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HEAVYLIFTING OPERATIONS FOR THE ASSEMBLY OF A 150 M LONG SIMPLY SUPPORTED BRIDGE DECK

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The new viaduct over the Cadiz Bay includes a removable deck to allow the navigation of large floating structures, higher than the 69 m clearance of the main cable-stayed span of the bridge. For this purpose, a 150 m long simply supported span was designed, which can be assembled and disassembled. The steel deck, weighing 4,000 metric tons, was completely manufactured onshore, the challenge being to move such a massive structure to its final position above the piers. It required for several heavylifting maneuvers, such as land transportation and load-out with two 6 × 28 axle lines of self-propelled modular transporters (SPMTs), sailing with a 100 m long barge and positioning the deck in-between the piers with a tight gap, a lifting with eight strand jacks 850 T capacity each and a final transversal shifting. The aim of this paper being to describe all the activities and the heavylifting equipment employed for the assembly of such a massive deck.

Keywords: Lifting, Strand jack, SPMT, Load out, Removable deck, Construction equipment.

1 BACKGROUND FOR THE NECESSITY

After several years in need of a direct access to the old town and the harbor of the city of Cadiz, last September of 2015 the second bridge of the city was completed. One of the main requirements of the 3,082 m long viaduct was to maintain the 400 m wide navigation canal of the Bay of Cadiz. However, this requirement was lately increased by the authorities up to 540 m (Manterola *et al.* 2014). For this purpose, the main part of the viaduct was designed as a cable-stayed bridge, with five spans 120 + 200 + 540 + 200 + 120 m, the main one keeping a free vertical clearance with the average sea level of 69 m (Manterola *et al.* 2014).

This clearance, the second highest in the world just below the Verrazano-Narrows Bridge (Escamilla 2017), although seemed not to be high enough for one of the main shipyards inside the bay. Their reasons were the possibility of manufacturing major vessels and, mainly, structures for the offshore industry (Escamilla *et al.* 2010), such us jackets and top sides, which can be transported vertically. Then, the final minimum clearance was set in 100 m high per 140 m wide (Manterola *et al.* 2014). Impossible to reach with ordinary highway slopes.

The direct solution was an additional span with a bascule bridge, 185 m long (Escamilla *et al.* 2010). However, this solution needs massive piers and special equipment to be opened and closed. And that was thought to be very expensive, both in terms of building and for maintenance, for such an unlikely necessity; a clearance higher than 69 m will be required too few times during the service life of the bridge. Then, the designer (CFCSL) came up with the idea to design a simply supported beam spanning 150 m (Spanish record), which could be disassembled when the real necessity for a higher clearance arose (see Figure 1). It could be temporarily placed on a barge and reassembled when possible, and would generate no vertical limitation. Now the questions were how to disassemble the deck and how it could be built.

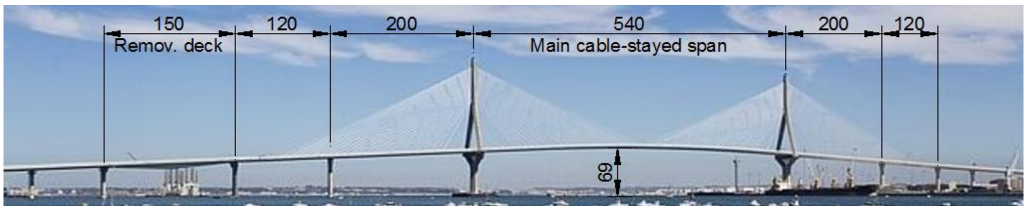

Figure 1. General elevation of the viaduct over the Cadiz Bay.

2 DESCRIPTION OF THE REMOVABLE DECK

The steel structure of the removable deck works as a simply-supported beam, spanning 150 m between piers P9 and P10, and is structurally independent of the rest of the viaduct. It is 145 m long (rest of the length consists of expansion joints), 33.2 m wide and the depth varies from 3 m, over the supports, to 8 m, at mid-span. It consists of a three-cell closed box, divided into a central 10 m wide box and two triangular boxes in cantilever (Escamilla *et al*. 2010).

From the beginning, the designer considered how the deck had to be built and, besides, in accordance with the fact that the structure had to be able to be disassembled. The adopted option consisted of lifting the entire deck by means of a system temporarily set on the piers, in the space left for the expansion joints. So as to ease the operation, the deck was decided not to be supported by the top surface of the piers their selves, but by concrete corbels (two per pier). Therefore, the deck just needed to include some pins (to be connected to the lifting system) and two cuts at every edge to pass through the corbels. Once the deck was above the corbels, it would be transversally shifted, then rested on the corbels. Additionally, the methodology provided a first proof about the feasibility of the assembly and disassembly of the deck in the future.

