Third Bosphorus Bridge –.

Conceptual design optimized for a fast track construction

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Abstract  The third Bosphorus bridge is considered as the future of transportation and commerce for Turkey, linking Europe and Asia. With a main span of 1’408 m, the bridge will be a breakdown record for the world longest span for railway bridges, carrying 8 lanes of motorway and 2 lanes of railway on a single level deck. The bridge is the first modern application of an hybrid cable system, a combination between a suspension and a cable stayed bridge. The governing reason to develop this concept was to make it possible to break the world record of combined road/railway spans with a very slender deck, and not with a classical double level truss deck. It was therefore possible to satisfy the clear wish of the authorities to respect the architecture of the two existing Bosphorus bridge, even with a main span of 1’408 m. The requirements insisted on an extremely short period of design and construction of 36 months. Such an extreme constraint had to be considered right from the beginning of the studies and the conceptual design did integrate the method statements for the construction as a key parameter. Consequently, the design has been optimized to emphasize simultaneities of activities and limit the construction time. The paper will focus on the conceptual aspects which could be considered to reduce the construction time.

1 Introduction

Late in February 2012, the KGM (Ministry of transportation of Turkey) issued tender documents for the construction, operation and transfer of North Marmara Motorway / Section Odayeri – Paşaköy including the design and construction of the 3rd Bosporus Bridge.

Connecting Europe with Asia, the main bridge will definitively become an iconic and an outstanding structure and will be a new landmark of Istanbul region. Consequently, for such a symbol, the authorities did express major concerns on
subjective and aesthetical consideration in parallel to the definition of the functional requirements for the structure. The main points are followings:

- Considering the location of the bridge between Garipçe and Poyraz, very close to the black sea, the necessary safety width for the navigation channel and the local bathymetric configuration, the minimum required span has been fixed to 1’275 m by the authorities.
- The bridge has to carry two times four lanes of roadway in addition to two railway tracks and two sidewalks mainly used for accessibility and maintenance.
- The bridge shall be a suspension bridge
- Aesthetic shall be an essential factor in the assessment of the proposals and the bridge should be in line with the architecture of the two existing bridges crossing the Bosphorus downtown.
- In addition, a very stringent and somehow out of usual scale requirement: the bridge has to be completed in an extremely short period of 36 month.

Explaining the development and the motivations which brought to that outstanding design is not the purpose and the goal of this paper. This publication will focus on the last point related to the very short construction time and will describe the specific decisions or concepts which have been developed aiming at reducing the global construction schedule.

2 A glance to the conceptual design

Combining all these requirements in a very elegant and efficient structure was an incredible challenge during which we had to stress all our creative and innovation mind to come out with the best and the most pleasant and elegant design up at the level required by this new symbol.

Let’s just remind that the bridge is a so called “High rigidity suspension bridge” breaking the world record for combined road/railway bridges with its 1’408 m of central span. It is a combination between a classical suspension bridge and a cable stayed bridge. The total length of the bridge is 2.3 km. To carry the 1’408 m of free span, two concrete towers of 322 m of height have been necessary.

The 2 x 4 lanes of roads and the 2 railway tracks are placed on a single level streamlined box-girder of 58.5 m of width. Due to its shape it provides an extremely good behavior and stability against the huge wind forces and the severe seismic conditions of the site.

The main span is entirely made of steel. The deck has a depth of 5.35 m which assures an elegant and very slender profile across the Bosphorus. The side spans, the ground approaches and the anchorage blocks are made of concrete.

As mentioned above, the bridge type is therefore called high rigidity suspension bridge due to the very high stiffness provided by its conceptual design,
able to resist very high wind loading and all seismic actions. This good behaviour is essential to operate the railway system without extreme deformation and rotation at the end and along the bridge.

Advanced technologies have been considered for all elements of the bridge, providing each time the most efficient solution to enhance durability and ease of maintenance.

3 Construction time

It can be easily said that detailing and construction of such an outstanding structure require usually about 2 years of design studies and 4-5 years of construction. Reducing all the process in 36 months plus about 6 months for the preliminary design and the preparation works has been more than a challenge. Usually, preliminary studies are done far before the construction time inclusive all the required preliminary investigations like geotechnical survey, wind measures, wind tunnel test, etc. In the case of the Bosphorus bridge, we started from a white page without reference project at the beginning of the competition which lasted only 8 weeks (initial 5 weeks + 3 weeks prolongation), and by the way without any geotechnical, wind or seismic data!

