Development of Short Span and Medium Span Footbridge Systems using UHPFRC in Czech Republic

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Abstract

In the first part, this paper presents the experimental development of an innovative medium span footbridge system made of UHPFRC. The load bearing structure is designed as a U-shaped beam and consists of 2 main precast prestressed beams, which are connected with precast bridge deck segments. This system is different from the commonly used segmental footbridge structures because a longitudinal prefabrication is used. The development of this system was initiated for several reasons – no need to assemble a falsework and a formwork in situ, no need for heavy cranes, the main load-bearing structure does not contain transverse joints, a possibility to prestress the structure in advance in factory. In the other part, the article discusses another system of short-span footbridges made of UHPFRC designed and used in the Czech Republic. These footbridges are in the shape of a slab with ribs, and they are manufactured and placed on the substructure as a whole, so they represent an advantage especially in terms of construction speed and low maintenance requirements.

Keywords: UHPFRC, footbridge, prefabrication, prestressing,

1. Introduction

Priority requirements for rapid construction are currently increasing. There are requirements to build quickly on site with minimal traffic restrictions during construction and minimal maintenance requirements during operation while maintaining a long service life, which is associated with sustainability and durability. The acceleration of construction process on site is generally made possible by using of prefabrication. By using new high-quality composite materials with a cement matrix (UHPFRC or UHPC) with optimized mechanical properties, these requirements can be fulfilled to the maximum. By using UHPFRC in conjunction with preload and optimized cross-sectional shape, it is possible to achieve a reduction in the consumption of primary raw materials while simultaneously increasing the static reliability and durability of the structure. The advantages of using UHPFRC for footbridges can be seen in particular in higher resistance to aggressive environments and thawing cycles, in lower overall maintenance costs. Another advantage of the application of high-quality concrete is, thanks to its high strength and the application of scattered reinforcement in the form of steel fibers, the possibility of designing subtle cross-sections without the need to use structural concrete reinforcement, which results in a reduction of the own weight of the supporting structure corresponding to lower requirements for the foundation of the structure and lower requirements and costs for transportation of parts. In addition, high-quality concrete shows a high-quality walking and visual surface without the need to apply additional insulation.

In the Czech Republic, a unique short span footbridge system (SSFS) was developed to meet the aforementioned requirements. Based on positive experiences with this system, another system for a span of around 30 m (98.43 ft.) is now under development.

2. Short Span Footbridge System

As a part of the grant project EPSILON supported by the Technology Agency of the Czech Republic and in cooperation with the company KŠ PREFA, Ltd., Pontex ltd. and with the Klokner Institute of the Czech Technical University the basic series of prestressed bridge girders from UHPFRC was developed. They are prepared for footbridges and cyclists bridges up to 20 meters (65.62 ft.) long the research was completed and finished as the so-called short span footbridge system - SSFS. The main goal of the research was the most economical use of UHPFRC, systematization of the production process and the possibility of universal application of components for footbridges of different spans, but under the conditions of production, transport and assembly of single-span superstructure using one prefabricated (precast) element.

2.1. System Description

Prefabricated UHPFRC footbridges of SSFS type are in the shape of a slab with ribs or rather of longitudinal load-bearing beams connected by a slab. An example of the cross-section of the structure and its variants are shown in Figure 1. The thickness of the slab is only 60 mm (2.36 in.) without standard steel reinforcement. The slab is supported by beams at constant distances, but the height of the beams themselves and their reinforcement made of pre-tensioned prestressing reinforcement can be individually designed and assessed for every intended use, or it is possible to use catalogue systematized dimensions and prestressing methods.

Newly developed production processes, the system of batching of fresh UHPFRC material and casting methods together with a specially designed moulding technique allow such a small thickness of the slab to be produced reliably and in quality, the absence of concrete reinforcement means that the design does not have to consider coverage requirements. It has been tested by many punching shear tests, all at once with well-established practice, such a thin "bridge deck" slab ensures a safe, durable and reliable structure, but in addition with a very low self-weight and overall height. The pre-tensioned prestressing reinforcement is fitted and installed under strict quality control and at the same time under favorable conditions in the interior of the precast production facility. The durability of the entire structure is thus ensured very reliably, in contrast to prestressed structures post-tensioned and injected on site. Because the entire prefabricated element is casted in one step, there are no working joints in span.

