Analysis of the Two Span Main Truss Girder of the Danube Bridge Between Ruse and Giurgiu in Accordance with Eurocode Requirements

Stoyan Ivanov [1] ✉, *Lazar Georgiev* [2]
✉ e-mail: sdenkov_fte@uacg.bg
[1] University of Architecture, Civil Engineering and Geodesy, Faculty of Civil Engineering, Steel, Timber and Plastic Structures, Sofia, Bulgaria
[2] University of Architecture, Civil Engineering and Geodesy, Faculty of Transport Engineering, Roads and Transport Structural Facilities, Sofia, Bulgaria
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Abstract The bridge over the Danube River between Ruse, Bulgaria, and Giurgiu, Romania, was constructed between 1952 and 1954. This paper focuses on the main truss girder of the bridge, which consists of two equal spans, each measuring 160 meters. The steel truss structure supports both road and railway traffic. A finite element (FE) model of the main truss has been developed and analyzed in accordance with contemporary Eurocode standards. The main truss elements have been verified, and a comparative analysis has been conducted. Conclusions are presented based on the findings.

1 Introduction

The Danube Bridge connecting Bulgaria (town of Ruse) and Romania (town of Giurgiu) is built between 1952 and 1954 for only two years and three months [1], [4]. This is the first contemporary bridge built between the two countries over their common border section of the Danube River.

The total length of the bridge is 2224m and the spans are (12x34,5) + (4x80) + (2x160) + 86 + (2x160) + (4x80) + (12x34,5). The bridge superstructure is symmetric over its central span, simply supported steel truss of 86m span, which can be lifted providing an additional 7,60m navigable vertical clearance. In the middle of the movable section of the bridge lies the state border between Bulgaria and Romania.

The main bridge approaches, from both sides, consists of 12 simply supported steel plate girder bridges, with spans of 34,5m each. In the original design, no composite action between the steel plate girders and the concrete plate on top is ensured. The main bridge superstructure consists of several continuous steel truss girders on two spans each. From both sides, after the approaching structures, there are first two continuous steel truss girders with spans 2x80m each and then one continuous steel truss girder with spans 2x160m each. Thus, the longest span of the bridge is 160m.

This article focuses specifically on one of main steel truss girders with a maximum span.
General view of the bridge is presented in **Figure 1** [2].

Figure 1: General overview of the bridge [2]

2 Description of the two span main truss girder

The two span 2x160m main steel truss girder is a double deck bridge superstructure. It carries both road and railway traffic, where the railway traffic is on the level of the bottom chord of the truss and the road traffic is situated above it, in between the top and the bottom chord. The bridge carries a single railway track and a roadway with 7,0m width. The distance between the two parallel steel trusses is 8,60m. And their overall height is 23m. The slenderness of the superstructure is $L/H = 160/23 \approx 7$.
General bridge cross section and side view are presented in **Figure 2** and in **Figure 3**.

The railway deck is of an open type without a ballast bed, consisting of two longitudinal beams (stringers) spaced 2.0 meters apart and cross beams placed at 10-meter intervals, corresponding to the nodes of the main steel truss. The road deck comprises a concrete slab supported by five longitudinal steel plate girders at 1,50m, which in turn rest on steel cross beams, spaced 10 meters apart.
The bracing of the bridge superstructure includes longitudinal "X"-type bracing at the level of the top and bottom chords, vertical frame-type bracing at 20-meter intervals, and portal frames at each support along the corresponding diagonals.
The cross sections of the main steel truss elements are built-up, composed of standard steel profiles connected by steel plates with the use of rivets. All truss nodes and connections are riveted.
The material used for the main trusses is steel Ст.3, with an ultimate strength (f_u) of 380 MPa and a yield strength (f_y) of 230 MPa. This steel grade closely corresponds to the contemporary steel

