Comparative Analysis Between the Hanger Arrangement in an 80 m Network Arch Bridge with Circular Hollow Cross-Sections

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Abstract. The hanger arrangement in network arch bridges is fundamental to the behavior of the bridge. As by definition, a network arch is a tied-arch bridge with inclined hangers that cross each-other at least twice. In the present paper, a comparative analysis of the hanger arrangement and the stresses distribution for a road bridge with a span of 80 m was conducted. Bridge spans in most parts of Romania are small and medium, up to 100 m, therefore there is a need to investigate and come with solutions to spans in the range of 50 to 100 m. The present study was conducted for a span of 80 m, with the bridge superstructure made of steel using circular hollow cross-sections for both the arch and the tie. The permanent and live loads were applied to the bi-dimensional structure.

Keywords: Trough road bridges · Network arch bridge · Hanger arrangement · Hollow circular cross-section

1 Introduction

Nielsen (1930), in his Ph.D. thesis [1], developed arches with sloping hangers. The V-configuration used reduces the bending in the arch, because a load on the left side of the span activates the sloping hangers to the right, resulting in an even load on the arch. Nielsen also applied for a patent in 1926, for a structure where the hangers crossed once. Tveit (1959), while working on his Master thesis [2] and then his PhD came to think of a configuration where hangers crossed each other at least twice, with the objective in mind of the best possible load distribution over the arch. The world first network arch was built in 1964, Steinkjer Bridge in Norway, with a span of 79.75 m and a rise of 12 m and an f/L ration of 0.15. Since than a great number of such structures have been erected around the world, for all bridge types: pedestrians, railway bridges and road bridges.

As already state, Network Arch Bridges (NAB) are arch bridges that have hangers that cross each other at least twice. The arches are made of steel, while, for distances between the arches of up to 20 m, Tveit [3] considers the tie should be made of concrete. Pipinato [4] published a study of a multiple span network arch bridge on a lightweight superstructure, where the arches are made of steel, using a circular hollow cross-section

L. Moldovan and A. Gligor (Eds.): Inter-Eng 2021, LNNS 386, pp. 110–119, 2022.
https://doi.org/10.1007/978-3-030-93817-8_12

and the tie is a steel-concrete composite cross-section The structure proposed by Pipinato [4] has a span of 130 m. A similar structure is the Bridge over the river Debra, a steel network arch with a span of 110 m with two inclined steel arches that link together in the keystone area [5]. In 2015 another study [6] investigating the influence of different hanger arrangements for a road bridge with a span of 100 m and an arch rise of 17 m was con-ducted, for circular hollow steel arches, inclined inward with 15 degrees after the tie beam-axis.

In the present study, based on the network arches with hollow circular cross-sections mentioned, we proposed and investigated the behavior of a similar structure, but for a smaller span, 80 m. The network arch proposed has vertical arches connected through wind bracings.

2 Structural Consideration

One of the major research interests when discussing NAB is the hanger arrangement. The available studies show that the number of hangers and their arrangement have a decisive influence over the bending moment distribution along the arch.

Teich in his PhD [7] devised and investigated five different hanger arrangements for bridge spans 100 m or larger and for 24, 36, 48 and 60 hangers. Based on his investigation, the best solutions are given by hanger arrangements 2 and 4. Hanger arrangement 2 is also known as the constant angle increase and 4 is the radial arrangement.

2.1 Constant Angle Increase (Incr)

For the 80 m structure investigated in the present paper, a variant of the constant angle increase of the hangers was investigated for 20 hangers, Fig. 1, 22 hangers, Fig. 2 and 24 hangers, Fig. 3.

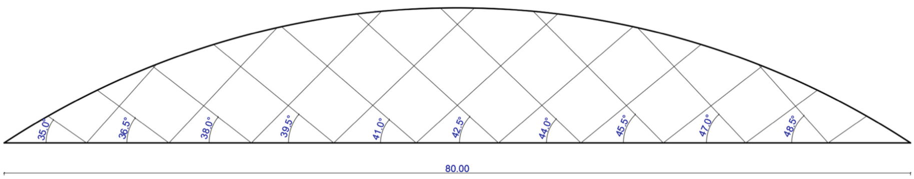


Fig. 1. Hanger arrangement for 20 hangers, constant angle increase with 1.5°.

