Improvement, reinforcement and protection of the foundations of the Sernada do Vouga railway Bridge

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ABSTRACT: The maintenance and rehabilitation of ancient art works has been the target of specific entities which have jurisdiction over the subject, namely as far the recognition and the diagnosis of abnormalities is concerned, as well as later conception and projection and execution of consolidation and improvement work.

However, in some situations, great problems have emerged in the development of the works, both due to the absence of construction projects and the lack of agreement between the existing project elements and the results from the carried out surveys over the diverse elements of the foundations of studied art works, as was the case of the Sernada do Vouga railway Bridge.

This present article intends to describe the various phases this improvement, reinforcement and protection work of this railway structure underwent, from the study to its completion.

1. INTRODUCTION / GENERAL DESCRIPTION

The Sernada do Vouga road-railway Bridge is a stone masonry piece built in the beginning of the past century – 1911 – and is placed at the PK 0.245 of the Vouga Line.

It is sited over an alluvium section of the Vouga River, immediately downstream of the river beach of Sernada. This structure was initially a simple way bridge, having been, at a later date, the object of a deep intervention, with the aim of transforming it into a road-railway connection, namely with the construction of a reinforced concrete roadway with two consoles for each side of the original deck.

It is composed of seven segmental arches with newels in the order of 22 metres, prolonged to both sides by avenue-type walls, which form the lateral sides of the abutments. They have a total length of 173 metres and a width of 3.70 metres in the container, being endowed of reinforced concrete consoles for a total width of 8.30 metres. The Bridge's axis presents a slight obliquity in relations to the direction of the River:

To the downstream and about 50 metres from the bridge, there is a riprap weir. Its is admitted that this hydraulic piece is posterior to the construction of the bridge and that it was destined for the construction of the river beach. However, studies carried out for this purpose, allowed us to notice that the weir, as it accumulate sediments upstream. It also tends to stabilise the riverbed of the Vouga River around the piers.

The available elements about the local geology where the Sernada Bridge is placed, are part of a report created from surveys carried out next to Pier P5. The geological profile drawn for this work area points out the presence of alluvium Formations made of sand, some burgaus and pebbles, about 14m thick, over schist formations that form the bed-rock.

This pier (P5) had already been the subject of a protection intervention with the construction of a sea-hoist in concrete, supposedly for the protection of the filling material of the foundation pivot.

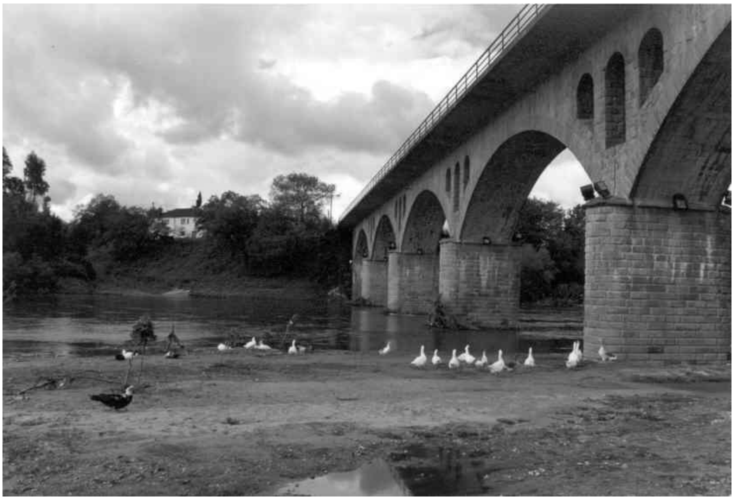


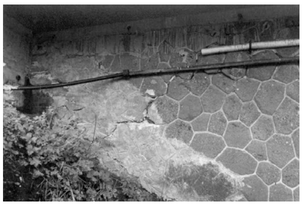
Fig. 1 – View of the Sernada do Vouga Bridge

2. INITIAL SURVEY OF THE DAMAGES

The survey of the damages was carried out via periodic maintenance and inspection visits that allowed the maintenance caretakers to make decisions concerning the need to make a more detailed inspection of the entire art work, in order to allow a deeper evaluation of the damages and an adequate choice of the improvement solutions that are usually used for this kind of structures.

