UHPC Bridge Deck Overlays: Feedback of Two Realizations on French Motorways

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Abstract

Until recently, on-site implementation of ultra-high-performance fiber-reinforced concrete (UHPC) overlays on concrete bridge decks has not been a popular technique in France, where experience has been rather gained on precast UHPC solutions. However, recent experience of UHPC overlay on-site implementation on two large motorway bridges in central-Eastern France (Burgundy Region), with special requirements of waterproofing, durability, and for one of the cases, structural strengthening brought by the thin reinforced UHPC layer, has emphasized specific issues for which special care has to be taken so that insurance can be given to the client that attractive promising rejuvenation/strengthening projects are satisfactorily realized and conformity to the durability expectation is provided. These issues include among others: constituents storage conditions, the UHPC mixer(s) power and capacity, rules of admixtures on-site adjustment depending on climate variations and control through fresh UHPC testing, the placement and finishing tools, workmanship education and availability. Experience in the UHPC consistence and mechanical performance sensitivity to these site conditions has been gained at a rather large scale. With this experience, guidance for appropriately following the NF P18 451 French Standard (execution of concrete structures – special rules for UHPC) can be drawn in terms of contractual management within the French context of stakeholders' responsibilities, UHPC performance specification and control, selection of the most proper offer with reliable description of UHPC implementation, delays for qualification, content of the suitability testing stage, anticipation of production rate, placement control etc.

Keywords: UHPC, overlay, specification, on-site production, bridge deck, waterproofing, consistence, sensitivity, control.

1. Introduction: Context and Scope of the Paper

This paper summarizes the lessons drawn by a motorway operator (APRR, in charge of some major motorways in Central-Eastern France such as between Paris and Lyon), client of two bridge deck rejuvenation operations in 2021 and 2022 using cast-on-site UHPC, and the client's advisor, represented by Cerema (French Highways Technical Agency) jointly with Gustave Eiffel University (comprising the former French Public Works Research Institute), acting for third party assessment in these operations.

Until recently, on-site implementation of UHPC overlays on concrete bridge decks has not been a popular technique in France, where experience has been rather gained on precast UHPC solutions (Toutlemonde et al., 2018). In fact, three complementary standards NF P18-710, NF P18-470 and NF P18-451 addressing design of UHPC structures, material specification and execution of UHPC structures respectively, have been published between 2016 and 2018, are called by the French declination of the common rules for precast products, and are available for easier contract implementation of UHPC. Even if clearly recognized in general for more than a decade (Thibaux, 2011), and significantly implemented in Switzerland (Brühwiler & Denarié, 2013; Moreillon & Ménetrey, 2013; Brühwiler, 2017) with a clear orientation of the related standard technical file SIA 2052, use of UHPC for bridge deck strengthening had however been most significantly experimented in France for orthotropic steel deck stiffening only (Hajar et al., 2013).

Thus, the recent experience on two large motorway bridges in Central-Eastern France (Burgundy Region), with special requirements of waterproofing, durability, and for one of the cases, structural strengthening brought by the thin reinforced UHPC layer, has emphasized specific issues for which special care has to be taken. This paper aims at summarizing these technical and organizational lessons, that have also been shared with the contractors, UHPC suppliers and technical supervisors, in order to promote conditions of technical success and performance for such major maintenance works that can serve sustainability, safety and cost efficiency for the road asset managers.

2. The Bridge Deck Rehabilitation Operations

2.1. General

General benefits of UHPC overlays for concrete bridge deck strengthening include optimization of added dead weight due to the material performance, reduction of jobsite duration (rapid material hardening), repair project efficiency (shorter anchoring lengths, high stiffness and low creep, easy material placement, durability). Design of the repaired concrete-UHPC composite deck is feasible based on NF P18-710 Annex V (V.1 and V.4 clauses). Execution is addressed by NF P18-451 especially in clauses 8.2.4, 8.4.1.1, 8.7 and 9 emphasizing surface preparation and joints. Documentation of waterproofing ability of a UHPC overlay is however not considered fully documented and is not covered by standards and technical approvals as for bituminous solutions.

2.2. Warren-type Bridge on A36 Motorway

For the twin 100m-long bridges with lateral Warren-type steel girders over the lateral channel to river Saône, having a composite deck made of an orthotropic steel plate connected to regular reinforced concrete, repeated wearing course degradations were to be eliminated by thickening the bituminous layers to 50 mm, while keeping the deck stiffness, the waterproofing function being ensured by the 35 mm UHPC used for substitution of 15 mm of the top deck concrete and replacing the former asphalt-waterproofing system (Figure 1). UHPC should also be implemented as a protective layer upon side beams.

Figure 1: UHPC overlay on the Warren-type A36 bridge, substituting top of the concrete slab and ensuring waterproofing as tested on a dedicated mockup.

