Comparative Analysis Between Two Constructive Solutions of a Steel Tied-Arch Road Bridge

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Abstract. Steel arches used as the road bridge superstructures are economically competitive solutions for the field of medium spans, offering at the same time architecturally appreciated solutions. In the urban areas, where considerations related to the aesthetic aspects and integration of the artwork with the architecture of the buildings in the vicinity of the site are important, there is a tendency to adopt the trough arch road bridges, the arches being carefully analyzed in terms of aesthetic and architectural aspect offered. Within a Feasibility Study for the construction of a new bridge over the Someş River in Cluj-Napoca, several constructive variants were analyzed: bridge on concrete beams with several spans, bridge on beams with composite steel-concrete structure and steel bridge on arches. The paper presents two variants of the bridge on the arches, with two and four carriage-lanes, including some aspects related to the design of the super-structure.

Keywords: Trough road bridges · Open vs. closed tied-arched · Eurocodes EN SR 1993 · Arch buckling resistances

1 Introduction

The road bridges designed with the resistance structure on steel arches, are economically competitive for the field of medium spans, compared to other structural types such as trusses, offering at the same time architecturally appreciated solutions.

The field of optimal spans for road bridges on arches largely overlaps with that of bridges on trusses, but often factors links as the duration of execution, consumption of manufacture operations and consideration of architecture aspects, situates the constructive solutions on arches on a more advantageous place compared to those on trusses.

Also, for a large part of the field of medium spans, bridges on steel arches can be compared economically with the bridges of concrete or composite steel-concrete structures, the latter being used mainly for bridges with more lanes of traffic with more spans, as is the case of highways. In urban areas, where the aesthetic, compatibility and integration of the work of art with the architecture of the buildings in the vicinity of

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the site are important, there is a tendency to adopt the solution with steel arches being carefully analyzed in terms of aesthetic and architectural aspect.

It should be mentioned that arches with vertical hangers are preferred in terms of visual aspect, having in view from the parallelism of the hangers from any eye angle of observation, compared to the solutions with inclined hangers, more structurally efficient.

In a Feasibility Study for the construction of a new bridge over the Someş River in Cluj-Napoca municipality, several constructive variants were analyzed: bridge on concrete beams with more spans, bridge on beams with composite steel-concrete structure and metal bridge on arches [1].

In the end, the bridge solution on the arches was chosen, but for this solution two variants were analyzed: the bridge with two lanes of traffic and the bridge with four lanes of traffic. The agreed variant was a tied-arches bridge of 46.0 m span and four carriage-lane with console elements for pedestrian sidewalks and cycle paths.

It should be noted that the bridge's decking had to be in a relatively small depth, driven by the connection of the carriage-lanes to the adjacent street roads and the assurances of the safety space resulting from the hydraulic calculation.

The paper presents the two variants of the bridge on the arches, including some aspects of a technical and structural nature, respectively aspects related to the design of the main elements of the structures, the circular arches with vertical hangers made of semirigid bars.

2 Technical Solutions Analyzed for the Superstructure

In the Feasibility Study conducted with Cluj Municipality for the Bridge over the Someş River in Cluj-Napoca, two constructive solutions have been developed for the bridge with a single span of 46.0 m, as it follows [1]:

1. Bridge with two carriage-lanes and pedestrian and cyclist sidewalks.
2. Bridge with four carriage-lanes and pedestrian and cyclist sidewalks.

2.1 Two-Carriage Lanes Bridge

Figure 1 [1] shows the plan view of the site with the solution found for solving the traffic flows, pedestrian, and bike paths on one-lane bridge and on the adjacent zones.

The superstructure of the bridge is on steel arches with semi-rigid hangers, a closed type bridge, where the arches are equipped with an upper bracing.

The elevation of the bridge is presented in Fig. 2 [1].

In Fig. 3 the bridge transversal cross-section and the bridge' rendering is presented.

The bridge superstructure consists of a composite steel-concrete deck, suspended on two steel box arches, with a variable depth of the cross-section in the vertical plane.