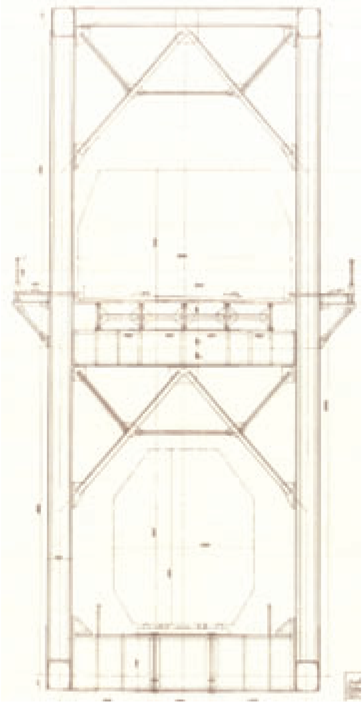


Figure 2: Bridge cross section

grade S235.
The overall steel consumption per square meter of the deck (area includes both road and railway decks) is approximately 880 kg/m^2.

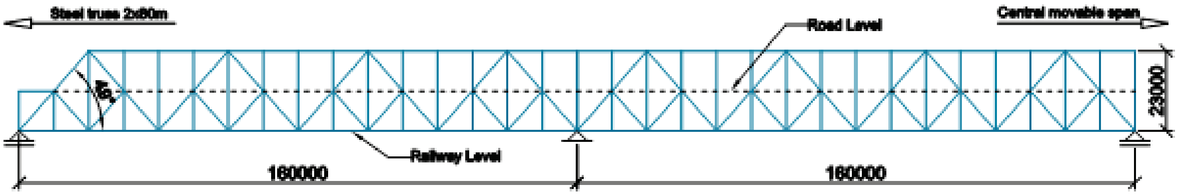


Figure 3: Side view of the main steel truss girders

3 FE model – analysis and results

Two-dimensional FE model of one of the two parallel steel main trusses is developed. The overall truss geometry corresponds to the original design. The cross sections of the elements are taken from the original static calculations. The FE model is presented in **Figure 4**. The material used is steel grade S235.

The model is subjected to dead and permanent loads, equally distributed between the two main trusses at a ratio of 50% each. Vertical traffic loads are applied in accordance with Eurocode 1, Part 2 [3]. For road traffic, load group gr1a is used, incorporating load model LM1 along with a reduced value for the vertical load on the sidewalks. The traffic lanes are arranged to ensure that one of the

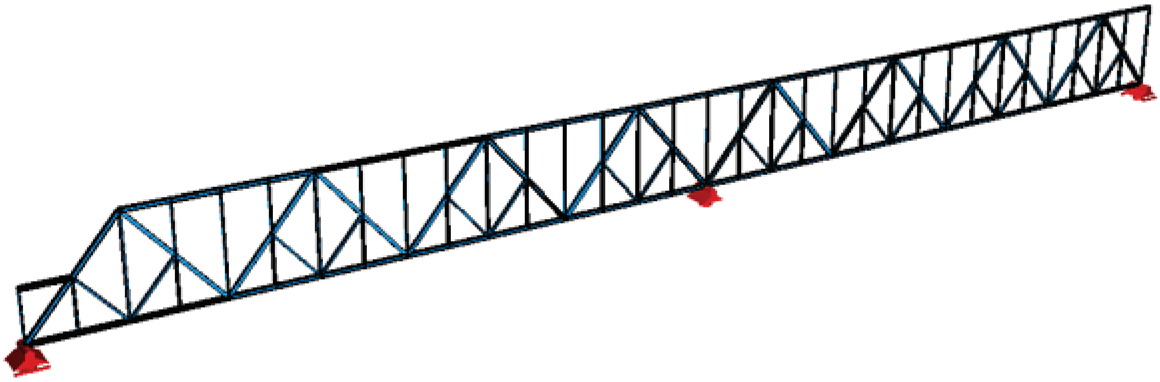


Figure 4: 2D finite element model of the main steel truss

trusses is loaded under the most adverse conditions. The solution in the transverse direction is not presented here.

