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BUTHAUMONT BRIDGE ON THE ORNE RIVER IN BONCOURT

Ziad Hajar (1), Frédéric Pastor (1), Ludovic Picard (1), Damien Champenoy (2) and Laurent Loutte (2)

(1) Eiffage Infrastructures, Vélizy, France

(2) Cerema Est, Metz, France

Abstract

The new bridge over the Orne river in Boncourt, Eastern France, is an original alternative to composite steel-concrete decks for single medium range spans. Its span of about 32 m is crossed with a prestressed girders deck composed of ITE® beams made of BSI®, and connected to a cast-in-situ conventional concrete slab. ITE® beam would stand for enlarged bottom flange I cross-section beam in French. Its particular shape and the use of UHPFRC allows for a quite slender deck structure, and a more efficient use of prestressing. The precast UHPFRC beams are supported by integral abutments, whose maintenance costs are expected to be low. The stiffness of the portal frame structure that is created this way is reduced by the use of small diameters piles for abutments foundations.

Résumé

Le nouveau pont de Buthaumont sur l'Orne à Boncourt (Meurthe et Moselle) constitue une alternative originale aux tabliers mixtes pour les ouvrages mono-travées de portée moyenne. Sa portée d'environ 32 m est franchie au lieu de cela par un tablier de type PRAD composé de poutres ITE® (poutres en I à Talon Elargi) en BSI®, connectées à une dalle en béton conventionnel coulée en place. Le large talon des poutres permet de concentrer une importante quantité de précontrainte sous leur centre de gravité, et en tirant profit des performances mécaniques du BFUP rend possible la construction de tabliers ultra minces. Ces poutres au matériau durable sont supportées par des culées intégrales, dont les coûts de maintenance sont eux aussi bas. Le faible diamètre des pieux permet de réduire la raideur d'encastrement du tablier dans les piédroits.

1. INTRODUCTION

Buthaumont Bridge in Boncourt, Meurthe-et-Moselle, France is a structure of modest length enabling the RD 603 road to cross the Orne River (figure 1). The existing triple-arch masonry bridge was built in the mid-19th century.

Figure 1: Overview of the structure (old and new bridges)

The call for tenders was published by the Programme Manager (Moselle Departmental Council) called for a new structure with a base solution of twin girders composite single-span deck, but left open the possibility for companies to include an alternative proposal for a UHPFRC (ultra-high-performance fibre-reinforced concrete) deck. It was in this context that Eiffage Génie Civil submitted an original alternative proposal of a full integral bridge with a span of about 32 m whose deck structure combined beams in UHPFRC, connected to an upper slab in conventional concrete.

2. DESCRIPTION OF THE STRUCTURE – BASIC SOLUTION

The Boncourt Bridge is a very old (mid-19th century) structure comprising three arches measuring 8.10 m, 9.90 m and 12.30 m wide, only two of which are used by the Orne River at low water. One of the three arches destroyed in 1940 was hastily repaired in 1943. The project to rebuild the structure about 10-m downstream from the existing bridge had to comply with the hydraulic requirement of no piers in the minor bed of the river, and that the underside of the deck had to be at least 1 m above the 100-year flood level.

The new Boncourt Bridge is a structure with a single span of 31.69 m that crosses the river with a 70 grades scew angle (figure 2). The deck is 13m wide, it carries an 11 m carriageway with two traffic lanes each 3.50 m wide, framed on either side by 2-m wide shoulders at the same level. The deck in the basic solution is a composite structure with two steel beams 1.40 m high and 7.00 m between their centre lines. The main beams carry a reinforced concrete slab 13 m wide by 30 cm thick on average. The full-retaining type abutments sit on four drilled tube piles with a diameter of 1200 mm.