The span of the bridge structure is of 46.00 m, the distance between the axis of the longitudinal tie-girders and between of the arches is of 9.00 m, and the total width of the deck is of 18,00 m.

The carriage deck width is of 7.80 m consisting of two 3.50 m lanes and 2×0.40 m safe spaces, and laterally on the 4.50 m cantilevers, the 1.50 m pedestrian sidewalks and 2.00 m cycle paths are arranged.

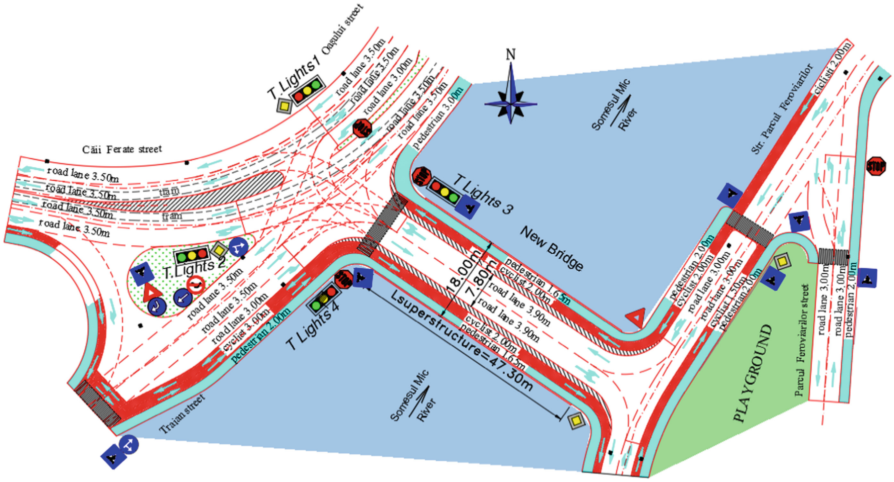

Fig. 1. Plan view of the Bridge with two carriage-lanes [1].

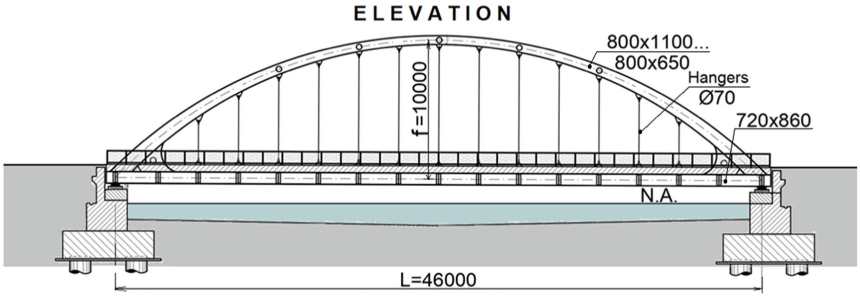

Fig. 2. Elevation of the Bridge with two carriage-lanes.

The main materials used for the resistance structure of the bridge structure are steel grade S355 M/N – for steel structure, S460 ML – for hangers; concrete Class C30/37 – for reinforce slab; reinforcement steel grade S500.

The arch rise measured between the axis of the longitudinal beams and the axis of the crown arch is of 10,00 m. The arches are made of 3 sections, and the site mounting joints are made by welding, resulting in a complete and watertight box section, so that the corrosion felt on the inside is practically negligible, by the lack of aeration and of a wetness.

For the horizontal plane buckling stability (in a transverse direction) connecting elements made of circular pipes, located outside the traffic gauge, are provided. The arches take over the loading from the deck by vertical round steel hangers located in the right of the cross-girders, at a distance of 2.85 m.

The deck beams consist of the following elements:

- two longitudinal beams with a semi-open box section (lower flange with hollows), with a section of 700 × 800 mm, also taking the role of the arch tie;
- double T cross-girder section, with variable depth between 800 mm to 900 mm, to ensure a cross-sectional slope of 2% for the water drainage.

The cross-girders are located at a distance of 2,85 m and are connected to the longitudinal beams with SIRP and a welded plate that ensure a semi-fixed connection at the ends of them. Side cantilevers – the construction with double T variable cross-section supports of the path for sidewalks and cycle paths.

