Light and Durable Steel-GFRP Pedestrian Bridges

Juan SOBRINO
President
Dr. Civil Engineer
PEDELTA
Barcelona, Spain
jsobrino@pedelta.es

Juan Sobrino graduated in civil engineering at the Technical University of Catalonia in 1990 and he received his PhD from the same University in 1994.

Director of PEDELTA, Structural Engineers.

Assistant Prof. at UPC., now teaching a bridge design course at Carnegie-Mellon Univ.

Summary

The use of advanced materials allows to building light, durable and aesthetics pedestrian bridges. Stainless steel and GFRP (Glass Fibre Reinforced Polymers) are high durable materials that provide outstanding mechanical properties and magnificent aesthetical possibilities. The larger construction cost can be offset during the life of the structure thanks to the minimum maintenance required by these materials.

Combination of steel and GFRP to build hybrid structures allows light and durable as well as stiff structures. Four case studies of footbridges with hybrid structure combining steel and GFRP are presented. All of these bridges are located in Spain.

Keywords: Pedestrian bridges, aesthetics, GFRP, Stainless Steel

1. Introduction

Advanced structural materials like stainless steel and GFRP (Glass Fibre Reinforced Polymers) are high durable materials that provide outstanding mechanical properties and magnificent aesthetical possibilities [1][2]. The increase in the use of these advanced materials in structural design can partially be attributed to the increasing awareness from the Public Administration about the use of materials that require a reduced maintenance in addition to having greater mechanical resistance, capacity to be reused, etc.

In spite of the impact that composite materials and stainless steel have had in the aircraft and naval construction industries, architecture or multitude of consumer products for more than 50 years, their presence in civil engineering structures is recent. In the last two decades some interesting structures, mainly pedestrian bridges, have been built.

Even if the cost of these materials are sensibly superior to that of conventional materials (carbon steel and concrete), a strictly economical decision based on life cycle cost of the structure does not prevent the use of structural solutions with composites or stainless steel thanks to the considerable economical saving from its reduced maintenance.

GFRP exhibits excellent mechanical properties and a reduced weight but due to its relatively low modulus of elasticity GFRP structures are flexible and sensitive to dynamic effects. Combination of GFRP and steel provides stiff structures and still a reduced weight. The Zumaia Pedestrian bridge, built in 2008, was the first hybrid stainless-steel-GFRP bridge structure based on this concept [3].

2. Pedestrian Bridge in Sant Fruitós del Bages (Barcelona, Spain)

Sant Fruitós is a small town with more than ten centuries of history. Located at 59km away from Barcelona, close to Manresa, it occupies a strategic position for road communications in Catalonia. The 20th century economic boost and population growth have led to the creation of new residential areas around the historic core, and consequently of new public infrastructures.

The neighbourhood of Rosaleda, a new residential area of Sant Fruitós which hosts more than 6% of its population is separated from a commercial district and the rest of the town by the N-141C, a national road. The crossing of this road has caused many accidents, some of them with casualties, on the last few years. The Municipality decided to eliminate this risk by building a pedestrian bridge. Additionally to its main function, the structure should be a new landmark and a gateway to the town, representing its dynamic and innovative nature.
The location of the bridge was fixed by the owner to provide a direct access to a bus stop. The bridge crosses the N-141C road with a vertical clearance of 5,5m connecting areas with almost a difference of 6 m in elevation.
Keeping in mind the gateway effect desired by the client, tilted Arch has been designed (Fig. 1), connecting the commercial area and a lift-stairway structure on the residential area (a ramp was avoided to maintain the privacy and reduce visual impact on the nearby houses).

Fig. 1 Sant Fruitos Footbridge.

