LA REPUBLIQUE BRIDGE IN MONTPELLIER

Romain Ricciotti (1), Frédéric Pastor (2), Ziad Hajar (2), Sébastien Bernardi (3)

(1) Lamoureux & Ricciotti, Ingénierie des structures, Bandol, France

(2) Eiffage Infrastructures, Vélizy, France

(3) Ductal® – LafargeHolcim, Paris, France

Abstract

The Lez in Montpellier is a surprising river. It remains very quiet and almost dry the most of the time. But each year, in a very few hours, the flood can suddenly reach a 10 m height. These dangerous floods frequently cause large damages over the river side. Thus, when the city council and the SERM decided to launch the competition for a 75 m long road bridge in 2010, a long span bridge with no support in the river was expected: suspension bridge, truss girders, bow string etc… In order to avoid these kinds of emphatic superstructures in the sweet landscape of Montpellier, architect and engineers proposed an innovative bridge all made with UHPFRC. This material provided a design with very thin piers and a slender deck, in order to obtain a perfect hydraulic transparency and a lighter impact on ground foundations. At the same time, the working time on site between two floods was drastically reduced. A special formulation of white UHPFRC using stainless fibres was developed for this project. At the end, the bridge was built by the firm Fondeville in 4 months, with a restricted budget and a better sustainability.

Résumé

Le Lez à Montpellier est une rivière imprévisible. Elle est très calme et même presque asséchée la plupart du temps. Mais chaque année, des inondations très violentes et soudaines peuvent provoquer la montée des eaux jusqu'à une hauteur de 10 m. Ces inondations dangereuses causent souvent de gros dégâts sur les abords de la rivière. Ainsi, lorsqu'en 2010, le conseil municipal et le SERM ont décidé de lancer un concours pour un projet de pont routier de 75 m de long, sans pile intermédiaire dans le lit de la rivière, les solutions envisagées ont été de types : pont suspendu, poutrelles treillis, pont en arc, etc. Pour réduire l'impact de ce type d'ouvrage sur le bel environnement autour du quartier de Montpellier, architecte et ingénieurs ont proposé une conception de pont innovant en BFUP. Ce matériau a permis une conception avec des piles très minces et un tablier élancé, afin d'obtenir une transparence hydraulique parfaite et un impact plus léger sur les fondations. De plus, le planning de réalisation de l'ouvrage a été considérablement réduit, réduisant le risque d'inondation pendant le chantier. Une formulation de BFUP blanc a été spécialement développée pour ce projet, avec l'utilisation de fibres en acier inoxydable. Le pont a finalement été construit en 4 mois par l'entreprise Fondeville, livrant un ouvrage durable et économiquement compétitif.

1. GENERAL DESCRIPTION

La République Bridge is a structure with three spans of 24 m, 25 m and 24 m and is 17 m wide. The beams of the deck are made of BSI® (Béton Spécial Industriel), a UHPFRC mix developed by Eiffage. They are 58 cm high and in the shape of an I-beam with an enlarged flange and compose a prestressed girder with a cast in-situ reinforced concrete slab. The whole is 80 cm high, which is a competitive length-to-height ratio.

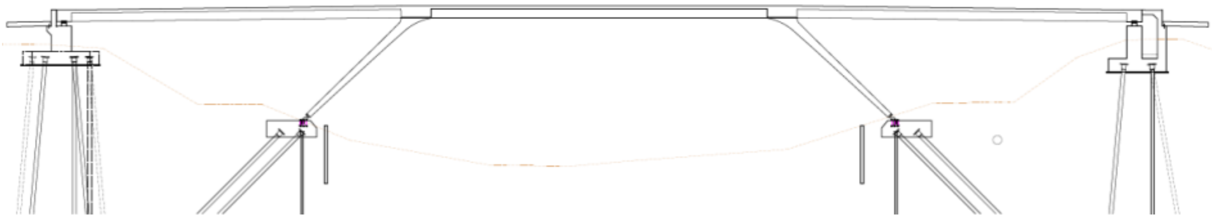

Figure 1: Longitudinal cross section

The 45° inclined piers are made of white Ductal®, an UHPFRC developed by Lafarge. Their complex shape is extremely thin at their bottom, and then widens as it gets closer to the connection with the deck. They are prestressed by 5 T15S tendons, which are almost centred. There is one set of piers to support each of the 17 beams per span. The deck lies on classic abutments at both ends.