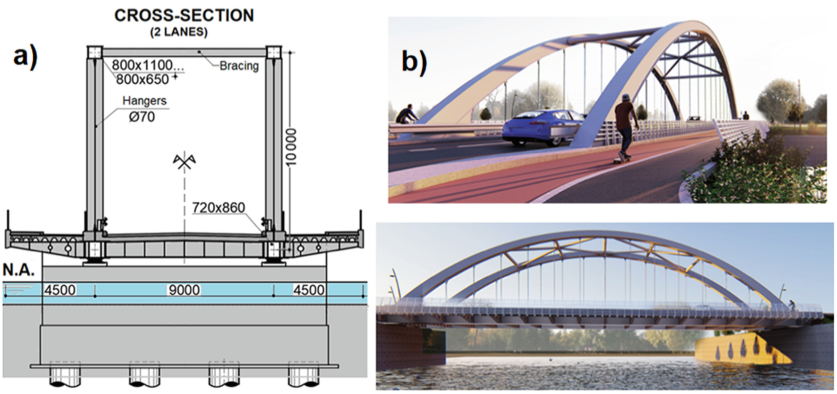

Fig. 3. Bridge with two carriage-lanes: a) Cross-section; b) Rendering.

2.2 Four-Carriage Lanes Bridge

Figure 4 [1] shows the plan view of sites for solving flows of traffic, pedestrian and bike paths on four carriage-lane bridge and on the adjacent zones.

The superstructure of the bridge is on steel arches with semi-rigid hangers, an open type bridge, the arches not being equipped with a superior brace, respective a free-standing arch.

The elevation of the bridge is presented in Fig. 5.

In Fig. 6 [1] the bridge cross-section and the rendering are presented.

In the four-carriage lane bridge variant, the distance between the axis of the longitudinal tie-beams and between the axis of the arches is of 16.50 m and the total width of the bridge deck is 26.00 m. The deck has a carriage way width of 14.40 m, consisting of four 3.50 m carriage-lanes with 2 × 0.20 m safety spaces and laterally on the 4.50 m cantilevers, are arranged pedestrian sidewalks of 1.50 m and cycle paths of 2.00 m.

The arches are designed as box with a variable section of 1200 × 1600 mm at the supports to 1200 × 850 mm the crown. The box cross-section is stiffened inside with longitudinal stiffening and transverse diaphragms between the walls. The arch rise measured between the axis of the longitudinal beams and the axis of the crown arch shall

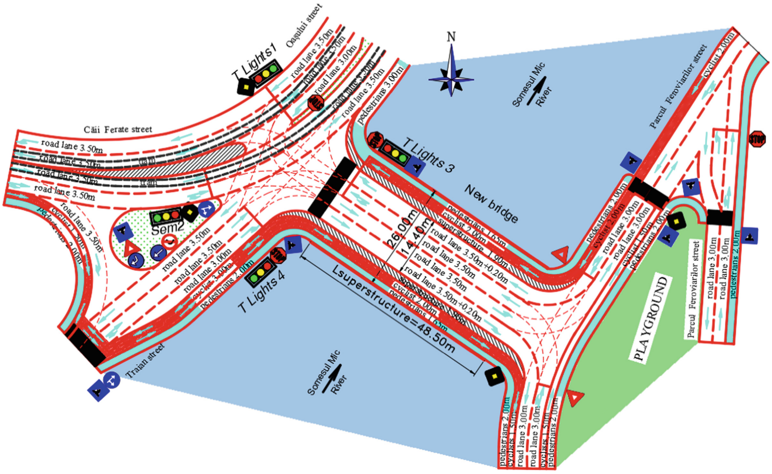

Fig. 4. Plan view of the Bridge with four carriage-lanes [1].