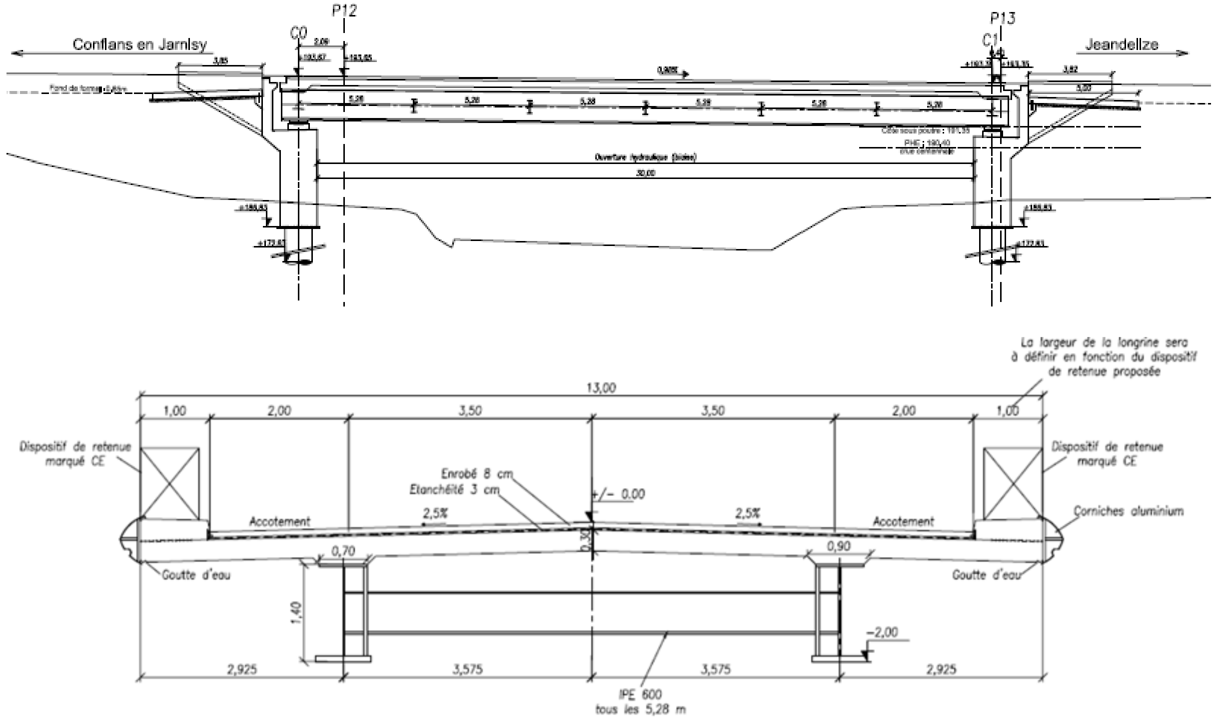

Figure 2: Base solution – Longitudinal and cross sections

3. THE ALTERNATIVE SOLUTION: AN INTEGRAL BRIDGE WITH ITE® BEAMS

3.1 General principle

The structural height of the composite deck in the base solution was around 1.90 m. One of the challenges of the potential alternative was to significantly reduce the height of the backfill behind the abutments of the base solution and so the deck thickness. To this end, Eiffage's proposal was for a prestressed girder deck with ITE® (I-beams with an enlarged bottom flange) in BSI® in order to optimise the deck's length-to-height ratio and so reduce its structural height to 1.25 m (figure 3). The shape of the ITE® beams (figure 4) and the high strength of BSI® made it possible to get the best use out of the prestressed concrete and achieve competitive length-to-height ratios.

Reducing the height of the backfill behind the abutments also opened up the possibility of optimising their foundations. Given the poor quality of the soil near the bed of the Orne, it was deemed preferable to fix the deck on the abutments in order to benefit from the latter's ability to balance part of the horizontal forces. We therefore sought to optimise the diameter of the piles in order to achieve the best possible flexibility in the foundations and to benefit from a more favourable redistribution of the stresses in the resultant frame.

In addition to quantity savings, this alternative capitalises on the all the advantages of integral bridges in terms of maintenance costs for the bearings and expansion joints, and the high durability of BSI®.