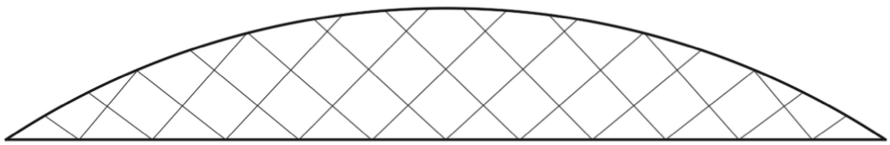


Fig. 2. Hanger arrangement for 22 hangers, constant angle increase with 1.5°.

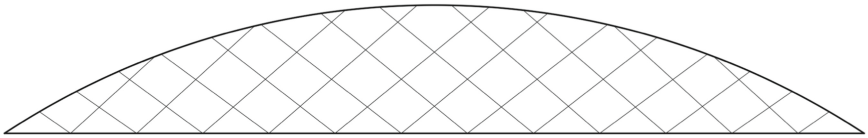


Fig. 3. Hanger arrangement for 24 hangers, constant angle increase with 1.5°.

The method to construct the hanger arrangement starts from dividing the length of the tie in equal parts. The starting hanger is inclined with an angle of 35°, then the slope increase is of 1.5° so that the angle variation is in the range 35°–48.5° for 20 hangers, 35°–50° for 22 hangers and 35°–51.5° for 24 hangers. Teich recommendation for 100–250 m span range and 24+ hangers in terms of the hangers' slope is between 35°–45°.

2.2 Radial Arrangement (RA)

The radial arrangement was proposed by Brunn and Schanack [8] in 2013 and has at its center the fact that if uniformly distributed loads act in the radial direction on the arch, then the bending in the arch about the horizontal axis is minimized. Following this idea, the hanger arrangement in Fig. 4 was devised by Brunn and Schanack [8].

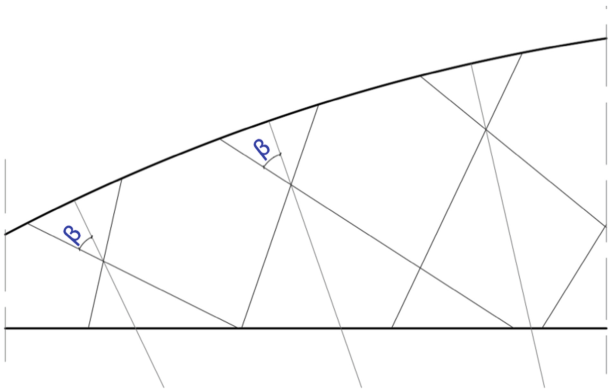


Fig. 4. The radial arrangement.

The hanger upper nodes are spaced equidistantly along the arch, while the hanger intersection lies on the radii of the arch that is part of a circle. The only variable is the angle of intersection between the hangers and the radii to the arch. The angle of intersection is the same for all hangers. The best results have been found for angles in the range 38° to 45°. The radial arrangement for the present study, for 20 hangers, is shown in Fig. 5, the value chose for β is of 38°, for 24 hangers is shown in Fig. 6 and for 24 hangers in Fig. 7.

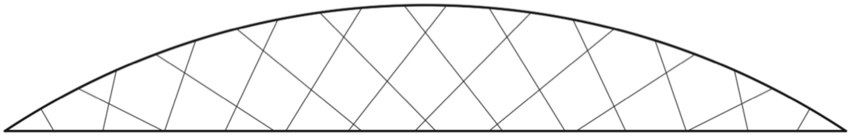


Fig. 5. Radial arrangement for 20 hangers, the angle between the hangers and the radii of 38°.

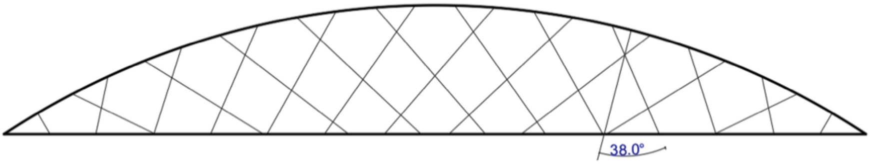


Fig. 6. Radial arrangement for 22 hangers, the angle between the hangers and the radii of 38°.

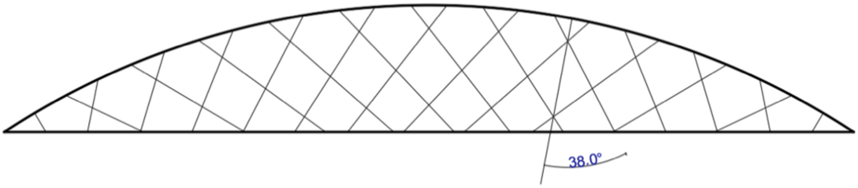


Fig. 7. Radial arrangement for 24 hangers, the angle between the hangers and the radii of 38°.