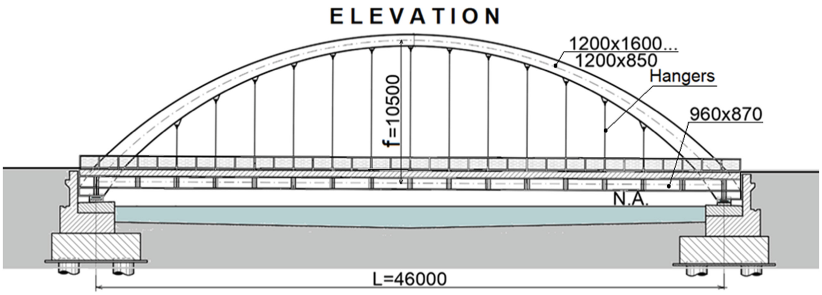

Fig. 5. Elevation of the Bridge with four carriage-lanes.

be of 10,50 m and the vertical hangers are located in the right of the cross-girders at a distance of 2.85 m.

The deck beams consist of the following elements:

– two longitudinal tie-beams with a semi-open box section (lower flange with hollows), with a section of 960 × 870 mm
– current double-T-section cross-girders with variable depth to ensure the 2% cross-slope between 870 mm to 1020 mm.

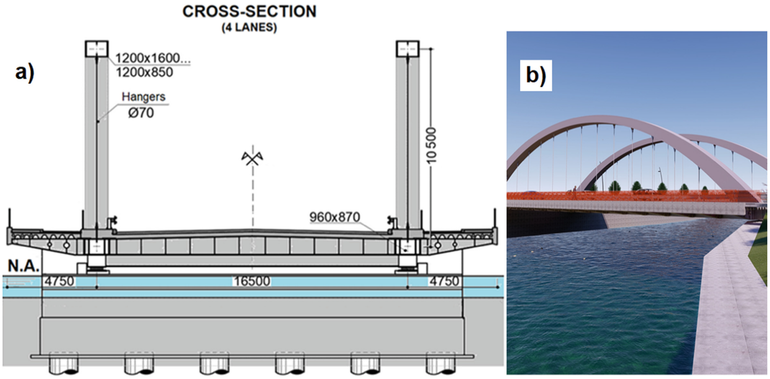

Fig. 6. Bridge with four carriage-lanes: a) Cross-section; b) Rendering

3 Design Aspects. Critical Buckling Force in the Arch

3.1 Critical Force for the In-Plane Arch Buckling for Both Type of Bridges

According to EN 1993-2: 2005 (SR EN 1993-2:2007), [2], with the cross-section axes given in Fig. 7, the critical buckling force for the in plane buckling of the arch, $N_{cr.y}$ is given by the equation:

$$N_{cr.y} = \frac{\pi^2 EI_y}{(\beta \overline{s})^2} \tag{1}$$

The critical length for the in-plane buckling of the arch:

$$L_{cr.y} = \beta \overline{s} \tag{2}$$

where: $\overline{s}$ – half length of the arch, EI_y – the flexural stiffness in the plane of the arch, β – the coefficient of the buckling length in plane of the arch (Fig. 8).

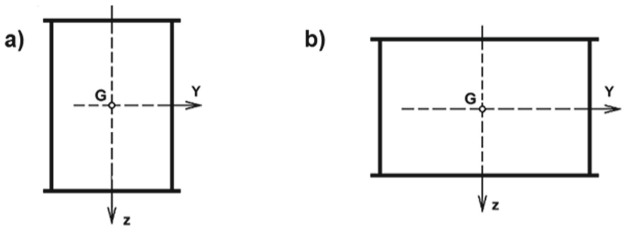

Fig. 7. Arch cross-sections: a) cross-section for two carriage-lanes; b) cross-section for four carriage-lanes.

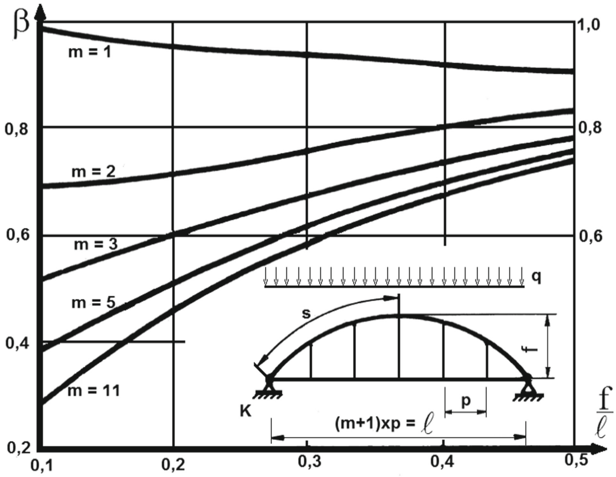

Fig. 8. Buckling factor β for arches with vertical hangers and tie-girder [2].

