

## **REPAIR AND CONSERVATION WORKS ON TAGUS SUSPENSION BRIDGE**

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### **ABSTRACT**

Completed in 1966, the magnificent Bridge over Tagus, also known as 25<sup>th</sup> April Bridge, is still one of the most important accesses to the city of Lisbon nowadays. Maintenance works have been successfully implemented on Tagus Suspension Bridge concerning both its concrete and metallic structural and construction elements. This paper presents the most relevant aspects of the repair and conservation works that pertain to the Bridge maintenance program and actions with respect to durability and appearance. The works were awarded by “Estradas de Portugal, SA”, the general concessionaire of the Portuguese Road Network, to a consortium of two Portuguese companies: AMAL and STAP.

**KEYWORDS:** suspension bridge, maintenance, mechanical repair, concrete repair, sprayed concrete, concrete injections, treatment of cracks, protective coatings.

### **1 INTRODUCTION**

The 25<sup>th</sup> April Bridge was the only crossing over Tagus with direct access to Lisbon until the late 1990s and is still a very important transportation infrastructure at the present time. The Bridge was designed from the outset to carry a roadway and a lower railway deck. In 1966 the Bridge was originally opened as a four lane road. In the summer of 1999 the lower railway deck was ready to be used after major preparatory works which included the retrofitting of the rigidity beam, the fitting of additional cables, the widening of the roadway to six lanes (maximum capacity) as well as coating of the bridge.

The Tagus Bridge consists of a metallic suspension structure with two carbon steel towers and is almost 2300m long between anchorages, with the central span being 1013m long. The bridge crosses the Tagus at a free sailing height of 70m and the two imposing towers, which are situated almost half a kilometer from the riversides, are 190,5m high from the water level. Its foundations at about 80m deep into basalt rock were also a world

record at the time of their sinking. In the north, the Bridge is connected to a concrete viaduct that is 945m long. The Bridge, when it was built, had the longest span among any European suspension bridge.



Fig. 1 South view of the Bridge over Tagus. Fig. 2 Inside view of the railway.

## 2 MAINTENANCE MANAGEMENT

The *Ponte 25 de Abril Office*, which was created within *Estradas de Portugal, SA*, the general concessionaire of the Portuguese Road Network, in November 2008, is responsible for promoting the development of inspection, maintenance and repair actions in order to guarantee the existence of appropriate conditions of service use of the Bridge over Tagus.

A new integrated management model was adopted by the *Ponte 25 de Abril Office* and in 2009 relevant activities were developed. The Conservation and Repair Project was awarded to Talprojecto and included two areas of intervention: repair works resulting from normal use of the infrastructure, identified through regular inspection activities by ISQ; enhancement of security and accessibility conditions for the staff performing the conservation tasks.

Others activities were: inspection and supervising contract awarded to ISQ following public invitation; validation by LNEC of the structure of the Quality Manual; preparation of tender documents for underwater inspection; management contracts for operation and maintenance of equipment installed on the bridge; acquisition of devices and miscellaneous supplies and maintenance contracts; preparation of tender for the Conservation and Repair Contract.

The conservation and repair works were awarded by *Estradas de Portugal, SA* to a consortium of two Portuguese companies: Amal and Stap. The works sum up to €7.985.617,61 and were divided between the contractors according to their specialization areas of businesses. Amal became in charge of the steel repairing works of the Bridge. The concrete rehabilitation works of the Bridge and its north viaduct access were performed by Stap.

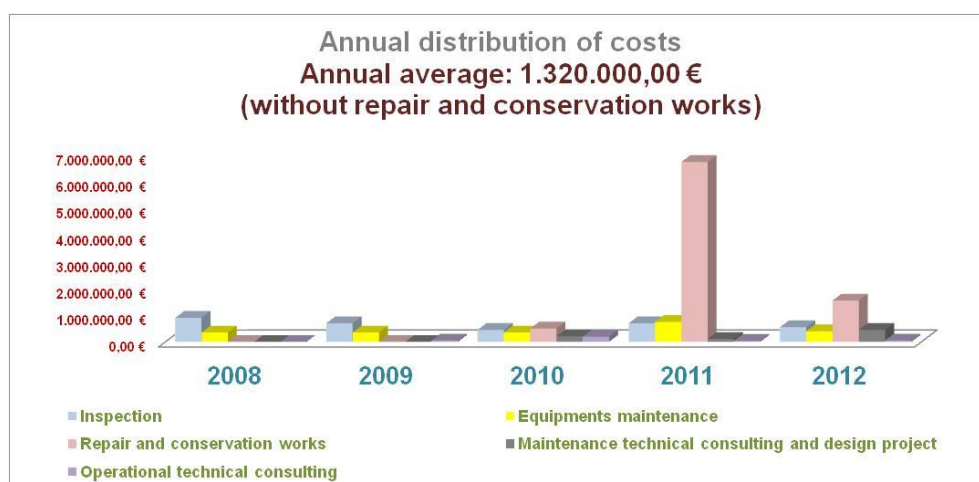


Fig. 3 25<sup>th</sup> April Bridge annual distribution of maintenance costs per activity.

