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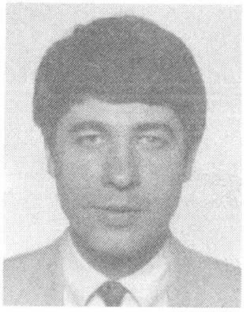

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Summary

The paper presents a proposal with a solution for a long-span bridge, which can be applied over the large rivers like the Danube river in Romania or similar. The bridge can be a highway, a railway or a combination of highway and railway bridge. The bridge in this solution consists in a cable-stayed bridge, which has an arch type Nielsen or Langer in the middle area of the main span. This arch strengthens the deck and allows to decrease the height of the pylon. The arch also improves the general stability of the structure by inclination of the arches towards the axis of the bridge and therefore by increasing the torsion rigidity.

1. Introduction

It is a known fact that the bridges having the longest spans are cable-stayed or suspension bridges. Up to now remarkable bridges have been constructed or are under construction. Main spans reach incredible sizes, such as in the cable-stayed bridges Normandie (France, 1994, with a main span of 856 m) and Tatara (Japan, to be finished in 1999, with a main span of 890 m), as well as the suspension bridges Humber (UK, 1981, with a main span of 1410 m), Grand Belt (DK, 1998, with a main span of 1624 m) and Akashi-Kaikyo (Japan, 1998, with its world's longest main span of 1990 m).
The purpose of achieving such impresive constructions is not just to set up world records, but to satisfy real society needs and at the same time with the minimize the negative impact on the environment. Such record constructions require creative design, construction methods and also maintenance procedures. One main task of the structural engineers is to make things simpler, especially construction methods and maintenance procedures. The authors of the present paper are proposing a new solution for a long-span bridge, which can supply a series of technical-economical advantages.

2. Brief commentary regarding the conception of cable-stayed bridges

The cable-stayed bridges generally have two pylons and three spans (Fig. 1), but sometimes can only have one pylon with two symmetrical or unsymmetrical spans (Fig. 2). For the well balanced cable-stayed bridges with three spans, the optimum ratio **l_1/l** is about **0.4** and the optimum ratio **h/L** is about **0.2**, where "**l_1**" is the lateral span length, "**l**" is the main span length and "**h**" is height of the pylon, above the carriageway level (Fig. 1 and Fig. 2).

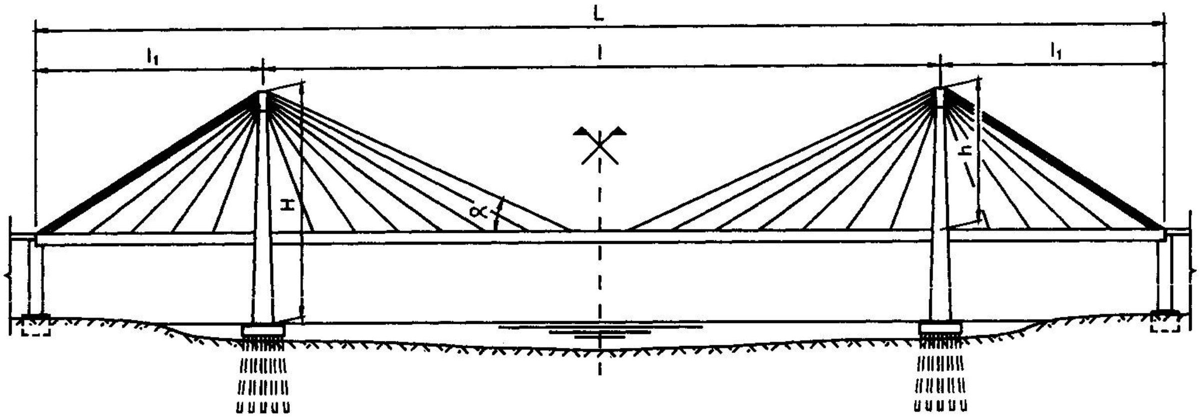


Fig. 1 Cable-stayed bridge having two pylons and three spans

Examining the cable-stayed bridges described in references [1] and [2], we can notice that the ratio l_1/l is varying in general between 0.33 and 0.45 and the ratio h/l is varying between 0.17 and 0.33 for most of the bridges. Averaging these values, we obtain the optimum ratio values presented above.

