Widening of the Elche de la Sierra Arch Bridge, Spain

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Introduction

It is neither economically feasible nor is there any technical justification to replace all the bridges that have reached the end of their design working life, or in which structural damage or anomalies have been observed. Also due to evolution of road traffic over the time, the traffic load carried by existing bridges is usually higher today than what it used to be when they were built. At the same time safety requirements for structures in general are becoming more and more demanding. Recent structural standards have grown less tolerant to the possibility of damage to structures. In other words, the level of acceptable risk has been lowered [1]. For all these reasons, the question whether existing structures are suitable for present and future service conditions or not is of increasing importance to the concerned authorities.

This article discusses the assessment of an existing arch bridge over 70 years old, conducted when the need arose to widen its deck. There were two reasons for doing the assessment. On one hand, widening the deck implies a change in use and on the other hand the requirements laid down in current standards are more restrictive than it used to be when the bridge was originally built. The challenge was to verify whether the existing structure would be reliable and fit for use with no further strengthening under the new service conditions.

Fig. 1: Existing bridge

Existing Bridge

The 40 m span arch bridge at Elche de la Sierra in the Spanish province of Albacete was built in 1927. It was based on the ideas and guidelines of the renowned engineer Eugenio Ribera (1864–1936), which had been compiled in an official standard on arch bridges. The Segura River is spanned by a twin arch, the two ribs being separated by a distance of 3,1 m. Each of these ribs is 1,0 m wide with a depth varying from 1,08 m at the springing to 0,94 m at the quarterpoint. The axis of each arch follows a parabola with a ratio of arch span, to rise of 1/10 (*Fig. 1*). Like the arch, the support walls of the roadway girder are 1,0 m wide. Measuring 0,25 m thick, they are spaced at an interval of 2,0 m from centreline to centreline. The deck girder, a double-ribbed, reinforced concrete slab, and the arches are connected monolithically at the crown. The abutments are constituted by walls designed to receive the thrust transmitted by the arches. In all, the structure including the accesses is 71,6 m long.

The use of profiles from structural steel to reinforce the arches (*Fig. 2*) makes this bridge a precursor of composite construction. While the bridge was being built these profiles supported the formwork, whereas at the final stage they are embedded in the concrete with which they constitute the composite cross-section of the arches. This technique had a dual advantage: it eliminated the need for complex traditional falsework, and thereby reduced the risk of damage from flash floods which could raise the water level in a short time.

According to the aforementioned official standard on road bridges, the original bridge deck was 6,0 m wide, with a 4,50 m carriageway and two 0,75 m sidewalks. Since the sidewalks had been removed at some unspecified past date prior to the intervention, the carriageway extended across the entire width of the deck. The improvement works for the Elche-Férez road, carried by the bridge called for widening the deck from 6,0 to 9,0 m.

Planned Intervention

The conceptual design for widening the arch bridge involved the construction of a new cast-in-place concrete slab. Under this solution, the existing slab played a dual role. On one hand it

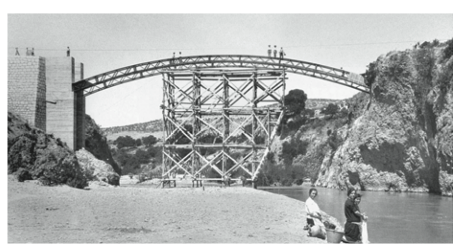

Fig. 2: Construction of the original bridge
(Photograph: Luis Escobar)

