Bridge
DESIGN & ENGINEERING

TALL STORY
SPANISH BRIDGE REACHES LOFTY HEIGHTS

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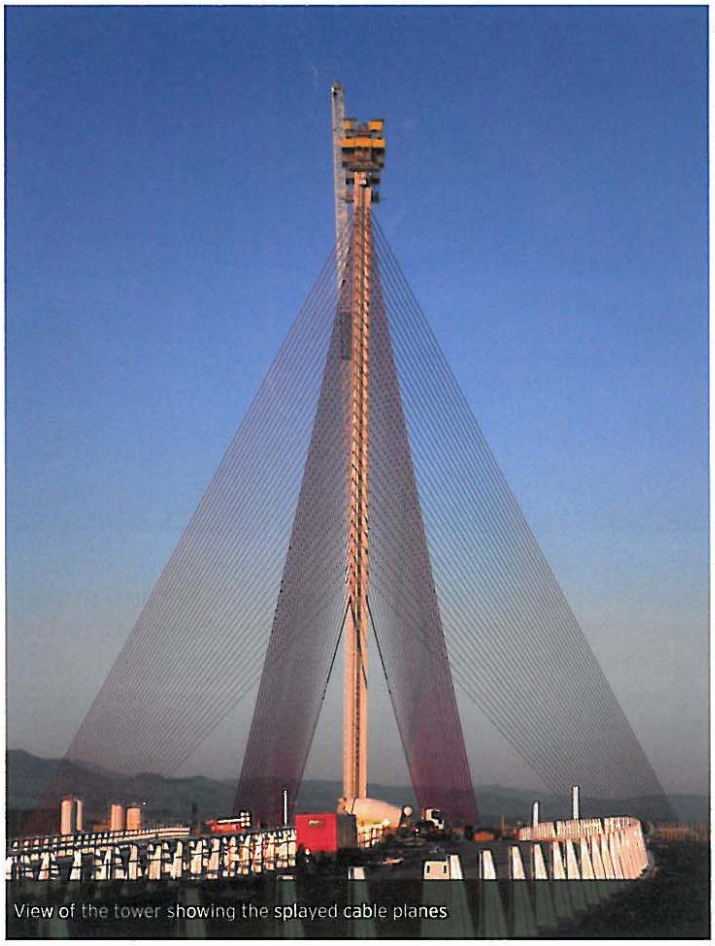
TALL STORY

A landmark structure will provide a new crossing of the Tajo River in Spain. **Ramón Sánchez de Leon** reports on the design and construction of the project.


View of the tower showing the splayed cable planes

Construction of a new bridge over the Tajo River in the province of Toledo in Spain was due to be completed as *Bd&e* went to press. The cable-stayed bridge, which has an inclined tower and splayed cables, provides a route over the river for a new highway in the town of Talavera de la Reina.

The river has a main channel 300m wide and a secondary channel 40m wide, separated by an island. The local administration wanted to create a bridge that would become a landmark structure for the city and the region; as a result a new cable-stayed bridge was designed for the route, with a single span and an inclined tower, and which is claimed to hold several records.

The main span of the cable-stayed bridge is 318m long, and is formed of a concrete slab with a depth of 2.75m and width of 36m. It carries two traffic lanes and two footways, and also incorporates a central reservation.

The single tower of the bridge rises to 185m height and is an inclined high-strength concrete structure, the cross-section of which reduces progressively from 16.5m by 4m cross-section at the base, to 4m square at the top. A steel box inside the concrete contains anchor points for the 152 stays which support the deck. The back-span stays are anchored in two underground, mass concrete elements.

A total of 52 piles which are 2.5m-diameter and 29m deep are used for the foundations of the main tower. A curved concrete viaduct which is 408m long is designed to carry the road across the smaller branch of the river.

The main span is suspended by 38 pairs of cables that are anchored every 7m along the deck, with forces being transferred to the tower through the stays. The inclination of the stays inclination causes significant compression in the deck and the tower, mainly close to the joint which connects the two elements. As a result, only the final 140m-long section of the main span requires prestressing; the remainder is formed of reinforced concrete.

