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FEASIBILITY OF PELJESAC BRIDGE VARIANTS

Strait crossing to Peljesac peninsula in southern part of Croatia is one strategic connection that will connect two parts of the Croatian territorium where the Republic of BiH comes to the Adriatic sea. This crossing has the length of about 2300 m and is estimated to be constructed as a bridge structure. Several bridge options are still in investigation but preliminay design and first cost estimations have depicted that the superstructure of the bridge should be performed in steel in order to minimise the weight of the structure. Substructure will be performed in concrete and geological conditions are showing necessity for pile foundations. Due to the soft soil layers underneath sea bed and unknown depth of stone formations mayor foundation type is proposed with 70 m deep reinforced concrete friction piles in steel pipe casings. The cost estimation is therefore very much depending on the substructure costs and on the number and location of foundation points. Construction cost estimations are showing how the relation between structural capacity and construction methodology for substructure and superstructure defines the most acceptable and feasible structural solution on example of the bridge to Peljesac strait crossing.

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1. PROJECT DEVELOPMENT

The connection between mainland and peninsula Peljesac is one strategic connection that will provide fix bond between two parts of Croatian territory. Republic of Bosnia and Herzegovina has approach to the Adriatic sea at one small part of the coast. This part of the coast divides Croatia into two parts that do not have any traffic connection within own territory. Therefore beside other approaches that are looking for feasibility of the structure and for the way how to pay-off the investment by traffic intensity, this connection will have mainly strategic reasons to be constructed. But this is also the main reason why to look for the optimal bridge structure that will offer required structural capacity and be at the same time economically most acceptable.

The idea to build this bridge is at least a decade old : the area of Peljesac peninsula has a low number of inhabitants because of several emigration periods when a lot of people left this part of Croatia due to the troubles with possibility to earn enough for their life. Therefore establishing of traffic connections could seriously improve possibilities for further development of micro and macro region and make preparations for opening new working places. How to construct this strait crossing was not a question from the very beginning : already first presentations of the crossing are showing a bridge connection as the only one that was investigated and predefined as a crossing option. The mayor reason was that the bridge is well-known and very often way used for all types of crossings in Croatia and has a long tradition in structural engineering society in comparison with e.g. tunnel crossings.

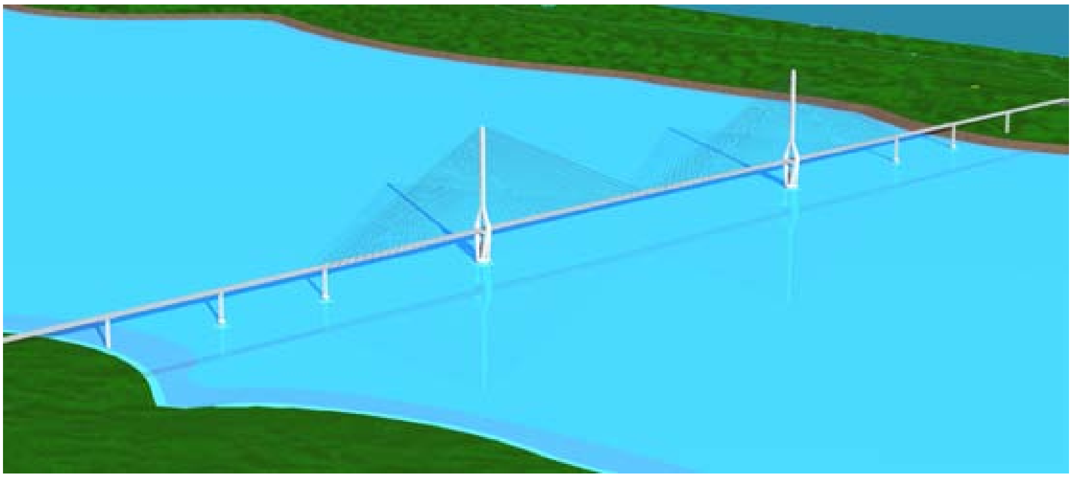

Figure 1 : Cable-stayed bridge crossing with approaching spans [**4**, **5**].