2.3 Network Arch Design

The dimensions of the bridge cross-section were chosen considering the Romanian requirements [9] for road bridges located on a class III road, with an upper bracing. The total distance between the arch axis is of 10 m, the two sidewalks are placed outside the arches.

The bridge cross-section elements are presented in Table 1 and the bridge cross-section is presented in Fig. 8. The geometrical arrangement of the lower bracing and the upper bracing is shown in Fig. 9. It is worth mentioning that the exact location of the upper wind bracing varies with the type of hanger arrangement proposed.

The analysis was undertaken considering the dead loads and the LM1 convoy. As stated in Eurocode 1 [10], the tandem system (TS) can be considered for bridges with a span larger that 10 m, as having a single axle with the load value equal to the TS load. The behavior of the superstructure in terms of stresses was investigated for the TS modeled as a single axle and as a moving vehicle with two axles. In the analysis the TS load was modeled as a moving load, while the distributed load from the LM1 convoy, UDL, was considered as loading the entire length and half of the length of the bridge, Fig. 10. The ratio between the distributed live load and the dead load is UDL/g = 0.42.

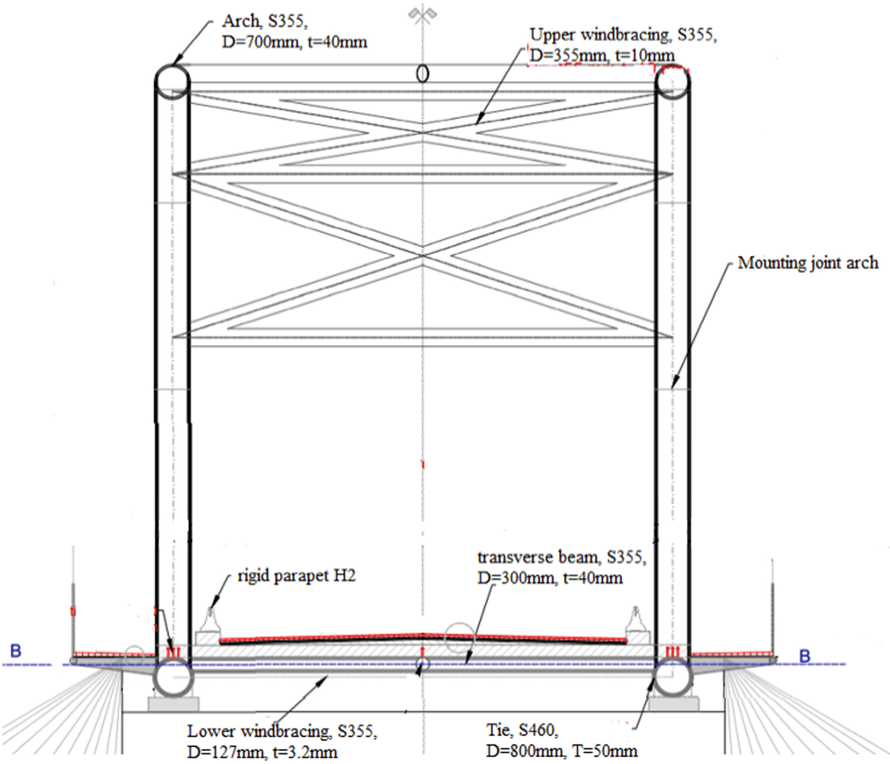


Fig. 8. Bridge cross-section.