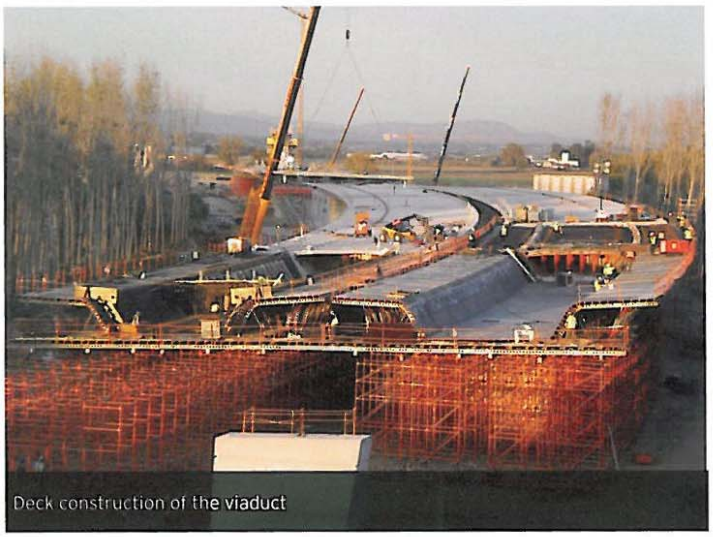
The deck and tower have a fixed connection which consists of a high-strength prestressed element. Under this element a short concrete pier links the deck and tower to the main foundation.

The inclined tower serves to reduce the bending moments, however it was still necessary to design a system of back-stays to stabilise the tower. These stays are connected to two mass concrete elements which offer sufficient weight to ensure the structural stability of the system. These anchor blocks are connected to the foundation of the main tower via two concrete beams, in order to balance the horizontal forces. Therefore only vertical forces are transmitted to the foundation, which is formed of 56 concrete piles.

A total of 152 stays make up the cable system; on the main span this is formed of two lateral planes of cables, in a semi-harp pattern. In the transverse direction the two planes of cables are separated by 28m, and longitudinally the pairs of cables are anchored every 7m along the bridge. Using such a system with two lateral planes improves the torsional behaviour of the deck and the two planes of back-stays assure the stability of the tower.


The river crossing includes a curved concrete viaduct across the smaller channel

The stays are formed of steel strands of 15.7mm diameter with an ultimate strength of 1,860MPa; the number of strands in the cables varies from 11 to 97. Each strand has galvanised wires and is protected by wax and covered in a co-extruded sheath of ▶


Deck construction of the viaduct

high density polyethylene. A red HDPE pipe with helical ribs is used to protect against rain-wind induced vibrations; moreover dampers are installed in every active anchorage to prevent vibrations at deck level. The longest stay is 411m, which its designers claim will be the second-longest in Europe after the Normandie Bridge in France.

In order to assure the life of the bridge it is necessary to avoid high stresses in the cables; hence the maximum stress in the cables is about 45% of the ultimate stress, which avoids fatigue problems. On the main span stays, the active anchor is at deck level, and on the back stays it is at the ground level anchor block.

A concrete hollow section forms the bridge deck, with slab thickness reduced to a minimum, which reduces its weight. High-strength white concrete has been used in some parts of the span.

The highest 28-day characteristic strength of the concrete is 80MPa, which is in the first part of the deck. Thickness of the deck slabs is limited between 220mm and 400mm. The equivalent thickness of the deck is 580mm, which is minimal when the dimensions of the bridge are considered.

To transmit the forces from the deck to the stays, transverse trusses are created by the use of post-tensioning steel tubes inside the deck and transverse prestressing in the bottom slab. Several finite element models were used to predict the behaviour of the deck slabs.

Very rigorous non-linear calculations were used to check all parts of the structure that include P-Delta effects and material non-linear behaviour. Under correct behaviour, as the deck stiffness reduces, the bending moments also reduce and the axial forces in the cables increase.

