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SUMMARIZE OF DETAIL DESIGN FOR PELJEŠAC BRIDGE PROJECT IN CROATIA

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Abstract

The Pelješac Bridge is a Extradosed cable-stayed bridge with the span arrangement 84 + 108 + 108 + 189,5 + 5 x 285 + 189,5 + 108 + 108 + 84 m = 2404 m under construction in Croatia at present. The purpose of this bridge is to achieve territorial continuity of the Republic of Croatia by connecting the southern exclave comprising the bulk of Dubrovnik-Neretva County with the remainder of the Croatian mainland. China Road and Bridge Corporation (CRBC) Joint Venture (JV) won the bidding of this project following the FIDIC Red Book Contract Condition in April, 2018. As the Contractor CRBC JV executed detail design with their own advantages based on the main design, which was issued by the Client Croatian Roads. In the detail design, the feasibility of construction technology of each element is firstly considered by CRBC JV technical staffs. After that, the other parts of detail design, i.e. the design for execution were prepared according to the construction technology and the main design. In the mentioned progress, the Contractor should communicate with the designer of the main design as closely as possible for higher efficiency. CRBC JV prepared the detail design for all elements of the whole bridge, including piles foundation, pile caps, pylons and piers, steel superstructures and etc. The main detail design ideas and details of each element will be introduced and described in this article for providing references for implementation of similar projects in the future.

Keywords: Pelješac bridge, detail design, foundation, pylon and piers, steel superstructure

1 Introduction

To be a national unity bridge, Pelješac Bridge will establish the connection between the mainland of Croatia and its geographically separated area, i.e. Dubrovnik – Neretva county. On 21 May, 2018, accompanied the effectiveness of construction contract between Croatian Roads and CRBC JV, a dream of unification of Croatian territory was about to come true. Following main design made by its Consultants, i.e. JV of University of Zagreb, Ponting d.o.o and Pipenbaher Inženirji d.o.o, the detail design is prepared by the Contractor, then reviewed and approved by the designer of main design, the auditor (Ramboll Group A/S) and the Engineer JV of Institut IGH d.d., Centar za organizaciju građenja d.o.o. and Investinženjering d.o.o..

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2 Main design scheme description

2.1 Location

The Pelješac Bridge (Mid-point coordinates 42º56'23" N and 17º32'38" E) crosses the Mali Ston bay of around 2140 m wide on the sea. Total length of the bridge between the both axes of the abutments is 2404 m, when the whole length of the bridge including abutment is 2440 m. It is located in a marine nature protection area, closed by Pelješac peninsula on one side and mainland on the opposite side.

2.2 Principle dimensions

The whole bridge was defined as extradosed cable-stayed bridge with the layout of 84 + 108 + 108 + 189,5 + 5 x 285 + 189,5 + 108 + 108 + 84 = 2404 m, in which 189,5 +5 x 285 + 189,5 m is the central cable stayed span part and 84 + 108 + 108 m is the approach span part on both sides (Fig.1). The 4,5m-high superstructure is made up of steel box girders, which were divided into 165 segments due to various erection methods, including 12m-long standard segments of main spans, 36~56-meter-long large segments and 12m-long segments of side spans.

Figure 1 Span arrangement of Pelješac Bridge [1]

2.3 Substructure

There were 6 pylons, 6 piers and 2 abutments on this bridge. For pylon No. from S5 to S10, the foundation was founded on 18 or 20 vertical grouped steel tubular piles in 4 rows, which were 2,0 m-diameter with the maximum length of 128,4 m. For the other piers at sea S3, S4, S11 and S12 were supported by 9 vertical grouped piles of diameter 1,8 or 2,0m, and of maximum length of 80,5m. In addition, the foundation of S2, abutments U1 and U14 were constructed by mass concrete, and the well foundation was adopted to S13, which consisted of 22 overlapped concrete or RC piles. The piles of S5 to S9 were end bearing piles, except that the other piles underwater were steel-concrete composite piles with concrete sockets. The pile caps dimensions of piers S3, S4, S11 and S12 were 17,0 x 17,0 x 4,50m, while the pile caps dimensions of pylons were 23,0 x 29,0 x 5,0m. All the piers were thin-wall hollow section with height range from 19,4 to 53,235m.