### 3 REPAIR AND CONSERVATION WORKS

#### 3.1 OBJECTIVES AND MAIN CONSTRAINTS

The Bridge over Tagus and its north viaduct have been subjected to almost unnoticeable maintenance works for nearly the last two years. The prime objectives of the works were namely the:

- execution of rehabilitation works due to normal use of the infrastructure, identified through regular inspection activities;
- measurement of the strength and re-fastening of the braces that fix the hangers to the suspension cables;
- creation of accesses and enhancement of security and accessibility conditions for the maintenance and inspection teams.

The Bridge repair and conservation contract was a major challenge for all of its stakeholders mainly due to its large dimensional aspects as well as its strategic importance. In fact, the Bridge corresponds to a heavy traffic crossing since 150000 vehicles, corresponding to 300000 users, daily cross the Bridge roadway, and 150 trains, corresponding to 80000 users, daily

pass the Bridge railway. Its north connection is made through a viaduct integrated in a crucial urban road network.

Other main constraints were due to:

- use of the road and railway platform exclusively in the night period (time schedule permitted by Lusoponte and Refer);
- road gangways with high circulation constraints;
- proximity of the railway to some working and/or circulation places;
- operable use of the evacuation gangways;
- lack of permanent access to the working zones;
- narrowness of the majority of the interior spaces, dim lightened and sometimes poorly ventilated.

## **3.2 SUSPENDED RIGIDITY BEAM**

### **3.2.1 Repair of the welds of the rigidity beam**

In certain zones of the rigidity metallic beam some seam welds were cracked. Those welds were reconstructed restoring its initial strength.

The cracks were first cleaned with abrasive discs until the complete removal of the fissures (Fig. 4). Penetrating liquids and magnetic crack detection were used to confirm the absence of fissures in the parts to be welded. The seam welds were repaired through manual arc welding by certified welders, following certified procedure and welding specification. After execution, each welding was fully inspected and non destructive tests were done – penetrating liquids, magnetic crack detection (Fig. 5) and ultrasonic tests. After the supervisor's approval, protective anti-corrosive coatings were applied.

### **3.2.2 Restoration of the anti-corrosive protective coating**

In some areas of the different elements that form the rigidity beam (nacelles of the inferior level, diagonal inferior bracings between stringers, superior transverse beams, railway deck stringers, etc.) the existing coating was damaged. The protective coating of those zones was restored through the application of a polyurethane based material.

Prior to the application of the coating system, the surfaces of the damaged areas were prepared and cleaned. The preparation of the surfaces was done with an electric grinder or manual brush until a ST3 grade was achieved. The coating system was then applied in accordance with the supplier's specifications and instructions.



**Fig. 4 A seam weld prepared for welding after preparation of surface. Fig. 5 Magnetic particle testing after welding.**



**Fig. 6,7 Anti-corrosive coating of the steel rigidity beam.**

### **3.2.3 Replacement of the central inspection walkway**

The central walkway, that is used to permit the access of teams for inspection of the structure that supports the road way, was replaced due to its bad conservation condition. The central walkway also includes the supporting mat for the infrastructure cables that cross the river and the galvanized wire netting that encases the walkway.

The walkway comprises a total of 199 modules of variable lengths according to the existing spans of the suspended part of the bridge. The modules were pre-fabricated in AMAL's factory and then transported to the construction site.

The assembly of the modules of the new central inspection walkway was always done at night (Fig. 8) during the periods without the passage of trains (Refer and Fertagus). During these works, the high voltage energy in the catenary had to be cut off.



**Fig. 8** Night installation works of the new modules of the central inspection walkway.

### **3.3 SUSPENSION BRIDGE TOWERS AND COLUMNS**

#### **3.3.1 Rehabilitation of the steel elements**

Similar to the works that were performed in the metallic elements of the rigidity beam, the restoration of the anti-corrosive protective coating was also done in certain scattered surfaces of the two towers and the three steel columns, including in the top and bases of the towers and the bases of the columns. The surfaces that were in bad conditions were cleaned and repainted.

