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Strengthening of Huisne bridge using Ultra-High-Performance Fibre-Reinforced Concrete

Thierry Thibaux
EIFFAGE TP, Neuilly sur Marne, France

ABSTRACT: Ultra-High-Performance Fibre-Reinforced Concrete (UHPFRC) is now increasingly used for innovative structures. This article describes a new application of this material to strengthen a prestressed concrete bridge near Le Mans (France).

Thin strips of UHPFRC were cast in situ along the webs of the beams, allowing the works to be performed more cheaply and faster than by conventional methods.

1 CONTEXT

The new tramway of the City of Le Mans (France) runs along a 15.1 km North-South route incorporating certain existing structures such as the bridge over the Huisne built in 1976.

This bridge, 65 metres long, consists of two parallel decks 15 metres wide, each comprising two independent spans supported by five prestressed, prefabricated I-beams of span length 31.60 m. On the central support in the river, the upper deck sections are connected by a small continuous slab.

To be compatible with the new project, this bridge, originally supporting a three-lane dual-carriageway road, had to be strengthened to receive:

– on the downstream deck: four road traffic lanes;
– on the upstream deck: the tram lane and a bicycle path.

2 GENERAL STRENGTHENING PRINCIPLES

The solution originally planned by the Project Manager to increase the bridge's load-bearing capacity was to use additional external prestressing and local reinforcements with flat carbon fibre sections.

Detailed studies of the bridge showed that the I-beams of height 1.80 m had been designed for optimum performance and could not accept the additional compression applied by the prestressing strengthening.

Accordingly, to achieve the required performance level, namely class I* service in longitudinal bending and class II** in transverse bending, the planned solution had to supplemented, because the concrete of the existing beams exceeded its compressive strength limit. Observing this, it was first considered executing intermediate cross ties at one-third and two-thirds of the span length to distribute forces among the beams. But this is a very difficult job to perform above the river and on the underside of the deck.

*Class I: Section always compressed even in serviceability limit state (French code).

**Class II: Tension lower than the concrete's cracking limit in serviceability limit state.

2.1 *UHPFRC reinforcement solution*

A simpler, more innovative solution was proposed by the contractor, i.e. making the webs of the existing beams slightly thicker with ultra-high-performance fibre-reinforced concrete (UHPFRC) and then applying the external prestressing strengthening.

This solution was applied on the two most heavily loaded beams of the downstream deck.

Accordingly, two continuous side cheeks 20 cm thick and 90 cm high were cast in situ on the bottom heels on either side of the I-beam webs (figures 1 and 2).

3 BENEFITS OF USING UHPFRC

3.1 *A very high Young's modulus*

UHPFRC materials are known for their high compressive strength (over 150 MPa) and also for their ultimate tensile strength (8 to 10 MPa) that can be adopted in structural design. Here, the main parameter is the very high Young's modulus of BSI®/CERACEM compared with that of an ordinary concrete. This parameter is

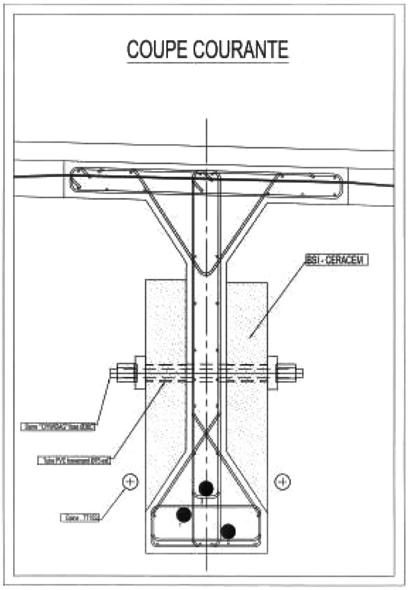

Figure 1. Standard cross section of a strengthened beam.

