

Case study of the effect on foundation of changing an arch bridge to a slab and girder bridge

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ABSTRACT: This paper presents the case study of the effect on the foundation of changing the structural system of a bridge from a plain concrete multi-arch bridge to a slab and girder one. The bridge was built in 1940 over the Cardener river and was designed according to a typology commonly used in that period: plain concrete ribbed arches without centering, with three arches spanning 11.5, 26.5 and 11.5 m. Piles that supported piers between arches were designed to balance the excess of horizontal force induced by the thrust of the main arch. In 1965, arches were substituted by a deck of precast girders with cast-in-situ slab. The forces and the barycenter of the vertical forces on the foundation changed in a radical way. Some of the piles resulted overstressed and other, almost completely discharged. Repair intervention was designed to assure good behavior and durability of the foundation.

1 INTRODUCTION

Many historical arch bridges had experienced radical transformations to improve its service conditions, i.e. enlargements of the platform, reduction of its slope. Depending on the period when these modifications were implemented, the care and respect to the existent structure could be very different.

In the case presented in this paper, a radical intervention was performed on a plain concrete multi-arch bridge changing its arches by a new deck of precast prestress girders with cast-in-situ slab (Fig.1). Apparently, at the moment when the intervention was carried out, vertical loads almost did not change and no further checking on the stress state of the foundation was performed. However, the change on the stress state of the foundation was very important, as is discussed in the paper, and could have produced consequences.

The original arch bridge was built in 1940 in Manresa (Catalonia) over the Cardener river to improve the access to the railway station. The bridge substituted a former steel footbridge, erected several years after railway arrived at the city in 1859. That footbridge was destroyed at the end of the Spanish Civil War in 1939.

The bridge was designed according to a typology commonly used in that period: plain concrete ribbed arches without centering. To built these bridges, instead of a centering a truss structure supported on the piers was placed to sustain the moulds and, then, the truss structure remained embedded in each arch. This way of building arch bridges was very competitive at that moment and allowed the erection of a significant number of bridges in an economic and industrialized system. The spans of the arches were 26.5 m for the main one and 11.5 m for the two adjacent arches, placed symmetrically at both sides of the main arch (Fig.1). The foundation of piers was on reinforced concrete piles of 40 cm of diameter. Some of the piles of the piers that supported the main arch were tilted parallel to the direction of the line of thrust at the foundation level to balance the excess of horizontal force induced by the thrust of the main arch, which span was more than two times larger than those of the adjacent arches.

The problem of the original bridge was that the deck of this arch bridge was higher than the road that was parallel to the riverside. So that, in 1965 it was decided to change the deck of the bridge to a lower level and the arches were substituted by a deck of precast girders with cast-in-situ slab. The forces and the barycenter of the vertical forces on the foundation changed in a radical way. Some of the piles resulted overstressed and others almost completely discharged.

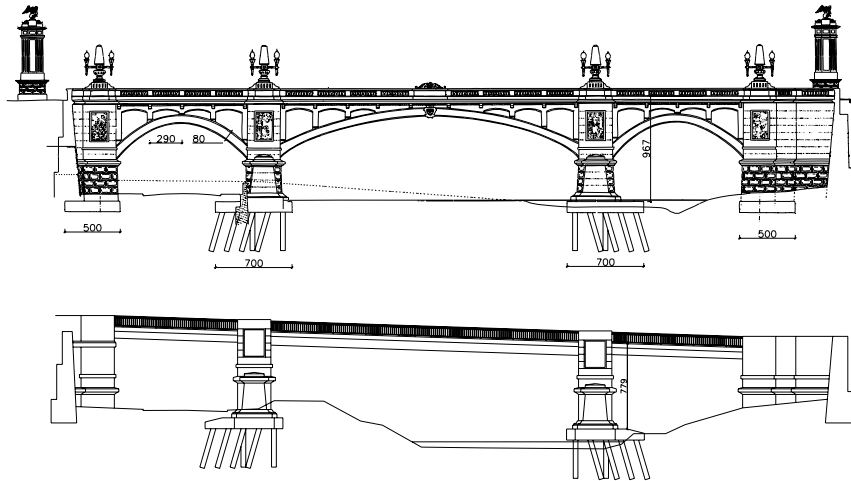


Figure 1 : Front view of the original arch bridge (design drawing) and the actual bridge

