AN INNOVATIVE APPROACH OF USING UHPC FOR METRO VIADUCTS

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Abstract

Systra had developed since 1996 a concept of U-shape viaduct, used for more than 300 km of metro viaducts throughout the world. In order to continuously improve the transportation infrastructures, SYSTRA has developed recently, with inputs from Lafarge Holcim, a new structural and architectural concept for metro viaducts, using UHPC.

The deck and the piers are made of a combination of UHPC and ordinary concrete. The lateral beams have openings in order to: clear the view from the metro passengers across the lateral beams, improve the architectural aspect and allow various esthetical expressions, and optimize the UHPC use. Thanks to this new design, the span between piers is about 45m to 50m (instead of formerly 35m for SYSTRA classical U-shape viaducts). This longer typical span facilitates the crossing of crossroads and various obstacles. Globally the carbon print of the UHPC viaduct is less pronounced than the classical viaducts, due to a better durability of UHPC.

Résumé

Systra a développé depuis 1996 un viaduc en U, utilisé pour plus de 300 km de viaducs de métro dans le monde. Afin d'améliorer continuellement les infrastructures de transport, SYSTRA a développé récemment, avec l'aide de Lafarge Holcim, un nouveau concept structurel et architectural de viaduc de métro, utilisant du BFUP.

Le tablier et les piles sont constitués par une combinaison de BFUP et de béton ordinaire. Les poutres latérales présentent des percements de façon à : faciliter la vue des passagers à travers les poutres latérales, améliorer l'aspect architectural et permettre des expressions esthétiques variées, et optimiser l'utilisation du BFUP. Grâce à cette conception, la portée entre piles est de 45m à 50m (au lieu de 35m pour le viaduc en U classique de SYSTRA). Cette portée type plus grande facilite le franchissement des carrefours et des obstacles variés. Globalement l'empreinte carbone du viaduc en BFUP est plus faible que celle des viaducs classiques, grâce à la meilleure durabilité du BFUP.

1. GENERAL CHARACTERISTICS OF METRO VIADUCTS

In many countries, metro lines are built on long viaducts. Generally these viaducts carry two tracks, one for each direction. The rolling stock can be rolling on rails or on tires. The power supply can be made through overhead catenary line, or a third rail. The track height above the ground varies usually from 7 to 12m. These structures being built in the heart of the town, their integration in the urban landscape is an important topic.

SYSTRA has already developed since 1996 a patented viaduct type, made from a U shape prestressed concrete deck supported on reinforced concrete piers, which has been used for more than 300 km of metro viaducts in the world [1]. The purpose of this paper is to present a new viaduct type, also dedicated to metro lines, using Ultra High Performance fiber reinforced Concrete (UHPC).

2. DESCRIPTION OF THE NEW VIADUCT

2.1 General design

It has been decided to take advantage of advanced material like UHPC to design a viaduct that is structurally and aesthetically attractive. It is also designed to integrate all the transportation systems, like the present SYSTRA classical U-shape viaduct. The following equipment is integrated in the design: track, emergency walkway, cable troughs, acoustic protection.

The deck and the piers are made from a combination of UHPC and ordinary concrete. The deck has globally a U shape, with two precast lateral beams of variable depth made from UHPC. These beams have openings in order to: clear the view from the metro passengers across the lateral beams, improve the architectural aspect and allow various esthetical expressions, and optimize the UHPC use.

