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IMPROVING THE SUSTAINABILITY OF CONCRETE BRIDGE CONSTRUCTION

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ABSTRACT

Bridge construction is one of the most challenging aspects of Civil Engineering Works from the point of view of the sustainability and environmental impact. From the different construction methods used for building long concrete viaducts, one used very often is the span by span method. This has the advantage that only the shadow of the bridge is somehow altered during construction period. No matter how small this impact is, it is to say that in a Life Cycle Assessment the shorter the construction period, the higher the sustainability. This paper aims to present a recent development for constructing concrete viaducts which reduces significantly construction deadlines, without any increase in CO_2 emission or energy consumption. The structural challenges to be overcome will be also presented along with their solution.

1. INTRODUCTION

Besides precast beams and the incremental launching method, there is another classical construction procedure for built concrete decks for long viaducts with medium spans; the span-by-span method with Movable Scaffolding System (MSS) (Fig 1). However, even if the method is fairly industrialized, its competitiveness is reduced due to its demanding execution time.

Figure 1. Movable Scaffolding System for span by span bridge construction method.

This work discusses a modification of the construction process of bridges executed span-by-span with MSS, focusing on the reduction of the critical path. At the same time, the paper analyzes the structural aspects involved in such improvement.

Self-supporting launching falsework are being used since the sixties. The first time this system of construction was used, was in Germany. The Krahnember viaduct, designed by Hans Wittfoth, was built in 1961. It was mainly from the seventies when the spread across Europe took place. Some of the most noteworthy performances of that time are the Glattfelden Lättenbrücke viaducts, Ponts sur le Viaduc du telent Chavornay, and Lac de la Gruyere, in Switzerland.

The usual spans achieved by the MSS method are in the range of 40-60 meters. The traditional incremental launching procedure consists in the execution of the inferior slab and flanges of the cross section in a first phase, subsequently executing the upper slab. Then, once the necessary concrete strength for prestressing is achieved, the tendons are stressed and the falsework advances to the next span. This sequence generally requires 2 weeks per span, although this period can be reduced by reducing curing times and continuing reinforcement and splicing activities at night, thus involving much higher costs. In both, the traditional incremental procedure and MSS, the falsework advances span by span, setting up the casting joint at a distance equal to 0.2 L from the piles, where L is the length of each span, so that the bending moments at the joint between longitudinal phases are as low as possible.

MSS represents a great advantage from the point of view of modern requirements of Occupational Health and Safety since involves an industrially prefabricated auxiliary structure that permits the use of a platform on which the collective security measures are implemented at the factory. Hence, operating risks are lower than for other systems.

2. PROPOSED IMPROVEMENT

In terms of reduction of execution time and, therefore, construction costs, it has been observed that a further evolution of the MSS method is based in building partial self-supporting schemes that allow to move the falsework forward, and later complete the transversal section by simpler auxiliary means, out of the critical path. Then, in order to improve the performance and execution time of each span of the deck, a construction sequence by transversal phases, is proposed. This sequence is different from the traditional one and a priori allows executing one span per week, with activities out of the critical path. This variation makes it a much more competitive methodology.

The new method (Fig. 2) considers the execution of the U-beam and flanges in a first phase (i.e. bottom slab, webs, and flanges of the upper slab). The first stage of prestressing takes place once the elements have reached the required strength. The prestressing force introduced in the structure is generally in the range of 50 to 60% of the final value. This introduces self-supportability to the executed span, so the falsework can move forward to the next span. The second phase, corresponding to the central area of the upper slab, can be executed later without disturbing the movement of the falsework, i.e. outside the critical path and with simpler auxiliary means.

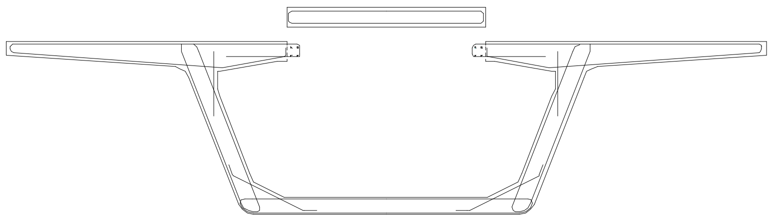

Figure 2. New method of construction by phases.