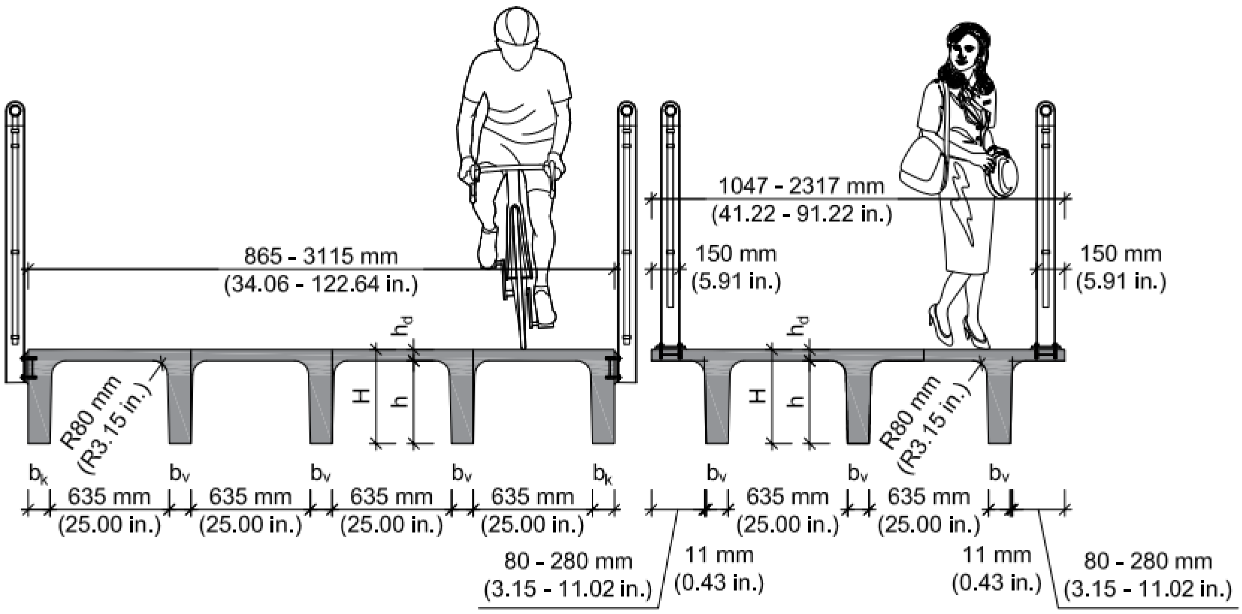

Figure 1 Typical cross-section of the short span footbridge system and the possible variants and basic dimensions

2.1.1. Handling Equipment and Railing Anchoring

Because the system of small span footbridges aims to make the most economical use of UHPFRC material parameters, the effort is to carry out the construction without waterproofing or surfacing, so it was necessary to design such handling equipment that would not be in the walkable area of footbridges. At the same time, the boundary conditions for the handling elements are geometrically such that their load-bearing capacity cannot be selected from the table values of commercial manufacturers of handling devices. KŠ PREFA therefore designed and tested in the Klokner Institute an innovative location and modified design of standard handling equipment in the parts of footbridges from UHPFRC.

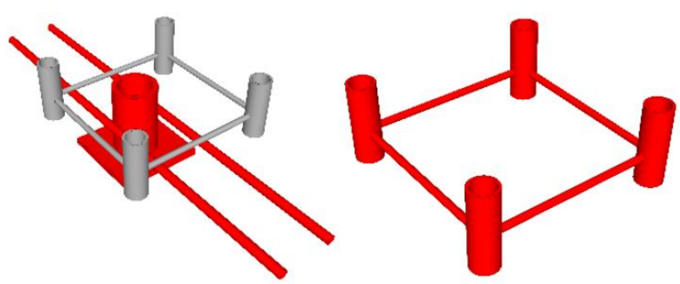

Figure 2 Hybrid anchoring element: Left for handling with bridge superstructure (highlighted in red), right for anchoring of railing

These hybrid anchoring elements allow both the handling of the prefabricated element in the factory and the installation on site, they remain in the structure throughout its life and thus allow the structure to be relocated, lifted for bearing replacement etc. The hybrid anchoring elements also serve for connecting the railing, they are at the same time hidden under the base or anchor plate of the railing posts, so that they do not interfere with the walking surface neither aesthetically nor functionally.

