La Porta d’Europa Bascule Bridge in Barcelona, Spain

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Fig. 1: Overall view of the bridge

Project Background

Due to increasing traffic volume and an extension of the docks, the Barcelona Port Authority decided to open a new harbour entrance, across an existing jetty. Consequently, part of the harbour will become an island. In order to ensure road traffic between this island and the mainland, while retaining the existing harbour entrance, the Port Authority decided to build a movable bridge over the new entrance.

Initially, a minimum horizontal clearance of 85 m was envisaged. Later, in view of the continuously growing size of ships using the harbour, this requirement was increased to 100 m. Taking advantage of the available space on either side of the waterway, two 300-m-long approach viaducts with 6.5% slopes were built. The movable bridge in its closed position has a clearance of 22 m, which allows smaller ships to pass underneath (Figs. 1 and 2).

Movable Span

The movable span consists of a stayed bascule bridge with two sheets and elevated steel frames and stays. The rotating hinges of the bridge are 109 m apart. In order to accommodate the counterpoise, each bascule sheet extends 14 m from the rotating hinge to its rear end, resulting in a total length of 137 m for the movable span (Fig. 3).

In the open position, rotated 75° with respect to the horizontal, the tips of the rotating sheets are about 74 m above water level, and there is a horizontal clearance of 92 m at 50 m above water level. The opening and closing operations are performed by two servo-hydraulically controlled pistons per sheet, and take about three minutes. In the event of a failure of either piston, operation using only one piston is possible at a reduced speed.

The bascule sheets have a typical x-shaped cross section. However, the webs have been laterally inclined and are situated at the edge of the deck, which consists of a 12-m-wide orthotropic plate carried by transverse girders approximately 4.2 m apart. The diaphragms are in turn supported by two lateral steel frames inclined at about 15° to the vertical plane and rising 15 m above the deck. Each frame consists of a horizontal edge girder running along the outside of the deck and a triangle composed of a compressed pylon, an end back stay, and a steel stay supporting the horizontal girder near mid-span.

The edge girders have a C-shaped cross section, with inclined webs adopting the inclination of the frames. The depth of the edge girders varies linearly between 1.84 m at mid-span and 4.16 m at the rear end, with a subsequent depth of 3.68 m at the rotating hinges. The compressed pylon, the end back stay, and the steel stay are made from 0.75-m-wide hollow-box cross sections of variable depth (Fig. 4).

The counterpoise is defined by the condition that the centre of gravity of the dead weight and permanent load for each sheet must coincide with the axis of the rotating hinge. Thus, when rotating the sheets, the resultant vertical loads will always pass through the axis of the rotating hinge, and the hydraulic devices merely have to resist friction and wind forces. The counterpoise, made of reinforced concrete, is located underneath the rear part of the deck and was calibrated before installation of the bascule sheets in order to account for execution tolerances.

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Fig. 2: Elevation of the bridge

Structural Engineering International 4/2000
Main Piers

Each of the two main water piers is made up of three reinforced concrete walls rising from a 3.0-m-deep transfer slab measuring 26.2 m x 15.6 m. The transfer slab is supported on 14 piles of 1.80 m diameter, extending 15 m into dense sand, with a total pile length of about 35 m. At its centre, the transfer slab accommodates the hydraulic pumps and other machinery.

The two lateral pier walls support the rotating hinges, which carry the entire dead weight and permanent load of the bascule sheets, as well as balanced superimposed loads. The three walls of each pier are completed by a prestressed rear transverse girder. This girder connects the ends of the lateral walls, supports the last spans of the approach viaducts, and resists reactions caused by non-balanced loads on the bascule sheets.

At the mid-height of the pier, the front wall facing the waterway exhibits a strong indentation to accommodate the pistons used to move the bascule sheets. In order to resist the heavy concentrated loads introduced by the pistons, the rotating hinges, the rear transverse girder, and the rear supports of the bascule sheets in the open position, all three walls were prestressed with tendons and bars in the horizontal and vertical directions (Fig. 5).

In their open and closed positions, the bascule sheets are supported by the rotating hinges and by locking devices at their rear end, which transmit their reactions to the rear transverse girders of the main water piers. These rear supports have to resist positive and negative reactions, depending on the position of superimposed loads and the direction of wind forces. In the closed position, negative reactions (downward forces) are required if the centre span is loaded. This type of reaction is transmitted by means of neoprene bearings located beneath the rear transverse girders of the main piers. On the other hand, if the rear part of the bascule sheet is loaded, positive reactions (upward forces) are needed. Such reactions are transmitted by means of servo-hydraulically controlled locking pistons. These pistons are connected to the rear end of the bascule sheet and rotate with the latter. Thus, in the open position, the same pistons can be used to lock the sheets in the open position and to transmit negative reactions to the bottom of the main water piers. Positive reactions in the open position are resisted by means of a second set of neoprene bearings.