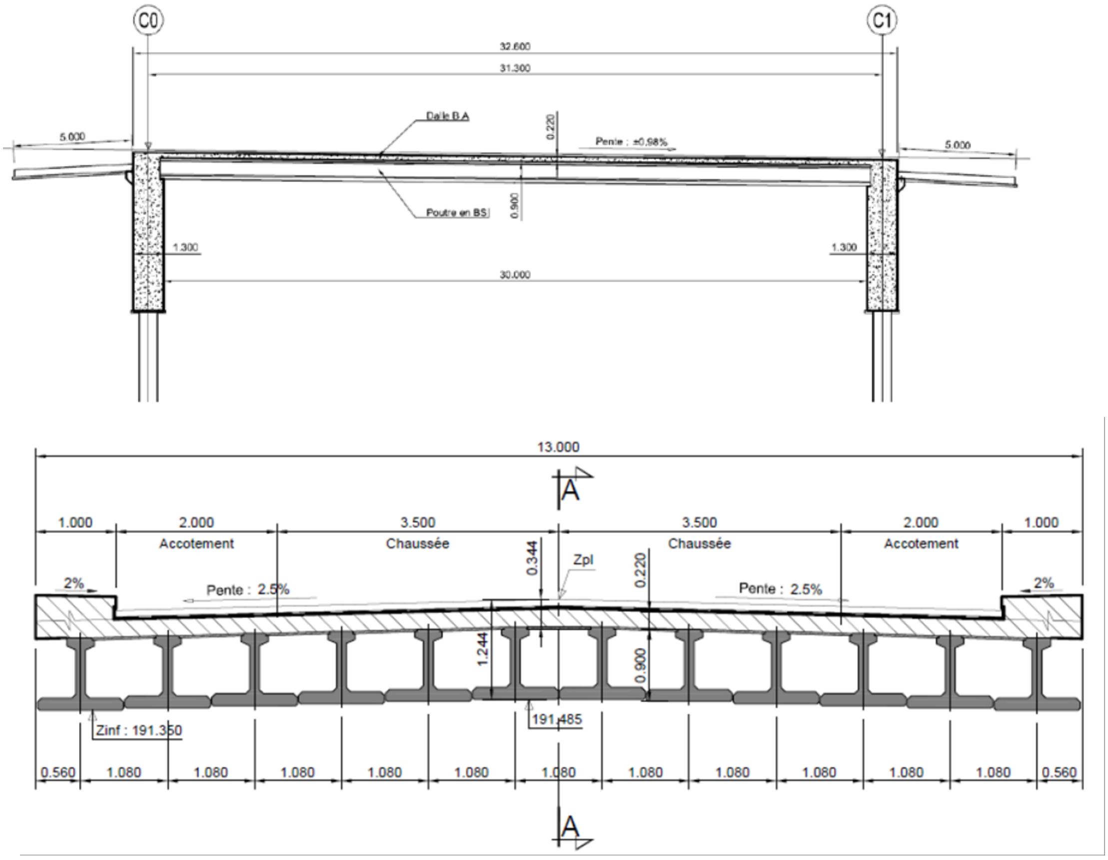

Figure 3: Alternative solution – Longitudinal and cross sections

It also makes it possible to secure and speed up the erection of the span, because once the beams have been installed, all the installation operations for the slab poured in situ (after installation of the sacrifical formworks and the steel reinforcements), progress rapidly and completely safely.

The deck is constituted of 12 prefabricated ITE® beams in BSI® with a length of 30.60 m, 90 cm high, and a slab poured in situ made with C35/45 conventional concrete 22 cm thick.