#### **3.3.2 Rehabilitation of the reinforced concrete bases (foundation blocks)**

Rehabilitation of the concrete structural elements of the Bridge was achieved through the application of three main techniques: sprayed concrete, hand applied mortar and treatment of cracks.

Spraying concrete through a dry-mix process was used to restore the damaged areas of reinforced concrete. Hand applied cementitious mortar was also applied to replace smaller surface layers of deteriorated concrete. Treatment of cracks was obtained through sealing and concrete injection with appropriate products.

Main difficulties associated with these works were due to its location in the river (Fig. 9) so that all of the equipment and materials necessary for the execution of the techniques had to be transported by boat as well as the supplying of water and energy.



**Fig. 9 Scaffolds for the south tower concrete repair works.**

Sprayed concrete proved to be a very effective technique for the repair of reinforced concrete. Sprayed concrete is a method of placing concrete at a high velocity and does not require formworks (Fig. 10). Because the concrete is installed at a high velocity, it will have a higher density than conventional concrete in most cases. The increased density will provide reduced permeability and higher durability. Sprayed concrete brings out a resistant and durable material, which has excellent adhesion characteristics to older concrete and reinforcement.



**Fig. 10 Sprayed concrete restoration of reinforced concrete.**

Application of sprayed concrete followed a sequence of required procedures. Surface preparation corresponds to the critical starting operation. All weak, loose and damaged concrete was totally removed through hammers and sand blasting (Fig.11, 13). The objective was to create a clean and sound surface with the proper surface roughness to receive the sprayed concrete.

After the surface preparation, the substrate was saturated with clean water and then allowed to dry free from water on the surface at the time of application. Sprayed concrete should not be applied to a bone-dry surface as the substrate will absorb water of the sprayed concrete mixture intended for hydration of the cement. Moreover, a bone-dry surface will tend to allow plastic and drying shrinkage cracks to form. Conversely, excess of water at the time of spraying will result in a high water-cement ratio at the interface between the substrate and the sprayed concrete which may lead in significantly lower bond strengths.

The dry cement based mixture was blown through the hose to the nozzle, where the water is injected immediately prior to application. Mixing is completed as the material impacts on the receiving surface, through manipulation of the nozzle (Fig. 12, 14). This requires a very highly skilled nozzleman, especially in the case of thick or heavily reinforced sections. The nozzleman's goal is to achieve adequate compaction and envelopment of the steel reinforcement.



**Fig. 11 Preparation of concrete surfaces. Fig. 12 Reconstruction of sections using sprayed concrete.**

Sprayed concrete success depends largely on the skill and experience of the nozzleman. For this reason, it is important to require that the nozzleman be trained and qualified for the application. Stap benefited from being a sprayed concrete contractor experienced in structural applications achieving the desired result in an economical and timely manner.

As with all concrete, proper curing and protection is also critical. Failure to cure properly will result in lower sprayed concrete strengths, cracking and delaminations.



**Fig. 13 Sandblasting preparation of damaged concrete surfaces.**

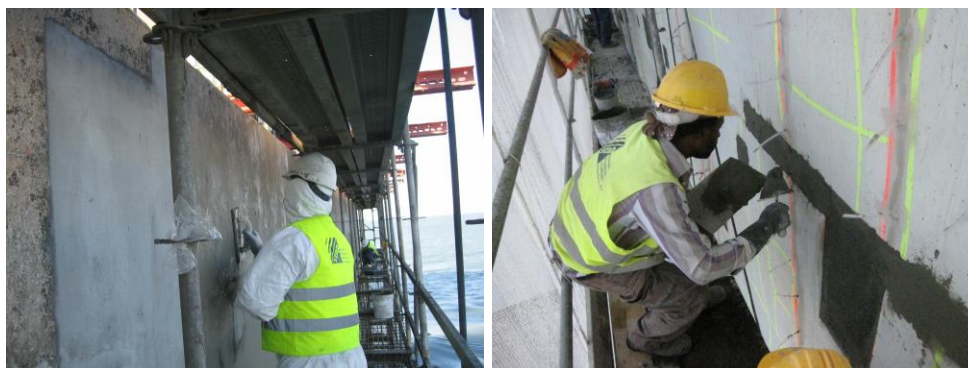


**Fig. 14 Concrete repair by sprayed concrete.**

Minor surface areas of damaged concrete were reconstituted using repair mortars which were manually applied. The mortars were pre-batched cement based, with controlled shrinkage and appropriate strength properties. The mortars were applied and compacted into the prepared substrate taking special care to avoid inclusion of entrapped air pockets

and making sure the reinforcement was completely wrapped thus protected against corrosion (Fig. 15, 16).

