Title: Third Bosphorus Bridge-An Overview

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Abstract

The Third Bosphorus, a stiffened suspension bridge with a main span of 1408m, overall length 2250m and width 59.4m, is believed to be the first of its type. The innovative hybrid suspension-stay cable supported deck is designed and constructed to carry 8 lanes of road traffic and twin track heavy rail, all on the same deck level.

The bridge is situated in a seismic region and exposed to a severe wind climate. The bridge was required to be constructed to a tight timeframe. These factors posed technical and planning challenges. The technical innovations featured in the paper include tower saddles, dehumidification, and structural health monitoring system.

From a Lenders' Technical Advisor perspective, this paper gives an overview of the technical challenges and how these were successfully addressed in bringing to fruition this truly unique crossing by the design.

Keywords:

stiffened suspension; cable stay; seismic; aerodynamics; hybrid; heavy rail; tower saddles; Pendle bearings; dehumidification; structural health monitoring.

1 Introduction

The Project comprises the design, construction, maintenance, and operation of the Northern Marmara Motorway. The main elements consist of 60km motorway, 35km of connection roads, 64 viaducts, 20 interchanges, road tunnels, rail tunnels and the technical centrepiece, the Third Bosphorus Bridge. The crossing is located near the northern end of the strait close to the Black Sea, between Garipçe on the European side and Poyrazköy on the Asian side. Figure 1. Project Location shows the road network. The Third Bosphorus Crossing is in Section III.

Figure 1. Project Location

This paper focusses on the Third Bosphorus Bridge, named the Yavuz Sultan Selim bridge. The stiffened suspension bridge with a main span of 1408m, overall length 2250m and width 59.4m, is believed to be the first of its type. It has been designed and constructed to carry 8 lanes of road traffic and twin track heavy rail, all on the same level.

The bridge is situated in a seismic region and exposed to severe wind climate. The client stipulated a tight timeframe, nominally 30 months, for the project. This posed technical challenges in relation to design, construction, and schedule planning.

While remaining independent, the Lenders Technical Advisor (LTA) worked closely with the designers, constructors, fabricators, and planners in order that the project completion could be achieved safely to the specified schedule and meet the quality criteria.

From an LTA perspective, the paper gives an overview of the technical challenges and how these were successfully addressed in bringing to fruition this truly unique crossing by the several design and construction teams involved. It pays attention to the benefits of collaborative working between all the parties involved.

Technical aspects featured include the following:

- Suspension and stiffening cable systems to carry road traffic and heavy rail
- Seismic design-articulation and Pendle bearings
- Aerodynamic testing
- Construction methodology
- Fabrication and assembly of steel boxes
- Design and construction schedule
- Tower saddles
- Erection of steel segments over water
- Dehumidification and Structural Health Monitoring

2 Lenders Technical Advisor (LTA) Role

2.1 Organisational Structure and Procurement Approach

The Project was procured under an Agreement with the Republic of Turkey Transportation Maritime and Communication Ministry General Directorate of Highways (KGM). The IC Ictas Insaat and Astaldi Construction (ICA) JV was successful in securing the concession. The bridge was procured under an Engineer, Procure and Construct (EPC) contract with Hyundai Engineering & Construction and SK Engineering and Construction JV. The main contracting parties involved in the procurement of the project are shown in Fig 2: Organization Structure.

The concession period for the project is ten years, two months, and 20 days, including a 'nominal'

Construction Period of 30 months. Revenue for the concession will be derived from real tolls, but with a specified traffic and revenue guarantee.

The Lenders to the ICA JV appointed Mott MacDonald as its Lenders Technical Advisor (LTA).

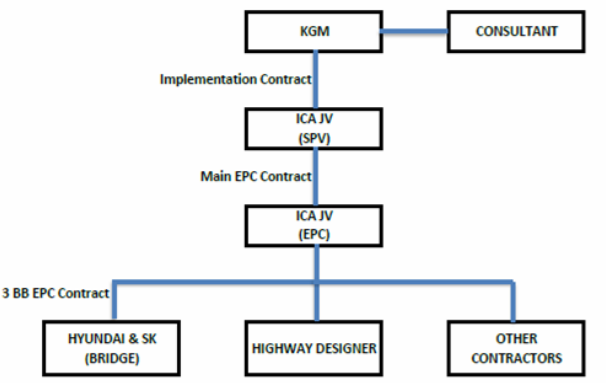

Figure 2. Organization Chart

2.2 LTA Scope

The LTA scope was wide ranging and encompassed the review and advice in relation to all technical, commercial and management aspects across the entire project life cycle. This included investigations and studies, design, testing, fabrication, construction and Operation and Maintenance.

