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Innovative materials for the Fifth Bridge in San Sebastian, Spain

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Ana LOREA
Civil Engineer
IngZero S.L.
Santander, SPAIN
alorea@ingzero.com

Ana Lorea, born 1978, received her civil engineering degree from the Univ. of Barcelona, Spain. She is the Project Director of IngZero Consultans S.L., Santander.

Sergio SAIZ
Civil Engineer
IngZero S.L.
Santander, SPAIN
ssg@ingzero.com

Sergio Saiz, born 1965, received his civil engineering degree from the Univ. of Cantabria, Spain. He is the Technical Director of IngZero Consultans S.L., Santander.

Summary

The Fifth Bridge over Urumea river in San Sebastian is a singular structure in which the materials have been optimized and used with their last constructive innovations in order to design a technological and slender arch bridge.

Keywords: Asymmetric composite arches; high performance self-compacting concrete HPC100; composite post-tensioning deck; stainless steel.

1. Introduction

To complete the urban development of the city of San Sebastián (North of Spain) on the right bank of the Urumea River, the City Council decided to undertake the construction of three new bridges that formed the road network between the two banks. One of those bridges was the so called Fifth Bridge or Lendakari Aguirre Bridge.

2. The bridge

2.1 Conception

The conception of the Fifth Bridge was ruled by the need of crossing the 80 meters´ river width without any support , and by the requirement of having the maximum visual permeability and formal integration into the urban environment.

The proposed solution is set to the specific geotechnical and urban surroundings, where the principal constraints concur on the left bank of the river.

With this conditions the solution projected is an asymmetric structure that concentrates the flow of loads on the right bank in a huge counterweight cell and has simple supports at the opposite.

Fig. 1: Night view upstream.

2.2 The arches, the deck and the rest

The Fifth Bridge is an asymmetric arch bridge of 80m length, the arch starts from the abutment 4.20m under the deck and overpasses it at 18m span creating a bow string of 62m. The arch has a thin-walled steel section with two inner cells filled with high-performance self-compacting concrete of 100MPa forming a composite section. The part of the arch under the deck is made of stainless steel Duplex 1.4462, for avoiding corrosion due to tides.

The deck has 27.5m width and is formed by composite girders in the transversal direction, and by a concrete prestress slab of 26cm depth in the longitudinal direction. Two longitudinal steel girders work together with the deck to tight the arches. The concrete of the deck C-45 has been irrigated in its early days to reduce shrinkage effects.

The plan is also asymmetric with four vehicle lanes, two sidewalks and one bike lane.

The transmission of loads to the arches is performed through 13 stain steel hangers. The sidewalk that is placed in the exterior part of the arch at the downstream zone is supported on a system of ribs that support the wooden floor.

2.3 The construction process

The erection of the Fifth Bridge was carefully studied because not only was the structural complexity but also the date of the erection coincided with the local parties and we did have restricted hours to occupy the left bank. Three cranes were used, two on the right side and one in the left side to lift the arches. The second critical point was the filling of the arches with concrete, which has been done in two steps.

Fig. 3: Lift of the first segment

Fig. 2: Erection of the first arch.

2.4 Conclusions

City bridge design requires a special effort towards the choice of forms, materials and structural typology and is a chance to engineers to experiment and put up to the limits the materials and technology available in civil engineering in order to achieve lighter and integrated structures in the urban environment.

This choice is not the cheapest nor the easiest but has it recognition by the citizen who daily uses the bridge.

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With this conditions the solution projected is an asymmetric structure that concentrates the flow of loads on the right bank in a huge counterweight cell and has simple supports at the opposite.

Fig. 1: Elevation from downstream.

Fig. 2: Night view upstream.

