STRAIT CROSSING ON ADRIATIC COAST : PELJEŠAC BRIDGE

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SUMMARY

In accordance with the present understanding of the development and the construction of fixed crossings a structural and economic feasibility analysis was performed for the optimum bridge crossing to the peninsula Peljesac in Croatia. The basic solution was a continuous hollow cast girder over columns and with 20 spans, where the maximum span is 120 m long. The second option is a combination of a cable-stayed bridge and the approaching bridges as a continuous hollow cast girder: the first variant with the maximum middle span of 500 m and the second variant with the middle span of 650 m. Analysies shows competitiveness of both options and a need for further analyses and optimization, particularly in the area of cable-stayed solutions where a lot of potential remains.

1. INTRODUCTION

The need for fixed links between islands and the mainland, or between the distant coastal lines of a bay, has been present for centuries all over the world. But only in the last hundred years or so have such links begun to come into existence more intensely due to the development of intense traffic, advanced constructing technology and extensive financing of such construction megaprojects.

An analysis of the types of crossings and their economic feasibility is an issue that has been observed for years on numerous examples of crossings all over the world, and for the time being it reached its peak in the fixed crossings Great Belt and Öresund in Denmark, as well as in the links between the islands of Japan. Observations on whether a bridge crossing or a tunnel crossing should be applied on a site will mostly depend on the location of the construction works. However, today's understanding of the economic feasibility of different facilities as well as the methodology of construction suggest that a rough border between a bridge and a tunnel would be at approximately 2 kilometers (**Kolić D., 1997)**.

The Croatian coast typically illustrates this phenomenon. Due to its indentedness it offers exceptional opportunities for carrying out of fixed links between a number of islands and the mainland, or among the islands. Croatia is familiar with the international practice, which served as a basis for the development of projects for the revitalization of the islands and their linkage with the mainland

The Croatian coast typically illustrates this phenomenon. Due to its indentedness it offers exceptional opportunities for carrying out of fixed links between a number of islands and the mainland, or among the islands. The need for a link between the mainland and the Pelješac peninsula is in the first place a strategic one. Such link enables unifying all parts of the Croatian state, independently of corridors through a foreign country. It represents an extensive infrastructural megaproject that will rank high on the list of priorities in the implementation of traffic connection plans of the Republic of Croatia (**Radić J., Kolić D., 2003)**. Building a fixed crossing would also enable a more intensive development of the micro and macro region, creating the preconditions for their rapid development.

2. THE MOST ACCEPTABLE TYPES OF BRIDGES

Considering which type of crossing would be most acceptable for the link with the Pelješac peninsula, preliminary examinations soon demonstrated that only the bridge crossing option should be considered (**Radić J., Kolić D., 2003).** The reason for this lies in the first place in the cost-effectiveness of the facility. Furthermore, the latest amendments to regulations, by which higher safety standards were introduced for tunnel constructions, caused a significant increase of construction costs of a number of constructive elements and measures that need to be carried out in order to reach the same safety level in tunnels as on open roads or on bridges. Those additional measures include in the first place: signaling, monitoring, air-conditioning, security against breaking of water and escape routes.

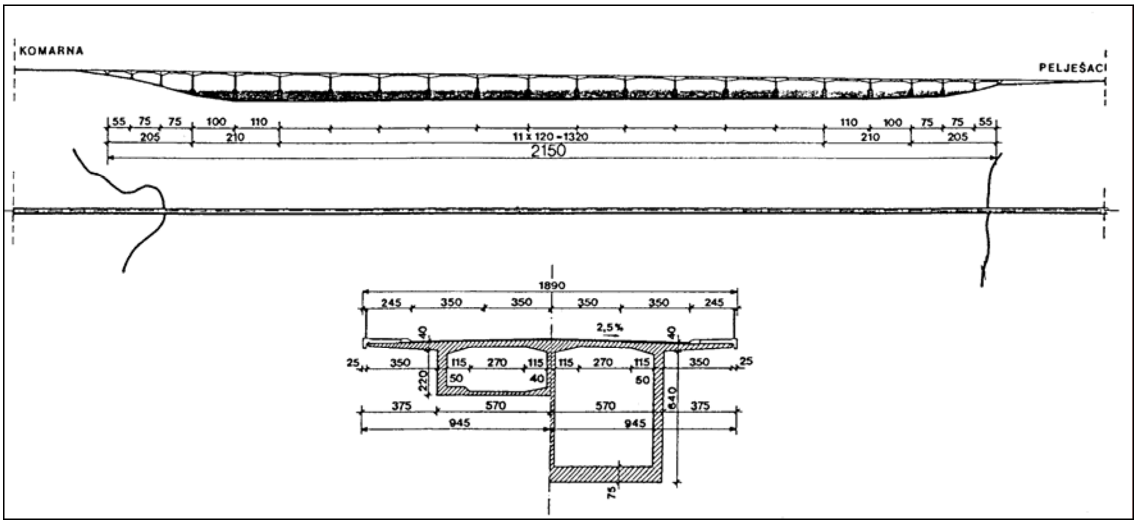

Fig. 1 *An option of the crossing with spans at max. 120 m and a low grade line, with free cantilever construction on columns or combined with precast 50 m long girders in the center of the field.*