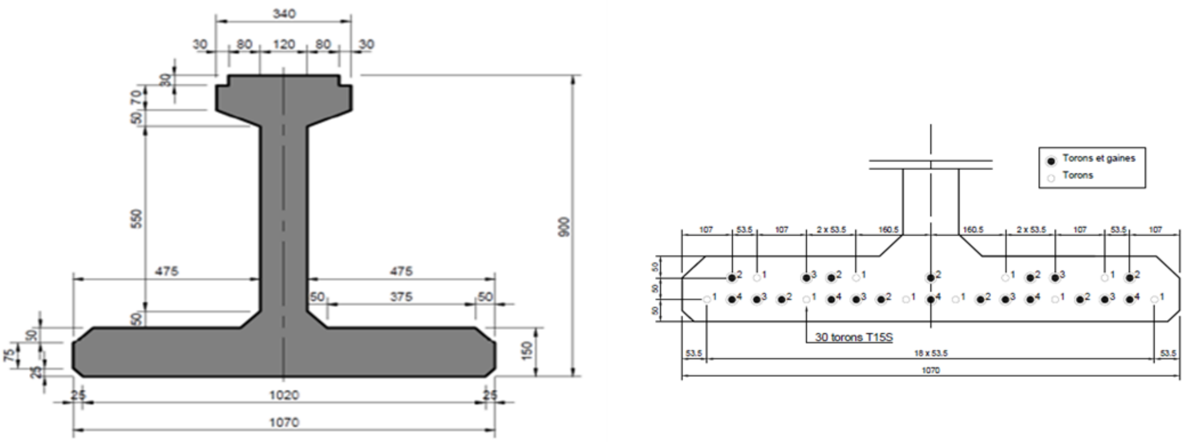

Figure 4: Cross section and detail of strands

The ITE® beams comprise:

- a broad 1,07 m lower flange, 15 cm thick, housing Class 1860 T15s strands, progressively anchoring thanks to sheathing of the strands ends. Four lengths of sheathing have been selected, helping limit the spalling and diffusion effects in the areas where the prestressing is introduced
- a constant 12 cm web,
- a 34 cm upper flange, on which are placed the rebars steel connectors to connect the prefabricated beams to the upper slab poured in situ.

The connection at the ends of the beams and the abutment (figure 5) is performed with rebars on the upper flange and some strands in the lower flange.

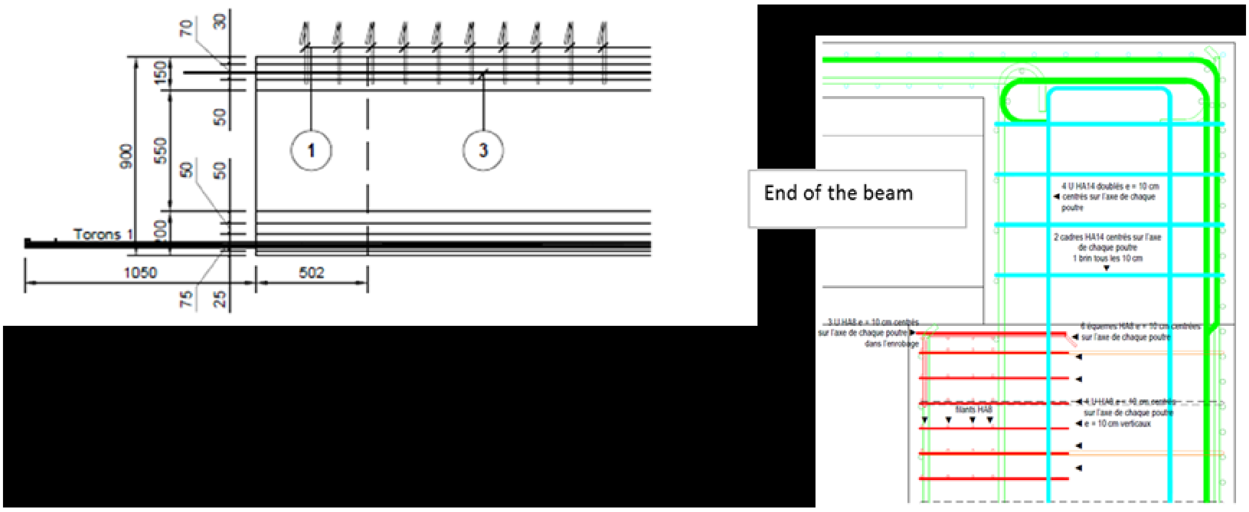

Figure 5: Connection between beams and abutment

3.2 The BSI® material

BSI®, a ultra-high performance fibre-reinforced concrete (UHPFRC)mix, is a material that has been developed and patented by Eiffage. The references for this material's use include three prior projects with ITE® beams: Pinel road bridge (Rouen), Sarcelles Bridge, and more recently Pont de la République in Montpellier, all in France.

