INNOVATIVE DESIGNS OF COMPOSITE BRIDGES IN SPAIN

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BIOGRAPHY

Juan Sobrino received his civil engineering degree from the Technical University of Catalonia (UPC) in 1990 and his PhD from the same University in 1994.

In 1994, he founded the Structural engineering company PEDELTA specialized in bridge engineering. Since that time, the company has designed more than 400 bridges worldwide.

The company has developed the design of different innovative bridges using new materials (GFRP, stainless steel, etc.) or new structural concepts and aesthetically pleasant structures.

Juan Sobrino collaborates with the Civil Engineering School of Barcelona (UPC) as an Assistant Professor of structural analysis. He is very active member of different Spanish and international technical associations (IABSE -Chairman of WC-8-, fib, etc) and member of ASCE, ACI, IBRACOM, AWS, etc.

SUMMARY

This paper describes four recent designs of road, railway and pedestrian composite steel-concrete bridges recently designed by the author in Spain.

Andoain footbridge: An elegant and very slender structure, with a main span of 68 m.

Menorca road bridge: One of the most interesting things in the development of bridge engineering is the exploration of new structural materials, like for example stainless steel with its excellent mechanical properties, magnificent durability and aesthetic possibilities. This arch bridge of 55-m is the first road bridge in Europe and maybe worldwide using stain-less steel for the structure.

Two bridges for the high speed railway line (HSRL) Madrid-Barcelona-French border in Barcelona. These are the first two composite bridges on this line and exhibit a considerable span length (75 m and 63 m each) for a HSRL viaduct.

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By

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FOOTBRIDGE OVER ORIA RIVER IN ANDOAIN

Andoain is a very active industrial town in the Basque country (Spain) with more than 13,800 inhabitants. In 2002, the City Council announced a design competition for a new footbridge over the Oria River connecting the centre of the village and new sport facilities and other public buildings on the other side of the river. This is a zone with increasing pedestrian traffic. The pedestrian bridge had to be respectful of the urban surroundings where it is located, have a minimum hydraulic interference with the river flow, that has suffered important floods, and a moderate cost. PEDELTA was awarded with the first prize for the winning solution consisting of a very slender steel footbridge with a length of 68 m. After the competition, the same team of engineers was asked to proceed with the construction design and the bridge was finally built in the summer months of 2005.

Conceptual Structural Design

The alignment of the bridge is at a skew angle to the river and the location is planned where the river is wide, resulting in a considerable span. The genesis of the new bridge is determined not only by these natural limits but by aesthetics and constructive aspects as well: the accessibility to the construction site is difficult and some movements of cranes were impossible.

Figure 1. Final view of the footbridge.

Three main aspects conditioned the structural design of the bridge: aesthetics, dynamic behavior and the construction erection process. The best balance of aesthetics, cost and serviceability behavior (vibrations) was achieved with the selection of a single span frame with a central steel part of 68 m (L) and two reinforced concrete supports at the extreme ends: one located on the left existing embankment and one integrated into an existing concrete wall on the other side of the river. This selected structural scheme allows an elastic rotational rigidity of the deck and, at the same time, minimizes the internal forces due to thermal movements. (Figure 1)

The final result, a sober and simple shape, conceals a complex process of searching for the optimum design, but at the same time exciting, as a result of a good team of structural civil engineers.

The main part of the bridge deck is a weathered steel structure, with yield strength of 355 MPa, accommodating a 3.6 m wide roadway. The free space for pedestrians is 3.2 m. The typical cross-section is a unicellular box girder with a top flange of 2.6 m width (Figure 2) and varying depth between 0.95 m (L/71.6) at centre span and 1.7 m (L/40) over the supports. The width of the bottom flange varies between 1.34 to 1.90 m. The top flange is a steel plate of 10 to 12 mm thickness, the bottom flange varies from 10 to 15 mm and the webs vary between 8 and 10 mm. The top flange is longitudinally stiffened with three ½ IPE 160 profiles and the bottom flange with two ½ IPE 160 or IPE 200 profiles, depending on location along the span. The box girder is also stiffened by transverse diaphragms every 4.0 m and additional transverse stiffeners between the diaphragms.