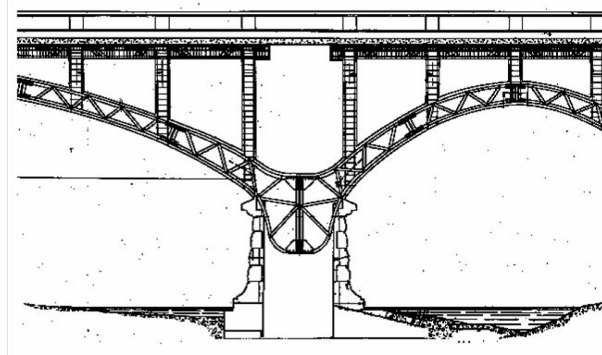


Figure 2 : Truss arches to self-support the centering of the concrete arches.

Regarding the foundation of the bridge, it was also affected by a change of the water level due to the demolition of an ancient barrage that diverted water to a small hydropower plant that provided power to a textile factory. The descent of the water level was large enough to leave on air the complete pile caps and the top ten centimeter of the piles. Also the river bed descended in a way that a significant length of the piles could experience erosion and chemical attack from the chlorides of the water.

After describing the structures and its actual state, the repair works that were done in the foundation of this bridge are presented.

2 DESCRIPTION OF THE BRIDGE

2.1 *Original arch bridge*

The city council of Manresa decided in 1940 to erect a new bridge in front of the railway station in the same place where it had been a footbridge, destroyed during the withdrawal of the republican army at the end of the Spanish Civil War (January 1939). The design, according to the aesthetics of the fascist regime of General Franco, had monumental characteristics as the access gates at both riversides. According to the oral tradition, many prisoners of war took part in the construction works, which lasted for almost three years.

The bridge was composed by three arches supported on two piers and two abutments, all of them –piers and abutments- were supported by a reinforced concrete (RC) pile foundation. The piles have a length of about four meters to transmit the loads to the bedrock and were collected

in a reinforced concrete pile-cap. The massive piers between arches and the abutments were of plain concrete. The deck of each span, also of RC, was supported by four individual arches of 1 m width built on a self-supporting centering that included an arch-shape steel truss that was leaved inside the concrete (Fig.2). This construction system was very commonly used since 1930 in Spain (Ribera, 1932), promoted by the Eng. Eugenio Ribera. The layout was symmetrical with a deck 13.74 m wide (Fig.3) and the free span of the arches was 11.5 m and 26.5 m, for the lateral and central arches, respectively. Unfortunately, and despite the monumental characteristics of the bridge, to provide enough drain capacity the platform level was finally placed at 2.15 m above the main road on the right riverside. In such conditions, the bridge served as a footbridge and as a playground to children without traffic because it was impossible to vehicles crossing on the bridge.

