New bridge over Tajuña River in Spain

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ABSTRACT

This bridge is 2.000 m long and 140m high due to environmental requirements. Strict economical restrictions led to a bridge design that could be constructed in 36 months. The bridge has 14 spans of 40+3x70+150+5x250+150+2x70+40 m. The deck has a very large 24.0 m wide, variable depth single-box cross section. The central part of the main span was designed with H-35 lightweight concrete whereas high performance H-75 concrete was used at the piers. The main 250 m spans are to be built by the balanced cantilever method. The piers are very high, up to 125 m, with a hollow box cross section at the bottom and two shafts at the top, all made of high performance H-75 concrete

1. DESIGN CONSTRAINTS

1.1 Functional and layout constraints

The plan layout of the bridge is straight in almost its entire length; in elevation it has a constant slope of -1.25% except at abutments.

The freeway's cross section includes two roadways, each of which houses two 3.50m lanes for traffic, interior and exterior hard shoulders (1.0m and 2.50m wide respectively) as well as double rigid barriers. Both roadways are separated 2.0m (measured between the inside edges of the interior shoulders). Transversely, the cross section has a 2% crown, which changes towards the abutments to a 2% camber.

1.2 Constructive constraints

Constructive constraints are of great importance in the case of this structure, due to the high altitude at which the road crosses the valley. This situation leaves cantilevered construction coupled with self-propelling formwork as the only choice. Current self-propelling formwork systems have a maximum span of 70-80m, therefore only

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the side spans may be built using this method. During the cantilevered construction of the main 250m spans, the deck must be fixed at the piers; in some cases it will be permanently fixed and in others only during construction.

The decks' height limits lightweight concrete strength to 35 N/mm², since at the present time stronger concretes cannot be pumped to such heights.

1.3 Aesthetic constraints

The magnitude of the structure and its height imply a large visibility from the valley beneath, therefore aesthetics have been a major factor in the design of this bridge.

Figure 1: Proposed solution – Tajuña valley with bridge.

1.4 Geotechnical constraints

The geotechnical characteristics at the construction site demand piled foundations.

1.5 Economic constraints

The dimensions of this bridge make cost another factor of prime importance, consequently all possible solutions where thoroughly assessed in this respect.

2. PROPOSED SOLUTION

The selected solution consists of a single prestressed concrete box-girder deck for both roadways, with a total width of 24.0m. The central reserve is 2.0m wide, including both rigid barriers.

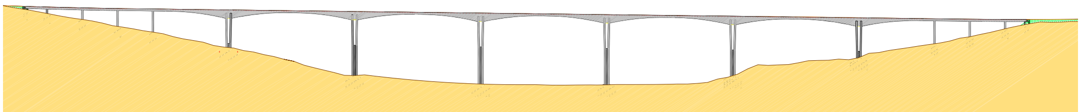

Figure 2: Proposed solution – Elevation view

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New bridge over Tajuña River in Span

The viaduct's total length of 1980.0m between abutment axes is distributed in 14 spans as follows:

40+3x70+150+5x250+150+2x70+40m. The decks' depth is constant and equal to 4.0m in the 40 and 70m spans, whilst in the cantilever spans it tapers from 16.50m at the piers (d/L = 1/15.2) to 4.0m at midspan (d/L = 1/62.5).

The box-girder is 7.5m wide, hence the length of the overhangs is 8.25m. This length implies the use of varying depth ribs (1.40m maximum), which are 5.0m apart. The separation between ribs has been chosen so that there is only one rib in each of the dowels which comprise the deck. Web thickness in the box-girder is 0.60m (constant) with top slab thickness varying between 0.32m and 0.20m. The bottom slab has a constant thickness of 0.30m for the 40 and 70m spans, and a variable thickness between 2.50m at the piers and 0.30m at the midspan section.