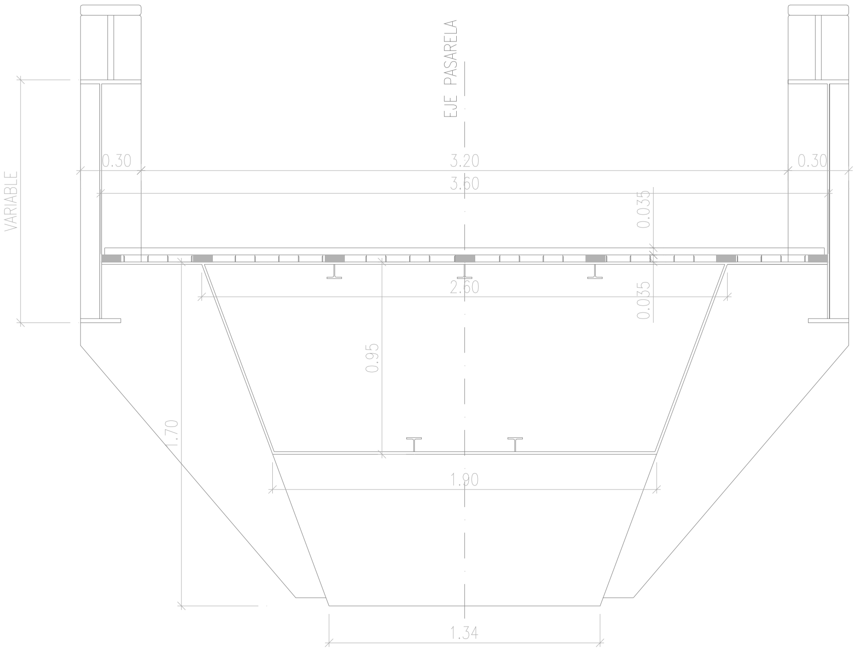

Figure 2. Typical cross-sections at mid-span and at supports.

The railings are designed to act as structural elements consisting of welded plate I-girders. The web is a vertical 10mm steel plate with stiffeners every 1m and the top and bottom flanges are continuous longitudinal plates 300x25mm and 200x15mm respectively. The railing is connected to the box girder along the web and the transverse stiffeners.

The steel deck, with a total weight of 94 tonnes, is fixed at both extremes in a reinforced concrete block of 3.8x4.5x2.25 m3 (Figure 3) using bolt connectors designed as a composite concrete steel structure (Figure 4). The concrete blocks are supported by 2 in situ reinforced concrete piles, 1.4-m in diameter and 10-m long, reaching a limestone substratum. This integral configuration allows for movements induced by thermal actions without internal forces whereas elastic rotational restriction of the girder is achieved to provide satisfactory structural behavior.

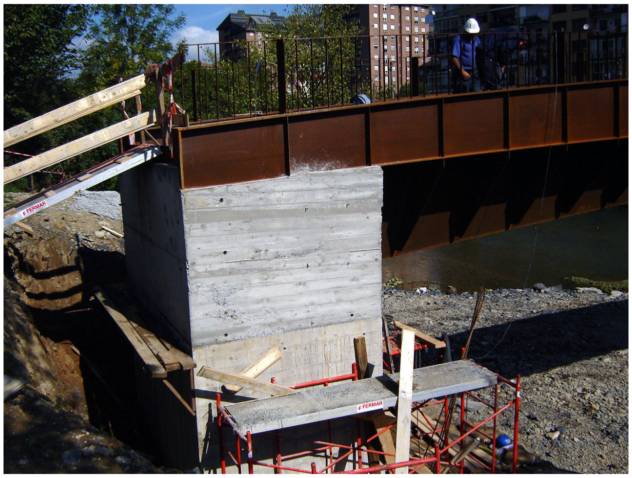

Figure 3. Reinforced concrete support

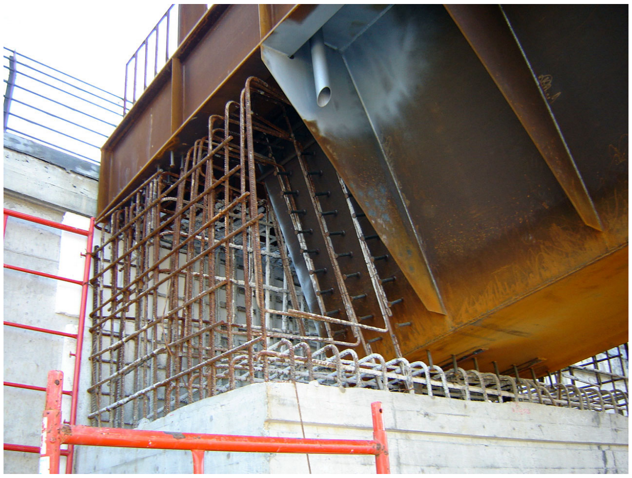

Figure 4. Cross-section at the edge of the steel beam with its connectors.

The bridge is finished with a carefully designed drainage system to reduce maintenance of the structure. The roadway surfacing is made of wood, the same material used in the handrail, which is pre-treated to resist abrasion and environmental effects. The railing is also supporting the illumination system concealed under the hand railing.

Structural Analysis

Design has been made according to the Spanish bridge Codes [1] [2], which have a similar basis of design as Eurocode 1 [3]. Characteristic live load (q_k) is 4kN/m^2 and frequent live load (q_f) is 2 kN/m^2.

The structural behavior of the bridge was modeled using a computer program based on finite element analysis. The structural model of the bridge is composed of beam and shell elements and is made on the basis of elastic theory including some geometrical non-linear analyses to obtain the critical loads that cause partial buckling of some structural elements. One of the main concerns was to evaluate the behavior of the railings that were designed as structural elements and are not directly connected to the main longitudinal box girder. The design of the transverse ribs was required to avoid deformations due to the transverse distribution of the structural elements (box girder and railings). Other structural models were developed using a 3-D frame model to simulate the general structural behavior, including soil interaction using spring elements.

