deck is supported by free sliding berings. Laterally, there are elastomeric + Teflon bearings. Finally, there are some longitudinal type POT bearings on the front transverse face of the deck used for sending the longitudinal forces due to the braking forces to the abutment.

4. METHOD OF CONSTRUCTION

The arch I sconstructed divided into two “halfarch”. Each halfarch is constructed using the cantilever segmental method (figure 12). There are 12 temporary ties made of high strength prestressing steel tendons supporting each halfarch (figure 13). Four of them are tying the arch to the main piers, P5 and P11. The other eight tying cables are connecting the arch to the deck. As it has been mentioned before the tension force on the deck is sent to the abutment using some prestressing tendons located into the deck itself.

Fig 12. Construction of the arch

There is also another set of cables connecting the middle of the main piers, P5 and P11 to the foundation of the adjacent piers; these set of cables is used for the regulation of the inclination of the main piers and also to accommodate the total bending moment on the base of the main piers while the arch is being constructed.

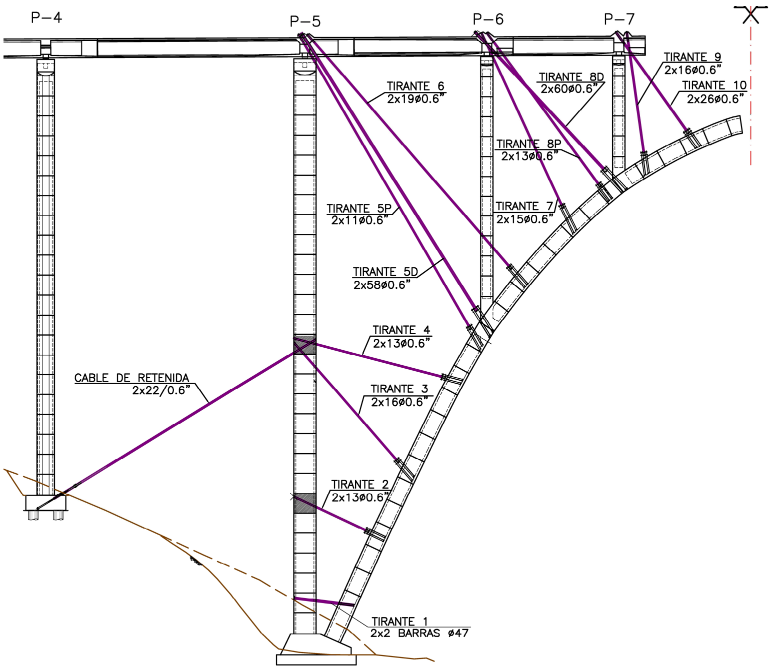

Fig 13. Structural scheme of the temporary ties for constructing the arch

The arch is being constructed at the same time as the piers and the deck is also being built. So, some segments of the arch, then the pier and then one span of the deck are built progressively. Once the two halfarch have been finished, then the central segment of the arch is cast in place. Finally the two spans of the deck from pier P7 to pier P9 are constructed.

The deck is constructed using a movable scaffolding. The movable scaffolding is supported on the piers (figure 14) and is used for constructing one complete span as one only segment. The construction joints are made close to 1/5 of the span length.

Fig 14. Support of the movable scaffolding of the deck on the piers

The pouring of the concrete of the deck is made on two stages: the first one is including the bottom slab and the lateral inclined webs of the box section; the second stage includes the top slab and the top cantilevers located on both sides of the top slab. PCP (precast concrete panels) are used as formwork of the said top slab.

5. SOME CONSIDERATIONS ON THE DESIGN

5.1. Comments on the wind loads

Due to the need of installing wind protection barriers on the deck, the depth of deck to be considered for the calculation of the wind load was really big. Also because of the location of the bridge on a deep valley, the expected wind peak velocity was really high (63 m/s).

