The Three Santiago Calatrava Bridges in Reggio Emilia, Italy

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Abstract

The three bridges in Reggio Emilia are singular steel structures designed by the Spanish engineer and architect Santiago Calatrava. These infrastructures are important links between the busy motorway A1, which links Milan to Bologna, passing the city of Reggio Emilia.

The main structure is the central bridge that spans the motorway mentioned above and the adjacent railway. There are also twin bridges across two roundabouts next to the main bridge. Specifically, one across the south roundabout connects with the motorway, whereas the north one allows the connection with the exhibition center and the new railway station *Mediopadana* (*Fig. 1*).

The three bridges have played an important role in the urban regeneration of the city and were inaugurated in October 2007.

Keywords: Santiago Calatrava; Italy; bridge; steel; cable; stayed; arch.

Introduction and General Description of the Bridges

The central tied arch bridge is 230 m long, with a 218 m clear span, and is 27 m wide made of 4000 t of S355 steel. The deck is supported by 50 pairs of cables and carries two lanes of traffic per direction and a footpath with glass pavement at each side.

The deck is a trapezoidal single-cell closed box girder from which cantilever ribs spring every 3,5 m to configure an overall 27 m wide deck (including lateral parapets). The box girder is made of plates of 30–60 mm thickness. The running surface for the vehicles is a steel orthotropic deck made of a 14 mm plate with open longitudinal stiffeners of 20 mm (*Fig. 2*).

Fig. 1: General view of the bridges

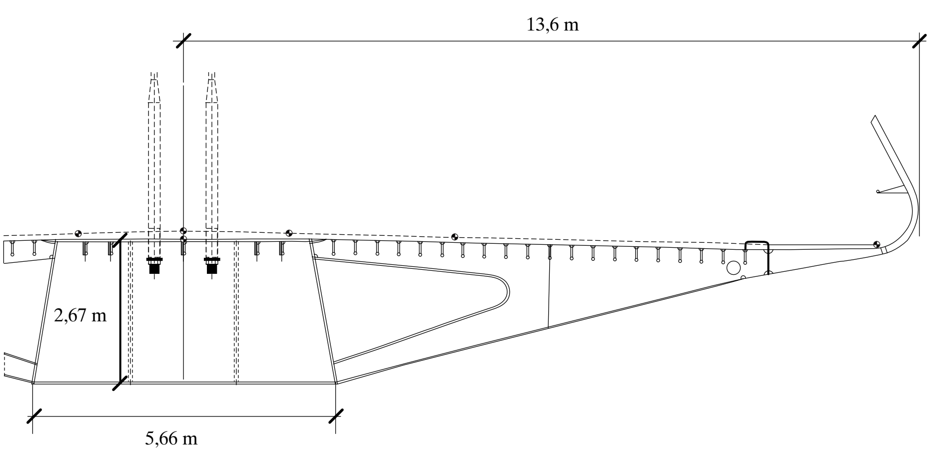

Fig. 2: Cross section of the central bridge

The arch, which rises over 45 m above the deck, consists of two four-sided trapezoidal boxes with 1,02 m distance between them. Both boxes are intermittently connected, which contributes significantly to the behavior of the arch for lateral buckling. It has to be noted that the inner face of each box is a truss and not standard plate. Therefore, depending on the stiffness being considered, the arch acts either as two partially closed boxes or as two partial channels. In addition to the architectural benefit, the arch is easy to inspection and maintenance during the service life of the bridge. The plate thicknesses of the arch range between 30 and 65 mm.

The 44 mm diameter cables of the main bridge are locked coil type with the fixed anchorage within the arch and the active anchorage in the central box girder. In this way, the torsional rigidity of the structure is predominantly controlled by the torsional stiffness of the central box girder.

In addition to the conventional pot bearings supporting the bridge, there is an absorber device placed at the deck to restrain the bridge longitudinally against the important seismic action of the area.

The twin bridges across the roundabouts are cable-stayed bridges each consisting of 1400 t of S355 steel. The central steel pylon is a 69 m high arch and rises 58 m over the platform. The pylon is positioned in the transversal plane to the direction of the bridge (*Fig. 3*) and divides the deck into two symmetrical spans of 90 m. The transversal section of the pylon is a non-regular seven-sided polygon made of 38 mm plates.

