# Three spans in one. Bridge in Benicarló.

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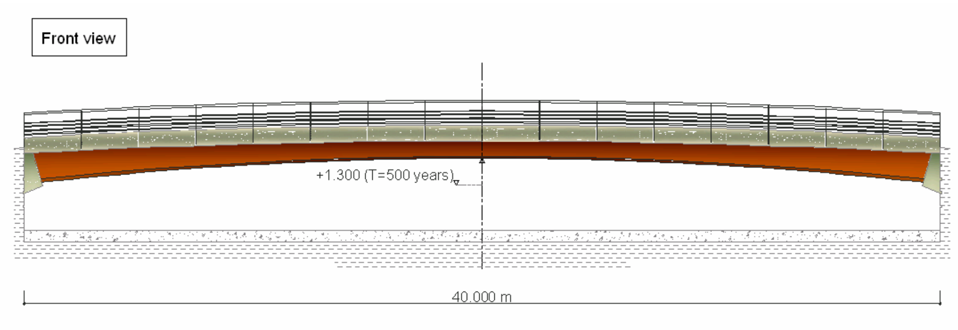
## Abstract

The design of this bridge over the channelling of the *Rambla de Alcalá* (Benicarló, Spain) has overcome very restrictive factors. Materials and forms have been very much optimized. The result of this has been a very slender bridge (1/40 at the centre of the span) with a transparent appearance that offers a pleasant view to observers and allows water flow in case of flood.

## 1. Scope




Length: 11.875 m + 43.625 m + 11.875 m
Section: pavement (5.575 m) + bridge road (7.5 m) + pavement (5.575 m)
Materials: reinforced concrete and composite structure
Foundations: deep foundation with cast in place reinforced concrete piles

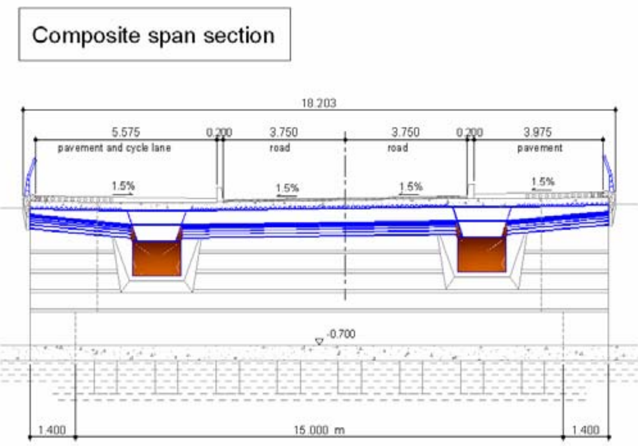
## 2. Background

The *Rambla de Alcalá* in Castellón —within the Land Valencia, Spain— is a short river with a very variable regime that runs through the town Benicarló and flows into the Mediterranean Sea. A road connecting several facilities runs parallel to the beach and crosses the riverbed at about 150 m of the seaside with an existing structure in a poor condition. The channelling of the *Rambla de Alcalá* along the mouth is now being planned, with a width of about 40 m and a depth of 4.50 m; therefore a new structure adapted to this new channel has to be built. Due to drainage conditions, the new bridge will require a minimum structural depth and no supports along the channel width. These restrictive factors together with poor foundation of the site and the presence of buildings nearby have determined the design of the structure.

