UHPFRC prestressed beams as an alternative to composite steel-concrete decks: The example of Pinel Bridge (France)

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ABSTRACT: This paper describes the design and construction of the third Pinel Bridge in France, in 2007. Located just to the west of Rouen, this small bridge has a single 27-m-long span and is 14-m wide. It will increase the traffic capacity of two existing bridges over three railroad tracks from two lanes to five. The bridge deck combines a conventional slab of standard reinforced concrete with seventeen parallel contiguous beams made of self-consolidating Ultra-High-Performance Fiber-Reinforced-Concrete (UHPFRC). The beams – designed by the contractor, Eiffage TP, as an alternative to a filler-beam deck – are prestressed with 28 internal strands placed in a very wide bottom flange.

1 GENERAL DESCRIPTION OF THE BRIDGE

Located in Le Petit Quevilly, just outside Rouen, Pinel Bridge is used by vehicles travelling between the south-bank expressway and roads serving Rouen Harbor. It is 27-m-long, has a high skew angle, and crosses three railroad tracks serving a marshalling yard (see figure 1).

The original single-lane bridge built during the 1970s was duplicated in 1996. These two bridges have concrete substructure units on shallow foundations and carry two lanes on parallel filler-beam decks connected only by a longitudinal expansion joint. They have two spans of 12.20 and 14.80 m. (see figure 2).

In 2008, the “La Motte” traffic circle south of Pinel Bridge will temporarily become the end of a new expressway joining the A150 motorway and southern expressway no. III via the new Gustave Flaubert vertical lift bridge (see figure 3). For this reason, the local authorities decided to widen the existing Pinel Bridge from two lanes to five.

This paper briefly describes the very conventional solution initially designed for the widening of this bridge, then details the design and construction of the much more innovative solution proposed by French contractor Eiffage TP. The variant solution combines UHPFRC beams, placed edge to edge, with an ordinary concrete deck slab (C35/45).

This is the fifth French road bridge to incorporate UHPFRC structural components. The first four are the two bridges of Bourg-lès-Valence, south of Lyons, the Saint-Pierre-la-Cour bridge in Mayenne (western France), and Chabotte Bridge on the A51 motorway (Grenoble-Marseille).

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1.1 General data on the initial solution

The new Pinel bridge has the following geometrical characteristics (see Figures 4 and 5):
- Single span of 27 m
- 14 m wide
• High skew: 64 gons (57°)
• Crossfall of 2.5%
• Circular longitudinal section with the highest point at mid span
• Roadway cross-section: three 3.50-m-wide traffic lanes and a 2-m-wide sidewalk
• Deck furniture and surfacing: 8-cm-thick wearing course, 3-cm-thick waterproofing system, steel right-hand safety barrier, concrete left-hand safety barrier, and two precast cornices.

As originally designed, the deck was supposed to be a filler-beam deck with 17 HEB700 steel beams.

1.2 General data on the Eiffage TP alternate bid

The alternate bid submitted by Eiffage TP proposed to modify two aspects of the initial design. The
main point concerns the deck: instead of building a filler-beam deck, it was proposed to build a superstructure made up of seventeen UHPFRC beams placed edge to edge and connected to an ordinary concrete deck slab (C35/45) (see figure 6).

In the Eiffage TP tender, the seventeen beams were identical and were placed at the crossfall angle required for the deck slab. Their main characteristics were as follows (see figure 7):

- Depth: 620 mm
- Bottom flange: 795 mm × 150 mm, plus gussets
- Web: thickness varies between 70 mm in the typical section and 120 mm close to the ends
- Top flange: 250 mm × 50 mm, plus gussets
- Prestress: 28 × T15.7/1860 MPa strands, all placed in the bottom flange, progressively anchored (some are ducted towards the ends to reduce load concentration)
- Beam/slab connection: rebar stirrups placed in the top flange (see figures 8 & 13).

At the ends of the UHPFRC beams, two crossbeams are cast at the same time as the deck slab to tie the beams together. To provide a strong connection, eight strands protruding from each UHPFRC beam are anchored in the crossbeams.

As designed in the Eiffage TP tender, the deck slab, whose thickness varies from 210 to 320 cm to obtain the circular longitudinal section, is built using precast panels and cast-in-place concrete of normal strength (C35/45). Given that the Eiffage TP alternate bid was slightly less expensive than the other tenders and totally satisfactory from the technical point of view, the owner of the bridge chose this solution.

2 CONSTRUCTION DESIGN

2.1 General data

The construction design was drawn up by Eiffage TP and checked by the large bridges division of Sétra. Conventional French construction regulations (BPEL & BAEL rules for reinforced and prestressed concrete) were used for general calculations. The guide “Ultra-High-Performance Fibre-Reinforced Concrete – Interim Recommendations” edited by Sétra and AFGC was used to check UHPFRC beam design.