The platform is 12,5 m wide and is supported by 25 pairs of cables. It is divided into one lane per direction for the vehicular traffic. The concept of the deck is identical to that of the central bridge, a central hollow box from which two cantilever ribs spring comprises a total 14,6 m wide deck (including lateral parapets). The ribs

Fig. 3: General views of one of the twin bridges across the roundabouts

are spaced longitudinally at 3,5 m centers. The box girder consists of 15 and 22 mm thick plates, and the floor for the vehicles is a steel orthotropic deck made of a 14 mm plate with open longitudinal stiffeners of 20 mm.

The 25 pairs of 60 mm diameter cables of the main bridge are locked coil type and they are anchored from the center of the deck to the pylon making a very original pattern.

Design of the Central Bridge

The central bridge, as a tied arch, is a single span structure with one support fully fixed in the longitudinal direction. The other end has a longitudinally sliding support with a 3500 kN shock absorber (lock-up device, LUD) provided to allow the low-velocity displacements primarily from temperature and to restrain the longitudinal direction for the seismic event. In this way, the horizontal forces from the seismic action are distributed at both abutments.

The main arch is the primary member in the structural scheme subject to direct compression. Many calculations were developed to study the buckling behavior due to the slenderness of the arch, including second-order nonlinear buckling analysis that was undertaken on a two-stage basis. In the first stage, a destabilizing load was applied to the model to invoke an imperfection at the crown of the arch of 270 mm within the geometry.[1] In the second stage, a nonlinear buckling analysis was carried out using the deformed shape from stage 1 as the starting point for the analysis.

In this type of structure, the cables restrain the in-plane buckling of the arch via the hung-deck with the out-of-plane buckling normally more restrictive (*Fig. 4*).

The springing of the arch is one of the main features of the bridge as the large oculus captures the attention of the users. This part plays an important role in the structural scheme as it is the element that transfers all the forces from the arch to the deck. The springing is mainly a box made of thick plates with internal stiffeners to avoid the local buckling of the webs.

The deck is the tie of the structural scheme and as such is the member that is subjected mainly under tension efforts. Nevertheless, the deck works also like a beam supported elastically by each pair of cables because it is the member of the bridge that supports directly the live loads.

The central bridge is supported by two reinforced concrete abutments that carry the reactions from the bridge to the ground by 36 piles of 1,5 m diameter.

The structure was erected taking into account that the traffic flowing along the motorway below should be maintained during the erection. The contractor proposed to launch from one side the deck with large segments of the arch on. The segments of the arch were lifted by means of three temporary towers provided with heavy lifting systems (*Fig. 5*).

Design of the Bridges over the Roundabouts

The twin bridges are cable-stayed structures with a central arch as the pylon of the structural scheme. It is the member subjected mainly to compression and it is placed at the mid-span.

