"TRES VOLTAS" VIADUCT
(A SOLUTION ROTATING PIERS)

Santiago Pérez-Fadón, MSc Civil Engineer, Ferrovial Agroman, Spain
José E. Herrero, MSc Civil Engineer, Ferrovial Agroman, Spain
Carlos J. Bajo, MSc Civil Engineer, Ferrovial Agroman, Spain
Fernando Gutiérrez, MSc Civil Engineer, Ferrovial Agroman, Spain
Marta Pérez, MSc Civil Engineer, Ferrovial Agroman, Spain

ABSTRACT

This bridge was design and built for a freeway in The Azores (Portugal). The other viaducts along that highway section are precast concrete I-girder decks spanning up to 42 m. Due to geotechnical aspects, it was not possible to place a pier in the middle of valley bed, and thus a 70 m span bridge seemed to be solution best suited to the problem. In order to use similar beams to those utilized in the other viaducts, a new solution needed to be worked out.

Two V shaped piers, one 82 m tall, were used to reduce the spans.

The main challenge was the erection of the pier pairs and, subsequently, the placement of the precast beams.

The viaduct's piers were erected vertically over steel hinges placed on each pile cap. After they were erected, the piers were ready to be rotated into their final positions. This was done with a system of stays arranged between the pier hammerheads and the adjacent pier foundations and abutments.

By means of SCC strand jack systems, and controlling the tensions and deformations of the cables using a central computer, the rotation was carried out successfully.

Once this operation was completed, precast beams were launched and connected to the piers.

The final complexion of the bridge was achieved by middle of November 2011.

Keywords: Azores, V06, viaduct, I-girders, rotation, hammerhead, stays, hinges.

1. INTRODUCTION

The before mentioned V06 bridge is part of the set of 23 viaducts that have been built for the SCUT Azores project on San Miguel Island (Portugal).

The project is divided into three main sections: Southern Alignment, North-Eastern Alignment and Northbound-Southbound Expressway.

The tender was won in 2005 and since then the development of the whole highway project has been carried out.

2. GEOMORPHOLOGICAL SURROUNDINGS

San Miguel Island is of volcanic origin and has the typical structure of this sort of soils; alternating layers of basalt flows, ashes, pumices, etc.

Eixo Sul, the southern alignment of the entire SCUT Azores project, where beds of ash and pumice frequently appear. These materials, highly susceptible to erosion, allow the continuous formation of large gullies or "grotas" leading to very deep valleys and ravines. Storm water runoff makes its way through these soils until it finds deeper bedrock levels, which are more resistant to erosion.

In addition to its volcanic nature, the island is located in the vicinity of the Azores-Gibraltar Fault. Therefore, seismic loads had to be taken into account, and the high probability of seismic events was added to the geotechnical aspects.

3. TYPOLOGIES

The design of the southern segment of the viaducts was also conditioned by the isolated nature of the location. This affected not only the initial project design but also the process of erection of the bridges. For example, in the North the widths of the valleys required long span viaducts to be used, while in the South (Eixo Sul), most of viaducts were fitted as precast I-girder decks spanning between 30 to 40m.

3.1. TYPOLOGIES CONSIDERED ON V06

The Ribera das Tres Voltas Valley is approximately 185m wide at its highest point, and the profile grade line runs around 100m above the river bed. These geometric constraints left us with two initial designs:

- A balanced cantilever precast segmental bridge with spans of 50-100-50 m
- Balanced cantilever cast-in-place segmental viaduct with span lengths 92.5-92.5 m. (See Figure 1)