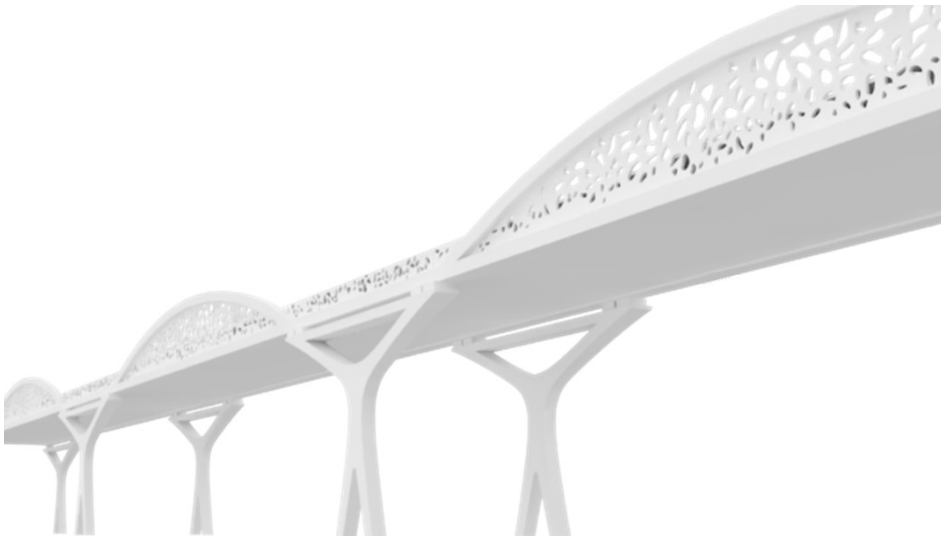

Figure 1: Viaduct overview

The variable depth optimizes the material, in order to get the minimum of quantity of UHPC with the maximum vertical stiffness in order to check the severe deflection criteria of a railway deck. The spans are simply supported on long pier elements, through elastomeric bearings or pot bearings.

Thanks to this new design, the span between adjacent piers is about 45m to 50m (instead of formerly 35 m with SYSTRA classical U-shape viaducts). This longer typical span facilitates the crossing of wide crossroads and various obstacles. There are fewer piers thanks to the increased length of spans.

Simple standard spans are 35 m long and straight. The difference between this span length and the variable pier to pier distance is supported on “extended piers” of variable length. If the track layout is curved, the typical simple spans remain straight, with an over-width to accommodate the lateral clearance, and there is a plane angle at the pier.

Deck elements are precast in order to improve the quality and to reduce the construction time. The two lateral UHPC beams are precast as full spans, and they are prestressed using pre-tension. The slab between the lateral beams is made from match-cast precast elements in ordinary concrete. They are supported on the lateral beams, connected to them with cast-in-situ longitudinal UHPC joints, and assembled by longitudinal post-tensioning.

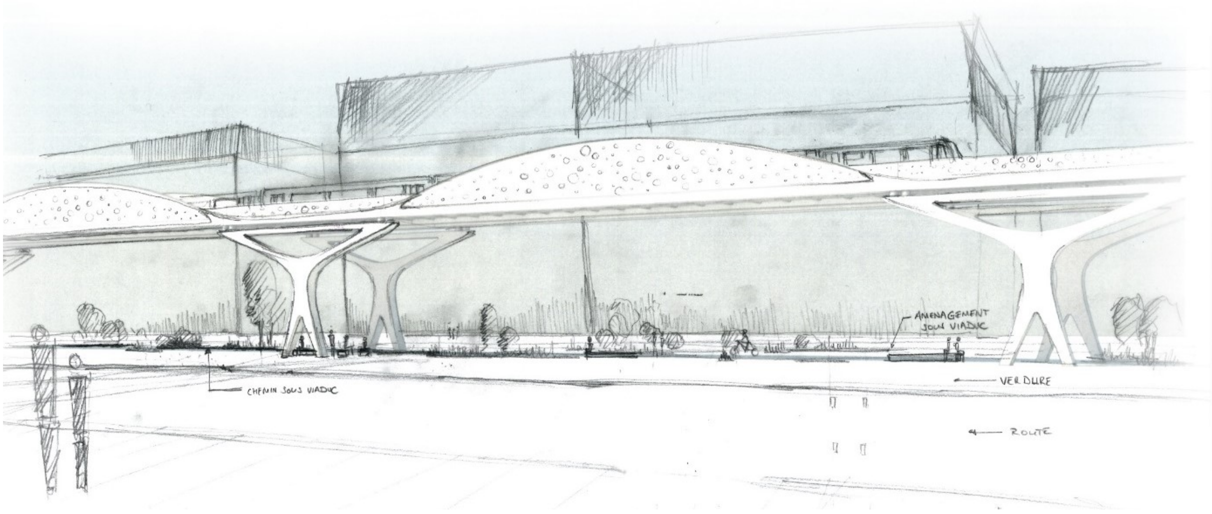

Figure 2: General layout

The piers shapes are not defined once for all. They will be adapted to the local context, following the intention of the architect of each project. However, two typical concepts have been studied: one concept with a central pier shaft which could be placed in the median of a highway, and another concept with two lateral piers in the case where the ground below the deck could be used for pedestrians. The piers can be made from UHPC, in order to get slender and architecturally pleasing shapes, or a combination of UHPC and ordinary concrete.

