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Expertise of a cable – stayed bridge under construction in Romania

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Abstract.
The paper presents the results of an expertise of the cable – stayed bridge over the Danube – Black Sea Canal at Agigea in the Constantza harbor zone. During its execution, there were made some changes to the initial solution in order to reduce the cost of the works. Following these changes it has in fact found that the cost has increased by 50 percent instead of reducing it. The bridge execution has stopped and an expertise was required to be proposed a new solution to reduce the cost of the work. An innovative solution applied to the bridge has reasonable solved this problem. The solution consisted in using a special hybrid structure for the superstructure of the main cable-stayed bridge having three spans of 80 m ; 200 m; 80 m.

Keywords. Cable-stayed bridge, Constantza harbor, innovative solution, hybrid structure.

1. Introduction

The need to improve the road traffic in the sea port of Constantza by linking the two zones (Northern and Southern) separated by the execution of Danube - Black Sea Canal has imposed a new crossing over the Canal at Agigea, in the area of kilometer 0 + 540, near its confluence with the Black Sea.

For the main bridge, the initial project provided a cable-stayed structure with 2 pylons and three spans: 120 m + 180 m + 120 m = 420 m, and for the approach viaducts: 4 spans of 60 m length each, with a total length of 240,80m on each side (see. Fig.1).

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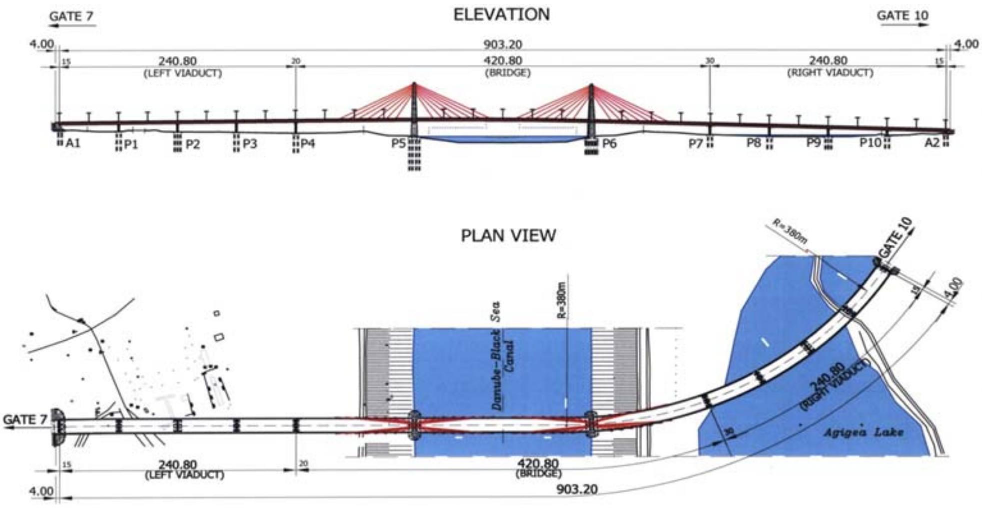


Fig. 1. Elevation and plan view of the bridge in accordance with the initial solution

Elevation of the main bridge in the initial solution is presented in Figure 2.

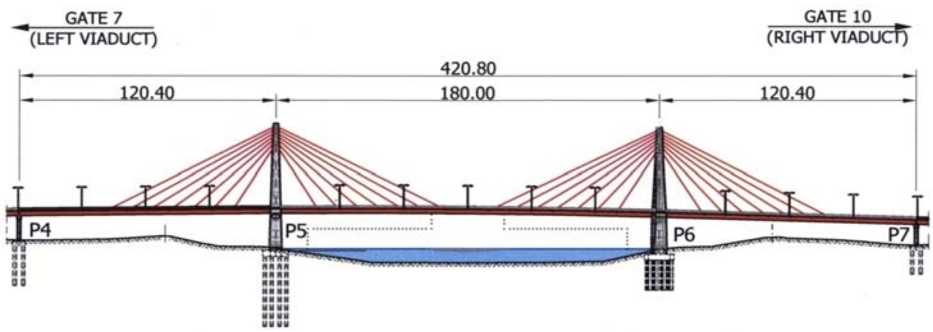


Fig. 2. Elevation of the main bridge in accordance with the initial solution

The superstructure of the cable-stayed main bridge and of the approach viaducts was provided to be achieved as a composite structure with (steel decks and reinforced concrete slabs).