Most of the bridge parts could be precast. The on-site assembly could thus be performed in a timeframe that matched the Lez low-water period.

2. MECHANICAL CHARACTERISTICS OF THE UHPFRC

2.1 UHPFRC for the beams

Table 1 shows the characteristics of the UHPFRC used for the beams.

Table 1: Grey BSI® UHPFRC

Density	27.5 kN.m^{-3}
Steel fibres (20mm length)	2.5% vol.
28-days characteristic compressive strength	165 MPa
28-days characteristic limit of elasticity under tension	-8.8 MPa
28-days characteristic maximal post-cracking stress	-7.1 MPa
28-days mean value of Young's modulus	57 GPa
Creep coefficient	1.0
Fibres length	20 mm

2.2 UHPFRC for the piers

Table 2 shows the characteristics of the UHPFRC used for the piers.

Table 2: White Ductal® UHPFRC

Density	25.0 kN.m^{-3}
Stainless steel fibres (13mm length)	1.25% vol.
28-days characteristic compressive strength	150 MPa
28-days characteristic limit of elasticity under tension	-8.5 MPa
28-days characteristic maximal post-cracking stress	-6.0 MPa
28-days mean value of Young's modulus	52 GPa
Creep coefficient	0.3
Fibres length	13 mm

3. DETAILED DESIGN

The design complies with the AFGC's June 2013 UHPFRC recommendations (AFGC is the French civil engineering association). The global efforts in the beams and the piers were first assessed with a 2d-model, that took into account the construction sequence, and some long-term effects related to prestressing, such as shrinkage and creep. A 3D-model completed this calculation, in order to prove the whole bridge or an individual pier had no risk of buckling. It was also used to ascertain the behaviour and the resistance of the bridge under some accidental load cases, a shock on a pier due to an object carried down by the river during a flood for instance. The bridge has also been deemed to have appropriate seismic resistance.

3.1 The beams

The beams are 58 cm high (Fig. 2). Their length ranges from 24 m on the two side spans to 25 m on the middle span. Their prestressing units have mostly been designed for a deflection purpose. The natural precamber obtained after the strands are cut is to cancel the deflection under dead load. Some deflections values are given in Table 3.

The beams were deliberately more precambered than the calculation deemed necessary, in order to balance the unknowns that usually alter the beams real deflection. According to the precise time the prestressing bench is released, or the hygrometric and thermal storage conditions, deflections can vary up to ±2 cm, which occurred. It has proved useful for similar bridges to give a little more precamber to prevent rainwater discharge issues.

Table 3: Calculated deflections of the beam for transient and final situations

	side spans - 24 m	middle span - 25 m
release of the prestressing bench (3 days)	81.8 mm	81.7 mm
before the deck slab is achieved (28 days)	95.5 mm	95.2 mm
after the deck slab is achieved	46.9 mm	42.0 mm
dead load and short-term shrinkage and creep	31.4 mm / 35.5 mm	38.6 mm / 39.8 mm
dead load and long-term shrinkage and creep	12.5 mm / 20.7 mm	32.9 mm / 35.6 mm