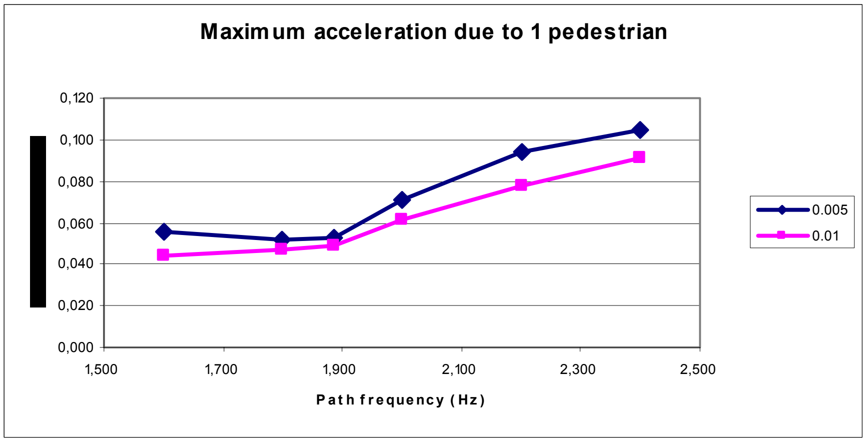

Figure 5. Maximum acceleration induced by 1 pedestrian crossing the bridge due to different pace rating and for two different critical damping values (0.005 and 0.01)

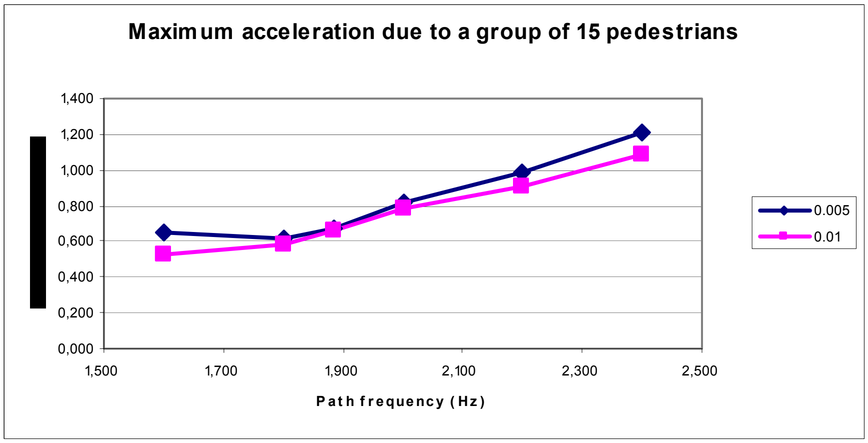

Figure 6. Maximum acceleration induced by continuous pedestrian stream crossing the bridge at different pace rating and for two different critical damping values (0.005 and 0.01)

The dynamic behavior was investigated using a computer program based on finite element method analysis [4]. Modal and temporal dynamic studies were carried out to estimate the vibrations induced by pedestrians. The selected structural scheme and dimensions of the box girder were conditioned by its dynamic structural behavior. The first flexural frequency of vibration is 1.89 Hz (near to the predominant pedestrian walk frequency between 1.7 and 2.3 Hz). Calculations of temporal dynamic numerical simulation using live models of Eurocode 1 and [4] have also been carried out. Figure 5 summarizes the maximum acceleration induced by one pedestrian at different pacing rate frequencies (simulating walk and running over the bridge). In case of continuous pedestrian streams, the results are summarized in Figure 6.

Experimental results obtained in the static and dynamic load tests (Figure 7) are in excellent agreement with theoretical prediction values taking into account structure-soil interaction and partial cracking of reinforced concrete piles.

Figure 7. View of the static load test using water containers.

Figure 8. Assembly verification of steel beam at steel yard.

Figure 9. Erection of steel beam.

Construction

Foundations and concrete supports were built by means of ordinary concrete construction techniques. The steel girder was prefabricated in three parts, weighing 25 tonnes each and measuring 23 m in length, in Vitoria (91 Km from Andoain) and transported by special road transports (Figure 8). The erection of the main part of the bridge was further complicated as some crane movements were not possible. A temporary peninsula was built to place temporary supports and cranes during erection of the steel girder. The three pieces were lifted to their final position, using two auxiliary supports, and finally welded together (Figure 9). Thereafter, the two concrete blocks were cast in situ to complete the final structure. Three weeks later, the temporary supports were removed and static load test carried out. The measured movements of the structure under construction were according to the theoretical predicted values.

The cost of the structure is about 535,000 euros (taxes included), which represents a cost of 2185 euro/m^2.

