BRIDGE OVER THE RIVER JARAMA AT TITULCIA (MADRID)

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Abstract: The deck of the Titulcia bridge is formed by a continuous three span stretch with an overall length of 134 metres, measured between the centre lines of the bearings on abutments. The 90 metre centre span is formed by a double, steel through arch bridge with a Bowstring type shape.

The deck is formed by a composite structure. It has two continuous, longitudinal girders located on both sides into which the two arches are fixed at their springings.

The arches supporting the central span stand alone, with no intermediate bracings. The structural design was drawn up discarding the classical intermediate joint between arches in order to provide the bridge with a modern, diaphanous look to vehicles passing over the roadway.

The arch cross section is rectangular and the vertical dimension varies, diminishing from the springings to the crown. The suspension system is formed by vertical, small diameter, circular cross-section hangers. The unit as formed by two slender arches supporting the deck via hangers, which can hardly be seen, provides a feeling of visual transparency to the observer located such a distance away that he has a full view of the whole bridge.

One of the most singular aspects, worthy of mention, involved the construction process consisting in dry land assembling the whole of the 135 m long steel structure plus the overall pre-slabs for the centre span and subsequently launching to their final position by pushing.

The structural design was integrated with the construction design and with the detailed study of the deck launching process. Used in the design phase, this methodology enabled a procedure characterised by its simplicity, absence of powerful auxiliary equipment and minimal environmental impacts to be developed.

The structure's conception, as well as the design and verification of its fundamental elements, was developed with the express consideration of the situations provided for during the construction process, which allowed for optimisation of the construction equipment and amount of material in the structure, which was provided with a minimum of supplementary elements earmarked to guaranteeing its proper stability during the assembly and launching process.

1 INTRODUCTION

The new bridge over the river Jarama forms part of the Titulcia by-pass (Madrid), belonging to the Madrid Community's M-404 Road.

The work undertaken represented a considerable improvement as regards the existing road, not just for avoiding having to pass through the town of Titulcia, but also, fundamentally, for the building of a new bridge over the Jarama to replace another, existing one whose structure proved inadequate for current traffic requirements (Figure 1).



Figure 1. - Titulcia Bridge. General Overview The old bridge appears on the upstream of the river

The old bridge's deck has three spans formed by metal lattice girders with piers of hewn stones. Due to the deck's scant width, the roadway over which vehicles run is formed by a single lane and it would have been necessary to avail of an alternative lane in both traffic directions, with traffic being regulated by traffic lights located at the bridge's ends.

Throughout the whole time, which elapsed since its construction, the old bridge has gradually deteriorated. Constant, heavy vehicle traffic affected the metal structure and, in addition, one of the piers located on the river Jarama's course had undergone major settling. The need for a by-pass and the construction of a new bridge over the river Jarama was obvious.

2 DESIGN CRITERIA

The existence of an old bridge and the expectations for it to remain in the future solely for pedestrian use after remodelling was borne in mind in selecting the shapes for the new Titulcia bridge located quite near to the existing one.

Moreover, the idea prevailed of having a deck formed by a metal structure with the purpose of keeping to surroundings similar in nature to the existing bridge whilst, at the same time, marking the differences deriving from the state-of-the-art's evolution that has occurred during the time elapsing from building the old bridge up to the present.

The contrast between two structures belonging to different ages materialises in the following external features characterising the type of new bridge:

- Three span deck with a 90 metre centre span amply striding over the river Jarama's normal course (Figure 2).



Figure 2. - Titulcia Bridge. Main span (90 m)

- Simplicity of shapes. The centre span is formed by a double through arch. The cross section of the arches is rectangular and the vertical dimension variable, decreasing from the springings to the crown. The suspension system is formed by vertical, circular sectioned, small diameter suspenders. The overall ensemble, formed by two slender arches supporting the deck with suspenders, which can hardly be seen, gives a sensation of visual transparency to an observer located such a distance away that he has a full view of the whole bridge. The shapes of the new bridge's deck heavily contrast with the appearance of the old bridge's metal lattice structure.
- The arches supporting the centre span are self-standing, with no intermediate bracings (Figure 3). The structural design was drawn up discarding the intermediate joint between arches in order to provide the bridge with a modern appearance. The transparency as seen in the new bridge when travelling over the roadway contrasts with the sensation of a "roof" given by the existing bridge's metal bracing framework, earmarked to ensure the cross stability of the upper chord of the large latticed side girders.



