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WIDENING, STRENGTHENING AND REPAIR OF A MASONRY BRIDGE IN PONTECESO (GALICIA, SPAIN)

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Abstract. *The paper summarizes the process of inspection, characterization of materials, assessment, project of the complete solution and the technical assistance to the execution of this masonry arch bridge. Special attention is given to the description the difficulties and boundary conditions of such a task, especially the durability of stones and the micro-piling of piers and abutments as a competitive solution to ensure the robustness of foundations, and insensitivity to scour, as well as rapidity of execution, avoiding under-water works. This bridge, which is included in the Catalogue of historical bridges of Galicia, has been widened, strengthened and repaired under the criteria of modern restoration recommendations and the principle of reversibility of intervention.*

This paper would not have been possible without the special contributions of Enrique Pardo, Director of the Project, and José Luis Rodríguez, Director of Works, both from the Bridge Authority of Galicia. The contractor was EXTRACO.

1 INTRODUCTION

The masonry arch bridge in Ponteceso (Galicia, Spain), fig. 1, was completed in 1879, substituting an old masonry bridge whose semicircular vaults were “desconcerted as a consequence of differential settlements in their piers and abutments, due to its position on a deep layer of mud”, as the author of the project, Manuel Tabuenca, reported in 1878. This engineer also informed about the “scour produced by the water, whose speed was increased by the reduced spillway that the thick piers provided”.

Fig. 1. Location of the Ponteceso bridge, in the province of La Coruña (Galicia, Spain).

In 2001 the bridge also showed some defaults that, after an assessment and surveying process ordered by the Bridge Authority of Galicia, led to a project to widen, strengthen and repair the bridge. With small variations regarding the original project, the works were completed in July 2004, only two months and a half after their beginning. This paper pretends to describe the essential aspects of this adventure.

2 DAMAGE DESCRIPTION AND FUNCTIONALITY PROBLEMS

The bridge consists of five circular vaults with 8,40 m free span, 1,30 m rise, 0,70 m thickness, about 0,30 m fill thickness above crown and almost 6 m width. The four piers were founded on wooden piles of about 10 m length, driven in mud, as were the abutments. Figure 2 summarizes the main geometrical features of the bridge.

The bridge was built on granit and orto-gneis stones, taken from a neighbouring quarry.

A rotation of the first pier from the left (fig. 2) was detected during the first inspection (fig. 3), inducing the opening of joints in the second barrel, incipient dropping of vaults and evident deformation of the roadway. Some durability problems were also detected at springings, showing a lesser quality of the stone as expected; moreover, calcium carbonate precipitated on surfaces. Figures 3 and 4 show different aspects of such situations.