Following this methodology, the deck was completely manufactured onshore, in a steel workshop close to the final location. The challenge was to move the massive structure, weighing 4,000 metric tons, from that place to piers P9 and P10.

3 MANEUVERS FOR THE ASSEMBLY OF THE DECK

Once the deck had been manufactured onshore, laying on temporary supports, the following three maneuvers were required to install it in the final position: (1) Land transportation from the steel shop to the dock; (2) Load-out to a barge and sea transportation; and (3) Lifting and positioning in the supports of the piers.

3.1 Land Transportation

This activity was decided to be performed by using self-propelled modular transporters (SPMTs). SPMT is a heavy transport equipment consists of a platform over wheels connected by using hydraulic suspensions. Two different modules can be used, in terms of number of axles. They include two suspensions per axle and two wheels per suspension. The capacity of each axle being 36 T. Several modules can be joined together in any shape, both hydraulically and electronically, so as to reach the required total capacity. They are self-propelled and can move and turn in every direction, even 600 mm vertically and 360º horizontally, controlled electronically. They can adapt to any floor conditions, keeping the platform in a desired slope and transferring to the ground a uniform load lower than ten metric tons per square meter.

For this operation, two SPMTs were used, 6 × 28 axle lines (168 suspensions) each. They were connected in a four-point hydraulic configuration, providing a total capacity up to 6,050 T. The total length in plan was 88.4 m, with a width of 8,230 mm.

For transport, the deck would be supported by eight steel beams set on the platform of the SPMTs. Their position matched with diaphragms of the deck and their depth was different, adapting to the slope and expected deflection of the deck. It was required for the beams to be longer than 11 m, as the distance between the webs of the deck was ten meters. Working under simple bending, they would transfer the 4,000 T from the deck to the 8,230 mm wide platform.

With the deck supported by the manufacturing supports and with the transporter beams already set below deck, a weigh-in was carried out. For this purpose, jacks including load cells were installed below the transporter beams, at both edges. After that, they took the weight of the deck, unloading the manufacturing supports, reaching a weight of 3,950 T and checking the predicted offset of the center of gravity from the longitudinal axis (Marti and Salamanca 2015).

With the deck supported by 16 jacks, the manufacturing supports were removed and the SPMTs placed below the deck. Following that, the weight was gradually transferred to the SPMTs and the land transportation started (see Figure 2). After four hours and 1.5 km, the deck reached the quay where a barge was waiting for.


Figure 2. General view of the land transportation with SPMTs (left) and the transporter beams (right).

3.2 Load-Out and Sea Transportation

The first maneuver consisted of loading the bridge on the pontoon. For this, not only was it necessary to deal with the 3 m variable tide, but also with the fact that the SPMTs were gradually getting on the pontoon the freeboard of the barge was decreasing. Thus, an electronically controlled and monitored ballasting system was installed, including 18 pumps, 950 m^3/h capacity each. The ballasting system of the pontoon itself (1,200 m^3/h) was just left as a contingency system, in accordance with the 20% required by Noble Denton 0013/ND, for a "Load-out class 2". The entire system allowed for keeping the elevation and the longitudinal and transversal inclinations of the barge within the acceptable parameters, along an entire tide.

The maneuver was performed in 90 minutes, with sea levels raising, starting two hours before the high tide. The wind speed was required to be lower than 50 km/h and wave height under 40 cm, to provide acceptable conditions (Marti and Salamanca 2015). See Figure 3.

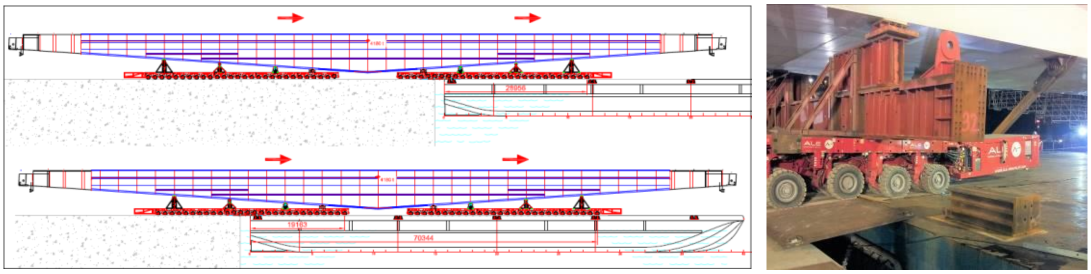

Figure 3. Sketch of two stages of the load-out (left) and picture of the SPMTs reaching the barge (right).

With the bridge already on the pontoon, the sea-fastening system was installed. It fixed the bridge to the barge, resisting the inertial loads during the navigation, meeting Nobel Denton standards. After that, the pontoon, measuring 100 m long, 33 m wide and 7.6 m deep, transported the 145-m long bridge along 3 km, with the help of three tugboats. Once close to piers P9 and P10, the barge was accurately positioned between the piers by means of six winches, with the additional challenge of a limited clearance of 40 cm (20 cm each end).

