Responsible Design and Delivery of the Constructed Project
Edited by Abdul-Malak, M., Khoury, H., Singh, A., and Yazdani, S.

ISBN: 978-0-9960437-5-5

FAST-PACED CONSTRUCTION OF THE NEW KHALIFA PORT BRIDGE PROJECT

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The significant growth and development in the United Arab Emirates in recent years necessitated considering advanced construction techniques for bridge structures. This paper presents features of the New Khalifa Port Project which consisted of bridge structures with a combined length of 3.64 km. The strict project design criteria, schedule and budget represented significant challenges which required considering specific designs using efficient precast elements and construction methods. The bridge structural system consisted of 39.8 m long precast, pretensioned modified AASHTO (American Association of State Highway and Transportation Officials) girders with cast-in-place concrete deck slabs. The main challenge was to optimize the size of the precast girder as the self-weight of the initially proposed elements exceeded the lifting capacity of the available equipment. The other challenge was to correlate between the British Standards and AASHTO LRFD (load and resistance factor design) code to design the girders for static and dynamic loads. The casting yard was set at 70 km from the project site and delivery roads were assigned to accommodate the special tandems carrying girders weighing 80 tons each. Lessons learned during design, fabrication, transportation and construction of the precast girders add on to the efficiency of the Accelerated Bridge Construction (ABC) processes.

Keywords: Girder, Precast, Prestressed, AASHTO, LRFD, Challenges.

1 INTRODUCTION

Precast elements are often used for the construction of bridge structures. Standard AASHTO girders can accommodate span lengths from 12 m up to 70 m. The girder size depends on the span length, load design criteria, service load stress criteria and most importantly the capacity of available lifting equipment. Design is usually performed using an internationally recognized design code such as the British Standards (1990, 2001, 2006) or AASHTO LRFD (AASHTO 2017). Nevertheless, constructability of precast structures can present major challenges that should be addressed by relying on the ingenuity of the project team.

This paper provides insight into the design and construction of the Khalifa Port bridge project in the United Arab Emirates (UAE) to satisfy stringent structural design and durability requirements. The Khalifa Port project comprises three structures with a total length of 3.64 km. The bridges connect islands made from reclaimed seabed material to the mainland. The main Port of Khalifa Island comprises two bridge structures, 1 km long each, labelled as the Highway Bridge and the Utility Bridge. The other island which serves as a marine terminal consists of a 1.64 km bridge structure, labelled as the Trestle Bridge. (Karapiperis *et al*. 2010).

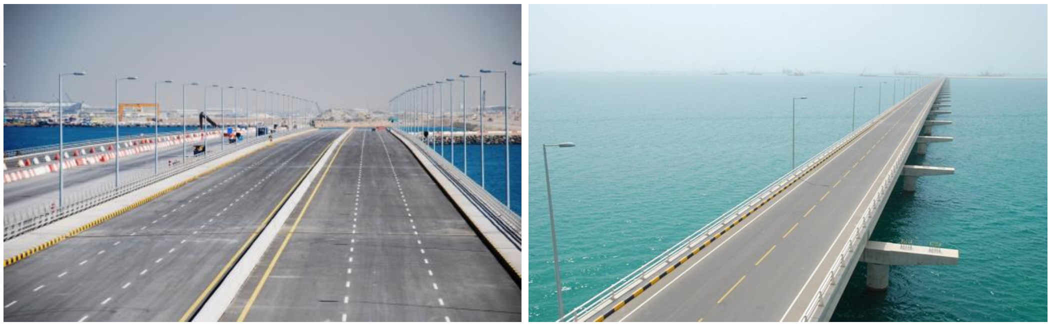
The casting yard was set at 70 km from the project site and delivery roads were assigned to accommodate the special tandems carrying girders weighing 80 tons each. Lessons learned during design, fabrication, transportation and construction of the precast girders that add on to the efficiency of the Accelerated Bridge Construction (ABC) process are presented in this paper.

2 OBJECTIVE AND OUTLINE

The main objective of the paper is to present the accelerated bridge design and construction process for the 3.64 km long bridge structures. Description of the bridge structures is first provided. Gaps in the originally submitted construction scheme that led to presenting alternative design and construction processes are then discussed. These range from using precast elements for substructure pier columns and pier caps to reducing the weight of the superstructure precast girders while maintaining its flexural rigidity. Emphasis is placed on proper coordination that led to the fast-track construction of the 3.64 km of concrete bridges within approximately 12 months.