First investigation of different bridge crossing started not more than 2 years ago and have been published in several articles in structural engineering society [**1**] and then further developed and improved through the set of works and estimations [**2, 3, 4**]. After two years of work in conceptual and preliminary design, comparing different options regarding structural buildability, durability and economical feasibility different new information have been published. Finally together with preliminary geological investigations they enable more precise and detailed approach and presentation of the possible bridge crossing. First construction cost estimations [**5**] and later on more details on different estimated possible structural solutions investigated so far [**6**] have been presented in last months. Anyhow further investigations and options are still in estimation and may follow to the optimal structural solution that should serve to project requirements and be one sound and feasible structure.

2. PRELIMINARY DESIGN

Estimation of preliminary design options that are derived so far have presented about 10 different solutions for crossings [**6**]. Presented options have investigated different span sizes ranging from 170 to 350 m, with different number and shapes of foundations ranging from 10-13 and having different types of superstructure. Options have been investigated with different usable widths of 12.5 and 15.0 m but during the development of options it has been mentioned that options width wider cross section and service width of 15.0 m would be more interesting due to the traffic and structural cross section capacity.

Option „5" : Among presented options the favourable one was the one with the lowest price (fig. 2) that has a continuous steel box girder of same height of 6.0 m along the entire bridge length. The superstructure is placed on 13 colums, spans are 130 + 12x170 + 130 m= 2300 m. The entire superstructure is on elevation enabling service area for ships of 150 x 35 m. The foundation of this option is based on 13 foundation plates, each placed on 8 reinforced concrete friction piles of 250 cm diameter in steel casings and 70 m deep. For this option as well as others that were not estimated so far construction costs have been estimated on basis of appropriate unit prices on Middle-European market in this year.

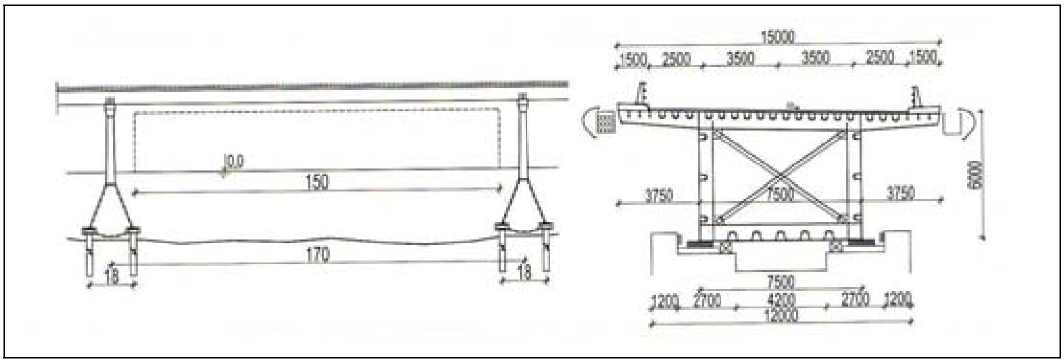

Figure 2 : Favourable option „5" from preliminary design phase [**6**].

Option „9" : Beside other options remarkable was also the one with cable stayed bridge as far more attractive solution with other characteristics that are offering same service capacity with different distribution of structural elements due to the other type of the structure. Stiffening girder is designed as a steel hollow box girder but with very heavy cross section type. Numer of piles underneath each foundation plate remained the same as in the case of option „5" but having more piles where pylons are staying on foundation plates and just 8 piles underneath foundation plates in approaching spans. The superstructure is placed on 12 columns including 2 pylons and with spans of 130 + 4x170 + 175 + 330 + 175 +4x170 + 130 = 2300 m. When estimating construction costs for this as well as for other options intention will be to point out the difference in construction technology or structural capacity and elements that have direct influence on the estimation of the final construction price.