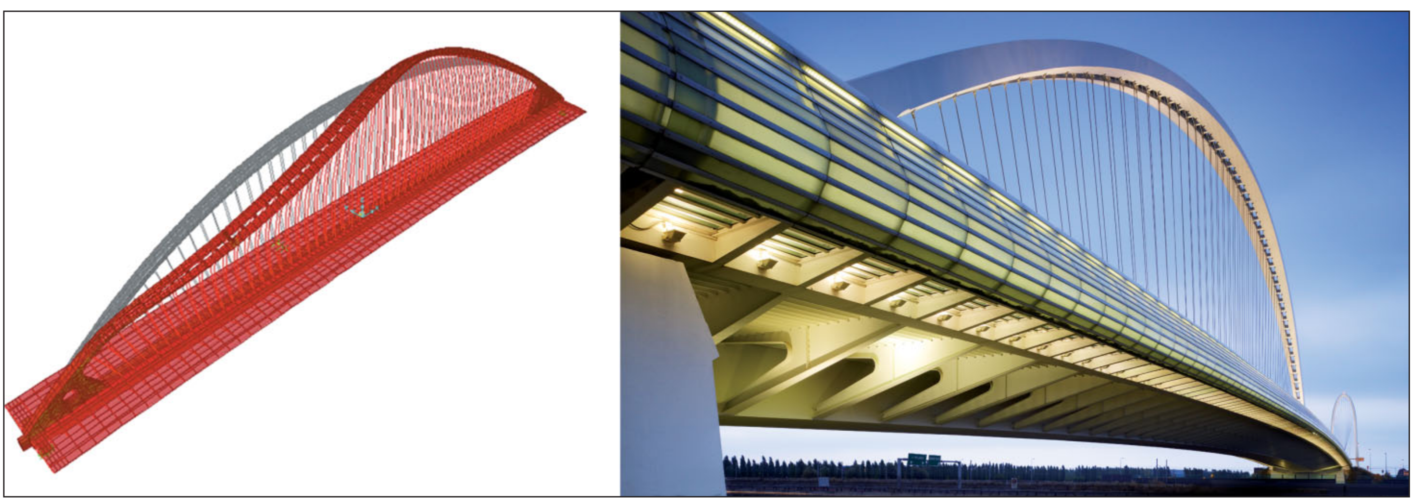

Fig. 4: One of the out-of-plane buckling modes of the arch and general view of the central bridge

Fig. 5: Erection of the central bridge

Both ends of the deck are sliding supported. The central support of the deck at the mid-span consists on a rigid connection with the pylon. This support is the point that restrains the deck longitudinally.

As both ends of the bridge are sliding supports, one of the critical load conditions was the unsymmetrical case of just one span loaded. In this case, the cables of the nonloaded span play the role of back stays. In the typology of bridge under this event, the resisting action is the bending and axial stiffness of the deck and two structural bars are placed at either end of the bridge to take the uplift which comes from the back stays.

For the torsional load cases, the pot bearings (compression-only supports) are also supplied with the couple of bars mentioned above (tension-only supports) placed at both sides of the transversal section. In this way, the torsional forces can be absorbed by taking advantage of the lever arm between one of the bars and the opposite pot bearing. Benefits in the cost of the bearings are also important because uplift-resisting devices are not necessary and the pot bearing can be standard. The bars are anchored to the end of the rib with a slotted pin which allows the longitudinal movements of the deck (*Fig. 6*).

The abutments are made of reinforced concrete and they carry the reactions from the bridge to the ground by 15 units of 1,5 m diameter piles at each abutment. The pylon is supported by means of two pile caps of 42 piles of 1,5 m diameter.

The erection of the cable-stayed bridges was more conventional but not less interesting. The erection consisted of supporting the deck with just two temporary supports. The pylon was erected in three large pieces (two straight legs and the tip of the arch) without any support. Then the cables were installed and putted in tension to remove the temporary supports.

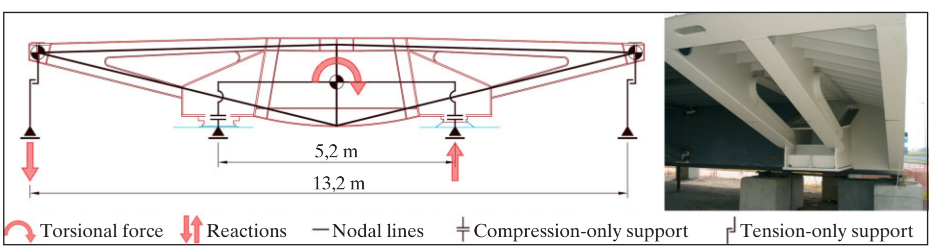

Fig. 6: Support schedule with non-linear elements in bridges over the roundabouts and detail

Conclusions

The paper presents the main structural features of the three Santiago Calatrava bridges in Reggio Emilia. The three S355 structural steel singular bridges have been efficiently designed according to the Italian regulations, although other international regulations have also been consulted. [1]

The use of locked coil cable stays forms a very clear and elegant pattern in the two structural typologies of the bridges.

The two erection procedures of the bridges have been also described in this manuscript. It has to be emphasized that the singular erection of the central bridge deck was launched simultaneously keeping the motorway in service, and the arch was lifted with heavy lifting systems

Acknowledgements

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Reference

[1] German National Standard, *DIN 18 800, Part 2: Structural steel work. Analysis of safety against buckling of linear members and frames*, Deutsches Institut Fur Normung, Berlin, Germany, 1990.

SEI Data Block

Owner:
TAV S.p.A. and Comune Reggio Emilia

Structural design:
Santiago Calatrava GmbH

Contractors:
Rodano Consortile Scarl. (general contractor); Cimolai S.p.A. (steel fabricator and erector)

Steel (t):
4000 (central bridge), 1400 (each twin bridge)

Concrete (m^3):
11 000 (central bridge), 9500 (each twin bridge)

Total cost (EUR million):
18 (central bridge), 8 (each twin bridge)

Service date: October 2007