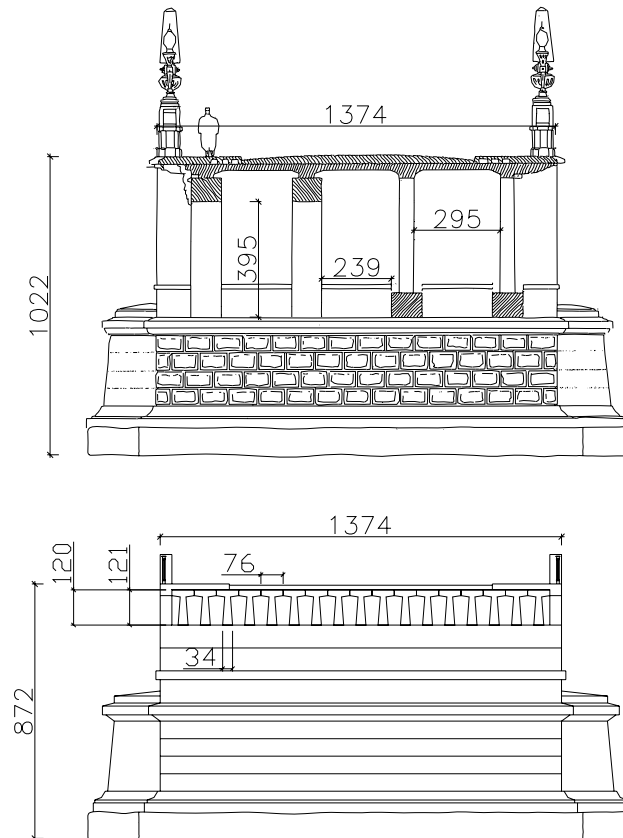


Figure 3 : Cross section of the original bridge (above) and the actual bridge (below).

Two decades later, with the increment of the urban traffic, it was necessary to solve this inconvenient by changing the level of the platform to the one of the road on the riverside. In 1964, the whole deck, including the slab, the arches and the upper part of the piers were demolished to build a new precast prestress girder deck, that is the bridge today. The possibility of taking advantage of the existing piers and foundations implied a significant economic saving.

2.2 Actual bridge

The Station Bridge over the Cardener river, is a three span bridge with a straight platform with a constant slope of 3%, that connects the way between the roads that run through the two river sides. On the right margin of the river there is the railway station. The axis of the bridge is

almost perpendicular to the river. The actual span of the girders between support axis are 27.5 m and 12 m for main and lateral spans, respectively.

Piers are very robust, built with plain concrete and covered by a stone veneer. The sizes of the piers are almost 15 m wide and 3 m deep. The abutments on the river side are similar to the piers and the support to the prestressed beams of the deck is very similar as is on the piers. As could be expected, geometry and capacity of piers is according to the former typology of the arch bridge. Obviously, in a new complete girder bridge the columns would had been significantly narrower.

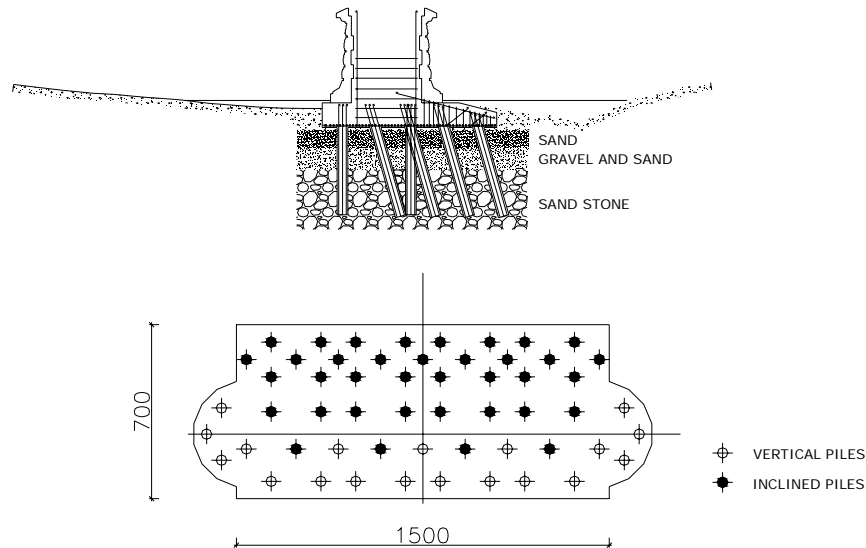


Figure 4 : Plan and front views of the foundation of the main piers.

The total length of the bridge is almost 63 m and the total width of the platform is 13.74 m. The deck of the main span is composed of eighteen precast and prestressed girders 120 cm deep (Fig. 3). Upper flanges of girders are in contact and support a concrete topping of less than 15 cm deep that was used mainly to slope forming. The girders of the narrower spans were placed in the same way with girders 105 cm deep.

The piers, that present cutwaters at both sides (in both senses of the flow), are supported on pile-caps which are 1 m deep. According to the original design drawings, the foundation of each column includes 56 RC piles of 400 mm of diameter and 3.60 m of length, enough to reach the bedrock (Fig.4). Pile reinforcement is composed of 6 rebars of $\Phi 14$ mm and a $\Phi 6$ spiral shear reinforcement. Only 19 piles of the total of 56 are vertical. The remaining 37 are inclined 16° to better resist the resulting thrust of the arches. The horizontal thrust of the main arch is significantly larger than the one produced by the lateral arch, which only compensates a small part of the main arch thrust. The structure resisted severe floods in years 1971 and 1982.