The scope included the review and comment on the adequacy of design and compliance with Standards, project budget, schedule, construction methodology, QA/QC, management structure, suitability of contractors, main suppliers, and key personnel.

2.3 Collaborative Working

An approach conducive to the achievement of a challenging programme for the technically complex structure was needed. The LTA embraced and promoted the following principles.

- Working closely and collaboratively with all the teams (including Design, Construction, Planning, and Management),
- Independent detailed reviews carried out timeously
- Regular workshops to discuss findings
- Constructive critique
- Avoidance of repeat reviews where possible
- Focus on programme and safety

2.4 Design Solution

The Third Bosphorus Bridge is a stay cable stiffened suspension bridge with a main span of 1408m and a total length of 2250m. The single-level deck carries two four-lane roadway, two cantilever walkways, and space for two railway lines along the centreline. The main span of the bridge comprises an aerodynamically streamlined steel orthotropic box girder deck. The side spans and ground approaches are constructed in concrete. The deck is supported by a combination of hangers, suspended from main cables, and stiffening stay cables. The hangers are attached to the deck between the railway and the highway along the central suspended zone of the main span. The stiffening stay cables are attached to the edge of the box girder in the main span and between the railway and the highway along the side/back spans and ground approaches.

The suspension bridge is stiffened with stay cables to satisfy the required deck profile under heavy rail loading.

The towers were built in concrete and are 322m high. Each tower comprises two inclined legs and a cross beam at deck level forming an A-frame. The tower legs are founded on 20m diameter concrete shafts excavated approximately 20m deep into rock. These foundations are situated on shore such that no part of the structure is placed in the water. A minimum 64m height clearance is provided over the navigation channel.

The main cable anchorages and ground approaches act as counterweights and are keyed into the rock. The concrete side spans include intermediate pier supports founded directly on rock. Vertical support is also provided to the deck at the tower cross beams.

The overall design concept is depicted in Figure 3. Bridge Elevation European Side (schematic) and Figure 4. Steel deck Cross section. Some of the special design features are described in the following sections.

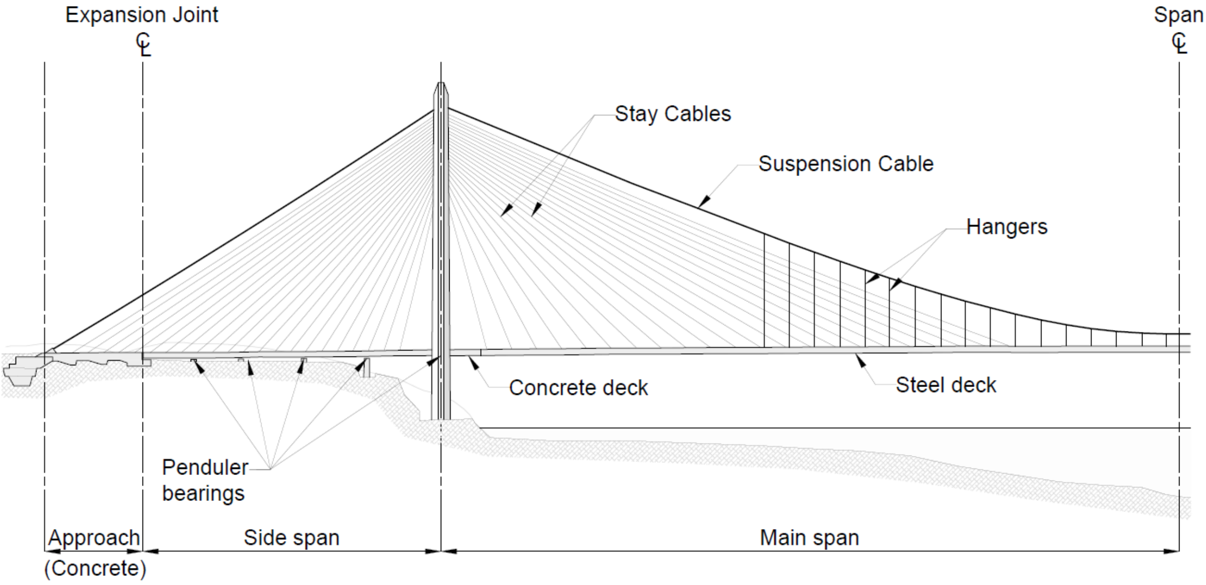

Figure 3. Bridge Elevation-European side (Schematic)