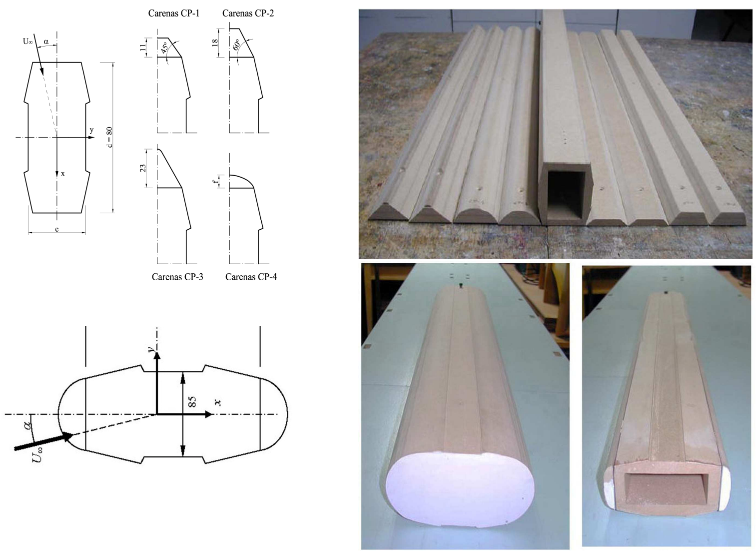

Fig 15. Models of the piers.

Consequently, the wind load was a relevant action for the designing of the bridge. Not only the design of the piers and of the arch was affected, but also the design of the deck because of torsional effects and transverse bending moment was relevant.

In order to reduce the effect of this important wind load on the bridge, some lab test were made in the "Laboratorio de Aerodinámica Ignacio Da Riva" of the "Universidad Politécnica de Madrid".

The results of the test demonstrated that the wind coefficient pressure on the piers, on the arch and on the deck where relevantly reduced from the values calculated accordingly the Eurocodes (EN1991-1.4). So, the forces and bending moments produced on the substructure and on the foundations were reduced from what it was expected based on a "normal" calculation.

The influence of the wind protection barrier on the deck was also analysed using a lab test study. The influence of the dynamic effect of the wind on the wagons of the railway was also analysed using some models; the influence of the height and of the inclination of the barriers was analysed (figure 16).

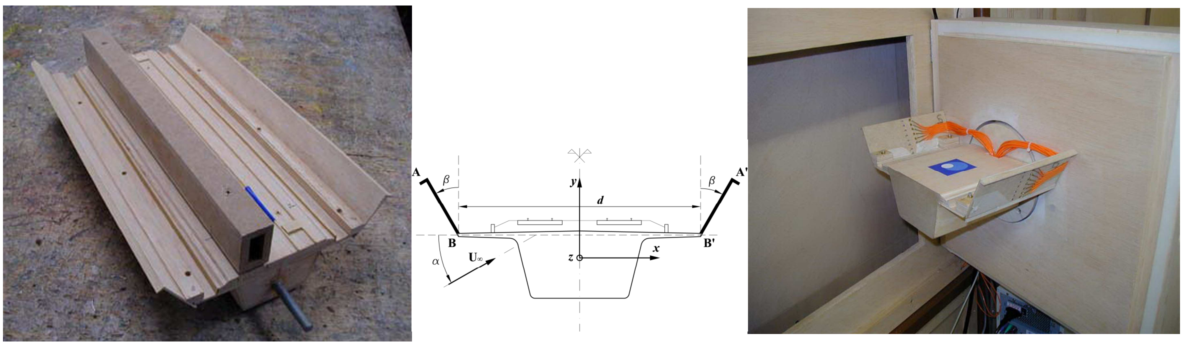

Fig 16. . Model of the deck, including wind protection barriers

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Finally, a detailed calculation considering the dynamic effect of the wind and also of the railway traffic itself was also made. The "Departamento de Mecánica de Medios Continuos y Teoría de Estructuras" of the Civil Engineering University of the "Universidad Politécnica de Madrid " collaborated on this detailed research.

As a result of the calculations it was demonstrated that the load son the arch and on the main and high piers produced by the transverse wind, are partially supported by the deck and sent to the remaining piers. In consequence it is necessary having a complex model of all the structure in order to properly evaluate the distribution of the loads due to the said transverse wind.

5.2. Comments on the prestressing of the deck

The prestressing tendons on the central spans of the deck are located mainly on the bottom slab, even on the sections where the deck is over the bearings of the piers.

