Challenging Construction and Erection Methods for the Izmit Bay Suspension Bridge and the 3rd Bosphorus Bridge

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Abstract: The paper is based on COWI's present involvement in two major bridge projects in Turkey - the Izmit Bay Suspension Bridge and the 3rd Bosphorus Bridge.

The Izmit Bay Suspension Bridge with a 1550m main span becomes the fourth longest bridge span in the world. The construction of this bridge started in January 2013 and will be completed mid 2016 giving a short construction time for such a large scale bridge project. The tight construction schedule requires a state of the art robust design, well proven but also challenging construction and erection methods ensuring the technical and financial success of the project. The paper describes the project development and the belonging important choices made for the towers, cables and suspended deck during detailed design to optimise the construction- and erection speed.

The 3rd Bosphorus Bridge is another unique bridge with a complex hybrid cable support system combining stay cables and suspension system. Therefore, construction control of geometry and force distribution during the construction stages is more complicated for this bridge compared to more conventional suspension or stay cable bridges. The paper describes the construction engineering assistance provided to the contractor and the computer modelling behind the different construction control activities with belonging supervision.

1 Design and construction of the Izmit Bay Bridge

The Izmit Bay Suspension Bridge is located 60km south-east of Istanbul and carries the new Gebze-Orhangazi-Bursa-Izmir motorway. The bridge consists of a three span continuous suspended box girder having a 1550m main span and two side spans of each 566m making it the fourth longest bridge span in the world, see bridge layout in Fig. 1.

Fig. 1: General arrangement of Izmit Bay Suspension Bridge
Given the short construction time of three and a half years and the fact that the bridge is located in one of the world's most seismically active regions adds to the design challenges. These conditions have amongst other things led to the choice of steel towers, prefabricated cable strands and bolted key connections in the suspended deck and towers.

### 1.1 Suspended deck

The suspended deck consists of a steel orthotropic stiffened box girder with a total height of 4.75m and a width of 30.1m excluding cantilevered walkways with additional width of 2.92m each side as can be seen in Fig. 2. The deck carries a dual three lane highway.

[Fig. 2: Suspended deck cross section]

The design is optimised with respect to weight and fabrication. By increasing the spacing between diaphragms from the normal 4.0-4.5m up to 5.0m, the number of expensive and time-consuming welding details is decreased thus limiting the construction time. Also with the purpose of keeping the thickness of steel plates to a minimum, appropriate steel grades have been applied to different parts of the deck, refer Fig. 3. As seen, high strength steel is utilised at centre of main span, at towers and at the abutments.

[Fig. 3: Distribution of steel grades over half the bridge length (symmetric)]

Choosing a large diaphragm spacing is of great importance to the critical fatigue stress, thus to achieve sufficient stiffness the trough dimensions have been increased accordingly. Although a 60mm surfacing is applied providing additional stiffness and load distribution locally, the composite action has not been taken into account in the design. The key deck dimensions have been compared to other well-known bridge projects and can be seen in Fig. 4 below.
1.1.1 Deck fabrication and erection

The deck is produced in typical sections of 25m only varying at bridge ends and at towers. In total 113 segments are fabricated and trial assembled at CIMTAS in Turkey and transported by sea to the bridge site, see Fig. 5 below. However to speed up the erection in the bridge line the typical 25m blocks were furthermore assembled two and two creating 50m mega blocks before shipment for erection in the bridge line.

The deck is designed with welded trough connections at the construction joints performed in the steel workshop, but bolted trough connections are introduced at the erection joints in order to speed up the sub-assembly process in the bridge line. The skin plates of the girder are welded with a transverse butt weld using ceramic backing, see Fig. 6.

The typical bridge diaphragms are designed as truss diaphragms composed by circular hollow sections (CHS) diagonal bracings connected through bolts to top and bottom beams of the diaphragm. The bolted connection is made with oversize holes in the gusset plates for easy and
fast sub-assembly further contributing to speed up the fabrication process and thus the total construction time, see Fig. 7.

The deck erection is executed using two different approaches. The unsuspended deck segments at the bridge ends and towers have been installed by means of a floating crane (Taklift7) having 1600 tons lifting capacity, see erection sequence 1 & 2 of Fig. 8. The suspended part of the deck has been lifted from a barge by lifting devices mounted on the main cables, see erection sequence 3-6 of Fig. 8. The segments have been lifted in the permanent hanger anchorages, which are located at the segment centre of gravity to avoid ballasting.