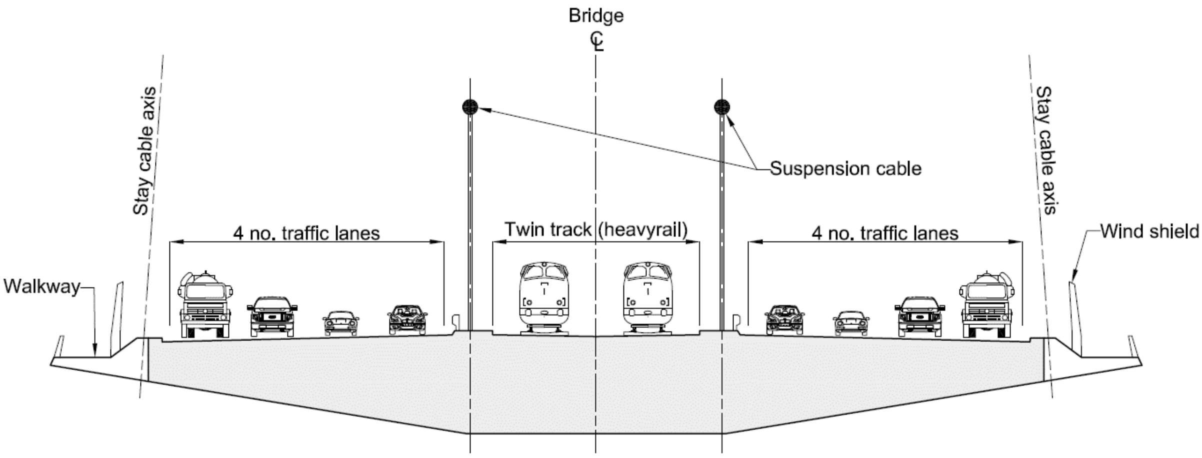

Figure 4. Steel Deck Cross Section (Schematic)

2.5 Bridge Articulation

The bridge deck is continuous between the expansion joints over a length of 1976m encompassing the main span and side spans. The expansion joints are located between the end of the side spans and the ground approaches (see above Figure 3-Bridge Elevation). The horizontal restraint, for seismic and live load effects, is provided by a system of Pendle spherical bearings on the side span piers and the tower cross beams. See Figure 5. Pendle Bearing (Schematic) and Figure 6. Pendle Bearing. The radius of curvature of the upper anchor plate is varied progressively between bearings along the deck to provide an efficient means of resistance against seismic and traffic Actions.

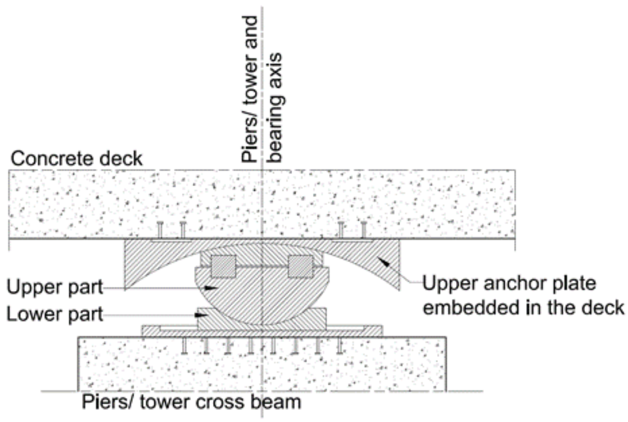

Figure 5. Pendle Bearing (Schematic)

Figure 6. Pendle Bearing

2.6 Tower Saddles

The suspension cables for the main span comprise fewer strands than those for the back spans. The suspension cables are supported on the two saddles, one on each tower leg. The additional strands for the back spans are also anchored to the tower saddles. The additional strands are needed to balance the forces and limit the deflections of the structural system.

The tower saddles are amongst the biggest ever manufactured for such an application. Due to their size, each saddle was manufactured in segments and bolted together in situ. Each segment was part-cast and part-fabricated. The trials showed that single casting could not meet the quality requirements.