During the work execution, some changes to the structure and sizes were carried out, as follows:

- replacement of the continuous composite structures on 4 spans of 60 m length each with structures of precast pre-stressed beams of 30 ÷ 40 m length at approach viaducts, resulting 8 spans on each side instead of 4 as in Figure 3.

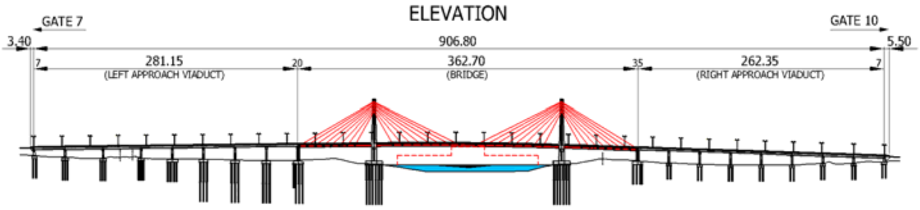


Fig. 3. Bridge elevation in accordance with the chenged solution

- increasing the main bridge central span from 180 m to 200 m and decreasing its side spans from 120 m to 80 m as in Figure 4.

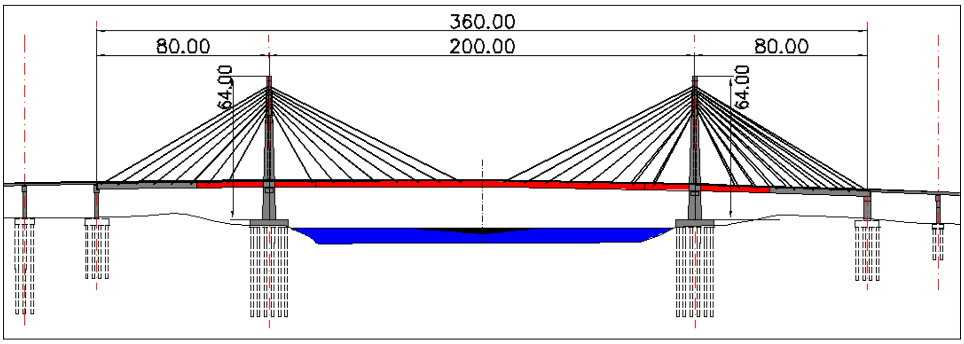


Fig. 4. Elevation of the main bridge in accordance with the changed solution

All these changes led to increase investment cost by nearly 50 percent, so that the bridge execution was stopped until finding a solution to mitigate its within acceptable limits. In this situation it was decided to ask an expertise [1] so that to find out a solution to reduce the investment costs, but maintaining the same standards of strength, safety and comfort in operation.

2. The analysis of the project and executed works

Although the documentation regarding the execution details has not been completed at the date of the present expertise, certain thoughts can be drawn from the analysis of the available information:

a) Increasing the span length from 180 m to 200 m has led to the increase of the efforts of the structure equal to the square of the spans:

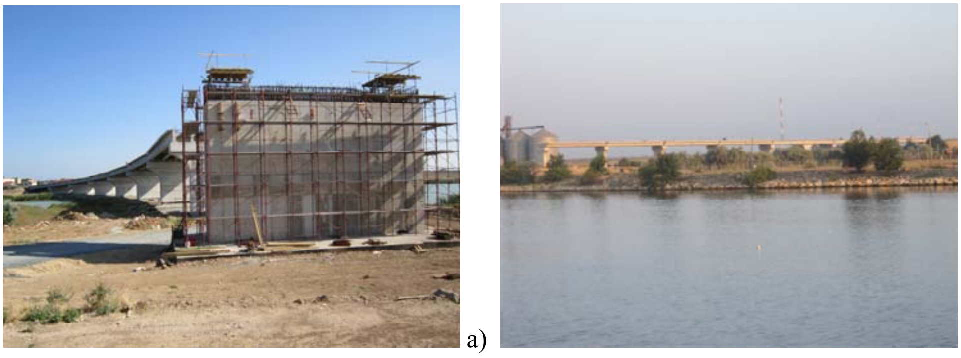
$$p\% = \frac{200^2}{180^2} \times 100 = 123{,}46\%$$

led to about to a quarter above the initial efforts.