3 DESCRIPTION OF THE BRIDGE STRUCTURES

The two-bound Highway Bridge is 28.9 m wide with three - 3.65 m traffic lanes and a 2 m wide walkway in each direction. It connects the Khalifa Port Industrial Zone to the mainland loading and unloading terminals (Figure 1a). The parallel 27.5 m wide Utility Bridge accommodates pipelines and conveyors and one lane for maintenance vehicles (Figure 1a). The 19.5 m wide trestle bridge accommodates a 10 m wide vehicle carriageway and a heavy-duty dry bulk conveyor gallery supported on protruding cantilevers from the pier caps (Figure 1b). The Highway and Utility bridges are supported by 14 AASHTO girders each while the Trestle Bridge is supported by 5 girders only. The concrete deck slab thickness is 225 mm for the Highway and Utility bridges and 250 mm for the Trestle Bridge. Continuity for the three bridges was achieved in the deck slabs along four consecutive spans with expansion joints provided every 160 m.



(a) Utility (left) and Highway (middle & right). (b) Trestle with protruding pier caps.

Figure 1. Khalifa Port bridges.

4 DESIGN

The design of the superstructure girders and slabs was performed using British Standards for static loads (BS 5400-2 2006, BS 5400-4 1990) and the American Association of State Highway and Transportation Officials load and resistance factor design (LRFD) method for the seismic loads (AASHTO 2009). For the Highway and Utility bridges, the AASHTO precast, prestressed girders were designed for HA and HB45 traffic loadings (BD *37/01*) with HB45 being the heaviest design truck and HA representing lane loading. The Trestle Bridge girders were designed for HA traffic loading only (Gergess and Tepavcevic 2011).

The original layout for precast girders consisted of 2,300 mm deep girders that were spaced at 2.05 m for the main highway bridge and at 1.98 m for the utility bridge (Figure 1a). The 2,300 mm deep girders spaced at 2.56 m were also used for the trestle bridge (Figure 1b).

Based on value engineering, a 2,200 mm deep girder with a 1,070 mm wide top flange and a 200 mm web was used. The 200 mm web thickness reduced the self-weight by 20% without affecting its stiffness (no prestressing strands were provided in the web). The top flange width of 1,070 mm (compared to 800 mm) enhanced the stability of the girder as the weak axis moment of inertia for the 2,200 mm deep girder was larger compared to the original girder.

The final design resulted in using 15.2 mm diameter prestressing strands with a tensile strength of 1,860 MPa. Ordinary reinforcement in the girders was grade 460B, high yield deformed steel (type 2) with a minimum yield strength of 460 MPa (Gerges and Gergess 2012).

4.1 Durability

The design criteria emphasized on durability, mainly the need to achieve a 100-year service life under the extremely high temperatures of the Persian Gulf region (temperatures up to 55°C) over harsh marine environment (salt water and humidity up to 100 percent).

Durability measures involved increasing the concrete cover for the steel rebar, imposing strict limitations on crack width and using corrosion inhibitors within the concrete mix. For the substructure elements, a 100 mm cover was used and a maximum crack width of 0.125 mm was allowed. For the pretensioned AASHTO girders, a cover of 50 mm was used and no cracking was allowed as per the design criteria for limiting tensile stresses in prestressed Class 2 elements (BS 5400-4 1990). For slabs and diaphragm, a cover of 50 mm was used as well and limits for the crack width were set at 0.150 mm for exposed surfaces and 0.175 mm for non-exposed surfaces.

4.2 Concrete Mix

The minimum 28-day compressive cube strength for the precast, prestressed girders was set at 50 MPa. The aggregates size did not exceed 20 mm and for AASHTO girders it was supplemented with an increased dosage of corrosion inhibitor. The concrete mix was subjected to tests (NT Build 492) to determine the chloride penetration in the concrete.

5 CONSTRUCTABILITY

The pier columns and caps were precast onshore, transported on floating crane barges, and lowered into their final positions (Figure 2a). Once in position, they formed the working surface on which the precast girders were laid and from which the cast-in-place slab was constructed. Stay-in-place corrugated galvanized iron sheets were used for casting the slab (Figure 2b). Precast- construction was highly valued due to the repetitive construction cycles anticipated in the project.

5.1 Bridge Bearings

Laminated elastomeric bearings placed on the reinforced concrete pier caps were used to support the girders (Figure 3). Bearings were sized to accommodate expansion/contraction and at the same time minimize the thermal forces applied to the substructure based on its low horizontal stiffness. They were also designed for seismic loads (AASHTO 2000). Fixity to the adjacent concrete surfaces was ensured using top and bottom checkered steel plates that were glued using epoxy mortar to the concrete.