Vertical railway traffic load model LM71 is used for the single track. The eccentricity, as specified in [3], is also considered in the solution for the transverse direction. An α-factor of 1.21 is applied in the calculations. Vertical traffic loads from both road and railway traffic are combined at their full values, without reduction.

Horizontal longitudinal loads, due to braking and acceleration on the railway line, are taken into account. Horizontal transverse loadings, such as wind and nosing forces, are not considered, as the model is two-dimensional. Accidental and earthquake design situations are not investigated.

The truss nodes are modeled as free to rotate for ULS and as stiff for SLS verifications.

The results from the analysis are presented below.

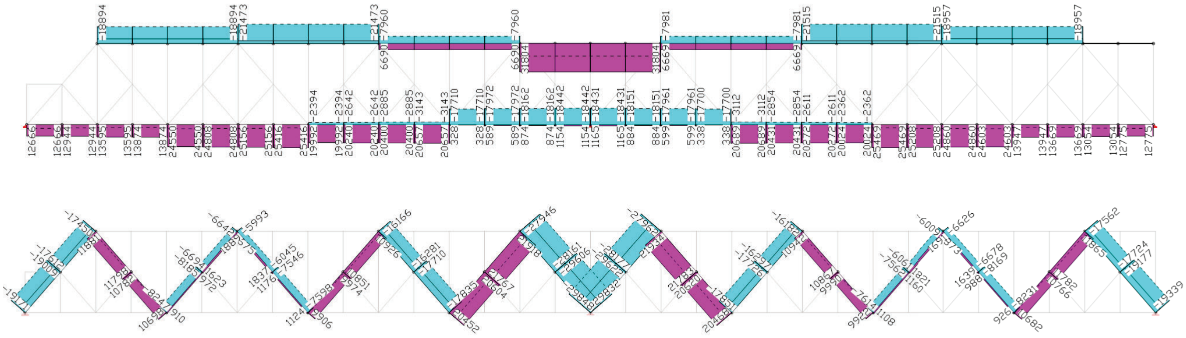


Figure 5: Design Normal Axial Force [kN]

The presented normal stresses in **Figure 6** are calculated for the Permanent and temporary design situation using gross cross section properties. The maximum tension stress in the chords is 200MPa

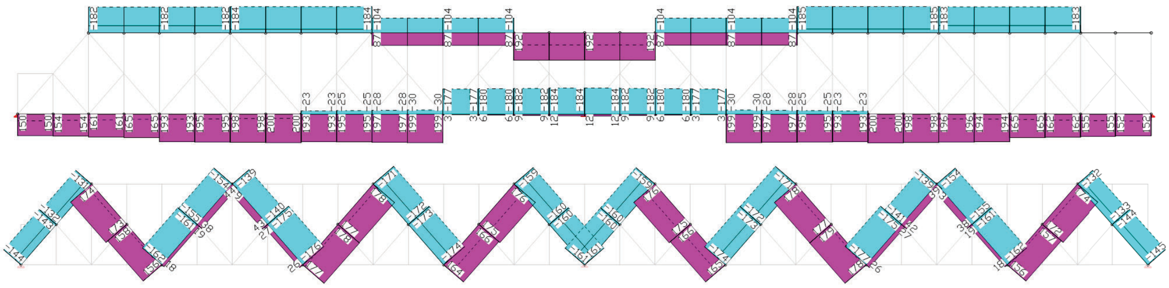


Figure 6: Design Normal Stresses [MPa]

and the minimum is -185MPa. For the diagonals the obtained design normal stresses for both tension and compression are 178MPa.