Of course, this situation requires extra materials for both the superstructure and the infrastructure.

b) Diversity and variety of foundation ground also led to more materials and works to the viaducts.
c) Regard the main bridge structure, there were reserves to improve it, thus saving steel material. This improvement comes from three directions:
- improvement of the entire structure of the main bridge by a new conception;
- improvement of the steel deck structure which was yet unexecuted;
- improvement of the execution technology.

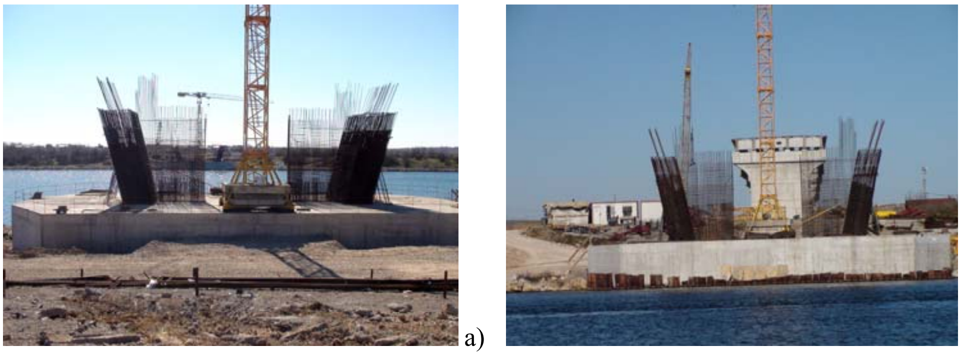
At the date of expertise elaboration there were completed a lot of works as follows:
- infrastructure and superstructure of the approach viaducts, as see in the Fig. 5;



a) b)

Fig. 5. Aproach viaducts: *a)on the right side;b) on the left side*

- infrastructure of the two pylons, as see in the Fig.6 [2];



a) b)

Fig. 6. View of the pylon infrastructure: *a) from the shore; b) from the water*

- the two segments of the steel deck over the two pylons having a length of amount 56m and a mass of amount 600 tones each as see in the Fig.7.

All these parts of the bridge that were yet constructed had to be introduced into proposed new bridge solution.

The solution proposed by the expertise, on which in the final work was carried out, is presented hereafter.

3. Description of the proposed solution

The proposed solution by the expertise for increasing the efficiency of the work took into account the following conditions:

- respecting the initial approval of the route and general bridge sizes;
- respecting prescriptions initial approved regarding the vertical, longitudinal and transversal profiles of the bridge route as well as navigable clearance under the bridge;
- keeping all the works already executed.

Fig. 7. The two segments of the steel deck over the pylons

Mainly, the proposed solution was based on a better equilibration of the structure concerning the three spans of the main bridge, which led to a reduction of efforts on the main structure, but also on more judicious composition of the superstructure deck to be executed, both in cross-section and longitudinal directions.

The improved bridge solution consisted of an innovative hybrid structure, partially made up of pre-stressed concrete in the side spans and partially of composite structure (steel deck connected with the reinforced concrete slab on the rest of superstructure (Figure 8).

The heavy weight pre-stressed concrete areas balance better the efforts from the central span, by reducing them.

For this solution, a computer simplified calculus was carried out, determining the stresses and deformations in the main characteristic sections in all phases of loading, including a calculus on execution stages. This calculus was meant to demonstrate the solution feasibility, but it did not removed completely the detailed calculation that had to be made when the modified project was carried out.

