

CONSTRUCTION OF THE U-SHAPED TRUSS FOOTBRIDGE OVER THE OVEJAS RAVINE IN ALICANTE

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Abstract

Since UHPFRC is a very expensive material, it is necessary to optimize structural system designs to consider UHPFRC as an alternative competitive material in structural applications. This process leads to UHPFRC lightweight structures that minimize the concrete needs. These new solutions are more similar to steel than concrete, and offer an improvement in durability and aesthetics properties as compared to steel structures.

The U-shaped Truss Footbridge over the *Ovejas* ravine in Alicante, devised only in UHPFRC with 45-metre span, has replaced a previous design in steel due to many factors such as its low cost; its expected high durability inside an aggressive environment close to the sea; and its aesthetics enhancement. This footbridge is probably going to be the first truss pedestrian bridge in which all the structural elements are made only of UHPFRC, as far as we know.

In this paper, the construction stages, some issues found during the mixing process in a precasting factory, and the footbridge current state of the construction process are presented.

Résumé

Le matériau BFUP étant relativement coûteux, il est nécessaire d'optimiser la conception des structures pour en faire un matériau alternatif compétitif. Cette optimisation conduit à des structures légères qui minimisent la quantité de béton utilisée. Les nouvelles solutions qui en découlent se rapprochent dans leur conception des structures métalliques tout en offrant des améliorations en termes de durabilité et d'esthétique.

Le passerelle en treillis à poutres latérales au-dessus de la ravine *Ovejas* à Alicante, d'une portée de 45m est une variante d'une solution métallique, variante retenue en raison de plusieurs facteurs dont son prix moins élevé, sa meilleure durabilité dans un environnement de bord de mer agressif, et une esthétique améliorée. Cette passerelle est probablement l'une des premières passerelles en treillis entièrement conçu en BFUP dans le monde.

Dans cet article, nous détaillerons les étapes de construction, les problèmes et solutions trouvés lors de la fabrication du BFUP dans une usine de préfabrication, ainsi que l'état actuel de la construction en cours.

1. INTRODUCTION

Ultra High Performance Fibre Reinforced Concrete (UHPFRC) has been used in several applications due to its performance properties. It has been reported that UHPFRC has an excellent durability even inside an aggressive environment, which leads to maintenance costs savings and to a service life improvement [1]. In the civil engineering field, the biggest benefit when UHPFRC is used is found out in precast-prestressed applications. This is due to high early compressive strength of the material and the possibility to make a heat treatment which improves its long-term properties. Furthermore, the high quality level required by UHPFRC is easier to obtain in precast factories [2].

However, there are some limiting factors to the widespread use of UHPFRC. The first issue is its high cost, 10 times higher than a conventional concrete in which the steel fibres represent, approximately, the 70% of the total prize, if a common UHPFRC with a 2% in volume of steel fibres is considered. The solution lies in the development of new structural systems which make full use of every single particle of UHPFRC so as to minimize the total volume required. Thus, it is necessary to readapt designs to more efficient cross-sectional shapes, and this is only possible by a suitable understanding of its mechanical behaviour. Here it lies the second issue to deal with. The lack of suitable design codes for all UHPFRC [3] makes the design process very complicated for engineers.

Despite of all limiting factors found out, UHPFRC is increasingly used in the civil engineering field due to the experience gained over the years and the hard work of researchers. Precast prestressed bridge construction, both road and pedestrian, has become one of the most successful field where the UHPFRC is being used. Examples of the latter are the Sherbrooke 60-m span pedestrian bridge built in Quebec in 1997 with a total dead weight of 4.4 kN/m² [4]; the Sakata Mirai (49.2 m in span) built in 2002 with a total dead weight of 4.6 kN/m² [5]; the Wild Bridge (70 m arch span) finished in 2011 in Austria [6] that has probably becomes in the UHPFRC structure that best takes advantage of the material properties.

2. SCOPE

The present work deals with the construction of the footbridge over the *Ovejas* ravine in Alicante, Spain. A short description of its design is given below. Since the footbridge is 45-metre span it is possible to transport the whole structure from the precasting factory to the final location by means of special transport. However, the whole footbridge is very difficult to cast in one segment without joints because of its complex design. Thus, the construction has been made in five stages whose detailed description is the main objective of this work. This paper also includes some issues about the mixing process and the surface finishes, as well as the prestressing release results, and currently appearance.

