Vidalta Cable-stayed Bridge

Leonardo FERNÁNDEZ
Ph. M. Sc. Civil and Structural Engineer
Carlos Fernández Casado, S.L.
Madrid, Spain
cfcsl@cfcsl.com

Lucía FERNÁNDEZ
M. Sc. Civil and Structural Engineer
Carlos Fernández Casado, S.L.
Madrid, Spain
luciafm@cfcsl.com

Antonio CANO
M. Sc. Civil and Structural Engineer
Carlos Fernández Casado, S.L.
Madrid, Spain

José CUERVO
Civil Engineer
Carlos Fernández Casado, S.L.
Madrid, Spain

Summary

The Vidalta Bridge is located on the outskirts of Mexico City, in a very deep valley with special conditions, which led to the creation of a unique cable stayed bridge.

Fig. 1. General view of the bridge

The total span between the building, where the bridge starts, and the opposite edge of the valley is 240 m, with the possibility of locating a support at 60 m from that first edge, so therefore the bridge is split into two spans of 60 and 180 m. Because of that, the stay tower has been inclined to reduce this difference, splitting the deck in two spans of 161.5 and 78.5 m.

This difference between the two spans has let to the smallest span being heavier by means of using a concrete section, and the another span lighter with a steel box section, to compensate the forces in the stays and achieve a balance in the tower.

A polygon of forces is created between the different elements of the bridge: towers, stays and deck, which is closed with a diagonal beam joining the foundation with the shorter span’s edge, achieving the global balance of the structure.

This bridge is the recipient of the 2013 Post-tensioning Institute (PTI, USA) award of Excellence.

Keywords: Cable-stayed bridge, concrete, steel, inclined tower, free cantilevers construction.

1. General outline of the project


Fig. 2. Upper bridge view

The Vidalta bridge crosses a great gorge in Mexico City, giving access to a group of dwellings situated on one of its edges.
The first requirement of the project was to alter the gorge as little as possible, and for this reason it should have only one support in the gorge, located close to the dwellings, in order to leave the gorge open and unshadowed. This support has given rise to a bridge with 60m and 180m spans.
The dimensions of the main span and the need to maintain as much light as possible coming into the gorge led us to seek a structure with the slenderest possible deck, in order to make the bridge as light as possible. This is achieved by a superstructure solution (suspension, cable-stayed or arch) and, from among those, the cable-stayed solution appeared to us the most appropriate.
The formidable difference between the spans of the bridge- the main being thrice that of the lateral- was the chief problem which the project presented; due to the difficulty of balancing the forces acting on the structure- especially those due to the stays- that this would lead to. Thus, to reduce as far as possible the difference between the spans, the tower located between them has been inclined towards the principal span in such a way that it supports the deck, and divides the spans a little more equally: 78m and 162m.
The deck has a width of 10.7m, which permits two lanes of traffic, and is stayed at the edges from the two pillars which form the tower, which is gently inclined transversally to the deck, framing the geometry of the stays, deck and tower; and which opens the drivers' view and reduces the feeling of confinement created by the two lines of stays. In each of these lines there are two sheaves of stays, the fore stays and the back stays, and the stays in each sheaf are parallel to each other.

2. Structural scheme of the bridge

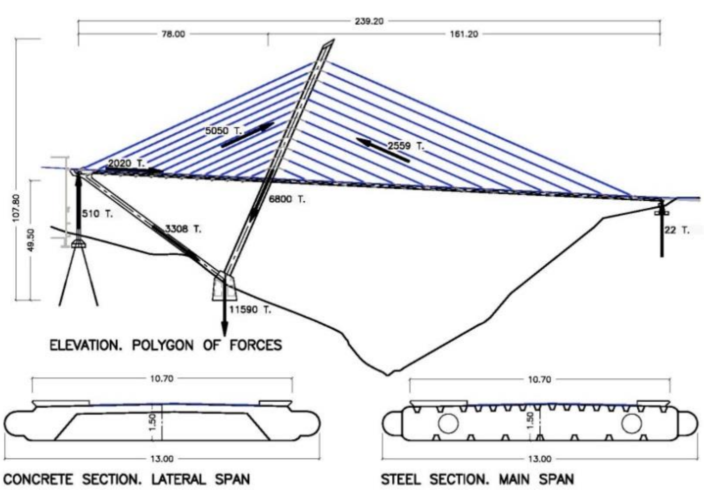

Fig. 3. Polygon of forces diagram

A basic prerequisite of cable-stayed bridges is that the resultant forces of the fore stays and the back stays should be balanced, giving a resultant force which coincides with the tower axis. However, in this case the tower resultant force is inclined and for this reason has a horizontal component, equal and opposite to that which appears in the deck, because the forces which the stays produce in the deck are equal and opposite to those produced in the tower. Due to this there is an unequal force on the deck, which had to be transmitted to the ground. The best solution is to lead it to the base of the tower, because, when combined with the tower's resultant force, the force transmitted to the foundations is vertical. This transmission has been achieved by means of a strut which joins the base of the tower with the end of the compensation span, where two vertical piers abutting the buildings are also situated. This completes a polygon of forces which balances the system formed by the tower, the stays, the deck, the strut and the vertical piers together with the other two deck bearings, the bearing on the tower and the one on the end of the principal span over the abutment. The bearings over the tower and over the abutments are sliding bearings, and the bearing at the end of the compensation span is fixed between the deck and the strut.