3. ADVANTAGES OF THE IMPROVED SOLUTION

There are a series of viaducts already executed in Spain following this construction sequence (González and Alcalá, 2008), (Pascual and Viartola, 2005), (Crespo et al, 2008). These examples have proven the following advantages with respect to the previous procedure:

- Permits the generation of a resistant core that accelerates the advance of MSS.
- Allows the use of simpler auxiliary means to execute the second phase, out of the critical path.
- Improves the construction performance and timing; from 1.5 to less than 1 week per span.
- Avoids the aesthetic issues at the web-flange union area.
- No uncovered prestressing ducts in phase 1.
- From the construction point of view, clarifies the load distribution between the falsework and the deck, since the falsework only has to support the weight of the first casting phase. The weight of the second casting phase is carried by the self-supporting core.
- Introduces an increase of capacity of the existing falsework, since it does not have to support the weight of the whole section but only that of the first casting phase, until prestressing.

4. PROBLEMS OF THE IMPROVED SOLUTION

However, the application of this procedure is constrained by connecting reinforcement and splicing issues linked to the casting phases. Specifically, the problem arises when connecting the reinforcement of the slab of the second phase with that of the first phase. Respecting the classic conditions for reinforcement splicing by overlapping provided by Codes and

Standards (CEB-FIP, 1993), (DIN 1045 , 1988), (Eurocode 2, 2004), (EHE-08, 2008) makes the solution unviable in practice. Regulatory requirements oblige to leave long protruding rebars to connect the two phases. In practice, this fact complicates the extraction of the interior formwork of the section. On the other hand, the use of mechanical splices, that would also ensure a compact geometry, would invalidate the solution due to its high cost. The use of welding to splice reinforcement on site is forbidden in Spain and in many neighboring countries due to the difficult quality control and loss of ductility of the welded reinforcement. Transversal prestressing of the slab is also a possible solution that would allow connecting the phases, but it is not always an economical option and does not have universal acceptance.

Consequently, for the successful implementation of the new method, it would be necessary to develop a compact splice geometry that would allow the removal of the inner formwork of the deck in an industrialized way. In this way, the straight protruding rebars that constitute a layer of reinforcement impeding the extraction of the inner formwork, are replaced by loop-type splices or loop-joints (Fig. 3) that to do not represent an obstacle for the removal of the internal formwork. This article presents an experimental study that supports the use of this type of splice geometry that is not covered by current Codes and Standards. Tests evaluate the fulfillment of the performances required by current regulations both in Ultimate Limit State (ULS) and Serviceability Limit State (SLS), under pure static flexural loading. This is done for a given splice geometry in slabs cast in phases with different types of concrete; normal strength concrete, self-compacting concrete, and high strength concrete.

Figure 3. Detail of loop joint connection between phases.

Shear transfer is also an issue for these compact geometries. Shear stresses in the joints are present due to torque, horizontal shear, creep and shrinkage. So shear off of the joint is also a subject to study. Though the study of the shear transfer in beams of high strength concrete, self-compacting concrete, and fiber reinforced concrete has been a research subject of many researchers in the last years (Johnson and Ramirez, 1989), (Mphonde and Frantz, 1984), (Polak and Dubas, 1996), (Wafa et al. ,1994), (Barragán, 2002), (Gettu et al., 2002), (Barros et al., 2004), (De la Cruz et al., 2009), (Godat et al. (2011), (Rizzo et al., 2009), (Lu et al. , 2009), (Thanoon et al. ,2010), (Sundarraja and Rajamohan, 2009), (Tahir et al., 2009), (González-Fonteboa et al., 2009), (Wang et al. ,2011), the shear-off response has had a more limited attention (Mattock, 2001), (Walraven and Stroband, 1994), (Barragán et al., 2000), (Barragán et al., 2006), (Gettu et al., 2002). Hence, shear off tests were also performed, but their results, even though positive, will not be presented in this paper.

