PREFABRICATED VIADUCTS FOR SATUOEIRAS

José M. Camara – Associate Professor I.S.Técnico and a JSJ Partner
Jorge M. Rocha – JSJ Consultant Engineer
JSJ – Consultoria e Projectos, Lda.
Av. Sidónio Pais, 18 – 3º dto. 1050-215 Lisboa, Portugal

SUMMARY

In this paper the structural design and construction main features of a cable transportation system in construction near Lisbon is presented. The system is based on a cable moved vehicle that runs over a viaduct on a fast developing urban area. The aesthetical integration of the design solution was a main goal since the project begun, so the columns design, the beams external appearance and other aspects were carefully detailed. The construction procedures and design criteria and details, especially in the connections between the prefabricated elements, are outlined. In this project it is shown how concrete can be not only a versatile and efficient material but also an attractive one.

1. GENERAL DESCRIPTION OF THE PROJECT

SATUOeiras is a light public transportation system that connects two main train lines near Lisbon (see fig. 1a). The whole project, with a total length of about 10km, is divided into four phases, the first one (1300m) in service since June 2004 (see fig. 1b), the second (1200m) one to be built this year and the other two in study.

a – Global layout

c – Middle station and connecting viaducts

b – Overall view of the first phase

Fig. 1 – General project layout

The vehicles run on specially built viaducts, connecting stations that are above the ground level (see fig. 1c). The power supply for the first phase is located in the first station and for the second phase in the end station at Lagoas. The system is fully automated and the unmanned vehicles' movement is achieved by gripping a continuously moving guiding cable that runs under them. The choice of this kind of system is due mainly to the maximum slope of the rail that is, in the first phase, 12.5%.

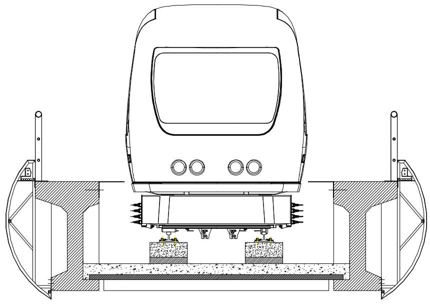

Fig. 2 – Cross section of the viaducts for the first phase

The viaducts allow for the passing of one vehicle, the intersection of the ascending and descending vehicles being limited to the stations. Their U cross section is composed by two post-tensioned beams, with heights from 1.70m to 1.75m, with a 0.25m thick slab connecting the bottom flanges (see fig.2). The top flange of the beams can be used as an emergency escape way.

2. DESCRIPTION OF THE STRUCTURE

2.1 General description

The first two phases of the system have five stations and four connecting viaducts, all of them structurally independent. The stations have a complex geometry, since they also include the duplication of the rail that allows for the crossing of the vehicles and, therefore, were always cast "in situ". The viaducts, on the other hand, were mainly built with prefabricated elements, in order to achieve a shorter construction period, with less interference with the surroundings and assuring the quality of the structure. The main beams, the transversal slab and the beams that support the rails were prefabricated and connected between them with "in situ" concrete (see fig. 3).

Fig. 3 – Construction phase of the connections between the prefabricated elements

Different construction solutions were adopted in the four viaducts. The first one, with a length of 360m, has two curves in plan with a radius of 130m and spans between 30m and 35m. These conditions made it difficult to use linear prefabricated beams, but the fact that the highest columns were about 20m high turned it interesting to avoid "in situ" casting. In order to minimise the visual impact of having straight beams with such a small radius, a special solution was developed in which the connections of the elements were located at around $^{1}/_{5}$ to $^{1}/_{4}$ of the span length (see fig. 4a). A standard 15m long prefabricated beam over the supports and span beams, with variable lengths and the same end detailing, were designed. A special connection between them, as described at §2.2, was then developed. This solution, in addition to the use of rounded cladding panels fixed to the outside of the beams, improved greatly the visual impact and aesthetical integration of the structure, disguising the angles between elements in such a way that they become practically unnoticeable (see fig. 4b).