Therefore further observations concentrate on an analysis of different bridge facilities and a comparison of individual types of bridge constructions. Collected bridge construction costs in different countries of Europe (**Correialopes, 1999**), (**Avigno-Calero, 2003**) offer a global overview of price fluctuations. But if those unit prices are still to be applied to future facilities, they should be taken with reservation, since:

- they emerged from the conditions at the local construction market, which depends on the degree of development of the region and accordingly on the price level
- they are based on local regulations and norms, which can considerably differ from country to country
- the share of the individual elements of the structure and the accompanying costs that led to the building of the final price are not familiar

An analysis of the price development trends that the most acceptable construction forms would be continuous systems, made of precast girders, hollow box cross-sections carried out on a formwork, or hollow box cross-sections carried out in free cantilever construction. Along with those types of bridges, the type of cable-stayed bridges is also manifest, which is the only one worldwide that shows a downward development trend of construction price. The reasons for this are in the first place the development of construction technology of cable-stayed bridges and the structure optimization in the past forty years of the twentieth century (**Kolić D., 1998)**. The analyses carried out in this study were directed chiefly to concrete construction types, but in the future certainly steel and composite systems and their combinations will have to be considered as well.

For crossing the span of 2,150 m, after examining international practice and unit prices of individual solutions the hollow box continuous system on several columns with the maximal span of approximately 120 m was chosen for a detailed analysis. An examination of the prices of similar bridges resulted in establishing a framework showing that the range of prices of similar bridges is in between 1300-2500 €/m² (**Correialopes, 1999**), (**Avigno-Calero, 2003**).

Within the first two options the analysis was concentrated on analyzing continuous hollow box girder across several spans with maximal span of 120 m and with two basic widths: as a two-lane (option 1) or a three-lane bridge (option 2). The results of the construction cost estimate are shown in Tab. 1.The entire bridge was analyzed assuming free cantilever construction with cross-section of varying height. An additional option that needs further analyses would have free cantilever construction elements in formwork from the columns, while the central part of the bridge would be constructed by mounting the precast girders at spans of up to 50 m. The construction period is assessed at approximately 3.5-4 years.

3. CABLE-STAYED BRIDGE OPTIONS

An analysis of the use of cable-stayed bridges started from scrutinizing the reasons for the recent reduction of the construction price of this type of bridges.

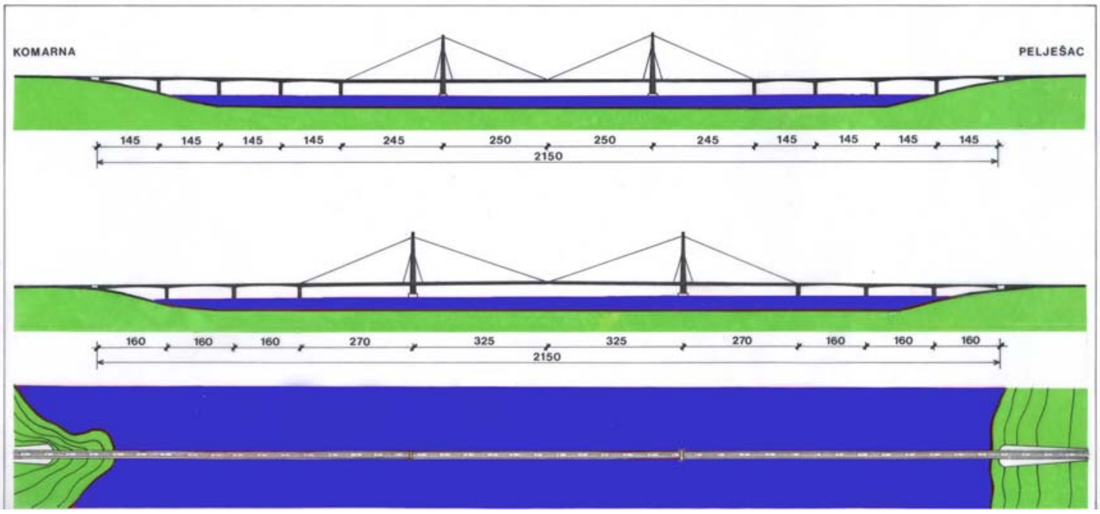

***Fig. 2**: Options of combined crossing to Pelješac: cable-stayed bridge in the middle and approaching bridges as continuous hollow box girder of varying height, with middle span of the CSB 500 m (up) and 650 m (below).*