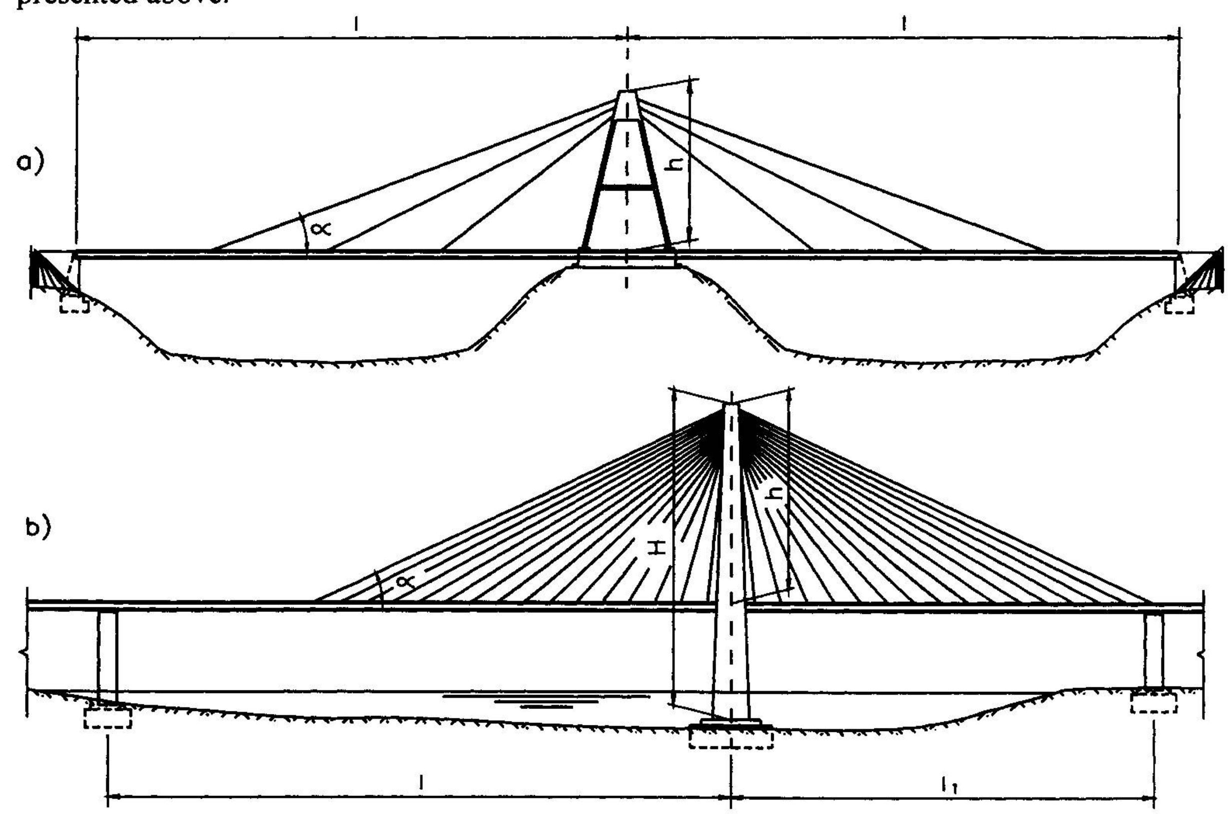


Fig.2 Cable-stayed bridge having one pylon and two spans.
a) symmetrical bridge; b) unsymmetrical bridge