Besides standard vehicle loading, Pinel Bridge is designed to carry a 120-tonne military vehicle.

2.2 Deck design

Although isostatic and with a moderate length of span, the bridge was not so easy to design, because of its skew and the materials used.

2.2.1 Numerical models

Calculations were run in parallel by Eiffage TP, with a numerical model using the ST1 software package, and by Sétra, with a numerical model using the PCP software package (both Sétra programs).
Both models are based on the same principle, i.e. a grid model for the concrete slab rigidly linked to beam elements modeling the UHPFRC beams.

Since the beams are pre-tensioned, the prestressing force introduced in the numerical model takes elastic shortening losses and thermal losses into account (including thermal losses induced by concrete warming as it sets).

The shrinkage and creep of UHPFRC are different from shrinkage and creep of conventional concrete: total shrinkage is $6 \times 7 \times 10^{-4}$ instead of $2 \times 2.5 \times 10^{-4}$, and the creep coefficient is 1 instead of 2. In the numerical model, shrinkage and creep are modeled with laws used for conventional concrete, but with parameters modified to fit UHPFRC behavior.

### 2.2.2 Normal stress

These beams can easily withstand normal stress. The most critical step for them is the transfer of force to the concrete when the strands are detensioned, just as for conventional pre-tensioned beams.

### 2.2.3 Shear stresses

For the two exterior units, the beam design proved to be slightly understrength with respect to shear forces. Both numerical models showed that the maximum shear stress—including effects due to torsion and prestressing force distribution—was very high in the left-hand and right-hand beams on the deck cross-section and slightly higher than the permissible value.

It was finally decided, therefore, to adopt two kinds of beams: ‘standard’ interior beams as already described and exterior beams in which the webs and top flanges are 3 cm wider.

<table>
<thead>
<tr>
<th>Distance to end</th>
<th>Web thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>−0 to 2 m</td>
<td>120 mm</td>
</tr>
<tr>
<td>−2 m to 5 m</td>
<td>70 to 120 mm</td>
</tr>
<tr>
<td>−5 m to mid span</td>
<td>70 mm</td>
</tr>
<tr>
<td>−10 m to end</td>
<td>100 mm</td>
</tr>
</tbody>
</table>

In the exterior beams, strands were anchored as close as possible to the ends in order to increase the mean compressive stress. To limit tensile force at the upper fiber, a single strand was added in the top flange (see figure 8).

### 2.2.4 Beam/slab connection

As the interface between beam and deck slab was not judged rough enough, for the purposes of calculation it was considered to be a slick interface through which the bonding stirrups have to resist by shear force alone. As a consequence, the stirrups were dimensioned like the shear studs for standard composite bridges. The hypothesis of zero frictional resistance is probably a little on the pessimistic side; it would be interesting to conduct laboratory tests to assess the shear resistance of the interface between normal concrete and UHPFRC.

### 2.2.5 Beam orientation

In order to facilitate their placement and to limit torsion, the beams were finally laid vertically, with a 17-mm height difference between adjacent beams to give the deck slab the required crossfall (see figure 9).

### 3 CONSTRUCTION

The bridge was built in 2007 by the Haute Normandie Agency of Eiffage TP.

#### 3.1 Casting of UHPFRC beams

##### 3.1.1 General considerations

The beams were cast in Veldhoven, near Eindhoven (Netherlands), by Dutch contractor Hurks Beton, which is Eiffage TP’s usual partner for UHPFRC structures. Hurks Beton has made beams for the Civaux and Cattenom nuclear-power-plant cooling towers and for the deck of the Bourg-lès-Valence bridges, for example.

##### 3.1.2 Ultra-high-performance fiber-reinforced concrete

The UHPFRC used for the Pinel Bridge beams is identical to that used for the Millau viaduct tollgate roof. It is a 165-MPa UHPFRC using the following mix design:

- 2360 kg of Ceracem BFM-Millau Premix (*) by Sika
- 45 kg of superplasticizer
- 195 kg of water
- 195 kg of steel fibers.

(*) Premix is a dry component consisting of cement and aggregate packaged in bulk bags.

##### 3.1.3 Construction methodology for UHPFRC beams

The construction methodology for UHPFRC beams is very similar to that for conventional prestressed beams
and uses a tensioning unit. Because of the big difference between the web thickness and the width of the bottom flange, Eiffage TP and Hurks Beton decided to concrete the beams in two stages:

- first, the bottom flange, using only the lower part of the mold
- then the web and the small top flange, after adding the upper part of the mold and the reinforcement for connection (see figure 10).

