Rehabilitation of the Ramalho Ortigão Viaduct

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The Ramalho Ortigão Viaduct is an overpass carrying a high volume of traffic. The viaduct goes over one of the main Lisbon, Portugal, city center access routes (Avenue Calouste Gulbenkian), which itself has high daily traffic levels. The original viaduct was designed by Engineer Edgar Cardoso and was built by the company Empec in 1972.

The viaduct is 400 ft (112 m) long, its deck measures 80.7 ft (24.6 m), wide and has an obliqueness of 45 degrees. The available crossing width between the faces of the pillars/abutments is 232 ft (70.7 m).

The longitudinal system comprises two longitudinal, prestressed, reinforced concrete cantilever beams and a central reinforced concrete simply-supported span. The location of the expansion joints coincide with the supports of the central span. The structure is extended in the pillar/abutment zones through cantilevers fixed at their ends to a foundation beam.

The two longitudinal cantilever beams have a 116 ft (35.4 m) long overhang supporting the central section, which has a span of 32.8 ft (10 m). These cantilever beams start at an elevation of 13.7 ft (4.2 m), and the height is 5.3 ft (1.6 m) at their ends. The variation in height of the box girder is attained through a parabolic curve, and the height at the center of the central section is 5.1 ft (1.5 m).

The transverse section is formed by a tri-cellular box girder 26.2 ft (8 m) wide with two cantilever beams, each 27.2 ft (8.3 m) wide. Next to the box girder, the transverse cantilever beams are 2.13 ft (0.65 m) high whereas at their edges, where there are trapezoidal section kerb beams, they are 7.1 in. (0.18 m) high. The transverse cantilever slabs were cast with 24 cylindrical pipes arranged along the main axis of the construction, interrupted by transverse ribs 5.9 in. (0.15 m) wide at 4.1 ft (1.25 m) intervals along the length of the construction, forming a grid of ribs in the two main directions. Next to the expansion joints of the central section, the transverse cantilever beams are solid for 3.9 ft (1.2 m) of their length.

The box girder webs are 1.3 ft (0.4 m) thick. The thickness of the lower flange varies, while the upper one is of constant thickness throughout the entire length of the construction. The upper flange of the central cell is solid, while the lateral cells have an upper flange with four rows of castings and transversely varying height, with the greatest height being on the transverse cantilever beam side.

The pillars/abutments have a U-shape cross section and its direct foundations have a rectangular section with 18.9 x 9.6 ft^2 (5.8 x 2.9 m^2).

On the back of the pillars/abutments, the cantilevers are 1.3 ft (0.4 m) thick and extend the walls of the tri-cellular box girder, with lengths and heights varying according to the alignment. These walls take the passive anchoring of the platform's longitudinal prestressing at various heights and in different longitudinal positions, and they are prestressed in the vertical direction between the footing and their top.

Structural Assessment

To understand the causes of the pathologies detected, the following sets of in-place assessments were carried out:

- Visual inspection and measurement of deformation:
    - In the visible zones, the construction did not show any significant structural cracking; and
    - The deck was greatly deformed in the central section zone, with a difference at the expansion joints of approximately 3.9 in. (100 mm) in the central alignment of the deck (7.5 in. [190 mm] on the Campolide side, and 3.5 in. [90 mm] on the São Sebastião side).
- Tests and measurements on the materials:
    - In general, no signs of corrosion were observed, the coverings were in good condition, and no concrete carbonation problems were detected; and
    - The compressive strength of concrete of the structure was high—greater than 6500 psi (45 MPa)—and reached approximately 7975 psi (55 MPa) in some cases.
- Static and dynamic tests:
    - The deck recovered from the deformed configuration after removal of the loads exerted during the static loading test; and
    - Vibration levels, which can be considered uncomfortable for human beings, have been recorded in the dynamic test.

In light of the tests performed, and after analyzing the project, it was realized that the reasons for the deformations in the longitudinal cantilever beams were related, in principle, with the long-term effects of the behavior of the concrete and the prestressed steel. This could only be assessed through a full understanding of the construction sequence, the execution times for each segment, the strength of concrete, the age of the prestressing, the precision of the trestles, and the cambers.