2.2 The overall structure

The Fifth Bridge is an asymmetric arch bridge of 80m length, the arch springs from the abutment 4.20m under the deck and overpasses it at 18m span creating a bow string of 62m. The arch has a thin-walled steel section with two inner cells filled with high-performance self-compacting concrete of 100MPa forming a composite section. The part of the arch under the deck is made of stainless steel Duplex 1.4462, for avoiding corrosion due to tides.

The deck has 27.5m width and is formed by composite girders in the transversal direction, and by a concrete prestress slab of 26cm depth in the longitudinal direction. Two longitudinal steel girders work together with the deck to tight the arches. The concrete of the deck C-45 has been irrigated in its early days to reduce shrinkage effects.

The transmission of loads to the arches is performed through 13 stain steel hangers

The plan is also asymmetric. The two parallel arcs, define an inner space formed by the upstream sidewalk and the driveway, and downstream flies a balcony between the two shores. That sidewalk is supported on a system of ribs that support the wooden floor.

To contain the impact of the structure in the surroundings the maximum height of the arch is 3.35m above ground. The efficient work of the abutment permits to reduce the equivalent span of the bridge and has a span-depth ratio of 1/24.

2.3 The foundation and abutments

The foundation is deep type.

On the left bank has been solved by a pile cap of micro piles on which the arches are supported by neoprene bearings, the micro piles (168x12.5mm) are driven to a depth of 36m to reach the rock substrate.

On the right bank the abutment that forms the counterweight cell is built over deep foundation (32x16.5x5m) comprising 1.50 metre diameter piles, the number of piles is 14. From this abutment arises the springings of the arches, four prestress walls act as backstays and receive the compression of the springings and introduce it to the pile cap.

The filling between walls is the counterweight ballast.

The elevation of the abutment is completed by a wall lined with stone front of the general channelling of the river at the bottom, and white on the upper “trencadís” (slices of ceramic).

2.4 The arches

The arches have a “v” shape tapered cross-section. Over the deck, the bottom is 0.50metres constant while the flanges (maintaining the same plane) rise in height; under the deck the bottom divides in two sheets in order to increase the area and then the compression capacity next to the spring line.

The exterior part of the section is made of 355MPa carbon steel in the upper part, and in the lower by stainless steel Duplex Type 1.4462. The section has two independent inner cells separated by a central web, that web is made of carbon steel in the whole arch. Those cells are filled with high performance self-compacting concrete HPC100. The continuity of that inner cells is one of the most problematic matters of the designing of the joints formed by the arch and the longitudinal girders.

Fig. 3: Arches and the central joint.

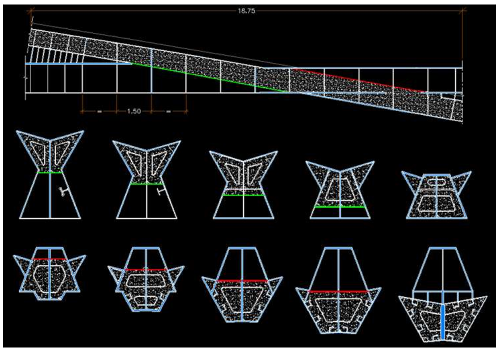

Fig. 4: Cross sections of central joint.

2.5 The longitudinal ribs, the deck and the joints.

Two carbon steel longitudinal girders work together with the deck to tight the arches.

They have trapezoidal cross section of 1.10 m height over the arches and 1.5 under the arches, the top flange is 0.50m and the bottom is 1.50m. These girders are embebed in the abutment to anchor the tension.

The deck has two families, one formed by the transversal beams and the other by the 3 longitudinal beams parallel to the main girders.

The transversal family work as composite beams connected to the deck. The separation between the beams is 3m (the same as between the hangers) and between the ribs that support the exterior sidewalk is 1.50m.

The whole system of cross beams are connected to a concrete slab of 26 cm, that is concreted on corrugated permanent shuttering sheet.

The longitudinal 3 beams are disposed to tune the bridge under dynamic effects of loading, to reduce vibration.

