Design of Izmir Bay Crossing Bridge

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Abstract The Izmir Bay Crossing Bridge is a part of a 6.8 km fixed link between Çiğli and İnciraltı regions in Izmir. Total bridge length is 4175 m. Two platforms, which have 21 m width each, will carry three lanes of highway traffic and a light railway system together. The cable-stayed bridge is located over the circulation channel, which has a total length of 590 m and a main span of 270 m. Pylon height is 88.7 m. The cable-stayed bridge will be constructed by free cantilever method and the rest of the bridge will be constructed by movable scaffolding system. The bridge has a post-tensioned box girder deck with a constant height of 2.5 m. It was particularly important during the design process to ensure structural performance of the bridge because of high seismicity and very poor soil conditions at the site. 2000 mm diameter steel driven piles are used for the foundations. First 20 m of the piles are assumed to be laterally unsupported by soil and pile cap stiffness and mass were considered in the global model for seismic analysis.

1 Introduction

Izmir Bay Crossing project was planned and designed under the tender of General Directorate of Highways. The final (tender) design was completed and approved at the end of 2017. The purpose of the project is to reduce the city traffic, to complete the ring road which is currently not forming a circle around the city and connecting the north and south coasts of the Izmir bay. In addition to the highway, a rail transportation system will also be included into the project.

The total length of the fixed link between Çiğli and İnciraltı regions of the Izmir bay is 6.8 km. The fixed link consists of a 4.2 km long bridge, 1.8 km long immersed tube tunnel and an artificial island in between. Immersed tube tunnel will be constructed under the current navigation channel of the Izmir bay. The shallow regions of the bay where the water depths are around 10 m will be crossed by the bay bridge. The location plan of the project is given in Fig. 1.

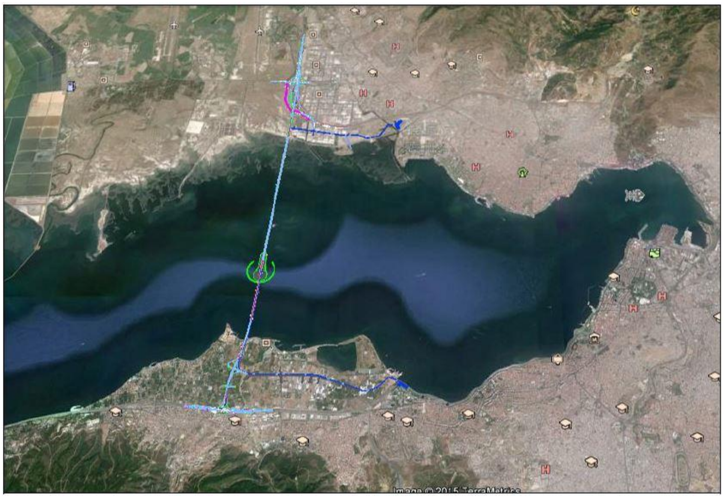

Fig. 1. Location plan

2 Description of the Bridge

Izmir Bay Crossing Bridge is a 4.18 km long bridge which consists of a 590 m long cable stayed central part and two approach bridges. North and south approach bridges have total lengths of 1735 m and 1850 m respectively. Post-tensioned concrete double cell box girder deck is used for the typical spans of 50 m. Cable stayed bridge has a 270 m concrete main span and 160 m side spans with intermediate piers. Deck is composed of two separate 21 m width platforms and is carrying three lanes of highway traffic and a light rail track on both platforms. Deck is connected to piers monolithically and at every 400 m there is an expansion joint. ϕ2000 mm diameter steel driven piles are used for the foundations. Each foundation is supported by 16 piles which have lengths between 70 to 86 meters.