2.2 Architectural concept

The design of this new viaduct type has been performed in association with architects from SYSTRA. The variable depth of the lateral girders creates an undulating shape which provides some visual interest to the viaduct. The intention is not to hide the viaduct, but to show its harmony.

Figure 3: Configuration with lateral piers

Figure 4: Configuration with central pier

The design of the openings shapes can be adapted for each project, according to the local architecture and culture. The shapes and the sizes of the openings can be modified independently, within certain limits. The UHPC can be cast with color pigments, in order to produce a colored material. The lateral girders could be used also, if required by the owner, to put some images or information led panels. The lateral girders could be illuminated during the night, in order to give a special attractive appearance. The UHPC has a very smooth and uniform surface, where dust does not accumulate.

2.3 Structural analysis

The viaduct comprises 35 m long isostatic straight spans on simple bearings (simple supports on long pier elements), consisting of:

- two prestressed UHPC precast lateral beams of variable height,
- prestressed regular concrete match-cast precast slabs, including reservations for fixing the rails.

The lateral beams, which are molded single pieces (nominal weight 34 tons if height at mid-span is 3.5 m), consist in a horizontal rectangular-shape top flange, a pre-tensioned trapezoidal bottom flange, and a perforated web.

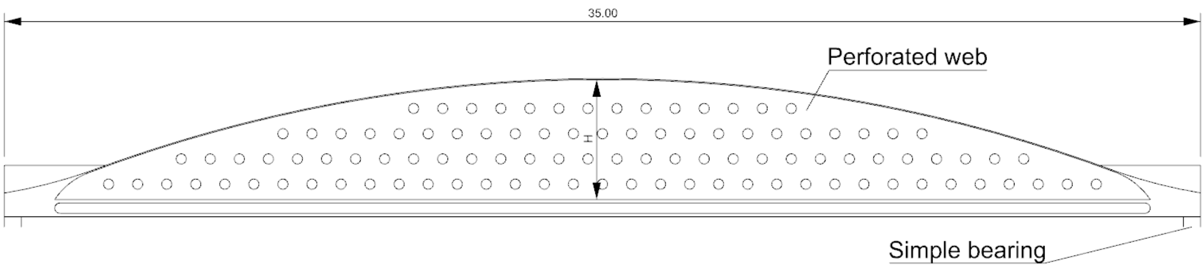

Figure 5: Lateral beam – external side view

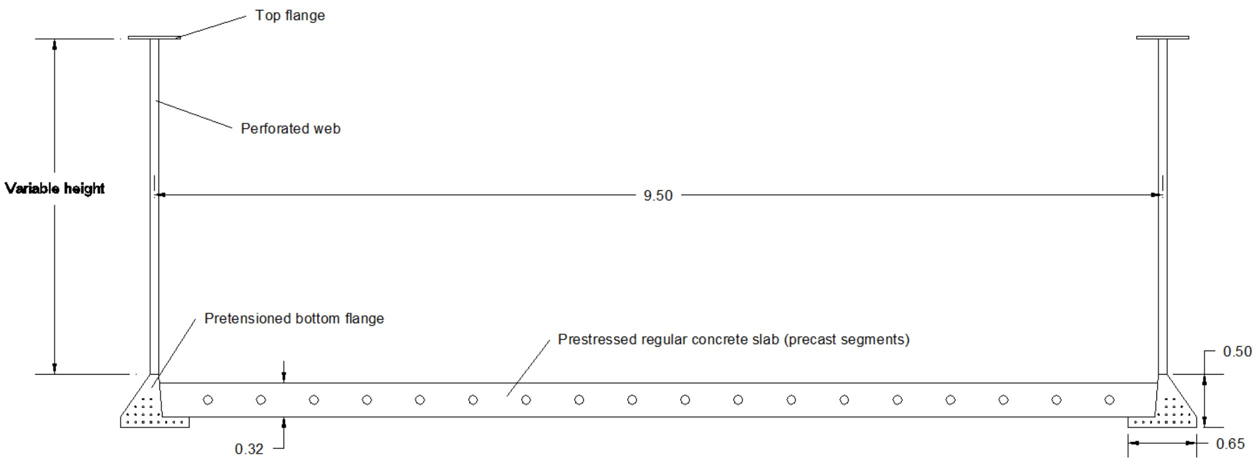

Figure 6: Deck cross-section

The central pier concept consists in a single central column in ordinary concrete, of variable height, with four inclined “branches” made of UHPC, of constant height. These branches bear a short clamped concrete deck, and support the 35m long isostatic decks through simple bearings located at their ends.