STAINLESS STEEL ROAD BRIDGE IN CALA GALDANA, MENORCA

As evidenced throughout the history of construction, the fundamental advances in structural engineering have always been related to the use of new materials. The emergent application of advanced materials with high mechanical properties and durability seems to confirm this, paving an attractive way for bridge engineering. The increase in the use of new materials in bridge design can partially be attributed to the increasing awareness from the Public Administration about the use of materials that require reduced maintenance in addition to having greater mechanical resistance, capacity to be reused, etc.

The future of civil engineering depends on continuous innovation, which is understood as being a permanent search for, and creative investigation of how we can intelligently and efficiently solve, in an ethical way, the challenges of the society, starting with the legacy of our predecessors.

Hence the use of new structural materials in bridge engineering constitutes a metaphor to innovation and, at the same time, a vindication of the enormous value of engineering, as an impelling element of the development and progress of the society, building bridges for the future and paving the way to the ones that follow.

Stainless Steel As Structural Material

Though the variety of the stainless steels is enormous, they contain as a common denominator the presence of at least 11 % of chromium that - with the presence of other components as nickel, molybdenum or nitrogen, among others – gives a steel alloy that exhibits a great corrosion resistance, ductility and mechanical strength, even when exposed to high temperatures, as well as excellent aesthetic possibilities and easy maintenance and cleaning. The chromium contained in the stainless steel forms soft, stable and transparent layer of chromium oxide (Cr_2O_3) on the surface (pasivation layer) that avoids corrosion

A wide alloy range has been developed to improve specific properties - it is possible to find more than 100 types of frequently used grades - related generally to the durability under different ambient or corrosive agents and mechanical characteristics. Four types of stainless steel exist according to their metallurgical structure: ferritic, austenitic, duplex and martensitic.

Duplex stainless steel is an austenitic-ferritic alloy with a microstructure of great corrosion resistance, excellent ductility and mechanical characteristics superior to the great majority of carbon steels. Thanks to their high strength, duplex steels are suitable for application in bridges and footbridges [1] [2]. With the existence of a wide range of duplex steel grades, the selection of the most suitable type clearly depends on the ambient aggressiveness, type of corrosion, mechanical properties, types of surface finish, and so forth.

Stainless steel, unlike the conventional carbon steel, presents a mechanical nonlinear behavior, even under reduced stress values, without having an elastic limit strength clearly defined. However, the value associated to a strain of 0.2% has been adopted as a conventional yield stress. For hot rolled plate, and taking as an example the duplex steel 1.4462 used in the bridge of Cala Galdana (Menorca) described in this section, mechanical properties of the material are summarized in table 1, comparing it with the stainless steel 1.4404 (ASTM 316 L) and the carbon steel S-355.

Mechanical property	**Stainless steel Duplex 1.4462**	**Stainless steel 1.4404 (ASTM-316L)**	**Carbon Steel S-355**
Tensile strength (MPa)	640	530	510
Conventional yield limit (MPa)	460	220	355
Elongation (%)	25	40	>15%

Table 1. Mechanical properties at 20ºC. Minimum specified values of three different steels.

Processes of construction of metallic structures with stainless steel are similar to those used for carbon steel but not identical adopting specific techniques for cutting, bending, forming, welding and finishing. For instance, austenitic steel exhibits excellent possibilities for bending (although it requires 50% more energy than carbon steel). Something similar happens for welding, making it difficult to weld duplex steel grades.

The contact of the stainless steel with other metals during the manufacturing or in its final location can cause galvanic corrosion. For this reason, manufacturing and assembly of the pieces must be carried out in zones where it does not come in contact with carbon steel, including using specific tools.

Austenitic or duplex stainless steel have points of fusion somewhat smaller than carbon steel, but its conductivity is smaller (30-60%, depending on the temperature) and the coefficient of thermal expansion is greater (45-50%). Therefore, during welding significant temperature gradient in the metal should be avoided, as it may cause the warping of plates or stress concentration as well as a variation of mechanical and corrosion resistance strengths. Welding consumables must also be specific to the stainless steel grade to guarantee equal mechanical and corrosion properties to those of the base material.

For the Cala Galdana bridge the welding techniques used were with SMAW inert gas (with covered electrode), MIG, FCAW and SAW, without preheating and not exceeding a temperature of 150ºC between two consecutive passes. Welding produces an oxidation of the base metal and a significant change of surface colour as well as in the appearance texture that should be corrected by means of a later treatment. This aspect is essential to guarantee the desired surface finish, colour and texture. In the bridge of Cala Galdana, after removing solid slag in the weld, a chemical treatment (pickling) has been applied by means of a pickling paste constituted by acids hydrofluoric and nitric. Its application, during 4 hours, allows the removing of contaminants and oxides generated during welding and facilitates the formation of the passive layer. Finally, in order to guarantee a uniform surface finish on the pieces, a blasting treatment with high pressure using glass micro-spheres has been applied.

Surprisingly, in spite of the impact that stainless steel has had in industry, naval construction, architecture and a multitude of consumer products for more than 50 years, its presence in civil engineering and, in particular, in structures, has been virtually nonexistent until just a few years ago. Nevertheless, there are some very interesting footbridges already built [5]: Abandoibarra (Bilbao), Channel of Sickla (Stockholm), Bad Via Gorge (Swiss), York Millenium Bridge (England), Chiavary (Italy), Andrésy (France), etc.

