Basarab Cable Stayed Bridge in Bucharest

Javier MANTEROLA
Pr. Dr. Civil Engineer
Carlos Fernández
Casado,S.L.
Madrid, SPAIN
jmanterola@cfcsl.com

Antonio MARTÍNEZ
Dr. Civil Engineer
Carlos Fernández
Casado,S.L.
Madrid, SPAIN
amartinez@cfcsl.com

Sivia FUENTE
Civil Engineer
Carlos Fernández
Casado,S.L.
Madrid, SPAIN
sfuente@cfcsl.com

Summary

Basarab cable stayed bridge is part of Basarab Flyover Bypass in Bucharest, and consists of a road, a tramway and a multimodal station. The length of the main span is 168 m supported by one pylon. The main span holds a covered tramway station. The fact that the bridge crosses over the tracks from Basarab Railway Station was critical in the construction of the deck.

The most demanding action for the bridge is the seismic load requiring the use of an innovative combination of seismic isolation devices: viscoelastic damping devices located both at the main tower and at the main abutment and hysteretic devices on the ramp abutments.

Keywords: Cable-stayed bridge. Tramway Station. Steel-concrete composite bridge. Incremental launching deck. Seismic isolation devices.

Fig. 1 General view of the area of the bridge

1. Introduction

The structure is a cable stayed bridge, with a 168 m main span over several railway tracks, and a railway and underground station, with a secondary viaduct attached to the central part on either side beyond the station.

The main viaduct is 365,5 m long, and is made up of the following spans: 56,5-75-168-36-30 m. The first two spans serve the purpose of balancing out the main one.

Two secondary ramps stem from the center of the main span. The first two spans of each ramp are an integral part of the main bridge whereas the rest are concrete slabs separated by joints located in special piers.

The decks of the main bridge and the first spans of the ramps are composite decks, whereas the final part of the ramps, piers, pile caps and piles are made of reinforced concrete.

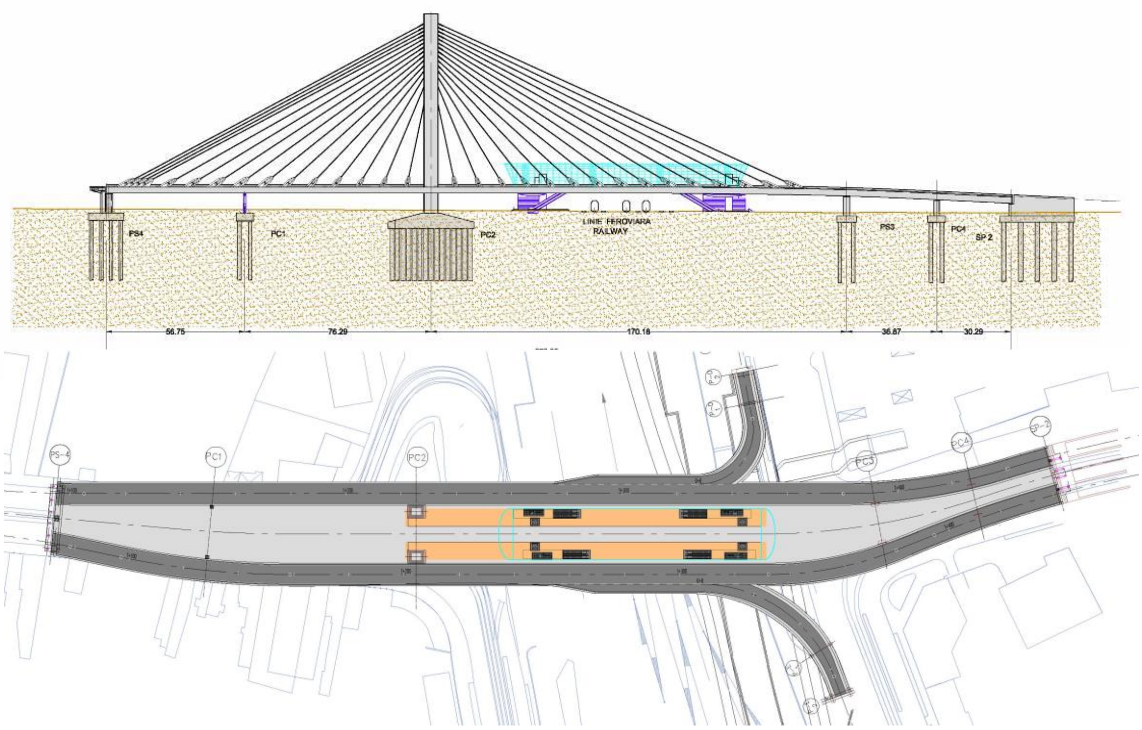

Fig. 2 Elevation and plan view of the bridge

4. Deck

4.1 Cross section

The cross section consists of two lateral carriageways and a central pedestrian platform with two tramway tracks.