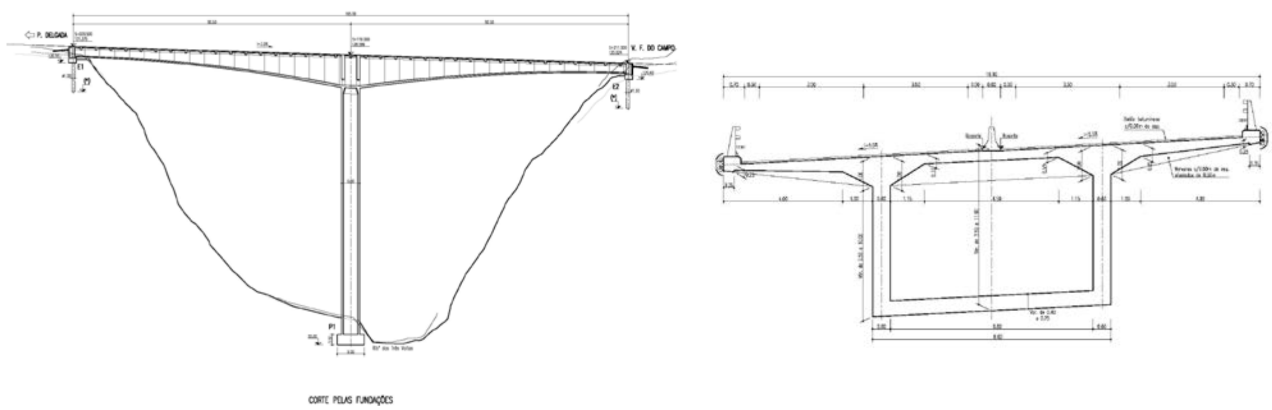

Fig. 1. Elevation and cross section of the first solution fitted

After careful consideration, the latter of the above mentioned designs was chosen as the preliminary design for two main reasons. First, in spite of there being five other cantilever precast segmental bridges with spans of up to 100m being constructed for the North-Eastern alignment, the Eixo Sul roadway required a width of 18m and the weight of a segment would have exceeded the maximum capacity of the launching gantry that had been shipped to the island. Second, this bridge would be the only cantilever segmental viaduct to be erected on the southern segment (Eixo Sul). Thus, the expenses resulting from the fabrication and additional means that would have had to be allocated to this process would have made it uneconomical.

It was finally decided to construct the bridge by means of cantilevers. Each cantilever was to be 92.5m in length and very similar to the ones being built, at the same time, for the Montabliz viaduct in Spain. In order to maintain the same form travelers, minimize changes, and to keep the same maximum depth and length, the new bridge segments had to be almost equal.

While carrying out the geotechnical investigation for the design of the pier foundations, a number of massive rocks were discovered in the river bed. It was impossible to bore through these rocks with the piling machines that had been shipped to the island, and as such, it was necessary to consider other design options. Eventually, the basis on which the final decision was taken relied upon auxiliary facilities that existed on the island.

3.2. ALTERNATIVE TYPOLOGIES V06

The presence of large blocks of rock in the river bed led us to reconsider the bridge design previously rejected, namely, a cantilever precast segmental bridge with three spans of 50-100-50m. However, the only way for this method to be possible would be to have a means of fabricating segments on site or to transport segments from the north, both of which were impossible to achieve.

Since other bridges throughout the Eixo Sul project were precast girder bridges, the possibility of building one for this particular case was studied. This would limit the spans to a maximum of 42m since that was the maximum beam length that could be constructed on the island.

Fig. 2. Rotation of Chonta viaduct piers. Opened in 1973

Launching this kind of bridge over a valley of such size would not be easy, due to its steep slopes (almost vertical) and its poor soil capacity. Under these conditions, it was decided to repeat the processes carried out at the CHONTA viaduct; a bridge built in Spain in the 70's with similar properties. This was adopted as the model for the final design of the structure of the Viaduct to be constructed over the Ribera das Tres Voltas Valley. (See Figure 2).