Even if the cost of the stainless steel is 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 adoption of structural solutions with stainless steel thanks to the considerable economical saving from its reduced maintenance.

Stainless Steel Bridge In Cala Galdana (Menorca)

UNESCO declared the island of Menorca a reserve of the biosphere thanks to the natural surroundings and its rich historical and ethnological heritage: an outdoor museum. Cala Galdana is, with its shell form, 450-m long and 45-m wide, one of the most beautiful beaches of the island. The surroundings are only partially urbanized, and they contribute to be the attractiveness of the island to tourists.

The torrent of Algendar terminates at the beach of Cala Galdana and its channel has been crossed for the last 30 years via a reinforced concrete bridge approximately 18 metres long. Due to its advanced state of corrosion induced by the marine atmosphere and an important support settlement in one of the abutments, the owner (*Consell Insular de Menorca*) decided to replace it by a new bridge. The new bridge should span the entire width of the old river channel, more than 40 m, fitting harmoniously in the natural surroundings and make use of material with great durability and minimum maintenance.

Figure 10. General view of the bridge over Algendar River.

During the design process, different structural and material alternatives were analysed. Finally, a duplex stainless steel arch structure was chosen due to its high resistance to corrosion from the marine atmosphere, as the solution that better responded to the owner's requirements. The new bridge has become a landmark for the island, thanks to the technological innovation of using stainless steel.

The solution has been designed fulfilling four explicit objectives: environmental respect (during construction and in service: recovery of the old river bed), high durability, minimum maintenance and a symbol of advanced technology (Figure 10).

Conceptual Structural Design

The overall length of the bridge is 55 m with a 13 m wide deck. The deck allocates 2 lanes of road traffic (7 m) and two lateral sidewalks, each 2 m wide that allows the pedestrians to enjoy the panoramic views from an excellent location.

The main structure consists of two parallel arches with an intermediate deck. The arches and the deck join at the abutments by means of an inclined strut that takes the horizontal component of the arch axial force and, consequently, do not transfer significant horizontal forces to the abutments. The stainless steel structure weighs 165 tonnes (225 Kg/m^2).

Figure 11. Abutment 2

Abutments consist of a big reinforced concrete block. As an aesthetic feature, the visible surfaces have been inclined to integrate them into the embankment and horizontal shallow channels have been spaced at 15 cm intervals to avoid large smooth surfaces. The first abutment has a footprint of 11.4x9.5 m^2 and 3.8 m high and is supported on 14 prefabricated concrete piles of 0.4x0.4 m^2 and 42 m long. The second abutment is directly founded on limestone. Its dimensions are greater to those of abutment 1, with a footprint of 11.5x13 m^2 and 7.2 m high. The visible surfaces have been treated in an analogous way to the other abutment to integrate them into the natural slope (Figure 11).

Each abutment supports the bases of the parallel arches and the two longitudinal beams of the deck. The arches are supported on POT bearings (900 tonnes of vertical load capacity and made up with stainless steel) and the beams on laminated elastomeric bearings. In order to avoid the vertical displacement of the deck with respect to the abutment, four vertical anchorages (constituted by 4 un-bonded post-tensioned cables with 12 strands of 0.6", each stressed at 70% of their maximum capacity) were applied. The inclined struts that connect the base of the arch and the end of the deck have been recessed into the front face of the abutment.

Two parallel arches with a free span of 45-m and an intermediate deck constitute the structural scheme. The main structure is made of duplex stainless steel grade 1.4462, which exhibits a high resistance to corrosion by chlorides (its mechanical properties have been defined in the previous section). The deck is made of reinforced concrete connected to a series of transverse beams (Figure 12).

Figure 12. View of the bridge from below

The arches rise to a total of 6-m (relation span/rise=7.5) and they are tied to the deck by means of two connected longitudinal beams. These longitudinal beams are again connected by means of transverse beams (Figures 13).

The arches have a triangular cross-section with a central web. Its depth is 0.70 m - constant throughout its overall length. However, the width of the section varies between 0.70 and 1 m. The central web of the section is transformed into a cellular plate that allows connecting the arch with the longitudinal deck beam.

Figure 13. General view of the bridge

The longitudinal beams are rectangular hollow sections of 1x0.5 m^2, constituted by plates with varying thicknesses between 15 and 25 mm. In the central zone with the arch above the deck, these beams have a central web that is connected to the web of the arch, allowing a direct transfer of the vertical loads of the longitudinal beam to the arch.

The transverse beams, spaced at 2 m, are formed by a rectangular cross-section 0.25 m wide and variable depth varying between 0.50 and 0.57 m (to obtain the deck cross-slope of 2%), constituted by plates of 10 and 12 mm. These beams are structurally connected to the reinforced concrete slab, having an average thickness of 0.30 m, by means of 4500 Bernold type studs of 20 mm in diameter.