2.2. Real Applications

Based on the research and development described above, the first few real applications of the UHPFRC small-span footbridge system were implemented in Czech Republic. An example of these structures are two footbridges in Čelákovice situated in the city center in the city park, see Figures 3 and 4. The bridges were designed with spans of 10.7 m and 7.9 m (35.10 ft. and 25.92 ft.), with a width of 3 m (9.84 ft.) and a cross-sectional height of 300 mm and 250 mm (11.81 in. and 9.84 in.). Because the footbridges are not secured against unwanted entry of vehicles, their structure was designed for the crossing of a 12-ton vehicle. Other realized structures are described in publication by Marek, there are given also more details.

Figure 3 View of the completed footbridge Čelákovice

Figure 4 Bottom view of the finished structure of footbridge Čelákovice

3. Medium Span Footbridge System

Based on positive experiences with SSFS system, the development of medium span footbridge system (MSFS) for spans of around 30 m (98.43 ft.) is now running in cooperation KŠ PREFA with Klokner Institute. The main idea was to preserve as many advantages as possible of the previous SSFS system - minimal traffic restrictions under the bridge, minimal structural height, high speed of construction and low maintenance requirements. For the application of UHPFRC material, the U-shaped cross-section proved to be suitable for footbridges.

The U-shaped bridges using parapet beams are preferably used mainly in areas with a low available construction height. The main beams are located on the sides of the bridge cross section and the construction height is therefore affected only by the bridge deck thickness. The greatest potential of the U-shaped bridges is especially in the area of the bridges for pedestrians and cyclists, which are not as wide as road bridges, and the bridge deck can therefore be relatively subtle. The main parapet beams can also be advantageously used as railings.

Several different U-shaped footbridges made of UHPFRC have already been built in Europe. The existing U-shaped bridges made of UHPFRC were always produced of precast prestressed segments connected with straight post-tensioned prestressed cables in the upper and lower flanges of the cross-section. The first UHPFRC U-shaped bridges were probably designed in France, see Resplendino. Currently the use of material UHPFRC for bridge structures is most widespread in Switzerland. The interesting examples of U-shaped footbridges made of UHPFRC see e.g. Géhin, Bertola.