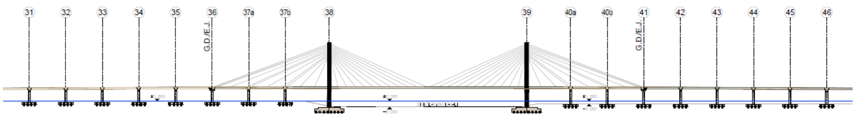

Fig. 2. Elevation view of the bridge (central part)

Fig. 3. 3D view of the bridge (central part)

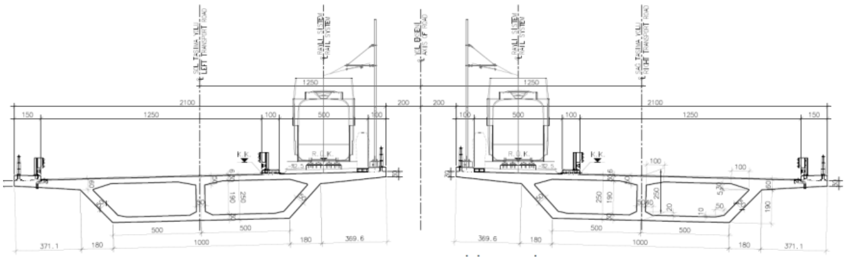

Fig. 4. Typical cross section of the deck

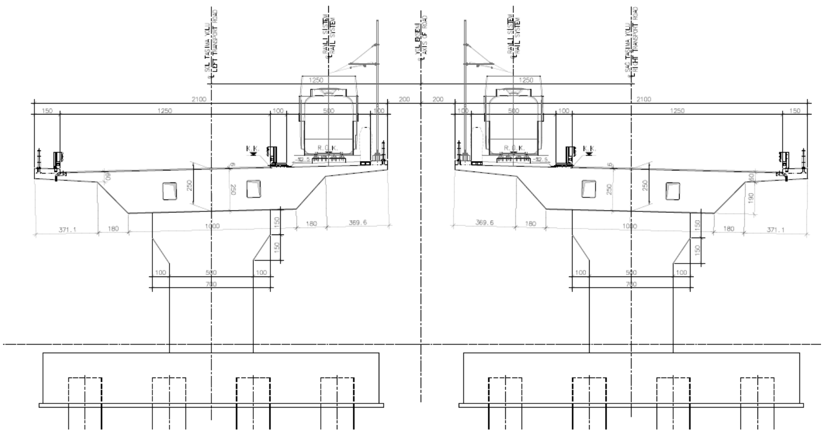

Fig. 5. Typical section of the piers

3 Design Criteria

3.1 Specifications

- KGM, Izmir Bay Crossing Special Technical Specification
- AASHTO LRFD Bridge Design Specifications, 2014
- AASHTO Guide Spec. for LRFD Seismic Bridge Design, 2011
- CALTRANS Seismic Design Criteria, 17th ed.

3.2 Materials

- **Concrete :**
  Post-tensioned deck and pylon : C50
  Piers and foundation: C40
- **Post tensioning tendons and stay cables :**
  Grade 1860, Ø15.7 mm (Low Relaxation), 7 wire (pr EN 10138-3)
- **Reinforcement bars :** Pylon : S500, Other : S420
- **Structural steel :** S355 (EN 10025)

3.3 Live Loads

Standard H30-S24 highway truck loading is used as the design load. For rail loads three different train loads (tramway, Izban commuter and metro) are taken into account. Both highway and railway loads are applied to the deck simultaneously.