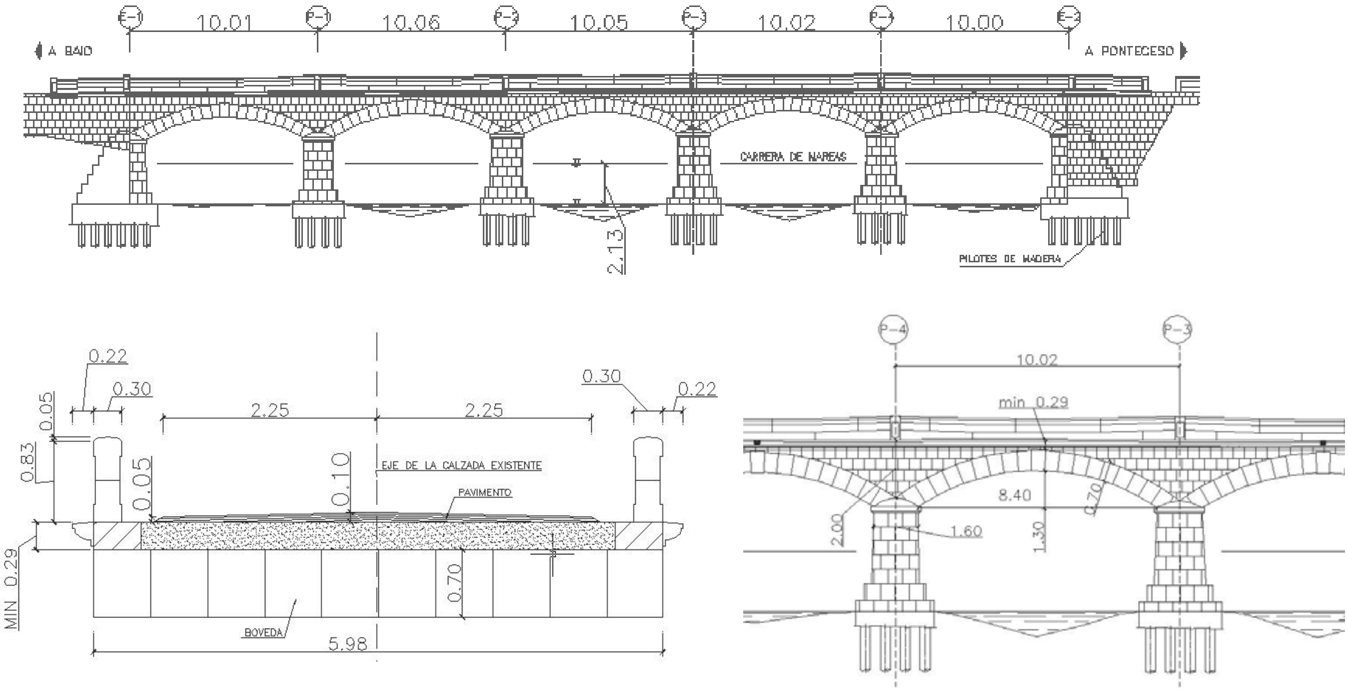


Fig. 2. Elevation, cross section at crown and detalis of the bridge prior to intervention.

Finally, the reduced witdh of the platform impaired the crossing of vehicles (fig. 4) and, moreover, pedestrian ran important risks when crossing the bridge, without the opportunity of enjoying a beautiful area like this. After a first assessment, the load was limited to 15 t.

3 ANALYSIS AND DIAGNOSIS

Prior to the beginning of the project, a set of surveys was ordered to characterize the complete geometry of the bridge, the geotechnical conditions of the ground, the depth of the mud layers and the depth of the rock bed. Furthermore, a petrological study of the stone was also carried out in order to know its mechanical properties and its durability. Such studies were fundamental for the proper definition of the project.

Fig. 3. Rotation of pier 1, opening of joints in barrel and settlement of roadway.

The structural analysis was carried out by means of a second level tool developed by the second author[1]: a thurst line calculation with control of internal forces and their comparison with a *N*-*M*-*V* interaction diagram according to the criterion of Mann-Müller, which was considered suitable enough for this purpose. Figure 5 shows one of the calculations, where special attention must be paid to the intermediate pier between two adjacent vaults. The total reaction is splitted into two forces, each located at the external sheets of the pier. This is more realistic and, simultaneously, more efficient, counteracting the moment on the pier by the different thrusts of vaults due to non-uniform live load.

Fig. 4. Dropping voussoirs, delamination at springings of the vaults, precipitation of calcium carbonate and functionality default of the bridge, too narrow to allow the crossing of vehicles and pedestrians.