In order not to transmit the horizontal component of the arch axial force to the abutments, two inclined struts - connecting the base of the arch and the end of the longitudinal beam - have been designed, which are anchored at the top of the abutments. The struts have a rectangular hollow cross-section, whose outer dimensions are 1x0.5 m^2, formed by plates, of 20 and 25 mm thickness, internally stiffened in both longitudinal and transverse directions.

Figure 14. View of the deck.

Figure 15. Railings.

The lateral sidewalks are separated from the road by the arches (Figure 14). These sidewalks are supported by means of a reinforced concrete slab supported on transverse cantilever ribs every 2 m connected to the longitudinal beam.

The railing has been designed with wood banisters with an elliptical cross-section, supported by posts of curved geometry made of stainless steel every 2 m joined to the end of the transverse ribs as if it was only one piece (Figure 15). Two different illumination systems have been designed: one guiding the walkway and roadway which is integrated in the concrete walls that separate both ways and an external lighting system, using 2 lighting posts and 8 floodlighting lamps 250W each, to illuminate the bridge from below. Pavement of walkways is made up of paving stones simulating typical limestone of Menorca. Pavement of the roadway consist of a 6 cm asphalt layer over an elastomeric bitumen-based waterproofing membrane, with reinforced and stabilized polyester mat reinforcement, and with a mineral finish on the upper side and thermofusible film on the underside.

The total cost of the bridge, including finishes and its accesses, is approximately 2.6 million euros. The cost of the structure is 1.6 million euros, which represents a cost of 2150 euros/m^2.

Structural Analysis

The analysis and design of the bridge has been carried out using the criteria from Eurocode 3, part 1,4, including consultation of bibliography and existing recommendations from European associations [6][7][8].

The structural behavior of the bridge is a self-anchored arch that does not transfer horizontal reaction forces to the foundations. In figure 16 the reactions as well as the transfer of axial internal forces among the main elements have been illustrated.

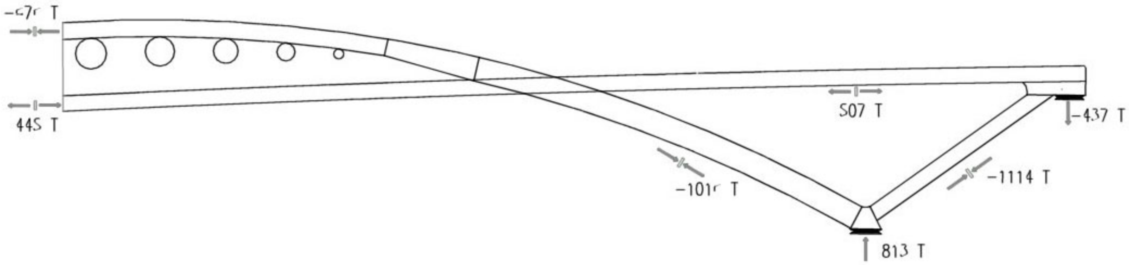

Figure 16. Distribution of reactions and axial forces (T) in the most unfavourable service combination.

The structural calculations have been made with a standard finite element program, developing diverse models or adjustments to contemplate the phenomena of softening of the stainless steel under stresses over 60% of the conventional elastic limit and the cracking effects in certain zones of the reinforced concrete slab. The model combines bar type and shell elements.

Deflections due to frequent traffic loads have been limited to L/1800 to avoid excessive dynamic vibrations, according to the specifications of the Spanish Code for composite bridges. Therefore, a more sophisticated dynamic analysis has not been carried out. The frequency of the first vertical mode is 2.88 Hz.

The steel stresses have been limited to 75% of the conventional elastic strength for the combination of frequent loads and up to 90% of this yield strength for the characteristic combination.

Once the construction of the bridge was completed, a static load test was carried out, considering different load stages, and measuring essentially vertical deflections. The structure presents a stiffer behavior than expected. The measured deflections were about 80% of the theoretical values, obtained with an average value of the modulus of elasticity of E=200 GPa. The deflections recovered elastically practically in their totality. Considering the results of the quality control of the steel, which affirms that the secant modulus of elasticity at 0.2 % is 16% superior to the one considered in the calculation model, explains the difference of deflections measured in the test of load.

Construction Process

The construction of the bridge began in October of 2004, starting with the demolition of the existing bridge, and was completed the first week of June 2005.

After the demolition of the existing reinforced concrete bridge a temporary emergency road was built to cross the river during construction, allowing water-drainage by means of a battery of 1.2 m diameter tubes. Thereafter the construction of foundations and abutments was carried out in situ using traditional methods.

The fabrication of the stainless steel plates, including cutting and preparation of edges (more than 1000 pieces), was carried out in Sweden by the company: Outokumpu. The assembly and elaboration of the pieces for the bridge was done in a steel yard in Asturias (about 800 km from the site), where also the first surface treatment by means of picking paste and blasting was done. The arches and the longitudinal beams were welded into 8 sections, including the transverse beams and ribs. These elements were then assembled on

Figure 17. Assembly of the steel structure on temporary supports.