3. DESIGN

The UHPFRC footbridge over the *Ovejas* ravine was devised as an alternative to a previous design in steel. It was completely necessary to keep the cost lower than the initial steel solution. Finally, and despite the large amount of initial conditions imposed by the contracting authority, it was possible to design a UHPFRC footbridge subject to the terms specified and economically viable. It consists of a U-shaped cross-section beam (fig. 1) with a 45-metre span and variable depth. The box webs are two modified wave-shaped Warren

beams which lead to an important material volume saving with an aesthetically pleasing appearance (fig. 2). Both lateral trusses are connected at the bottom by an X-shaped truss where a total of 18 prestressing 15.2-mm diameter strands are located [7]. The deck is located right in the middle of the lateral webs and it consists of 3-m width and 3-cm thick slabs from steel fibres supported by transverse and longitudinal ribs. The design leads to an aesthetically pleasing appearance, with a total dead load of 4.8 kN/m² and a total cost of about 950 €/m².

The structural calculations were made according to the SETRA-AFGC recommendations [8]. It was also performed a representative test of footbridge to check those problems that stay out of these recommendations [9].

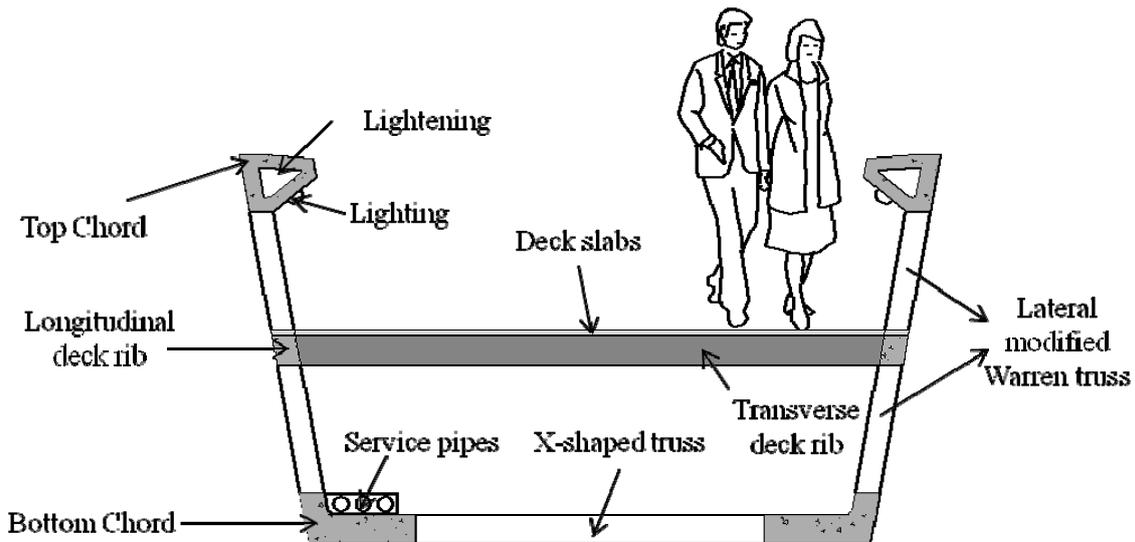


Figure 1: Cross section at mid span and footbridge main elements

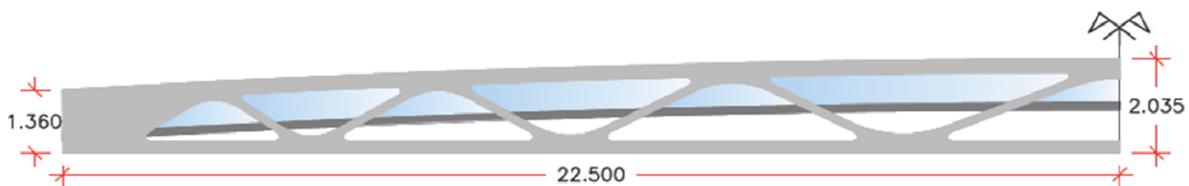


Figure 2: Longitudinal elevation of the footbridge

The footbridge design leaves no details to chance. A truss Warren system where the main elements are working alternatively in compression and tension is very suitable for this concrete and take full advantages of its mechanical properties.

Besides, the wave-shaped Warren beam means that the slope and length of the diagonals are variable (fig. 2). This solution makes sense for the shear load transfer. At mid span, the axial stress is lower than at supports and it is possible to increase the diagonals length. As a result, even though the buckling length is longer, the axial load on the diagonal is lower at mid span. It does make a slender design possible.