Among the damages that were identified, we should point out the following:

- Various cracks in the inner frame of the vault;
- Significant detachment of the frame's face from the vault's body;
- Cracks on the wing walls of the abutments, namely on the Sernada side, showing the presence of differential settlements in the foundations;
- Unveiling of the deck on the Sernada side;
- Infiltration and cracks in the arches and at the base of the concrete consoles;
- Signs of deshoeing and/or de-confining of the piers and abutments, being pier P5 certain to have been object of a previous intervention;
- Erosion and degradation of the foundation massifs of the piers;
- Degradation and deshoeing of the Reno gabions/mattresses downstream of the Bridge, as a consequence of a recent intervention, after which, it was verified that the existing weir, place downstream of the Bridge (Pic. 8) will not have been strong enough to stop the strength of the waters to degrade and deshoe the gabions. Consequently, the riverbed showed signs of serious erosion that might lead to infra-excavation phenomena in the foundations of the piers and consequent structural instability.



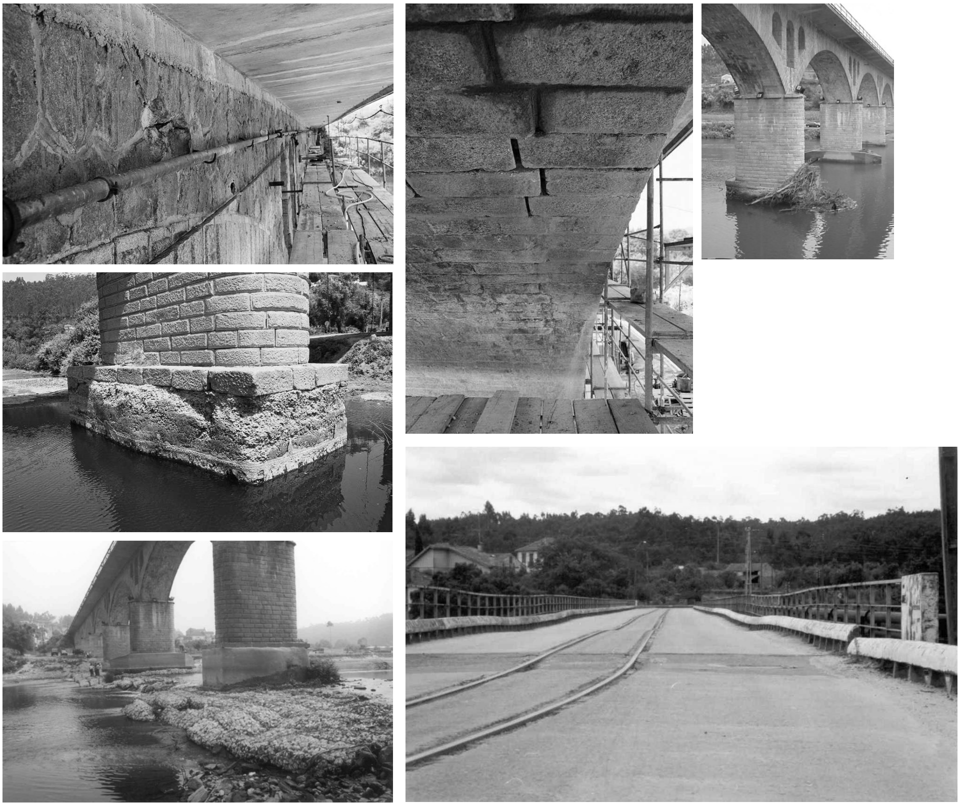


Fig. 2, 3, 4, 5, 6, 7, 8, 9 and 10 – Damages found on the Bridge

3. MAIN FACTORS FOR INSTABILIZATION

One of the main factors for loss of stability that was taken in account for the behaviour of the foundation of the art works was the action of the watercourse of the Vouga River.

The cyclic and continued action of the floods caused generalised and localised infra-excavations next to the piers and abutments. This temporary phenomenon resulted in a diminished stability of the foundations, not only during the floods but also later, due to the restocking on the riverbed of materials with worse resistance characteristics.

The degradation of the protection elements originated a direct attack of the water against the foundation massifs. For example, the corrosion of the metallic plates surrounding the pivots, allowed the water to attack the filling material of the pivots and its consequent degradation. The deterioration of the protection ripraps diminished the retention capacity of the confining material of the shoes, as well as the dissolution of the free plaster of the mortars and the concretes caused their desegregation and consequent formation of cavities.

Another loss of stability factor that was taken into account was the vibration caused by the circulation of heavy vehicles, so the restriction of circulation was one of the implemented actions before and during the intervention.

4. STUDIES CARRIED OUT / DIAGNOSIS

In face of the damages that might put in question the structural behaviour of the artwork, detailed or exceptional inspections became necessary to establish the cause or causes that originated the deficient behaviour of the structure or its foundations.