The discrepancy between the vibration modes, measured experimentally and analytically, is possibly due to the strong restraint in some zones of the corbels, which led to the joining of the web edges. For example, this restraint was seen in the construction through the squashing of the lower zone of the support corbel on the São Sebastião side.

Taking into account the problems detected, it was possible to state with a high degree of certainty that the construction was not in danger of collapsing but, rather, was in a process of deterioration, with a foreseeable loss of durability occurring. Accordingly, it was decided to go ahead with the rehabilitation project.


Assembly of the working platform


Removal of concrete

Repair and Strengthening Solutions

- Objectives:
  - To establish a new grade line without any angular points, to reduce the dynamic action caused by traffic, thus lowering vibration levels;
  - To reduce the stress state of the longitudinal cantilever beams with partial recovery of the deformation; and
  - To fully respect current design codes (including consideration of seismic action, which is of great importance in Lisbon).
- Structural solutions:
  - Substitution of the central reinforced concrete section with a composite steel and concrete section, with the transverse cantilever beams of the new section, next to the kerbs functioning like an orthotropic metal slab, due to its reduced thickness;
  - Use of L40/44 D1.8 light structural concrete in the composite span and in the fillings over the longitudinal cantilever beams;
  - Extension of the overhang of the corbels for the better fitting of the support devices and their possible substitution;
  - Use of carbon fiber-reinforced polymer (CFRP) fabrics to increase the resistance of the longitudinal box girder to the lateral forces/longitudinal torsion; and
  - Use of carbon fiber laminates to increase the bending moment strength of the transverse cantilever beams.
- Other works:
  - Reprofiling the grade line, the cornices, and the guardrails;
  - New pavements;
  - New expansion joints;
  - Injecting and/or sealing cracks;
  - Replacing minimum covering;
  - Repairing concrete in zones where steel reinforcements are visible; and
  - Painting the concrete structure with acrylic paint.

Strengthening and Rehabilitation Works

Putting up public thoroughfare protection

The first step taken was to put up a platform to protect the public thoroughfare and allow the work to proceed with traffic being affected as little as possible.

Table 1

Cement	Fly Ash	Fine grained sand	Structural clay 2/4	Structural clay 4/8	Water	Admixture
950 lb	220 lb	860 lb	1111 lb	448 lb	37.5 gal.	2.3 gal.
430 kg	100 kg	390 kg	504 kg	203 kg	142 L	8.6 L

Table 2

Time	Compressive strength, psi (MPa)	Modulus of elasticity, ksi (MPa)
28 hours	6048 (41.7)	—
94 hours	6062 (41.8)	—
7 days	6788 (46.8)	2575 (17,750)
14 days	8050 (55.5)	—
28 days	8064 (55.6)	2800 (19,300)

This structure was very carefully studied so it could be used for both the protection of the public thoroughfare and shoring up the central concrete segment during the phase when the latter was being removed.

Removal of central concrete segment

As mentioned previously, the central reinforced concrete section was replaced by a composite steel and concrete section, thus achieving a substantial reduction in the weight of this structural element (approximately 50%).

The weight of the original central segment was approximately 275 tons (250 metric tons) and so it was necessary to divide this up into lighter units to be able to remove it quickly and safely.

Fitting of the metallic segment

The manufacturing of the metallic segment was studied to reduce the on-site fitting time to the minimum. Accordingly, it was prefabricated in the work yard and transported in nine main elements.

The various elements were put on top of the shoring structure so that they could be aligned and leveled using the shoring units and small hydraulic jacks. After all the prefabricated sections had been fixed in place, the closing steel plates were fitted along with the connectors that ensure the connection of the metallic structure to the reinforced concrete. The entire metallic structure was then covered with an epoxy protective paint.