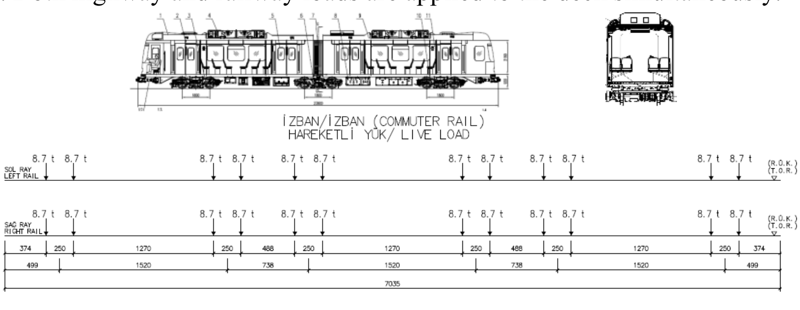

Fig. 6. Rail system loads

3.4 Seismic Loads and Performance Criteria

Izmir bay is a highly seismic region with very poor soil conditions. Izmir and its surroundings have been the scene of intense earthquake activity since historical periods. A high seismicity is observed along the active faults in the region Alluvial deposits are variable thickness, about 100 meters in the middle of the Bornova area and increase towards the bay. According to the results of the drillings the depth of the base rock in gulf area varies from 60 to 300 meters. The marine alluviums observed in Izmir Gulf are mainly composed of soft to very soft clay with included sand lenses. The design spectrums for NEHRP site class E are given below.

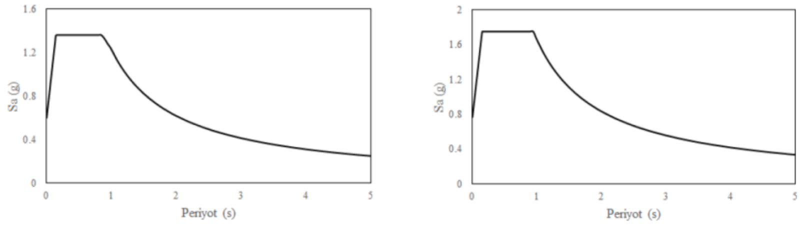

Fig. 7. Design spectrums (Tr=1000 yrs and 2475 yrs)

The two-level design criteria approach is utilized to ensure that the Izmir Bay bridge which is constructed in a highly seismic area represents functional adequacy and economy while reducing life-threatening failure. The performance criteria is determined as follows:

- For Design EQ (D1,Tr=1000 yrs); Controlled Damage Performance Level

This performance level corresponds to a state where non-extensive, repairable damage occurs in structures and/or in their elements under an earthquake. In this case, short-term (few weeks or months) interruptions in related operations may be expected.

- For Design EQ (D2,Tr=2475 yrs); Life Safety Performance Level

This performance level corresponds to a state where extensive damage is expected in structures. But for this project; seismic joints used in the immersed tunnel and isolator bearings used in the bridge are not allowed to be damaged.

4 Analysis and Design

A 3D finite element model of the bridge was built and analyzed using Midas Civil program with post tensioning tendons in all construction stages accordingly. Static analysis, construction stage analysis with time dependent material properties, moving load analysis, unknown load factor calculations for cable stayed bridge and multimode spectrum analysis are conducted. Verifications for serviceability and ultimate limit states are performed in accordance with the rules set out in AASHTO LRFD Bridge Design Specifications.

Fig. 8. Structural models of approach bridge and cable stayed bridge

4.1 Determination of Final Geometry of the Cable Stayed Bridge

Cable stayed bridge geometry should be close to road geometry after the completion of the deck with superimposed loads. Also distribution of the bending moments due to permanent loads in the deck should be close to a beam elastically supported at the cable anchor points. This requires the determination and adjustment of the initial cable forces. The “unknown load factor” and “cable force tuning” functions in Midas Civil help to calculate initial cable tension forces while satisfying the specified constraint conditions of zero and the range of maximum and minimum values for displacements, reactions, member forces, etc.

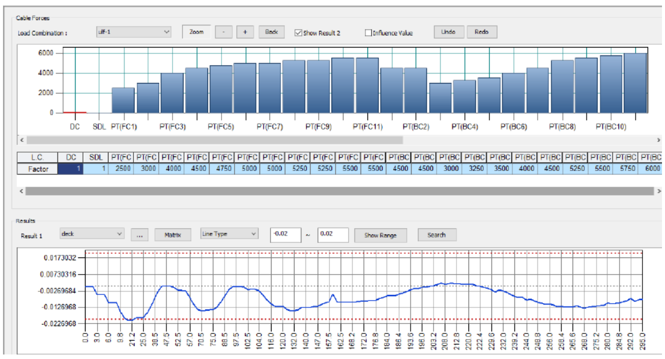

Fig. 9. Unknown load factor and cable tuning calculations

4.2 Live Load Analysis

Moving load analysis is conducted considering both highway and railway loads by defining the lanes, vehicles and loading scenarios. Worst positions of the vehicles for the maximum load effects are calculated by influence line method.

