



Bridge

DESIGN & ENGINEERING

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Slender footbridge for World Heritage site

A new bridge that has been built in the World Heritage city of Toledo in central Spain was carefully designed to complement the sensitivity of its setting. The project created a new connection across the Tajo River, close to the former Arms Factory.

The other main criteria of the design was that it should have as little impact on the environment as possible – for this reason, engineers decided to build a bridge that would span right across the river, with no piers in the water. The Tajo River is about 90m wide at this point, and to allow for a flood of 500-year return period, it was necessary to extend the main span to 105m.

The cable suspension bridge that was chosen was designed by consultant Estudio AIA for the Toledo City Council, and built by contractor FCC Construcción with steel fabricator Horta Coslada. The result is similar to a bridge on the site that was washed away early last century when flooding raised the river 7m above its normal level.

It is relatively transparent, hence it does not block views of the historical buildings in the city centre. Use of a suspension bridge also meant that construction could be carried out without impacting on the river.

The suspension bridge has a main span of 105m; the deck is 6m wide while the main cables are 9m apart. The steel towers are 22m high and the deck is a composite section with a steel box and a concrete slab. Hangers are spaced every 3m, connecting to transverse beams. The pylons are tied back to the anchor blocks with two steel pipes for each tower, which eliminate axial deformation.

The cables are 84mm-diameter locked-coil strand; the hangers, which are spaced every 3m, are 16mm-diameter seven-wire strand.

These elements were designed with fatigue considerations, so that the maximum force will be less than 45% of the breaking force; for the main cable the breaking force is 7,045kN, and for the hangers it is 240kN. The cables are protected against corrosion by the use of galvanised steel.

Four steel towers were built from



The new bridge in its World Heritage setting; the slenderness of the design is intended to complement views of Toledo

rigid steel box section, two on each bank. They are made encastre at the bottom, using steel prestressing bars to attach them to the foundations. The box section has additional steel plates to increase its transverse stiffness, since there is no bracing between the pylons. A special steel element was designed for the top of each pylon, to which main cables and back-stays are connected.

To minimise horizontal deformation at the top of towers, they are designed using elements with the same steel section, hence increasing axial stiffness. Each tower is connected to the foundation by a pair of tie-backs formed of steel pipes with a diameter of 220mm and a thickness of 20mm.

They are made of the same type of steel as the rest of structure, S-355, and each has a maximum force of 2,000kN under service loading. The pipes are anchored to the foundations using a special double steel T-beam element.

The deck is a composite box section consisting of a steel box section with 800mm webs, 2m bottom plate and 300mm top flanges. This is covered by a 6m-wide, 150mm thick brown-coloured concrete slab. The connection between the concrete and the steel is made with studs; they are 16mm diameter and are placed 150–200mm apart. They are closer together near the bridge supports due to creep, shrinkage and temperature effects.

The box has longitudinal stiffeners at the bottom and transverse stiffeners every 3m, corresponding with the positions of the transverse beams.

The deck is built using steel S-355

and concrete grade C-35/40. The presence of the concrete slab improves the aerodynamic behaviour of the structure by increasing its weight and transverse stiffness.

The anchors for the tie-back pipes consist of prestressed steel bars 20m long which are anchored into the ground. The bars have a diameter of 36mm and a total prestressing force of 400kN in each one. There are 12 steel bars for each pair of tie-back pipes, to ensure that the ground below the foundation is always in compression.

All construction took place without encroaching on the river, an important factor in terms of protecting the environment. The first stage was to install the piles and the rest of the foundation elements. After that, the anchorage was installed in the ground.

Once the concrete foundation was finished, the steel structure could be installed. First the four towers were lifted in a single elements, using a 200t crane. The tie-backs were then installed, to allow the main cable to be erected. Cable erection was a very simple process, although the hangers were connected to the main cable before it was installed, to avoid any work having to be carried out in the river. The locked-coil cable was slowly unwound from its reel and lifted up over the provisional saddle that was placed at the top of the tower. Once the cable had been passed over the south tower it was pulled to the north tower.

A special steel element which uses prestressed steel screws was designed to connect the hangers to the main



Erection of the bridge superstructure

cable. Prestressing forces had to be applied in two stages; the first stage with only the cables installed, and the second when the full permanent load was applied, in order to take account of the Poisson effect.

The deck was built in five segments; the steel box sections were the only elements that were transported from the steel factory. The transverse beams were connected to the box section before the whole thing was erected and installed on the cables.

Once all five steel box segments were placed they were connected, and then the concrete slab was constructed in situ over the steel section. Before the bridge could be opened to the public, a load test was carried out to check its structural behaviour. A significant dead-load was imposed along the main span – it was more than 1,200kN, which represents half of the design load.

The maximum vertical deflection of 130mm occurred with only half the main span loaded, as predicted by the computer model.

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