REVIEW ON FIRST STRUCTURAL APPLICATIONS OF UHPC IN COLOMBIA

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Abstract:

Although ultra-high performance concrete (UHPC) is a relatively new material in Colombia, commercially available since approximately 2016, several interesting structural applications have been developed. Among them, two pedestrian bridges, the first is at the EAFIT University in the city of Medellín (2017) and the second at the National University in the city of Manizales (2018), building slab reinforcement for special equipment assembly (2017) and sections of ultra-thin pavement overlays (2017 and 2018). This paper gives an account of these applications, their designs, material and construction processes.

Keywords: UHPC, Pedestrian Bridges, Precast segments/girders, slab reinforcement, Overlay, Pavements

1. Introduction

The ultra-high-performance concrete is a promising material and its applications around the world have been growing remarkably during the past decade due to its mechanical and durability advantages (Graybeal, B.A., 2017). In Colombia, this kind of material was developed recently and was commercially available in 2016. Since then, two pedestrian bridges, a structural reinforcement slab, and a series of pavement overlays sections have been built.

The Eafit university pedestrian bridge joins the principal campus with the language center that is located across of the second most important avenue in Medellín, Las Vegas avenue. The bridge total length is 110 m and has 4 spans, the main span is 43 m long. The architectural concept is a Katana, a legendary Japanese sword. Therefore, it tries to conserve simple design lines, sutile curves and lightweight criteria's. The structural design was intended to decrease construction time using some ABC aspects, considering 29 precast UHPC girders/segments, each one with a 10 ton weight, and post-tensioned method with 24 cables.

The National University (UNAL) pedestrian bridge is part of a new building at its campus in Manizales, Caldas. The bridge total length is 30 m and two 15 m spans, it was built with 14 precast UHPC segments/girder, each one with a 3 ton weight, and post-tensional method with 3 cables. The architectural design considers animal bone structures, specifically a fish skeleton. This design allows both, the main beam and the deck, to be poured in one single segment.

Unlike the two bridges, the building slab reinforcement and the ultra-thin overlays are cast-in-place applications. The first one was a solution to improve the load capacity of the 17th floor slab at the Medellín clinic to allow the installation of two electromagnetic tomograhs. This reinforcement consists in three post-tensioned slabs, two solid and one unidirectional. The ultra-thin overlays were pavement rehabilitations areas, initially considered as a testing pilot. The greatest challenges in these applications were the production process and the logistics for the UHPC placement.

This paper shows the main applications built in Colombia, its architectural and structural concepts and their construction processes using Ultra High-Performance Concrete.

2. Architectural and Structural design

All applications listed were thought to fulfill sustainability design concepts (Abbas, S., M. L. Nehdi and M. A. Saleem, 2016). Especially because they use a low cement content UHPC mixture design, with only 700 kg/m3-1175 lb/yd3. The ultra-high strength is achieved thanks to compactness and particle packing concepts (De Larrard, F., and T. Sedran, 1994, De Larrard, F., and Thierry S., 2002).

The most obvious design aspects in the EAFIT bridge are the thickness of the box girder walls (12 cm) and the high aesthetic shape and surface finish. Basically, the whole structure recalls the singular shape of the samurai's sword. Its main structural element is an asymmetrical girder box, Figure 1. Finite element analysis, FEA, and Building Information Modelling, BIM, were used at the structural design stage. Initial simulations acknowledge the material behavior curves, its final strength is given by f´c=150MPa and ft=5MPa. Passive reinforcement was disposed for controlling torsion and bending stresses. All 29 segments were joined by a plug-socket system, 23 perimetral post-tensioned cables and 1cable with preferential layout conform the final structure, figure 2. Foundations were poured in place using conventional concrete, f´c=50MPa, isometrical view of the footbridge is showed in Figure 3.