Table 4: Calculated stresses of the beam for transient and final situations

load case	allowed stress range	side span beams		middle span beams	
		σ_{min} (MPa)	σ_{max} (MPa)	σ_{min} (MPa)	σ_{max} (MPa)
release of the prestressing bench (upper fibre)	-6 MPa $\leq \sigma_c \leq$ 60 MPa*	-4.3	12.0	-4.3	13.1
release of the prestressing bench (lower fibre)		12.3	39.8	12.3	39.9
dead load (upper fibre)	0 MPa $\leq \sigma_c \leq$ 82.5 MPa	**	37.7	**	38.4
dead load (lower fibre)		10.1	40.3	10.7	43.3
SLS load (upper fibre)	-8.8 MPa $\leq \sigma_c \leq$ 99 MPa	**	46.4	**	46.8
SLS load (lower fibre)		2.0	44.8	4.5	49.0

* The characteristic compression of the UHPFRC is f_{cj} = 100 MPa when the prestressing bench is released. The tensile stress is then limited to $0.06f_{cj}$ = 6 MPa and the compressive stress to $0.6f_{cj}$ = 60 MPa.

** Once the deck slab is cast, there is no more need to check the tensile strength of the upper fibre of the beam. The deck behaves then as some composite section.

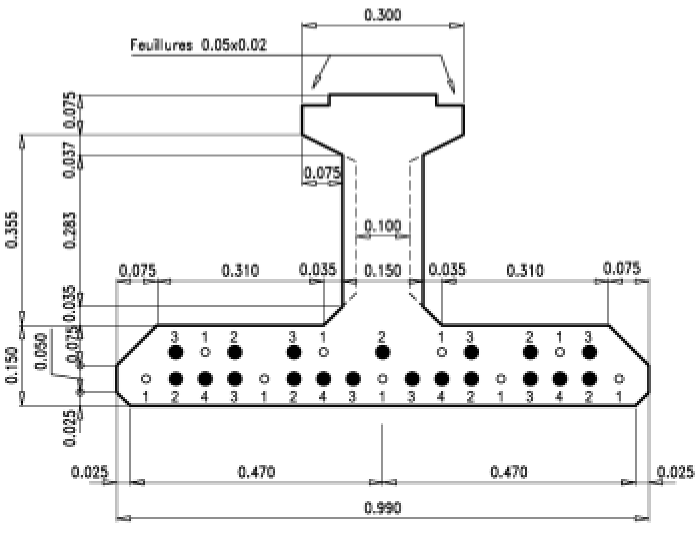

Figure 2: ITE® beam cross section

The prestressing force is therefore first designed for a precamber target value. As a result, the calculation of the beams shows a margin of resistance. They are not in tension under SLS load cases (Table 4). The prestressing tendons have been sheathed on different lengths to set the upper fibre tensile stress of the beams under the required value.

The web gets thicker at both ends of the beams, from 10 cm to 15 cm thick. The maximum shear stresses are there added to the efforts due to the diffusion of the prestressing force. A locally thicker web allows for the total shear stress at the end of the beams to be 8.7 MPa, a stress level that requires no reinforcement bars in the UHPFRC.

3.2 The piers

The slenderness of the piers being one of the essential characteristics of the environmental aspect of the project designed by the architect and the engineers.

Thanks to a specific heat treatment (limiting creep and shrinkage), a tailored Ductal® mix design was stiff enough to satisfy the structural choice calculated during the competition. This formulation exceeded 150 MPa as characteristic compressive strength, a threshold imposed by the AFGC recommendations for using the guidelines for the design. But this formulation also had the advantage of matching the aesthetic ambition of this project: a perfect whiteness.

The piers of La République bridge benefit from a world first: a formulation integrating 1.25 % of stainless steel fibers which prevents the appearance of rust points on the surface. Complementing the zero connected porosity of UHPFRC, this formulation ensures an inertness to the chemical, air and water aggressions which guaranties a high maintenance-free durability. This white Ductal® formulation with stainless steel fibers was thus a 100 % white and durable formula even in an environment where the humidity could be extreme.

The post-tensioned UHPFRC piers were delivered prefabricated directly on the job site, thus saving time and safety.

