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Comparison of variants for New Peljesac Bridge in Croatia

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ABSTRACT: The southern part of Croatia, including the city of Dubrovnik, is currently separated from the rest of Croatia by a small coastal stretch belonging to the state of Bosnia and Herzegovina. A fixed link between all parts of Croatia will be established after completion of the Mainland-Peljesac Peninsula Bridge. Construction of the bridge started in 2007, but it was slowed down and finally abandoned in 2012 due to lack of funds. The client recently requested new economically more viable solutions. Two alternative bridge solutions were proposed in the new preliminary design, a continuous steel beam bridge and a multi-span extrados semi-integral bridge with hybrid deck. Finally, the multi-span extradosed semi-integral bridge with hybrid deck was chosen for further design. Both preliminary designs will be described in the paper.

Keywords: box girder bridge, multi-span extradosed semi-integral bridge, steel deck, hybrid deck, deep foundations, cable stayed steel bridge.

1 INTRODUCTION

The Mainland-Peljesac Peninsula Bridge is the largest civil engineering structure to be built in Croatia in the near future. A fixed link between all parts of Croatian territory will be established after completion of the Mainland-Peljesac Peninsula Bridge over a navigable sea strait, with minimum required navigation clearance of 200 × 55 m (Figure 1).

This is a specific request of the neighboring country of Bosnia and Herzegovina, although the Mali Ston Bay is ecologically an extremely vulnerable area, where any larger ship traffic might

Figure 1. Location of Peljesac Bridge.

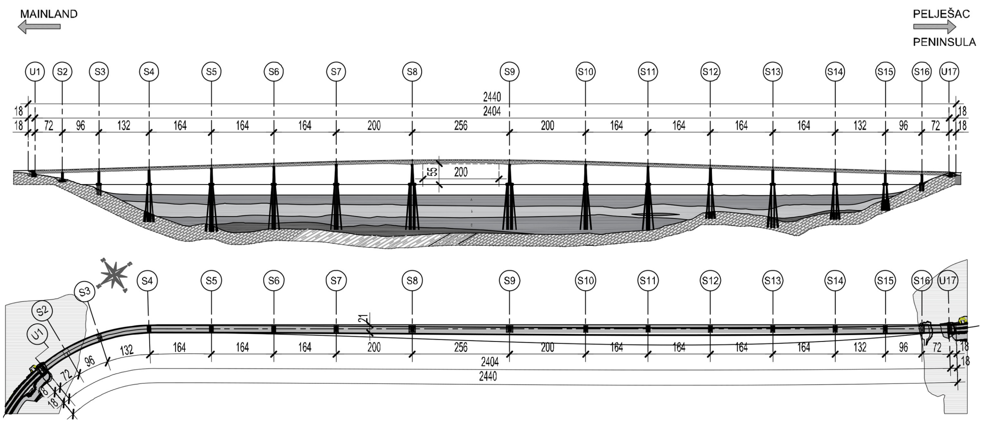

Figure 2. Continuous steel box girder bridge – longitudinal layout and ground plan.

disturb the delicate environmental balance of one of the European natural habits of oyster mussel and clam farms, and although there is no navigation channel currently chartered in this area.

The bridge site is exposed to strong winds with maximum average 10-minute wind speeds of 33.4 m/s and wind gust speeds of 47.1 m/s. The bridge site also lies in the highly active seismic zone with ground acceleration $a_g = 0.41$ g and extremely adverse foundation soil conditions. The seabed at the bridge alignment is almost level at -27 m elevation, with the stratigraphic pattern of a series of sub-horizontal layers and irregular top of the rock along the bridge. The foundation soil alongside the planned location is extremely poor, as has been confirmed by detailed geotechnical procedures and by carrying out extensive off-shore investigations, including continuous shear wave survey and geotechnical explorations from a specially equipped drill ship, drilling boreholes and taking out samples in 2004 and 2009.

The distance over the obstacle amounts to approximately 2.140 m at the sea level, while the distance at the grade line elevation is 2380 m. The total length of the bridge is 2440 m. According to the Investor's Terms of Reference, the roadway in each direction is comprised of 3.5 m wide traffic lanes, 2.5 m wide stopping lanes, and 0.5 wide marginal strips on both sides. In his additional request, the Investor required that the traffic lanes are divided in the bridge axis by safety barrier which increased the total bridge width.