Furthermore, despite the top chord is free to buckle on its entire length, the intermediate position of the deck prevent this top chord buckling problem. Top chord is also hollowed to enhance its radius of gyration and to reduce its weight.

4. DOSAGE AND MIXING PROCESS

One of the requirements specified by the contracting authority was that the footbridge had to be made in two colours: greenish grey for the superstructure and light brown for the deck. To that end, it was decided to include pigment in the UHPFRC dosage. The UHPFRC mixture for both greenish grey and light brown colours is shown in table 1.

For both dosages, a characteristic compressive strength of 138 MPa was achieved without curing treatment. Since a light colour is more difficult to obtain in a concrete with such amount of cement and silica fume, the light brown colour was got by replacing cement by quartz flour and by using fluid catalytic cracking catalyst (FC3R)[10], which are both white, as well as red and yellow pigment.

The slump flow test results were 760 mm and 750 mm for greenish grey and light brown, respectively. Its bending behaviour was also characterized in lab by means of 100x100x500 mm prismatic specimens. Its characteristic flexural strength was 25 MPa for both concretes.

Table 1: UHPFRC mixtures for the two types of concrete designed

	Greenish grey	Light brown		Greenish grey	Light brown
	<i>Kg/m³</i>			<i>Kg/m³</i>	
Cement	1000	800	Fibers OL 13/0.16	78.1	78.1
SF	150	-	Fibers RC80/30BP	78.1	78.1
FC3R	-	120	Superplasticizer	11.22	10.56
QF	-	160	Green pigment	23	-
Silica Sand 0.5 mm	300.5	734.4	Yellow pigment	-	21.6
Silica Sand 1.8 mm	700.5	314.7	Red pigment	-	3.24
Total water	201.3	199.8	w/b	0.175	0.185

The quality control for all batches mixed during the manufacturing process was intense. The specimens made for each batch are summarized in table 2. All batches were always lower than 1.5 m³. The results obtained from their tests show that all required mechanical properties have been achieved.

Table 2: Quality control for each batch

NUMBER	SHAPE	SIZE	TESTS
1	Cylindrical	Φ150 / 300-mm height	Compression test and Elastic Modulus
2	Prismatic	100x100x500 mm	Flexural test and inverse analysis
1	Prismatic	150x150-600	Flexural test and inverse analysis
2	Prismatic	150x30x450	Flexural test and inverse analysis
8	Cubic	100x100x100	Compression test

5. CASTING STAGES

The footbridge has been made in five stages. The first four stages correspond with the superstructure made with greenish grey concrete. The last stage is the deck construction using the light brown concrete. Nowadays, the first four stages are completed while the fifth is about to be built. In figure 5, the footbridge cross-sectional shape at mid span and the different building stages are shown. It is also shown the construction joints that are formed during casting.

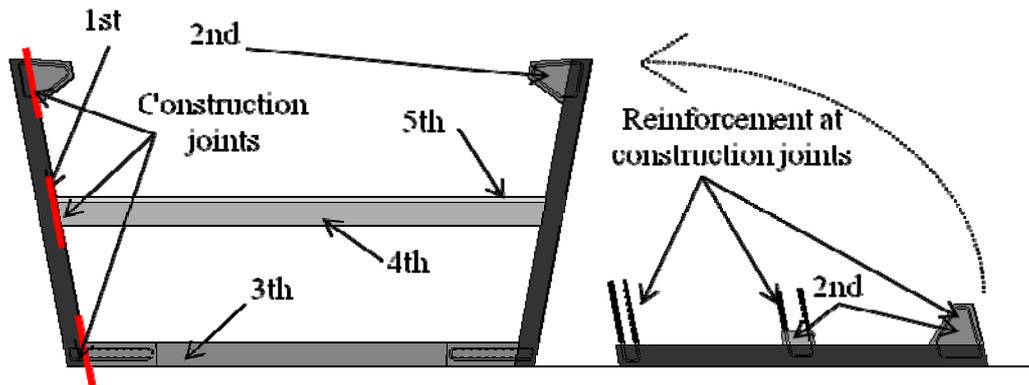


Figure 4: Casting stages and detail. 1st and 2nd stages in a horizontal position

5.1 First Stage

In the first stage, the lateral trusses that form the box girder webs are cast in a horizontal position (fig. 4). The holes that configure the truss shape are made of steel sheets (fig. 5). Since the trusses are perfectly symmetrical, it has been decided to cast them in four steps. At each step one half of a truss is cast. This way of casting reduces formwork costs, since the same formwork elements are used for the four elements. Since the sheet steel pieces must be used on both sides, they cannot have a conical shape. Moreover, they must be easy removable and stiffen enough. Final solution for these pieces is shown in figure 5. Once these steel pieces were correctly stacked on their final position, they were fixed by means of magnets to the formwork table. Afterwards, the reinforcement was placed.