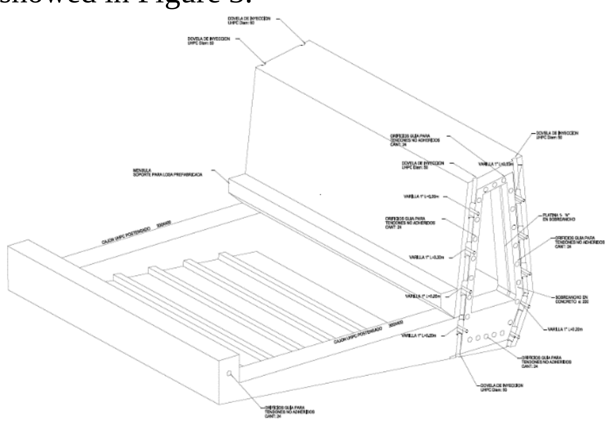

Figure 1. Isometric view of EAFIT girder box.

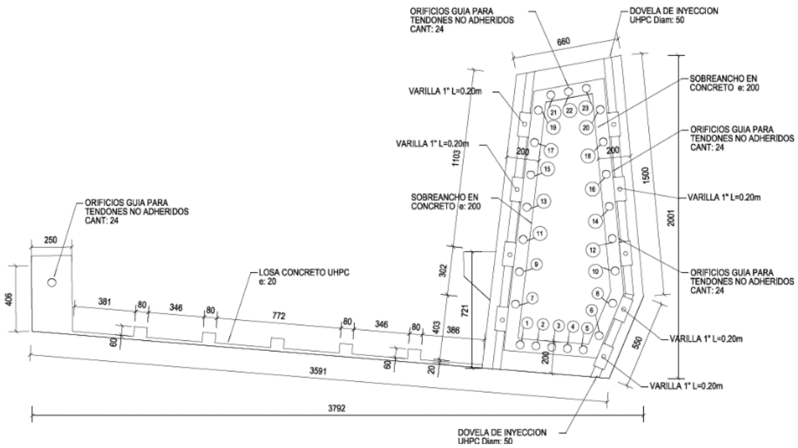

Figure 2. Cross section of the EAFIT girder box.