Figure 3: Variable section of the piers

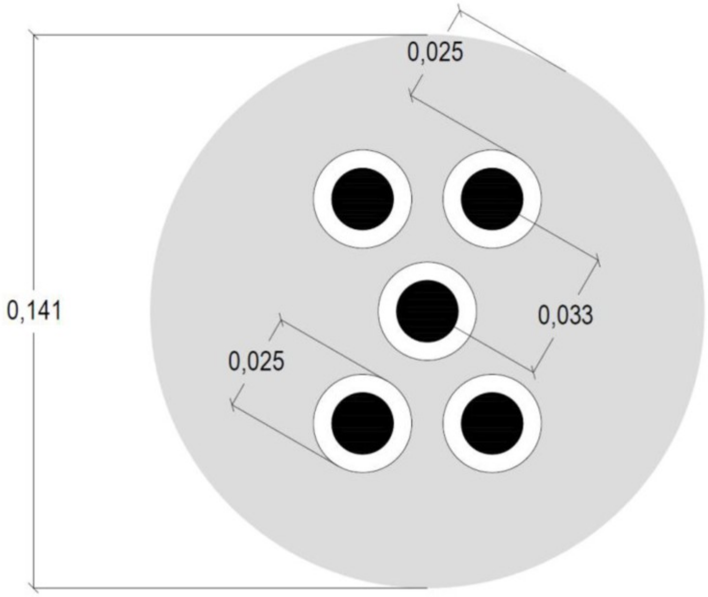

Figure 4: Post-tensioning zone of the piers (5 T15S tendons)