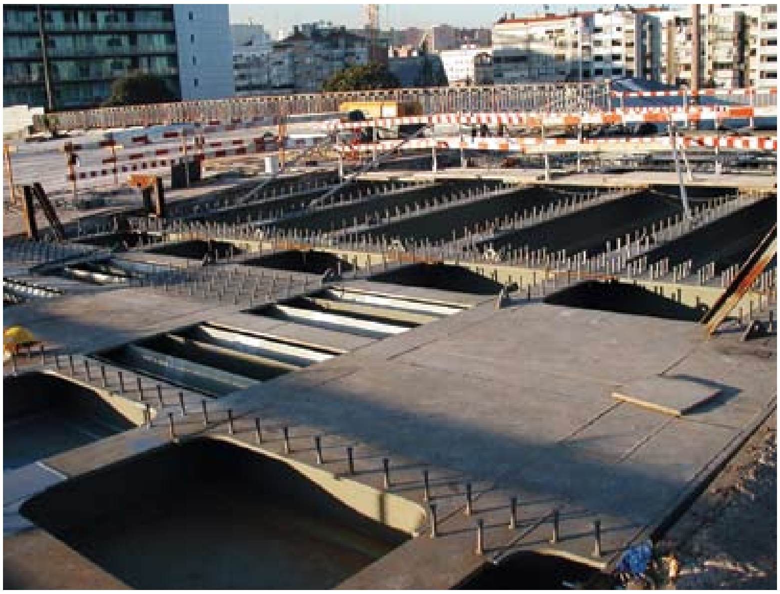
Application of light structural concrete

Light structural L40/44 D1.8 type concrete was applied to the entire slab of the deck and it was the first time this type of concrete was used in Portugal. It took approximately 3 months to study the composition of this concrete, with all of the planned tests being carried to guarantee the homogeneity of the final product. The final composition of this structural material is given in Table 1.

Internal reinforcement with CRFP fabrics

External reinforcement with CRFP fabrics

External reinforcement with CRFP laminates



General view of the metal structure

Application of cold asphalt

Before the deck was concreted, several test panels were made to analyze the most suitable way of working with this type of concrete and the setting process.

Once the homogeneity of the concrete was guaranteed, it was applied to the entire slab of the deck in different thicknesses so as to achieve the new grade line planned. The concrete was applied by direct discharge and the characteristics shown in Table 2 were achieved.

Application of carbon fiber fabric

The carbon fabric was applied in one or two layers, as per the final design, using automated equipment to impregnate the fibers with the resin.

The main difficulty in applying the carbon fibers was not related to any specific technical aspect but did concern ensuring the safety of the workers when applying the fibers to the interior surfaces of the viaduct cells. The work was mostly carried out in confined spaces and it was necessary to use ventilation equipment for the cells and to equip the workers with individual breathing apparatus to avoid any problems of intoxication through the inhaling of fumes from the epoxy resin used for impregnating the carbon fibers.

Application of carbon fiber laminates

To guarantee the bending moment strength of the fixing sections of the lateral cantilever beams, carbon fiber laminates were applied to the upper side of the slab, in the transverse direction. The main difficulty of this operation was ensuring the correct surface moisture of the concrete (less than 4%) because there was heavy rainfall at the time the laminates were applied.

After the carbon fibers had been applied and the deck had been given its variable-thickness concrete coating, using the light structural concrete, it was decided to apply cold bitumen instead of standard bitumen, which reaches a temperature of up to 248 °F (120 °C), to prevent damage of the epoxy resin.

Load testing after completion of the works

The main objective of the load testing carried out by the Laboratório Nacional de Engenharia Civil (National Civil Engineering Laboratory-Lisbon) was to check the deformation and vibration modulus values of the viaduct after the repair and strengthening, comparing these with the forecast values set out in the final design.

To find out these values, static and dynamic loading tests were carried out. The structural response of the viaduct was as follows:

- Static load test
  - Good agreement of the experimental and the analytical results; and
  - Linear-elastic response for the load level adopted.

Load testing

- Dynamic load test
  - Good agreement of the experimental and the analytical results, particularly with regard to the vibration frequencies and modulus; and
  - Lower vibration amplitude of the structure caused by traffic, due to the absence of angular points.

Ramalho Ortigão Viaduct

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