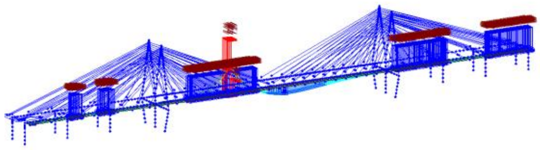

Fig. 10. Moving load analysis

4.3 Seismic Design

In order to take into account the soil-structure interaction in the analysis, the horizontal and rotational stiffness of the pile foundation are calculated by nonlinear pushover analysis. The soil is defined by nonlinear p-y curves and pushover curves are obtained by pushing the isolated pile foundation model for each degree of freedom. Then the capacity curves are used to determine the stiffness of the foundation and these values are defined in the global model. Also pile cap mass is lumped at the foundation level. As a result, the actual vibration frequencies are calculated. Since the first 20 m from the seabed is very weak clay with SPT values ranging from 0 to 5, the lateral resistance from soil is assumed to be zero.

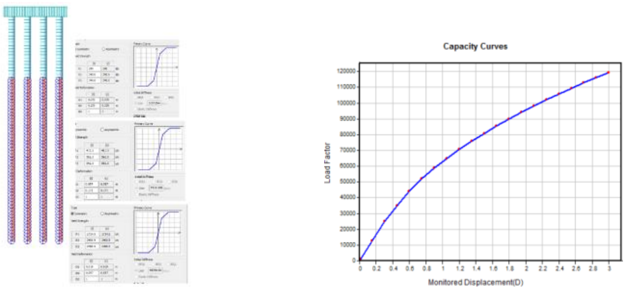

Fig. 11. Pile foundation modelling for pushover analysis

For approach bridge, the fundamental vibration periods for longitudinal and lateral directions are calculated around 2 seconds. Longitudinal displacements are calculated as 0.75 m and 0.50 m at the deck and foundation level respectively. It is seen that implementation of mass and stiffness of the foundation makes significant contribution to the deformations of the bridge.

5 Construction Method

During the final design stage, the construction method alternatives were studied by considering the site conditions, length of the bridge, time and cost. For the approach bridge which is 7170 m long with two separate platforms, movable scaffolding system is determined to be the most suitable construction method.

The construction of decks with several spans with movable scaffolding systems (MSS) may be a very efficient and competitive constructive method. This solution is generally used for the 40-60 m span range. Moreover, the use of MSS may represent very significant cost reductions if the access to the front line of the site is difficult – for example, high piers or water access, because this may imply for significant cost of elevation equipments. It is possible to complete a span around 5 days in this method. As a result, it is considered as the most advantageous method for the Izmir bay bridge which has 144 spans in total (except for the cable stayed part).

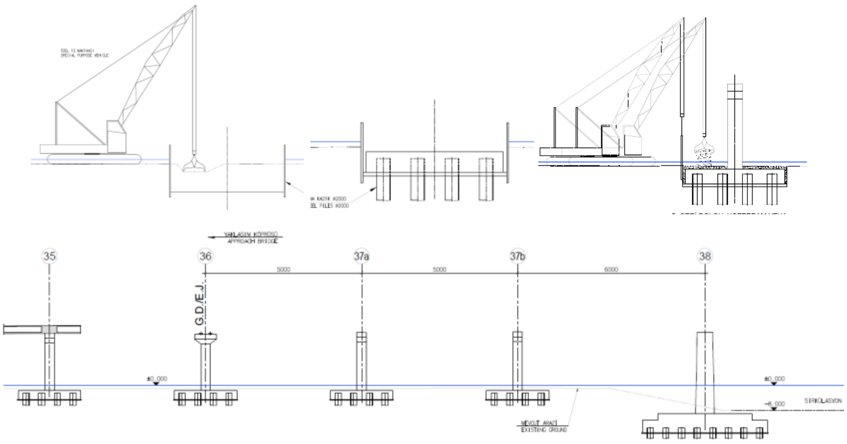

Fig. 12. Construction stages of substructure

The construction method for the main span of the cable stayed part is selected as the cantilever method which is the most common method for cable supported decks. The side spans of the cable stayed bridge will be completed by MSS method. After the completion of the side spans and pylon elevation, main span segments will be cast in-situ by form traveller.

