# New thin UHPC deck for the "Grand Pont" of Thouaré-sur-Loire – How to extend serviceability of a 19th century steel through-truss bridge?

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## Abstract:

The "Grand Pont" of Thouaré-sur-Loire is a 430 yards long steel through-truss bridge crossing the Loire river in Nantes area (France) bearing an increasing commuting traffic of 10 500 vehicles a day.

The structure was suffering significant pathologies related mainly to waterproofing failure that could have led to the collapse of the brick masonry arches supporting the structure or to a steel floor beam breakage.

The operation of rehabilitation and improvement of the level of service of the "Grand Pont" of Thouaré-sur-Loire involved among others the complex realization of a new integral UHPC deck.

This very thin deck, made up of UHPC prefabricated slabs, connected on site with UHPC joints, allowed to relieve the bridge of half of the deck dead weight.

The gain in thickness also enabled to reinforce the 135-year-old steel structure, which has been completely conserved, by superimposing new metallic beams without changing the finished level of the roadway.

The implementation of this construction technique allowed to drastically reducing the completion time of the project and traffic interruption.

## Keywords:

Steel through-truss bridge, UHPC deck, prefabricated slabs, UHPC connections, completion time

## 1. Description and pathology of the bridge

### *1.1. Description*

The "Grand Pont" is a structure that enables the RD 37 road to cross the river Loire between Thouaré-sur-Loire and Saint-Julien-de-Concelles. Erected in 1882, it is a steel through-truss bridge type, supported either by brick masonry arches or by reinforced concrete slabs.

This structure, located on the northern branch of the Loire, has a total length of 430 yards, and is divided into seven 49 yards spans with two 42 yards spans on the river banks. The floor beams, spaced every 2,0 yards, support on the 5,25 yards wide central part, brick masonry arches built with lime concrete, the upper surface of which are aligned with the upper level of the deck sole. This bridge provides a roadway of 5,05 yards wide, with two traffic lanes, edged with sidewalks with a useful width of 0.84 yard.

Car traffic over the "Grand Pont" at Thouaré-sur-Loire has become heavier and has reached saturation point, with mainly commuter traffic now reaching 10,500 vehicles per day. Circulation is limited to vehicles of less than 3,8 tons, with an exemption for the vehicles of less than 8,8 tons (2,2 + 6,6) used for agricultural purposes on the island as well as for the service vehicles (winter maintenance) or emergency vehicles of less than 17,6 tons (6,6 + 11,0).

**Figure 1: General view of the bridge before renovation**

### *1.2. Pathologies*

Although the structure has been properly and regularly maintained, anti-corrosion protection on the metal framework in particular, it is nonetheless presenting significant pathologies related mainly to a lack of waterproofing. In fact, rainwater flows along the edges of the sidewalks, leaking into the body of the embankment and percolates through the lime concrete into the brick masonry arches.

So over the years, the roughcast mortar is being washed away and the bricks are splitting up, this phenomenon being accentuated in periods of frost and thaw. Number of bricks can be seen to be sinking, as well as brick fragments falling off. When the water comes out of the brick masonry arches, it continues to cause damage by creating damp on the overhead part of the floor beam.

Major localized corrosion can also be seen along the tympanum of the arch, with a significant loss of material with frequent and extensive perforations. The organized monitoring of the structure, by annual and more detailed periodic inspections, has enabled the damages to be monitored and the structure's level of service to be guaranteed.

**Figure 2: Corrosion pathologies of the bridge**

## 2. Bridge rehabilitation program

### *2.1. Initial program of renovation*

Given the risk of a brick masonry arch collapse or of a floor beam breakage, the structure was placed under more frequent monitoring and a repair program was drawn up at the end of 2014, along with the initial budgetary decisions.

The initial rehabilitation program project was including:

- Removal and repair of the most damaged brick masonry arches.
- Reparation and strengthening of the corroded floor beams by bolting on damaged parts reinforcing metal sheets.
- Reparation of the concrete deck, setting up of new waterproofing layer and of a surface bituminous concrete.
- Repainting of the all structure.

The budget allocated to these works was set at €4.8 million excluding taxes, with a completion deadline of 12 months, and no complete interruption of traffic.