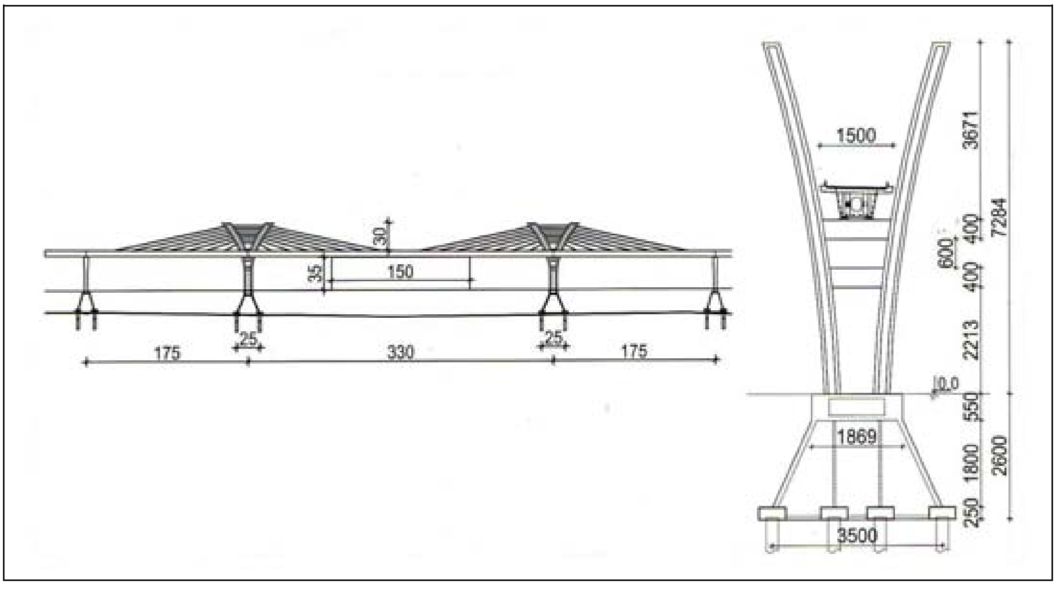

Figure 3 : Option „9" from preliminary design phase [**6**].

3. INVESTIGATION OF A FEASIBLE BRIDGE CROSSING

Investigating project boundary conditions, general circumstances and traffic requirements all estimations in very early project phases depicted geological conditions as a mayor actor that may have very strong influence on the overall construction costs. This estimation has been approved with results of first borings done from the ship and after testing all boring logs. Gelogical investigations has shown that the seabed has first 7 meters of very weak sedimentary soil layer and afterwards until the depth of about 70 meters clay soil layers of different consistency and characteristics has been found. After first 70 meters some type of stone formation, probably limestone or breccia layers are to be expected. Therefore first estimation have defined pile foundation as a basic foundation type. The number of piles had to be defined on the weight of superstructure and the part of the substructure down to the foundation plate.