1.2 Steel towers
The Izmit Bay Suspension Bridge is designed with two H-shaped steel towers reaching approximately 235m in height. The tower legs are interconnected by two cross beams as shown in Fig. 9 below. The towers are dehumidified.
Steel is utilised as material due to the location in a seismic active region reducing the oscillating mass during an earthquake and thereby the loads introduced in the tower. Using steel also enables the possibility to prefabricate tower segments and stiffened panels increasing the construction speed compared to concrete towers. The tower erection to full height is done in less than 3 months with the two towers erected in parallel.

The tower structural components are generally fabricated from high grade steel S460N/NL to further reduce the seismic mass of the tower and to reduce lifting weight. The tower is designed to be in accordance with Eurocodes section class 2 allowing for plastic deformation under the critical seismic load cases, which governs part of the tower design.

Using high strength friction grip (HSFG) bolted connections for the longitudinal stiffeners inside the towers allow for faster erection since several tower blocks can be installed prior to welding of the horizontal joints in the tower skin plates. This also limits the time for which an expensive floating crane is needed. The erection joint of the tower is shown in Fig. 10, where the bolted stiffener connections are in place before initiating welding of the joint in the skin plates.
Each tower consists of in total 22 blocks. Each of the first 11 blocks are assembled at the fabrication yard and installed using a floating crane. Due to limited lifting height and crane capacity the remaining 11 blocks (block 12-22) are erected panel by panel using a self-climbing crane mounted on the tower lower cross beam, see also Fig. 11.

![Fig. 11: Tower erection.](image)

Block assembly erection from block no.1-11, panel assembly erection from block no.12-22.

### 1.3 Cable works

The two 3025m long main cables consist of 110-112 prefabricated parallel wire strands (PPWS), which after compaction to 20% air voids have diameters of 781mm and 788mm respectively. The PPWS are chosen over the more commonly used aerial spinning in order to shorten the construction time. The PPWS are delivered on site on reels and hauled from a unreeler located at the north anchorage. The hauling system is supported by a tram system which is installed on the catwalk spanning between anchor blocks, see Fig. 12 below.

![Fig. 12: Izmit Bay Bridge catwalk](image)
2 Construction of the 3rd Bosphorus Bridge

The 3rd Bosphorus Bridge is a part of the new Northern Marmara Motorway Project and with a length of 2164m and a main span of 1408m. It is the world's first cable stayed suspension (hybrid) bridge carrying both road and rail traffic. The general layout is shown in Fig. 13.

2.1 General information

![Fig. 13: General layout of 3rd Bosphorus Bridge](image)

The back span girder is a prestressed concrete box cast on scaffolding and the main span is a closed steel box girder, both 5.5m high and 58.5m wide carrying 8 traffic lanes and 2 rail tracks. The main span consists of 2x28 segments each 24m long and 1 key-segment 9m long. Each segment weighs from 820 ton to 965 ton, with the key-segment weight of 360 ton.

The bridge has two expansion joints between the anchorage of back span stay 16 and 17.

The two A-shape towers are 330m high in-situ cast concrete. The main cables are prefabricated parallel wire strands (PPWS) 13.5m apart, 122 strands in back span and 113 strands in main span. The 2x4x22 stay cables are parallel strand system (PSS) 12.7m apart in back span and 48.8m apart in main span. The longest stay is 597m, which is the longest installed stay cable in the world. The 2x2x17 hangers are parallel wire strand (PWS) 13.5m apart. A view of the different cable planes can be seen in Fig. 14.

![Fig. 14: The different cable planes and lift of segment 5 at the European side](image)
2.2 Erection of main span girder

20 of the 22 stay segments on each side were erected as for a normal cable stayed bridge with the deck segments being lifted by two derrick cranes mounted on the deck of the girder. The remaining 2x8 hanger segments and the key-segment were lifted by lifting gantries mounted on the main cables. All segments were transported to the site by barges. Segment 1 to 4 near the towers were first lifted by a floating crane to a set of self-propelled modular transporter and then transported on shore to the lifting position of the derrick cranes. Due to the shoreline, segment 5 and 6 had to be transferred from the floating crane to the derrick cranes in mid-air, refer Fig. 14. The remaining segments were lifted by the derrick cranes directly from barges.

The suspended part was constructed in continuation of the cantilevered stay part, which made the demand on the first suspended segments very high. A system of temporary hangers was introduced used to pull the main cable down towards the deck and segments were lifted simultaneously at the Asian and European side to minimise longitudinal displacements, see Fig. 15.