Figure 5: Steel formwork for lateral trusses

In fig. 6, the reinforcement at construction joints, the reinforced mesh at supports, the top chord lightening, a tensile diagonal, and the longitudinal rib are shown. This picture corresponds with the upper node next to the support. Note that, the reinforcement is higher at nodes where the shear forces transmission is also greater. The hollowed top chord consists of PVC pipes attached to each other. There is no lightening at nodes.

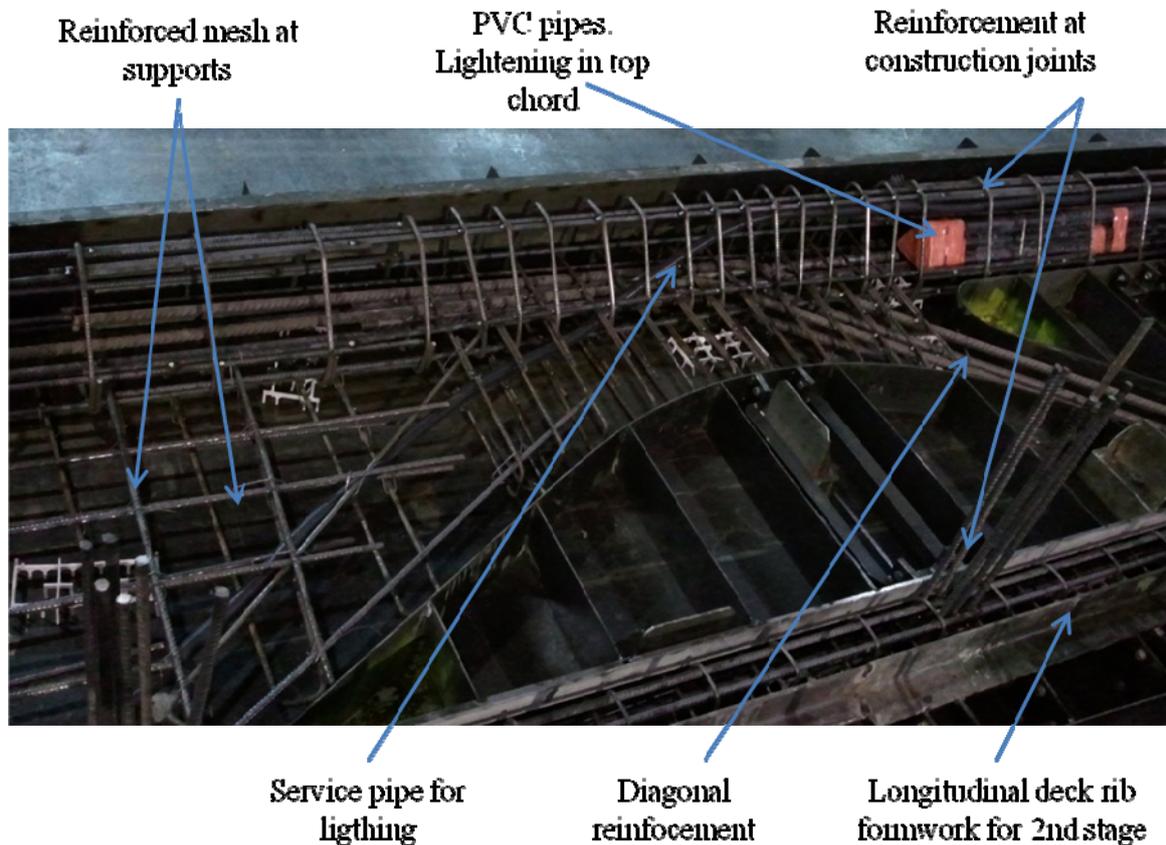


Figure 6: Reinforcement distribution and elements

5.2 Second Stage

In the second casting stage the top chords and the longitudinal deck ribs are cast (fig. 4). This phase took place five hours after the first was finished, once the concrete of the first stage had enough strength such as to resist the pressure of the new concrete (fig. 7). Because of the high reinforcement density in the top chord due to the shear needs at construction joint and the narrow pouring opening, the casting required a special method. A funnel was used to ensure the concrete went through the reinforcement and filled the formwork correctly without any big air hole inside it. The funnel and how the concrete was poured are shown in fig. 7.