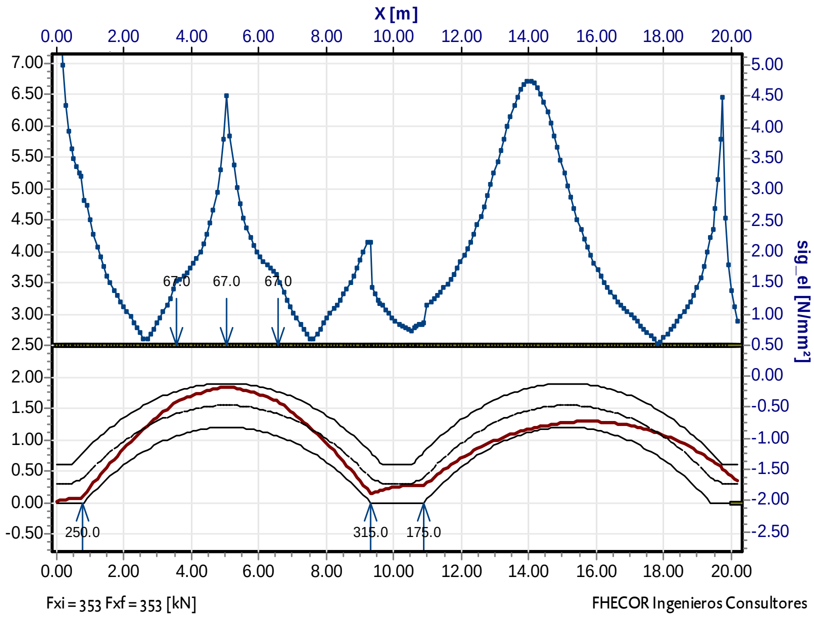


Fig. 5. Analysis of the bridge with a second level tool

The structural assessments of the structure, in the states before and after the intervention, was carried out by using the mechanical properties derived from the petrological study.

4 PROJECT

Once confirmed that the bridge was founded on a soil in poor condition and that there were no guarantees for its stabilization, the extent of durability problems and the functionality restrictions (traffic) were evident, the Bridge Authority of Galicia decided to go ahead with the project of widening, strengthening and repair (fig. 6). Two additional features conditioned the project: firstly, the bridge is included in the Catalogue of historical bridges of Galicia and, secondly, the solution should had to be achieved rapidly —to minimise the disturbance of a closed road, daily used by trucks from neighbouring seaports— and cheaper, in terms of comparison than a new bridge of equal length and width.

The Heritage Authority of Galicia allowed to increase the width of the platform and, after the study of different solutions, finally decided to accept a non-symmetrical widening, so that the downstream elevation, once repaired, could keep its original appearence, since that part of the bridge was going to face a river park. The upstream elevation should be affected, as little as possible, by the widened platform.

Fig. 7 shows the cross section of the final solution, compared to its original dimensions. As can be seen, the road platform was constructed by means of a concrete slab, consisting of partially precast elements, and the pedestrians' sidewalk was made of a galvanised steel grid, quite transparent in order to avoid exececessive shade on the upstream elevation and, in addition, to avoid excessive eccentrity on the piers and abutments.

