BRIDGE OVER THE TER RIVER IN GIRONA SPAIN. COMPLEX – SIMPLICITY

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BIOGRAPHY

Juan Sobrino, Ph.D., P.E., PEng, ing, ICCP, is the founder and President of PEDELTA Inc. with office in Coral Gables, FL, Toronto, Spain, Colombia and Peru. Juan earned a MSc (1990) and PhD (1994) in civil engineering from the Technical University of Catalonia (UPC). Juan is registered PE in four States and three Provinces in Canada. He has been responsible for the concept and detailed design of more than 500 bridges worldwide, including some long spans and landmark projects. He has promoted the use of advance materials in bridge construction and aesthetics values as important as efficiency, economy and constructability. Juan was part-time professor for 17 years at the UPC in Barcelona (Spain) before he moved to North-America. Between 2011 to 2014 was Adjunct professor at Carnegie-Mellon University in Pittsburgh, PA. Juan is a frequent invited speaker in international conferences and universities.

Javier Jordan, MSc, PE, PEng, ICCP, is the technical director and Senior Vice-President of Pedelta. He earned a MSc in civil engineering from the Technical University of Catalonia (UPC) in 1996. He is registered in FL and in the Province of Ontario in Canada. Javier has been involved in the design of the most relevant bridges developed in PEDELTA during the last 15 years. Javier is involved in various international bridge Associations and is one of the experts of the evolution group "Bridges" of Eurocode-4, parts 1-1 and 1-2 (Steel Bridges).

SUMMARY

A unique steel bridge concept has been developed for a new vehicular crossing over the Ter River in Girona (Northeast of Spain). The bridge was opened to traffic on March 31st, 2015.

The key design challenge was achieving an appropriate landmark quality in this special nature setting, within a very tight budget. The proposed design was based on our aesthetic philosophy of "complex simplicity", a contemporary interpretation of a classic structure type (King Post Truss) that gives a unique identity to the bridge, scaled and proportioned to fit within the existing landscape. The proposed design minimizes the amount of materials, an under-recognized sustainability strategy, and utilizes weathering steel that achieves a long service life and will require very little maintenance.

The bridge is a nine-span, continuous deck with an overall length of 1,593 ft. The three central spans feature a steel structure with a 394 ft main span over the Ter River.

This paper discusses the concept, detailed design, structural behaviour and bridge erection.

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Project Overview

A unique steel bridge concept (Figure 1) has been developed for a new vehicular crossing over the Ter River in Girona (70 miles north of Barcelona). The bridge was opened to traffic on March 31st, 2015.

Girona is a mid-sized city; the capital of a Spanish province that annually attracts over 4.7 million tourists. The city features well preserved historic buildings - some of them dated back to the Roman foundations -, the medieval and old Jewish neighbourhood, cultural events, and famous internationally recognized restaurants. This charm city occupies a strategic position for road and rail communications between Spain and France. The 20th century economic boost and population growth led to the creation of new residential and industrial areas around the ancient city, which increased the mobility demands and there was a pressing need to improve the circulation and traffic congestion to reach the city center from north. In 2003, the Municipality of Girona and the Spanish Ministry of Public Roads (MFOM) signed an agreement to develop the design and construction of a new bridge over the Ter. The bridge is located in front of the main city hospital, and enhances the connectivity to the northern neighbourhoods, linking the city's Ring Road and the N-IIa expressway.

In a public competition in 2005, Pedelta was awarded the opportunity to conduct the concept and detailed design of the bridge. The design extended for over two years due to some environmental constraints. At the design phase, the riverbanks were incorporated into the Natura 2000 network and, as a consequence, the bridge and the main span lengths were not only governed by the hydraulic capacity but to mitigate impact on the well-preserved flood plain's vegetation.

Figure 1. General bird's eye view.

Bridge Concept

The bridge is perceived as a powerful structure with a clear identity but does not overpower the landscape, interacting smoothly with the urban surrounding of the city and the environmentally protected area of the Ter River. The structure exhibits a complex simplicity: new forms that are visually strong in a minimal and elegant way, pure curved lines that can be easily followed by viewers and a well-balanced composition based on

The direct interaction between the design engineers, the Ministry of Public Works and other involved agencies was crucial to effectively address all project issues and public concerns. At early stages, the design team developed renders and cost estimates that were essential to efficient decision making and expedite the overall design process.