Rehabilitation of structural concrete was also accomplished with the treatment of cracks that was used to restore material integrity and avoid harmful consequences of voids and cracks in concrete like the penetration of aggressive agents that might induce corrosion of steel reinforcement. Low viscosity resins are injected into cracks and when cured form a durable and structural adherent seal.



**Fig. 15, 16 Hand applied mortar repair of reinforced concrete.**

Another technique used to repair concrete was the treatment of cracks that was used to restore material integrity and avoid harmful consequences of voids and cracks in concrete like the penetration of aggressive agents that might induce corrosion of steel reinforcement. The low viscosity resins are injected into cracks and when cured form a durable, structural bond-seal with a compressive strength exceeding the strength of the concrete.

The basic steps of the injection process were: cleaning the surface for crack exposure; installation of injection ports (ports are typically placed at 13cm to 20cm spacing, with increased spacing on wider cracks); surface sealing with an epoxy based material to contain the injected resin in the crack (the entire exposed crack is covered with the paste, leaving only the port holes uncovered); injection of the cracks and removal of the ports. The injection usually begins at the lowest port (from the bottom up) and continues until the resin begins to exit through the adjacent port. That's the visual sign that the crack has been filled to that level. The port is then capped and the process is repeated moving on to the next port along the crack (Fig. 17). After all of the ports are injected, adequate time for the epoxy resin to completely cure was allowed. Following cure, the ports and the sealing were removed by cutting or grinding.

All surfaces became then ready for the application of intended aesthetic results (Fig. 19). Figure 20 shows cleaning of surfaces before receiving final paints.



**Fig. 17, 18 Concrete injection of cracks.**



**Fig. 19 Hand applied mortar concrete repair and treatment of cracks.**

### **3.3.3 Interior and top of the towers**

Inside the towers, new caps and other protections for openings on the floors at the different levels were fabricated and erected. At the top of the towers, new protections were installed and sealant materials were applied.



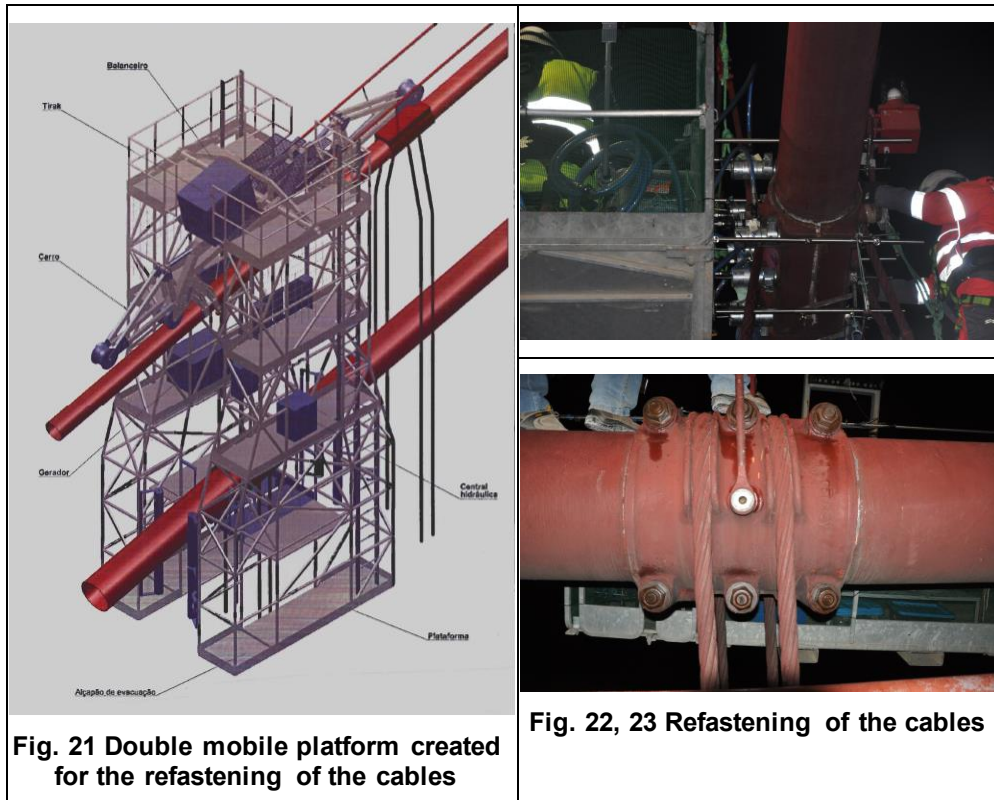
**Fig. 20 Preparation of surfaces for the application of final coating system.**

### **3.4 CABLES**

Re-fastening of the bolts of the braces that fix the principal and secondary suspension cables was done with specific hydraulic tensioners up to a previously calculated stress. The hangers (vertical cables) are fixed on the braces. The braces cannot slide along the cables and this is avoided by checking the tightness of all bolts existing on the braces. For each tensioning operation, a report is done indicating the sequence of the tensioned bolts, the measurements and the hydraulic pressure. After completion of the tensioning procedures, a silicon sealant was applied on the joints of the braces and their protective anti-corrosion coating was restored.