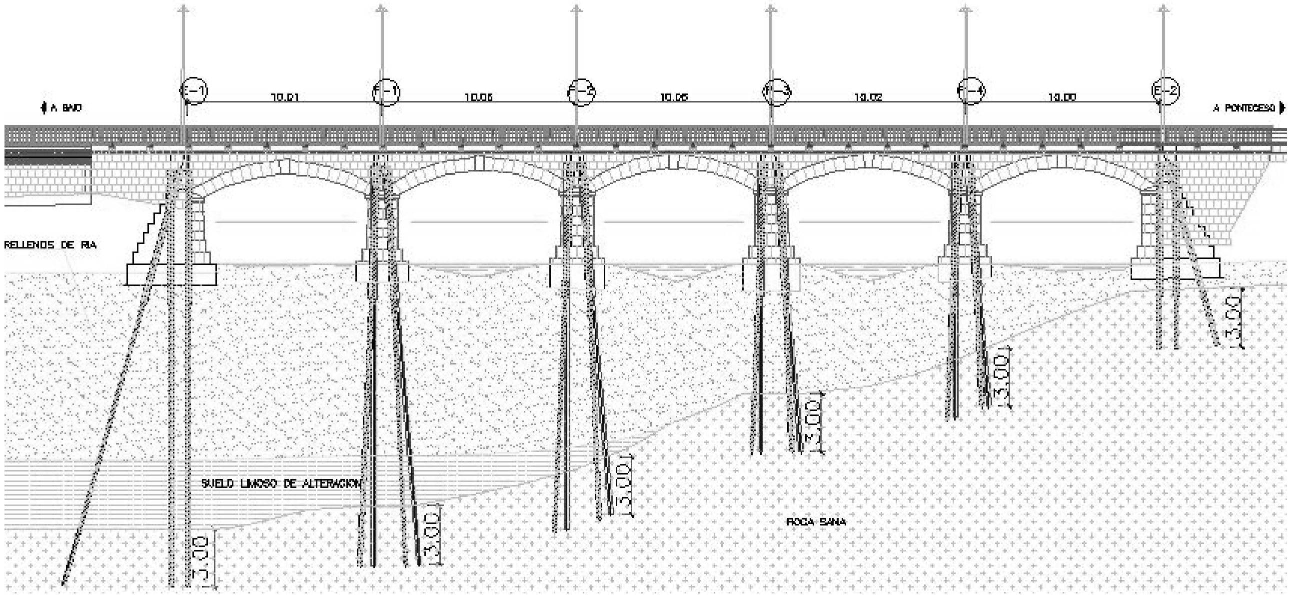
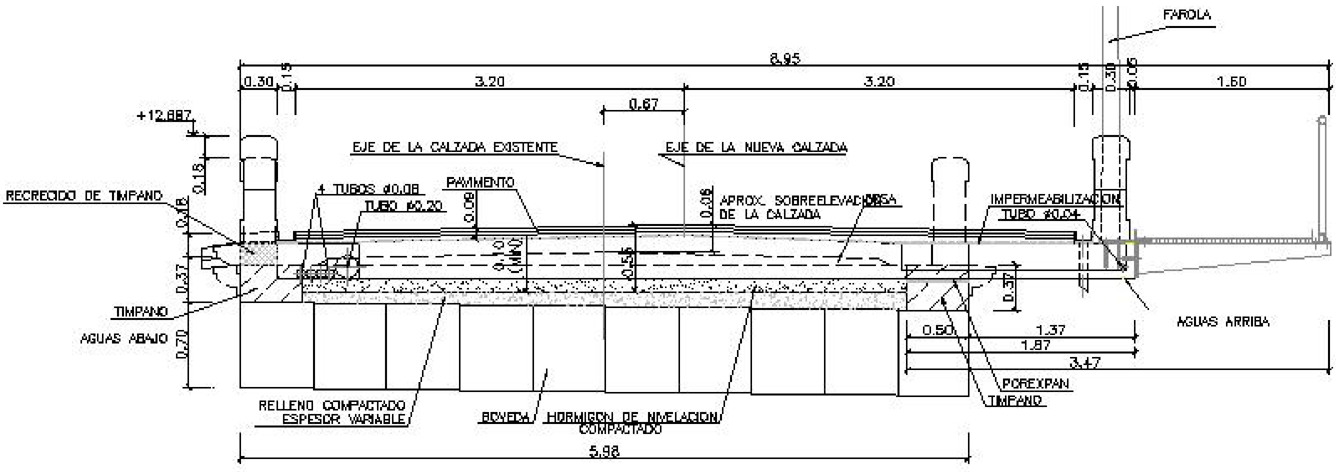


Fig. 6. General elevation of the projected and executed solution. The micro-piled abutments and piers guarantee stability of movements and sufficient bearing capacity for the loads required by the current standard



on road bridges.

Fig. 7. Cross section of the widened platform. The deformed shape of the barrel reflects its real state detected after the geometrical survey. Therefore, it was necessary to adapt slabs and geometry specifically for each barrel, pier and abutment.