The ratio $l_1/l = 0.4$ is required by the necessity of a good stress distribution on the deck in both the side and main spans. When the l_1/l ratio is too small, the stresses increase in the main span, but when the l_1/l ratio is too big, the stresses increase in the side spans. The l_1/l ratio can be decreased if heavier construction materials are used for side spans, and lighter for the main span. For instance, lower l_1/l ratio could be obtained if the concrete or composite type structures are used for the deck in the side spans and metal structures in the main span. Such structures are used more and more in bridge engineering. A suggestive example is the Normandie bridge, which has reinforced concrete side spans and metal structure central span. The decreased l_1/l ratio allows the pylons to be closer to the riverbanks, thus diminishing the construction difficulties, reducing the investment cost, as well as the execution time period.

The $h/l = 0.2$ ratio is required by the need to have the α angle - between the most inclined cable axis and the average level of the supported deck (see Fig. 1 and 2) – less than 25°. Even though, theoretically, it is recommended that this angle be larger than 30°, the practice shows that this condition is difficult to be respected. Sometimes the α angle is smaller, having values of 25° and even 20°. A small α angle leads to an inefficient cable and big axial stresses in the deck. A large α angle leads to a high pylon. The pylon height is therefore determined by the h/l ratio. We can notice that for the optimum ratio $h/l = 0.2$ the pylon height is big enough to lead to construction difficulties and large investment costs. Considering that the total pylon height "H" is much bigger, because it also includes the height under the superstructure, we conclude that pylon units play a significant point in the investment cost. It is often said that the sum of the total height of the two pylons, including the foundation depth, equals or exceeds the main span length. This observation highlights the pylon importance as part of the cable-stayed bridge structure, as well as an important part of the total investment cost. Analyzing the pylon cost – height diagram, we can see that the investment cost does not increase proportionally with the height, but quicker, (Fig. 3).

A solution for diminishing the pylon height, respectively the h/l ratio and also the l_1/l ratio is presented below. This solution was elaborated for a combined highway and railway bridge over the Danube river in Romania, but it can be adopted anywhere else, under similar conditions.

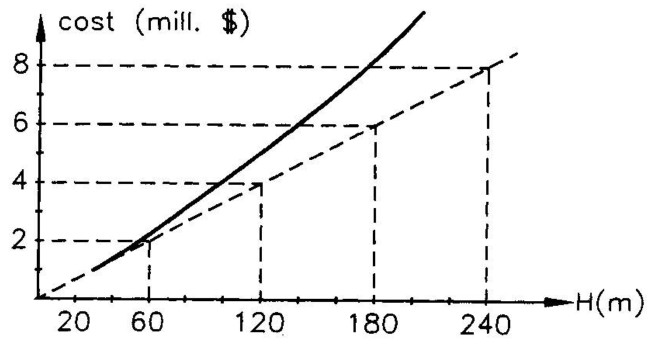


Fig. 3 Pylon cost-height diagram

3. Structural Concept

A new bridge could be placed over the Danube river in areas where the river bed is approximately 1000m wide.
A solution for an efficient crossing is a bridge with a large main span, and pylons placed as close to the riverbanks as possible.
Thus two important requirements are accomplished as follows:

- navigation on the Danube can be open at all times;
- pylon foundation construction can be done from the riverbanks;

The accomplisment of the second requirement leads to the following benefic effects:

- decrease of the investment cost by lowering the cost of the pylons;
- opportunity of a better foundation execution under a better control than in the case of the execution from "the water".

The proposed solution for a bridge carrying two railroad tracks and four highway lanes is a cable-stayed bridge having two pylons and a truss deck stiffened in the middle area of the main span by means of a Nielsen type arch having inclined hangers, or Langer type having vertical hangers (Fig. 4).