The lateral pier concept is also a mix between ordinary concrete and UHPC. Top branches are linked with a prestressed concrete tie rod and bear the short and the main deck through simple bearings. Studies have been made also to integrate the tie-rod in the short deck and to hollow out the UHPC column part.

Structural analysis of standard span and piers has been done using finite elements software. The lateral beams and the slab have been modelled with plate elements.

Classical static analysis has been performed, under dead loads, prestressing, live loads, wind loads. The construction phases have been taken into account, including shrinkage and creep, with special laws for the UHPC. The lateral buckling of the slender lateral beams has been carefully checked with geometrical second order effects and concrete cracking.

A dynamic analysis under moving metro loads has been performed in order to check the vertical acceleration of the track and to compute the real dynamic impact coefficient.

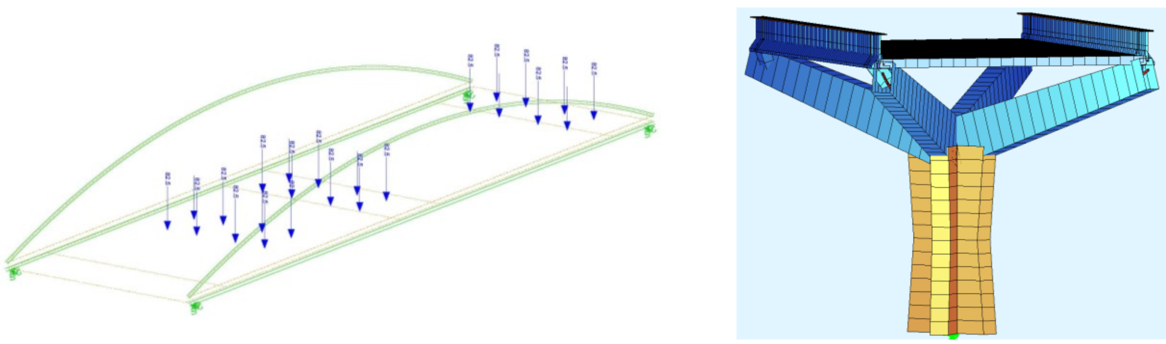

Figure 7: Standard span and central pier models previews

2.4 Construction methods

Construction methods have been studied in order to reduce construction time.

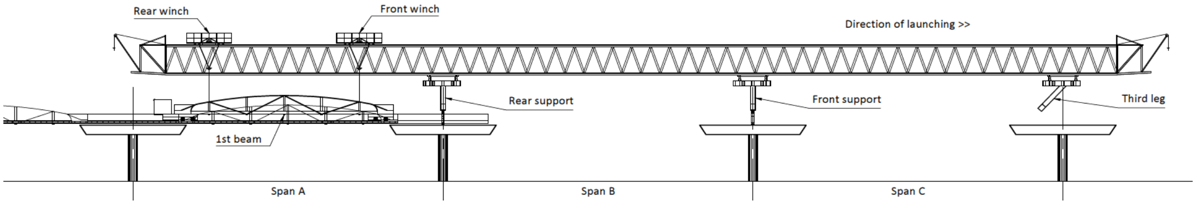

Figure 8: One phase from the construction sequence

Piers and their short deck are the first elements to be built. Depending on the type of the pier, UHPC elements are precast, ordinary concrete vertical elements are cast-in-place, and ordinary concrete inclined elements are precast. Then precast lateral beams and precast slab elements are brought on site on the already built deck. For the lateral beams, an integrated wheels system is designed to prevent them from rotating transversally. A launching gantry is put on top of the piers, and is used to move and place the two lateral beams at their final position. It is used also to place the precast slabs. The lateral beams are stabilized transversally while installing and prestressing the precast slabs, and pouring UHPC longitudinal closures between the lateral beams and the precast slabs. When a whole span is built, the launching gantry is moved forward to build the next span. The estimated construction cycle is 3 days per span.