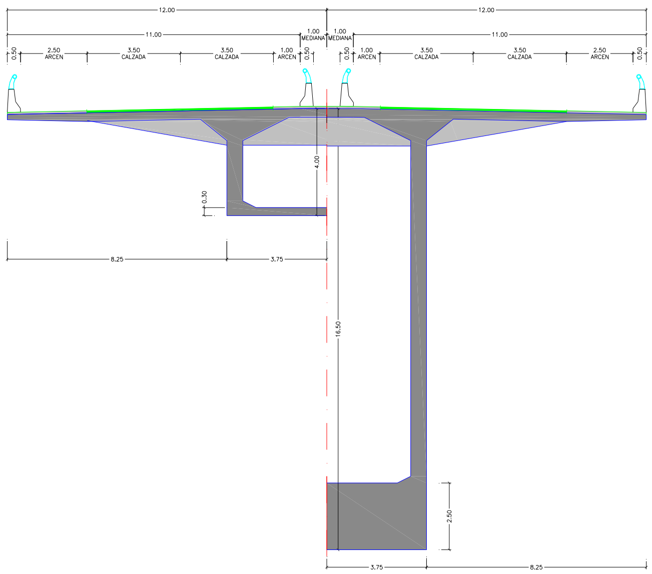

Figure 3: Proposed solution – Cross section at midspan and piers.

The deck will be built using both high performance and lightweight concrete, lightweight concrete for the overhangs and the central portions of the cantilever spans, and high performance concrete for the box girder at the piers and in the 40 and 70m spans. This aspect will be more thoroughly discussed in the next chapter, construction process.

Prestressing in the 40 and 70m spans consists of 5 or 6 tendons per web which are put in tension at the end of each stage. This is reinforced with additional prestressing along the bottom slab once the deck is complete. Prestressing in the cantilevered spans serves two purposes; tendons in the top slab are needed to ensure that the

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structure is self-supporting during construction, whereas tendons in the bottom slab, which are put in tension once the deck is complete, are needed at the SLS and ULS. Tendons in the top slab are put in tension two by two in each construction stage.

Figure 4: Proposed solution – 3D View.

There are two types of piers, the first type (corresponding to the side spans, piers 1 to 4 and 11 to 13) have a hollow rectangular cross section of 7.5 x 3.0m with 0.30m thick walls, and heights ranging between 9.5 and 46.3m. The deck is supported at these piers by POT bearings, which allow displacement along the longitudinal axis.

The second type of piers (piers 5 to 10) is required to fix the deck during the balanced cantilever construction process whilst remaining flexible with respect to longitudinal displacements; their height ranges from 59.2 to 124.8m. Each of them consists of two hollow rectangular shafts, with a 9.0m axis-to-axis longitudinal separation at the top which 50m bellow is reduced to 5.0m; from that point to the pier foundation both shafts become a single vertical shaft.

Shaft dimensions at the top are 8.50x3.0m, 0.25m thick in the transverse direction and 0.35m thick in the longitudinal direction. The shafts have a 1/66 slope in the transverse direction and a 1/166 slope in the longitudinal direction. Piers 6 to 9 are fixed to the deck, piers 5 and 10 however are hinged to increase their flexibility with regard to longitudinal displacements. During construction they will be fixed to the deck using reinforcement bars.
The deck is supported at the abutments by a pair of 9.0m long, 2.30m wide walls reaching to the wall which contains the embankment. This design follows the need to absorb the decks' longitudinal displacements, (mainly due to rheological and thermal loadings), whilst also housing both the expansion joint and the

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damper system. These elements are very large due to the fact that the deck has no intermediate joints along its 1980m length.

Piled foundations have been used both at the piers and at the abutments, with 1.80m diameter piles. Foundations for piers 1 to 4 and 11 to 13 consist of 9 piles with a 14 x 14m variable depth pile cap. Piles 5 to 10 comprise 49 piles each, with a two-way prestressed pile cap 36 x 36m wide and variable (3 to 8m) depth. Abutment foundations consist of 6 piles each, with a variable geometry pile cap 3m deep.

3. CONSTRUCTION PROCESS

Construction will proceed as follows:

- Foundation construction
- Pier and abutment construction. Piers will be built using travelling formwork.
- Deck construction. Work on spans built using self-propelling formwork and cantilever spans may proceed simultaneously.
- The side spans (built on self-propelling formwork) will be constructed in two stages, firstly the 9.5m wide box girder with high performance H-75 concrete and then the 7.25m long overhangs with HL-35 lightweight concrete.