In the past five decades, reasons such as cross-section optimization, advanced knowledge on dynamic characteristics of the stiffening girder cross-section and on the impact of wind and earthquake, the decrease of the price of cables (which were a prevailing factor in determining the price of cable-stayed bridges fifty years ago), the development of numerical programs for static and dynamic construction analyses, as well as the development of construction technology have expanded the scope of competitiveness of cable-stayed bridges. Analyses carried out for different widths of stiffening girder and of the exposure to road and railway traffic, or both parallelly, as is the case with urban bridges, show that this type of bridge construction is remarkably economical and would be taken into consideration as particularly adequate for the crossing to Pelješac (**Kolić D., Radić J., 2004**). The comparison of cable-stayed bridges was conducted in the first place with continuous hollow box girders with a varying cross-section and height. Therefore it was concluded that for further analyses in case of a crossing to Pelješac independent types of those two bridge types will have to be analyzed, and the most favorable combination of dimensions and distribution of spans of those two types of bridges in one building stated.

4. OPTIMIZATION OF FIXED CROSSINGS

According to the existing knowledge on cable-stayed bridges two options were made, for which it was assumed that in the sense of construction and economic feasibility the results would be competitive with the conventional solution of a continuous hollow box girder with cross-section of varying height, analyzed in this paper as options 1 and 2.

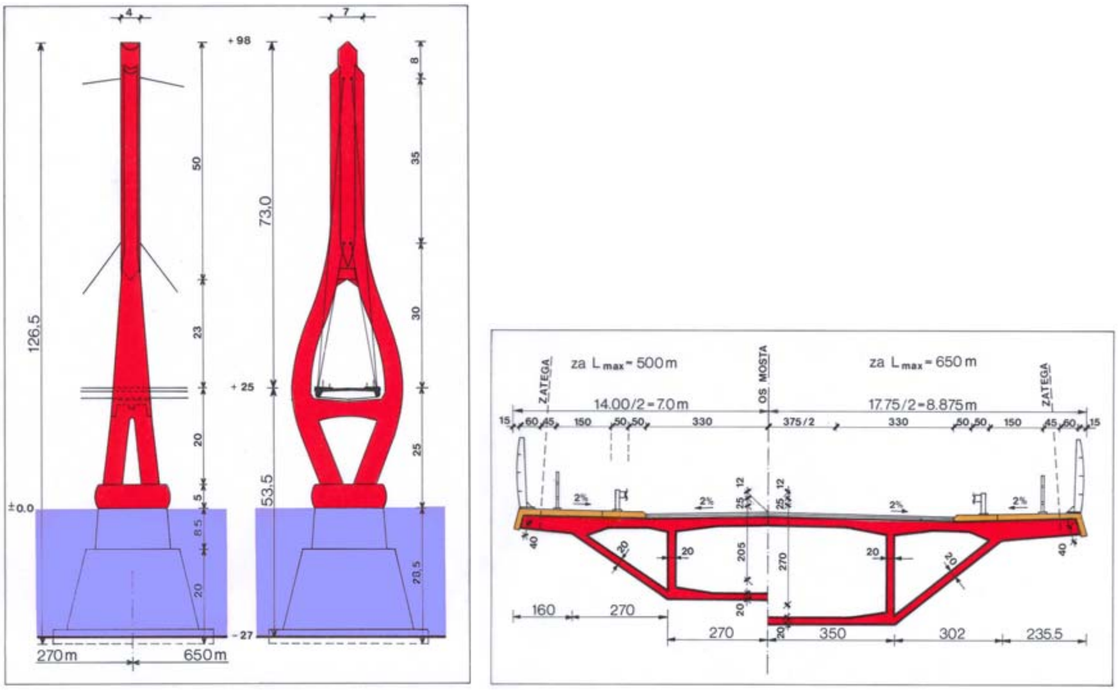

***Fig. 3**: Pylon of cable-stayed bridgeand cross-sections for middle spans of 500m (left) and 650 m (right).*

Two options of a combined CSB crossing to Pelješac are being analyzed, with similar dispositions, and following differences :

- <u>Option 1</u> CSB middle span 500 m, CSB total length 990 m, approaching constructions carried out as continuous hollow box girder over 8 spans, with the maximal span of 145 m

- Option 2 CSB middle span 650 m, CSB total length 1190 m, approaching constructions as a continuous hollow box girder over 6 spans, max. span 160 m

The traffic demand under the bridge at this point determined the height of the stiffening girder at approximately 25 m above sea-level, and the span between the pylons in both options allows clearance under the bridge of minimally 400 m in width. The traffic demand on the bridge is defined as the basic solution with two lanes and walkways on both sides. An additional option would be a stiffening girder with three lanes, designed particularly for the traffic in the peak of a season.