The key design challenge was achieving an appropriate landmark quality in this special nature setting, within a very tight budget. Prior to the final design, the design team presented a set of various alternatives that comprised steel and concrete box girders with variable depth, arches for the main span and the preferred option: a contemporary reinterpretation of a classical structure: a steel structure with two King Post Trusses.

The proposed design was based on our aesthetic philosophy of "complex-simplicity", which gives a unique identity to the bridge, scaled and proportioned to fit within the existing landscape. The proposed design minimizes the amount of materials, an under-recognized sustainability strategy, and utilizes weathering steel that achieves a long service life and will require very little maintenance.

Early in the preliminary design phase, the bridge length was nearly 1,263'. To fulfill environmental and hydraulic requirements, the total bridge length was finally set at 1,591' with a main span of 394' over the main channel. The use of steel over the river was a driving factor to minimize environmental impact and mitigate risk of floods during construction. During the construction, Pedelta was asked by the owner and the contractor to re-design the approaches, initially in steel, with concrete keeping the same outer geometry to facilitate the timely completion of the bridge.

Figure 2. View looking east from the bridge.

Bridge Description

The bridge is a nine-span, continuous deck with an overall length of 1,593' with nine continuous spans measuring, east to west, 108', 151', 151', 191', 394', 191', 151', 151' and 105' (Figure 3). The three central spans over the river stream are steel and the three approach spans on each side are concrete.

The platform is 65' wide and has been designed to accommodate four traffic lanes, a central median and two side walkways for both pedestrians and cyclists. This traffic lane configuration will be achieved once the west connection will be widened. The current lane arrangement accommodates two traffic lanes, two segregated cyclist lanes and two side walkways. The bridge connects to the existing roads through two new roundabouts at each end.

The three central spans feature a steel structure and the three approach spans at each side are concrete. The main span over the Ter River is a 394' long King Post Truss with curved diagonal members suspending the central part of the deck. This suspender splits into two branches over the 191' spans on either side to create two gateways. Since the main spans have an overhead structure above the roadway, the geometry of the two curved diagonals over the side spans was conditioned by the vertical clearance. A minimum 18.5' vertical clearance is provided at the bridge curb.

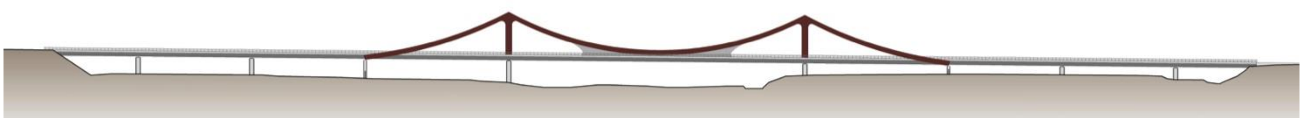

Figure 3. Elevation.

The deck is continuous and expansion joints are placed at the abutments to increase the service life of both the steel box and the substructure. The steel portion consists of a curved steel box girder with a curved soffit and slightly slanted webs, 71" deep at the center and 4'-11" deep at the intersection with the webs, and 24'-3" wide in composite action with a top slab. The steel box girder is transversally stiffened every 13', coinciding with overhang's rib sequence. The steel box girder is in composite action with a reinforced concrete top slab along the bridge. The 11 in top slab is 65'-4" wide, which includes 20'-6" long overhangs supported by ribs spaced at 13' centres. Double composite action has been used at the intermediate supports of the three central steel spans to reduce the thickness of the bottom steel flange and increase ductility in negative moment regions. In order to ensure composite action, both slabs are connected to the flanges with shear connectors (3/4" in diameter and 8"high studs). The top slab is made up of partial depth precast panels 3.5" thickness with a cast in place topping to provide a continuous surface and compensate potential out of tolerance thickness. Each panel is 13' in length, which is the span of the ribs and top transverse stiffeners. Both portions of the slab are reinforced with one matt of reinforcing each.

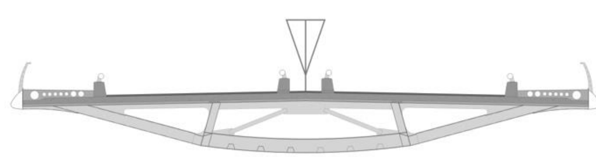

Fig. 4. Typical cross-section.

The curved diagonal members, from which the three steel spans are suspended, connect to two towers that rise 57' above the deck. The steel pylons have a hexagonal cross-section, 9' long and 2'-7" wide. The pylons are subject to significant internal forces, and are filled with self-compacting concrete. The pouring sequence with selfconsolidating concrete was analyzed together with the contractor to avoid undesirable deformations and stresses on the steel plates.