Figure 18. Assembly of the bridge.

temporary supports for later welding. In parallel, the studs were placed, by means of manual welding (Figures 17 and 18) and finally, a surface treatment of the zones next to the welds was carried out by means of blasting. After tensioning vertical anchorages, joining the deck and abutments, prefabricated reinforced concrete elements were placed to configure the final cast in situ reinforced concrete slab. The bridge was completed with the fitting of railings, waterproofing of the deck, pavement, illumination, etc. To reduce the duration of the work, some of the abovementioned stages were not carried out sequentially.

An exhaustive quality control process has been undertaken, increased by the innovative character of the material, having intensified all the internal controls of the welds both off and on site with techniques such as ultrasonic tests, X-rays and magnetic particles, etc.

TWO BRIDGES FOR THE MADRID-BARCELONA-FRENCH BORDER HIGH SPEED RAILWAY LINE (BARCELONA)

Two bridges are currently under construction near the city of Barcelona, Spain, and will be the first composite viaducts on the Madrid-Barcelona-French border High-Speed Railway Line. The bridges have been designed according to a similar concept: composite concrete-steel deck suspended on structural steel tied members. Incremental launching construction method is used on the two bridges to avoid interference with other existing infrastructures that are vital for the city of Barcelona.

- The first bridge (Llinars Bridge) crosses, at a very high skew angle, one of the busiest highways in Spain in Llinars (45 km north Barcelona).
- The second bridge (Llobregat Bridge) crosses several existing infrastructures (highway, road and railway). The bridge is about 15 km from Barcelona and very close to the international Airport.

Conceptual Structural Design

Llinars Bridge

This high speed railway viaduct has an overall length of 574 m. The first part of the bridge is a continuous structure with 5 spans of 45+71+75+71+45 m crossing the highway; the second part is a continuous prestressed concrete bridge crossing the Mogent River with a maximum span of 48 m. The location of piers is controlled by the high skew angle of the highway crossing and by the launching process. Due to the limited vertical clearance requirement -to reduce environmental impact at the site-, the depth of the deck should be limited to 2 m below the railway line. Nine different alternatives, comprising several structural types including concrete and composite (steel-concrete) solutions were technically and economically studied. The

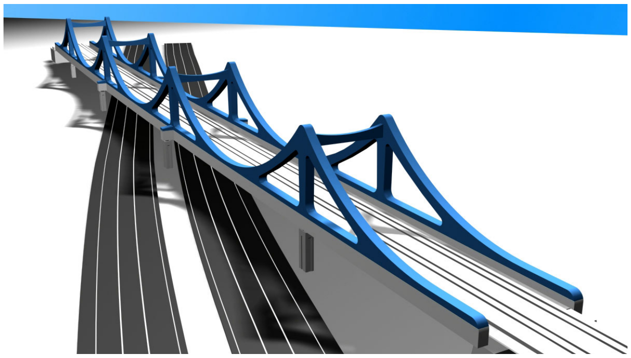

Figure 19. Llinars HSRL bridge.

Figure 20. Llinars HSRL bridge.

final bridge is a suspended composite bridge which clearly shows the flow of forces. An effort has been made to develop an aesthetically pleasant solution, very transparent and well fitted to the site. The solution provides minimum interference with existing road traffic on the highway, even during its construction. The use of steel and concrete prefabricated elements will be crucial to reduce the construction time.

The bridge, 17.2 m wide, accommodates 2 ballasted tracks, with a platform width of 14 m. The composite concrete-steel deck consists of parallel transverse I-beams 1 m deep, 3.55m apart. These floor beams are connected with the 1.6m wide longitudinal box girders having a varying depth of between 3.5 and 6 m. The longitudinal beams are suspended from curved tied steel box members supported from 15m high steel pylons (Figures 19 and 20). All the elements are made up of welded stiffened plates. The superstructure is supported on concrete piers and abutments and the substructure is founded on piles with a diameter of 1.5 m.

The final steel weight used in the bridge is about 2643 T (615 Kg/m^2 referred to a platform width of 14 m).

Llobregat bridge

This high speed railway viaduct is in concept similar to Llinars Bridge but with a different geometry. The overall length of the bridge is 870 m. The first part of the bridge is a continuous composite structure with 6 spans of 44+63+63+63+63+44 m crossing different infrastructures; the second part is a continuous prestressed concrete bridge cast in situ –span by span- crossing the Llobregat River with a maximum span of 50 m. Due to the limited vertical clearance requirement -to reduce environmental impact at the site-, the depth of the deck should be limited to 2 m below the railway line. The solution provides minimum interference with existing infrastructures (roads and railway), even during its construction.