The construction of the bridge was already in progress when the project was abandoned due to lack of funds. The client recently requested new economically more viable bridge solutions in order to apply for EU funding, with Croatia now an EU member state.

Two alternative solutions were proposed, a continuous steel box girder bridge and a multi-span semi-integral extradosed bridge with hybrid (predominantly steel) deck, both fully respecting the original road alignment and the already constructed bridge parts.

2 CONTINUOUS STEEL BOX GIRDER BRIDGE

The bridge deck is continuous over 16 spans with the overall length of $L = 72.0 + 96.0 + 132.0 + 3 \times 164.0 + 200.0 + 256.0 + 200.0 + 4 \times 164.0 + 132.0 + 96.0 + 72.0 = 2404.0$ m (Figure 2).

The deck structure is a continuous trapezoidal single steel box girder with constant depth $d = 6.4$ m, except in the main navigation span and the two neighboring spans, where the box girder depth increases parabolically to the maximum vertical webs projection of 10.6 m above piers S8 and S9. Webs are inclined at 78.7°. The cross section of the deck is symmetrical with double-pitched transverse roadway slope of 2.5%. The deck plate is cantilevered out symmetrical from both webs. Web spacing at the top (connection to the deck plate) amounts to 11.0 m and at

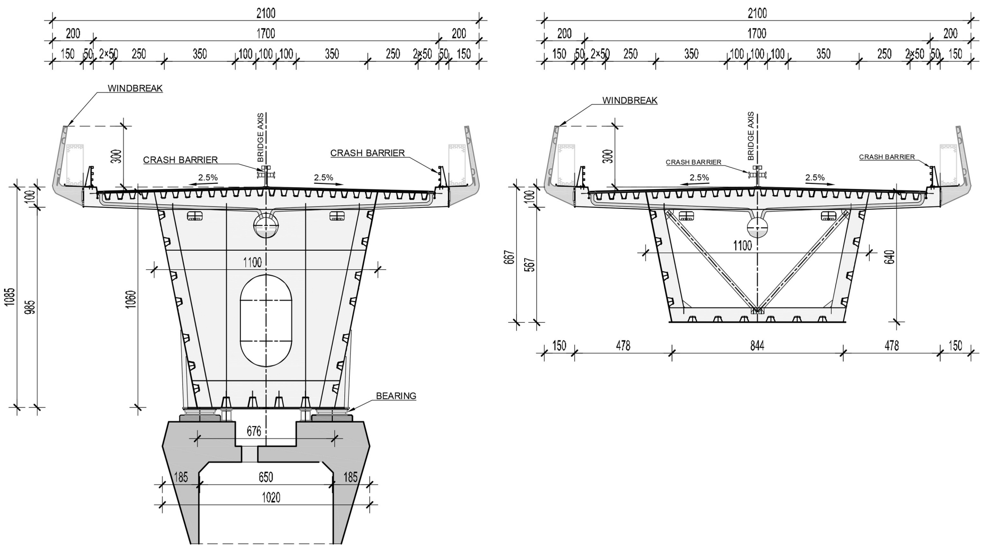

Figure 3. Box girder bridge – deck cross section above main span piers (left) typical deck cross-section (right).

the bottom (connection to bottom chord) 8.44 m for the standard cross section with the web height of 6.4 m. The total steel weight of the bridge deck is 25,500.0 t.

Vertical actions of the steel bridge deck are carried over to the bridge substructure by steel spherical structural bearings. Horizontal actions of the steel bridge deck in the longitudinal direction are taken over by a combination of viscous shock-transmitters and fixed bearings.

There are 15 piers in total (S2–S16). The pier S2 is on land, the pier S16 is at the border between land and sea and all others piers are in the sea. All piers are of box cross section with variable dimensions. The end at the top has specially formed capital. Abutments at bridge ends are massive with parallel wings.