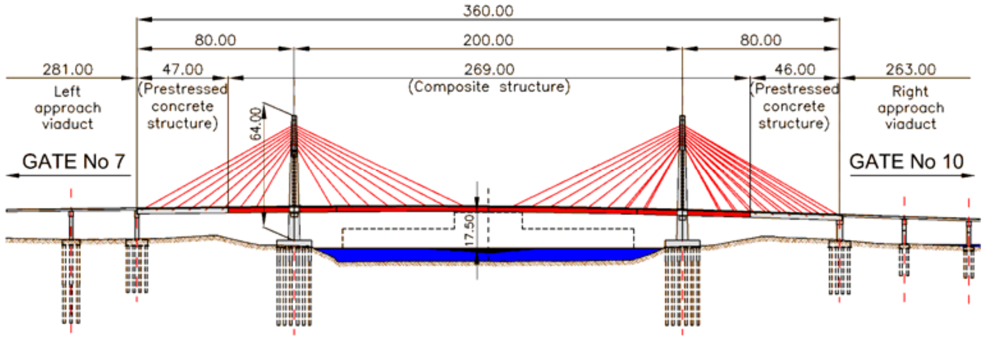
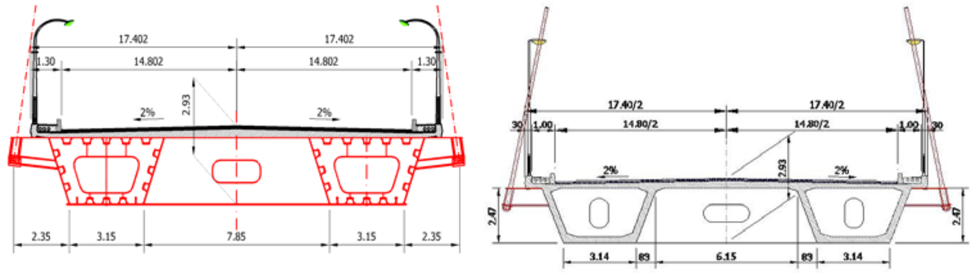


Fig. 8. Elevation of the main bridge in the proposed solution

3.1 The pre-stressed concrete decks were achieved at the two ends of the cable-stayed bridge superstructure in the side spans, on a length of 47.00 m from the end of the gate 7 and a length of 46.00 m from the Gate 10a bis (Figure 8).

In the cross-section, these decks have the same outer shape and dimensions as the composite decks already designed (Figure 9).



a) b)

Fig. 9. Cable-stayed bridge superstructure. Cross-section:
a)composite deck; b)pre-stressed concrete deck

Therefore, the superstructure consists of two main box girders with height of the exterior webs of 2.47 m and bottom flanges of 3.14 m wide. The distance between the axes of the main beams is of 11.00 m.

The reinforced concrete slab of the carriage-way has the same shape and dimensions in cross section as the composite deck.

The junction between the pre-stressed concrete decks and the composite deck was provided to be carried out through special reinforced concrete crossbeams with thickness of 1.00 m over the entire cross-section width. The connexion of the two types of structures is carried out by connectors welded on the metal elements of the deck in contact with the concrete, by continue reinforcement bars in the concrete deck and by the pre-stressing cables whose anchors are placed on opposite sides of the steel diaphragms in contact with the concrete of the joining cross beams.

3.2 The composite structure. The composite structure consists of steel deck in cooperation with the reinforced concrete slab.

The steel deck has two main box girder with the slanting webs, open to the top. The distance between the main girder axes is 11.00 m. The top flanges consist of steel plates with a thickness of 30 mm and a constant width of 500 mm. Bottom flanges have a thickness of 20 mm and a constant width of 3,140 mm.

The webs have a thickness of 15 mm, excepting the areas of junction between the cantilevers and the stay cables having a thickness of 20 mm.

The cross beams webs consist of steel plates with thickness of 15 mm and height of 2,435 m. They are provided with gaps of 2.0 m and height of 400 mm in order to install the utility pipes on the bridge. These gaps are trimmed with sheet 8 mm thick and 200 mm wide.

The steel deck flanges are provided with flexible connectors for cooperation with the concrete slab. The concrete slab has the same shape and structure as that of the pre-stressed concrete deck.

3.3 The bridge pylons. It was provided to improve the form and structure of ***the bridge pylons*** for a better safety in operation and a better aesthetics.

Therefore, the following proposals for changes were conceived and adopted, without major influences on the building as a whole, maintaining the main dimensions in terms of height, width and thickness:

a) inserting a reinforced concrete diaphragm with semi ovoid hole having a thickness of 1.00 m below the girder of the bearing bench;
   This structure will radically improve the seismic behavior of the bridge structure reducing substantially the amount of reinforcement of the pylon bearing benches beams, which are particularly stressed.
b) inclination of pylon legs in areas of the stay cable anchorages.