3 Foundation

3.1 Steel tubular piles

As requested in the main design, the Contractor completed the supplementary geological investigation reports in advance. The main designer determined the final pile length, the Contractor completed the corresponding detail design of pile foundation as well as the construction method statements. The worldwide largest pile driving barge from China were adopted to achieve the driving of extra-long steel pile (No.TP7) once successfully, and the length of 130,6 m was set the worldwide record for once pile driving. The final pile length was listed in Table 1.

Table 1 The general piles information of pier S3~S12

Pier No.	Pile length (From pile top) [m]		
	Steel tubular pile	**Concrete part**	**Total length**
S3	33,6~39,6	38,6~44,6	38,6~44,6
S4	72,1~77,1	78,1~83,1	78,1~83,1
S5	115,7~117	42,6	115,7~117
S6	122,6~126,6	42,6	122,6~126,6
S7	128,1	42,6	128,1
S8	128,4	42,6	128,4
S9	118,5~122	42,6	118,5~122
S10	83,3~84,6	89,3~90,6	89,3~90,6
S11	73,1	75,7	75,7
S12	49,3~53,3	56,3~61,3	56,3~61,3

In the main design, the over 80-meter-long piles were suggested to be driven in two parts, which had to be welded on site. It would bring high risk of quality at the connection of the two parts as the execution class of steel structure was the highest class EXC4 B+ referring to EN 1090-2 [2]. The Contractor evaluated the risks and their own pile driven capacity, then decided to drive each steel pile in one time. The whole extra-long piles were manufactured in workshop and transported to the site. Due to the wall thickness were 40mm and 60mm, the straight seam pipe processing technology were adopted finally. The raw materials were followed EN 10025 [3], and fabrication and quality control were in accordance with EN 10219-2 [4].

3.1.1 Pile head

The pile heads were extended into the pile cap for 2,6 m. For better connection between steel tubular pile and pile cap, external and internal shear rings were set and welded at the pile head. Each shear ring was separated into three elements with 50~75mm gap between each other for the convenience of processing.

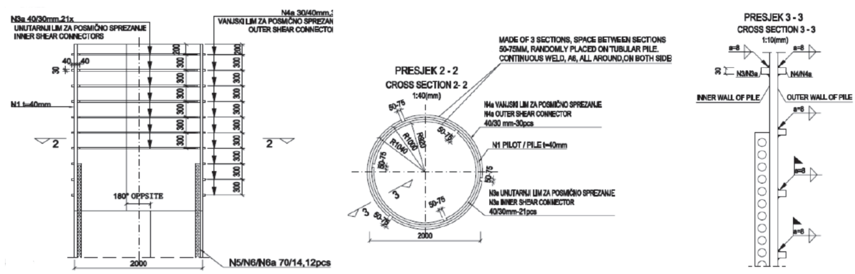


Figure 2 Details of pile head

3.1.2 Pile toe

Due to different bearing types and diameters of piles, there were three types of pile toes according to the main design. Type A and Type C were used for concrete-socket piles and Type B, which was strengthened by vertical stiffeners, was for end bearing piles. Chamfer of slope 4:1 was adopted at each pile toe for better penetration into rocks.