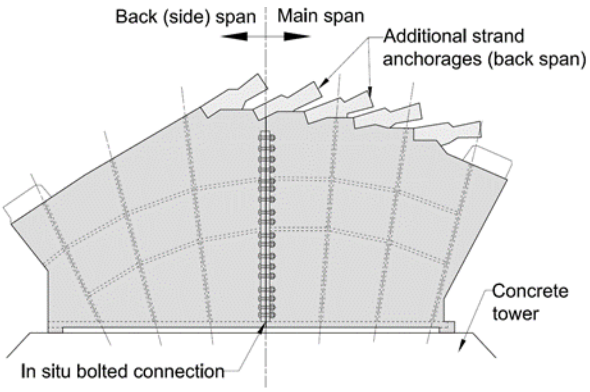

Figure 7. Tower Saddle (schematic)

A schematic of the tower saddles is shown in Figure 7. Tower Saddle (schematic) and Figure 8. Tower Saddle-Side Span Strand Anchorage.

Figure 8. Tower Saddle. Side Span Strand Anchorage

2.1 Wind Tunnel testing

Wind tunnel tests were carried out at the Politecnico di Milano Wind Tunnel Laboratory. Tests included boundary layer test, high speed-lower turbulence test and tests for selected construction stages for the tower and the bridge. See Figure 9. Wind Tunnel Test-Construction Stage.

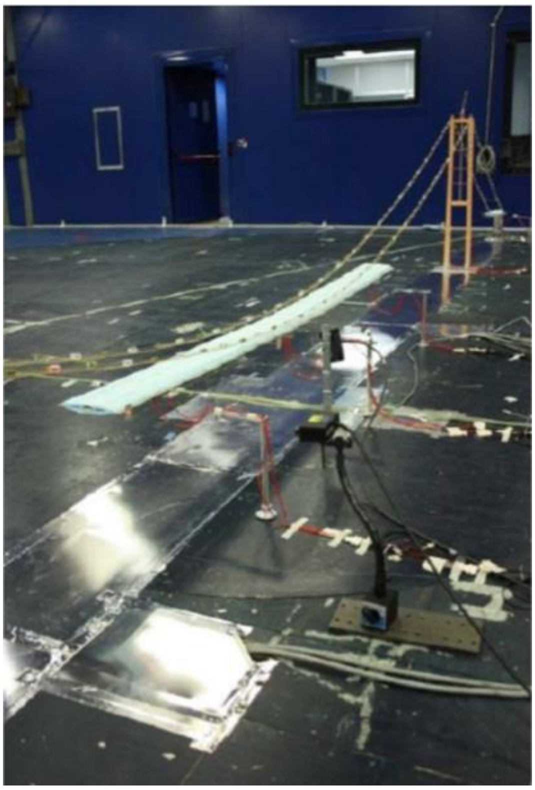

Figure 9. Wind Tunnel Test-Construction Stage

3 Fabrication and Erection

3.1 Fabrication

The steel plate for the box girder was supplied principally from South Korea. All the boxes were fabricated in Turkey. The panels for the box segments were fabricated at several yards including TGE, NETA and SEDEF GEMI at Tuzla, north of Izmit bay and shipped to Altinova, south of Izmit bay, where these were assembled to form box segments.

A 'U' trough stiffened bridge deck panel under fabrication at Tuzla is shown in Figure 10. Deck Panel Fabrication. A ready painted box at Altinova is shown in Figure 11. Box ready for Shipment.

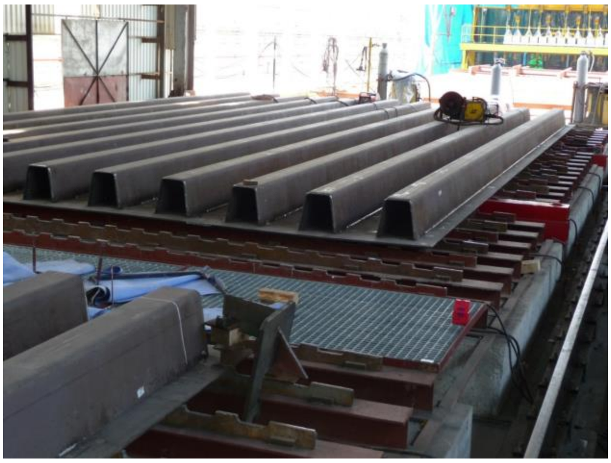

Figure 10. Deck Panel Fabrication

Figure 11. Box ready for Shipment (Altinova)

3.2 Erection

The boxes were shipped by barge and held close to the bridge site until erection.