4 Design philosophy

As a consequence, the reduction of the construction time became immediately one of the most relevant and governing criteria for the design. It was of course obvious that the architecture, the structural behaviour and the global concept of the bridge would not have to suffer from decisions or specific disposal developed only to reduce the construction time. The concept is global and we considered the problem of construction time as an integrated parameter which shall definitively not alter the equilibrium or the aesthetic of the bridge.

Considering the outstanding size and in particular the unusual loading level (live loads are almost 60% of the permanent loads) our design philosophy
described above has been naturally completed by what we consider as essential rules leading to the architectural and technical success of a project:

- Privilege the structural logic
- Privilege simplicity
- Privilege the use of local materials and local construction experiences
- Paying a particular attention to the neighbourhood relation with the structure and to the type of use

This is the philosophy which has been applied to come out with this outstanding structure (see Fig 1.) which includes many technical particularities which help to reduce the construction time and to respect the requirement defined by the owner.

5 Global construction scheme

As explained above, the global concept of the hybrid bridge has been dictated by the severe loading schemes and the critical operational limit states defined by the railway.

But globally, the hybrid system helps for the global construction time as it calls naturally for simultaneous activities. No clear critical path to be followed from the beginning to the end of the construction, many operations can be done at the same time allowing for good global construction time performance.

On a classical suspension bridge, the critical path is quite clear: pylon foundations, pylons and anchor blocks must be completed on both side before starting with the installation of the temporary elements necessary to install the main cable. After that completion, the main cable can be installed, the cable bands installed, and the erection of the main span deck can start.

On the third Bosphorus bridge, no reason to wait for completion of the pylons nor for the one of the anchor blocks, or for the installation of the main cable or the cable bands to start the lifting of the first segments.

What was needed is the completion of the side span and of the towers until the first stiffening cable anchorages. From that point, the lifting of the segment could have been started while the towers could have been completed, so as the anchor blocks and the ground approaches. All these operations be done far before the installation of the main cable.

It means that once the towers are completed, and the saddle installed, the temporary works for the main cable installation could start and the main cable could be installed while the cable stayed deck was progressing towards the centreline of the bridge on a length of 500 m on each side.

When the first segment could be lifted from the main cable after its completion and after installation of the cable bands, almost 2/3 of the deck length was already completed.

The following scheme (fig 2.) gives the general construction sequences as proposed during the tender phase with the corresponding planning. The fact that
the contractor did finally chose to complete the pylons before starting the cable stayed cantilevering was a pure decision based on procurements delays and on site congestion. It was not structurally required to wait that point to start the deck. Even more, the global safety situation of the pylon during construction would have been more easy to handle with some stiffening cables already installed.

Fig2: General construction scheme -
6 Conceptual issues for fast track construction

6.1 Main span – Location of towers

Definitively, one of the biggest decisions of the project was to increase the main span from the minimum required distance of 1275 m to 1’408 m.

It was extremely courageous and audacious from the contractor to accept this proposal from the designer to increase the main span by 133 m. But as foreseen, this was for sure one of the best and soundest decisions taken on the project.

With the minimum required span, at least one of the towers would have rested in the Bosphorus, calling for difficult and time consuming off shore foundations. From our preliminary geotechnical investigations during the competition, we could identify high strength and dense rock directly on both shores, extremely suitable for easy tower foundations.

Those, analysing the risks of complications, delays and costs brought by an off shore construction, in addition to the interference with the navigation, with the fishermen and the risk of environmental hazards, ut has been considered as much more efficient and safe to secure the construction time and the costs to remain on shore with the foundations. The direct consequence is of course an increase of the main span by 133 m which had to be considered in the balance.

At the end of the day, the rock quality appeared to be as good as expected and the towers have been founded on two single cylindrical shaft of 20 m of diameter by 20 m of depth each. These shaft could have been excavated 15 m apart from the sea water without temporary wall bearing and without any drop of water. Only two month have been necessary to complete the shafts of the tower legs. No off shore construction could have compete with such a short time and the global construction time could seriously benefit from that short period.

6.2. Towers:

Initially, during the competition, the towers were planned to be made of steel. This decision was taken as a safety precaution due to the lack of seismic and geotechnical data. We were concerned about having too much weight placed at a high level on the bridge.

After having performed a geotechnical and seismic survey, we could analyse more precisely the impact of the weight and could appreciate that the design of the bridge is much more governed by the wind effects than by the seismic one. Consequently, the global weight of the tower would not have a huge importance, considering also the fact that we have excellent ground and foundation conditions.
Following local parameters could then be considered:

- Local contractors are well used to do quality concrete constructions with a very high efficiency.
- Concrete is a cheap and easy to make material which can use local components.
- Considering the quick foundation construction, the concrete tower construction can start immediately from the beginning at the same time as the anchor blocks, the side spans, and the fabrication of steel segments in the factory.
- Local specialized steel factories will be enough busy to produce the anchor boxes and the steel segments. Adding tower segment would have pushed the steel fabrication on a very critical path.