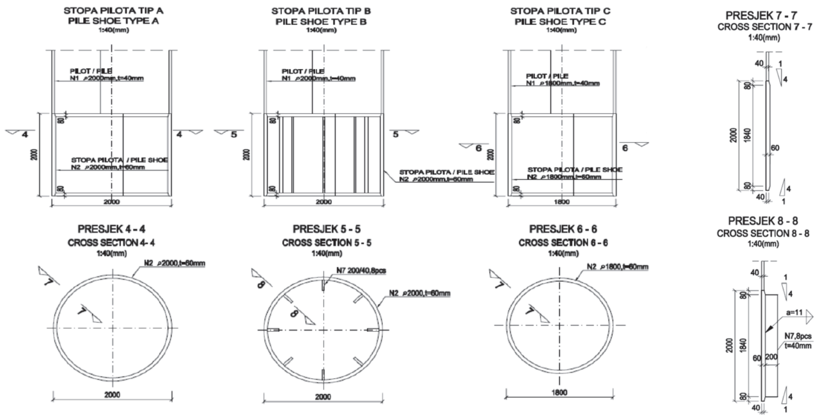


Figure 3 Details of pile toes

3.1.3 Connections between steel plates of pile body

The welding connection between steel plates of pile body were referred to EN 1993-2: 2006 [5] and EN1090-2 [2]. The butt welds of circumferential seams were adopted to the connection of pile segments. The longitudinal seams of all the standard segments on one pile body were totally staggered with the joints on adjacent segments, in order to ensure the reliable mechanical performance.

3.1.4 Pile driving

The output energy of driven hammer with 600 KJ was recommended in the main design. However, in the stages of detail design and construction, the Contractor finally adopted the hydraulic hammer with much higher kinetic energy (E_k) 800 KJ to improve the driving efficiency. Moreover, it could reduce the high risk for the construction, which the real measured skin resistance of soil and rock around the piles were underestimated just in case. The pile driving procedure and stoppage criteria were prepared by professional engineers. The stoppage criteria combined the maximum blow counts of certain penetration at required energy and allowable stress were shown below:

- Penetration ≥1500 blows / 1500 mm at $E_k \geq 650$ KJ
- Penetration ≥ 650 blows / 250 mm at $E_k \geq 700$ KJ
- Penetration ≥ 650 blows / 10 cm at $E_k \geq 700$ KJ
- Penetration ≥ 170 blows / 5 cm at $E_k \geq 700$ KJ
- The allowable stress at pile toe position was limited up to $0,9f_y/2 = (0,9 \cdot 460)/2 = 207$ MPa. (steel grade of pile toe S460)

3.2 Pile caps

In the main design, concrete cofferdams were used for the construction of pile caps. The connection between cofferdam and the steel tubular pile was below the cofferdam which will increase the construction risks. For minimizing the underwater construction, the monolithic precast concrete cofferdams were modified to the cofferdam composed by steel walls and precast concrete bottom slabs. The new solution could also reduce the risks of lifting irregular shape of cofferdam elements.

3.2.1 Cofferdam of pile cap

The bottom slabs of cofferdam were designed to prefabricate on precast yard beside the bridge. For S3, 4, 11 and 12, they were casted in one time. For S5-10, they were consisted of three parts and connected by post casted joints. See Fig.4.

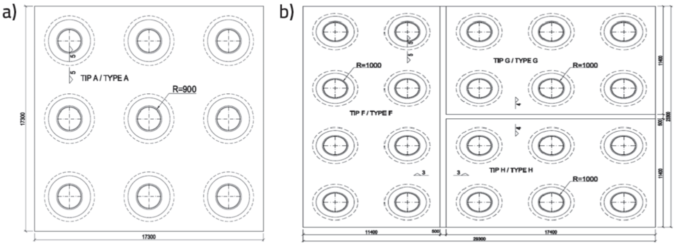


Figure 4 Configuration and joint detail of concrete bottom slab

The bottom slabs of cofferdam were lifted to the pier position above pile top and the joint parts (Fig. 4) were constructed. Then the steel walls and stiffen parts were installed and the whole cofferdam were moved down to the design level by hydraulic decentralized system. The gaps between steel piles and cofferdams were filled by sealing concrete subsequently. When the sea water inside cofferdam was pumped out completely, the pile caps could be constructed.

3.2.2 Pile caps reinforcements

Pile caps of No. S5-S10 were casted in 3 layers, S3-S4 and S11-S12 in 2 layers.