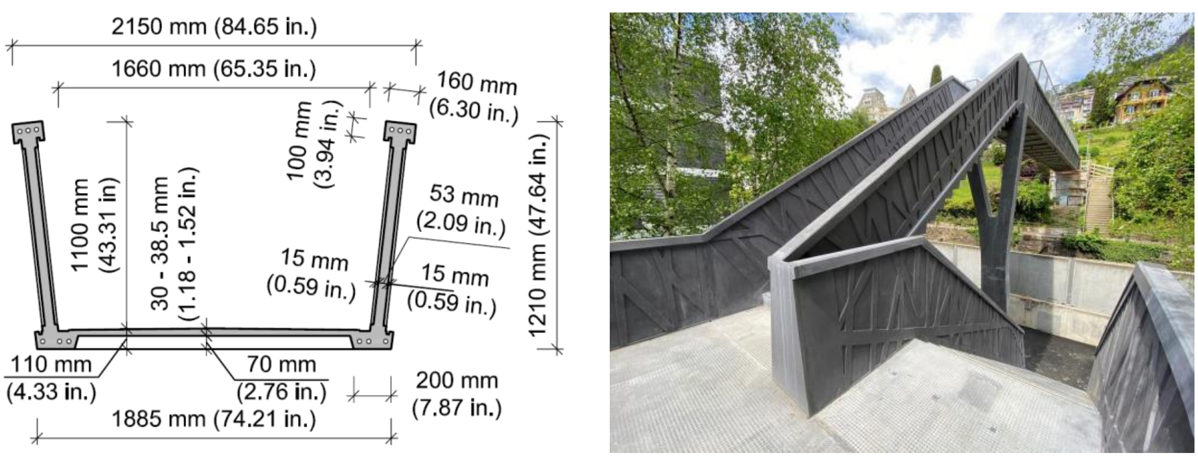

Figure 5 The Chaumény footbridge - Example of very subtle post-tensioned U-shaped segmental bridge with span ca. 22.5 m (73.82 ft.) from Switzerland, figure is taken from Géhin

2.1. System Description

The main idea of the structural design is different from the solutions using transverse prefabrication used so far. Our target is to apply a longitudinal prefabrication of main structure from UHPFRC, that means a continuous load-bearing structure without transverse joints for the whole span (full length of the bridge). There is no need to assemble the falsework and the formwork in situ, and it is not necessary to use such large cranes as if the structure were installed as a whole after assembly outside the final position. The design of the bridge system assumed that the bridge will be designed as a footbridge for pedestrians and cyclists and the crossing of rescue or maintenance vehicles up to 12 t and that the clear width between railings will be 3.00 m (9.84 ft.) Expected span range is approx. 20 - 35 m (65 ft. - 115 ft.).

The footbridge consists of two separate precast prestressed beams made of UHPFRC connected and stiffened by bridge deck. The bridge deck consists of precast UHPFRC elements with transversal ribs. The precast bridge deck is installed between the beams, see Figures 6 and 7. At the ends of the footbridge, the cast in-situ cross members are designed to stiffen the structure.

The shaping of the cross-section of the beams was mainly influenced by structural, static, but also architectural requirements. From a static point of view, it was necessary to design prestressing strands or cables and concrete reinforcement for the connection to the bridge deck and the assembly condition. The design requirements meant complying with the requirements for concrete cover according to the currently valid regulations (see Coufal) for designing structures from UHPFRC in the Czech Republic, which are relatively strict compared to, for example, common practice in Switzerland. The minimum cover of the cable duct must be at least 50 mm (ca 2 in.) in the Czech Republic. As can be deduced from cross-section in Figure 5, the cable duct has a cover of approx. only 25 mm (ca. 1 in.) in the case of the Chaumény footbridge.

According to the Czech standard, the required height of the handrail for footbridges with cyclist traffic is 1300 mm (51.18 in.), if a handrail with a width of 500 mm (19.69 in.) is used, a handrail with a height of 1100 mm (43.31 in.) can be used. Especially from an architectural point of view, a lower height is significantly better in the case of massive railings, and therefore a width of 500 mm (19.69 in.) of the upper flange of the main beams was designed. From an aesthetic point of view, the option of a smooth web without ribs was preferred for the main beams.

The material and construction solution of the footbridge allows for a directly walkable surface with recognized monolithic joints. Drainage can be ensured by a one-sided longitudinal slope of the footbridge to the bridge end, or by transverse joints between individual parts of the bridge deck repeating in a regular grid.