Pier S2, S16 and part of the column S3 have been constructed in the first attempt of construction. Pier S2 on land has been constructed on shallow foundations on sound rock with foundation plate 4.0 m deep and 15.0 × 20.0 m in layout. Pier S3 is founded on 12 in sea vertical bored piles Φ1.5 m, about 15 m deep. Total pile lengths vary from 25 m to 27 m. The pile cap layout plan is 12.5 × 16.5 m with the depth of 3.5 m. Pier S16 is founded on 12 bored piles which penetrate 16 m into sound rock. The pile layout plan is 10.6 × 16.8 m with the depth of 3.0 m.

Driven steel piles Φ 2.0 m are utilized for foundations of 12 remaining piers S4–S15. A combination of vertical and battered piles in slight inclination of 5% has been selected. Battered piles significantly reduce horizontal movements of the pile caps and the whole bridge structure and take up an important part of horizontal actions due to wind and earthquake by their axial resistance. Piers S4 & S12–S15 are founded on 8 piles connected by a pile cap 11.0 × 18.0 m in plan, piers S5–S7 and S10–S11 on 10 piles with a pile cap 12.0 × 18.0 m in plan and piers S8–S9, which support the main navigation span, are founded on 16 piles connected to a pile cap 18.0 × 18.0 m in plan (Figure 4). The corrosion protection of steel piles is three-fold: additional wall thickness, passive cathodic protection with welded sacrificing anodes and special paint coatings.

3 MULTI-SPAN SEMI-INTEGRAL EXTRADOSED BRIDGE WITH HYBRID DECK

Based on the principle of comprehensive optimization method, authors systematically developed various bridge structure alternatives, ranging from the smallest possible span (120 m) to the longest

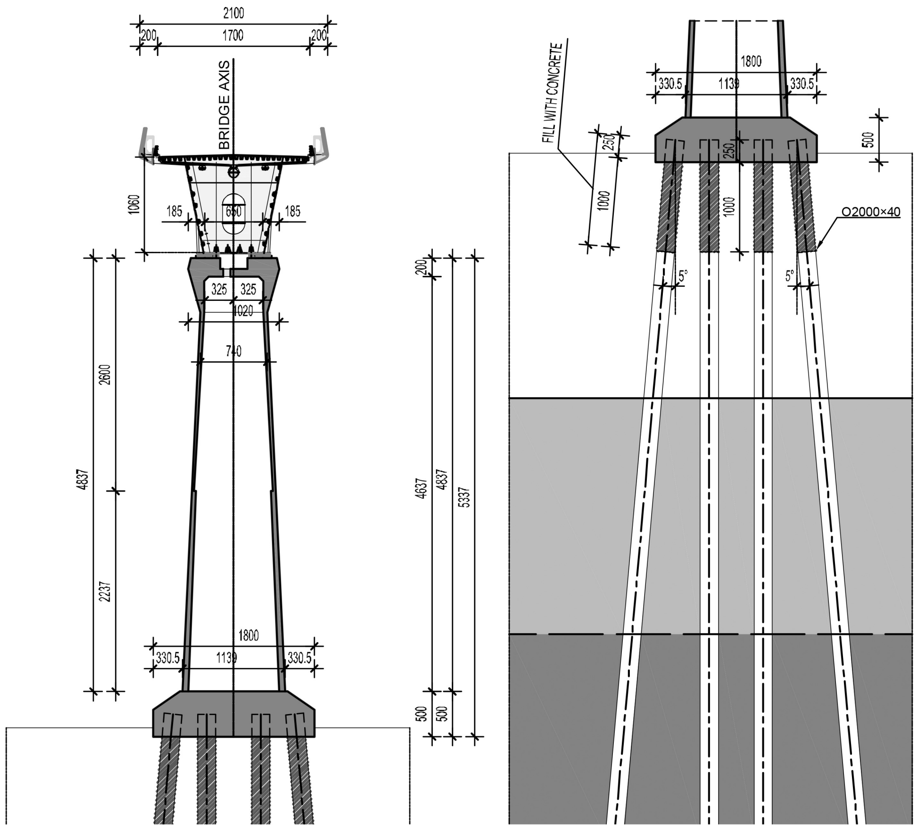

Figure 4. Pier S8 – cross section.

span (400 m). Changes of crucial criteria within the set of structural, technological, shape-related and economic parameters were analysed at the stage of an optimum bridge concept development. Authors tried to create a structurally, technically and technologically up-to-date, and financially optimal & competitive bridge, the price of which practically remains in the framework of a smaller span girder bridge, for which a greater number of pier positions significantly increases the construction price demanding deep foundations in the sea, on steel piles sometimes exceeding 120 m in length.