The developed reconnaissance action span various areas of knowledge, namely from construction and structural behaviour technologies, both of the foundations and the analysed structures, in the domain of hydrology, geology and geotechnics and similar sciences.

a) Topographical and boatimetrical survey of the area enveloping the structure

The topographical and boatimetrical surveys (Pic. 11) of the surrounding area of the Sernada Bridge allowed to gather basic data to develop the hydrological studies of the flood flows and the protection project of the piers from lesser riverbed of the river.

b) Underwater inspections of the foundations

The observation of the conservation and state characteristics of the underwater supports was carried out via an underwater inspection that recorded them on tape.

From this inspection was also possible to establish which "holes" under pier P5 only referred to the deshoeing of the breakwater, carried out at a later intervention, which started to work partially as a console. Thus, the reports from the local inhabitants, who said that this pier had some abnormalities, were not founded, namely concerning the possibility to dive from one side to the other of the pier, i.e. revealing the existence of eventual hiding-places. (Pic. 6).


Fig. 11 and 12 – View of the boatimetrical survey and underwater inspection

c) Hydrological and Hydraulic studies of the Vouga River in the Sernada Bridge section

The Sernada Bridge section is placed downstream of the point where the Vouga and Caima Rivers meet, the latter being its right bank tributary.

The calculation of the full flood efflux for the set of the basins, associated to return periods of 100 and 1000 year periods, was made via the application of the Fuller method, which led to values of 2318 m3/s and 3256 m/s.

A mathematical model simulated the hydraulic behaviour of that stretch of the Vouga River, where the Sernada Bridge and the riprap weir are implanted, the latter downstream of the former. The calculus program that was used in this analysis and determination of the water levels was the HEC-RAS [1] model, developed by the U.S. Army Corps of Engineers. These results lead to draining depths between 8.4 and 10m and draining speeds between 3.2 m/s and 3.5m/s.

In relation to the determination of the erosion localised around the piers, as it this was the case of an alluvium riverbed, the vertex system developed around them will tend to produce an erosion ditch in the area near the obstacle. This erosion ditch will depend on various factors, such as the shape of the pier, its thickness, the alignment of the bridge in relation to the axis of the minor riverbed, the geometrical characteristics of the minor riverbed, drainage parameters and the grainulometric curve of the bottom material. The application of various formulae, recommended by Les Hamill [2], to determined the maximum depth of the erosion ditch (local erosion), allowed to conclude that it varied between 3.0 and 5.0m.

d) Geological and geotechnical Surveys

Two important actions to gather basic and specific information for the evaluation of the causes that were affecting the behaviour of the foundations, were the recognition of its characteristics and geometry, as well as the geological geotechnical characterisation of the surrounding grounds.

The definition and methodology that were adopted when carrying out the surveys were aimed at characterising the type and geometry of the pier foundations and of the formations where these foundations were set and supported.

Thus, in the supports that could be reach from land, (abutments E1 and pier P1 and P3) probing holes were made via rotation. These were inclined and started from the bottom of the foundations, allowing the reconnaissance of both the materials that the foundations were made of, as well as the formations sited immediately under them.

Vertical surveys were carried out on these same supports crossing the alluvium formations and continuing through the adjacent schist formations for about 5m.

This probes were complemented by recognition wells opened next to the base of the supports, in order to observe their respective characteristics and conservation state.

For the river piers, a distinct methodology was adopted, with the use of rotated vertical probing holes, started from the deck of the bridge until the bottom of the foundation was reached. The drilling was continued in the alluvium formations, with telescopic reduction of the drilling diameter, until the schist formations that formed the bedrock were reached and crossed.



Fig. 13, 14 and 15 – Carrying out a probe, samples of the collected material and view of a reconnaissance well

From the analysis of the obtained data, it was possible to observe the following:

The bridge's piers are founded on pivots Carried out with metallic and wooden mould and filled up with badly mortared masonry.

The supports observed on the tray are only corresponded by the deficient founding conditions of pier P1, and not pier P1 and P2, as it was initially evaluated, as pier P2 is founded directly on the schist formation.

With the exception of pier P2 and abutment E2, all other supports are founded in alluvium formations of low supporting capability, working essentially by lateral attrition of the foundation pivot itself.

The metallic plates that exist at the top of the pivots were totally or partially corroded, which made the filling material to be uncovered, and exposed to the erosive action of the river’s water.

The rails’ settlement boxes were in an advanced state of degradation, allowing the infiltration of water via the filling material of the masonry arches’ inner frame, and the consequent formation of stalactites on its inner frame and loss of fine materials.