For ITE® beams, the BSI® mix used has the following characteristics:

- characteristic compressive strength: $f_{ck} = 160$ MPa
- characteristic tensile strength: $f_{ctk,el} = 8.0$ MPa
- characteristic post-cracking tensile strength: $f_{ctfk} = \sigma_f(w = 0.4\text{ mm}) = 8.5$ MPa
- mean tensile strength: $f_{ctm,el} = 10.5$ MPa
- mean elasticity modulus: $E_{cm} = 58$ GPa
- creep (loading at $t_0 = 2$days): $\varphi(\infty, t_0) = 1.0$
- autogenous shrinkage: $\varepsilon_{ce,\infty} = 600$ µm/m
- drying shrinkage: $\varepsilon_{cd,\infty} = 240$ µm/m
- density: $\rho = 27.5$ kN/m^3

4. DETAILED DESIGN

The UHPFRC 2013 recommendations of the AFGC (French Civil Engineering Association) were applied to justify the BSI® components. A comparative calculation using UHPFRC NF P 18-470 and NF P 18-710 standards, at the time in the process of being compiled, was often performed by way of comparison, but never brought the results into question. It did make it possible to add recommendations to the guide, especially with regard to the ductility condition.

The detailed design focussed initially on studying the beams, the evolution of their stresss and deformations condition over time, whether at young age or longer term, thanks to a model taking into account the construction phasing. It was in particular shown that the tensile strength of BSI® (figure 5) was sufficient to avoid any passive reinforcements in the beams.

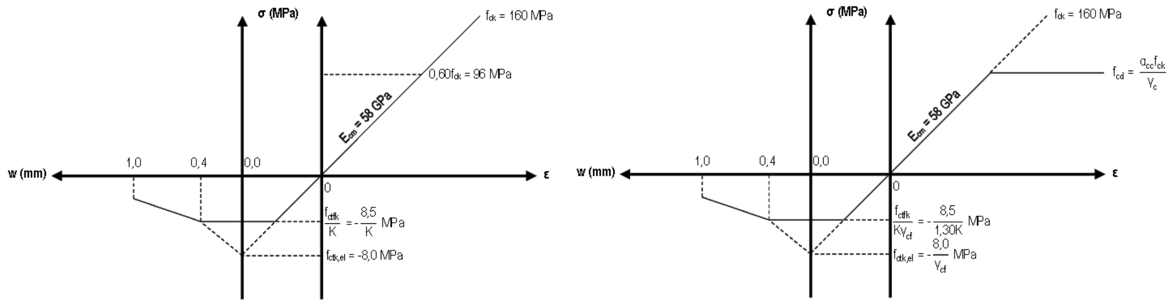

Figure 6: SLS and ULS laws for BSI®

A 3D model of the structure was also used alongside the phased model for the transverse bending and torsional strength study of the deck.

Shortly after starting the detailed design, a significant horizontal creep of the compressible soil layers was revealed directly under the backfill area behind the abutments. As a result, the displacements imposed by the soil deformation on the piles was incompatible with their size. The solution to increase the diameter of the piles was not satisfactory because it would result in stiffening the foundations so increasing the moments in the structure.

Eiffage suggested a technical solution which involved a final double tubing around these piles.. This solution is less costly than improving the soil and made it possible to stay close to the initial dimensions. While the effect of horizontal creep on the piles was negated, the beneficial effect of the soil's frontal reaction was lost over the length of the tubed pile. The pile diameter therefore still had to be increased from Ø 800 mm to Ø 1000 mm.

4.1 Normal and shear stresses in the beams

The prestressing dimensions were initially selected to offset the final deflection of the beams under almost permanent load. This decision made it possible to avoid the complications that would arise from producing beams with bench-created camber.

The result is a significant safety margin with regard to normally admissible stresses in concrete (Table 1). The beam would therefore be checked in a simply supported configuration situation, thereby adding to the structure's robustness.

The maximum shear stress at ULS in the core of the beam ends is around 8,0 MPa, which breaks down into 6.7 MPa due to the shear stress and 1.3 MPa due to prestressing distribution at the anchorages. It is worth remembering here that the prestressing is stepped. This level of stress does not require any reinforcement with passive reinforcements; by way of comparison, the contribution of the fibers alone to the shear resistance of BSI® is 7.2 MPa.

Table 1: Normal stresses in ITE® beams

	Maximum tensile stress on upper flange	Maximum compressive stress on lower flange	Tensile stress on lower flange
At strands release	-2.5 MPa	36 MPa	None
SLS – Quasi-Permanent loads combinations	-	33 MPa	None
SLS - Characteristic loads combinations	-	36 MPa	None

4.2 Beam deformation

The prestressing force was calculated such that the beams had a camber of about 30 mm on commissioning. This margin provides leeway to absorb several unforeseen effects during installation and hygrometric conditions differing from the calculation hypothesis, or releasing the prestressing strands later than expected, without risking arriving at a beam deflection directed downwards upon commissioning.