The bridge has been conceived as inventive structure. The central system is a multi-span semi-integral bridge with six low pylons and five 285.0 m openings, so that a full symmetry in space has been achieved (Figure 5). In landscape, the bridge appears as a very light and peaceful composition. The integrally conceived bridge structure, with a hybrid superstructure, ensures seismic stability of the bridge without installation of big bearings and seismic dampers. Bearings and guiders installed on shear keys are planned only at end parts of the bridge – at abutments and piers 2-4 and 11-13.

The extradosed cable-stayed deck, and 33 m high centrally placed reinforced-concrete pylons, are elastically restrained to piers so that in its central part measuring 1832 m (76% of the total bridge length) the bridge is a frame structure without bearings, which provides for an additional stability of the bridge in case of seismic action and wind gusts.

The bridge deck is a continuous hybrid box structure that is suspended in its central part by stays on to six centrally placed reinforced concrete pylons (multi-span cable-stayed bridge). The steel superstructure 19.50 m in width is a three-cell box with overhangs (Figure 6). The total width of the superstructure with the wind screen amounts to 22.40 m.

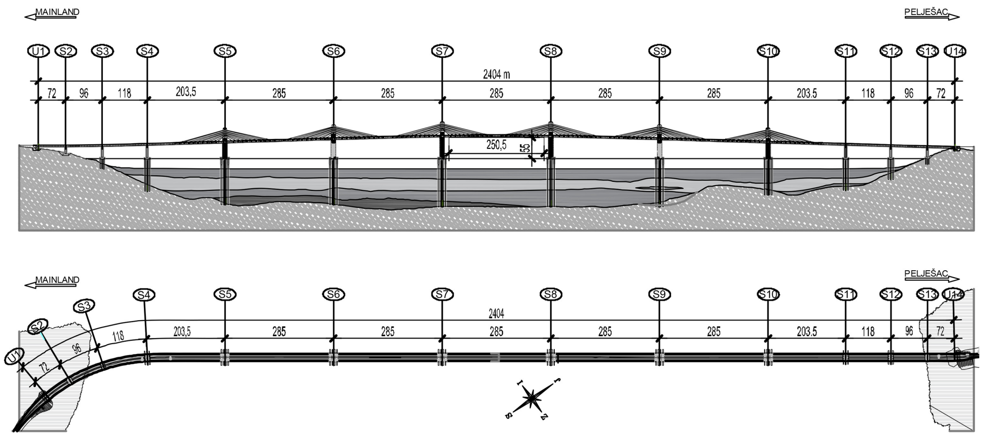

Figure 5. Multi-span semi-integral extradosed bridge – longitudinal layout and ground plan.

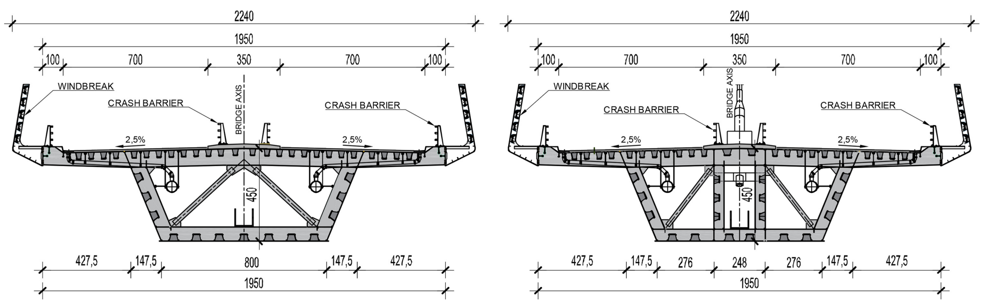

Figure 6. Multi-span semi-integral extradosed bridge – deck cross-sections; not suspended (left), suspended (right).