Figure 3. View from the roadway. There are no bracings between arches

Environmental requirements were borne in mind for selecting a construction process which involves launching the complete deck so as to cause minimum impacts on the surroundings (Figure 4).



Figure 4. Launching the complete deck

3 STRUCTURAL CHARACTERISTICS

The new bridge's deck is formed by a continuous three span stretch with an overall length of 134 metres measured between centres of bearings on abutments. The 90 metre centre span is formed by a double through arch with a Bowstring type scheme (Figure 5).



Figure 5

The deck's metal structure is formed by two longitudinal girders located on both sides, into which the two arches are fixed at their springings. Powerful cross braces which remain hidden inside the deck and are assigned to providing a very stiff elastic fixing in the perpendicular plane were provided in the arch support areas. The structural qualities of this scheme were clearly shown throughout the calculation process, which demonstrated that there was a high degree of safety as regards side buckling of the arches which were bereft of intermediate joining braces (Figure 6).



Figure 6. Structural scheme

The deck suspension system also contributes to increasing safety against side buckling, which is partially prevented by the constraint provided by the vertical suspenders as the structure is deforming.

Apart from the said braces, the two longitudinal girders are joined by a set of varying thickness metal cross members, separated 3.00 m between centres, on which a 20 centimetre thick concrete slab was built, forming a composite steel/concrete structure.

CORTEN type steel was used. The suspenders are passive and are formed by 90 mm outside diameter-drilled rods, covered by 1 mm thick, stainless steel tubes.

The piers are reinforced concrete and have a cutwater shape to ease the passing of the river current in the event of large rises in the water level. The foundations of piers and abutments are formed by 1 metre diameter, 25 metre deep piles.

4 VERIFICATION OF THE TRANSVERSAL STABILITY OF THE ARCHES

Two different procedures were used to determine the degree of safety to the archs' side buckling:

- Non-linear calculation in theory of large movements and small deformations.
- Calculation of buckling seeking the point where the structure's equilibrium bifurcation occurs.

4.1.- Non-linear calculation.

Non-linearity between stresses and movements in an arch type structure has particular relevance in very low rise/span ratio arches. The Titulcia arch has a 15 metre rise for a 90 metre span, which therefore gives a rise/span ratio =1/6, which is a normal figure in this type of structure. As it is not an arch with an excessively low rise/span ratio, the non-linear calculation was not expected to give results very different to those of the elastic and linear calculation. In the case of arches with very low rise/span ratios (f/l>1/10) considering the deformed geometry, a considerable increase in stresses would certainly occur.

When making a non-linear calculation, a choice must be made between two types of calculation:

- Geometric non-linearity. The ratio between stresses and deformations is linear, but the structure's deformed geometry is taken into consideration.
- Non-linearity in material performance. Apart from considering the structure's deformed geometry, non-linear constitutive equations for materials are taken into account.

The first calculation method was chosen for the case of the Titulcia Bridge. Therefore, the worst combinations obtained in the elastic and linear calculation were chosen, since it is not possible to superimpose loads. An incremental procedure was carried out, increasing forces from a nil value (no load applied) up to a figure of three times the structure's service loads. The process has to be incremental because when entering the structure's geometric matrix, the axial force in each step is unknown. Obviously, this latter value (β =3), will produce stresses in the material which would cause the structure to collapse, but the issue is to verify possible deviation in its linear behaviour. Modification of the structure's initial geometry due to deformations the loads introduce is taken into account in each load step. A linear analysis is made within each load step with the geometry obtained in the previous step. The structure's calculation can be improved in each load increase by comparing the final deformed structure's curve obtained with the initial one for the increase and

repeating with the final geometry if the difference were significant, which did not actually happen in practice.