This is an unusual location of the prestressing tendons that are usually located near the bottom slab on mid span but near the top slab when they get the section of the bearing of the piers.

This unusual location is due to the fact that the support of the deck on the arch is not a rigid support but it depends on the stiffness of the arch itself. That is, the supports of the deck on the arch are working as "quasi linear" (elastic) supports and so, the positive bending moment (tension on the bottom side) prevails on the calculations compared to the negative (tension on the upper side) bending moment (Figure 17)

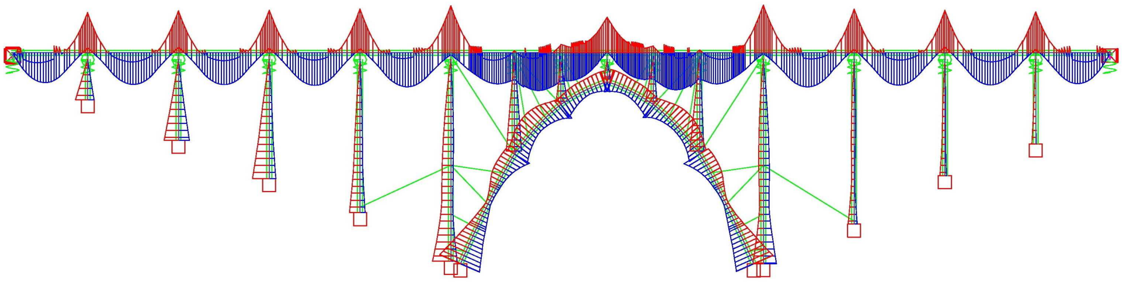

Fig 17. .Ultimate Limit State. Bending moments

5.3. Comments on the design of the piers

As it has been said the "fixed point" of the deck is the right abutment (E2 abutment). It has already been mentioned that free sliding bearings have been defined for piers P1 and P2, P7, P8 and P9. Nevertheless, fixed type POT bearings have been defined for the remaining piers, including piers P3, P4, P5 and P6 that are far away from the fixed point of the deck (E2 abutment).

The reason is that the piers are very high and, so, they have a reduced stiffness. That means that they are capable of properly resisting the bending efforts produced by the deformation on the top of the pier produced by the thermal action + creep and shrinkage. Defining the said bearings as fixed bearings, then the piers is working as a fixed-pinned column that is resisting the second order effects much better than a fix-free (cantilever) column.

6. SOME COMMENTS ON THE CONSTRUCTION

6.1. Temporary cables for the construction of the arch

The arch was constructed using a movable scaffolding. It was a segmental construction following the well known "cantilever method". Some temporary cables were used for resisting the bending moment due to the dead load of the concrete when constructing the segments of the arch.

The temporary cables were made of high strength prestressing steel tendons Y-1860-S7 type; the strands were 0.6" in diameter and 150 mm^2 in area. The ultimate load was 279 kN/strand.. The temporary cables of the main piers were made of 2 tendons of 22 strands; the retaining cables of the main piers were made of 2 tendons of 60 strands. The temporary cables close to central segment of the arch were made of two tendons of 22 strands.

The connection of each temporary cable to the arch was made using high strength steel bars in order to regulate the tension on the temporary cables while the arch is being constructed.

Fig 18. Connection of the temporary cables to the pier and to the foundation

6.2. The construction of the segments of the arch

The usual procedure for constructing each dosel-segment of the arch was as follows:

- Movement of the movable scaffolding once the strength of the concrete of the previous dowel is over the target calculated value.
- Installation of the new temporary cables (some new cables were installed once the dowels D3, D6, D10, D12, D13, D15, D18, D20, D21, D22 y D24 were finished)
- Adjusting the movable scaffolding to the correct position, taking into account the calculated “counterdeflection”
- Placement of the reinforcing of the new segment.
- Adjusting again the position of the scaffolding.
- Cast in situ the concrete of the new dowel.

7. MONITORING DURING THE CONSTRUCTION OF THE ARCH

The segmental construction of the arch using a movable scaffolding is a complex method of construction. So, a very detailed controlling of the construction is needed. In consequence a the monitoring of some elements during the construction was proposed.

The goal was having a good knowledge of the “load security factor” available on each stage of the construction and having the tools for getting a good reliability on the final geometry of the constructed arch.