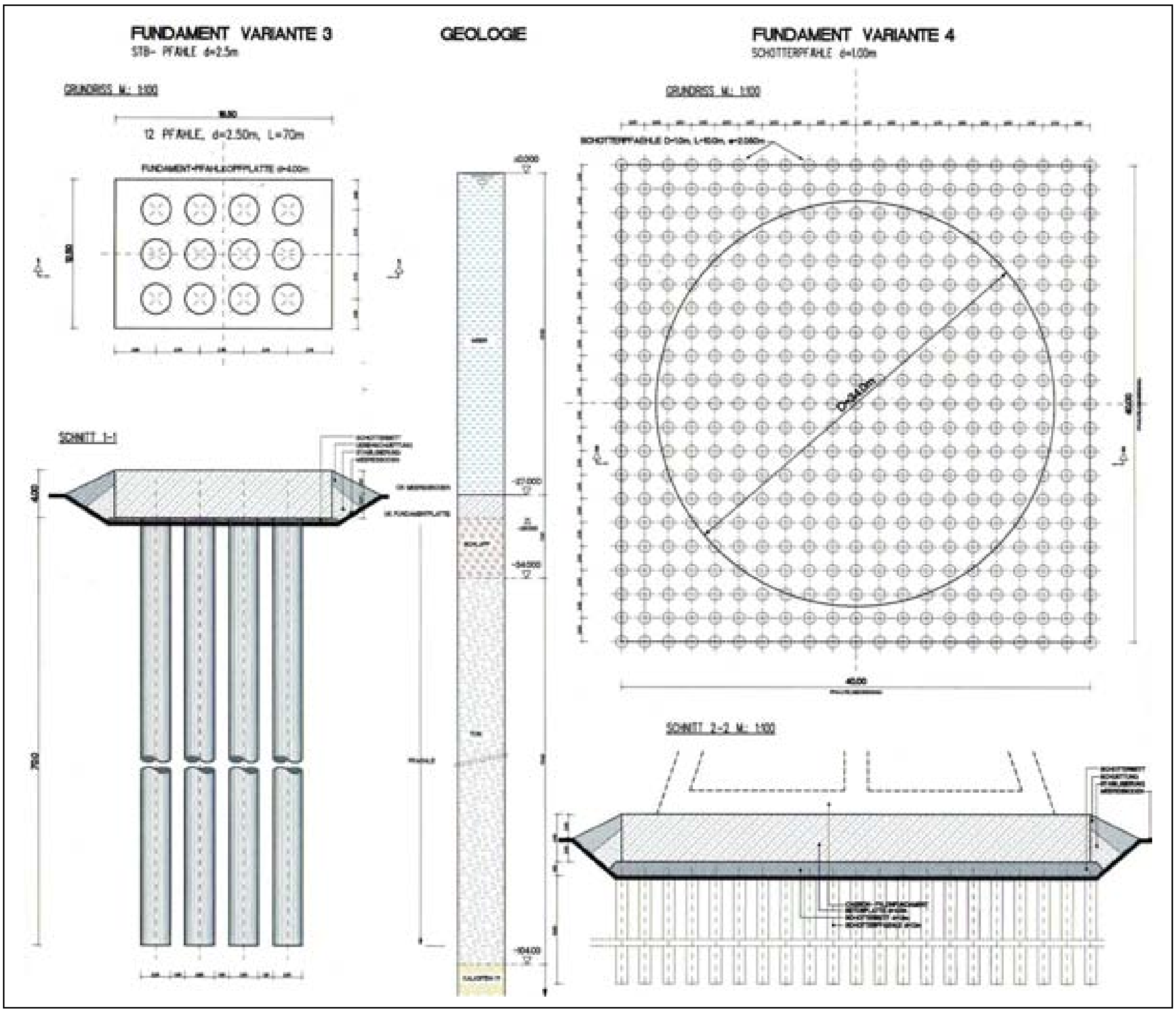

Figure 4 : Two investigated foundation options : reinforced concrete 70.0 m deep bored piles (left) and soil improvement with stone columns (right).

Even though deep friction piles are often used for such type of foundations other methods should be also investigated and estimated as e.g. soil improveemnt methods. Such methods using soil improvement like the one with steel pipes jacked into the soil body underneath the foundation plate have been used on bridge project Rion-Antirion in Greece. Also another method using stone columns has been used for the soil improvement of immersed tube project Aktion-Preveza in Greece too, in very similar geological conditions and very active earthquake area as the one on the Adriatic coast is.