3.2 Critical Force for the Out of Plane Buckling of the Arch

Critical force for the out of plane buckling of arches with overhead bracing and final frames. Case of two- carriage lanes bridge.

For the out of plane of the arch, according to EC3-2 - Annex D [2], the critical buckling force, in the case of arch systems fitted with upper bracing and end frames (portal frames), shall be determined with the equation:

$$N_{cr.z} = \frac{\pi^2 EI_z}{(\beta h)^2} \tag{3}$$

Critical length in the out of plane of the arch: $L_{cr.z} = \beta \cdot h$

The geometrical buckling characteristics of the final portals for arches are given in Fig. 9 and the value of h_r may be taken as the mean of all hanger's length multiplied by $1/sin\alpha_k$.

The coefficient of buckling length β for the out of plane buckling of arches with overhead bracing and final frames are taken in accordance with EC3-2 - Annex D, [2], and is given in Fig. 10.

Critical force for the out of plane buckling of arches without overhead bracing. Case of four- carriage lanes bridge (free-standing arches).

The critical buckling force in the out of plane of the arches without overhead bracing is given by the equation:

$$N_{cr.z} = \frac{\pi^2 EI_z}{(\beta l)^2} \tag{4}$$

where: l – the arch span, EI_z – the out of plane flexural stiffness, β – the out of plane buckling coefficient.

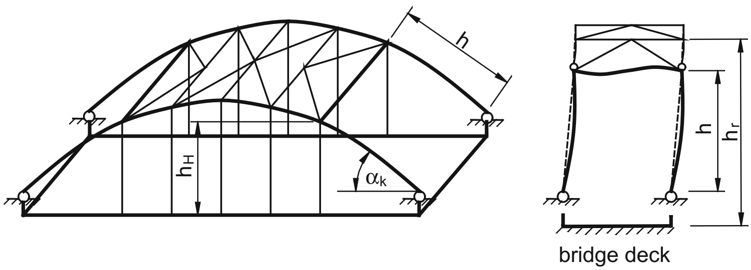

Fig. 9. Geometrical buckling characteristics of the final portals for arches [2].

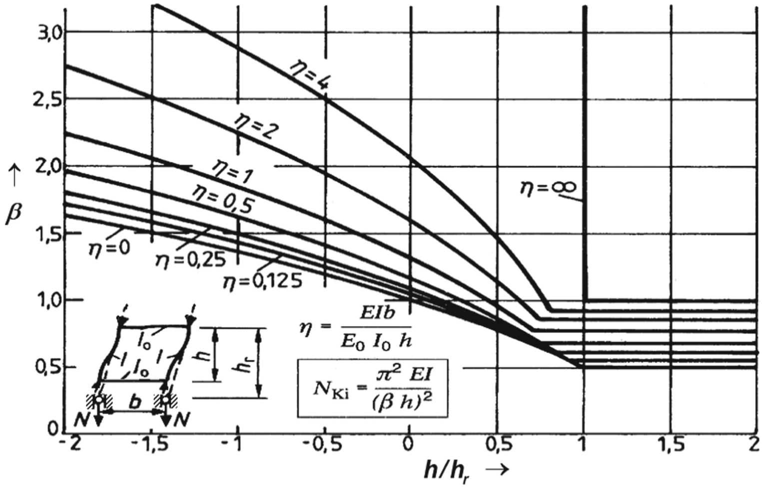

Fig. 10. Diagrams of buckling length factor β - final portals [2].