2.1 Description of the Structure

The use of a bow-string reinterpretation - a classical structure as main element - and the stainless steel and GFRP (glass fibre reinforced polymer) – high-performance and structurally innovative materials – are the key concepts. The leaned arch creates a dynamic and tense feeling, and joins the deck for greater structural efficiency. The structure is sober, very transparent and simple, yet very expressive thanks to the use of extremely slender elements and the arch geometry. The crossing is now accessible to disabled people and bicycles, by the slender concrete stairs and panoramic lift on the residential side, and the embankment stairs/ramps and stairs on the other.
The structure, with an overall length of 55 m, is a tied arch with an intermediate deck. The main components are made of duplex stainless-steel. The 40m span arch has a triangular section, almost equilateral, only 0,45m high, and it is tilted in plan and elevation, forming an angle of 30 degrees with the vertical plan. The arch cross-section is fabricated with 20 mm steel plates. The 3m wide deck consists of a longitudinal trapezoidal box girder with ribs. The box cross-section is made with 10 mm thickness plates. Its shape is almost triangular, 1,60m wide, with constant depth of 0,6 m. The webs are 0,15 and 0,60 m in height. The 1,40m long ribs have a variable depth between 0,09 and 0,15 m. The deck is connected to the arch at one of the ends (lift side) and in one intermediate section (36 m from the lift side). Stainless steel bars hangers, 28 mm in diameter, spaced every 3 m, connect the deck and the arch.

The arch is supported in the lift structure and on the other side rest over a small pier. To do not transmit any horizontal force to the pier's foundation, an inclined strut element connects the end of the arch, 5 m below the deck level, to the deck creating a V shape below the deck (Fig. 2).

The light arch and the deck connected through hangers define one of the most characteristic features of the structure, a very attractive visual lightness and slenderness.

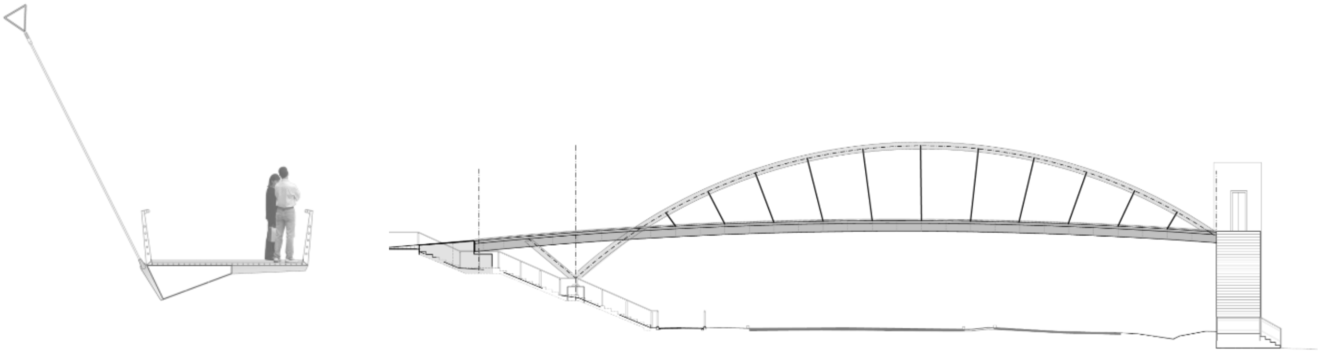

Fig. 2 Sant Fruitos Footbridge. Typical cross-section and elevation.

The 1.4162 duplex stainless steel used in this footbridge contains less nickel than other duplex stainless types. Therefore, its price is less variable and much lower than other duplex steels. It is suitable for environments with an average level of aggressiveness and it has a conventional yield strength of 480 MPa (more than 35% those of S355 carbon steel).

The deck consists of GFRP panels 0,5m wide 4 cm in depth simply supported on the ribs or on the box girder. To avoid sliding, these panels have a quartz sand surface coating.

2.2 Construction

The construction processes with stainless steel are similar to those with carbon steel but not identical. Specific techniques of cutting, bending, welding or finish have been adopted.
The box was divided into two segments, supported by temporary supports. After the assembling of the box and its connection to the lift structure, the arch was placed and connected to the deck through the stays. During construction the traffic was closed for a few hours only, in two different nights (Fig. 3).

Fig. 3 Sant Fruitos Footbridge. Assembly of the arch.