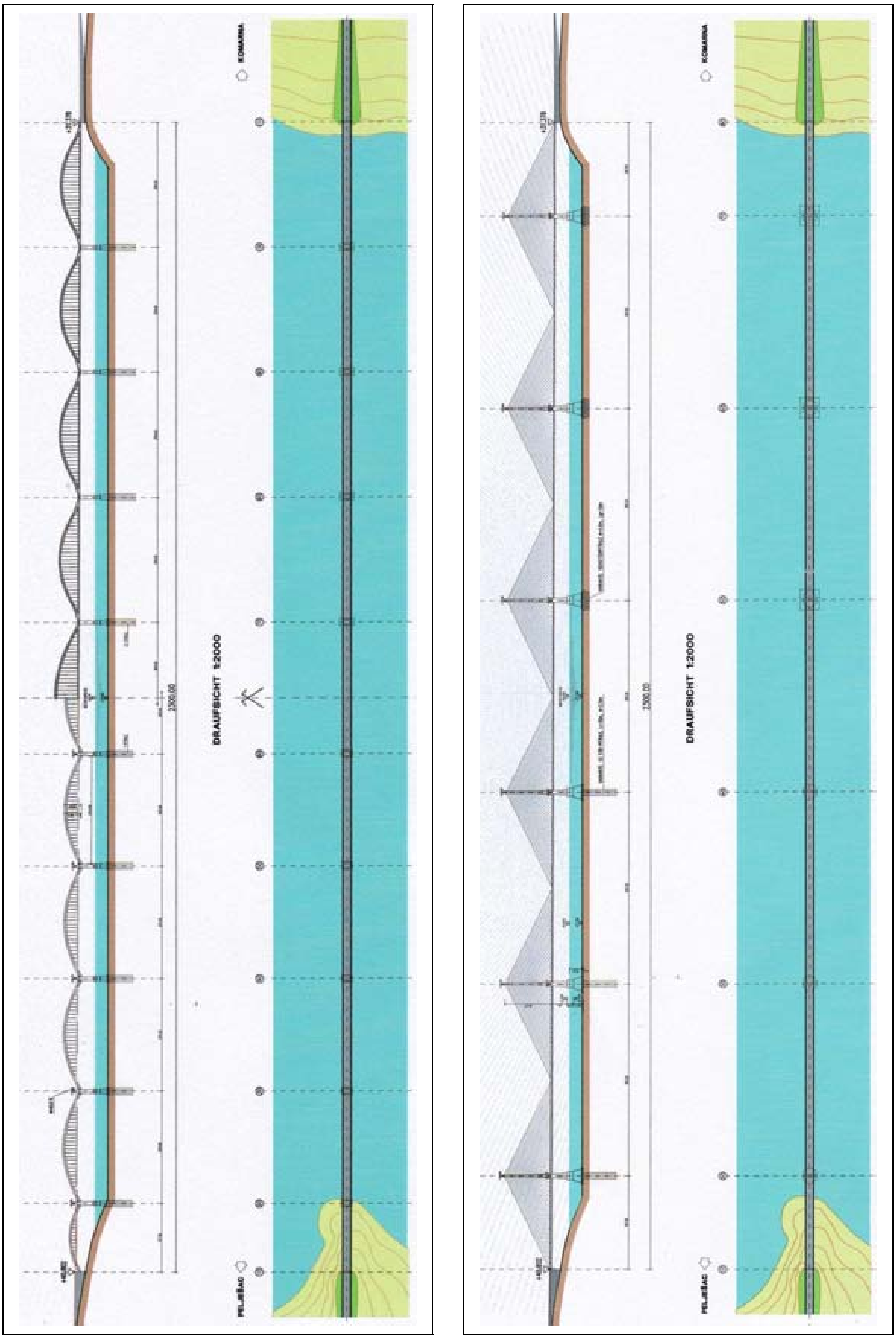

Figure 5 : Three investigated options : set of concrete arches with 225 m spans, set of „Langer girder“ steel arches with spans 300 and 250 m , cable stayed bridge with 6 pylons and 385 m spans.

Therefore as shown on fig 4. beside RC pile foundation that was calculated and estimated for different bridge options the stone column soil improvement measures have been designed for the most interesting bridge option and construction costs have been estimated in comparison to the pile foundation (options 6 and 7 in the table 1).

Construction cost estimation and evaluation of options has been made for two options from [**6**] mentioned in table 1 as options „2“ and „3“ and for the solution with cable stayed bridge and approaching spans.This solution was already shown in the work [**4** and **5**] and consists of a cable stayed bridge with a middle span of 500 m, stiffening girder made as steel hollow box girder and with approaching spans of 160 m length : 4*160 + 245 + 500 +245 + 4 * 160 = 2270 m. This option has been estimated in the table 1 as solution „1“. Preliminary design in the work [**6**] has caused design of further options that may be very much competitive and feasible options as shown in the table 1.

Set of arches as solution for the crossing caused design of two arch options : set of RC arches above the deck and set of Langer girder steel arches.

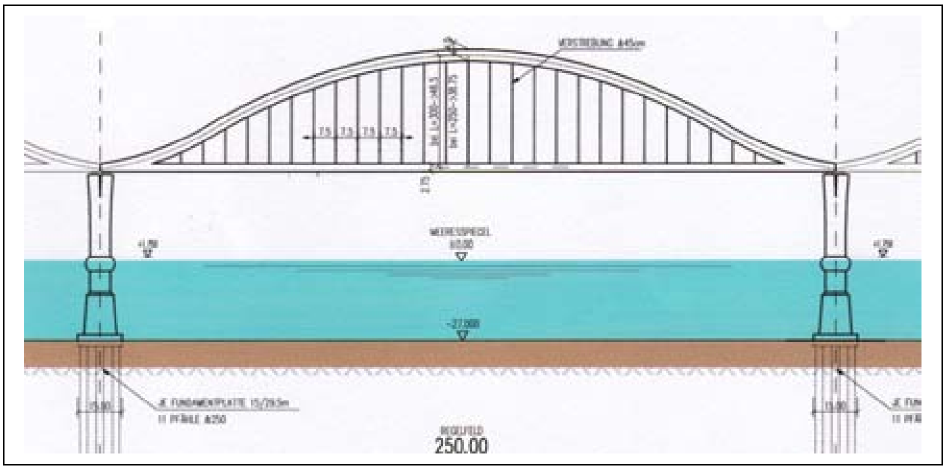

Figure 6 : Typical „Langer girder“ steel arch span of 250.0 m.