3.3. DESCRIPTION OF THE FINAL PROJECTED STRUCTURE

The finally structure has five spans of between 32 and 42m. Transversely, the deck consists of five 2.20m deep precast girders spaced at 3.65m and a 25cm thick reinforced concrete slab. (Figure 3)

The girders were treated as simple supported spans until they become continuous by means of a transversal concrete diaphragm that was built in a second phase. It allows a rigid connection between girders and piers, completely unifying them without the need for a bearing device.

The continuity of negative moments in the piers can be achieved by regular steel reinforcement in the concrete slab, created after the piece of slab cast over the piers had cured. Therefore, beams should support the weight of the greater part of the concrete slab as a simple span in order to decrease final negative bending moments in bents.

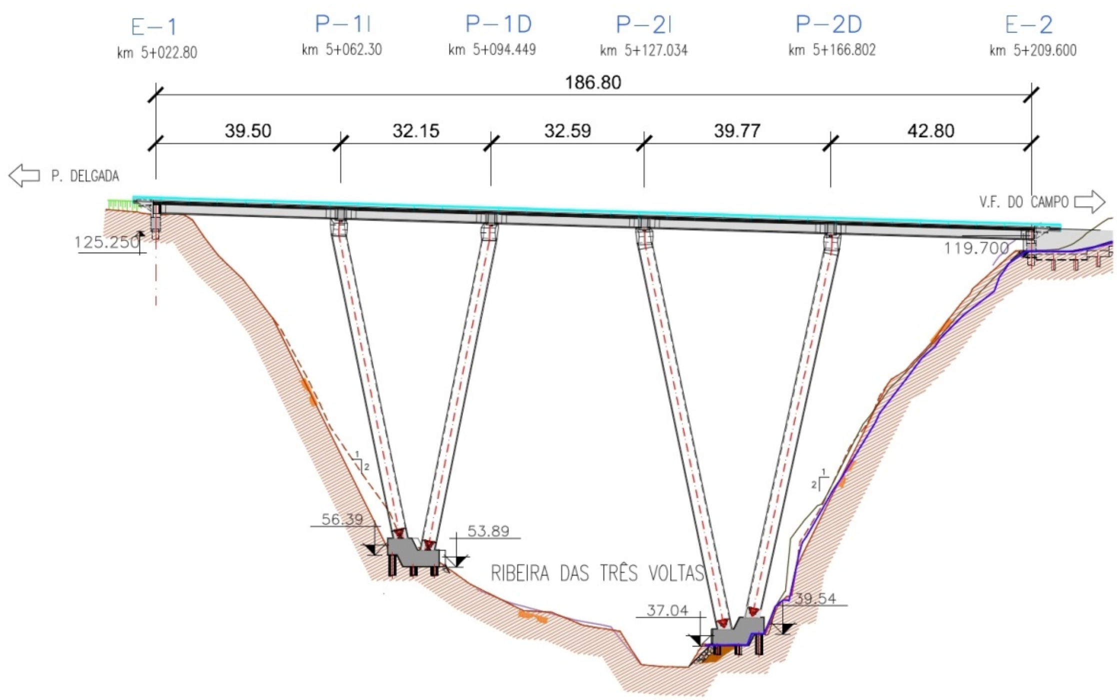

Fig. 3. Elevation of the projected structure

The viaduct's piers have different heights due to the valley morphology and the infill embankments built to reduce excavations. Thus, the first pair of piers is 65m high, while the second pair is 90m in height above its foundation.

The pier cross sections are 8.00 x 3.00 m hollow rectangular sections and are crowned with 18m long hammerheads. These hammerheads, in their final position, have a 3% longitudinal slope due to deck super-elevation, and form an angle of approximately 12° with the center line of each pier.

Each pier pair has a different angle of separation to the other, due to the outcome of a static equilibrium. There are no moments in the foundations because of the hinges from the combination of permanent loads. The angle between piers and a vertical axis is approximately 11.5 °, in their final positions.