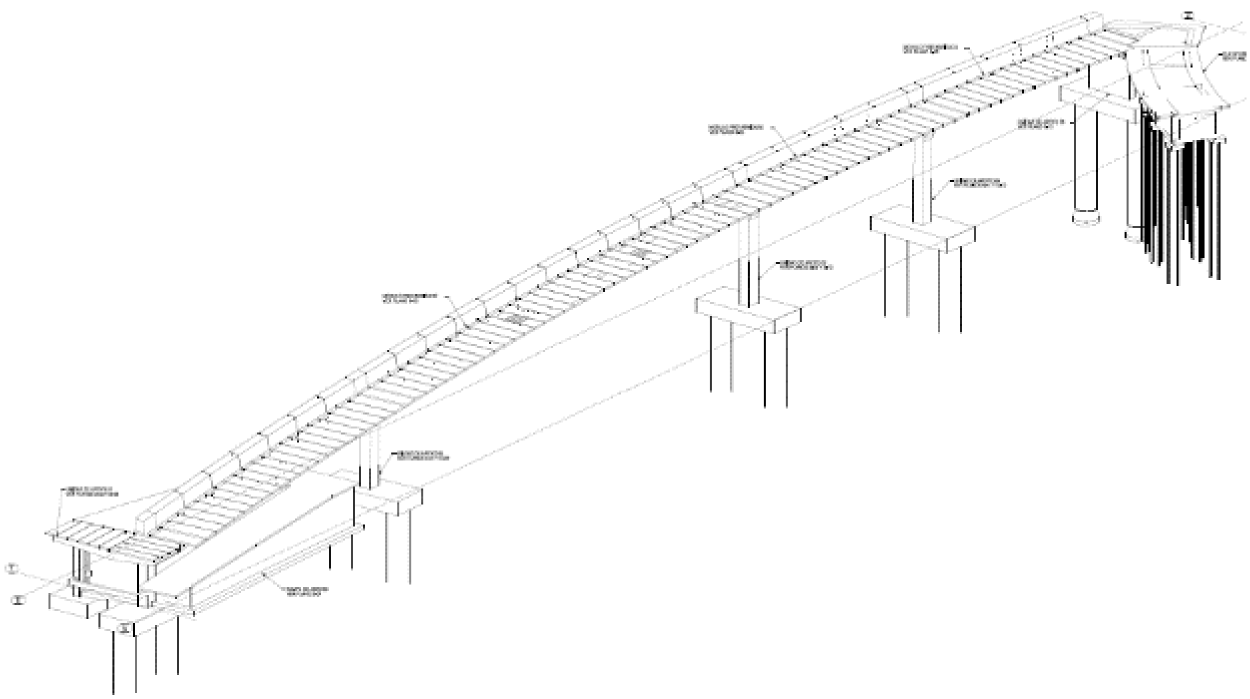

Figure 3.Isometrical view of EAFIT footbridge.

The design of the UNAL footbridge has a main beam also with a plug-socket joint system, 3 post-tensioned cables were used to get the 14 segments together. The deck and main structure were casted in one single piece, Figure 4, and foundations were casted using regular f'c=50MPa concrete. Three columns were disposed to support the main structure Figure 5.

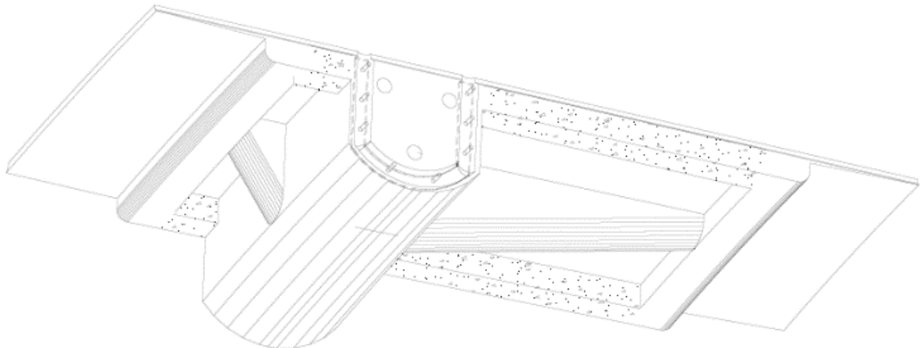

Figure 4. Isometric segment view of UNAL footbridge.

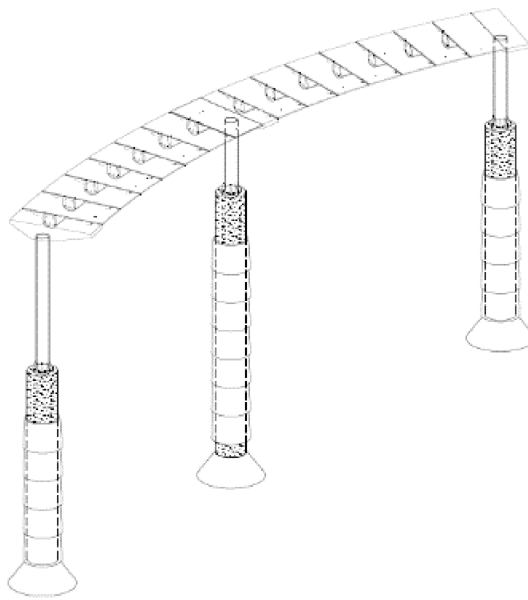

Figure 5. Isometric view of UNAL footbridge.

Architectural and structural designs in both, EAFIT and UNAL bridges, considered three main objectives; rapid construction, causing minimal disruption at the universities and building long-lasting facilities (FHWA, Accelerated bridge construction manual, 2011). In the case of EAFIT, the most critical aspect was minimal disruption as the bridge crosses a main avenue in Medellín that must be in service 24/7. On the other hand, UNAL bridge has several considerations around the prefabricated segments to allow rapid installation. Both projects have horizontal and vertical curved geometries and used no bonded post-tensioned systems.