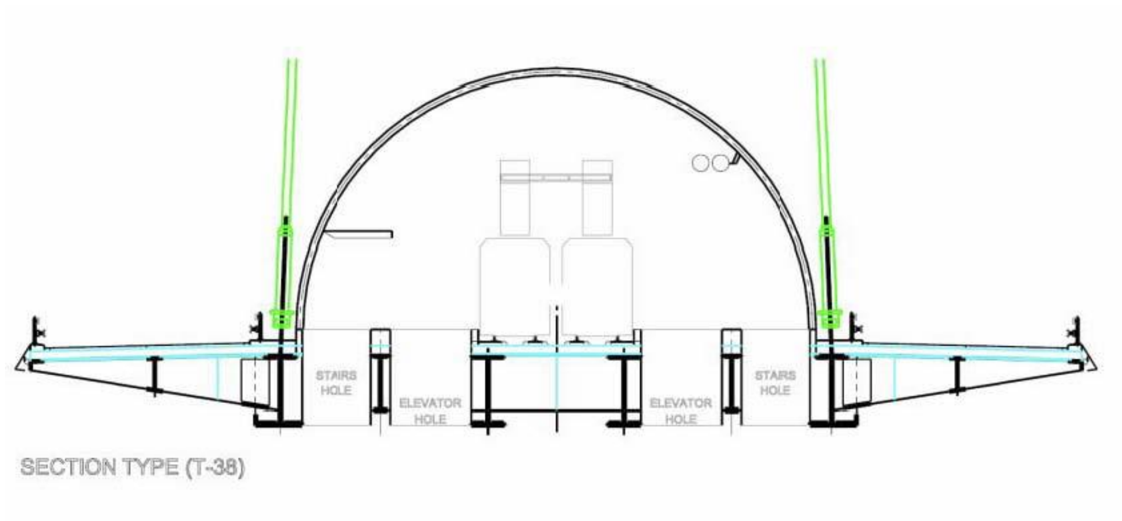

Fig. 3 Cross Section

There are 15 pairs of stays on each side of the pylon, anchored along the median strip between the road and the tramway a 10 metres.

The central part of the main span holds a covered tramway station. At this very same point the carriageways become wider because of the entry of an additional lane from the ramps.

The total width of the bridge is variable from 37,9 to 43,40 m in the central part, and narrows down along first and last spans at the end of the platform.

4.2 Grid

The structure of the deck of the cable stayed bridge consists of two continuous steel girders 2,5 m deep along the axis of the anchorages of the stays. It also features 77 orthogonal steel beams 5 m apart, which is the opening of the slab. The depth of cross beams is 2 m between the two girders and varies along the cantilever which is approximately 10 m long.

This grid is very convenient in this case as it easily solves the holes in the deck adding several secondary longitudinal girders to span station stairs, escalators and elevators, as well as the tower.

The composite ramps are box girders with depth varying from 2,00 to 0,65 m. The concrete slab is 0,35 m deep.

Fig. 4 Scheme and photograph of the steel grid

4.3 Special areas

Three special areas can be distinguished in the deck: around the tower, the area of stairs and elevators and the intersection with the ramps.

The deck is pinned at the tower. The main girders turn to surround the legs of the tower and the concrete slab has a hole so the tower can go through it. The deck is transversally fixed in every case, and longitudinally fixed for service loads and damped for the ultimate state of seismic load.

The damping devices are anchored to two longitudinal short beams connected to the slab, and they transmit the load to a transverse brace that ties the pylons under the deck. This cross beam also receives transverse forces through a key that stems from the deck.

Vertically the deck is supported on the pier through two sets of neoprene-teflon bearings lying on corbels which also prevent the deck from lifting.

In the area of the station intermediate secondary girders span the holes of the station where cross beams are interrupted, and another exterior beam is needed to support the cantilever.

In the special area that corresponds to the intersection between the main deck and the ramps a truss is used to resist horizontal forces.