Fig. 4. Aerial view of the construction of foundations

The Pier foundations consist of 18 piles, 1.50m in diameter and 25m in length, and stepped pile caps. The abutments rest over 5 floating piles 1.50m in diameter and 30 to 38m long. (See Figure 4)

4. CONSTRUCTION PROCESS

The construction process began with the pier foundations and abutments. Subsequently, piers were vertically constructed using climbing formwork. These piers rest on steel hinges arranged to accomplish the rotation of the piers to their final positions.

Fig. 5. Temporary bracing

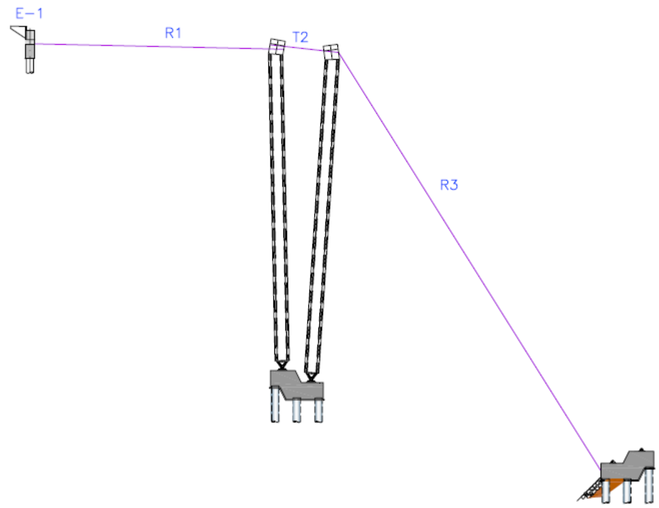

Fig. 6. Sketch of stay opening process

The equilibrium of each pair of piers during the vertical erection was achieved by bracing both with St. Andrew's crosses; these consisted of a set of Macalloy high strength bars, as ties, and rolled steel profiles placed between piers, as struts. (Figure 5).

Once the piers were positioned correctly, the hammerheads were built maintaining a 12º angle between the piers and the center line.

When the construction of the piers had been finished and they were ready to be rotated, several sets of stays, necessary for the movement, were placed. There were three different groups of stays:

- Group R1, back stays arranged between the abutment and left pier.
- Group T2, cables placed between both piers to be opened.
- Group R3, back stays arranged between the right pier and the foundation pile cap of adjacent piers. (Figure 6)

The movement is performed by consecutively activating the jacking system of groups R1, T2 and R3. The structural sketch of the cable-stayed system is as follows. Group T2 stays, which were placed between piers, were needed to balance the overturning moment caused by the weight tilting effect of each pier when its center line is displaced from the vertical position. The other cable families, called "back stays", are responsible for taking the pair of piers out of their equilibrium position, and balancing all the effect of all the overturning forces which were created.

The backstays which anchor the pair of piers to the ground, that is to say, those between the abutment and the left pier and those between the right pier and the foundation of the adjacent pair of piers, consist of 4 tendons with 7 strands. Meanwhile, there are 4 tendons with 8 strands between the piers. The cross-sectional area of the strands was 150 mm^2.

Moreover, an additional 8 strands were placed within the tendons between the piers as a contingency in case unexpected events occur. Fortunately, there was no need for these auxiliary strands during the opening of the first pair of piers.

Once each pair of piers was opened and tilted to its final position, the central girders of each span were placed and connected to hammerheads and abutments. After the pier-to-girder concrete connection had gained its proper strength, the bottom hinges, located in the pile caps, were restrained by encasing them in concrete. This will achieve the force continuity needed between the foundation and the pier.

5. ROTATION OF ELEMENTS. HINGES AND JACKING SYSTEMS

The jacking units used for the rotation of piers were regular lifting jacks, placed directly on the abutments, hammerheads and throughout the frameworks. They were always working in tension, on the foundation of the adjacent piers (Figure 7). The tension was controlled by means of a central computer, all data was collected in the board of operations.