The curved diagonal members themselves have a triangular cross-section 4'-7''wide with a constant depth of 6'-7" in the main span and a smooth variable depth in the two adjacent spans. The suspension member at the main span remains above the deck and the two branches at the adjacent spans are connected to the deck at piers 3 and 6 (Figure 5). These elements have been curved with constant radius to improve the aesthetics of the structure. Bending induced by the curvature is not critical. At the main l span the suspension member is connected to the girder through a vertical steel plate.

All steel components are made of welded stiffened plates with thicknesses ranging from 15 to 70 mm. Weathering steel with a yield stress of 350 MPa (equivalent to Grade 50W) is used in all plates except ribs, the vertical plate connecting the suspension member and the deck at mid span, and stiffeners which are painted. The design specifies three types of through-thickness (Z- specifications) for the plates along the bridge (1). The total weight of the structure is 3,050 tons. Quality control has been defined according to European Standards (2, 3, 4).

The coating system used for the painted elements consists of a standard three-layer system. The color selection was essential to improve the final appearance. It was decided to select a grey color to create a harmonic combination between concrete and weathering steel. The coating system has been design to reach a 15-year life.

Figure 5. Panoramic view of the bridge during construction.

The three approach spans at each end are made of cast-in-place concrete using the same outer shape of the steel section. These side spans were built in post-tensioned concrete using a span-by-span erection sequence. The concrete deck has the same outer shape used in the steel section. All the internal post-tensioning tendons have 27 0.5-in strands Grade 270. In order to improve durability of the deck´s reinforcing steel the top slab is protected with an asphaltic waterproofing system and two courses of an asphalt-wearing surface.

The bridge substructure and foundations have been arranged to minimize environmental impact. Special attention was given to the aesthetic design of piers. The pier´s shafts of piers have two curved faces (faces perpendicular the bridge axis) and plane faces in the longitudinal direction. The cross-section of piers 1, 2, 4, 5, 7 and 8 is constant with height and can be inscribed in a rectangle 242" wide and 84"deep.

Piers 3 and 6 have a pair of inclined columns to achieve a more striking visual connection between the piers and the overhead steel diagonals. The cross-section of these two piers can be inscribed in a rectangle 95" wide 55"deep. The surfaces have vertical grooves to improve its visual appearance.

All piers and abutments are founded on 5’ diameter reinforced concrete drilled piles that reach the sound rock below the alluvial deposits. The piles are approximately 43’ deep and were socketed into the sound marl rock two to four diameters to attain bearing capacities in service of 1,000 to 2,250 kips.

The number of piles varies accordingly to the support reactions. Piers 4 and 5 are each supported by nine piles. Piers 3 and 6, at the ends of the steel spans, are each supported by three piles per column, and the rest of the piers are each supported by four piles. The superstructure rests of neoprene bearings at the abutments and the piers at the approaches, while in piers 4 and 5 it rests on POT bearings. The piers near the main stream were built on a temporary peninsula that also provided a platform from which the steel bridge deck could easily be assembled over temporary supports and avoid crane capacity issues.

Figure 6. Piers 3 and 4.

Structural Behaviour

The bridge structural analysis has been conducted using proprietary software packages RM Bridge V8 © Bentley and Robot © Autodesk. The model includes both substructure and superstructure and it accounts soil-structure interaction (Figure 7). A complete step-by-step analysis, modeling the actual erection sequence has been performed. It allows taking into account the actual duration of the stages, cracking and long term concrete effects. The parametric nature of the structural model has allowed a rapid response to the various alternatives and changes common in a project of this nature. The time dependent effects and the consequences of modifying some erection phases have been calculated automatically during the step-by-step calculation. A second-order structural analysis allowed optimizing the design of the suspension members and keeping the dimensions constant along its length.

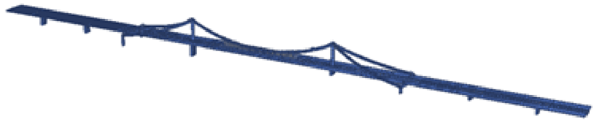

Figure 7. Global RM-Bridge Structural Model.

To determine transverse bending moments, shear-lag stresses and other local effects, various finite element models have been performed in the linear/elastic domain. These refined models have been used to analyze the different construction phases, integrating all elements, box steel girder, ribs, diaphragms and the slab (Figure 8). Other analyses were carried out to determine the distribution of stresses on the structural nodes and areas that would be strongly stiffened (Figure 9). The analyses used elastic 3D shell elements and, in some cases, considered geometrical imperfections.

