UHPFRC FOOTBRIDGE IN LE CANNET DES MAURES

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Abstract

A UHPFRC footbridge has been built by Eiffage Infrastructures in le Cannet des Maures southern France, that crosses a railway line. Its design is remarkable for its purity. The U-shaped deck cross-section needed no added superstructure or equipment once precast, since the UHPFRC could fulfill all the requirements on its own, from assuming the shape of a parapet to being slightly textured to prevent slipping on the deck floor. The Cannet des Maures footbridge is also innovative due to its construction method. The segments were precast round 650 km away from the site, and then transported to an assembly area located nearby the final footbridge position. The deck was there fully assembled on a temporary structure, and prestressed, to become a 84 tons monolithic package that was carried out onto its definitive supports by a 750 tons mobile crane. The whole point of this construction sequence was to fit in the short time-frame of traffic interruption set by the French national railway operator SNCF.

Résumé

Eiffage Infrastructures a achevé la construction d'une nouvelle passerelle en BFUP franchissant une voie ferrée dans la commune du Cannet des Maures. Son design brille par sa pureté. La section en U du tablier ne requiert aucun équipement ou superstructure d'apport dès lors que le BFUP peut remplir tous les rôles, de la constitution d'un garde-corps à la formation d'une matrice anti-dérapante au sol. Le caractère innovant de cette passerelle réside également dans son mode de construction. Les voussoirs ont été préfabriqués à 650 km du site, et transportés sur une aire d'assemblage à proximité de l'emplacement de la passerelle, où le tablier a été assemblé et mis en précontraint pour ne plus former qu'un colis monolithique de 84 tonnes, acheminé par grue jusqu'à ses appuis définitifs. L'intérêt de ce phasage de chantier est le respect de la courte fenêtre d'interruption de trafic ferroviaire imposé par la SNCF.

1. INTRODUCTION

The Le Cannet des Maures footbridge (fig. 1) is a UHPFRC structure crossing the Marseille-Ventimiglia railway line separating the municipality into two distinct sectors. It therefore provides a link between the town centre and a leisure park.

Figure 1: The footbridge in its environment

This footbridge is notable for:

- its adapted and streamlined monolithic U cross-section, with its balustrade, forming a structure that has no added superstructure components that would otherwise require maintenance;
- on-site work reduced to the construction of the abutments thanks to works prefabrication of the combined segments, their assembly offsite, and the footbridge's fully completed deck dropped into place by a crane.

2. GENERAL DESCRIPTION

The footbridge is a simply supported structure with a 34 m span and 2.50 m useful width. It is composed of 14 precast segments each 2.35 m long and two 1.00 m end segments bringing the total length to 35 m. These segments are assembled with a combined-epoxy type joint and post-tensioned prestressed.

The centre line of the footbridge's plan view is straight and its side elevation describes a parabolic radius of 415 m at its mid-span summit, resulting in a slope of less than 4% at the ends in order to comply with regulations for people with reduced mobility.

Shear keys are placed at the joint of the segments, which, combined with epoxy cementing and post-tensioned prestressing of the segments makes this assembly of separate elements behave as a monolithic unit.

The prestressing comprises 46 strands, class 1860 TBR (2 x 12T15S in the lower section of the cores, 2 x 3T15S in the upper section of the webs and 16 x 1T15S in the lower slab), protected by rigid metal ducts with cement grout.

Architectural openings carefully placed in the cores allow for views through the footbridge. Additionally, with its ochre colour added to the mix and coated with a protective varnish, the footbridge blends harmoniously with its surrounding environment.

LED bar lighting integrated into the structure's cores provides a sweep of light along the path at night.

With a standard section (fig. 2) of about 0.6 m², approximately 1.65 t/m, the total weight of the deck is about 60 tonnes. The light weight of the structure attributable to the mechanical performance of UHPFRC allows for small structural thicknesses (average thickness of 12 cm and a minimum of 8 cm) leading to handling and foundation savings.

The abutments are composed of portals structure made in S355 Corten steel (two metal columns with a tubular cross-section of Ø610 x 14.2 mm, and distance between centre lines of 2.70 m, connected at the top by a cross beam with a rectangular cross section of 450 x 250 x 12.5 mm). The tops are closed with a stiffened plate supporting the bridge elastomeric bearings 200x200x4(8+3).

Their foundations are superficial footings in reinforced concrete measuring 5.00 x 2.70 x 0.80 m. They bear two 1.05 x 1.05 m blocks each, supporting the metal drums.

At either end of the footbridge, access is provided by Corten stairswith concrete steps, or a glazed lift in a stapled glass and metal structure shaft.