It was also demanded to study the feasibility of the later addition of two overhanging structures, each with a useful width of 2 meters enabling pedestrians and cyclists to cross on either side of the bridge.

### *2.2. Structural requirements*

The first stage consisted in reviewing the structural requirements with different *scenarii* of service loads: two lanes of 3.85 tons vehicles representing a distributed load of 1135 daN per yard of deck, exceptional crossing of two vehicles of 8,8 and 13,2 Tons and isolated accidental circulation of a 20,9 tons vehicle.

The operational load for the overhanging structures was fixed at 420 daN per sq yd, in accordance with the Eurocodes.

It quickly became obvious that repairing all the brick masonry arches as initial, or implementing a new reinforced concrete deck, would not enable a sufficient reserve load-bearing capacity to allow pedestrians and cyclists to cross the bridge on overhanging structures.

### *2.3.Design of a new thin UHPC integral deck*

New technical solutions that met the structural requirements (a significant saving in dead weight and the possibility of building the overhangs) and geometric requirements (maintaining the current road level) had to be imagined, whilst keeping to costs and deadline requirements.

The idea of using UHPC for its mechanical qualities conducted to an innovative design solution consisting in:

- Removing the existing masonry arches and replacing them with thin UHPC slabs
- Benefit of the "new" space between the existing beam and the UHPC deck to install new girders (existing deteriorated beams are conserved for cost issues but neglected in calculation).
- Connecting the slabs and girders on site with UHPC joints.
- Implementing a thin road surface dressing.

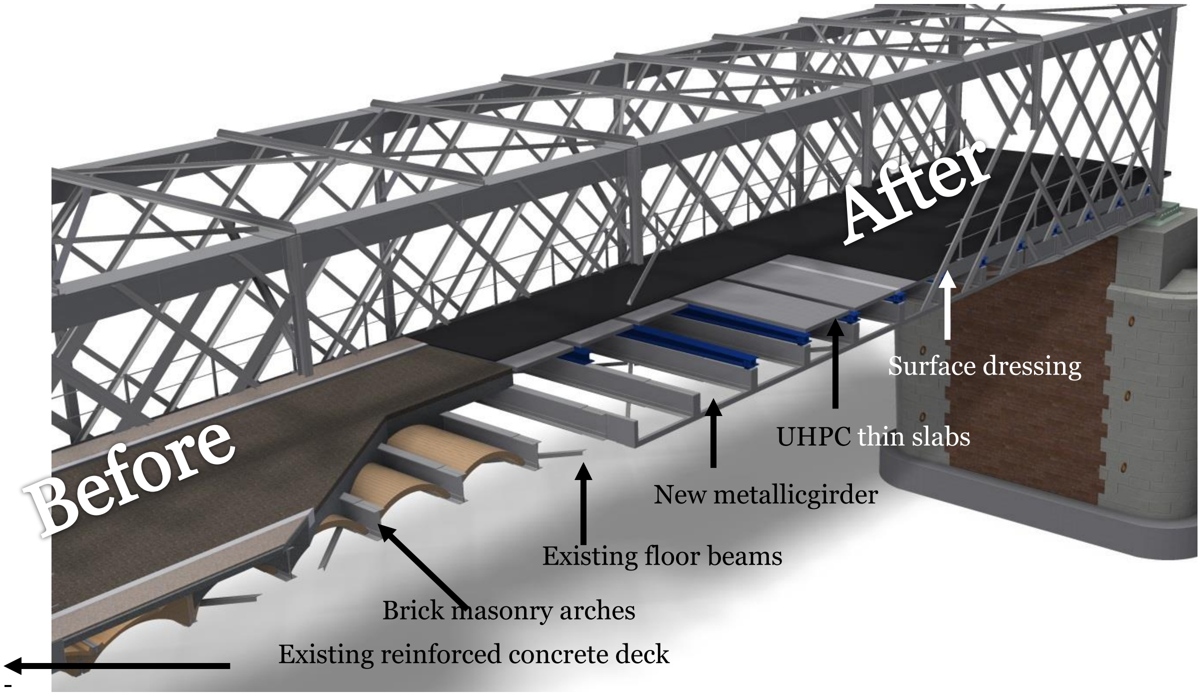

**Figure 3: General view of the bridge renovation concept**

Structural calculations led to the design of a continuous full-width slab (roof shaped) resting on the floor beams of a constant thickness of 3,54 inches.