In order to fulfill the two mentioned requirements, three different kind of monitoring were installed:

- Installation of strain gauges on some important sections of the arch
- Monitoring of the tension on the temporary cables
- Topographic survey of the movements and the rotation of the piers.

7.1. Installation of strain gauges

Some Stalin gauges were installed on some relevant sections of piers P5 and P6, and also on the central segment of the arch.

Using a sophisticated software specially designed for this monitoring, the axial load and the bending moments were obtained and compared to the results of the calculations during all the stages of the segmental construction.

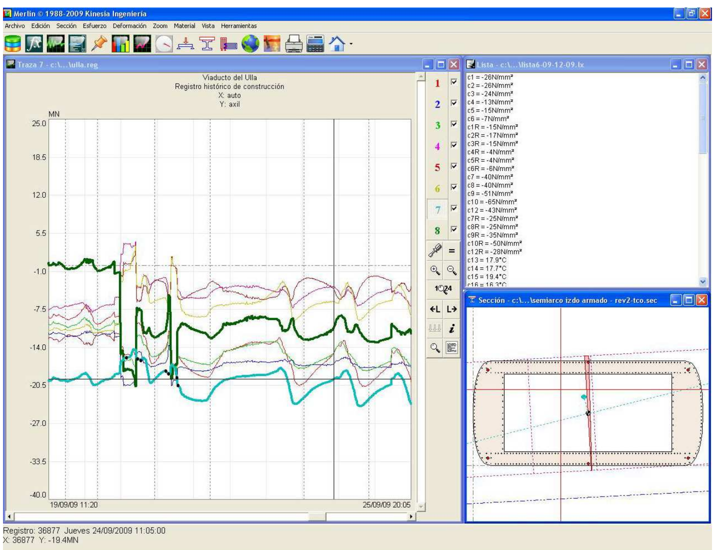

Fig 19. Results of the monitoring of the relevant cross section of pier P5

7.2. Monitoring the tensions of the temporary cables

The knowledge of the real load on each temporary cable during the construction process was very necessary. So, load cells (figure 20) were installed on each anchorage of each temporary cable.

The measured loads were compared with the expected values from the calculations and as a result of this procedure the actual load on the temporary cables was dully adjusted.

Also some cell loads were installed on the longitudinal berings of the abutments, in order to measure the actual value of the tension on the tension cables located into the deck..

Fig 20. Load cell on temporary cable and on the longitudinal bearing of the abutment

7.3. Measurement of the movements and rotations of the piers

Five clinometers for measuring the inclination of the top of the piers were installed. Also a detailed controlling of the horizontal movement of the top of the piers and of the segments of the arch was made.

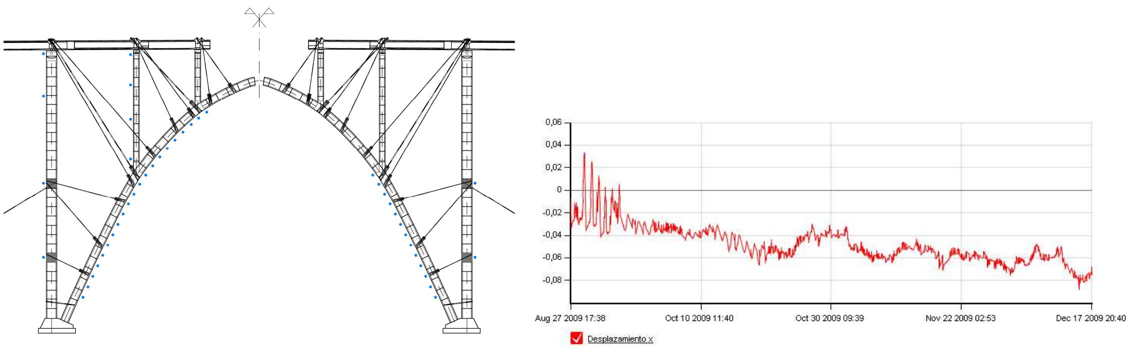

Fig 20. Results of the measurement of the movement of the central segment of the arch

Some high accuracy topographical apparatus were used in order to achieve a reliability on the measured deflections equal to ±10 mm