The cross section of the steel families is double "T" not symmetrical. The lower wing of these profiles is wider and is closed by triangular cells.

The slab is post-tensioned longitudinally by a family of 34 tendons with 12 strands of 16mm. This postension allows the deck to work with the main girders without losing stiffness due to cracking.

The concrete was C-45 has been irrigated in its early days to reduce shrinkage effects.

The joint between the arches, that have to had their inner concrete cells continuous and the main girders were geometrically very complex. The flow of forces could not be interrupted and have to be transferred to each element at the joints. Local geometric and analytical models were done to study the best solution. Finally two inner diagonals were fixed that cross the complete joint and permit the flow of concrete in the joint. In that zone diaphragms every 1.50m were disposed to make the section between arch and girder to work together.

3. The construction process

3.1 Overall

The technology used for the construction of the structure was standard and can be estimated without any time and cost uncertainties arising from the planning of the works nor from the works itself.

3.2 First Stage

The arches and main girders were prefabricated in a workshop proceeding to transport and subsequent assembly on site. The assembly shop keeps a very high quality standards and the geometry achieved the “V” tapered shape for the arches with no deviations.

While the steel structure is done in the workshop the works at the bridge site start. In a first phase the piles of the counterweights on the right bank and the micro piles on the left are done.

Simultaneously an artificial peninsula is erected in the river to make a dry box in which to work on the abutments protected by sheet piling.

On this peninsula shoring towers are placed to support temporary the springings of the arches. The interference in the watercourse that produces the artificial plateau is minimal, since it takes place in the shallow area.

Fig. 5: Workshop jobs in the central joint.

Fig. 6: Works in the abutment.

3.3 Second Stage

In a second phase the foundation elements are concreted, the pile caps in the left and right side.

After completing the foundation elements and placed the temporary propping, we proceed to place the springings of the arches in the right side.

Fig. 7: Lift of the first segment.

Fig. 8: Filling the arches.

3.4 Third stage

The filling of concrete of the springings and the joint of the arches is made.

Simultaneously the assembly of the rest of the steel parts of the bridge is done in the park located on the right bank.

3.5 Forth Stage

Once the concrete has reached the required resistance the second segment of the arches are lifted and placed by crane.

In this same phase from the right bank the first fourteen crossbeams are placed. As soon as the beams are placed the sheet, which will make permanent formwork for the concrete slab, is also placed to provide a safe working platform for operators.

The erection of the Fifth Bridge was carefully studied because not only was the structural complexity but also the date of the erection coincided with the local parties and we did have restricted hours to occupy the left bank. Three cranes were used, two on the right side and one in the left side to lift the arches.

Fig. 9: Assembling of the arches.

Fig. 10: Erection of the first arch

3.6 Fifth stage

At this stage we proceed to remove the temporary shoring of the arches simultaneously by lifting them with two erection devices. Once the arches have their final configuration begin the removal of the temporary peninsula.

3.7 Sixth stage

It continues the work of assembling the rest of the crossbeams to the main girders and, after finishing the steel assembly, the concrete is poured for the central part of the arches.

3.8 Seventh stage

The slab is concreted. To reduce the effects of early age shrinkage of concrete and trying to reach a compromise between low shrinkage and high strength (early post-tensioning) we proceeded to the irrigation of the concrete slab. After vibrated the concrete we proceeded to inundate the slab with water, keeping it under water during 72 hours, then proceeded to seal with a cationic emulsion ECR-1 on the wet concrete. Thus bitumen membrane retains water and reduces hydraulic shrinkage.

Once the concrete has reach its resistance, the deck can be use for the works. The lateral ribs that support the sidewalk are placed from the deck to outside .

Fig. 11: Filling of the arches and test of the concrete.

3.9 Eighth stage

In the final phase and having executed the deck we proceed to the completion of the works in the upper structure , reconstituted the road, implementation of the pavements, installation of handrails and lighting and projection systems.