• Reinforcements arrangement

Due to the high seismic intensity, the reinforcement ratio of pile caps was rather high. Take S7 as example, 3-6 layers reinforcements D40 at bottom and 3-4 layers reinforcements D28 at top of each direction were adopted. The reinforcement was lengthened by couplers (D > 28 mm) or overlapping (D ≤ 28 mm). Due to the concrete pouring stratification, the typical stirrups were divided into three overlapped parts as shown below for the convenience of placing main reinforcements. (Fig. 5)

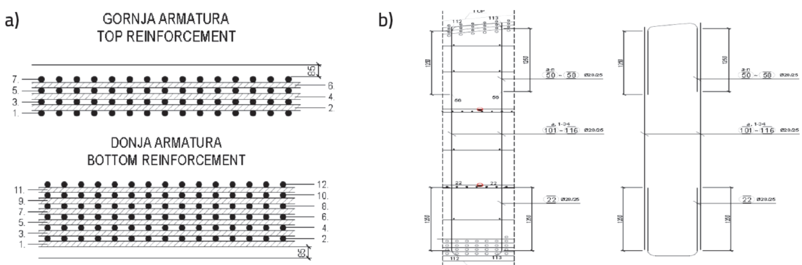


Figure 5 Arrangement of reinforcements

• Pier reinforcements embedded into pile caps

The pier reinforcements were embedded into pile caps for transferring loads from the superstructures. The embedded reinforcement bars were supported at the top of the first casting layer of pile caps. If there were conflictions between pier reinforcements and the piles, the reinforcements could be cut and welded on steel tubular piles or supported on the top surface of concrete piles.

4 Piers and pylons

The piers and pylons were both constructed by hydraulic climbing formwork system. In the main design, the segment length of piers and pylons were both 4m. In order to improve the construction efficiency, the pier segment length was adjusted to 4,5m, but the pylon segment length was kept as 4m because of the position of anchor links on them. Most of the main reinforcements from pylons were directly connected with the reinforcements from piers in concrete part of main girder. The reinforcements type D40/D50@150 mm were used for pylons, as well as D32/D40@150 mm for piers.

5 Stay cable system

There were 60 stay cables in single cable plane, and individual cable consisted of 55, 73, 91 or 109 galvanized strands of Y1860 S7-16.0. The upper pylon was 40m high above deck level. The cables were connected between deck anchorages, which were located at horizontal distances of between 22.5 m and 130.5 m from the piers, and the link systems in the pylons, which were located at between 19.25 m and 37.25 m above deck level (Fig. 6 a). The cable length was between 33 m and 137 m. The limited strength $0.55f_{uk}$ = 1023 MPa was at construction stage, $0.45f_{uk}$ = 837 MPa for SLS and $0.67f_{uk}$ = 1240 MPa for ULS at operational stage.

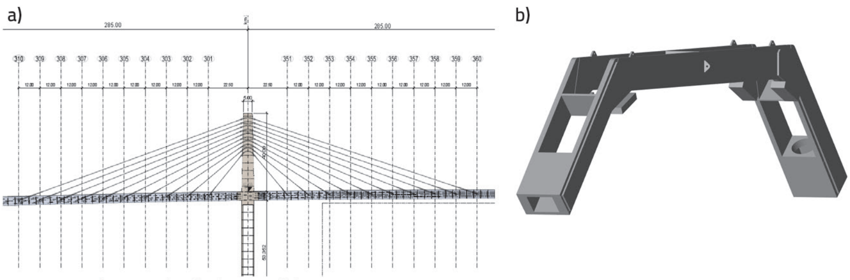


Figure 6 Layout of stay cables: a) Layout of stay cables, b) Link anchor box on pylons

For fulfilling requirements of main design, the VSL SSI 2000 Stay Cable System were adopted. The link anchor systems were made up of S355 steel plates and S235 + C450 shear studs, used as the anchors on pylons (Fig. 6 b).

6 Steel superstructure

6.1 General description

The steel superstructure was a three-cell and 4,5m-high orthotropic box girder. The top and bottom plates were 22,5 m (including the wind fairing) and 8,1 m wide respectively. The middle cell was 3,0 m wide for main spans (Fig.7) and 8,0 m wide for approach spans. The inclined bottom slab was 24° towards horizontal. The base segment at the pylon position will be casted in-situ, which was rigid connected with the pylons, connected with the steel box girder by shear studs. The base segments were strengthened in the longitudinal direction by post-tensioned strands.