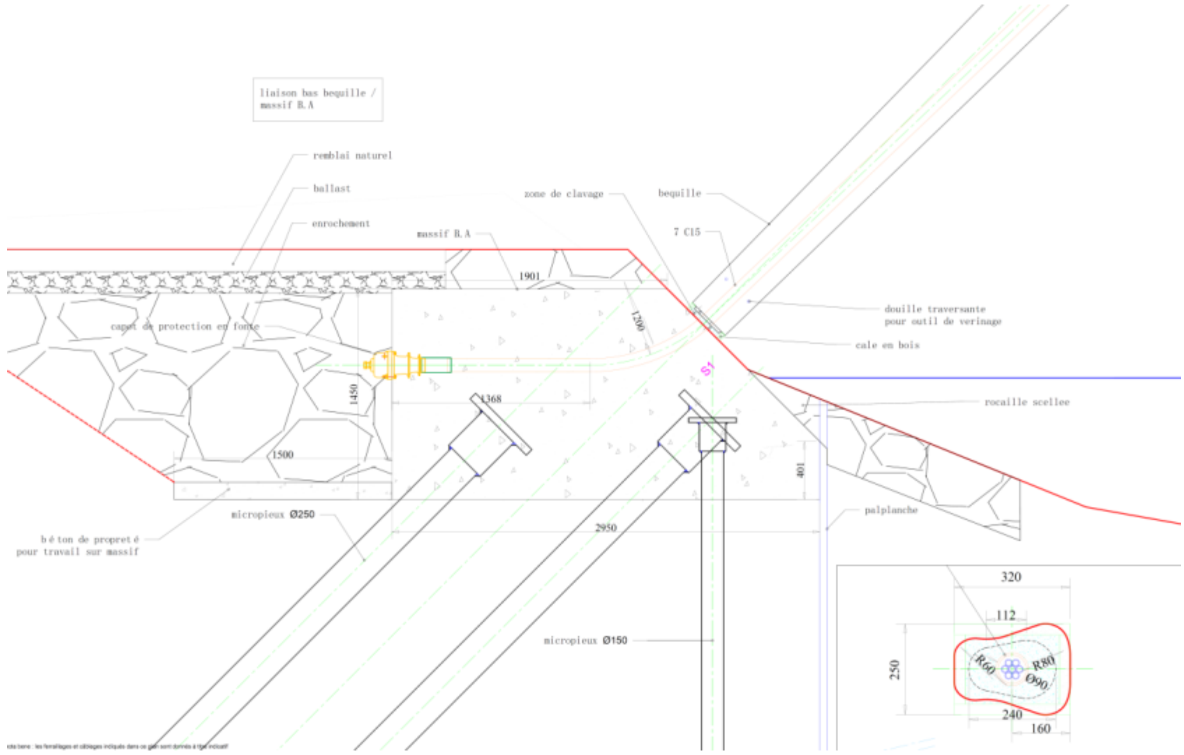

Figure 5: Details of the pier-foundation connection

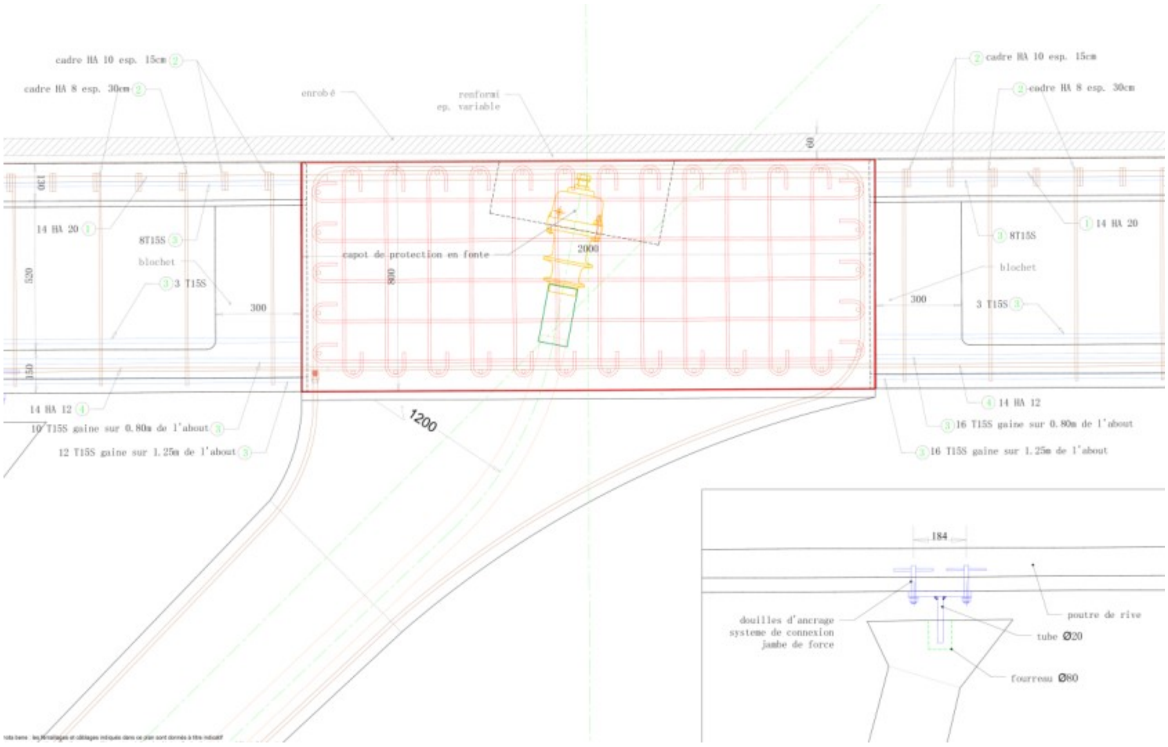

Figure 6: Details of the pier-deck connection

The piers have a complex geometry (Fig. 3) that demanded a 3D-drawing. The prestressing cables in it (Fig. 4) are straight, and follow such a path that the bending moment due to the prestressing force cancels the bending moment due to dead load. They are centered at the bottom of the piers, where the rocker bearing allows no bending moment (Fig. 5), and are slightly moved towards the lower fibre as they get close to the top of the piers (Fig. 6). The distance between the center of mass of the pier and prestressing cables axis is given in Figure 3, in which 0 m is the level of the bottom of the pier and 9.67 m is the top (vertical projection). With such a prestress, the deflection of the piers remains under 1 mm, which was important for a construction whose achievement relied on a precise assembly of different precast elements. The rocker bearing at the bottom of the piers (Fig. 5) allows no bending moments in the weakest cross-sections area. Calculation shows that SLS stress levels are comprised between -8.5 and 5.2 MPa, and that the concrete coating around the cables is always compressed.