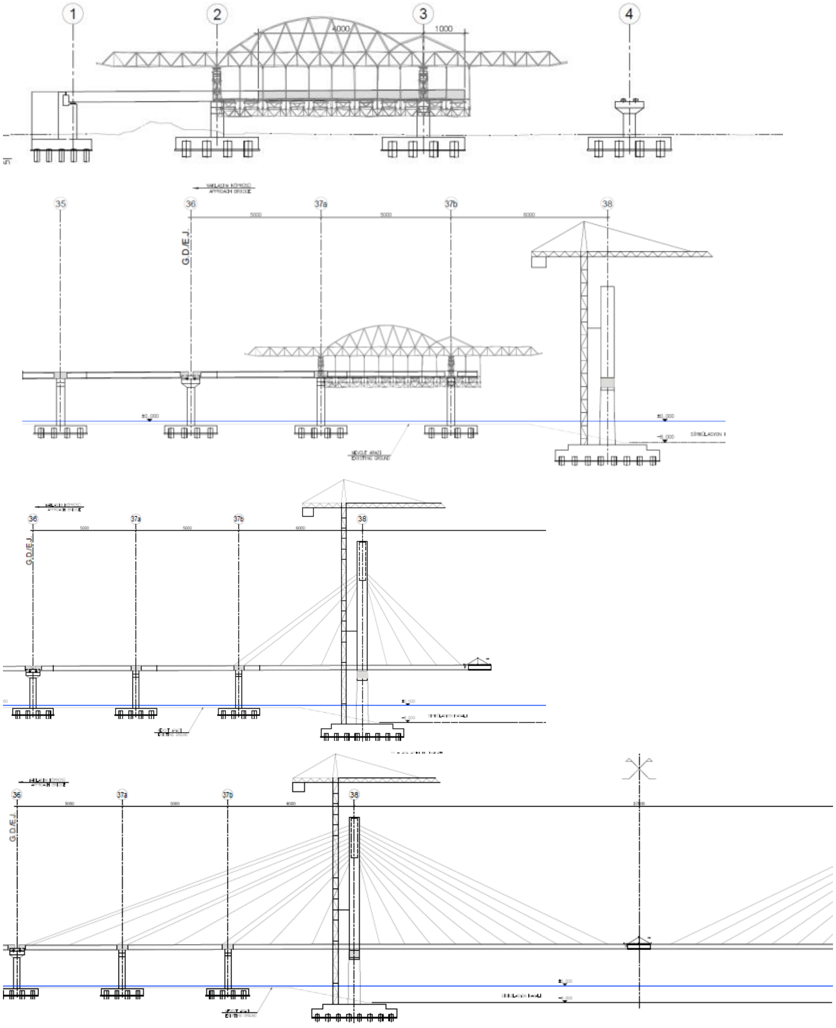

Fig. 13. Construction stages of deck

6 Conclusion

Designing a long water crossing bridge in very poor soil conditions and high seismic region is a challenging task. Standard span lengths and modern construction technologies make this bridge feasible. In poor soil conditions, it is necessary to include the foundation stiffness and mass in the analysis. This can be done by modelling all the substructure elements in the global model or by defining the lumped stiffness and mass properties in the global model. The stiffness properties are calculated from a seperate model, which a pushover analysis is performed with nonlinear soil springs. As a result, realistic vibration frequencies and deformations are calculated.

Acknowledgments This document was prepared for the Istanbul Bridge Conference 2018.

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