Major issues for this operation included ensuring perfect bond of the overlay to the existing concrete, guaranteeing waterproofing, which has led to specification of a T3-class (hardening) UHPC mix, limitation of restraint-induced cracking, and special design and execution provisions for joints. On-site operations were to be achieved within ten days per deck. Aiming to risk limitation, a hardening UHPC mix with 3.75% fiber content was selected based on its identity card, and two levels of consistence (for the sub-horizontal deck surface and for covering the side beams, respectively) were specified and should be achieved with variation of the superplasticizer dosage. Suitability test operations included sequential validation of achievability of the UHPC requirements (fresh and hardened UHPC specification) and of the execution procedures, especially critical details (joint at the edge of the side beams, dilation end joints, rainwater spouts), on a large-scale (5 m x 10 m) instrumented mockup reproducing the 2% general slope of the deck.

Trial UHPC implementation for this mockup helped adjusting placement methods (full-length vibrating screed) and acceptance criteria for surface preparation (rough ordinary concrete before UHPC placement, hydroblasted UHPC before bituminous concrete implementation), absence of visible cracks and waterproofing efficiency were successfully verified after 48 hours-ponding. Severe temperature variations during the days of production for the first bridge turned out critical for regularity of the fresh UHPC consistence, leading to high variability of entrained air content, delays imposed by admixture adjustment and time for air release, and demanding hard adaptations of the placement sequence. Emergency transverse joints that had been prepared were systematically necessary. For the second deck however, regularity of the UHPC production was significantly enhanced and the implementation schedule did not need to be updated.

2.3. Pont d'Ouche Viaduct

Rejuvenation of the Pont d'Ouche twin 500 m-long viaducts was motivated by the insufficient capacity of lateral safety barriers with respect to updated heavy vehicle loads and environmental protection of the Ouche river valley. The UHPC overlay thus provides both waterproofing and increased capacity in the central part of the decks, with only 35 mm-thickness, and anchoring of the additional reinforcing bars taking the lateral dynamic load in case of a shock on the guard rail with increased 60 mm-thickness upon the edge beams (Figure 2). Moreover, a 40 mm-continuous UHPC layer should protect the surface of side beams.

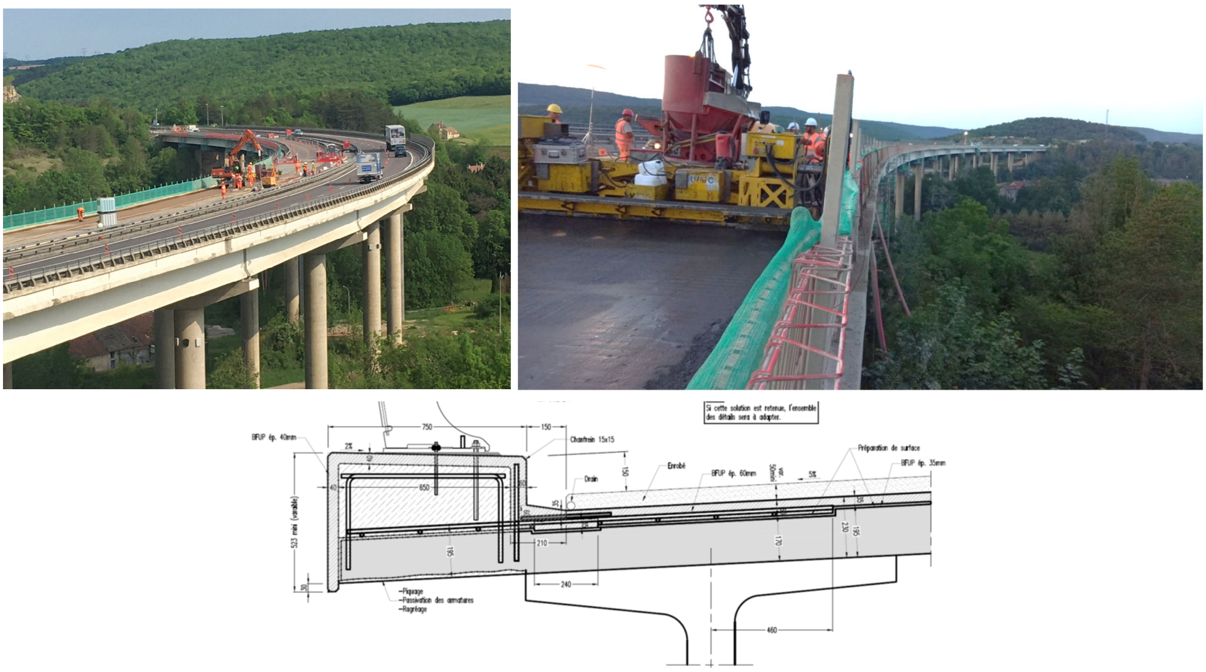

Figure 2: UHPC overlay on the Pont d'Ouche multi-span prestressed concrete girder twin bridges, ensuring waterproofing, surface protection and structural reinforcement for safety barrier anchoring.