The other two applications used cast-in-place UHPC. The Medellín clinic acquired four electromagnetic tomographs, each one weights approximately 5 ton and the current concrete slab wasn't designed with that bearing capacity, in order to reinforce this area a UHPC post-tensioned unidirectional slab was specified. Figure 6 shows the reinforcement of unidirectional slabs (a), the actual UHPC slab (b), and the final result with one of the tomographs installed. The slab reinforcement was designed in UHPC because the material fits the operational requirements of the medical equipment that was being installed, the use of metallic plates was discarded because it produces interference and wrong lectures in tomographs.

a.) Prepared cast on site b.) Post-stress process c.) Installed tomograph

Figure 6. Reinforcement process carried out at Medellin clinic.

UHPC ultra-thin overlays is an application being studied for pavements rehabilitation. As part of the research project four test sections were built, they are shown on Figure 7; Guayabal concrete plant (a), ICC precaster plant (b), 12 de Octubre neighborhood (c) and Bogotá-Facatativa national highway (d). It should be noted that overlay application made at the 12 de Octubre neigborhood has a media slope of 7 %. The test segments vary between 2-5 cm of thickness depending of the design traffic requirements.

a.). UHPC overlay, Argos Concret plant.

b.) UHPC Pavement ICC precaster plant.

c.) UHPC Pavement 12 de Octubre neighborhood.

d.) UHPC overlay Bogotá-Facatativa.

Figure 7.Overlays and pavement applications using UHPC in Colombia.

It is important to highlight that Colombia, mainly the city of Medellín, is innovating in the use of UHPC, understanding that its mechanical and durability properties bring advantages in applications around infrastructure, buildings and roads.

3. Precast and cast-in-place applications

Applications treated in this paper used two methods of fabrication: precast and cast-in-site. The method election was based on each project conditions. The EAFIT footbridge main challenge was not interrupting the normal traffic operation in Las Vegas avenue, which the bridge crosses. To achieve this requirement, the project was designed to be formed by 29 precast segments. While the precaster finished making the 20th segment at the plant, the on-site team began the scaffolding process, plywood decks and leveling jacks were used to support the box girder elements. Figure 8 and Figure 9 show the details described before.

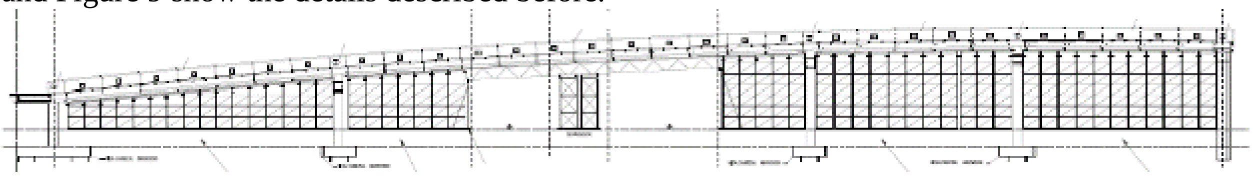

Figure 8. EAFIT footbridge scaffolding design.

Figure 9. EAFIT footbridge plywood decks and scaffolding process.

The UNAL footbridge is a good example on how a precast structure can help to industrialize a construction process, minimizing costs and time. Each segment just weights 3 tons, this makes them easy to transport between cities (Medellín to Manizales) and reduces the equipment and time required for their assembly.
Figure **10** shows the process.

a.) Scaffolding process global view

b.) Scaffolding process lateral view

Figure 10. UNAL footbridge scaffolding process.