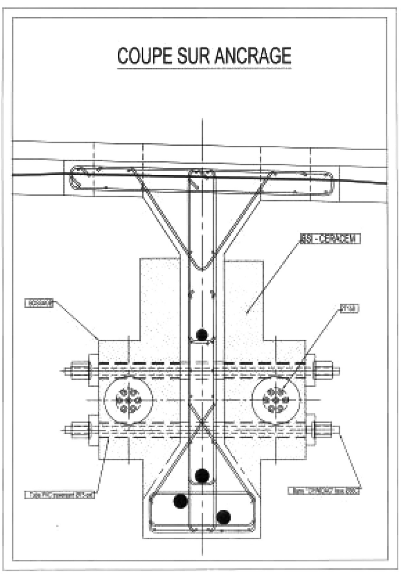

Figure 2. Cross section on anchor.

extremely important in the case of repair or strengthening of an existing structure, column or beam.

It can be observed that the add-on section in UHPFRC "drains" the forces, relieving the existing concrete accordingly.

Now, when reinforcement prestressing is applied, the corresponding force P is distributed in proportion to the cross sections and moduli.

Let us take, for example, a beam of cross section S1 made of ordinary concrete of modulus E1. It is reinforced with an add-on section S2 in UHPFRC of modulus E2.

Under the effect of centred prestressing strengthening P, stresses σ_1 and σ_2 are such that:

$$P = S1\, \sigma_1 + S2\, \sigma_2$$

$$\varepsilon = \frac{\sigma 1}{E1} = \frac{\sigma 2}{E2} \quad \textit{hence} \quad \sigma 1 = \frac{E1}{E2}\ \sigma 2$$

where ε = relative shortening

In the case of BSI®, the UHPFRC developed by EIFFAGE, the Young's modulus is about 64 MPa, i.e. twice that of an ordinary concrete.

Hence $\frac{E1}{E2} = 0.50$

The stress in the existing concrete will therefore be twice as low as in the strengthening UHPFRC.

It should also be noted that the deferred (long-term) modulus of BSI is three times higher than that of an ordinary concrete, reducing creep strain accordingly.

3.2 *Self-placing performance*

The execution of concrete strengthening under and above an existing deck is difficult due to vibration phenomena. Here, the completely self-placing nature of the BSI® simplified the works.

3.3 *Reinforcements "incorporated" at mixing*

For strengthening beams made of conventional concrete, complete concrete reinforcing cages would have had to be placed under the deck, inside the formwork. Here the fibre structure of the UHPFRC (2.5% by volume, i.e. 200 kg of fibres per cu. m) replaces the reinforcing bars to dampen the shear force and local forces.

BSI® was therefore adopted here for these three specific advantages (high modulus, self-placing nature, fibre structure) and not for its compressive strength qualities.

4 DETAILED DESCRIPTION OF THE STRENGTHENING

On the Huisne Bridge the existing I-beams with a web 20 cm thick were strengthened with two side cheeks 20 cm thick, 90 cm high and 22 m long. The three sections are linked by (nailed) prestressed cross bars placed on the longitudinal cable anchor blocks and along the web.

Photo 3. Mixing plant.

These connecting cross bars are tensioned one week after pouring the BSI®, so as to allow the material to perform its shrinkage relative to the existing concrete beams. This technique prevents the risk of cracking through constrained differential deformation of the two materials.

4.1 *UHPFRC production and processing*

The BSI®/CERACEM is delivered in premix form (mixture of the dry components), in bags. It is mixed on site by means of two mixers (photo 3).

During mixing, the water, superplasticizer and fibres are added. This on-site production made it possible to process 40 cu. m of UHPFRC, at a rate of 10 cu. m per day. Concreting, without vibration, was performed via six pouring channels per side cheek.

These pouring channels, 200 mm in diameter, were inserted into holes drilled in the deck, providing access to the upper part of the formwork (photo 4).

The technique of alternating concreting runs produced the desired uniformity for the various UHPFRC pouring operations.

The 28-day strength tested on cubes was 182 MPa on average.

This result was achieved despite unfavourable temperature conditions (6°C) and without using heat treatment.

After setting, the two side cheeks were therefore simply “laid” on the bottom heel of the existing beams. After shrinkage of the UHPFRC, joining was performed by transverse prestressing (Dywidag bars of dia. 36 and 32 mm) (photo 5).

The design calculations for strengthening with BSI® were carried out using the provisional recommendations of the French Civil Engineering Association (AFGC) entitled “Bétons fibrés à Ultra Hautes Performances”, of January 2002.