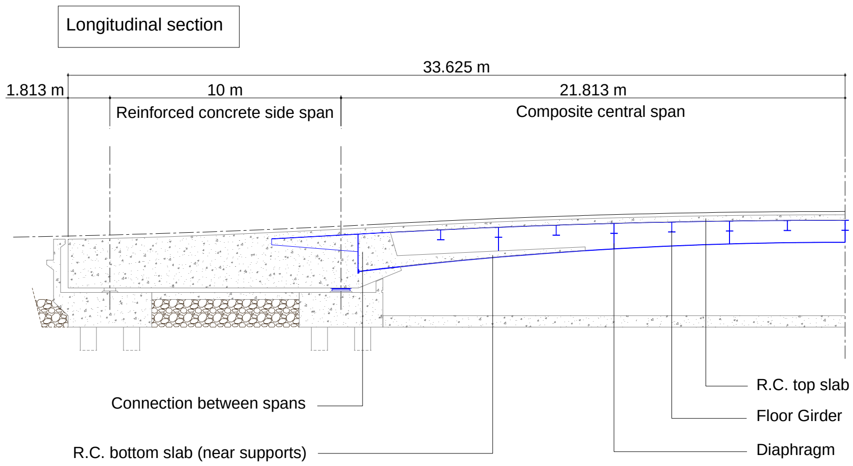

## 3. Description of the structure

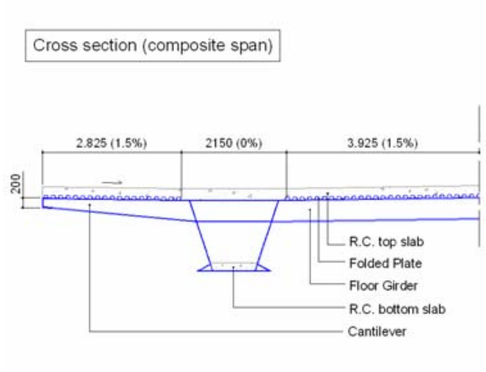
The primary structural system consists of a symmetric deck with three spans. The main one is a composite structure (steel—concrete) and the two side spans have been designed with reinforced concrete sections.

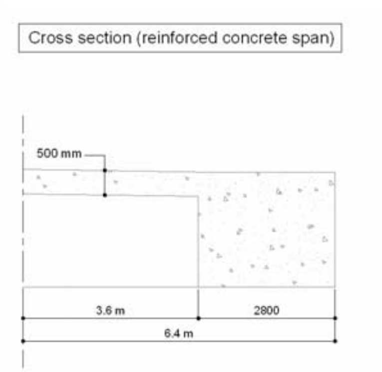
The central span is 43.625 m long and the side spans are 11.875 m long. The structural depth of the central span must be reduced as much as possible due to hydraulic draining reasons. This can be achieved by means of choosing a proper structural system, where short and heavy side spans compensate the positive bending of the central lighter one, allowing for a reduced section depth of the central span. This is necessary in order to let water flow in case of flood.



By designing the central span as a composite section, the bridge weight is minimized. The weight of the side spans, conveniently distributed, has to compensate the loads and forces acting on the central span. Therefore, high and powerful sections are needed there. As a result, positive bending moments acting on the central span are reduced by the increase of negative bending forces on the support sections. This conception is very suitable for this structure, for it allows both reducing the depth in the central span and using stronger sections for the compensation spans.




### 3.1 Composite span

The composite deck consists of two built-up box steel plate girders with variable depth. Transverse I-beams every 2.50 m support a 0.23 m reinforced concrete slab on top.

Box girders are made of S355 J2G1W high corrosion-proof steel plates. Depth varies between 970 mm in the center of the deck and 1,570 mm in end sections. The bottom flanges are made of 1.500 mm wide and 20 to 22 mm thick steel plates. Girder webs are slanted all along the central span (18º measured from a vertical line). Top flanges are made of 15 mm thick plates with a constant width of 2,150 mm. A 12 mm thick slanted plate joining web and bottom flanges is placed in order to stiffen the cantilevered end of the bottom flange. Every 5 m 15 mm thick transversal diaphragm plates are designed.

A concrete slab is arranged on the bottom flange close to the ends (along 8.2 m) in order to resist compressions caused by negative bending.

In order to resist transversal bending and to transmit loads to box girders, floor beams have been arranged every 2.5 m matching the position of diaphragms. Floor beams steel is S275. They are I-beams, with a constant 450 mm depth between girders and a variable depth in cantilevers. Both top and bottom flanges are made of 20 mm thick and 300 mm wide plates, webs being made of 15 mm plates.