Figure 8. 3D FE model for the bridge superstructure.

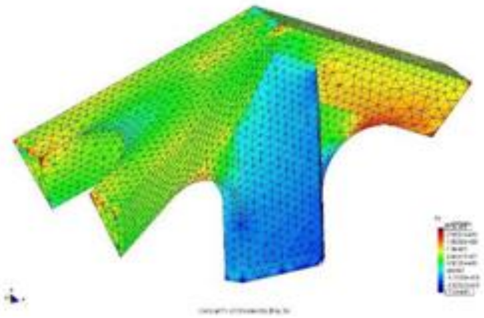

Figure 9. 3D FE local model for top of the steel tower and suspenders.

The design included many challenging tasks to model all construction stages and achieve optimal use of materials, resulting in significant cost savings for such a signature structure. The bridge has been designed in accordance with Spanish Bridge Codes and the European Standards for steel and concrete structures (5, 6 and 7).

Erection

The construction of the piers, abutments and temporary supports started in 2011. During the bridge construction, Pedelta provided construction-engineering services to the contractor adapting the design and approving the final erection and assembly procedures. In some cases, it was necessary to update the pre-cambers and re-design structural details.

The approach spans are made of cast-in-place, post-tensioned concrete and were built with a traditional span-by-span procedure on falsework (Figure 10). The deck is built using a traditional false work. The pouring and post-tensioning has been divided in two phases. The first phase is composed by the central core of the deck and was partially post-tensioned (60%). At this point the formwork can be moved forward to the subsequent span, while the rest of the pouring and tensioning can be performed afterwards.

Figure 10. Areal view during construction.

The steel box girder was assembled from 20 different segments, some of which were assembled on-site in pairs and lifted to their final positions on 9 temporary supports. These steel towers were supported on pile caps above micropiles. The steel girder and the cantilever ribs were field-welded. All welds were controlled using European Standards.

Pedelta was retained to review shop drawings and worked closely with the steel fabricator and erector subcontractor (URSSA) to review critical details and facilitate both fabrication and erection. The work required careful planning and analysis to accommodate deflections and erection geometry restrictions.

Upon the completion of the steel box girder, the lower concrete slab inside the box at the negative bending moment regions was cast in place (double composite action). Afterwards the pylon’s segments were lifted, assembled and partially filled with concrete. Erection continued with the installation of the curved diagonal members. These components were split into six segments in the central span and were installed using temporary props on top of the box girder to ensure proper alignment, plumbing and stability during erection. Jacks were placed and used for elevation control and height adjustment.

After the central curved steel ties had been correctly placed and welded, the rest of the segments were lifted using four temporary supports for each lateral curved steel element. Once the connections were completed, all the temporary elements were removed in the specified order. The erection and assembling procedures unfolded on complex stages that required an exhaustive geometric control. While the tied members were being welded, partial-depth precast panels were installed. Once all the panels were installed, the reinforced top slab was poured. After the slab reached its proper strength, the temporary supports under the box girder were removed in a specified sequence.

Thermal effects during construction were a major concern to ensure proper assembly and reduce thermal residual stresses. Longitudinal and lateral displacements at the ends of the bridge at different construction stages and air temperatures were measured during the course of construction, and correlated to update the structural models to assist in the decision making process for field assembly.

Various steel cross sections at the main span were monitored with strain gauges and thermocouples. Both predicted and actual values agreed reasonably. For the temperature effect, it was found that the thermal horizontal gradient effect was the main cause of displacements during construction of steel components above the deck.

The steel bridge erection was completed within the allotted timeframe with no impact on the project schedule. Finally, a static load test was carried out in order to check the structure's performance.

The bridge was opened to traffic on March 31st, 2015. The structure is a significant achievement for the community and promises to support the economic and population growth of Girona. Its beauty and grace are sure to make it a source of pride for the community for many years to come.

Conclusions

This unique bridge exhibits a complex simplicity: new forms, pure lines that can be easily followed by viewers, well balanced composition based on symmetrical shapes, and a complex structure.

This project makes clear that the aesthetics values of a bridge are as important as efficiency, economy, sustainability and constructability. Bridges, as a long lasting construction, modify the landscape and their influence in the life of various generations is something that we cannot forget when planning and designing a bridge.

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Credits

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