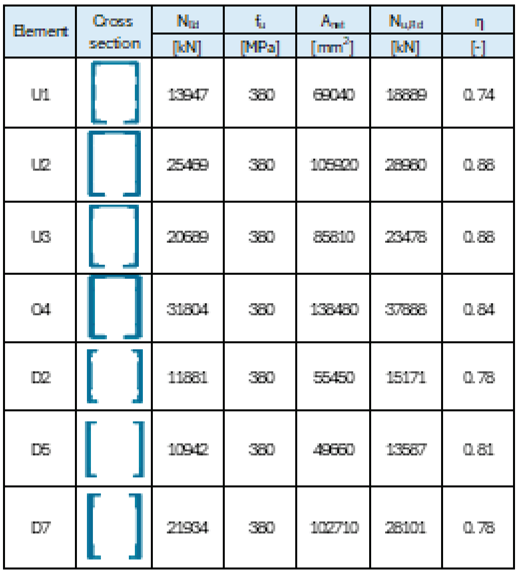
4 Verifications

Verifications for the main truss elements are presented for ULS and SLS. In addition, the deflection of the truss is also verified according to the requirements of the Eurocode.

4.1 ULS verifications

The verifications for main truss elements in tension are fulfilled for the gross cross sections since the presented normal stresses are less than the design yield strength, which is 230MPa, if γ_{M0}=1,0 is accepted.
The verifications for the net cross sections (reduced with the holes for the rivets) of selected truss elements are presented in **Table 1**.

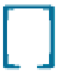
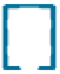
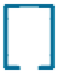
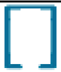
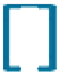
Table 1: Tension verification of selected truss elements



Element	Cross section	N_{Ed}	f_u	A_{net}	$N_{u,Rd}$	η
		[kN]	[MPa]	[mm^2]	[kN]	[-]
U1		13947	380	69040	18889	0.74
U2		25469	380	105920	28980	0.88
U3		20689	380	85810	23478	0.88
O4		31804	380	138480	37888	0.84
D2		11881	380	55450	15171	0.78
D5		10942	380	49660	13587	0.81
D7		21934	380	102710	28101	0.78

Compression verifications of selected truss elements are presented in **Table 2**. The checks are made for buckling in the plane of the truss. For out of plane buckling the effective length is the same and the moments of inertia of the cross sections are either with similar or higher values.

Table 2: Compression verification of selected truss elements

Element	Cross section	N_{Ed}	f_y	$l_{k,y}$	I_y	$N_{cr,y}$	λ_y	Φ_y	χ_y	A	$N_{b,Rd}$	η
		[kN]	[MPa]	[cm]	[cm^4]	[kN]	[-]	[-]	[-]	[mm^2]	[kN]	[-]
O1		-18957	230	1000	1327500	275140	0.295	0.567	0.952	103880	20675	0.92
O2		-21515	230	1000	1450800	300696	0.299	0.569	0.950	116680	23172	0.93
U4		-18442	230	1000	1283400	266000	0.294	0.566	0.952	100080	19924	0.93
D1		-19339	230	1524	1601800	142941	0.463	0.671	0.864	133000	24018	0.81
D6		-17851	230	1524	1299600	115965	0.451	0.663	0.870	102440	18638	0.96
D8		-29848	230	1524	1996400	178154	0.489	0.690	0.849	185080	32864	0.91

From the presented tables above, it can be seen that the verifications for the presented truss elements are fulfilled.

4.2 SLS verifications

Verifications for the Serviceability Limit State (SLS) include a stress check based on the characteristic design combination and an assessment of deflections. For the stress check, the truss nodes are modeled as stiff, meaning that bending moments are also considered. The calculated stresses are shown in **Figure 7**, where the maximum compression stress is -211 MPa and the maximum tension stress is 200 MPa. Both values are below the characteristic yield strength of 230 MPa.

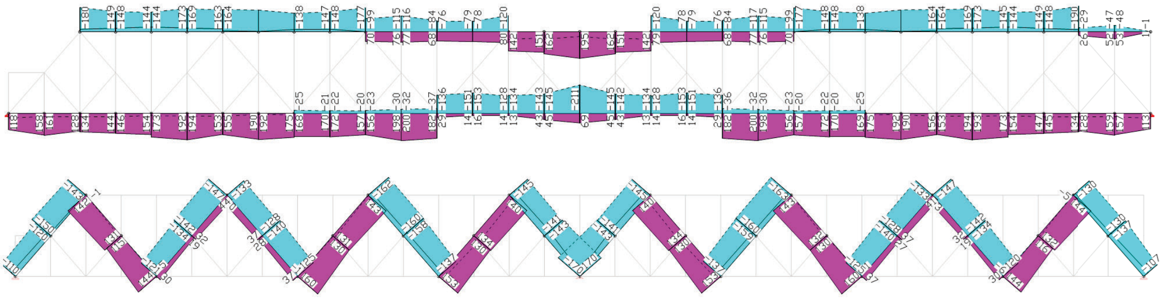


Figure 7: Characteristic Normal Stresses [MPa]