There are several benefits for introducing a RC slab on top of the in-fill material above the trasdos of barrels (but never on top of spandrel walls): vertical actions can be much better distributed, which reports a higher bearing capacity of barrels, and horizontal actions can be directly transmitted to the abutments due to the much higher in-plane stiffness of the slab than that of the filling material beneath the former roadway. Finally, the use of partially precast slabs enables to widen the platform as required in a rapid way.

For the sake of reversibility of interventions, in accordance to the Venice or Isacarshah Restoration Recommendations, the use of precast slabs lying directly on the in-fill is fully adaptable to the possibility of being dismantled if new future generations decide to build a new bridge far enough from the historical one, recovering the primitive appearance of the bridge.

The micro-piling of piers and abutments were designed in such a way that the piers themselves constituted a pile-cap. This decision was taken after considering the possibility of creating a plynth or basement at the bottom of each pier and arranging the micro-piles around it. This possibility was disregarded due to the difficulty of working beneath the vaults, the tidal movements of the water level and the unaesthetical appearence of such a solution. On the contrary, the pier itself would transmit the vertical forces from the barrels and platform to the micro-piles by bond or friction along the distance between the springings of vaults and the bottom part of the pier. However, one of the disadvantages of this solution was the increased length of micro-piles and the highly required accuracy of execution, due to the high density of holes, that had to be located on the outer parts of the piers and not inside the in-fill material, of much poorer quality. Figs. 8 and 9 respectively show the adopted solution of micro-piling and the strut-and-tie models used to design them. While it was possible to find a path of struts without ties on the abutments, the piers required horizontal nailing to equilibrate the tensile forces generated around the mechanism of bond transfer between piles and piers.

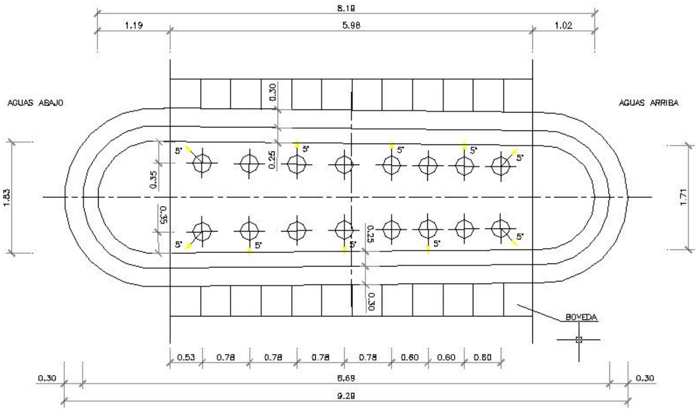


Fig. 8. Layout of micro-piles within the piers, as a combination of vertical and inclined piles to carry out both vertical and horizontal actions.

5 EXECUTION

The order in which the foreseen activities should succeed revealed to be essential, especially in this case of high concentration of piles and bad soil quality. Indeed, an attempt to shorten the time of execution provoked an alarming situation since the vertical displacement of the crown of the second barrel (second on the left in fig. 10), induced new defaults, ring-spandrel separation and crushing of springing voussoirs, as shown in fig. 11.

Moreover, the drilling operation, with rather reduced stone cover and relatively high horizontal pressure during drilling, induced some other problems, as shown in fig. 12.