Pylons are 33.0 m in height and so the pylon height to span ratio is $33.0/285.0 = 11.60$. Hence the bridge can be classified as being somewhere at the limit between cable-stayed and extrados bridges. The continuous box superstructure is characterized by the systemic length of 2404.0 m which is divided as follows: $72.0 + 96.0 + 118.0 + 203.5 + 5 \times 285.0 + 203.5 + 96.0 + 72.0 = 2404$ m. Pylons are made of solid concrete and they measure 2.20×5.0 m at the top, and 2.20×6.2 m at the superstructure level. The high strength concrete type C60/75 shall be used for the realization of pylons.

Stay-cables are basic structural and load bearing elements of the cable-stayed bridge. The superstructure is supported with stays arranged in a single plane, spaced at 12.0 m intervals. Stay-cable length ranges from the smallest $2 \times 27.5 = 55$ m to the largest $2 \times 135 = 270$ m. Each stay consists of at least 75 and of no more than 109 strands.

Bridge piers 3–12, located in the sea are founded on driven steel piles 2000 mm in diameter, 55–125 m in length. At the sea level the piles are fixed to the concrete pile cap and, in this way, an appropriate load bearing capacity and horizontal stiffness of foundations will be ensured. Pile cap is 5.0 m thick with layout dimensions of 22.0×24.0 m. Pile caps also protect piers against direct vessel impact in case of vessel collisions.

Relatively low piers S2-S4 and S11-S13 (measuring 18.5–31.33 m in height) are of box section and their external measures are constant, which greatly facilitates their realization. The piers are of octagonal cross section and they measure 4.0 m in longitudinal direction, and 10.0 m in transverse direction. The cross-sectional wall thickness is constant. In transverse direction, the walls are 0.50 m thick, and in the longitudinal direction (along the bridge length) 0.60 m thick.