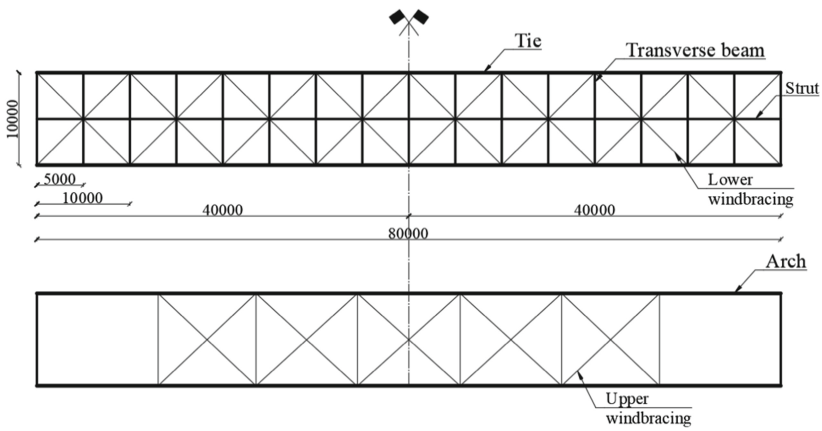
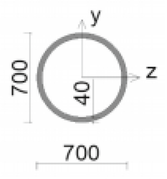
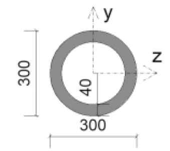
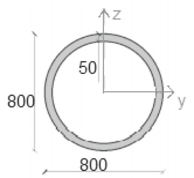
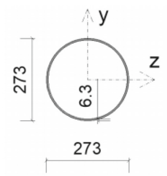
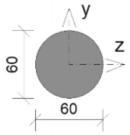
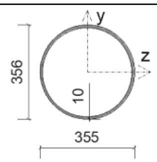


Fig. 9. Geometrical arrangement for the lower and upper wind-bracings of the bridge.

The comparative analysis of the behavior of the network arch was investigated for 20, 22 and 24 hangers, for two different hanger arrangements as stated above.

Table 1. Bridge cross-sections.

Element	Cross-section	Element	Cross-section
Arch S355		Transverse beam S355	
Tie S460		Strut S355	
Hanger S355		Upper bracing S355	

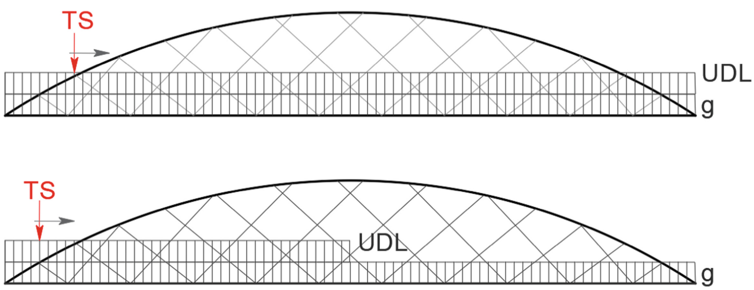


Fig. 10. Loading cases.

3 Stress Distribution

The bending moment and axial forces in the arch for the hanger arrangements under consideration are presented in Fig. 11 for the TS modeled as a vehicle with one axel. The investigation was also carried out for TS modeled as a vehicle with two axels, but the variation in the value of the unitary stresses is very small.

In Fig. 11 the compression force in the arch is represented as a column, while the bending moment as a line. The blue column represents the maximum compression force in the arch, while the entire span is loaded with the dead load and the convoy, TS+UDL. The best distribution of the compression force in the arch is obtained for the Radial Arrangement (RA) with 20 and 22 hangers, while for 24 hangers a slight increase in the value of the corresponding bending moment is observed. For the Constant angle Increase Arrangement (Incr) in Fig. 11, both the compression in the arch and the bending moment are larger than in the case of RA. For the case of only half of the structure loaded with UDL (yellow column and line in Fig. 11), the improvement in the stress distribution in the RA vs Incr is even better. When analyzing the behavior in terms of the highest bending moment in the arch with the corresponding compression force (orange and green representations), we can notice a small increase in the maximum value of M and N in the RA, but the compression force in the arch, for the highest value of the bending moment is over 20% smaller than the maximum compression force.