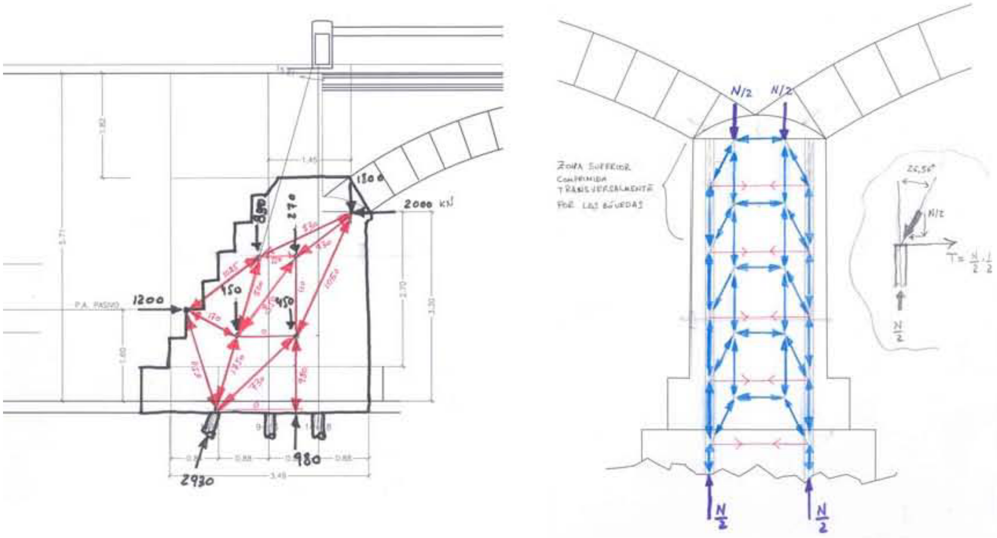


Fig. 9. Strut-and-tie models in abutments (left) and piers (right) to design horizontal nailing.

Fig. 10. Drilling machines installing micro-piles on abutment 1 and pier 2, respectively.

Fig. 11. Ring-spandrel separation and crushing of the springing voussoirs induced by wrong doing while drilling pier 1.

Fig.12. Partial breaking of the ashlar's cover of a drillhole (left) and transverse movement induced by transverse pressure (right).

The material lost by deterioration of the gneis stone and the spalling induced by the thrust line at the springings of barrels was replaced by tixotropic mortar, especially designed for the purpose (3 parts of white portland cement, 3 parts of white siliceous sand 3 mm, 15% biotite), and confined with stainless steel rods ∅ 10 mm every 0,30 m, as shown in fig. 13.

After micro-piling, nailing of piers and repairs of vaults were concluded, the placement of precast slabs began, as well as the re-installation of parapets and courses of original pieces.

Fig.13. Repair of lost material at springing of voutes.

Figures 14 and 15 show different views of the completed structure. Indeed, the downstream elevation recovered its primitive appearance, as required, and the upstream elevation showed relative minor influence of the RC slab due to the reduced value of the protruding length and the presence of the galvanised steel grid for the pedestrians' sidewalk. It is worth mentioning how the presence of ducts (phone, electricity wires) spoils the appearance of the bridge much more than the RC slab and the pedestrians' sidewalk.

6 CONCLUSIONS

- The intervention in this bridge showed the importance of analizing the mechanical properties of bridges: durability of stones is not unlimited and the intervention must ensure compatiblity of products with old units and mortars.

- Micro-piles connected by bond to the old piles and the piers acting as pile-caps have shown an interesting solution to avoid complicated works around piers.
- The installation of a RC slab on top of the in-fill material can efficiently distribute live load on the barrel's extrados, increasing its loadbearing capacity, as well as leading horizontal actions to the abutments.
- The original structural pattern can be preserved and improved, avoiding "bridging" the bridge.
- The reversibility of intervention has been guaranteed, including the dismantling of special elements, such as cornices, within the bridge.

Fig. 14. Downstream appearance of the bridge once the works were completed.

Fig. 15. Upstream appearance of the bridge once the works were completed (left). East-south wall, renewed in stone and completed keeping the cornices of the upstream elevation in order to guarantee the reversibility of the intervention by using exactly the same units of the bridge.

REFERENCES

[1] Martínez, J.L. *Theoretical and experimental determination of interaction diagrams in masonry structures and application to the analysis of historical constructions*. PhD Thesis. Universidad Politécnica de Madrid, 2003 (in Spanish).