For the operation of re-fastening of the bolts, it was necessary to design and build a double mobile platform that moved along each cable and was fixed next to each brace (Fig. 21, 22, 23). Due to the relative position of the two cables (principal and secondary), one above the other, and the existence of the vertical cables with regular spacing, the platform for the two cables was a unique device system that was only supported by the superior cable. The conceived platform comprised a tubular profiles rigid structure and a set of operative mechanisms.

Other works related to the cables were: verification and correction of electric lines – fairy lights and airway obstruction; replacing the plastic clamps (that hold the electric cables to the cables); refastening of screws and replacement of cable-grips; installation of new hand rails on existing vertical stairs.



### 3.5 CABLES ANCHORAGE BLOCKS

In the north central block (the original older one), shotcrete was applied to rehabilitate the exterior face of the coverage of the block as shown in Figure 24. Other works related to the anchorage blocks were waterproofing of the coverage of the south anchorage block, repair of the drainage system, replacement of stairs and platforms and installation of protection devices. Regarding the south anchorage block, repair of concrete was achieved through hand applied mortar and crack injection of interior and exterior surfaces (Fig. 25, 26).

### 3.6 NORTH ACCESS VIADUCT COLUMNS AND CANTILEVERS

Crack injection and hand applied mortar were the selected techniques to rehabilitate the reinforced concrete of the north viaduct columns and cantilevers (Fig. 27). Other relevant work was the repair of the anticorrosive protection of the anchors of the vertical pre-stress of the transverse decks (Fig. 28).



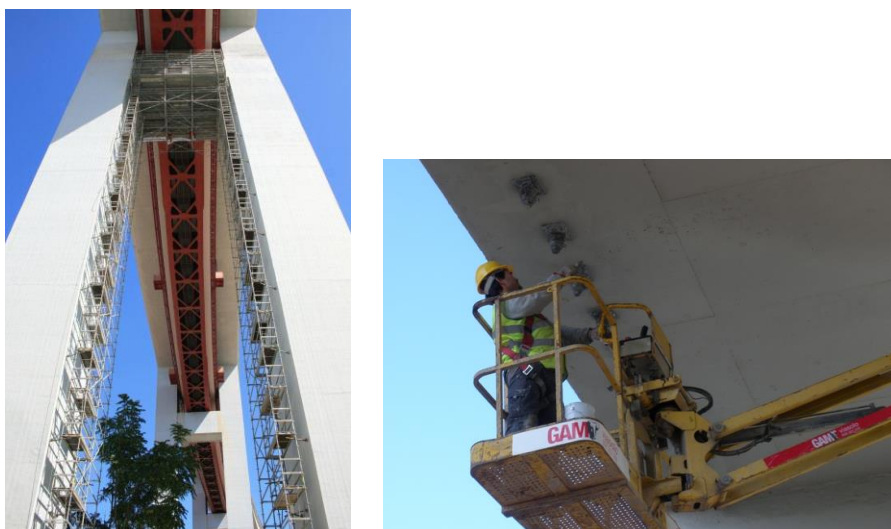
**Fig. 24 North anchorage block restoration by sprayed concrete.**



**Fig. 25, 26 Treatment of concrete cracks. Concrete injection.**

### **3.7 NORTH ACCESS VIADUCT SLAB**

Accesses to the inferior zones of the joints of the north access viaduct slab were created.



**Fig. 27** View of the scaffolds for the repair works. **Fig. 28** Repair of the anticorrosive protection of the anchors.

#### **4 CONCLUSIONS**

Maintenance management is an important process both from the point of view of structural performance and life-cycle impacts of constructions. The Tagus suspension bridge has been subjected to almost unnoticeable repair and conservation maintenance works for nearly the last two years. Such barely perceptible maintenance actions effectively contribute to protect the structure and extend its lifespan. Durable structures undoubtedly meet sustainability growing needs.

The maintenance works corresponded to functional beneficications and metallic and concrete rehabilitation. Specialized rehabilitation techniques requiring considerable expertise were used on the Bridge. Both of the two contractors, Amal and Stap, have been acting on the rehab market for years, benefiting from being comprised of qualified professionals as well as constant technological and innovation efforts.

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