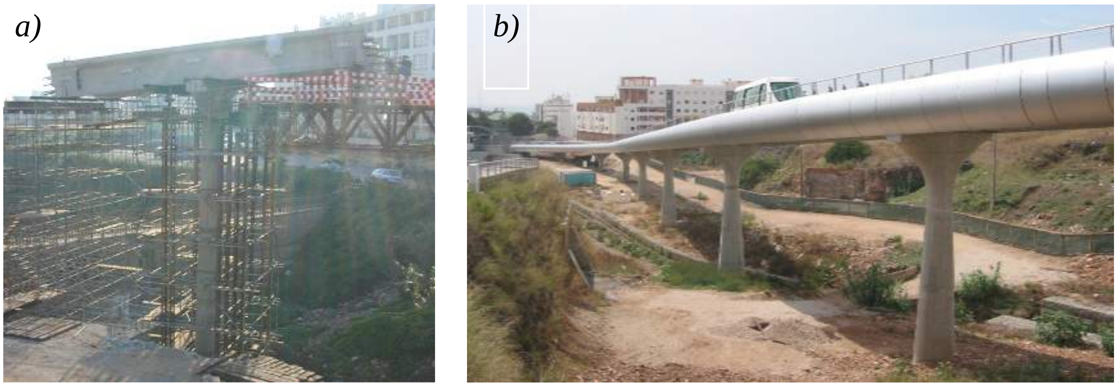

Fig. 4 – Construction phase and final view of the first viaduct in service

The second viaduct runs along an urban avenue, almost in a straight line, about 7m above the ground, with a length of 460m and spans of 33m (see fig. 5a). A traditional solution was adopted in this case, with prefabricated beams over the full span, connected on top of the columns. As in the first viaduct, cladding panels were adopted to improve the aesthetics of the structures. Also for this purpose, the bottom slab is discontinuous in these two viaducts allowing for GRC grids, which assure some transparency for an observer at the ground level (see fig. 5b).

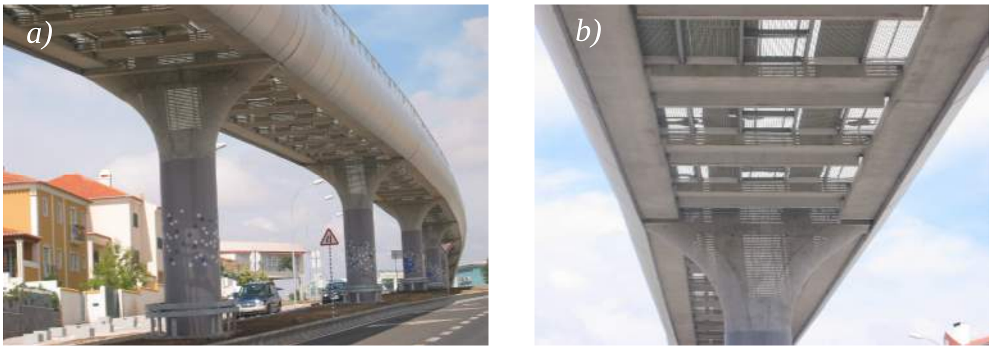

Fig. 5 – Final view of the second viaduct and detail of the underside view

As shown in figs. 4 and 5, the columns have a rectangular based cross section with two half circles at the tops. For the higher columns of the first viaduct a variable depth was adopted, which improved the structural behaviour and its aesthetics. The columns capitals were designed to correctly transmit the beam reactions and have a curvature that fitted well with the cladding panels.

The conception of the third and fourth viaducts was somewhat different, as they were integrated in a less urban environment and some design options were adapted to these circumstances.

The third viaduct has a length of 500m, average spans of 37m and it starts with a 50m radius curve in plan and a span length of 67m. A metallic arch suspends the viaduct, maintaining the same deck visual feature as that of the first phase (see fig. 6).

Fig. 6 – Preview of the start of the third viaduct with the metallic arch

For the rest of this viaduct prefabricated elements were used in the straight part of the track, being the curved one cast “in situ”. This option for “in situ” casting was adopted as the needed scaffolding height was small and the viaduct is not inserted in an urban area. As no cladding panels are used in this phase, a greater attention was given to the external face design of the main beams. A special cross section was adopted, with rounded corners, which give a favourable aspect to the whole structure (see fig. 7).

Fig. 7 – Cross section and preview of the third and fourth viaducts appearance

The fourth viaduct has a length of 580m with average spans of 37m, unless when crossing the A5 highway, where a 45m span was required. Being a straight viaduct, the structure is based on the same general prefabricated solution with 36.3m long beams. Over the motorway there is a cantilever at the column’s top that supports the beams during construction and, when in service, increases the section height (see fig 8).