Intersection with box girders is designed so that the diaphragm matches the I-beam web, and a 20 mm thick plate is placed as a prolongation of the lower wing of the I beam. The upper wing is welded to the upper wing of the box girder. This arrangement gives the I-beam structural continuity through the box girder.

The reinforced concrete slab is 0.23 m thick and it is cast on a 59 mm deep and 12 mm thick folded steel plate that is used as a shattering. Concrete on the slab is C30/35, and reinforcement steel is S500.

**3.1.2 Reinforced concrete span**

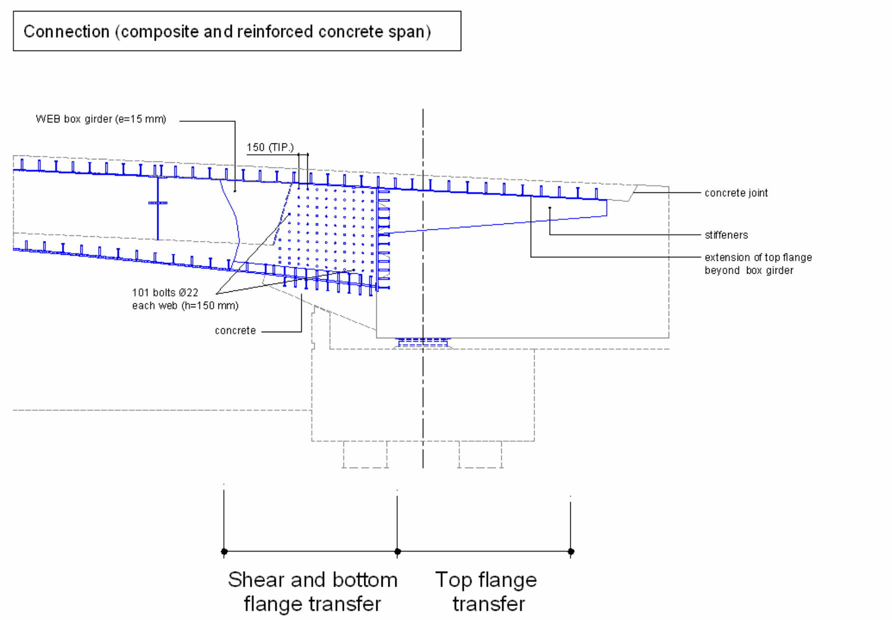
The reinforced concrete spans are designed as a 10 x 10 m plane grillage formed by four reinforced concrete beams supported on four points. A 50 cm thick slab covers the central hollow space. The concrete is C30/35, and reinforcement steel is S500. Concrete longitudinal beams are set as a continuation of the box girders of the composite deck. Cross-section is 2.8 m wide, with variable depth between 1.8 and 1.2 m.

The transverse beams that close the grillage in cross direction are called braces. The front brace is closer to the central span, whereas the back one is further. The front brace has been designed with a cross-hollow-rectangular section in order to reduce the load on the front pile cap, which supports a higher load than the back pile cap. Exterior dimensions are 1.5 m x 2.5 m, thickness being 0.25 m. Back braces are heavy solid members in order to compensate bending moments on the composite span. The cross section is rectangular and 3.625 m wide, with an average depth of 2.15 m

The concrete slab presents a 50 cm edge and is placed in the central hollow of the frame.

### 3.1.3 Connection between central span and side spans

Connection between the central composite span and the side reinforced concrete spans requires special attention. Transfer of sheer forces and bending moments is ensured along two transition zones. After the end of the pure composite section, the steel girder is encased with reinforced concrete, forming the first part of the transition, with variable depth between 1.9 m and 2.6 m and a length of 1.9 m. This arrangement ends on top of the intermediate supports. The second transition zone is beyond this intermediate supports; the top flange and the webs of the box girder stretch into the reinforced concrete span along 3.6 m.