Favorable conditions of UHPC implementation include experience of the motorway operator (APRR), the supervisor (Ingérop), the UHPC premix supplier (Vicat) and internal control laboratory (Sigmabéton) who had been involved in the previous works on the A36 bridge. As a result, specifications regarding fresh control of UHPC had been improved, a higher delay between suitability testing and beginning of the works on-site has been scheduled, and comprehensive verifications on the mockup have been foreseen. Moreover, experience of the contractor in overlay placing has led to enhanced anticipation of production rates with powerful mixers and use of a customized finisher for ensuring the UHPC placement and sliding surface forming.

Difficulties of the project yet include strong requirements related to schedule of onsite operations due to the motorway usage, realization of the first bridge overlay in 2022 being split into three periods (two half-decks plus side beams); care also had to be paid on the use of prototype mixers, prototype production of fiber-containing premix, management of two UHPC-mixes by the two contractors (one dealing with the horizontal part of the deck, one with the side beams) and induced organizational interfaces. Moreover, climatic conditions for the first deck rejuvenation in 2022 have corresponded to a rather severe heat wave: night temperature hardly got below 25°C while outer temperature during the day reached 36°C. Ensuring satisfactory implementation given these constraints has forced to activate some emergency or risky adaptations, such as: modification of the mixing sequence to incorporate fibers into the powders; realization of emergency joints in case of forced UHPC end of supply; implementation of bituminous concrete layer although reception of the UHPC surface had not been completed and defects corrected; and unprepared UHPC bucket handling for realization of the side beams overlay, with incidental consequence.

3. Lessons Learned

3.1. Project Preparation and Contract Specifications

Specifications of the projects have been based on the series of French Standards on UHPC, complemented by several SIA 2052 provisions for detailing and limiting value of deformations. For UHPC used as an overlay only for the waterproofing function, conformity to NF P18-710 may not be required, which relaxes the minimum compressive strength criterion. A hardening-type T3 UHPC as defined in NF P18-470 is however recommended to promote multiple fine cracking. Besides, applicability of structural design rules (justification of the composite section, e.g. for rebars bond transmitting accidental shock forces in the Pont d'Ouche case) requires a type S-UHPC to be used. In fact, current available mixes having a high fiber content may hardly meet the 150 MPa-minimum characteristic strength when produced on-site. To ensure acceptability of the solution even for lower compressive strength UHPC, it was experimentally verified on a mockup rebars anchoring to be ensured with a high margin, the capacity limitation (based on the ordinary concrete to UHPC bond) largely exceeding the requirement (Figure 3). Such a test combined with waterproofing verification on a representative mockup (Figure 4) advocates for due time scheduled for the suitability tests and possible iteration before initial production for the site.

Formal conformity to NF P18-470 with respect to durability was hardly verified due to difficulties in measuring the chloride migration coefficient of UHPC with a high steel fiber content; namely, the electric potential difference imposed to accelerate chloride migration induces an electric current which is not representative of the actual material behavior in case the fiber content is high enough to significantly increase the material conductivity. As an interim measure, it has been decided to characterize and control the migration coefficient of the mix without fibers.

Figure 3: Test of rebars anchoring in UHPC

Figure 4: Mockup ponding for waterproofing efficiency testing

3.2. UHPC Mix On-site Production and Supply

Use of the same premix for UHPC for the different parts of the works with different mixers and admixture dosages has confirmed that the "identity card" summarizing material properties shall clearly be related to production conditions. In fact, the list of values for the UHPC characteristics is certainly not intrinsic to the commercial premix designation. Moreover, variability in the premix water demand, possibly amplified by severe thermal conditions, had to be faced and increased variability of the final characteristics. In sum, depending on the mixers' capacity and mixing power, and on the adapted superplasticizer content in order to reach a Ct to Ca consistency, the duration of the mixing sequence has ranged from 10 to 45 minutes, and the resulting tensile behavior was T2 or T3 mainly depending on the post-mixing scatter in fibers orientation, entrained air and fiber local content in the test specimens. Representative qualification of the UHPC mix (suitability test) based on a trial production with the real facilities is thus confirmed as clearly critical for assessing conformity, namely effective achievement of the project specifications.