(a) Precast pier columns. (b) Corrugated metal sheets.

Figure 2. Construction process for precast piers and girders.

Experimental testing was performed to confirm the ability of the bearings to deform and transfer the design loads. The maximum shear deformation was measured at 155 mm due to seismic, thermal and time-dependent creep and shrinkage deformations.

Lateral stability between the precast girders was ensured by monolithically casting in-situ 1,950 mm deep by 500 mm wide diaphragms centered with the transverse axis of the bearings.

Figure 3. 2.2 m deep, 39.6 m long AASHTO girder.

6 CHALLENGES

The tight construction schedule and the need to keep costs within budget represented significant challenges during design, fabrication, transportation and erection of the precast elements.

6.1 Selection of Precast Girders

Selection of the girder type was governed by cost and constructability. The use of longer spans can reduce the number of intermediate piers, but the size and weight of the girders was limited by the availability of suitable lifting equipment. To reduce weight, girders were first designed as continuous over the supports using in-situ concrete diaphragms between the girder ends allowing negative moments to develop at the supports and limiting positive moments at the centers of the spans. This scheme was not adopted due to potential cracking of the solid end diaphragms which affects durability and service life of the bridge structures. Consequently, the girder size was based on the conventional single span design method where the precast girders are laid out as simply supported and continuity is achieved only in the deck slabs over the supports.

To reduce weight, an optimized 2,200 mm deep girder with 800 mm bottom flange, 1070 mm top flange and 200 mm web was used without changing the total number of girders (Figure 3). This also increased the compression axial stress due to prestress which allowed reducing the number of prestressing strands to 48 compared to 52 in the original design.

6.2 Fabrication

Fabrication of the girders was done at a casting yard distant 70 km from the project site (Figure 4a). 906 precast girders were produced during a period of 9 months at a peak rate of 36 girders per week (6 girders per day). 10 – 140 m long prestressing lines were set for production with a 1,200 tons bulkhead capacity (for the jacking prestress force). Three sets of steel and GRP molds were used for casting. 16 tons of 15.24 mm high strength prestressing strands were consumed daily.

(a) Casting yard. (b) Construction site.

Figure 4. Fabrication and erection of precast girders.

6.3 Transportation

Transporting the 80 tons girders to site was carefully planned to ensure that the associated roads and junctions can accommodate the special tandems. 200 tons multi-axial hydraulic trailers were used to deliver up to 13 precast girders per day. Two gantry cranes with a capacity of 70 tons each were used for handling the precast girders at the casting yard (Figure 4a).

6.4 Erection

Precast girders were loaded on barges and lifted using heavy-duty floating cranes for offshore erection (Figure 4b). Erection of the girders required high precision in operation of cranes during lifting. They had to be accurately placed on the supporting bearings within the setting time of the epoxy mortar applied to the checkered plates of the bearing pads (Figure 3). For this purpose, temporary steel guide frames were fixed to the pier cap to guide the lifted girders into place (Figure 3). These frames could also resist possible impact when placing the precast girder in place.

7 CONCLUSIONS

This paper described the process of accelerating the construction of 3.64 km of bridges. Value engineering led to changing the construction scheme from cast-in-situ to precast for substructure piers and adopting the conventional simple span methodology with continuity in the topping slab for superstructure precast girders. Proper coordination between the contractor’s construction engineering consultants, precast fabricators and the client facilitated implementation of the modified design and construction schemes which led to the fast-track construction of the 3.64 km of concrete bridges within approximately 12 months. This was in line with the construction schedule and within the project budget.

Based on findings from the design and construction processes, the following conclusions were made:

- Value engineering resulted in reducing the weight of the precast girders by 20% while maintaining its flexural rigidity and stability.
- Precast construction for substructure pier caps and columns and superstructure girders was highly valued due to the repetitive construction cycles.
- The concept of using simple spans instead of making the girders continuous for composite loads and live loads was preferred for durability and maintainability.
- The use of elastomeric bearing pads contributed to reducing the magnitude of the seismic forces transmitted to the foundations.

Acknowledgments

The author acknowledges the contribution of Archirodon Construction, Abu Dhabi Ports Company (ADPC) (client for Khalifa Port Bridges project) and Al-Meraikhi Industrial Complex in the United Arab Emirates.

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