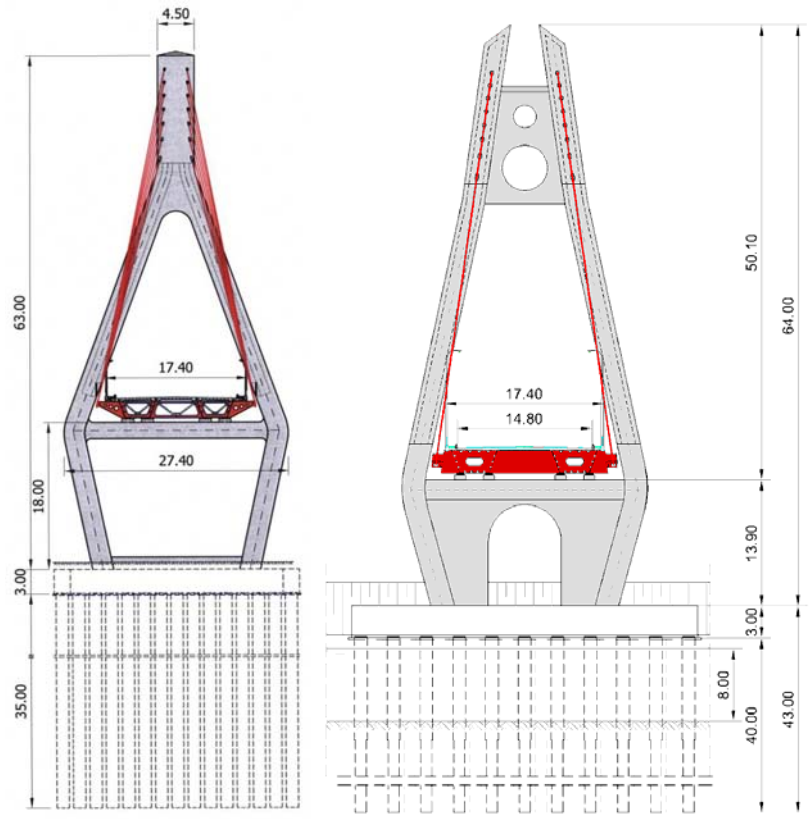
This change allows the stay cables to have the same inclination transversely, thereby simplifying the execution of cantilevers for connecting the stay cables to the deck. In this area the legs are linked together by a hollow diaphragm, which can be carried out more easily than the stability beams initially provided.

The pylon legs are box shaped above the way level. The holes inside the pylon legs are rectangular shaped with side of 2.0 m along the bridge and 1.50 m transversely.

At the bottom, the boxes are provided with holes with height of 2,0 m and width of 1,0 m for the access inside the boxes.

The top sides of the legs and upper side of the top diaphragm are provided with inclined plans to prvent the snow accumulation and icecle formation,that could fall down on vehicles in traffic passing under the pylons.

The shape proposed for pylons is shown in Figure 10.



a) b)

Fig. 10. Shape and sizes of the pylons: *a)in the initial solution; b) in the proposed solution*

4. Main results of the structure calculus

For the structure of the bridge in the proposed solution a simplified computer calculus was carried out to determine the stresses and displacements in the characteristic sections. The calculus was performed using the software SAP2000. The structure scheme consisted of both elements type bars for main girders, cross beams and pylon legs, and elements type shell for reinforced concrete slabs and diaphragms, as well as for modeling of stay cables (see Figure 11)[3].

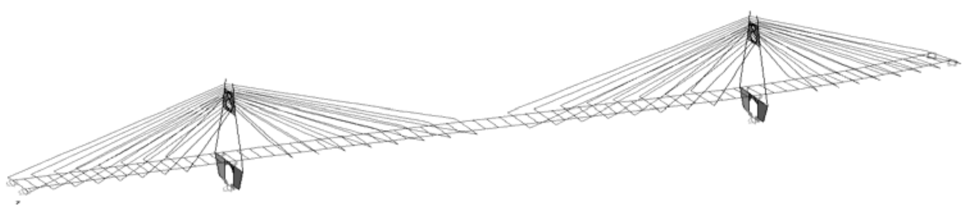


Fig. 11. Scheme of main bridge structure for computer calculus.