The result of the analysis (see figure 7) clearly showed that the bridge performs linearly up to a load coefficient in the order of β =1.60, for which value the maximum stress is below the elastic limit. This means to say that the linear elastic calculation made is totally valid.





4.2.- Calculation of the critical buckling load.

Apart from making the structure's non-linear calculation, its critical buckling load was determined. This is an aspect, which could have become critical due to the absence of cross bracing between the arches. The critical buckling load was calculated by cancelling out the determining factor of the stiffness matrix plus the geometrical matrix:

$|K_e + \mathbf{l} \cdot K_g| = 0$

The values of λ define the arch's compression and those that cancel out the determining factor are those causing instability. Obviously, the lowest value of λ is that which produces the critical buckling load. A non-linear elastic calculation was made in the same way as the foregoing. The hypotheses considered were the same as for the non-linear calculation, paying particular attention to those producing movement outside the plane of the arch.

Once the calculation had been made, a critical buckling load close to 5.5 times the service loads was obtained. Naturally, this buckling occurs outside the plane of the arch for a one-wave mode.

Such a high value indicates that safety as regards the arch's buckling is very high and does not prove critical due to the fact that the hypothetical bridge collapse situation because of its state of stress would occur before the arch would commence to buckle.

5 CONSTRUCTION PROCESS

One of the most unique aspects worthy of mention was the construction process, consisting in assembling the whole of the metal structure, 135 m long, on dry land and then launching to its final position by pushing.

The structural design was integrated with the construction project and with the detail study of the deck's launching process. This methodology used in the design phase enabled a procedure to be developed which was characterised by its simplicity, absence of potent auxiliary equipment and minimum environmental impacts.

The structure's conception, as well as the design and checking of its fundamental elements, was developed with the express consideration of the situations envisaged during the building process, enabling optimisation of the construction equipment and amount of materials in the structure itself, which only had to be provided with a minimum of supplementary elements earmarked to guaranteeing its adequate stability during the assembly and launching process.

The metal structure was dry land assembled, supported on concrete blocks separated 30 m from each other, on which small metal pieces fitted with polyamide plates on their top were first placed. The top surface of these plates proved adequate for sliding the deck. The metal arches were provisionally joined to the deck's bngitudinal girders by means of metal, vertically arranged tubes, assigned to withstanding the compressive stresses envisaged during the launching phase. These tubes are the only supplementary structural elements the structure needed for launching and were removed once launching had concluded (Figure 8).



Figure 8

Supports were made on the river bed by means of provisional, circular sectioned piers, with each having its foundations formed by a 1.00 m diameter pile in a pier-pile arrangement.

Once the metal structure had been dry land assembled, the preslabs belonging to the 90 metre centre span were placed and a joint launching took place, whereby manoeuvres were avoided that might have been necessary should the preslabs have been assembled in the centre of the river, once the structure was in its final position (Figure 9).



Figure 9

The pushing system was formed by two prestressing jacks arranged in a horizontal position at the rear of the metal structure. Each of the jacks was prepared for stressing a cable made up by four (4) 0.6" diameter strands and 266 kN ultimate tensile strength which ran underneath the deck and were anchored at the opposite end into a metal piece fixed to the abutment.

The deck was launched to its final position by loading the jacks and successive anchorages to recover the piston strokes.

The preslabs' placing was then completed using cranes located on the banks. The supplementary reinforcements were then placed on the preslabs and the deck slab was concreted without the need for formwork. Once the final structure had been formed, the provisional piers and artificial islands in the river course were removed. The Titulcia by-pass, within which the bridge dealt with in this Paper is located, came into service in December, 2002. The work was managed by the Community of Madrid with the Engineer Antonio Domingo acting as Manager and VIAS Y CONSTRUCCIONES performing the construction work.