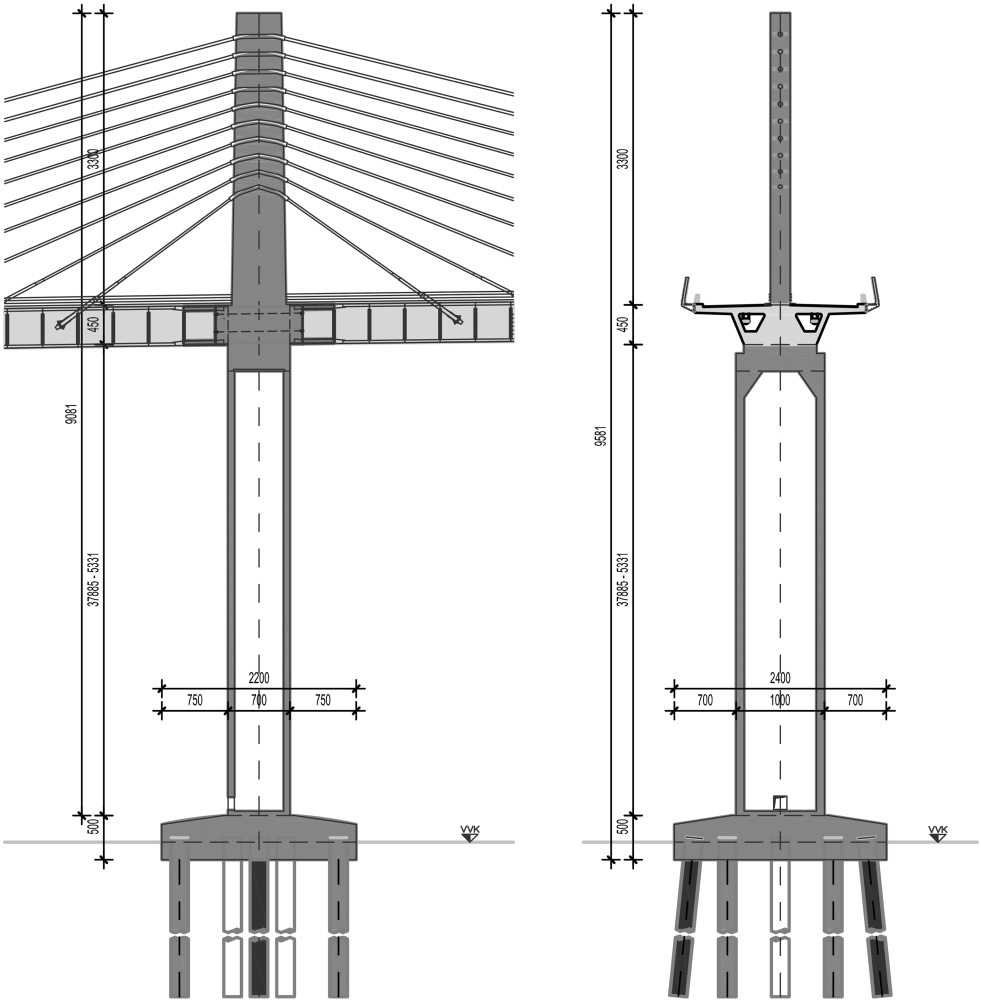

Figure 7. Pylons: Longitudinal section (left), Cross section (right).

Piers S5–S10, representing the bottom part of pylons, are 37.88–53.30 m high (Figure 7). The piers are of box cross-section and their external measures are constant, which greatly facilitates their fabrication. The piers are of octagonal cross section and they measure 7.0 m in longitudinal direction, and 10.0 m in transverse direction. The cross-sectional wall thickness is constant. In transverse direction, the walls are 0.70 m thick, and in the longitudinal direction (along the bridge length) 0.90 m thick.

4 CONCLUSION

The construction of original Mainland – Pelješac Peninsula Bridge was abandoned due to lack of funds. It was necessary to design new economically more viable bridge solutions in order to apply for EU funding.

The key challenges for the bridge design are high bridge alignment at approximately +90 m elevation, adverse soil conditions, high seismicity of the site and stringent ecological requirements.

Figure 8. Computer rendering of continuous box girder steel bridge.

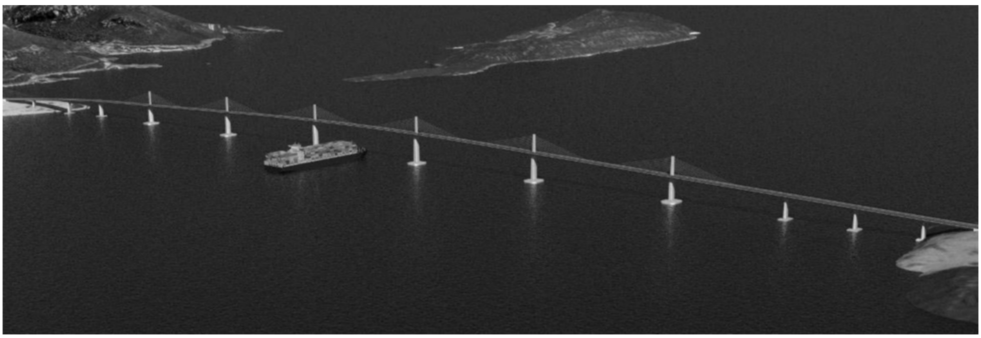

Figure 9. Computer rendering of multi-span semi-integral extradosed bridge – aerial view.

Two independent design offices proposed two alternative solutions. Continuous steel box girder bridge and a multi-span semi-integral extradosed bridge with hybrid deck.

In both preliminary designs the road alignment adopted in the original design, total bridge length of 2404 m and already constructed bridge substructure parts were fully respected.

Due to all fore mentioned reasons, first alternative solution was design of a very light bridge. Bridge deck is designed completely in steel and most of the driven piles are designed as slightly battered to facilitate the reduction of dimensions of pile caps in plan to a minimum, and also to increase the foundation stiffness.

From the architectural point of view we can conclude that the author wanted to create structure which would blend harmonically into the environment and not impose on it.

In the second preliminary design, authors tried to create something unique in appearance and structurally up-to date. Multi-span semi-integral bridge is a large, impressive and excellently designed engineering structure with soul and character.

Thanks to an inventive approach to the design of this extreme bridge with an integral structure, featuring a hybrid deck suspended to six pylons, the bridge meets crucial design criteria of appearance, stability, durability, usability and economy in construction, which should be reflected in subsequent maintenance costs.

An independent French consultant in their preliminary study preferred multi-span semi-integral extradosed bridge alternative. Based on these recommendations the Investor decided to choose the multi-span extradosed bridge for further design.

Figure 10. Computer rendering of multi-span semi-integral extradosed bridge – close-up view.

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