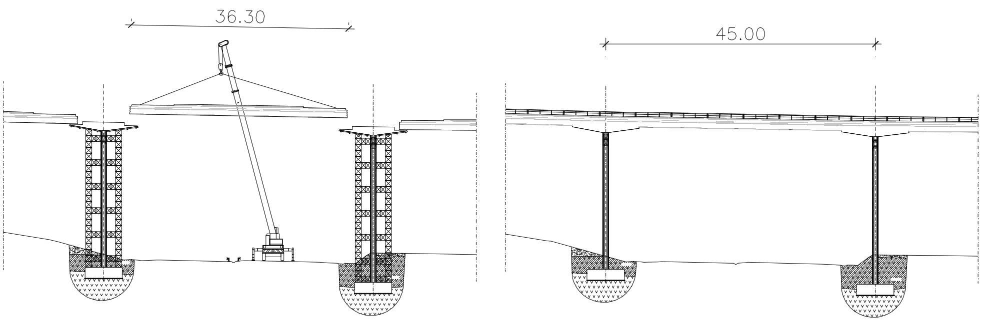

Fig. 8 – Construction procedure and final aspect of the highway crossing

2.2 Connections between the prefabricated beams

In this project three different types of connections between main prefabricated beams were adopted. This need arose from geometric constraints, in the first viaduct, and from serviceability design considerations, in the others.

In the first viaduct, with the connections located at sections of small stress resultants, they were done with a special grout and local post-tensioning of 3m long cables (see fig. 9a). The post-tensioning design criteria at these joints, which have no ordinary reinforcement, guarantees the limit state of decompression for full load, after considering some redistribution for the permanent loads due to time effects.

In the second viaduct the connections, located above the columns, are more traditional ones, with “in situ” casting and ordinary reinforcement giving continuity to the structure (see fig. 9b). In these joints the serviceability design criteria was to limit the eventual crack width to a characteristic value of 0.15mm. Due to permanent load redistribution effects, the reinforced concrete stress tends to reduce in time.

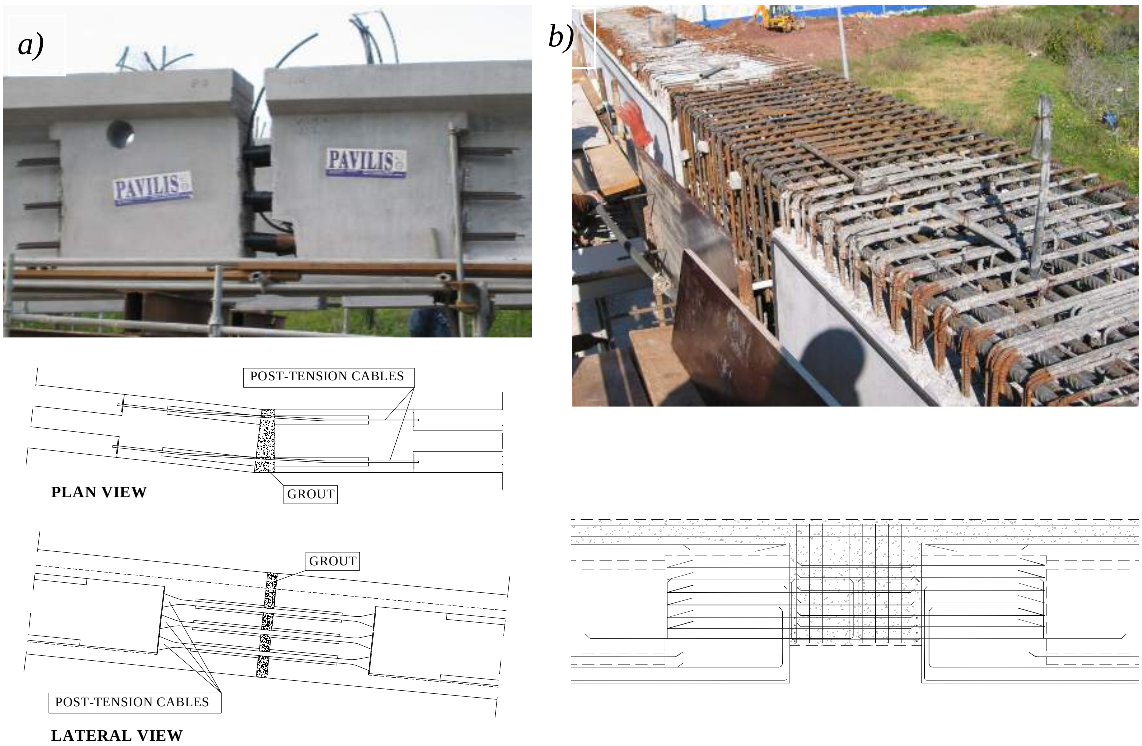

Fig. 9 – Connections details of the first phase viaducts

For the third and fourth viaducts the solution was identical. Because of the longer spans and the increase of the dead load, due to a continuous bottom slab and slightly heavier prefabricated beams, a reinforced and prestressed connection was adopted. Therefore 8m long cables were used over the supports, with the anchorages located at the internal face of the beams, not altering the viaduct external aspect (see fig. 10). Between the prefabricated and “in situ” built spans the prestress cables were used to connect them and give continuity to the structure. At the crossing of the highway, on the fourth viaduct, longer cables were used, with some adaptations to the specific conditions.