Placed at the current level of the roadway, the UHPC slabs let a space of about 8 inches over the existing floor beams which enabled new metallic girders to be inserted (bolted to the undamaged ends of existing floor beams), which can alone withstand all the road service loads.

UHPC slabs are connected to each other and to the new girders using Nelson studs (working in a mixed cross-section). A metallic frame is also fitted to each extremity of the girders for the implementation of the future overhanging structure.

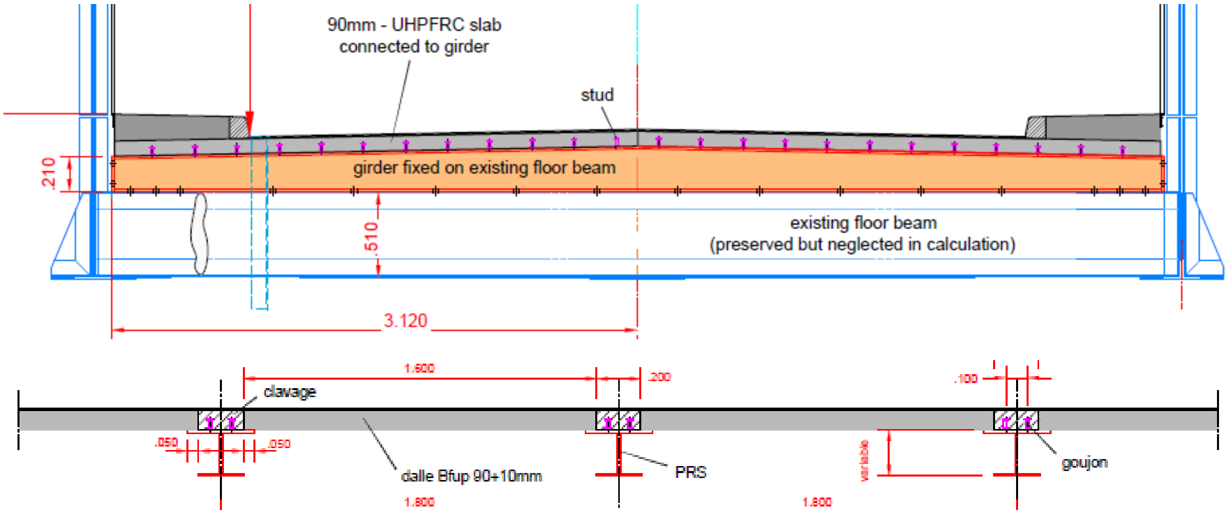

**Figure 4: New bridge structure after rehabilitation.**

The economical optimization during the construction phase led to the realization of a metallic profile of constant inertia from an expanded and reinforced standard profile. The UHPC slabs must then follow the shape of the roadway slope and thus have a thickness varying from 2,75 in at the edge to 4,60 in on the axis of the structure. This new design also allowed casting the slabs upside down with rather simple molds.