The theoretical nominal deflections of the beams at different dates are provided below:

- at strands release: +55 mm
- at 28 days: +80 mm
- after pouring the slab: +35 mm
- after short-term service: +30 mm
- after long-term service: +20 mm

The actual deflection measured for the beams correspond on average to the theoretical one, and reflect comparable upwards creep deflection.

5. PREFABRICATION OF THE ITE® BEAMS

The ITE® beams were prefabricated at the Matière plant in Brive-la-Gaillarde (France), which has a prestressing bench suitable for long beams.

After assembly in the mould and installation of the prestressing wires, the beam concreting (~ 9 m^3) could begin; it required several batches of BSI® to be made from a premix delivered in big bags, along with other components: additives, water and steel fibres (195 kg/m^3). For each batch, a series of tests were systematically carried out to check the properties in the fresh state, and ensure its proper application. The BSI® was fed from the mixer to the concreting point using a perfectly sealed 2 m^3 container. The batches of around 1.6 m3 were repeated until the mould was completely filled.

Given the large difference between the dimensions of the lower flange and the web, concreting (figure 7) was carried out in two phases:

- The first phase concerned the lower flange, with only the lower section of the mould in place. The concreting was performed gradually over the flange thickness to ensure correct coating of the layers of prestressing strands.
- The second phase of concreting concerned the web and upper flange; it was performed in the continuity of the first after installing the upper section of the mould. A mechanical system

of "claws" was used to ensure a perfect blend of the various layers and a good bond at the flange-web junction.

After having completed the beam concreting, an anti-evaporation product was sprayed onto the flattened surface.

Figure 7: Concreting the beams

The early age strength control tests were performed by tracking maturity readings using temperature sensors placed in the lower flange and the top section of the web. The mould was opened once the exothermal peak was reached for all the probes. The cables tension was released after achieving an average compression resistance in the concrete of at least 100 MPa.

Figure 8: Beam transfer and storage

After releasing the strands, the beams were transferred to the storage area (figure 8), where they were laid on blocks placed to correspond with the final bearing points. The beam dimensions were systematically checked along with periodic deflection checks of the beams in the prefabrication plant's storage area.

6. BEAM INSTALLATION AND CREATION OF THE DECK

The beams were transported by train from Brive-la-Gaillarde and then by truck to the construction site. The deck is comprised of 12 UHPFRC beams, 30.60 metres long, and installed and fixed into two abutments forming the structure's supports (figure 9).


Figure 9: Installing the beams

A 300-tonne mobile crane was used over a period of two days to position the 12 beams each weighing about 23 tonnes in accordance with the following schedule:
- Day 1 morning: installation of the crane and its counterweights
- Day 1 afternoon: installation of six beams
- Day 2 morning: installation of six beams
- Day 2 afternoon: disassembly of the crane

The two side beams were fitted on the ground with a timber frame to allow for side formwork of the 22-cm top slab.

Figure 10a: bridge soffit

Figure 10b: Installing the precast panels

Once the beams had been installed (figure 10), the sacrificial formworks of the deck slab using precast panels was installed in the grooves left in the beams specifically for this purpose. The steel reinforcements of the slab totalled 44 tonnes of reinforcement (ratio of 308 kg/m^3). After finalising the side formwork for the entire slab, concrete was pumped in place making sure to phase the work to balance the loads on the beams.

7. CONCLUSION

The technical solution for an integral bridge using ITE® beams in BSI®, implemented for the reconstruction of the Buthaumont Bridge over the Orne River in Boncourt, confirmed the advantages, in terms of cost and construction time, of this alternative solution for a single-span structure within a span range of 25 to 35 m.

By capitalising on the exceptional mechanical strength of UHPFRC, ultra-thin bridge decks can be constructed that adapt to high geometric and construction constraints (reduced size, watercourses or roads in service), and rapid and secure installation of the deck.

This solution of integral bridge type using UHPFRC also minimises the overall cost of the structure through reduced maintenance costs (no bearings or expansion joints).