Generally, the segments were lifted directly from the barge by Derrick cranes and erected (Figure 12. Lifting of Boxes by Derrick Crane). However, sections of the bridge deck adjacent to the towers, mainly on the European side, lie over land which is inaccessible from the water borne vessels. For those sections, the boxes were transported from the barge to the bridge erection site on a Transporter Unit, and erected by Derrick Cranes supported on the previously constructed section of the deck, and welded.

The cantilever construction of the deck progressed from both the European and Asian sides continually. In parallel with the cantilever erection, the suspension cables were installed by the Preformed Parallel Wire (PPW) method.

The 'middle section' of the main span deck over the Bosphorus was erected by lifting of the boxes from the barges by a Turn-Table lifting hoist supported on the suspension cables. Figure 13. Turn Table Lifting Hoist and Figure 14. Bridge Deck Erection from Suspension Cables depict this method.

Figure 12. Lifting of Boxes by Derrick Crane

Figure 13. Turn Table Lifting Hoist

Figure 14. Bridge Deck Erection from Suspension Cables

Figure 15. Suspension cable Wrapping

4 Dehumidification

A dehumidification system has been installed to ensure that the vulnerable parts of the bridge remain 'dry'. These include the steel box girder, the suspension cables, and the tower legs including the space around the tower saddles.

The elastomeric wrapping of the suspension cables (Figure 15. Suspension Cable Wrapping) was leakage-tested to demonstrate that the wrapping and caulking parts are sufficiently air proof to contain the dehumidified air injected to prevent corrosion of the cable. The air test was conducted with air blown in at a pressure of 2000 Pascal and leakage detected with soap water and measurement of any drop in pressure.

5 Structural Health Monitoring

The bridge has been instrumented with a comprehensive system of sensors. These include Triaxial Accelerometer (18 units mounted at various locations including tower legs and suspension; cables); Bi-Axial Accelerometer (56 units at tower top, tower legs and stay cable); GPS Sensor (5 units at tower top and main span deck); Tilt Meter (5 units at tower top); Wind Sensor (5 units at tower top and main span deck). The real-time monitoring of bridge performance is carried out from the control centre and compared against predicted values.

The O&M procedures are invoked should the observed performance warrant this. For example, in the event of excessive wind speed the bridge may be closed to high sided vehicles.

6 Schedule

The Owner had stipulated a contractual design and construction period of 30 months. For a technically complex bridge this was a very challenging timeframe, particularly bearing in mind the weather conditions during the winter period when the wind climate can be severe and restrict sensitive construction activity such as deck erection. Several factors contributed to the successful completion of the bridge on time and within budget. These are described below.

- The successful integration of the design and construction processes.
- The successful management and coordination of the international supply chain
- The design process and its approval involved teams of designers, specialist consultancies and laboratories, contractor's design management, construction engineers, independent checking engineers, the Employer's project management, lenders, and the lenders' advisors. The close cooperation between all the parties was key to the success of the project.
- The construction process involved sophisticated on-site construction management linked to an extended supply chain of sub-contractors and manufacturers. Full integration of the specialist capabilities of the design team, construction team and the supply chain was a key factor.

- Careful planning and where possible early start of some activities.
- The assured control of major complex design and build projects required the effective implementation of rigorous quality management through quality controls/checks operating within a robust quality assurance environment through all phases of the project.

7 Conclusions

The Third Bosphorus, a stiffened suspension bridge designed and constructed to carry 8 lanes of road traffic and twin track heavy rail, is a unique structure. It features amongst the world's greatest bridges. The superlatives include, one of the longest spans to carry road and heavy rail, the tallest suspension bridge towers and one of the widest decks.

The close collaboration and cooperation of the many parties involved was pivotal in bringing to successful fruition this unique structure in what was a tight timeframe. It is, in my view, a great engineering achievement and a tribute to the engineering fraternity.

Figure 16. Bridge (July 16) captures the bridge in the final stages of completion. The bridge was opened to traffic on 26th August 2016.

Figure 16. Bridge (July 2016)

8 Acknowledgements

The contribution of all those involved in bringing the Third Bosphorus Bridge to fruition is acknowledged. The parties involved include the following:

- KGM–Owner
- Chodai/Yuksel-Owner's Engineer
- IC Ictas and Astaldi–Concessionaire and EPC Contractor,
- Hyundai and SK-Bridge EPC Sub-Contractor
- Bridge Design Group-Michel Virlogeux, T Engineering, Greisch, Temelsu, Lombardi, CSTB, Fugro and Setec
- Mott MacDonald-Lenders Technical Advisor