Fig. 12: View of the arches from the deck

4. Analysis and calculation

Analyzing, designing and calculating have been together since the earliest days of this bridge, making a global design process.

Several numerical models have been realised and numeric simulation of parts of the bridge have been done in order to study local effects. The global model has included the whole construction process and has been verified during the construction.

It has also included the time dependent effects of the different concretes of the bridge, the losses due to postension, creep and shrinkage. The behaviour of concrete in the inner cells of the arches has been represented with the endogenous shrinkage due to the non exchange of water with the ambient. The cracking of the concrete in the transversal direction of the deck and in the starts of the arches has been modelled also.

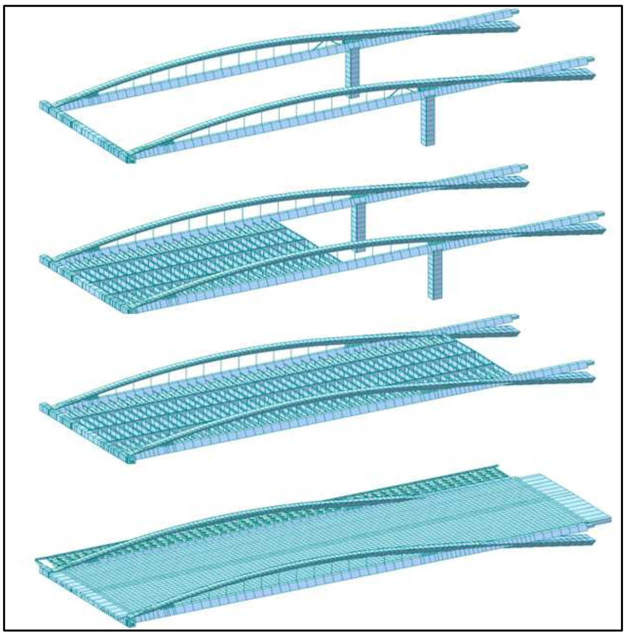

Fig.13: Global model and stages

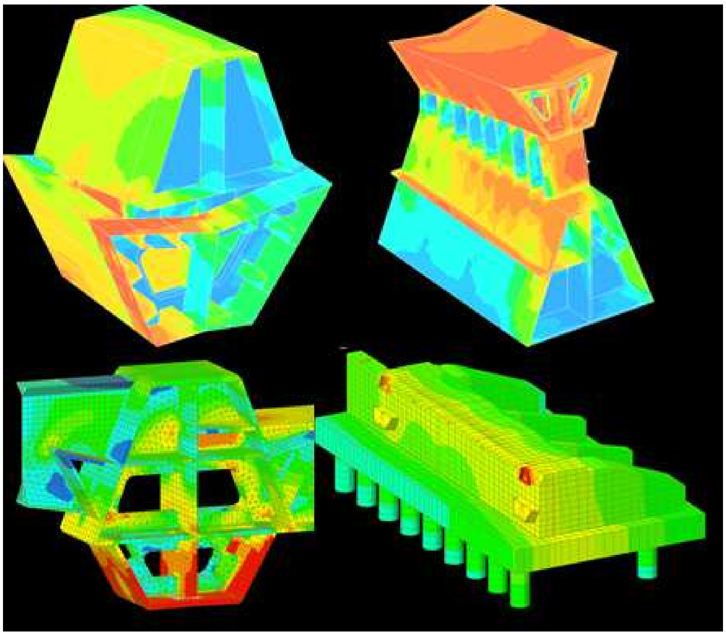

Fig. 14: Local models

5. Conclusions

City bridge design requires a special effort towards the choice of forms, materials and structural typology and is a chance to engineers to experiment and put up to the limits the materials and technology available in civil engineering in order to achieve lighter and integrated structures in the urban environment.

This choice is not the cheapest nor the easiest but has it recognition by the citizen who daily uses the bridge.