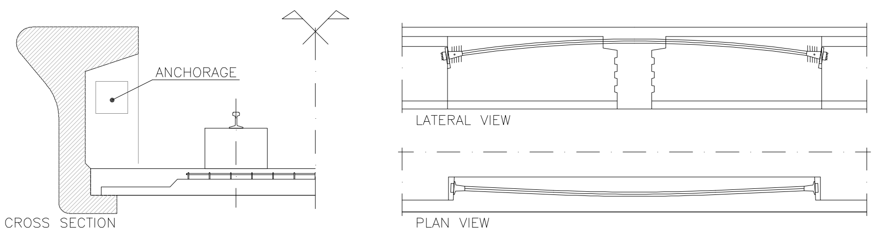

Fig. 10 – Details of the connections on the viaducts of the second phase

2.3 Stress distribution over the lifetime of the prefabricated structure

In viaducts built with prefabricated elements, stress redistribution occurs with time in the structure. The reason is the modification of the cross section proprieties and of the structural static system. The extent of the redistribution depends on a number of factors, being the most important concrete creep and construction procedure. The values of stresses obtained, in the first viaduct, for span and support beams, are shown in fig. 11.

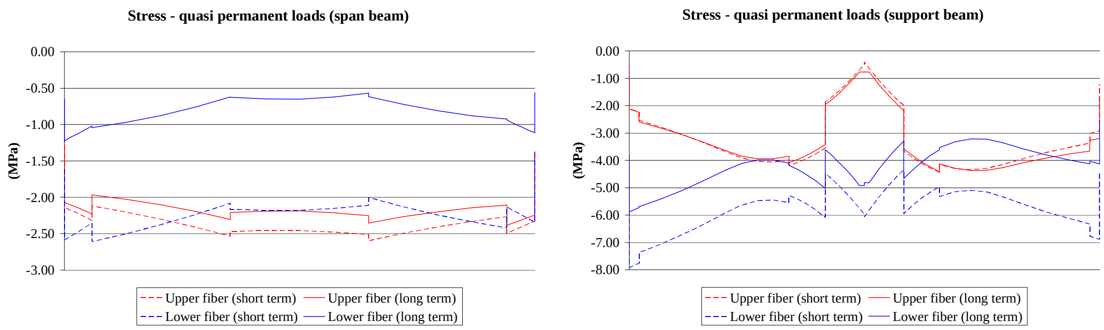

Fig. 11 – Stress distribution for two beams in the first viaduct

The decompression of the connection between the beams was verified in a separate model. An elastic analysis of the stress distribution due to the post-tensioning was performed (fig. 12) showing a good stress distribution at the joint. It was verified that the acting moment in these sections, for the rare combination of loads, was always smaller than the decompression one.

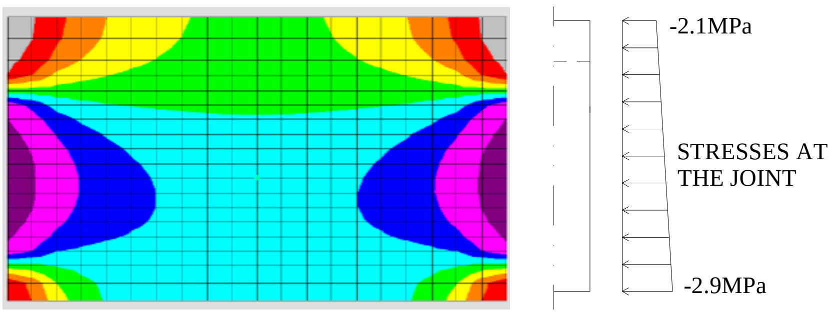

Fig. 12 – Stress distribution in the connection due to the post-tensioning of the cables

3. CONCLUSIONS

This article describes the main features of construction and design of a new transportation system built near Lisbon. It highlights the possibilities arising from the use of prefabrication in the construction of viaducts in urban areas with different cross sections. The columns were designed to ensure a good aesthetical integration of the whole system, and details were adopted to minimise the visual impact of some elements, like anchorages and supports. This project shows that concrete can be not only a versatile and efficient material, but also an attractive one.

Teixeira Duarte, SA was the constructor of the structure’s first phase, finished in September 2003, and the mechanical system was developed by POMA OTIS.