When the four pieces that form the lateral trusses were cast, they were placed with their definite slope. A conventional formwork to produce industrial prestressed concrete U-shaped beams was used as a support reference. In fig. 8, it can be seen how each half truss was transported and how they were connected.



Figure 7: Top chord formwork preparation and second casting stage

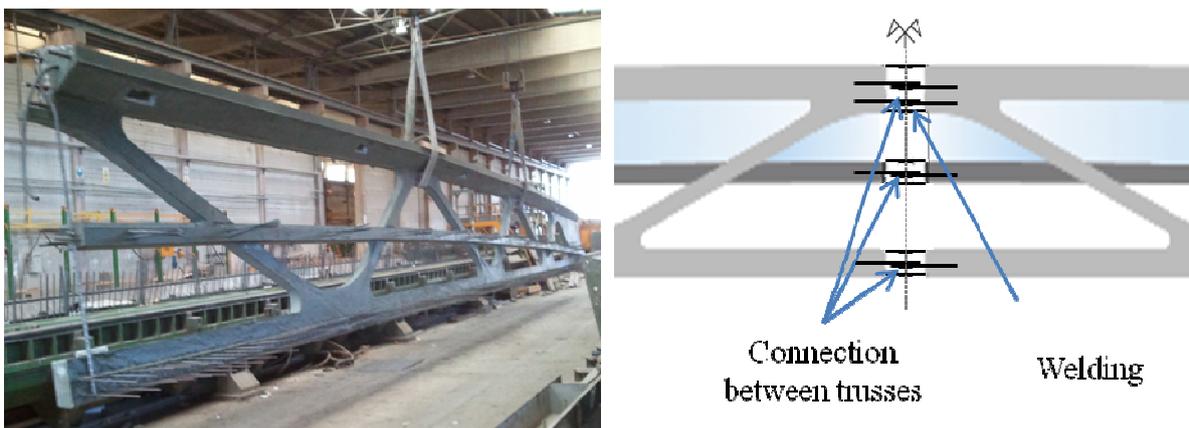


Figure 8: Half lateral truss transport (left) Longitudinal connection between each half of the lateral truss on the top chord (right)

5.3 Third Stage

In the third stage, the bottom chord and truss were cast on the floor, following a similar process to that used in the lateral webs. This stage was carried out in two separated steps in order to reuse the sheet steel pieces of bottom truss, since the X-shape bottom truss is symmetric. The prestressing strands were previously located and tensioned. Then, the reinforcement at construction joints was placed and connected to the reinforcement of the first stage. The longitudinal rebars of the X-shape truss diagonals were also placed (fig. 9). After casting, the connection between each half of the lateral truss was made at mid span. This connection was performed by means of 25-mm diameter rebars anchored on each half truss piece and welded to the rebar belonging to the other half (fig 8). The connection was made at the top chord, at the longitudinal deck rib and at the bottom chord. After welding all rebars, these zones were cast to complete the joint.



Figure 9: 3rd step. X-shaped bottom truss

5.4 Fourth Stage

In the fourth stage the transverse ribs were cast. They connect the two lateral trusses and give stiffness to the footbridge. These ribs will support the thin slabs which form the deck. In fig. 10 the transverse ribs can be seen. Seven days after transverse ribs casting, the prestressing strands were released. The displacement at mid span after prestressing release was 2.8 cm as it has been previously calculated. After 28 days, the deflection reached 5 cm and still keeps on this measurement nowadays. No problems were detected during the loading.