2.3 Structural behaviour

In a pedestrian structure with such slender elements it is fundamental to ensure good performance both static and dynamic, in order to ensure an appropriate level of safety and comfort for that user. To this aim, tests of static and dynamic load have been performed.

The static load test was carried out by placing pallets, with a uniformly distributed load of up to 2,4 kN/m^2. The static deformation obtained in this test was slightly higher than expected as a consequence of the adjustment of the stays. Deformation recovery was very good (above 95%).

The dynamic test was conducted with people walking, running or jumping (1 to 9 people) including eccentric load cases. 21 different load cases were defined covering a wide range of probable situations. The response of the bridge to dynamic load met the regulations, and was very similar to the results of the dynamic calculation. Measured critical damping ratio is 0.0127.

3. Two Pedestrian Bridges over the High Speed Railway in Vilafant (Spain)

The high speed railway line connecting Barcelona and the French border crosses the Municipality of Vilafant 6 m below the ground level. To cross the sunken railroad, two pedestrian bridges have been planned. The structure, with one span of 46 m, is monolithically connected with the abutments. The use of unusual geometric shapes fabricated using stainless-steel and GFRP are blended in an innovative fashion, giving rise to an austere and elegant solution (Fig.4).

The two bridges have a main longitudinal span of 45,2 m and a width-deck of 4 m. The structures are built-in on both abutments. The cross-section consists of two supported Vierendeel trusses combined with double-sheets of GFRP as structural webs. The height of the trusses is variable being 3,4 m at the elastomeric support and 1,2 m at mid-span. The bottom chord has an innovative shape prominent to the outward of the bridge. The chord has constant height of 350 mm and constant width of 376 mm. The thickness of the bottom-chord varies according with the structural needs. The top-chord has a triangular-shape with constant height and width of 350 mm. The thickness of the chord is constant of 20 mm along the whole bridge. The trusses located on both ends of the bridge have the same triangular-shape as the top-chord previously mentioned.

Fig. 4 Vilafant footbridges. Render.

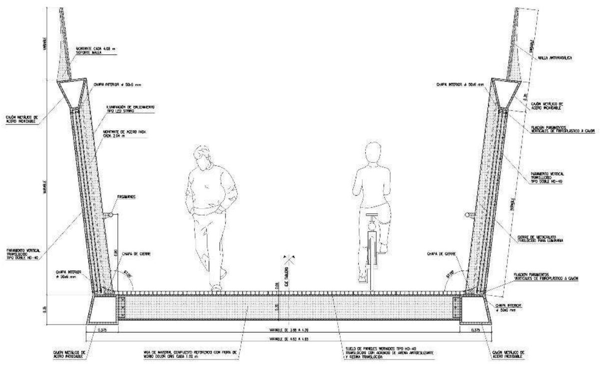

Fig. 5 Vilafant footbridges. Typical cross-section.

The cross- section width is 4,6 m and the walkway width is approximately 4,3 m (Fig. 5). The deck will be built using GFRP panels (HD-40). Two different transverse girders are used, type I 300x150x15 mm made of GFRP and stainless-steel girders. The steel girders have a rectangular shape of 350x300x20mm. The spacing between the GFRP is 1,020 m and the steel girders are place among them every two trusses. The both end transverse girders are also made of stainless duplex steel. The stainless steel girders are welded to the bottom chord on all the sides to provide lateral stability.

The connection between the bottom chord and GFRP transverse girders is made through bolt connection considered as a pinned connection. The GFRP panels located between the Vierendeel trusses consist of two plates with 4 mm thickness. The GFRP panels are connected to both chords with stainless-steel bolts. The GFRP floor panel simply supported on the floor girders and the connection is made with standard bolts which are specifically built for these kinds of panels.

The abutments of the bridge are made of reinforced concrete. The height of the abutment is approximately 9,6 meters and it has been built in two different stages. On the first stage, the total height of the abutment is 8,10 meters and a steel sheet has been left embedded for the posterior placing of the steel structure. The final concreting is carried out once the footbridge is located and welded to the steel bearing plate. The width of the abutment is 5,6 meters. Green walls aligned with the abutments help to integrate the footbridge with the surroundings.