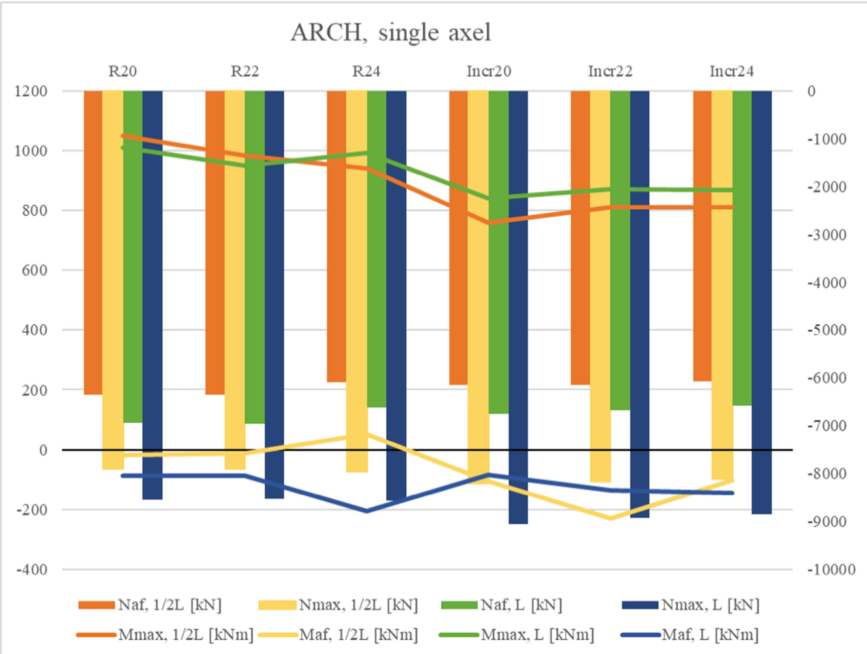


Fig. 11. Bending moment and compression force in the ARCH.

In Fig. 12 the bending moment and the axial force in the Tie is represented. For the maximum axial force in the tie, the best bending moment distribution can also be seen in the RA, with a minimum of M for 24 hangers, that is expected as the higher the number of hangers, the smaller is the value of the bending in the tie. On the other hand, the maximum bending moment sees an increase in the RA for a smaller number of hangers. In Incr arrangement, for the maximum value of the axial force, the bending moments are also increased with 30 to 50%.

In case of NAB a very important aspect is the hanger behavior in terms of hanger relaxation. For the medium span investigated, both RA and Incr with 24 hangers lead to hanger relaxation in at least one of the loading cases. As expected, the worst behavior is to be seen in case of half the span loaded by UDL force from the convoy. For 22 hangers, only the Incr arrangements leads to hanger relaxation for half the span loaded by the convoy. The best behavior for the investigated span is observed for RA with 20 and 22 hangers, where no relaxation and no bending occur in the hangers. The lowest value of the tension in the hangers occur for 22 hangers, the value of the axial force is 8% smaller than for 20 hangers and 38.5% smaller that the case of Incr with 20 hangers, the only other configuration where no relaxation occurs. The variation of the tension force vs. the number of relaxed hangers occurring in each configuration is presented in Fig. 13.

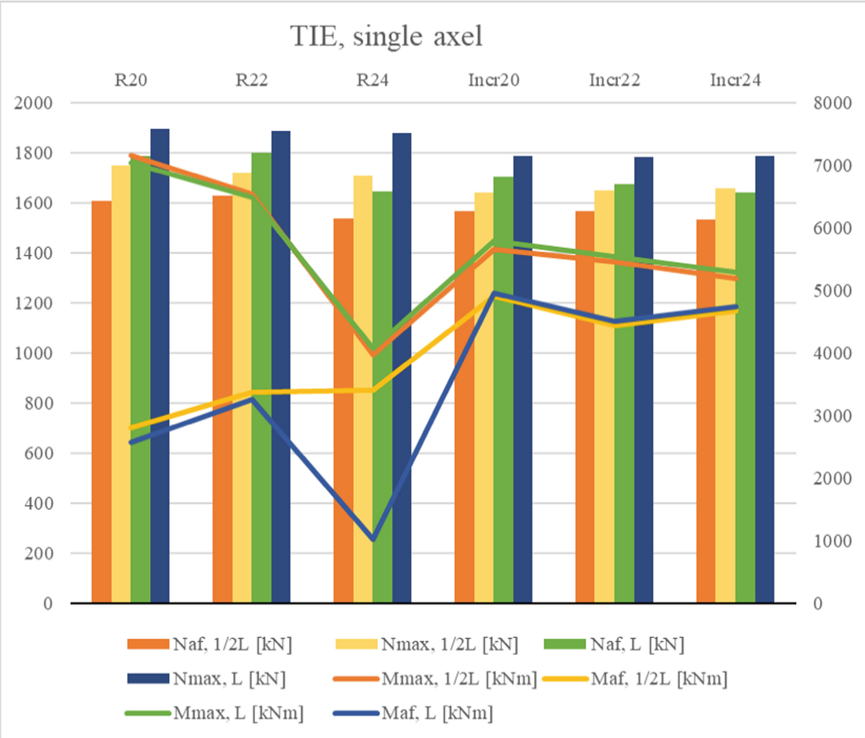


Fig. 12. Bending moment and axial force in the TIE.