Analyzing the results of calculation performed led to the following conclusions:
The maximum stresses within the metal in the characteristic sections do not exceed any admissible stress, either on phased loading, or maximum total loading.
Therefore, the maximum compression stress in absolute value in the most stressed bearing section is less than the admissible stress, namely:

$$\sigma_{inf}^{max} = |-167{,}76\,|MPa < \sigma_a = 240\,MPa \quad (1)$$

and the maximum tensile stress is also less than the admissible stress, namely:

$$\sigma_{sup}^{max} = 104{,}98\,MPa < \sigma_a = 240\,MPa \quad (2)$$

In the median section of the central span, the maximum compression stress in absolute value is less than the admissible stress, namely:

$$\sigma_{s}^{max} = |-146{,}96\,|MPa < \sigma_a = 240\,MPa \quad (3)$$

and the maximum tensile stress is also less than the admissible stress, namely:

$$\sigma_{i}^{max} = 110{,}75\,MPa < \sigma_a = 240\,MPa \quad (4)$$

The tensile effort within the cables proposed to carry out the stay cables do not exceed the capable efforts; ratios $\frac{N_{ef}}{N_{cap}} = 0{,}72 \div 0{,}99$

a) The maximum deflection of the useful load at the central span is 0.2484 m, leading to a ratio

$$\frac{f}{l} = \frac{0{,}2484\,m}{200\,m} = 0{,}001242 < \frac{f_a}{l} = \frac{1}{700} = 0{,}0013 \quad (5)$$

that means a good behavior in operation.
The deflection of 0.2024 m resulting from permanent loads will be canceled by counter deflection carried out during the execution.

a) The maximum deflection at the pylon top from live loads is 0.1412 m, leading to a ratio:

$$\frac{f}{l} = \frac{0{,}13209\,m}{63\,m} = 0{,}0021 < \frac{f_a}{l} = \frac{1}{400} = 0{,}0025 \quad (6)$$

that means the pylon base reinforcement is not an unsolvable problem.
At the same time it was also performed a calculation of the structure, taking into account the proposed execution technology, finding out that this technology is feasible, as the most effective in carrying out this work.

However a detailed calculation was necessary to establish the stresses and displacements in all sections of the structure and to make some corrections in the structure composition in order to obtain extra savings of metallic material.

Complete and detailed calculations were also needed to determine the stresses and displacements within the pylons for their correct sizing at all sections.

5. Conclusion

The bridge over the Danube - Black Sea at Agigea km 0 + 540 was designed in a special solution of cable-stayed structure, requiring complex calculations and complicated details for its structure. During the execution there were carried out a series of changes of the work, due to the founding ground variability or execution technology.

Increasing the central span from 180 m to 200 m led to greater efforts in the structure and consumption of materials with negative effects on investment costs.

The work beneficiary requested an expertise for design and elements already executed, aiming to get a better economic efficiency of this investment, taking into account the experience in this kind of structures of the technical expert.

The technical expertise proposed an innovative solution that fully used all the elements already executed, but led to lower consumption of metallic material, thus reducing the most important weight in evaluating the investment costs.

When choosing the proposed solution the following conditions were considered:

➢ to maintain the shape, appearance and size of the work endorsed and approved;

➢ to assure the same conditions of strength, stability, comfort and durability as at the original solution tendered and adopted.

Mainly, the proposed solution consisted in hybrid structure of cable-stayed bridge, by replacing of some the superstructure areas of the side spans with pre-stressed concrete decks instead of composite decks.

This modification leads to a better balance of efforts between spans, with favorable effects of reducing these efforts in the main span, and consequently of saving metallic material.

At the same time a more efficient structure of the metallic deck in the central span was proposed.

By adopting the proposed solution the amount of metallic material has been reduced of about 30 percent related to the original solution and the investment cost was reduced by about 20 percent. The completed bridge is presented in Figure 12.

Fig. 12. Airy view of cable-stayed bridge over Danube - Black Sea Canal at Agigea

References

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