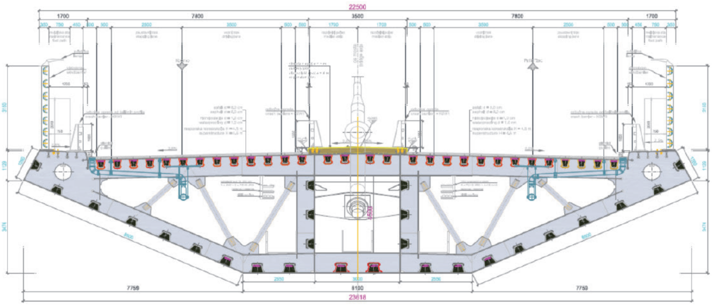


Figure 7 Standard cross section with stay cables

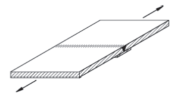
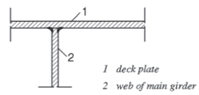
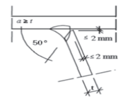
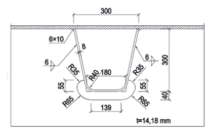
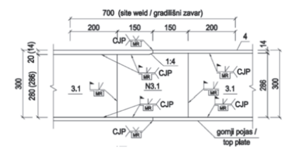
6.2 Erection method

The 165 steel superstructure segments would be erected by several erection methods. The standard 12 m-long segments of main span would be installed by derrick crane, and the segments of side spans on land would be lifted by floating crane and slipped forward to the final position by jacks on temporary steel frames. The segments of side spans at sea were 36~56 m long, which would be erected by floating crane with the lifting capacity of 1000 tons and assembled by cradles.

6.3 Overall calculation and welds design

Some minor modification of thickness of steel plates was adopted in detail design to improve the welds quality by using automatic welding sufficiently. During the construction stages, the maximum tensile stresses were 92 MPa and 80 MPa on the top and bottom plates respectively, and the corresponding minimum compressive stresses were -64 MPa and -112 MPa. And during the operational stage, the corresponding maximum tensile stresses were 247 MPa and 250 MPa, as well as the minimum compressive stresses were -158 MPa and -282 MPa respectively. Based on the calculation, all the welds types of girder were defined referring to EN 1993-2 [5] shown in Table 2.

Table 2 The main welding connections on steel box girder

Position	Welds type	Legend
Connection between deck plates / webs / bottom slabs	Single and Double V-welds with ceramic or metallic backing strip (CJP)	
Connection between deck plates and webs / bottom slabs and webs / cross frame and longitudinal slab	Twin fillet welds	
Stiffeners to the deck plates / webs / bottom slabs	T-Butt welds (partial penetration)	
Stiffeners to the web of cross frame	Fillet welds	
Continuity of the stiffeners	Butt welds	

6.4 Details of temporary matching connection

The erected segments could be temporarily positioned by site temporary matching elements, which located at the edges of segments, so as to control the fit-up gaps of the adjacent segments. The temporary - matching elements could be installed only if they meet accuracy requirements of the assembly test. When the connection of the adjacent segments has been welded totally on site, those elements could be removed. These elements were divided into 3 types, in which type D1 and D3 were connected with D40 rib bar and type D2 means connection with welded steel plates. These elements could also bear certain construction forces including "Bura" wind.

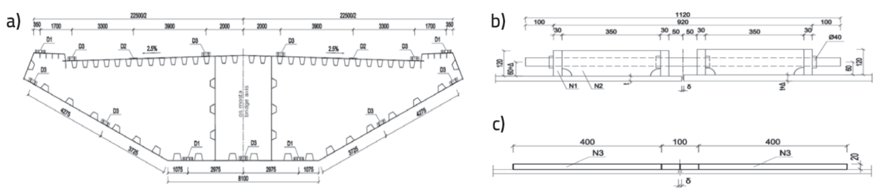


Figure 8 The configuration of site temporary matching on steel box girder: a) Arrangement of site temprary matching, b) Details of D1, D3, c) Details of D2

7 Conclusion

The detail design connected the main design and construction works. The designers of detail design must grasp the main theme of the main design and accurately refine the design documents for the construction on site. The designers of detail design communicated closely with the stakeholders mentioned in the first paragraph for obtaining ultimate consistent for the execution on site. Most of the detail design has been completed so far and the construction work is ongoing. Due to the great efforts of all stakeholders, the project is on the right way to completion.

References

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