Unlike the two bridges reported before, the slab reinforcement and the pavement overlay applications were approached with a cast-in-place strategy. The UHPC for the slab was mixed on site with two planetary mixers and kept in 10 ordinary mixers to pour 1,3 m3 at a time, readymix was not possible because the project was in a 17th floor and pumping was not permitted in the building, Figure 11.a shows the project site. The UHPC for the overlays was produced in a readymix plant and transported in a mixer to the site.

a) Reinforcement slab casted on site.

b) UHPC thin overlay

Figure 11. Mixing and pouring on site projects.

4. Construction process

Defining the casting process is very relevant when using UHPC because it determines the fiber distribution and orientation. The segments of the EAFIT bridge were casted upside down and the elements for the UNAL bridge were casted in the right position as shown in Figure 12.a and 12.b. In both cases the K factor was calculated to ensure the tensile strength (Pastor, F.; Hajar Z. and Dal Palu P., 2017 & López, J.A.; Serna, P; Camacho, E.; Navarro, J., 2013).

(a) Casting of EAFIT´s bridge segment

(b) Casting of UNAL´s bridge segment

Figure 12. Casting process.

Once the foundations were built, the scaffolds and leveling jacks were installed so the UHPC bridge segments could be localized in their final position. The next step was casting the joints between the segments with UHPC mixed on site. The segment directly above de pillars were casted with regular 50 MPa concrete, this was intended to absorb any misposition or tolerance of the placing process.

Figure 13. Preparing segment above the pillar for casting.

Once the UHPC segments were in position and the pillar segments were casted, the cables were spun to start the post-tensioning process. Hydraulic jacks were used to apply 16 and 19 tons of tension to each cable. Finally, the scaffolds were removed and the bridge was load tested using water tanks to achieve 450 kg/m2.

As mentioned before, the reinforcement slab project at Medellin clinic, supposed several challenges in the production process of UHPC. Formwork was made with wood and polymeric expanding foam was used to seal all possible leaks. After 3 days, the post-tensioning process was carried out. Finally, polyurethane coating was used as final surface.

The greatest challenge in overlay and pavement applications was placing the UHPC using conventional equipment. Truss screeds and compacting roller were used to spread the material. The final step was giving the macrotexture to the surface using a cutter with circular steel blade. Figure 14 shows the placing procedure.

Figure 14. Overlay placing.

The experiences described before are proof that design and construction requirements for UHPC projects can be met with the technology and equipment available in Colombia. The experience and knowledge acquired is now accessible for future projects. Table 1 summarize the projects developed and their main considerations.

Table 1.Projects developed in Colombia.

Project	**Volume (m^3)**	**Description**
EAFIT Footbridge	140	Precast segments, foundation and abutments cast on site
UNAL Footbridge	16	Precast segments, foundations and encased columns cast on site

Slab reinforcement, Medellin clinic	12	Cast-in-place, post-tensioned
Overlays/pavements	25	Cast-in-place, thickness 2, 3, 4 cm

5. Discussion/UHPC considerations

The material used in all applications had the same mix design, with a 200 to 260 mm diameter in the modified flow table test, and a compressive strength of 150MPa (22,000 psi). The tensile and bending strengths where 5 MPa and 18 MPa each, with an elastic modulus of 40 GPa (Lopez, J.A., Serna, P., Navarro-Gregori, J., Camacho, E, 2015). Only in the 12 de Octubre neighborhood pavement, a modified mix was applied seeking a thixotropic behavior for placing it in a 7 % slope terrain.

Experiences around the world have shown that UHPC is a versatile material that can be used in the construction of footbridges, deck panels, bridge joints, special precast elements, structural rehabilitation, marine platforms, precast walls, urban furniture, pavement and industrial floors, and other architectural applications. (Kalny, Kvasnicka, & Komanec, 2016;).

6. Conclusions

UHPC properties allow developing different applications that are cost effective with low maintenance requirements. Generally, UHPC elements are lightweight and enhance aesthetical designs, making construction processes faster and permitting rapid service times.

The diversity of applications shown in this paper indicate the versatility of the material and open the doors for new ways of using UHPC. Infrastructure applications are an attractive potential market in Colombia.

7. References

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