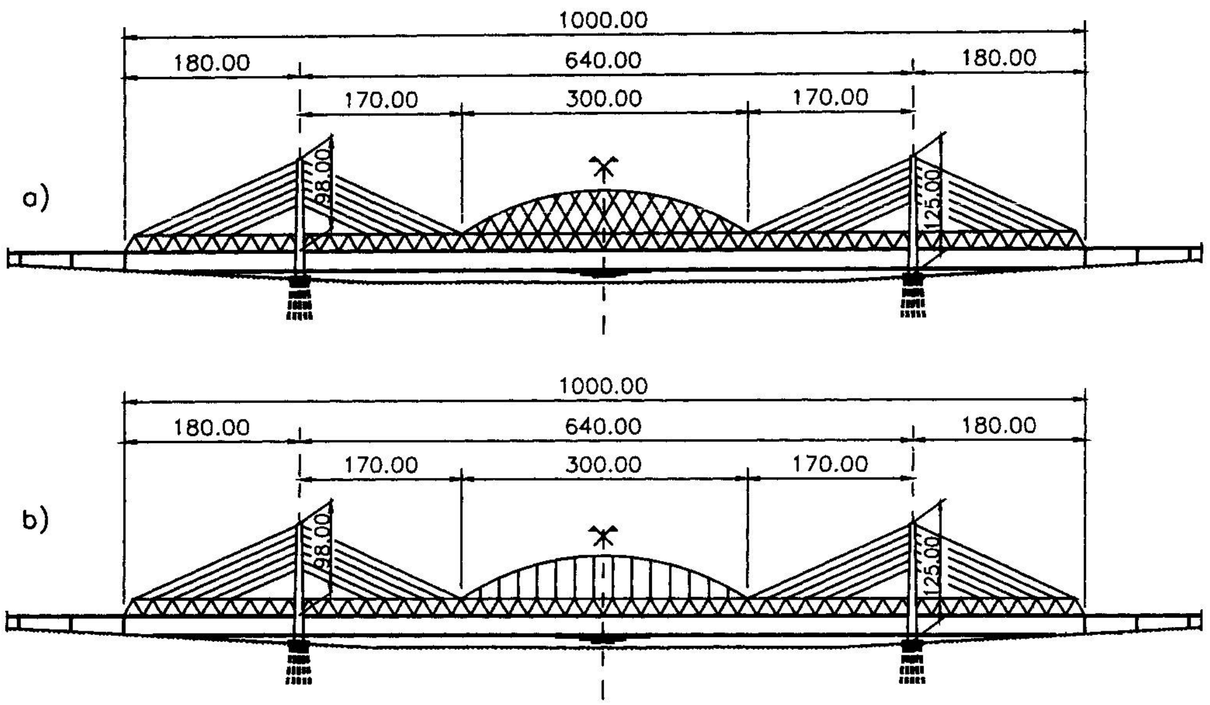


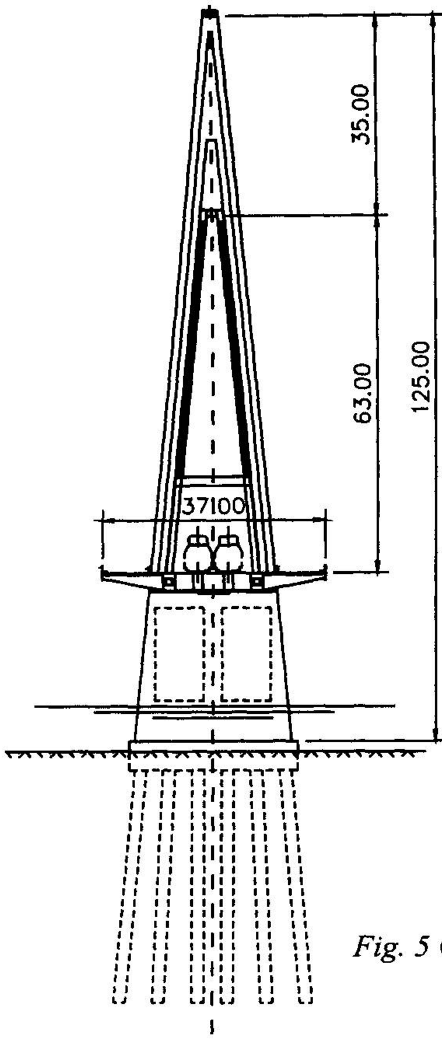
Fig. 4 Cable-stayde bridge stiffened by means of a middle arch. Elevation
a) arch type Nielsen; b) arch type Langer

In this way it is created a strengthened spatial structure, well balanced, having a good transverse stiffness, able to support all loads. The two railroad tracks are placed between the two stiffening arches and the four carriageways are placed on the side cantilevers (Fig. 5).