The piers have been checked against buckling thanks to a 3D-model that took an initial shape imperfection into account. The safety factor is a little higher than 3. The second order efforts that were calculated this way were superimposed on the efforts given by the 2D general model. The resistance of the piers remained checked, with a crack opening of 0.2 mm.

The stability of the bridge in the case a pier broke down could also be checked thanks to this 3D-model.

4. SUITABILITY TESTS

The optimization of the quantity of fibers, the result of numerous tests on prototype parts (Fig. 7) carried out in collaboration with the engineers, allowed to retain the same structural reliability as with the traditional steel fibers, as illustrated from the bending response from specimens sawn from the mock-up (Fig. 8). A technical choice that also reveals economic relevance.

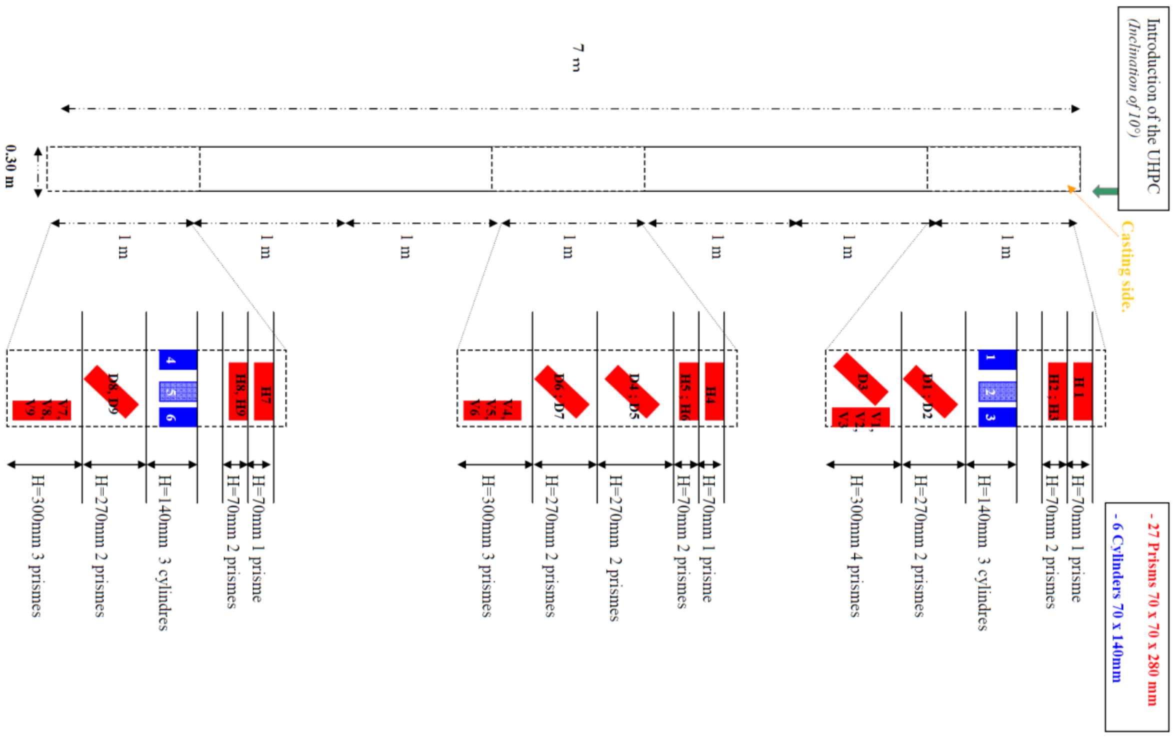

Figure 7: Scheme of the extracted samples from the mock-up of piers

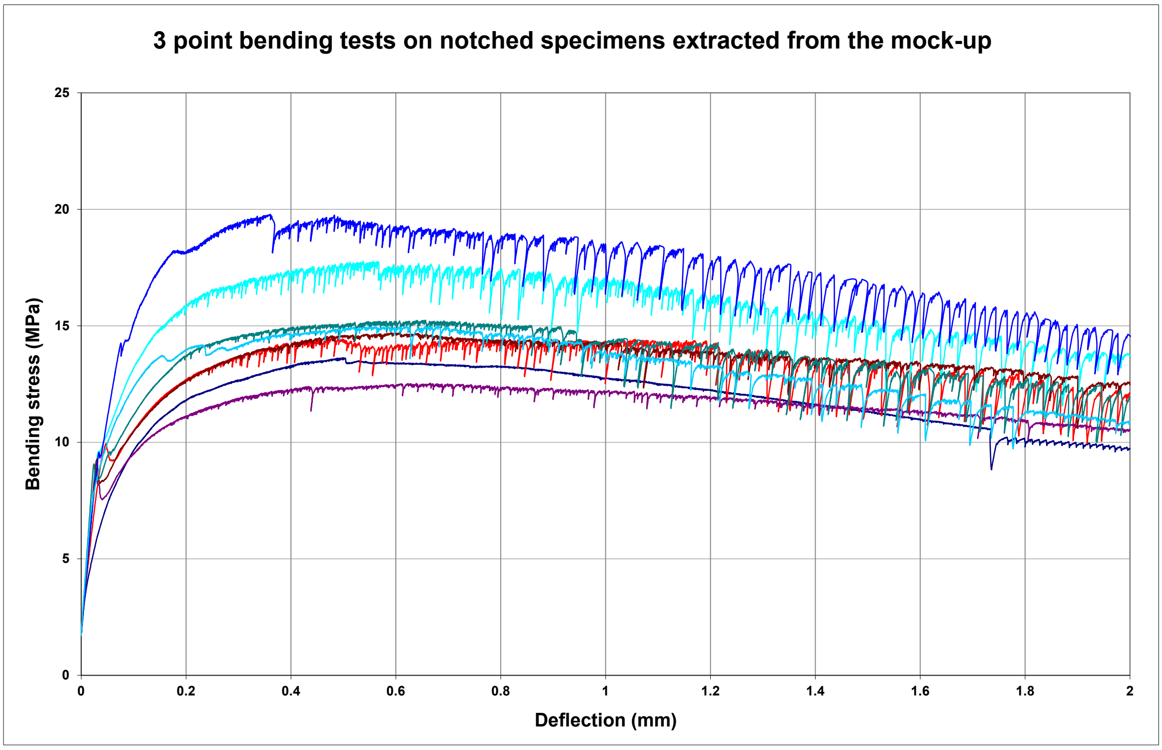

Figure 8: Effect of the metallic stainless fibres on the post-cracking bending behavior

5. CONCLUSION

La République Bridge will stay as a reference work among UHPFRC projects, combining architectural elegance and structural robustness. Its innovative design, made possible by the use of UHPFRC, allowed optimizing both geometric and construction methods. The use of prefabrication proved the winning bet for a realization in 4 months.