The cables crossed the abutment bents and hammerheads by means of steel deviators, which were different shapes depending on the cable anchor type at their end. The deviators linked to the jacking units were trumpet-shaped rectangular cross sections. Those deviators prevented the strands from touching the interior walls throughout the movement.

Fig. 7. Lifting units arrangement for pile caps and hammerheads

At the head of the pier active units, framework was placed in order to permit rotation of the whole system, in case any anomalous contacts of the strands at the end of saddles were to be detected. In the end, it wasn’t necessary to make any adjustments to the cable trajectories, since contact between the stands was never detected.

The hinges are the elements that define the axis of rotation of the piers. Each pier rests on a pair of hinges, 1.85m in length, that were spaced at 7.00m. The structural idea of the hinge is based on a 200mm diameter rod pin resting on a cylindrical shape base, which is supported by transversal gusset plates welded to a horizontal plate, which in turn, is bolted to the pile cap. At the same time, the pier rests on the rod pin via a cylindrical shape base, connected to the concrete by a triangular steel truss (Figure 8).

Fig. 8. Lateral view and detail of hinges

Each rod pin is attached at its ends to a larger diameter circular steel plate that prevents transversal displacement in the piers throughout the operation and is used as a support against the effects of lateral force.

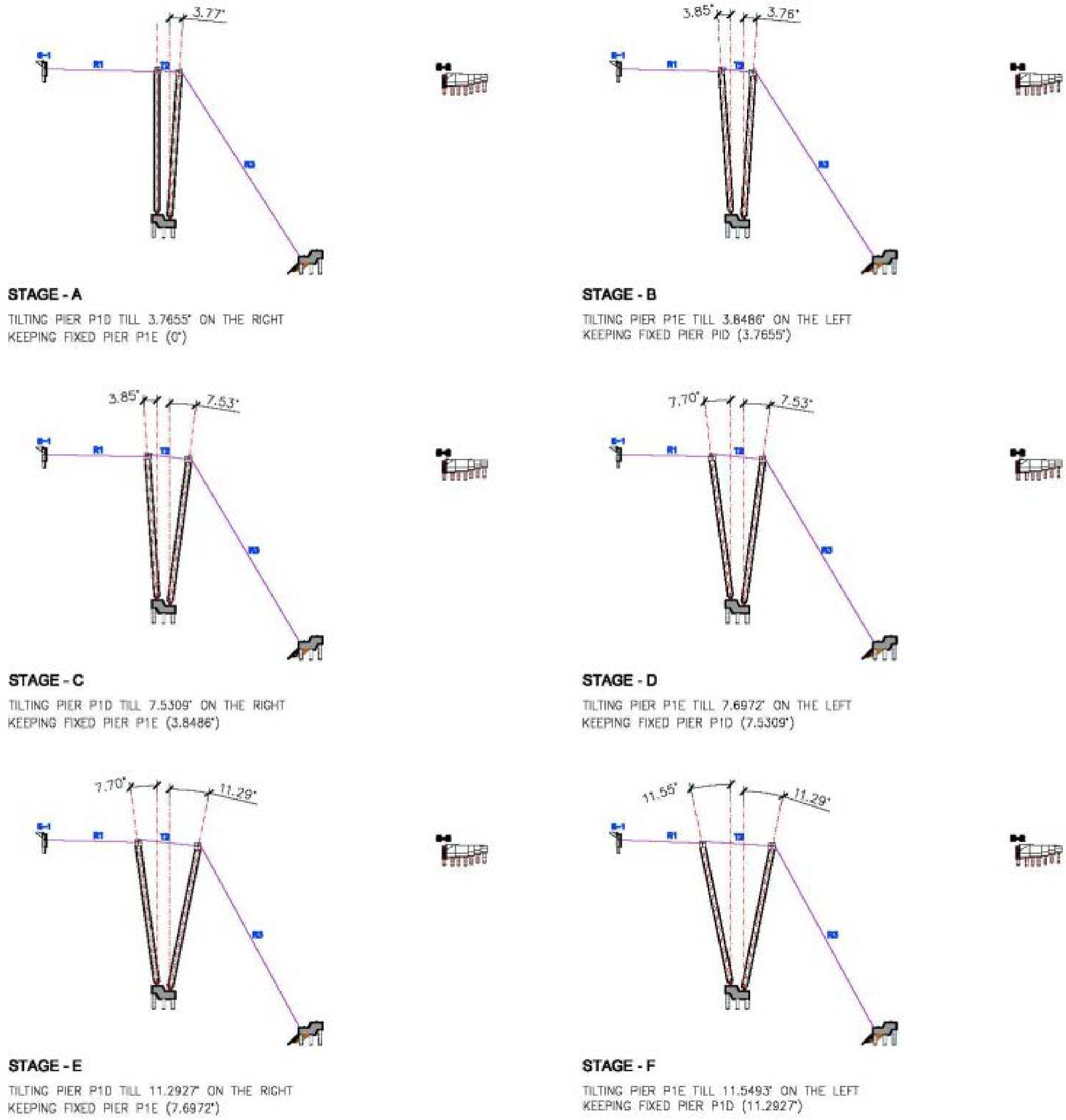

Figure 9. Opening phases of first pair of piers

6. ROTATION OF PIERS

The opening of each pair of piers does not affect the other; jacking devices used in the opening of the first pair are used in the rotation of the second one.

As mentioned before, the angle formed by each pier to the vertical axis in its final position is approximately 12°. Movements performed correspond to 4º angle openings, so, each pier is rotated to its final position in three steps. (Figure 9)