Photo 4. Pouring by pouring channel.

Photo 5. A fully strengthened beam.

Photo 6. Anchor block anchorage by bars.

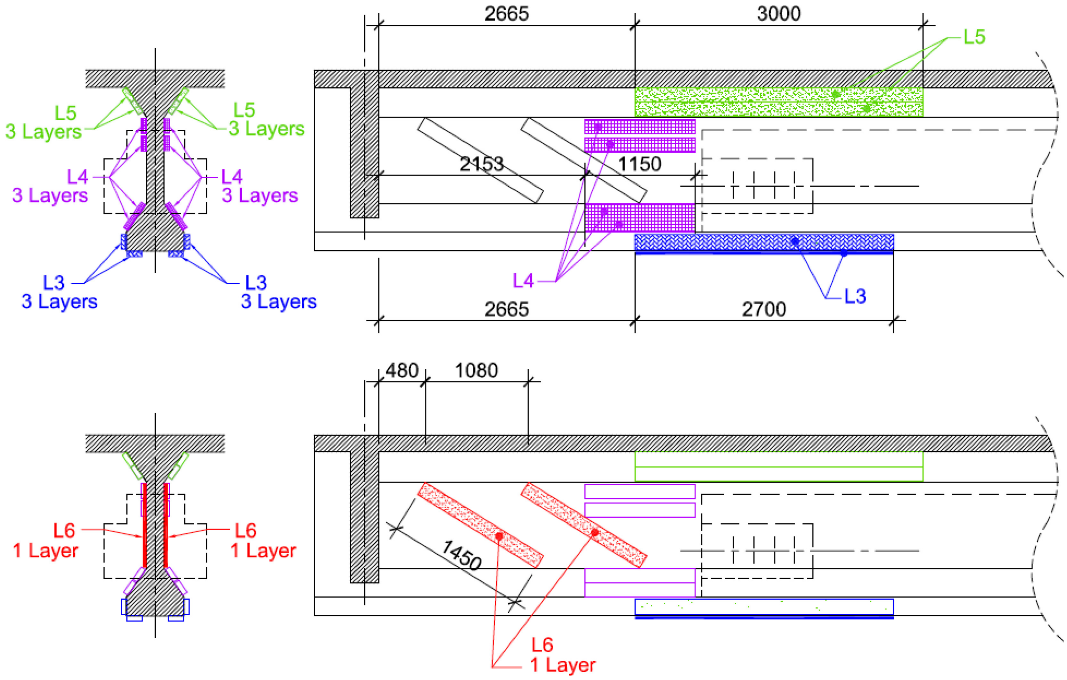

Figure 7. Carbon-fibre reinforcements-layout.

4.2 *External prestressing*

Keying prestressing by bars and additional prestressing by cables were performed by the Prestressing Division of EIFFAGE Travaux Publics, distributor of the Dywidag process in France.

The prestressing units employed consist of 7 T 15 S and 4 T 15 S cables (photo 6).

4.3 *Carbon fibre reinforcements*

Bonded flat bar reinforcements were placed on two deck areas:

- on the underside and topside of the deck section, to meet the transverse bending requirements of Class II of the French regulations;
- to the rear of the 7 T15 S anchors of the beams with UHPFRC side cheeks so as to balance the excess shear and the tensile stresses resulting from the prestressing strengthening (Figure 7).

5000 metres of Sika Carbodur thin strips of width 150 mm were bonded in this way.

5 CONCLUSION

Cast-in-situ UHPFRC is a new technical solution for strengthening engineering structures. Its high modulus, self-placing nature and the elimination of reinforcing bars are decisive benefits of the technique for tricky work under trafficked bridges.

In this way, the Huisne Bridge was able to be strengthened for a lower cost and in a shorter time. The tests under load gave full satisfaction.

REFERENCE

Provisional recommendations of the AFGC: “Bétons fibrés à Ultra Hautes Performances” (ultra-high-performance fibre-reinforced concretes) – January 2002.

GLOSSARY

UHPFRC: ultra-high-performance fibre-reinforced concrete.

BSI®/CERACEM: tradename