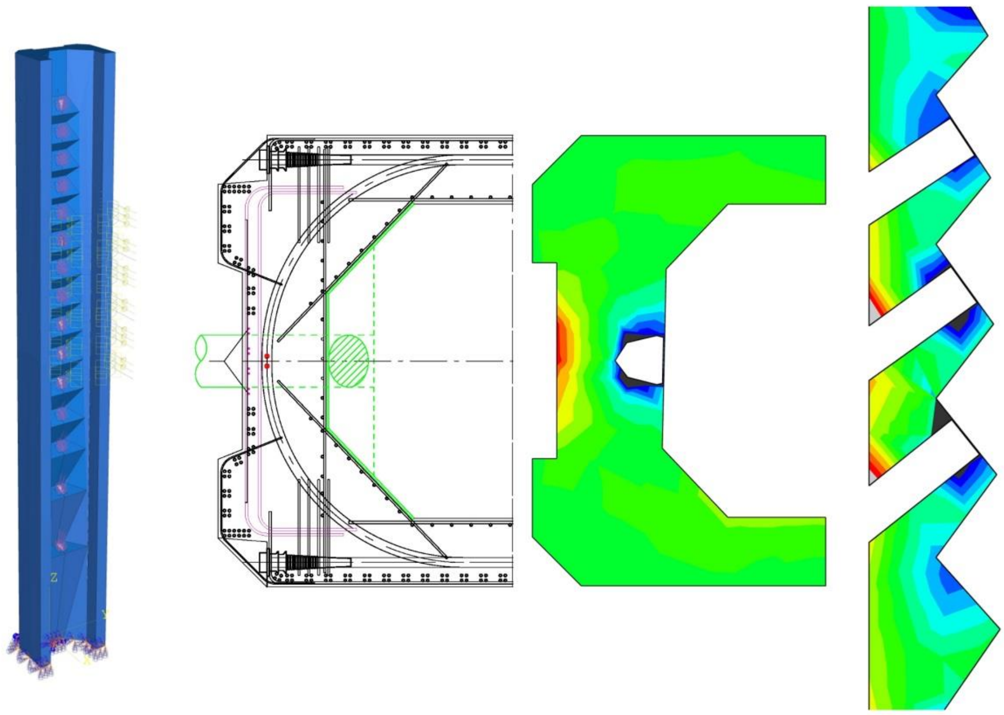

Fig. 5 Pylon 3D finite element model

5. Pylon

5.1 Elevation

The tower, pier 2, is 80 m high and it is formed by two hollow legs braced by a prestressed concrete girder under the deck, and three pairs of hinged, steel girders in the top part.

The foundation is asymmetrical, constrained by preexisting utilities for city services. It is a deep foundation with 52 piles 1,80 m in diameter.

5.2 Bearings at the tower

Transverse bearings are located in the centre of the lower beam.

There are also four mechanical fuses that work as fixed supports for service loads and break when the reaction reaches 1000 tons to let the damping devices function.

These are placed between the diaphragm of the deck and the concrete brace below it, and designed to support 250 tons each.

5.3 Stay anchorages at the tower

Stays need to be prestressed from the tower, and therefore the interior size of the tower is considerable.

A transverse presstressing is required to balance the effect of the local loads on the walls of the tower.

Also the left stay anchorage axis of the deck is aligned, whereas the right one is slightly curved. This effect introduces unbalanced transverse forces in the pylon.

A complete 3D finite element model with brick elements was developed to control the stress level and reinforcement of the tower.

To simplify the laying out of the stays a metal box was used as a lost cofferdam.

6. Piers and abutments

6.1 Pier-Abutment PS4

The pier-abutment where the structure begins consists of a concrete frame that supports at one side three slabs 1,60 m deep of the previous viaduct, and at the other, transverse forces of the cable stayed bridge. The brace has a hole to locate transverse bearings.

As it works also as a truss of the cable stay bridge, a hinged steel pier is located inside each leg of the frame. These hinges support 2000 tons in tension each one and allow longitudinal movements.

The pier foundation consists of 24 piles 1,50 m in diameter.

6.2 Pier 1

Pier 1 are two steel piers, hinged in both directions so longitudinal and transversal displacements are allowed.

The clearance needed for the tramway limited the size of pier 1. This is the reason why no transverse forces could be supported there. It consists of two steel piers hinged in both directions allowing longitudinal and transversal displacements.

6.3 Piers 3 and 4

Piers 3 and 4, the ones outside the cable stay area, are concrete frames, each one composed of two legs and a brace.

The vertical forces of the deck are supported by sliding bearings, which can support tension due to the seismic loads.