These steps are not carried out just once; the procedure consists of completing the first opening stage of 4º on one pier before performing the same operation on the other in order to maintain a balance between the pair (Figure 10).

The rotation began with phases A and B (Figure 9). These early stages were used to calibrate the calculation models, with tensions obtained from the cables. Thus, it was possible to work out the friction in the hinges and the variations in the self-weight of piers. After these first movements, the friction in the hinges and the self-weight deviations of the piers were found to be negligible, so they were not considered during the rest of the operation.

Fig. 10. System of stays arranged in the opening of the first pair of piers

The whole operation was finished with 274 alternative jacking movements, and took approximately 15 hours, spread over three non-consecutive days.

In Figure 11 the operation stresses of each of the four cables that composed each group of stays are listed. It can be observed that while the T2, shown in red, values keep increasing as the piers rotate and the angle is larger, the R1 and R3 values, shown in blue and green respectively, range swing above and below an average value of 20 tons. This is due to its role of balancing the system and avoiding the “V” swinging to both sides while the opening is being carried out.

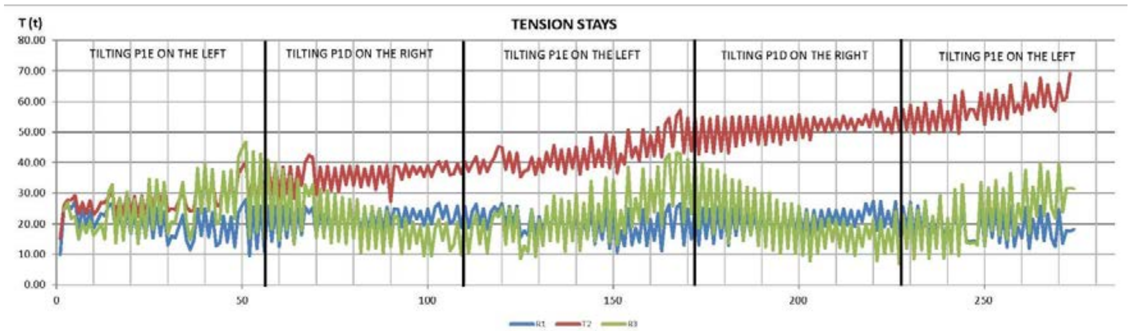

Figure 11. Operating stresses of stays throughout the opening

The tension of the Group R1 was restricted to 27 metric tons per tendon to limit the force transmitted to the abutment. This threshold increased the number of intermediate steps performed throughout the opening process. As mentioned before, the early stages of the movement were used to calibrate the system and detect variations due to piers self-weight and friction in the hinges. It was possible to check that these deviations were negligible and the maximum stress deviations measured in cables were less than 5% of the calculated figures.