Solution „4“ in table 1 consists of a set of RC arches with spans : 137.5 + 9*225 + 137.5 = 2300 m (fig.5a, left), the construction stays on 10 columns and is proposed with steel deck structure. Even though already constructed on several places around the world this solution came out as a very expensive one as shown in the table 1.

Solution „5“ in table 1 (fig.5b, right and 6) consists of a set of steel „Langer girder“ type arches with spans : 4 * 250 + 300 + 4 * 250 = 2300 m. The construction has 9 separate pieces placed on 8 columns in the sea : Langer girder arches that may be constructed independently in the yard on the bank and transported by barges to the position of columns and then lifted to the place as last experiences with the Kosicka bridge in Bratislava shows. Based on this example and similar spans that would be used on Peljesac location this solution seems very much interesting as estimated costs are showing in the table 1.

Solution „6“ in table 1 (fig. 5c and 7,8) consists of a set of cable stayed bridges with middle spans of 385 m and 6 pylons having spans : 187.5 + 5 * 385 + 187.5 = 2300 m. The construction has 6 pylons placed on big foundation plates of 34 m diameter on the seabed. Foundation has been made by RC piles of 70 m depth and with 12 piles underneath each plate. Cost estimation shows this solution as the most acceptable and favourable solution regarding cost but also regarding construction time.

Solution „7“ in table 1 (fig. 5c and 7,8) is the same one regarding all structural elements except foundation part : instead on RC piles foundation plate lays on the gravel layer that is placed on a raster of stone columns. Stone column solution has the role of soil improvement and consists of 1.0m diameter stone columns in raster 2.0*2.0 m on the sea bed area 40*40 m having together about 400 stone columns per foundation plate. Cost estimation compares this solution as a very competitive one in comparison with RC piles.

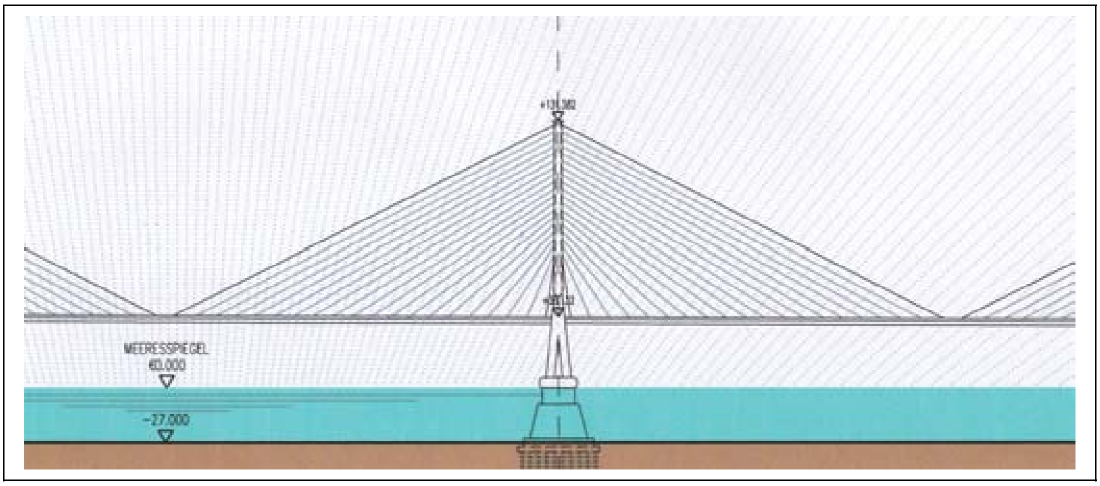

Figure 7 : Typical cable stayed bridge span of 385.0 m.