3.3 Final Lifting

The final maneuver consisted of lifting the deck 33 m, from the barge to the corbels at the top of the piers. As mentioned previously, two lifting systems were installed (one per pier), including two lifting points each. The lifting points were connected to the 345 m in diameter lifting pins of the bridge trough steel strips. See Figure 4.

Figure 4. Strips connected to the deck (left) and strand jacks of a lifting point (right).

Every lifting point comprised two strand jacks 850 T capacity each (see Figure 4.), the total lifting capacity of the synchronized system being 6,800 T. Every jack comprised 54 strands, each 18 mm in diameter, and was placed at the top the lifting frames specifically installed in the piers.

3.3.1 *Lifting frame in pier P9*

The lifting frame installed at the top of P9 comprised several steel beams (see Figure 5). A main 3.30 m high support beam was placed at the top the pier. It was just 975 mm wide, due to the tight space available once the deck had reached its final elevation. Above the support, three 18.5 m long longitudinal beams were installed in cantilever. At the edge of the cantilever, two transversal top beams were set. They included PTFE (polytetrafluoroethylene) pads at the top and two skid beams to allow the final shift. The distance between the skid beams was 8 m, matching with the pins of the deck. Finally, above each skid beam, two 850 T capacity strand jacks were installed.

By the time of the operation explained in this paper, the viaduct behind pier P9 had already been completed. It allowed the installation of a 670 T counterweight at the rear part of the longitudinal beams, to prevent them from overturning. Due to the large thermal movements of the already built viaduct, which would provoke considerable longitudinal loads to the frame (even though a sliding surface between the longitudinal beams and the viaduct had been installed), a swinging system was designed. It allowed the lifting frame to be independent of the counterweight, minimizing the longitudinal loads.

Figure 5. Lifting frame installed in pier P9. The picture at the left shows the deck already installed.

3.3.2 *Lifting frame in pier P10*

A similar structure was installed in P10. The only difference is the way of preventing the system from overturning, as behind P10 no viaduct had been already built. As a consequence, two retaining strand jacks (500 T capacity each) were located at the rear part of the longitudinal beams and fixed to the anchorages previously set in the pile cap of P10. See Figure 6.

Figure 6. Lifting frame installed in pier P10 (left) and anchorage to the pier cap (right).

3.3.3 *Final lifting and adjusting*

Once the strips had been connected to the pins, the strands were individually pre-stressed, controlling the elevation of the barge deck so as to prevent any cable from overstressing.

Starting at low tide and ballasting or deballasting the barge as required, the 4,000 T deck was gradually being loaded on the four lifting points. Meanwhile, the mooring system was gradually being released and the SPMTs adapted to the new deflections of the bridge as a result of changes in the support conditions. Once the bridge was completely hanging on the lifting system (see Figure 7), a random check of some strands was carried out, testing that the real force per strand (not necessarily exactly uniform) was inside the permissible limits pre-established.

Once lifted 2 m, and acting only on the strand jacks of P10, the deck was tilted to reach its final slope of 5%. After that, the deck continued being lifted, passing through the corbels as mentioned in previous sections (see Figure 7), and reached its final elevation seven hours later.

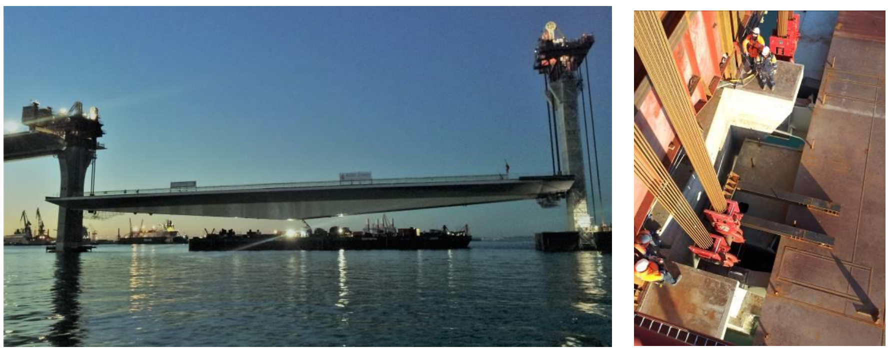

Figure 7. Starting of the lifting (left) and the deck passing through the corbels (right).

The deck was then finally shifted transversally. For this purpose, one skid beam had been installed below each pair of strand jacks, allowing them to slide along PTFE pads placed at the top of the lifting frames. With the help of two push-pull jacks per skid, the deck was displaced 2 m. Once it had been confirmed to be over its final position, it was lowered. The lifting system also had the ability to adjust the deck longitudinally, although it finally was not required. The entire assembly operation of the deck then had been completed in just one week.

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