The two footbridges of Vilafant are expected to be completed by the end of 2011. The stainless-steel structure is completed and it has been divided into two sections to facilitate transport and assembly at the site (Figs. 6 and 7).

Figs.6 and 7 Stainless-steel structure at the steel yard.

4. Pedestrian bridge over Segre River in Lleida (Spain)

A new pedestrian bridge over Segre River in Lleida has being completed and inaugurated in October 2010. The bridge connects the city centre and the University Campus. The structure located in a dense urbanized area has been designed to have a strong character but not dominating the environment (Figs. 8 and 9).

4.1 Description of the Structure

The bridge is a continuous composite steel-concrete girder with four spans of 36,3+49+44,3+33 m. The three reinforced concrete slender piers are rigidly connected to the deck. In this way, a bridge with integral piers enables an elegant and slender structure.

The main part of the deck consists of a 5 m wide steel box girder, with a 2,7 m wide cantilever in one of the side, using a hybrid steel and translucent GFRP planks for the platform (Fig 10).

Abutments are integrated into, either existing or new, walls defining a continuous with the built environment of the city.

The deck consists of a composite box girder, with double composite action over the piers, with cantilever at both sides.

Figs. 8 and 9 Footbridge over Segre River. General views.

In the upstream side the cantilever supports translucent GFRP planks for the structural pavement. The same translucent panels have been used in some parts of the railing (Fig 11). This high performance structural material requires little maintenance in the aggressive situation of de-ice salt, is lightweight and self-finished, and has been design to allow backlighting.

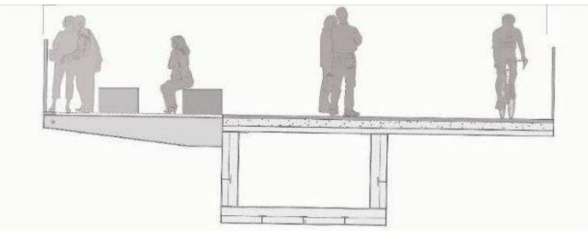

Fig. 10 Typical Cross Section.

Fig. 11. Railings with GFRP panels.

The composite steel-concrete/steel-GFRP deck enabled the construction to be prefabricated, which resulted in reduced construction time, minimal environmental impact and reduction of the dead weight.

The night experience of the footbridge is characterized by a lit path marked by thousands of computer controlled LED bulbs. The advanced light system allows a full colour palette with dynamic performance. Tones of gradated colours matching the seasons have been design along with special set-ups for celebrations and bank holidays. At night, the footbridge becomes a firefly hovering over the river inviting the citizens to stroll by and feel engage with this public space.

Translucent composite materials (GFRP) have been used in the form of structural floor panels and wall panels for both the railing and the flooring.

The static and dynamic performance was a main concern during the design. People are highly sensitive to vibrations and finishing details. Both static and dynamic tests were performed, and the obtained structural response was very similar to the predicted one, and met all the reference regulations.

4.2 Construction

The construction process follows a typical sequence dominant for composite steel-concrete bridges without temporary supports. The steel structure was divided into segments and mounted on site by temporary supports. After the assembling of the box and its connection to the piers, the concrete slabs were poured. Following GFRP planks and finishing was quickly done.

5. Five Steel-GFRP Pedestrian Bridges over T-11 Highway in Tarragona (Spain)

The T-11 footbridges are five similar footbridges The footbridges are located in different positions along T-11 highway and the two-span continuous Vierendeel truss with span length varying between 19,5 m and 29 m (Fig. 12). The typical cross-section is 2,85 m wide with a free walkway of 2,12 m (Fig. 13). The footbridge has both curve layout and elevation.

Fig. 12 Visualization of the T-11 footbridge.