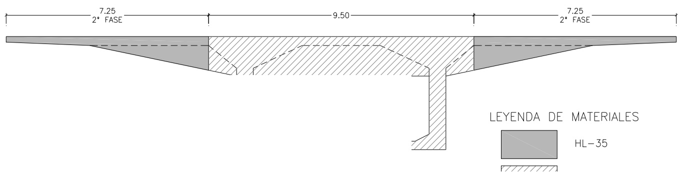

Figure 5: Cross section construction stages in the 40 and 70m spans.

Construction stages for side spans are as follows:

- Construction of span 1 and 1/5 of span 2.
- Construction of the remainder of span 2 and 1/5 of span 3.
- Construction of the remainder of span 3 and 1/5 of span 4.
- Construction of the remainder of span 4 and 14.0m of span 5.
- Dismantlement of self-propelling formwork and assembly at abutment 2.
- Construction of span 14 and 1/5 of span 13.
- Construction of the remainder of span 13 and 1/5 of span 12.
- Construction of the remainder of span 12 and 14.0m of span 11.
- Dismantlement of self-propelling formwork.

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- Balanced cantilever spans will also be built in two stages, the first stage is to be built with 14.7m wide dowels, with ribs and overhangs being built in a second stage. Dowels from the pierhead to 9 are of high performance H-75 concrete, whilst dowels 10 to closure are to be built with HL-35 lightweight concrete.

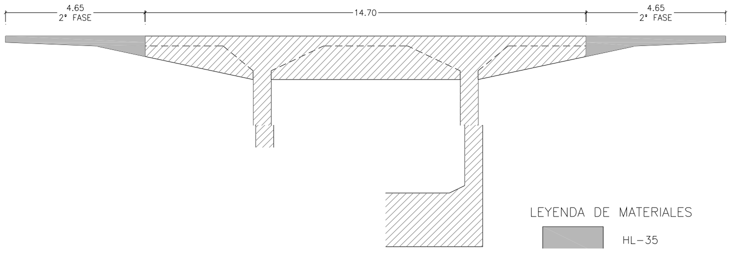

Figure 6: Cross section construction stages for balanced – cantilever spans.

Each 125m long cantilever is divided into 27 dowels, plus the pierhead and closure stitches. The pierhead section is 14.6m long, dowels 1-7 are 2.5m long, 8-26 are 5.0m long whilst dowel 27 is 4.0m long. The closure stitch is 2.4m long. Maximum dowel weight is 426 ton.

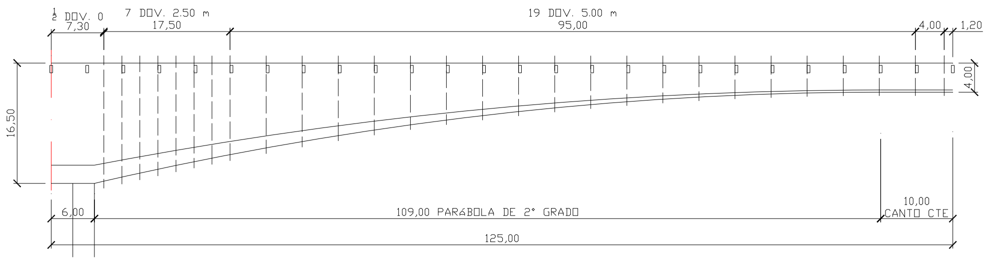

Figure 7: Distribution of dowels for each 125m long cantilever.

Construction stages for cantilever spans are as follows:

- Pierhead sections on piers 5 to 10 will be built using formwork supported directly on the pier; once completed form travellers will be built on them.
- One dowel on either side of the piers will be built in each stage, which includes placing of reinforcement bars, concrete pouring and curing, top slab tendon tensioning and grouting as well as form traveller displacement. Each stage will take 1 to 2 weeks, depending on which dowel is built.
- Once the closure stitch is built tendons connecting both cantilevers along the bottom slab will be put into tension.