7. LAUNCHING AND ERECTION OF THE BEAMS

Once both piers were opened and in position, central girders of each span were installed to maintain the equilibrium of the "V", before removing the stays. These beams, once connected to the hammerheads and the abutments, were the elements that maintained the equilibrium of the pair of piers and allow the launching of the other girders. (Fig 12)

Figure 12. Launching of the first viaduct girder. View from upstream.

For the erection of the central spine, the horizontal movement was restricted by a jacking system. These hydraulic jacks were placed between the rear wall of both abutments and the lower part of the beams at the outer-most spans. These jacks were kept in place until every element of the dead load was applied.

The stays between the piers were kept until all girders have been placed correctly and well connected to the piers or the abutments with the help of prestress bars. Those bars connected each beam to blocks on the top of the cap, see Figure 14. With this system the horizontal component due to the weight of each beam was taken by the previous beam.

The order of launching the beams was determined with the goal of maintaining the system balanced trying to avoid horizontal movements. The dimensions of the bridge were defined so that there was no bending moments at pier foundations under dead load. Only live loads and thermal loads will cause the movement of the whole system.

The beam placement occurred in the following procedure (every span had five beams):

- Central spine beams of every span but third.
- Two adjacent beams at first span.
- Other four beams at second span.
- The last two beams at first span.
- Two adjacent beams at fifth span
- Other four beams at fourth span.
- The last two beams at fifth span.
- The five beams left at middle span. (Fig 13)

Figure 13. Central spine beam at middle span

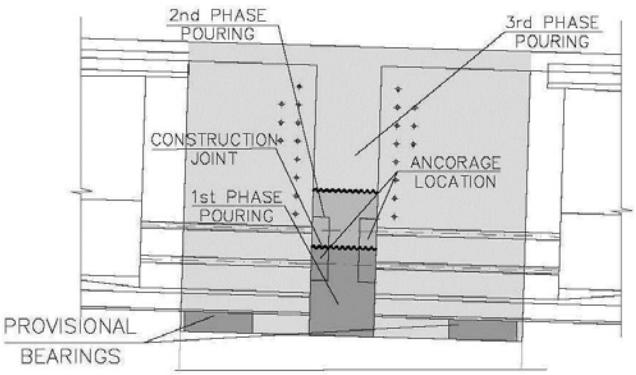

Figure 14. Connection between beams

The bridge was completed by the middle of November 2011 (Fig 15), and the motorway was finally opened by the middle of December 2011.

Figure 15. Overall view of the bridge

8. CONCLUSION

With this solution the capacity of regular precast beams has been improved jumping a big obstacle. The rotation of big piers is really safe and smooth thanks to a computerize system of stays and jacks.

9. ACKNOLOWEGES

- **PROPERTY:** SECRETARIA REGIONAL DE HABITAÇÃO E EQUIPAMENTOS. REGION AUTÓNOMA DOS AÇORES.
- **CLIENT:** EUROSCUT AZORES. CINTRA, S. A.
- **STRUCTURAL CONCEPT:** TECHNICAL OFFICE FERROVIAL.
- **VIADUCT DESIGN:** TECHNICAL OFFICE FERROVIAL, PROES.
- **ROTATION PROJECT:** TECHNICAL OFFICE FERROVIAL.
- **OPENING MANEUVER:** ALE HEAVY LIFTING.