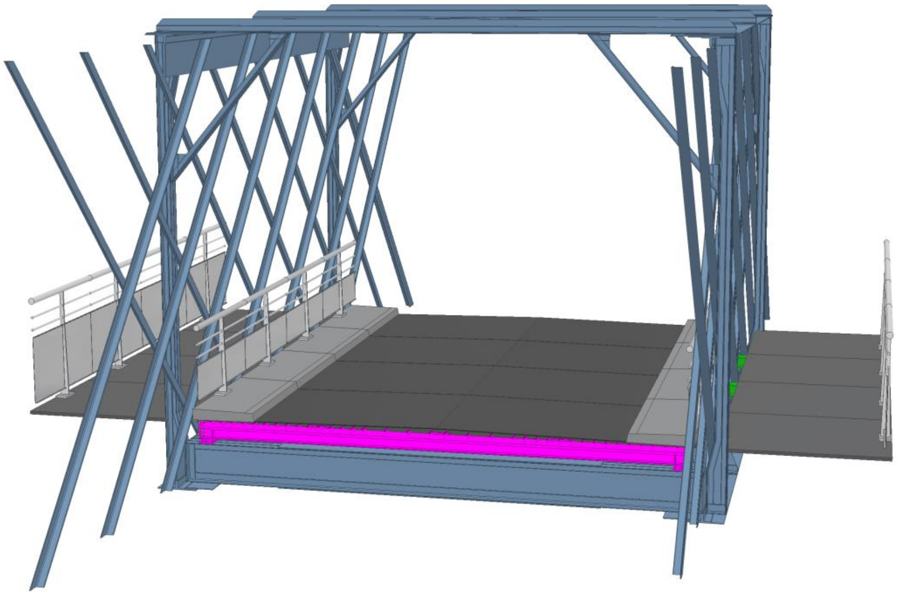

**Figure 5: New bridge structure after economical optimization with overhangs (not realized yet)**

## 3. Construction phase

### 3.1.Demolition of the masonry arches, repainting of the structure and new girder installation

First stages of the construction consisted in removing all the brick masonry arches representing more than 2500 tons of waste, or about 75% of the current deck weight.
The structure was then fully repainted and new girders have been progressively installed.

**Figure 6: Pictures of brick masonry arches demolition and of new girders installation after repainting.**

### 3.2.Production of the UHPC Slabs

218 slabs were required for the deck construction. Each one weighs 5070 lbs and measures 6.78 yd long and 1,73 yd wide. Thickness is 2,75 in on the edge and 4,60 in at the axis. Slabs are reinforced by rebars aligned on the axis of the bridge.

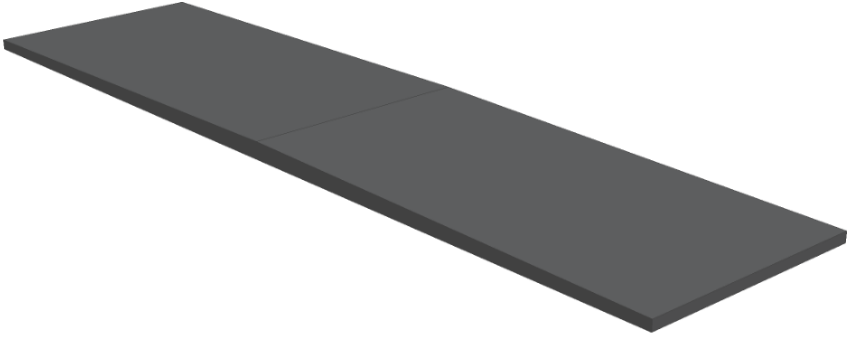

**Figure 7: UHPC slabs design.**

SMART$^{UP}$ [Structure] Grey 2,5% FM (a product of Vicat group) was chosen for the manufacture of the slabs as well as for their connection on site to new girders. The use of this product allowed reaching the following properties (according to UHPC French standards NF P 18-470)

| | |
|---|---|
| Characteristic strength in compression ($f_{ck}$)<br>*according to NF EN 12390-3* | ≥ 21,8 ksi |
| Characteristic value of the elasticity limit in traction ($f_{ctk,el}$)<br>*according to NF P 18-470* | 1,28 ksi |
| Characteristic value of the post-cracking strength in traction ($f_{ctfk}$)<br>*according to NF P 18-470* | 1,13 ksi |

| | |
|---|---|
| Mean value of Young's modulus ($E_{cm}$)<br>*according to NF EN 12390-13* | 6400 ksi |
| Poisson's ratio | 0.2 |

**Table 1: UHPC (SMART$^{UP}$ [Structure] Grey 2,5% FM) mechanical performances**

| | |
|---|---|
| Water porosity at 90 days<br>*(according to NF P 18-459)* | ≤ 6,0 %<br>*(Dp+ : improved porosity)* |
| Chloride diffusion coefficient at 90 days<br>*(according to NF P 18-462)* | $\leq 0{,}1.10^{-12}$ sq yd.s$^{-1}$<br>*(Dc+ : improved resistance to the diffusion of chloride ions)* |
| Apparent permeability to gases at 90 days<br>*(selon NF P 18-463)* | ≤ 1.10-19 sq yd<br>*(Dg+ : improved resistance to gaseous transfers)* |
| Abrasion index<br>*(CNR protocol)* | 1,1<br>*(RM1 – material resistant to "hydraulic" abrasion)* |