With these parameters, it has been considered as much more efficient to build the tower in concrete instead of steel as it was beneficial for the global duration of construction due to the construction simultaneities.

Fig 3: The main span has been increased by 133 m to remain on shore with the towers

### 6.3. Steel anchorage boxes

Prefabricated steel anchorage boxes for the stiffening cables, to be installed in the concrete tower ease seriously the formwork, reinforcement and casting works of the pylons, which have to be performed between 208 m and 304 m of height. Prefabrication of the boxes can be done while the first 208 m of the pylons are casted. Installation of the box is done one lift in advance to reduce the time of each lift.

At the end, as estimation, it did reduce the global timeframe of the pylons by approximately 2 months.
6.4. Position of the expansion joints

The expansion joints are not located at the end of the bridge but 75 m before the anchor blocks (see fig. 5). The main reasons for that are structural:

- Limitation of the dilatation length and the opening of the joints
- Limitation of the horizontal longitudinal displacements under the passage of trains.
- Stabilisation of the pylon by stiffening cables directly anchored on the ground
- Global stabilisation of the bridge by introduction of a tensile force in the main span.

The direct consequence of that position is the limitation of the side span length. These elements are rather complicated and require an important excavation. By limiting their length, the global construction schedule is obviously reduced.

6.5. Ground approaches.

Between the expansion joints and the anchor blocks, the stiffening cables are anchored in the ground approaches. This simple concrete element uses its weight
to equilibrate the uplift coming from the stays and is designed as successive shear keys to transfer the stay cable horizontal reaction directly to the ground.

As the ground conditions are rather good, no need to have a concrete structure to carry the roadways. The ground approaches are therefore concentrated below the railway tracks, incorporating two maintenance galleries under the cable anchors.

The construction and excavation volumes are limited to the strict minimum what appears as a benefit to the global schedule and costs.

Fig 6: Limitation of the ground approaches structural width

### 6.6. The indirect consequences of the partial suspension

As explained above, the global concept of the hybrid bridge with a partial suspension of the main span helps to the reduction of construction time thanks to the possible simultaneity of activities at site.

But another very important consequence goes in the direction of time and cost reduction. As already mentioned, the third Bosphorus Bridge will have to carry extremely high loads due to the combined traffic Rail/road. Apart of having a much worse structural behaviour, a classical suspension bridge in that situation would have need extremely high capacity main cables, what means a huge quantity of high strength steel for a limited efficiency. Not only the installation of this out of scale cables would have taken a very long time, but also the special cast steel parts like the tower saddles or the splay saddles would have been at the limit of the casting possibilities not talking about the cable bands. All these cast steel parts would have required a very long time and would have been on the critical path from the beginning with in addition a very high risk of fabrication hazards.

By suspending the central part only, the main cables dimensions have been drastically reduced. Consequently, the anchorage blocks could be seriously reduced, the size of the cast steel saddles and cable bands could have been maintained within a reasonable size either for the fabrication, the transportation and the installation.

Giving an exact estimation of the number of months saved by all these sizes and element reductions is almost impossible, but it definitively did impact the
global schedule in a large scale, limiting also the risk of fabrication and installation hazards.

Fig 7: Mixed cable system allows for co-activities and reduction of main cable size

7. Conclusions

The third Bosphorus Bridge has finally been constructed in a extremely short period of time of about 6 month. If the bridge design itself covers several world records amongst the world longest main span for combined rail/road traffic, the construction schedule is definitively an impressive and never reached challenge for such an outstanding structure. ICA construction (concessionaire) and HDSK (EPC contractor) maintained a huge pressure at site and could organize all jobs in a formidable way which led to that result.

But as shown by this paper, this success could have been possible thanks of course to an excellent site organisation, but also to a multitude of conceptual issues and decisions. Clearly, the conceptual design took this important parameter from the first day as one of the governing issue. All the details described above putted one after the others could allow for such a success. It is almost impossible to consider a classical design and to decide afterwards for a fast track construction. On such a technical and challenging structure, the result would never have been so successful.

Construction timeframe is an important issue which has to be considered during the conceptual design, but it should definitively not affect the performance and the architecture of the bridge for its all lifetime. A bridge shall never keep its construction stigmata during its all life.