Figure 10: 4th step. Transverse ribs

5.5 Fifth Stage

In the fifth stage, the deck slabs are made and put in place between the transverse ribs. This stage is now about to be performed. Meanwhile, two aesthetical issues are being handled. On the one hand, the surface which is going to be in direct contact with people was the free surface during its casting in the first and second stages. On these surfaces, bubbles could not be avoided giving a non suitable finishing (fig. 11). That is why it was decided to paint the surface using the same colour as the greenish grey concrete, after filling the bubbles with mortar. On the other hand, steel fibres appeared at corners where the formwork was not properly sealed. This is a serious problem in the footbridge structure above the deck, mainly in the top chord which is used as railing. By melting sight fibres using a blowlamp it was possible to hide them without affecting the concrete surface appearance. In figs. 11 and 12 the footbridge at its current state is shown.

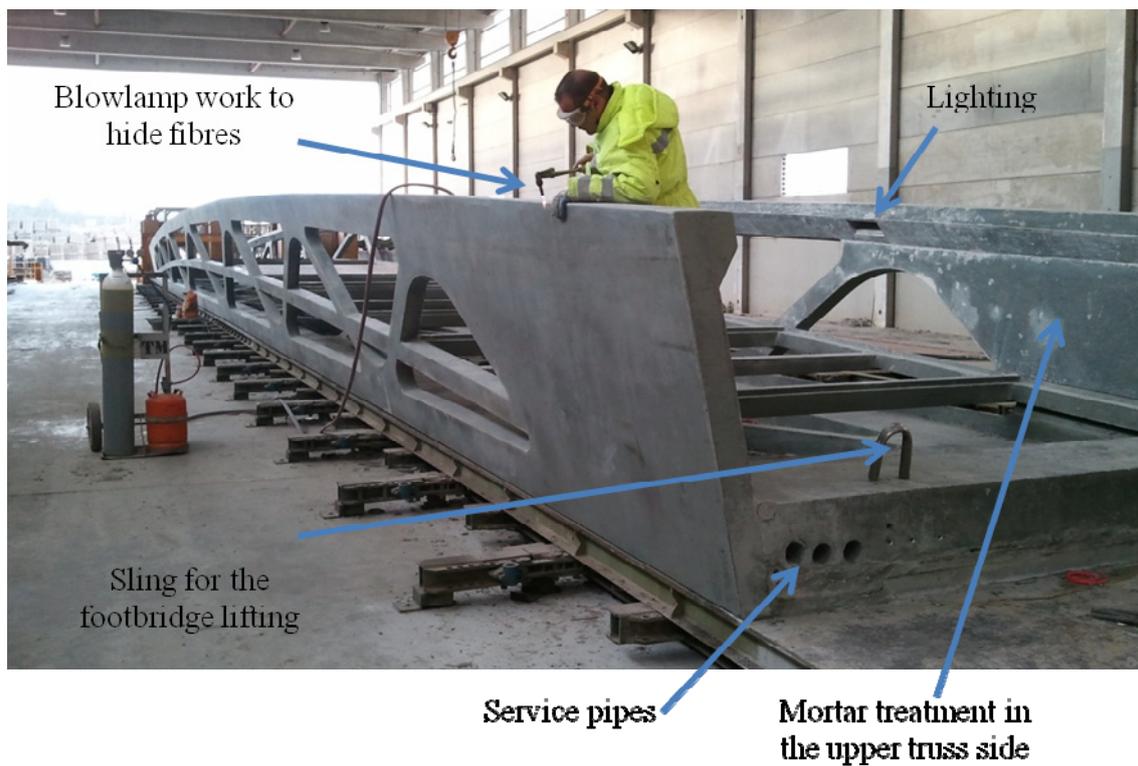


Figure 11: Footbridge just after prestressing released. Elements and works



Figure 12: Footbridge 28 days after prestressing released supported in concrete blocks

6. CONCLUSIONS

The construction of the U-shaped truss footbridge over the *Ovejas* ravine in Alicante, Spain, has been successfully carried out. The construction system used and a suitable design have reduced both the material volume and manufacturing resources needs, to the point that the UHPFRC footbridge becomes an economically viable alternative to a previous steel footbridge design. No problems at construction joints due to shrinkage and shear forces have been noticed. Moreover, the prestressing strand release was successful and all the structure elements have worked properly after loading.

ACKNOWLEDGEMENTS

This work has been developed inside both “FIBAC” and “FISNE” research projects, with references BIA2009-12722 and BIA2012-35776, supported by the Spanish Ministry of Science and Innovation. Support for this project is gratefully acknowledged. We also wish to thank, Generalitat Valenciana and the companies Prevalesa S.L. and ICOSA Ingeniería Civil S.A and Ministerio de Educación Cultura y Deporte for its FPU scholarship program.

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