- In spans 5 and 11, a 12.2m gap will remain between the portion built on the self-propelling formwork and the cantilever. This portion will be finished using formwork suspended from the edges of the cantilever and the adjoining 70m span. It will be built entirely with HL-35 lightweight concrete in two stages, using the same detailing

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as in the side spans. Once the curing of the concrete is complete the tendons in the lower slab will be put into tension, thus completing the structure.

- Ribs and overhangs will be built using form travellers

- Once the structure is complete barriers, paving and other details will be completed.

4. CALCULATION

A single FEM model, which includes the complete sequence of the construction process, has been used to calculate the structure. Long term stress redistribution effects have been taken into account using the Spanish EHE model. Creep coefficients have been calculated as an average of all the dowels, considering both the date in which they were loaded and the date at which construction ends.

Pier calculation was done using a specific model for each pier which took into account both geometric and material non linearities. Each pier was modelled independently from the deck, considering the corresponding restraints at its head: none for piers 1–4 and 11–14, blocked longitudinal displacements for piers 5 and 10, and embedded for piers 6–9.

Loadings included, depending on the pier, either horizontal forces or imposed displacements, axial forces and bending moments obtained from a linear calculation, and wind on the shaft. Pier stability has been studied both during the construction process and with the completed structure.

Transverse bending was calculated using slab models, which included the position of ribs in order to determine how much bending was absorbed by the ribs and how much was absorbed by the longitudinal bending of the slab between ribs. The results of these models were used to gauge actions to be introduced in the cross section models which study its behaviour as a frame.

4.1 Calculation model

The overall model is a 3D FEM model using bar-type elements. It contains a number of subsystems which take into account the different stages of the construction process as well as the varying cross section properties.

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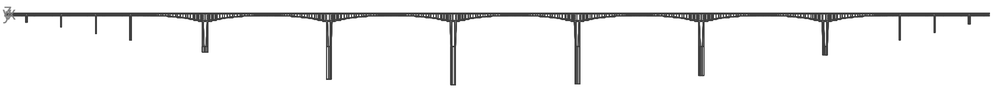

Figure 8: Elevation view of the FEM model

Each construction stage has been modelled in a different subsystem so as to introduce the loads due to the construction of the next dowel on the previous dowel. During construction piers 5 and 10 are fixed to the deck, once the structure is complete the support system changes in order to allow rotation, in accordance with the fixed POT bearings used. Loads applied during the construction process are as follows:

- Self weight of the next dowel, with a single out-of-balance dowel.
- Prestressing of the current stage.
- Form traveller displacement.
- Construction live load, on one or both cantileveres.
- Transverse or longitudinal wind, simultaneous with vertical wind.

4.2 Non linear pier calculation model

Every pier has been calculated as an independent support with a specific model considering both mechanical and geometric non linearities. Piers have been conservatively modelled as cantilevers in the transverse direction, disregarding the restraining capacity of the other piers and deck. Restraints in the longitudinal direction are different for each pier, for piers 1 to 4 and 11 to 13 displacements and rotations are both free since they are equipped with sliding POT bearings. Piers 5 to 10 have both displacements and rotations free during the construction process, however once the structure is complete they have different restraints; piers 5 and 10 have blocked displacements but are free to rotate (they are equipped with fixed POT bearings), whereas piers 6 to 9 have both displacements and rotations blocked.

4.3 Cross-sectional analysis

Transverse bending has been studied using plate models which include the position and stiffness of the ribs. Since two different types of concrete have been used on the deck, and since the second stage of construction has different widths along the bridge, several such models have been considered in order to account for all possible combinations.

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In view of the results obtained from these models, two different reinforcement areas have been included in the slab. The first, heavily reinforced area, has a width of 3.0m and is centred on the ribs, whereas the second 2.0m wide strip is located between ribs.

Web bending has been studied at pier and midspan sections, as well as at dowels 7, 13 and 19, using a bar model of the cross section. Loads on these models have been determined from the maximum shear forces and bending moments obtained from the plate models, and have been introduced in a self-balancing load state.

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