### 3.1.4 Steel-concrete connection

Connections between steel plates and concrete slab is achieved by means of steel bolts.

### 3.1.5 Bearing elements

The intermediate supports are confined neoprene bearings, being X cm in diameter and Y cm thick. One is fixed, another one is free and the other two are guided.

Back supports are elastomeric bearings class 2, 500 x 600 x 5(11+5) mm, anchored with epoxy resin.

In some loading conditions, reactions on back supports are negative (tractions). Therefore, anchorage to the foundation is needed. Four 32 mm in diameter pre-stressing bars are arranged in every support.

**3.1.7 Foundation**

Intermediate supports lie on a reinforced concrete pile cap (15 x 3.625 x 1.5 m) that lies on two rows of eight 65 cm in diameter cast in place reinforced concrete piles (23 to 24 m long).

Back supports lie on a reinforced concrete pile cap (13.625 x 3.625 x 1.5 m) that lies on two groups of four 65cm in diameter cast in place reinforced concrete piles (19 to 20 m long).

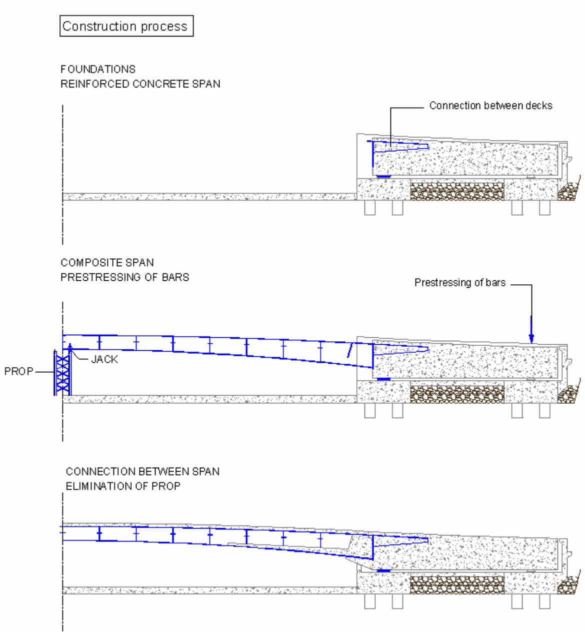
The back pile cap acts as a counterweight in certain load conditions and ensures the necessary security against negative reactions on the back supports.

**3.2 Construction process**

The construction process has taken into consideration the risk of a sudden flood, thus trying to minimize works in the channel.

The process has been planned as follows:

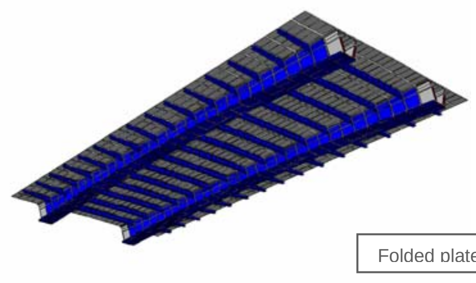
1. Foundation works
2. Construction of side spans
3. Installation of a temporary support in the centre of the channel
4. Assembly of the steel structure and casting of bottom and top slabs
5. Dismantling of the temporary support and finishing works



### 3.3 Analysis

Structural analysis has been based on both a folded plate model and a grillage model. The folded plate model has been used to check the behaviour of the structure against vibrations, seismic actions and the stress state of the steel part of the structure in service limit states. The grillage model has been used to design and check all elements in ultimate limit states. Member forces history due to different construction phases has been taken into account.

The result of a dynamic analysis shows that the bridge has a non-resonant behaviour for a heavy vehicle driving at a speed range between 0 and 90 km/h.



Folded plate model

### 3.4 Cost

The foreseen cost of the bridge deck remains within the usual range for this kind of structure. However, foundation has increased the overall cost of the bridge, because of the low soil properties.