As outlined above, the outer planes of the superstructure are laterally inclined at about 15° to the vertical plane. This inclination was adopted for various reasons. First, from an aesthetic point of view, the inclination results in a better orientation for sun lighting, helping to produce a bright border cornice in the bridge. The transverse inclination has not only been applied to the outer planes of the deck, but also to the steel frames that stay the bridge.

If two supporting planes with transverse inclinations are created and rotated along their longitudinal axes, their ends approach mutually, strongly increasing the impression of structural integrity in the moveable sheet. Two inclined planes, instead of two vertical ones, offer the visual advantage of ideally defining their mutual line of intersection, thus emphasising the central plane of the bridge. The inclination also has a technical benefit, namely the substantial increase in the stiffness of the transverse box beam that connects the ends of the two frames.

Fig. 3: Elevation of the movable bridge

Fig. 4: Cross section of the movable bridge

Fig. 5: View of the water pier with the rotating sheet in the open position
Each main water pier is protected from ship impact by two cylindrical cofferdams of 18 m diameter located 12 m from the piers. The cofferdam walls were made from plane sheet piles driven 6 m into dense sand. After excavating the mud from inside the cofferdams, they were filled with sand and topped by a 2-m-deep reinforced concrete slab resting on the sand. In order to improve the transfer of impact loads, the slab was provided with a heavily reinforced edge girder that penetrates deeper into the cofferdam.

The main water piers, designed as open concrete boxes, are strong yet delicately shaped. The piers should convey a feeling of force and beauty. Their strength is required as they are the bases of the open frame consisting of the rotated sheets.

In order to increase the strength and the impression of safety that the piers must convey, all external planes are inclined. Moreover, four horizontal bands protrude from the external planes of the concrete box, adopting their inclination, to enhance the aesthetic quality of the structure which otherwise, due to its large size, would have appeared dull and clumsy.

The open box offers the additional advantage that the rotation of the sheets, and the corresponding movement of the counterweights, is fully visible from the docks. Thus, the functionality of this complex structure becomes completely understandable for the observer, a fact that constituted a clear aim of its designer. The rear transverse girders constitute a virtual closure of the box, strongly marking the space where the rotation of the counterpoises takes place.

**Approach Viaducts**

The approach viaducts, built as successive spans, are made up of a fully prestressed continuous concrete deck with slender vertical piers. The cross section is triangular in the span and trapezoidal, with a 3.60-m-wide bottom surface, over the piers. The deck is typically 12 m wide, with a depth of 1.50 m at mid-span increasing to 2.28 m over the piers (Fig. 6).

Each viaduct is composed of nine spans, measuring $24 + 6 	imes 30 + 35.5 + 30.8$ m, resulting in a total length of 270.3 m. Both viaducts exhibit a maximum slope of 6.5%. While the mainland viaduct is straight in plan, the other viaduct incorporates a pronounced curve with a minimum radius of 100 m (Fig. 7). This required an increase of the deck width to 13 m.

Each pier is typically provided with a 3-m-deep capital of variable elliptical cross section, which accommodates the bearings and provides enough space for the future positioning of jacks in order to replace the bearings. The pier shafts below the capital have a curved but constant cross section of 2.00 m x 1.50 m (outer dimensions), with vertical indentations on all four main faces. Originally, it had been planned to support these piers on single piles of 2.00 m diameter in order to facilitate piling in the jetty and the excavation of the large blocks of rock that make up the jetty. However, in the viaduct rising from the jetty the excavation of these piles was problematic, and it was decided to change the foundation of the mainland viaduct piers to two piles of 1.50 m diameter.

Between the approach viaducts and the main water piers, there are V-shaped piers producing the effect of a springboard. Each of these V-shaped piers, acting as a double support for the deck and separated by 18 m, rests on three piles of 2.00 m diameter.

The composition of the deck, capitals and pier shafts, conceived with the aims of clean and harmonious forms as well as constructability and economy, results in a simple and elegant form. The soffit of the approach viaducts gives rise to interesting shapes, resulting from the change of the triangular cross section in the span to a trapezoidal one over each intermediate pier.

The main difficulty of the approach viaducts, from an aesthetic point of view, consisted in their visual connection with the strong main water piers. This has been solved through the adoption of the V-shaped piers which, by means of their slenderness, facilitate and promote this connection.

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**SEI Data Block**

**Owner:**
Barcelona Port Authority, Barcelona

**Structural design:**
Arenas y Asociados, Santander

**Contractor:**
FCC, Madrid; Guia Martort, Barcelona

**Steel (t):**
- Structural: 1100
- Reinforcing: 1540
- Prestressing: 110

**Concrete (m³):**
17400

**Total cost (USD millions):**
16

**Service date:**
July 2000

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Fig. 6: Scheme of the approach viaducts

Fig. 7: View of an approach viaduct

220 Structures in the Mediterranean