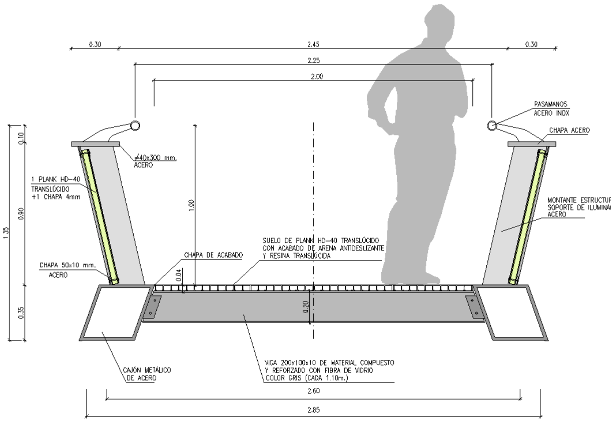

Fig. 13. Typical cross-section

The bottom chord has an trapezoidal shape with inclined webs to increase sun light reflection. The thickness of the bottom chord varies among the footbridges depending on the different spans and placing always the thickest over the pile for having the higher negative moments. The maximum thickness used is 18 mm and the minimum 12 mm. The top chord is considered as a structural member that works on tension or compression. The top chord is a steel plate 35mm x 300 mm. The handrail is made of polished stainless steel and it will be placed over the top chord.

The deck is also built with two different kind of transverse girders. Typical floors beams are I 200 x 100 x10 GFRP girders spaced at 1,1 m. The connection between the chord and the GFRP girders is made through stainless steel bolts which makes a pinned connection. Steel floor girders with rectangular shape are placed every 4,4 m to increase lateral stability of the floor system. The two end transverse girders are also made of steel but the shape differs from the ones located along the bridge. These steel girders are welded to the bottom chord on all sides.

The GRFP web panels located between the trusses consist of one single panel with 4 mm laminate-thickness. This panel is connected with a GRFP plank 4 mm thickness which is glued to the previous one with translucent epoxy adhesive. The GFRP floor panels are mounted over the girders and the connection is made with standard bolts.

The lighting system is integrated inside the trusses giving a minimalist view and guidance for pedestrians along the footbridge. The access to the footbridge is improved by building concrete-ramps on both sides of the highway which will fulfil the current accessibility requirements and will improve the functionality of the urban area.

The end columns will support both the ramps and the cantilever for the footbridge. The piers have a circular cross-section 0,45 m in diameter and approximately 6 m height. The central pier is placed on the central median of the highway and it has a Y-shaped.

The ULS requirements have been checked in all the structural members of the footbridge, such as chords, transverse girders and Vierendeel trusses. The main issue for the ULS verification is the composite collaboration of the GFRP panels and the steel members. The principal objection of using this combination is the lack of ductile behavior of the planels in comparison with the steel ductility. The available information on this issues remains insufficient due to the main researchers are still carried out on other fields. Due to that, the ULS verification on the trusses has been done without considering the GFRP collaboration.

The collaboration between the trusses and the GFRP planks has been considered for all the SLS verification such as deflection or vibration. GFRP elements provide a large damping compared to steel (about 2-3% of the critical damping) and this is very beneficial for the dynamic behavior of such light structures.

An intense experimental research was done during the construction of another pedestrian bridge located in Zumaia (Basque country, Spain). The main goal of this research is to improve the current knowledge on this innovative material. As we have mentioned previously, there are still uncertainties on the behaviour of this material when used on structures.

The tests were focus on determining the ultimate loads of the material under compressive and tensile forces. Furthermore, the connection using adhesive or steel bolts have been analysed. Figure 14 show some of the performed tests to evaluate the capacity of the bolted connections. Mechanisms of failure are due to shear-out failure or bearing failure, depending on the load and the distance of the bolt to the edge of the panel. Design manual provided by the GFRP supplier [4] is an excellent tool for designing the connections and the failure loads predicted with the simplified formula is in good agreement with the failure loads obtained at the experimental test. Panels subjected to axial loads have an elastic behaviour and they fail due to buckling instability that can be predicted by the Euler critical load (Fig 15).

Fig. 14 Experimental research on GFRP. Bolted connections. *Fig. 15. Axial load test on GFRP pannels*

6. References

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