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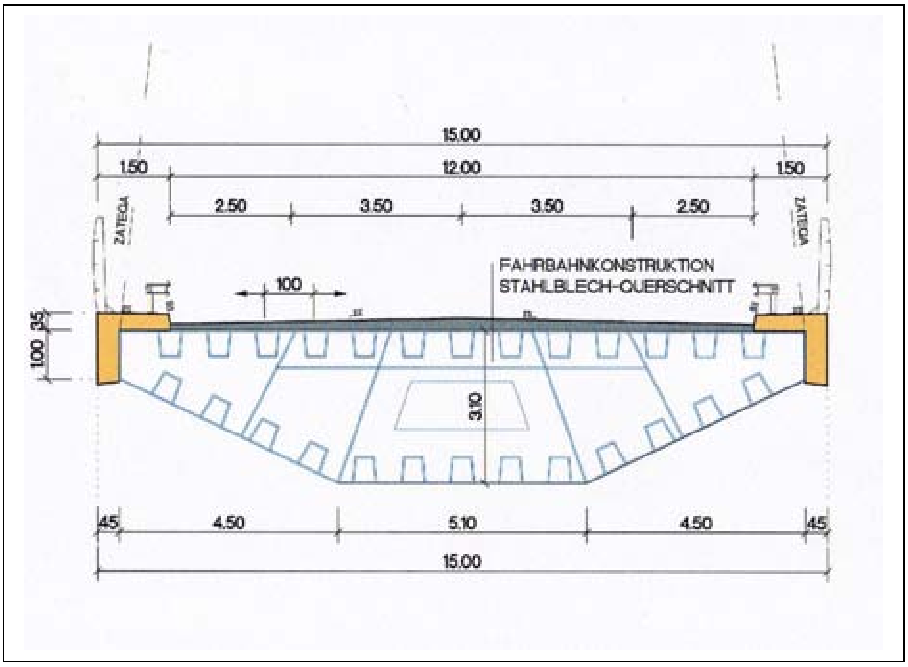

Figure 8 : Regular cross section of a cable stayed bridge span of 385.0 m.

Cost comparison of different solutions shown in the table 1 favorizes solution 6 (and 7) as the most appropriate and most acceptable one. Other solutions have shown several elements and structural inconsistencies that has increased the price of these variants beyond solution „6“ as e.g .:

- **solution „1“** (10 % more expensive than „6“) has a big middle span of the cable stayed bridge and the increase of the price by long stay cables as well as the amount of cable stays causes increase of the price. Even though this solution offers less foundations in the sea the entire distribution of structural elements makes the price higher. Generally this solution is not so structurally and therefore also economically stable as the solution 6 (7).
- **solution „5“** (11 % more expensive than „6“) is very interesting option that in any case may be applied on this crossing and is feasible from structural and from economical point of view, anyhow needs more detailed analysis regarding construction methodology
- **solution „3“** (13 % more expensive than „6“) still interesting even though the increase of the price came from to low pylon height that causes need for very strong cables (212 kg/m² of deck

service in comparison with 156 kg/m² by solution „1" and 152 kg/m² by solutions „6" and „7". Also the amount of steel needed for the stiffening girder seems to be overestimated.

- **solution „2"** (18 % more expensive than „6") even most favourable solution at the moment has a huge amount of steel required for the box girder that causes overall price so high
- **solution „4"** (341 % more expensive than „6") out of further estimation beside reduction of the weight due to the steel deck girder

Nr.	Structure type	Max. Span [m]	No.of Found.	Tot. Costs [Mill.€]	Unit Costs [€/m²]	Substr. Costs [%]	Superstr. Costs [%]	Relat. [%]
1	Cable stayed bridge (fig.1) 2 pylons RC piles 70 m deep	500	8	226.0	6.559	47.0	53.0	110
2	Variant "5", steel box (fig.2) 13 columns RC piles 70 m deep	170	13	241.0	6.989	52.0	48.0	118
3	Variant "9", cable-stayed (fig.3) 2 pylons RC piles 70 m deep	330	12	231.0	6.691	48.0	52.0	113
4	RC Arch bridge, steel deck (fig.5a) 10 columns RC piles 70 m deep	225	10	700.0	20.312	17.0	83.0	341
5	Langer girder, steel arches (fig.5b) 8 columns RC piles 70 m deep	300	8	227.0	6.589	44.0	56.0	111
6	**Cable stayed bridge, (fig.5c,7,8) 6 pylons , steel box RC piles 70 m deep**	**385**	**6**	**205.0**	**5.914**	**40.0**	**60.0**	**100**
7	Cable stayed bridge, (fig.5c,7,8) 6 pylons, foundation on "Stone columns"	385	6	209.0	6.054	42.0	58.0	102

Table 1 : Cost estimation of most interesting options.

4. CONCLUSION

All presented solution are showing further potential for improvements and price corrections what is usual part of further steps of the design procedure. However optimisation process has opened the area for different other options showing that each specific crossing location has different circumstances and other set of parameters and relations among them defines the optimum bridge solution.

It has been also shown that the harmony in the distribution of separate structural elements and relations among them cause also well-balanced economic solution with most acceptable construction price. Therefore recent investigations define options to be further investigated and defined in next design steps.

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