A mechanical anchorage that emerges out of the diaphragm of the deck goes through the brace of the pier and transmits the transversal loads to this brace with another pair of bearings allowing longitudinal movements.

6.4 Abutment 2

The deck is also transversally fixed at the abutment in the same way.

The abutment also supports a longitudinal force of 3000 tons due to seismic forces. Eight longitudinal damping devices of 375 tons are placed to reduce the seismic loads.

The abutment is piled with 25 piles with a diameter of 1,80 m

6.5 Composite ramp piers

The first pier of each composite ramp is a concrete pier with one sliding bearing that can only support vertical loads and allows longitudinal and transverse movements.

At the second piers of each ramp both decks, composite box and concrete slab are supported independently. These consist of concretes pier followed by a concrete wall between the decks where the joints are located, one at each side of the wall.

The steel box is supported by a single bearing, and a steel brace embedded in the pier pins the girder for traction forces. The concrete girder is supported by two sliding pots for vertical loads, and a brace with two sliding bearings placed vertically for transversal forces. A special design has been developed for these piers.

6.6 Concrete ramp piers

The rest of the piers in the ramps are concrete piers with sliding bearings, that can transmit tension forces, and a block that fixes the girder transversally with two more bearings.

The abutments of the ramps are provided with sliding bearings to support transverse and vertical forces of the deck.

Two hysteretic damping devices of 175 tons each will be placed at both abutments to reduce longitudinal forces.

Left ramp is founded on the retaining walls of the subway through auxiliary slabs. The shape of the piers helps to reduce the sectional forces of this beam. The depth of the beam is limited by the tunnel clearance. The span of the ramp is 11 meter long to minimize reactions.

7. Calculation

7.1 General model

Two different finite element models have been developed: A bar element model for the global structural analysis and another one in which the grillage of the concrete slab has been substituted by shell elements to fit the structural behavior. This second one has been used to check the first one and to obtain the reinforcement of the slab.

7.2 Tower

The tower has been modeled with a complete solid element model to analyze the local effects of the anchor plates and to design the needed transverse presstressing and reinforcement.

7.3 Seismic effects: loads and supports

Seismic loads govern the design of the substructure. The acceleration is 0,86 g up to a period of T=1,6 s

The bridge is longitudinally fixed to the tower for service loads, and supported with damper devices at the tower and the abutment for seismic loads.

It is transversally fixed at every support except P1, which is a steel strut, and the first piers of the ramps.

It was not possible to fix the composite ramps to the piers because the mass of the main bridge would have lied on these piers through the ramps boxes.

For that reason the ramp provokes a local vibration mode that produces transverse bending moments in the deck that dimension the box.

The secondary ramps follow a similar scheme with damping devices at the abutments and transversally fixed at piers and abutments.

Seismic effects have been analyzed according to the Romanian Standard carrying out a multimodal spectral analysis based on the design spectra tested with a non linear dynamic model including the damping devices.

With the use of these devices the longitudinal forces are reduced by 75% with 15 cm of displacement.

It has been verified that a damping device that works only in the longitudinal direction reduces all the forces that come from a mode with longitudinal component, including the transverse forces.

8. Construction stages

Fig. 6 Construction of the deck by incremental launching

The following scheme was followed:

1. Incremental launching of the main deck from PC2 to ramp intersection. This was neccesary to avoid provisional supports between the railway tracks.

2. Construction of the rest of the steel with provisional supports.

3. Prestressing of cable stays to balance the weight of the steel and removal of provisional supports along the cable-stayed zone.

4. Placement of preslab and cast of the slab in stages of 10 metres at each side of the tower up to PS4 and 20 metres before PC3 where the last stay is anchored.

5. Preslab and cast from last stay to SP2 with provisional supports along this area.

6. Removal of provisional supports from PC3 to SP2

7. Second prestresing of stays up to final forces of the stays.

8. Construction of the station

Fig.7 Final aspect of the bridge from one of the ramps

9. Conclusion

The most significant features of the Basarab Cable-Stayed Bridge are:

- A main span 168 m long
- The need of supporting a tramway station, and two road carriageways with a maximum width of 43.40 m.
- A steel-concrete composite deck that has to support the access ramps with a singular layout.
- High seismic loads in Bucharest area that required the use of an innovative combination of seismic isolation devices: viscoelastic damping devices located both the main tower and the main abutment and hysteretic devices on the ramp abutments.
- Its location over the tracks of Basarab railway station demanded an incremental launching construction of the deck.