2.3 ASSESSMENT OF THE FOUNDATION

A visual inspection of the foundation revealed that there was an evident degradation of concrete in the pile-cap of the pier closer to the right riverside, including large concrete losses and rusted reinforcement (Fig.5). In addition, the pile-cap is entirely out of the water, which passes through the piles. In actual conditions, the fluctuation of water level affects the uncovered height of the piles which, in consequence, can deteriorate in a faster pace both chemically and mechanically. Finally, it is worth noting that Cardener river water presents a very high chloride contents due to existence of common and potassium salt mining activities upwards of the river basin. An extend the explanation related to the changes of water level and the stress state of the pile foundation is presented in next two sections.

2.4 Evolution of the river bed

From 1943 the riverbed has experienced several changes, as the analysis of the documents of the design in 1940 and the actual topography reveal. Probably the most significant change is the descent of the normal water level that left the pile-cap above the water (Fig.5). In fact, normal water level is nowadays 15 cm below the pile-cap. Such descent on the normal water level was due to an anthropogenic modification of the river-bed produced by the reduction of the height of a small dam place 300 m away that was originally built at the beginning of the nineteenth century to divert water to provide power in a textile factory. Also the transverse section of the river-bed under the bridge has experienced significant changes as reflects Fig 1. In particular, a dike was erected to protect from floods the way that goes under the lateral span on the left riverside.



Figure 5 : Picture of the pier where piles are partly visible between the pile-cap and the water level.

2.5 Stress state on piles

The stress state on the pile foundation was checked in the original state and in the actual state. In fact, the calculation of the forces acting on the foundation in original conditions was found within the drawings of the original design. Fig 6 shows the graphic statics diagram of the forces acting on the pier and on the pile-cap due to dead load and live load acting on the main span, which produces the largest horizontal force and eccentricity on de pile-cap. In such configuration, maximum compressive stress on the piles was 2.87 N/mm² and the distribution was quite uniform. So, the foundation was adequately conceived to resist the loads transmitted by the arches and the pier, with the eccentricity towards the lateral arch and most of piles inclined towards the direction of the unbalanced horizontal thrust. The most loaded piles were those placed towards the lateral span.

When the deck was substituted, a deep change on the foundation occurred, as is shown in Fig 6. In fact, the maximum stress on a pile in the actual state -when acting the dead loads- was 4.52 N/mm², a severe 57% overstress if compared with the original configuration. In this actual configuration the most stressed piles are the vertical ones placed next to the main span (Fig.6). If the live load is applied on the main span, including the 600 kN vehicle and the distributed 4 kN/m² prescribed in the bridge actions code IAP-98 (Ministerio de Fomento, 1998), 5.09 N/mm² was computed. In addition, if a loss of surface cover of 40 mm is assumed in the piles –due to erosion and/or chloride attack-, that reduction of the pile cross-section produces an overstress till 8.00 N/mm². That is an inadmissible compressive stress for that concrete.

It is worth-noting that the total weight of the bridge almost not changed with the deck substitution.

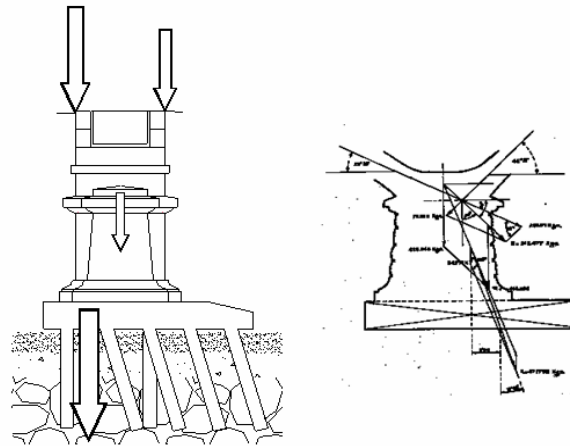


Figure 6 : Actual (left) and original (right) force distribution on the foundation of the pier.