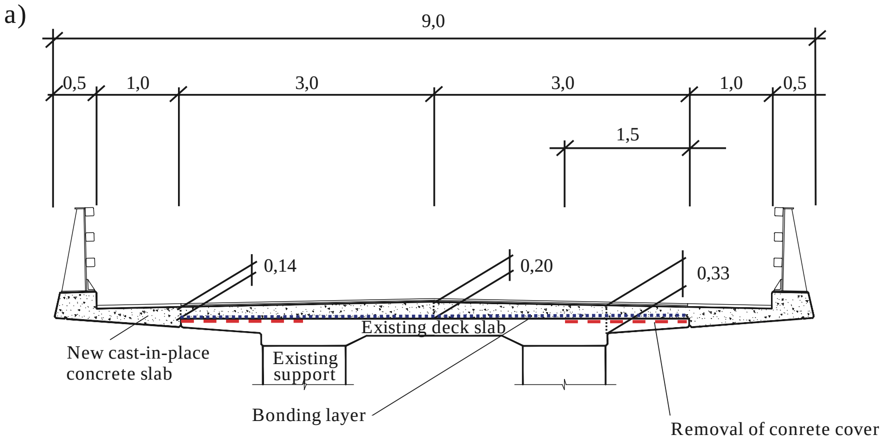

Fig. 3: Structural solution a) Cross-section

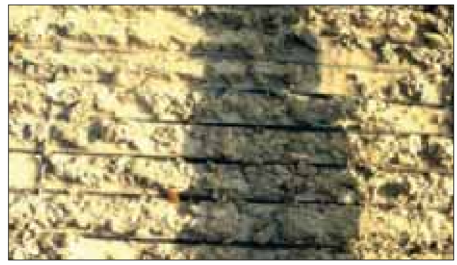

Fig. 3 b): Transverse reinforcement on the existing deck slab

acted as formwork for the central part of the new slab, and on the other hand by means of suitable bonding composite action was to be achieved from the existing and the new concrete, incorporating the latter into the structural system of the widened bridge (*Fig. 3a*). The minimum thickness of the new concrete layer was determined in such a way that the shear forces at the transition section between the new deck slab cantilever and the built-up part of the existing slab could be transferred with no need for any mechanical connection.

The need to ensure the composite action of the existing and new concretes in the widened deck slab and to guarantee due performance under service conditions, especially to attenuate cracking in the new concrete cast against the existing deck, called for a series of measures:

- The concrete cover was to be removed in a way such as to ensure that, after the widening of the deck, the upper layer of the existing transverse reinforcement was embedded in the new concrete (*Fig. 3b*). In this way, a mechanical connection between the two concretes was achieved by means of the existing reinforcement. The concrete cover was only to be removed in strips 1,5 m wide on both sides of the deck slab (*Fig. 3a*), that is in the areas of maximum longitudinal shear forces due to the combined global action effects and transverse bending moments.
- A bonding layer was to be applied to the surface where the two concretes are in contact.
- A concrete with reduced shrinkage strain was to be used to widen the deck slab.
- Reinforcement was to be placed as required to control cracking in the new concrete.

As far as the existing structure was concerned, the structural solution involved no strengthening or alteration of arches, support walls of the roadway girder, or arch abutments. Structural assessment was conducted to substantiate whether the bridge under the new service conditions was fit for use or not.

Assessment

Overview

The essential difference between assessing existing structures and designing new structures lies in the type of information available. In new constructions, the parameters used in structural load and resistance models are based on expected values, and provisions must be made for any construction process inaccuracies through mere anticipation. When the structure to be analysed already exists, many of these uncertainties can be reduced because the calculation models may be updated with site specific data obtained from in situ inspections, measurements, and material testing. In existing structures, model accuracy can always be enhanced by obtaining more data on actual loads and resistance of the structure analysed. Consequently, assessments are normally phased procedures in which the conservative default load and resistance models used at the outset are updated and improved upon from one phase to the next to gradually adjust these models to greater precision.

The phased assessment procedure used in the Elche de la Sierra arch bridge based on a combined application of deterministic and probabilistic assessment methods in which the updated data can be readily introduced in the evaluation of structural safety, yields considerable benefits. Whereas, an assessment conducted according to the design standards presently in force would underestimate structural safety. More often than not, and most certainly in the case of the bridge analysed in this study, the cost of updating the information is offset by significantly lower intervention costs since, an overly conservative assessment may lead to unjustified restrictions on traffic loads, not to mention the unnecessary strengthening or demolition of existing structures.

Updating Information

The quality of assessment of an existing structure is wholly contingent upon the quality of information on which it is based. For this reason, compilation and updating of the available information are very likely the most important steps in assessing the reliability of such structures.

In this case, the available information was relatively abundant. Both the official standard on Ribera's arch bridges mentioned above and recent studies on a number of these bridges that are still in service, contain very relevant data. Moreover, the process of compiling information on the Elche de la Sierra Bridge led to the location of certain documents from the original design, drawings included.

Based on the available information, a very limited data gathering programme was designed in order to confirm the validity of the data previously compiled and to fill in any existing gaps. With these aims in mind a statistical review was conducted on the geometry of the main members, as well as properties of the materials used. A visual inspection was likewise run to detect possible damage to the structure such as cracks, spalling, or signs of corrosion. The structure was found to be in reasonable condition despite the apparent lack of maintenance. In particular, no serious damage or signs of advanced deterioration was observed. Finally, a geotechnical survey was conducted to confirm the assumptions made for the condition of the bridge foundations. The soil tests which were carried out showed no significant difference between these assumptions taken from the available original design calculations and the observed geotechnical parameters, particularly the soil resistance.