5. TESTS

The main principal stresses to which the casting joint is subjected are those coming from the transversal flexure of the upper slab. This is why the tests performed in this study involve slabs under pure flexure. Results will be useful to study the behavior under SLS and ULS.

The slabs consist of 0.285x0.60x2.90 rectangular prisms (Fig 4). The element simulates a piece of the slab of the bridge deck, and it is cast in 2 phases. The casting of the first phase was done against a bulkhead made out of a phenolic wood board leading to a very smooth interface surface (figure 4).

Figure 4. Details of the slab: loop joint at casting joint and phenolic panel at casting joint

The behavior of the joint under normal stresses (N) is evaluated for normal strength conventional concrete (NSC). Three tests have been carried out. The reference slab is called control slab (C), with continuous longitudinal reinforcement along the entire length of the slab. The other two slabs reinforcement is a loop joint type that consisted of 3 loops of 20 mm rebars in each joint. The loops were transversally connected by 6 rebars of 16 mm diameter.

All slabs were subjected to a 4-point bending (figure 5). Hence, the central portion of the slab, and therefore the joint, remains under pure bending stresses..

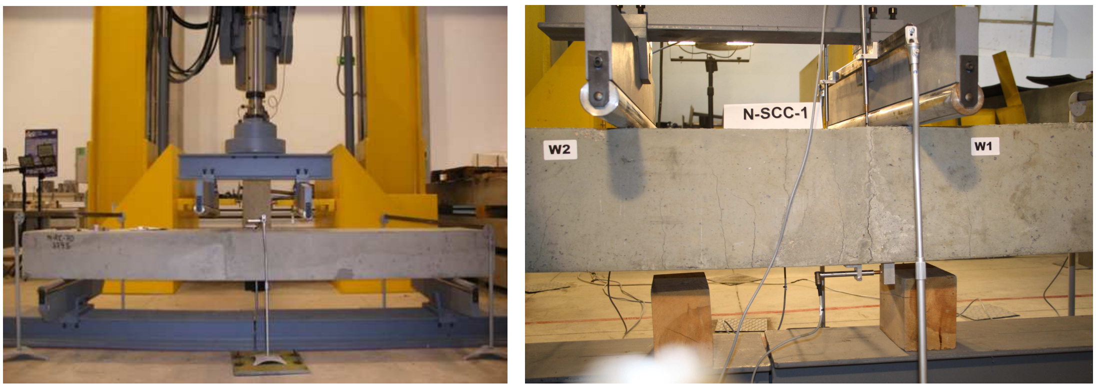

Figure 5. Pure Flexural Test configuration and detail of LVDTs

In all the tests that were carried out, concrete components included a CEM I 52.5R cement, crushed limestone sand (0-4 mm) and gravels (5-12 and 12-20 mm), siliceous sand (0-4 mm), and two chemical admixtures from BASF Construction Chemicals, a policarboxilate-based high range water reducing admixture (HRWRA, Glenium C-355).

Steel used for reinforcement was a B 500SD (UNE 36065 EX), with a limit of proportionality of 500 MPa, ultimate tensile strength of 575 MPa, elongation at break 16%, and a total elongation at maximum load of 7.5%.

6. RESULTS

The three NSC slabs tested present a very similar behavior in terms of vertical deflection, stiffness and ductility. The crack opening response is also very similar. In all slabs, the first cracks appeared at the casting joint. Note that the real cracking moment is 0.14 times the theoretically calculated according to EHE-08; At all levels of crack opening, the real experimental moment is always lower than the one predicted by the codes (figure 6), which leaves the design at the unsafe side. The difference of behavior is justified by the presence of the casting joint, nevertheless, the behaviour of the three slabs is very similar, though the difference of the reinforcement type at the joint (Dragosavic et al., 1975), (Rosenthal et al., 1978), (Hao, 2004).