3. Materials

We have seen that one of the basic prerequisites of cable-stayed bridges is that the forces in the stays are at equilibrium in the tower, which defines the load on the compensation stays, due to the loads of the fore stays.

Another prerequisite of cable-stayed bridges is that the vertical components of the forces of the stays are balanced by the weight of the bridge, to minimalize its bending moments. However, this balance cannot be achieved if the spans of the bridge are unequal because one weighs more than the other. The only manner to achieve balance, in such a case, is to alter the weights of the spans, making the longer lighter and increasing the weight of the shorter. This is why, in this bridge, the main span is made of metal and the compensating span of concrete. The structure of the metal span is formed of a box-girder of dimensions required by the acting forces. Once the size, and therefore the weight, of the main span girder has been determined, the dimensions of the concrete deck section are calculated so that its weight balances that of the main span, and thus is the equilibrium of the structure achieved.

The tower, the strut, the vertical piers, and the abutment are also made of concrete. The deck, the strut, and the vertical cylindrical piers will have prestressing steel. The tower and the abutments will only have reinforcement.

4. Description of the bridge

Fig. 4. General view of the bridge

The bridge is composed of three principal elements: the deck, the tower and the strut. The ends of the deck are supported on the cylindrical piers and on the abutment.

4.1 Deck

The deck is 10.7m of usable width, extended on its two edges with semi-circular plates where the stays are anchored; it has a depth of 1.5m. Longitudinally it is divided into two clearly distinct stretches, the metal and the concrete, although its depth and the form of the edges is the same, so that there is a continuity of form throughout the whole deck. The only difference is the material.

The metal deck is a box girder extended with the elements for anchoring the stays, with diaphragms each 3 meters, and metal trapezoidal longitudinal stiffeners above and below, with the necessary separation on the upper part to make a orthotropic plate to carry vehicles. The stays are anchored in the lateral elements of the girder, in tubes which transmit the forces to the girder through diaphragms.

The concrete deck is formed of two longitudinal beams at the edges, joined by an upper slab and prestressed transverse beams. As we have seen, the size of the concrete section is governed by its weight which must be sufficient to balance the vertical forces of the stays. These are anchored in the same places in the concrete section as they are in the metallic section.

Fig. 5. Bridge under construction. Steel deck

An especially complex element of the deck is the end node where the deck, the strut and the vertical piers, come together. The three elements are prestressed because the piers have tension, and the strut and the deck have bending moments.

The connexion of the concrete deck and the metal deck is to be found at two meters from the deck support on the tower, with a connecting section 3m's in length where the metal girder is concreted internally, and both materials are connected to transmit the forces, particularly the axial force, of the steel section to the concrete section.

4.2 The tower

The tower has a total length of 106.6m, and a height over its foundations at the upper end of 97m of which 38m is from the foundations to the deck supports over the transverse beams, and 59m from the supports to the top of the tower. It is formed of two pillars inclined towards the principal span in the vertical plane of the axis of the bridge, and slightly inclined outwards transversally to the deck. They are joined by a transverse beam which supports the deck.

The pillars have an almost square cross section with sides of 3m with an inset on the faces from which the stays extend. It has a hollow section with an interior space of 1.5 x 2.3m in which the stays are anchored. Between each level of anchors, the interior space has prestressed diaphragms which join the faces of the anchors. These are to reduce the transverse bending moment of the sides of the girder.

The cross section of the pillars is constant throughout their length except for a narrowing at the level of the transverse beam and the deck.

The longitudinal reinforcement of the tower is passive throughout its length. The transversal is strengthened by prestressing bars, which resist transverse tension generated by the stay anchors.

4.3 Strut

The strut is comprised of two inclined beams, of square cross-section, of sides 2.2m and a length from its foundations to the node of the deck and the vertical piers of 69.5m. It contains a hollow with a diameter of 1.1m and a principle prestressing to resist the dead load bending moment due to its span.