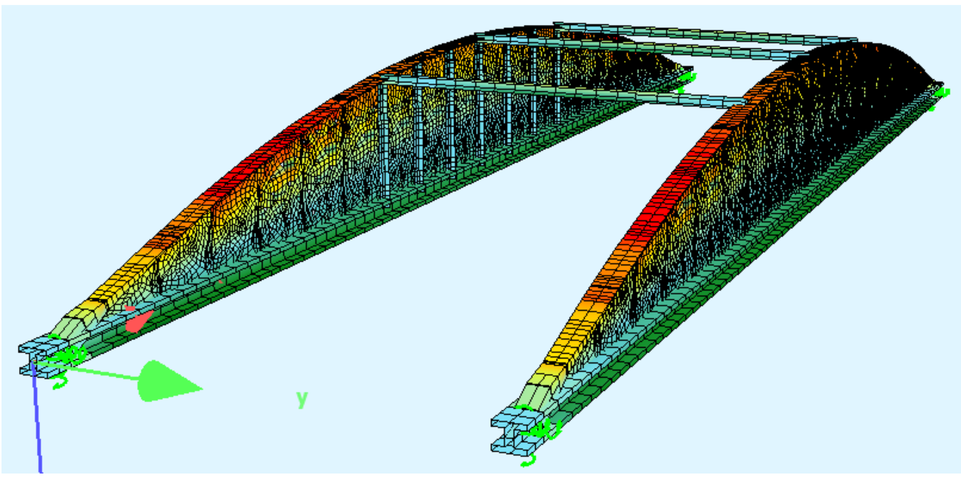

Figure 9: View of temporary phase with lateral beams stabilization

2.5 Sample elements

Two samples elements of the UHPC lateral beam have been molded by Lafarge Holcim in its research center. In order to determine K coefficient values (according to UHPC standard NF P18-710 [2]) in the different parts of the sample, some test tubes have been collected in the web in different directions.

Figure 10: Sample element

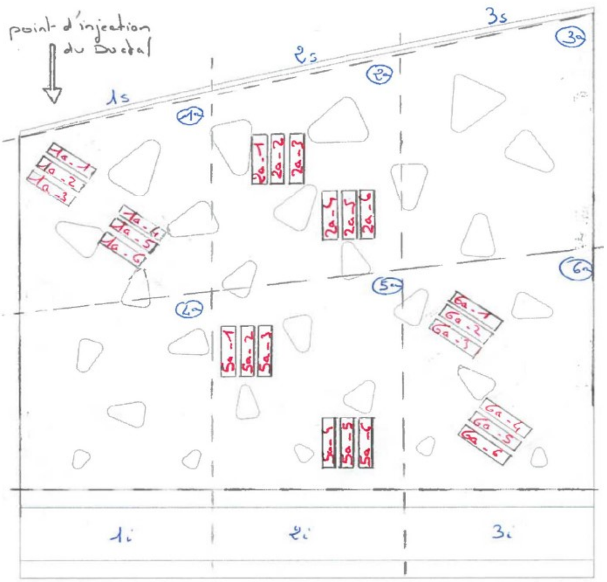

Figure 11: Test tubes localisation in sample element

3. ADVANTAGES OF THE NEW VIADUCT

The reduced number of piers compared to a traditional viaduct is a huge advantage because it means less interference with the existing utilities, less works for diversion of utilities, and so, less risks finding unknown utilities which could delay the construction schedule. The reduction of the number of piers allows also a faster construction, and a better integration in the urban environment. The longer spans allow more possibilities for the crossing of large crossroads. The smaller weight allows a reduction of the foundations by about 15 %.

The estimated construction cost is equivalent to the SYSTRA classical U-shape viaduct, which itself is lower than a box-girder viaduct. The construction schedule is also similar.

The quantity of cement per cubic meter of concrete is larger for UHPC than for ordinary concrete, but the volume of UHPC is smaller than the volume of ordinary concrete of a classical viaduct. So, globally, the volume of cement per linear meter of viaduct is similar for the new viaduct and for a classical viaduct. So, the environmental impacts due to the construction materials, in terms of greenhouse gas emission and energy consumption, are similar.

But UHPC has a much higher durability than ordinary concrete, due to its very high compactness (low porosity to water, low oxygen permeability, low chloride diffusion coefficient). So it needs less maintenance, and has a potentially longer life time. So, globally the environmental impacts of the UHPC viaduct are smaller than for the classical viaducts.

4. CONCLUSION

The new proposed metro viaduct uses any type of UHPC for its longitudinal lateral beams, for closure pours, and for some parts of the piers. It allows 29 % longer spans than classical U shape viaduct, and saves foundations compared to classical viaducts, due to its reduced weight.

It has an enhanced architectural aspect compared to the classical metro viaducts. It creates minimal disturbance during construction, and has smaller environmental impacts than classical metro viaducts, for a similar cost.

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