3 INTERVENTION

It was decided to intervene because:

- (1) it was evident that the piles in direct contact with water –about 1 m of its length-, were subjected to several attacks (erosion and oxidation of reinforcement in presence of chlorides);
- (2) some piles were over-stressed in service conditions due to the change of force distribution when substituting the deck;
- (3) it was necessary to protect damaged piles with a diameter of 32 cm from impact produced by materials swept away in the river.

The intervention had to:

- (1) provide chemical and mechanical protection of the piles;
- (2) reconstitute the original section of piles or also enlarge its section a bit to avoid stresses over 4 N/mm^2 in ancient piles built below water level;
- (3) according to the latter, most piles had to be strengthened and this was very difficult because separation between them is normally lesser than 0.80 m;
- (4) not affect the traffic on the bridge;
- (5) not reduce the hydraulic section of the river; and finally;
- (6) provide long term stability and durability.

To achieve such objectives two kinds of intervention were devised. The first consists in placing a sheet pile lining around the pile-cap aimed to provide a dried enclosure, which would allow the repair and strengthening of the piles. Later on, the volume enclosed could be filled with concrete. This alternative presented some difficulties such as sink the sheet piles under the bridge due to the limited height and the large stone blocks that were detected in the ground investigation. Another difficult aspect was to work within the piles.

A second alternative consists in working always from the surface. In that case, the objective was to prepare an enclosure around the pile-cap of the pier by placing a kind of diaphragm wall made of grout injections. Then all the volume comprised by the bedrock and the pile-cap as horizontal limits and the grout diaphragm wall as vertical limit could be filled in by grout and cement injections. This alternative eliminates the main disadvantages of the first alternative and was the selected one.

The complete construction process was (Fig.7):

- (1) Place infill gravel within the river bed and the pile-cap;
- (2) Grout injection to built columns that form an enclosure all around the pile-cap of the pier;
- (3) Cement injection of all material inside the enclosure. That enclosure assured that no cement injection could go to the water, which could provoke heavy environmental damage;
- (4) Restitution of the normal the river bed by removing the mortar enclosure where required;

(5) Visible parts of the pile-cap where repaired removing rust from reinforcement and damaged concrete using partial hydro-demolition and applying structural repair mortars.

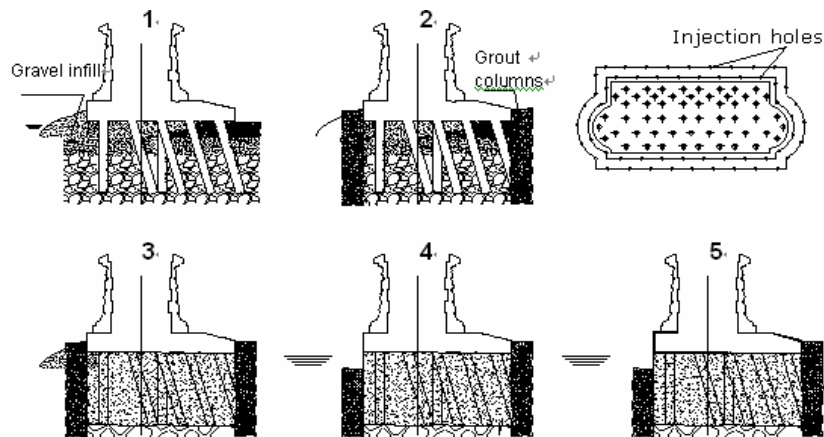


Figure 7 : Process of the intervention.

4 CONCLUSIONS

A real case study of the effects on the foundation of changing the structural system of a bridge was described. from a plain concrete multi-arch bridge to a slab and girder one. In the case studied, the foundation of the piers that between arches were designed to balance the excess of horizontal force induced by the thrust of the largest arch. The substitution of the arches by a deck of precast girders changed radically the distribution of forces on the foundation, overstressing some piles and completely unloading others

A careful analysis of the actual conditions of the bridge helped to design the best intervention without affecting the traffic, neither the river bed.

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