The bridge infrastructure is made of reinforced concrete, but the towers can be made out of steel. The bridge superstructure is metallic, but for the side spans it is recommended to have a heavier composite structure, in order to balance better the stresses in the three spans.

Comparatively examining the bridge in the proposed solution with a classical cable-stayed bridge having the same length (Fig. 6) we can observe the following:

- l_1/l ratio is reduced to a value of $180 / 640 = 0.28$, compared to the ratio of $l_1/l = 220 / 560 = 0.39$ for the classical solution;
- h/l ratio is reduced to a value of $98 / 640 = 0.15$, compared to the ratio of $h/l = 116 / 560 = 0.2$ for the classical solution;
- the pylons are shorter with approximately 18 m each and are closer to the riverbanks with 40 m.



All these changes produce the following technical and economical advantages:
- simpler construction methods for the pylon, especially for the heavy foundations placed in the river bed water;
- decreases the bridge construction time, by lowering the pylon height as well as ensuring the possibility of constructing the arch span and the side spans simultaneously;
- lower investment;
- the bridge estetics are pleasant and appealing.

The construction phasing for the bridge is schematically shown in Figure 7 and includes the following stages:
1. infrastructure construction using the well known classical methods (see Fig. 7a);
2. simultaneous construction of the side spans by mounting into the cantilevers of the deck units and the structure type Nielsen by assembling on the riverbanks (see Fig. 7b);
3. mounting of the central structure type Nielsen by launching it on the water and then by lifting it up to the final position by means of hydraulic jacks and steel bands (see Fig. 7c);
4. carriageway construction and final operations.