4.4 Vertical Piers

Fig. 6. Frontal view of the bridge

The vertical piers are two cylinders of 1.5m in diameter which support the node of the deck with the strut. These piers are necessary for the equilibrium of the system because the horizontal force, as we have seen the deck generates, is dissipated in compression on the strut, and in tension on the vertical piers so that the sum is equal to horizontal force of the deck. For this reason the piers have prestressing throughout their length to the foundations, which in turn are anchored to the earth, by means of prestressed anchors.

4.5 Foundation of the tower and the strut

As we have seen, the resultant of the axial forces of the tower and the strut is vertical and is transmitted to the foundations. The foundation is direct with a depth in the earth of 8m due to the slope of the land, and it is achieved by means of a box girder which supports the tower on one side and the strut on the other. The base of the support has a surface area of 17x10 m.

4.6 Bearings

As we have seen, the joint of the end of the deck with the strut and the vertical piers is a rigid node where the system of forces within the structure is in balance.
The deck, as well as by this node, is supported on the transverse beam which joins the two tower pillars, and on the abutment at the end of the deck.
The deck bearings over the tower are sliding, and there are two horizontal bearings over the transverse beam to transmit the vertical load, and two vertical ones between the lateral edges of the deck and the tower pillars, to resist the traversal horizontal forces which are generated in the deck by earthquakes.
The deck support over the abutments is oblique, which gives rise to compression and tension loads. For this reason the supports have been made of metal struts anchored in the deck and the abutment which allow longitudinal displacement, and compression and tension loads. As well as the struts, vertical bearings have been placed on the edges of the deck, just as in the tower, to resist transverse horizontal forces due to seismic events.
Structural resistance to transverse seismic effects is by means of the rigid connexion at the end of the deck and through the bearings on the tower and the abutments. The longitudinal effects are met by means of the same polygon of forces which balance the horizontal loads on the deck.

5. Construction sequence

The uniqueness of the bridge structure has necessitated a similarly unique process of construction to maintain the equilibrium between the partial structures. The stages of this process have been the following:

1. Construction of the foundations and the vertical piers.
2. Construction of the struts over a formwork.
3. Construction of the first section of the tower, from the foundations to the level of the deck. It was built using climbing formwork and, to resist the forces caused by its inclination, it was stayed at various heights from the struts.
4. Construction of the concrete deck over a formwork supported on towers over the struts which in their turn would transmit the load to the earth through lower towers.

Once the prestressing of the deck was finished, it was left supported only by the vertical towers.

5. The erection of the metal deck, the construction of the upper part of the tower and the installation of the stays.

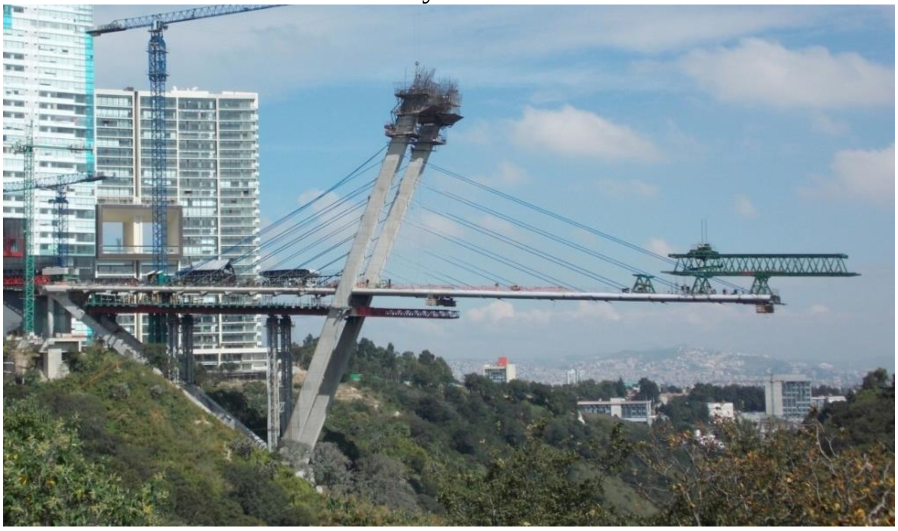

Fig. 7. Bridge under construction

The metal deck was built by free cantilever system from the tower to the opposite abutment in sections of 6m in length. The stays were anchored every 12m and for that reason alternate sections are stayed.

The erection of the metal sections, the construction of the upper part of the tower, and the installation and tensioning of the stays was done in cycles which required the construction of 4.38m of the tower, the erection of two 6m metal sections and the installation and tensioning of one pair of fore stays and one pair of back stays.

This cycling was essential, because, as in all cable stayed bridges, a free cantilever requires staying as soon as possible to reduce the forces acting on it. And in this bridge, in particular, the inclination of the tower did not allow the construction to advance without the stabilising effect of the stays.

To finish, the free cantilever was fixed to the abutment and the bridge’s construction was complete.