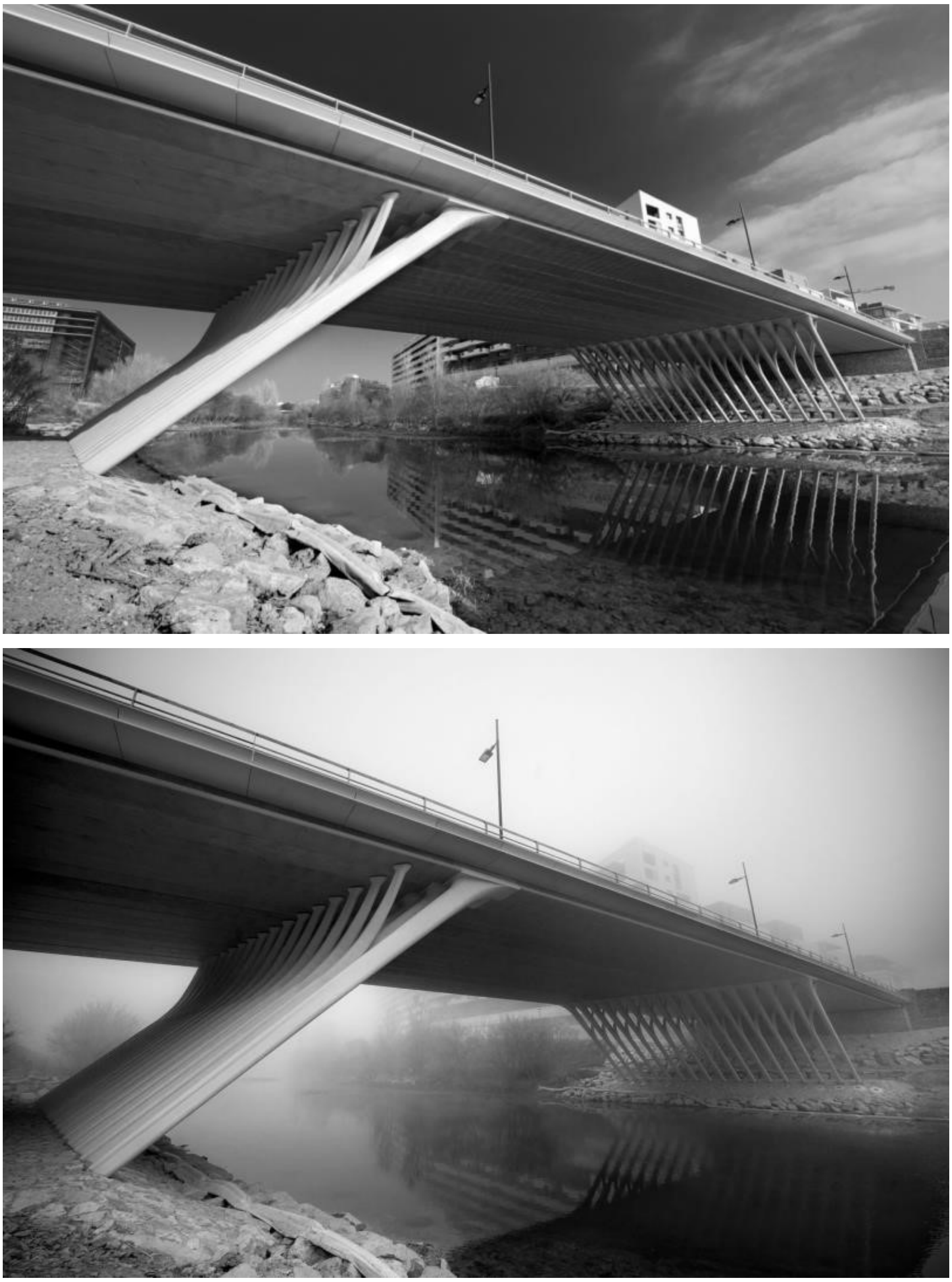

Figure 9: Overview of La République bridge (sunny and foggy conditions)

Figure 10: View of piers supporting the deck (robustness and graceful)

REFERENCES

[1] AFGC 2013, “Ultra High Performance Fibre-Reinforced Concretes – Recommendations”, Revised edition, June 2013.

[2] EN 1992-1-1. NF EN 1992-1-1 Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings, October 2005. ISSN 0335-3931. AFNOR | French standard institute.

[3] F. Toutlemonde, J. Resplendino, “Designing and Building with UHPFRC. State of the Art abd Development”, Wiley, 2011.