The reduction in supporting capacity of the filling material of the container via the loss of fine materials caused a redistribution of charges in the central area of the drums and subsequent displacement of the stone facing materials.

5. DESCRIPTION OF THE TECHNICAL SOLUTION

Bearing in mind the degradation state seen in the superstructure and at the foot of the piers and abutments, both in the major (E1, P1 and P3) and minor (P4, P5 and P6) riverbeds and their deficient foundation conditions and the need to guarantee a higher degree of safety, as the weir was showing an increased state of degradation, it was considered necessary to carry out the following work:

a) Consolidation and improvement of the tray, masonry arches, drums and container.

The consolidation of the material that form the structure of the bridge was performed via the procedure normally used for this type of undertaking, namely the consolidation of the filling material of the container through the injection of a cement welder and sand and putting on sole bars, re-closing joints, levelling the pavement and repairing de settlement boxes of the railway rails..

In order to maintain the external look of the masonries, the heads of the sole bars were imbued and disguised with the own stone that was removed during the drilling.

Fig. 16, 17 and 18 – Improvement of the arches, placement of transversal sole bars on the drum walls and improvement of the tray

b) Consolidation and reinforcement of the foundations in abutment E1 and piers P1 and P3

The solution consisted of a system of indirect foundations composed of injected micro-stakes sealed in the schist massif, which transferred the charges directly to the bed-rock, via the stabilisation of the pier and the abutment, thus resisting to vertical and horizontal forces, as well as flexor moments at their base. They were complemented, in order to work as a set, with a heading massif in reinforced concrete, in a round plant-shaped, hugging the top of the pivots of the piers and the abutment.

In order to guarantee the transmission of the charges from the pier and the abutment to the micro-stakes, pre-effort sole bars were placed, crossing laterally the massif and the pivots.

Additionally, and to protect the foundation soil of the pivots from a possible lateral erosion by infra-excavation in flood situations, a system was implemented to improve the soils via impregnation injections with cement welder. Beyond complementing the lateral protection of the pivot’s foundation soil, these injections equally improve its supporting capacity, allowing a more direct transmission of the charges, once its consolidated, to the rocky strata.

Fig. 19 and 20 – Placing the micro-stakes

c) Consolidation and reinforcement of the foundations in piers P4, P5 and P6

The main goal of this intervention was to create an efficient stabilisation solution that was not dependent from the solutions that would be adopted for the weir, place downstream of the Bridge, which might be:

- remove the weir, assuring the stability of the bridge via the reinforcement of its foundations and returning the river to its initial condition, a clearly more favourable solution for the conservation of migratory fish;
- build a new weir with a transposition system which allowed the efficient circulation of the aquatic fauna, especially migratory fish;
- or, as a final solution, keep the present situation, bearing in mind that there will be no resolution for this problem in the short/medium term.

Fig. 21 and 22 – The weir downstream of the Bridge

In the definition of the solution for the consolidation of the foundations of pier P4 and P6, sited in the minor riverbed, and in order to make the behaviour of these pier autonomous in view of possible infra-excavation phenomena, it was considered for dimensioning effects, the worst scenario, i.e. that the weir does not exist.

The hydraulic study carried out for the effect by the COBA Company, showed a local 5m deep erosion, added by a general 2.0m erosion, in the case the weir was removed.

Bearing in mind the results of the surveys on the three piers, it was verified that in the most unfavourable of the studied cases, the was a potential deshoeing risk of piers P4 and P5, with the foundation of pier P6 remaining in a limit situation, that was very compatible with the safety criteria.

Thus, based on the geotechnical survey and the hydraulic study that had been carried it, the indirect transmission of charges from the Bridge to the tougher strata was made, at bigger depths, where the lowering of the riverbed would not make itself be felt.

In this way, the adopted solution for these piers was based on micro-stakes, being similar to that applied to piers P1 and P3. However, as piers P4 and P6 had been subjected to the floods and excavation of the riverbed, it was important to guarantee an additional protection for the micro-stakes. In this way, the execution of two lines of jet grouting surrounding the entire pivot was done, at a depth that would not be affected by the riverbed’s erosion. The external files are about 10.0m under the heading massif, reducing to 8.0m in the areas under the arches. The inner columns have a similar speed to the external file, but are two metres higher in depth.