Deflections caused by traffic loads are crucial in railway operations, as they impact both serviceability (comfort) and safety by preventing derailment. To assess comfort criteria, Eurocode 0, Figure A2.3 can be referenced. However, because the specified values apply only to spans less than 120 meters, a special analysis is required for this bridge to verify compliance with comfort standards. To ensure safety against derailment, the deflection should be less than L/600, which in this case equals 270mm. The calculated maximum deflection, based on the characteristic value of the LM71 load model (with α=1.0), is 67mm, well within the 270mm limit.

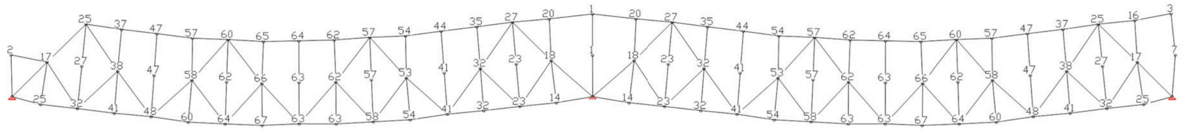


Figure 8: Vertical deflections from LM71 [mm]

5 Conclusions

The bridge over the Danube River between Bulgaria and Romania, connecting the towns of Ruse and Giurgiu, was commissioned in 1954. Over its 70 years of service, several rehabilitations and repairs have been carried out, including renewing the corrosion protection of the steel structure, renewing the waterproofing of the decks, strengthening the bridge piers and riverbed, and repairing the central lifting section of the bridge [1]. Reconstruction related to the replacement of the reinforced concrete plate of the road deck of the bridge is currently underway [5]. However, major structural repairs or reconstruction of the main steel trusses have not been necessary, as no significant damage or issues have been identified.

A recent recalculation of the main steel trusses, with span 160 meters, according to contemporary standards (Eurocode), confirms that the truss elements meet verification requirements related with load bearing capacity, despite not assessing transverse loadings, accidental design scenarios as well as fatigue checks.

Based on this, it can be concluded that the bridge is likely to meet its intended design life of 100 years, provided that current service conditions and necessary maintenance and inspection measures are provided. This conclusion is further supported by other examples of steel riveted truss bridges (primarily railway bridges) in Europe, some of which are over 100 years old and still in operation. Despite challenges such as open railway decks and reduced clearances, these old riveted steel trusses have demonstrated their durability and reliability over time when proper maintenance is ensured.

6 References

[1] Gogev, I. Tsenov P., Ivanova S., Bairov I, (1999): “60 years Danube Bridge between Ruse and Giurgiu”, Vip Style, 2014, (in Bulgarian).

[2] https://www.europarl.europa.eu/topics/en/article/20140306STO37815/the-bridge-where-two-alphabets-meet, 08.2024.

[3] Eurocode 1991-2:2003 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges.

[4] Gogev I., Georgiev L., Partov D., Lepoev M., “DANUBE BRIDGE BETWEEN RUSE AND GIURGIU. CONSTRUCTION AND MAINTENANCE”,10th International Conference on Bridges in Danube Basin 25th to 27th September 2019 in Vienna, ISBN: 978-3-9502387-2-3 ., pp.108÷111.

[5] Jiponov A., “Inspection and retrofitting of Danube bridge – Ruse – Giurgiu – challenges and innovative approaches”, IABSE Symposium Manchester 2024, pp.139-147, ISBN: 978-3-85748-204-5 .