Option 1 would be carried out as a CSB with two pylons in water on 3 m thick filled round foundation plates at 27 m under the sea. On the foundation plate a cone-shaped caisson would be constructed for the sunken part of the pylons. On the surface the caisson would have a rounded head, shaped so as to absorb possible crashes with ships more easily. The body of the pylon would be carried out in slip-formwork. The approaching bridges on both sides would be carried out in free cantilever construction from columns previously made in the same way as pylons. Only the parts from the abutments to the first columns, reachable from the mainland, would be made on a formwork due to the agreeable construction price. The cross-section would be carried out in the shape of a box, primarily due to the necessary rigidity in the statical sense and resistance to dynamical impact.
Option 2 would be carried out in the same way, only with different dispositions of elements and parts of structure, as represented in figure 2.

5. AREAS OF FEASIBILITY

An analysis of cost estimate results offered a number of interesting indications (Tab. 1):

- continuous hollow box girder of varying height is still the absolute and relatively most feasible solution (opt. 1 and 2), see Tab.1

Opt.	**Bridge type**	**Max. span L_{max} [m]**	**Bridge width B [m]**	**Pylon height H [m]**	**Price per surface unit [€/m²]**	**Total constr. price [mill. €]**
1	Cont.holl. box girder, var. cross-section height	120	14.00	--	**1576.2**	47.4
2	Cont.holl. box girder, var. cross-section height	120	17.75	--	**1614.8**	61.6
3	Cable-stayed bridge with a 500 m main span	500	14.00	150	**1860.0**	55.9
4	Cable-stayed bridge with a 650 m main span	650	14.00	165	**2228.2**	67.1
5	Cable-stayed bridge with a 500 m main span	500	17.75	150	**1637.0**	62.5
6	Cable-stayed bridge with a 650 m main span	650	17.75	165	**1968.1**	75.1

Tab. 1 *: Cost estimate for different options of the crossing to Pelješac.*

- the combination with a CSB with the middle span of 500 m with the same width of cross-section of the stiffening girder (14.00 m) is competitive with the construction in opt. 1 and 2

- the combination with a CSB with the middle span of 500 m with a larger width of the cross-section of the stiffening girder (17.75 m) is even more competitive with opt. 1 and 2, showing the capacity of CSBs for broad roadways at larger spans

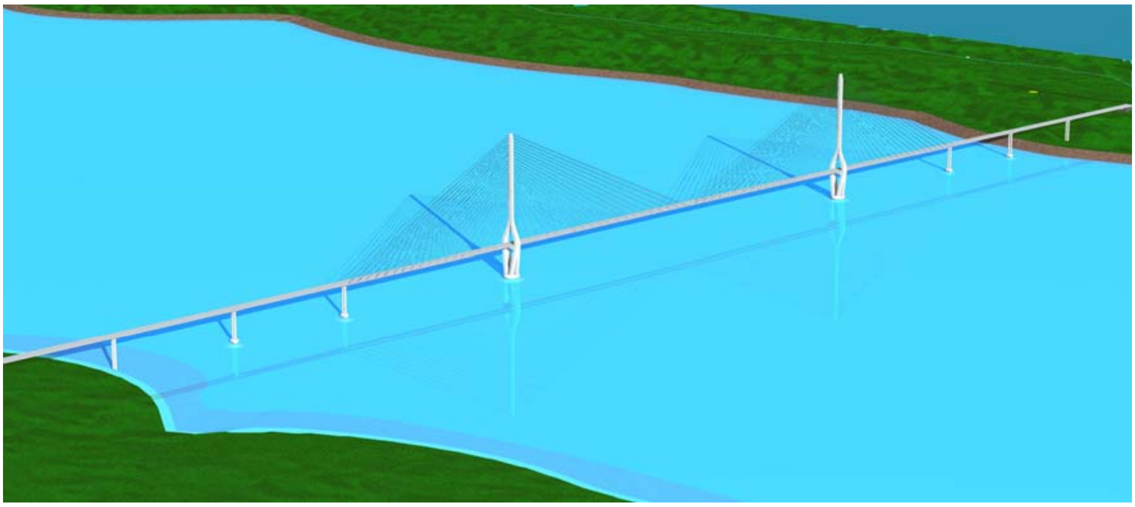

Fig. 4: *3-D Simulation of a cable-stayed crossing evaluated in the study of variants (Tab.1).*

6. CONCLUSIONS

To conclude, let us primarily point that other materials apart from concrete should also be analyzed and possible composite and metal elements of the crossing construction estimated. All price analyses have shown that the prevailing element (approximately 25-35%, depending on the option of the forming of the individual prices) is the undersea foundation. Although a favorable geological forecast is assumed, still there is a high possibility of unexpected works, which can cause a drastic cost increase.

7. REFERENCES

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