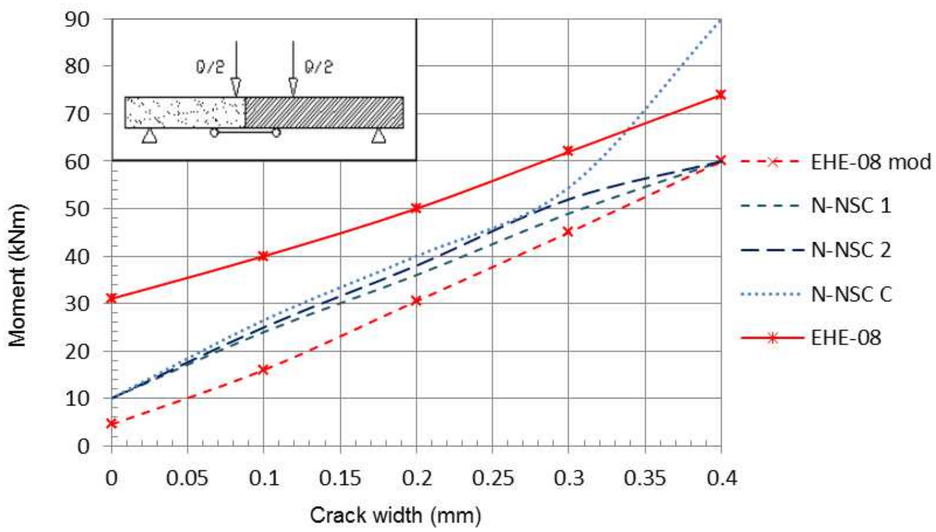

Figure 6. experimental moment M_k-crack width w_k responses and theoretical predictions

Since the real cracking moment of the slabs is significantly lower than the theoretical value calculated by EHE-08 (0.14 Mcrit theoretical) the theoretical formulation proposed by this code was modified by applying a coefficient equal to 0.14 to Mcrit. Including this value in the EHE-08 formulae, a highly accurate fitting is obtained with the experimental values. Hence, the modified formulation represents a validated criteria to estimate crack openings in this type of joints (figure 6).

In terms of ULS, test results indicate failure loads in the range of 300 to 320 kN, which are higher than the estimations from the formulae of Codes analyzed in this study, in the range of 243 to 247.8 kN (table 1).

SLABS	Failure load (experimental)		CEB-FIP 1993 / EC-2 and EHE-08		ACI-318	
	Q(kN)	M (kNm)	Q(kN)	M (kNm)	Q(kN)	M (kNm)
N-NSC-C	320.0	146.8	247.8	114.3	245.1	113.1
N-NSC-1	300.0	137.8	246.1	113.6	243.3	112.3
N-NSC-2	300.0	137.8	246.1	113.6	243.3	112.3

Table 1. Comparison between experimental and theoretical values of failure loads (Pure flexural)

7. CONCLUSIONS

This paper encourages the use of a very environmentally friendly construction method for long concrete viaducts: the span by span construction method with travelling scaffolding. This has the advantage that only the shadow of the bridge is somehow altered during construction period. Moreover, even the piers and their foundations may be constructed from the deck in some extreme sensitive environments. No matter how small this impact is, it is to say that in a Life Cycle Assessment the shorter the construction period, the higher the sustainability. This paper presents a recent development for constructing concrete viaducts which reduces significantly construction deadlines, without any increase in CO2 emission or energy consumption. The structural challenges to be overcome are also presented along with their solution. The use of a compact splice geometry is possible and would allow and easy demoulding and an earlier movement of the travelling scaffolding, making the modified construction method not only more competitive, but also more environmentally friendly (due to the reduction of the construction period) with respect to the current solution, increasing sustainability.

8. ACKNOWLEDGEMENT

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