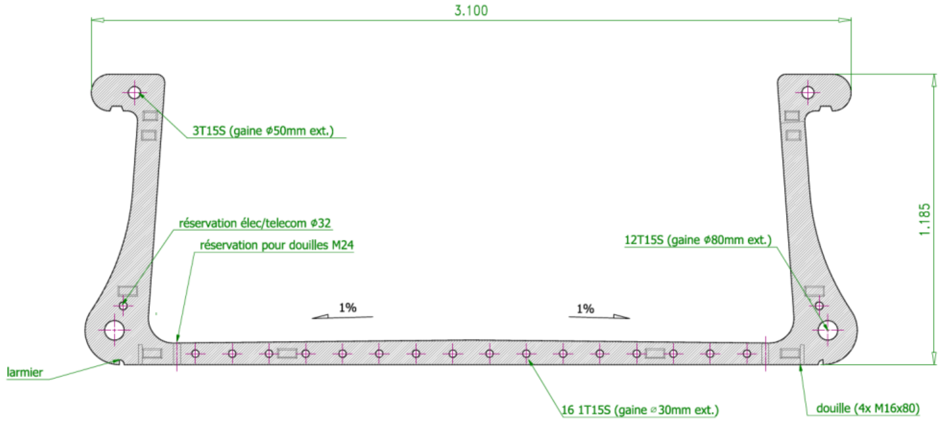

Figure 2: Typical cross section of the deck

3. THE ARCHITECTURAL APPROACH

The footbridge's superstructure and equipment are notable for their discretion since they are hidden in the structure. Most of the usually visible parts have been handled as extensions of the deck or as internal constituent elements (fig. 3).

Figure 3: View of the deck

The most obvious of these is the balustrade, which it is difficult to classify as structure or superstructure. The same applies to the skid-free treatment of the pavement, which has been achieved by engraving the surface of the UHPFRC, and not by the addition of a coating, as it is usually the case. The LED lighting is embedded in the concrete when poured. The power supply for the bridge and the lifts, and the associated communication cabling, pass through boxouts in the segments.

So, there is nothing that appears to be or is visible as mere equipment. The structure adapts and even disappears where necessary. When in addition to the boxouts for the cabling and lighting, the space required for the prestressing tendons deducted from the cross-section in BSI®, there remains just the smallest amount of concrete, just enough to coat all these internal organs and to form a whole.

4. SEGMENTS PRECASTING

The segments were prefabricated at a plant in Neuchâtel, Switzerland. To enable the reuse of the same mould, the parabolic profile of the structure was approximated so that the angle between two adjacent standard segments was always identical; the resultant slight angle gap compared with the theoretic profile was corrected in the end segments.

It was decided to pour the segments upside down (fig. 4), to allow for a good concrete flow and encourage the distribution of the fibres in the two directions of the slab. The first segment produced was used as form for the second, at their surface contact, and so on two-by-two. This method ensured a good connection between segments, especially between the male and female shear keys.

Figure 4: A segment after formwork removal, with its wind bracing system

A temporary structure was used to stiffen the segments during concreting. Form was removed when reaching a compressive strength of 100 MPa. The segments were then turned right side up using the fixtures included for this purpose, and then provided with a bracing structure, a sort of support stay to set their geometry and prevent any deformation that such an element with this weight-to-height ratio might suffer in the short term from the effects of shrinkage and creep; this structure included the lifting devices for future handling, as well as the anchorages blocks for prestressing segments assembling.

5. DECK ASSEMBLY AND PRESTRESSING

In order to limit the number of operations to be performed above the SNCF railway line, the segments of the deck were assembled and prestressed on an assembly area located near the final installation site of the footbridge (fig. 5).

A temporary structure was erected for this purpose. It consisted of two shoring towers bearing HEB 160 beams, which profile approximated the footbridge's one before it cambers. The segments were placed on this structure using free rollers for longitudinal displacement.

Figure 5: Placement of the first two segments on the temporary structure

The assembly operation proceeded as follows:

1. Placement of a first segment mid-span
2. Placement of a neighbouring segment
3. Application of the epoxy to both joint surfaces. This operation could be performed in a heated shelter if required by the exterior temperature
4. Form contact between the two segments using prestressing bars,
5. Repeat from step 2 for each symmetrically opposite segment
6. Once all the segments had been assembled, a pair of lower prestressing cables were tensioned, gradually and symmetrically
7. The falsework was removed and the deck rose off its temporary supports
8. The upper prestressing cables were in part tensioned to recompress the upper deck fibre. The remaining lower and upper cables were then gradually tensioned
9. The cable ducts were injected and the prestressing anchors sealed.

The complete deck was ready to be lifted and moved to its final position.

6. LIFTING AND INSTALLING THE DECK ON ITS FINAL ABUTMENTS

The deck had to be installed (fig. 6) without interrupting the rail traffic or the catenary power supply, an operation that was planned long in advance. A lifting procedure was submitted for the rail operator SNCF's approval as a prior before starting the work.