In the out of plane of unbracing arches according to EC3-2, [2], the coefficient of buckling length is calculated using Eq. (5):

$$\beta = \beta_1 \beta_2 \tag{5}$$

The coefficients β_1 and β_2 shall be taken in accordance with Table 1 and Table 2, taken from [2].

For the evaluation of the coefficient β_2, EC3-2 does not specify how the rate $\frac{q_H}{q}$ is assessed or evaluated. For the evaluation of this rate, the following equation can be used, [3]:

$$q_H = \frac{q}{1 + \frac{EI_G}{EI_{ARCH}}} \tag{6}$$

The papers [4] and [5] were also used in the elaboration of the resistance calculations.

Table 1. β_1 factor.

Value of β_1 factor					
f/l	0.05	0.10	0.20	0.30	0.40
I_z - constant	0.50	0.54	0.65	0.82	1.07
$I_z = \dfrac{I_{z.0}}{cos\alpha_B}$	0.50	0.52	0.59	0.71	0.86

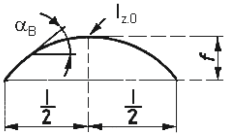

Table 2. β_2 factor.

	Loading mode	β_2	Comments
1	Conservative (deck is fixed to the top of the arch)	1	q – total load
2	By hangers	$1 - 0.35\frac{q_H}{q}$	q_H– part of the load transmitted by the hangers
3	By posts	$1 + 0.45\frac{q_{st}}{q}$	q_{st}– part of the load transmitted by the posts

4 Conclusions

Road bridges with a resistance structure made of steel tied arches are economically competitive for the field of medium spans and offers architecturally successful solutions. The optimal spans for road bridges on arches largely overlaps with that of truss bridges and bridges having composite steel-concrete structure, but often factors related to the duration of execution, the volume of manufacture, maintenance operations, and especially architectural considerations, place constructive solutions on tied-arches on a more advantageous place compared to other solutions.

In a Feasibility Study for the construction of a new bridge over the Someş River in Cluj-Napoca, Romania, several constructive variants were analyzed, and, in the end, the bridge solution based on the tied arches was chosen.

For this solution two variants were analyzed: the bridge with two carriage-lanes of and the bridge with four lanes of traffic. The agreed variant was a tied-arches bridge of 46.0 m span and four carriage-lane with console elements for pedestrian sidewalks and cycle paths.

The stability check of steel arches is an important technical problem, and in Euronorms SR EN 1993-2:2007. Eurocode 3: Design of steel structures. Part 2: Steel Bridges (EC3-2), are presented equations and diagrams with which critical buckling forces can be assessed for the in-plane arch and for the out of plane arch.

As regards the consumption of the main materials at the 4 carriage-lane bridge in comparison to the 2 carriage-lanes bridge have resulted as follows:

– Steel S355 bridge superstructure: S_(4-Lanes) = 1.65·S_(2-Lanes)

– Concrete C 30/37 in slab, sidewalks: $C_{(4\text{-Lanes})} = 1.45 \cdot C_{(2\text{-Lanes})}$
– Reinforcement steel BST 500: $R_{(4\text{-Lanes})} = 1.40 \cdot S_{(2\text{-Lanes})}$.

In the case of the open bridges (without upper bracing), one of the service limit state (SLS) verification condition consists to limit the horizontal arch deflection to a value of $\delta_H = f/1500$, a condition from which a much larger cross-section in the horizontal direction of the arch (rigidity about to z-z axis) can results, or a stronger end cross-girder compared to the intermediate ones.

Both solutions were applied in case of the open bridge structure.

References

1. Feasibility study elaborated by S.C. Miranda Project SRL and XC PROJECT SRL, Cluj-Napoca
2. SR EN 1993-2/2007. Eurocode 3: Steel structures. Part 2: Steel bridges
3. Romeijn, A.: Steel Bridges, Course CT 5125, TU Delft (2006)
4. Moga, P., Gutiu, St.: Poduri metalice. Conformarea suprastructurilor, UTPress, Cluj-Napoca (2020)
5. Moga, P., Gutiu, St., Danciu A.D., Moga C.: Poduri metalice. Ghid de proiectare, UTPress, Cluj-Napoca (2020)