Because of the time needed to prepare the second phase after placement of the concrete of the bottom flange (30 to 60 minutes), a kind of skin can form at the top of concrete. This has been encountered previously on other projects. To ensure proper interpenetration of the concrete paste and fibers of the two stages, the skin has to be broken. This is achieved with a special steel fitting developed by Hurks Beton which is placed in the lower part of the mold before placement of concrete for the bottom flange and is removed when the top part of the mold is in place.

As with standard prestressed beams, the setting of the concrete was monitored by thermistors placed one meter from the ends of the beam, in the upper part of the web and in the bottom flange. The mold was struck as soon as maturity readings indicated the concrete was stronger than 101 MPa, which usually takes about 24 hours.

The ends of the UHPFRC beams are skewed as much as the bridge, i.e. 64 gons. In order to prevent the risk of any part of the pointed ends breaking off immediately after the application of prestressing forces (when the beam camber and rests solely on its ends), two pads were placed at the ends of the formwork, reducing beam depth at that point.

### 3.1.4 Suitability test

Before the start of beam casting, and as specified in the French AFGC/Sétra recommendations relative to UHPFRC structures, a suitability test was performed on the concrete. For UHPFRC structures, this test must validate the concrete mix design and the fitness of the material for the conditions of the works and for the concreting methodology. Generally, the test confirms these parameters and makes it possible to determine the fiber-orientation coefficient, $K$, using which the tensile strength contribution of the fibers can be calculated. Unfortunately, the test sometimes reveals that the concreting methodology is inappropriate and orients too many fibers in the same direction.

For Pinel Bridge, the suitability test consisted of a 5-m-long section of beam built with one of the ends of the mold and with the same concrete and strands used for the actual beams (see figure 11). This production prototype was concreted under the same conditions as those proposed for the actual beams: same plant, same mixer, same two mold parts, same way of placing the shear stirrups in the UHPFRC, etc.

Eighteen cores were taken from this production prototype: six horizontal, six vertical, and six inclined. Their locations (see figure 12) might appear strange, but it must be remembered that core samples can be taken only in areas where the web thickness is constant. The cores were notched then tested in centre-point loading in the Sika laboratory in Gournay-en-Bray, Normandy (Sika is Eiffage TP’s Premix supplier).

As observed on some other UHPFRC projects, the results of the first tests were not immediately satisfactory:

- the first test specimen was destroyed immediately after removal from the mold because the web surfaces contained a lot of bug holes which could have affected the results of bending tests on the cores extracted;
- the second specimen was no more satisfactory, with evidence of unsuitable fiber orientation (Eiffage TP feels this was probably the combined result of poor fiber storage conditions and too small a batch).

### 3.2 Transport and placement of UHPFRC beams

The beams were transported by train from Veldhoven in the Netherlands to Sotteville-lès-Rouen, and then...
by truck to the construction site. The seventeen beams were lifted into place by a 300-tonne truck-mounted crane during track closure on June 9, 2007.

As decided at the construction design stage, the fifteen interior beams were placed on elastomeric bearings, with no caulking, and steel stools were used to stabilize them transversally. The two exterior beams, with thicker webs, were placed on temporary steel ‘chock release’ jacks, the elastomeric bearings being placed and caulked only after the deck slab had been cast.

3.3 Concreting of deck slab

The deck slab was built with 36-mm-thick Duripanel sacrificial precast panels and a C35/45 ordinary concrete topping. Concrete placement took about five hours, the slab parts forming abutment crossbeams being concreted last to limit torsion effects in the beams.

4 ADVANTAGES OF EIFFAGE TP ALTERNATE BID

The beams used on this project are UHPFRC beams developed by French contractor Eiffage TP. These beams are the main component of a new deck structure which the contractor sees as an economical alternative to filler-beam decks, particularly when spans are longer than 20 m and cross roads or railroads.

In terms of design, the main advantages of this structure are the very great durability of UHPFRC beams and the possibility of designing very thin decks (on Pinel Bridge, the depths of the beams and deck
slab are 1/43rd and 1/31st of the span respectively). Such a structure is also lighter than a filler-beam deck (approximately 40% less in the case of Pinel Bridge), which can reduce the cost of foundations under certain ground conditions.

During construction, the main advantages of these beams are their great stability and the rapidity and safety of work to be conducted after beam erection. Since the beams are placed edge to edge, sacrificial precast deck panels can be placed very quickly and almost without disturbance to traffic below. Reinforcement and concrete for the deck slab is also placed more quickly than for a filler-beam deck (low volume of concrete, no transverse bars through the beams, etc.).

The erection of Pinel Bridge has confirmed the advantages of this innovative solution. Although some points can yet be perfected (e.g. excessive duration of preliminary concreting test, quality of soffit and top surface, etc.), it demonstrates that UHPFRC can be a very interesting material for bridges.

REFERENCES