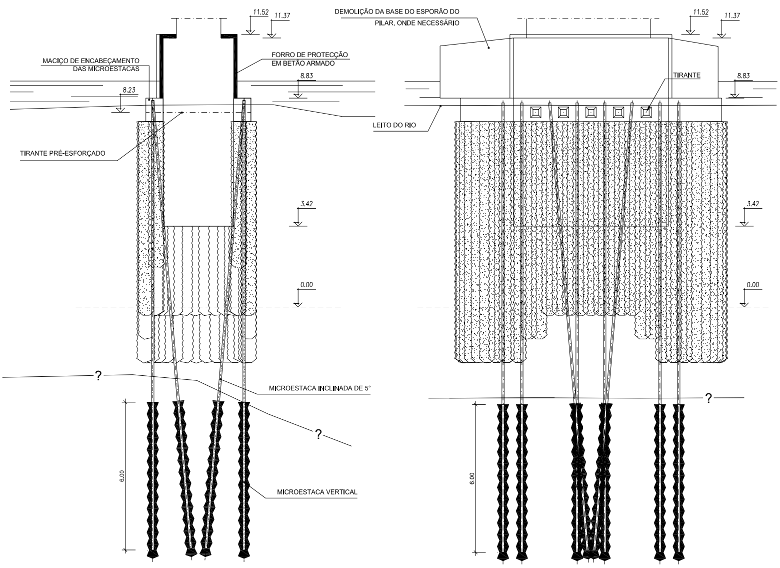


Fig. 23 and 24 – Lateral and Vertical Projection of the reinforcement of the foundations of Pier P5

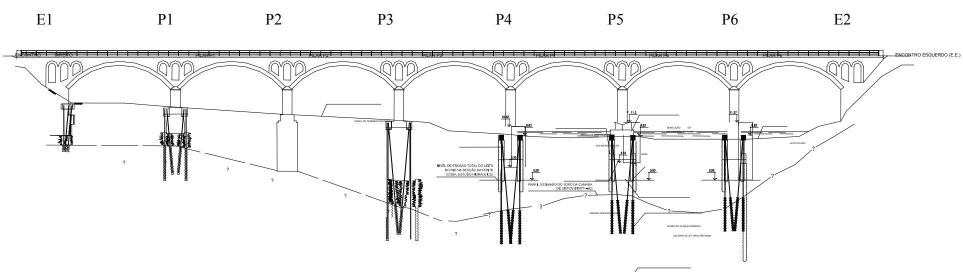


Fig. 25 – Lateral and Vertical Projection of the reinforcement and protection work








Fig. 26, 27, 28, 29, 30, 31, 32 and 33 – Sequence of the works

In order to reduce the apartment of the jet-grouting columns and the micro-stakes in relation to the axis of pier P5, part of the massif, presently acting as a console, was demolished.

Though this solution was thought out for the case of floods with a return period of 100 years and subsequent excavation on the riverbed, particularly, in the pier area, the reposition of the riverbed was carried in this action al well, at least at the level of the generalised erosion.

It should be pointed out that the careful evaluation of the characteristics of the pivots, associated to the interpreted geological profile developed from the carried out surveys, ruled out the possibility of carrying out a jet-grouting solution on the pier and abutment of the major riverbed – E1, P1 and P3 as a substitution for the micro-stakes, as the depth of the bases of the pivots would diminish in a significant way the efficiency of the solution.

To end, it should be still registered that for the protection solution of the minor riverbed, via the placing of a gabion carpeting, similar to the one implemented at a previous intervention, was conclude that it was not compatible with some of the possibilities considered for the weir. Thus, consolidation work had to necessarily focus on the foundations of the pier themselves.

The work lasted for 3 months and was projected and carried out by the Company Teixeira Duarte.

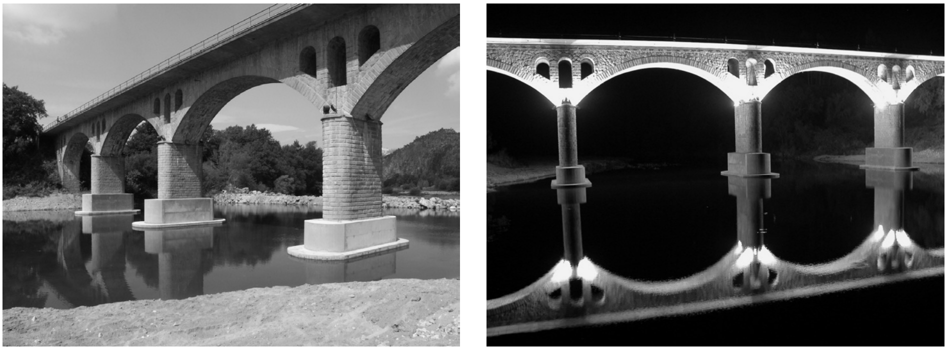


Fig. 34 and 35 – General view of the finished work

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