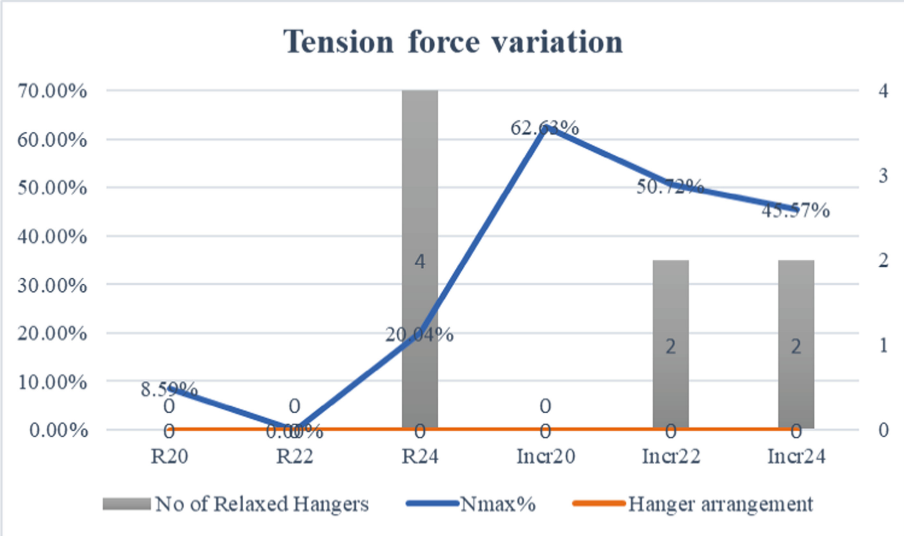


Fig. 13. Hanger behavior in terms of tension variation and hanger relaxation.

4 Conclusions

Network arch bridges can lead to a great reduction of steel and concrete used due to an improved distribution of the stresses in the arch, tie and hangers. The problem to be solved is to find the best hanger configuration for the required span so no or little hanger relaxation occurs and the bending moments to have a lower constant variation along the arch. For the investigated span of 80 m, the optimum configuration was found to be the radial arrangement with 22 hangers. A greater number of hangers leads to hanger relaxation and higher compression forces in the arch. For 24 hangers in the radial arrangement, 4 hangers are relaxed, while for the 20 and 22 hangers, no hangers were relaxed. For the Increases angle configuration, for 22 and 24 hangers, 2 of the total number of hangers are relaxed, while for configuration Incr20 no hangers are relaxed. Therefore, further investigation will be carried out for a lower number of hangers in this configuration. Another issue to be further investigated in terms of hanger arrangement is what happens with smaller spans. As the span decreases, the ration between the arch rise and the span needs to be increased in order to accommodate an upper wind bracing and the free passage gauge.

References

1. Nielsen, O.F.: Foranderlige Systemer med anvendelse på buer med skraatstillede Hængestenger (Discontinuous systems used on arches with inclined hangers), Ph.D. Thesis, Gad Copenhagen (in Danish) (1930)
2. Tveit, P.: "Bogebruer med skrå krysstilte hengestenger", (Arch bridges with inclined intersecting hangers), Ph.D. thesis presented at the Tech. Univ. of Norway. 64 pages, 78 drawings, in Norwegian (1959)

3. Tveit, P.: How to design economical network arches. IOP Conf. Ser. Mater. Sci. Eng. **471**, 052078 (2019). https://doi.org/10.1088/1757-899X/471/5/052078
4. Pipinato, A.: Structural analysis and design of a multispan network arch bridge. Bridge Eng. **169**(1), 54–66 (2016). https://doi.org/10.1680/jbren.14.00013
5. Mato, F., Cornejo, M.O., Sánchez, J.: Design and construction of composite tubular arches with network suspension system: recent undertakings and trends. J. Civ. Eng. Architect. **5**(3), 191–214 (2011)
6. Vlad, M., Kollo, G., Marusceac, V.: A modern approach to tied-arch bridge analysis and design. In: Acta Tehnica Corviniensis – Bulletin of Engineering Tome VIII, Fascicule 4, ISSN: 2067–3809 (2015)
7. Teich, S.: Beitrag zur Optimierung von Ntezwerkbogenbrucken (Contribution to Optimizing Network Arch Bridges), PhD Thesis, Technischen Universitat Dresden, Germany (in German) (2012)
8. Brunn B., Schanack F.: Calculation of a double track railway network arch bridge applying the European standards, Diploma Thesis, Dresden University of Technology (2013)
9. STAS 2924-91. Poduri de sosea. Gabarite, Institutul Roman de Standardizare (in Romanian)
10. SR EN 1991-2: Actions on structures – Part 2: Traffic loads on bridges