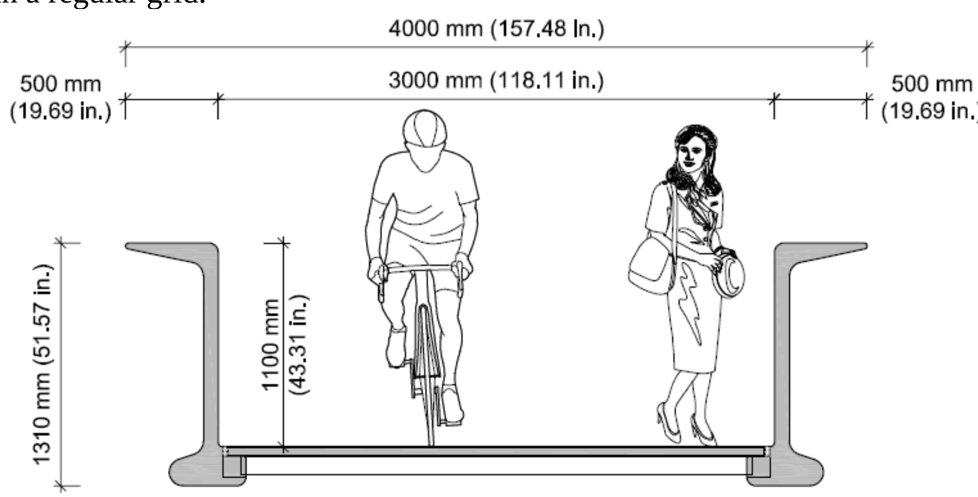

Figure 6 Schema of cross-section of an innovative footbridge structure MSFS

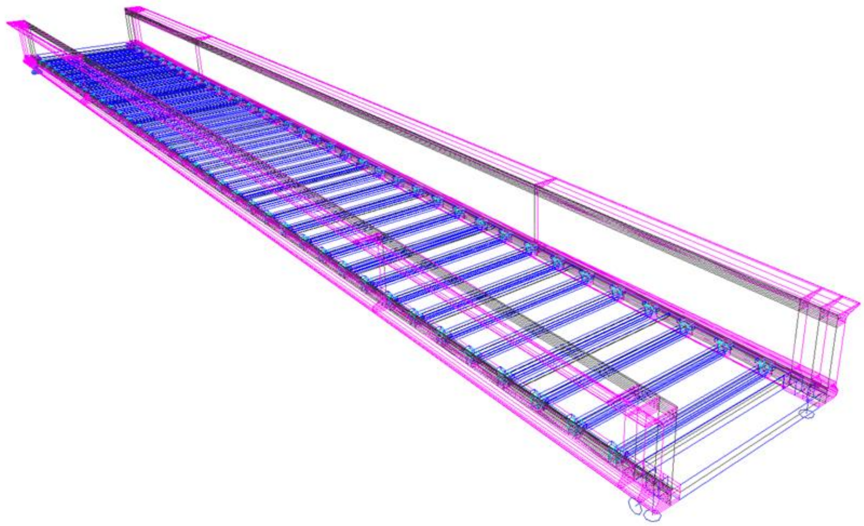

Figure 7 3D view of computational model in program SCIA Engineer

The expected construction method consists in the assembly of two separate main beams with I-shaped cross section on the supports and the step by step install of precast bridge deck panels, which are connected by screws with main beams.

In terms of the static design of the structure, the biggest challenge is to ensure the stability of the long slender precast prestressed beams during the construction phases, where the individual main beams act independently (during transport and assembly of the bridge). In order to ensure the stability of the beams during the assembly, it was therefore not possible to use pre-tensioned strands it was necessary to design post-tensioned tendons using gradual tensioning. After connecting of the beams with the bridge deck in “half-frame” in the final construction stage, significant stability improvements of footbridge structure are reached. The rigidity of the footbridge in the transverse direction is further ensured by cast in-situ UHPFRC connections at the bridge deck ribs and bottom flange of beams. The connections between the beams and the bridge deck has to be designed to be sufficiently rigid in bending, to have sufficient load-bearing capacity, and to be easily realized on the construction site at the same time. An experimental verification of mechanical characteristics of these joints is currently in preparation.

4. Conclusions

In the first part, the article summarized the developed system of prestressed short span bridges (SSFS) made of ultra-high-performance concrete, including its first successful real applications. The system of prestressed UHPFRC elements is especially suitable for footbridges or bridges, where rapid construction and long-term service life is required. Using of the SSFS system is beneficial in places with difficult access and if necessary to maintain traffic under the bridge during construction. The structural system SSFS makes it possible to design and build load-bearing structures up to 20 m (65.62 ft.) in length and allows for large variability of width arrangements.

In the second part, the current experimental development of an innovative technology of U-shaped footbridges made of UHPFRC using longitudinal prefabrication was introduced. This year, the plan is to implement a prototype footbridge with a span of 25 m (82.02 ft.).

5. Acknowledgements

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