Assumptions

Based on the information existing prior to the study, the updated data on geometric dimensions and material properties and the results of the visual inspection; a structural safety evaluation was conducted on the existing bridge. It was assumed that the deck slab had already been enlarged according to the planned intervention (*Fig. 3a*). Although no spalling of the concrete covering the steel profiles embedded in the arches were observed, this kind of damage can not be ruled out at high levels of internal forces and moments (Ultimate Limit State) due to the lack of bonding between the concrete and the profiles. A conservative approach thus required determining arch strength and stability without considering contribution of the concrete cover.

Structural Analysis

Regardless of the assessment method, deterministic or probabilistic, the issue of arch bridge instability after widening the deck slab had to be addressed. The buckling shape of the system depends on many parameters. It includes arch slenderness, the boundary conditions at the supports, the contribution of the deck to overall system stability and the arrangement of traffic loads, amongst others. In this study second-order moments were estimated with a procedure based on calculating instability.

The critical load case for buckling consists of permanent loads plus live loads

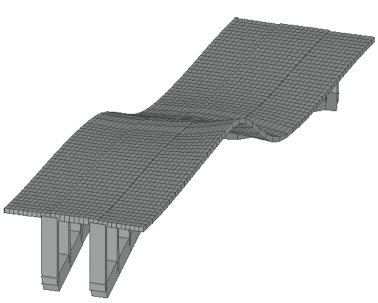

Fig. 4: Antisymmetrical buckling shape

Fig. 5: Hydrodemolition of the existing concrete cover

applied to one half of the arch span, leading to an antisymmetrical buckling shape of the system (*Fig. 4*). A minimum value of the buckling load multiplier in the order of 12 has been obtained, a figure that may be viewed as normal for arch bridges built in the 1920s', although the minimum value for modern bridges is normally much lower, almost half of that figure. The buckling load multiplier provides an estimate of the increase in arch moments due to second-order effects, in this case approximately 9%.

Intervention

The construction procedure adopted to implement the structural solution described above in the section "Planned Intervention" was quite simple. After removing the surface course and demolishing the imposts on the existing bridge, the concrete cover was removed down to the transverse reinforcement in strips 1,5 m wide along the edges of the existing slab, to contribute to the bonding between the existing and new concretes. For this purpose, hydrodemolition techniques were used (*Fig. 5*) to protect the existing structure from possible damage.

Before casting the concrete with reduced shrinkage strain, surface of the existing slab was treated with a bonding layer. For the casting of the deck slab cantilevers a travelling formwork was used. The bridge was load-tested after the paving operations were completed.

Simplicity of the structural solution and adopted construction procedure made it possible to complete the enlargement work on schedule (*Fig. 6*). Substantiation of the fact that the structure could reliably accommodate the new service conditions with no need for further strengthening was instrumental in meeting this deadline.

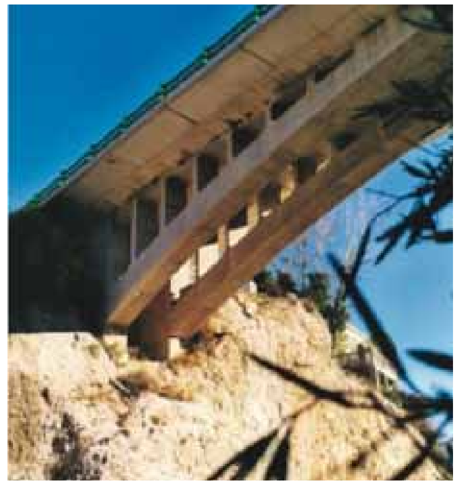

Fig. 6: Bridge over the Segura River at Elche de la Sierra after the widening
(Photograph: Paco Gómez)

References

[1] SCHNEIDER, J. *Sicherheit und Zuverlässigkeit im Bauwesen – Grundwissen für Bauingenieure.* Verlag der Fachvereine AG, Zürich, und Teubner Verlag, Stuttgart, 1994. ISBN 3-519-0504-4 (Teubner).

SEI Data Block

Owner:
Junta de Castilla-La Mancha

Structural engineers:
P. Tanner and J. L. Bellod, Cesma Ingenieros, Madrid

Main contractor:
Vías y Construcciones

In situ concrete (m^3):	135
Estimated total cost (€):	420 000
Service date:	2002