**Table 2: UHPC (SMARTUP [Structure] Grey 2,5% FM) durability performances**

The slabs have been casted upside down on wooden mold at the pace of 4 slabs a day. Concreting methodology has been defined to favor a preferential orientation of the metallic fibers following the length of the slabs (perpendicular to the rebar and bridge axis).

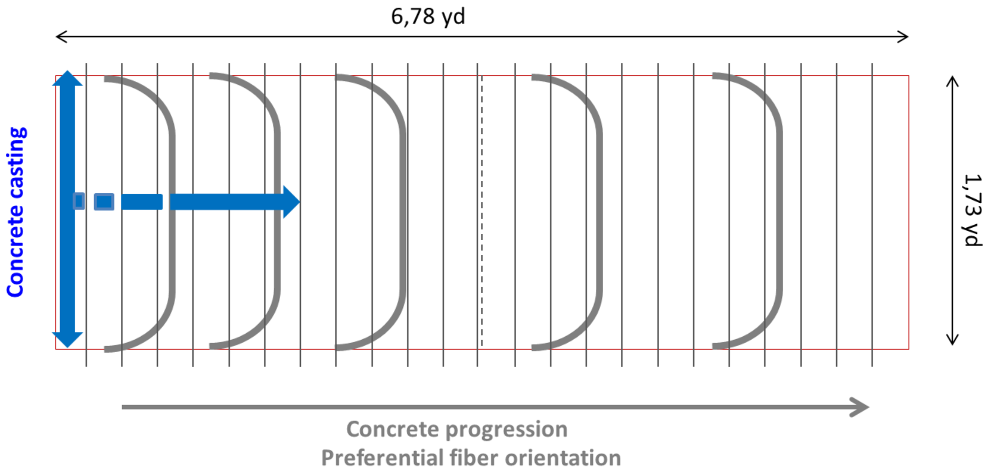

**Figure 8: Methodology of concrete casting for slab production**

6 types of slabs were produced: standard slabs (2 types for holding the steel in staggered rows), end slabs (with a much shorter length for the junction with the abutment) and special slabs (2 types, identical to the standard slabs but with 2 reservations for the rainwater downpipes).

**Figure 9: Pictures of slabs being produced / having been produced.**

Slabs edges were mechanically sanded (making the surfaces rough and metallic fibers slightly pulling out of the slabs) to enhance future adhesion with the UHPC joint.

### 3.3.Installation of the UHPC Slabs

The slabs were transported to the site vertically to comply with the local load regulations. The slabs were then twisted using a special tool for placing them flat, ready to be positioned in their final place. When several slabs were in place on the metal sections, the UHPC connections could then be done.

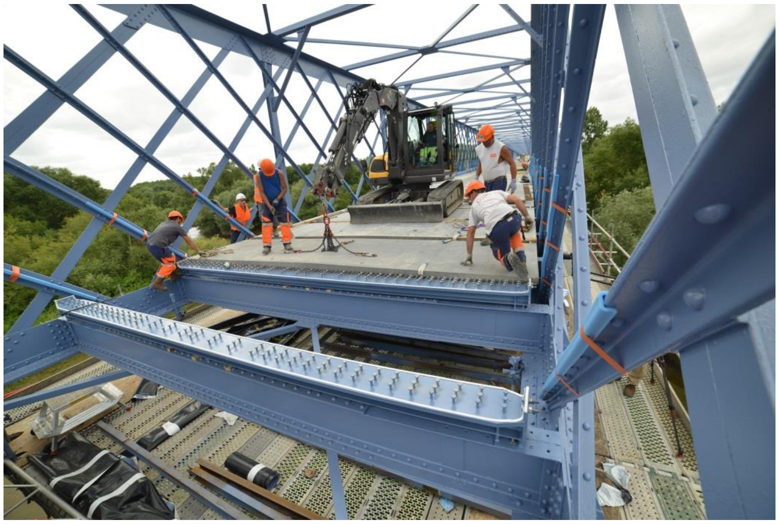

**Figure 10: Picture of a slab installation.**

### 3.4.UHPC connections

Suitability tests were carried out at the site facilities with the purpose of checking that the UHPC (SMART$^{UP}$ [Structure] Grey 2,5% FM) was properly distributed through the very dense reinforcement and connectors "net" (8 connectors per meter in the central part and twice the quantity on both extremities, 0,63 in diameter and 1,97 in height).