Thermal sensitivity of the admixtures turned out critical so that they can be kept efficient. Freezing during the night emphasized the necessity of adapted storage provisions and re-homogenization before introduction in the mixer. Heat waves leading to an initial temperature of constituents over 25°C imposed adaptation of the superplasticizer dosage and duration of the mixing sequence. Anticipation of these adaptations could not be fully tested during the suitability phase. A decision scheme was established, based on frequent consistency measurements, with a target range of control values and a widened acceptability range. In case the control value fell into this widened range, a corrective action should be taken (e.g. small increase in the superplasticizer dosage, or increase in the mixing duration) and efficiency of this correction should be validated by checking the control value of the next mix to come back in the strict acceptability range. In case of important modification of the superplasticizer (SP) dosage, specimens were fabricated for control of the compressive and tensile properties on hardened UHPC. Rigorous observation of this scheme constituted a constraint, although it favored regularity of the produced material for the placement. Attention should be paid on side effects of increasing the dosage of superplasticizer, such as higher air entrainment and viscosity.

In fact, efficiency of the fresh UHPC supply at an adapted rate so that the placement work be done without interruption appeared as a key for the success, and anticipation of this imposed production rate turned out critical. Precision of the dosage of constituents and track control of the effective mix-proportions and mixing sequence, and efficient introduction of the fibers, shall be checked thoroughly before launching of UHPC production.

3.3. UHPC Placement and Post-Placement Treatments, Organizational Aspects

Consequences of deviations in the fresh UHPC consistence and further effects on the placed material have been made evident from the jobsites experience. Excessive viscosity will consume energy from the workmanship, especially if no automated finisher has been provided (Figure 5). This may result in "waves" of excessive thickness at limits of UHPC deliveries. Excessive fluidity may lead to segregation and possible fiber balls that need to be eliminated by thorough visual inspection before ensuring thickness control (Figure 6). Even in a reduced consistence range, fiber will orient along the matrix flow if the matrix is more viscous (Figure 7a) instead of keeping random in case the finisher does not need consuming much energy for placing the mix (Figure 7b).

Figure 5: UHPC overlay extrusion with hand-drawn vibrating screed

Figure 6: Preliminary UHPC placement before thickness equalization by the finisher

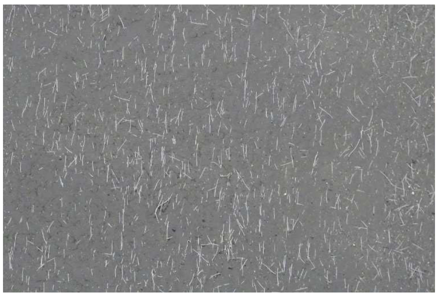

Figure 7a: UHPC made of preblended constituents. Thixotropic consistence. Surface after hardening and hydroblasting. Fibers oriented along the finisher direction

Figure 7b: UHPC made with same constituents Fluid consistence (+ 2 kg/m^3 SP dosage) Surface aspect. Random fiber orientation

Figure 8: Simultaneous manual operations for UHPC placement before and beyond the finisher

Continuous UHPC supply to avoid heavy work for intermixing deliveries and preventing cold joints was evidenced as desirable, leading to necessary anticipation to avoid small UHPC deliveries at "edges" or along the end joints. Subsequently, a numerous and skilled enough team has to be made operational for UHPC placement (Figure 8). Moreover, care was confirmed to be necessary for preparation of the rough saturated dry surface to obtain full capacity of the existing concrete/UHPC bond, as demonstrated from the results of control pull-out specimens on the mockups. This motivated formal surface contradictory control before UHPC placement. Contradictory control of the immediately and thoroughly cured, then hydroblasted UHPC surface, with sufficient delay before bituminous pavement layers implementation, also turned out as a mandatory step to be kept as the last chance for remediation of possible defects in the UHPC implementation.

4. Concluding Remarks

Interest of UHPC for bride deck rehabilitation was confirmed from the recent experience of A36 Warren-type and Pont d'Ouche viaducts. Ensuring efficiency of the as-built project to meet as-designed expectations much relied on the execution organization and control. Quality of UHPC on-site supply (depending on mixers capacity, control and storage of the constituents, anticipation of thermal sensitivity etc.) so that regularity in the consistence can be ensured and promote smooth placement has turned out a key aspect, to be anticipated and ensured also from contract and organizational aspects. Monitoring of the effective durability of the UHPC overlays has been organized with a representative slab specimen submitted to natural ageing (including deicing salt spray) just along the motorway sites. Further lessons of these rehabilitation operations should be drawn in terms of: "UHPC qualification" for personal, revision of some reinforcement detail provisions, early enough preparation, suitability trial production and validation of procedures. These lessons should be the basis of a guidance document to be prepared for structure owners, to help them make rehabilitation operations with UHPC a success. They may also help next scheduled UHPC on-site implementation for rehabilitation of steel bridge decks or culverts.

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