Figure 6: Lifting operation of the deck in a very constrained environment

The deck's length-to-height ratio meant having to use a custom-made spreader for it to be craned. The total lift weight was 84 tonnes, taking into account the safety coefficients demanded by SNCF, to be moved along a distance of 35 metres.

These parameters and the equipment availability on the operation date led to using a mobile crane with a capacity of 750 tonnes. Its position and rotational direction were more or less dictated by the tight space available between a hangar, a transformer station, a road in use, and the deck on its assembly area.

The delivery of the crane components required considerable logistics and was spread across some ten days; its assembly took one week.

Figure 7: Placing the deck on its supports

After several months' preparation, the actual assembly of the deck on the site took a week:

- Monday, 16 and Tuesday, 17 March 2015: assembly of the awnings to protect the catenary wires and acceptance by SNCF;
- Wednesday, 18 March: delivery, installation of the abutments and the stair frame;
- Friday 20 March: deck lifting trials and acceptance of the hoisting system;
- Saturday, 21 March, after a final check of all elements of the hoisting procedure, the green light was given at 8.00 am to begin the operation, witnessed by a sizeable audience. It was successfully completed three hours later (fig. 7).

7. DETAILED DESIGN

The deck structure's design and calculation were generated in a 3D model. It was indeed important to have a good view of the geometry of the structure. Working in 3D allowed to precisely 'sculpt' certain complex details, like the batter of the lattice openings, and to provide the prefabricator with a complete definition to be used directly to make the moulds in which the segments were poured.

The 3D also proved crucial when producing the drawings for the deck ends that had to include, in a reduced volume, the prestressing cable anchors, expansion joint, and high and low voltage power cables crossing the structure.

Using the results of this work, an ST1 calculation model was created. This software was chosen for its capacity to process the effects of prestressing and creep using behavioural laws for adaptable materials, as well as its multi-purpose application. Studying the structure under service loads, as well as under seismic actions and study of the dynamic behaviour were ultimately performed using a single model.

The justifications for the deck structure were conducted in accordance with the AFGC (French Civil Engineering Association) June 2013 UHPFRC recommendations, which are compatible with the Eurocodes. The specific nature of this regulatory framework concerns in particular factoring in FRC's post-cracking tensile strength.

Eiffage used its own-developed UHPFRC, called BSI® (Béton Spécial Industriel®), with the following characteristics:

- characteristic compressive strength: $f_{ck} = 160$ MPa
- characteristic tensile strength: $f_{ctk,el} = -8.5$ MPa
- characteristic post-cracking tensile strength: $f_{ctfk} = \sigma_f(w = 0.4 \text{ mm}) = -8.5$ MPa
- Mean elasticity modulus: $E_{cm} = 58$ GPa
- creep (loading at $t_0 = 2$ days): $\varphi(\infty, t_0) = 1.0$
- density: $\rho = 27.5$ kN.m^{-3}

No traction is allowed in the joints between two segments. Therefore, at mid-span, the SLS compressive strength is close to 0 MPa in the deck, and is around 66 MPa in the handrails.

The absence of any conventional reinforcement in the area around the introduction of the prestressing strands, was tested experimentally on anchoring blocks in a laboratory.

For suitability tests, a sample element (fig. 8) representative of the actual structure was created in order to validate the concreting means and methods, and to measure the K coefficient for fibre dispersion and orientation. The K coefficients measured on the samples taken from this prototype are given in Table 1.

Table 1: Orientation factors K as identified from the mock-up (suitability test)

Sampling zone	K_{global}	K_{local}
1	1.15	1.32
2	1.00	1.26
3	1.27	1.83
4	1.00	1.00
5	1.32	1.57

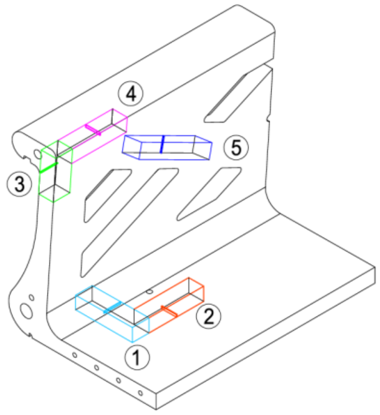

Figure 8: mock-up – sawing samples

In addition to characterising the UHPFRC through tests, the behaviour of the entire footbridge was validated using static and dynamic load testing. The static tests revealed a deflection comparable to that determined by the calculations. The same applies to dynamic tests that combined a first vertical vibration mode at about 2.3 Hz, compliant with the expected readings; this frequency meets the required average comfort level, according to French norms. Finally, the structural damping coefficient measured during these tests was 0.4.

8. CONCLUSION

The use of UHPFRC, and the mechanical performances of the material, made it possible to proceed with a graceful deck concept characterised by an attractive and extremely fine, streamlined U cross-section. The structure's light weight made its construction fast and facilitated its installation. Finally, the very high durability of UHPFRC points to low maintenance cost.