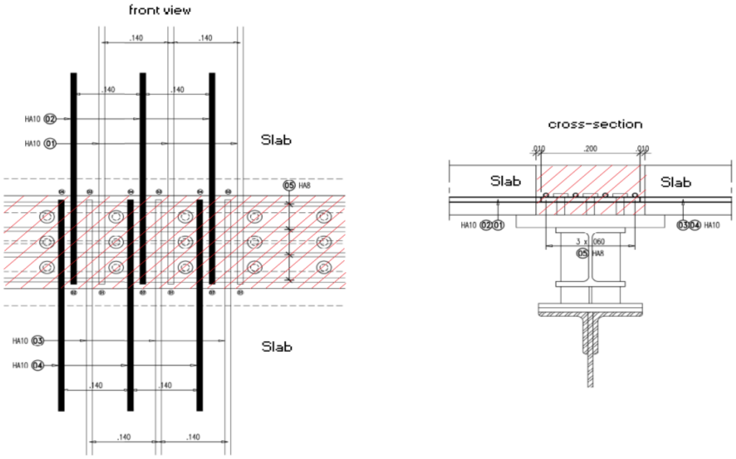

**Figure 11: UHPC connections design**

This also enabled to optimize the necessary UHPC fluidity as well as to define the correct quantities of materials required for the actual volume of the joints.
UHPC was casted directly on the joints from one side to the other. To achieve the roof shaped of the joints, counter-molds were installed with 3 "chimney pressure" to ensure the perfect filling of the joints.

**Figure 12: Pictures of a UHPC connection realization**

Contractor teams were trained to UHPC preparation and quality protocols by Vicat who also supplied the adapted mixers to produce about 48 gal of UHPC per joint. UHPC component (fibers and admixtures) were also supplied in pre-weighed bags to avoid any dosing error issues as well as to allow a faster concreting of the joints.

### *3.5.Roadway finish and bridge release to service*

Once this cycle has been completed, the sidewalks could be erected on the slabs, as well as the application of a thin road surface dressing.
Whereas the owner had initially scheduled a traffic interruption of the bridge for a period of 12 months, the massive use of prefabricated slabs coupled with fast UHPC connections on site contributed to reduce the completion time of the project at only 6 months.

**Figure 13: Picture of the finished bridge**

## 4. CONCLUSIONS

Rebuilding the deck of the "Grand Pont" of Thouaré-sur-Loire in UHPC enabled the inherent difficulties of the project to be overcome: reducing the weight of the structure, completion of the project in a very tight schedule, whilst enabling in a close future to improve the daily life of the users by the creation of overhanging structures for cyclists and pedestrians.

The advantages of this constructive solution permitted to reduce the operations on the existing structure (thus reducing uncertainties), to handle lightweight elements suitable with the narrow geometry of the cage, to reduce the completion time of the project and above all to drastically decrease the dead weight of the structure to restore the serviceability in safe conditions of the bridge.

This example of bridge renovation project leads the way to many other concrete applications. There are numerous metallic structures that must be preserved for aesthetical, historical or operational aspects whose carrying capacity needs to be drastically improved (urban bridge or why not railway structures).

It is already planned to duplicate this technical solution on the bridges of Mauves sur Loire, representing 660 yd of deck (identical to the Grand Pont of Thouaré-sur-Loire), located three miles upstream, starting from 2019. On this occasion, it would probably be appropriate to optimize the design of the UHPC slab by conceiving for example an embossed structure and to rework the interface between the prefabricated part and the part casted on site (field cast connection).