Fig. 15: Lifting of the first two hanger segments and turntable and lifting gantry

2.2.1 Installation of lifting gantry on main cable

The four lifting gantries were hoisted from the deck to the main cables by strand jacks mounted on the main cables. The gantries were placed on turntables and lifted up in between the two main cables. Due to the position of the lift, approximate ¼ of the length in the main span, the turntable had to be very high (~12m) to be able to rotate the gantries above the main cables. These lifts were very critical operations and because of the closely spaced main cables and the high turntable, temporary hangers had to be installed to stabilise the entire cable system and to minimise deformations of the main cables.

2.2.2 Set-back of tower saddles

The longitudinal movement of the towers during the main part of the construction was primarily controlled by the stay cables and the lifting of the stay segments. The five longest stays in the back spans are anchored in the same solid concrete anchor block as the main cables and during construction, until installation of the key-segment, the expansion joints were fixed, contributing to the stiffness of the back span stays.

To avoid cable slippage of the main cable at the tower saddles, an equilibrium in the horizontal force had to be maintained by applying an initial set-back of the tower saddles of 2.7m. As the construction of the suspended part progressed, the tower saddles were set-forward in total 13 steps varying from 0.40m to 0.05m.
2.2.3 Erection of key-segment

Before installation of the key-segment, the fixed connection at the expansion joints was removed and each bridge side was jacked towards land to make room for the lifting of the key-segment. The two jacking arrangements consisted each of 42 jacks with a total capacity of 210MN per bridge side, see also Fig. 16.

Fig. 16: Jacking arrangement at the European side

Due to the difference in angles of the stay cables between back span and main span and the anchoring of the five longest back span stays in the anchor block, the normal force in the girder is not symmetric around the towers. Consequently, the girder will tend to move towards land if not restrained. At the final joint welding at the key-segment the system of jacks is set to maintain a constant force of 38MN with a tolerance of +/-5% during the welding process.

2.3 Construction engineering assistance and geometry control

COWI provided construction engineering assistance, among other things, to optimise the cycle time for installation of girder segments, which included: lifting of segment, welding of skin plates, welding of u-ribs, stressing of stays and moving of derrick cranes. The final cycle time becomes 7 days. COWI also developed a detailed finite element model including all necessary construction phases, from which results were used to perform geometry control checks.

Fig. 17: Example of results from finite element model. Deflections are measured from the final bridge geometry and scaled by factor 10
The charts in Fig. 17 show the forces in the different cables. To the left is the forces in the stay cables, the middle chart is the forces in the temporary hangers and at the right is the forces in the permanent hangers. Dynamic wind analyses were performed for each phase for two wind speeds. Depending on the activity in the individual phase, either a high erection wind speed of 26.1 m/s or a low erection wind speed of 13.5 m/s is used. The black dots on the charts indicates the cable force due to dead load, the red and blue dots are the maximum and minimum effects of the dynamic wind loads, and the grey lines indicates the total capacity of the cables.

The results were among other things, used to check the complicated erection sequences of the suspended part. The main activities in one sequence was; lifting of segments, welding of segments, installation of temporary hangers, set-forwards of the tower saddles and installations of permanent hangers. The high flexibility of the main cable versus the relative stiff cantilever of the deck resulted in phases in which temporary hangers were stressed/restressed to specific forces to avoid slacking or overstressing of other cables.

2.4 Measuring of hanger forces

After the installation of all hangers based on geometry control, the hanger forces were measured by Taut String Method (vibration method) to ensure correct installation forces. For the short hangers this method however was not feasible as the stiffness of the hangers was too high. Measuring the force by hydraulic jacks was found too time consuming, so instead the geometry of the hanger forks on the main cable was measured. The hanger force was then calculated from the difference in the measured kink and the theoretical target kink between three adjacent forks. In Fig. 18, the kinks in the main cable can be observed, from which the hanger forces was calculated.

![Fig. 18: Kinks in main cables](image)

2.5 Comparison with conventional erection methods for suspension bridges

As described in this paper the erection methods utilised for the 3rd Bosphorus hybrid cable bridge become somewhat more complex when compared with conventional suspension bridges. Erection equipment shall be obtained for two different cable systems with a complicated interaction between them making the entire construction engineering and the erection geometry control much more complex. The girder erection can however be initiated before the towers are completed in full height and for the completed bridge, the deck girder becomes somewhat stiffer being beneficial for the coming rail traffic.