Fig. 5 Cable-stayed bridge in the proposed solution. Cross section

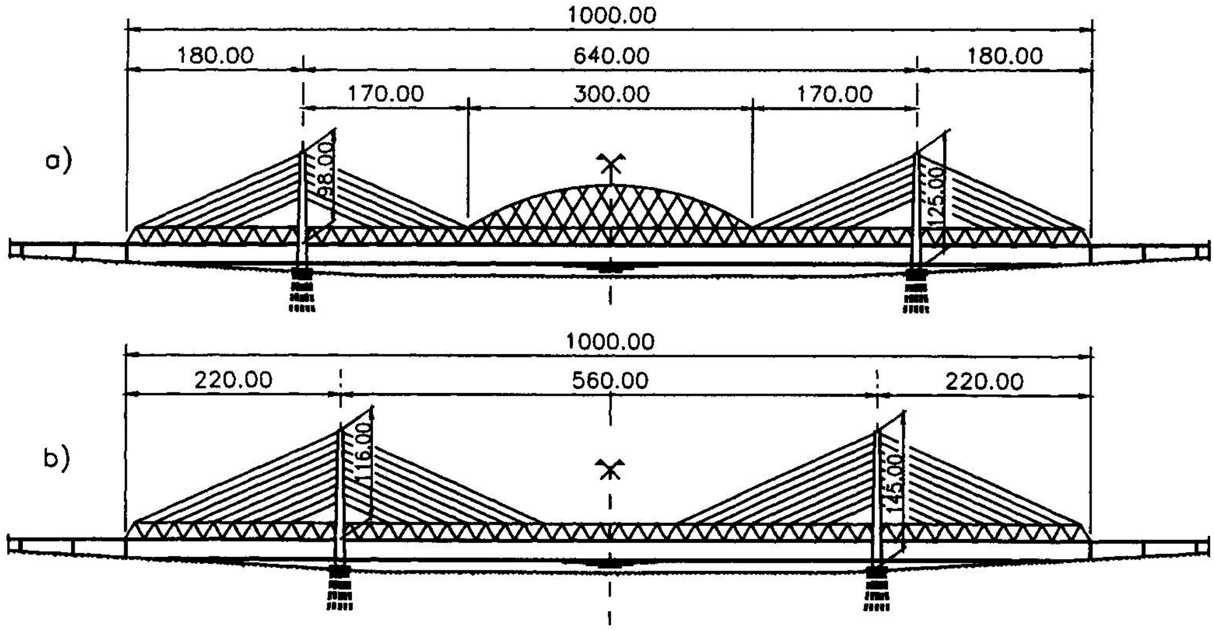


Fig. 6 Comparative cable-stayed bridge solutions
a) Proposed solution; b) Classical solution

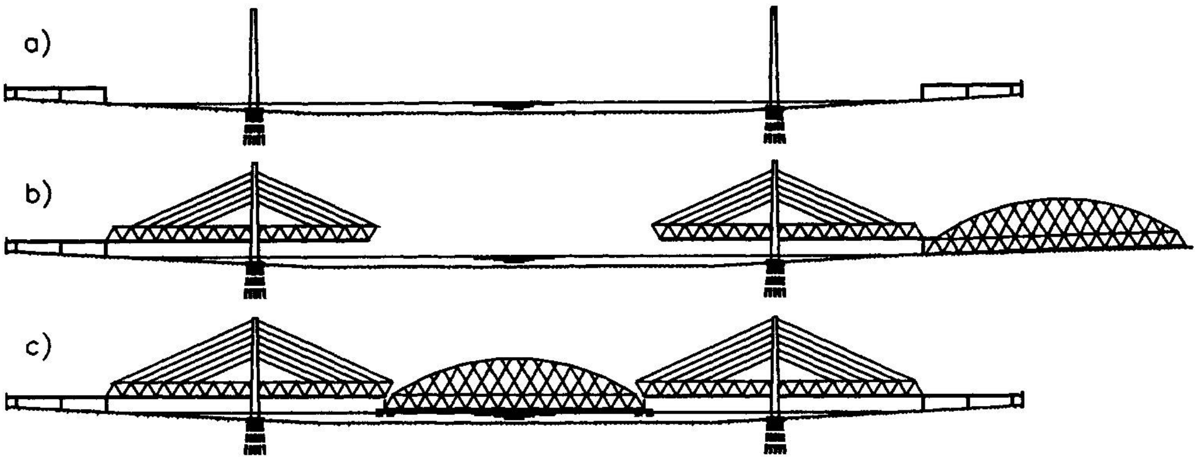


Fig. 7 Schematized technology for the bridge in the proposed solution
a) infrastructure construction; b) side structure execution; c) structure type Nielsen mounting

4. Conclusions

The idea of additional strengthening of the long-span superstructures in the middle area of the main span is rather old and it's been used in different ways. Even Leonardo da Vinci has among his sketches a type of cable-stayed bridge, consolidated in the middle area with similar arches type Nielsen [1]. Another bridge that it's known is a transbording bridge in Marseille von Arnodin, having a span of 140 m and similar structure to the one we are proposing – cable-stayed structure consolidated in the central area with a truss girder having parabolic upper side flanges [1]. We can mention other works similar to the presented one, such as: The Firth of Forth bridge in Scotland (1883 – 1890) by Baxer and J.Fowler [3], [5], footbridge at Oberschöneweide in Berlin [5], the Quebec bridge (1917) [4].

The bridge solution proposed in this paper transposes the idea in the long-span modern bridge area. It is obvious that thorough studies are still needed for the practical use of the solution and maybe the most important topic would be the testing of the structure on a model in the aerodynamic tunnel. The authors consider their solution as a modest and maybe useful contribution to the diversified multitude of new and daring ideas in the field of the long-span bridges.

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