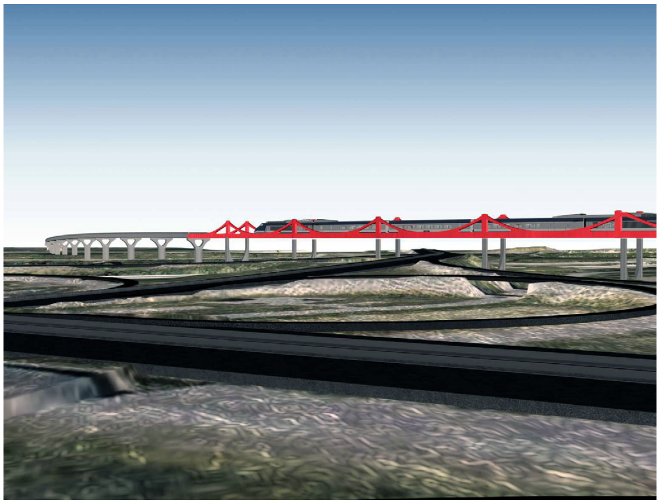

Figure 21. Llobregat HSRL bridge.

The bridge, 17 m wide, accommodates 2 ballasted tracks, with a platform width of 14 m. The composite concrete-steel deck likewise consists of parallel transverse I-beams 1 m deep, 3 m apart. These floor beams are connected with the 1.5m wide longitudinal box girders having a varying depth of between 3.5 and 5.5 m. The longitudinal beams are suspended from curved tied steel box members supported from 11.5m high steel pylons (Figure 21). All the elements are made up of welded stiffened plates. The superstructure is supported on concrete piers and abutments and the substructure is founded on piles with a diameter of 2 m.

The final steel weight used in the bridge is about 2637 T (554 Kg/m^2 referred to a platform width of 14 m).

Structural analysis

The bridges have been modeled using a computer program based on finite element analysis [9]. Special attention has been given to the structural behavior of the bridge under different types of high speed trains crossing the bridge with speeds ranging from 150 Km/h to 420 Km/h according to Eurocode 1 [3]. The maximum acceleration obtained under these high speed moving loads is about 1.8 m/s^2 lower than the admissible value according to Eurocode 1 (Figure 22). A significant horizontal load due to braking and traction of 7000 KN has conditioned the design of the fixed support at one of the extremes.

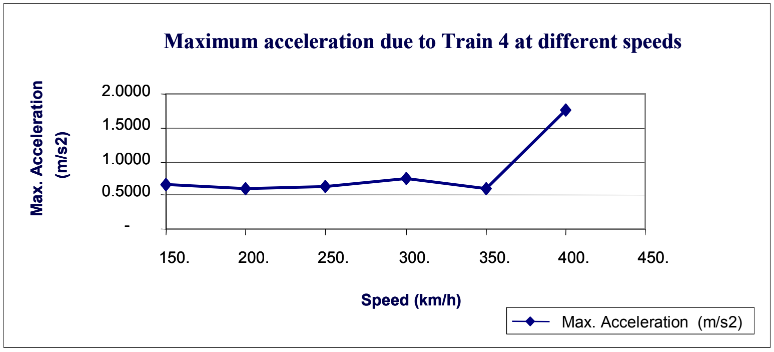

Figure 22. Maximum accelerations induced by train 4 of Eurocode 1 for different speeds.

Construction

The bridges are currently under construction and are expected to be completed by mid 2006. At present, the substructure of Llinars bridge has been completed and the steel structure is being fabricated by the company URSSA in Vitoria (Figure 23). Construction of the Llobregat bridge began in July 2005 and at present, foundations are being built and the steel works at yard will be initiated in December 2005.

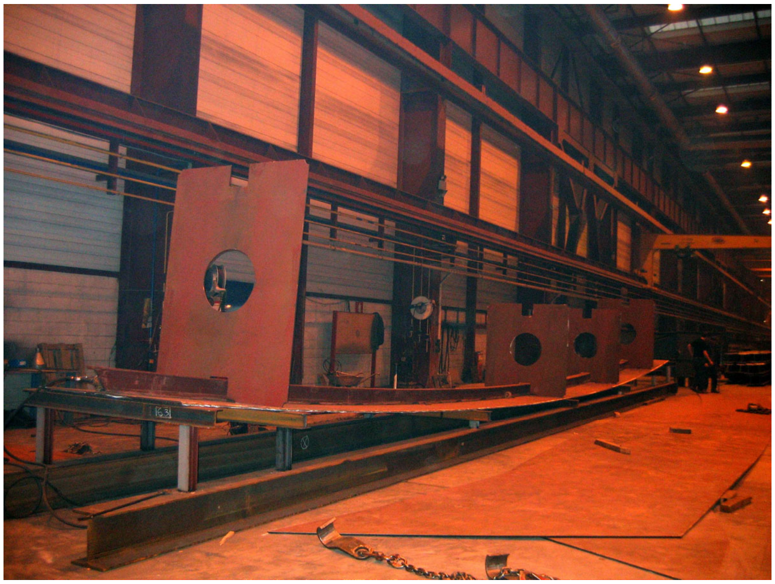

Figure 23. Fabrication of Llinars bridge.

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