The joint between the tower and deck is formed of a special prestressed concrete element which has to achieve equilibrium between the forces in the tower and the deck. The deck is 36m wide, the tower width is 4m; hence the connection element contains a lot of prestressing cables in both the longitudinal and transverse directions, to achieve the static equilibrium. This element, which is made of high-strength concrete, also improves the distribution of forces across the pile cap.

Finite element models of this particular element were used to check the heat of hydration predicted during construction. This was considered necessary because of the large size of the element, and the absence of construction joints.

The bridge has a single concrete tower which is inclined at 22.5º from the vertical and rises to a height of 185m, making it the tallest bridge tower in Spain. High-strength white concrete of strength 70MPa is used across the full height of the tower, which has a hollow box cross-section with variable depth and a width of 4m across its height.

In the upper 140m of the tower is a steel box section which is formed of S-355 steel with thicknesses of 30mm and 40mm and a 3m-square cross-section; this box contains the anchors for the cables. The stays transmit the forces to the lateral steel plates through transverse steel plates inside the box section.

One benefit of the internal steel box section is that it increases the structural capacity of the tower, and also it served as permanent formwork during the construction. The steel box is connected to the concrete along the whole height and works as a composite section. As the tower stiffness reduces, the bending moments reduce as well, and the cables axial forces increase, improving the structural behaviour.

The piles of the main tower foundation extend into dense sand that is present at 10m depth. Above the piles is a pile cap of 36m by 32m with a depth of 6m. Between the pile cap and the tower-deck joint is a large concrete pier which distributes the forces over the pile cap.

Two large concrete blocks with vertical prestressing are used as anchors for the back stays, and these are designed to assure the structural stability of the bridge even when they are under water. They are each 65m long, 19.4m wide and 9.5m deep, with a weight of approximately 30,000t.

When the bridge was designed, extensive investigations were carried out into the aerodynamic behaviour of the structure. Moreover, the bridge dimensions made it advisable to carry out a wind tunnel test. However the deck is designed with an aerodynamic profile and the whole structure is made of concrete, which increases the weight and helps the structure to achieve an appropriate aerodynamic response.

The test confirmed that this was so, both in the final configuration and during bridge construction stages. The only risk to the structure was under wind speeds of about 300km/h at the deck level, but climate data for the region suggested that this wind velocity was almost impossible. While foundation construction was under way, 21 temporary supports were built from a platform in the river bed. The deck was then constructed in 14m-long stretches on these supports.

Tower erection was carried out in 3m lifts using climbing formwork. Although the tower is inclined, the construction joints were made horizontal. Hence there is an angle between the tower axis and the construction joints, which creates an additional tangential force in the joint.

Tests were carried out using different angles and concrete textures to ensure the safety of these joints, and special elements were designed in the joint to create an orthogonal surface with respect to the tower axis. Cable installation took place at the same time as the tower erection was carried out.

After installation, the cables were prestressed to 85% of their theoretical final stress. Once temporary supports had been removed and the full dead load imposed, the cables were stressed to their final stress.

The construction process of the bridge was modelled in order to assure the safety of the structure; all stages were checked, and a rigorous study was carried out to predict the ages and material properties of every part of the structure. Creep and shrinkage had to be modelled correctly.

A curved concrete viaduct which is 408m will carry the road across the secondary channel of Tajo River and the island. The bridge has seven intermediate spans that are each 48m long, and two spans of 36m length, and the deck is formed of twin concrete box sections. Each concrete box carries one traffic lane and one footway, and is 16.5m wide and 2.7m deep, similar to the deck of the cable-stayed bridge. The construction cost of the bridge is US$91 million

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Owner: Junta de Comunidades de Castilla-La Mancha
Design: Estudio AIA
General contractor: Ute Sacyr - Aglomancha - Bárcenas
Cable stays and prestressing system: VSL
Steel structure: Elte